Transport for NSW

Beaches Link and Gore Hill Freeway Connection

Appendix O

Surface water quality and hydrology

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Technical working paper: Surface water quality and hydrology

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Prepared for

Transport for NSW

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Glossary of terms and acronyms

Term	Definition
Ammonia	The most reduced form of inorganic nitrogen available, preferentially utilised by plants and aquatic micro-organisms.
Annual exceedance probability (AEP)	The likelihood of occurrence of a flood of given size or larger occurring in any one year. AEP is expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of five per cent, it means that there is a five per cent risk (ie a risk of one in 20) of a peak flood discharge of 500 m^3/s or larger occurring in any one year.
ANZECC	Australian and New Zealand Environment and Conservation Council
ANZG	Australian and New Zealand Guidelines
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
Aquatic ecology	Flora and fauna that live in or on water for all or a substantial part of the lifespan (generally restricted to fresh/inland waters).
Bedrock	Rock of a substantial thickness and extent underlying a relatively soft and variable surface.
Biota	All organisms in a given area (including flora and fauna), considered as a unit.
BTEX	Benzene, toluene, ethylbenzene and xylenes. Naturally occurring compounds in crude oil.
Catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. Always relates to an area above a specific location.
CEMP	Construction Environmental Management Plan
Chlorophyll-*a*	A measure of the amount of algae growing in a waterway.
CM Act	*Coastal Management Act 2016* (NSW)
Culvert	An enclosed channel for conveying water below a road.
Cut and cover	A method of tunnel construction whereby the structure is built in an open excavation and subsequently covered.
Dissolved oxygen	A measure of the amount of oxygen dissolved in water.
DPI	Former NSW Department of Primary Industries (now Department of Planning, Industry and Environment (Regions, Industry, Agriculture and Resources))
Ecosystem	A functional unit of energy transfer and nutrient cycling in a given place. Includes all relationships within the biotic community and between the biotic components of the system.
Electrical conductivity	The measure of a material's ability to accommodate the transport of an electric charge.
Embankment	An earthen structure where the road (or other infrastructure) subgrade level is above the natural surface.
Erosion	A natural process where wind or water detaches a soil particle and provides energy to move the particle.
Environmental water	Water that is allocated and managed specifically to improve the health of rivers, wetlands and floodplains. Also known as water for the environment.

Term	Definition
Fill	The material placed in an embankment.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
Floodplain	Area of land which is inundated by floods up to and including the probable maximum flood event (ie flood prone land).
Geomorphology	The study of shaping of the landscape by water, wind and other processes. Commonly used to describe the condition of streams as they are shaped by erosion and/or accretion of sediments.
Gross Pollutant Trap	A device designed to capture stormwater pollution thereby retaining gross pollutants, litter, sediment and associated oils before it has a chance to enter waterways.
Groundwater	Water that is held in the rocks and soil beneath the earth's surface.
Groundwater dependent ecosystem (GDE)	Refers to communities of plants, animals and other organisms whose extent and life process are dependent on groundwater, such as wetlands and vegetation on coastal sand dunes.
Habitat	The place where a species, population or ecological community lives (whether permanently, periodically or occasionally). Habitats are measurable and can be described by their flora and physical components.
Hydrology	The study of rainfall and surface water runoff processes.
Impact	Influence or effect exerted by a project or other activity on the natural, built and community environment.
Interchange	A grade separation of two or more roads with one or more interconnecting carriageways.
meq/L	Milliequivalents per litre
mg/L	Milligrams per litre
mL	Millilitres
Median	The central reservation which separates carriageways from traffic travelling in the opposite direction.
Median (statistical term)	The median is the middle value in a list of numbers found by ordering all data points and selecting the one in the middle.
Metals	Occur naturally at trace levels in the environment. Includes the elements arsenic, cadmium, copper, chromium, iron, lead, manganese, mercury, nickel, selenium and zinc.
microSiemens per centimetre (mS/cm)	A measure of electrical conductivity. Commonly used to measure the salinity of water.
MUSIC (model)	Model for Urban Stormwater Improvement Conceptualisation
Motorway facility and ventilation outlet	Facility for the mechanical removal of air from the mainline tunnels, or mechanical introduction of air into the tunnels. May comprise one or more ventilation outlets.
NO_x	Oxidised nitrogen

Term	Definition
Nutrients	Nutrients in aquatic environments promote the growth of algae and increase turbidity which in turn reduces light and may affect plant growth. Generally excessive nutrient inputs lead to excessive algal growth and formation of nuisance blooms. Nutrients consist of nitrogen (including total nitrogen, oxidised nitrogen and ammonia) and phosphorus (including total phosphorus and filterable reactive phosphorus).
OEH	Former NSW Office of Environment and Heritage (now Department of Planning, Industry and Environment (Environment, Energy and Science)
Oxidised nitrogen	Represents the level of free nitrogen within the water column that is readily available to plants.
PAH	Polycyclic aromatic hydrocarbons are hydrocarbon molecules found mainly in crude oil and coal as well as in processed fossil fuels and tar.
pH	A measure of the acidity or alkalinity of a waterway.
Portal	The entry and/or exit to a tunnel.
Project	Refers to the construction and operation of the Beaches Link and Gore Hill Freeway Connection, which includes: twin tolled motorway tunnels connecting the Warringah Freeway at Cammeray and the Gore Hill Freeway at Artarmon to the Burnt Bridge Creek Deviation at Balgowlah and the Wakehurst Parkway at Seaforth (the Beaches Link). The Beaches Link would include upgrade works along Wakehurst Parkway and the road network around the Burnt Bridge Creek Deviation. Connection and integration works along the existing Gore Hill Freeway at Artarmon (the Gore Hill Freeway Connection).
Project footprint	The land required to construct and operate the project. This includes permanent operational infrastructure (including the tunnels), and land required temporarily for construction.
Riparian	The part of the landscape adjoining rivers and streams that has a direct influence on the water and aquatic ecosystems within them.
Roads and Maritime	NSW Roads and Maritime Services. Now Transport for NSW.
RTA	NSW Roads and Traffic Authority. Now Transport for NSW.
Runoff	The part of the rainfall on a catchment which flows as surface discharge past a specified point.
Scour	The erosion of material by the action of flowing water.
SEARs	Secretary's environmental assessment requirements and specifications for an environmental assessment prepared by the Secretary of the NSW Department of Planning, Industry and Environment under section 115Y of the *Environmental Planning and Assessment Act 1979* (NSW).
Sediment	Material, both mineral and organic, that is being or has been moved from its site of origin by the action of wind, water or gravity and comes to rest either above or below water level.
Sedimentation	Deposition of sediment usually by water.
SHWQIP	Sydney Harbour Water Quality Improvement Plan
SMCMA	Sydney Metropolitan Catchment Management Authority
Spoil	Surplus excavated material.

Term	Definition
Staging	Refers to the division of the project into multiple contract packages for construction purposes, and/or the construction or operation of the overall project in discrete sections.
Stockpile	Temporarily stored materials such as soil, sand, gravel and spoil/waste.
Stream order	A classification system which assigns an 'order' to waterways according to the number of additional tributaries associated with each waterway, to provide a measure of system complexity.
Surface water	Water flowing or held in streams, rivers and other wetlands in the landscape.
Swale	A shallow, grass-lined drainage channel.
Terrestrial	Living or growing on land (ie terrestrial flora or fauna).
Threatened	As defined under the Threatened Species Conservation Act 1995 (NSW), a species, population or ecological community that is likely to become extinct or is in immediate danger of extinction.
Total Kjeldahl nitrogen	The total concentration of organic nitrogen and ammonia. An abundance of nutrients in the water leads to excess plant growth and eventually to eutrophication.
Total nitrogen	A measure of all the nitrogen species found in a waterway including oxidised nitrogen, ammonia and total organic nitrogen.
Total phosphorus	A measure of both biologically available species (known as filterable reactive phosphorus) and the unavailable species.
Toxicity	The degree of danger posed by a substance to human, animal or plant life.
TPH	Total Petroleum Hydrocarbon
Tributary	A river or stream flowing into a larger river or lake.
TRH	Total recoverable hydrocarbons
TSS	Total Suspended Solids
Turbidity	A measure of light penetration through a water column containing particles of matter in suspension.
Transport for NSW	Project proponent
Urban design	The process and product of designing human settlements, and their supporting infrastructure, in urban and rural environments.
VOC	Volatile organic compounds
Water Act	*Water Act 1912* (NSW)
WM Act	*Water Management Act 2000* (NSW)
Waterway	Any flowing stream of water, whether natural or artificially regulated (not necessarily permanent).

Term	Definition
Wetland	Wetlands are areas of land that are wet by surface water or groundwater, or both, for long enough periods that the plants and animals in them are adapted to, and depend on, moist conditions for at least part of their lifecycle. They include areas that are inundated cyclically, intermittently or permanently with fresh, brackish or saline water, which is generally still or slow-moving except in distributary channels such as tidal creeks which may have higher peak flows. Wetlands may be constructed for the purposes of removing pollutants from runoff.
WQIP	Water Quality Improvement Plan
WQO	Water Quality Objective
WSUD	Water sensitive urban design

Executive Summary

Transport for NSW is seeking approval under Division 5.2, Part 5 of the *Environmental Planning and Assessment Act 1979* to construct and operate the Beaches Link and Gore Hill Freeway Connection (the project), which would comprise two main components:

- Twin tolled motorway tunnels connecting the Warringah Freeway at Cammeray and the Gore Hill Freeway at Artarmon to the Burnt Bridge Creek Deviation at Balgowlah and Wakehurst Parkway at Killarney Heights, and an upgrade of Wakehurst Parkway (the Beaches Link)
- Connection and integration works along the existing Gore Hill Freeway and surrounding roads at Artarmon (the Gore Hill Freeway Connection).

This technical working paper presents the assessment of potential impacts during construction and operation of the project on surface freshwater. Impacts associated with marine water quality are addressed separately in Appendix Q (Technical working paper: Marine water quality).

Major waterways near the project

The waterways relevant to the project are located within the Sydney Harbour and Parramatta River Catchment and the Northern Beaches Lagoons Catchment (which consists of Narrabeen Lagoon and catchment, Dee Why Lagoon and catchment, Curl and Manly lagoons and their catchments and Manly Dam (within the Manly Lagoon catchment)). The waterways in proximity to the project include:

- Willoughby Creek at Neutral Bay and Cammeray – discharges to Willoughby Bay within the Sydney Harbour and Parramatta River Catchment
- Flat Rock Creek at Naremburn and Willoughby – discharges to Long Bay within the Sydney Harbour and Parramatta River Catchment
- Quarry Creek at Cammeray – discharges to Flat Rock Creek (see above)
- Burnt Bridge Creek at Balgowlah – discharges to Manly Lagoon within the Northern Beaches Lagoons Catchment
- Trefoil Creek at Frenchs Forest – discharges to Middle Creek/Narrabeen Lagoon within the Northern Beaches Lagoons Catchment
- Manly Creek at Allambie Heights – discharges to Manly Dam within the Northern Beaches Lagoons Catchment.

Current condition and waterway health

The project footprint and its surroundings are dominated by residential areas, and some industrial and commercial developments with existing water quality in all waterways indicative of a highly urbanised catchment, with elevated nutrients and heavy metals and low dissolved oxygen concentrations. Surface water quality of waterways relevant to the project have been heavily impacted by urban development and are influenced by both point and diffuse sources of pollution including stormwater, wastewater overflows and leachate from contaminated land. Some of the waterways have also undergone a substantial change from natural to artificial, hard (concrete-lined) channels and underground box culverts. This together with an increase in impervious areas has resulted in increased runoff of greater velocities and transport of sediments and contaminants to downstream receiving environments.

Construction impacts

Construction of the project would involve a variety of activities that could impact surface water quality including:

- Utilities relocation
- Establishment of construction support sites
- The localised adjustment of a small section of Burnt Bridge Creek as part of surface connections at Balgowlah
- Drainage works associated with an existing aboveground watercourse within Flat Rock Reserve at the Flat Rock Drive construction support site (BL2)
- Surface works
- Tunnel excavation
- Wastewater discharges from wastewater treatment plants.

These construction activities have the potential to impact on surface water quality, waterway form and geomorphic processes, including:

- Erosion of soils and sedimentation of waterways which could result in changes to channel bed and bank conditions
- Accidental leaks or spills of chemicals and fuels during construction
- Exposure of contaminated soils and groundwater
- Discharge of poorly treated wastewater
- Construction activities next to or within watercourses
- Bridge, culvert and channel realignment works
- Changes to creek flow rates and volumes caused by wastewater treatment plant discharges which could lead to scouring
- Changes to impermeable surfaces and potential for subsidence below watercourses.

The impacts assessed are typical on major road projects. With the application of the proposed environmental management measures and treatment of wastewater discharges, potential impacts on surface water quality and geomorphology are considered minor and manageable.

Operational impacts

Operation of the project would involve a variety of activities that could impact surface water quality including:

- New or modified roads resulting in increased impervious road surfaces
- Groundwater and tunnel drainage management and treatment systems, including the Gore Hill Freeway wastewater treatment plant
- Gore Hill Freeway Connection: these surface road works are located primarily within the existing road corridor with discharge to a mixture of formalised drainage and urban creek systems that discharge to Middle Harbour
- Surface connections at Balgowlah: these surface road works are located primarily within the existing road corridor with discharge to Burnt Bridge Creek and Manly Creek
- Wakehurst Parkway: these surface road works are located wholly within the existing road corridor with widening into greenfield road corridor areas which discharge to creeks that drain to Many Dam
- Operational ancillary infrastructure including motorway facilities at Warringah Freeway, Gore Hill Freeway, Burnt Bridge Creek Deviation and Wakehurst Parkway, the motorway control centre in Artarmon, and the two tunnel support facilities at Gore Hill Freeway in Artarmon and Wakehurst Parkway in Frenchs Forest.

The potential impacts to water quality from these operational activities could include:

- Potential increase in scouring from increased road runoff
- Change in flow and velocity leading to stagnation of a waterway or an increase in turbidity and nutrient concentrations from increased sediment loads
- Increased impervious surfaces which can increased levels of heavy metals and other toxicants
- Spills/leaks of fuels or oils from vehicles
- Discharge of poorly treated tunnel wastewater
- Scour or mobilisation of sediments at outlet locations
- Impacts to baseflow of surface creeks due to groundwater drawdown.

Impacts to geomorphology could arise from the creation of impervious surfaces and dewatering and discharge of water from the Gore Hill Freeway wastewater treatment plant. These processes could cause scour or change the bed profile and sediment processes of Flat Rock Creek. Given the discharge of treated tunnel water would have a minor increase on baseflow rates and the distance between the proposed discharge location and section of the creek that is not concrete lined, the potential operational impacts on geomorphology are considered minor and manageable with the application of proposed standard mitigation measures.

Baseflow impacts at Flat Rock Creek and Quarry Creek during the operational phase have the potential to be substantial (39 per cent and 69 per cent reduction respectively after 100 years of operation), noting operational wastewater treatment plant discharges to Flat Rock Creek may offset this impact. Substantial base flow impacts at Burnt Bridge Creek are also expected during operational phase with up to a 96 per cent reduction being modelled. Baseflow impacts are modelled conservatively without tunnel linings designed and installed to reduce groundwater inflows into the tunnels. As the baseflow impacts are likely to be lower than that predicted in the Appendix N (Technical working paper: Groundwater) due to conservative modelling assumptions, additional gauge data would be collected to confirm the modelled results during further design development.

Management of impacts

Construction

The key water quality objective would be to ensure downstream waterways including Willoughby Creek, Flat Rock Creek, Quarry Creek, Burnt Bridge Creek, Manly Creek, Manly Dam, Narrabeen Lagoon, Manly Lagoon and Trefoil Creek are protected against potential impacts from surface runoff generated during the construction phase of the project. Construction methods would be in accordance with *Managing Urban Stormwater – Soils and Construction, Volume 1* (Landcom, 2004), *Volume 2D* (NSW Department of Environment, Climate Change and Water (DECCW), 2008) and the *ANZECC Guidelines and National Water Quality Management Strategy* (ANZECC/ARMCANZ, 2000). The ANZECC guidelines (ANZECC/ARMCANZ, 2000) indicate that several physical-chemical and toxicant parameters need to be controlled to maintain the required protection level for aquatic ecosystems during the construction and operational phases of the project. Water quality would be monitored in accordance with the construction freshwater quality monitoring program proposed in Section 8.1.

Surface water quality during construction would be managed using:

- Detailed erosion and sediment control measures to manage excavations, stockpiles and rainfall runoff from surface works, minimising risk of erosion and sedimentation and pollutant loading of downstream waterways
- Wastewater treatment plants would be designed to treat wastewater generated from tunnel groundwater ingress and rainfall runoff in tunnel portals
- Wastewater would be treated to meet the Australian and New Zealand Guidelines (ANZG) (2018) and the ANZECC guidelines (ANZECC/ARMCANZ, 2000)
- During the further design development phase of the project, tunnel linings would be specified and installed during the construction phase to limit groundwater ingress into the tunnels in order to meet the 1L/s/km criteria as discussed in Appendix N (Technical working paper: Groundwater).

The project construction is therefore likely to have a negligible impact on the water quality objectives (WQOs), which are currently not being met.

Operation

During the operation of the project, tunnels would incorporate drainage infrastructure to capture and treat wastewater generated from groundwater ingress and rainfall runoff in tunnel portals. The Gore Hill Freeway operational wastewater treatment plant is proposed to treat discharge and manage adverse impacts on the receiving environment at Flat Rock Creek. Whilst the WQOs are currently not being met, the treated discharge would meet the ANZG (2018) guidelines so that the project would work towards achieving the WQOs over time. Similarly, runoff from the Gore Hill Freeway connection would be treated via sediment basins that would result in discharge of runoff with lower total suspended solids and total phosphorus. Total nitrogen levels are estimated to be slightly higher in runoff but are unlikely to impact on achieving the WQOs.

Surface water quality during operation would be managed using:

- Procedural controls (ie Operational Environmental Management Plan) including water management controls and a maintenance and inspection program for operational controls
- Physical controls to treat and contain rainfall runoff and accidental spills
- Operational phase monitoring as per the operational water quality monitoring program to assess and manage impacts on receiving water while the project site stabilises and to identify water quality conditions post development.

Conclusion

Changes to flow paths during construction and discharges from the wastewater treatment plant during construction and operation would be accommodated within the existing stormwater network and therefore unlikely to have a material impact on the stormwater system.

There would be no extraction of surface water as part of the construction and operation of the project. However, there is the potential for a reduction in the availability of environmental water due to groundwater drawdown during construction and operation of the project, namely at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek.

Due to the implementation of water quality controls and treatment of tunnel discharge water to the ANZG (2018) guidelines, the construction and operation of the project is expected to have a negligible influence of the goals to achieving WQOs.

As surface water runoff would be accommodated within the stormwater network, impacts to geomorphology are considered unlikely. There is an increased risk of erosion and sedimentation from wastewater treatment plant discharges to waterways and from localised adjustments of two waterways. However, if appropriate environmental management measures are implemented, impacts to geomorphology are expected to be low.

The activities associated with the construction and operation of the project have the potential to impact on the surface water quality and geomorphology of the existing environment. With the implementation of environmental management measures and appropriate treatment of wastewater discharge, the project would have minimal impacts on the surface water quality.

Based on the project proposed, there are minimal adverse cumulative surface water impacts anticipated during both construction and operation phases. The residual risk to sensitive receiving environments and environmental values is expected be low provided the proposed environmental management measures are implemented, maintained and monitored.

1. Introduction

This section provides an overview of the Beaches Link and Gore Hill Freeway Connection (the project), including its key features and location. It also outlines the Secretary's environmental assessment requirements addressed in this technical working paper.

1.1 Overview

The Greater Sydney Commission's Greater Sydney Region Plan – A Metropolis of Three Cities (Greater Sydney Commission, 2018) proposes a vision of three cities where most residents have convenient and easy access to jobs, education and health facilities and services. In addition to this plan, and to accommodate for Sydney's future growth the NSW Government is implementing the Future Transport Strategy 2056 (Transport for NSW, 2018), that sets the 40 year vision, directions and outcomes framework for customer mobility in NSW. The Western Harbour Tunnel and Beaches Link program of works is proposed to provide additional road network capacity across Sydney Harbour and Middle Harbour and to improve transport connectivity with Sydney's Northern Beaches. The Western Harbour Tunnel and Beaches Link program of works include:

- The Western Harbour Tunnel and Warringah Freeway Upgrade project which comprises a new tolled motorway tunnel connection across Sydney Harbour, and an upgrade of the Warringah Freeway to integrate the new motorway infrastructure with the existing road network and to connect to the Beaches Link and Gore Hill Freeway Connection project
- The Beaches Link and Gore Hill Freeway Connection project which comprises a new tolled motorway tunnel connection across Middle Harbour from the Warringah Freeway and the Gore Hill Freeway to Balgowlah and Killarney Heights and including the surface upgrade of the Wakehurst Parkway from Seaforth to Frenchs Forest and upgrade and integration works to connect to the Gore Hill Freeway at Artarmon.

A combined delivery of the Western Harbour Tunnel and Beaches Link program of works would unlock a range of benefits for freight, public transport and private vehicle users. It would support faster travel times for journeys between the Northern Beaches and areas south, west and north west of Sydney Harbour. Delivering the program of works would also improve the resilience of the motorway network, given that each project provides an alternative to heavily congested existing harbour crossings.

1.2 The project

Transport for NSW is seeking approval under Part 5, Division 5.2 of the *Environmental Planning and Assessment Act 1979* to construct and operate the Beaches Link and Gore Hill Freeway Connection project, which would comprise two components:

- Twin tolled motorway tunnels connecting the Warringah Freeway at Cammeray and the Gore Hill Freeway at Artarmon to the Burnt Bridge Creek Deviation at Balgowlah and the Wakehurst Parkway at Killarney Heights, and an upgrade of the Wakehurst Parkway (the Beaches Link)
- Connection and integration works along the existing Gore Hill Freeway and surrounding roads at Artarmon (the Gore Hill Freeway Connection).

Key features of these two components is provided in Section 1.4.

1.3 Project location

The project would be located within the North Sydney, Willoughby, Mosman and Northern Beaches local government areas, connecting Cammeray in the south with Killarney Heights, Frenchs Forest and Balgowlah in the north. The project would also connect to both the Gore Hill Freeway and Reserve Road in Artarmon in the west.

Commencing at the Warringah Freeway at Cammeray, the mainline tunnels would pass under Naremburn and Northbridge, then cross Middle Harbour between Northbridge and Seaforth. The mainline tunnels would then split under Seaforth into two ramp tunnels and continue north to the Wakehurst Parkway at Killarney Heights and north-east to Balgowlah, linking directly to the Burnt Bridge Creek Deviation to the south of the existing Kitchener Street bridge.

The mainline tunnels would also have on and off ramps from under Northbridge connecting to the Gore Hill Freeway and Reserve Road east of the existing Lane Cove Tunnel. Surface works would also be carried out at the Gore Hill Freeway in Artarmon, Burnt Bridge Creek Deviation at Balgowlah and along the Wakehurst Parkway between Seaforth and Frenchs Forest to connect the project to the existing arterial and local road networks.

1.4 Key features of the project

Key features of the Beaches Link component of the project are shown in Figure 1-1 and would include:

- Twin mainline tunnels about 5.6 kilometres long and each accommodating three lanes of traffic in each direction, together with entry and exit ramp tunnels to connections at the surface. The crossing of Middle Harbour between Northbridge and Seaforth would involve three lane, twin immersed tube tunnels
- Connection to the stub tunnels constructed at Cammeray as part of the Western Harbour Tunnel and Warringah Freeway Upgrade project
- Twin two lane ramp tunnels
- Eastbound and westbound connections between the mainline tunnel under Seaforth and the surface at the Burnt Bridge Creek Deviation, Balgowlah (about 1.2 kilometres in length)
- Northbound and southbound connections between the mainline tunnel under Seaforth and the surface at the Wakehurst Parkway, Killarney Heights (about 2.8 kilometres in length)
- Eastbound and westbound connections between the mainline tunnel under Northbridge and the surface at the Gore Hill Freeway and Reserve Road, Artarmon (about 2.1 kilometres in length).
- An access road connection at Balgowlah between the Burnt Bridge Creek Deviation and Sydney Road including the modification of the intersection at Maretimo Street and Sydney Road, Balgowlah
- Upgrade and integration works along the Wakehurst Parkway, at Seaforth, Killarney Heights and Frenchs Forest, through to Frenchs Forest Road East
- New open space and recreation facilities at Balgowlah
- New and upgraded pedestrian and cyclist infrastructure
- Ventilation outlets and motorway facilities at the Warringah Freeway in Cammeray, the Gore Hill Freeway in Artarmon, the Burnt Bridge Creek Deviation in Balgowlah and the Wakehurst Parkway in Killarney Heights
- Operational facilities, including a motorway control centre at the Gore Hill Freeway in Artarmon, and tunnel support facilities at the Gore Hill Freeway in Artarmon and the Wakehurst Parkway in Frenchs Forest
- Other operational infrastructure including groundwater and tunnel drainage management and treatment systems, surface drainage, signage, tolling infrastructure, fire and life safety systems, roadside furniture, lighting, emergency evacuation and emergency smoke extraction infrastructure, Closed Circuit Television (CCTV) and other traffic management systems.

Key features of the Gore Hill Freeway Connection component of the project are shown in Figure 1-2 and include:

- Upgrade and reconfiguration of the Gore Hill Freeway between the T1 North Shore & Western Line and T9 Northern Line and the Pacific Highway
- Modifications to the Reserve Road and Hampden Road bridges
- Widening of Reserve Road between the Gore Hill Freeway and Dickson Avenue
- Modification of the Dickson Avenue and Reserve Road intersection to allow for the Beaches Link off ramp
- Upgrades to existing roads around the Gore Hill Freeway to integrate the project with the surrounding road network
- Upgrade of the Dickson Avenue and Pacific Highway intersection
- New and upgraded pedestrian and cyclist infrastructure
- Other operational infrastructure, including surface drainage and utility infrastructure, signage and lighting, CCTV and other traffic management systems.

A detailed description of the project is provided in Chapter 5 (Project description) of the environmental impact statement.

Subject to obtaining planning approval, construction of the project is anticipated to commence in 2023 and is expected to take around five to six years to complete.

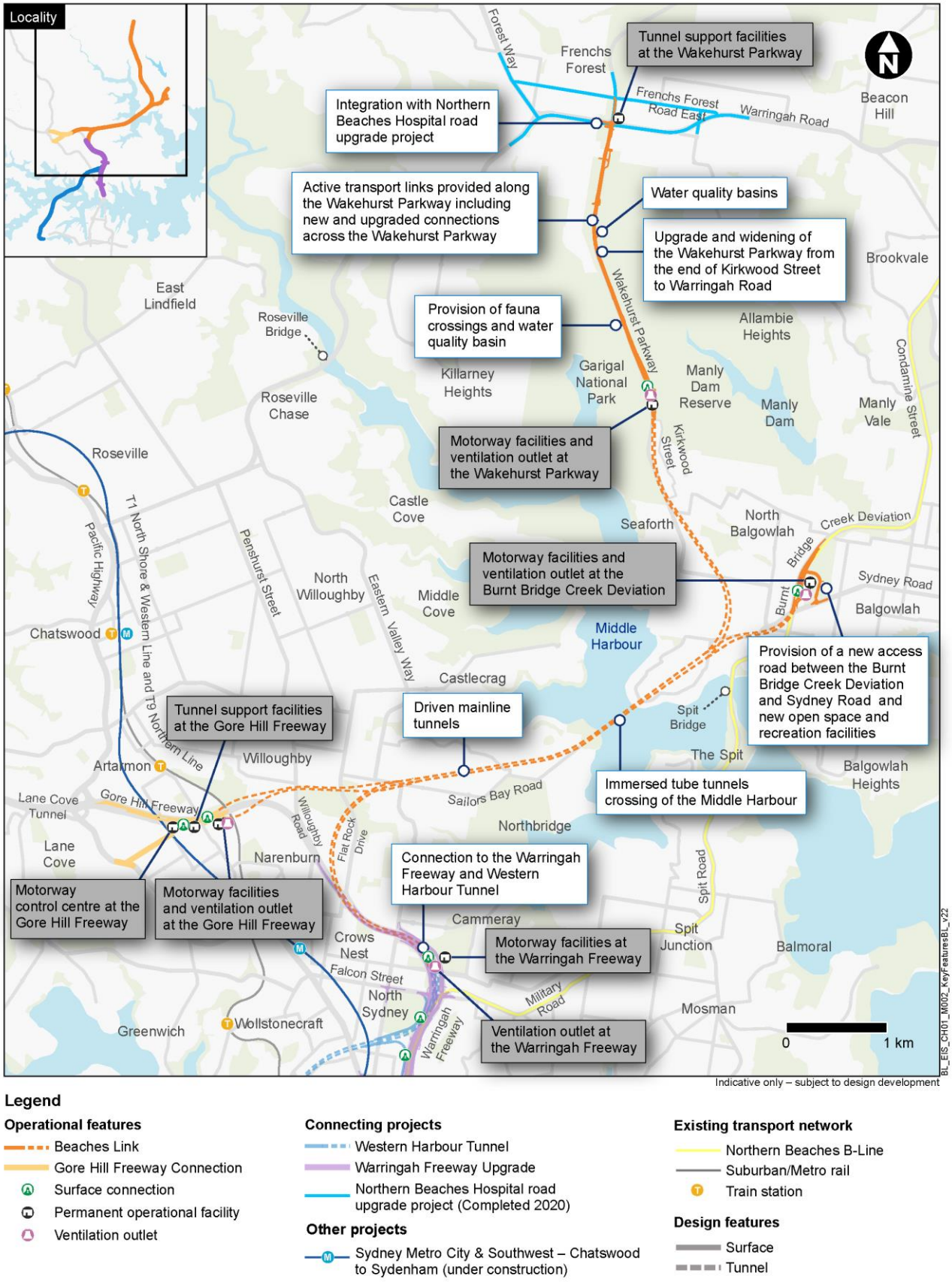

Figure 1-1 Key features of the Beaches Link component of the project

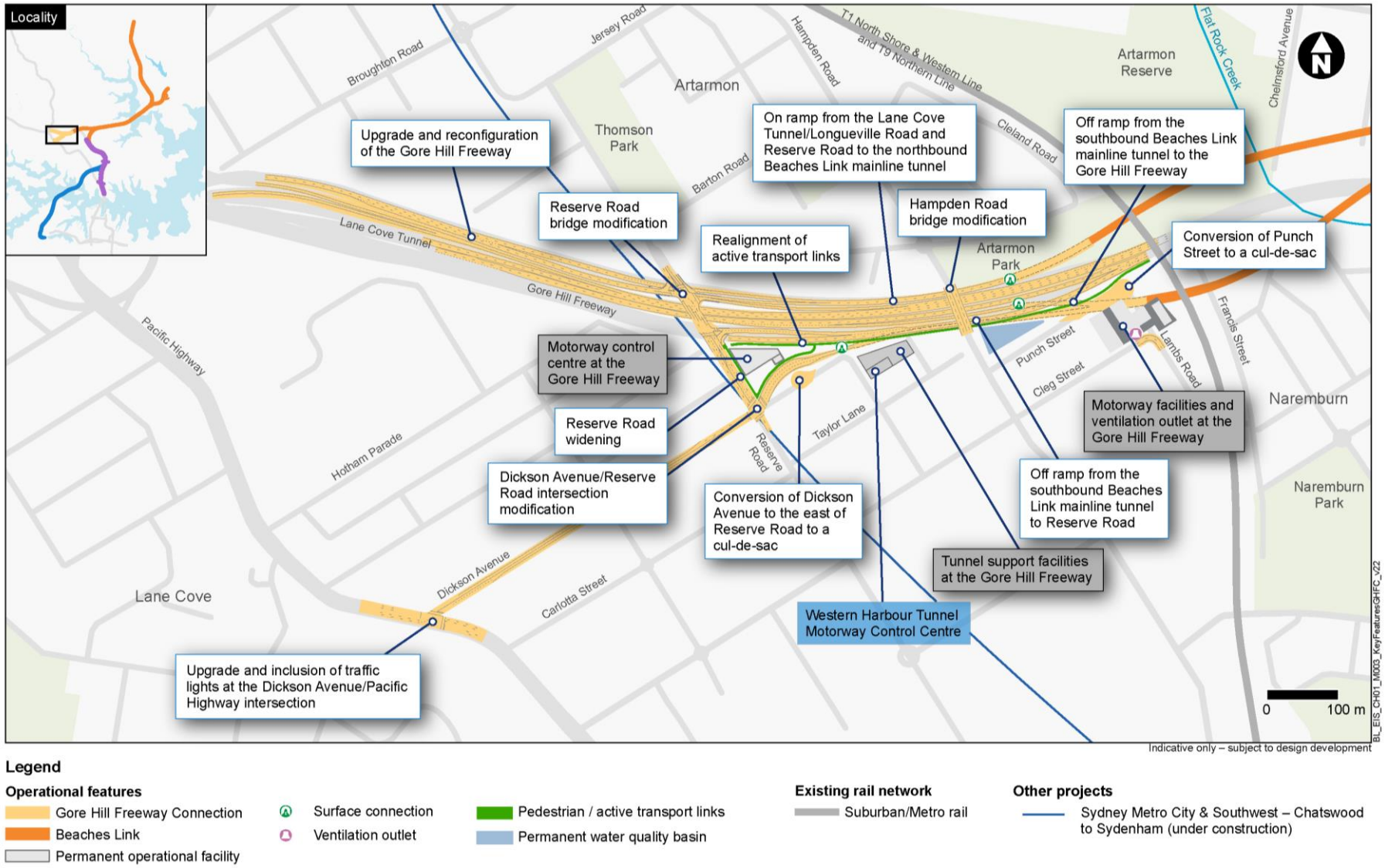

Figure 1-2 Key features of the Gore Hill Freeway component of the project

1.5 Key construction activities

The area required to construct the project is referred to as the construction footprint. Most of the construction footprint would be located underground within the mainline and ramp tunnels. However, surface areas would also be required to support tunnelling activities and to construct the tunnel connections, tunnel portals, surface road upgrades and operational facilities.

Key construction activities would include:

- Early works and site establishment, with typical activities being property acquisition and condition surveys, utilities installation, protection, adjustments and relocations, installation of site fencing, environmental controls (including noise attenuation and erosion and sediment control), traffic management controls, vegetation clearing, earthworks, demolition of structures, building construction support sites including acoustic sheds and associated access decline acoustic enclosures (where required), construction of minor access roads and the provision of property access, temporary relocation of pedestrian and cycle paths and bus stops, temporary relocation of swing moorings and/or provision of alternative facilities (mooring or marina berth) within Middle Harbour
- Construction of the Beaches Link, with typical activities being excavation of tunnel construction access declines, construction of driven tunnels, cut and cover and trough structures, construction of surface upgrade works, construction of cofferdams, dredging and immersed tube tunnel piled support activities in preparation for the installation of immersed tube tunnels, casting and installation of immersed tube tunnels and civil finishing and tunnel fitout
- Construction of operational facilities comprising:
  - A motorway control centre at the Gore Hill Freeway in Artarmon
  - Tunnel support facilities at the Gore Hill Freeway in Artarmon and at the Wakehurst Parkway in Frenchs Forest
  - Motorway facilities and ventilation outlets at the Warringah Freeway in Cammeray (fitout only of the Beaches Link ventilation outlet at the Warringah Freeway (being constructed by the Western Harbour Tunnel and Warringah Freeway Upgrade project), the Gore Hill Freeway in Artarmon, the Burnt Bridge Creek Deviation in Balgowlah and the Wakehurst Parkway in Killarney Heights
  - A wastewater treatment plant at the Gore Hill Freeway in Artarmon
  - Installation of motorway tolling infrastructure
- Staged construction of the Gore Hill Freeway Connection at Artarmon and upgrade and integration works at Balgowlah and along the Wakehurst Parkway with typical activities being earthworks, bridgeworks, construction of retaining walls, stormwater drainage, pavement works and linemarking and the installation of roadside furniture, lighting, signage and noise barriers
- Testing of plant and equipment and commissioning of the project, backfill of access declines, removal of construction support sites, landscaping and rehabilitation of disturbed areas and removal of environmental and traffic controls.

