Appendix

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Appendix Q

Marine water quality

January 2020

Roads and Maritime Services

Western Harbour Tunnel and Warringah Freeway Upgrade

Technical working paper: Marine water quality

January 2020

Prepared for

Roads and Maritime

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Executive Summary

This report has been prepared to support the environmental impact statement for the Western Harbour Tunnel and Warringah Freeway Upgrade project and to address the environmental assessment requirements of the Secretary of the Department of Planning, Industry and Environment (formerly Department of Planning and Environment) ('the Secretary's environmental assessment requirements') on marine water quality.

A review of existing and historical water quality information and field data collection were used to understand the water quality characteristics of Sydney Harbour. The total suspended solids concentration is a key water quality characteristic that typically reflects the effects of project activities and particularly dredging works. In Sydney Harbour total suspended solids is generally less than one milligram per litre (mg/L) during extended dry periods and peaks to around eight to 40 mg/L, depending upon the rainfall intensity producing catchment runoff. Following isolated rainfall events, the total suspended solids generally decreases to the pre-event values within a few days to a week. During the wetter months, typically January to March, the regular fresh events lead to elevated background total suspended solids concentrations of around four to eight mg/L.

The marine ecology assessment (Cardno, 2020) considered that marine ecosystems are well adapted to the total suspended solids variability in Sydney Harbour. Adopting the approach of McArthur et al (2002) it was assumed that marine biota are likely to become stressed when exposed to periods of reduced light that occur when the total suspended solids exceeds its long term, 95^{th} percentile concentration (the marine ecology tolerance limit). This premise forms the basis for assessing the potential effects of the dredging on water quality and the marine ecology.

The proposed 51 week program of dredging activities and projections of the dredge plume dispersion are described in Technical working paper: Hydrodynamic and Dredge Plume Modelling (RHDHV, 2020). A range of mitigation options were incorporated into the design of the dredging and construction program (RHDHV, 2020). Predictions of the footprint of dredge-related suspended sediment plumes were compared to the existing water's total suspended solids concentrations to assess the potential effects of the project dredging activities.

The marine ecology tolerance limit and the frequency of occurrence of the predicted excess suspended sediment plumes were used to derive boundaries for a Zone of Moderate Impact and a Zone of Influence. The Zone of Influence is confined to a distance of less than 500 metres from the dredging operation and is focused along the eastern shore of Balls Head Bay.

The dredging and construction activities are likely to cause temporary spikes in the suspended sediment concentrations in the identified Zones of Moderate Impact and Influence but the rapid dispersion within the Sydney Harbour waters is not likely to result in any significant water quality effects outside of these zones. Monitoring during the dredging activities will provide data to assess the efficacy of the mitigation measures and compliance of the activities with this assessment.

A closed environmental clamshell attached to the arm of a backhoe dredge is proposed to be used to remove the top layer of sediment on the harbour floor. This dredging technique will minimise the risk of sediment and contaminants within the sediments being mobilised into the water during dredging. This control, in conjunction with the behaviour of sediment-bound contaminants, means it is unlikely that water quality would be significantly impacted by contaminants mobilised from dredging and marine construction activities.

Onsite water capture within land-based construction activities occurring adjacent to marine waterbodies will be treated prior to discharge to the marine waters. The onsite water treatment processes are described in Technical working paper: Surface water (Jacobs, 2020). Treatment plant discharge concentrations will be managed in accordance with the ANZECC Water Quality Guidelines, considering the existing marine environment. This approach will be adopted as the framework for ensuring that the project either maintains or improves marine water quality.

1 Introduction

This section provides an overview of the Western Harbour Tunnel and Warringah Freeway Upgrade (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), a plan 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 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 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 Gore Hill Freeway to Balgowlah and Killarney Heights and including the surface upgrade of Wakehurst Parkway 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 south and 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 harbour crossings.

1.2 The project

Roads and Maritime Services (Roads and Maritime) is seeking approval under Division 5.2, Part 5 of the *Environmental Planning and Assessment Act 1979* to construct and operate the Western Harbour Tunnel and Warringah Freeway Upgrade (the project), which would comprise two main components:

- A new crossing of Sydney Harbour involving twin tolled motorway tunnels connecting the M4-M5 Link at Rozelle and the existing Warringah Freeway at North Sydney (the Western Harbour Tunnel)
- Upgrade and integration works along the existing Warringah Freeway, including infrastructure required for connections to the Beaches Link and Gore Hill Freeway Connection project (the Warringah Freeway Upgrade).

Key features of the Western Harbour Tunnel component of the project are shown in Figure 1-1. The key components which are relevant to this report includes:

- Twin mainline tunnels about 6.5 kilometres long and each accommodating three lanes of traffic in each direction, connecting the stub tunnels from the M4-M5 Link at Rozelle to the Warringah Freeway and to the Beaches Link mainline tunnels at Cammeray. The crossing of Sydney Harbour between Birchgrove and Waverton would involve a dual, three lane, immersed tube tunnel
- Connection to the stub tunnels at the M4-M5 Link project in Rozelle and to the mainline tunnels at Cammeray (for a future connection to the Beaches Link and Gore Hill Freeway Connection project)
- Surface connections at Rozelle, North Sydney and Cammeray, including direct connections to and from the Warringah Freeway (including integration with the Warringah Freeway Upgrade), an off ramp to Falcon Street and an on ramp from Berry Street at North Sydney
- Other operational infrastructure including groundwater and tunnel drainage management and treatment systems, signage, tolling infrastructure, fire and life safety systems, lighting, emergency evacuation and emergency smoke extraction infrastructure, CCTV and other traffic management systems.

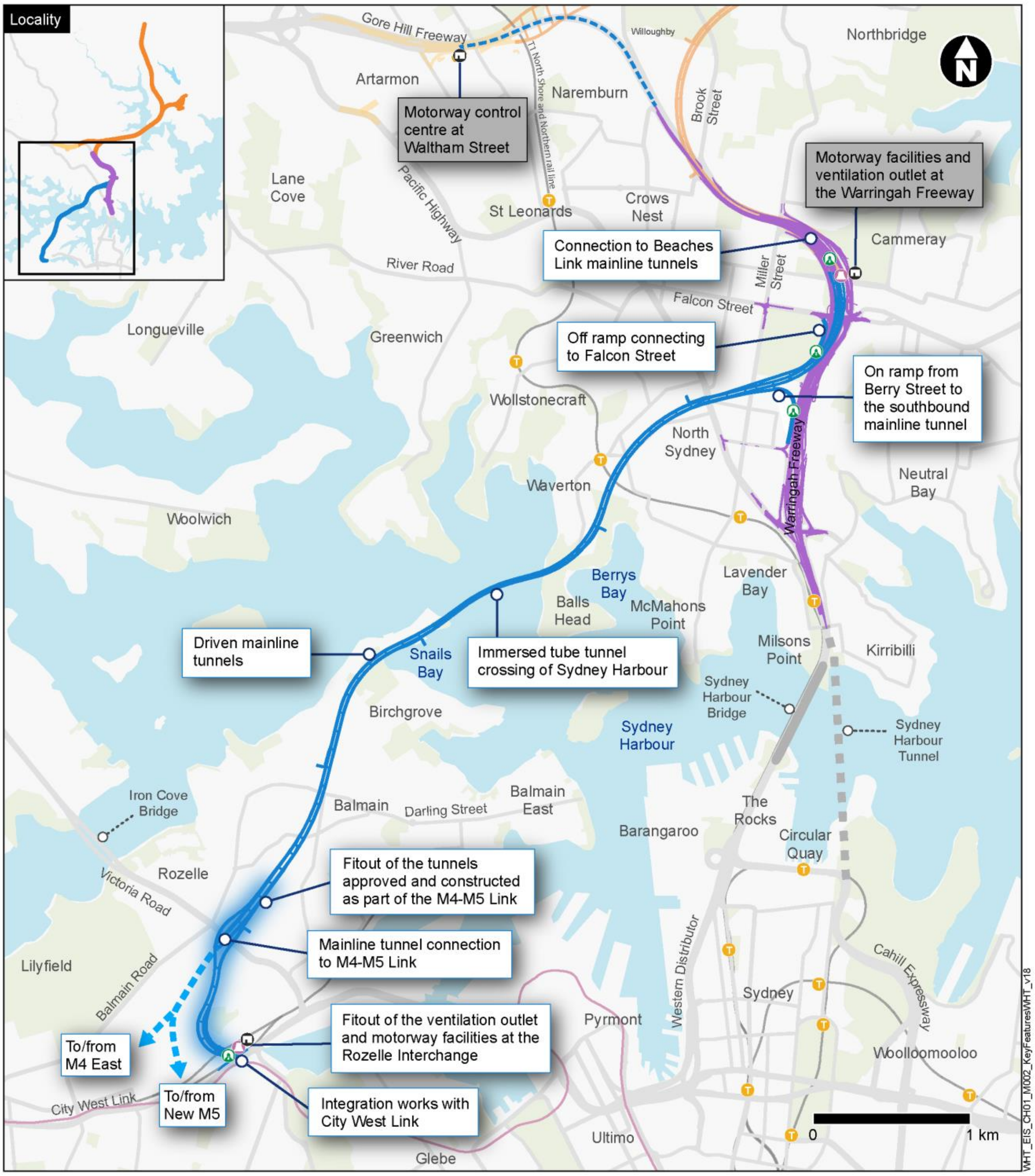
Key features of the Warringah Freeway Upgrade component of the project are shown in Figure 1-2 and would include:

> Upgrade and reconfiguration of the Warringah Freeway from immediately north of the Sydney Harbour Bridge through to Willoughby Road at Naremburn
> Upgrades to interchanges at Falcon Street in Cammeray and High Street in North Sydney
> New and upgraded pedestrian and cyclist infrastructure
> New, modified and relocated road and shared user bridges across the Warringah Freeway
> Connection of the Warringah Freeway to the portals for the Western Harbour Tunnel mainline tunnels and the Beaches Link tunnels via on and off ramps, which would consist of a combination of trough and cut and cover structures
> Upgrades to existing roads around the Warringah Freeway to integrate the project with the surrounding road network
> Upgrades and modifications to bus infrastructure, including relocation of the existing bus layover along the Warringah Freeway
> Other operational infrastructure, including surface drainage and utility infrastructure, signage, tolling, lighting, CCTV and other traffic management systems.

A detailed description of the project is provided in Chapter 5 (Project description) and construction of the project is described in Chapter 6 (Construction work) of the environmental impact statement. The project alignment at the Rozelle Interchange shown in Figure 1-1 and Figure 1-5 reflects the arrangement presented in the environmental impact statement for the M4-M5 Link, and as amended by the proposed modifications. This project would be constructed in accordance with the finalised M4-M5 Link detailed design (refer to Section 2.1.1 of Chapter 2 (Assessment process) of the environmental impact statement for further details).

The project does not include ongoing motorway maintenance activities during operation or future use of residual land occupied or affected by project construction activities, but not required for operational infrastructure. These would be subject to separate planning and processes at the relevant times.

Subject to the project obtaining planning approval, construction is anticipated to commence in 2020 and is expected to take around six years to complete.



Legend

Operational features
- Western Harbour Tunnel
- Warringah Freeway Upgrade
- Communications cable for motorway control centre
- M4-M5 Link tunnel fitout and commissioned as part of Western Harbour Tunnel
- Surface connection
- Permanent operational facility
- Ventilation outlet

Connecting projects
- Beaches Link
- Gore Hill Freeway Connection
- M4-M5 Link connections (indicative)

Existing rail network
- Heavy rail
- Light rail
- Train station

Figure 1-1 Key features of the Western Harbour Tunnel component of the project

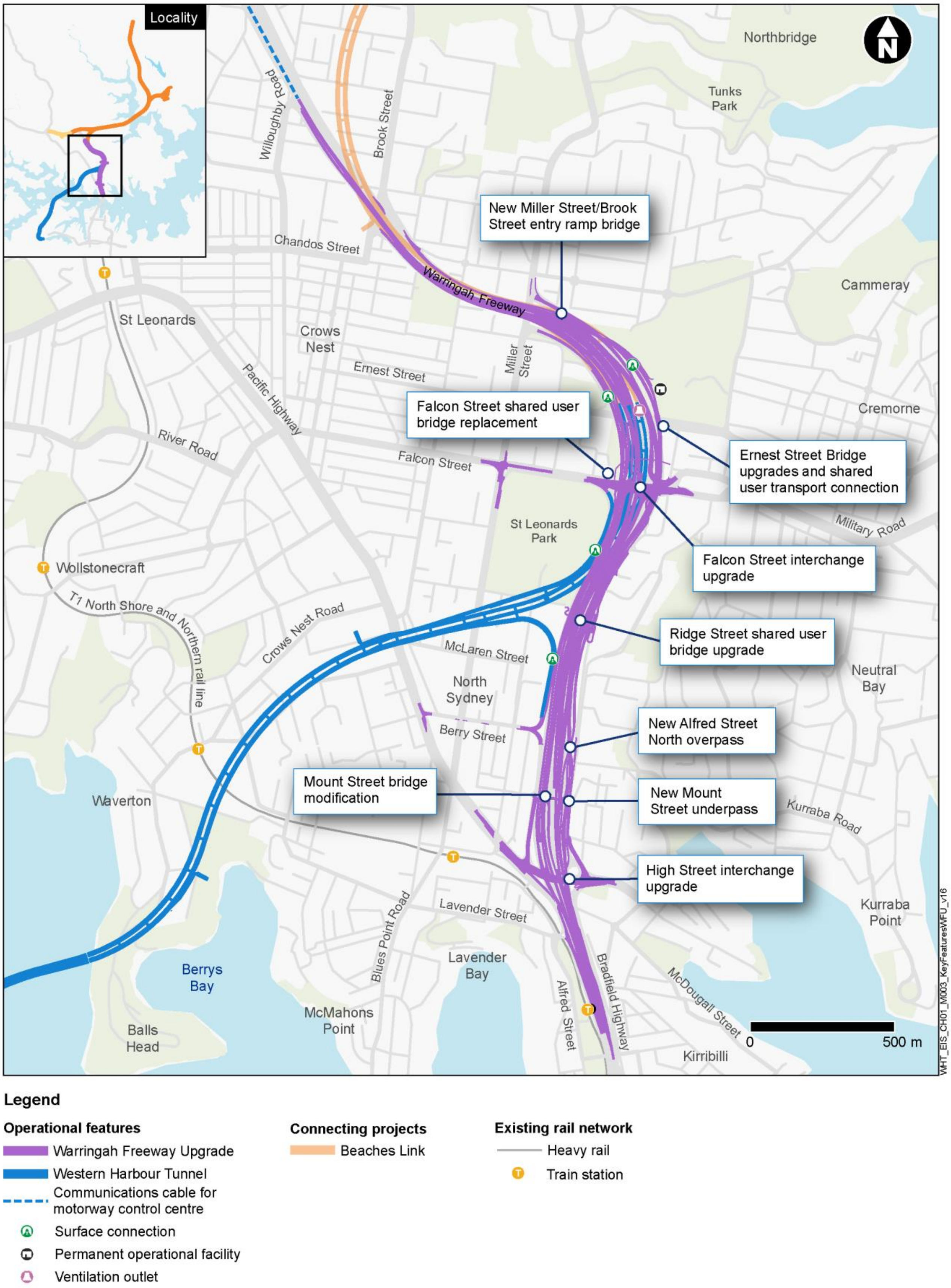


Figure 1-2 **Key features of Warringah Freeway Upgrade component of the project**

1.2.2 Immersed tube elements

The immersed tube tunnel would connect to the driven mainline tunnels in Sydney Harbour offshore from Yurulbin Point at Birchgrove and from Balls Head at Waverton.

The immersed tube tunnel would be installed as a series of pre-cast units in a trench excavated in the bed of Sydney Harbour. Fill and armour materials would be placed around the immersed tube tunnel units for stability and protection. The top of the immersed tube tunnel, including rock armour, would not reduce the navigation depth of existing shipping channels. The immersed tube tunnel would accommodate three traffic lanes.

An indicative cross section of the immersed tube tunnel crossing of Sydney Harbour is shown in Figure 1-3. An indicative long section of the immersed tube tunnel is shown in Figure 1-4.

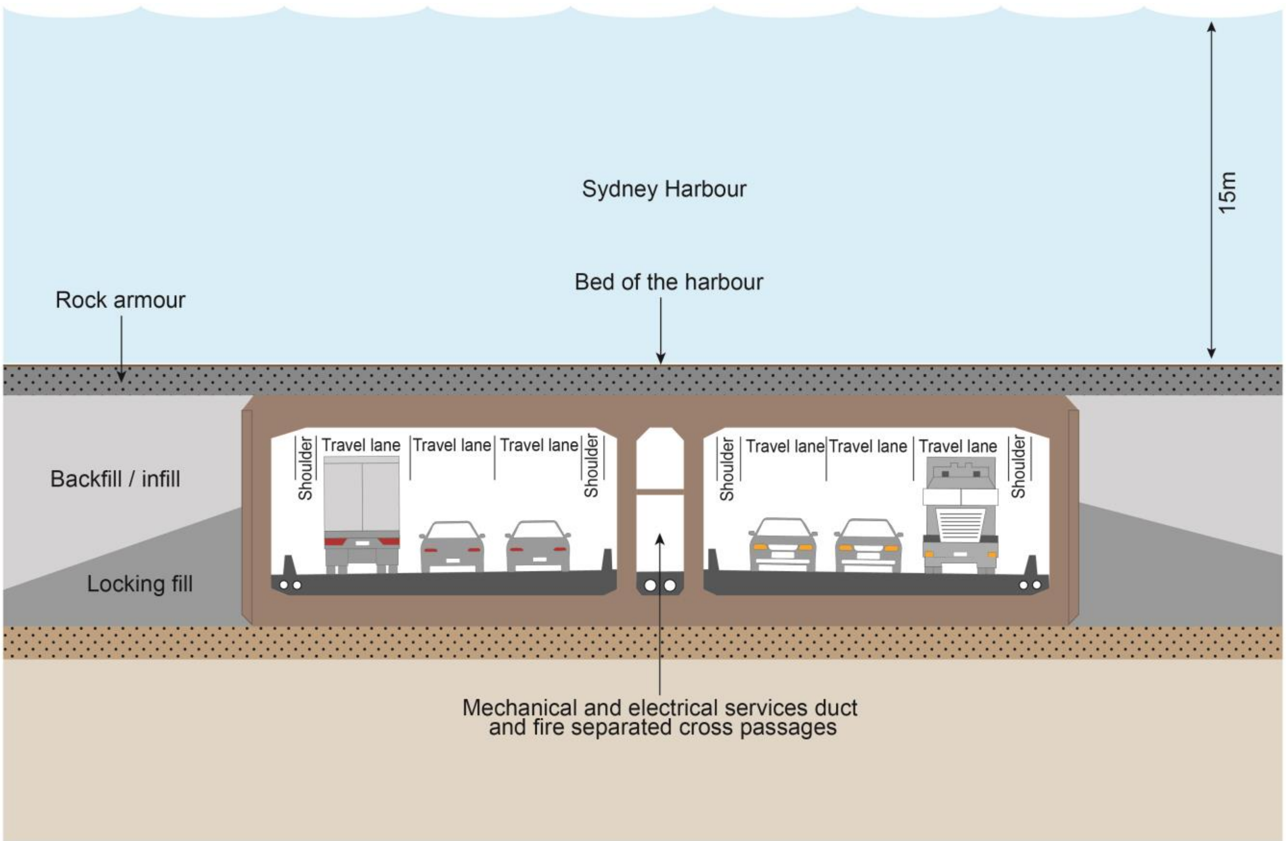


Figure 1-3 Indicative cross section of the immersed tube tunnel (Sydney Harbour)

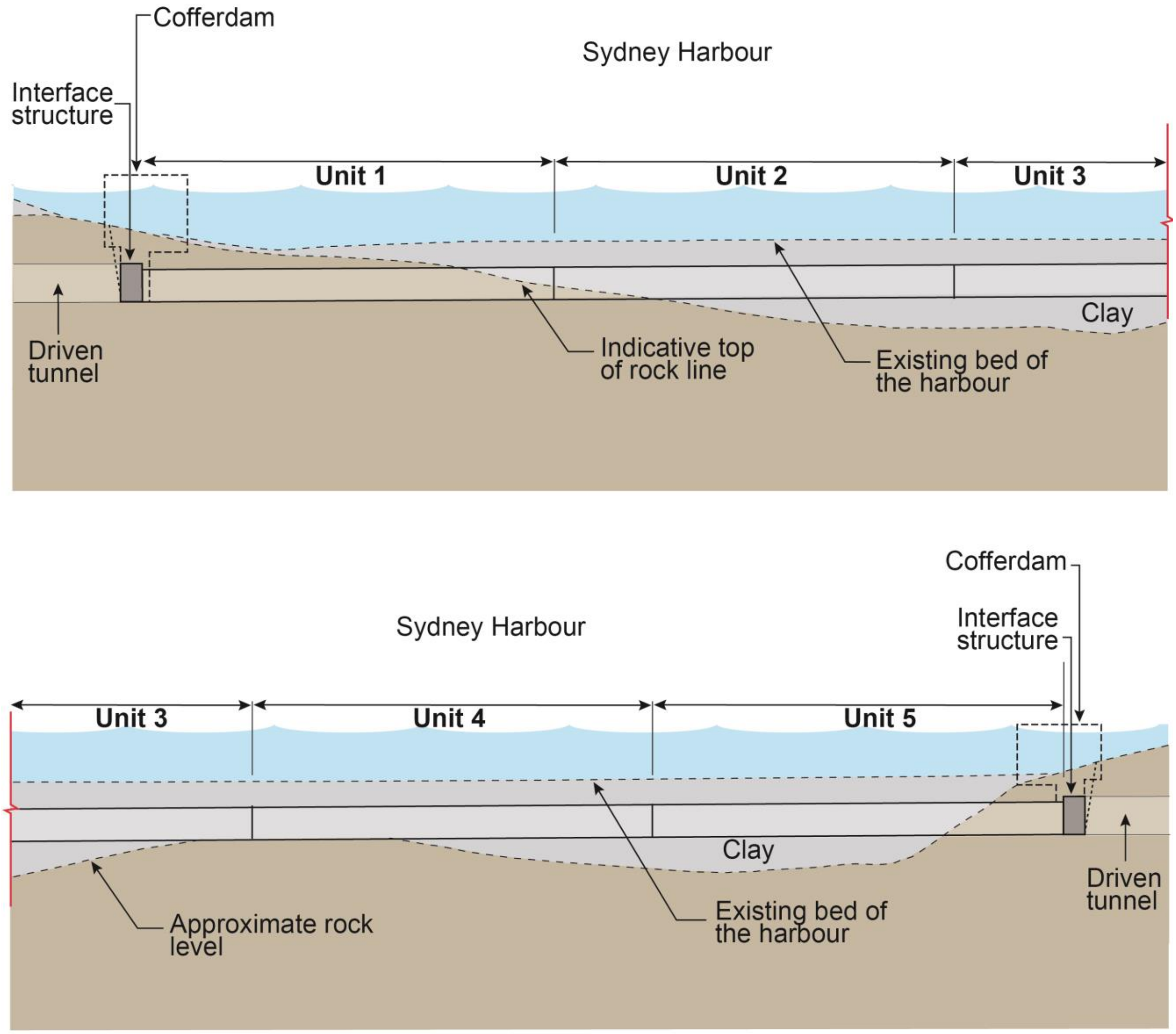


Figure 1-4 **Indicative long section of the immersed tube tunnels (Sydney Harbour)**

1.2.3 Other operational ancillary infrastructure

As part of the groundwater and tunnel drainage management and treatment system, a water treatment plant would be constructed and operated at Rozelle. The water treatment plant would discharge into Rozelle Bay, via the local stormwater system.

The design of the water treatment plant is discussed in Technical working paper: Surface water (Jacobs, 2020). Discharge criteria for the plant would be determined using the ANZECC Water Quality Guidelines, considering the existing marine environment. This approach would be adopted as the framework for ensuring that the project either maintains or improves marine water quality. This is further discussed in Section 5.2 of this report.

1.3 Key construction activities

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

Key construction activities relevant to this report would include:

> Early works and site establishment, with typical activities being property acquisition, utilities protection, adjustments and relocations, installation of site fencing, environmental controls (including noise

attenuation) and traffic management controls, vegetation clearing, earthworks and demolition of structures, establishment of construction support sites including acoustic sheds and associated access decline acoustic enclosures (where required), temporary relocation of swing moorings within Berrys Bay, and relocation of historic vessels

> Construction of Western Harbour Tunnel, with typical activities being excavation of tunnel construction accesses, construction of driven tunnels, cut and cover and trough structures and construction of cofferdams, dredging 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 of a motorway control centre at Waltham Street in Artarmon, motorway and tunnel support facilities and, ventilation outlets at the Warringah Freeway in Cammeray, construction and fitout of the project operational facilities that form part of the M4-M5 Link Rozelle East Motorway Operations Complex, a wastewater treatment plant at Rozelle and the installation of motorway tolling infrastructure

> Construction of the Warringah Freeway Upgrade, with typical activities being earthworks, bridgeworks, construction of retaining walls, stormwater drainage, pavement works and linemarking and the installation of road 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 1-5), and would include tunnelling and tunnel support sites, civil surface sites, cofferdams, mooring sites, wharf and berthing facilities, laydown areas, parking and workforce amenities. Only six construction support sites are relevant to this report. These are:

> Rozelle Rail Yards (WHT1)

> White Bay (WHT3)

> Yurulbin Point (WHT4)

> Sydney Harbour south cofferdam (WHT5)

> Sydney Harbour north cofferdam (WHT6)

> Berrys Bay (WHT7).

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

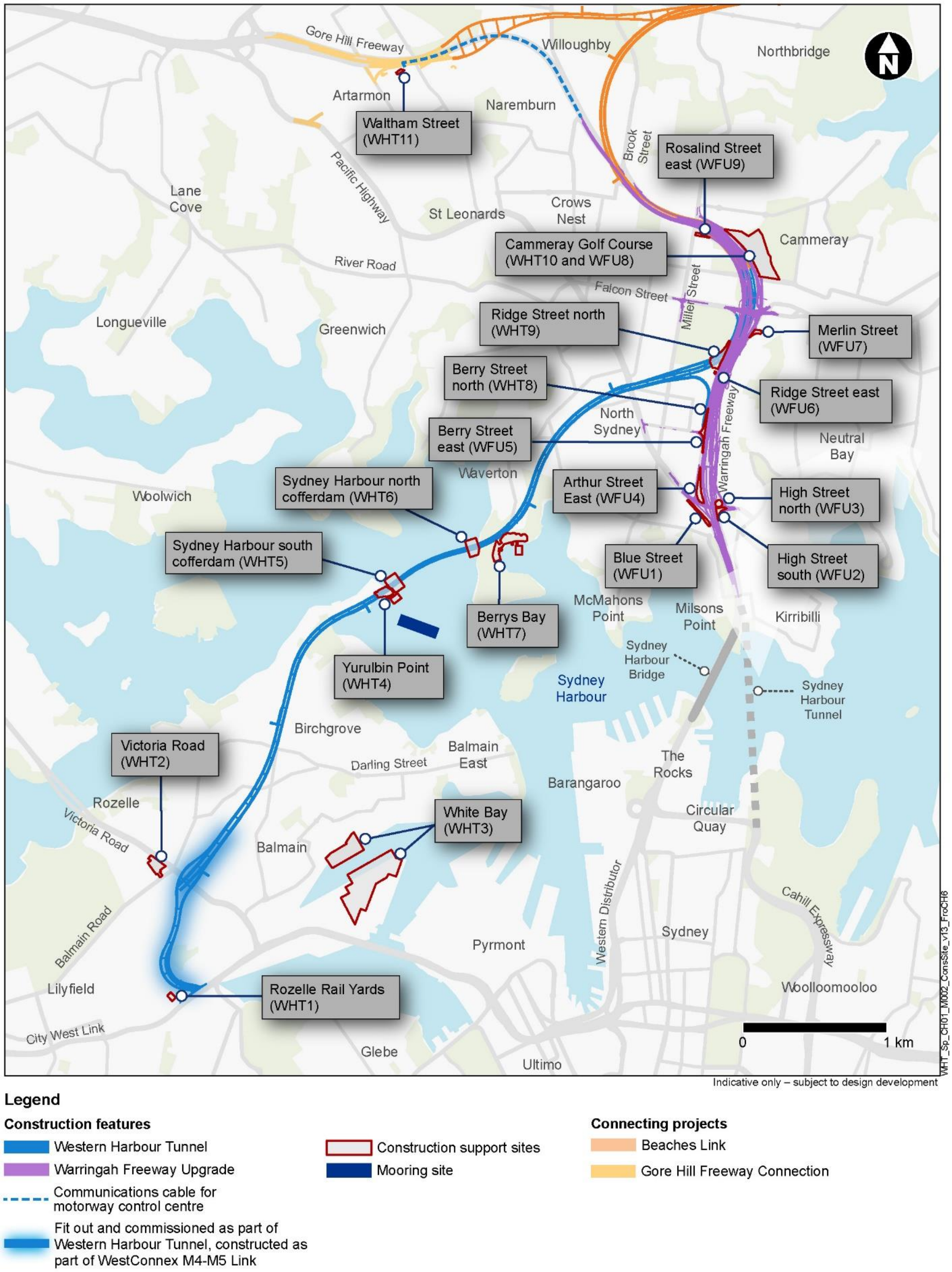


Figure 1-5 **Overview of construction support sites**

1.4 Project location

The project would be located within the Inner West, North Sydney and Willoughby local government areas, connecting Rozelle in the south with Naremburn in the north.

Commencing at the Rozelle Interchange, the mainline tunnels would pass under Balmain and Waverton, then cross Sydney Harbour between Birchgrove and Balls Head. The tunnels would then continue under Waverton and North Sydney, linking directly to the Warringah Freeway to the north of the existing Ernest Street bridge.

The motorway control centre would be located at Waltham Street, Artarmon, with a trenched communications cable connecting the motorway control centre to the Western Harbour tunnel along the Gore Hill Freeway and Warringah Freeway road reserves.

The Warringah Freeway Upgrade would be carried out on the Warringah Freeway from around Fitzroy Street at Milsons Point to around Willoughby Road at Naremburn. Upgrade works would include improvements to bridges across the Warringah Freeway, and upgrades to surrounding roads.

1.5 Purpose of this 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 (formerly the Department of Planning and Environment) ('the Secretary's environmental assessment requirements').

This report focuses on the water quality of Sydney Harbour and potential impacts of the project during construction and operation.

1.6 Secretary's environmental assessment requirements

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

Table 1-1 **Secretary's environmental assessment requirements – as relevant to marine water quality**

Secretary's environmental assessment requirements	Where addressed
10.1 (b) state the ambient NSW Water Quality Objectives (NSW WQO) (as endorsed by the NSW Government [see www.environment.nsw.gov.au/ieo/index.htm]) and environmental values for the receiving waters (including groundwater where appropriate) relevant to the project and that represent the community's uses and values for those receiving waters, including the indicators and associated trigger values or criteria for the identified environmental values in accordance with the ANZECC (2000) Guidelines for Fresh and Marine Water Quality and/or local objectives, criteria or targets endorsed by the NSW Government	This report assesses impacts to all marine water quality values related to the project in accordance with the NSW WQO and ANZECC Water *Quality Guidelines (2000 and 2006)* and provides supporting information for the Aquatic Ecology impact assessment.
(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	The impacts of the construction and operation of the project is outlined within Section 5.1 and Section 5.2. For surface water quality impacts refer to Section 5 and 6 of Technical working paper: Surface water (Jacobs, 2020). Existing groundwater quality is described in Section 5.5 of Technical working paper: Groundwater (Jacobs, 2020).
(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.	Mitigation measures are outlined within Section 6.

