TOONDAH HARBOUR

APPENDIX 2 - G

WATER QUALITY
TECHNICAL REPORT

Toondah Harbour

Water Quality Technical Reference Report

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freshwater estuarine marine

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Introduction

This report addresses the water quality components of the final guidelines for the preparation of a draft environmental impact statement (EIS) for the Toondah Harbour project under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). In this report, current baseline water quality data is compared to the relevant water quality objectives (WQO), and results of modelling (BMT 2022) are used to assess likely impacts to water quality from the proposed works.

Water quality, and in particular the concentration of nutrients, contaminants and suspended solids is a key determinant of the ecological health of estuarine and marine communities. The results of this assessment are used in the assessment of impacts to marine ecology (EIS Chapter: Marine Ecology).

Methods

Available literature and data for water quality in the vicinity of the proposed development was collated and reviewed, including data collected as part of the Ecological Health Monitoring Program (EHMP) Queensland, and data collected during the maintenance dredging of Toondah Harbour and the Fison Channel in 2019. In addition, water quality loggers were installed at five sites for between approximately 18 months and four years. This data was used to describe current conditions and to provide background information to assist in the assessment of the impact of the proposed development on water quality in this area.

Existing Environment

Moreton Bay is one of the largest estuarine bays in Australia and supports a diverse range of ecosystems. While water quality in the bay deteriorates following heavy rainfall and floods, these are usually short-term changes, lasting from weeks to months. The north-eastern section of the Bay has the best water quality due to little pollution and regular oceanic flushing, while the south-western bay has poorer water quality, that regularly exceeds Queensland WQOs.

Toondah Harbour is approximately 20 km south of the Brisbane River estuary and approximately 17 km north of the Logan River estuary. Water quality in the vicinity of the project footprint is highly variable and influenced by several environmental factors, including tidal state, season and wind.

Overall, turbidity near the project footprint was consistently higher than the relevant WQO. Turbidity was also higher in spring and summer than in autumn and winter, and was higher at the loggers around low tide, likely due to wave action in the shallow water resuspending sediment.

The concentration of nutrients near the project footprint was typically above WQO, and highest in summer and lowest in winter.

Assessment of Potential Impacts

Modelling of potential impacts to water quality indicates that:

- the internal waterways created by the project are likely to be well flushed, and it is unlikely there will be phytoplankton blooms or eutrophication within these waterways
- while there may be slight increases in the concentration of total nitrogen and phosphorous in the internal waterways, these increases are very small compared to current concentrations
- in wet weather conditions there is likely to be a reduction in the concentration of total suspended solids, total nitrogen and total nutrients in the intertidal area southwest of the ferry terminal due to an increase in the proportion of treated stormwater flows
- stormwater from the project will not significantly negatively impact the management intent of Area C2, nor the nearby High Ecological Value waters in Area HEVa1284
- during both dredging campaigns most of the increases to turbidity are confined to the channel
- changes to turbidity due to dredging are likely to be limited to the dredge campaigns, with turbidity returning to ambient levels once dredging ceases
- the modelled increases in turbidity during the dredging campaigns are typically short-lived (around 20 NTU for a few hours per day immediately outside the channel) and are usually less than ambient maximums (which often exceed 100 NTU in nearshore areas)
- a combination of regional forcing and intertidal dynamics results in the net northward transport of the dredge sediment plume, particularly over the ebbing tide phase
- in both dredging stages, the plume is advected to the east, before sweeping northward due to tidal exchange near Sandy Island, and
- significantly, from an ecological perspective, the period of high turbidity is not increased by the proposed dredging, as peaks due to dredging coincide with ambient high turbidity.

While flushing is likely to be adequate without the proposed additional connections from the internal waterways to the Bay, it is recommended they are created, as this will decrease flushing times and assist in maintaining good water quality.

Monitoring Dredging and Reclamation

Water quality will be monitored throughout the dredging and reclamation works, and during ongoing use and operation.

During dredging, water quality will be assessed up- and down-current of the dredge activity, and will be logged every 15 minutes at nearby sensitive habitats and control sites. BPAR and the ecological condition of habitats at nearby sensitive habitats and controls will also be monitored. Investigation and management triggers will be set for both water quality downstream of dredge activities and for BPAR at nearby sensitive habitats.

When an investigation trigger is reached or exceeded, the likely cause will be investigated and determined. Where investigations indicate the exceedance is likely due to dredge related activities, management measures (including modifying or ceasing dredging) will be implemented to rectify the issue.

Monitoring Water Quality Within the Marina

Water quality will be visually assessed daily within the internal waterways. Water quality will also be monitored monthly for the first twelve months in the areas of predicted maximum flushing times (i.e. in the central marina, and the marina entrance channel) and at two background points.

If after 12 months water quality does not comply with the expectations of the models, is significantly poorer than historical water quality, and/ or is poorer than at the control sites, water quality data will continue to be collected each month, until such time as these expectations are met. Further, the cause of the poor water quality will be investigated, and management measures (e.g. aeration, re-evaluation of stormwater management) implemented to improve it.

If, after twelve months, water quality in the channels and marina complies with the expectation of the models, or is not significantly different to historical data or to water quality at the control sites, water quality data will only be collected after significant rainfall events (i.e. > 20 mm within a 24 hour period) for three years.

Where the percent saturation of dissolved oxygen is within WQO outside the development but is not within the WQO inside the development:

- monitoring of dissolved oxygen will be increased to daily
- the cause will be investigated, and
- the waterway managed to prevent the percent saturation of dissolved oxygen decreasing to less than 85%.

Where the annual median concentration of nutrients, chlorophyll a, or enterococci is higher than the background (control) conditions and exceeds the WQO, the cause and impacts will be investigated, and where necessary management actions implemented to rectify this.

After the completion of works, water quality monitoring of the marina will be required to assess any changes in water quality due to runoff and altered hydrodynamics. Water quality will be measured in the marina, ferry terminal harbour and channel quarterly over two years for:

- physico-chemical parameters measured in situ (i.e. dissolved oxygen, pH, salinity and turbidity);
- nutrients (e.g. total nitrogen, total phosphorous, oxides of nitrogen, organic nitrogen, ortho phosphorous, ammonia)
- total suspended solids, and
- chlorophyll a.

Conclusions

Stormwater management, dredging activities and reclamation works have been designed to minimise impacts to water quality. The proposed works will also be subject to an Environmental Management Plan that ensures detrimental impacts to water quality are minimised by using appropriate:

- erosion and sediment controls, including the use of silt fences where possible
- management of potential acid sulfate sediments, and
- chemical (including fuel) management and containment.

Based on the modelling of potential impacts, and where monitoring and these management plans are effectively implemented, there is likely to be little long-term significant negative impact to water quality as a result of the Project.

1 Introduction

1.1 Project Description

Toondah Harbour is an existing marine facility in the suburb of Cleveland in Redland City, approximately 30 km south of Brisbane. The harbour serves as the base for water taxi, passenger and vehicular ferry services between the mainland and Minjerribah (North Stradbroke Island), as well as a public boat ramp for recreational vessels. The overwater areas are made up of a mix of tidal and intertidal habitats with the majority being intertidal mudflat but also include existing wet berths, swing basin and the public navigation channel known as the Fison Channel.

The harbour was constructed on reclaimed land, and has operated since 1972 when it was used as barge terminal to support sand mining operations on Minjerribah (North Stradbroke Island), with vehicular ferries commencing in 1974. The most recent upgrades occurred in the early 2000s when additional hard stand car parking and the boat ramp were added.

In June 2013, the Queensland Government declared Toondah Harbour a priority development area (PDA) under the *Economic Development Act 2012* (ED Act) at the request of Redland City Council (RCC). The intent of the PDA is to revitalise the harbour and establish Toondah Harbour as a high-quality urban environment that capitalises on the high amenity of Moreton Bay and provides opportunities for a range of activities including outdoor dining, tourism facilities, residential, commercial development, marina and a public beach.

After an open tender process run by Economic Development Queensland and RCC, Walker Group Holdings Pty Limited (the proponent) was announced as the preferred developer of State and Council land in the PDA. The proponent proposes to develop a mixed use residential, commercial, retail and tourism precinct including new ferry terminals and a marina in accordance with the Toondah Harbour PDA Development Scheme adopted by the Queensland Government in 2014. Key components of the project include:

- capital dredging of approximately 500,000m^3 of marine sediment to widen and lengthen Fison Channel to meet the minimum requirements for safe navigation set out in the PIANC (2014) Harbour Approach Channels Design Guidelines and Australian Standard 3962 – 2001 Guidelines for the Design of Marinas
- provision of a dredge spoil pond for ongoing maintenance dredging of the marina coves and entrance channel

- an upgraded ferry port including improved vehicle and people waiting and loading facilities, increased car parking for ferry users, berthing for ferry tourism operations, transport hub and improved marine service facilities
- beneficial re-use of the dredged material on the tidal flats north of the ferry port to create a landform for the recreational, tourism, residential and marina uses (the reclamation areas)
- an approximately 200 berth marina and associated facilities, and
- a network of open space and recreational areas including a 3.5 hectare (ha) foreshore park, a wetland and cultural education centre and range of boardwalks, plazas, nature trails and pocket parks.

Capital dredging to widen and deepen the Fison Channel and extend the swing basin is an integral part of the project. The existing public navigation channel is 2.55km long and typically 45m wide (excluding batters) with a target depth of -2.5m LAT. It extends from the swing basin immediately in front of the existing barge berths, via three significant bends to exit into deeper water approximately 1.5km past Cassim Island. The swing basin's existing diameter is significantly less than the accepted minimum of 1.5 times the maximum length of vessels currently using the harbour. Fison Channel itself is too narrow for larger vessels, such as the frequent passenger and vehicle ferries, to safely pass each other. It is therefore operating as a one-way access with vessels forced to wait at either end for the channel to clear prior to commencing navigation. Channel use is constantly monitored by the ferry operators to safeguard against navigational issues. Barges travelling to and from Minjerribah (North Stradbroke Island) are also regularly observed 'bottoming out' in the channel, generating turbidity plumes and risking damage to the vessels.

Capital dredging of Fison Channel has been designed to provide safe, two-way navigation for all vessels including vehicle ferries. The swing basin diameter will be increased to improve manoeuvrability and Fison Channel widened to 75 m (excluding batters) with a target depth of -3 m LAT. The increased target depth results in dredging to the end of the channel (approximately 2.55km) to meet the natural sea floor depth. Dredging will result in the disturbance of approximately 530,000 m3 of material including an allowance for over dredging.