Temporary construction support sites would be required as part of the project (refer to Figure 1-3), and would include tunnelling and tunnel support sites, civil surface sites, cofferdams, mooring sites, wharf and berthing facilities, laydown areas, parking and workforce amenities. Construction support sites would include:

- Cammeray Golf Course (BL1)
- Flat Rock Drive (BL2)
- Punch Street (BL3)
- Dickson Avenue (BL4)
- Barton Road (BL5)
- Gore Hill Freeway median (BL6)
- Middle Harbour south cofferdam (BL7)
- Middle Harbour north cofferdam (BL8)
- Spit West Reserve (BL9)
- Balgowlah Golf Course (BL10)

- Kitchener Street (BL11)
- Wakehurst Parkway south (BL12)
- Wakehurst Parkway east (BL13)
- Wakehurst Parkway north (BL14).

A detailed description of construction works for the project is provided in Chapter 6 (Construction work) of the environmental impact statement.

- Middle Harbour north cofferdam (BL8)
- Spit West Reserve (BL9)
- Balgowlah Golf Course (BL10)
- Kitchener Street (BL11)
- Wakehurst Parkway south (BL12)
- Wakehurst Parkway east (BL13)
- Wakehurst Parkway north (BL14).

A detailed description of construction works for the project is provided in Chapter 6 (Construction work) of the environmental impact statement.

- Middle Harbour north cofferdam (BL8)
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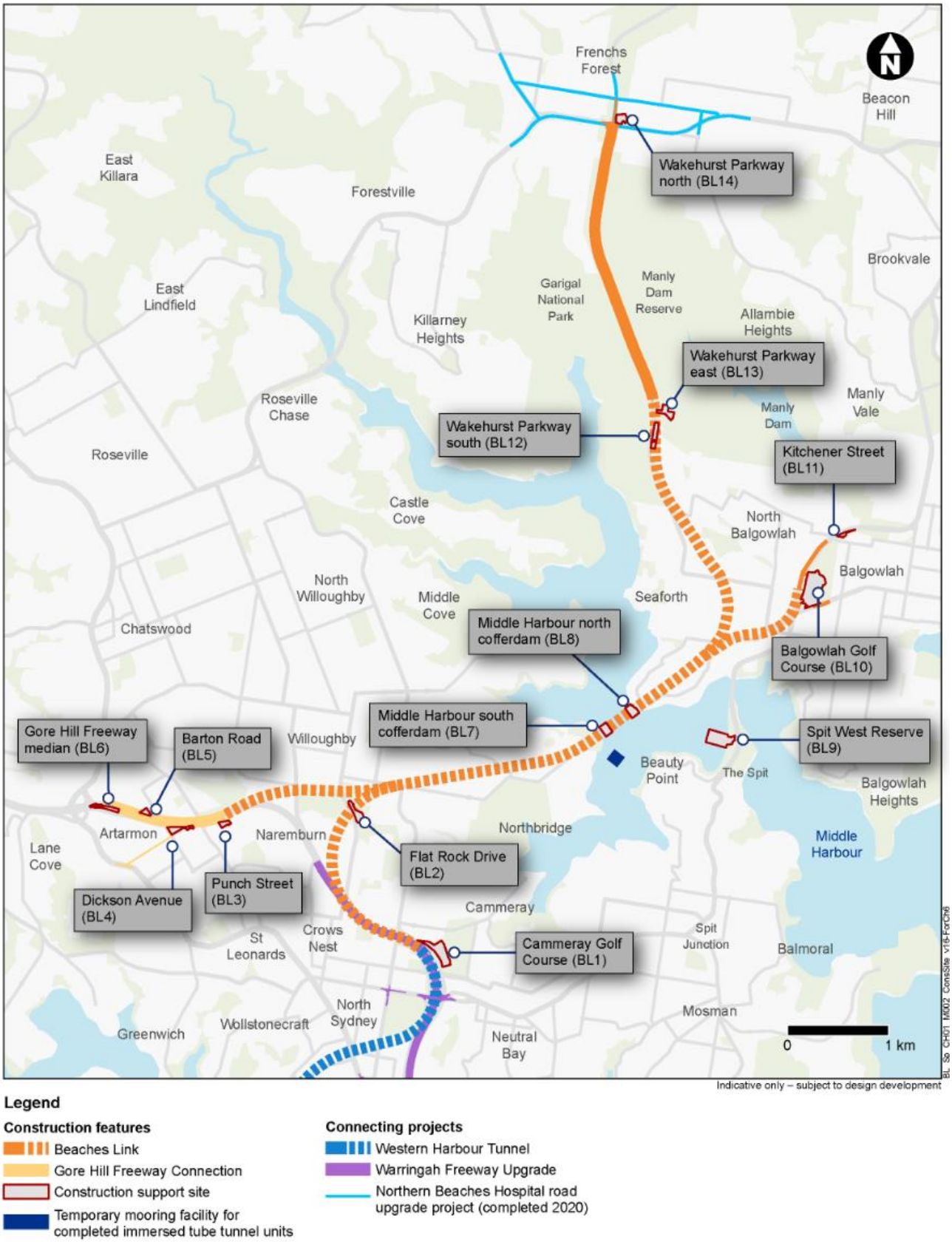

Figure 1-3 Overview of the construction support sites

1.6 Purpose of the report

This report has been prepared to support the environmental impact statement for the project and to address the environmental assessment requirements of the Secretary of the Department of Planning, Industry and Environment ('the Secretary's environmental assessment requirements').

This report described the state of the existing surface freshwater environment and identifies the potential impacts that may arise from the construction and operation of the project and measures to manage the potential impacts. Impacts on marine water quality associated with the project are addressed separately in Appendix Q (Technical working paper: Marine water quality).

Recommendations for water quality monitoring during construction and operation to assess freshwater impacts are also provided. This report should be read in conjunction with Appendix Q (Technical working paper: Marine water quality), Appendix N (Technical working paper: Groundwater) and Appendix M (Technical working paper: Contamination).

1.7 Secretary's environmental assessment requirements

The Secretary's environmental assessment requirements relating to surface water quality and hydrology, and where these requirements are addressed in this report, are outlined in Table 1-1.

Table 1-1 Secretary's environmental assessment requirements – water (hydrology and quality)

Secretary's environmental assessment requirements	Where addressed
9. 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 (GDEs) likely to be impacted by the project, including rivers, streams, wetlands and estuaries as described in Appendix 2 of the *Framework for Biodiversity Assessment – NSW Biodiversity Offsets Policy for Major Projects* (OEH, 2014).	A description of waterways and catchments is presented in Section 4.1 of this report. Refer to Appendix N (Technical working paper: Groundwater) for a description of groundwater resources and Appendix S (Technical working paper: Biodiversity development assessment report) for a description of groundwater dependent ecosystems.
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.	Section 3.4.1, Section 5.1 and Section 6.1 of this report.
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:	Section 5.2 to Section 5.5 of this report for construction phase. Section 6.2 to Section 6.5 of this report for operational phase.
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	Refer to Section 5.4 of this report for construction phase and Section 6.4 for operational phase. Refer to Appendix R (Technical working paper: Flooding) for assessment of impact on flood behaviour including volumes, durations and velocities.

Secretary's environmental assessment requirements	Where addressed
fauna and flora and access to habitat for spawning and refuge;	Refer to Appendix Q (Technical working paper: Marine water quality) and Appendix S (Technical working paper: Biodiversity development assessment report) for assessment of impact on aquatic connectivity, water dependent 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;	Refer to Section 5.4 and Section 5.5 of this report for construction phase. Refer to Section 6.4 and Section 6.5 for operational phase. Refer to Appendix N (Technical working paper: Groundwater) for assessment of impact on groundwater flow, groundwater users and the potential for settlement. Refer to Appendix S (Technical working paper: Biodiversity development assessment report) for assessment of changes on groundwater availability and flows.
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;	Section 5.5 of this report for construction phase and Section 6.5 for operation phase. Refer to Appendix N (Technical working paper: Groundwater) for assessment of changes on groundwater availability and flows.
d) direct or indirect increases in erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses;	Section 5.2 and Section 5.4 for construction phase, and Section 6.2 and Section 6.4 for operational phase. Refer to Appendix S (Technical working paper: Biodiversity development assessment report) for assessment of impact on riparian vegetation.
e) minimising the effects of proposed stormwater and wastewater management during construction and operation on natural hydrological attributes (such as volumes, flow rates, management methods and re-use options) and on the conveyance capacity of existing stormwater systems where discharges are proposed through such systems; and	Refer to Section 5.1, Section 5.3 and Section 8.1 of this report for construction phase. Refer to Section 6.1, Section 6.3 and Section 8.2 of this report for operational phase.
f) measures to mitigate the impacts of the proposal and manage the disposal of produced and incidental water.	Refer to Table 8-1 and Table 8-3.

Secretary's environmental assessment requirements	Where addressed
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.	The details of the final landform, including management and rehabilitation measures, are provided in Chapter 22 (Urban design and visual amenity). Landscape treatments for the project are detailed in Chapter 5 (Project description). The management of voids (shafts and access declines) is detailed in Chapter 6 (Construction work).
5. The Proponent must identify any requirements for baseline monitoring of hydrological attributes.	Refer to Table 8-1 of this report for construction monitoring and Table 8-3 of this report for operational monitoring.
6. The assessment must include details of proposed surface and groundwater monitoring.	Refer to Section 8.1 of this report for construction water quality monitoring. Refer to Section 8.2 of this report of operational water quality monitoring. Refer to Appendix N (Technical working paper: Groundwater) for details of proposed groundwater monitoring.
7. The Proponent must identify design approaches to minimise or prevent drainage of alluvium in the paleochannels.	Refer to Appendix N (Technical working paper: Groundwater).
10. Water – Quality	
1. The Proponent must:	
a) describe the background conditions for any surface or groundwater resource likely to be affected by the development;	Current surface water quality of key waterways with the potential to be affected is described in Section 4.5. Groundwater quality is described in Appendix N (Technical working paper: Groundwater).
b) state the ambient NSW Water Quality Objectives (WQOs) (as endorsed by the NSW Government) and environmental values for the receiving waters (including groundwater where appropriate) relevant to the project, 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;	The water quality guidelines and objectives applied in the assessment of surface water quality are presented in Section 2.2 and Section 4.5. The water quality guidelines and objectives applied in the assessment of marine surface water quality are presented in Appendix Q (Technical working paper: Marine water quality).

Secretary's environmental assessment requirements	Where addressed
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;	Existing groundwater quality is described in Section 5.5 of Appendix N (Technical working paper: Groundwater) and summarised in 5.2 of this report. Discharge points are presented in Figure 5-1. Discharge quantities for construction are described in Section 5.1 and in Section 6.1 for operation. Surface water quality impacts are described within Section 5.2 of this report for construction and Section 6.2 of this report for operation. For marine water quality impacts refer to Section 5 of Appendix Q (Technical working paper: Marine water quality).
d) identify the rainfall event that the water quality protection measures will be designed to cope with;	Operational water quality targets are designed based on pollutant load reduction (rather than a rainfall event) (refer to Section 6.2.1). Construction measures would be designed in accordance with the Blue Book and relevant guidelines (refer to Section 8.1), as well as the design criteria provided in Table 8-2.
e) assess the significance of any identified impacts including consideration of the relevant ambient water quality outcomes;	Refer to Section 4.5, Section 5, Section 6 and Annexure A of this report.
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;	Section 5.2, Section 6.2, Section 7 and Section 8 of this report.
g) justify, if required, why the WQOs cannot be maintained or achieved over time;	Section 4.5 documents the existing water quality which does not meet the current ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines and water quality objectives. Treatment of wastewater to meet ANZG (2018) and ANZECC/ARMCANZ (2000) would maintain or improve existing water quality.
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;	Refer to Section 8 of this report.

Secretary's environmental assessment requirements	Where addressed
i) identify sensitive receiving environments (which may include estuarine and marine waters downstream including Burnt Bridge Creek, Quarry Creek and Flat Rock Creek) and develop a strategy to avoid or minimise impacts on these environments;	Refer to Section 4.2 for sensitive receiving environments. Refer to Section 5.2 and Section 6.2 for assessment of impact on these environments, and Section 8.1 and Section 8.2 for environmental management measures. Refer to Appendix Q (Technical working paper: Marine water quality) for assessment of impacts on marine water quality including environmental management measures.
j) identify proposed monitoring locations, monitoring frequency and indicators of surface and groundwater quality;	A surface water quality monitoring program was implemented for this assessment and it is anticipated that the same monitoring sites and indicators would be monitored in the future (refer to Section 3.2, Annexure A and Annexure B). This would be reviewed during the construction planning phase as prescribed in the mitigation measures outlined in Section 8.1 and Section 8.2.
k) identify how the development meets the objectives of the *Coastal Management Act 2016* and management objectives of relevant Coastal Management Areas defined under the *Coastal Management Act 2016*; and	The objectives of the *Coastal Management Act 2016* are provided in Section 2.1.4. Construction and operation of the project would meet the objectives of the *Coastal Management Act* as discussed in Section 5.6 and Section 0.
l) demonstrate consistency with any relevant certified Coastal Management Program (or Coastal Zone Management Plan).	The Greater Sydney Harbour Coastal Management Plan and Clontarf/Bantry Bay Estuary Management Plan is relevant to this assessment as discussed in Section 2.2.6. The project is consistent with the management objectives of this plan as referred to in Section 5.6 and Section 0.
2. The assessment should consider the results of any current water quality studies, as available, in the project catchment.	Refer to Section 3.1 of this report. Refer to Refer to Appendix N (Technical working paper: Groundwater) for a discussion on current groundwater quality studies.
13. Soils and contamination	
8. The Proponent must assess the impact 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.	Refer to Section 6.2.3 of this report. Refer to Appendix M (Technical working paper: Contamination) for a discussion on soil erosion hazard.

2. Legislative and policy context

2.1 NSW Legislation

The following NSW legislation and statutory requirements are relevant to the assessment of the surface water impacts of the project during construction and operation:

- *Protection of the Environment Operations Act 1997*
- *Water Management Act 2000* and *Water Act 1912*
- Sydney Regional Environmental Plan (Sydney Harbour Catchment) 2005.

2.1.1 Protection of the Environment Operations Act 1997

The *Protection of the Environment Operations Act 1997* (POEO Act) regulates air and water pollution, noise control and waste management.

Section 120 of the POEO Act makes the pollution of waters an offence. Environment protection licences under Chapter 3 of the Act are required for a broad range of activities listed in Schedule 1 of the POEO Act and aim to address water pollution issues created by those activities. The project would involve the construction, widening and re-routing of roads and road tunnel emissions, which are listed as road construction activities in Schedule 1 of the POEO Act. An environment protection licence for road construction and road tunnel emissions would be required for the project.

2.1.2 Water Act 1912 and Water Management Act 2000

The *Water Act 1912* (NSW) and the *Water Management Act 2000* (NSW) (WM Act) are the two key pieces of legislation for the management of water in NSW and contain provisions for the licensing of water access and use. The *Water Act 1912* (NSW) is being progressively phased out and replaced by the WM Act.

The aims of the WM Act are to provide for the sustainable and integrated management of the State's water sources for the benefit of both present and future generations. The WM Act implicitly recognises the need to allocate and provide water for the environmental health of the State's rivers and groundwater systems, while also providing licence holders with more secure access to water and greater opportunities to trade water through the separation of water licences from land. The WM Act enables the State's water resources to be managed under water sharing plans, which establish the rules for the sharing of a particular water source between water users and the environment, and rules for the trading of water in a particular water source.

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 2018 (NSW), roads authorities are exempt from the requirement to hold a water access licence to take water for road construction and road maintenance.

The Water Sharing Plan for the Greater Metropolitan Region Groundwater Source (DPI, 2011) is also relevant to the project and is further discussed in Appendix N (Technical working paper: Groundwater).

2.1.3 Sydney Regional Environmental Plan (Sydney Harbour Catchment) 2005

The Sydney Regional Environmental Plan (Sydney Harbour Catchment) 2005 (Sydney Harbour REP) 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. The Sydney Harbour REP aims to establish a balance between promoting a prosperous working harbour, maintaining a healthy and sustainable waterway environment and promoting recreational access to the foreshore and waterways.

The planning principles for land within the Sydney Harbour Catchment REP as relevant to this assessment are:

- Action is to be taken to achieve the targets set out in *Water Quality* and *River Flow Interim Environmental Objectives: Guidelines for Water Management: Sydney Harbour and Parramatta River Catchment* (published in October 1999 by the Environment Protection Authority), such action is to be consistent with the guidelines set out in *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC/ARMCANZ, 2000)
- Development is to improve the water quality of urban runoff, reduce the quantity and frequency of urban runoff, prevent the risk of increased flooding, and conserve water.

The following points from Division 2 (Matters for consideration) of the Sydney Harbour Catchment REP are also relevant to this assessment:

- Development should have a neutral or beneficial effect on the quality of water entering the waterways
- The cumulative environmental impact of the development.

2.1.4 Coastal Management Act 2016

The previous *Coastal Protection Act 1979* was implemented through a series of coastal zone management plans. However, coastal zone management plans have been superseded by the development of coastal management programs in four areas across NSW as part of the coastal management legislation reform gazetted in the *Coastal Management Act 2016* (CM Act). The four areas are defined in the CM Act as part of the State Environmental Planning Policy (Coastal Management) 2018 (Coastal Management SEPP) (refer to Section 2.2.5). Management objectives are listed in the CM Act which defines the coastal zone as comprising four coastal management areas:

1) Coastal wetlands and littoral rainforests area – land which displays the hydrological and floristic characteristics of coastal wetlands or littoral rainforests and land adjoining those features
2) Coastal vulnerability area – these are areas subject to coastal hazards (such as coastal erosion and tidal inundation)
3) Coastal environment area – land containing coastal features (such as the coastal waters of the State, estuaries, coastal lakes, coastal lagoons and land adjoining those features, including headlands and rock platforms)
4) Coastal use area – land adjacent to coastal waters, estuaries, coastal lakes and lagoons where development is or may be carried out (at present or in the future).

2.2 Water quality guidelines and policies

The water quality assessment has been prepared in accordance with the following key relevant guidelines and policies:

- *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (Australian and New Zealand Governments and Australian state and territory governments) (ANZG, 2018)
- *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (Australian and New Zealand Environment and Conservation Council (ANZECC)/Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), 2000)
- *NSW Water Quality and River Flow Objectives* (NSW Department of Environment, Climate Change and Water (DECCW), 2006)
- *Guidelines for Managing Risks in Recreational Waters* (National Health and Medical Research Council (NHMRC), 2008)
- *Sydney Harbour Water Quality Improvement Plan* (Sydney Metropolitan Catchment Management Authority (SMCMA), 2010)
- *Approved Methods for the Sampling and Analysis of Water Pollutants in NSW* (DECC, 2008)

- *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).

2.2.1 Australian and New Zealand Guidelines for Fresh and Marine Quality

The Australian and New Zealand Environment and Conservation Council (ANZECC/ARMCANZ, 2000) published *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* to provide benchmarks for assessment of the existing water quality of waterways. The guidelines have recently been updated to incorporate new sciences and knowledge developed over the past 18 years (ANZG, 2018). Together they form part of the National Water Quality Management Strategy and list a range of environmental values assigned to a water body.

The ANZG (2018) and ANZG/ARMCANZ (2000) water quality guidelines and objectives to be applied in the assessment of surface water quality are presented in Table 2-1. These guidelines and objectives are dependent on nominated environmental values. The objective adopted for the protection of aquatic ecosystems is "*to maintain and enhance the ecological integrity of freshwater and estuarine ecosystems, including biological diversity, relative abundance and ecological processes.*" Aquatic ecosystems are defined as ecosystems that depend on flows, or periodic or sustained inundation to preserve their ecological integrity (eg rivers, creeks, wetland and groundwater dependent ecosystems (GDEs)).

The ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines provide default trigger values for physical and chemical stressors, and toxicants for rivers, estuaries and lakes in different regions across Australia. Both guidelines continue to be applied for this assessment as the default trigger values for aquatic ecosystems for the relevant geographic region 'Southeast Coast' have not yet been completely updated. These default trigger values are proposed to be applied in the absence of a suitable reference site for water quality trigger values.

ANZECC/ARMCANZ (2000) indicates that the guidelines have not been designed for direct application to discharge criteria. Nonetheless, adopting the relevant triggers values as discharge criteria would be protective of the desired environmental values of the receiving waters.

Table 2-1 Guidelines for Protection of Aquatic Ecosystems (ANZG, 2018 and ANZECC/ARMCANZ, 2000)

Indicator	Freshwater (95% species protection)+	Estuarine (95% species protection) +	Freshwater (90% species protection) ++	Estuarine (90% species protection) ++	Freshwater lakes and reservoirs
Conductivity (µs/cm)	200-300	No guideline	200-300	No guideline	20-30
pH	6.5-8.5	7-8.5	6.5-8.5	7-8.5	6.5-8
Dissolved oxygen (% saturation)	85-110	80-110	85-110	80-110	90-110
Turbidity (NTU)	6-50	0.5-10	6-50	0.5-10	1-20
Total Suspended solids (mg/L)	No guideline	No guideline	No guideline	No guideline	No guideline
Ammonia (µg/L)	20	15	20	15	10
Oxidised nitrogen (µg/L)	40	15	40	15	10
Total nitrogen (µg/L)	350	300	350	300	350
Total phosphorus (µg/L)	25	30	25	30	10
Chlorophyll-a (µg/L)	3	4	3	4	5
Benzene (µg/L)	950	500	1300	900	*
Toluene (µg/L)	180	180	230	230	*
Ethylbenzene (µg/L)	80	80	110	110	*

Indicator	Freshwater (95% species protection)+	Estuarine (95% species protection) +	Freshwater (90% species protection) ++	Estuarine (90% species protection) ++	Freshwater lakes and reservoirs
o – xylene (µg/L)	350	No guideline	470	No guideline	*
m – xylene (µg/L)	75	75	100	100	*
p – xylene (µg/L)	200	No guideline	250	No guideline	*
m+p – xylene (µg/L)	No guideline	No guideline	No guideline	No guideline	*
Bromofluorobenzene	No guideline	No guideline	No guideline	No guideline	*
Dichloroethane	No guideline	No guideline	No guideline	No guideline	*
Manganese (mg/L)	1.9	0.08	2.5	0.08	*
Naphthalene (µg/L)	16	50	37	90	*
Iron (mg/L)	0.7^	0.18^	0.95^	0.34^	*
Arsenic (III) (mg/L)	0.024	No guideline	0.094	No guideline	*
Arsenic (V)	0.013	No guideline	0.042	No guideline	
Cadmium (mg/L)	0.0002	**0.0007**	0.0004	0.014	*
Chromium (mg/L)	0.001	0.0044	0.006	0.02	*
Copper (mg/L)	0.0014	0.0013	0.0018	0.003	*
Nickel (mg/L)	0.011	**0.007**	0.013	0.2	*
Lead (mg/L)	0.0034	0.0044	0.0056	0.0066	*
Zinc (mg/L)	0.008	0.0052^	0.015	0.0089^	*
Silver (mg/L)	0.05	0.1	1.4	1.8	*
Mercury (mg/L)	**0.00006**	**0.0001**	0.0019	0.0007	*

Bolded *values are the 99% species protection limit for toxicants that bioaccumulate*
**90th and 95th percent species protection freshwater guidelines used as there are no freshwater lakes and reservoir guidelines.*
^Draft Default Guideline Value (DGV) (ANZG 2020)
+ 95% species protection limit will be applied during operation of the project (except for toxicants the bioaccumulate, for which the 99% species protection limit will apply)
++90% species protection limit will be applied during construction of the project (except for toxicants the bioaccumulate, for which the 99% species protection limit will apply)

2.2.2 NSW Water Quality and River Flow Objectives

The *NSW Water Quality and River Flow Objectives* (WQOs) (DECCW, 2006) are the agreed environmental values and long-term goals for NSW's surface waters. They are consistent with the agreed national framework for assessing water quality set out in the ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines.

The ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines provide the technical guidance to assess the water quality needed to protect the environmental values set out in the WQOs. The project falls within the Sydney Harbour and Parramatta River Catchment and the Northern Beaches Lagoons Catchment. The waterways relevant to the project have been classified as 'waterways affected by urban development', being: Willoughby Creek, Quarry Creek, Flat Rock Creek, Burnt Bridge Creek, Manly Creek, Trefoil Creek and Manly Dam. Based on this classification, nominated environmental values include protection of aquatic ecosystems, protection of visual amenity and protection of primary and secondary contact recreation.

2.2.3 Guidelines for Managing Risks in Recreational Water (NHMRC, 2008)

The *Guidelines for Managing Risks in Recreational Water* (NHMRC, 2008) aim to protect the health of humans from threats posed by the recreational use of coastal, estuarine and fresh waters.

The guidelines provide recommended values for indicators that may pose a risk to human health. These indicators are relevant for waterways that may be used for recreation and have the possibility of being impacted by runoff during the construction and operation of the project.

2.2.4 Sydney Harbour Water Quality Improvement Plan

The *Sydney Harbour Water Quality Improvement Plan* (Greater Sydney Local Land Services, 2015) (SHWQIP) was developed by Greater Sydney Local Land Services and NSW Office of Environment and Heritage (OEH) in coordination with a range of stakeholders. The SHWQIP provides a coordinated management framework for local councils, State government agencies and Commonwealth government agencies who have an interest in improving the future health of Sydney Harbour and its catchments. This plan applies to the greater portion project footprint which ultimately drains to Sydney Harbour.

The main objective of the SHWQIP "*is to identify threats to water quality in the harbour and its tributaries and to set targets for pollutant load reductions (in terms of total nitrogen, total phosphorus, suspended sediment and pathogens) required to protect the condition and values of the Sydney Harbour, its tributaries, estuaries and waterways. The WQIP is designed to give focus and direction to water quality policy development and on-ground implementation throughout the Sydney Harbour catchment*".

While the SHWQIP does not include pollutant reduction targets for individual developments, catchment load and estuary condition targets have been developed for sub-catchments and local government areas using feasible scenario options for both the management of stormwater and improvements in sewer outflow performance. These targets are based on the following scenario including assumptions of feasible change/actions:

- Water Sensitive Urban Design (WSUD) incorporated into 70 per cent of infill developments
- WSUD retrofitted into 10 per cent of existing urban areas
- Improving sewer overflow performance to limit overflows to no more than 40 events in 10 years.

The targets are designed to provide direction to change rather than being prescriptive of the exact management actions that would be carried out to achieve these goals. It is acknowledged that different scenarios to that assumed above could also achieve the targets.

2.2.5 State Environmental Planning Policy (Coastal Management) 2018

The Coastal Management SEPP updates and consolidates the SEPP 14 (Coastal Wetlands), SEPP 26 (Littoral Rainforests) and SEPP 71 (Coastal Protection) into a single integrated policy.

The Coastal Management SEPP aims to promote an integrated and co-ordinated approach to land use planning in the coastal zone in a manner consistent with the objectives of the CM Act (Refer to Section 2.1.4).

While the SEPP does not apply to the project because of its declared status as State Significant Infrastructure, the sensitivity of areas mapped under the SEPP has been considered in this assessment.

2.2.6 Coastal Zone Management Plans

The study area traverses through the North Sydney, Mosman, Willoughby City and Northern Beaches local government areas. A Clontarf/Bantry Bay Estuary Management Plan (Manly Council, 2008) was endorsed in 2008 which addressed the portion of Middle Harbour estuary and foreshore on the boundary of the former Manly Council local government area (now Northern Beaches Council). However, NSW Local Land Services completed the Greater Sydney Harbour Estuary Coastal Management Program Scoping Study (BMT WBM, 2008) in 2018 to facilitate the development of the Greater Sydney Harbour Coastal Management Program. This program would soon supersede the Clontarf/Bantry Bay Estuary Management Plan (Manly Council, 2008) and provide more coverage over the study area. A vision and objectives were presented in this report that are consistent with the CM Act for inclusion in the development of the Greater Sydney Harbour Coastal Management

Program. The objectives of the program, relevant to surface water quality and references to applicable parts of this and related parts of the environmental impact statement are outlined in Table 2-2.

Table 2-2 Greater Sydney Harbour coastal management program objectives relevant to marine water quality

Coastal management objectives	Consideration
To protect and enhance natural processes and environmental values of the Greater Sydney Harbour coastal zone.	Section 4 (this report) and Appendix T (Technical working paper: Marine ecology) with respect to the protection of environmental values of the estuary.
To support the social and cultural values of the Greater Sydney Harbour and maintain public access, amenity, use and safety.	Section 4 (this report) with respect to the maintenance of the estuary as a public amenity and for public use and safety.

Clontarf Bantry Bay Estuary Management Plan

The project traverses through the Clontarf/Bantry Bay Estuary Management Plan area which was endorsed in February 2008. The plan addressed the portion of Middle Harbour estuary and foreshore within the then Manly Local Government Area border (Manly Council, 2008). It covers an area of approximately 350 hectares and includes the suburbs of Balgowlah Heights, Clontarf and Seaforth, and the Spit Bridge is located halfway between the foreshores of the management plans area.

The Clontarf/Bantry Bay Estuary Management Plan (Manly Council, 2008) has several key management issues and of relevance to this assessment are the following issues (and their respective goals):

- Water Quality and Pollution –ensure that the water quality of the estuary is suitable for maintaining healthy natural aquatic ecosystems, and for recreational pursuits
- Estuary Use – improve and meet the environmental, socio-economic and recreation needs of estuary use
- Aquatic/Intertidal Habitat Conservation Management – restore and maintain a healthy and diverse mix of aquatic and intertidal habitats that will maintain and improve biodiversity and ecological function of the estuary.

The focus of this assessment is to manage water quality and pollution, and in doing so this will work towards achieving the goals associated with estuary use and aquatic/intertidal habitat conservation management.

3. Assessment methodology

The methodology for the assessment of surface water quality and geomorphology is outlined in the following sections and has included:

- Desktop data and literature review of available sources
- Field assessment of geomorphology and water quality monitoring to support and enhance the findings of the desktop analysis and refine the understanding of potential issues during construction and operation
- Classification of sensitive receiving environments and identification of environmental values relevant to the project and assessment of existing geomorphic characteristics
- Assessment of the potential construction and operational impacts relating to water supply, water quality and hydrodynamics
- Identification of appropriate treatment measures to mitigate potential impacts
- Development of construction and operation water management strategies and mitigation.

3.1 Desktop review

The desktop assessment involved a review of existing information that was available for the surface water environment upstream and downstream of the project footprint to understand the existing environment and the potential impacts of the project. The review of information included data collected by Willoughby City Council, North Sydney Council and Northern Beaches Council, as well as the following sources:

- GHD (2015), *Sydney Harbour Catchment Coastal Zone Management Plan Scoping Study*. Literature and Data Review – Management and Use of Sydney Harbour
- Hedge L.H., Johnston E.L., Ayong S.T., Birch G.F., Booth D.J., Creese R.G., Doblin M.A., Figueira W.F., Gribben P.E., Hutchings P.A., Mayer Pinto M, Marzinelli E.M., Pritchard T.R., Roughan M., Steinberg P.D. (2013), *Sydney Harbour: A systematic review of the science*, Sydney Institute of Marine Science, Sydney, Australia
- Lyall and Associates (2017), *Flat Rock Creek Catchment Flood Study and Overland Flow Mapping Volume 1*. Draft Report for Public Exhibition
- Sydney Water (2016), Water Quality Monitoring Program for Willoughby City Council. Spring 2015-Autumn 2016
- The National Atlas of Groundwater Dependent Ecosystems (the GDE Atlas, http://www.bom.gov.au/water/groundwater/gde/) to identify the location and groundwater dependence of surface water systems and vegetation
- DPI (2011) *Water Sharing Plan for the Greater Metropolitan Region groundwater sources 2011*
- Water quality data collected between 2014 and 2016 as part of Transport for NSW's Northern Beaches Hospital road upgrade project (SMEC, 2017).

Existing water quality monitoring data was obtained for six monitoring sites relevant to the project. Monitoring locations are listed in Table 3-1 and shown in Figure 3-1.

A number of guidelines and management procedures relevant to the assessment of surface water quality are presented in Section 2.2, which also describes how these guidelines and procedures have been applied to determine existing water conditions along the project to help identify the appropriate water quality management and mitigations measures for implementation during the construction and operational phases of the project.

Table 3-1 Existing monitoring sites

Site name (refer to Figure 3-1)	Waterway	Data custodian
NSC_QC	Quarry Creek	North Sydney Council
WCC_FR1	Flat Rock Creek downstream	Willoughby Council
WCC_FR2	Flat Rock Creek upstream	Willoughby Council
NBC_BBC	Burnt Bridge Creek at end of Pitt Street	Northern Beaches Council
NBC_MD	Manly Dam (near wall)	Northern Beaches Council
NBC_CC	Manly Creek	Northern Beaches Council
NBC_TC	Trefoil Creek	Northern Beaches Council
SMEC_SW2	Trefoil Creek	Transport for NSW SMEC

3.2 Field assessment

Site visits were carried out to monitor water quality and to visually assess the conditions of the watercourses relevant to the project. Nine monitoring locations were selected and for most locations, monitoring was generally carried out immediately upstream and downstream of the project alignment unless site access was prevented. Additional monitoring was carried out within Manly Dam, which is located downstream of the project, given its importance as a sensitive receiving environment and its use for primary recreation. Sites labelled 'a' were located upstream of the proposed crossing, whereas sites labelled 'b' and (if required) 'c' were located downstream of the proposed crossing. Monitoring locations are listed in Table 3-2 and shown in Figure 3-1.