1.7 Avoid and minimise

Under the Roads and Maritime *Biodiversity Guidelines: Protecting and managing biodiversity on RTA projects* (Roads and Traffic Authority (RTA), 2011) the management of biodiversity should aim to:

1. Avoid and minimise impacts first
2. Mitigate impacts where avoidance is not possible
3. Offset where residual impacts cannot be avoided.

NSW Department of Planning, Industry and Environment (DPIE) (Regions, Industry, Agriculture & Resources) requires that proponents should, as a first priority, aim to avoid impacts upon key fish habitat as a general principle. Where avoidance is impossible or impractical, proponents should then aim to minimise impacts. Any remaining impacts should then be offset with compensatory works. NSW DPIE assesses activity and development proposals in relation to general policies and with consideration for the 'sensitivity' of the affected fish habitat.

The Secretary's environmental assessment requirements issued for the project specifically identified the following as a key issue and desired performance outcome:

'The project design considers all feasible measures to avoid and minimise impacts on terrestrial and aquatic biodiversity.'

The project has been designed to avoid and minimise potential impacts to marine water quality and marine ecology. The existing project footprint has been reduced as far as practicable to avoid areas of marine vegetation and habitat. Standard management measures would be implemented at construction sites to minimise potential impacts to marine water quality and its flow-on impacts on marine ecology. These include:

> Treatment of tunnel wastewater via a treatment plant prior to discharge from construction sites to avoid adverse impacts to water quality in the harbour

> Installation of silt curtains during dredging

> Use of a closed environmental clamshell bucket to dredge the top layer of marine sediment

> Construction staging

> Management of contaminated sediments and acid sulfate soils.

The project description is outlined in Chapter 5 (Project description) and the methods of construction for dredging and wastewater treatment plants are described within Chapter 6 (Construction work) of the environmental impact statement and would be further refined during further design development, aiming to reduce the area of impact to marine water quality, vegetation and habitat.

The secondary impacts of marine water quality to marine ecology as a result of the project are discussed in the Technical working paper: Marine ecology (Cardno, 2020).

1.8 Legislative context

Legislation and planning policies relevant to the protection of marine water quality in this report are provided below. These statutory instruments provide conditions, matters for consideration, guidance notes and requirements to seek authorisation (licences and approvals) to carry out various actions and activities. The list of NSW and Australian Government legislation and guidelines with relevance to this assessment are:

> NSW *Environmental Planning and Assessment Act 1979* (EP&A Act)

> NSW *Coastal Management Act 2016* (CM Act)

> Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)

> *Australian and New Zealand Environment and Conservation Council/Agriculture and Resource Management Council of Australia and New Zealand* (ANZECC/ARMCANZ, 2000)

> *NSW Water Quality and River Flow Objectives* (DECCW, 2006)

> *National Health and Medical Research Council: Guidelines for Managing Risks in Recreational Water* (NHMRC, 2008)

> *Sydney Harbour Water Quality Improvement Plan* (Greater Sydney Local Land Services, 2015).

1.8.1 Environmental Planning and Assessment Act 1979

All projects assessed as state significant infrastructure under Part 5, Division 5.2 of the EP&A Act requires an environmental impact statement to address the Secretary's environmental assessment requirements (see Section 1.6).

According to the Secretary's environmental assessment requirements, the environmental impact statement must assess marine water quality impacts.

1.8.2 Coastal Management Act 2016

The previous *Coastal Protection Act 1979* was implemented through a series of coastal zone management plans (CZMPs). However, CZMPs will now be superseded by the development of coastal management programs in four areas across NSW as part of the coastal management legislation reform gazetted in the new CM Act. The four areas are defined in the new CM Act as part of the new State Environmental Planning Policy (Coastal Management) 2018 (Coastal Management SEPP). The Coastal Management SEPP will integrate and improve current coastal-related SEPPs and ensure that future coastal development is appropriate and sensitive to our coastal environment, and that public access to beaches and foreshore areas is maintained. The Coastal Management SEPP is the single land use planning policy for coastal development, bringing together and modernising provisions from SEPP 14 – Coastal Wetlands, SEPP 26 – Littoral Rainforest and SEPP 71 – Coastal Protection.

1.8.3 Environment Protection and Biodiversity Conservation Act 1999

The EPBC Act protects nationally and internationally important flora, fauna, ecological communities and heritage places, which are defined in the EPBC Act as Matters of National Environmental Significance (MNES). MNES relevant to marine biodiversity are:

- Wetlands of international importance
- Nationally listed threatened species and ecological communities
- Migratory species
- Commonwealth marine areas.

The significance of impacts on MNES is determined in accordance with the *Significant Impact Guidelines 1.1 – Matters of National Environmental Significance* (Department of the Environment (DoE), 2013).

Where an action is likely to have a significant impact on a MNES, the action is referred to the Australian Government Environment Minister. The referral process involves a decision on whether or not the action is a 'controlled action'. When an action is declared a controlled action, approval from the Minister is required.

1.8.4 Australian and New Zealand guidelines for Fresh and Marine Water Quality

The Australian and New Zealand Environment and Conservation Council/Agriculture and Resource Management Council of Australia and New Zealand (ANZECC/ARMCANZ, 2000) provide guidelines for water quality. The guidelines have recently been updated to incorporate new science and knowledge developed over the past 20 years (ANZG, 2018). Together they form part of the National Water Quality Management Strategy and list a range of environmental values assigned to water bodies classified according to their climate zone, proximity to population centres and uses as well as other common identifiers. These objectives and guidelines provide benchmarks for assessment of the existing water quality and are dependent on the environmental values assigned to the waterway.

The ANZG (2018) and ANZECC/ARMCANZ (2000) Water Quality Guidelines recommend development of a scientifically rigorous understanding of local water quality variability to form the basis for the assessment of potential impacts of proposed developments. Where local data on the broad suite of water quality parameters is not available, the ANZECC guidelines provide generic water quality criteria (scientifically-based benchmark values) for a wide range of parameters. The ANZECC/ARMCANZ (2000) Water Quality Guidelines state that 'the Guidelines are not intended to be used as mandatory standards because there is significant uncertainty associated with the derivation and application of water quality guidelines'. However, the guidelines provide a useful basis for assessing risks to aquatic ecosystem health.

For the protection of aquatic ecosystems near the project, the ANZECC/ARMCANZ (2000) default trigger values for physical and chemical stressors for 'South-East Australian slightly disturbed lowland rivers and estuaries' would typically apply. However, in heavily urbanised and modified environments such as that surrounding the project, water quality indicators often exceed the recommended ANZECC/ARMCANZ (2000) default trigger values. The revised ANZG (2018) guidelines provide some additional default values but are yet to be issued as a final form. As such, the default ANZECC/ARMCANZ (2000) and ANZG (2018) trigger values may not be suitable for comparison against ambient water quality of Sydney Harbour. The alternative approach recommended by ANZECC is to determine site specific trigger values based on background water quality monitoring data.

The ANZECC Water Quality Guidelines are not suitable for direct application to construction water discharge quality. The guidelines however have been derived to apply to the ambient waters that receive construction water discharges, and to protect the environmental values of the receiving environment. In general, the treated water discharges from the construction sites would be relatively low flows, in comparison to the tidal flows in the harbour, and at concentrations below the adopted threshold for marine receiving waters species protection. If required a gradient monitoring approach to assessing the footprint of the discharge plume would be adopted to assess any effects on the marine receiving water quality. This approach would be consistent with the philosophy outlined in the ANZECC/ARMCANZ (2000) and more recent ANZG (2018) Water Quality Guidelines applicable to the marine and estuarine waters receiving environment of Sydney Harbour.

1.8.5 NSW Water Quality and River Flow Objectives

The NSW Water Quality and River Flow Objectives (DECCW, 2006) are consistent with the agreed national framework of the ANZECC Water Quality Guidelines (ANZECC/ARMCANZ, 2000) and its recent update ANZG (2018). The NSW objectives are 'primarily aimed at maintaining and improving water quality, for the purposes of supporting aquatic ecosystems, recreation and where applicable, water supply, and the production of aquatic foods suitable for consumption and aquaculture activities' (DECCW, 2006).

Specific Water Quality Objectives have been developed for Sydney Harbour and the Parramatta River catchment. The waterways within the study area, relevant to this assessment, have been identified as Upper Estuary (Iron Cove) and Lower Estuary (Rozelle Bay, Snails Bay and Berrys Bay). Based on this classification, the Water Quality Objectives and nominated environmental values relevant to the project include:

- Protection of aquatic ecosystems – ecological condition of waterways and their riparian zone (Lower and Upper Estuary)
- Protection of visual amenity - aesthetic qualities of waters (Lower and Upper Estuary)
- Protection of primary contact recreation – water quality for activities, such as swimming (Lower and Upper Estuary)
- Protection of secondary contact recreation - water quality suitable for activities, such as boating and wading (Lower and Upper Estuary).

The protection of aquatic foods (cooked) has also been identified for the Lower Estuary as a long-term objective of the community. However, from 2006 Sydney Harbour has been closed to commercial fishing as a precautionary measure due to elevated levels of dioxins in some fish and seafood. Recreational fishing is still allowed but recreational fishers are recommended to follow dietary advice from the Ministry of Health on the consumption of seafood.

The relevant NSW Water Quality river flow objectives and their application to the project are presented in Table 1-2 below.

Table 1-2 **River flow objectives**

River flow objective	Applicable waterway	Consideration
Maintain wetland and floodplain inundation	Upper and Lower Estuary	This is considered in Technical working paper: Flooding (Lyall and Associates, 2020)
Manage groundwater for ecosystems	Upper Estuary	Refer to Technical working paper: Groundwater (Jacobs, 2020)
Minimise effects of weirs and other structures	Upper and Lower Estuary	Not applicable. No weirs or fish barriers are proposed as part of the project.
Maintain or rehabilitate estuarine processes and habitats	Upper and Lower Estuary	Refer to Technical working paper: Marine ecology (Cardno, 2020)

1.8.6 Guidelines for Managing Risks in Recreational Water

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 have been considered as part of the assessment of the project to understand the current recreational water quality and threat to public health of waterways that have the potential to be impacted by runoff during the construction and operation of the project.

1.8.7 Sydney Harbour Water Quality Improvement Plan (Sydney Metropolitan Catchment Management Authority)

The Sydney Harbour Water Quality Improvement Plan (Greater Sydney Local Land Services, 2015) was developed by Greater Sydney Local Land Services, NSW Office of Environment and Heritage (now the Department of Planning, Industry and Environment (Environment, Energy and Science)) and local government in collaboration with a range of stakeholders. This plan provides a coordinated management framework for the local councils, state government agencies and federal government agencies that have a stake in improving the future health of Sydney Harbour and its catchments. This plan applies to the majority of the study area which ultimately drains to Sydney Harbour. While the plan itself does not include pollutant reduction targets for individual developments, catchment load and estuary condition targets have been developed for 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 scenarios including assumptions of feasible change/actions:

> Water sensitive urban design incorporated into 70 per cent of infill developments

> Water sensitive urban design 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 should be carried out to achieve these goals. It is acknowledged that different scenarios to that assumed above could also achieve the targets. Targets are currently available for some of the Sydney Harbour sub-catchments. No targets are available for Rozelle Bay and the project would aim to comply with the ANZECC.

1.9 Previous investigations for the project

A preliminary environmental investigation (PEI) identified the key issues to marine water quality potentially associated with the project (Cardno, 2016). The PEI supported a State Significant Infrastructure application for the project.

This report builds on and incorporates the relevant details from these previous investigations where appropriate.

1.10 Other project investigations

The marine ecology assessment has been informed by predictions of changes to marine water quality, sedimentation, hydrodynamics, underwater noise and mobilisation of contaminants during construction. These predictions were detailed in various specialist reports including:

> *Western Harbour Tunnel and Warringah Freeway Upgrade Technical working paper: Marine ecology* (Cardno, 2020)

> Summaries from the *Western Harbour Tunnel and Beaches Link Geotechnical Investigation: Contamination Factual Report – Marine Investigations* (Douglas Partners and Golder Associates, 2017)

> *Western Harbour Tunnel and Warringah Freeway Upgrade Technical working paper: Contamination* (Jacobs, 2020)

> *Western Harbour Tunnel and Warringah Freeway Upgrade Technical working paper: Surface water* (Jacobs, 2020)

> *Western Harbour Tunnel and Warringah Freeway Upgrade Technical working paper: Hydrodynamic and dredge plume modelling* (Royal Haskoning DHV, 2020).

1.11 Definitions

The following definitions are used in this report:

> This report: this marine water quality technical paper

> The project: refers to that described in Sections 1.2 and 1.3

> Project area: refers to the area to be directly impacted by the project

> Study area: refers to the estuarine areas from the highest astronomical tide (HAT) encompassing the project area, and areas adjacent from Gladesville Bridge and the open water area just to the east of Garden Island and Robertsons Point (about 1197.84 hectares) (Figure 1-6).

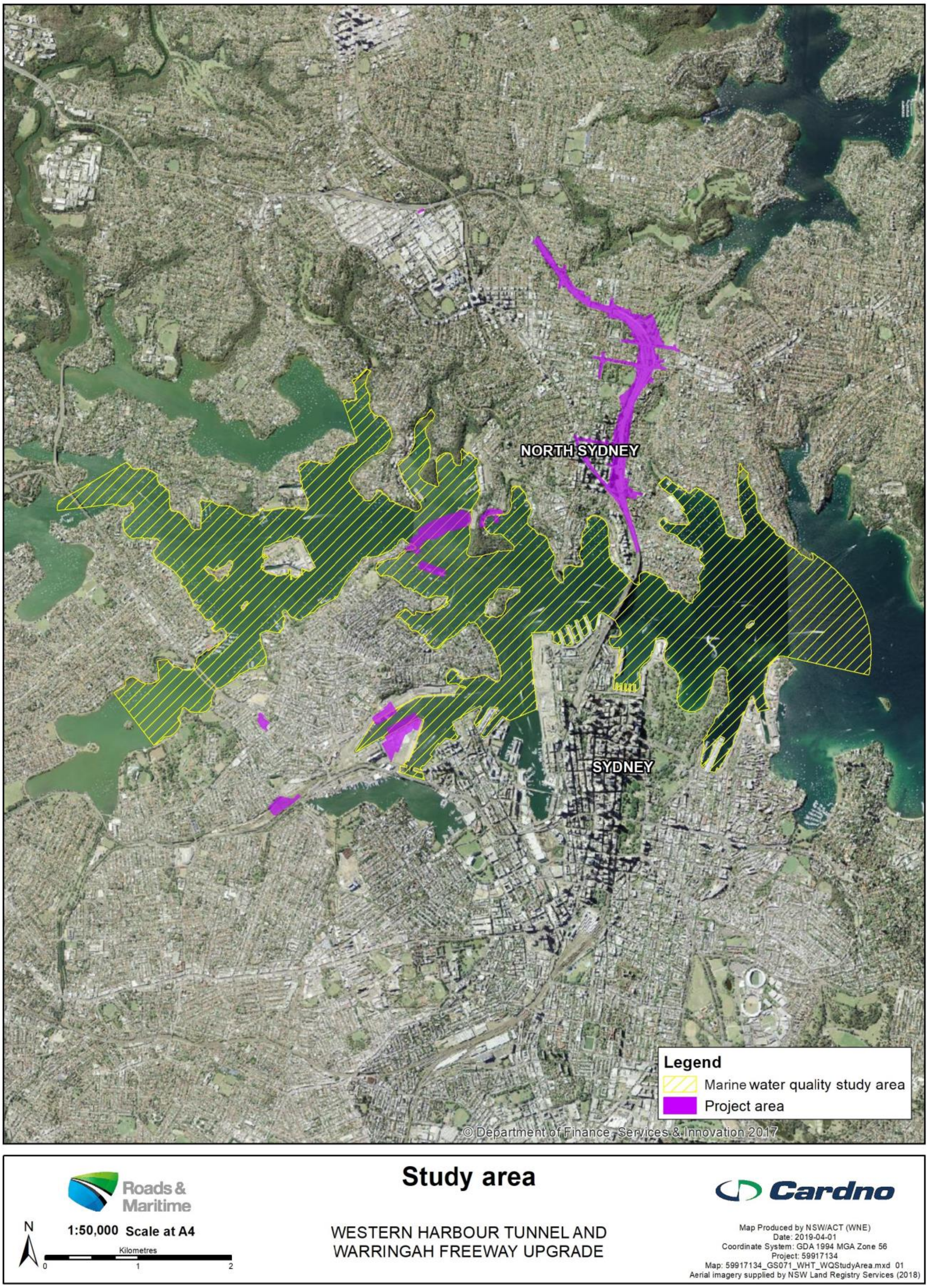


Figure 1-6 Marine water quality study area

2 Methods

2.1 General approach

The potential effects of the project on marine water quality were assessed including dredging and tunnel construction activities. In addition, the effects of treated surface water and groundwater discharges from the construction sites to the harbour on water quality were also assessed.

Natural variability of key water quality parameters were identified through a review of existing information, supplemented by two months of field data collection. Existing information included a range of historical water quality data collection programs and the Sydney Harbour Ecological Response Model (SHERM). Field data was collected at a number of sites in Sydney Harbour spanning the area that might be affected by the dredging and construction activities.

Predictions of the suspended sediment plumes and sediment deposition likely to be generated by the dredging and construction activities have been simulated by Royal Haskoning DHV group and are reported in Technical working paper: Hydrodynamic and dredge plume modelling (RHDHV, 2020).

The existing and collected data was analysed to provide a site specific statistical summary of key water quality parameters, including the key tolerance limits of the marine ecology. Results of predictive modelling of the dredging-related suspended sediment plumes were combined with the natural system variability and ecosystem tolerance limits to provide an interpretation of potential impacts on the water quality of Sydney Harbour.

The potential for localised increases in turbidity associated with construction activities (ie piling, construction of temporary wharf facilities and vessel movements) and discharges from the onshore activities to stormwater network and ultimately harbour waters was also considered.

Estimates of these and other water quality effects (ie contaminants in sediment mobilised during dredging) were used to inform the marine ecology impacts assessment, discussed in Cardno (2020).

2.2 Review of existing and historical water quality information

2.2.1 Historical water quality assessments

There is a range of existing and historical water quality information available for Sydney Harbour (refer to Table 2-1). Typically, water quality investigations in Sydney Harbour have focused on information required for specific areas where there are known water quality issues, for example dispersion of contaminants from historical industrial sites in Homebush Bay, or to assess impacts of proposed activities by state agencies and private developers. The information reported in these studies was used to develop an understanding of the natural variability in turbidity and total suspended solids within the harbour.

Table 2-1 **Summary of articles containing water quality information on Sydney Harbour**

Article	Focus area
Birch and O'Hea (2007)	Homebush Bay
Cardno (2008)	Parramatta River estuary
Hatje et al. (2001, 2003)	Homebush Bay and Parramatta River estuary
Laxton et al (1990-2008)	Sydney Harbour
Robinson GRC Consulting (1999)	Upper Parramatta River estuary
Harrison (2013)	Parramatta River and Middle Harbour
Taylor and Birch (1999)	Parramatta River estuary
Lend Lease (2017)	Darling Harbour

The historical data utilised to inform the natural variability within Sydney Harbour was the water quality sampling in the harbour carried out by the former Catchment Management Authority (CMA, now Water NSW) from January to June 2013 (Harrison, 2013). A range of in situ water quality measurements (including turbidity) were taken at 25 locations within Middle Harbour and the Parramatta River (refer to Figure 2-1). A YSI model 6600 V2 sonde fitted with a YSI model 6136 turbidity sensor was used for in situ data collection.

Where sufficient preserved water samples were available a subset of samples were analysed for total suspended solids (photometric method). This data allowed for the relationship between total suspended solids (total suspended solids in mg/L) and turbidity (in NTU, nephelometric turbidity units) to be determined – see Section 3.2.1).

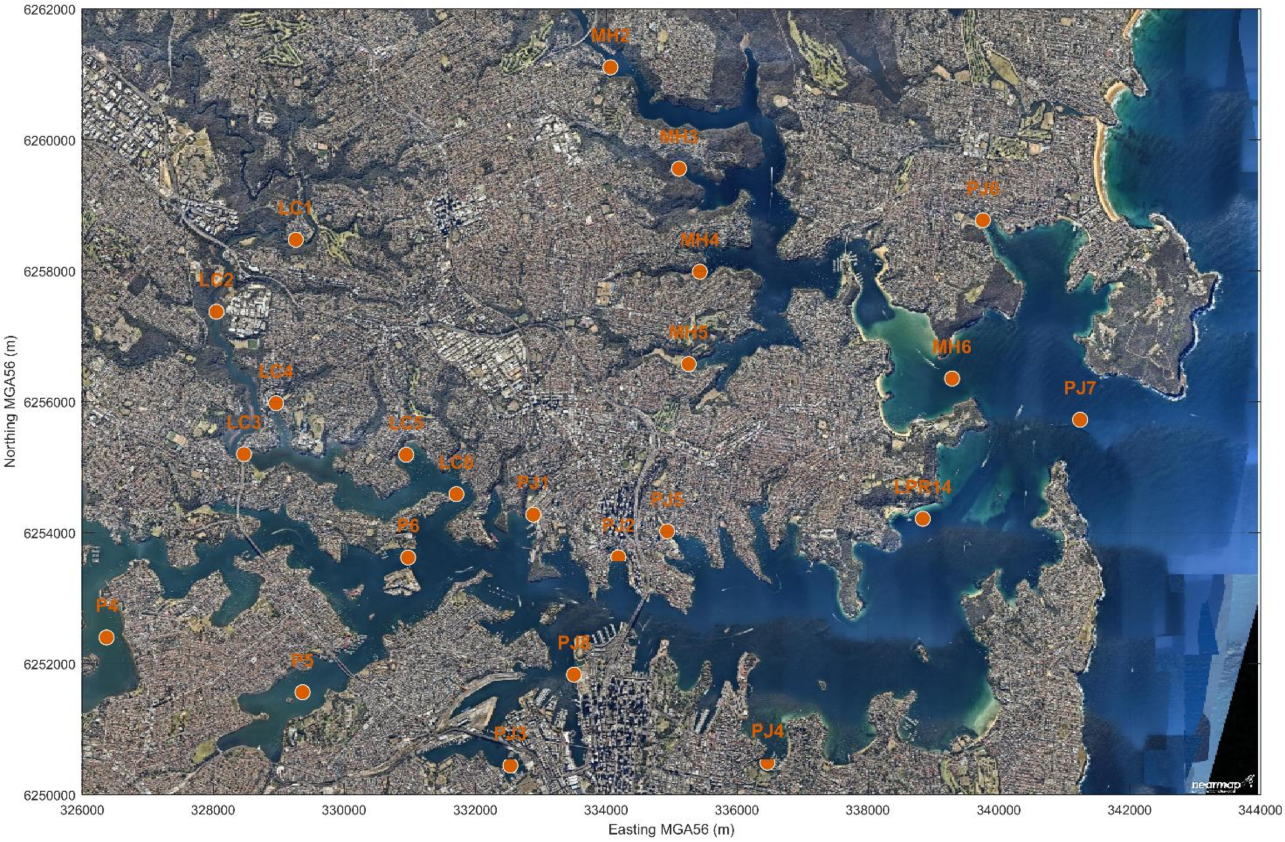


Figure 2-1 **Sydney Harbour monitoring sites adopted by the Upper Parramatta Trust CMA (2013)**

2.2.2 Sydney Harbour Ecological Response Model

The former Upper Parramatta Trust Catchment Management Authority (now part of Greater Sydney Local Land Services) supported a range of historical studies including water data collection, modelling of catchment rainfall runoff and constituent loads and development of the Sydney Harbour Ecological Response Model, or SHERM (Cardno, 2015). SHERM was developed by Cardno using the Deltares suite of hydrodynamics and water quality models (for descriptions see www.deltares.nl/en/software-solutions). SHERM includes the learnings from a long history of modelling in Sydney Harbour and was developed by Cardno over a three year program using the Deltares suite of hydrodynamics and water quality models (for descriptions see www.deltares.nl/en/software-solutions). SHERM simulates numerous physical, nutrient, algal and biological processes in response to tidal forcing, river inflows, wind, waves and atmospheric heat fluxes.

SHERM was not run specifically for this project. Available simulation results were used from a 12 month simulation period (April 2012 to March 2013), comprising an initial three-month calibration period and a subsequent nine month investigative period. This 12 month simulation period includes typical annual, summer and winter catchment inflows (Stewart, 2013) and as such can be considered representative of the range of seasonal influences on water quality characteristics of the actual harbour waters. The seasonal influences and catchment inputs characterised in SHERM are appropriate for the current catchment conditions.

To simulate the broad range of water quality variables and space-time scales SHERM comprises a suite of three models with differing grid resolution within the broader Sydney harbour:

> hydro - high resolution hydrodynamics grid (around 100,000 cells from 10 metres to 150 metres cell sizes and eight vertical layers) to simulate the water levels, currents, salinity and temperature response to tides, wind, 173 sub-catchment inflows and surface heating

- WAQ - a medium resolution water quality grid (20,000 cells at approximately 100 metre scale) for simulating dispersion and response of a broad number of water quality variables to catchment loads and internal processes
- WQBox - a coarse water quality box model grid (33 laterally averaged boxes ranging from around one to four kilometres in length and eight vertical layers) to simulate long term water quality behaviour in response to drought/wet cycles (Figure 2-2).

The hydro model outputs provide the currents and water level variations in the harbour. These outputs form the inputs to the WAQ and WQBox models to model dispersion. In addition to simulating the transport between box elements the WAQ and WQBox models simulate the in situ water quality processes that affect concentrations within each element.

Outputs of the model 12 month simulations (April 2012 to March 2013) used in this investigation include the simulated fields of temperature and salinity from the hydro model and temperature, salinity, suspended sediments, underwater light and light extinction from the WQBox model.

Figure 2-2 **Cardno (2015) SHERM 33 Element Box Model Set-up**

The catchment inflows and water quality inputs to the SHERM estuary models, from the rivers (Parramatta and Lane Cove rivers) and multitude of creeks, streams and stormwater channels (including sewer overflows) that flow into Sydney Harbour were simulated using the catchment source (see www.ewater.com.au/products/ewater-source/for-catchments/) and Simhyd rainfall runoff and water quality simulation tools (Stewart, 2013). The wider Sydney Harbour catchment was divided in 550 sub-catchments and the flows and water quality simulated for each of these then aggregated into 173 inputs to the estuary SHERM. The overall estuary component of SHERM upstream of the Western Harbour Tunnel includes more than 100 inflows that contribute flows, sediment and loads of waterborne constitutes to the estuary model. The sub-catchment daily flows and water quality concentrations at the creeks near Rozelle Railyard, Snails Bay and Balls Head Bay were used to inform estimates of the natural variability for comparison with the likely discharge from the project areas during construction and operation.

2.3 Field data collection

The historical data sets and SHERM outputs provide information on the background water quality in Sydney Harbour. Dredging programs also require information at a short time resolution, eg hourly, to assess potential effects of the dredging activity. To supplement the available information on natural variability, field data was collected to provide ongoing turbidity and total suspended solids measurements at sites in the vicinity of the project crossing of Sydney Harbour.

To support assessment of the potential effects of the dredging, the existing Sydney Harbour water quality information was supplemented with higher temporal resolution turbidity and water quality information through field data collection over the two-month period.

The project specific data collection included:

- Four water quality monitoring moorings deployed from 5 December 2017 to 31 January 2018

- Water sampling and profiling carried out over two days (18 and 31 January 2018)
- The collation of meteorological and oceanographic data to provide key information on the weather and ocean conditions that are key drivers of the water quality response.

2.3.1 Deployment program

A water quality sampling program was designed to examine the existing conditions within the study area and was informed by preliminary estimates of the dredge plume footprint.

Four fixed water quality monitoring moorings (refer to Figure 2-3) comprised a variety of sensors (refer to Table 2-2) configured on a fixed harbour bed frame were deployed for the two-month monitoring period from 5 December 2017 to 31 January 2018. Instruments included a NexSens Submersible Datalogger (SDL500) with WET Labs ECO NTU (Nephelometric Turbidity Unit) turbidity and PAR (Photosynthetically Active Radiation) light sensors, a Sea-Bird Electronics MicroCAT SBE37SMP conductivity and temperature logger and a WET Labs EcoFLNTUSB fluorometric chlorophyll-a and turbidity logger.

Table 2-2 **Summary of fixed water quality monitoring sensors at the four sites**

	Sensor distance from seabed (m)	Sample frequency (min)	Wrights Point - Drummoyne (WHT1) Depth: 6.0 m AHD	Birchgrove Wharf - Birchgrove (WHT2) Depth: 6.0 m AHD	Berrys Bay - Waverton (WHT3) Depth: 5.9 m AHD	Cremorne Point - Cremorne (WHT4) Depth: 6.1 m AHD
Turbidity	0.51	15	X	X	X	X
	0.51	10	X	X	X	X
Photosynthetically Available Radiation (PAR)	0.51	15	X	X	X	X
	1.98	15		X	X	
Chlorophyll-a (Chl-*a)*	0.51	10	X	X	X	X
Salinity	0.67	15	X	X	X	X
Pressure	0.67	15	X	X	X	X
Temperature	0.67	15	X	X	X	X

2.3.2 Water sampling and profiling

In addition to the four moorings, vertical profiles and water samples were collected from a vessel during two field campaigns, 18 and 31 January 2018. Vertical water profiles were collected at eight sites in Sydney Harbour including the four fixed monitoring sites (refer to Table 2-3 and Figure 2-3). A Sea-Bird Scientific SBE 19plus V2 SeaCAT profiler fitted with turbidity, PAR, conductivity, temperature, depth, fluorometric Chlorophyll-a, pH and dissolved oxygen (DO) sensors was lowered through the water column from the surface to the seabed at each site.

Water samples were collected at a depth of 1.5 metres below the water surface at each profile site. Water samples were transferred to the laboratory ALS for determination of total suspended solids and chlorophyll-*a (*Chl-*a)* concentrations.