Dredging will be carried out mechanically using a barge mounted backhoe dredge or similar, transported to the reclamation areas via hopper or flat top barges and unloaded at a temporary dock constructed specifically for the purpose of unloading the dredged material. A perimeter bund will be established around the northern and southern reclamation areas to contain the dredged material and limit indirect impacts outside of the project footprint. The bund will comprise an inter-locking sheet piling cut-off wall, vibrated into place, within a rock revetment bund capped by a trafficable gravel vehicle and machinery access at a level above highest astronomical tide (HAT).

Beneficial reuse of dredge materials is proposed to reclaim land for development areas. The formation of land through reclamation works will be split into two broad stages tied to the two proposed dredging campaigns. Stage 1 (referred to as the northern precinct) will incorporate the northern residential and central marina precincts and 2 is the southern residential precinct. In parallel with Stage 1, the new ferry port and associated car parking will be constructed. The development of the balance onshore area will occur concurrently with the landform stages over the life of the project. Works to upgrade the port will be carried out early in the project staging and will commence in the first year of construction. The stages are broadly described below.

Stage 1 Reclamation - Northern Residential and Central Marina Precinct

The initial development sequencing will produce the northern precinct, which includes the northern residential area and foreshore park as well as the central marina precinct including commercial space. The delivery of the northern precinct will entail enclosing the entire area by sheet piling and creating of a bund using imported rock armouring, stabilised landform earthworks and marina earthworks, subdivisional roadworks, and utility servicing ready for allotment building works to commence.

The northern precinct will be formed using stabilised material from within the bunded area and material excavated to create the internal waterways and marina. Once material has been removed from this area, a receiving dock and dredge material transfer area will be constructed, and the first dredging campaign will commence to create the port swing basin and deepening and widening of the inner navigation Channel. The dredge material will be used to create the landform around the marina with temporary earthen bunds used to separate internal works areas.

Stage 2 Reclamation - Southern Residential Precinct

The southern residential precinct is anticipated to commence approximately six years after the start of works; however, the timing may change as a result of several factors such as commercial requirements and ongoing review of the environmental management framework. This precinct encompasses close to half of the residential yield for the project as well as a boat ramp for non-motorised vessels, rock breakwater, conservation area and will provide open water access to the marina.

Construction staging will be similar to Stage 1 with the entire precinct enclosed by sheet piling and rock bund, and material within the reclamation area and internal access Channel stabilised and utilised for land formation before the second dredging campaign commences and material used to create the landform. Water access to the marina will be provided early in this stage creating improved water flow for the marina.

Ferry Terminal and Land-side Residential Development Area

The delivery of carpark works will comprise the stabilisation of the existing dredge spoil disposal area and the clearing of mangroves and construction of earthworks to provide a significant extension to the existing carparking facility servicing the island ferry operations. Additional fill material requirements will be supplied from nearby quarries or using stabilised material from the main reclamation area works. The construction of the car park for the ferry port will include upgrading of the waterline revetment works, as required.

The project has been designed to balance cut and fill with all dredged and excavated sediments to be dried on site and used within the reclamation, minimising the requirement for imported material. The only materials expected to be sourced externally for construction of the landform is rock armouring for the creation of the external bunds, agricultural lime to treat potential acid sulfate soils and a small amount of quarry material to assist in stabilising the dredge material.

A stormwater quality management strategy is proposed for the site consisting of education, streetscape/ foreshore parkland bioretention systems, bioretention basins, gully baskets and rainwater tanks. Streetscape bioretention systems are proposed to be adopted to treat all roads and car parks within the development. Further details are provided in the BMT Technical Report (BMT 2022).

1.2 Scope of Study

This report addresses the surface water quality requirements of the EPBC Act EIS Guidelines for the preparation of a draft EIS and other legislative requirements issued by the Australian Government Department of the Environment and Energy (DEE) (now the Department of Agriculture, Water and the Environment (DAWE)) in 2019. The requirements include:

- a summary of State government legislation and policies with respect to management of, and impacts to, water quality

- an assessment of baseline water quality, and comparison to the relevant water quality objectives (WQO), comprising the:
  - Australian & New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018)
  - Moreton Bay environmental values and water quality objectives (DERM 2010a) for aquatic ecosystem, moderately disturbed water area - Area C2 (Central Bay) and for aquatic ecosystem, high ecological value – Area HEVa1284
  - Redland Creeks environmental values and water quality objectives (DERM 2010b) for aquatic ecosystem, moderately disturbed mid estuary, and
- an assessment of impacts on marine water quality resulting from construction and ongoing uses (i.e. dredging, excavation, reclamation, construction and increased use). The assessment of impacts is based on the outcomes of coastal processes and hydrodynamic modelling provided in BMT Technical Report (BMT 2022). All references to modelling in this report are based on this Chapter.

2 Legislation, Policy and Planning Instruments

2.1 National Water Quality Management Strategy (NWQMS)

The purpose of the NWQMS is to protect the nation's water resources by maintaining and improving water quality, while supporting dependent aquatic and terrestrial ecosystems, agricultural and urban communities, and industry. Channels for delivery of the NWQMS comprise (Water Quality Australia 2017):

- Policy that enables effective water quality management for the delivery of fit for purpose water that supports community values.
- Process (framework) for the development and implementation of management plans. These plans focus on the reduction of pollution released into coastal pollution hotspots and other aquatic ecosystems.
- Guidelines that are developed using best available scientific evidence, providing benchmarks and targets for managing water quality across a range of risk profiles and uses.

The National Water Quality Guidelines provide default guideline values (DGV) for a range of stressors, but advise site-specific guideline values should be developed following the methods in the NWQMS and used in preference to the DGV.

The delivery framework for the strategy is detailed in the National Water Quality Management Strategy Charter and includes developing water quality management plans for catchment waterways using the following steps (Australian Government 2018):

- Step 1 - Examine current understanding
- Step 2 - Define community values and management goals
- Step 3 - Define relevant indicators
- Step 4 - Determine water/sediment quality guideline values
- Step 5 - Define draft water/sediment quality objectives
- Step 6 - Assess if draft water/sediment quality objectives are met
- Step 7 - Consider additional indicators or refine water/sediment quality objectives
- Step 8 - Consider alternative management strategies
- Step 9 - Assess if water/sediment quality objectives are achievable
- Step 10 - Implement agreed management strategy.

The DGVs in the National Water Quality Guidelines are not mandatory and have no formal legal status, but that, where appropriate, state, territory or local jurisdictions may incorporate the processes and tools, including the DGVs, provided within the Water Quality Guidelines, into their water quality protection policy and regulatory tools (ANZG 2018). In accordance with the NWQMS the State of Queensland has developed site-specific guidelines for waters throughout the State (Section 2.3). As per the NWQMS site-specific guidelines are referred to in this report.

2.2 Environmental Protection Act 1994[1] (EP Act)

The objective of the EP Act is to protect Queensland's environment while allowing for development that improves the total quality of life, both now and in the future, in a way that maintains ecological processes (ecologically sustainable development). This includes protection of Queensland's waters and wetlands.

2.3 Environmental Protection (Water and Wetland Biodiversity) Policy 2019[2] (EPP Water and Wetlands)

The purpose of this policy is to achieve the objective of the EP Act in relation to waters and wetlands by:

- identifying environmental values for waters and wetlands
- identifying management goals for waters
- stating water quality guidelines and water quality objectives to enhance or protect the environmental values
- providing a framework for making consistent, equitable and informed decisions about waters, and
- monitoring and reporting on the condition of waters.

As recommended by the NWQMS, the State of Queensland has used the framework of the NWQMS to develop water quality management plans for waters throughout the State (site specific guideline values), using the steps outlined in Section 2.1. The NWQMS advises that site specific guidelines should be used in preference to National default guidelines.

[1] *Environmental Protection Act 1994*. Current as of 25 May 2020.

[2] Environmental Protection (Water and Wetland Biodiversity) Policy 2019. Current as of 1 December 2019.

The site-specific guidelines and supporting maps for south-east Queensland are provided under Schedule 1 of the EPP Water and Wetlands, with interactive maps also provided online (DES 2022).

Environmental values (EVs) for water are the qualities that make it suitable for supporting aquatic ecosystems and human use. These EVs need to be protected from the effects of habitat alteration, waste releases, contaminated runoff and changed flows to ensure healthy aquatic ecosystems and waterways that are safe for community use (DERM 2010a).

Water quality guidelines (WQGs) are numerical concentrations (or descriptive statements) for key indicators (e.g. total concentration of nitrogen) that protect an EV. WQGs are used to develop Water quality objectives (WQO) (DERM 2010a).

WQO are long term goals for water quality management. They are numerical concentrations (or descriptive statements) of indicators that will support and protect the designated EVs. They are based on scientific criteria and WQGs and may be modified by other inputs (e.g. social, cultural and economic) (DERM 2010a).

Different types of waters, and the management intent for each type, are defined in the EPP Water and Wetlands:

- **High ecological value (HEV) waters**: The biological integrity of HEV water is effectively unmodified or is highly valued. In HEV waters, WQO are to be maintained. In Moreton Bay there is another sub-category of HEV waters: HEV waters (achieve). The management intent for these waters is to achieve the WQO.
- **Slightly disturbed waters**: Physical and chemical indicators of slightly disturbed waters are slightly modified, and they have the biological integrity of HEV waters. In slightly disturbed waters, water quality is to be improved where needed, to achieve WQO.
- **Moderately disturbed waters**: In moderately disturbed waters biological integrity is adversely affected by human activity to a relatively small but measurable degree. In moderately disturbed waters, water quality needs to be maintained, or improved where needed, to meet WQO.
- **Highly disturbed waters** are significantly degraded by human activity. In highly disturbed waters, water quality needs to be improved to meet the WQO.

EVs and WQO for Moreton Bay are provided in the EPP Water and Wetlands: Moreton Bay environmental values and water quality objectives (DERM 2010a). Water types and management intents for Moreton Bay are shown in Figure 11.1, and for the area in the vicinity of the proposed development in Figure 11.2.