Table 3-2 Project water quality monitoring sites

Site name (refer to Figure 3-1)	Waterway	Location
2b	Willoughby Creek downstream	Primrose Park, Cremorne
3a	Burnt Bridge Creek upstream	Footbridge Worrobil Street, Balgowlah
3b	Burnt Bridge Creek downstream	Kitchener Street, Balgowlah
5a	Flat Rock Creek upstream	Grandview Street, Naremburn
5b	Flat Rock Creek downstream (upstream of Quarry Creek inflow)	Flat Rock Reserve, Northbridge
5c	Flat Rock Creek downstream (downstream of Quarry Creek inflow)	Tunks Park, Northbridge Suspension bridge
6b	Manly Dam mid (downstream)	Mid dam – Section 4 picnic area, Allambie Heights
6c	Manly Dam downstream	Dam wall, Allambie Heights
7b	Manly Creek downstream	Allambie Heights

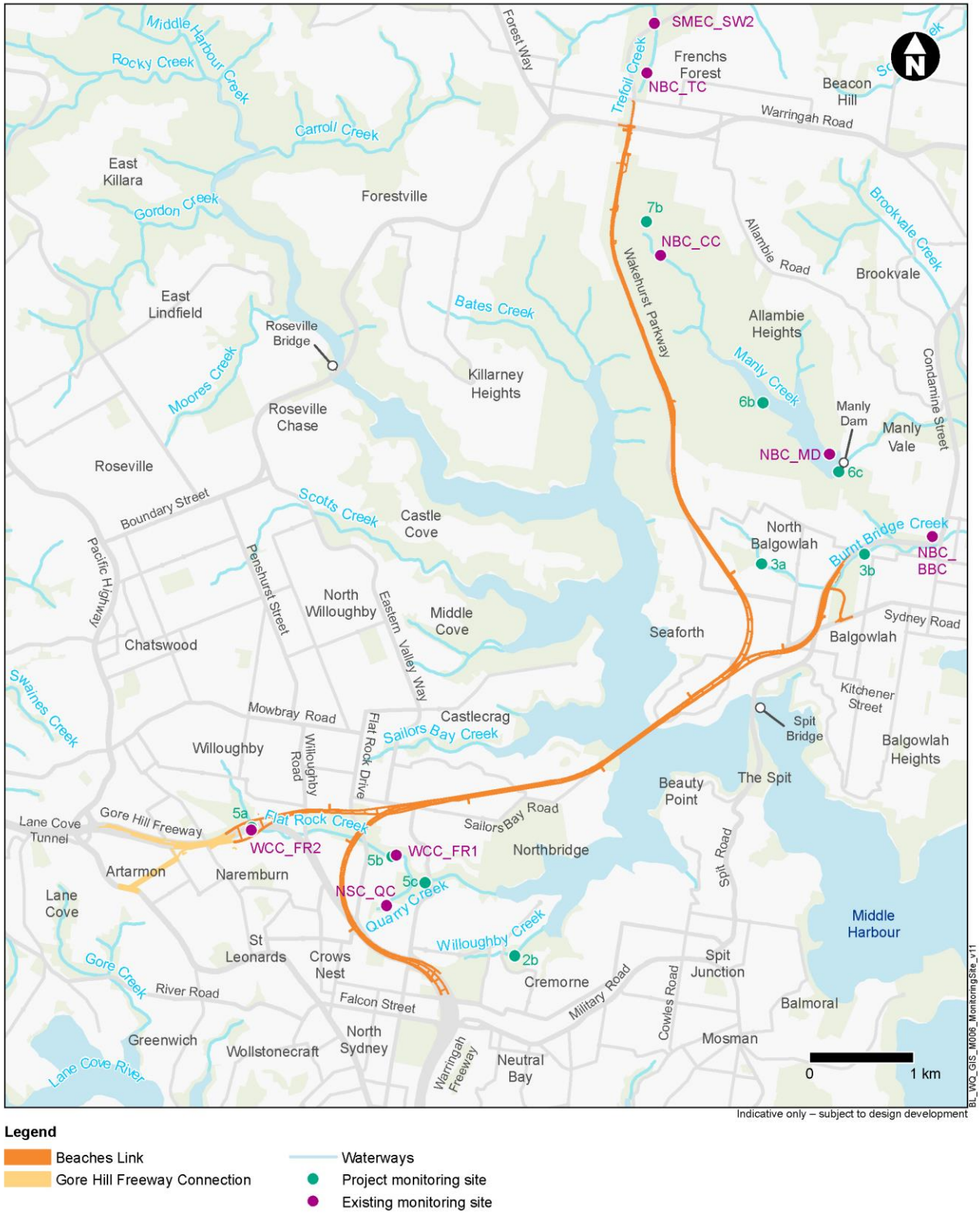

Figure 3-1 Water quality monitoring sites

The monitoring dates for each sampling event are provided in Table 3-3. Dry weather is classified as less than 15 millimetres of rainfall 24 hours before sampling as recorded at the Bureau of Meteorology rainfall gauge (Gauge #066011). Wet weather sampling is classified as 15 millimetres or more of rainfall recorded at the same gauge 24 hours before sampling. It was anticipated that monitoring would comprise three dry weather and three wet weather events conducted between October 2017 and January 2018 however, due to antecedent dry weather conditions, only one wet weather event was captured. The data is sufficient for the purposes of this assessment however, additional monitoring would be required to update the baseline condition closer to construction.

Table 3-3 Monitoring dates and event type (dry/wet)

Date	Dry/Wet	Rainfall (preceding 24 hours)
31 October – 1 November 2017	Dry	0mm
21 – 22 November 2017	Dry	0mm
14 – 15 December 2017	Dry	0mm
9 January 2018	Wet	28mm
18 – 19 January 2018	Dry	0mm
1 – 2 February 2018	Dry	0mm

Water quality was monitored in-situ and with grab samples. In-situ water quality parameters, temperature, conductivity, salinity, pH and dissolved oxygen, were measured using a calibrated YSI Pro Plus multi-parameter water quality meter. Turbidity was measured using a Hach turbidimeter.

Measurements were generally collected between 15 and 30 centimetres below the surface depending on the depth of water. Sampling depth was recorded in the field. For each parameter measured in-situ, three replicate measurements were recorded about 10 metres apart from the access point to the site. Each parameter was then reported as the average (arithmetic mean) of the three measurements (refer to Annexure A).

Grab samples were also collected at each site and sent to the laboratory for analysis. The analytical suite for laboratory analysis included:

- Chlorophyll-*a*
- Total nitrogen
- Total phosphorus
- Total suspended solids
- Total metals (arsenic, cadmium, chromium, copper, lead, nickel, zinc, mercury, manganese and iron)
- Organic compounds (BTEX and TRH).

Water quality data collected during the monitoring program would be used to establish a benchmark for discharge quality from water treatment plants during construction planning.

3.3 Site classification

3.3.1 Sensitive receiving environments

Sensitive receiving environments were identified using aquatic habitat as an indicator, which was assessed against the Department of Planning, Industry and Environment's *Policy and Guidelines for Fish Habitat Conservation and Management* (NSW DPI, 2013) and *Fish Passage Requirements for Waterway Crossings* (Fairfull and Witheridge, 2003). Sensitive receiving environments are identified based on the following considerations:

- Key fish habitat (NSW DPI, 2013)
- Records of threatened species listed under the *Fisheries Management Act 1994* and *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)

- Groundwater and surface water dependent vegetation and fauna communities listed under the *Biodiversity Conservation Act 2016* (BC Act) and *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)
- State Environmental Planning Policy (Coastal Management) 2018 and Ramsar Wetlands
- Whether the catchment falls within a drinking water catchment
- Areas that contribute to aquaculture and commercial fishing
- Activities and decisions made upstream affect water quality downstream, particularly the cumulative impacts of nutrients and sediment.

Willoughby Creek, Quarry Creek, Flat Rock Creek, Burnt Bridge Creek, Manly Creek, Many Dam, Trefoil Creek and Bantry Bay are the downstream receiving environments relevant to this assessment. The water quality within these waterways is integrally linked to the level of pollutants that are discharged from the highly urbanised catchment. Catchment runoff can result in elevated nutrient levels and subsequent algal blooms, which are undesirable given the proximity to popular recreation areas surrounding Middle Harbour and Manly Dam.

3.3.2 Environmental values

Environmental values are values or uses of the environment that are important for a healthy ecosystem or for public benefit or health. They are values that require protection from the effects of pollution and waste discharges (ANZECC/ARMCANZ, 2000). The Department of Planning, Industry and Environment (Environment, Energy and Science) nominated several environmental values for the Sydney Harbour and Parramatta River Catchment and the Northern Beaches Lagoons Catchment and relevant indicators and guideline levels which are used in protecting the environmental value (DECCW, 2006).

The relevant recognised environmental values for the purposes of this assessment, include:

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

3.3.3 Water quality criteria

As identified in the Secretary's environmental assessment requirements, the desired performance outcome for the project in relation to surface water quality is that:

"The project is designed, constructed and operated to protect the NSW Water Quality Objectives (WQOs) where they are currently being achieved, and contribute towards achievement of the WQOs over time where they are currently not being achieved, including downstream of the project to the extent of the project impact including estuarine and marine waters (if applicable)".

The assessment included consideration of the performance of the project against the water quality guidelines and objectives outlined in Section 2.2 and provided in Table 2-1. The performance against these objectives during construction and operation is presented in Section 5.2.3 and Section 6.2.5, respectively.

3.4 Approach to the assessment of potential impacts

3.4.1 Water balance

A water balance was prepared for both the construction and operation of the project taking into consideration water supply sources (including groundwater, harvested rain water, treated project water, and municipal supplies), project water demands during construction and operation, and surplus water requiring discharge after treatment.

Modelled groundwater inflows presented in the Appendix N (Technical working paper: Groundwater) have been apportioned to each wastewater treatment plant and rooftop harvested rainfall has been estimated at temporary construction support site buildings and permanent ancillary infrastructure buildings.

The potential for the re-use of treated groundwater and rainwater has been assessed with respect to the project's water usage estimations to provide an approximate supply and demand balance.

3.4.2 Assessment of construction impacts

The assessment of the potential impacts during construction involved:

- Identification of construction activities that have the potential to mobilise sediments and other pollutants to the surface water environment, and the assessment of the potential impacts to the water quality of downstream receiving environments
- Assessment of the potential impacts of construction wastewater treatment plant discharges into receiving environment on water quality. For this assessment:
  - The pollutants likely to be present in each wastewater treatment plant catchment were used to undertake the assessment (refer to Appendix N (Technical working paper: Groundwater))
  - The ANZG (2018) and ANZECC/ARMCANZ (2000) water quality guidelines were used regarding the relevant environmental objectives of aquatic ecosystems, visual amenity and primary and secondary contact recreation
- Assessment of geomorphology impacts resulting from the construction wastewater treatment plants. This assessment was based on field work observations and the two-year ARI event flow rates for each waterbody to establish whether the proposed treated discharges would alter the geomorphology of the receiving watercourse
- Assessment of the potential impact of environmental water availability, including changes due to impacts to surface creek baseflows as a result of groundwater drawdown
- Assessment of changes to the North Sydney Council stormwater harvesting scheme during construction
- Identification of appropriate treatment measures to mitigate the impact of the construction phase of the project.

3.4.3 Assessment operational impacts

The assessment of the potential impacts during operation involved:

- Identification of operational infrastructure or activities that have the potential to mobilise sediments and other pollutants to the surface water environment, and the assessment of the potential impacts on the water quality of downstream receiving environments
- Assessment of the potential impacts on water quality of operational wastewater treatment plant discharges into receiving environment
- Assessment of potential geomorphological impacts on creeks due to wastewater treatment plant discharges, subsidence and changes to baseflows as documented in Appendix N (Technical working paper: Groundwater). Baseflow impacts are modelled conservatively without tunnel linings designed and installed to reduce groundwater inflows into the tunnels. Due to conservative modelling assumptions, baseflow impacts are likely to be lower than that predicted in Appendix N (Technical working paper: Groundwater).

- Assessment of changes to the North Sydney Council stormwater harvesting scheme during operation
- Identification of appropriate treatment measures to mitigate the impact of the operational phase of the project.

3.4.4 Assessment of cumulative impacts

The assessment of surface water cumulative impacts involved:

- Identification of major projects that are likely to overlap with the project
- Identification of common sensitive receivers for each project, and assessment of likely cumulative impacts
- Identification of mitigation measures.

4. Existing environment

4.1 Waterways and catchments

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

Sydney Harbour and Parramatta River Catchment is a drowned river valley characterised by steep-sided banks which are eroded up to 85 metres into the Hawkesbury Sandstone and overlying Ashfield Shale (NSW Department of Mineral Resources, 1983). Sea level rise flooded the valley about 17,000 years ago, forming a flood tide delta – the Sydney Harbour estuary. The configuration of the Sydney Harbour estuary catchment drainage system and the orientation of bays and shorelines are controlled by geologic structures (faults and fractures) (Hedge et al., 2013). The catchment comprises both natural and urban landscapes rich in cultural, geological and biological diversity and heritage. The catchment covers Sydney harbour, the Parramatta and Lane Cove Rivers and Middle Harbour.

The Sydney Harbour and Parramatta River Catchment spans over 25 local government areas. It is a highly urbanised catchment (86 per cent) which results in rapid runoff during high precipitation events. The downstream catchment is tidal with tides in the harbour being semidiurnal, reversing every six hours (GHD, 2015).

The Northern Beaches Lagoons Catchment consists of Narrabeen Lagoon and catchment, Dee Why Lagoon and catchment, Curl Curl and Manly lagoons and their catchments and Manly Dam (within the Manly Lagoon catchment). Relevant sub-catchments to the project include Narrabeen Lagoon, Manly Lagoon and Manly Dam. Narrabeen Lagoon is the largest of the coastal lagoons within the Northern Beaches local government area and an important environmental and recreational area (SMEC, 2011). Manly Lagoon is a small shallow coastal lagoon in the Northern Beaches local government area in is considered of poor water quality due to local pollution sources including urban stormwater runoff, sewage overflows, former landfill leachate and illegal discharge and dumping of industrial and trade waste (Cardno, 2010). Manly Dam is discussed in Section 4.1.5.

The main bodies of water near the project are the Middle Harbour estuary and the freshwater Manly Dam. The main waterways and catchments with the potential to be impacted by the project are shown in Figure 4-1 and described in the following sections.

The project and surroundings are dominated by residential areas (ranging from low to high density), with some industrial and commercial developments within the suburbs of Artarmon, St Leonards and Willoughby. In the northern end of the project, the Garigal National Park (and Bantry Bay) and Manly Dam War Memorial Park are located to the west and east of Wakehurst Parkway respectively.

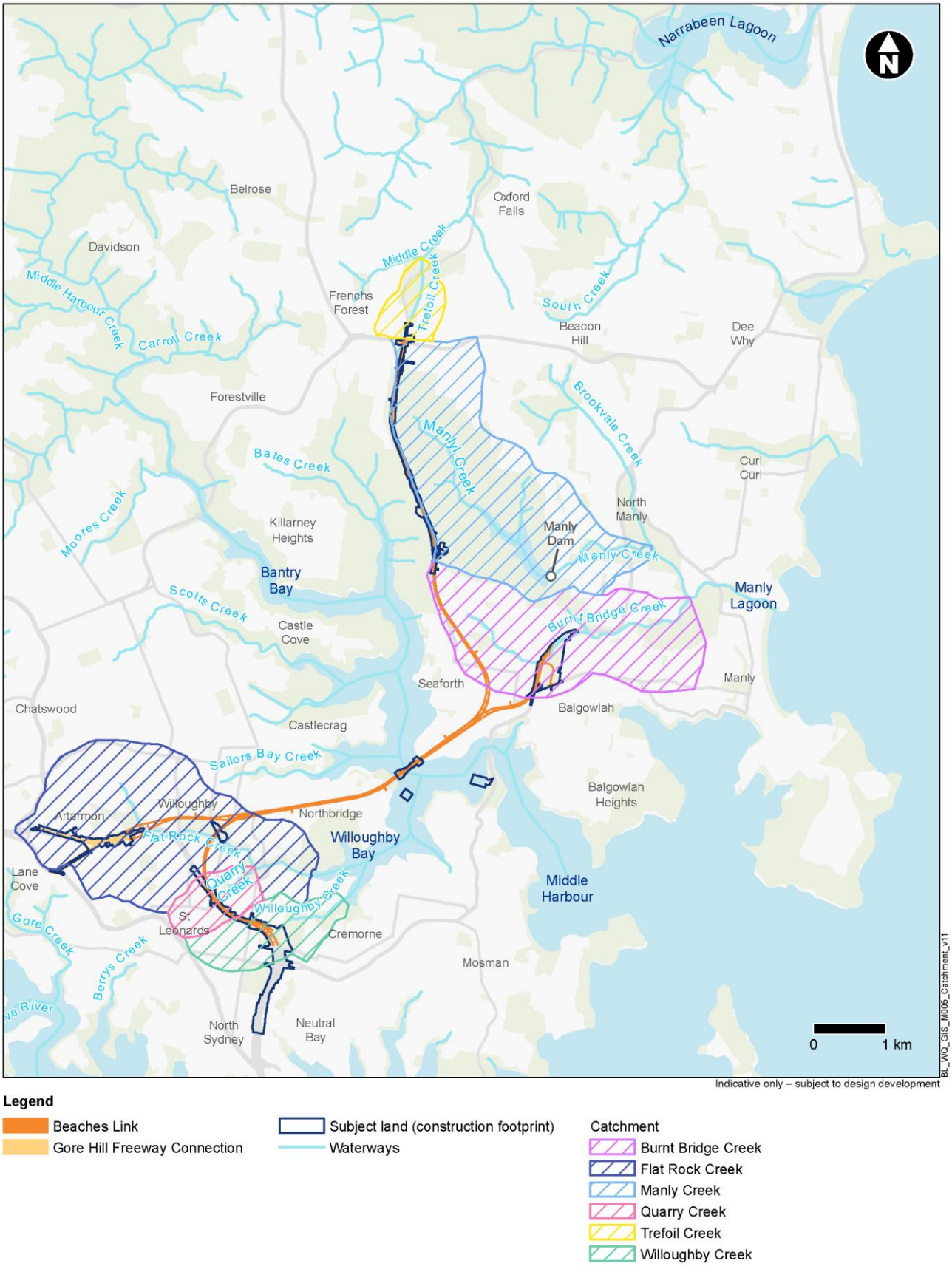

Figure 4-1 Waterways and catchments

4.1.1 Willoughby Creek

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 (Figure 4-2). Willoughby Bay and Long Bay are popular boating and swimming areas for local residents. The development of impervious surfaces within the catchment has increased the volume and rate of runoff, which has in turn necessitated flood mitigation measures primarily in the mid and upper catchment. Semi-natural channel morphology exists within sections where the presence of bedrock has negated the need for channel stabilisation initiatives. There are no GDEs recorded within 500 metres of Willoughby Creek (BoM, 2018).

Figure 4-2 Willoughby Creek, Primrose Park. Looking downstream (left photo) and pooling under dry waterfall (right photo)

4.1.2 Quarry Creek

Quarry Creek is a small natural estuarine tributary of Flat Rock Creek, which drains Cammeray and has a history of being quarried for sandstone. The creek has steep embankments on both sides now densely vegetated by weeds and has limited accessibility (Figure 4-3). Limited site access has prevented assessment of Quarry Creek however it is likely to have similar geomorphic conditions to the downstream extents of Flat Rock Creek, with a steep catchment characterised by bedrock steps and rocky riffle/runs with low to moderate flow during dry weather. The Coastal Sandstone Gully Forest GDE is recorded as extending along the entirety of Quarry Creek (BoM, 2018).

Figure 4-3 Quarry Creek steep bedrock steps upstream and likely transition to rocky riffle/runs downstream

4.1.3 Flat Rock Creek

The Flat Rock Creek catchment has a total area of about seven square kilometres and includes the suburbs of Artarmon, Willoughby, Naremburn, Northbridge, St Leonards, Cammeray and Crows Nest. Flat Rock Creek is the main waterway in the catchment predominantly comprising low to medium density (with some high density), residential, commercial and industrial uses. Areas of open space within the catchment include Gore Hill Oval, Talus Reserve, Naremburn Park, Artarmon Reserve, Bicentennial Reserve and Tunks Park (Lyall and Associates, 2017). There are minor named and unnamed tributaries that drain to Flat Rock Creek including two on the southern side and three on the northern side (Lyall and Associates, 2017).

The natural drainage characteristics of the Flat Rock Creek catchment have been altered by residential, commercial and industrial development. The creek is predominantly a concrete-lined (open and closed) stormwater channel draining the suburbs of Artarmon, Naremburn and Willoughby. The channel travels underground from between Grandview Drive at Naremburn and Flat Rock Drive at Willoughby and has low flows during dry weather (Figure 4-4). Flat Rock Creek at its downstream reach drains a relatively steep catchment characterised by rocky riffle/runs with low to moderate flow during dry weather (Figure 4-5).

The substrate consists primarily of bedrock and boulders and riparian vegetation both native and exotic (Sydney Water, 2016). The end point is a tidally influenced naturalised estuary at the base of Flat Rock Gully discharging into Long Bay (Figure 4-6). The downstream reaches are surrounded by native coachwood forests with popular walking tracks and give access to large sporting fields at Tunks Park, Cammeray. In its original state, this area would have contained mangrove thickets and mudflats (NSC, 2003).

An overview of the surface lining conditions of Flat Rock Creek is provided in Figure 4-7.

Flat Rock Reserve at its upstream extent (where the creek is installed within an underground box culvert between Willoughby Road, Willoughby and 150 metres east of Flat Rock Drive, Northbridge (refer to Figure 4-7 Surface lining of Flat Rock Creek)) was previously a council waste disposal site in the 1930s. In 1934, the Walter Burley Griffin Incinerator was built, with ash generated from the incineration of refuse deposited until the incinerator was closed in 1967 when it became obsolete. From the 1940s, industrial and domestic waste was tipped and burnt in the area on both sides of Flat Rock Drive and into Flat Rock Reserve, which ceased in 1985 when it was deposited with mixed household and industrial waste and soil fill.

Appendix S (Technical working paper: Biodiversity development assessment report) notes GDEs mapped as 'moderate to high potential for terrestrial GDE' at the lower reaches of Flat Rock Creek at Munro Park. Ecosystems mapped include Coastal Sandstone Gully Forest and Sandstone Riparian Scrub Coastal Sand Forest.

Figure 4-4 Flat Rock Creek: concrete-lined stormwater channel (left photo) and point where creek begins to flow underground (right photo)

Figure 4-5 Flat Rock Creek: boulder strewn bed (left photo) and riffle/run formation (right photo)

Figure 4-6 Flat Rock Creek: lower estuarine section

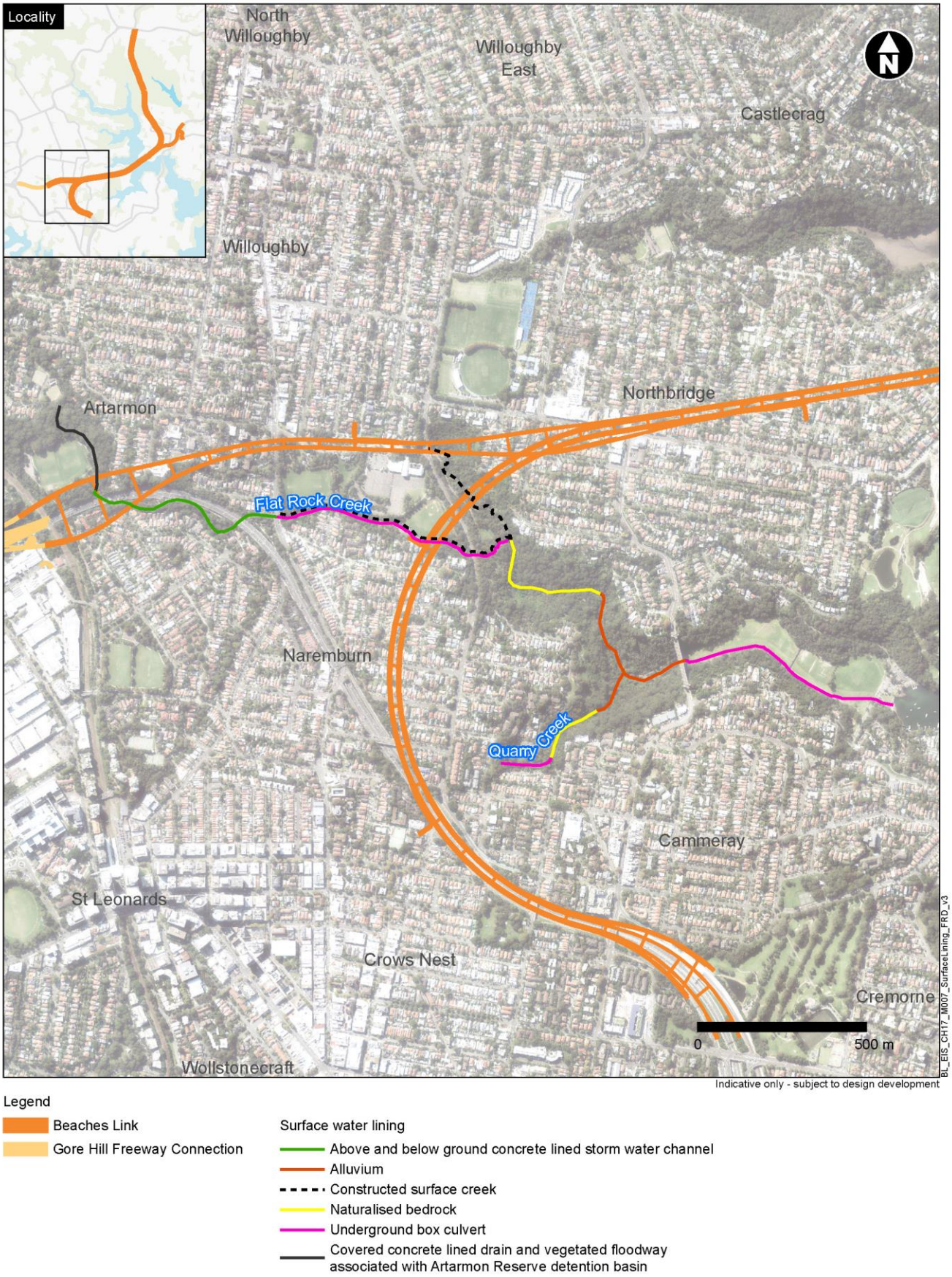

Figure 4-7 Surface lining of Flat Rock Creek

4.1.4 Burnt Bridge Creek

The Burnt Bridge Creek catchment has a total area of over 3.8 square kilometres and is situated on a plateau at Seaforth, North Balgowlah and Balgowlah about 120 to 130 metres above sea level. The catchment contains a wide variety of land-uses including residential areas, the Balgowlah Industrial Estate, two golf courses and roads.

Burnt Bridge Creek is an urban, intermittent waterway which flows through Seaforth, North Balgowlah, Balgowlah and Manly Vale into Manly Lagoon. Burnt Bridge Creek is a freshwater, first order stream which receives stormwater from the surrounding urban development at multiple locations along its length. The freshwater creek runs for about four kilometres and is a vital ecological corridor of regenerated habitat that provides a range of important habitats for a diversity of local flora and fauna. The main soil landscapes are Lambert and Hawkesbury which have very high to severe erosion potential (UWS, 2004). The section of the creek immediately downstream of the project's Burnt Bridge Creek Deviation surface road works has been highly modified over time for adjacent construction works which have included original Burnt Bridge Creek Deviation surface road works, trunk sewer line works within the invert of the creek and earthworks and drainage works to form and shape the present golf course layout.

The creek is in parts naturalised with rock, sand and mud substrate with narrow vegetated buffer zones (Figure 4-8). There are also a number of constructed waterway crossings, concrete and rock fill structures (including rock gabion structures and constructed rock walls) along the course of the creek (Figure 4-9). There is a shared user path running from Clontarf Street Seaforth to Manly along the revegetated corridor under the deviation.

An overview of the surface lining conditions of Burnt Bridge Creek is provided in Figure 4-10.

The creek has been substantially degraded over the years largely due to the pressures generated from urban areas including a dense sewage system network and many stormwater outlets discharging to the creek (UWS, 2004). It is expected that increased stormwater runoff has contributed to the loss of coarse and fine-grained sediments from the channel, leaving a scoured bedrock bed and eroded mud banks. This has resulted in Burnt Bridge Creek suffering from poor water quality (from stormwater and wastewater overflows), extensive weed infestation, erosion of creek banks, build-up of sediment and reduced biodiversity. To manage the impact of stormwater pollution on downstream waterways, the Balgowlah Golf Course Stormwater harvesting Dam was installed in 2013. Since then, pollutant loads into Manly Lagoon have been reduced and allowed the golf course to extract water from the dam rather than Burnt Bridge Creek allowing creek water to remain as environmental flows which has improved the ecological conditions in the creek (Manly Council, 2014).

Surface runoff discharging into Burnt Bridge Creek between Burnt Bridge Creek Deviation and north of Kitchener Street currently does not receive any water quality treatment. The section of creek through the golf course has been modified with water flow controlled via a weir and the creek realigned in the past for the deviation. It is known to experience hazardous flooding and has channel velocities of 7.7 metres per second downstream of Kitchener Street (Lyall & Associates, 2020).

Figure 4-8 Burnt Bridge Creek: upstream at Worrobil Street, Balgowlah (left photo) and downstream at Kitchener Road crossing (right photo)

Figure 4-9 Burnt Bridge Creek: concrete stormwater outfalls (top left photo), constructed rock and concrete walls at Kitchener Road crossing (top right photo) and riparian vegetation downstream of proposed culvert showing previous disturbance caused by sewer pipeline and associated pit installation (bottom photo)

Figure 4-10 Surface lining of Burnt Bridge Creek

4.1.5 Manly Dam

Manly Dam drains a catchment of 5.11 square kilometres which is largely classified as open space, of which 78 per cent is bushland cover. The catchment contains some commercial and industrial areas and residential areas (to the north and north east) (UWS, 2004) which only amount to 10 per cent impervious cover. The catchment is bounded by major roads and has both a stormwater and wastewater network (including three wastewater overflows within it). Many Dam was built in 1892 as a water supply dam for the Manly area, and at times neighbouring suburbs where it supplied drinking water up until 1933, although was briefly used in 1942 during a period of drought (OEH 2020). Manly Dam and its catchment are now used primarily for public recreation.

The Manly Dam catchment is characterised by sandstone slopes, rock platforms and gullies, although there are some shale areas (Figure 4-11). Over half of the catchment has gradients steeper than 10 degrees and soils have very high to severe erosion potential (UWS, 2004). The steep terrain and urban interface has created challenges in the management of the dam's water quality including blue-green algal blooms, largely due to external nutrient loading from various catchment activities (UWS, 2004).

Manly Dam is one of the largest freshwater lakes in Sydney which currently provides a valued facility for swimming, fishing, water-skiing, canoe/kayaking and boating. The gully/creeks contributing to the dam and the dam water body is unlikely to be susceptible to increased flows associated with the construction and operation of the project, given the bedrock controls and the anticipated small increase in flows relative to the range of flows that the gully/creeks experience during storm events.

There is moderate potential for Coastal Sandstone Gully Forest GDE to be located on the east and west banks at the mount of Manly Dam (BoM, 2018). There is also high potential for Sandstone Gully Forest GDE downstream on the east bank. The Coastal Sandstone Plateau Heath GDE also has moderate potential to be present in areas to the north of the Manly Dam wall. Immediately downstream of the dam, the creek is polluted and heavily infested with weeds.

Figure 4-11 Manly Dam vegetated hillslopes (left) and sandstone shoreline (right)

4.1.6 Manly Creek

Manly Creek (previously known as Curl Curl Creek) catchment drains the urban areas of Frenchs Forest and flows into Manly Dam via War Memorial Park. The channel is formed of bedrock shelves, boulder and cobble runs and riffles, and pools that hold some sediment (Figure 4-12). The channel is generally two to three metres wide except at the ford where it is 20 metres wide and banks are generally low and stable (OEH, 2016). During storm events the creek is likely to experience high velocity flows. Riparian vegetation creates greater bank stability however, natural scouring of bed and banks is likely to occur during high rainfall events. The creek is unlikely to be susceptible to increased flows associated with the construction and operation of the project, given its bedrock controls and the anticipated small increase in flows relative to the range of flow that the creek experiences during storm events.

Groundwater dependent ecosystems have been recorded downstream at Manly Creek (BoM, 2018), including the potential habitat for the Red-crowned Toadlet. There is low potential for Coastal Sandstone Plateau Heath GDE around 120 metres east of Manly Creek and moderate potential for Costal Sandstone Gully Forest GDE where Manly Creek discharges into Manly Dam (BoM, 2018).


Figure 4-12 Manly Creek: bedrock shelves (left) and pool (right)

4.1.7 Trefoil Creek

Trefoil Creek is around 850 metres in length and drains to the north through the suburbs of Frenchs Forest and Oxford Falls. The creek crosses underneath the Wakehurst Parkway before discharging into Middle Creek which is the main waterway flowing to Narrabeen Lagoon. The area consists of low density housing and substantial bushland surrounding the Wakehurst Parkway which is susceptible to flooding and road closures. Trefoil Creek is a natural waterway engorged through a gully located near the corner of Frenchs Forest Road and the Wakehurst Parkway. The creek line is narrow; less than one metre in width; characterised by dense native and exotic vegetation; sediment substrate and rocky outcrops (Figure 4-13). Potential habitat for the Red-crowned Toadlet exists along Trefoil Creek (GHD, 2015).

The natural drainage upstream in Trefoil Creek has been altered as a result of runoff flowing from Frenchs Forest Road. During dry weather, flows are very low however, increased flows are also likely to occur during storm events. The gully/creek has been susceptible to increased sediment runoff associated with the construction and operation of the Northern Beaches Hospital road upgrade project.

Figure 4-13 Trefoil Creek: Upper reaches

4.1.8 Drainage catchments

Some surface works would be located on catchments dominated by drainage lines rather than watercourses. Surface works that would be located on drainage catchments are:

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

4.2 Sensitive receiving environments

As shown in Figure 4-1, Willoughby Creek, Quarry Creek, Flat Rock Creek, Burnt Bridge Creek, Manly Creek, Manly Dam and Trefoil Creek are the main waterways relevant to the project. All these watercourses, except for Willoughby Creek and Burnt Bridge Creek, are considered sensitive receiving environments.

Willoughby Creek, Quarry Creek and Flat Rock Creek drain to Middle Harbour, which is also considered a sensitive receiving environment. Marine water quality is discussed in Appendix Q (Technical working paper: Marine water quality).

Willoughby Creek is a highly urbanised stormwater channel that drains underground through Cammeray Golf Course and then via concrete pipes and channels down the escarpment and through Primrose Park into Middle Harbour. The creek contains limited natural features such as entrenched bedrock substrate with pools and overhanging vegetation. These features would classify the creek as 'Type 3 minimally sensitive Key Fish Habitat'. The creek is not considered a sensitive receiving environment.

Flat Rock Creek was assessed at three locations to determine if it is a sensitive receiving environment. Upstream of the alignment (site 5a), Flat Rock Creek is concrete stormwater channel with very limited riparian habitat. Downstream of the alignment, Flat Rock Creek (site 5b) is freshwater and situated within a steep predominantly bedrock gorge. Further downstream Flat Rock Creek (site 5c) becomes a tidally influenced estuarine habitat where Quarry Creek tributary meets Flat Rock Creek. Emergent macrophytes, bank undercutting, dense overhanging vegetation and instream woody debris were identified as potential fish refuge. One GDE (Coastal Sandstone Gully Forest) has been identified within 500 metres of the downstream receiving environment. As such, downstream Flat Rock Creek and Quarry Creek are both characterised as 'Type 1' highly sensitive Key Fish habitat according to *the Policy and Guidelines for Fish Habitat* (DPI, 2013) and classified as sensitive receiving environments.

Burnt Bridge Creek is a freshwater, first order stream receiving multiple inflows of stormwater. Upstream, the waterway consists of a natural bedrock and mud substrate, while downstream it is a highly modified bedrock entrenched channel with rock fill on the on the embankments. Burnt Bridge Creek is considered 'Type 2' moderately sensitive Key Fish Habitat (DPI, 2013) due to the limited aquatic habitat and urbanisation of the channel. It is not considered a sensitive receiving environment.

Manly Creek is located downstream of the alignment and was assessed at one location (Site 7b). It is a first order stream which flows directly into Manly Dam. Manly Creek is considered 'Type 1', highly sensitive Key Fish Habitat (DPI, 2013) due to potential fish refuge such as submerged woody debris, residual pools and the creek's location within Garigal National Park protected area. The Coastal Sandstone Gully Forest GDE is within 100 metres of Manly Creek. Additionally, there are some patches of Coastal Upland Swamp located in catchments on the eastern side of Wakehurst Parkway. These fall within the endangered ecological community Coastal Upland Swamp in the Sydney Basin Bioregion, as listed under the *NSW Biodiversity Conservation Act 2016*. As such, Manly Creek is considered a sensitive receiving environment. A small section of Garigal National Park is located within 500 metres of the headwaters of Manly Creek, situated on the western side of the Wakehurst Parkway. Topographically Manly Creek flows down a south eastern slope away from the national park.