Table 2-3 **Location details of profiling and fixed monitoring sites**

Monitoring site	Site reference	Coordinates (WGS84)
Wrights Point, Drummoyne	WHT1	329180 E, 6253853 N
Pulpit Point, Hunters Hill	WHTP1	330097 E, 6253318 N
Onions Point, Woolwich	WHTP2	331454 E, 6254166 N
Manns Point, Greenwich	WHTP3	332131 E, 6253621 N

Monitoring site	Site reference	Coordinates (WGS84)
Birchgrove Wharf, Birchgrove	WHT2	332150 E, 6253445 N
Berrys Bay, Waverton	WHT3	333243 E, 6253687 N
Goat Island	WHTP4	333354 E, 6252935 N
Cremorne Point, Cremorne	WHT4	336188 E, 6253411 N

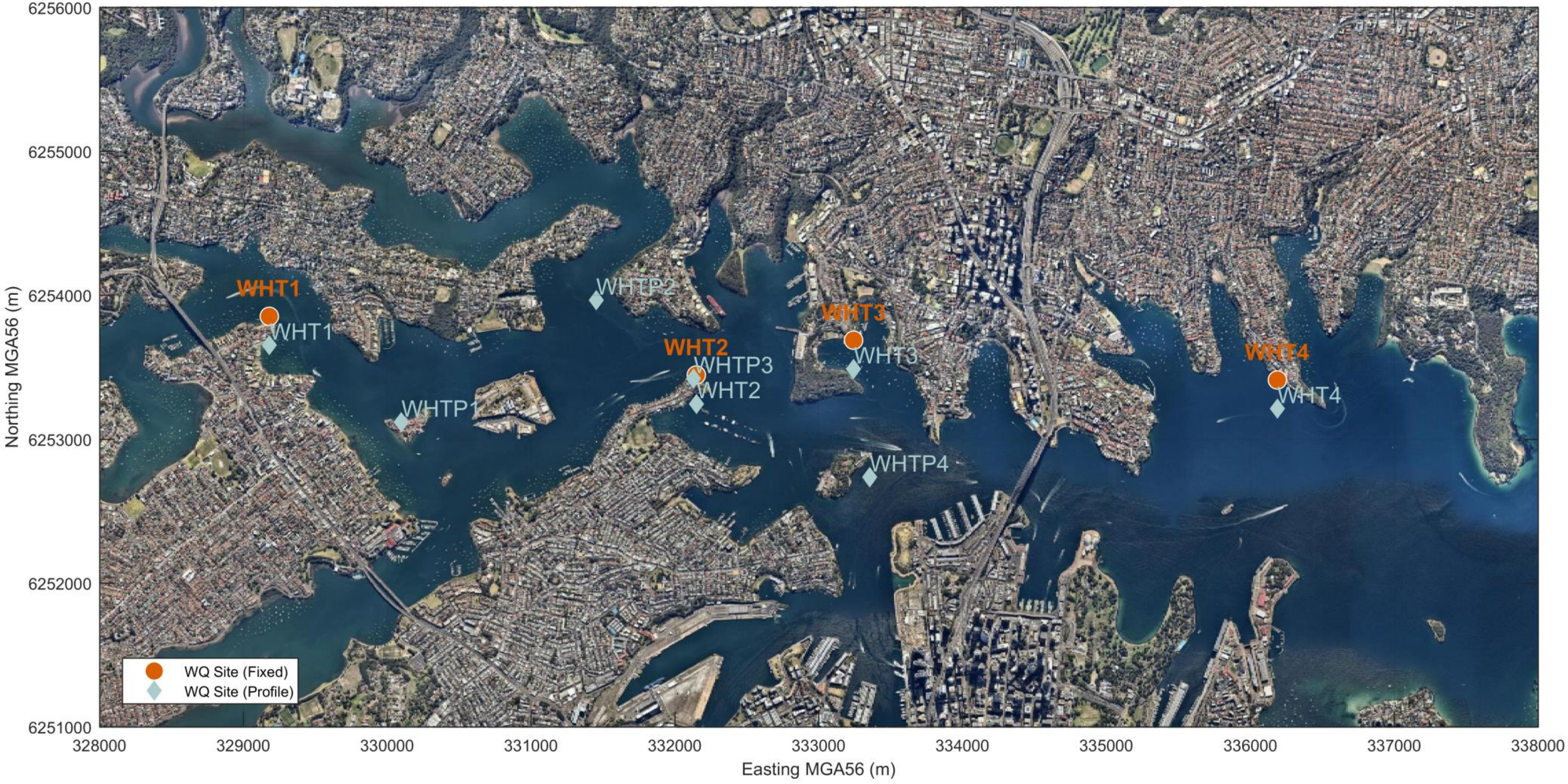


Figure 2-3 **Water quality monitoring sites within Sydney Harbour**

2.3.3 Supplementary meteorological and oceanographic data

Meteorological and oceanographic data (refer to Table 2-4) were collated for the period of the field data collection. These data provided the physical context for the water quality response of the system and are a key input to inform the understanding of environmental processes governing water quality within Sydney Harbour.

Wind speed and direction were obtained from the Australian Bureau of Meteorology (BoM) for the Sydney Harbour meteorological station at Wedding Cake West (station ID: 066196). Air temperature, daily rainfall and daily global solar exposure were obtained from BoM Observatory Hill meteorological station (station ID: 066062).

Downwards shortwave radiation data was obtained from the United States National Centre for Environmental Prediction (NCEP) Climate Forecast System Version 2 (CFSv2). Data was extracted from the CFSv2 global model grid, which has a resolution of 0.2 degrees (around 20 kilometres), at hourly temporal resolution. This model estimates the clear sky solar radiation hitting the land surface (ie assuming an absence of atmospheric attenuation due to cloud cover).

Recorded and predicted harbour water levels were obtained from the BoM National Tidal Centre using water level records from the Fort Denison tide gauge operated by Manly Hydraulics Laboratory.

Table 2-4 **Summary of Sydney Harbour meteorological and oceanographic data utilised in this investigation.**

Parameter	Data location	Data source	Period of data	Frequency
Wind speed and direction	Sydney Harbour (Stn 066196)	BoM	2000-2018	30 mins
Air temperature	Sydney (Stn 066062)	BoM	1859-2018	Daily
Daily rainfall	Sydney (Stn 066062)	BoM	1859-2018	Daily
Daily global solar exposure	Sydney (Stn 066062)	BoM	1990-2018	Daily
Downwards shortwave radiation	Latitude: -33.83° Longitude: 151.16°	CSFv2	2011-2018	Hourly
Recorded and predicted Sydney Harbour water levels	Fort Denison	BoM NTC	2017-2018	10 mins

2.4 Dredging effects simulations

The harbour bed within the mainline tunnel construction footprint includes a range of different sediment types, including soft surficial sediments and harder material beneath the seabed. To remove this material, the program of dredging works comprises a sequence of dredging operations. As described in Section 7 of RHDHV (2020) the dredging required for construction of the immersed tube tunnel would remove about 950,000 cubic metres of harbour bed material of which a very small fraction (less than two per cent) would be mobilised into the surrounding waters. The dredging program was designed to operate for around 10 hours per day during daylight hours (Monday to Friday) and would run for around 51 weeks. The dredging program (RHDHV, 2020) has included a range of mitigation measures to reduce potential environmental effects.

RHDHV (2020) modelled the tidal dispersion of the suspended sediment concentrations (SSC) introduced into the water column by the dredging activities. The model focused on the dredging processes as the key source of suspended sediments entering the surrounding waters and its subsequent dispersion and settling into the waters of Sydney Harbour and provided estimates of the dredging-related suspended sediments dispersion. In the following, the model results are referred to as 'excess SSC' (mg/L) to reflect that they only represent the dredging contribution to suspended sediment concentrations.

2.5 Ecosystem tolerance levels

The Western Australian Environmental Protection Authority Technical guidance document *Environmental Impact Assessment of Marine Dredging Proposals* (EPA, 2016) provides a useful approach for presenting predictions of the likely range of environmental impacts of dredging, which in turn, provides the basis for facilitating the transfer of these predictions into recommended conditions and environmental monitoring and management strategies. This approach has been used in Technical working paper: Marine ecology (Cardno, 2020) to assist with the assessment of impacts from this project. The effects of dredging are mapped in terms of zones of impact and influence.

To delineate these zones, the potential impact of dredging related excess turbidity and excess sedimentation on a particular type of habitat or biota, an assessment of estimated ecological tolerance limits for each habitat type or biota is required.

Tolerance limits for habitats are generally derived in two different ways:

> Tolerance limits for turbidity are derived from water quality monitoring data, arguing that resident flora and fauna are adapted to local conditions but would be stressed if exposed to conditions that regularly exceed normally prevailing background concentrations

> Tolerance limits for sediment deposition are derived from habitat-specific dose-response experiments and field observations reported in the scientific literature.

Given dose-responses were unavailable for most species in the study area, tolerance limits for habitats were derived from marine water quality monitoring data. It was assumed that aquatic plants and primary producers are adapted to the natural turbidity variability up to the 95^{th} percentile and that above this value they may become stressed.

The natural variability in total suspended solids concentrations in the vicinity of the mainline tunnel was determined from the available historic data, the SHERM outputs and additional data collected as part of the project-specific water quality monitoring program. Tolerance limits were defined by the 95^{th} percentile observed total suspended solids concentration minus the median total suspended solids concentration. These tolerance limits were then applied to the predicted dredging-related excess suspended sediment concentrations (excess SSC) to determine where potential effects may arise within the zones as follows (refer to Figure 5-1):

> Zone of High Impact: the dredged area and in the immediate vicinity where sediment is likely to be displaced and deposited. Defined as the project disturbance footprint. Impacts to benthic habitat and/or biota in these areas are predicted to be severe and often irreversible

> Zone of Moderate Impact: the area where dredge plumes combined with natural system variability exceeds the 95^{th} percentile of the natural system for more than 10 per cent of the time. Impacts to benthic habitat and/or biota within this zone are predicted, but the disturbed areas may recover after completion of the dredging and disposal operations and it is expected that there would be no long-term modification of the benthic habitats

> Zone of Influence: the area where dredge plumes combined with natural system variability exceed the 95^{th} percentile of the natural system for more than five per cent of the time but no impacts to benthic habitat or biota expected.

2.6 Project discharges to Sydney Harbour

During construction and operation, water treatment plants would discharge into Sydney Harbour (refer to Section 1.3). These plants would discharge treated water via the local stormwater network. The discharge water quality (Technical working paper: Surface water; Jacobs, 2020) and estimates of the existing environment water quality (refer Section 3.2.2) were used to assess the operational phase impacts on Sydney Harbour water quality.

3 Existing environment

3.1 Overview of water quality processes in Sydney Harbour

Sydney has a temperate, humid climate with abundant sunshine and significant rainfall. Precipitation averages 1309 millimetres per annum varying from 156 millimetres in the wettest month of March to 60 millimetres in the driest month of September. The region is prone to droughts with extended periods of very low rainfall lasting several months. The regular rainfall-induced catchment runoff leads to significant loads of sediment, nutrients and other waterborne constituents entering the waterway and affecting the quality of water within the Sydney Harbour estuary.

The wider Sydney Harbour estuary is comprised of four connected estuarine water bodies including the Parramatta and Lane Cove rivers estuaries that drain the major portion of the broader Sydney Harbour estuary (refer to Table 3-1). The broader estuary is influenced by ocean tides, episodic catchment runoff and wind events. The area is also subject to seasonal wind patterns characterised by the summer sea breeze cycle and occasional strong winds and heavy rain as intense low pressure systems propagate through the region.

Table 3-1 **Summary of physical characteristics for relevant estuaries**

	Port Jackson	Middle Harbour Creek	Lane Cove River	Parramatta River	Total Sydney Harbour Estuary
Entrance location	-33.83, 151.29	-33.82, 151.26	-33.84, 151.18	-33.84, 151.19	**-33.83, 151.29**
Catchment area (km^2)	55.7	77.0	95.4	252.4	**480.5**
Estuary area (km^2)	29.1	6.1	3.0	13.7	**51.9**
Estuary volume (GL)	376.4	81.9	12.6	69.7	**540.6**
Average depth (m)	13.0	13.4	4.2	5.1	**9.0**

Reproduced from NSW State Government: from www.environment.nsw.gov.au/estuaries/list.htm

3.1.1 Mixing and physical processes

Mixing and dispersion of water masses introduced into the estuary is a key factor in determining the water quality response to catchment runoff, re-suspension of bed sediments during stirring events, and ocean inputs. Using the Hansen and Rattray (1966) classification scheme the mixing characteristics vary between a well-mixed estuary during dry periods and a partially mixed estuary following intense rainfall runoff from the catchment. The temperature and salinity characteristics of the different water masses introduced to the estuary provide a key indicator of mixing and dispersion and vertical stratification that affects the vertical mixing processes.

Rainfall event recurrence intervals are listed in Table 3-2 to highlight the importance of events intensity for the suspended sediments loads to the estuary. These daily rainfall recurrence intervals from one month recurrence event up to 10-year recurrence were generated from an extreme value analysis of daily rainfall totals recorded at the BoM Observatory Hill station from 1858 to 2017.

Table 3-2 **Average recurrence of daily rainfall totals: Observatory Hill 1858 to 2017**

Recurrence interval	Daily rainfall (mm)
1 month	25.9
2 months	40.1
3 months	50.2
6 months	68.0
1 year	92.2
2 years	113.3

Recurrence interval	Daily rainfall (mm)
10 years	168.9

The quality of the waters within the Sydney Harbour estuary reflect the balance between the upstream catchment loads of varying quality (depending on the land use and practices within the catchment), the downstream ocean inputs and the tidal flushing that mixes the different water masses. Tidal flushing intensity diminishes from the ocean entrance at the Heads to the upstream extremities near the river (Parramatta and Lane Cover rivers) and numerous creek (eg Powells and Duck Creeks) inputs. During frequent rainfall the creek and river flows carry suspended particles and dissolved substances into the estuary causing the estuarine waters to become turbid. Following runoff these particles are dispersed into the estuary by tidal and wind-induced currents and settle to the bed where they can be resuspended by subsequent rainfall events. The dispersion process effectively dilutes the introduced constituents and over time their concentrations diminish toward the pre-runoff concentration. In general, the turbidity varies along the estuary from clearer low turbidity oceanic waters near the mouth to higher turbidity near the river/creek inputs. In addition, the temporal variability is characterised by higher turbidity following significant inflows and relatively low turbidity during dry periods. These key processes that determine natural water quality and their influence on key aquatic habitats is shown schematically in Figure 3-1.

The catchment loads of nutrients and sediments support a diverse range of aquatic ecosystems within the estuary. In the vicinity of the Western Harbour Tunnel mainline tunnel the key habitats include intertidal and subtidal rocky reef, sparse fringing seagrass communities and soft-bottom biota in the deeper waters.

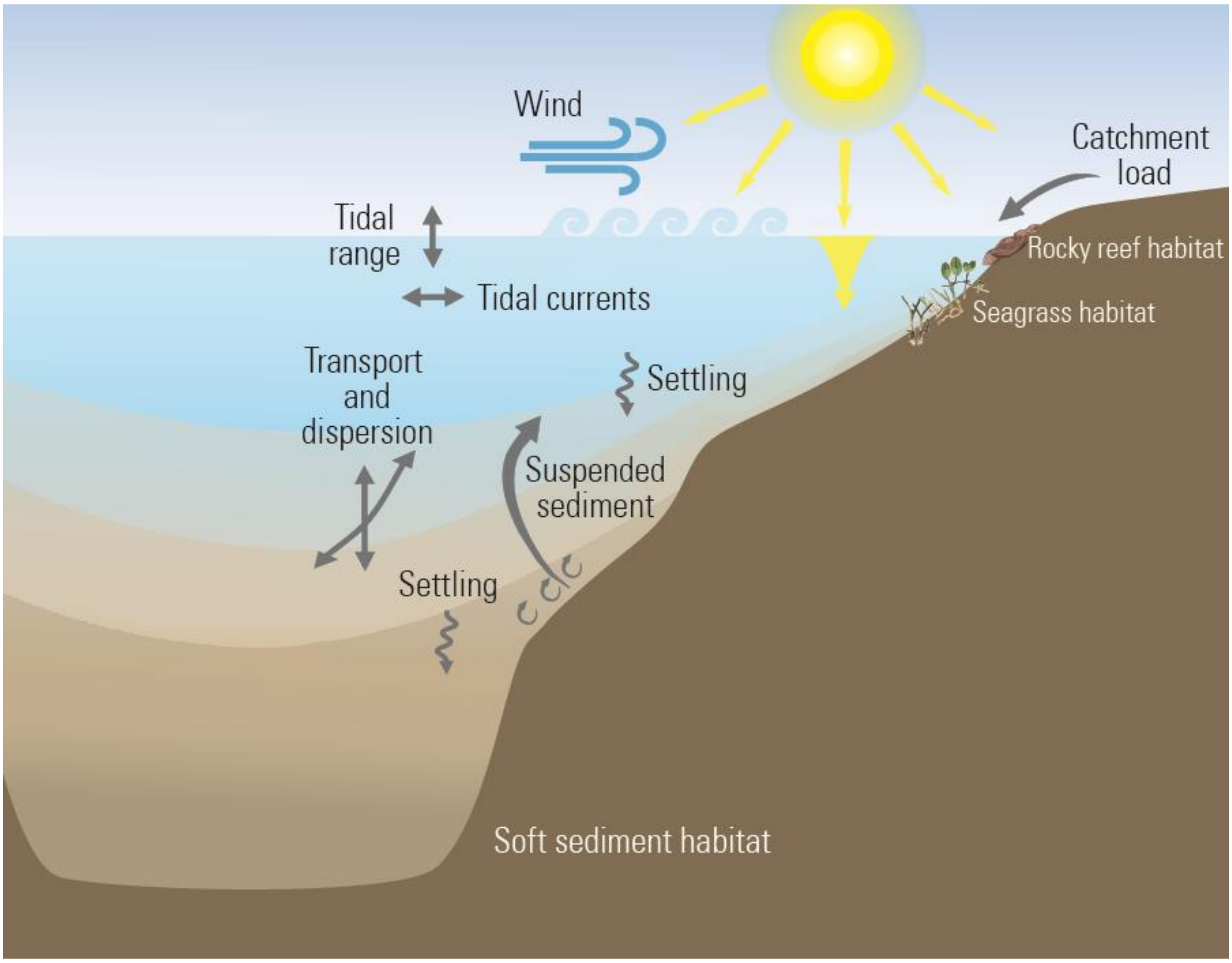


Figure 3-1 **Water quality processes schematic**

Suspended sediment concentrations provide a measure of particulate inflow, as well as re-suspension of sediments. The presence of suspended sediments in the water column is important for the transport of pollutants attached to particles, and for issues relating to smothering of biota and alteration in aquatic habitat. Turbidity is a measure of light attenuation due to total suspended solids, that provides a measure of suspended clay and silt particles, phytoplankton and detritus. High turbidity impacts the aesthetic quality of the water, along with reducing aquatic plant growth. Suspended matter can originate from point sources such as sewer outfalls, industrial sites and stormwater drains. Generally, most of the suspended matter deposited in estuaries and coastal areas comes from soil and stream bank erosion within the upstream catchment (ANZECC and ARMCANZ, 2000). For this reason, turbidity in most estuaries is highly dependent on flow, with very large increases noted during flood events. In rivers, total suspended solids concentrations generally increase considerably during the early part of a flood event as sediment is washed into the river from the catchment and deposited sediment is resuspended (ANZECC and ARMCANZ, 2000).

The key water quality variables that affect aquatic communities within an estuary are turbidity and total suspended sediments as these affect the underwater light regime that impacts on the photosynthesis of aquatic plants.

3.1.2 Suspended matter, light and primary production

The turbidity at a particular location depends on a range of complex physical processes including intermittent suspended sediment inflows, interactions with bed material, local re-suspension and transport processes and proximity to sources of material.

Suspended sediments attenuate light penetration through the water column and thereby limit pelagic and benthic primary production (the process of converting light energy into biomass). As the suspended sediment settles to the harbour bed it may smother benthic organisms and affect the type of organisms and plants that can exist in this environment.

Fluctuations in light and rates of sedimentation occur naturally in Sydney Harbour due to regular re-suspension of particulate matter by the tidal currents, wind-driven mixing and runoff. Increases in sedimentation and turbidity can influence the health of sensitive receivers within both the water column and the benthic habitats.

This link between the suspended matter, light and primary production is the key water quality process to be investigated as part of this impact assessment. The related effects on biota is the subject of the marine ecology assessment (Cardno, 2020).

3.2 Review of historical water quality information

3.2.1 Historical turbidity assessments

There is a range of existing and historical water quality information available for Sydney Harbour (Table 2-1). The information reported in these studies is summarised below to develop an understanding of the natural variability in turbidity and total suspended solids within the broader harbour.

For the shallow waters within Homebush Bay, Birch and O'Hea (2007) determined that during inflow events there is little variation between typical distributions of total suspended solids for bottom and surface waters. Hatje et al. (2001) analysed the temporal variations in total suspended solids at various locations along the Parramatta River Estuary. Their results suggested that anthropogenic influences such as increased urbanisation of catchments leads to more stormwater outlets with higher runoff discharge and increased sediment delivery. This results in an increase in turbidity variability at smaller temporal scales within the harbour waters.

Diurnal variability of the concentrations of suspended particulate matter has been assessed within the Parramatta River Estuary at 14 locations from Duck River to Port Jackson (Hatje et al., 2001, 2003b). The key processes of bottom sediment re-suspension and vertical water column mixing are known to influence the overall turbidity, whilst seasonal influences (eg wetter period in late summer) have some limited effect within the estuary (Hatje et al., 2001, 2003b). A number of authors note that wind waves are a key contributor to sediment re-suspension within the estuary while tidal re-suspension of sediments is negligible (Birch and O'Hea, 2007; Taylor and Birch, 1999).

Robinson GRC Consulting (1999) monitored turbidity levels within the upper reaches of the Parramatta River Estuary over the period of 1990 - 1997. The mean turbidity values for the Parramatta River, downstream of the weir, ranged around 15-20 NTU during dry weather to over 50 NTU following wet weather, due to the influx of suspended sediment associated with bank erosion and overland flow. The mean annual turbidity for the surface waters immediately downstream of the Silverwater Bridge was recorded at 7.7 NTU while bottom waters had a turbidity value of 21.9 NTU. Turbidity values for the sampling station just downstream of the Gasworks Bridge were of a similar range, with surface waters recording a mean annual turbidity of 13.3 NTU and bottom waters was 21.5 NTU (Robinson GRC Consulting, 1999).

Bishop (2007) assessed the impacts of bottom sediment re-suspension with regards to turbidity for the Upper Parramatta River Estuary (between Ermington and Rydalmere). The study concentrated on the effects of boat generated waves (wash-waters). This section of the river is heavily utilised by purpose-built low-wash boats, however, other vessels also commonly pass through this reach and it was shown that turbidity can be directly linked to boat wash. Whilst it is stated that there is no significant effect on the sedimentology, the distribution of sediment particles was shown to affect water quality, thereby altering the local ecology (Bishop, 2007).

Laxton (1997) and Birch and O'Hea (2007) conducted water quality sampling and analyses in order to investigate total suspended solids and the chemistry of suspended particulate matter at numerous locations along the Parramatta River. Laxton (1997) presents a statistical summary of total suspended solids and turbidity (presented here in Table 3-3) for the upper Parramatta River and Duck River based on monthly water quality sampling from 1990 to 1996.

Table 3-3 **Laxton (1997) total suspended solids and turbidity for Upper Parramatta River and Duck River**

Statistical Parameter	Turbidity (NTU)	TSS (mg/L)
90%	64.5	34.4
Median	11.9	7.6
10%	5.0	3.8

Birch and O'Hea (2007) collected water samples at ten sites along three transects in Homebush Bay under three weather conditions; calm (25 June 2004), calm/heavy-rain (18 August 2004), and high-wind/heavy-rain (2 October 2004). A summary of total suspended solids and turbidity values measured during the sampling periods is presented in Table 3-4.

Table 3-4 **Birch and O'Hea (2007) total suspended solids and turbidity for Homebush Bay**

Conditions		Turbidity (NTU)	TSS (mg/L)
Calm (quiescent) conditions	Mean	7.2	7
	Range	1.4 to 10.3	3.2 to 18.5
High precipitation	Mean	29.4	17.2
	Range	13.9 to 48.7	7.8 to 41.2
High wind/heavy rainfall	Mean	56.8	20.8
	Range	3.3 to 138.3	11.2 to 41.6

The above studies focused on the upper Parramatta River. Further downstream monthly reports of turbidity data are available for the Darling Harbour area through the *Barangaroo Monthly Water Quality reports* (Lend Lease, 2017). These reports summarise results of water quality monitoring at Barangaroo South during the period from April 2012 to December 2017. The monthly minimum, maximum and mean are summarised in Table 3-5. These data indicate the clearer waters of this reach of the Sydney Harbour as distinct from the more turbid waters of the shallow upper estuary areas from Homebush Bay and further upstream towards Parramatta.

Table 3-5 **Summary of Barangaroo monthly water quality turbidity (NTU) report: April 2012 to December 2017**

Statistical parameter	Monthly minimum	Monthly average	Monthly maximum
Maximum	3.2	8.4	61.2
90th percentile	1.9	4.6	25.3
Median	0.7	2.4	13.2
10th percentile	0.0	1.6	5.7
Minimum	0.0	0.7	3.5

Total suspended solids and corresponding turbidity data from the CMA water quality monitoring program have been classified by their location into the Sydney Harbour sites (PJ1, PJ2, PJ3, PJ5, PJ8, P5, P6, LC5 and LC6, refer to Figure 2-3). This data set was then analysed to derive percentiles of total suspended solids and turbidity (refer to Table 3-6).

Table 3-6 **CMA total suspended solids and turbidity data percentiles in Sydney Harbour**

Statistical Parameter	Turbidity (NTU)	TSS (mg/L)
Maximum	22.3	25.7
95th percentile	15.6	17.9
90th percentile	6.4	8.1
50th percentile (Median)	2.5	3.3
10th percentile	0.9	1.3
5th percentile	0.8	1.0
Minimum	0.4	0.7

The data was also used to derive a relationship between total suspended solids (mg/L) and turbidity (NTU) using linear regression analysis (refer to Figure 3-2). It should be noted that this fit is based on relatively small data-set comprising low turbidity and total suspended solids values typically collected primarily during fair weather. The analysis showed the broad range of values gave a strong correlation, with a coefficient of determination of $R^2 = 0.94$. The relationship shown is used in the following figure to convert measured turbidity (NTU) values to total suspended solids (mg/L) concentrations. For the Western Harbour mainline tunnel sites the relationship is total suspended solids = 1.10 x NTU + 0.57.

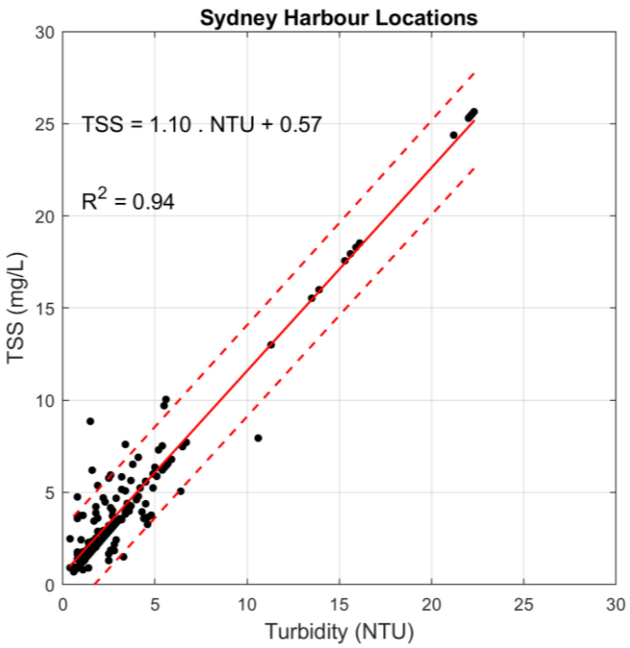


Figure 3-2 **Total suspended solids vs turbidity relationship based on CMA water quality data**

3.2.2 Sydney Harbour water quality

The project's receiving waters are marine environments which include the intertidal and subtidal ecosystem of the harbour and its estuarine tributaries. General guidelines for the protection of marine ecosystems, including Sydney Harbour have been discussed in the Technical working paper: Marine ecology (Cardno 2020) and are summarised in Section 1.8. Water quality is a key driver of the marine ecosystem and hence water quality guidelines form a key component of marine ecosystem protection objectives.

The waterways within the study area are used for recreation (including swimming, boating and aesthetics), commercial activities (commercial shipping and tourism) and are also an ecological resource. The ANZECC (2000) guidelines provide discussion on the mechanisms by which contaminants may enter estuarine waters and subsequently be dispersed into these waters. The guidelines provide advice on a broad suite of potential contaminants and the importance of dissolved and particulate (bound to sediment particles) forms for the subsequent dispersion into the estuary sediments and waters.

Commercial fishing in Sydney Harbour, Parramatta River and other connected tidal waterways has been banned since 2006 as a precautionary measure due to elevated levels of dioxins in some fish and seafood. The pathway for these contaminants to enter the food chain is complex but water borne concentrations have been identified as a component of this pathway. The sources of these contaminants are generally located near the historic industrial areas that typically drained into Homebush Bay. Generally, these contaminants are attached to fine sediment particles and their dispersion around the estuary via the process of sediment remobilisation and subsequent settling leads to their gradual dilution and redistribution around the harbour.

Water quality in Sydney Harbour within the project area is generally within the ANZECC guidelines with occasional exceedances typically associated with stormwater runoff events or strong winds causing stirring and mobilisation of bed sediments. Water quality sampling was carried out in the Harbour by the CMA (Harrison, 2013) on six occasions between January and June 2013. Sites relevant to the project area include P5 Iron Cove Bay, P6 Cockatoo Island, PJ1 Balls Head Bay, and PJ2 Lavender Bay (refer Figure 2-1). Sampling of physical (temperature, salinity, pH and dissolved oxygen) and chemical (total nitrogen and total phosphorus and chlorophyll-a) parameters was carried out. These data (Table 3-7) indicate that the water quality is generally within the ANZECC guidelines for protection of aquatic ecosystems with occasional exceedances.

Table 3-7 **Summary of CMA data from six sampling times (between January and June 2013) and four sites (P5, P6, PRJ1 and PRJ2), compared to ANZECC (2000) guideline criteria**

	Temp °C	Salinity ppt	pH	Turbidity NTU	Chl-a µg/L	Dissolved oxygen %	Secchi Depth m	TP µg P /L	TN µg N/L	TSS mg/ L
ANZECC Upper limit			*7.0*		*4*	*110*	*1.6*	*30*	*300*	
ANZECC Lower limit			*8.5*			*80*				
Minimum	16.1	27.9	7.8	0.4	1.0	81	1.2	18.5	124	0.8
Median	22.3	32.9	8.0	1.2	2.7	92	4.0	27.8	268	1.8
Max	24.7	35.2	8.3	4.5	8.9	134	5.8	46.0	371	5.6
Mean	21.5	32.7	8.0	1.7	3.1	97	3.8	28.5	259	2.4
Sample count	24	24	24	24	24	24	19	24	24	24
% Exceedances			0%	0%	25%	17%	5%	42%	17%	

As reported in the M4-M5 Link technical working paper, previous water quality monitoring completed on behalf of Sydney Motorway Corporation (by AECOM) and UrbanGrowth NSW (by the University of Sydney) indicated:

- At Rozelle Bay, elevated levels of heavy metals (copper, chromium, lead and zinc), nitrogen, phosphorous, nitrate, oxides of nitrogen, ammonia and chlorophyll-a. On occasions, the pH was also outside the ANZECC guideline levels and turbidity exceeded guideline levels
- At Iron Cove, indicated elevated levels of metals (chromium, copper, lead, mercury and zinc), nitrogen, nitrate and phosphorus were recorded. The turbidity also exceeded guideline levels and the pH was outside guideline levels on occasions
- At White Bay, indicated elevated levels of metals (copper and zinc), nitrogen, nitrate and phosphorus, were recorded. Turbidity also exceeded guideline levels on occasions.