Under the EPP Water and Wetlands, the project footprint and part of the broader Investigation Area are in moderately disturbed waters (Area C2). The Investigation Area is a conservative estimate of the area of potential impact to the coastal processes and water quality from the project (BMT 2022). The northern section of the Investigation Area is in HEV waters (maintain, Area C1). Offshore of the proposed Channel, between Cassim and Coochiemudlo Islands there is an area of HEV waters (achieve, Area HEVa1284).

The management intent for Area C2 is for water quality to comply with the WQO and for the median depth distribution of the seagrass *Zostera muelleri* of 2.2 m AHD to be maintained.

The WQO for HEV Area C1 are to maintain existing water quality (20^{th}, 50^{th} and 80^{th} percentiles), habitat, biota, flow and riparian areas, and to maintain the existing median depth distribution of the seagrass *Z. muelleri* of 2.2 m AHD.

The WQO for area HEVa1284 are to achieve effectively unmodified water quality (20^{th}, 50^{th} and 80^{th} percentiles), habitat, biota, flow and riparian areas, and to maintain the existing median depth distribution of *Z. muelleri* of 1.9 m AHD.

2.4 Queensland Planning Act 2016[3] and State Planning Policy (SPP)[4]

The proposed development is a declared PDA under the *Economic Development Act 2012* (ED Act), and consequently will be assessed under that Act. Under this Act assessment of State interests (defined in the State Planning Policy (SPP), an instrument under the Planning Act) are considered.

Water quality is a state interest under the SPP. The SPP provides design objectives for stormwater management for developments (Table 2.1).

Table 2.1 SPP stormwater management design objectives.

Pollutant	Criteria
Total suspended solids	80% reduction
Total phosphorus	860% reduction
Total nitrogen	45% reduction
Gross pollutants (5 mm or larger)	90% reduction

[3] Planning Act 2016. Current as of 1 October 2020.

[4] State Planning Policy 2017. Current as of July 2017.

3 Assessment Methods

Water quality, and in particular turbidity, total suspended solids and nutrient concentrations are important determinants in the distribution, composition and ecological health of marine habitats (EIS Chapter: Marine Ecology, Sections 5). Consequently, the current condition of water quality was assessed using existing data and via a field campaign to provide context for potential impacts from the proposed development.

3.1 Desktop Methods

3.1.1 Literature Review

Available literature and data for water quality in the vicinity of the project footprint was collated and reviewed, including data collected as part of the Ecological Health Monitoring Program (EHMP) by Healthy Land and Water (HLW) and data collected during the maintenance dredging of Toondah Harbour and the Fison Channel in 2019. This data was used to describe current conditions and to provide background information to assist in the assessment of the impact of the proposed development on water quality in this area.

3.1.2 Analysis of EHMP data

HLW have collected water quality data throughout Moreton Bay and catchments as part of the EHMP approximately each month since 2000. The following data is recorded at each site:

- turbidity (NTU)
- chlorophyll *a* (µg/L)
- phaeopigments (µg/L)
- total nitrogen (mg/L)
- ammonia (mg/L)
- oxides of nitrogen (mg/L)
- organic nitrogen (mg/L)
- total phosphorus (mg/L)

- ortho phosphorus (mg/L)[5]
- dissolved oxygen (% saturation)
- pH
- Secchi depth (m)
- salinity (g/L)
- electrical conductivity (mS/cm), and
- water temperature (°C).

Data for the seven sites near the project footprint (Figure 11.2) were compared to the relevant WQOs, including Human Health Primary Contact WQO (Table 3.1). As per the Queensland Water Quality Guidelines 2009:

- for sites in HEV areas (C1 and HEVa1284) the 75th confidence interval ranges of the 20th, 50th and 80th percentiles of water quality data were compared to the WQO, where the WQO is not within the 75th confidence interval for a percentile, the water quality parameter does not comply with the WQO.
- for all other sites, the 50th percentile was compared to the WQO.

The management intent of HEV waters is to maintain their natural values and condition, while the intent in moderately disturbed waters is to improve their natural values and condition towards HEV condition.

The DVG from the NWQMS are provided in Table 3.2 for context, noting that under the NWQMS, site specific guidelines should be used, not the DVG.

[5] Filterable reactive phosphorus is generally considered to be chemically indicative of ortho phosphorus

Table 3.1 EHMP sites, Water Area and human health primary contact WQO.

EHMP Site	Site Description	Water Type	Water Area	WQO Comparison[3]	Human Health Primary Contact WQO
E01200	Offshore of Raby Bay, 4 km north east of the PDA	enclosed coastal	C1	75^{th} CL of percentiles	pH: 6.5– 8.5 DO: >80%
E01201	Offshore of the end of the proposed Channel	open coastal	HEVa1284	75^{th} CL of percentiles	pH: 6.5 – 8.5 DO: >80%
E04500	Mouth of Eprapah Creek, to the south of the PDA closest inshore EHMP site	enclosed coastal	HEVa1284[1]	75^{th} CL of percentiles	pH: 6.5 – 8.5 DO: >80%
E04503	Eprapah Creek 0.6 km upstream from the mouth	middle estuary	HEVa1284[1]	75^{th} CL of percentiles	pH: 6.5 – 8.5 DO: >80%
E00309	Northern Broadwater, 7 km south east of the PDA, and 5 km south east of the end of the Channel	enclosed coastal	C2	median	pH: 6.5 – 8.5 DO: >80%
E00500	Moreton Bay, just south of the Investigation Area	enclosed coastal	C2	median	pH: 6.5 – 8.5 DO: >80%
E00501	Moreton Bay East of the Investigation Area	open coastal	C2	median	pH: 6.5 – 8.5 DO: >80%

[1] These objectives were used for lower Eprapah Creek as waters shown on the plan as being mid estuary and occurring within/adjoining Moreton Bay, may have water quality characteristics more in common with their adjacent downstream water areas and under such circumstances, reference should be made to WQO for the corresponding Moreton Bay water areas (DERM 2010b).

[2] Data collection stopped at these sites in August 2014.

[3] The statistic that is compared to the WQO (CL = Confidence Limit).

Table 3.2 DGV for estuaries in south-east Australia (ANZG 2018)

Parameter	Unit	DGV
Chlorophyll a	$\mu g\ L^{-1}$	5
Total phosphorous	$\mu g\ L^{-1}$	30
Filterable reactive phosphorous	$\mu g\ L^{-1}$	15
Total nitrogen	$\mu g\ L^{-1}$	300
Oxidised nitrogen	$\mu g\ L^{-1}$	15
Ammonia	$\mu g\ L^{-1}$	15
Dissolved oxygen	% Saturation	80 to 110
pH	pH units	7.0 to 8.5
Turbidity[1]	NTU	0.5 to 10

[1]Low turbidity values are normally found offshore, and higher values in estuarine and inshore coastal waters due to wind-induced resuspension or to the input of turbid water from the catchment.

3.1.3 Analysis of Data from the Dredge Campaign in 2019

To provide context for the proposed dredging, water quality data collected during monitoring of dredging in 2019 are summarised.

Toondah Harbour and the Fison Channel were dredged between 9 May 2019 and 2 August 2019 using two different dredgers, the 'Faucon' and the 'Port Frederick'. To comply with the Environmental Authority (EA)[6] for this work, depth profiles of turbidity and pH were monitored down-current and up-current of the dredging activity each week.

In the EA the up-current site was defined as 50-100m up-current from any location where sediment was disturbed during the regular conduct of the dredging activity, and the down-current site was defined as less than, but not more than 350 m down-current of the dredging activity. Water quality was monitored 22 times during the course of the dredging, with the collection positions varying each time with the location of the dredging activity, and the direction of the current (Figure 11.3 Position of the barge and up and downstream monitoring sites during the 2019 dredging campaign).

Water quality measurements were only collected during tidal flows. The turbidity and pH at the down-current monitoring point were compared to the background value (BV: the average of readings from the depth profiles at the up-current point on that day). In the EA, an exceedance was defined as:

- when the BV is less than 100 NTU, turbidity at the down-current monitoring point more than 10 NTU above the BV, and
- when the BV is more than 100 NTU, turbidity at the down-current monitoring point more than 10% above the BV.

3.2 Field Methods

3.2.1 Turbidity Loggers

There a seagrass beds in the vicinity of the proposed dredging. The lower depth limit, and hence the distribution of seagrass, in this area is likely limited by light availability (EIS Chapter: Marine Ecology, Section 5.6). Dredging may decrease the amount of available light by increasing the amount of suspended sediment in the water column, and thereby increasing turbidity (EIS Chapter: Marine Ecology, Section 8.1). Consequently, turbidity was measured at the deepest end of the seagrass bed in the Investigation Area in order to

[6] Under the EP Act an Environmental Authority (EA) is required for Environmentally Relevant Activities (ERA -activities that may cause environmental harm).

characterise existing conditions. Water quality loggers (YSI 600OMS Sonde) were installed as close as possible to the sediment surface (

Figure 3.1) at five sites:

- sites L1: mid-distance from the proposed dredging, and close to shore (22 September 2015 to 30 January 2018)
- sites L2: close to ferry movements in the existing channel and the proposed dredging (22 September 2015 to 30 January 2018)
- site L3: mid-distance from the proposed dredging, offshore, but close to Sandy Island, and near coral outcrop (22 September 2015 to August 2019)
- sites L5: close to the existing channel and the proposed dredging (2 February 2018 to 28 August 2019), and
- sites L6: close to the existing channel and the proposed dredging, inshore (2 February 2018 to 28 August 2019).

Each site was at the deepest end of a seagrass bed. While seagrass was sparse near each logger, it persisted through the logging period.

While the distribution of coral is also impacted by light availability (and hence turbidity) the distribution of coral near the proposed dredging is limited, and consequently water quality was not measured specifically over coral outcrops.