Manly Dam was monitored at two locations (Site 6b and 6c). Manly Dam is considered 'Type 1', highly sensitive Key Fish Habitat (DPI, 2013) due to potential fish refuge such as submerged woody debris and residual pools The Coastal Sandstone Gully Forest GDE is within 100 metres from Manly Dam. As such, it is considered a sensitive receiving environment.

Trefoil Creek is a freshwater ephemeral stream, about 850 metres in length which drains to the north of the alignment via Middle Creek into Narrabeen Lagoon. Potential habitat for the Red-Crowned Toadlet has been identified in the headwaters of Trefoil Creek. The headwaters are located within 300 metres of the end of the project's upgrade road works on the Wakehurst Parkway. Due to the Red-Crowned Toadlet being listed as Vulnerable under the *NSW Biodiversity Conservation Act 2016*, Trefoil Creek is considered a sensitive receiving environment.

The Wakehurst Parkway surface road works would be located to the east of Garigal National Park. National Park land slopes towards Bantry Bay. There are no named waterways at this location but several drainage lines.

Littoral rainforests and the Proximity Area for Littoral Rainforest are located within 500 metres of the mainline tunnel at Seaforth, Middle Harbour. Coastal Wetlands and the Proximity Area for Coastal Wetlands are located approximately one kilometre from the surface connections at Balgowlah. Coastal Wetlands and the Proximity Area for Coastal Wetlands are also located within 500 metres of the Wakehurst Parkway at Bantry Bay in Garigal National Park. Figure 4-14 shows the location of the littoral rainforests and coastal wetlands (including proximity areas) in relation to the project.

Figure 4-14 Littoral rainforest and coastal wetlands

4.3 Environmental values

Environmental values have been assigned to each waterway and will be used to determine existing water quality (Table 4-1). Aquatic ecosystems and visual amenity apply to all waterways within 500 metres upstream and downstream of the project footprint. Flat Rock Creek and Manly Creek walking tracks are situated close to the creek banks and rock crossings occur through the watercourse. Secondary contact recreation guidelines would apply for all waterways except for Burnt Bridge Creek which is a stormwater channel with little accessibility.

Long Bay is a popular boating area where people are frequently in direct contact with the water and downstream of Flat Rock Creek. Similarly, Manly Dam is used for swimming and water-skiing which are considered primary contact recreational activities. The water quality of each of the waterways with the potential to be impacted is discussed below. The results of the water quality monitoring conducted for the project at each waterway are presented in Annexure A.

Table 4-1 Assigned environmental values for waterways

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

4.4 Existing water quality infrastructure for road pavement runoff

4.4.1 Warringah Freeway

Drainage from the existing Warringah Freeway road surface and nearby road networks in North Sydney currently discharge to existing council drainage systems, ultimately discharging to Sydney Harbour or Middle Harbour. The existing stormwater drainage systems collect runoff from substantial upstream urban areas within North Sydney and Willoughby councils and discharge to the harbours.

The existing Warringah Freeway does not currently have any specific spill risk management devices.

4.4.2 Gore Hill Freeway

Drainage from the existing Gore Hill Freeway currently discharges to existing water quality basins located at Punch Street and Artarmon Oval. Basin discharges then travel in local drainage systems into Flat Rock Creek which ultimately discharges into Middle Harbour.

4.4.3 Balgowlah

Water quality treatment is not provided at Burnt Bridge Creek Deviation between Sydney Road and north of Kitchener Street, however the weir located within the golf course provides some water quality treatment by default and capturing some coarse sediment. Stormwater runoff is collected through a pit and pipe network that discharges into Burnt Bridge Creek via several cross drainage pipes without treatment. Several council drainage systems are interconnected to the pavement or cross drainage systems in this area which do not receive water quality treatment.

4.4.4 Wakehurst Parkway

Water quality treatment is not provided along the Wakehurst Parkway aside from the operational water quality infrastructure that was constructed as part of the Northern Beaches Hospital road upgrade project at the northernmost end of the project. Road runoff is collected through natural drainage lines before reaching the receiving waters. Flows travelling to the west reach Middle Harbour while flows travelling to the east reach Manly Dam.

4.5 Existing surface water quality

Surface water quality of waterways relevant to the project have been heavily impacted by urban development. The water quality is influenced by both point and diffuse sources of pollution including stormwater, wastewater overflows and leachate from contaminated land. Some of the waterways have also undergone a substantial change from natural to artificial, hard (concrete-lined) channels and underground box culverts. This together with an increase in impervious areas has resulted in increased runoff of greater velocities and the transport of sediments and contaminants to the downstream receiving environment.

The water quality of each of the waterways with the potential to be impacted is discussed below. The results of water quality monitoring completed for this assessment for each waterway are presented in Annexure A.

4.5.1 Willoughby Creek

Water quality monitoring of Willoughby Creek at Primrose Park, Cremorne between October 2017 and February 2018 has shown very high levels of nutrients, elevated concentrations of zinc and copper at all times, and iron on occasion (refer to table A-1 in Annexure A). Total phosphorus and total nitrogen concentrations were generally five to 10 times the recommended guideline limit for protection of aquatic ecosystems and oxidised nitrogen was measured at more than 50 times the recommended guideline. Dissolved oxygen levels were low, likely due to the low flow and isolated pools where monitoring was carried out. There were no detections of BTEX or hydrocarbons.

In summary, the indicators which frequently failed to meet the ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines for protection of aquatic ecosystems were dissolved oxygen, copper, zinc, oxidised nitrogen, total nitrogen and total phosphorus.

4.5.2 Quarry Creek

Quarry Creek in North Sydney is a tributary of Flat Rock Creek which flows into Long Bay in Middle Harbour. North Sydney Council undertook testing of this creek between 2001 and 2011 for a range of water quality indicators (Table 4-2). Summary statistics provided by North Sydney Council suggests that the water quality of the creek has elevated median concentrations of copper, zinc, total nitrogen and total phosphorus. Both pH and dissolved oxygen are towards the upper recommended limits with median pH exceeding eight. Faecal coliform counts are also very high indicating microbial contamination.

Table 4-2 Quarry Creek water quality data summary (North Sydney Council)

Indicator	Quarry Creek		ANZG (2018), ANZECC/ARMCANZ (2000) guidelines
	East	West	
Faecal coliforms (cfu/100mL)	2500	4500	<1000 (secondary contact)
Dissolved oxygen (% sat)	91.8	106.9	85 – 110
Total nitrogen (mg/L)	**2 (0.049)**	**1.8 (0.009)**	<0.35mg/L
Total phosphorus (mg/L)	**0.14 (0.049)**	**0.17 (0.009)**	<0.025mg/L

Indicator	Quarry Creek		ANZG (2018), ANZECC/ARMCANZ (2000) guidelines
	East	West	
Turbidity (NTU)	11	22	<50NTU
Total zinc (mg/L)[1]	**0.052 (0.018)**	**0.06 (0.01)**	0.008mg/L
Total lead (mg/L)[1]	**0.0015 (0.018)**	**0.001 (0.009)**	0.0034mg/L
Total copper (mg/L)[1]	**0.01 (0.018)**	**0.005 (0.01)**	0.0014mg/L
pH (pH units)	8.02	7.5	6.5 – 8.5
Electrical conductivity (µS/cm)	400	212	200-300µS/cm

Note 1: Total metal results represent the hardness adjusted value as per ANZECC/ARMCANZ (2000) which *"recommends adjusting the trigger value for hardness related metals to account for local water hardness".* This is important because the trigger values for these metals have been derived for soft waters (30mg/L $CaCO_3$) corresponding to high toxicity.
Note 2: Cells with bolded figures demote an exceedance of guidelines. Number in brackets denotes wet weather median.

Monitoring carried out between October 2017 and February 2018 also shows that Quarry Creek has elevated nutrients, copper and zinc concentrations (refer to Table A-2 in Annexure A). Specifically, the indicators which exceeded recommended guidelines on all sampling occasions were copper, zinc, oxidised nitrogen, total nitrogen and total phosphorus. Dissolved oxygen and iron exceeded guideline limits 50 per cent of the time.

4.5.3 Flat Rock Creek

The water quality of Flat Rock Creek is monitored by North Sydney Council at two locations in the middle of the catchment and towards the downstream end (Table 4-3). The mid-catchment site is a concrete-lined channel and according to North Sydney Council is frequently found to contain rubbish. Generally, median in-situ indicators are compliant in the creek with pH, dissolved oxygen, turbidity and conductivity all within guideline limits. Metal concentrations are low with the exception of total copper and zinc which was detected in elevated concentrations during dry weather. Nutrient concentrations are very high, particularly total nitrogen indicating eutrophic conditions. Microbiological contamination is also evident, particularly at the downstream site with high counts of faecal coliforms and enterococci.

Monitoring of Flat Rock Creek was also carried out as part of this water quality assessment at three locations, upstream of the proposed crossing (5a), and downstream of the proposed crossing at Flat Rock Reserve (5b) and Northbridge Suspension Bridge (5c) (refer to Table A-3, Table A-4 and Table A-5 in Annexure A). Flat Rock Creek site 5c is the most downstream site, located downstream of the Quarry Creek confluence. Recent monitoring corresponds with previous monitoring trends whereby the creek shows elevated nutrient levels (NOx, total nitrogen and total phosphorus) and elevated concentrations of heavy metals copper and zinc. Iron concentrations were elevated on occasion at sites 5a and 5b, and always at site 5c. pH levels were high at the upstream site (5a) but complied downstream. Dissolved oxygen levels showed the opposite trend and were compliant at the upstream site but very low and below recommended limit for protection of aquatic ecosystems at the downstream site. Overall nutrient concentrations decreased downstream whereas metal concentrations increased.

Table 4-3 Flat Rock Creek quality data summary (North Sydney Council, 2011)

Indicator	Flat Rock Creek		ANZG (2018), ANZECC/ARMCANZ (2000) guidelines
	Upstream (WCC_FR2)	Downstream (WCC_FR1)	
Faecal coliforms (cfu/100mL)	235	**1880**	<1,000 (secondary contact)
Enterococci (cfu/100mL)	**150**	**340**	<230 (secondary contact)
Dissolved oxygen (% sat)	100.1	85.7	85 – 110
Total nitrogen (mg/L)	**1.320**	**3.89 (3.02)**	<0.35mg/L
Total phosphorus (mg/L)	**0.042**	**0.043 (0.034)**	<0.025mg/L
Turbidity (NTU)	4.6	5.9	<50NTU
Total zinc (mg/L)[1]	**0.014**	**0.03 (0.021)**	0.008mg/L
Total lead (mg/L)[1]	0.001	0.001 (0.001)	0.0034mg/L
Total copper (mg/L)[1]	**0.005**	**0.005 (0.004)**	0.0014mg/L
pH (pH units)	7.98	7.64 (7.82)	6.5 – 8.5
Conductivity (µS/cm)	305	401	125 – 2,220µS/cm

Note 1: Total metal results represent the hardness adjusted value as per ANZECC/ARMCANZ (2000) which *"recommends adjusting the trigger value for hardness related metals to account for local water hardness".* This is important because the trigger values for these metals have been derived for soft waters (30mg/L $CaCO_3$) corresponding to high toxicity.
Note 2: Cells with bolded figures demote an exceedance of guidelines. Number in brackets denotes wet weather median.

In summary, pH, copper, zinc, oxidised nitrogen and total nitrogen and phosphorus failed to comply with the recommended limits for the protection of the nominated environmental values on all sampling occasions at the upstream site. Total iron failed to comply on four of the six sampling occasions and chlorophyll-*a* failed twice (refer to Water quality monitoring results in Annexure A). At the downstream sites, dissolved oxygen, copper, zinc, iron, oxidised nitrogen, total nitrogen and total phosphorus exceeded recommended limits on all sampling occasions and lead exceeded guidelines on 50 per cent of sampling occasions. The poorer water quality downstream may be influenced from leachate from the former landfill site.

4.5.4 Burnt Bridge Creek

As part of this assessment the water quality of Burnt Bridge Creek has been measured at two locations over a three-month period to gain an appreciation of ambient water quality (refer to Table A-6 and Table A-7 in Annexure A). The locations were chosen due to each section having different features such as a naturalised freshwater creek upstream (3a) and a combination of concrete and bedrock manmade stormwater drainage system downstream (3b).

The current water quality of Burnt Bridge Creek could be considered poor and generally did not meet the required limits for protection of aquatic ecosystems for many indicators. Dissolved oxygen levels were low at both sites, particularly upstream where concentrations were generally less than 31 per cent saturation (except for the wet weather event which had dissolved oxygen of 81 per cent). Downstream the concentrations were higher ranging between 67 and 83 per cent saturation but still fell below the lower limit of 85 per cent saturation. Total metal concentrations were elevated for copper, lead, zinc and iron. Total metal concentrations were generally higher at the upstream sites except for zinc which was higher downstream on three of the five sampling occasions. Similar to total metal concentrations, nutrients were very high at both sites, but the upstream site had notably higher concentrations of total nitrogen and total phosphorus. Hydrocarbons and BTEX were also sampled for but not detected in Burnt Bridge Creek on any occasion.

The water quality at Burnt Bridge Creek is also monitored quarterly by Northern Beaches Council at a site located at the end of Pitt Street, Manly Vale (NBC_BBC). Water quality monitoring conducted at Burnt Bridge between 2015 and 2016 by the council was reported in their annual report. Total nitrogen and oxidised nitrogen were very high on all sampling occasions. Ammonia and total phosphorus were also elevated at times. Despite elevated levels of nutrients, chlorophyll-a levels remained low and complied with the ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines (NBC, 2016).

In summary, the indicators which failed to meet the ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines on most occasions in Burnt Bridge Creek were dissolved oxygen, copper, zinc, oxidised nitrogen and total nitrogen at both site 3a and 3b. The indicators lead, iron and total phosphorus, also frequently failed to comply with the guidelines at the upstream site (3a).

4.5.5 Manly Dam

As part of this assessment the water quality of Manly Dam Creek was measured at two locations: mid-way between Manly Creek and Manly Dam wall, accessed via a small beach located at the most westerly point of the carpark access way (site 6b); and downstream next to the dam wall (site 6c) (refer to Table A-8 and Table A-9 in Annexure A). At these locations, the water quality was generally good.

Dissolved oxygen levels, while recorded just below the recommended limit of 90 per cent saturation on most occasions are not uncommon during warmer conditions. Total nitrogen and oxidised nitrogen were generally elevated above recommended limits however total phosphorus complied on all occasions except for the wet weather event. Metal concentrations which are elevated elsewhere in the project alignment, were low with only copper, zinc and iron recorded above recommended limits on one occasion at the dam wall.

Overall, the water quality of the dam could be considered good but does exhibit elevated nitrogen concentrations. The indicators which frequently exceeded the recommended ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines for protection of aquatic ecosystems in Manly Dam were dissolved oxygen, oxidised nitrogen and total nitrogen.

4.5.6 Manly Creek

As part of this assessment the water quality of Manly Creek was measured at a site around 300 metres from the Wakehurst Parkway over a three-month period to gain an appreciation of ambient water quality (refer to Table 4-4 and Table A-10 in Annexure A). At this site dissolved oxygen was low and below recommended guideline limits on all occasions. Concentrations of copper and zinc were also high as was iron on a single occasion. Nutrient concentrations varied, total phosphorus was low and complied with the relevant guidelines however total nitrogen and oxidised nitrogen were very high on all occasions. Chlorophyll-a concentrations were compliant, below the recommended limit of 3µg/L at all times.

The water quality of Manly Creek is also monitored quarterly by Northern Beaches Council near the current monitoring site. Water quality monitoring conducted at Manly Creek between 2015 and 2016 by the council was reported in their annual report. Total nitrogen, oxidised nitrogen and total phosphorus were high on all sampling occasions as was turbidity. Ammonia and chlorophyll-a levels remained low and complied with the ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines (NBC, 2016).

Water quality at Manly Creek was also monitored as part of the Northern Beaches Hospital road upgrade project. Sampling was carried out between November 2014 and November 2016 at two locations: SW4, a drainage line accessed from Warringah Aquatic Centre carpark and SW5, a drainage line next to the business park at the north side end of Aquatic Drive (SMEC, 2017). During this monitoring period, elevated levels of heavy metals (chromium, copper, iron, lead and zinc) were recorded as were elevated concentrations of nutrients including total phosphorus and total nitrogen (Table 4-4).

In summary, the indicators which failed to meet the ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines on most occasions in Manly Creek were dissolved oxygen, total nitrogen, oxidised nitrogen, copper and zinc.

Table 4-4 Manly Creek water quality data summary (Northern Beaches Hospital road upgrades, SMEC 2017)

Indicator	Manly Creek (SW4)		Curl Curl Creek (SW5)		ANZECC/ARMCANZ (2000) guidelines
	Dry weather	Wet weather	Dry weather	Wet weather	
Total nitrogen (mg/L)	**0.9**	**0.45**	**0.75**	**0.5**	<0.35mg/L
Total phosphorus (mg/L)	**0.1**	0	**0.1**	**0.06**	<0.025mg/L
Total zinc (mg/L)[1]	**0.04**	**0.079**	**0.017**	**0.061**	<0.008mg/L
Total lead (mg/L)[1]	0.003	0.003	0.003	**0.0055**	<0.0034mg/L
Total copper (mg/L)[1]	**0.004**	**0.0075**	**0.002**	**0.0065**	<0.0014mg/L
Total chromium	0.001	0.001	0.001	**0.002**	<0.001
Total iron	0.275	0.25	0.002	0.0065	<0.008
pH (pH units)	7.3	6.9	6.7	6.7	6.5 – 8.5
Electrical conductivity (µS/cm)	430	180	430	270	200-300µS/cm

Note 1: Total metal results represent the hardness adjusted value as per ANZECC/ARMCANZ (2000) which *"recommends adjusting the trigger value for hardness related metals to account for local water hardness".* This is important because the trigger values for these metals have been derived for soft waters (30mg/L $CaCO_3$) corresponding to high toxicity.
Note 2: Bolded numbers demote an exceedance of guidelines.

4.5.7 Trefoil Creek

The water quality of Trefoil creek was monitored as part of the Northern Beaches Hospital road upgrade project. Sampling was carried out between November 2014 and November 2016 at the drainage line off Nandi Avenue, Frenchs Forest (Table 4-5). During this monitoring period, elevated levels of heavy metals (copper, iron, lead and zinc) were recorded during wet weather sampling. Concentrations of nutrients including total nitrogen were also elevated during wet weather. During the construction of this project, drilling struck a redundant stormwater drain which increased sediment loads flowing into the drainage line and into Trefoil Creek, impacting water quality and the local environment (EPA, 2018).

Table 4-5 Trefoil Creek water quality data summary (Northern Beaches Hospital road upgrade project, SMEC)

Indicator	Trefoil Creek		ANZG (2018), ANZECC/ARMCANZ (2000) guidelines
	Dry weather	Wet weather	
Total nitrogen (mg/L)	**0.6**	**0.6**	<0.35mg/L
Total phosphorus (mg/L)	<0.005	<0.005	<0.025mg/L
Total zinc (mg/L) *	<0.001	**0.04**	0.008mg/L
Total lead (mg/L) *	<0.001	**0.0055**	0.0034mg/L
Total copper (mg/L) *	<0.001	**0.0045**	0.0014mg/L
Total chromium	<0.001	0.001	0.001
Total iron	0.65	0.585	0.7
pH (pH units)	7.2	7.05	6.5 – 8.5
Electrical conductivity (µS/cm)	480	245	200-300µS/cm

Note 1: Total metal results (*) represent the hardness adjusted value as per ANZECC/ARMCANZ (2000) which *"recommends adjusting the trigger value for hardness related metals to account for local water hardness".* This is important because the trigger values for these metals have been derived for soft waters (30mg/L $CaCO_3$) corresponding to high toxicity.
Note 2: Bolded numbers demote an exceedance of guidelines.

4.6 Water quality trigger values

The Australian and New Zealand Environment and Conservation Council (ANZECC/ARMCANZ, 2000) have default guidelines for water quality which have been collated and updated in the ANZG (2018) water quality guidelines. These guidelines provide benchmarks for assessment of the existing water quality of the river. The application of the criteria is dependent on the environmental values assigned to the waterway.

Default trigger values for toxicants, such as metals, pesticides and other organic and inorganic chemicals provided in the ANZG (2018) have been derived using advanced statistical analysis of data on the long term toxic effects on aquatic biota. The default trigger values have been developed to protect designated percentages of aquatic life. As such, development of water quality trigger values is not needed for toxicants, however values should be consistent with an appropriate per cent protection level for the site.

In heavily urbanised and modified environments such as the environment surrounding the project, water quality indicators often exceed the recommended ANZECC/ARMCANZ (2000) default trigger values for physical and chemical stressors for estuarine and lowland river ecosystems. A targeted water quality monitoring program was carried out to collect water quality data at each waterway that has the potential to be impacted by the project. This information confirmed that the receiving environments for the construction and operational water treatment plant discharges from the project are highly disturbed ecosystems.

Due to the absence of a suitable reference site within the dataset to develop site specific trigger value criteria, it is proposed to adopt the ANZECC/ARMCANZ (2000) default trigger values for physical and chemical stressors for estuarine and lowland river ecosystems and the ANZG (2018) 90 per cent species protection levels for toxicants when designing wastewater treatment plants. For toxicants known to bioaccumulate, the ANZG (2018) 95 per cent species protection level would be adopted.

As project wastewater treatment plants would discharge into moderately to highly disturbed waterways with significant tidal exchange that would provide dilution and mixing, adopting the ANZG (2018) 90 per cent species protection levels would be unlikely to result in ecological impacts to downstream water quality.

4.7 Contamination

Areas of environmental interest for contamination along the alignment are discussed in detail in Appendix M (Technical working paper: Contamination). Each of the areas was given a risk ranking from low to high, to indicate the potential for contamination. An assessment of whether the contamination is likely to be present in the groundwater is discussed in detail in Appendix N (Technical working paper: Groundwater). Areas of environmental interest with assigned moderate to high exposure risk rankings that that have the potential to impact on downstream surface water quality include:

- Cammeray Golf Course – has moderate potential for contamination of downstream Willoughby Creek as a result of the construction of the Cammeray Golf Course construction support site (BL1) for works associated with the Warringah Freeway and mainline tunnel connection. Likely contaminants include heavy metals, hydrocarbons (mainly PAH), asbestos, pesticides and PCB
- Punch Street, Artarmon and Freeway Hotel on Reserve Road, Artarmon – has moderate potential for contamination of Flat Rock Creek as a result of construction of the Punch Street construction support site (BL3) and Motorway Control Centre for works associated with the Gore Hill Freeway Connection. Likely contaminants include heavy metals, hydrocarbons, pesticides, PCB, nutrients, cyanide, VOC and asbestos
- Flat Rock Reserve at Northbridge and Willoughby Leisure Centre and Bicentennial Reserve at Willoughby – has moderate to high potential for contamination of Flat Rock Creek as a result of construction of Flat Rock Drive construction support site (BL2) and tunnelling works associated with the Beaches Link. Likely contaminants include heavy metals, hydrocarbons, pesticides, PCB, nutrients, cyanide, VOC, asbestos and landfill gas
- Balgowlah Golf Course and residential property in Dudley Street and Balgowlah – has moderate potential for contamination of downstream Burnt Bridge Creek as a result of the construction of the Balgowlah Golf Course construction support site (BL10), new open space and recreation facilities and the surface works associated with the Balgowlah Connection. Likely contaminants include heavy metals, hydrocarbons, pesticides, PCB and asbestos.
- Residential properties on Judith Street/Kirkwood Street, Sydney Water Reservoir site (and surrounds) and Wakehurst Parkway from Seaforth to Frenchs Forest – moderate to high potential for contamination of downstream Manly Creek and Trefoil Creek as a result of the construction of the Wakehurst Parkway south construction (BL12) support site, Wakehurst Parkway East construction support site (BL13), roadwork and tunnelling associated with the tunnel connections at Wakehurst Parkway, Killarney Heights and upgrade and integration works along the Wakehurst Parkway. Likely contaminants include heavy metals, hydrocarbons, pesticides and asbestos.

4.7.1 Acid sulfate soils risk

Acid sulfate soils (ASS) are the common name given to naturally occurring sediments and soils containing iron sulfides (principally iron sulfide or iron disulfide or their precursors). The exposure of the sulfide in these soils to oxygen by drainage or excavation leads to the generation of sulfuric acid. Areas of ASS can typically be found in low-lying and flat locations which are often swampy or prone to flooding.

ASS risk maps from the CSIRO ASRIS database were reviewed to ascertain the probability of ASS being present across the project area. Based on this information, the generalised ASS classes and probability across the project area has been assessed as follows:

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

A review of the ASS risk maps from the Willoughby Local Environmental Plan 2012 and the Manly Local Environmental Plan 2013 indicated that the project would be located within areas of Class 5 ASS risk or areas

with no probable ASS risk (unclassified). The Mosman Local Environmental Plan 2012 identified areas underlying The Spit as an ASS area (land up to 5 metres AHD) but did not provide an ASS class for this area. The ASS risk maps from the Warringah Local Environmental Plan 2011 did not classify the project area as an ASS risk. The North Sydney Local Environmental Plan 2013 does not contain ASS risk maps. The respective local environmental plans do not cover ASS risk within Middle Harbour.

Where relevant, the local environmental plans detail that development consent is required for the carrying out of the following work which may disturb, expose or drain ASS and cause environmental damage within the respective risk classes:

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

Probability of ASS occurrence (from ASRIS) along the alignment is presented in Figure 4-15. Detailed assessment of ASS is provided in Appendix M (Technical working paper: Contamination.

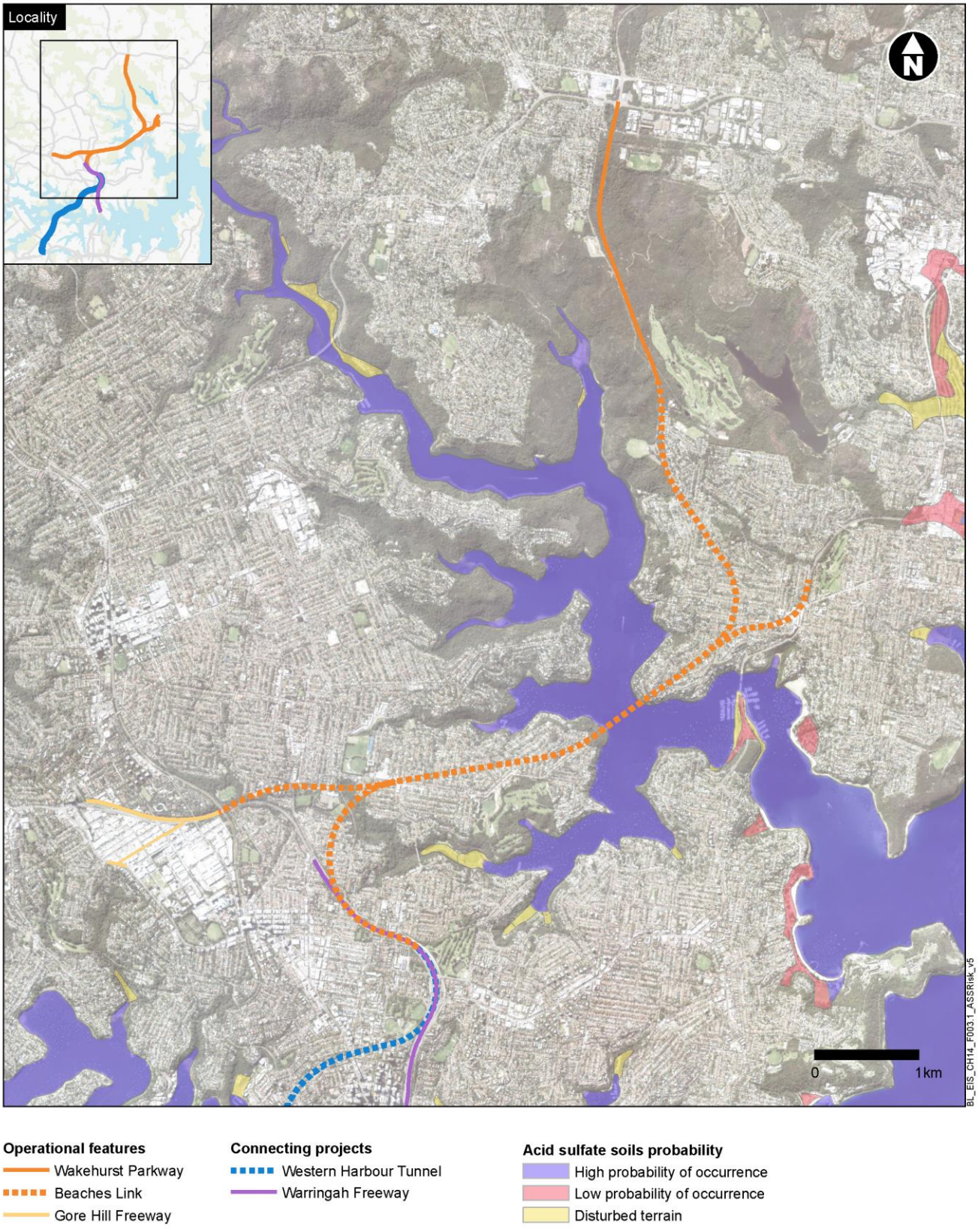

Figure 4-15 Acid sulfate soil risk classification (ASRIS)

4.8 North Sydney Council stormwater harvesting scheme

North Sydney Council has established an extensive stormwater harvesting scheme, which includes a storage dam at Cammeray Golf Course of about 45 metres by 35 metres in size. The dam receives stormwater harvested from the surrounding catchments that is then used to irrigate a number of community parks and the golf course itself. Harvested water is also piped through the existing stormwater system back to St Leonards Park, which is used to irrigate the public parklands and North Sydney Oval. The dam also serves as a sediment settlement pond which improves the quality of water re-entering the catchment and harbour.

The dam has become habitat for wildlife such as ducks since its construction and saves about 30 million litres of clean water each year (North Sydney Council, 2018).

The dam would be directly impacted by the proposed Western Harbour Tunnel and Warringah Freeway Upgrade. The golf course area impacted would also be utilised later by the Beaches Link and Gore Hill Freeway Connection project for undertaking project works in the Warringah Freeway and Cammeray areas. Transport for NSW has committed to implementing a permanent solution to replace the storage dam (subject to agreement of an alternative location) prior to removal of the existing dam so that no net impact to water reuse by North Sydney Council would occur during the construction period or operational period. The replacement facility would aim to maintain the operational functionality of the current harvesting scheme to ensure similar adequate supply for North Sydney Council's water use needs, including its connection to the Green Park stormwater drain and its role in providing for the irrigation of the golf course and other parks in the North Sydney local government area. The solution would also include replacement of the associated harvesting scheme infrastructure eg gross pollutant trap, water treatment plant and pump out facility.

Several options for the alternate location are currently being investigated by the Western Harbour Tunnel and Warringah Freeway Upgrade project in consultation with Cammeray Golf Course operators and North Sydney Council.

4.9 Balgowlah Golf Course stormwater harvesting dam

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

5. Assessment of construction impacts

Construction of the project would involve a range of activities at different locations within the project footprint. Construction of the project presents a risk of degradation of downstream water quality if management measures are not implemented, monitored and maintained throughout the construction phase. Water quality management and mitigation measures would be an integral part during construction activities.

5.1 Water use and water balance

This section provides a preliminary assessment of the water balance during construction of the project based on the groundwater inflow estimates presented in Appendix N (Technical working paper: Groundwater). The water demand estimates in Table 5-1 and the groundwater inflows that would be available for reuse after treatment at each construction wastewater treatment plant (refer to Figure 5-1 for the location of the construction wastewater treatment plants). Middle Harbour south cofferdam (BL7), Middle Harbour north cofferdam (BL8) and Spit West Reserve (BL9) construction support sites are not considered in water demand estimates as net water consumption and demand is expected to be zero for the cofferdams, and as such they were not included.

5.1.1 Construction water use

Construction water usage estimates have been developed as part of the project design and are shown in Table 5-1. The total volume of water required during construction of the project is estimated to be around 2.6 megalitres per day which equals around 950 megalitres per annum. The water usage estimates are averages during the entire construction period. The actual water usage during construction is expected to show considerable variation during this period depending on the nature and extent of construction activities taking place.

Table 5-1 Construction daily water demand breakdown

Activity[1]	Tunnelling works (kL/d)	Surface works (kL/d)	Office use (kL/d)	Total (kL/d)
Surface works[2]	0	368	0	368
Cammeray Golf Course (BL1)	144	10	5	159
Flat Rock Drive (BL2)	574	40	21	635
Punch Street (BL3)	85	30	10	125
Balgowlah Golf Course (BL10)	353	441	16	810
Wakehurst Parkway east (BL13)	178	360	10	548
Total	**1334**	**1249**	**62**	**2645**

Note 1: Middle Harbour south cofferdam (BL7), Middle Harbour north cofferdam (BL8) and Spit West Reserve (BL9) construction support sites are not included in the water demand estimates

Note 2: Surface works estimates include works along the existing Gore Hill Freeway, surface works between the mainline tunnels and Balgowlah and Killarney Heights, and surface works at Wakehurst Parkway.

5.1.2 Tunnel construction wastewater management

Temporary construction wastewater treatment plants would be designed to treat wastewater generated from tunnelling activities (including from heat and dust suppression), or rainfall runoff collected from the tunnel portals.

Indicative construction wastewater treatment discharges and discharge points are presented in Table 5-2. The treated water discharge points are shown in Figure 5-1.

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 for treatment prior to discharge to receiving waterways.