Results of recent monitoring at Whites Creek, which discharges into Rozelle Bay (refer to Technical working paper: Surface water) aligned with the findings of the M4-M5 Link, in that water quality of Whites Creek was generally poor with elevated concentrations of nutrients and heavy metals (copper, lead, zinc and iron) entering the marine environment through the existing stormwater system. Dissolved oxygen levels were also low on occasion and pH and turbidity were elevated.

3.2.3 SHERM outputs

To assist in the characterisation of the natural variability, results from the existing SHERM Hydro high resolution model was used to assess the hydrodynamics. A period over the three months July to September 2011 was selected that includes a number of significant inflow (rainfall) events that represent the extent of natural variability. The modelled salinity time series and a snapshot long section of isohalines (lines of constant salinity) along the centre of the Sydney Harbour estuary from Shark Island upstream to Gladesville Bridge are shown in Figure 3-3. An indicative snapshot of the system on 23 August 2011 indicates the partially mixed nature of the system with the salt wedge propagating upstream following the small inflow event some two days prior to the snapshot. The time series figure indicates the typical response to freshwater inflow events and subsequent saline ingress to the estuary during post event recovery to higher salinity values. The SHERM water quality box model, WQBox, simulation results for total suspended solids at the study area are shown in Table 3-4 for the surface, mid-depth and bottom layers for the one year period April 2012 to April 2013. The figure also shows the daily rainfall recorded at the BoM rain gauge at Observatory Hill in Sydney, as an indicator of catchment runoff.

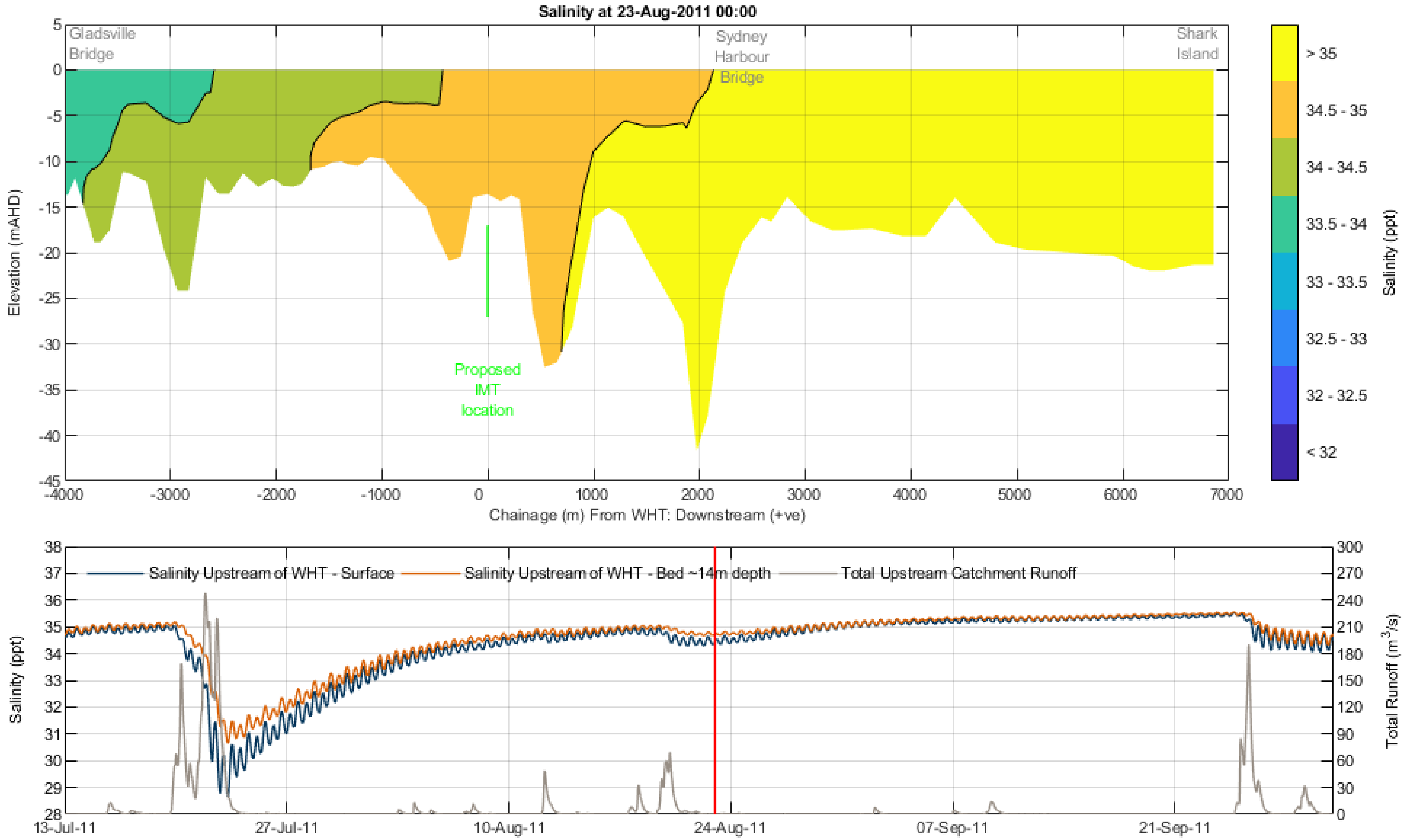


Figure 3-3 **SHERM High Resolution Water Quality model salinity results (reproduced from LLS)**

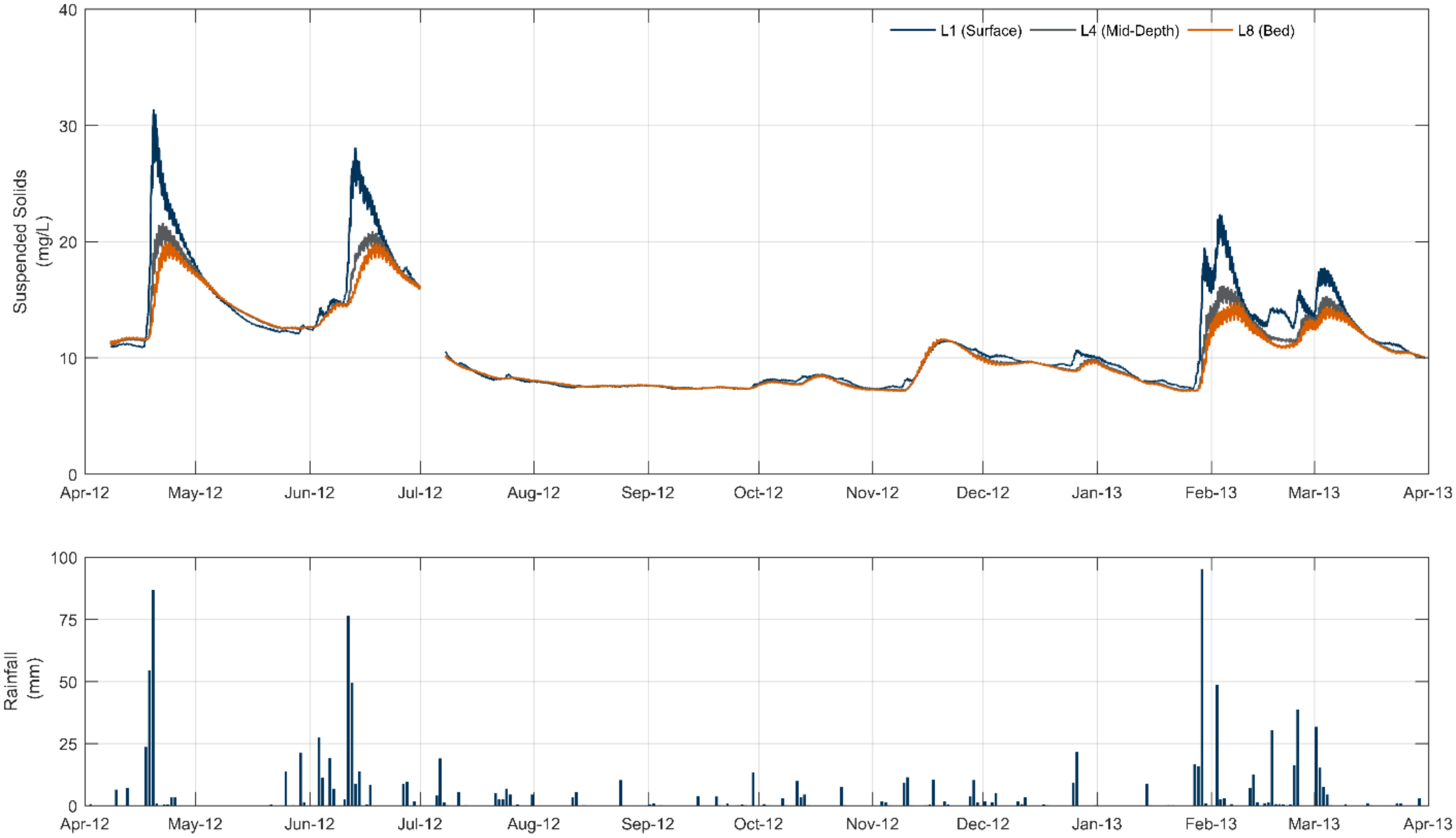


Figure 3-4 **SHERM WQBox model total suspended solids (mg/L) in box model cell 9 that includes the immersed tube tunnel location**

The 12-month simulation occurs over a period of average total rainfall with four discrete major rainfall-runoff events, including April 2012 (165 millimetres over three days), June 2012 (125 millimetres over two days), February 2013 (177 millimetres over seven days) and March 2013 (142 millimetres over two weeks). Using the information on average recurrence presented in Table 3-2 the daily rainfall total of 87 millimetres that occurred on 19 April 2012 approximates a one year daily rainfall recurrence.

The typical scenario of higher total suspended solids in response to the rainfall and catchment inflows is clearly visible in Figure 3-5. The time series of total suspended solids indicates the vertically well-mixed, low background suspended sediment concentrations during prolonged dry periods. High rainfall and catchment flow events generate peaks in total suspended solids and the rainfall event of April 2012 resulted in total suspended solids peak of 31 mg/L.

Table 3-8 shows only a small magnitude difference between the 5th percentile total suspended solids (around 7 mg/L) and the median total suspended solids (around 10 mg/L) which indicates a relatively low level of statistical variability during dry periods.

The post event recovery period (that is, the time for conditions to return to values similar to the values prior to the event) varies depending upon the magnitude of the rainfall event and the antecedent conditions. Larger rainfall events show an average recovery time of around 20 days while for smaller rainfalls events, recovery times range from five to 10 days.

Table 3-8 **SHERM Model total suspended solids (mg/L) statistics derived from box 9 (depth 14 m AHD) covering the Western Harbour mainline tunnel**

Statistical Parameter	Surface	Mid-depth	Bottom
Maximum	31.4	21.6	20.0
95th percentile	20.8	18.6	17.7
90th percentile	17.5	16.0	15.5
50th percentile (median)	10.0	9.6	9.5
10th percentile	7.5	7.4	7.4
5th percentile	7.4	7.3	7.3
Minimum	7.3	7.2	7.1

3.3 Field data collection results

3.3.1 Conditions during collection period

Rainfall, solar radiation and air temperature conditions during the deployment period are presented in Figure 3-5. Collectively the deployment period was drier than average, with monthly total rainfall of 47.2 millimetres and 37.8 millimetres for December and January respectively – compared to the long term monthly mean values of 101.7 millimetres and 117.5 millimetres. Rainfall was recorded on 29 of the 61 days during the period, with the average rainfall day of 2.9 millimetres. The largest rainfall event occurred on 9 January 2018, when 18.6 millimetres fell over a 24-hour period.

Downwards shortwave solar radiation (DSWR) and daily global solar exposure (DGSE) are presented in Figure 3-6. Over the 61 day period, around 20 days received less than 20 MJ/m^2 of DGSE indicating moderate to high cloud cover on those days. Conversely, on the 21 cloud-free days with subsequently intense solar radiation, DGSE was typically 30 MJ/m^2 and shortwave radiation (DSWR) peaked around 1000 W/m^2.

In terms of air temperature, the deployment period was hotter than average, with an average daily maximum of 27.8°C and 27.9°C for December and January respectively – compared to the long-term averages of 25.2°C and 26.0°C. December experienced four days exceeding 35°C, with a maximum temperature of 38.3°C on 20 December 2017. January experienced one day exceeding 35°C, with a maximum recorded temperature of 43.4°C on 7 January 2018.

Figure 3-6 shows winds during the deployment period generally followed the daily sea-land breeze cycle with higher winds in the afternoon (peaking around 25-35 kilometres per hour), followed by calmer periods during the evening. Winds were predominantly north-easterly, interspersed with periods of stronger southerlies. A maximum wind speed of around 60 kilometres per hour was recorded on both 14 and 20 December 2017. A noticeably high wind period was recorded during the deployment from 14 to16 January 2018 when strong south to south-westerly winds exceeding 30 kilometres per hour persisted for over 72 hours.

Tides during the deployment displayed the typical fortnightly spring/neap cycle – with periods of particularly large spring tides experienced during early December, early January and late January – as indicated by the daily average tidal range (refer to Figure 3-6). Spring tides at this time of year are generally stronger (that is, high tides are higher and low tides are lower) due to the Earth's position in its elliptical orbit being closer to the sun (in an orbital phase called perihelion). These spring tides were further exacerbated by the presence of a 'supermoon' (the phenomenon whereby a full moon or a new moon approximately coincides with the closest distance that the Moon reaches to Earth in its elliptic orbit).

Consequently, the astronomical tide reached close to the local long-term highest astronomical tide (HAT) of 1.1 metres AHD on seven occasions during the sampling period. Figure 3-8 shows tidal residuals of +0.1 metres to +0.3 metres during these periods resulted in the extremely high tides recorded at Fort Denison. Peak tide levels of 1.35 metres AHD, 1.36 metres AHD and 1.15 metres AHD were recorded on 6 December 2017, 3 January 2018 and 31 January 2018, respectively. Figure 3-8 shows that the daily tide range during these periods was generally around 2.0 metres.

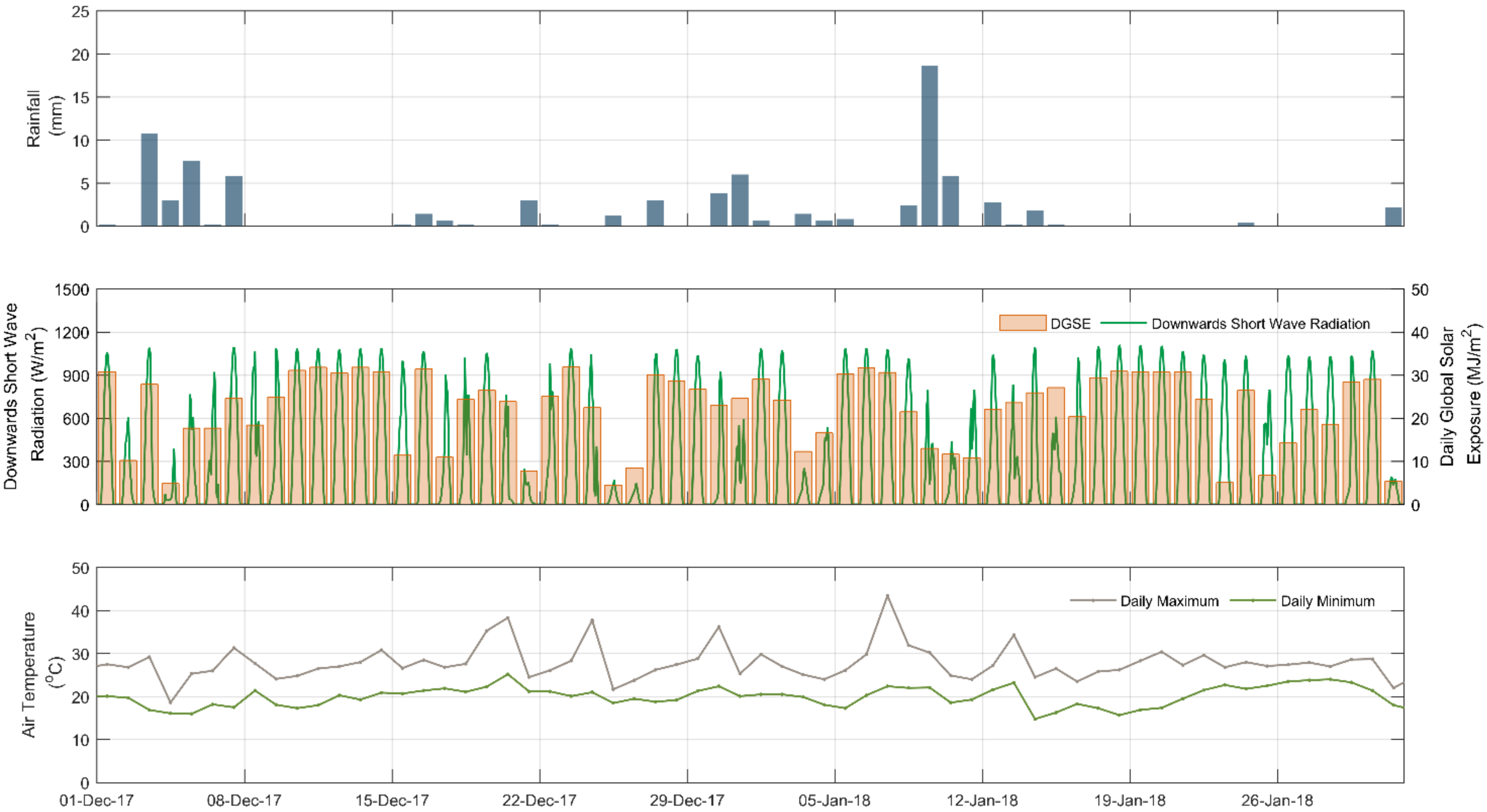


Figure 3-5 Rainfall, solar radiation and air temperature during deployment period

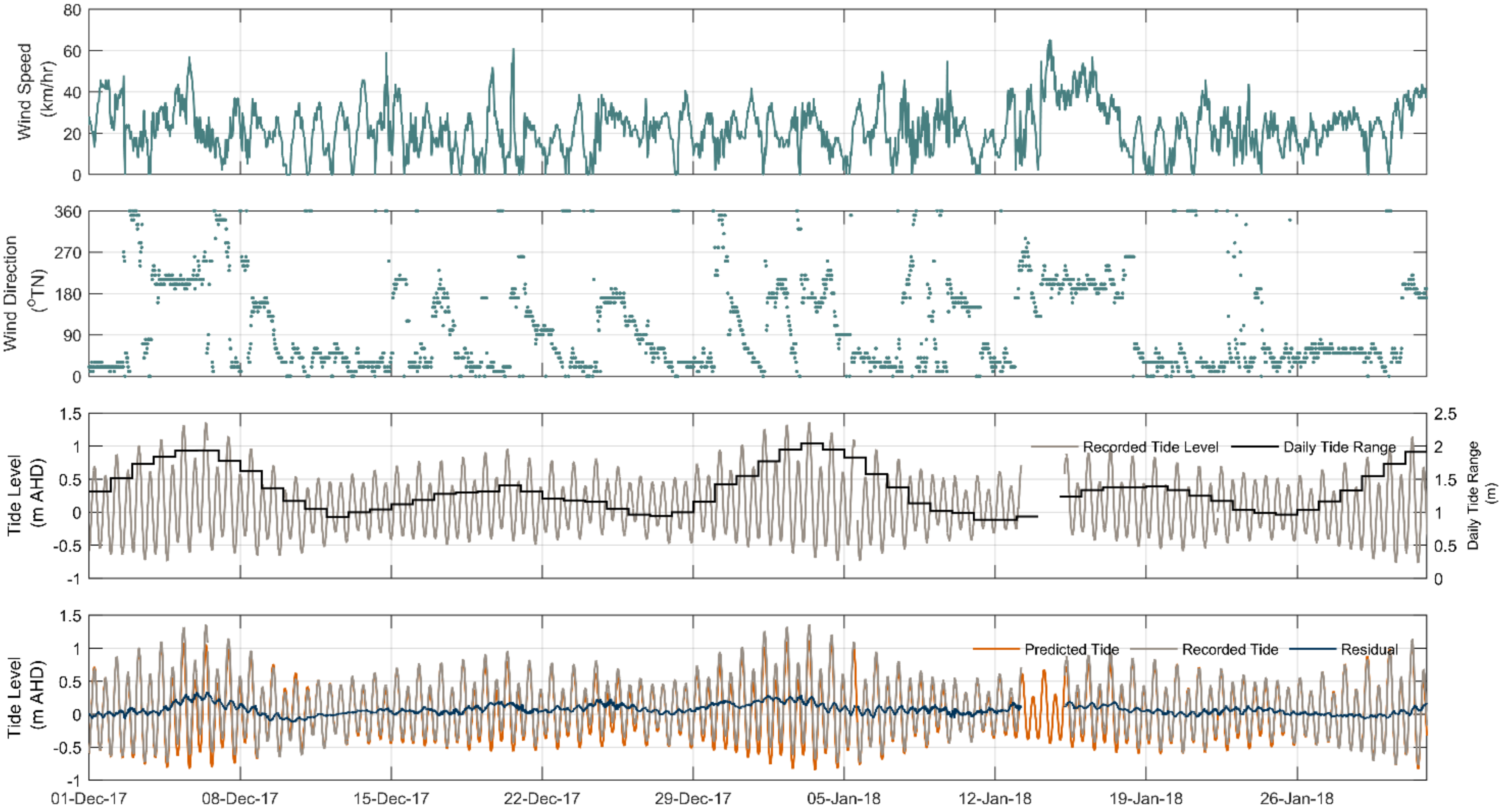


Figure 3-6 **Wind and tide conditions during deployment period**

3.3.2 Salinity and turbidity

As highlighted in Section 3.3.1, the deployment period was drier than average and the influence of this low rainfall is evident in the water quality parameters. Data collected at Berrys Bay, Waverton (monitoring site WHT3), shows measured time series of near-bed turbidity, salinity, temperature, alongside water levels and rainfall (Figure 3-7). Note the logarithmic scale on the turbidity figure to highlight the variability across the range of values. Figures showing the data collected at all four sites are presented in Appendix A.

There was very little variation in turbidity over the two months, with the maximum hourly average less than 3 NTU.

Turbidity at the depth of the adjacent fixed loggers were extracted from the profiles and compared to the total suspended solids derived from laboratory analysis of water samples collected during profiling. No clear relationship could be derived from the measurement dataset which is not surprising given the very low values of the turbidity and total suspended solids that are less than the general measurement error.

Water temperatures ranged from 20°C to 25°C, gradually increasing over the deployment, as the warmer weather continued into the summer period. This temperature range was consistent for all four monitoring sites.

The near-bed salinity values ranged between 35 and 35.5 psu. Following a rainfall event on 9 January 2018, salinity decreased by about 0.3 psu. Following this event it remained dry for the second half of January and the salinity gradually increased by about 0.4 psu over this three-week period.

The recorded turbidity was found to be relatively consistent across the three fixed water quality monitoring sites nearest the Western Harbour mainline tunnel location for the duration the two-month monitoring period. The upstream monitoring site WHT1 showed slightly higher values reflecting the typical gradient (increasing turbidity with increasing distance upstream) within Sydney Harbour. Generally, turbidity was less than 3 NTU with a median value less or equal to 0.5 NTU (Table 3-9). A large proportion of these turbidity values were very low and within the sensor accuracy (±2 NTU).

Table 3-9 **Instantaneous turbidity statistics (in NTU) in Sydney Harbour (monitoring sites WHT1 to WHT4)**

Statistical parameter	WHT1	WHT2	WHT3	WHT4
Maximum	40.7	5.1	9.4	21.9
95th percentile	5.4	2.7	2.7	2.6
90th percentile	4.8	2.5	2.4	2.2
50th percentile (median)	3.4	1.9	1.7	1.3
10th percentile	2.6	1.5	1.2	0.9
5th percentile	2.4	1.4	1.1	0.8
Number of good samples	5439	5435	5442	5389

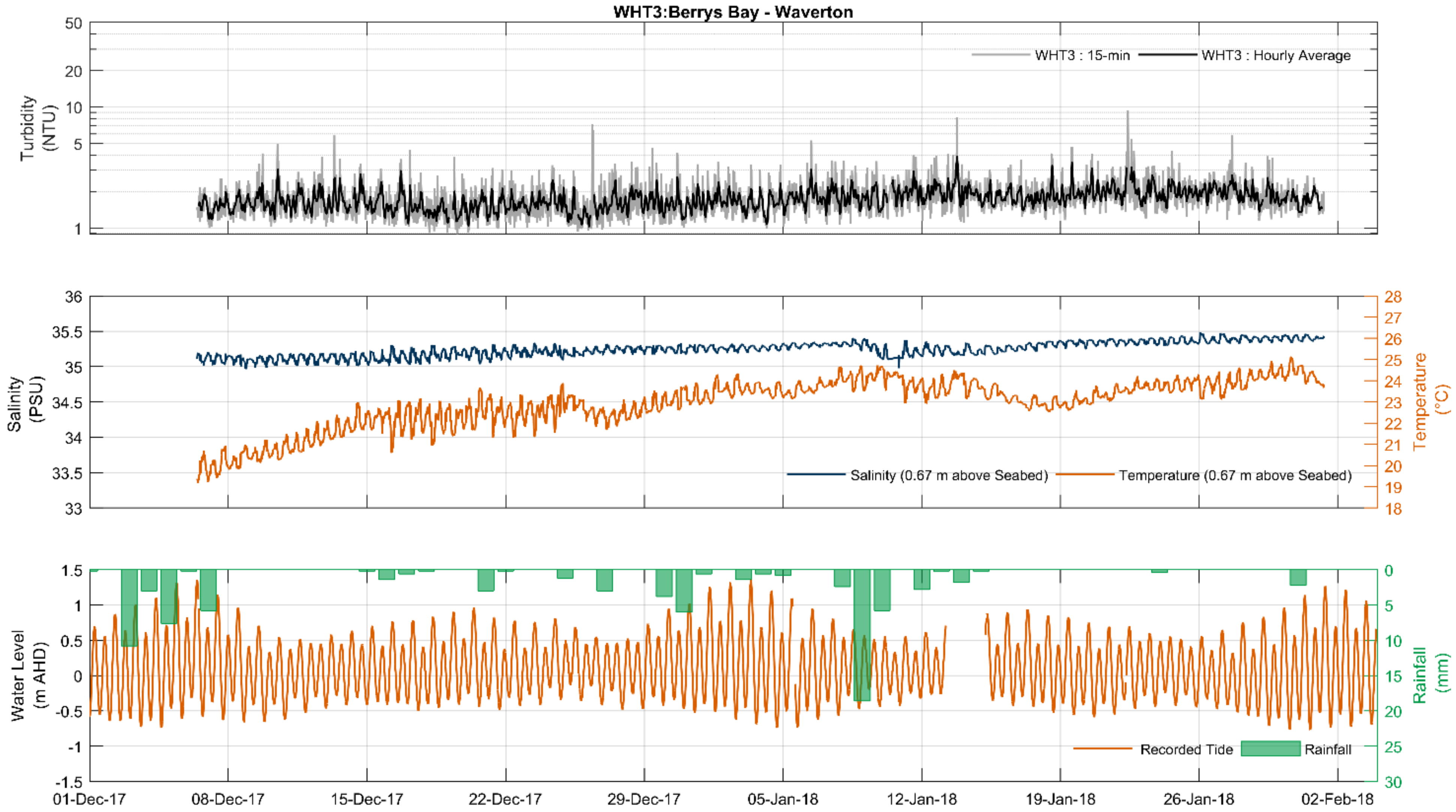


Figure 3-7 **Turbidity, salinity, temperature, water level and rainfall time series for fixed water quality monitoring sites**

3.3.2.2 Vertical structure of Sydney Harbour

To investigate the vertical and longitudinal structure of the waters in Sydney Harbour, water quality profiles were collected at eight sites along Sydney Harbour on 18 January 2018 and 30 January 2018. Profile depths ranged from nine metres to 20 metres along the sites that were aimed to sample at the deepest point of the cross section. Vertical profiles of turbidity, salinity, density, PAR (measured and modelled), dissolved oxygen and chlorophyll-a are presented against depth below the water surface for site WHTP4 in Figure 3-8. Figures for all eight profile sites are presented in Appendix A.

The 18 January 2018 sampling occurred just over a week after a few relatively small rainfall events during the second week of January. The 30 January 2018 sampling followed a dry period of two weeks when no rain fell and it would be expected that the saline oceanic waters would progress upstream as a salt wedge through this period. While the salinity shows very small increase of around 0.02 psu, the water temperature rose by about 2 ºC over the 12 days from 18 to 30 January. The temperature increase resulted in a density decrease of about 0.5 kgm^{-3}.

There is evidence of the weak spatial variation between the eight sites and temporal development between the two sampling days. As with near-bed turbidity time series deployments, the profile turbidity was consistently very low, less than 2 NTU, at all sites, for both exercises and being slightly higher at the sites further upstream. The density profile indicates a weak vertical stratification on 18 January 2018 and well-mixed conditions on 30 January 2018.

Chlorophyll–a was about 10 µg/L and showed slightly higher values upstream and little change between the 18 and 30 January 2018 profiles. Dissolved oxygen concentrations were generally greater than six mgDO/L and vertically well-mixed.

The PAR profiles indicate good light penetration through the water column as is expected within the relatively clear waters. The euphotic depth, where light decreases to one per cent of its surface value, was typically between seven and 10 metres depth (refer to Table A-2 in Appendix A).

Temperature and salinity characteristics reflect the strong mixing by the tidal currents resulting in vertically homogenous conditions and a weak gradient increasing upstream.