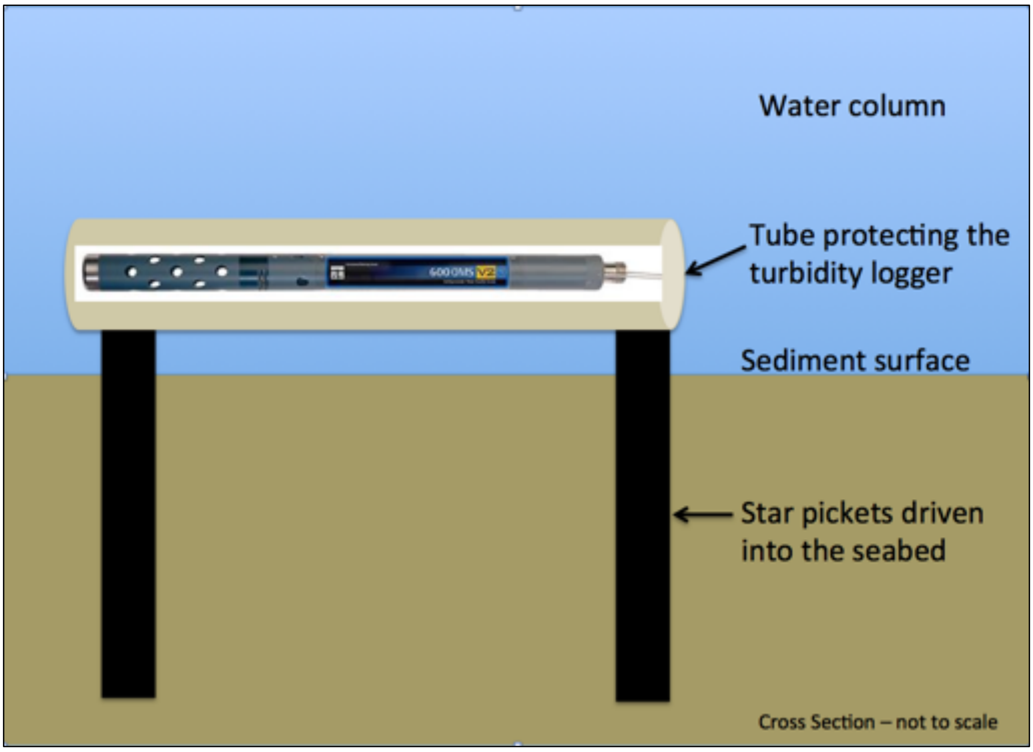

Figure 3.1 Deployment of turbidity logger.

Turbidity (NTU) was recorded every 15 minutes at each site. Data was downloaded, and the loggers calibrated every two weeks, except where weather conditions did not allow safe access. In these instances, the loggers were calibrated as soon as safely possible. The loggers were calibrated with turbidity standards of 0, 126 and 1000 NTU, and the sensors automatically cleaned every 15 minutes to prevent fouling and bubbles forming on the optical surface.

3.2.2 Analysis of Data

Prior to analysis turbidity data was 'cleaned', with likely erroneous readings removed where:

- all data where the specific conductivity value was less than 20 mg/L, as low conductivity measurements indicated periods when the logger was exposed at low tide, or when it was being serviced
- all turbidity values less than -3 NTU, with the remaining negative turbidity values (i.e. negative values greater than -3 NTU) converted to 0 NTU
- all turbidity values within periods (i.e. the time between two calibration dates) where negative turbidity values comprised more than half of the recorded readings
- isolated turbidity spikes above 50 NTU, where a spike was defined as exceeding the mean of the preceding and succeeding two samples (i.e. half hour prior and following) by a factor of 10, since momentary spikes in data may indicate passing debris (e.g. plant detritus) or small animals (OzCoasts 2020) and are not reflective of actual turbidity
- turbidity values where obvious drift was observed, where drift was defined as when the baseline turbidity values (i.e. 6 hr rolling average) regularly increased until the next calibration where the baseline values immediately decreased, and where
- all turbidity values within periods where negative values and isolated spikes comprised more than a third of the recorded readings.

Once data was reviewed and cleaned, data from each logger was compared to the WQO, and statistically analysed. Basic statistical analyses comprised calculations of the 10th, 20th, 50th, 80th and 90th percentiles, mean values, minimum values and maximum values. Box and whisker plots were created to help infer any long-term trends in turbidity. Data was then analysed using SPSS Statistics to determine if there were any statistical differences or correlations with season (winter, spring, summer and autumn), wind direction, tide height, and at site 2, ferry activity

The ferry timetables were used to estimate the time each ferry passed Site L2. As Site L2 is five minutes by ferry from the terminal, five minutes were subtracted from the arrival time, and five minutes added to the departure time. Turbidity records were then allocated to categories, depending on the time since the last ferry. The following categories were used:

- ferry passed within 0-5 minutes of the sample time
- ferry passed within 5-10 minutes of the sample time
- ferry passed within 10-15 minutes of the sample time, and
- ferry passed the logger more than 15 minutes from the sampling time.

In order to assist in assessing impacts to key receptors such as seagrass and coral, rolling two-week averages of daytime (6 am to 6 pm) turbidity were calculated.

4 Existing Environment

4.1 General Description

4.1.1 Moreton Bay Water Quality

Moreton Bay is one of the largest estuarine bays in Australia, and supports a diverse range of ecosystems. While water quality in the bay deteriorates following heavy rainfall and floods, these are usually short-term changes, lasting from weeks to months (Maxwell PS et al. 2013, Saeck et al. 2013 and Saeck et al. 2019,). Water quality in Moreton Bay, including nutrients and water clarity, has been monitored for decades. Nutrients are important as they stimulate primary productivity, but an over-abundance of nutrients can lead to algal growth and a subsequent loss of critical habitats, such as seagrass meadows. Water clarity is important as key habitats such as seagrass bed and coral communities require light to photosynthesise, and high sediment loads can also result in the deposition of sediment and smothering of habitats.

There are considerable pollutant pressures along the western shoreline, largely due to sediment export from the upper catchments (Saeck et al. 2019). Additionally, there are over 30 sewage and industrial treatment plants discharging directly into Moreton Bay and its estuaries (Gibbes et al. 2014), as well as numerous discharges into the freshwater creeks, that are a significant source of nitrogen and phosphorus.

Water quality in Moreton Bay is driven by freshwater inputs as well as wave, wind and tidal action (Gibbes et al. 2014). The north-eastern section of the bay has the best water quality due to little pollution and regular oceanic flushing (McEwan J et al. 1998), while the south-western bay has poorer water quality, that regularly exceeds Queensland water quality guidelines (Saeck et al. 2019). Over the past 20 years, in the western, central and southern areas of the bay, the concentration of total phosphorus has frequently exceeded guidelines, although recently it appears to have decreased (Saeck et al. 2019). In contrast, the concentration of total nitrogen has remained consistent over the past 18 years, with minor increases in the north-central and north-eastern zones of the bay.

Toondah Harbour is approximately 20 km south of the Brisbane River estuary and approximately 17 km north of the Logan River estuary. It is considered to be in the ‘Central Bay’ in the EHMP.

Since 2001, the concentration of total nitrogen and total phosphorus has decreased in both the Brisbane and Logan estuaries, attributed to changes in extractive industry use, and improvements in industrial and sewage discharges (Saeck et al. 2019). The minor increased concentration of total nitrogen noted across Moreton Bay (i.e. in the north-central and north-eastern zones) is likely due to historic contributions (i.e. 2011 floods) that are trapped in the bay sediments and get resuspended over time, since water coming from the estuaries has slowly been improving.

Water clarity typically decreases after heavy rainfall and flood events, due to increased catchment run-off and stimulation of pelagic productivity due to an increase in nutrients. Water clarity is also affected by resuspension of sediment by wind. In the western bay, mean annual turbidity is significantly higher in years with higher than average north or south-easterly winds (Saeck et al. 2019).

The ecosystem health of the bay and its catchments has been monitored, and report cards produced for the past 20 years. The 2020 report card (Healthy Land and Water 2020) indicated that in 2019-2020:

- oceanic circulation appears to have flushed some mud out of the bay, although a significant mud patch remained in the Central Bay
- there was an increase in the distribution of seagrass in the bay, and
- water quality averaged over all of the Central Bay (the section of the Bay that includes the project footprint) was in excellent condition, although turbidity and the concentration of total nitrogen were often over the WQO[7].
- The 2021 report card (Healthy Land and Water 2021) indicated that:
- water quality had slightly improved in the Central Bay, with nitrogen, algae and turbidity remaining stable
- due to continued resuspension and flushing into the deeper parts of the Bay and limited inputs from the catchment, the extent of mud is likely to have remained very low.

However, the floods in 2022 are likely to have increased turbidity, and the extent of mud in the Bay, with up to 5 times more silt and mud than in the 2011 floods (HLW pers comm. 2022).

Priority management for the Central and Western Bay in the 2021 Report Card (Healthy Land and Water 2021) comprised:

- measures to reduce sediment running off development and construction sites, and high-risk erosion sites, and
- continued investment in minimising wastewater treatment plant and other industrial discharges, to maintain long term improvements in water quality.

[7] Water quality for the Central Bay is not directly assessed against the appropriate WQO for each water type in the Central Bay in the report card online presentations.

4.2 Assessment of EHMP Data

While turbidity was frequently above the 50th and 80th percentile WQO at each site (Figure 4.1, Figure 4.2), median turbidity complied at sites E01200 and E00501. Turbidity was highly seasonal, with lowest turbidity in winter (June/July) and highest turbidity in late summer and early autumn (February/March).