Table 5-2 Construction wastewater treatment plants and discharge points

Plant location	Discharge location	Ultimate receiving waters
Cammeray Golf Course construction support site (BL1)	Local stormwater	Willoughby Creek
Flat Rock Drive construction support site (BL2)	Local stormwater	Flat Rock Creek
Punch Street construction support site (BL3)	Local stormwater	Flat Rock Creek
Balgowlah Golf Course construction support site (BL10)	Local stormwater	Burnt Bridge Creek
Wakehurst Parkway east construction support site (BL13)	Drainage channel to be formed at the eastern section of the temporary construction support site	Wakehurst Golf Course dam for reuse by the golf course (via overland flow)

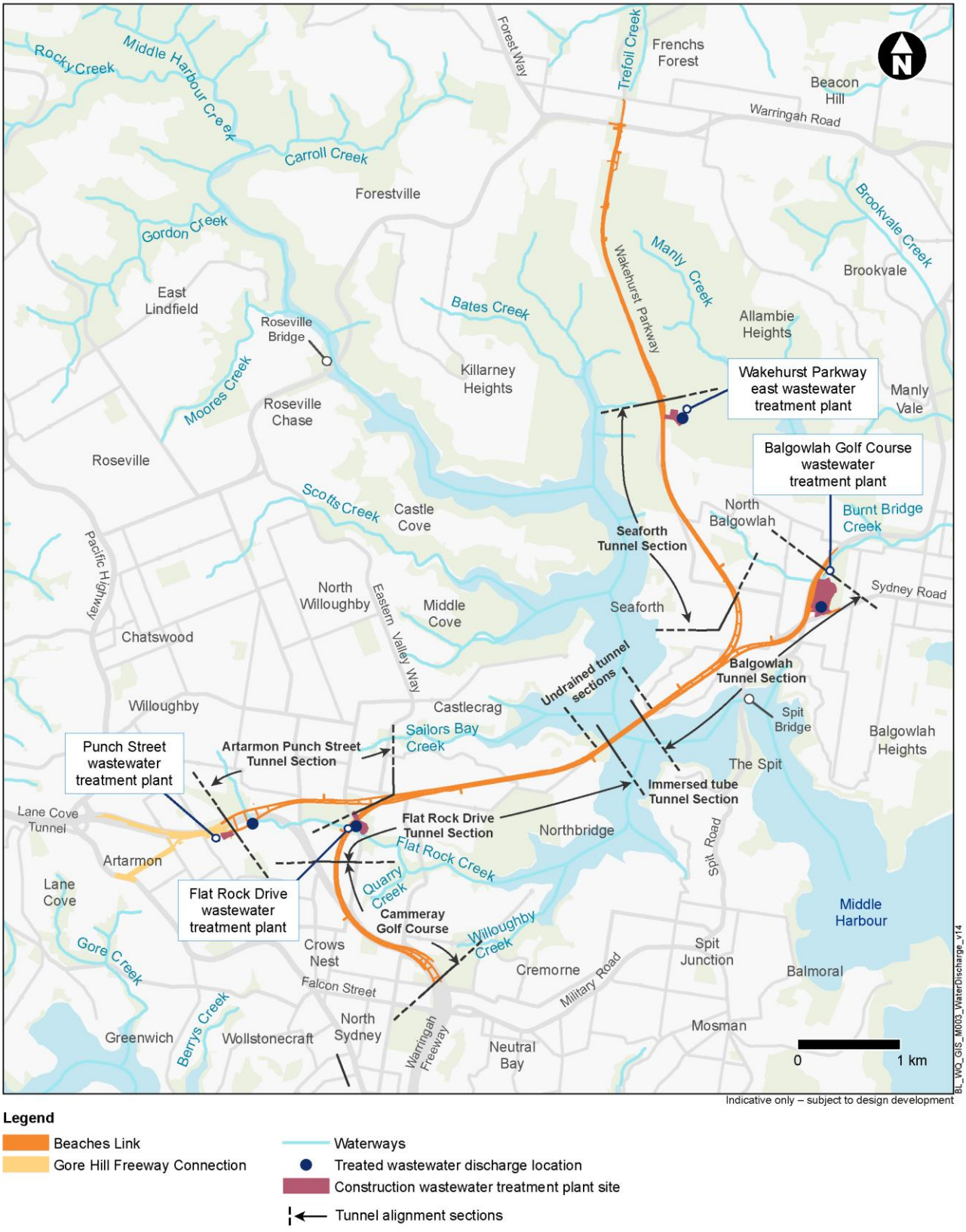

Figure 5-1 Wastewater treatment plants and discharge locations

5.1.3 Water balance

The water balance for the construction phase is shown in Table 5-3.

Non-potable water uses would include roadheader supply, dust suppression, plant washdown and rock bolting. Some demand activities are consumptive such as concrete batching and the water used in the offices is assumed to be discharged to sewerage network. There would also be minor losses in the system due to evaporation. The remainder would be treated and discharged at the locations shown in Figure 5-1.

There is potential for some of the water supply for the non-potable demand during construction to be sourced from treated groundwater inflows and treated rainwater harvested from building rooftops. The deficit for the non-potable demand and any potable demand would be sought from the Sydney Water supply network. Where possible, the use of non-potable water over potable would be preferential however this is dependent on the location and nature of the water use activity and quantity and quality of available water at the time.
Water availability would show variation as construction progresses as well as seasonally due to climate and it is expected that the potential for treated wastewater reuse would also show variability.

Table 5-3 Construction water balance (based on average groundwater inflows)

Activity	Total water demand (kL/d)	Consumptive use (kL/d)	Groundwater inflows (kL/d)[3]	Harvested rainwater (kL/d)	Treated wastewater reused (kL/d)	Sydney water supply (kL/d)	Discharge quantity (kL/d)
Surface works[1]	368	368	0	0	185	183	0
Cammeray Golf Course (BL1)	159	15	278	1	127	32	296
Flat Rock Drive (BL2)	635	61	440	1	305	331	711
Punch Street (BL3)	125	40	347	1	130	0	308
Balgowlah Golf Course (BL10)	810	457	521	1	263	547	428
Wakehurst Parkway East (BL13)[2]	548	370	30	1	199	349	10
Total	**2645**	**1311**	**1616**	**5**	**1209**	**1442**	**1753**

Note 1: Surface works estimates include works along the existing Gore Hill Freeway, surface works between the mainline tunnels and Balgowlah and Killarney Heights, and surface works at Wakehurst Parkway.

Note 2: 95 per cent of all treated water at the Wakehurst Parkway east construction wastewater treatment plant would be recycled at the construction support site and reused for construction activities associated within the Wakehurst Parkway surface road works.

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.

5.2 Impacts on surface water quality

Potential risks to surface water quality from tunnelling and surface activities are discussed in the following section.

5.2.1 Tunnelling activities

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

- Groundwater ingress
- Rainfall runoff in tunnel portals and ventilation outlets
- Heat and dust suppression water
- Washdown runoff.

Tunnel wastewater, if discharged untreated or poorly treated, has the potential to impact ambient water quality of the receiving waterways by introducing increased nutrient loading, resulting in algal growth with increased risk to human health. There is also potential for reduction in visual amenity and impacts to aquatic species as a result of heavy metals or other toxicants.

The wastewater treatment plant at Cammeray Golf Course would discharge treated wastewater generated from sources identified above to Willoughby Creek via the local stormwater system and subsequently into Middle Harbour. The Flat Rock Drive and Punch Street wastewater treatment plants would discharge treated wastewater into Flat Rock Creek via the local stormwater system and subsequently into Middle Harbour. The Balgowlah Golf Course wastewater treatment plant would discharge treated wastewater into Burnt Bridge Creek via the local stormwater system and into Manly Lagoon. The wastewater generated from the Wakehurst Parkway east wastewater treatment plant would reuse 95 per cent of the recycled wastewater for the Wakehurst Parkway upgrade works, discharging only 10KL/day to a drainage channel to be formed at the eastern section of the site, which would drain naturally towards Wakehurst Golf course dam for reuse by the golf course.

Suspended solids and heavy metals (particularly iron and manganese) would be the key water quality indicators that are most likely to impact receiving water quality if wastewater is not adequately treated before discharge.

The project construction wastewater treatment plants would treat the tunnel inflows estimated in Table 5-3 as well as other wastewater generated by tunnelling activities. Table 5-4 lists the contaminants likely to be present in tunnel inflows at each wastewater treatment plant catchment based on the existing groundwater quality as documented in Appendix N (Technical working paper: Groundwater) and selected areas of environmental interest (as listed in Section 4.7). In summary:

- Sampling of groundwater bores in the area identified key pollutants that pose a risk to water quality of Flat Rock Creek, Burnt Bridge Creek and Manly Creek in excess of the ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines. These pollutants of concern are provided in Table 5-4 (refer Annexure B for all indicators)
- Total recoverable hydrocarbons (TRH) (C10-C16 (F2)) were detected in groundwater in concentrations that exceed the current background concentrations recorded in both Flat Rock Creek and Burnt Bridge Creek. The discharge of untreated tunnel inflows could be toxic to the aquatic flora and fauna within the creeks and the hydrocarbons can settle and become embedded in the sediment
- Elevated levels of some nutrient species were identified in groundwater samples. Total nitrogen exceeded the recommended ANZG (2018) and ANZECC/ARMCANZ (2000) at Flat Rock Creek and total phosphorus exceeded the recommended ANZG (2018) and ANZECC/ARMCANZ (2000) at both Flat Rock Creek and Burnt Bridge Creek. In the case of Flat Rock Creek, the median concentrations in groundwater samples for total nitrogen and phosphorus were below existing background levels. At Burnt Bridge Creek, total phosphorus concentrations were higher in groundwater than background concentrations in surface water of Burnt Bridge Creek. Total nitrogen and phosphorus were also elevated in the groundwater samples relevant to Manly Dam. Concentrations both exceeded the ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines

and background concentrations within the dam. As nutrients are already elevated in both these systems, the addition of more nutrient-rich water in notable volumes could result in eutrophication and algal blooms

- Ammonia concentrations in groundwater are very high, more than ten times the recommended limit for aquatic ecosystems in Flat Rock Creek and three times in Burnt Bridge Creek. High levels of ammonia can lead to excessive growth of algae and other plants which can degrade ecosystem condition by clogging creeks. Ammonia comprises ionised ammonia and un-ionised (toxic) ammonia. Toxic ammonia poses a risk to water quality as it increases exponentially with increased pH levels and temperature which can then be harmful to aquatic life. Therefore, pH is an indicator that would also be managed in the treatment process so that levels in the creeks remain acceptable. Heavy metal concentrations, particularly iron and manganese are elevated in groundwater. Filtered iron concentrations marginally exceeded the total background concentration recorded in Flat Rock Creek but was 34 times background concentrations recorded in Burnt Bridge Creek. Filtered manganese concentrations are five times and 17 times higher in groundwater than concentrations in Flat Rock Creek and Burnt Bridge Creeks respectively. This presents a risk to water quality if appropriate treatment does not occur before discharge as the discharged water could be rapidly oxidised causing precipitation of iron and manganese oxides/hydroxides out of solution. This could aesthetically impact the creek as the water can become reddish/brown and result in algal blooms and thick mats of iron-oxidising bacteria. These impacts could then decrease dissolved oxygen levels and impact on surface water aquatic ecology.

Table 5-4 Summary of groundwater pollutants that if untreated or poorly treated could exceed ANZECC/ARMCANZ (2000) for Flat Rock Creek and Burnt Bridge Creek

Indicator	Units	Median[1] Flat Rock Creek (Site 5c)[2]	Median[1] Burnt Bridge Creek (Site 3b)	Median Manly Dam (Site 6c)	ANZG (2018), ANZECC/ ARMCANZ (2000)
TRH C10-C16 (F2)	µg/L	50	50	Not detected	No guideline
Ammonia as N	µg/L	325	70	10	20
Nitrogen (total)	mg/L	1.85	0.2	0.825	0.35
Phosphorus (total)	mg/L	0.18	0.165	0.03	0.025
Iron (filtered)	mg/L	0.82	14.5	0.11	0.7
Manganese (filtered)	mg/L	0.272	0.374	0.0.21	1.9

Note 1: Median concentration from monitoring of groundwater bores

Note 2: The ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines for estuarine ecosystems apply to Flat Rock Creek (site 5c) being ammonia (0.015mg/L), total nitrogen (0.3mg/L), oxidised nitrogen (0.015mg/L), total phosphorus (0.03mg/L) and filterable reactive phosphorus (0.005mg/L)

The wastewater treatment plants at Cammeray Golf Course (BL1), Flat Rock Drive (BL2), Punch Street (BL3), Balgowlah Golf Course (BL10) and Wakehurst Parkway east (BL13) construction sites would treat wastewater generated from tunnelling activities to a standard suitable for discharge based on ANZG (2018) and ANZECC/ARMCANZ (2000). Suspended sediments and contaminants above relevant guideline values are likely to be the key water quality indicators that could impact receiving water quality if tunnel wastewater is not adequately treated. The type, arrangement and performance of construction wastewater treatment plants would be developed and finalised during detailed construction planning. Construction wastewater treatment plants would be designed to maintain the water quality outcomes of the receiving ambient environment so that water quality objectives are achieved.

5.2.2 Surface activities

Disturbance to the land surface would be required to support tunnelling and to construct surface infrastructure such as roadways, bridges, tunnel portals, motorway facilities and ancillary operations buildings. The highest risk of impacts on surface water quality during construction of surface works would be associated with:

- **Removal of vegetation**. The removal of vegetation could increase risk of erosion and sedimentation within the surrounding waterways. Appendix S (Technical working paper: Biodiversity development assessment report) indicates the project construction would result in the removal of exotic and native vegetation including urban plantings and native vegetation communities. Most vegetation that would be removed is located along the Wakehurst Parkway at Killarney Heights and Frenchs Forest due to the realignment of Wakehurst Parkway around the cut and cover and trough structures of the ramp tunnel and the upgrade and widening of the Wakehurst Parkway. Additionally, vegetation would be removed at the Flat Rock Drive (BL2) construction support site and areas of vegetation at Balgowlah, including the localised adjustment of a small section of Burnt Bridge Creek. The removal of riparian vegetation at Burnt Bridge Creek has the potential to impact bank stability and surface water quality if mitigation measures are not implemented.
- **Earthworks**. Sedimentation can result when rain or runoff meets exposed areas and stockpiles. Sediment becomes suspended and transported to receiving waters located downstream. Once sediments enter waterways, they can directly and indirectly impact on the aquatic environment. Direct impacts include reducing light penetration (limiting the growth of macrophytes), clogging fish gills, siltation and 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. Activities which would involve earthworks in the project footprint include surface road upgrade works, relocation of facilities and removal of vegetation
- **Demolition works**. The removal of buildings and modification and construction of bridges and other civil engineering structures, such as tunnel portals, retaining walls, active transport infrastructure (bridges, paths, etc), drainage, culverts, noise barriers, fencing, tolling gantries, lighting and signage could provide a source of pollutants including asbestos and other building materials, pollutant-laden soils, or heavy metals and chemicals. Demolition can also generate dust and airborne pollutants. These pollutants once mobilised can be picked up by stormwater runoff and distributed to downstream receiving waterways via the drainage network
- **Disturbance of areas of environmental interest for contamination**. Disturbances of these areas (refer to Section 4.7) could result in exposure of contaminants such as hydrocarbons, metals and pesticides. This could increase acidity in waterways and mobilisation of heavy metals (refer to Appendix M (Technical working paper: Contamination)) for further detail
- **Activation of acid sulfate soils**. There is the possibility of potential acid sulfate soils being present within sediments within Middle Harbour. If unmanaged, this could pose a risk to water quality of Middle Harbour. Appropriate acid sulfate soils management measures would be developed and implemented to manage this risk. Refer to Appendix M (Technical working paper: Contamination) for further detail
- **Accidental spills**. Accidental spills or leaks could occur from spillage of diesel during refuelling, and leakage of hydraulic and lubricating oil from plant and equipment. Washdown water from plant washing and concrete slurries also have the potential to enter waterways
- **Relocation of utilities**. The relocation of utilities would involve soil disturbance by trenching and underboring and construction of new utility routes. The disturbance of soil by machinery could increase the potential for soil erosion which has the potential to impact on downstream water quality. Further detail on utilities relocations can be found in Chapter 6 (Construction work) of the environmental impact statement

- **Changes to water availability and flows**. Construction would result in treated wastewater discharges to Willoughby Creek, Flat Rock Creek and Burnt Bridge Creek via the local stormwater network. About 296 kilolitres per day would be discharged into Willoughby Creek from the Cammeray Golf Course wastewater treatment plant. About 1019 kilolitres per day would be discharged into Flat Rock Creek from the Flat Rock Drive and Punch Street wastewater treatment plants. About 428 kilolitres per day would be discharged into Burnt Bridge Creek from the Balgowlah Golf Course wastewater treatment plant. About 10 kilolitres per day would be discharged from the Wakehurst Parkway east wastewater treatment plant. The project would not extract water from creeks or the harbour.

A summary of project-specific potential impacts to surface water quality are outlined in Table 5-5. Identified construction surface water quality impacts will be managed via standard erosion and sediment control management and mitigation measures for all work sites and surface works areas (Refer to Section 8.1). With the implementation of appropriate measures during construction, impacts to ambient water quality of receiving environments would be temporary and manageable with no long-term impacts expected.

Table 5-5 Summary of construction impacts on surface water quality

Location/construction component	Potentially impacting construction activities	Potential surface water quality impact	Waterway potentially impacted
All construction support sites. Additional sites with surface works: • Unsealed areas within the Burnt Bridge Creek Deviation road reserve and Balgowlah Golf Course • Unsealed areas within Wakehurst Parkway road reserve.	• Earthworks including vegetation removal and topsoil stripping, relocation of utilities • Demolition works • Establishment of sites and installation of construction support site facilities • Piling and excavations including tunnel access declines • Concrete works and retaining walls • Vehicle movements to and from sites • Onsite storage of chemicals/fuel • Accidental spills/material released during transportation of building waste from demolition sites • Activities associated with construction for permanent works • Exposure of contaminated sediments from disturbance of land • Surface works including construction support sites, pedestrian bridge, tunnel excavation, upgrades to intersections.	• Smothering aquatic life and affecting the ecosystems of downstream sensitive creeks and waterways through increased sedimentation • Elevated turbidity, nutrients and other contaminants and low dissolved oxygen levels from exposed soil resulting in increased sedimentation • Increased alkalinity because of chemicals used in treatment and curing of concrete, and concrete dust being transported to waterways via stormwater and wind • Increased acidity in waterways due to the exposure of contaminated soils such as acid sulfate soils • Soil and pollutants entering waterways via stormwater runoff from vehicle transfer of soils via nearby roads • Pollution from increased litter and debris being washed into waterways from storms and wind.	• Willoughby Creek and Willoughby Bay via stormwater from Cammeray Golf Course (BL1) • Flat Rock Creek and Long Bay via stormwater from Punch Street (BL3), Flat Rock Drive (BL2), Gore Hill Freeway Median (BL6), Barton Road (BL5) and Dickson Avenue (BL4). • Burnt Bridge Creek via stormwater from Balgowlah Golf Course (BL10) and Kitchener Street (BL11) via storm water from Wakehurst Parkway south (BL12). • Manly Creek and Manly Dam, via stormwater from Wakehurst Parkway north (BL14) and Wakehurst Parkway east (BL13).

Location/construction component	Potentially impacting construction activities	Potential surface water quality impact	Waterway potentially impacted
Wastewater treatment plants: • Cammeray Golf Course (BL1) • Flat Rock Drive (BL2) • Punch Street (BL3) • Balgowlah Golf Course (BL10) • Wakehurst Parkway east (BL13).	• Operation of construction wastewater treatment plants.	• Discharge of inadequately treated water from construction wastewater treatment plant directly into creek or via stormwater network, leading to a decline in water quality due to elevated levels of nitrogen and ammonia • Discharge high volumes of wastewater which could scour the creek and increase turbidity of downstream waterways • Increased levels of TRH and heavy metals (particularly iron and manganese) which could bioaccumulate and are toxic to aquatic biota and fish affecting their liver and gills.	• Willoughby Creek and Willoughby Bay via stormwater from Cammeray Golf Course (BL1) • Flat Rock Creek directly from discharges at Flat Rock Drive and via stormwater network from Punch Street (BL3) • Burnt Bridge Creek from discharges at Balgowlah Golf Course (BL10). • Wakehurst Golf Course dam from Wakehurst Parkway east (BL13) via drainage channel and overland flow

Location/construction component	Potentially impacting construction activities	Potential surface water quality impact	Waterway potentially impacted
Drainage works associated with an existing aboveground watercourse within Flat Rock Reserve at Flat Rock Drive construction support site (BL2). Localised adjustment of Burnt Bridge Creek as part of surface connections at Balgowlah.	• Drainage works and localised adjustment of existing waterway.	• Elevated turbidity, nutrients and other contaminants and low dissolved oxygen levels from exposed soil during realignment resulting in increased sedimentation • Increased levels of heavy metals which could bioaccumulate and are toxic to aquatic biota and fish • Increased alkalinity as a result of chemicals used in treatment and curing of concrete, and concrete dust being transported to waterways via stormwater and wind • Decline in aquatic life, vegetation and ecosystem function downstream due to habitat removal and fill materials in existing waterway • Changed flow rates resulting in scour and erosion.	• Downstream to Flat Rock Creek • Burnt Bridge Creek.

Location/construction component	Potentially impacting construction activities	Potential surface water quality impact	Waterway potentially impacted
Construction works at tunnelling support sites including: • Cammeray Golf Course (BL1) • Flat Rock Drive (BL2) • Punch Street (BL3) • Balgowlah Golf Course (BL10) • Wakehurst Parkway east (BL13).	• Excavation for tunnelling support • Vegetation removal and topsoil stripping • Removal of existing paved areas • Establishment of construction support sites, installation of site facilities • Relocation and protection of utilities • Stockpiling and transport of materials. • Exposure of contaminated sediments from disturbance of land	• Elevated turbidity, nutrients and other contaminants and low dissolved oxygen levels from exposed soil resulting in increased sedimentation • If mitigation measures are not established during construction, sediment would be more easily eroded and transported into the receiving waterways • Increased concentrations of heavy metals, hydrocarbons and other contaminants (either direction transported to a waterway or attached to sediment) which are toxic to aquatic biota • Increased concentrations of hydrocarbons in downstream waterways which can decrease dissolved oxygen levels and result in fish kills.	• Willoughby Creek (from Cammeray Golf Course BL1) • Flat Rock Creek (from Flat Rock Drive (BL2) and Punch Street (BL3) • Burnt Bridge Creek (from Balgowlah Golf Course (BL10)) • Manly Dam (from Wakehurst Parkway east (BL13)).
Stockpiles and cut and cover locations within 500 metres of a waterway are proposed to be located at: • Punch Street, Artarmon (BL3)- within Flat Rock Creek • Flat Rock Drive (BL2) - within 500 metres of Flat Rock Creek • Balgowlah Connection (within 500 metres of Burnt Bridge Creek)	• Stockpiling of spoil or construction materials (eg earthwork materials, crushed rock, mulch and vegetation) • Cut and cover and trough excavations (including possible option for blasting at cuts >5m along Wakehurst Parkway).	• Excavations washing into waterways, leading to increased levels of turbidity and sediment loads posing risk to sensitive receiving environments • Risk to water quality of downstream watercourses during rainfall if the stockpiles are not managed appropriately	• Flat Rock Creek and Long Bay via stormwater from Punch Street (BL3) and Flat Rock Drive (BL2) • Burnt Bridge Creek via stormwater from Balgowlah Golf Course (BL10) and Kitchener Street (BL11). • Manly Creek and Manly Dam via stormwater runoff from Wakehurst Parkway south and east (BL12 and BL13)

Location/construction component	Potentially impacting construction activities	Potential surface water quality impact	Waterway potentially impacted
• Wakehurst Parkway (within 500 metres of Manly Creek and Trefoil Creek).		• Risk of movement of sediment off steep slopes during high volume rain events • Dust deposited on surfaces from blasting activities being washed in local waterways via runoff.	• Trefoil Creek via stormwater runoff from Wakehurst Parkway north (BL14).
Surface works within construction footprint.	• Management and haulage of spoil during tunnelling and excavation activities • Stockpiling of spoil • Dredging works • Installation and construction of temporary buildings • Demolition, modification and construction of bridges and other civil engineering structures • Modifications to surface roads • Management and haulage of spoil during tunnelling and excavation activities.	• Exposure of acid sulfate soils, which could lead to increased acidity in waterways (noting the general ASS probability along the alignment as either B4 (low probability/very low confidence) or C4 (extremely low probability/very low confidence) (Jacobs, 2020b)) • Exposure of contaminated soils potentially containing high levels for sulfate, ammonia and hydrocarbons, which would result in reductions in water quality • Increased levels of heavy metals which could bioaccumulate and are toxic to aquatic biota and fish.	• The risk of ASS within the areas to be disturbed by construction activities are low to negligible however, there is the possibility of potential ASS being present within sediments within Middle Harbour and/or the Spit (refer to Appendix Q (Technical working paper: Marine water quality)) • Flat Rock Creek and Burnt Bridge Creek.

Location/construction component	Potentially impacting construction activities	Potential surface water quality impact	Waterway potentially impacted
Works within: • Wakehurst Parkway surface road works construction footprint • Wakehurst Parkway south (BL12) and Wakehurst Parkway east (BL13) construction support site.	• Vegetation removal and topsoil stripping • Establishment of sites and installation of construction support site facilities • Cut to fill bulk excavations for road formation • Construction of retaining walls and noise walls • Excavations/trenching for basins, drainage works including catch drains • Modifications to surface roads • Vehicle movements to and from sites • Stockpiling of spoil, construction and demolition materials • Relocation of utilities • Onsite storage of chemicals/fuel • Accidental spills/material released during transportation of building waste from demolition sites • Activities associated with construction for permanent works.	• Excavations washing into drainage lines, leading to increased levels of turbidity and sediment loads posing risk to Garigal National Park • Risk to water quality of downstream drainage lines, Manly Dam and Bantry Bay during rainfall if the stockpiles are not managed appropriately • Risk of movement of sediment off steep slopes during high volume rain events.	• Manly Creek, drainage lines within Manly Dam War Memorial Park and Many Dam have the potential to be impacted from the realignment and upgrade of the Wakehurst Parkway • Garigal National Park drainage lines flowing towards Bantry Bay have the potential to be impacted from the realignment and upgrade of the Wakehurst Parkway • Wakehurst Golf Club drainage lines flowing towards Manly Dam have the potential to be impacted from Wakehurst Parkway south (BL12) and Wakehurst Parkway east (BL13) construction support site.

Location/construction component	Potentially impacting construction activities	Potential surface water quality impact	Waterway potentially impacted
Culverts: • Installation and/or extension of culverts and basins in waterways	• Instream works • Clearing of bed and banks • Instream bed levelling • Temporary diversion of water if present at time of construction • Concrete works.	• Construction and/or extension of culverts has the potential to create instream barriers, increase erosion and interfere with natural flow regimes • Leakage/spills of hydrocarbons or other chemicals from construction machinery and concreting • Sedimentation can result in increased turbidity levels, reduced visual amenity and smothering of aquatic ecosystems. Instream structures can lead to scour and deposition of sediments due to changes in flow rates.	• Aboveground watercourse within Flat Rock Reserve flowing into Flat Rock Creek • Burnt Bridge Creek • Eastern and western sides of Wakehurst Parkway • Flat Rock Creek at Gore Hill Freeway

5.2.3 Impact on NSW water quality objectives during construction

The project would treat wastewater from tunnelling activities to meet the ANZG (2018) 90 per cent species protection level for toxicants (or the ANZG (2018) 95 per cent species protection level for those that bioaccumulate)) and the ANZECC/ARMCANZ (2000) default trigger values for physical and chemical stressors.

During the earthworks and surface works identified in Table 5-5, a number of erosion and sediment controls would be required to mitigate and manage potential erosion and sedimentation impacts from the project, including impacts to water quality. Temporary sediment basins would be used in catchments where the erosion hazard exceeds 150 cubic metres/year (200 tonnes/year) of soil loss. The final location and size of all sediment basins would be determined during further design development and construction planning. Based on preliminary investigations, it likely that temporary sediment basins would be required for works associated with the realignment and upgrade of the Wakehurst Parkway and surface road works at Balgowlah. Discharges from temporary sediment basins and construction wastewater treatment plants would be monitored and managed to ensure that the NSW WQOs continue to be met at waterways where WQOs are currently being achieved, or alternatively, where they are not being met that discharges work towards achievement of the WQOs over time.

Alternative erosion and sediment control measures would be implemented in locations where sediment basins cannot be provided because of site, soil and drainage constraints to constructing large scale sediment basins. For these catchments, smaller sediment basins, sediment sumps, mulch bunds, sediment fences or similar combinations of thereof would be used. However, to manage potential associated risks, these catchments would also be subject to enhanced erosion control measures and best management practice, such as limiting the size of disturbed land at any one time.

With the implementation of the environmental management measures detailed in Section 8.1 and expected water quality from discharges from wastewater treatment plants and temporary sediment basins, pollutant loading to the receiving waterways is considered to be low compared to the existing pollutant loading from Willoughby Creek, Flat Rock Creek, Burnt Bridge Creek, Manly Dam, Manly Creek and Trefoil Creek catchments.

The project construction is therefore likely to have a negligible influence on whether the NSW WQOs of receiving waterways are protected (if currently met) or achieved (if currently not met).

Refer to Appendix Q (Technical working paper: Marine water quality) for a discussion on impacts on NSW water quality objectives of marine environments.

5.3 Impacts to local stormwater system

As noted in Section 5.1.2 construction wastewater treatment plants located at Cammeray Golf Course construction support site (BL1), Flat Rock Drive construction support site (BL2), Punch Street construction support site (BL3) and Balgowlah Golf Course construction support site (BL10) would discharge into the local stormwater network. Most of the treated water from the construction wastewater treatment plant at the Wakehurst Parkway east construction support site (BL13) would be reused at the construction support site and for construction activities associated with the Wakehurst Parkway upgrade. Surplus water (10KL/day) would be discharged to a drainage channel to be formed at the eastern section of the support site and subsequently flow into the nearby golf course dam via overland flow, for reuse by the golf course.

Table 5-6 shows the discharge relevant to each wastewater treatment plant. There would be a period of about six months when the wastewater treatment plants at the Cammeray Golf Course construction support site (BL1) and Western Harbour Tunnel and Warringah Freeway Upgrade project Cammeray Golf Course construction support site (WHT10) would discharge concurrently into the local stormwater system. The cumulative discharge from these two wastewater treatment plants is also presented in Table 5-6.

The discharge flow rate is estimated to be between 0.001 and 0.008 kilolitres per second and is unlikely to have a material impact on the local stormwater system. Changes to flow (stormwater runoff) due to surface works are anticipated to be accommodated within the existing stormwater network. This would be confirmed during detailed construction planning (refer to Section 8.1).

Table 5-6 Construction wastewater treatment plants discharge quantity and estimated duration of operation

Plant location	Discharge quantity (kL/d)[1]	Estimated duration of operation
Cammeray Golf Course construction support site (BL1)	296	Three years and three months
Cammeray Golf Course construction support site (BL1) and Western Harbour Tunnel and Warringah Freeway Upgrade project Cammeray Golf Course construction support site (WHT10) (cumulative discharge)[2]	321	Six months
Flat Rock Drive construction support site (BL2)	711	Four years
Punch Street construction support site (BL3)	308	Three years and nine months
Balgowlah Golf Course construction support site (BL10)	428	Four years
Wakehurst Parkway East construction support site (BL13)	10	Three years and six months

Note 1: Construction wastewater treatment plants discharge into local stormwater system except for Wakehurst Parkway East construction support site (BL13) which would discharge into a drainage channel formed in the eastern part of the construction support site.
Note 2: Cumulative impact during the time the two wastewater treatment plants would be discharging concurrently into the local stormwater system.

5.4 Impacts on geomorphology

Construction of the project would involve a variety of activities with the potential to impact on the waterway form and geomorphic processes. Geomorphology impacts could potentially arise in the following ways:

- Treated water discharges from construction wastewater treatment plants have the potential to impact creek channel bed and bank conditions due to changes in baseline volumes and velocities
- Temporary changes in creek flows and velocities within Burnt Bridge Creek downstream of the project while localised adjustments are carried out. Works would be staged to ensure creek flows and velocities are not notably changed and to avoid downstream erosion and bed and bank stability impacts
- Minor changes to creek flows and increased risk of sedimentation during installation of the culvert within an aboveground watercourse within Flat Rock Reserve. The culvert would be sized to not restrict the free flow of water and would be designed with low gradient and scour protection so as to minimise impacts to geomorphology. Additionally, installation of culverts would be in accordance the *Temporary Stormwater Drainage for Road Construction technical guideline* (Roads and Maritime Services, 2011)
- Mobilised sediment could build up in the streams if not appropriately managed
- Impermeable surfaces created by the project would lead to increases in the volume and rate of runoff, which could cause erosion within the instream channel.

The wastewater treatment plant at Cammeray Golf Course construction support site (BL1) would discharge into the local stormwater system which would ultimately discharge into Willoughby Creek at a continuous average rate of about 0.003 kilolitres per second (that is, three litres per second) for about three years. There would be also a period of about six months when the wastewater treatment plants at the Cammeray Golf Course construction support site (BL1) and Western Harbour Tunnel and Warringah Freeway Upgrade project Cammeray Golf Course construction support site (WHT10) would discharge concurrently into Willoughby Creek at a continuous average rate of about 0.004 kilolitres per second (that is, four litres per second). These discharge flows are considered minor when compared to creek flows experienced during a two-year average recurrence

interval (ARI) event (1.7 kilolitres per second). Cammeray Golf Course wastewater treatment plant discharges into Willoughby Creek are not anticipated to change the creek geomorphology as the creek is a modified concrete and rock channel that handles greater flows during frequent flood events than is expected to be discharged during construction. 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.

Construction wastewater treatment plants at Flat Rock Drive (BL2) and Punch Street (BL3) construction support sites would discharge into Flat Rock Creek via the local stormwater network at a cumulative and continuous average rate of about 0.012 kilolitres per second (that is 12 litres per second) for about four years. This cumulative flow is considered minor when compared to creek flows experienced during a two-year ARI event (0.02 kilolitres per second). Construction wastewater treatment plant discharges into Flat Rock Creek are not anticipated to change the form of the creek channel and banks as they are able to handle greater flows during frequent flood events. There is also little potential for further incision of the concrete-lined sections and rocky riffle/runs at Flat Rock Creek.

The construction wastewater treatment plant at Balgowlah Golf Course construction support site (BL10) would discharge into Burnt Bridge Creek via the local stormwater network at a cumulative and continuous average rate of about 0.005 kilolitres per second (that is, five litres per second) for about four years. This cumulative flow is considered negligible when compared to creek flows experienced during a two-year ARI event (29.7 kilolitres per second) and is not expected to change the stability or form of Burnt Bridge Creek channel or banks.

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

The susceptibility of Flat Rock Creek and Burnt Bridge Creek to further degradation as a result of increased flows is considered low based on assessment of their current stability and the relatively low level of discharges anticipated compared to frequent ARI events. Standard mitigation measures to manage geomorphology impacts on these creeks are presented in Section 8.1.

Impacts to geomorphology as a result of increased mobilised sediment or increased surface runoff (volume or velocity) could occur where activities are near watercourses. This includes Willoughby Creek, Flat Rock Creek, Burnt Bridge Creek, Manly Creek and along drainage lines that pass under Wakehurst Parkway. Impacts to Flat Rock Creek are considered to have low potential given the concrete-lined or piped nature of the creek. Elsewhere, the potential for impacts would be mitigated through standard construction support site management practices.

Works along the Wakehurst Parkway, the Wakehurst Parkway south construction support site (BL12) and east construction support site (BL13) are unlikely to change the bed and bank conditions of the existing drainage lines to Middle Harbour and Manly Creek provided environmental safeguards outlined in Section 8.1 are implemented.

5.5 Impacts on environmental water availability and flows

Water extraction from surface waters is not proposed during construction of the project.

Surface environmental water availability and flows have the potential to be reduced as a result of groundwater drawdown during construction of the project. Baseflow impacts are modelled conservatively without tunnel linings designed and installed to reduce groundwater inflows into the tunnels. Baseflow impacts are likely to be lower than that predicted in Appendix N (Technical working paper: Groundwater) (due to conservative modelling assumptions). The Technical working paper found:

- Maximum predicted drawdown at Willoughby Creek during the construction phase is up to three metres. The creek is lined in this region and therefore baseflow impacts are not expected
- There is the potential for a baseflow reduction of more than five per cent to occur at Burnt Bridge Creek. Baseflow reductions at Flat Rock Creek and Quarry Creek at the end of construction is expected to be 20 per

cent and 23 per cent respectively and has the potential to impact on GDEs. As this impact would also occur during operation, this is further discussed in Section 6.5

- The drawdown beneath Burnt Bridge Creek, North Balgowlah is estimated to be up to five metres. There would be maximum of 79 per cent reduction in baseflow at the end of construction
- An estimated drawdown of less than one metre is expected at Manly dam resulting in maximum baseflow reduction 2 percent.

Manly Creek and Trefoil Creek would be unaffected by changes to baseflow.