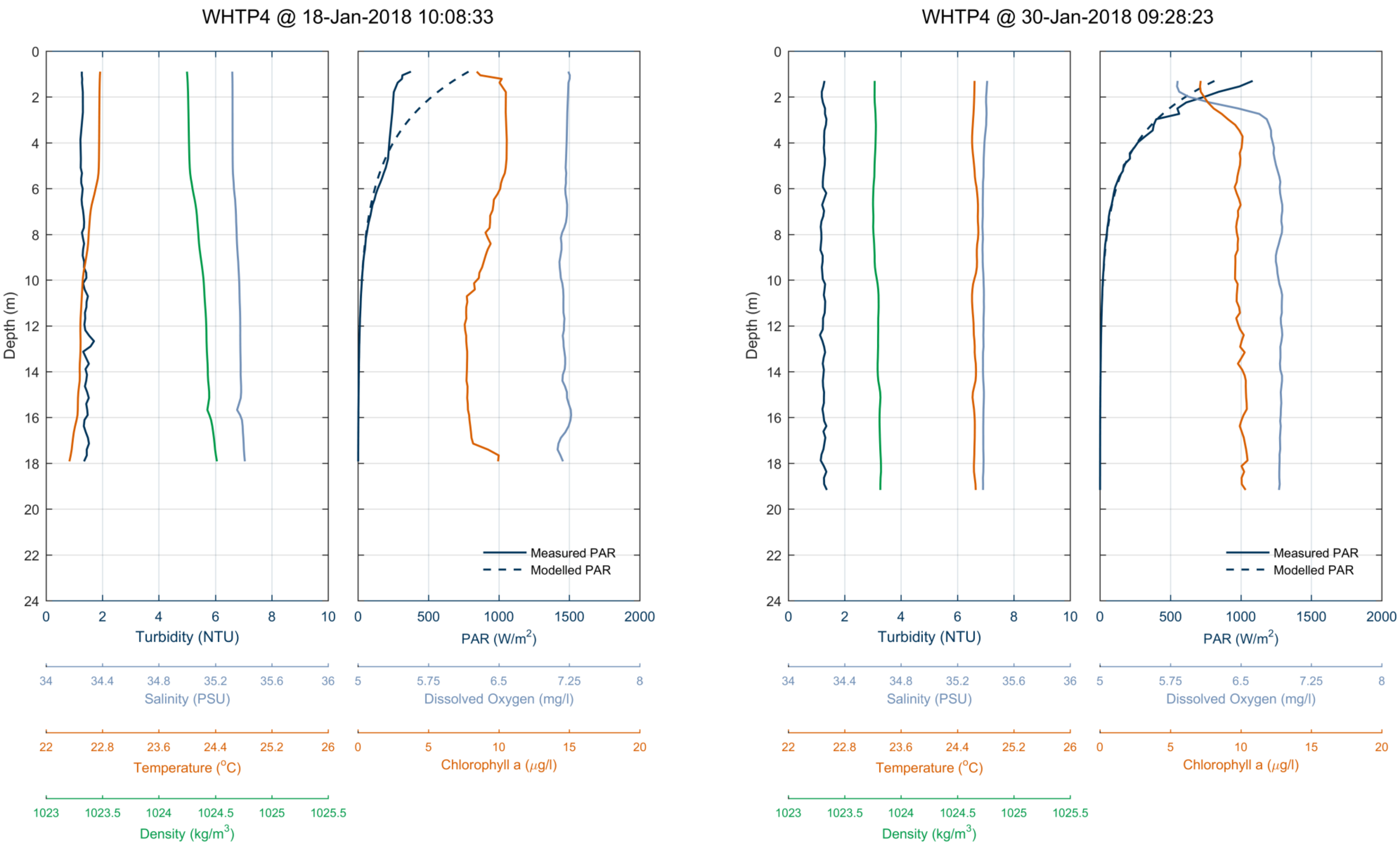


Figure 3-8 **Vertical profiles of water quality parameters at site WHTP4 on 18 and 30 January 2018**

3.3.3 Light extinction

The photosynthetically available radiation (PAR) time series data collected at the fixed monitoring sites are shown in Figure 3-9. The underwater PAR at the 0.5 metres above the bed and two metres above the bed in water depth 6.8 metres AHD show a generally lower value after 6 January due to the depth increase to 8.5 metres AHD following the servicing and redeployment of the mooring. The vertical light profiles were used to determine the light extinction coefficient. The extinction coefficient expresses the rate at which light is dispersed and absorbed by suspended particles and dissolved substances as it propagates down through the water column. Applying the exponential decay of light with depth expressed by the Beer-Lambert law, a curve fitting routine was applied to the PAR profile to derive the extinction coefficient and surface light values. The fitted curve is shown in the profile in Figure 3-9 and results of the profile-derived values compared to the time series estimates, at the time of the profile, presented in Appendix A (Table A-2).

The PAR values from the fixed deployments tended to be slightly lower than the profile readings but the difference between the two depths were consistent between the instruments.

Turbidity and chlorophyll-a provide an indication of the suspended particles and micro-plankton that influence the light extinction. Modelling of the extinction coefficient as a function of suspended matter (total suspended solids in mg/L) and chlorophyll-a (Chl-a in µg/L) concentrations typically uses a relationship for the total extinction coefficient, K, (Cardno, 2015):

$$K = k_b + 0.08 \times \text{total suspended solids} + 0.015 \times \text{Chl-a}$$

where the background clear water extinction, k_b, is around 0.1 m^{-1} and coefficients are derived from field data for the particular water body of interest.

Applying this relationship to the profile information indicates that for typical values of chlorophyll-a of five to 15 µg/L and low total suspended solids = 1 mg/L (refer to Figure 3-9 and Appendix A) that the chlorophyll-a forms a significant contribution to light extinction. Conversely, during turbid fresh events when total suspended solids is often greater than 10 to 15 mg/L the total suspended solids dominates light extinction.

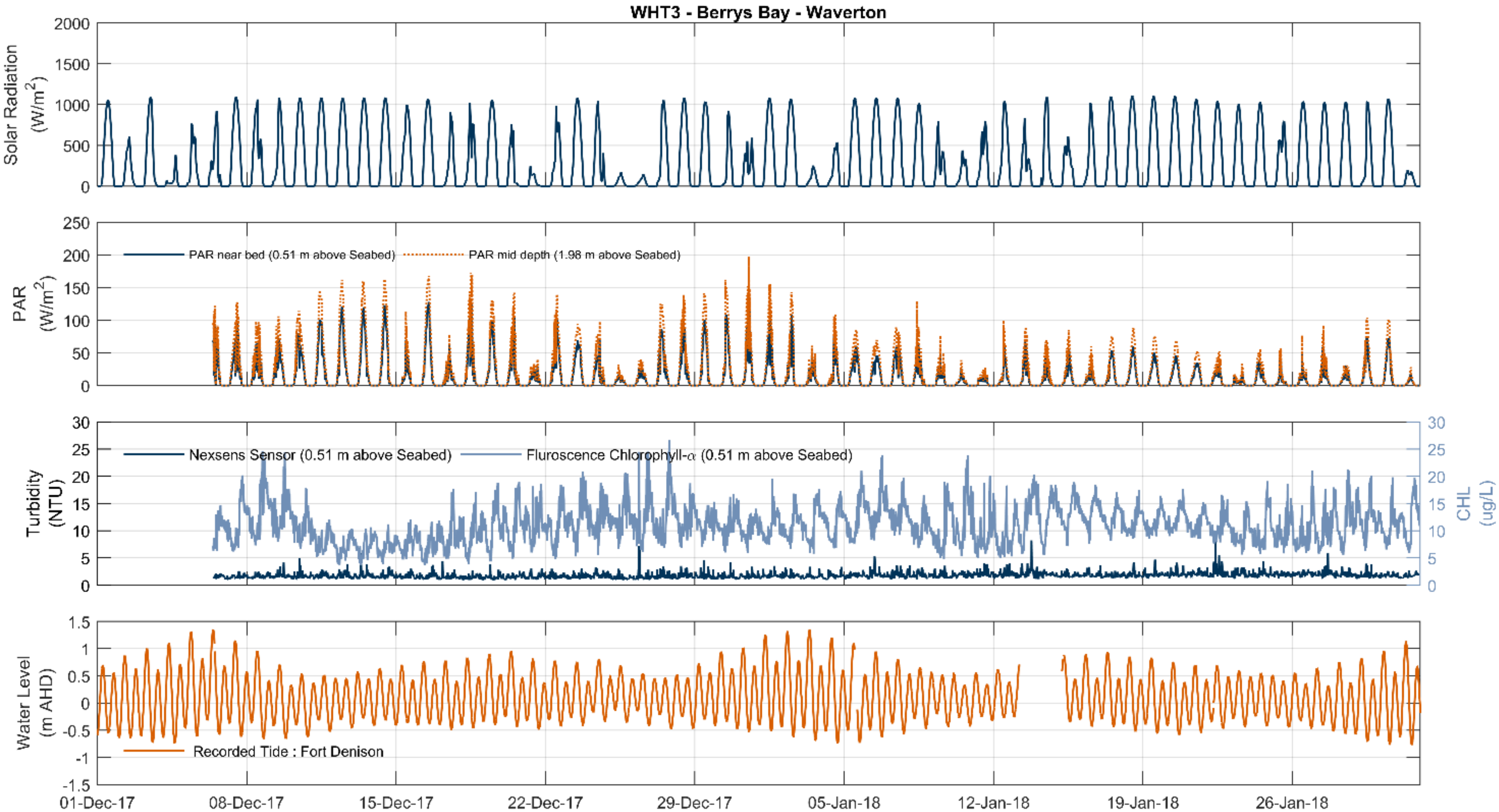


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Figure 3-9 **Time series surface radiation, underwater PAR, turbidity and chlorophyll-a and water level for water quality monitoring site WHT3**

3.4 Summary of background variability in turbidity

The natural variability in total suspended solids in Sydney Harbour is characterised by elevated values during wet weather runoff events that decline to very low values during the subsequent dry periods. The duration of elevated turbidity conditions depends on the size of the rainfall/runoff event and intervening period since the previous rainfall event. Sydney's rainfall is distributed across the year and typically dry periods range from a fortnight to a few months. The magnitude and duration of the event peak turbidity both increase with the increasing rainfall intensity of the event. Typically, an isolated one-month recurrence rainfall event produces a turbidity response that peaks around 15 mg/L for about one hour and decreases over the next two days to around 5 mg/L whereas a one-year recurrence rainfall event produces a peak of around 30 mg/L and declines over the next five to eight days.

When deriving an estimate of the natural variability in total suspended solids it is important to understand whether the data sets utilised provide a representative sample of the underlying statistical distribution. In order to develop an estimate of the variability of the natural waters of Sydney Harbour total suspended solids datasets from various sources that each represent different subsamples of the underlying distribution are summarised in Table 3-10. The three available datasets are characterised by the particular conditions during sampling. Comparing the three datasets suggest the SHERM results represents a higher estimate of low range total suspended solids (less than median) values, while the CMA and collected data do not include samples representative of the high rainfall runoff events.

Table 3-10 **Summary of total suspended solids and rainfall statistics from various data sources, for Sydney Harbour**

Statistical parameter	SHERM data TSS (mg/L)	CMA data TSS (mg/L)	Collected data TSS (mg/L)
Maximum rainfall event recurrence during data collection	1 year	6 month	<1 month
Sampling interval	1 hour	~1 month	5 minutes
95th percentile	20.8	15.6	3.5
90th percentile	17.5	6.4	3.2
50th percentile (median)	10.0	2.5	2.4
10th percentile	7.5	0.9	1.9
5th percentile	7.4	0.8	1.8

The natural variability in total suspended solids was determined by combining subsets of the three datasets selected based on the one month sampling of the CMA data. The three datasets comprise of a random selection of three values from the collected data time series observations (two month duration), the complete CMA data set (Harrison, 2013) at the nearest Sydney Harbour sites and the eight points of the modelled peak total suspended solids extracted from the eight events following rainfall with recurrence intervals greater than one month. The results of this process, the estimated total suspended solids variability of the existing waters of Sydney Harbour in the vicinity of the mainline tunnel alignment, are presented in Table 3-11. These values are used to support the impact assessment.

Table 3-11 **Natural variability total suspended solids percentile values in Sydney Harbour near the immersed tube tunnel crossing location**

Statistical parameter	Ambient TSS (mg/L)
95th percentile	18.7
90th percentile	11.9
50th percentile (median)	3.1
10th percentile	1.4
5th percentile	1.0

4 Potential impacts

4.1 Construction

Potential impacts on marine water quality may occur during the following project construction activities:

> Dredging of harbour sediments
> Harbour construction activities
> Land based construction activities.

These dredging and construction activities may impact marine water quality through the following potential key impact pathways:

- Increased turbidity as the dredge plume disperses into the harbour waters and the associated reduction in light that may restrict periods of growth of primary producers such as seagrass and rocky reef aquatic plants
- The settlement of suspended sediments generated by dredging on plant habitats causing smothering of benthic plants and organisms (eg seagrass and rocky reef habitat)
- Increased turbidity associated with construction activities (ie piling, construction of temporary wharf facilities and vessel movements)
- Mobilisation of contaminants associated with the transportation and dispersion of disturbed sediments
- Direct impact on water quality from discharges, runoff, spills and leaks.

There are a range of water quality processes that influence turbidity and sedimentation within the natural environment (refer to Section 3.1). These same processes drive the transportation and dispersion of dredging-related excess suspended sediment concentrations (refer to Figure 4-1). However, dredging-related excess suspended sediment concentration would lead to an increase in the frequency of occurrence of elevated turbidity and total suspended solids and potentially a persistence of the elevated total suspended solids over periods longer than the period to which the natural system is adapted.

Short intense bursts of elevated total suspended solids may also affect marine ecology. Sensitive habitats may respond to these stimuli differently. For example, seagrass are adapted to very short bursts of intense turbidity that occur during significant freshwater runoff events and hence are unlikely to be sensitive to intense bursts associated with the excess dredging effects. They are more sensitive to prolonged periods of darker conditions and hence the frequency and duration of excess SSC are more likely to be of concern.

Harbour construction activities that have the potential to impact marine water quality associated with the project include:

- Construction activities that are carried out directly within the waterway or harbour, including dredging and piling activities for cofferdams (WHT5 and WHT6) as well as construction of construction support site infrastructure at Rozelle Rail Yards (WHT1), Berrys Bay (WHT7) and temporary mooring site at Snails Bay. These activities have the potential to reduce water quality as well as the potential to disturb contaminated sediments
- Vessel movements may also generate localised plumes of excess suspended sediments associated with vessel wash in shallower waters, generally less than five to ten metres water depth
- Potential for spills or leaks of fuels and/or oils from maintenance or re-fuelling of construction plant or equipment that could be eventually discharged into waterways or directly to waterways (in the instance of harbour construction activities)
- The transport, treatment and/or temporary storage of dredged material that is unsuitable for offshore disposal while temporarily stored on barges or at the White Bay construction support site (WHT3).

Land based construction activities that have the potential to impact marine water quality due to construction activities occurring immediately adjacent to marine waterbodies include:

- Land based activities that lead to the exposure or handling of soils (including removal of pavement, vegetation clearance, stripping of topsoil, excavation, disturbance of contaminated soil, stockpiling and materials transport). This may result in soil erosion and off-site transport of sediment via air or runoff to receiving waterways. This could impact water quality, such as increased turbidity, lowered dissolved oxygen levels and increased nutrients

> Potential for spills or leaks of fuels and/or oils from maintenance or re-fuelling of construction plant or equipment or vehicles incidents that could be eventually discharged to waterways (if carried out on land).

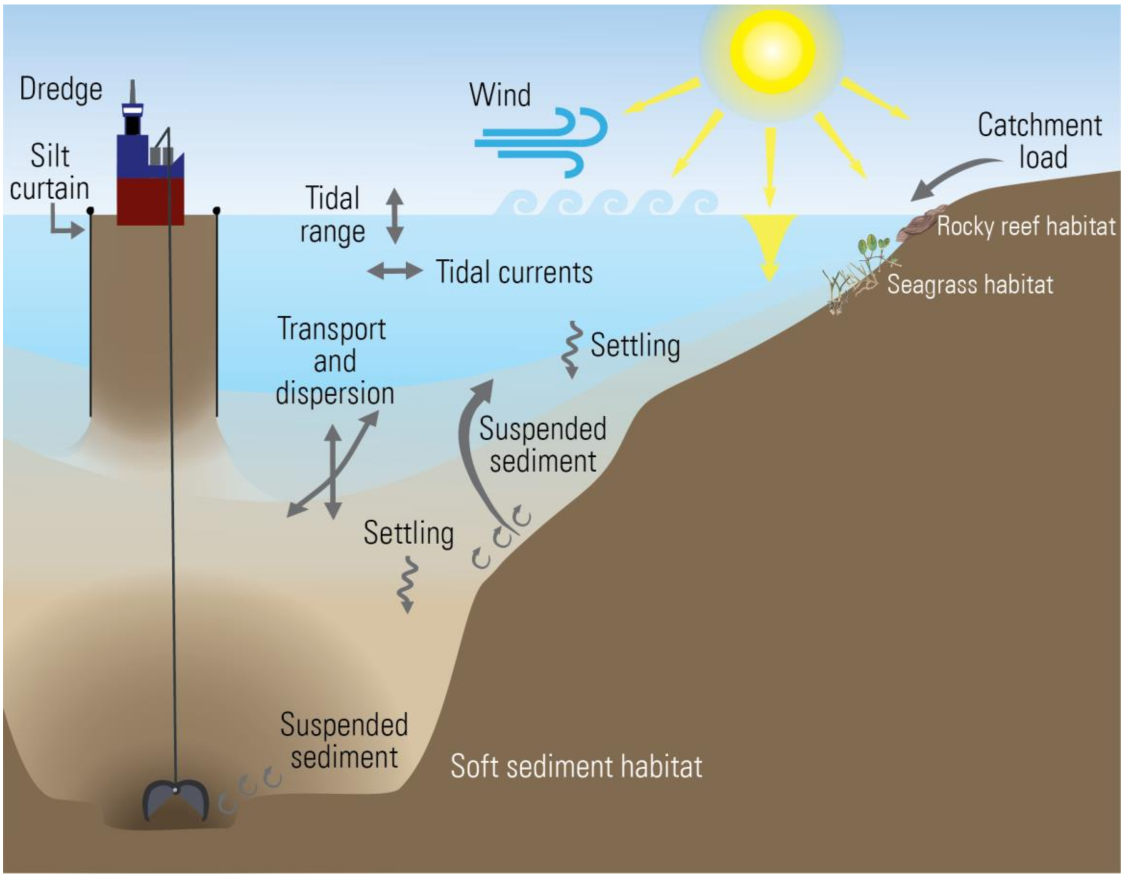

Figure 4-1 Schematic showing the effects of dredging

Sediment sampling carried out for the project (for Sydney Harbour, White Bay and Berrys Bay) found that selected contaminants were generally above guideline criteria (where available) in samples collected (Douglas Partners and Golder Associates, 2017, Jacobs, 2020). These contaminants were within the top one metre of sediments with minor detections of contaminants above guideline criteria from deeper sections. Minor detections of selected contaminants were detected in samples collected from depths of greater than one metre. Contaminants above guideline criteria included:

> Polycyclic aromatic hydrocarbons (PAHs)

> Total recoverable hydrocarbons (TRHs)

> Organochlorine pesticides (OCPs)

> Tributyltin (TBT)

> Arsenic

> Copper

> Mercury

> Lead

> Silver

> Zinc.

Dioxins were detected above laboratory levels of reporting in sediment samples taken from Sydney Harbour and White Bay (Technical working paper: Contamination, Jacobs, 2020). Testing for dioxins at Berrys Bay was not carried out.

Dredging and project construction activities have the potential to mobilise these contaminants. Dredging of these materials would be carried out using a backhoe dredge with a closed environmental clamshell. As discussed in RHDHV (2020) the dredge would be enclosed within a silt curtain extending below the water surface. This method provides current best practice for removal of potentially contaminated sediments while minimising the leakage of fine material to the surrounding waters.

4.2 Operation

Key potential impacts associated with the operation of the project that could impact marine water quality are associated with:

- Discharges of poorly treated tunnel wastewater at Rozelle Bay
- Increased stormwater runoff and associated increases in pollutant loading from roads that drain directly to marine environments
- Scour and/or mobilisation of contaminated sediments at new or modified outlet locations
- Poor maintenance of stormwater quality treatment devices
- Spills or leaks of fuels and/or oils from vehicle accidents or from operational plant and equipment.

5 Impact assessment

5.1 Construction

5.1.1 Increased turbidity

The potential impact of the excess SSC generated by dredging activities was assessed using the approach discussed in McArthur et al. (2002) and is further detailed in the Western Australian Environmental Protection Authority Technical guidance document *Environmental Impact Assessment of Marine Dredging Proposals* (EPA, 2016) (refer to Section 2.5). This approach develops tolerance limits for turbidity that are derived from water quality monitoring data, on the basis that resident marine flora and fauna are adapted to local conditions but would be stressed if exposed to conditions that regularly exceed normally prevailing background concentrations. It was assumed that aquatic plants and primary producers are adapted to the natural turbidity variability up to the 95^{th} percentile and that above this value they may become stressed.

The natural (or background) variability in total suspended solids concentrations in the vicinity of the mainline tunnel was determined from the available historic data, the SHERM outputs and additional data collected as part of the project-specific water quality monitoring program. The tolerance limit of the local marine ecology to excess suspended sediment concentrations generated during a dredging campaign is determined as the difference between the 95th percentile and the median natural total suspended solids concentrations (Table 3-11).

The tolerance limit was then applied to the predicted dredging-related excess suspended sediment concentrations (excess SSC), provided by the plume dispersion modelling (RHDHV, 2020) to determine the zones of potential effects. The Zone of Moderate Impact is the area where dredge plumes combined with natural system variability exceeds the 95th percentile total suspended sediment concentration of the natural system for more than 10 per cent of the time. Similarly, the broader Zone of Influence is the area where dredge plumes combined with natural system variability exceed the 95th percentile total suspended sediment concentration of the natural system for more than five per cent of the time.

The dredge plume predictions provided by the plume dispersion modelling (RHDHV, 2020) were used to derive the above zones. Excess SSC percentage occurrence maps are presented in RHDHV (2020) Appendix B for each key stage of the dredging program, comprising:

- Week 1 to 15
- Weeks 15 to 21
- Weeks 21 to 42
- Weeks 42 to 51
- Week 1 to 51 (entire program).

The Zone of Moderate Impact and Zone of Influence was determined for each of the above key dredging program stages. The outer extent of each of these zones were then merged to create a predicted Zone of Moderate Impact and a predicted Zone of Influence for the overall project dredging activities.

The boundaries of the zones described above are shown in Figure 5-1. Water quality effects of the proposed 51 weeks of dredging are restricted to a small area that reflects the tidal transport of the dredge plume material, and is within a distance of a few hundred metres of the dredging activities.

The plume dispersion model (RHDHV, 2020) calculates the excess SSC concentration in five vertical layers (from water surface to sea bed) at each five minute interval through the 51-week dredging period. The model produces a (51-week x 5 minute) time series of excess SSC within each model grid cell (typically 10 metres x 10 metres). For the assessment of effects on water quality the time-series excess SSC were extracted from the model at the water quality monitoring locations WHT1 to WHT4 (refer to Figure 2-3) and WH1 and WH2 (RHDHV, 2020). The model time series outputs were averaged over the depth (five layers) and daily averages calculated.

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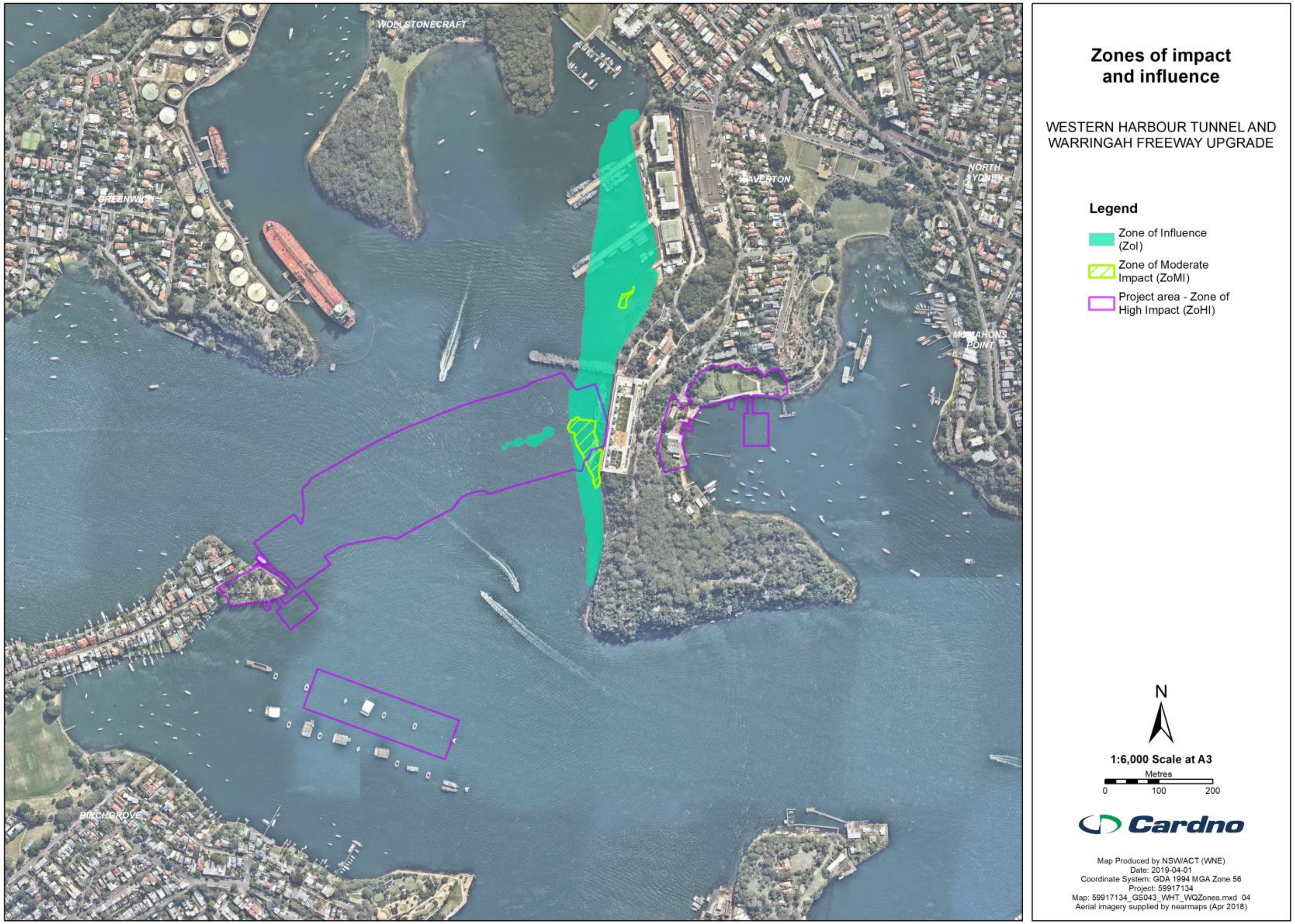

Figure 5-1 **Zones of Moderate Impact, High Impact and Influence for the dredging program**

The daily-averaged excess SSC for the 51-week dredging program at monitoring site WH2 in Balls Head Bay, adjacent to the immersed tube tunnel crossing location, is presented in Figure 5-2. This shows patterns of excess SSC plumes generated during the different phases of the dredging program. An example of one of these periods from weeks 25 to 30 is presented in Figure 5-3 to highlight the short term variability demonstrated by the instantaneous five minute modelled values. This figure indicates the intermittent nature of the plume dispersion with excess SSC peaks occurring for short periods as the tidal currents sweep the plume past the monitoring site during the five to six hours of daily dredging operations across the five days shown.

At site WH2 the 95th percentile excess SSC was 1.5 mg/L and the median value 0.4 mg/L as determined from the five minute values over the 51 week period of dredging. Assuming the excess SSC occurs in addition to the ambient water median concentration (3.1 mg/L, refer to Table 3-11) then the SSC 95th percentile concentration would equate to a total SSC of 4.6 mg/L (1.5 mg/L plus 3.1 mg/L) which is well below the background 90th percentile concentration (11.9 mg/L) and the tolerance limits for the marine environment.

The duration of excess SSC events is also short with daily-average concentrations exceeding 2 mg/L SSC for around 12 days out of the 51 weeks of dredging. Effectively the median total SSC during the dredging period would increase from 3.1 mg/L to 3.5 mg/L, equivalent to the background 65th percentile.

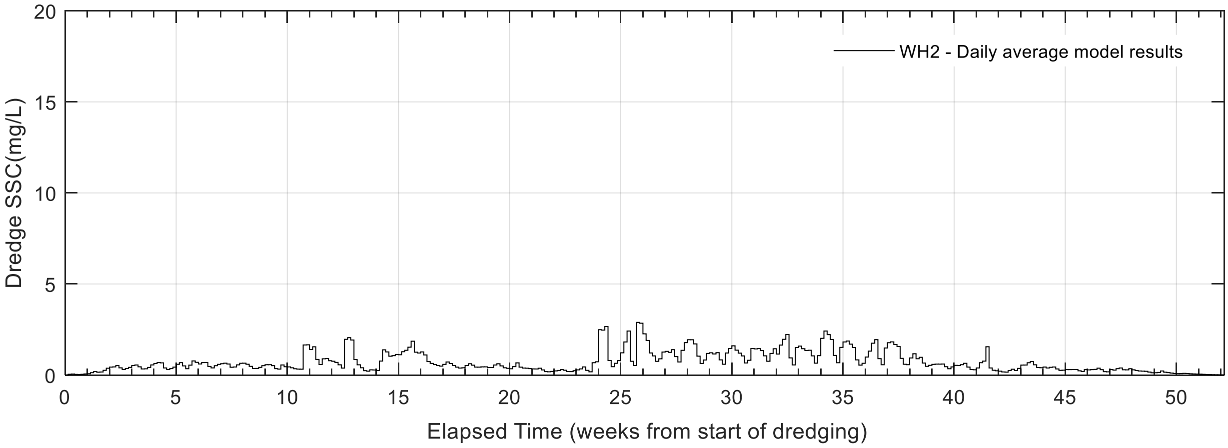

Figure 5-2 **Predicted dredge suspended sediment concentration (depth and daily averaged) at site WH2 in Balls Head Bay (from RHDV, 2020)**

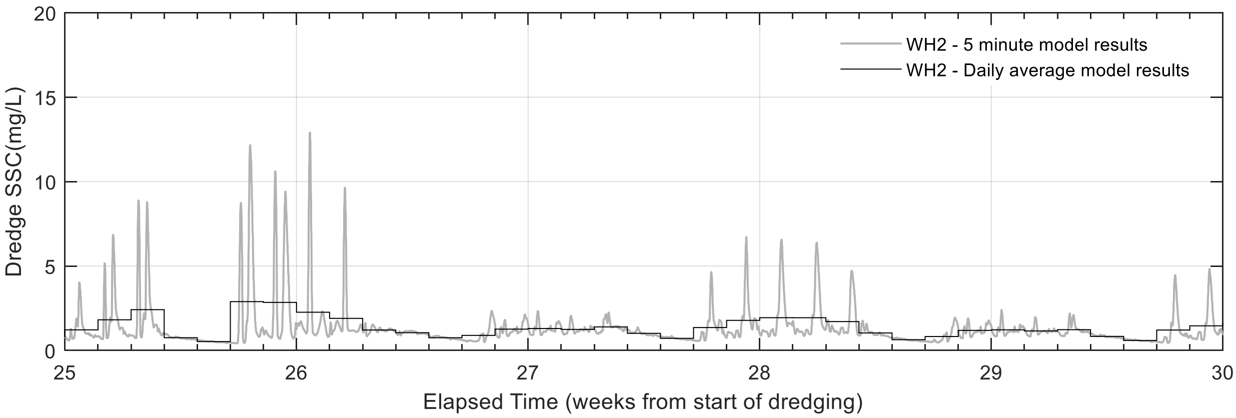

Figure 5-3 **Predicted dredge suspended sediment concentration (depth and daily averaged, and depth averaged five minute interval) at site WH2 during weeks 25 to 30 in Balls Head Bay (from RHDV, 2020)**

Construction activities (ie piling, construction of temporary wharf facilities and vessel movements) are likely to lead to mobilisation of bed sediments within shallower waters and the formation of short-lived localised plumes that disperse rapidly into the ambient waters. These activities and the plumes generated are likely to lead to elevated total SSC over small areas and for periods less than 10 minutes. These small intermittent plumes are unlikely to lead to any measureable effects.