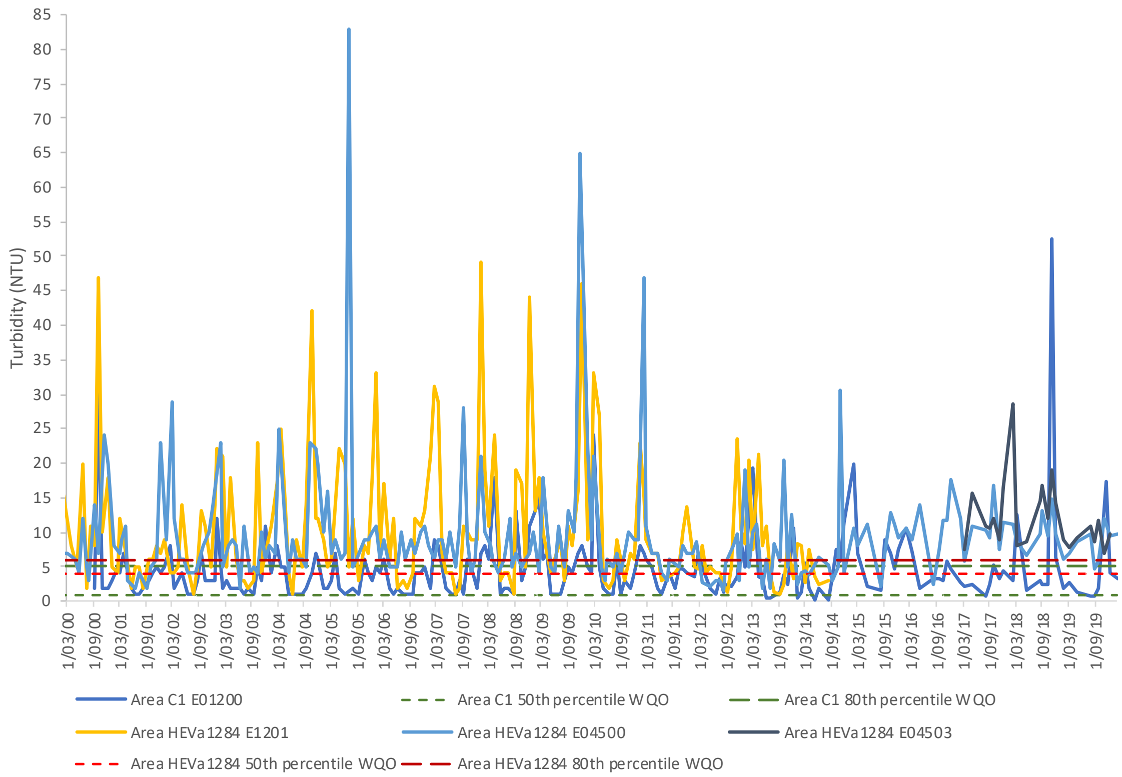

Figure 4.1 Turbidity at sites C1 and HEVa1284 (in HEV waters) and the 50th percentile WQO.

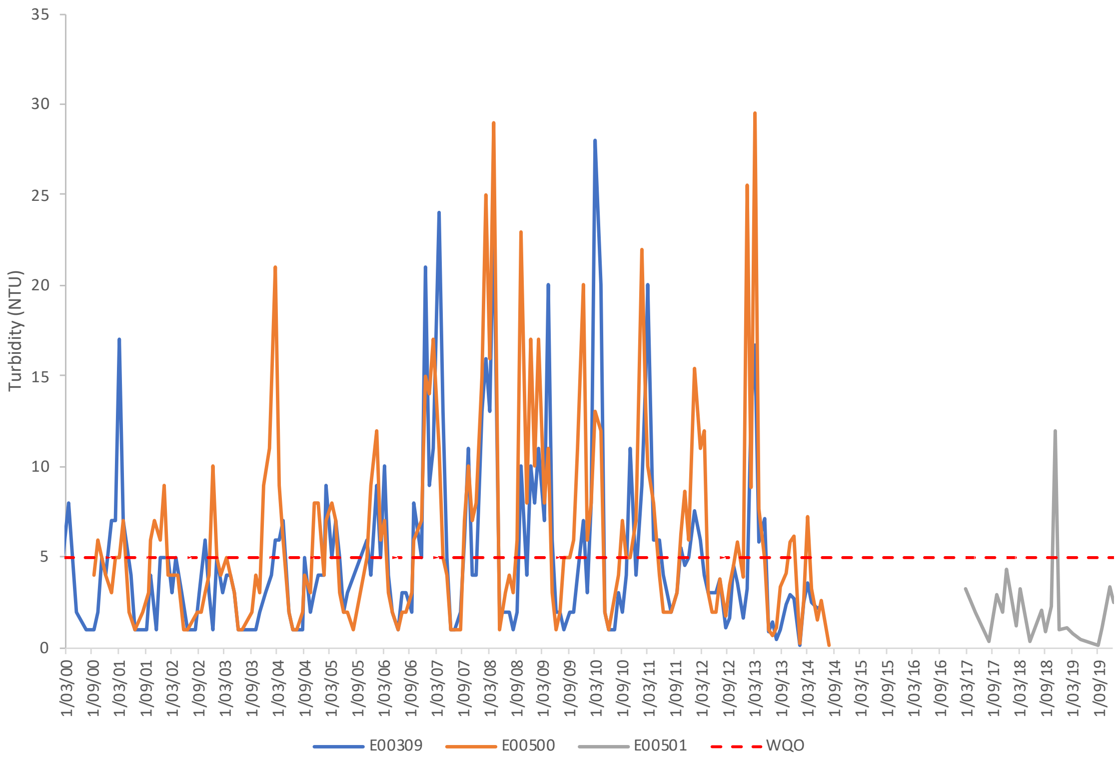

Figure 4.2 Turbidity at sites in area C2 (in moderately disturbed marine water) and the WQO.

4.2.1 Comparison of EHMP data to WQO

At all of the EHMP sites, water quality complied with the Human Health Primary Contact WQO, as the percent saturation of dissolved oxygen was > 80% and pH was between 6.5 and 8.5.

In the HEV areas, over the period 2000 to 2020, the following were indicative of poorer water quality than the WQO:

- At site E01200 (offshore of Raby Bay) turbidity, and the concentration of chlorophyll a, total nitrogen and organic nitrogen were higher than the WQO, and dissolved oxygen and Secchi depth were lower (Table 4.1, Appendix A).
- At site E01201 (offshore of the end of the proposed channel) turbidity was higher than the WQO, and Secchi depth was lower (Table 4.1, Appendix A).
- At site E04500 (mouth of Eprapah Creek) turbidity and the concentration of chlorophyll a, total nitrogen, oxidised nitrogen, ammonia, organic nitrogen, total phosphorus and filterable reactive phosphorus were higher than the WQO, and dissolved oxygen and Secchi depth were lower (Table 4.1, Appendix A).

- At site E04503 (Eprapah Creek) turbidity and the concentration of chlorophyll a, total nitrogen, ammonia, organic nitrogen and total phosphorus were higher than the WQO, and dissolved oxygen and Secchi depth were lower (Table 4.1, Appendix A).

That is, at most of the nearby HEV sites, turbidity, the concentration of nutrients and the concentration of chlorophyll a were higher than the WQO, and Secchi depth was lower.

In the moderately disturbed coastal area, the following were indicative of poorer water quality than the WQO:

- At site E00309 (Moreton Bay, south of the Investigation Area) the concentration of chlorophyll *a* was higher than the WQO, and Secchi depth was lower (Table 4.2, Appendix A).
- At site E00500 (Moreton Bay, south of the Investigation Area) turbidity was higher than the WQO, and Secchi depth was lower (Table 4.2, Appendix A).
- At site E00501 (Moreton Bay, east of the Investigation Area) the concentration of organic nitrogen was higher than the WQO, and depth was lower (Table 4.2, Appendix A).

That is, while water quality at the nearby sites in moderately disturbed waters in Moreton Bay Area C2 mostly complied with the WQO, water quality at the sites in Redlands Creek did not comply, with turbidity, and the concentration of nutrients significantly exceeding the WQO, and the percent saturation of dissolved oxygen and Secchi depth less than the WQO.

Table 4.1 Median water quality data and the 50th percentile WQO for sites within HEV areas.

	HEV Area C1		HEV Moreton Bay Area HEVa1284			
Parameters	**WQO[1]**	**Site: E01200**	**WQO[2]**	**Site: E01201**	**Site: E04500**	**Site: E04503**
	50th	**50th**	**50th**	**50th**	**50th**	**50th**
Turbidity (NTU)	1	3	4	8	7	7
Chl *a* (µg/L)	0.8	0.9	1	1	1.3	1.3
Total nitrogen (µg/L)	130	150	150	150	220	220
Oxidised N (µg/L)	2	1	2	1	4	4
Ammonia N (µg/L)	3	2	3	1	5	5
Organic N (µg/L)	120	144	150	146	201	201
Total phosphorus (µg/L)	15	14	22	19	39	39
Filterable reactive phosphorus (FRP) (µg/L)	5	5	10	6	18	18
Dissolved oxygen (% saturation)	100	99	100	105	90.6	90.6
pH	8.2	8.1	8.2	8.2	8.0	8.0
Secchi depth (m)	4.5	1.9	2	1.1	1	1

[1] WQO are for Area C1 – Central Bay (Table 2).

[2] WQO are for Area HEVa1284 – Central Bay (Table 2).

[3] WQO are for Primary human contact for coastal, estuarine and freshwater (Table 4)

This table is only for reference, please see Appendix A for complete comparison of data to WQO.

Data in red indicates the water quality data was poorer than WQO, noting higher Secchi depth is indicative of better water quality.

Table 4.2 Median water quality data compared to the WQO for sites within moderately disturbed coastal areas.

Parameters		Moreton Bay Area C2			Redland Creek Mid-estuary Area S2		
		E00309	E00500	E00501		E04501	E04502
	WQO[1]	50th	50th	50th	WQO[2]	50th	50th
Turbidity (NTU)	< 5	4	5	2	<8	11	9
Chl *a* (µg/L)	< 1.0	1.1	0.9	0.5	<4	3	3
Total nitrogen (µg/L)	< 160	150	150	160	<300	690	820
Oxidised N (µg/L)	< 2	1	1	1	<10	140	210
Ammonia N (µg/L)	< 5	1	1	2	<10	71	100
Organic N (µg/L)	< 150	136	142	156	<280	434	480
Total phosphorus (µg/L)	< 20	15	16	5	<25	77	120
Filterable reactive phosphorus (FRP) (µg/L)	< 8	5	5	1	<6	34	53
Dissolved oxygen (% saturation)	95-105	103	104	96	85-105	77	63
pH	8.2 - 8.4	8.2	8.2	8.1	7.0-8.4	7.6	7.2
Secchi depth (m)	> 2.7	2	1.5	2.7	>1	0.7	0.7

[1] WQO are for Area C2 – Central Bay (Table 2).
[2] WQO are for Area S2 – Mid Estuary (Table 2)
[3] WQO are for Primary human contact for coastal, estuarine and freshwater (Table 4)
Data in red indicates the water quality data was poorer than the WQO, noting higher Secchi depth is indicative of better water quality.

4.2.2 Seasonal Data at EHMP Sites in the Investigation Area

To determine seasonal variation in water quality in areas close to the proposed works, water quality data was also summarised for each season at the three EHMP sites in, or closest to, the Investigation Area: site EO1201 near the end of the proposed channel; site EO4500, at the mouth of Eprapah Creek; and site E00500, to the immediate south of the Investigation Area (Appendix A).