The project would not impact the stormwater harvesting scheme implemented by North Sydney Council at the storage dam at Cammeray Golf Course. Transport for NSW has committed to implementing a permanent solution to replace the storage dam prior to removal of the existing dam as part of the Western Harbour Tunnel and Warringah Freeway Upgrade project so that no impact to water reuse by North Sydney Council will occur during the construction period or operational period. The reinstatement and management of impacts to North Sydney Council stormwater harvesting scheme prior to the reinstatement of the permanent solution form part of the Western Harbour Tunnel and Warringah Freeway Upgrade project.

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

5.6 Impacts to Coastal Environment Areas

The key objectives of the CM Act relevant to this project are to protect and enhance coastal environmental values and to maintain and improve water quality and estuary health. Wastewater discharges to Burnt Bridge Creek during construction have the potential to impact on the coastal environment areas and coastal wetlands if poorly treated water is discharged. By treating wastewater discharges during construction to meet the ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines, environmental values would be protected and the objective of maintaining or improving water quality would be met.

Standard erosion and sediment control measures including temporary sediment basins would be implemented to treat runoff from construction areas associated with the realignment and upgrade of the Wakehurst Parkway and surface road works at Balgowlah which are upstream of coastal wetland areas to not impact on water quality and protect environmental values.

The project construction is therefore likely to have a negligible impact on Coastal Environment Areas and works towards achieving the management goals of the Clontarf/Bantry Bay Estuary Management Plan.

Refer to Appendix Q (Technical working paper: Marine water quality) for discussion of the impact the construction of the mainline tunnel could have on the littoral rainforests at Seaforth and other coastal areas.

6. Assessment of operational impacts

Operation of the project has the potential to alter the water balance of surface and groundwater systems, and impact on surface water quality and geomorphology. Details and an assessment of the likelihood of those impacts is provided in the following sections.

6.1 Water use and water balance

This section provides a preliminary assessment of the water balance during operation of the project. Groundwater inflow estimates documented in Appendix N (Technical working paper: Groundwater) have been used to provide an indicative estimate of likely inflow volumes that would be pumped to the Gore Hill Freeway wastewater treatment plant which is the only permanent facility currently planned and is expected to treat all groundwater inflows during the operational period. The location of the Gore Hill Freeway wastewater treatment plant is shown in Figure 6-4.

The project-wide operational water demand estimates have been split into two key requirements, these being washdown water and deluge testing. The data provided are shown in Table 6-1 as project-wide daily averages. These activities are expected to occur at certain times in particular locations and therefore the peak daily demand would be greater than the average.

Water supply for any non-potable demand during the operational phase can be sourced from the capture and treatment of groundwater inflows. This would be dependent on water availability when it is required and the suitability of the water quality for the intended purpose. The average groundwater inflows during the operational phase are shown in Table 6-1.

Table 6-1 Operational water balance (average groundwater inflows) for the Gore Hill Freeway wastewater treatment plant

Water demand		Average groundwater inflows (kL/d)[1]	Treated groundwater re-used (kL/d)	Water make-up from other sources (kL/d)	Discharge quantity (kL/d)
Washdown (kL/d)	Deluge Testing (kL/d)				
2	8	1435	10	-	1425

Note: 1. Averaged over 100 year project life

6.2 Impacts on surface water quality

Potential risks to surface water quality include:

- Increased impervious surfaces and the discharge of stormwater
- Tunnel discharges of potentially contaminated groundwater
- Erosion and sedimentation from recently disturbed sites
- Impacts to water availability and flows.

Table 6-2 provides a summary of the potential impacts and the downstream receiving waterways at risk.

Table 6-2 Summary of potential operational impacts on surface water quality

Location/component	Potential operation impacts	Potential surface water quality impact	Waterway potentially impacted
Operation of the project (entire alignment) and new or modified roads resulting in increased road surfaces including: • Connections to and from the Warringah Freeway • Connections to and from the Gore Hill Freeway • Connections to and from the Burnt Bridge Creek Deviation • Connections to and from Wakehurst Parkway • Upgrade and integration works along the Gore Hill Freeway between the Gore Hill Freeway/Pacific Highway and the T1 North Shore and Northern rail line (the Gore Hill Freeway Connection) • Upgrade and integration works along and around the Burnt Bridge Creek Deviation and Sydney Road, at Balgowlah, including a new access road • Upgrade and integration works along the Wakehurst Parkway, at Killarney Heights and Frenchs Forest. This includes widening and realignment of Wakehurst Parkway.	• Increased erosion and sedimentation • Increases in impervious areas and to a lesser extent from future increases in traffic resulting in increased pollutants from road runoff • Increased volume of road runoff associated with the introduction of additional impervious surfaces • Spills or leaks of fuels and/or oils on road surfaces due to vehicle accidents or heavy vehicles transporting such materials.	Increased flow and increased area of impervious surfaces and changes to geomorphology such as changing the channel, bed profile and sedimentation process. This can: • Increase sediment loads and nutrients • Reduce light penetration through the water column, impacting aquatic flora and fauna • Stimulate the excessive growth of algae and aquatic plants leading to toxic conditions • Increase siltation of waterways and associated smothering of aquatic flora and fauna • Lead to decay of organic matter and some hydrocarbons which can decrease dissolved oxygen levels affecting fish and aquatic life • Increase levels of heavy metals (including aluminium and iron) which are toxic to aquatic biota and fish • Increase levels of litter, oils and grease.	• Willoughby Creek • Flat Rock Creek • Burnt Bridge Creek • Manly Creek and Manly Dam • Trefoil Creek.

Location/component	Potential operation impacts	Potential surface water quality impact	Waterway potentially impacted
Groundwater and tunnel drainage management and treatment systems, including the Gore Hill Freeway wastewater treatment plant.	• Discharge of poor quality wastewater • Alteration of the water table and changes to local hydrology due to groundwater drawdown • Change of instream flows and velocity.	• Stagnation of a waterway or changes in levels of turbidity, nitrogen and phosphorus, should flows be notably lower • Increased pollutant levels given poor groundwater quality including metals (iron and manganese) and hydrocarbons which can be toxic to aquatic species. These concentrations are higher than background levels in Flat Rock Creek which if discharged untreated could impact on water quality. • Increased sedimentation and turbidity due to increased flow and velocities in discharge from operational treatment plant. This can reduce light penetration through the water column, impacting aquatic flora and fauna.	• Groundwater drawdown would potentially impact base flows for Quarry Creek, Flat Rock Creek and Burnt Bridge Creek. This is discussed further in Section 6.5. • Water collected by the tunnel drainage system would be treated and discharged to Flat Rock Creek via a new drainage pipe.
Operational ancillary facilities including: • Motorway facilities and ventilation outlets at the Warringah Freeway, Gore Hill Freeway, Burnt Bridge Creek Deviation, and Wakehurst Parkway. • A motorway control centre in Artarmon • Tunnel support facilities at the Gore Hill Freeway in Artarmon and Wakehurst Parkway in Frenchs Forest.	Spills or leaks of fuels and/or oils from vehicle accidents or from operational plant and equipment.	Increased levels of heavy metals (including aluminium and iron) which are toxic to aquatic biota and fish.	This could occur at any of the receiving waterways located downstream of the alignment.

6.2.1 Impervious surfaces and stormwater discharges

Surface water quality controls for the project have been approached as follows:

- Where possible, provide water quality treatment that meets the design targets listed in Table 6-3. These targets are as described in *Draft Managing Urban Stormwater – Council Handbook* (EPA, 2007). This was carried out using the eWater Water Quality MUSIC model that uses recorded historical rainfall data (not design events) together with user defined parameters on catchments, land use, event mean concentrations and other input parameters to predict water quality treatment outcomes. Rainfall designed events are not used in the MUSIC model as the required outputs need to represent the long term impacts that are best described by the use of long term rainfall data and these outputs are expressed as average annual pollutant loads.
- Where the design targets cannot be met due to site constraints, 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 following aspects need to be considered when assessing site constraints:
  - Practical spatial constraints, existing structures and utilities
  - Maintenance access and safety considerations
  - Environmental sensitivity and clearing impacts
  - Performance gained against targets.
- Provide accidental spill containment of up to 40 cubic metres where possible.
- Provide Gross Pollutant Traps where space is available.

Table 6-3 Operational water quality design targets

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

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

Water quality control measures that form part of the project would include:

- New or modified drainage would be provided along the Gore Hill Freeway, and along modified or new surface roads at Balgowlah, Killarney Heights and Frenchs Forest
- New water quality basins have been proposed within the new open space and recreation facilities at Balgowlah and along Wakehurst Parkway

The final suite of water quality controls for the project would be confirmed during further design development.

A Model for Urban Stormwater Improvement Conceptualisation (MUSIC) was carried out to predict stormwater discharge pollutant loads from impervious surfaces. The MUSIC modelling results are presented in the following sections for locations where stormwater would be discharged. Modelling results presented are preliminary and subject to further design development.

The performance of proposed water quality controls could potentially diminish over time if such devices are not adequately maintained during the operational phase. A maintenance regime of water quality control devices would be developed during further design development (refer to environmental management measures in Section 8.2).

6.2.1.1 Warringah Freeway

Surface water drainage for the project at the surface connections to the Warringah Freeway is designed so that stormwater intercepted at the tunnel on and off ramp portals is directed into the tunnel drainage system, and directed to the wastewater treatment plant (refer to Section 6.2.2). The project would not adjust any surface water drainage that would be constructed as part of the Warringah Freeway Upgrade, which would include a new drainage network around the project portals to minimise the potential for the ingress of water.

6.2.1.2 Gore Hill Freeway Connection

Within the Gore Hill Freeway Connection catchments, there are two existing water quality basins located at Punch Street and Artarmon Oval which ultimately discharge to Flat Rock Creek via local drainage systems (refer to Section 4.4.2).

The MUSIC model results for the Gore Hill Freeway Connection stormwater catchments (Figure 6-1) are shown in Table 6-4. These results show that the proposed water quality strategy would achieve reductions on annual pollutant exports when compared to existing conditions. These reductions are around 17 per cent for total suspended solids, 12 per cent for total phosphorus, and 10 per cent for total nitrogen.

The operational water quality design targets for the project would not be achieved for the following reasons:

- Any expansion of the Artarmon Oval basin would have potential heritage impacts. Impacts of an increased impervious area discharging to this basin are offset by additional water quality treatment at the Punch Street basin
- The Punch Street basin is located between existing road reserves and any supplementary extension is limited by land availability and proximity to the tunnel dive structures. The basin invert is located higher than the adjacent cut and cover tunnel and deepening is not practical
- There is limited residual land available on the southern side of the Gore Hill Freeway Connection to provide any additional basins. The area is severely constrained by road corridors and infrastructure (including utilities), particularly below ground high voltage electricity cables
- Meeting the target requirements would require an estimated three-fold increase in the current basin surface areas. This is not feasible or practical given the highly developed nature of the corridor.

Based on these results, the Gore Hill Freeway Connection would maintain or improve existing water quality conditions and would not decrease the water quality of downstream drainage lines.

Table 6-4 MUSIC model results for Gore Hill Freeway Connection

Pollutant	Unit	Existing conditions	With project and proposed controls
Total suspended solids	kg/year	16,500	13,700
	% reduction	N/A	67
Total phosphorus	kg/year	35	31
	% reduction	N/A	57
Total nitrogen	kg/year	221	200
	% reduction	N/A	31

Note: % reduction represents the percentage reduction when comparing the project with and without the proposed controls

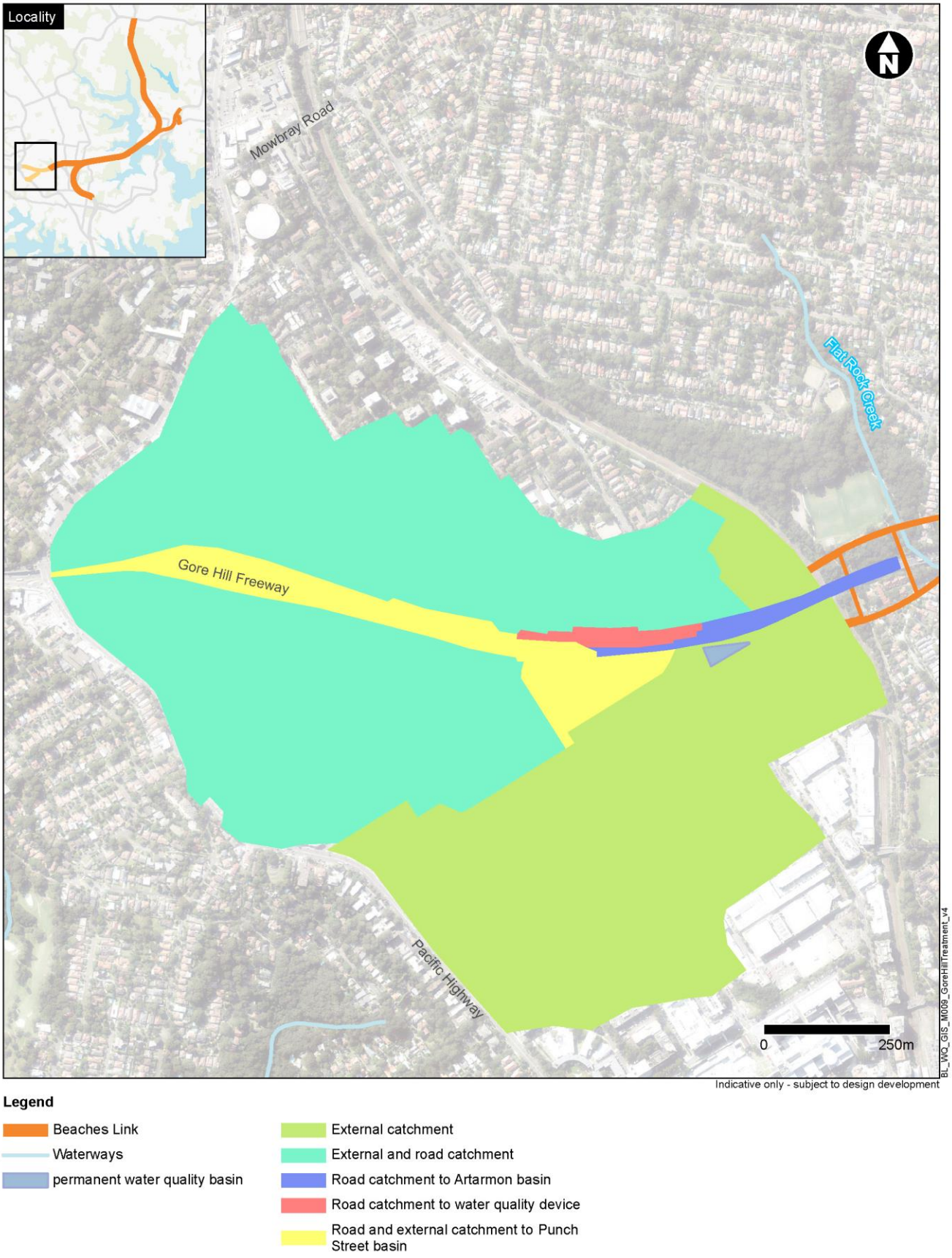

Figure 6-1 MUSIC model catchment for Gore Hill Freeway Connection

6.2.1.3 Surface connections at Balgowlah

Burnt Bridge Creek Deviation between Sydney Road and south of Kitchener Street does not have any existing water quality treatment devices. Stormwater runoff is collected through a pit and pipe network that discharges freely to Burnt Bridge Creek without treatment, however; within the Balgowlah Golf Course, the existing pond provides some water quality treatment to runoff currently discharging into it.

There are four separate sub-catchments relevant to surface connections at Balgowlah (refer to Figure 6-2). These fours sub-catchments are:

1. Sub-catchment 1 – Road catchment – South of the access Road (2.97 ha)
2. Sub-catchment 2 – Road catchment – North of the access Road (1.247 ha)
3. Sub-catchment 3 – Access Road (0.944 ha)
4. Sub-catchment 4 – Balgowlah Golf Course, north and south of Access Road (8.697 ha).

The surface runoff from the above sub-catchments would all be diverted to a water quality treatment system located in the Balgowlah Golf Course site near Burnt Bridge Creek as shown in Figure 6-2, except for sub-catchment 2 which cannot be connected to the proposed basin. This sub-catchment would receive treatment through a gross pollutant device that is also capable of capturing accidental spills. The proposed water quality treatment system consists of a biofiltration basin and vegetated swales located upstream of the basin.

Sub-catchment 1 would also be treated by a gross pollutant device before it discharges into the basin, as space in this sub-catchment would allow a gross pollutant trap to be installed. Sub-catchment 4 which represents the largest area would receive treatment through the swales and the biofiltration basin as shown in Figure 6-2. An accidental spill pond is being proposed immediately upstream of the biofiltration basin to capture any accidental spills from sub-catchments 1, 3 and 4. The minimum volume of spill would be 40 cubic metres. This pond would retain any accidental spills such as petroleum hydrocarbons and therefore provide protection for the biofiltration basin.

The initial MUSIC model results for the combined stormwater catchments associated with the surface connections at Balgowlah are shown in Table 6-5. The results predict that the water quality strategy at Balgowlah would not achieve the operational water quality design targets (refer to Table 6-3) for total suspended solids and total phosphorus. However, the water quality strategy would provide a reduction in annual pollutant exports, when compared to existing conditions providing an overall beneficial outcome, with significant reduction reductions for total suspended solids from 17,600 kg per annum to 3600 kg per annum. The reductions for total phosphorus, and total nitrogen are smaller but are considered to be very reasonable improvements.

Based on the initial MUSIC model results, the surface connections at Balgowlah would not decrease the water quality of Burnt Bridge Creek. Initial MUSIC model results are based on proposed open space and recreation facilities and motorway operational facilities. The proposed open space and recreation facilities are subject to confirmation through further community consultation and the final agreed facilities may change the final MUSIC modelling for the Balgowlah golf course area.

Table 6-5 MUSIC model results for surface connections at Balgowlah

Catchment /pollutant	Unit	Existing conditions	With project and proposed controls
Total suspended solids	kg/year	17,600	3,610
	% reduction	N/A	84
Total phosphorus	kg/year	33	15
	% reduction	N/A	62
Total nitrogen	kg/year	193	86
	% reduction	N/A	57

Note: % reduction represents the percentage reduction when comparing the project with and without the proposed controls

Figure 6-2 MUSIC model catchment for Balgowlah connections

6.2.1.4 Wakehurst Parkway

There are currently no existing water quality controls along this section of the Wakehurst Parkway, except for controls that form part of the Northern Beaches Hospital road upgrade project at the northern extent of the project footprint.

The pavement drainage system for Wakehurst Parkway has been designed to discharge to water quality basins or treatment swales before draining into the natural creeks that ultimately discharge to Bantry Bay in Middle Harbour or Manly Dam. At the northern and southern ends of the project area, pavement runoff would be discharged into the existing council drainage system.

The proposed water quality controls consist of two permanent basins, 18 swales and two in line gross pollutant traps.

The MUSIC model results for the Wakehurst Parkway stormwater catchments (Figure 6-3) are presented in Table 6-6 to Table 6-9. The results show that the project would provide an improvement to water quality when compared to existing conditions, except for total nitrogen; however, the impact on the downstream waterways is not considered to represent potential adverse impacts.

The project operational water quality design targets (provided in Table 6-3) would not be achieved at the Wakehurst Parkway as this would require additional land acquisition, clearing of native vegetation and fencing requirements near publicly accessible areas. It would also require higher treatment efficiency controls such as biofiltration swales which would not be possible due to topographical constraints.

The overall combined results for all the project areas are provided in Table 6-6. The individual results for the proposed basins, swales and gross pollutant traps are provided in Table 6-7, Table 6-8 and Table 6-9 respectively.

Table 6-6 MUSIC model results for the overall combined Wakehurst Parkway catchments

Catchment/pollutant	Unit	Existing conditions	With project and proposed controls
Total suspended solids	kg/year	11,000	5,460
	% reduction	N/A	86
Total phosphorus	kg/year	23	20
	% reduction	N/A	69
Total nitrogen	kg/year	100	188
	% reduction	N/A	29

Note: % reduction represents the percentage reduction when comparing the project with and without the proposed controls

Some assumptions in the water quality model are conservative in the absence of field tests, which would be carried out during further design development. For example, it was assumed that the exfiltration rates for the basins and swales are zero which would need to be confirmed during further design development. The increase in total nitrogen load that is predicted for the project (188 kilograms per year) (Table 6-6) may reduce if field tests confirm that a small exfiltration rate exists for the sub-soils.

Based on these results, the Wakehurst Parkway surface road works would not decrease the water quality of the Garigal National Park drainage lines, Bantry Bay, Manly Dam or Manly Creek.

Table 6-7 MUSIC model results for the two proposed water quality basins at Wakehurst Parkway

Catchment/pollutant	Unit	Existing conditions	With project and proposed control (basin)
CH2950			
Total suspended solids	kg/year	1,790	561
	% reduction	N/A	90
Total phosphorus	kg/year	4	2
	% reduction	N/A	78
Total nitrogen	kg/year	15	19
	% reduction	N/A	47
CH4250			
Total suspended solids	kg/year	4,780	1,620
	% reduction	N/A	84
Total phosphorus	kg/year	9	5
	% reduction	N/A	72
Total nitrogen	kg/year	36	44
	% reduction	N/A	38

Note: % reduction represents the percentage reduction when comparing the project with and without the proposed controls

Table 6-8 MUSIC model results for the proposed swales at Wakehurst Parkway

Catchment/pollutant	Unit	Existing conditions	With project and proposed control (swale)
CH2280			
Total suspended solids	kg/year	8	185
	% reduction	N/A	83
Total phosphorus	kg/year	0	1
	% reduction	N/A	62
Total nitrogen	kg/year	0	7
	% reduction	N/A	11
CH2320			
Total suspended solids	kg/year	153	0
	% reduction	N/A	96
Total phosphorus	kg/year	0	2
	% reduction	N/A	78
Total nitrogen	kg/year	1	0
	% reduction	N/A	32

Catchment/pollutant	Unit	Existing conditions	With project and proposed control (swale)
CH2520			
Total suspended solids	kg/year	329	0
	% reduction	N/A	93
Total phosphorus	kg/year	1	5
	% reduction	N/A	74
Total nitrogen	kg/year	3	0
	% reduction	N/A	22
CH2525			
Total suspended solids	kg/year	203	8
	% reduction	N/A	96
Total phosphorus	kg/year	0	0
	% reduction	N/A	78
Total nitrogen	kg/year	1	1
	% reduction	N/A	36
CH2675			
Total suspended solids	kg/year	303	15
	% reduction	N/A	95
Total phosphorus	kg/year	1	0
	% reduction	N/A	77
Total nitrogen	kg/year	2	1
	% reduction	N/A	31
CH2775			
Total suspended solids	kg/year	4	55
	% reduction	N/A	94
Total phosphorus	kg/year	0	0
	% reduction	N/A	76
Total nitrogen	kg/year	1	5
	% reduction	N/A	26
CH2985			
Total suspended solids	kg/year	6	139
	% reduction	N/A	90
Total phosphorus	kg/year	0	1
	% reduction	N/A	71
Total nitrogen	kg/year	1	8
	% reduction	N/A	18

Catchment/pollutant	Unit	Existing conditions	With project and proposed control (swale)
CH3125			
Total suspended solids	kg/year	6	114
	% reduction	N/A	91
Total phosphorus	kg/year	0	1
	% reduction	N/A	72
Total nitrogen	kg/year	1	7
	% reduction	N/A	19
CH3320			
Total suspended solids	kg/year	205	14
	% reduction	N/A	95
Total phosphorus	kg/year	0	0
	% reduction	N/A	76
Total nitrogen	kg/year	1	1
	% reduction	N/A	28
CH3250			
Total suspended solids	kg/year	55	60
	% reduction	N/A	92
Total phosphorus	kg/year	0	0
	% reduction	N/A	73
Total nitrogen	kg/year	1	4
	% reduction	N/A	20
CH3300			
Total suspended solids	kg/year	184	257
	% reduction	N/A	86
Total phosphorus	kg/year	1	1
	% reduction	N/A	67
Total nitrogen	kg/year	2	10
	% reduction	N/A	14
CH3400			
Total suspended solids	kg/year	182	11
	% reduction	N/A	95
Total phosphorus	kg/year	0	0
	% reduction	N/A	77
Total nitrogen	kg/year	1	1
	% reduction	N/A	29

Catchment/pollutant	Unit	Existing conditions	With project and proposed control (swale)
CH3450			
Total suspended solids	kg/year	596	71
	% reduction	N/A	92
Total phosphorus	kg/year	1	0
	% reduction	N/A	74
Total nitrogen	kg/year	4	5
	% reduction	N/A	21
CH3800			
Total suspended solids	kg/year	11	100
	% reduction	N/A	94
Total phosphorus	kg/year	0	1
	% reduction	N/A	76
Total nitrogen	kg/year	1	8
	% reduction	N/A	27
CH3825			
Total suspended solids	kg/year	849	83
	% reduction	N/A	94
Total phosphorus	kg/year	2	1
	% reduction	N/A	75
Total nitrogen	kg/year	6	7
	% reduction	N/A	23
CH3975			
Total suspended solids	kg/year	560	212
	% reduction	N/A	89
Total phosphorus	kg/year	1	1
	% reduction	N/A	71
Total nitrogen	kg/year	5	10
	% reduction	N/A	17
CH4110			
Total suspended solids	kg/year	124	112
	% reduction	N/A	87
Total phosphorus	kg/year	0	0
	% reduction	N/A	68
Total nitrogen	kg/year	1	5
	% reduction	N/A	15

Catchment/pollutant	Unit	Existing conditions	With project and proposed control (swale)
CH4450			
Total suspended solids	kg/year	8	83
	% reduction	N/A	91
Total phosphorus	kg/year	0	0
	% reduction	N/A	72
Total nitrogen	kg/year	1	5
	% reduction	N/A	20

Table 6-9 MUSIC model results for the proposed in line gross pollutant traps at Wakehurst Parkway

Catchment/pollutant	Unit	Existing conditions	With project and proposed control (gross pollutant trap)
CH2170			
Total suspended solids	kg/year	2,540	1,050
	% reduction	N/A	80
Total phosphorus	kg/year	4	6
	% reduction	N/A	30
Total nitrogen	kg/year	311	25
	% reduction	N/A	30
CH5000			
Total suspended solids	kg/year	124	99
	% reduction	N/A	80
Total phosphorus	kg/year	0	1
	% reduction	N/A	30
Total nitrogen	kg/year	1	2
	% reduction	N/A	30

Note: % reduction represents the percentage reduction when comparing the project with and without the proposed controls

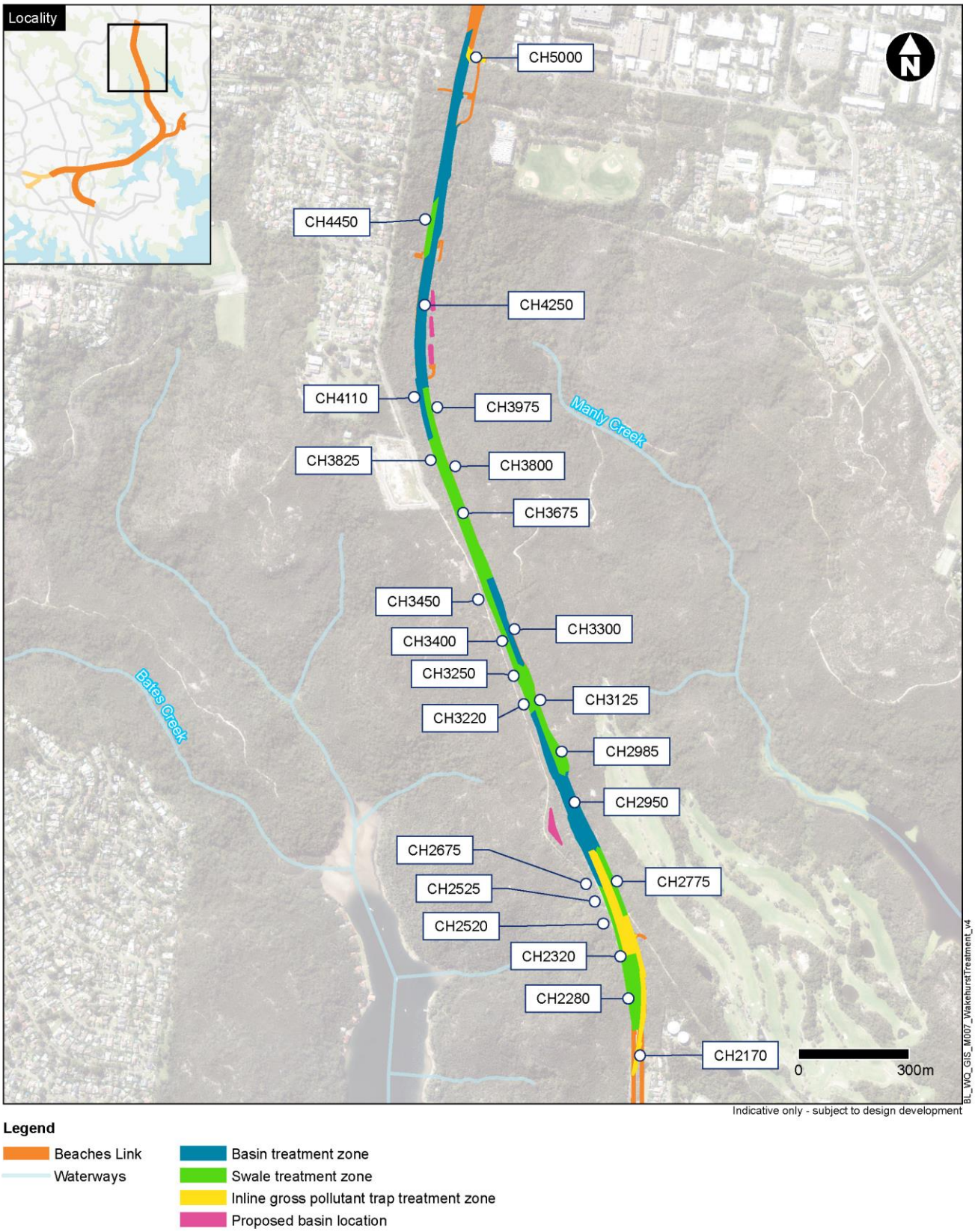

Figure 6-3 MUSIC model catchment for Wakehurst Parkway

6.2.2 Tunnel discharges

A drainage and sump system would be installed within the tunnels to collect:

- Groundwater inflow to the tunnels
- Stormwater entering the tunnels
- Deluge water in the event of an incident or during routine testing of emergency systems
- Washdown water
- Spills and leaks.

Water intercepted by the tunnel drainage system would be collected within a tunnel sump system located on the south-western side of Middle Harbour and then pumped to the surface to the Gore Hill Freeway wastewater treatment plant (Figure 6-4). Treated wastewater would then be discharged via a new drainage pipe connecting to an extent of Flat Rock Creek which is within a concrete lined stormwater channel.

Groundwater bores in the area generally exhibit elevated concentrations of metals, nutrients (total nitrogen, total phosphorus and ammonia) and are likely to contain traces of petroleum products as inferred by detection of total recoverable hydrocarbons (refer to Table 5-4 and Annexure B). This groundwater is generally of poorer quality with respect to these indicators than the water quality of receiving waterways and therefore, the Gore Hill Freeway wastewater treatment plant would focus on these water quality indicators for treatment.

The wastewater treatment plant would need to be designed so that the wastewater would be of suitable quality for discharge to the downstream receiving environment (Flat Rock Creek). Additionally, appropriate tunnel lining would be in place to reduce groundwater inflow into the tunnel to the required criteria of 1L/second/km thereby reducing the amount of inflows requiring treatment and disposal. Appendix N (Technical working paper: Groundwater) provides further details on groundwater inflow.

If tunnel inflows are not treated to a suitable standard during project operation, there is the potential for deterioration in the water quality of Flat Rock Creek which would increase the toxicity of the creek to aquatic species. The Flat Rock Creek water quality monitoring discussed in Section 4.5.3 found elevated levels of nutrients (total nitrogen, total phosphorus and ammonia) and metal concentrations (iron and manganese). Groundwater quality monitoring of bores in the vicinity of the creek is documented in Appendix N (Technical working paper: Groundwater) and revealed concentrations of these same indicators are notably higher in the groundwater. The operational wastewater treatment plant would be designed to meet the guideline values for the relevant physical and chemical stressors set out in ANZECC/ARMCANZ (2000), the ANZG (2018) 95 per cent species protection levels for toxicants, and the ANZG (2018) 99 per cent species protection levels for toxicants known to bioaccumulate, and the draft ANZG default guideline values for iron (in fresh and marine water) and zinc (in marine water) of which public comments are under consideration as of November 2020. Additionally, pH correction would be part of the treatment to maintain ammonia-based pollutants within acceptable limits to meet the water quality objectives.

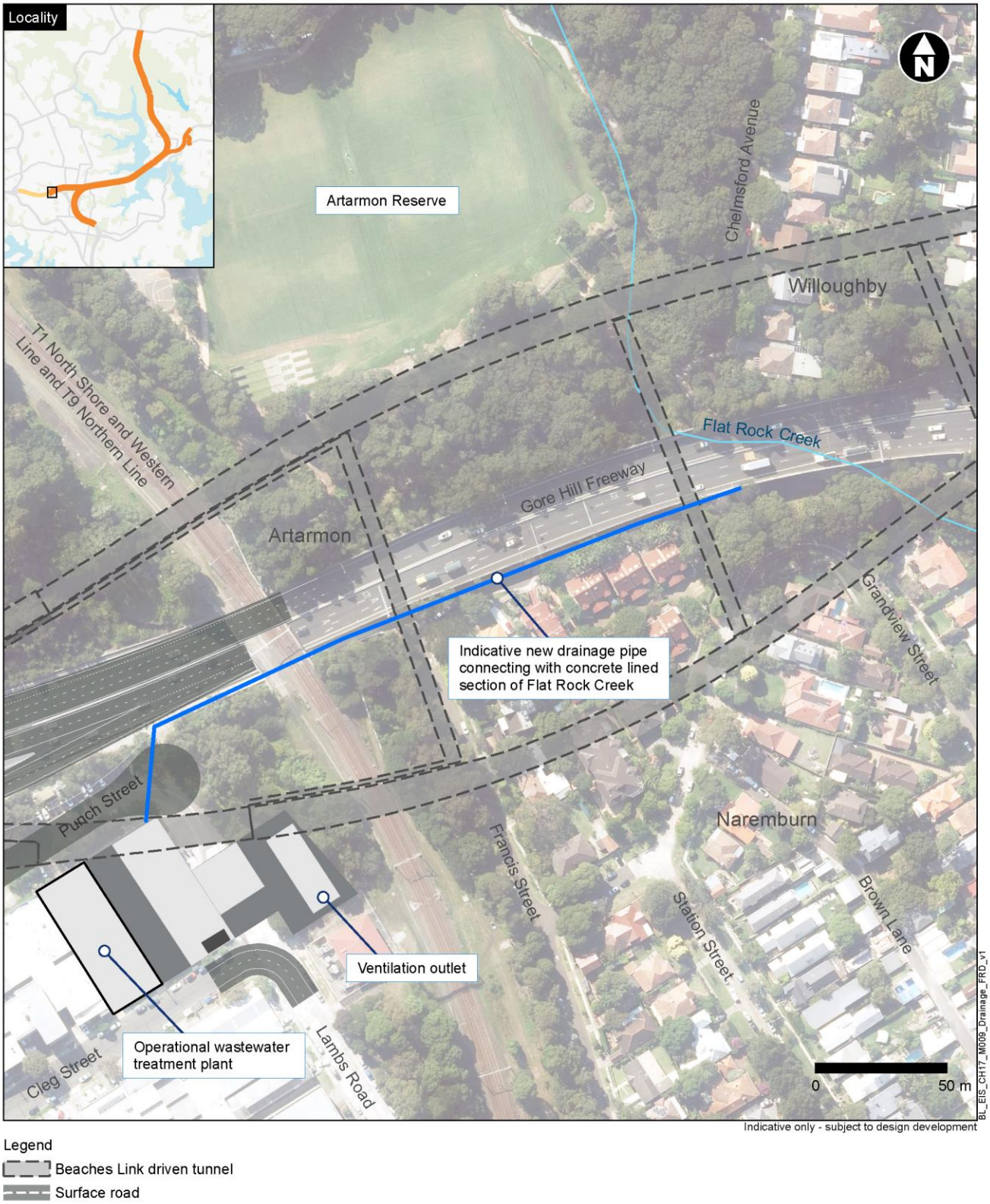

Figure 6-4 Gore Hill Freeway wastewater treatment plant discharge location

6.2.3 Erosion and sedimentation

Recently disturbed sites which have been rehabilitated would remain susceptible to scour and erosion from stormwater runoff until the soils and vegetation are completely established. As such there is the potential for sediment transport and sedimentation to occur at downstream waters, particularly after storm events. Suitable stabilisation and management techniques would be implemented during the periods of vegetation establishment to minimise the potential for erosion within areas of rehabilitation of temporary construction support sites near Flat Rock Creek.