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

The results indicate that the dredging program and construction activities would not have a substantial impact on marine water quality. The potential impacts of the changes in water quality on the marine environment are further discussed in the Technical working paper: Marine ecology (Cardno, 2020).

5.1.2 Sedimentation

The cumulative deposition of dredged sediments two weeks after the cessation of dredging is presented in RHDHV (2020) Figure 7-10. The accumulated sediment shown in Figure 7-10 of RHDHV (2020) shows a reasonably broad band of sedimentation less than 0.5 centimetres around the harbour downstream to Shark Island and upstream to the Gladesville Bridge. The area of sedimentation exceeding one centimetre is confined to less than 200 metres radius of the Coal Loader Wharf in Balls Head Bay. Sedimentation is difficult to measure in the field and the accuracy of current techniques is typically around two centimetres or greater. From a practical perspective the effects of sedimentation after the 51 week dredging program are likely to be negligible and not measurable other than perhaps immediately next to the dredge footprint. This level of sedimentation is unlikely to result in a measurable impact to the marine environment as it is similar to the existing overall sedimentation rate of 2.5 to three millimetres per year estimated from 30 metres of sediment accumulation in the harbour (Roy, 1981).

5.1.3 Mobilisation of contaminants

Contaminants of various types are known to occur as deep as one metre below the seabed in some areas and contamination is generally greater in the main arm of Sydney Harbour than in other parts (Douglas Partners and Golder Associates, 2017). Data regarding contaminant levels within Sydney Harbour, White Bay and Berrys Bay (as discussed in Technical working paper: Contamination (Jacobs, 2020)) show levels of contaminants within the top one metre of sediments would largely exceed guideline criteria (Douglas Partners and Golder Associates, 2017). Furthermore, in a study for the Sydney Metro City project (Geochemical Assessments 2015), mean concentrations in sediment of lead, mercury, and normalised concentrations of DDT group contaminants, various individual and total PAHs and TBT exceeded relevant sediment quality guideline values at one or more of the sampling locations. Concentrations of polycyclic dibenzo dioxins and furans (PCDD/Fs) also exceeded a safe sediment value and a probable effects level.

The behaviour of sediment-bound contaminants when resuspended into the water column is important for determining the potential for adverse environmental effects from dredging. In the study for the Sydney Metro City project, Geochemical Assessments (2015) carried out laboratory elutriation tests (by simulating re-suspension of sediment in ambient seawater) for identified contaminants, apart from total petroleum hydrocarbons (TPHs). These tests demonstrated that trace metals and all organic contaminants, including PCDD/Fs, are likely to remain bound to sediment particles and are not likely to dissociate and be released into the water column as dissolved phases. The minor component of contaminants that might be released to dissolved phases would be expected to re-adsorb to suspended particulate materials and resettle to the estuary bed.

Model predictions (RHDHV, 2020) of dispersion and settlement of the small amount of dredged sediments mobilised into the surrounding waters suggest some of these sediments would accumulate in intertidal areas. Most of this predicted sediment accumulation in intertidal areas occurs during phases of dredging of the deeper uncontaminated sediment (Douglas Partners and Golder Associates, 2017) and would have negligible effect on water quality.

A backhoe dredge with a closed environmental clamshell has been proposed for removal of the upper 0.5 to one metre layer of sediment which has been shown by initial testing to be contaminated. This control in conjunction with the behaviour of sediment bound contaminants, means it is unlikely that water quality would be significantly impacted by contaminants mobilised from dredging and marine construction activities. Dredge-induced accumulations of sediment in intertidal areas are most likely to be derived from uncontaminated sediment dispersed during the dredging of the deeper uncontaminated sediment (Douglas Partners and Golder Associates, 2017).

Potential impacts on marine ecology as a result of the mobilisation of contaminants is further considered in the Technical working paper: Marine ecology (Cardno, 2020).

5.1.4 Construction water discharges

Construction water (including stormwater water) would be generated from construction support sites (refer to Technical working paper: Surface water (Jacobs, 2020)). A number of construction support sites would also capture and treat construction water from tunnelling activities, which would be generated from groundwater ingress, rainfall runoff in tunnel portals and shafts, suppression water and washdown runoff. A large proportion of tunnelling wastewater would be generated by groundwater ingress.

Based on previous major road projects and data collected for the project, groundwater is typically characterised as containing heavy metals (eg iron, manganese, zinc, copper), nutrients (eg ammonia, total phosphorous, etc), suspended solids, hydrocarbons and other compounds. It is also expected, given proximity to harbour areas, that groundwater ingress would also be saline (refer Technical working paper: Groundwater (Jacobs, 2020)).

During construction, the wastewater generated in the tunnel would be captured, tested and treated at a construction water treatment plant prior to reuse or discharge, or disposal offsite (Technical working paper: Surface water (Jacobs, 2020)).

There is the potential for sediment to be scoured and mobilised where stormwater is discharged to receiving waterways and bays, including Rozelle Bay, Iron Cove, Snails Bay and Berrys Bay. This could include turbidity in the immediate vicinity of the discharge location, if not appropriately managed. Scour protection and energy dissipation measures would be provided as required at any outlets.

The water treatment plants would need to remove iron, manganese, suspended solids, hydrocarbons and other compounds, as well as pH correction. The plants would also need to address salinity and other contaminants such as ammonia.

Tunnel wastewater, if discharged untreated or without sufficient treatment, could have the potential to impact the receiving waterway due to increased pollutant loading (nutrients and heavy metals). This could result in algal growth, reduction in visual amenity and impacts to aquatic species.

While the ANZECC/ARMCANZ (2000) and the more recent ANZG (2018) Water Quality Guidelines are not suitable for direct application to wastewater quality, they can be applied to the ambient waters that receive wastewater discharges, and to protect the environmental values that they support. Section 3.2.2 describes the quality of the ambient waters in the vicinity of the project and identifies a range of existing pollutant sources that must be considered in assessing the impact of the project of the marine environment.

The ANZECC/ARMCANZ (2000) and recent update ANZG (2018) Water Quality Guidelines, considering the existing marine environment, would be adopted as the framework for ensuring that the project either maintains or improves marine water quality in accordance with the NSW Water Quality and River Flow Objectives (DECCW, 2006).

Potential impacts from discharges to the harbour marine water quality would be mitigated through the treatment sequence that is being developed as part of the detailed design program. If required, monitoring of discharges during construction activities would adopt a gradient monitoring approach (from the discharge point to a distance deemed to be within the ambient harbour waters) likely to be within approximately 100 metres of the discharge outlet. This distance would be determined during the particular construction activities using standard plume dispersion estimates applied to the measured outlet discharge (kL per day).

The expected discharge volumes from tunnelling construction support sites and expected discharge locations are described below. This accounts for a proportion of treated groundwater being re-used in construction activities. The type, arrangement and performance of construction wastewater treatment facilities would be developed and finalised during detailed design.

Table 5-1 **Estimated discharge volumes from construction water treatment plants**

Construction support site	Estimated discharge volume Kilolitres per day	Receiving environment
Rozelle Rail Yard (WHT1)	94	Rozelle Bay, via local stormwater
Victoria Road (WHT2)	453	Iron Cove, via local stormwater
Yurulbin Point (WHT4)	282	Snails Bay, Sydney Harbour
Berrys Bay (WHT7)	266	Berrys Bay, Sydney Harbour

The rate of discharge would be determined at each stage of construction activity and water demand, and discharges are likely to be generally continuous with variable flow rates. Marine receiving environments Rozelle Bay, Iron Cove, Snails Bay and Berrys Bay would receive discharges from the project. As they are large tidal waterways, the discharge volumes would not impact natural flow variability and as outlined above treatment sequences would be designed to maintain or improve the water quality of the receiving ambient environment.

The M4-M5 link project would also utilise water treatment and discharge to Rozelle Bay (WestConnex M4-M5 Link environmental impact statement, Appendix Q Surface water and Flooding, 2017). The proposed volume of the discharge is similar to this project's proposed discharge also to Rozelle Bay. Adopting the discharge control treatment plants would minimise the potential for cumulative impacts of the discharges from this project and the M4-M5 Link, on flow variability within Rozelle Bay and on the marine water quality. The treatment processes presently being implemented as part of the M4-M5 link project (WestConnex M4-M5 Link environmental impact statement, 2017) will be reviewed as part of the final design for this project. As this project is connecting to the M4-M5 within the same substrata it is anticipated that similar treatment processes will be implemented.

On the basis that appropriate treatment is achieved, tunnel wastewater discharges during construction would pose a negligible impact on receiving water quality.

5.2 Operation

Treated tunnel water flows from the operational water treatment plant at Rozelle would discharge to Rozelle Bay. Around 189 mega litres (ML) per year would be discharged. This would increase the stormwater flow entering Rozelle Bay, and would be in addition to the discharge flows associated with the M4-M5 Link treatment plant (estimated at 693 ML per year).

As Rozelle Bay is a large tidal waterway, the minor increase in annual stormwater flow as a consequence of the project (or the cumulative impact of the project and the M4-M5 Link) would pose a negligible impact on natural flow variability and marine water quality.

Increases to impervious surfaces would increase the volume of stormwater runoff, and associated increases in pollutant loading. Pollutants from road surfaces typically comprise total suspended solids, nutrients (eg total nitrogen and total phosphorous), oils, greases, spills, petrochemicals and heavy metals. In the context of the project, potential impacts on the marine environment due to increases in stormwater volume and pollutants would be limited to impacts associated with changes and alterations to surface roads in the vicinity of Rozelle and Annandale.

As discussed in Technical working paper: Surface water (Jacobs, 2020), project design targets have been adopted and are based on *Draft Managing Urban Stormwater – Council Handbook* (EPA, 2007). Operational water quality treatment controls would be designed when selecting and sizing operational water quality treatments. If the targets cannot be met, for instance due to size constraints, water quality treatment would be designed so that surface water quality would be equal or better than existing conditions as required under the NSW Water Quality Objectives.

Alterations and changes to the Rozelle Interchange (as approved) by the project would result in a minor change to the amount of impervious surfaces, as well as modifications to the stormwater network that would be delivered as part of the M4-M5 Link. The changes are not considered to be of sufficient scale that would alter the outcomes of the M4-M5 Link assessment, with only minor increases in pollutant loading as a result of the project (Technical working paper: Surface water; Jacobs, 2020). The selection of the final stormwater controls would be determined during further design development and in conjunction with the M4-M5 Link, with consideration to the project water quality targets (Table 5-2).

Table 5-2 **Operational water quality design targets**

Pollutant	Minimum reduction of the annual average load
Total suspended solids	85%
Total phosphorus (TP)	65%
Total nitrogen (TN)	45%

Accidental spills (such as lubricants, oils and chemicals) could potentially occur during the operation of the project. Any spill has the potential to pollute downstream waterways, including marine environments. The severity of the potential impact would depend on the type of contaminant, the size of the spill and the location of the spill relative to the receiving environment, as well as emergency response times to the incident. In the case of this project, spills that could occur on surface roads in Rozelle and Annandale could impact Rozelle Bay, given the proximity to this waterway. Spills that occur within the tunnel would be managed via the tunnel drainage system.

Spill control measures would be required to reduce the potential for environmental impacts, and would be coordinated with any controls proposed as part of the M4-M5 Link for the surface road network. Provided appropriate controls are in place, there would be a low risk of impacts to receiving water quality. The potential long-term effects of treated wastewater discharge from the Rozelle Railyards water treatment plant to Rozelle Bay are likely to include a small change to the existing stormwater outlet flow and quality characteristics. Any potential effects in the future may be mitigated through adjustment of the water quality treatment systems within the water treatment plant.

6 Mitigation of impacts

In developing the concept plan for the Western Harbour Tunnel component of the project it was recognised that there would be potential impacts on the marine water quality and ecology in Sydney Harbour. Based on the methods adopted for similar activities within the harbour and on experience with similar projects in the marine environment, a number of measures for avoiding and minimising potential impacts on marine water quality and marine ecology were incorporated into the design and proposed construction activities. The project footprint has been reduced as far as practicable to avoid areas of marine vegetation and habitat. Standard management measures would be implemented at construction support sites to minimise potential impacts on marine water quality and potential flow-on impacts to marine ecology. As discussed in Section 1.7 these would include:

> Treatment of tunnel wastewater via a treatment plant prior to discharge from construction sites to avoid adverse impacts to water quality in the harbour
> Installation of silt curtains during dredging
> Use of an environmental bucket to dredge the top layer of marine sediment
> Construction staging
> Management of contaminated sediments and acid sulfate soils.

These management measures incorporated into the design and construction method are discussed in Chapter 5 (Project description) and Chapter 6 (Construction work) of the environmental impact statement and would be refined during further design development. Following selection of the dredging contractors and their proposed methods a detailed plan for managing dredging activities, the Dredging Environmental Management Plan (DEMP) would be developed. The aim of the DEMP is to outline the procedures to be adopted during dredging activities to minimise the area of impact to marine water quality, vegetation and habitat.

The DEMP would incorporate an adaptive management approach that utilises ongoing monitoring and assessment of triggers to provide early warning of potential ecosystem stress. Defined management responses to these indicators would be agreed in the development of the DEMP and likely include a Triggered Action Response Plan that defines the detailed monitoring program, data analysis, trigger assessment, reporting and decision framework for responding to any trigger exceedances. The response would include a range of mitigations.

Mitigation may include adjustments to the dredging activities such as moving the dredge to other areas, changing the dredging method (eg dredging on ebb tide only), and ultimately cessation of dredging for a period to reduce stress to the environment. Additional strategies may include installation of silt curtains surrounding the nearshore seagrass patches. These responses would be tailored to the conditions observed and to minimise risks of any long term impact on the marine environment. The suspended solids/turbidity criteria would be derived from the information presented in Table 3-11 and the final dredging program proposed by the selected dredging tenderer.

Based on the predictions of the effects of the proposed dredging program it is likely that the proposed program would have negligible effects on the marine ecosystem of Sydney Harbour. The analysis of the preceding sections provides a reasonable level of confidence that the management plans with designated monitoring and triggered response activities would provide the safeguards for the protection of the marine environment.

The secondary impacts of marine water quality to marine ecology as a result of the project are discussed in the Technical working paper: Marine ecology (Cardno, 2020).

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APPENDIX

A

SYDNEY HARBOUR
WATER QUALITY PROFILES

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Western Harbour data collection program: Dec 2017 to Jan 2018

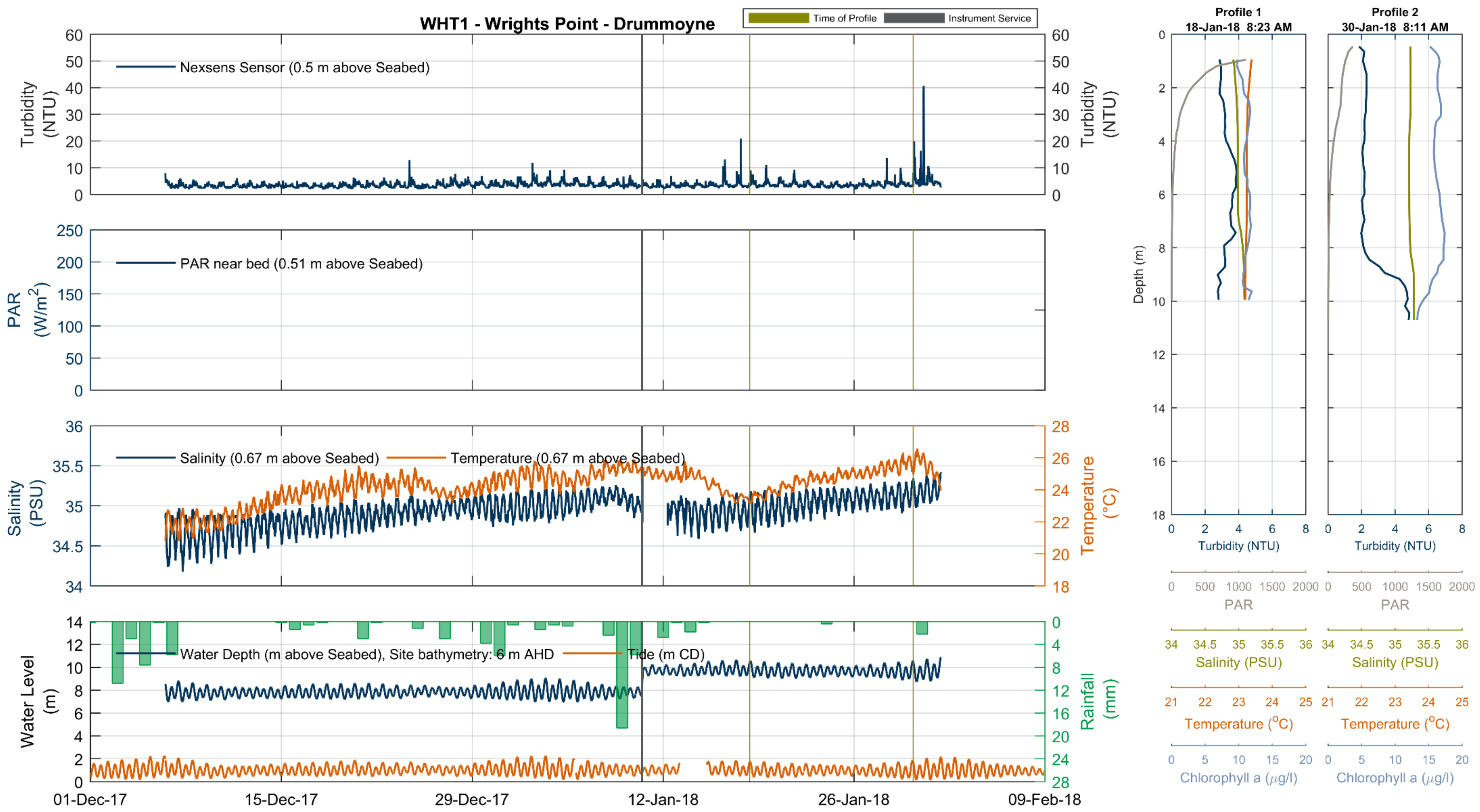
Vertical water profiles were collected at fixed water quality monitoring sites WHT1, WHT2, WHT3 and WHT4, as well as four additional locations within Sydney Harbour (Figure A-1 and Table A-1). A Sea-Bird Scientific SBE 19plus V2 SeaCAT Profiler CTD combined with various sensors (Satlantic PAR, FLNTURT, SBE18 pH, SBE43 DO), recorded turbidity, PAR, CTD, Chl-a, pH and dissolved oxygen (DO) as it was lowered through the water column from the surface to the seabed.

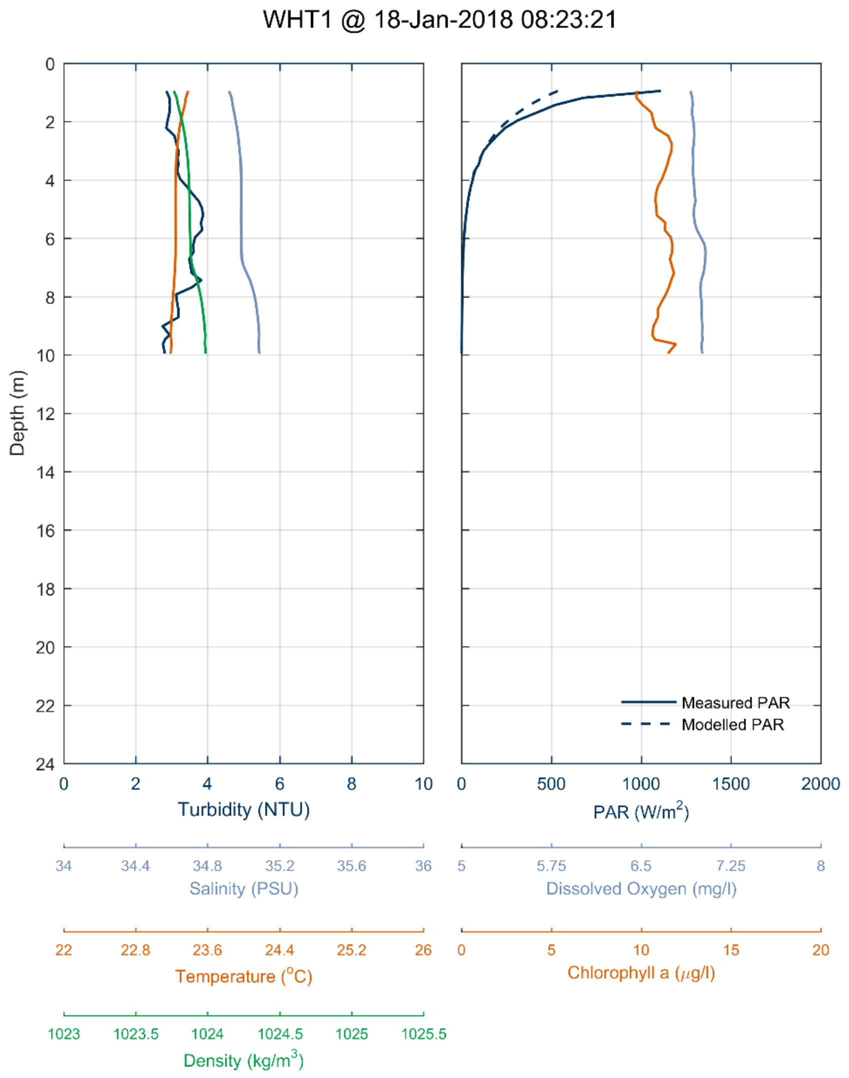
Water samples were also collected at each profile location at a depth of ~1.5m below the water surface and analysed by ALS for Total Suspended Solids (TSS) and Chlorophyll-*a* (Chl-*a)* concentrations.

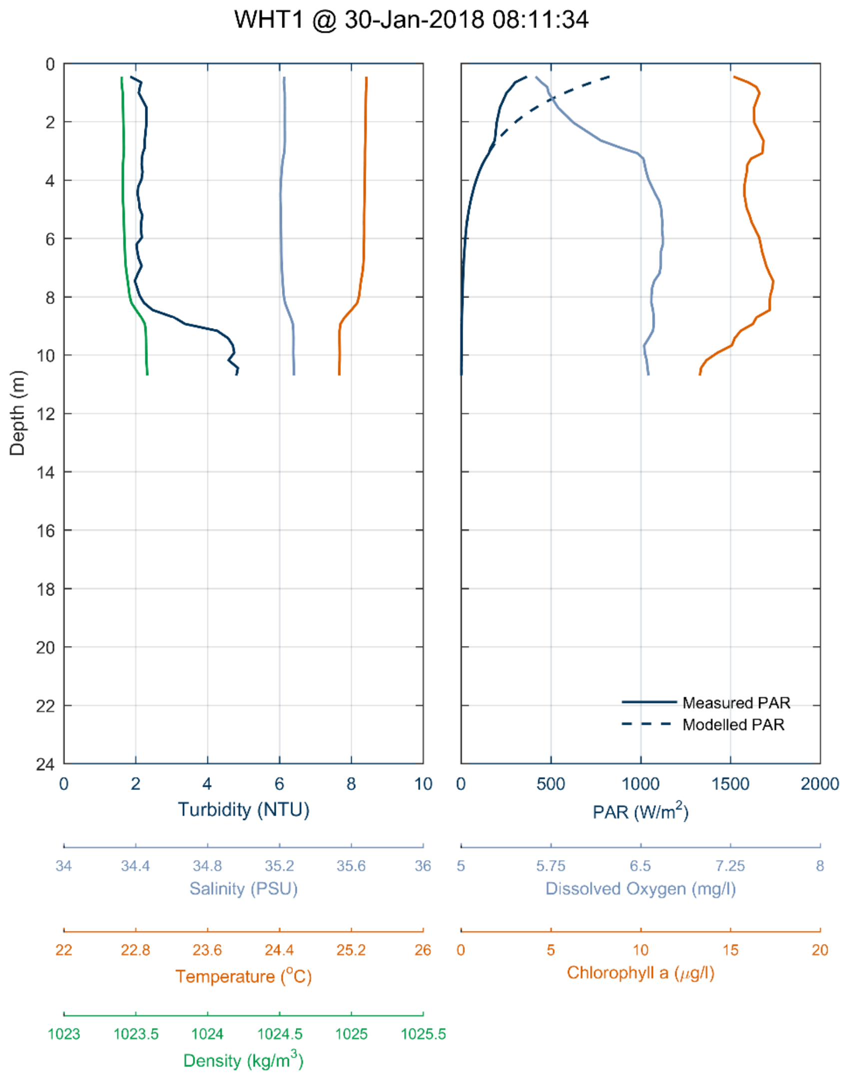
Table A-1 Location Details of Monitoring Sites

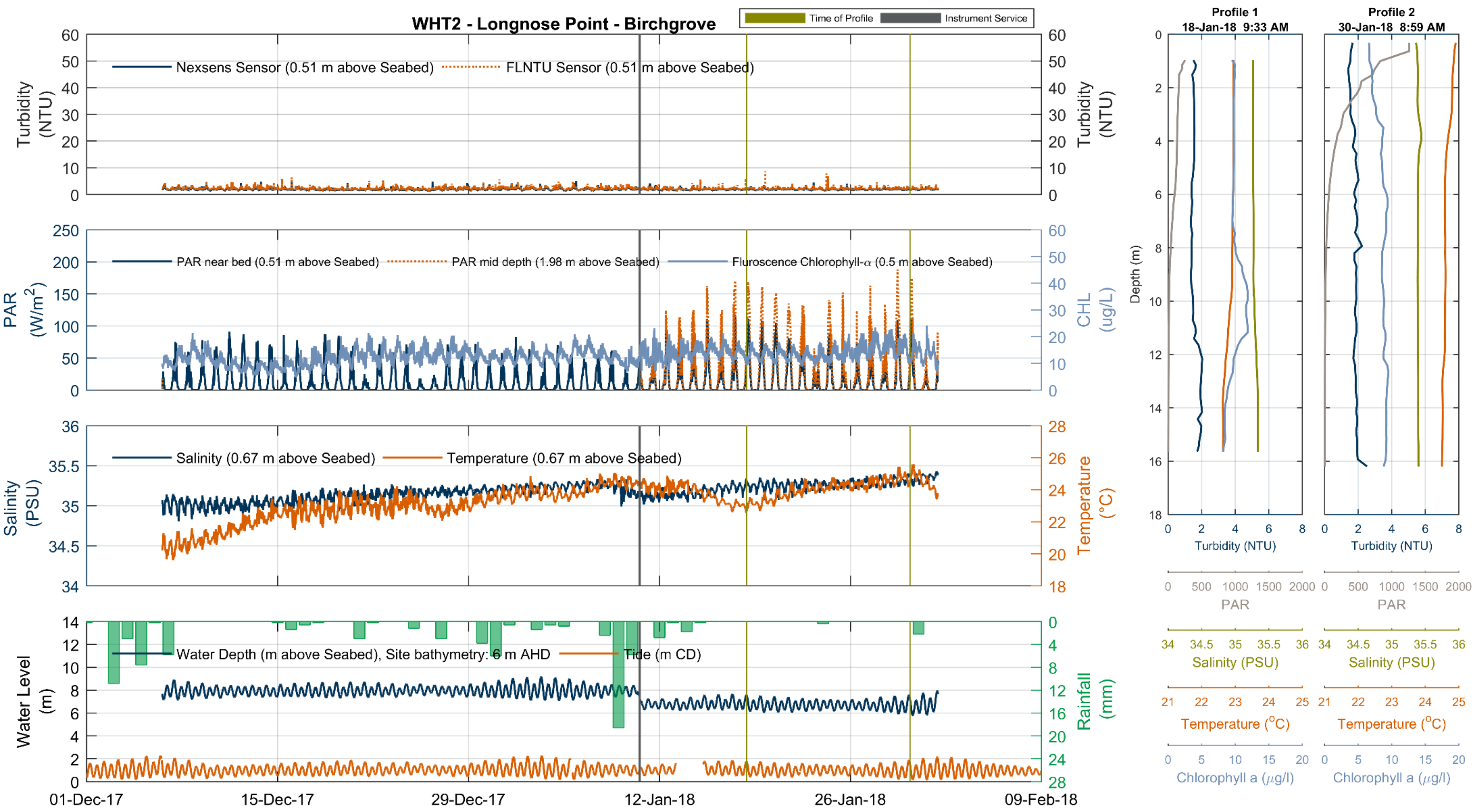
Site	Monitoring Site Reference	Coordinates (WGS84)
Wrights Point, Drummoyne	WHT1	329180 E, 6253853 N
Pulpit Point, Hunters Hill	WHTP1	330097 E, 6253318 N
Onions Point, Woolwich	WHTP2	331454 E, 6254166 N
Manns Point, Greenwich	WHTP3	332131 E, 6253621 N
Birchgrove Wharf Point, Birchgrove	WHT2	332150 E, 6253445 N
Berrys Bay, Waverton	WHT3	333243 E, 6253687 N
Goat Island	WHTP4	333354 E, 6252935 N
Cremorne Point, Cremorne	WHT4	336188 E, 6253411 N