Overall, turbidity, Secchi depth, chlorophyll a, and nutrients were highly variable, both between and within seasons, and were generally highest in summer. In summary:

- Turbidity was highest during summer, and lowest in winter for all three sites; the median turbidity was highest at HEV open coastal site E01201.
- Chlorophyll *a* was highest during summer and lowest in winter for all three sites; the highest median concentration was at HEV enclosed coastal site E04500.
- Total nitrogen was highest during summer and lowest in winter at all three sites; the highest summer median concentration was at HEV enclosed coastal site E04500, which also showed higher variation in nitrogen concentrations throughout all seasons.
- The median concentration of filtered reactive phosphorous was highest during autumn and lowest during winter and spring at sites E01201 and E00500; HEV enclosed coastal site E04500 had the highest median concentration during winter and lowest in spring and summer and had the highest median concentration of these three sites.
- Dissolved oxygen (% saturation) was fairly stable throughout the seasons at all three sites, with the highest median concentrations between winter and spring; the lowest median % saturation of dissolved oxygen was at site E04500 during autumn.
- The median Secchi depth was highest during winter and lowest during summer, with the lowest median Secchi depth at HEV open coastal site E01201 during winter.

4.2.3 At Site E01201 (end of the dredge Channel) median:

- turbidity was highest during summer and lowest in winter
- chlorophyll *a* was highest during summer and lowest in winter
- total nitrogen was highest during summer and lowest in winter
- filterable reactive phosphorus (FRP) was highest in autumn and lowest in spring
- dissolved oxygen (%) was consistent through all seasons, but was slightly lower in summer, and median

- Secchi depth was highest in winter and lowest in summer (Figure 4.3).

4.2.4 At Site E04500 (mouth of Eprapah Creek) median:

- turbidity was highest during summer and lowest in winter
- chlorophyll *a* concentration was highest and most variable during summer, and lowest during winter
- total nitrogen was variable during spring and autumn, with the highest median during summer and lowest in winter and spring
- FRP concentration was highest during winter, and lowest in summer
- dissolved oxygen (% saturation) was relatively even throughout all seasons with the highest median during winter, and the lowest in autumn, and
- Secchi depth was highest in winter and lowest in summer (Figure 4.4).

4.2.5 At Site E00500 (to the immediate south of the Investigation Area) median:

- turbidity was highest during summer and lowest in winter
- chlorophyll *a* concentration was highest during summer and lowest in winter
- median total nitrogen concentration was highest during summer and lowest in winter
- concentration of FRP was highest during summer and autumn, and lowest in winter and spring
- dissolved oxygen (% saturation) was highest in winter and spring, and lowest in autumn, and
- Secchi depth was highest in winter and lowest in summer (Figure 4.5).

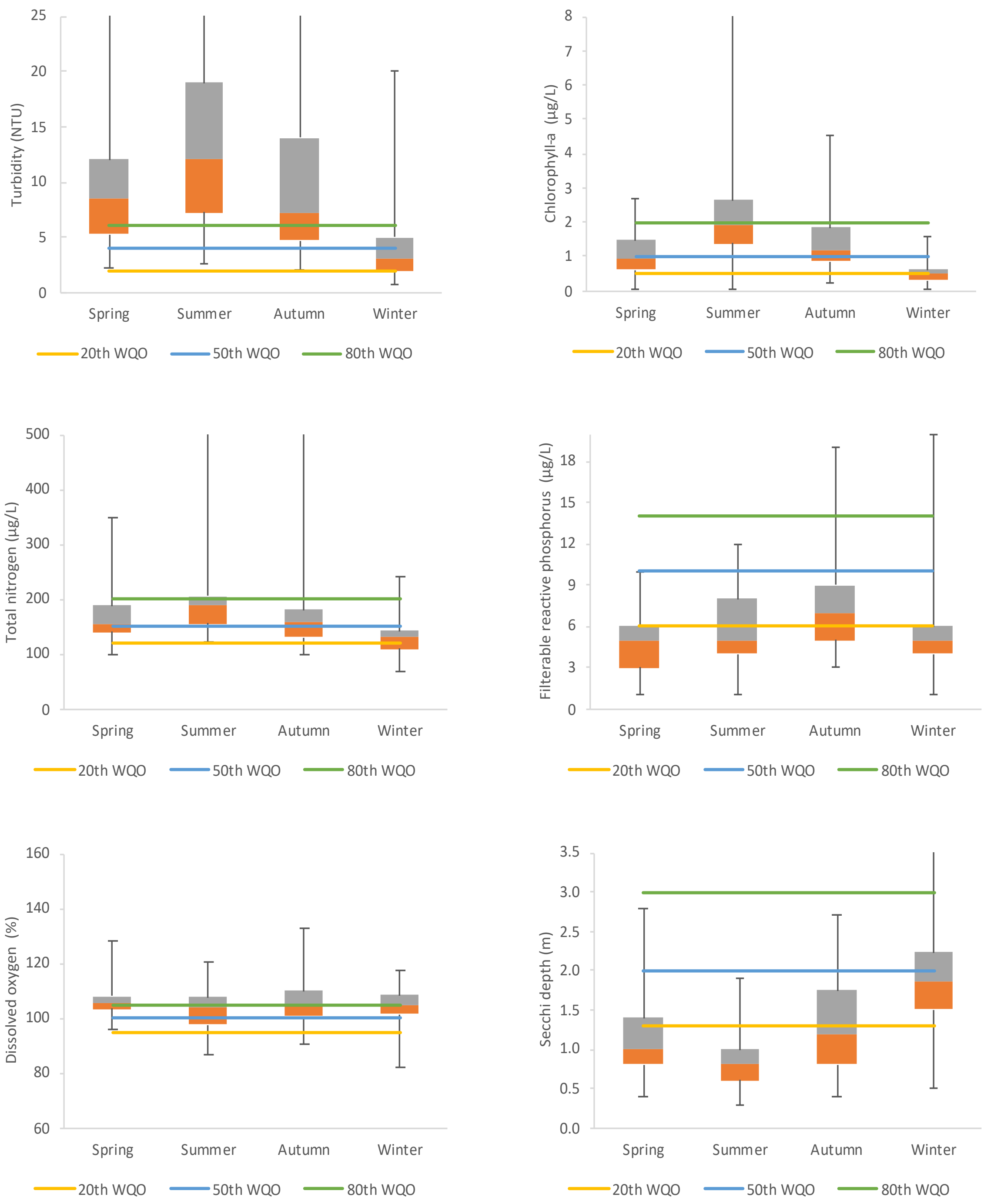

Figure 4.3 Water quality in each season at Site E01201.

Box-whisker plot for each water quality by season at Site E01201. Boxes indicate the lower and upper quartile. Vertical lines extending from each box represents the minimum and maximum values recorded for that season.

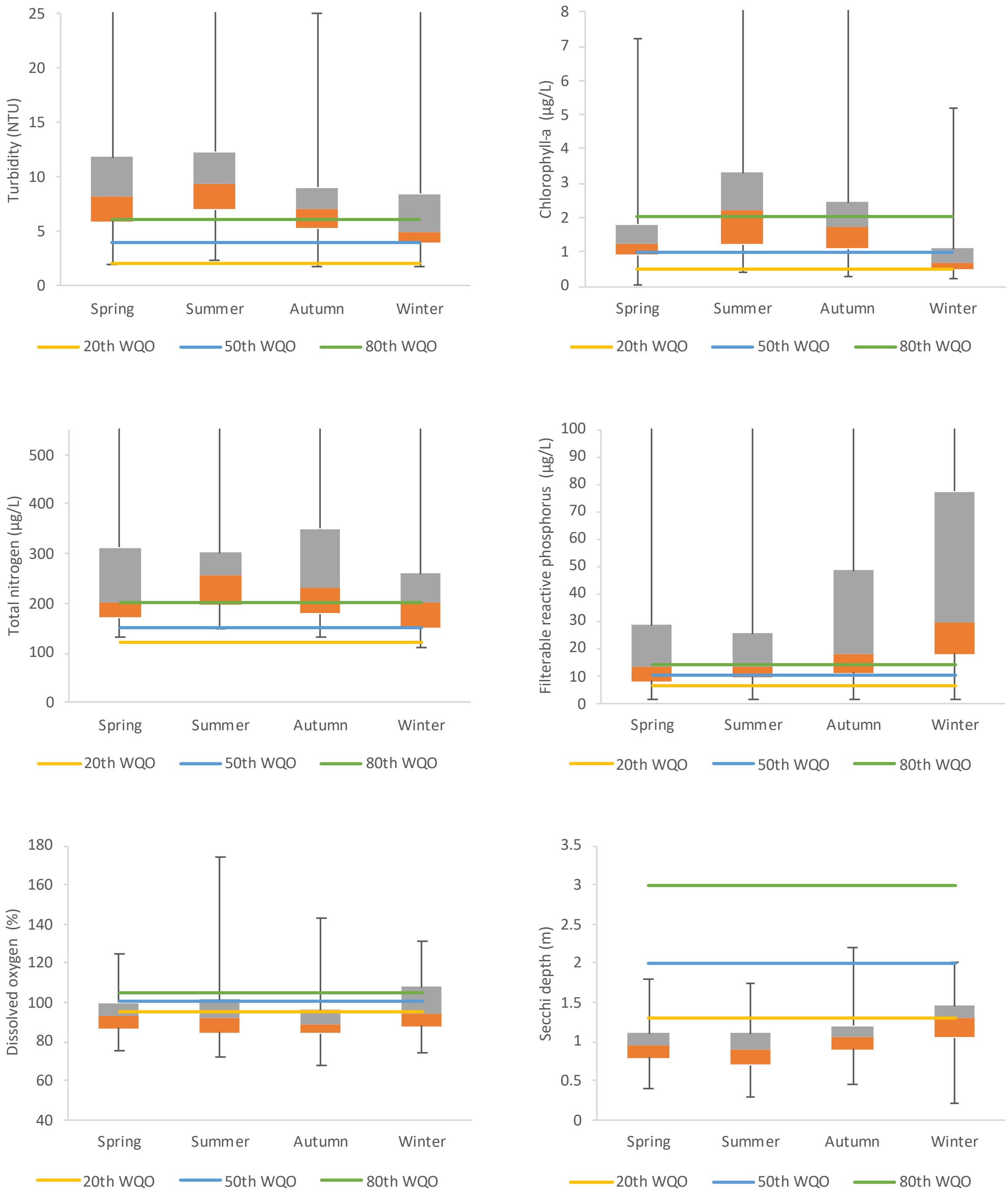

Figure 4.4 Water quality in each season at Site E04500.