In addition, increased impervious surface area and disturbance along the Wakehurst Parkway has the potential to increase the risk of erosion and scour within adjacent waterways including Manly Creek, Manly Dam and at the drainage lines crossing Garigal National Park.

Provided appropriate controls are implemented, short-term impacts during the establishment period would be expected to be manageable with negligible impacts on receiving water quality.

6.2.4 Spills

Though unlikely, the risk of accidental spillage of hazardous materials would always be present. Without satisfactory means of containment, the spillage of contaminants could pass rapidly into the project drainage system, particularly where surface works including widening of the road to allow for increases in traffic. This increase presents a higher risk of waterway contamination of Flat Rock Creek, Trefoil Creek, Burnt Bridge Creek, Manly Creek, Manly Dam and Middle Harbour should an accident or spill occur.

Accidental spills of chemicals or petrol in road accidents can cause severe damage to the ecology of waterways and therefore environmental protection would be required.

Spill containment along surface roads would be achieved through the provision of physical controls and would be determined further design development (refer to Section 8.2).

6.2.5 Impacts in NSW water quality objectives during operation

During operation, the project would treat tunnel inflows and road tunnel runoff at the Gore Hill Freeway wastewater treatment plant. The plant would be designed to treat key indicators of concern to a level that is consistent with the ANZG (2018) and ANZECC/ARMCANZ (2000) water quality guidelines and the NHMRC (2008) recreational water quality guidelines.

Runoff from the Gore Hill Freeway Connection is predicted to meet or improve existing water quality conditions (refer to Section 6.2.1.2) and would not decrease the water quality of Flat Rock Creek. Similarly, runoff from the surface connections at Balgowlah is predicted to provide a reduction in annual pollutant exports to the Burnt Bridge Creek catchment (refer to Table 6-5) with no worse impact on the existing water quality.

Runoff from the realigned and upgraded Wakehurst Parkway is predicted to reduce exports on annual total suspended solids and total phosphorus but would exhibit a minor increase in annual total nitrogen (refer to 6.2.1.4). Elevated concentration of nitrogen are already recorded in both Manly Creek and Manly Dam with concentrations generally higher in Manly Creek. As previously mentioned, there are many pools along the length of Manly Creek that may assist in holding some sediment (to which nutrients would be bound). These are unlikely to decrease the water quality of Garigal National Park drainage lines, Bantry Bay, Manly Dam or Manly 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 NSW WQOs for Flat Rock Creek, Burnt Bridge Creek, Manly Dam and Manly Creek catchments. The potential for increased loads of nitrogen into Manly Dam would not impact on the suitability for it be used for primary contact recreation. The NHMRC (2008) refer to elevated levels of phosphorus as the primary cause of algal blooms. The Northern Beaches Council actively monitor the dam and advised that the last significant algal bloom was almost 30 years ago and the dam is consistently open to recreational users.

Refer to Appendix Q (Technical working paper: Marine water quality) for a discussion on impacts on NSW water quality objectives of marine environments.

6.3 Impacts to local stormwater system

Treated wastewater from the Gore Hill Freeway operational wastewater treatment plant would discharge into the local stormwater system at a flow rate of about 0.016 kilolitres per second (that is, 16 litres per second). This discharge rate is unlikely to have a material impact on the local stormwater system.

6.4 Impacts on geomorphology

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

Gore Hill Freeway wastewater treatment plant discharge volumes would be ultimately received into Flat Rock Creek via the local stormwater system at a flow rate of about 0.016 kilolitres per second (that is, 16 litres per second). This rate is lower than the creek flow rate under a two-year ARI flood event (0.02 kilolitres per second). It is therefore considered that Flat Rock Creek bed and banks would be able to receive expected wastewater treatment plant flow rates without impacting the creek form and geomorphic processes.

The proposed localised adjustment of Burnt Bridge Creek would be required to enable the realignment of the southbound carriageways of the Burnt Bridge Creek Deviation and accommodate the Beaches Link portals. The localised adjustment is presented in Figure 6-5 and would include an extension to the existing culvert. The creek has experienced noticeable degradation over the years due to a variety of pressures generated from previous realignment/deviation works and runoff from surrounding urban areas, resulting in poor water quality, erosion and scour of creek banks, build-up of sediment and replanted vegetation (Local Government NSW, 2014). The capture of stormwater via the Balgowlah Golf Course Stormwater Harvesting Dam has eliminated the need to extract water from the creek allowing the re-creation of more natural conditions due to less stormwater entering the creek at high velocity, resulting in environmental improvement.

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

Arup and WSP (2020) assessed the potential for settlement and potential impacts as a result of the project. The key findings relevant to this assessment are:

- Cumulative long-term surface settlement from tunnelling works and groundwater drawdown is expected to be nil or very minor at creeks intersected or in proximity to the tunnel. The risk of rock cracking from such surface settlement is negligible because the ground movement would be insufficient to cause any noticeable change in permeability of the rock cover. The exception of this is the cumulative long-term surface settlement predicted at Flat Rock Creek within poorly consolidated fill beneath Flat Rock Baseball Diamond. At this location, settlement is predicted to be up to 85 millimetres.
- Contours of calculated surface angular distortion have been developed based on the calculated surface settlement data. The calculated maximum settlement is at the north east section of the link at Balgowlah Connection, Burnt Bridge Creek, Wakehurst Parkway Connection and north of the Warringah Freeway portal with the maximum settlement being 35 to 40mm in these areas
- Settlement is not expected to have noticeable impacts on Flat Rock Creek or Burnt Bridge Creek form and geomorphology as the creek drainage infrastructure along both these creeks would be designed as culverts and would mitigate some of predicted settlement impacts.

Geomorphology impacts such as increased erosion or sedimentation could potentially arise from:

- Incorrect design of diversion grade, sinuosity or channel capacity that does not allow for transitioning of flows from upstream, through the diversion and to downstream sections of the creek
- Grade control or bank stabilisation works which are not constructed in accordance with design to withstand hydraulic forces across full range of flows expected.

These impacts would be managed via the environmental management measures discussed in Section 8.2.

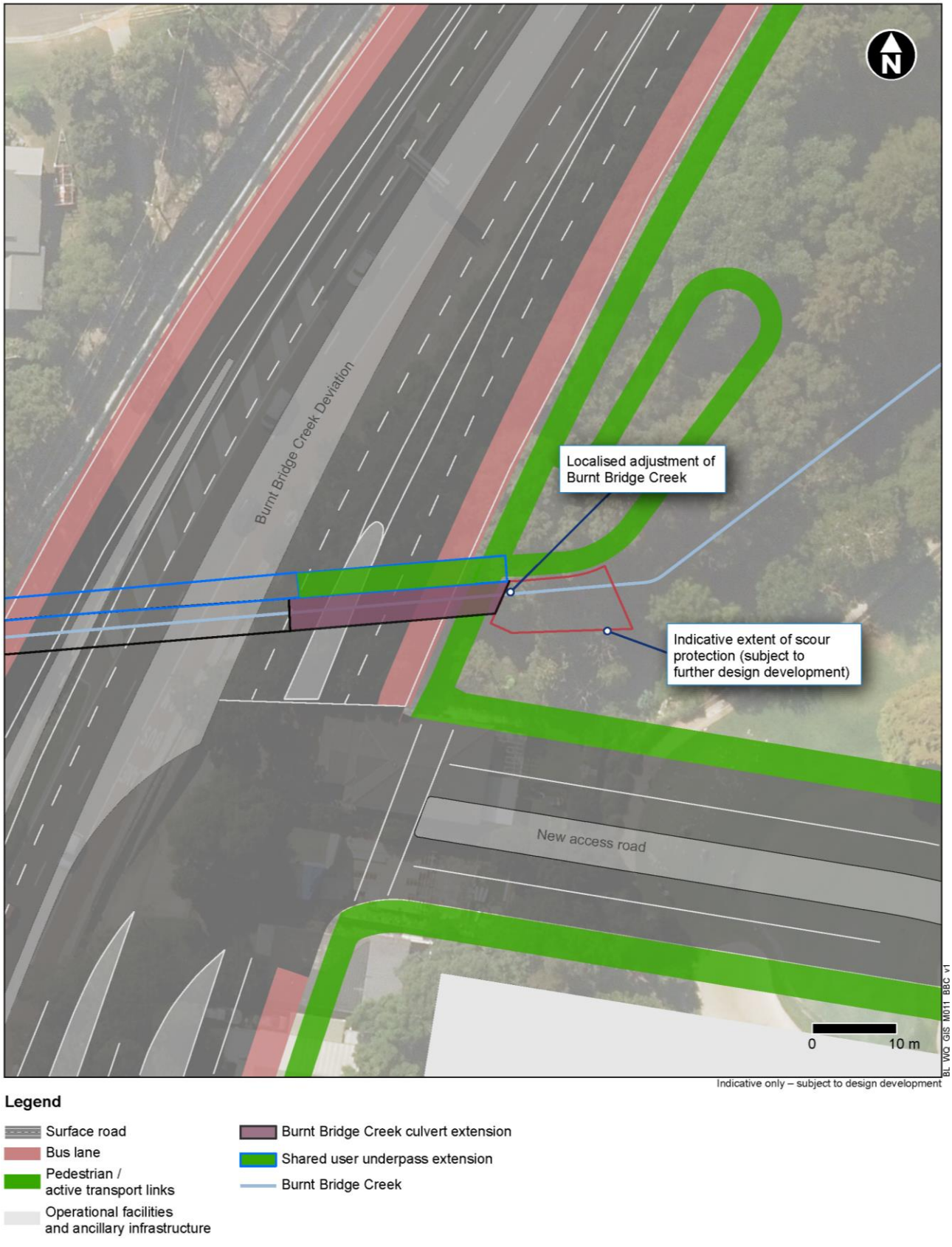

Figure 6-5 Burnt Bridge Creek realignment

6.5 Impacts on environmental water availability and flows

Water extraction from surface waterways is not proposed for the operational phase of the project.

The stormwater harvesting scheme implemented by North Sydney Council at the storage dam at Cammeray Golf Course would not be impacted by the project.

Surface environmental water availability and flows have the potential to be reduced due to groundwater drawdown due to the project. Appendix N (Technical working paper: Groundwater) predicts that:

- The maximum predicted drawdown at Willoughby Creek, Cammeray during the operational phase is predicted to be up to six metres. Despite this, baseflow reductions are likely to be negligible
- Maximum water table drawdown beneath Burnt Bridge Creek, North Balgowlah is predicted to be up to six metres. The predicted reduction in baseflow is estimated to be a maximum 16.8 kilolitres per day (a 96 per cent reduction) after about 100 years of operation. Baseflow impacts at Burnt Bridge Creek during the operational phase have the potential to be considerable
- The drawdown beneath Quarry Creek during the operational phase is predicted to be up to 18 metres and would occur in the upper reaches. The maximum predicted drawdown at Flat Rock Creek during the operational phase is predicted to be up to 29 metres. The conservative baseflow impacts at Flat Rock Creek and Quarry Creek during the operational phase have the potential to be considerable (39 per cent and 69 per cent reduction respectively after 100 years of operation)
- Treated wastewater from the Gore Hill Freeway operational wastewater treatment plant would be discharged into Flat Rock Creek via the local stormwater system at a rate of 16 litres per second. This would likely offset operational impacts estimated for Flat Rock Creek
- An estimated drawdown of less than one metre is expected at Manly Dam resulting in maximum baseflow reduction of two per cent
- Manly Creek and Trefoil Creek would be unaffected by changes to baseflow.

The predicted impact to the baseflow of Quarry Creek, Flat Rock Creek and Burnt Bridge Creek has the potential to be considerable. However, as described in Appendix N (Technical working paper: Groundwater), predicted baseflow is a conservative (high) estimate as:

- The modelled groundwater inflows to the tunnels were controlled by the formation permeability, which in some cases causes inflows to the tunnels greater than 1 L/s/km. However, a construction requirement for the project is that the tunnel inflows do not exceed 1 L/s/km on average, and the tunnels would be treated during construction to ensure that this is the case. Therefore, actual tunnel inflows and associated groundwater level drawdown would be less than predicted by the modelling
- It is assumed that there is a single connected groundwater system in between the watercourses present and the proposed underlying tunnel. In reality, the system will be stratified, possibly with disconnected aquifer horizons. The predicted maximum drawdowns beneath the creek are therefore unlikely to be fully realised and the predicted reductions in baseflows are therefore conservative
- For watercourses and waterbodies other than Flat Rock Creek, Quarry Creek and Burnt Bridge Creek, the whole length or area at the base of the creek or dam is considered to be unlined. This means that surface water and groundwater are linked, and changes in groundwater could affect surface water in the watercourses and waterbodies. At the time of modelling there was no information on the nature of creek bottom surfaces for Willoughby Creek and Sailors Bay Creek. Should any of these watercourses be lined, the reduction baseflow would be less than that predicted
- Groundwater inflows to the tunnels would be collected, treated and discharged to local waterways (Willoughby Creek, Flat Rock Creek and Burnt Bridge Creek). This is expected to offset baseflow reduction to these waters, as the additional creek flows could partially feed the surrounding groundwater system.

6.6 Impacts to Coastal Environment Areas

As mentioned in Section 6.2.5, the project would treat tunnel inflows and road runoff from the surface road works at Balgowlah and the upgraded and realigned Wakehurst Parkway. There would be no direct runoff to areas identified as coastal wetlands or littoral rainforests or areas in proximity to these areas. Therefore, there would be negligible impact to Coastal Environmental Areas and the project would contribute to achievement of the management goals of the Clontarf/Bantry Bay Estuary Management Plan.

Refer to Appendix Q (Technical working paper: Marine water quality) for a discussion on impacts to coastal areas of marine environments.

7. Assessment of cumulative impacts

This section provides an overview of the potential water quality cumulative impacts associated with project.

The projects considered in the cumulative impact assessment for surface water and hydrology are presented in Table 7-1. The major projects considered relevant for potential cumulative surface water and hydrology impacts is where there is an immediate interface during construction and/or operation with the project. Other projects occurring in the broader locality (eg projects in North Sydney or Artarmon within urban areas) would likely have a negligible increase in surface flows or runoff. Combined with the distance to downstream waterways, the cumulative impact is expected to be negligible.

The potential cumulative impact of the project and the other major projects identified in Table 7-1 are presented in Table 7-2. Provided controls are implemented, maintained and monitored, the cumulative impacts of the projects on downstream receivers and sensitive receiving environments would be minimal.

Table 7-1 Projects considered in the cumulative impact assessment

Project name	Brief project description	Relevant locations
Approved projects and/or projects under construction		
Sydney Metro City & Southwest (Chatswood to Sydenham) *Under construction, estimated for completion in 2024*	The Chatswood to Sydenham component of Sydney Metro City & Southwest involves the construction and operation of a 15.5 kilometre metro line from Chatswood, under Sydney Harbour and through Sydney's CBD out to Sydenham. Components of the project relevant to this assessment include: • Chatswood dive site • Artarmon substation • Crows Nest Station • Victoria Cross Station.	Beaches Link Gore Hill Freeway Connection
Proposed projects		
Western Harbour Tunnel and Warringah Freeway Upgrade *Construction estimated from 2021 to 2026*	The Western Harbour Tunnel and Warringah Freeway Upgrade project comprises a new tolled motorway tunnel connection across Sydney Harbour, and an upgrade of the Warringah Freeway to integrate the new motorway infrastructure with the existing road network and to connect to the Beaches Link and Gore Hill Freeway Connection project.	Beaches Link Gore Hill Freeway Connection

Table 7-2 Summary of potential cumulative impacts

Common receivers	Common downstream sensitive receivers	Potential impacts on common receivers during construction of the project	Construction mitigation measures	Potential impacts on common receivers during operation of the project	Operational mitigation measures	Construction and operation residual impacts
Sydney Metro City & Southwest (Chatswood to Sydenham)						
Stormwater drainage system	Flat Rock Creek Sydney Harbour	Increased water quality pollutants, sediment loads and litter into waterways	Soil and water management measures in accordance with the Blue Book Staging of works, stockpile management, water quality monitoring. Construction of wastewater treatment plant.	Increased water quality pollutants, sediment loads and litter into stormwater drains.	Drainage upgrades Flood mitigation measures Water quality monitoring Staging of works, stockpile management.	Provided controls are implemented, maintained and monitored, impacts on downstream receivers would be minimal.
Western Harbour Tunnel and Warringah Freeway Upgrade project						
Flat Rock Creek Willoughby Creek	Long Bay Willoughby Bay	Increased water quality pollutants, sediment loads and litter into waterways Cumulative treated wastewater discharges into Willoughby Creek. However, cumulative treated wastewater discharges would have negligible impact on the creek geomorphology, water availability and flow Cumulative groundwater drawdown, leading to impacts on base flow of Quarry Creek and Flat Rock Creek.	Soil and water management measures in accordance with the Blue Book Staging of works, stockpile management, water quality monitoring Construction of wastewater treatment plant	Increased water quality pollutants, sediment loads and litter into waterways Impacts on drainage infrastructure Flood impacts due to redirection of overland flows Cumulative groundwater drawdown, leading to impacts on baseflow of Quarry Creek and Flat Rock Creek.	Drainage upgrades Flood mitigation measures Water quality monitoring Staging of works, stockpile management.	Provided controls are implemented, maintained and monitored, impacts on downstream receivers would be minimal Impacts to the baseflow of Quarry Creek and Flat Rock Creek would occur because of groundwater drawdown that occurs due to the project. Contributions by the Western Harbour Tunnel and Warringah Freeway Upgrade to the cumulative groundwater drawdown and baseflow impacts are negligible.

8. Monitoring and environmental management measures

Water quality management and mitigation measures would be an integral part during construction activities and when operational. This section provides an overview of these measures.

The key water quality objective is to ensure downstream waterways are protected against potential impacts from surface runoff generated during the construction and operation phase of the project. This is consistent with the ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines.

Monitoring and environmental management measures are proposed with the objective of minimising any short-term impacts that may be encountered on downstream waterways and sensitive receiving environments. The implementation of these measures would ensure that the water quality objective of the protection of aquatic ecosystems is met and that any changes in water quality result in a neutral or beneficial effect.

8.1 Management of construction phase impacts

The impacts of construction as discussed in Section 5 would generally be mitigated using the procedural, site management, physical and monitoring controls as listed in Table 8-1.

Standard controls and procedures would be implemented during construction activities to manage potential impacts to water quality in creeks and drainage lines within or downstream from the project construction footprint. Water quality during construction would be managed using:

- Procedural controls
- Site management controls
- Physical controls
- Monitoring.

Water quality would be managed within the area bounded by the project, including, but not limited to:

- Construction support sites
- Access and haulage tracks
- Earthworks stockpile and storage areas
- Vegetation stockpile areas
- Washdown facilities
- Temporary sediment basins, following the criteria in Table 8-2.

Final environmental controls and monitoring requirements would be determined during construction planning and in accordance with:

- *Managing Urban Stormwater: Soils and Construction*, *Volume 1*, Landcom, 4th Edition (known as the Blue Book Volume 1)
- *Managing Urban Stormwater: Main Road Construction*, *Volume 2D*, NSW DECCW (known as the Blue Book Volume 2)
- *Road Design Guideline*, Section 8 Erosion and Sediment (Roads and Traffic Authority, 2003a)
- *Guideline for Construction Water Quality Monitoring* (Roads and Traffic Authority, 2003b)
- *Erosion and Sediment Management Procedure* (Roads and Traffic Authority, 2009)
- Transport for NSW's QA Specification G38 – Soil and Water Management
- Technical Guideline - *Temporary stormwater drainage for road construction* (Roads and Maritime, 2011)
- Technical Direction Geotechnology – Geotechnical design and construction requirements for sediment basins (Roads and Maritime, GTC 2016/001).

With due consideration of these proposed mitigation and environmental management measures, there would be minimal adverse surface water impacts. The residual risk to sensitive receiving environments and environmental values identified in Section 4.2 and Section 4.3 respectively is expected be low provided the proposed mitigation and environmental management measures are implemented, maintained and monitored.

Table 8-1 Summary of environmental management measures for construction

Impact	Environmental management measure	Location^
Erosion and sedimentation	Erosion and sediment measures should be implemented at all construction work sites and surface road upgrades in accordance with the principles and requirements in *Managing Urban Stormwater – Soils and Construction, Volume 1* (Landcom, 2004) and *Volume 2D* (DECCW, 2008), and relevant guidelines, procedures and specifications of Transport for NSW. Erosion and sediment control measures should be inspected and maintained throughout the works to ensure effective. A soil conservation specialist should be engaged for the duration of construction of the project to provide advice regarding erosion and sediment control including review of Erosion and Sediment Control Plans.	BL/GHFC
	The design criteria for the sizing of temporary sediment basins should satisfy the Environment Protection Licence (EPL) for the project, and should be based on the requirements of Transport for NSW QA specifications G36 (Environmental Protection) and G38 (Soil and Water Management), and *Managing Urban Stormwater – Soils and Construction, Volume 1* (Landcom, 2004) and *Volume 2D* (DECCW, 2008). The 85th rainfall percentile should only be applied for basins upstream of sensitive receiving environments (ie Quarry Creek, Flat Rock Creek, Trefoil Creek, Manly Creek and Manly Dam). Elsewhere, the 80th rainfall percentile should be adopted.	BL/GHFC
	Where temporary sediment basins are required, a discharge impact assessment, commensurate with the potential risk and consistent with the National Water Quality Guidelines (ANZG (2018)) and *Managing Urban Stormwater – Soils and Construction, Volume 1* (Landcom, 2004) should be prepared prior to construction to inform the discharge criteria.	BL/GHFC
	Disturbed floodplain environments next to the watercourses and/or along overland drainage lines should be stabilised as soon as practical following disturbance.	BL/GHFC
Spills and leakages	Emergency spill measures, including material bunding and appropriately sized and stocked spill containment kits, should be developed to avoid and manage accidental spillages of fuels, chemicals, and fluids during construction.	BL/GHFC
Wastewater discharges	Discharges from wastewater treatment plants during the construction phase should be required to meet the following discharge criteria: • the relevant physical and chemical stressors set out in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000), and • the ANZG (2018) 90 per cent species protection levels for toxicants generally, with the exception of those toxicants known to bioaccumulate, which would be treated to meet the ANZG (2018) 95 per cent species protection levels, and • the draft ANZG default guideline values for iron (in fresh and marine water) and zinc (in marine water).	BL

Impact	Environmental management measure	Location^
Local stormwater system capacity	Further design development should confirm the local stormwater systems capacity to receive construction wastewater treatment plant inflows. If there is a stormwater infrastructure capacity issue with existing infrastructure, mitigation measures such as storage detention to control water outflow during wet weather events should be implemented within the construction support site.	BL
Freshwater quality monitoring	A freshwater quality monitoring program for the construction of the project should be developed and implemented, with consideration of the freshwater monitoring being carried out by Western Harbour Tunnel and Warringah Freeway Upgrade project and operation/post construction monitoring being undertaken as part of the Northern Beaches Hospital road upgrade project. The program should be developed in consultation with the Environment Protection Authority, Department of Planning, Industry and Environment (Natural Resources Access Regulator), Department of Planning, Industry and Environment (Water), and relevant councils. Sampling locations and monitoring methodology should be in accordance with the *Guideline for Construction Water Quality Monitoring* (RTA, 2003) and ANZG (2018). If exceedances of the criteria established under the freshwater monitoring program are detected, a management response should be triggered and appropriate mitigation measures to address the exceedance should be identified and implemented.	BL/GHFC
Watercourse geomorphology	The potential for scour and erosion of watercourse bed and banks will be considered during the design of new discharge outlets. Construction work activities within or next to the watercourses and drainage lines should be minimised as much as practical to minimise disturbance of sediments in or near the waterway.	BL/GHFC
	During construction, the drainage and adjustment works associated with an existing aboveground watercourse within Flat Rock Reserve and Burnt Bridge Creek should be staged to ensure creek flows and velocities are not substantially changed and to avoid downstream erosion and bed and bank stability impacts.	BL

^Note: BL = Beaches Link, GHFC = Gore Hill Freeway Connection

The design criteria for construction sediment basins is provided in Table 8-2.

Table 8-2 Design criteria for sizing construction sediment basins

Parameter	Value	Comment
Rainfall Parameters		
Rainfall depth duration (days)	Five-day	Five-day to be adopted as standard duration typically used in the EPL issued under the under the *Protection of the Environment Operations Act 1997*
Rainfall percentile	80th and 85th	85th percentile to be adopted for sensitive areas (ie catchments draining to Quarry Creek, Flat Rock Creek, Trefoil Creek, Manly Creek and Manly Dam). 80th percentile to be adopted at all other locations
Rainfall depth (mm) – five-day	80th – 29.7mm 85th – 38.8mm	For Sydney as derived from the Blue Book
Volumetric runoff coefficient (Cv)	Varies (0.56 to 0.74), in the range of 26mm to 60mm rainfall depth.	0.64 to be adopted for Group D Hydrologic Soils of high runoff potential, for the 85th percentile rainfall depth.
Rainfall intensity for two-year average recurrence interval (ARI), 6 hr duration	14mm/hr	14mm/hr and has been adopted from Rainfall Intensity IFD tables. Also refer to derived rainfall erosivity in this table.
Revised Universal Soil Loss Equation (RUSLE) Parameters		
Soil/sediment type	C, D, or F	Varies along the alignment. Mainly type F, type D and small localised pockets of type C. Type D has been adopted for deeper subsoils.
Erodibility, k	Varies k=0.024 to k=0.042	K= 0.04 to be adopted as a reasonable value for the typical soils found in this area. However, this selection could be reduced or improved at the construction planning phase through site specific soil testing.
Rainfall erosivity, R	4,285	R= 4,285 to be adopted based on the Bureau of Meteorology rainfall intensities for the site.
Hydrologic soil group	D	For high runoff potential, refer to Appendix F of the Blue Book
Soil cover (C)	1	Corresponding to expected type of activities on site
Soil conservation practices (P)	1.3	Corresponding to expected type of activities on site

Parameter	Value	Comment
Length slope factors (LS)	Variable	Determined separately for main roadway; and steeper embankment areas (cut and fill)
Sediment yield time period (months)	Two to six months	Four months to be a reasonable period that accounts for the likely maintenance frequency during construction for the removal of captured sediments.
EPL requirements	N/A	The EPL would most likely require that sediment basins be designed for an 85th percentile.

8.2 Management of the operational phase impacts

Mitigation and environmental management measures for the operational phase of the project are presented in Table 8-3.

Table 8-3 Summary of environmental management measures for operation

Impact	Environmental management measure	Location^
Surface water quality discharges	Water quality treatment controls for stormwater should meet the design targets, where possible. Where the design targets cannot be met due to site constraints, water quality treatment controls should be provided to meet or improve existing conditions to ensure that there is no impact on surface water quality as a result of the project.	BL/GHFC
Spill containment	Spill containment controls along surface roads will be confirmed during further deign development an determine with consideration of: • The environmental sensitivity of the receiving waterways • The likelihood of vehicle accidents informed by the annual average daily traffic (ADADT) loading along the surface road • Where implementation of control measures may have a negative impact on other areas of environmental importance, such as biodiversity and heritage.	BL/GHFC
Operational Wastewater discharge	The permanent wastewater treatment plant at Artarmon should be designed to treat wastewater generated from tunnel groundwater ingress and rainfall runoff in tunnel portals and achieve the following discharge criteria: • The relevant physical and chemical stressors set out in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000), and • The ANZG (2018) 95 per cent species protection levels for toxicants generally, with the exception of those toxicants known to bioaccumulate, which would be treated to meet the ANZG (2018) 99 per cent species protection levels, and • The draft ANZG default guideline values for iron (in fresh and marine water) and zinc (in marine water).	BL

Impact	Environmental management measure	Location^
Water quality monitoring	Operational phase monitoring of surface water quality should be described in the operational water quality monitoring program, and should be carried out in line with the Roads and Maritime *Guideline for Construction Phase Water Quality Monitoring* (RTA, 2003). As a minimum, monthly monitoring should be carried out for the first year of operation or until a suitably qualified and experienced independent expert determines that a site has adequately stabilised and stormwater basin discharge criteria are achieved. Should any of the discharge criteria be exceeded, a management response should be triggered and appropriate mitigation measures to address the exceedance should be identified and implemented. The management response should be documented within the operational water quality monitoring program.	BL/GHFC
Local stormwater system capacity	The capacity for the local stormwater system to receive operational wastewater treatment plant inflows should be confirmed during further design development. If there is a stormwater infrastructure capacity issue with existing infrastructure, mitigation measures such as storage detention to control water outflow during wet weather events should be implemented within the motorway facility site.	BL
Balgowlah stormwater harvesting dam	The need for a stormwater harvesting water quality basin at Balgowlah should be assessed and determined during further design development. If the stormwater harvesting water quality basin is considered to be required, a suitable alternate location and future use should be determined as part of the dedicated consultation process regarding the final layout of the new and improved public open space and recreation facilities at Balgowlah.	BL
Connection to Sydney Water stormwater assets	The need for direct connection to Sydney Water stormwater assets will be reviewed during further design development and in consultation with Sydney Water. Where direct connection to a Sydney Water stormwater asset is required the project should install and operate water treatment devices during operation to achieve the Sydney Water pollutant load reduction targets where feasible and reasonable.	BL/GHFC
Burnt Bridge Creek geomorphology	The localised adjustment of Burnt Bridge creek should be designed with consideration of existing channel conditions and an understanding of existing hydrology to minimise alterations to, and erosion of, the bed and banks. The gradient, sinuosity and channel capacity should be consistent with upstream and downstream sections. The extension to the existing culvert should be designed with low gradient and scour protection to minimise impacts to geomorphology. Where required, the adjustment should include grade controls and bank stabilisation works to manage anticipated high velocity conditions.	BL

Impact	Environmental management measure	Location^
Water sensitive urban design	Opportunities for water sensitive urban design (WSUD) should be considered during the development of the design for the stormwater management system for the new and upgraded road infrastructure and during development of the urban design and landscape plans. Identified WSUD features should be implemented where practical and with consideration to best management practice guidelines including Transport for NSW's *Water sensitive urban design guideline* (Roads and Maritime Services, 2017).	BL/GHFC

^BL = Beaches Link, GHFC = Gore Hill Freeway Connection

With due consideration of these proposed environmental management measures to be implemented as part of the project's operation, there would be minimal adverse cumulative surface water impacts anticipated.