Figure A-1 Water Quality monitoring sites within Sydney Harbour

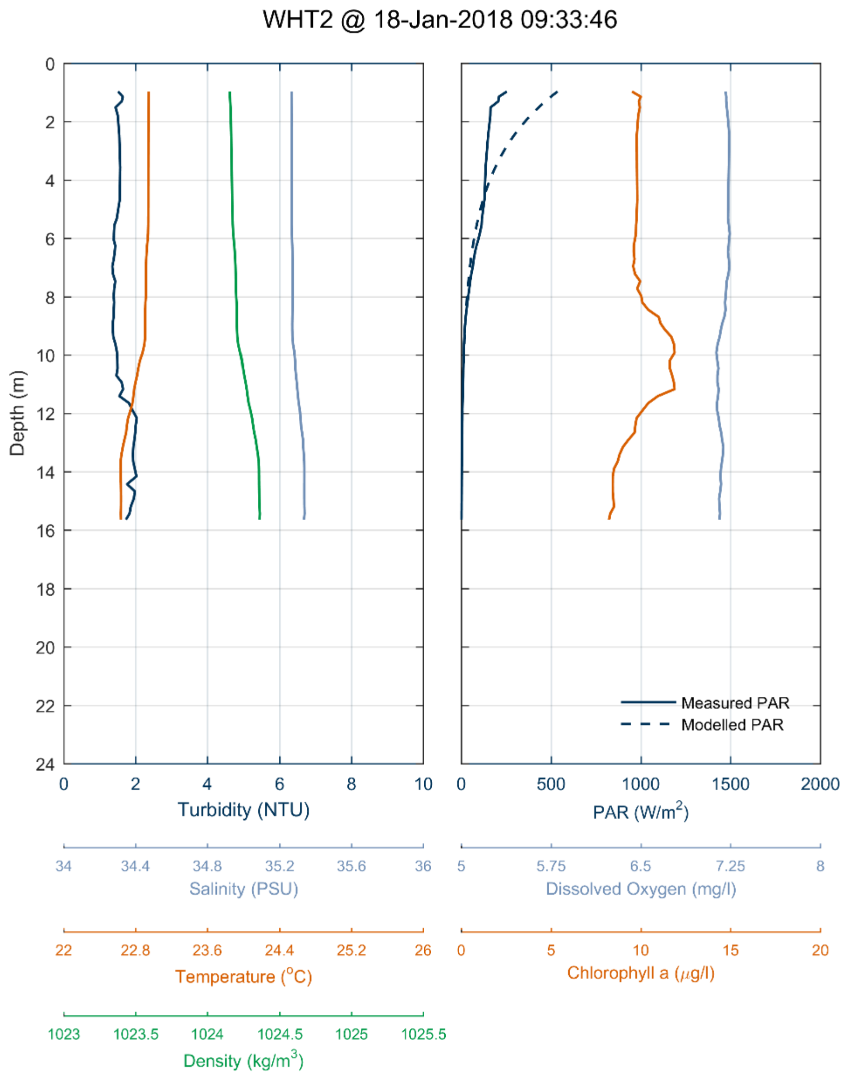

WHT1 - Wrights Point - Drummoyne
Time of Profile
Instrument Service
Turbidity (NTU)
Nexsens Sensor (0.5 m above Seabed)
PAR (W/m2)
PAR near bed (0.51 m above Seabed)
Salinity (PSU)
Salinity (0.67 m above Seabed)
Temperature (0.67 m above Seabed)
Temperature (°C)
Water Level (m)
Water Depth (m above Seabed), Site bathymetry: 6 m AHD
Tide (m CD)
Rainfall (mm)
01-Dec-17
15-Dec-17
29-Dec-17
12-Jan-18
26-Jan-18
09-Feb-18
Profile 1
18-Jan-18 8:23 AM
Profile 2
30-Jan-18 8:11 AM
Depth (m)
Turbidity (NTU)
PAR
Salinity (PSU)
Temperature (°C)
Chlorophyll a (µg/l)

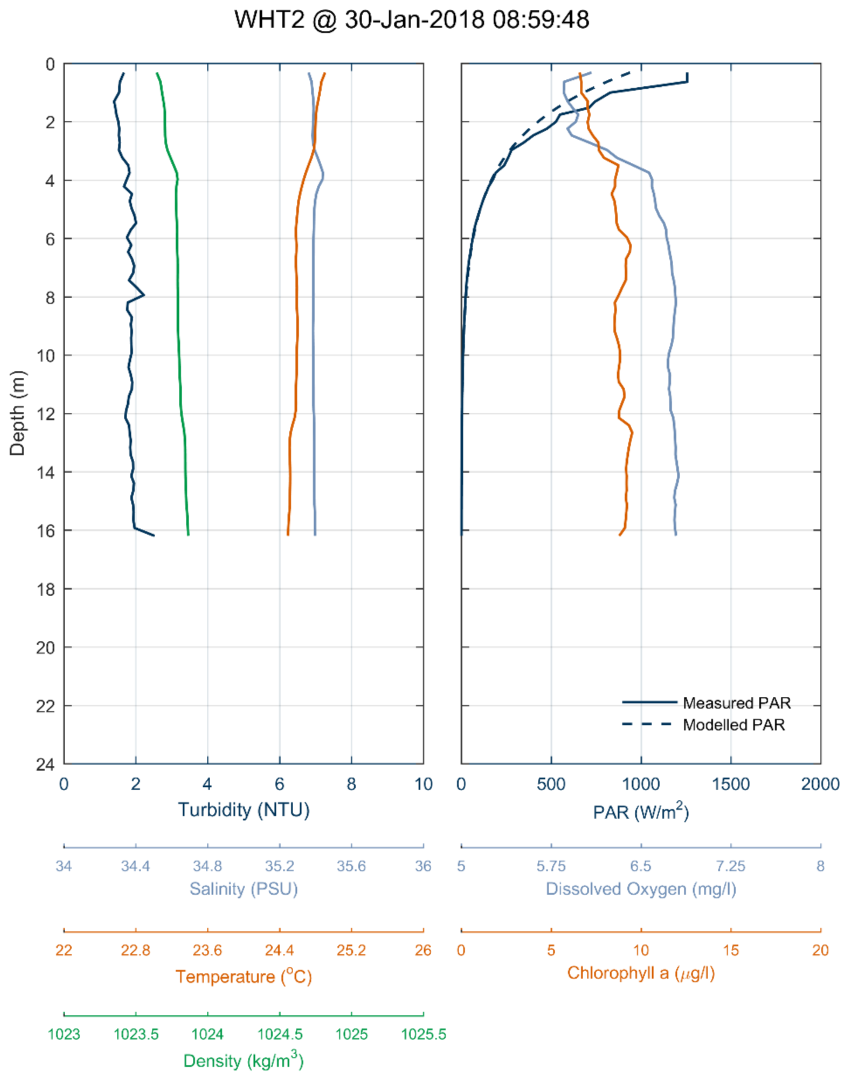

WHT1 @ 18-Jan-2018 08:23:21
Depth (m)
Turbidity (NTU)
PAR (W/m2)
Measured PAR
Modelled PAR
Salinity (PSU)
Dissolved Oxygen (mg/l)
Temperature (°C)
Chlorophyll a (µg/l)
Density (kg/m3)

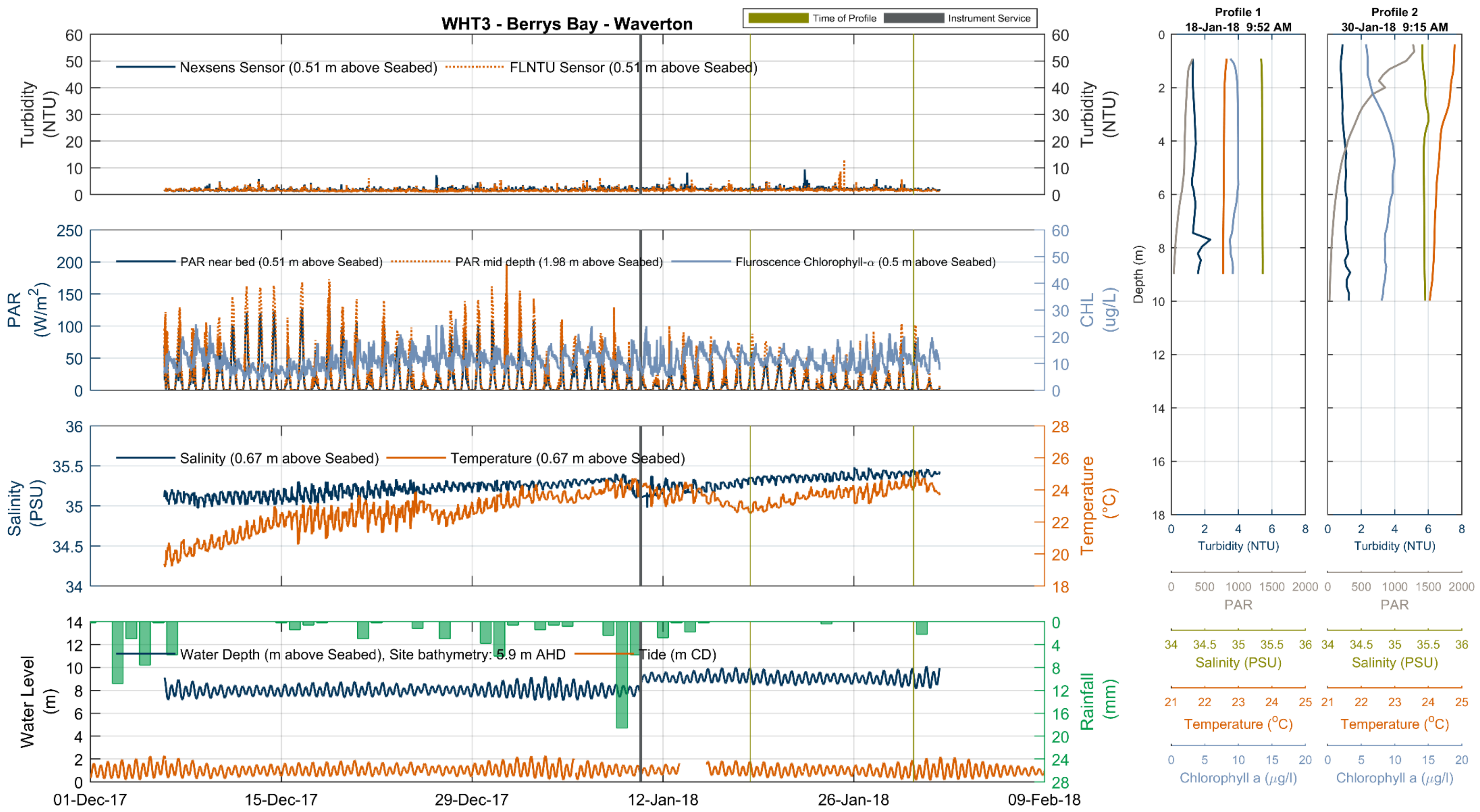

WHT1 @ 30-Jan-2018 08:11:34
Depth (m)
Turbidity (NTU)
PAR (W/m2)
Measured PAR
Modelled PAR
Salinity (PSU)
Dissolved Oxygen (mg/l)
Temperature (°C)
Chlorophyll a (µg/l)
Density (kg/m3)



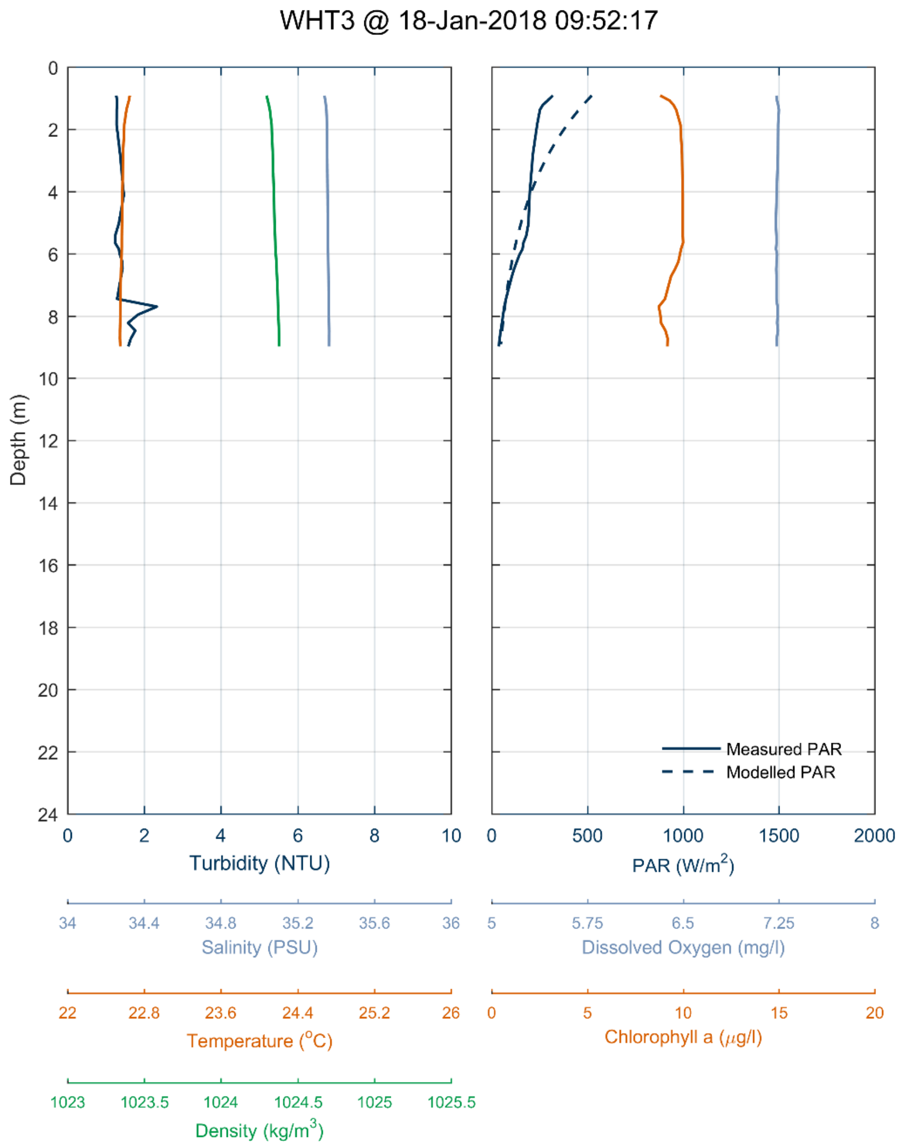
WHT2 - Longnose Point - Birchgrove
Time of Profile
Instrument Service
Turbidity (NTU)
Nexsens Sensor (0.51 m above Seabed)
FLNTU Sensor (0.51 m above Seabed)
PAR (W/m2)
PAR near bed (0.51 m above Seabed)
PAR mid depth (1.98 m above Seabed)
Fluroscence Chlorophyll-α (0.5 m above Seabed)
CHL (ug/L)
Salinity (PSU)
Salinity (0.67 m above Seabed)
Temperature (0.67 m above Seabed)
Temperature (°C)
Water Level (m)
Water Depth (m above Seabed), Site bathymetry: 6 m AHD
Tide (m CD)
Rainfall (mm)
01-Dec-17
15-Dec-17
29-Dec-17
12-Jan-18
26-Jan-18
09-Feb-18
Profile 1
18-Jan-18 9:33 AM
Profile 2
30-Jan-18 8:59 AM
Depth (m)
Turbidity (NTU)
PAR
Salinity (PSU)
Temperature (°C)
Chlorophyll a (μg/l)

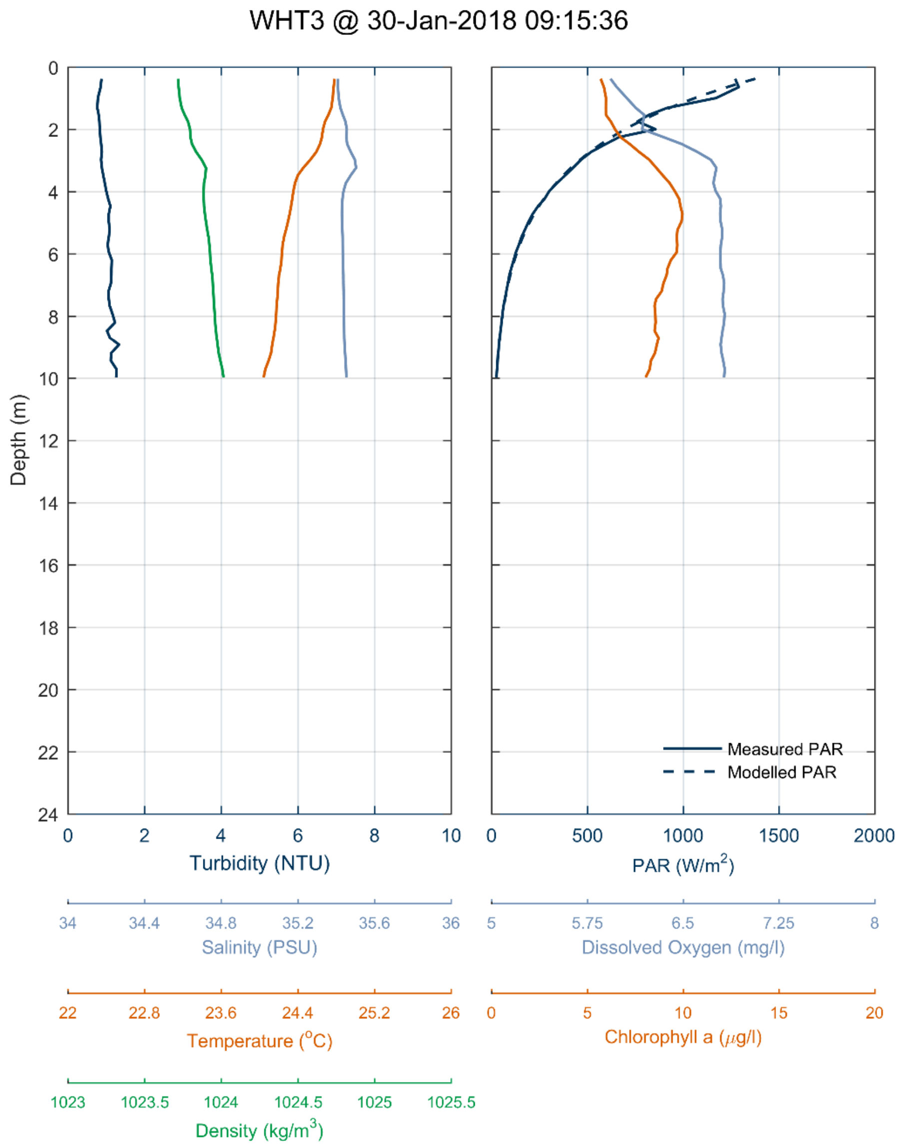

WHT2 @ 18-Jan-2018 09:33:46
Depth (m)
Turbidity (NTU)
PAR (W/m2)
Measured PAR
Modelled PAR
Salinity (PSU)
Dissolved Oxygen (mg/l)
Temperature (°C)
Chlorophyll a (µg/l)
Density (kg/m3)

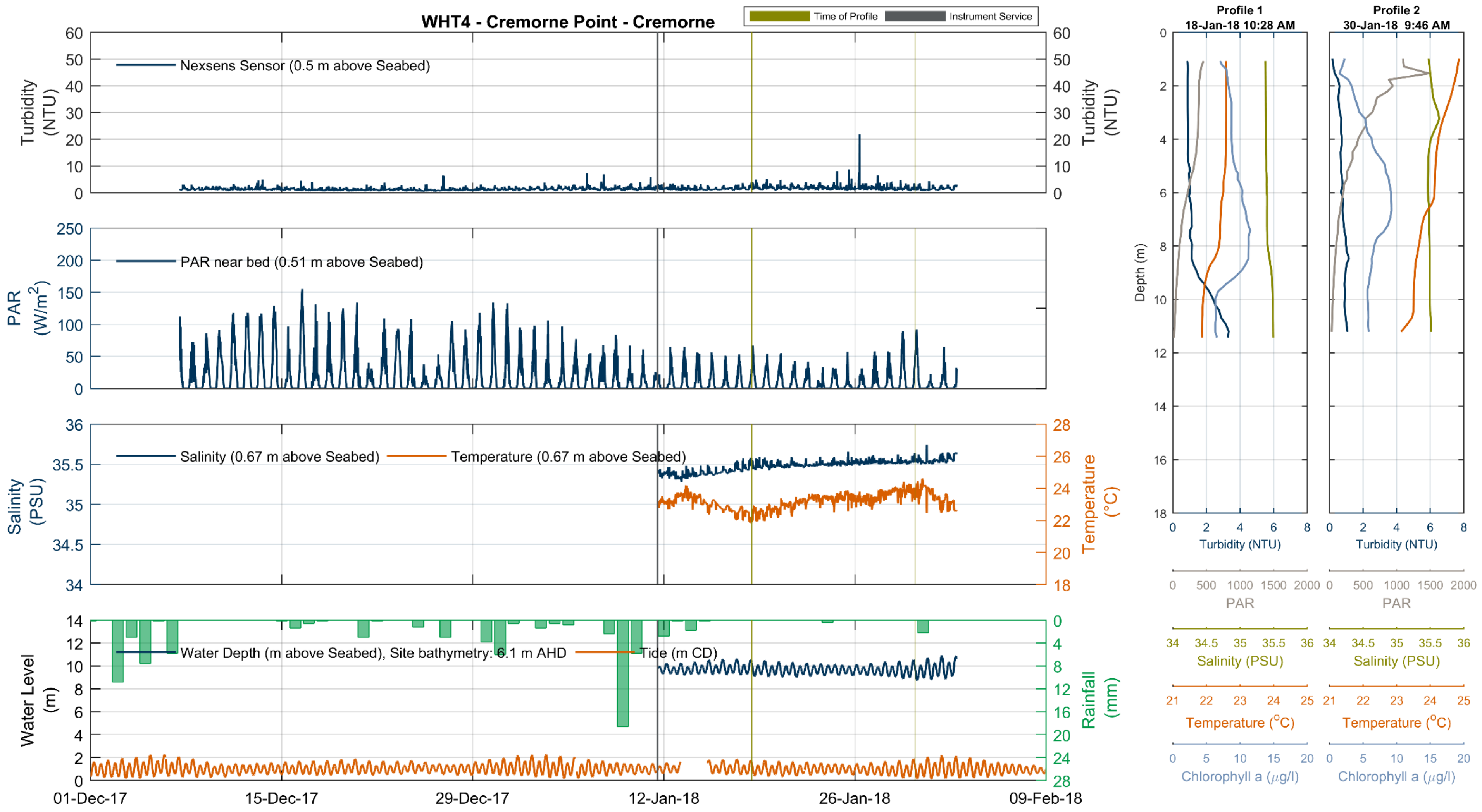

WHT2 @ 30-Jan-2018 08:59:48
Depth (m)
Turbidity (NTU)
PAR (W/m2)
Measured PAR
Modelled PAR
Salinity (PSU)
Dissolved Oxygen (mg/l)
Temperature (°C)
Chlorophyll a (µg/l)
Density (kg/m3)

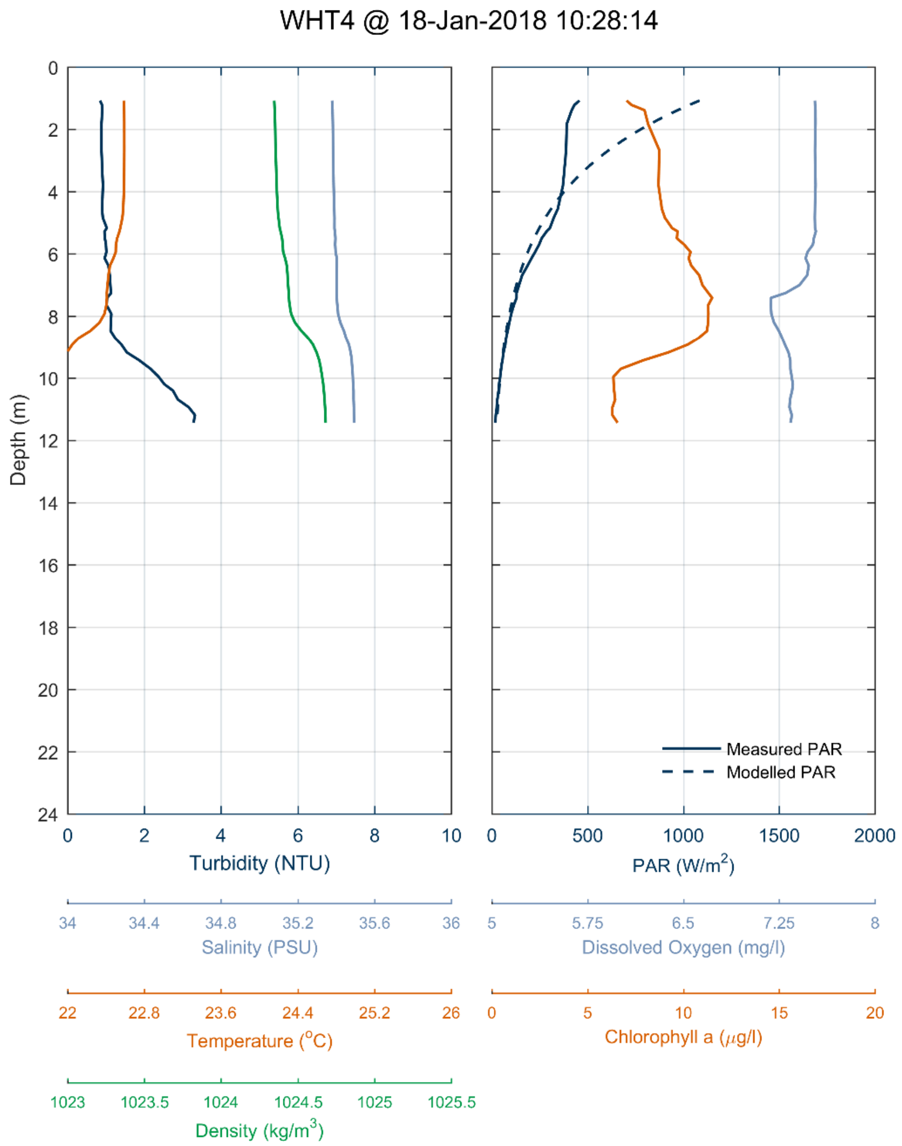


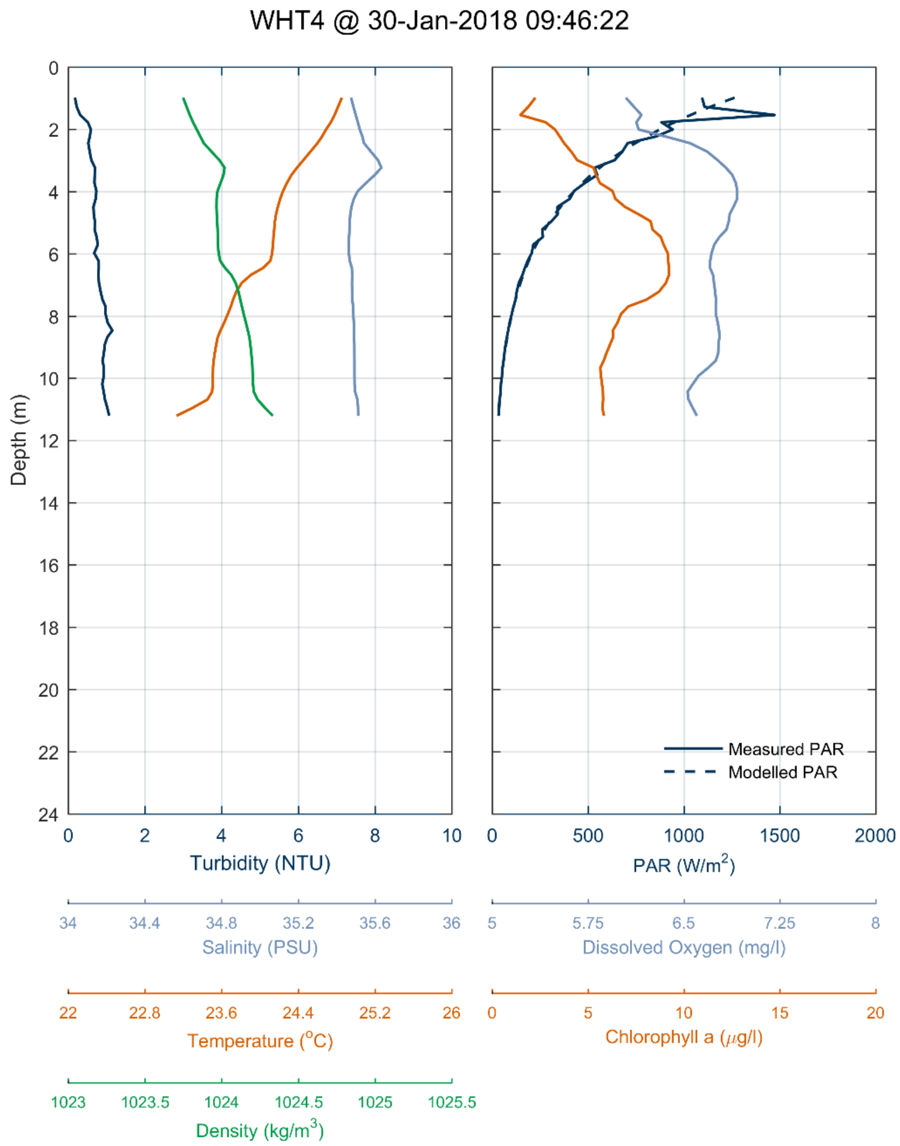
WHT3 - Berrys Bay - Waverton
Time of Profile
Instrument Service
Nexsens Sensor (0.51 m above Seabed)
FLNTU Sensor (0.51 m above Seabed)
Turbidity (NTU)
PAR near bed (0.51 m above Seabed)
PAR mid depth (1.98 m above Seabed)
Fluroscence Chlorophyll-α (0.5 m above Seabed)
PAR (W/m2)
CHL (ug/L)
Salinity (0.67 m above Seabed)
Temperature (0.67 m above Seabed)
Salinity (PSU)
Temperature (°C)
Water Depth (m above Seabed), Site bathymetry: 5.9 m AHD
Tide (m CD)
Water Level (m)
Rainfall (mm)
01-Dec-17
15-Dec-17
29-Dec-17
12-Jan-18
26-Jan-18
09-Feb-18
Profile 1
18-Jan-18 9:52 AM
Profile 2
30-Jan-18 9:15 AM
Depth (m)
Turbidity (NTU)
PAR
Salinity (PSU)
Temperature (°C)
Chlorophyll a (μg/l)

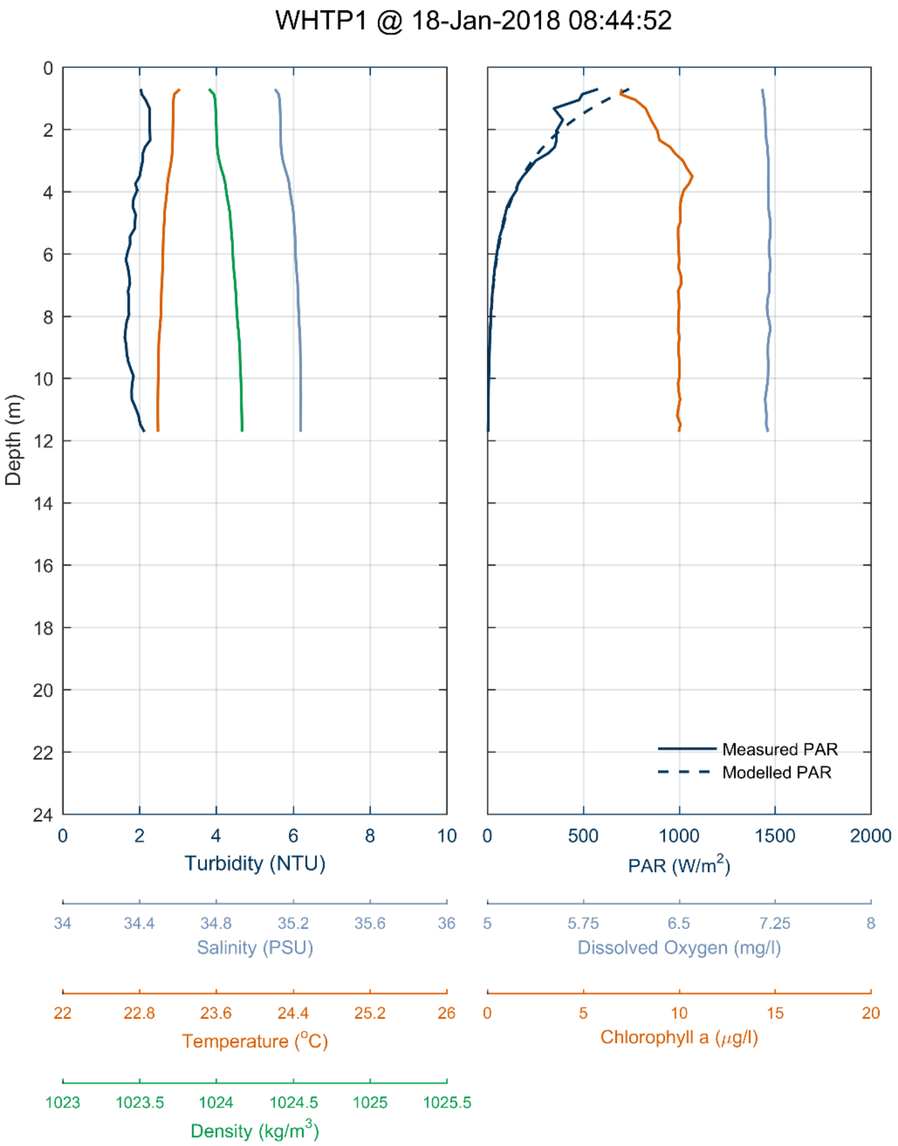

WHT3 @ 18-Jan-2018 09:52:17
Depth (m)
Turbidity (NTU)
PAR (W/m2)
Measured PAR
Modelled PAR
Salinity (PSU)
Dissolved Oxygen (mg/l)
Temperature (°C)
Chlorophyll a (µg/l)
Density (kg/m3)