Box-whisker plot for each water quality by season at Site E04500. Boxes indicate the lower and upper quartile. Vertical lines extending from each box represents the minimum and maximum values recorded for that season.

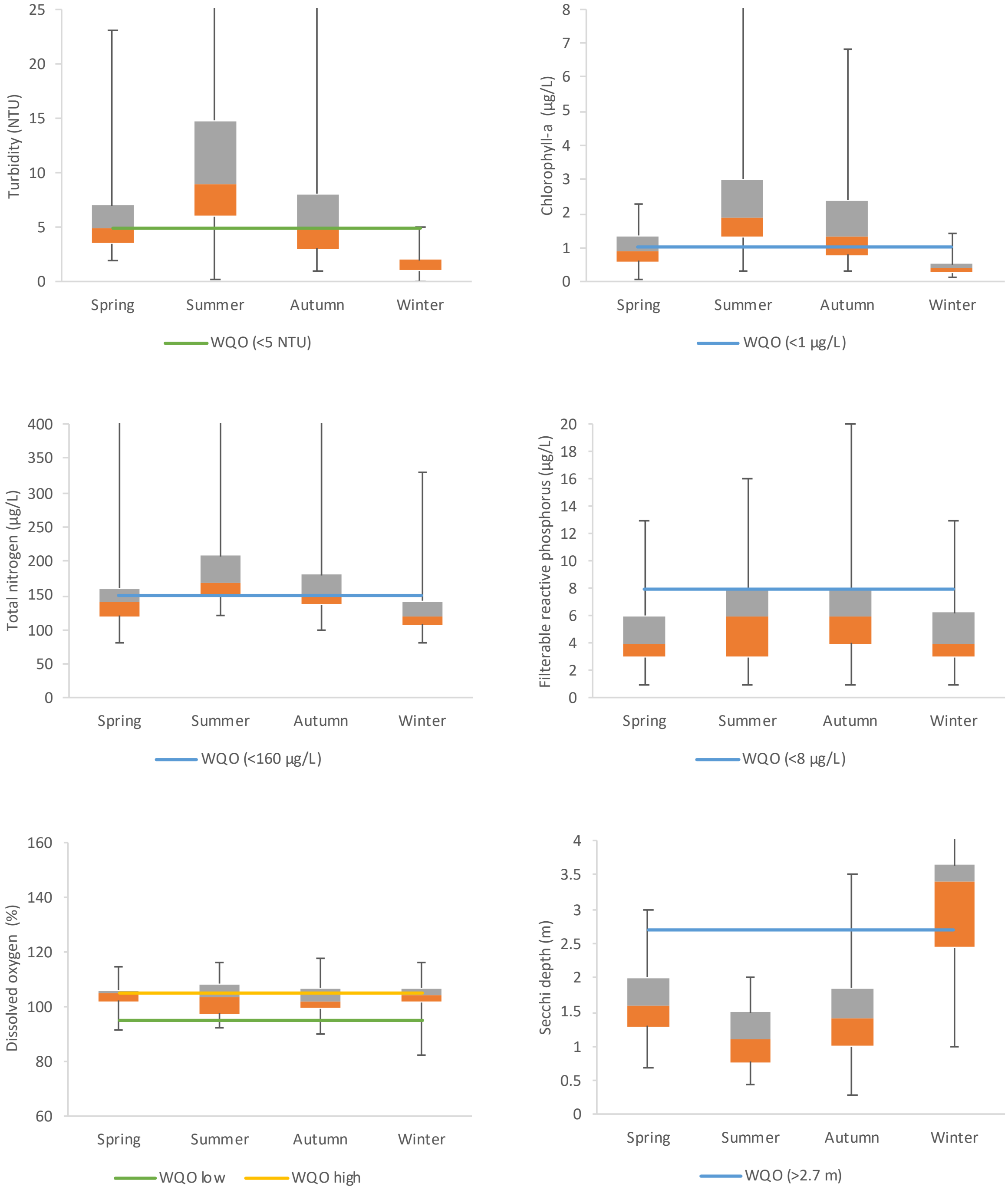

Figure 4.5 Water quality in each season at Site E00500.

Box-whisker plot for each water quality by season at Site E00500. Boxes indicate the lower and upper quartile. Vertical lines extending from each box represents the minimum and maximum values recorded for that season.

4.3 Assessment of Data from the Dredge Campaign in 2019

While visible plumes were sometimes associated with the dredging in 2019 (Figure 4.6), turbidity only exceeded the Background Value (BV) twice. Both exceedances were during operation of the trailing suction hopper dredge and not the backhoe dredge. The exceedances were on:

- 10 May 2019 when the BV was 17 NTU and the downstream value was 32.4 NTU, and
- 16 May 2019 when the BV was 10 NTU and the downstream value 350 m from the dredge was 27.4 NTU.

In both instances, dredging stopped and turbidity had returned to background values by the following day.

Turbidity was monitored during the dredge campaign at site L6 (near the harbour), site L5 near the channel and site L3 (the site furthest offshore and away from the Fison Channel). Turbidity was highly variable during dredging, with for example, peaks in turbidity at site L6 commonly prior to dredging commencing and coinciding with low tide (Figure 4.7 and Figure 4.8). That is, peaks in turbidity in the harbour due to existing conditions and use (e.g. ferries and boats) can exceed peaks due to dredging.

Figure 4.6 The 'Faucon' dredging on an incoming tide.

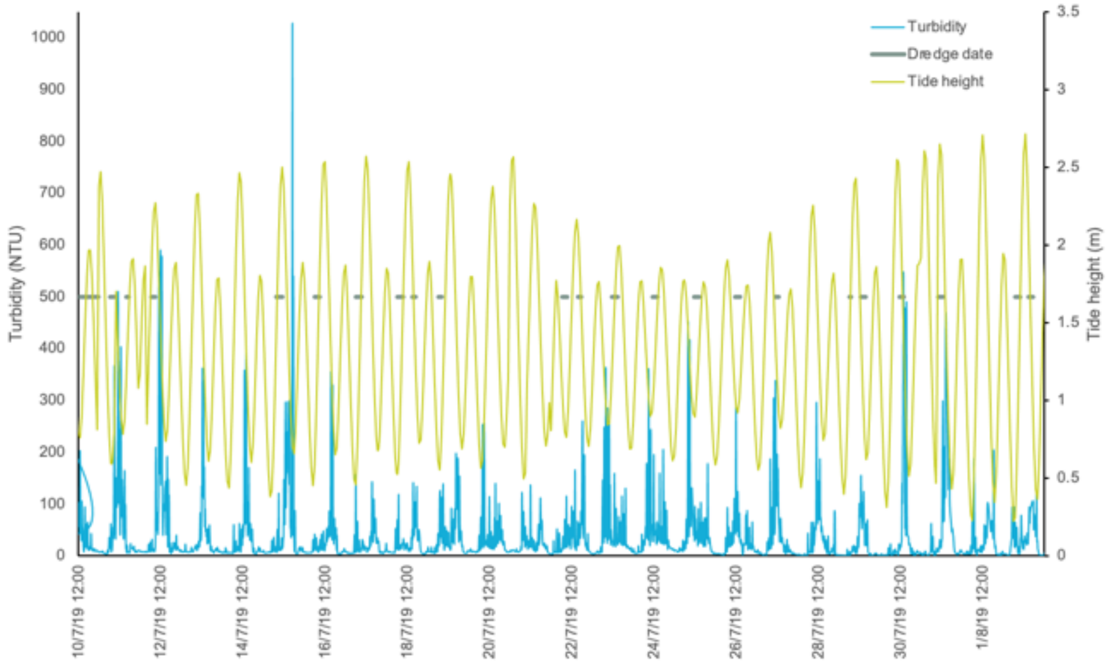

Figure 4.7 Turbidity at L6 from 11 July to 2 August 2019 during maintenance dredging.

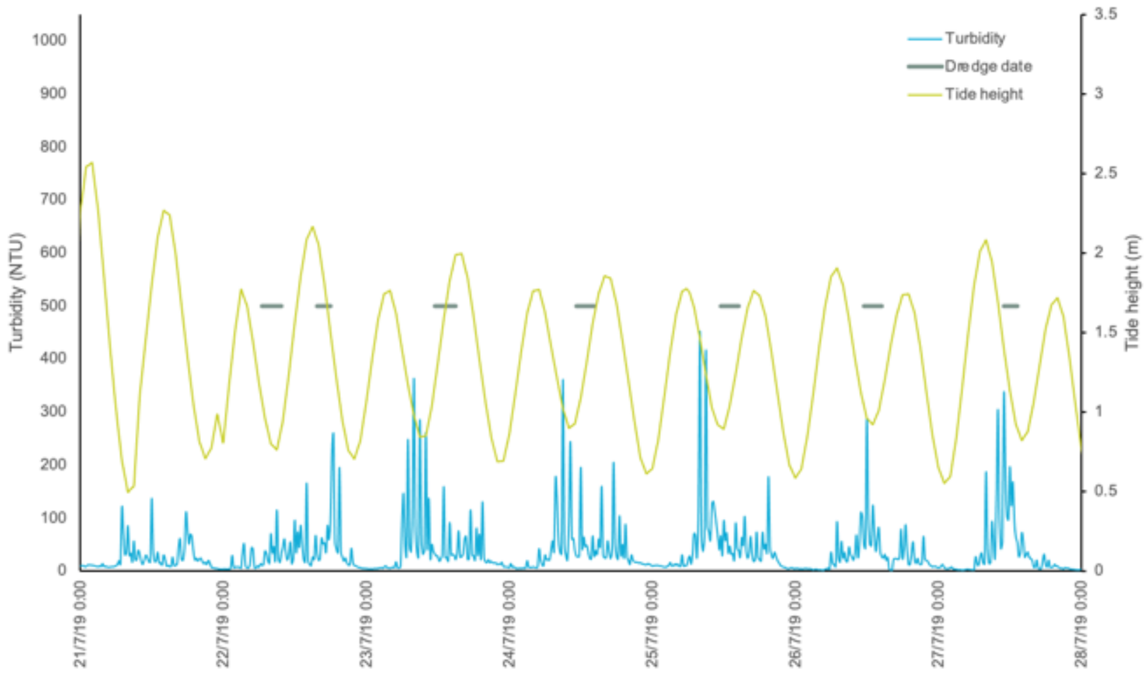

Figure 4.8 Turbidity at L6 from 21 July to 28 July 2019 during maintenance dredging.