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Annexure A. Water quality monitoring results

Table A.1 Site 2b – Willoughby Creek downstream (where values in red indicate an exceedance or outside guideline range of the ANZECC/ARMCANZ lowland river guidelines)

Parameter	Units	Guideline criteria	Willoughby Creek downstream monitoring – lowland river					
		ANZECC/ARMCANZ 2000 and ANZG 2018	31 Oct 2017 (dry)	21 Nov 2017 (dry)	14 Dec 2017 (dry)	9 Jan 2018 (wet)	18 Jan 2018 (dry)	1 Feb 2018 (dry)
Dissolved oxygen	% sat	85-110	73	62.6	84.7	103.6	75	84.4
Electrical conductivity	µS/cm	200-300	399	248	443	198	277	282
pH	pH units	6.5-8	7.71	8.14	7.59	7.63	8.35	8.67
Turbidity	NTU	6-50	2.2	3.5	6.43	14.8	12	13.83
Total suspended solids	mg/L	NG	6	8	<5	12	10	6
Arsenic	mg/L	0.013	0.001	0.001	<0.001	0.001	Not analysed	Not analysed
Cadmium	mg/L	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	Not analysed	Not analysed
Chromium	mg/L	0.001	<0.001	<0.001	<0.001	0.003	Not analysed	Not analysed
Copper	mg/L	0.0014	0.006	0.013	0.014	0.016	Not analysed	Not analysed
Lead	mg/L	0.0034	<0.001	0.002	0.003	0.006	Not analysed	Not analysed
Manganese	mg/L	1.9	0.004	0.008	0.019	0.011	Not analysed	Not analysed
Nickel	mg/L	0.011	0.002	<0.001	0.017	<0.001	Not analysed	Not analysed
Zinc	mg/L	0.008	0.031	0.049	0.148	0.075	Not analysed	Not analysed
Iron	mg/L	0.7	0.21	0.24	0.8	0.36	Not analysed	Not analysed
Mercury	mg/L	0.0006	<0.0001	<0.0001	<0.0001	<0.0001	Not analysed	Not analysed
Oxidised nitrogen	mg/L	0.04	2.76	1.18	3.18	5.04	0.87	1
Total Kjeldahl nitrogen	mg/L	NG	0.5	0.4	1	1.5	0.5	0.4
Total nitrogen	mg/L	0.35	3.3	1.6	4.2	6.5	1.4	1.4
Total phosphorus	mg/L	0.025	0.13	0.14	0.27	0.14	0.1	0.11
Chlorophyll-*a*	mg/L	3	<1	1	<1	<1	<1	1

NG= No Guideline

Table A.2 Site 4 – Quarry Creek (where values in red indicate an exceedance or outside guideline range of the ANZECC/ARMCANZ lowland river guidelines)

Parameter	Units	Guideline criteria	Quarry Creek monitoring – lowland river					
		ANZECC/ARMCANZ 2000 and ANZG 2018	31 Oct 2017 (dry)	21 Nov 2017 (dry)	14 Dec 2017 (dry)	9 Jan 2018 (wet)	18 Jan 2018 (dry)	1 Feb 2018 (dry)
Dissolved oxygen	% sat	85-110	NOT SAMPLED	74.6	82.4	NOT SAMPLED	86	92.7
Electrical conductivity	µS/cm	200-300		399	338		312	232
pH	pH	6.5-8		8.55	7.6		7.91	8.03
Turbidity	NTU	6-50		79.9	9.5		3.5	3.9
Total suspended solids	mg/L	NG		113	11		8	10
Arsenic	mg/L	0.013		0.001	<0.001		<0.001	<0.001
Cadmium	mg/L	0.0002		<0.0001	<0.0001		<0.0001	<0.0001
Chromium	mg/L	0.001		0.006	<0.001		<0.001	0.001
Copper	mg/L	0.0014		0.026	0.003		0.004	0.014
Lead	mg/L	0.0034		0.002	<0.001		<0.001	0.006
Manganese	mg/L	1.9		0.085	0.009		0.003	0.025
Nickel	mg/L	0.011		0.004	<0.001		<0.001	0.002
Zinc	mg/L	0.008		0.041	0.03		0.062	0.104
Iron	mg/L	0.7		1.94	0.16		0.11	0.78
Mercury	mg/L	0.0006		<0.0001	<0.0001		<0.0001	<0.0001
Oxidised nitrogen	mg/L	0.04		0.81	0.97		0.97	0.98
Total Kjeldahl	mg/L	NG		1	0.9		0.5	0.4
Total nitrogen	mg/L	0.35		1.8	1.9		1.5	1.4
Total phosphorus	mg/L	0.025		0.21	0.14		0.16	0.06
Chlorophyll-*a*	mg/L	3		<1	<1		<1	<1

NG= No Guideline

Table A.3 Site 5A – Flat Rock Creek upstream (where values in red indicate an exceedance or outside guideline range of the ANZECC/ARMCANZ guidelines)

Parameter	Units	Guideline criteria	Flat Rock Creek upstream monitoring – lowland river					
		ANZECC/ARMCANZ 2000 and ANZG 2018	31 Oct 2017 (dry)	21 Nov 2017 (dry)	14 Dec 2017 (dry)	9 Jan 2018 (wet)	18 Jan 2018 (dry)	1 Feb 2018 (dry)
Dissolved oxygen	% sat	85-110	53.85	93.2	85.2	99.47	91	98.4
Electrical conductivity	µS/cm	200-300	509	333	397	163	342	314
pH	pH units	6.5-8	9.03	9.37	8.28	7.31	8.5	8.22
Turbidity	NTU	6-50	3.72	2.71	5.06	18.97	4.53	7.34
Total suspended solids	mg/L	NG	10	11	<5	16	14	7
Arsenic	mg/L	0.013	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cadmium	mg/L	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.001	0.001	0.008	<0.001	0.001	<0.001	0.001
Copper	mg/L	0.0014	0.006	0.007	0.004	0.01	0.002	0.004
Lead	mg/L	0.0034	0.002	<0.001	<0.001	0.002	0.001	<0.001
Manganese	mg/L	1.9	0.02	0.012	0.02	0.035	0.013	0.049
Nickel	mg/L	0.011	0.002	<0.001	0.003	<0.001	0.001	0.002
Zinc	mg/L	0.008	0.036	0.01	0.074	0.08	0.034	0.02
Iron	mg/L	0.7	0.53	0.25	0.36	0.78	0.18	0.75
Mercury	mg/L	0.0006	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Oxidised nitrogen	mg/L	0.04	2.04	5.62	9.75	3.03	1.05	1.39
Total Kjeldahl nitrogen	mg/L	NG	4.2	1.8	2.6	1	0.6	1.6
Total nitrogen	mg/L	0.35	6.2	7.4	12.4	4	1.6	3
Total phosphorus	mg/L	0.025	0.05	0.04	0.07	0.07	0.03	0.06
Chlorophyll-*a*	mg/L	3	<1	<1	11	4	2	<1

NG= No Guideline

Table A.4 Site 5b – Flat Rock Creek downstream 1 (where values in red indicate an exceedance or outside guideline range of the ANZECC/ARMCANZ guidelines)

Parameter	Units	Guideline criteria	Flat Rock Creek downstream 1 monitoring – lowland river					
		ANZECC/ARMCANZ 2000 and ANZG 2018	31 Oct 2017 (dry)	21 Nov 2017 (dry)	14 Dec 2017 (dry)	9 Jan 2018 (wet)	18 Jan 2018 (dry)	1 Feb 2018 (dry)
Dissolved oxygen	% sat	85-110	92.9	77.3	65.5	67.1	85.3	24.3
Electrical conductivity	µS/cm	200-300	412	348	436	573	456	27850
pH	pH units	6.5-8	8	7.79	7.21	7.33	7.82	7.01
Turbidity	NTU	6-50	7.3	8.3	11.7	27.4	4	3.91
Total suspended solids	mg/L	NG	11	8	<5	18	8	<5
Arsenic	mg/L	0.013	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cadmium	mg/L	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.001	<0.001	0.003	<0.001	0.001	<0.001	<0.001
Copper	mg/L	0.0014	0.008	0.004	0.008	0.015	0.004	0.008
Lead	mg/L	0.0034	<0.001	<0.001	<0.001	0.005	<0.001	0.002
Manganese	mg/L	1.9	0.008	0.013	0.016	0.039	0.007	0.049
Nickel	mg/L	0.011	0.002	0.002	0.001	0.001	<0.001	0.002
Zinc	mg/L	0.008	0.024	0.022	0.064	0.102	0.023	0.149
Iron	mg/L	0.7	0.77	0.64	1.11	0.67	0.54	0.49
Mercury	mg/L	0.0006	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Oxidised nitrogen	mg/L	0.04	2.85	2.32	4.69	2.32	2.8	3.68
Total Kjeldahl nitrogen	mg/L	NG	1.3	1.1	1.1	1.8	1	<0.2
Total nitrogen	mg/L	0.35	4.2	3.4	5.8	4.1	3.8	3.7
Total phosphorus	mg/L	0.025	0.04	0.04	0.04	0.18	0.08	<0.02
Chlorophyll-*a*	mg/L	3	<1	<1	<1	2	1	5

NG= No Guideline

Table A.5 Site 5c – Flat Rock Creek downstream 2 (where values in red indicate an exceedance or outside guideline range of the ANZECC/ARMCANZ guidelines)

Parameter	Units	Guideline criteria	Flat Rock Creek downstream 2 monitoring – estuarine					
		ANZECC/ARMCANZ 2000 and ANZG 2018	31 Oct 2017 (dry)	21 Nov 2017 (dry)	14 Dec 2017 (dry)	9 Jan 2018 (wet)	18 Jan 2018 (dry)	1 Feb 2018 (dry)
Dissolved oxygen	% sat	80-110	19.3	21.5	24.5	74.7	36.7	28.2
Electrical conductivity	µS/cm	n/a	3211	324	7533	383	27977	41330
pH	pH units	7-8.5	7.15	7.61	7.17	7.46	7.16	7.16
Turbidity	NTU	0.5-10	5.6	16.9	7	30.7	9.1	4.3
Total suspended solids	mg/L	NG	8	11	<5	20	16	<5
Arsenic	mg/L	NG	<0.001	<0.001	<0.001	<0.001	0.001	0.001
Cadmium	mg/L	0.0007	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.0044	<0.001	<0.001	0.001	0.002	<0.001	<0.001
Copper	mg/L	0.00143	0.005	0.017	0.006	0.02	0.005	0.006
Lead	mg/L	0.0044	<0.001	0.005	0.004	0.006	0.002	0.001
Manganese	mg/L	0.08	0.045	0.052	0.016	0.032	0.044	0.062
Nickel	mg/L	0.007	0.002	0.001	<0.001	0.002	0.001	0.001
Zinc	mg/L	0.0052	0.028	0.067	0.054	0.12	0.044	0.097
Iron	mg/L	0.18	0.76	0.9	0.76	0.59	0.52	0.39
Mercury	mg/L	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Oxidised nitrogen	mg/L	0.015	2.9	0.27	2.73	2.12	1.35	1.68
Total Kjeldahl nitrogen	mg/L	NG	0.7	0.7	0.8	2	1.4	<0.5
Total nitrogen	mg/L	0.3	3.6	1	3.5	4.1	2.8	1.7
Total phosphorus	mg/L	0.03	0.04	0.16	0.05	0.23	0.54	<0.05
Chlorophyll-*a*	mg/L	4	<1	<1	1	<1	1	6

NG= No Guideline

Table A.6 Site 3a – Burnt Bridge Creek upstream (where values in red indicate an exceedance or outside guideline range of the ANZECC/ARMCANZ guidelines)

Parameter	Units	Guideline criteria	Burnt Bridge Creek upstream monitoring – non-tidal					
		ANZECC/ARMCANZ 2000 and ANZG 2018	31 Oct 2017 (dry)	21 Nov 2017 (dry)	14 Dec 2017 (dry)	9 Jan 2018 (wet)	18 Jan 2018 (dry)	1 Feb 2018 (dry)
Dissolved oxygen	% sat	85-110	15.7	30.5	21	81.5	19.1	74
Electrical conductivity	µS/cm	200-300	221	304	197	156	304	461
pH	pH units	6.5-8	8.1	7.89	7.39	7.27	7.21	7.66
Turbidity	NTU	6-50	7.16	2.09	7.56	10.09	12.16	10.4
Total suspended solids	mg/L	NG	5	----	17	16	26	10
Arsenic	mg/L	0.013	0.001	----	0.002	0.001	0.001	0.001
Cadmium	mg/L	0.0002	<0.0001	----	<0.0001	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.001	<0.001	----	<0.001	<0.001	0.001	<0.001
Copper	mg/L	0.0014	0.002	----	0.006	0.007	0.005	0.015
Lead	mg/L	0.0034	0.001	----	0.003	0.004	0.007	0.005
Manganese	mg/L	1.9	0.076	----	0.124	0.021	0.18	0.092
Nickel	mg/L	0.011	0.002	----	0.001	<0.001	0.002	0.002
Zinc	mg/L	0.008	0.01	----	0.04	0.039	0.067	0.232
Iron	mg/L	0.7	1.78	----	1.37	0.38	2.12	0.44
Mercury	mg/L	0.0006	<0.0001	----	<0.0001	<0.0001	<0.0001	<0.0001
Oxidised nitrogen	mg/L	0.04	0.1	<0.01	2.75	0.73	1	0.21
Total Kjeldahl nitrogen	mg/L	NG	0.6	0.6	1	0.6	1	0.4
Total nitrogen	mg/L	0.35	0.7	0.6	3.8	1.3	2	1.4
Total phosphorus	mg/L	0.025	0.12	0.11	0.19	0.1	0.1	0.11
Chlorophyll-*a*	mg/L	3	<1	<1	<1	<1	<1	1

NG= No Guideline

Table A.7 Site 3b – Burnt Bridge Creek downstream (where values in red indicate an exceedance or outside guideline range of the ANZECC/ARMCANZ guidelines)

Parameter	Units	Guideline criteria	Burnt Bridge Creek downstream monitoring – non-tidal					
		ANZECC/ARMCANZ 2000 and ANZG 2018	31 Oct 2017 (dry)	21 Nov 2017 (dry)	14 Dec 2017 (dry)	9 Jan 2018 (wet)	18 Jan 2018 (dry)	1 Feb 2018 (dry)
Dissolved oxygen	% sat	85-110	76.7	76.4	72.2	88.1	67.3	83
Electrical	µS/cm	200-300	206	233	210	162	223	197
pH	pH units	6.5-8	7.77	7.79	7.3	7.6	7.46	7.73
Turbidity	NTU	6-50	2.69	3.18	5.97	9.06	2.71	2.21
Total suspended solids	mg/L	NG	<5	----	6	13	8	<5
Arsenic	mg/L	0.013	<0.001	----	<0.001	<0.001	<0.001	<0.001
Cadmium	mg/L	0.0002	<0.0001	----	<0.0001	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.001	<0.001	----	<0.001	<0.001	<0.001	<0.001
Copper	mg/L	0.0014	<0.001	----	0.006	0.006	<0.001	0.002
Lead	mg/L	0.0034	<0.001	----	0.003	0.004	<0.001	<0.001
Manganese	mg/L	1.9	0.015	----	0.031	0.016	0.01	0.007
Nickel	mg/L	0.011	0.002	----	<0.001	0.001	<0.001	<0.001
Zinc	mg/L	0.008	0.006	----	0.021	0.041	0.017	0.011
Iron	mg/L	0.7	0.27	----	0.65	0.32	0.25	0.22
Mercury	mg/L	0.0006	<0.0001	----	<0.0001	<0.0001	<0.0001	<0.0001
Oxidised nitrogen	mg/L	0.04	0.43	0.34	2.06	0.48	0.3	0.3
Total Kjeldahl	mg/L	NG	0.3	0.4	0.7	0.5	0.3	0.3
Total nitrogen	mg/L	0.35	0.7	0.7	2.8	1	0.6	0.6
Total phosphorus	mg/L	0.025	0.02	0.02	0.06	0.07	<0.01	<0.01
Chlorophyll-*a*	mg/L	3	<1	2	<1	<1	2	1

NG= No Guideline

Table A.8 Site 6b – Manly Dam mid (where values in red indicate an exceedance or outside guideline range of the ANZECC/ARMCANZ guidelines)

Parameter	Units	Guideline criteria	Manly Dam mid monitoring – non-tidal					
		ANZECC/ARMCANZ 2000 and ANZG 2018	31 Oct 2017 (dry)	21 Nov 2017 (dry)	14 Dec 2017 (dry)	9 Jan 2018 (wet)	18 Jan 2018 (dry)	1 Feb 2018 (dry)
Dissolved oxygen	% sat	90-110	78.5	72	76.3	96	75.7	82.8
Electrical conductivity	µS/cm	20-30	202	203	212	224	224	206
pH	pH	6.5-8	7.75	7.89	7.57	7.32	7.59	7.99
Turbidity	NTU	1-20	10.68	3.6	6.63	7.84	12.37	7.38
Total suspended solids	mg/L	NG	10	----	<5	10	27	6
Arsenic	mg/L	0.013	<0.001	----	<0.001	<0.001	----	----
Cadmium	mg/L	0.0002	<0.0001	----	<0.0001	<0.0001	----	----
Chromium	mg/L	0.001	<0.001	----	<0.001	<0.001	----	----
Copper	mg/L	0.0014	<0.001	----	<0.001	<0.001	----	----
Lead	mg/L	0.0034	<0.001	----	<0.001	<0.001	----	----
Manganese	mg/L	1.9	0.005	0.005	0.006	0.007	----	----
Nickel	mg/L	0.011	<0.001	----	<0.001	<0.001	----	----
Zinc	mg/L	0.008	<0.005	----	<0.005	0.01	----	----
Iron	mg/L	0.7	0.29	0.19	0.22	0.2	----	----
Mercury	mg/L	0.0006	<0.0001	----	<0.0001	<0.0001	----	----
Oxidised nitrogen	mg/L	0.01	5.58	0.01	0.05	0.05	0.03	0.04
Total Kjeldahl nitrogen	mg/L	NG	0.7	0.3	0.3	0.3	0.4	0.3
Total nitrogen	mg/L	0.35	6.3	0.3	0.4	0.4	0.4	0.3
Total phosphorus	mg/L	0.01	<0.01	<0.01	<0.01	0.02	<0.01	0.03
Chlorophyll-*a*	mg/L	5	2	2	1	2	4	5

NG= No Guideline

Table A.9 Site 6c – Manly Dam wall (where values in red indicate an exceedance or outside guideline range of the ANZECC/ARMCANZ guidelines)

Parameter	Units	Guideline criteria	Manly Dam wall monitoring – non-tidal					
		ANZECC/ARMCANZ 2000 and ANZG 2018	31 Oct 2017 (dry)	21 Nov 2017 (dry)	14 Dec 2017 (dry)	9 Jan 2018 (wet)	18 Jan 2018 (dry)	1 Feb 2018 (dry)
Dissolved oxygen	% sat	90-110	83.8	75.9	86.3	98.9	87.9	89.8
Electrical	µS/cm	20-30	202	205	212	220	223	205
pH	pH units	6.5-8	7.7	7.86	7.57	7.61	7.85	7.87
Turbidity	NTU	1-20	5.71	6.72	6.63	5.23	87.9	4.79
Total suspended	mg/L	NG	7	14	6	14	14	10
Arsenic	mg/L	0.013	<0.001	<0.001	<0.001	<0.001	----	----
Cadmium	mg/L	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	----	----
Chromium	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	----	----
Copper	mg/L	0.0014	<0.001	0.002	<0.001	<0.001	----	----
Lead	mg/L	0.0034	<0.001	<0.001	<0.001	<0.001	----	----
Manganese	mg/L	1.9	0.004	0.008	0.005	0.006	----	----
Nickel	mg/L	0.011	<0.001	<0.001	<0.001	<0.001	----	----
Zinc	mg/L	0.008	<0.005	0.014	<0.005	<0.005	----	----
Iron	mg/L	0.7	0.24	0.31	0.18	0.16	----	----
Mercury	mg/L	0.0006	<0.0001	<0.0001	<0.0001	<0.0001	----	----
Oxidised nitrogen	mg/L	0.01	0.14	0.42	0.03	0.03	0.02	0.03
Total Kjeldahl	mg/L	NG	0.3	0.3	0.3	0.6	0.3	0.3
Total nitrogen	mg/L	0.35	0.4	0.7	0.3	0.6	0.3	0.3
Total phosphorus	mg/L	0.01	0.01	<0.01	<0.01	0.04	0.03	<0.01
Chlorophyll-*a*	mg/L	5	2	3	2	2	4	6

NG= No Guideline

Table A.10 Site 7b – Manly Creek (where values in red indicate an exceedance or outside guideline range of the ANZECC/ARMCANZ guidelines)

Parameter	Units	Guideline criteria	Manly Creek monitoring – non-tidal					
		ANZECC/ARMCANZ 2000 and ANZG 2018	31 Oct 2017 (dry)	21 Nov 2017 (dry)	14 Dec 2017 (dry)	9 Jan 2018 (wet)	18 Jan 2018 (dry)	1 Feb 2018 (dry)
Dissolved oxygen	% sat	85-110	61.4	44.6	57.8	NOT SAMPLED	55.3	61
Electrical conductivity	µS/cm	125-2220	418	481	475		435	445
pH	pH	6.5-8	7.31	7.22	7.59		7.65	7.55
Turbidity	NTU	6-50	3.7	2.3	13.5		2.7	5
Total suspended	mg/L	NG	6	<5	13		5	5
Arsenic	mg/L	0.013	<0.001	<0.001	<0.001		----	----
Cadmium	mg/L	0.0002	<0.0001	<0.0001	<0.0001		----	----
Chromium	mg/L	0.001	<0.001	<0.001	<0.001		----	----
Copper	mg/L	0.0014	0.003	0.003	0.008		----	----
Lead	mg/L	0.0034	<0.001	<0.001	<0.001		----	----
Manganese	mg/L	1.9	0.004	0.01	0.008		----	----
Nickel	mg/L	0.011	0.001	<0.001	<0.001		----	----
Zinc	mg/L	0.008	0.006	0.01	0.019		----	----
Iron	mg/L	0.7	0.18	0.17	0.89		----	----
Mercury	mg/L	0.0006	<0.0001	<0.0001	<0.0001		----	----
Oxidised nitrogen	mg/L	0.04	2.02	0.67	0.63		0.24	0.38
Total Kjeldahl	mg/L	NG	0.3	0.3	0.5		0.3	0.3
Total nitrogen	mg/L	0.35	2.3	1	1.1		0.5	0.7
Total phosphorus	mg/L	0.025	<0.01	<0.01	0.1		<0.01	<0.01
Chlorophyll-*a*	mg/L	3	<1	<1	<1		<1	<1

NG= No Guideline

Annexure B. Groundwater monitoring results

The following table presents the results of boreholes located in the Flat Rock Drive and Punch Street construction wastewater treatment plant catchment, which would discharge into Flat Rock Creek via the local stormwater system.

Table B.1 Median groundwater results (where values in red indicate an exceedance of the ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines)

Chemical Group	Indicator	Units	Median	ANZG (2018), ANZECC/ ARMCANZ (2000) Lowland River^	ANZG (2018), ANZECC/ ARMCANZ (2000) Estuarine^
Lead	Lead (Filtered)	mg/L	0.0005	0.0034	0.0044
Major Anions	Alkalinity (Hydroxide) as CaCO3	mg/L	0.5	No guideline	No guideline
	Alkalinity (total) as CaCO3	mg/L	253	No guideline	No guideline
	Anions Total	meq/L	17.2	No guideline	No guideline
	Chloride	mg/L	175	No guideline	No guideline
Major Cations	Calcium (Filtered)	mg/L	76.5	No guideline	No guideline
	Cations Total	meq/L	16.9	No guideline	No guideline
	Magnesium (Filtered)	mg/L	21.5	No guideline	No guideline
	Potassium (Filtered)	mg/L	7	No guideline	No guideline
	Sodium (Filtered)	mg/L	121	No guideline	No guideline
PAHs	Acenaphthene	µg/L	0.5	No guideline	No guideline
	Acenaphthylene	µg/L	0.5	No guideline	No guideline
	Anthracene	µg/L	0.5	No guideline	No guideline
	Benz(a)anthracene	µg/L	0.5	No guideline	No guideline
	Benzo(a)pyrene	µg/L	0.25	No guideline	No guideline
	Be+O30+B22	µg/L	0.5	No guideline	No guideline
	Benzo(k)fluoranthene	µg/L	0.5	No guideline	No guideline
	Benzo[b+j]fluoranthene	mg/L	0.0005	No guideline	No guideline
	Chrysene	µg/L	0.5	No guideline	No guideline
	Dibenz(a,h)anthracene	µg/L	0.5	No guideline	No guideline
	Fluoranthene	µg/L	0.5	No guideline	No guideline
	Fluorene	µg/L	0.5	No guideline	No guideline
	Indeno(1,2,3-c,d)pyrene	µg/L	0.5	No guideline	No guideline
	Naphthalene	µg/L	0.5	16	50
	Polycyclic aromatic hydrocarbons	µg/L	0.25	No guideline	No guideline

Chemical Group	Indicator	Units	Median	ANZG (2018), ANZECC/ ARMCANZ (2000) Lowland River^	ANZG (2018), ANZECC/ ARMCANZ (2000) Estuarine^
	Phenanthrene	µg/L	0.5	No guideline	No guideline
	Pyrene	µg/L	0.5	No guideline	No guideline
TRH	TRH C10-C16 (F2)	µg/L	50	No guideline	No guideline
	TRH >C16-C34	µg/L	50	No guideline	No guideline
	TRH >C34-C40	µg/L	50	No guideline	No guideline
	TRH >C10-C16 less Naphthalene (F2)	µg/L	50	No guideline	No guideline
	TRH >C10-C40 (Sum of total)	µg/L	50	No guideline	No guideline
	TRH C6-C10 less BTEX (F1)	µg/L	10	No guideline	No guideline
	TRH C6-C10 (F1)	µg/L	10	No guideline	No guideline
BTEX	Benzene	mg/L	0.0005	0.95	0.5
	Ethylbenzene	mg/L	0.001	0.08	0.08
	Toluene	mg/L	0.001	0.18	0.18
	Total BTEX	µg/L	0.5	No guideline	No guideline
	Xylene (m & p)	µg/L	1	No guideline	No guideline
	Xylene (o)	µg/L	1	350	No guideline
	Xylene Total	µg/L	1	No guideline	No guideline
Inorganics	Ammonia as N	µg/L	325	20	15
	Alkalinity (Bicarbonate as CaCO3)	mg/L	193	No guideline	No guideline
	Carbonate Alkalinity as CaCO3	mg/L	0.5	No guideline	No guideline
	Fluoride	mg/L	0.2	No guideline	No guideline
	Ionic Balance	%	4.09	No guideline	No guideline
	Total Kjeldahl nitrogen	mg/L	1.9	No guideline	No guideline
	Nitrates, expressed as N	mg/L	0.025	No guideline	No guideline
	Nitrite (as N)	mg/L	0.005	No guideline	No guideline
	Nitrogen (Total Oxidised)	mg/L	0.02	0.04	0.015
	Nitrogen (Total)	mg/L	1.85	0.35	0.3
	Phosphorus	mg/L	0.18	0.025	0.03
	Reactive Phosphorus as P	mg/L	0.005	0.02	0.005
	TDS	mg/L	688	No guideline	No guideline

Chemical Group	Indicator	Units	Median	ANZG (2018), ANZECC/ ARMCANZ (2000) Lowland River^	ANZG (2018), ANZECC/ ARMCANZ (2000) Estuarine^
Metals	Arsenic (Filtered)	mg/L	0.001	0.013	No guideline
	Barium (Filtered)	mg/L	0.0945	No guideline	No guideline
	Boron (Filtered)	mg/L	0.08	0.94	No guideline
	Cadmium (Filtered)	mg/L	0.00005	0.0002	0.0007
	Chromium (III+VI) (Filtered)	mg/L	0.0005	0.001	0.0044
	Cobalt (Filtered)	mg/L	0.0005	0.0014	0.001
	Copper* (Filtered)	mg/L	0.0005	0.0014	0.0013
	Iron (Filtered)	mg/L	0.82	0.7	0.18
	Manganese (Filtered)	mg/L	0.272	1.9	No guideline
	Mercury (except as provided in item 13) (Filtered)	mg/L	0.00005	0.0006	0.0001
	Nickel* (Filtered)	mg/L	0.0005	0.011	0.007
	Zinc* (Filtered)	mg/L	0.0038	0.008	0.015
TPH	C10 - C36 (Sum of total)	µg/L	25	No guideline	No guideline
	Fuel (C6–C9 fractions)	mg/L	0.01	No guideline	No guideline
	TRH C10-C14	µg/L	25	No guideline	No guideline
	TRH C15-C28	µg/L	50	No guideline	No guideline
	TRH C29-C36	µg/L	25	No guideline	No guideline

^ the ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines for estuarine ecosystems apply to Flat Rock Creek (site 5c). The lowland river guidelines apply to Flat Rock Creek (site 5a and 5b)

The following table presents the results of boreholes located in the Balgowlah Golf Course construction wastewater treatment plant catchment, which would discharge into Burnt Bridge Creek via the local stormwater system.

Table B.2 Median groundwater results (where values in red indicate an exceedance of the ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines

Chem Group	Indicator	Units	Median	ANZG (2018), ANZECC/ARMCANZ (2000)
Lead	Lead (Filtered)	mg/L	0.0005	0.0034
Major Anions	Alkalinity (Hydroxide) as CaCO3	mg/L	0.5	No guideline
	Alkalinity (total) as CaCO3	mg/L	77.5	No guideline
	Anions Total	meq/L	4.3	No guideline
	Chloride	mg/L	69.5	No guideline
Major Cations	Calcium (Filtered)	mg/L	13.5	No guideline
	Cations Total	meq/L	4.66	No guideline
	Magnesium (Filtered)	mg/L	7	No guideline
	Potassium (Filtered)	mg/L	2	No guideline
	Sodium (Filtered)	mg/L	48	No guideline
PAHs	Acenaphthene	µg/L	0.5	No guideline
	Acenaphthylene	µg/L	0.5	No guideline
	Anthracene	µg/L	0.5	No guideline
	Benz(a)anthracene	µg/L	0.5	No guideline
	Benzo(a)pyrene	µg/L	0.25	No guideline
	Be+O30+B22	µg/L	0.5	No guideline
	Benzo(k)fluoranthene	µg/L	0.5	No guideline
	Benzo[b+j]fluoranthene	mg/L	0.0005	No guideline
	Chrysene	µg/L	0.5	No guideline
	Dibenz(a,h)anthracene	µg/L	0.5	No guideline
	Fluoranthene	µg/L	0.5	No guideline
	Fluorene	µg/L	0.5	No guideline
	Indeno(1,2,3-c,d)pyrene	µg/L	0.5	No guideline
	Naphthalene	µg/L	0.5	16
	Polycyclic aromatic hydrocarbons	mg/L	0.00025	No guideline
	Phenanthrene	µg/L	0.5	No guideline

Chem Group	Indicator	Units	Median	ANZG (2018), ANZECC/ARMCANZ (2000)
	Pyrene	µg/L	0.5	No guideline
TRH	TRH C10-C16 (F2)	µg/L	50	No guideline
	TRH >C16-C34	µg/L	50	No guideline
	TRH >C34-C40	µg/L	50	No guideline
	TRH >C10-C16 less Naphthalene (F2)	mg/L	0.05	No guideline
	TRH >C10-C40 (Sum of total)	µg/L	50	No guideline
	TRH C6-C10 less BTEX (F1)	µg/L	10	No guideline
	TRH C6-C10 (F1)	µg/L	10	No guideline
BTEX	Benzene	mg/L	0.0005	0.95
	Ethylbenzene	mg/L	0.001	No guideline
	Toluene	mg/L	0.001	No guideline
	Total BTEX	µg/L	0.5	No guideline
	Xylene (m & p)	µg/L	1	No guideline
	Xylene (o)	µg/L	1	350
	Xylene Total	µg/L	1	No guideline
Inorganics	Ammonia as N	µg/L	70	20
	Alkalinity (Bicarbonate as CaCO3)	mg/L	90	No guideline
	Carbonate Alkalinity as CaCO3	mg/L	0.5	No guideline
	Fluoride	mg/L	0.075	No guideline
	Ionic Balance	%	2.635	No guideline
	Total Kjeldahl nitrogen	mg/L	0.2	No guideline
	Nitrates, expressed as N	mg/L	0.02	No guideline
	Nitrite (as N)	mg/L	0.005	No guideline
	Nitrogen (Total Oxidised)	mg/L	0.02	0.04
	Nitrogen (Total)	mg/L	0.2	0.35
	Phosphorus	mg/L	0.165	0.025
	Reactive Phosphorus as P	mg/L	0.005	0.02
	TDS	mg/L	316	No guideline

Chem Group	Indicator	Units	Median	ANZG (2018), ANZECC/ARMCANZ (2000)
Metals	Arsenic (Filtered)	mg/L	0.0005	0.013
	Barium (Filtered)	mg/L	0.052	No guideline
	Boron (Filtered)	mg/L	0.025	0.37
	Cadmium (Filtered)	mg/L	0.00005	0.0002
	Chromium (III+VI) (Filtered)	mg/L	0.0005	0.001
	Cobalt (Filtered)	mg/L	0.0005	0.0014
	Copper* (Filtered)	mg/L	0.0005	0.0014
	Iron (Filtered)	mg/L	14.5	0.7
	Manganese (Filtered)	mg/L	0.374	1.9
	Mercury (except as provided in item 13) (Filtered)	mg/L	0.00005	0.0006
	Nickel* (Filtered)	mg/L	0.0005	0.011
	Zinc* (Filtered)	mg/L	0.0025	0.008
TPH	C10 - C36 (Sum of total)	µg/L	25	No guideline
	Fuel (C6–C9 fractions)	mg/L	0.01	No guideline
	TRH C10-C14	µg/L	25	No guideline
	TRH C15-C28	µg/L	50	No guideline
	TRH C29-C36	µg/L	25	No guideline

The following table presents the results of boreholes located in the Wakehurst Parkway east (BL13) wastewater treatment plant catchment, which would discharge into to a drainage channel to be formed at the eastern section of the site (which would drain towards a Wakehurst Golf course dam for reuse by the golf course).

Table B.3 Median groundwater results (where values in red indicate an exceedance of the ANZG (2018) and ANZECC/ARMCANZ (2000) guidelines

Chemical Group	Indicator	Units	Median	ANZG (2018), ANZECC/ARMCANZ (2000)
Lead	Lead (Filtered)	mg/L	0.0005	0.0034
Major Anions	Alkalinity (Hydroxide) as CaCO3	mg/L	0.5	No guideline
	Alkalinity (total) as CaCO3	mg/L	0.5	No guideline
	Anions Total	meq/L	3.9	No guideline
	Chloride	mg/L	116	No guideline
Major Cations	Calcium (Filtered)	mg/L	6.5	No guideline
	Cations Total	meq/L	3.45	No guideline
	Magnesium (Filtered)	mg/L	7	No guideline
	Potassium (Filtered)	mg/L	0.5	No guideline
	Sodium (Filtered)	mg/L	59	No guideline
PAHs	Acenaphthene	µg/L	0.5	No guideline
	Acenaphthylene	µg/L	0.5	No guideline
	Anthracene	µg/L	0.5	No guideline
	Benz(a)anthracene	µg/L	0.5	No guideline
	Benzo(a)pyrene	µg/L	0.25	No guideline
	Be+O30+B22	µg/L	0.5	No guideline
	Benzo(k)fluoranthene	µg/L	0.5	No guideline
	Benzo[b+j]fluoranthene	mg/L	0.0005	No guideline
	Chrysene	µg/L	0.5	No guideline
	Dibenz(a,h)anthracene	µg/L	0.5	No guideline
	Fluoranthene	µg/L	0.5	No guideline
	Fluorene	µg/L	0.5	No guideline
	Indeno(1,2,3-c,d)pyrene	µg/L	0.5	No guideline
	Naphthalene	µg/L	0.5	16
	Polycyclic aromatic hydrocarbons	mg/L	0.00025	No guideline
	Phenanthrene	µg/L	0.5	No guideline
	Pyrene	µg/L	0.5	No guideline

Chemical Group	Indicator	Units	Median	ANZG (2018), ANZECC/ARMCANZ (2000)
TRH	TRH C10-C16 (F2)	µg/L	50	No guideline
	TRH >C16-C34	µg/L	50	No guideline
	TRH >C34-C40	µg/L	50	No guideline
	TRH >C10-C16 less Naphthalene (F2)	mg/L	0.05	No guideline
	TRH >C10-C40 (Sum of total)	µg/L	50	No guideline
	TRH C6-C10 less BTEX (F1)	µg/L	10	No guideline
	TRH C6-C10 (F1)	µg/L	10	No guideline
BTEX	Benzene	mg/L	0.0005	0.95
	Ethylbenzene	mg/L	0.001	No guideline
	Toluene	mg/L	0.001	No guideline
	Total BTEX	µg/L	0.5	No guideline
	Xylene (m & p)	µg/L	1	No guideline
	Xylene (o)	µg/L	1	350
	Xylene Total	µg/L	1	No guideline
Inorganics	Ammonia as N	µg/L	10	20
	Alkalinity (Bicarbonate as CaCO3)	mg/L	90	No guideline
	Carbonate Alkalinity as CaCO3	mg/L	0.5	No guideline
	Fluoride	mg/L	0.05	No guideline
	Ionic Balance	%	4.185	No guideline
	Total Kjeldahl nitrogen	mg/L	0.15	No guideline
	Nitrates, expressed as N	mg/L	0.765	No guideline
	Nitrite (as N)	mg/L	0.005	No guideline
	Nitrogen (Total Oxidised)	mg/L	0.765	0.04
	Nitrogen (Total)	mg/L	0.8125	0.35
	Phosphorus	mg/L	0.03	0.025
	Reactive Phosphorus as P	mg/L	0.005	0.02
	TDS	mg/L	256	No guideline
Metals	Arsenic (Filtered)	mg/L	0.0005	0.013
	Barium (Filtered)	mg/L	0.017	No guideline
	Boron (Filtered)	mg/L	0.025	0.37
	Cadmium (Filtered)	mg/L	0.00005	0.0002
	Chromium (III+VI) (Filtered)	mg/L	0.0005	0.001
	Cobalt (Filtered)	mg/L	0.0005	0.0014
	Copper* (Filtered)	mg/L	0.0005	0.0014
	Iron (Filtered)	mg/L	0.11	0.7

Chemical Group	Indicator	Units	Median	ANZG (2018), ANZECC/ARMCANZ (2000)
	Manganese (Filtered)	mg/L	0.021	1.9
	Mercury (except as provided in item 13) (Filtered)	mg/L	0.00005	0.0006
	Nickel* (Filtered)	mg/L	0.001	0.011
	Zinc* (Filtered)	mg/L	0.009	0.008
TPH	C10 - C36 (Sum of total)	µg/L	25	No guideline
	Fuel (C6–C9 fractions)	mg/L	0.01	No guideline
	TRH C10-C14	µg/L	25	No guideline
	TRH C15-C28	µg/L	50	No guideline
	TRH C29-C36	µg/L	25	No guideline

Note 1: Total metal results (*) represent the hardness adjusted value as per ANZECC/ARMCANZ (2000) which *"recommends adjusting the trigger value for hardness related metals to account for local water hardness".* This is important because the trigger values for these metals have been derived for soft waters (30mg/L $CaCO_3$) corresponding to high toxicity