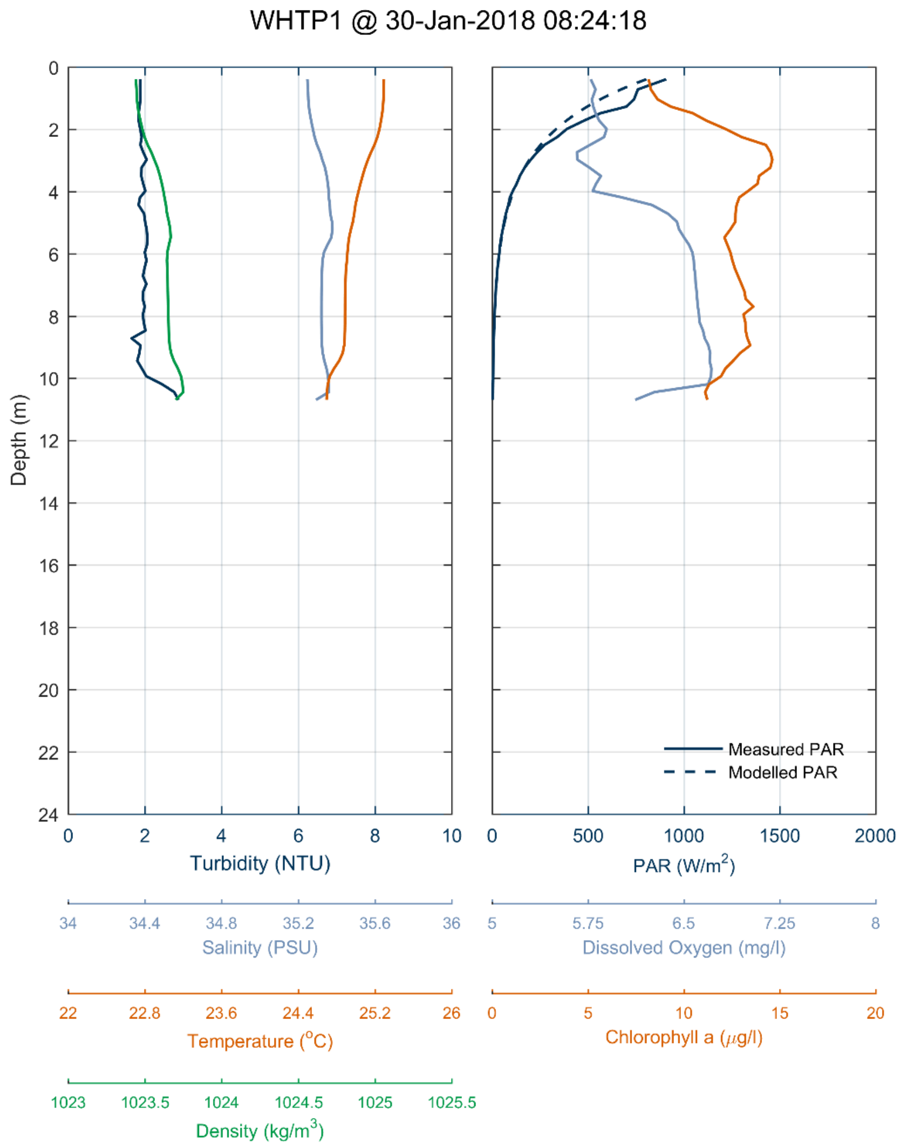

WHT3 @ 30-Jan-2018 09:15:36
Depth (m)
Turbidity (NTU)
PAR (W/m2)
Measured PAR
Modelled PAR
Salinity (PSU)
Dissolved Oxygen (mg/l)
Temperature (°C)
Chlorophyll a (µg/l)
Density (kg/m3)

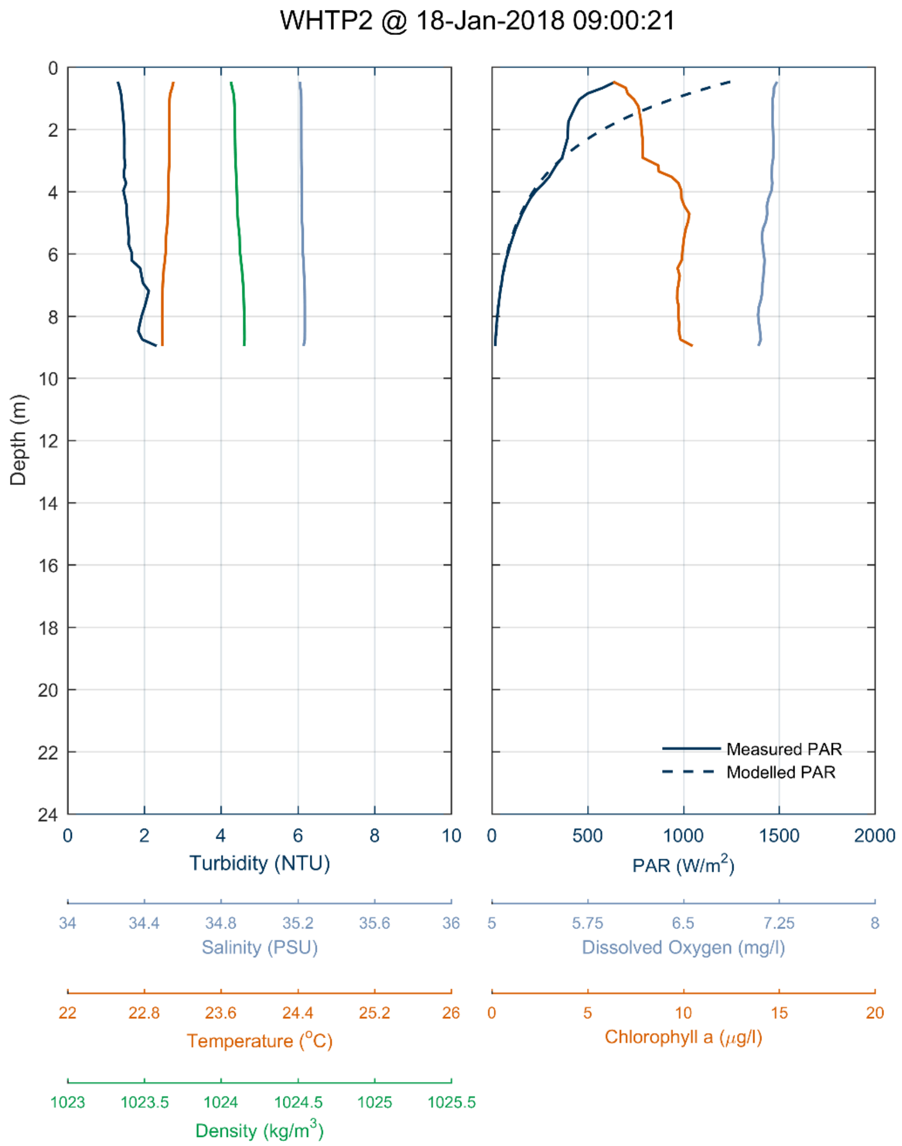

WHT4 - Cremorne Point - Cremorne
Time of Profile
Instrument Service
Nexsens Sensor (0.5 m above Seabed)
Turbidity (NTU)
PAR near bed (0.51 m above Seabed)
PAR (W/m2)
Salinity (0.67 m above Seabed)
Temperature (0.67 m above Seabed)
Salinity (PSU)
Temperature (°C)
Water Depth (m above Seabed), Site bathymetry: 6.1 m AHD
Tide (m CD)
Water Level (m)
Rainfall (mm)
01-Dec-17
15-Dec-17
29-Dec-17
12-Jan-18
26-Jan-18
09-Feb-18
Profile 1
18-Jan-18 10:28 AM
Profile 2
30-Jan-18 9:46 AM
Depth (m)
Turbidity (NTU)
PAR
Salinity (PSU)
Temperature (°C)
Chlorophyll a (μg/l)

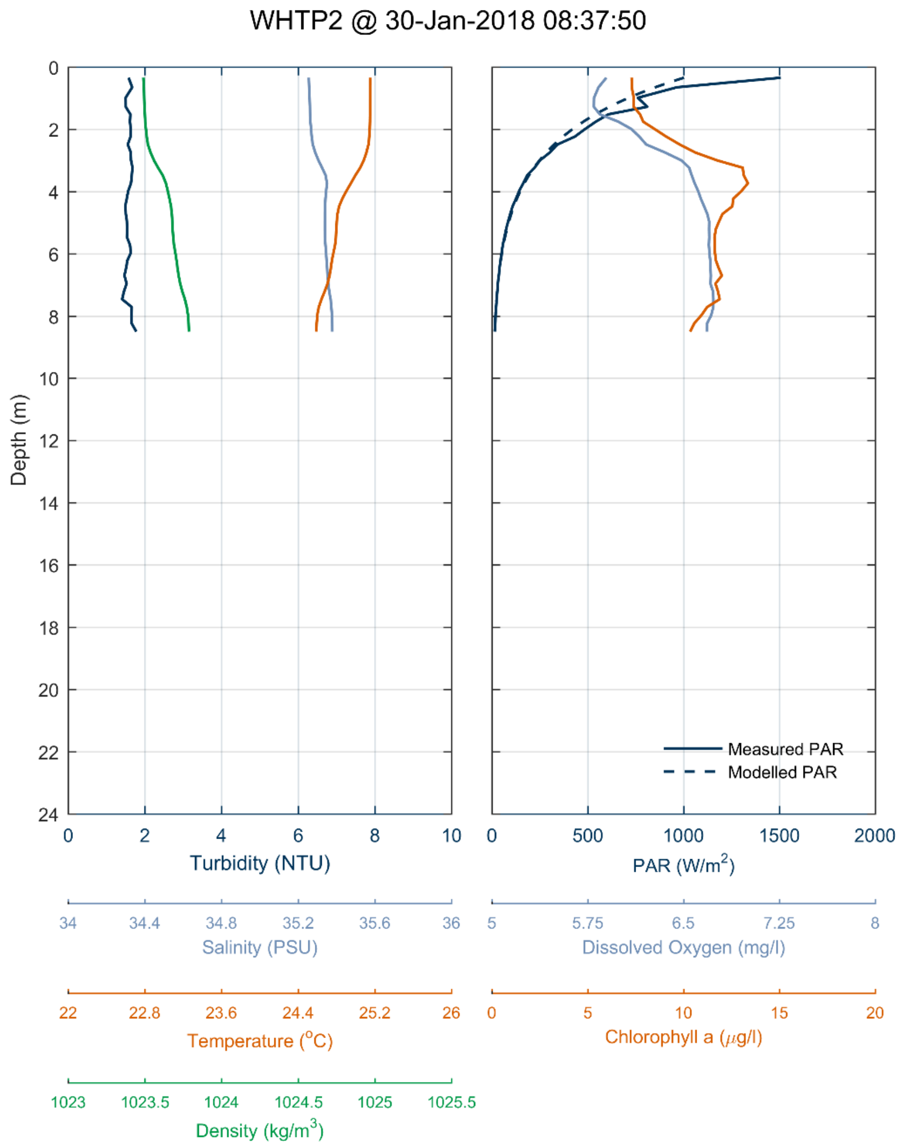

WHT4 @ 18-Jan-2018 10:28:14
Depth (m)
Turbidity (NTU)
PAR (W/m2)
Measured PAR
Modelled PAR
Salinity (PSU)
Dissolved Oxygen (mg/l)
Temperature (oC)
Chlorophyll a (µg/l)
Density (kg/m3)

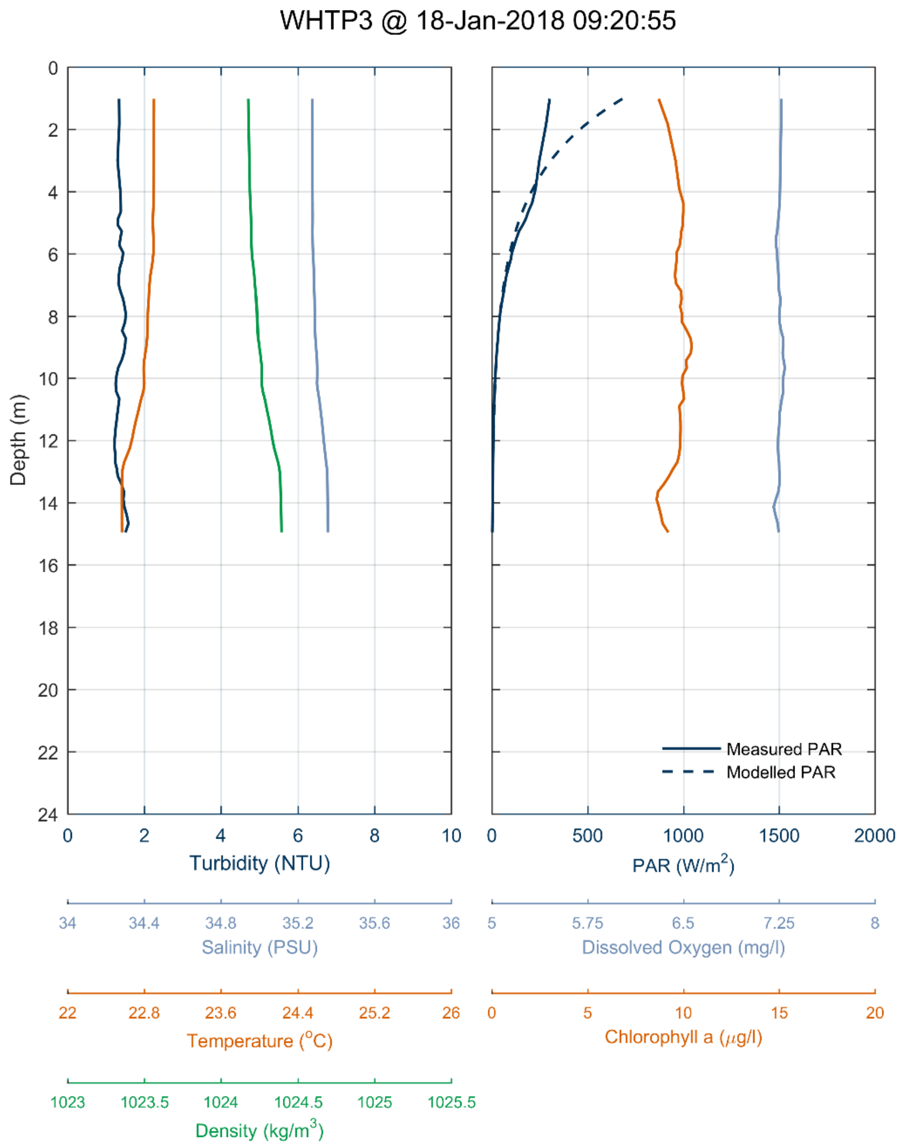

WHT4 @ 30-Jan-2018 09:46:22
Depth (m)
Turbidity (NTU)
PAR (W/m2)
Measured PAR
Modelled PAR
Salinity (PSU)
Dissolved Oxygen (mg/l)
Temperature (oC)
Chlorophyll a (µg/l)
Density (kg/m3)

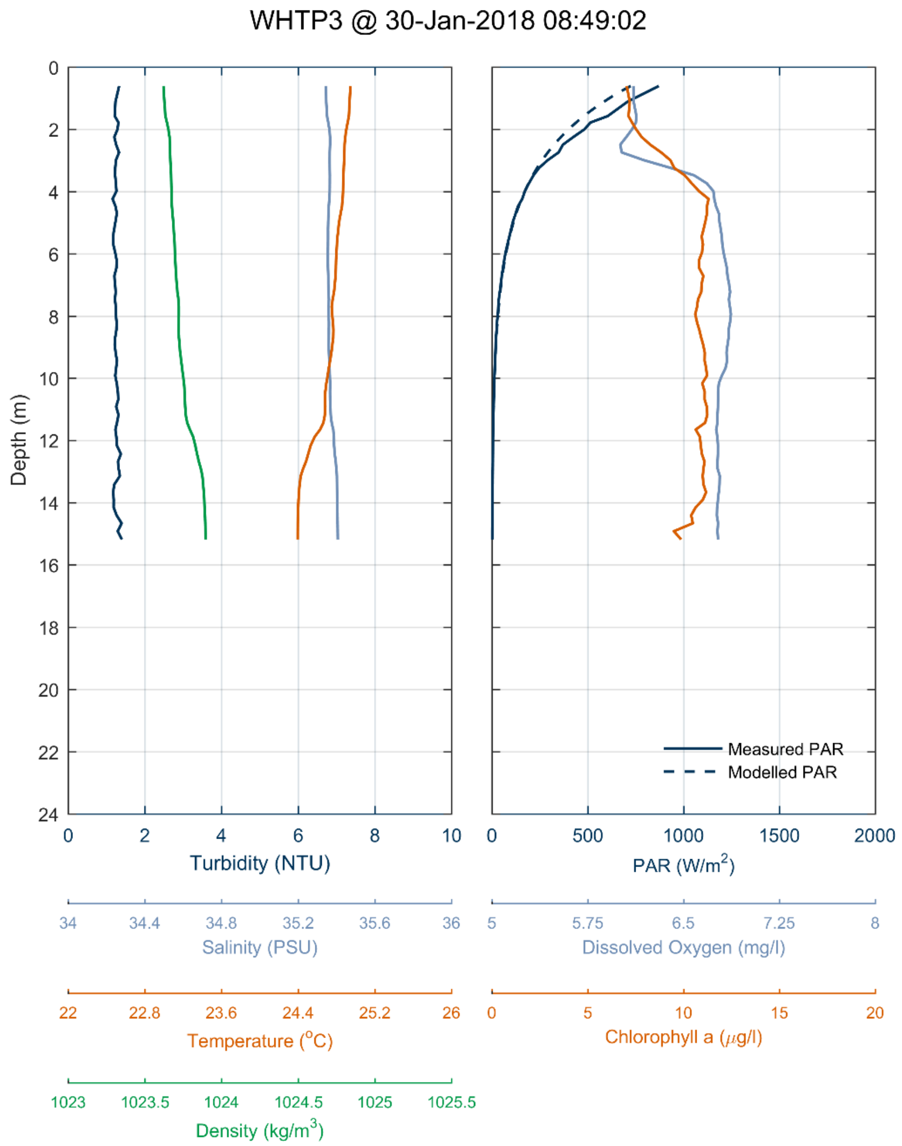

WHTP1 @ 18-Jan-2018 08:44:52
Depth (m)
Turbidity (NTU)
PAR (W/m2)
Measured PAR
Modelled PAR
Salinity (PSU)
Dissolved Oxygen (mg/l)
Temperature (oC)
Chlorophyll a (μg/l)
Density (kg/m3)

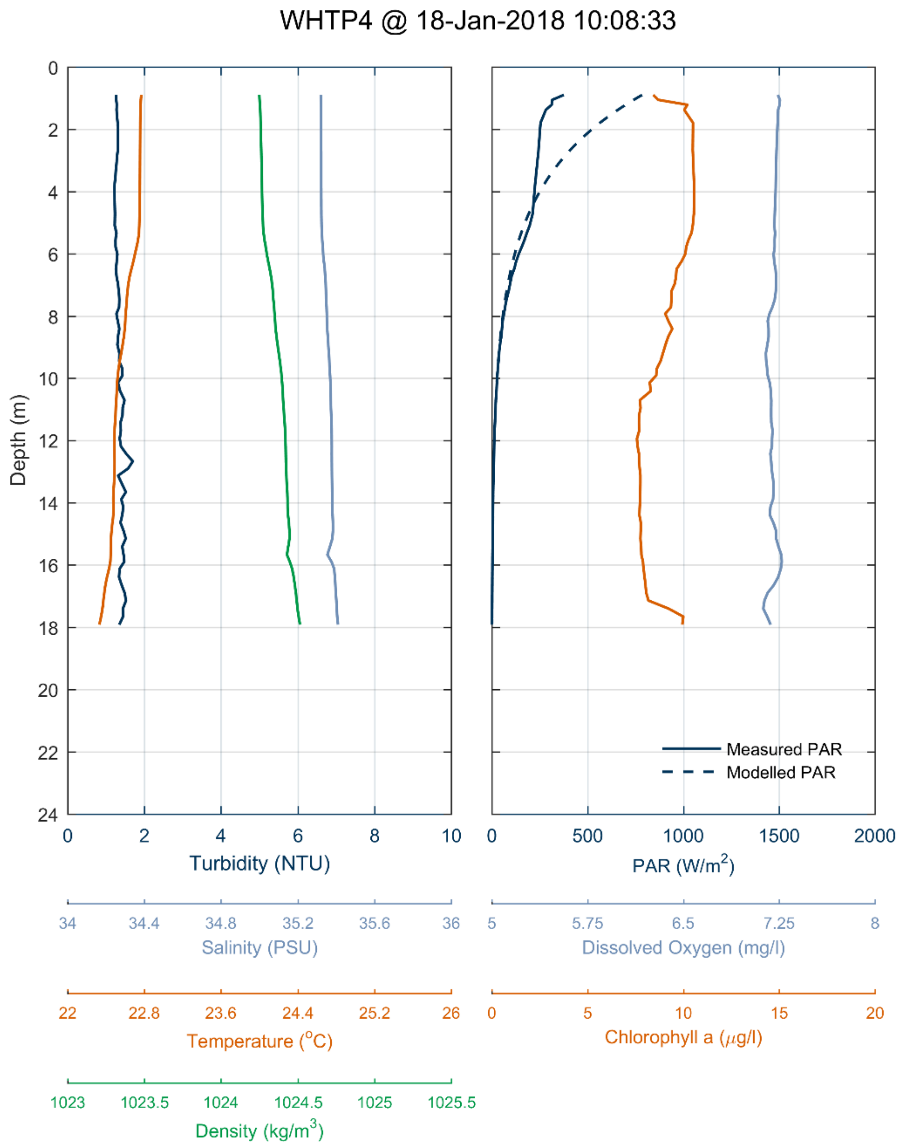

WHTP1 @ 30-Jan-2018 08:24:18
Depth (m)
Turbidity (NTU)
PAR (W/m2)
Measured PAR
Modelled PAR
Salinity (PSU)
Dissolved Oxygen (mg/l)
Temperature (oC)
Chlorophyll a (μg/l)
Density (kg/m3)


WHTP2 @ 18-Jan-2018 09:00:21
Depth (m)
Turbidity (NTU)
PAR (W/m2)
Measured PAR
Modelled PAR
Salinity (PSU)
Dissolved Oxygen (mg/l)
Temperature (°C)
Chlorophyll a (µg/l)
Density (kg/m3)


WHTP2 @ 30-Jan-2018 08:37:50
Depth (m)
Turbidity (NTU)
PAR (W/m2)
Measured PAR
Modelled PAR
Salinity (PSU)
Dissolved Oxygen (mg/l)
Temperature (°C)
Chlorophyll a (µg/l)
Density (kg/m3)


WHTP3 @ 18-Jan-2018 09:20:55
Depth (m)
Turbidity (NTU)
PAR (W/m2)
Measured PAR
Modelled PAR
Salinity (PSU)
Dissolved Oxygen (mg/l)
Temperature (°C)
Chlorophyll a (μg/l)
Density (kg/m3)


WHTP3 @ 30-Jan-2018 08:49:02
Depth (m)
Turbidity (NTU)
PAR (W/m2)
Measured PAR
Modelled PAR
Salinity (PSU)
Dissolved Oxygen (mg/l)
Temperature (°C)
Chlorophyll a (μg/l)
Density (kg/m3)


WHTP4 @ 18-Jan-2018 10:08:33
Depth (m)
Turbidity (NTU)
PAR (W/m2)
Measured PAR
Modelled PAR
Salinity (PSU)
Dissolved Oxygen (mg/l)
Temperature (oC)
Chlorophyll a (µg/l)
Density (kg/m3)

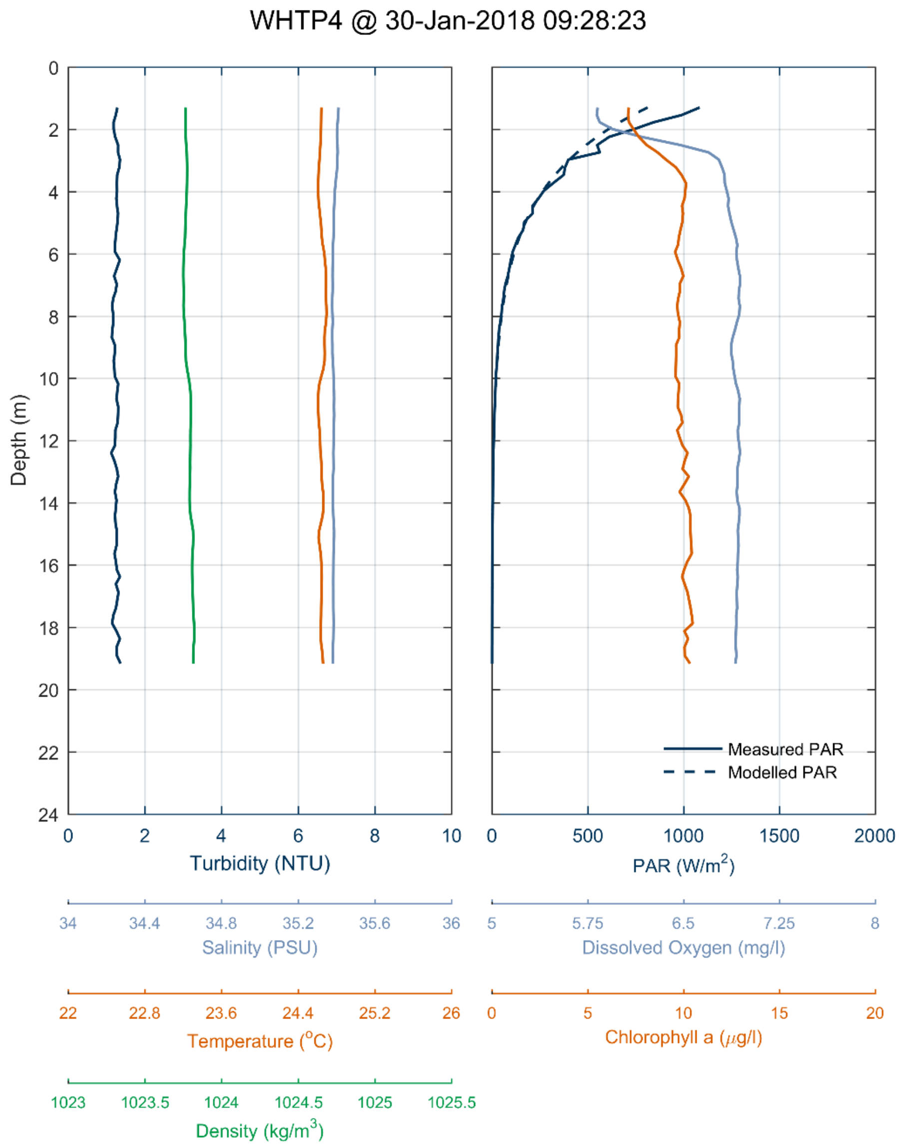

WHTP4 @ 30-Jan-2018 09:28:23
Depth (m)
Turbidity (NTU)
PAR (W/m2)
Measured PAR
Modelled PAR
Salinity (PSU)
Dissolved Oxygen (mg/l)
Temperature (oC)
Chlorophyll a (µg/l)
Density (kg/m3)

Table A-2 Light extinction, turbidity and chlorophyll-a values derived from the vertical profiles and from the time series fixed deployment sites

Curve fit parameter	Site WHT1		Site WHT2		Site WHT 3		Site WHT 4	
Date/Time	18/01/2018 8:23	30/01/2018 8:11	18/01/2018 9:33	30/01/2018 8:59	18/01/2018 9:52	30/01/2018 9:15	18/01/2018 10:28	30/01/2018 9:46
Profile derived parameters								
Depth at upper fixed sensor (m)	8.69	8.71	5.70	5.47	7.95	7.67	8.48	7.94
Profiler PAR (Wm^{-2})	0.9	1.7	51.7	47.3	42.3	37.9	47.2	59.7
Depth at near-bed sensor (m)	9.95	10.03	6.95	6.70	9.16	8.93	9.70	9.42
Profiler PAR (Wm^{-2})	1.0	2.7	64.4	44.3	36.2	42.5	50.9	61.1
Extinction coefficient, K (m^{-1})	0.71	0.64	0.41	0.47	0.33	0.42	0.39	0.36
Surface light, I_0 (Wm^{-2})	1420	1228	1915	1603	2030	1702	2196	1894
Photic depth, z_p (m)	6.45	7.17	11.16	9.78	13.80	10.98	11.91	12.70
Light profile curve fit coefficient of determination R^2	1.00	0.99	0.99	1.00	0.90	1.00	0.97	1.00
Turbidity at near-bed sensor depth (NTU)	2.8	4.5	1.4	1.9	1.6	1.1	2.8	1.0
Turbidity depth-average (NTU)	3.3	2.7	1.6	1.9	1.5	1.1	1.5	0.8
TSS depth-average (mg/L)	4.2	3.5	2.4	2.6	2.2	1.7	2.3	1.5
Fluorescence chlorophyll-a (µg/L)	11.5	13.9	9.6	9.2	9.0	8.0	6.3	5.8
Time series parameters								
PAR at mid-depth sensor (Wm-2)	2	4	86	84	63	64	76	102
PAR at near-bed sensor depth (Wm^{-2})	-	-	40	47	26	30	30	45
Extinction coefficient, K (m-1)	-	-	0.54	0.52	0.46	0.44	0.43	0.39
Turbidity (NTU)	3.0	8.1	2.0	1.7	2.0	1.5	3.8	1.0
Fluorescence chlorophyll-a (µg/L)	-	-	10.5	11.2	10.3	9.1	-	-

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