4.4 Assessment of Turbidity Logger Data

Overall, turbidity recorded by the loggers was highly variable with the median significantly exceeding the WQO at each site. Median turbidity (NTU) was typically lowest in July of each year at each site, ranging from 0.7 (at site L2 in Jul 2017) to 14.4 (at site L6 in July 2019) (Figure 4.9). Turbidity was lowest at site L3 (overall median: 6 NTU), the site furthest offshore and away from the busiest recreational and commercial boating activity. Overall, median turbidity was similar at sites L1 (11.2 NTU), L2 (10.9 NTU) and L5 (11.5 NTU) and was highest at L6 (22.2 NTU), which was in the harbour, and closest to ferry activity (Figure 4.9). The summarised turbidity data and statistical analyses are presented in Appendix A (Tables A.10 to A.20).

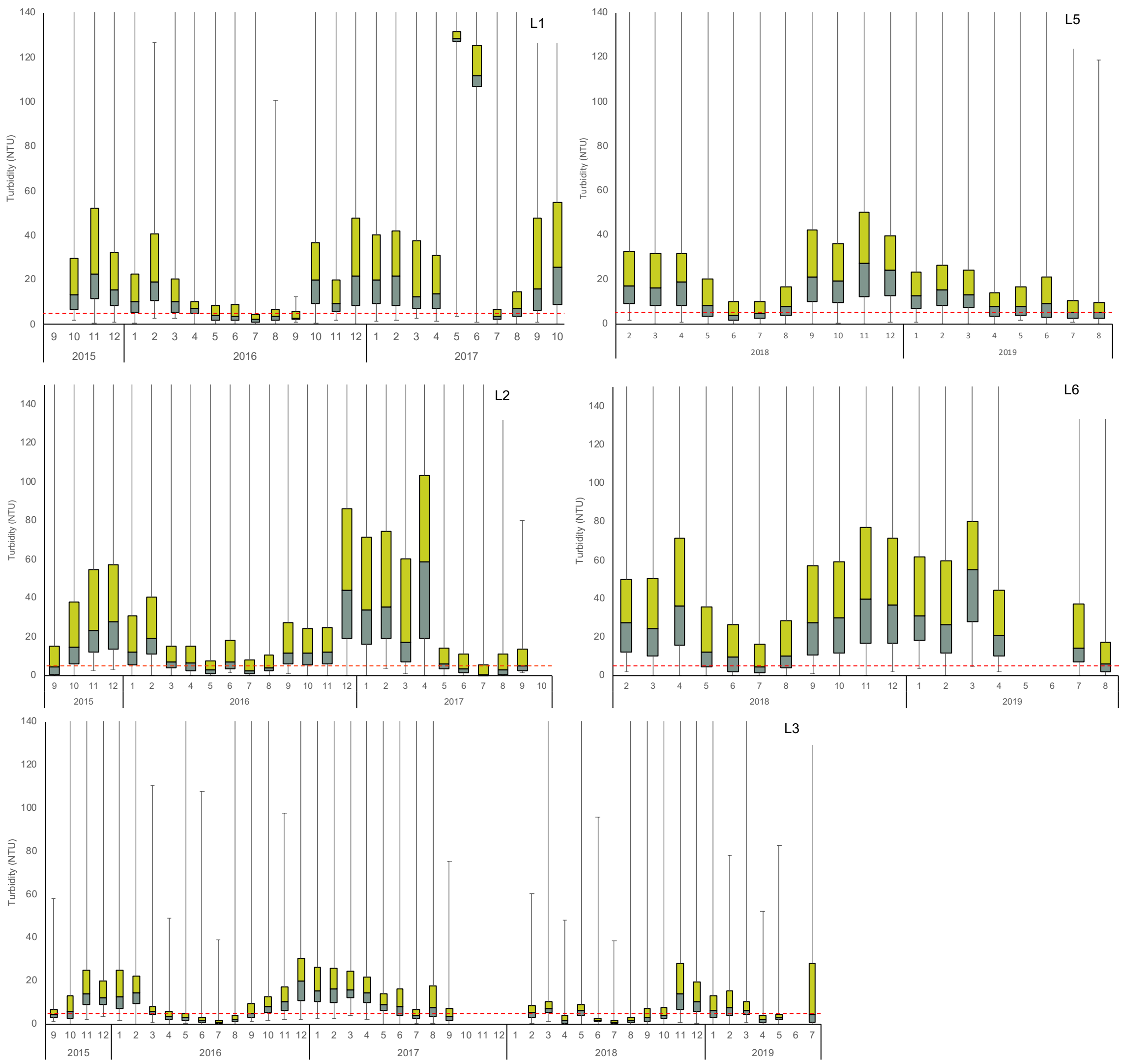

Figure 4.9 Monthly turbidity (NTU) at each site, and the WQO.

4.4.1 Seasonal Effects

The median turbidity at each logger exceeded the WQO in every season, except during winter at L1 (4.7 NTU) and L3 (1.9 NTU). These two loggers were furthest from Fison Channel and less likely to be impacted by ferry operations. At each logger, turbidity was lowest in the winter months, with medians ranging from 1.9 NTU (at site L3) to 8.4 NTU (at site L6), and highest in either spring or summer, ranging from 6.7 NTU (Spring at site L3) to 33.7 NTU (Spring at site L6) (Figure 4.10). Pearson's correlations of data from each logger indicated there was a significant difference between seasons; however, the relationships were not strong (R values less than 0.2; Appendix A).

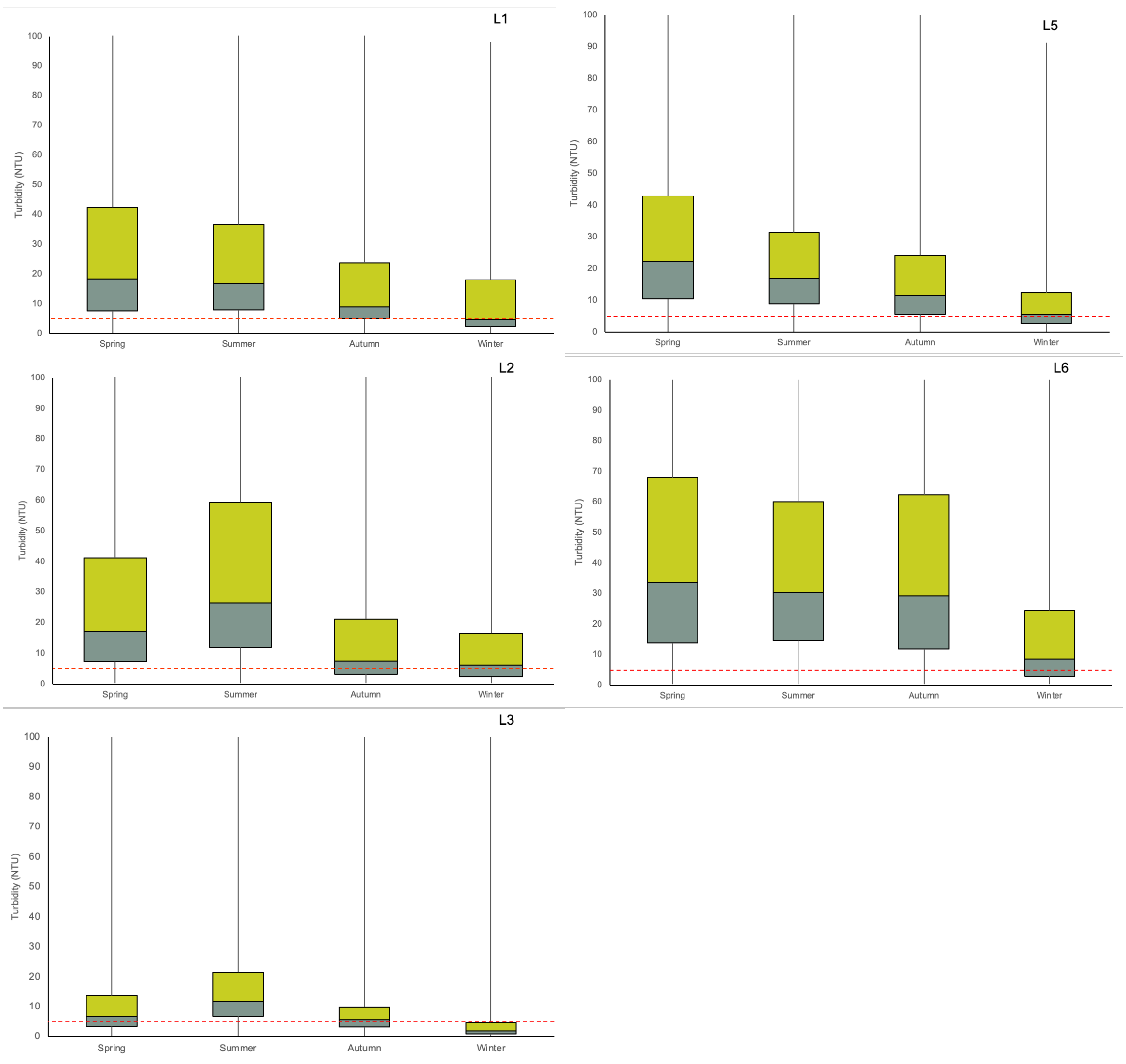

Figure 4.10 Seasonal turbidity at each site, and the WQO.

4.4.2 Impact of the Ferry on Turbidity

Data from each logger was assessed to determine if current ferry activities had an impact on turbidity using one-way analysis of variance (ANOVA). There were significant differences in turbidity with relation to ferry activity at sites L1, L2, L5 and L6 ($p<0.001$); however, there was no effect of ferry activity at site L3, the site furthest offshore and away from the Fison Channel ($p=0.086$; Appendix A).

The difference in turbidity at sites L1, L2, L5 and L6 were due to higher turbidity recorded when ferries had passed within 15 minutes than when no ferries had passed within 15 minutes. For example, the median turbidity at site L6 when ferries passed within 15 minutes ranged from 29 to 39 NTU, compared to 11 NTU when ferries passed more than 15 minutes from the time the data was recorded (Figure 4.11).

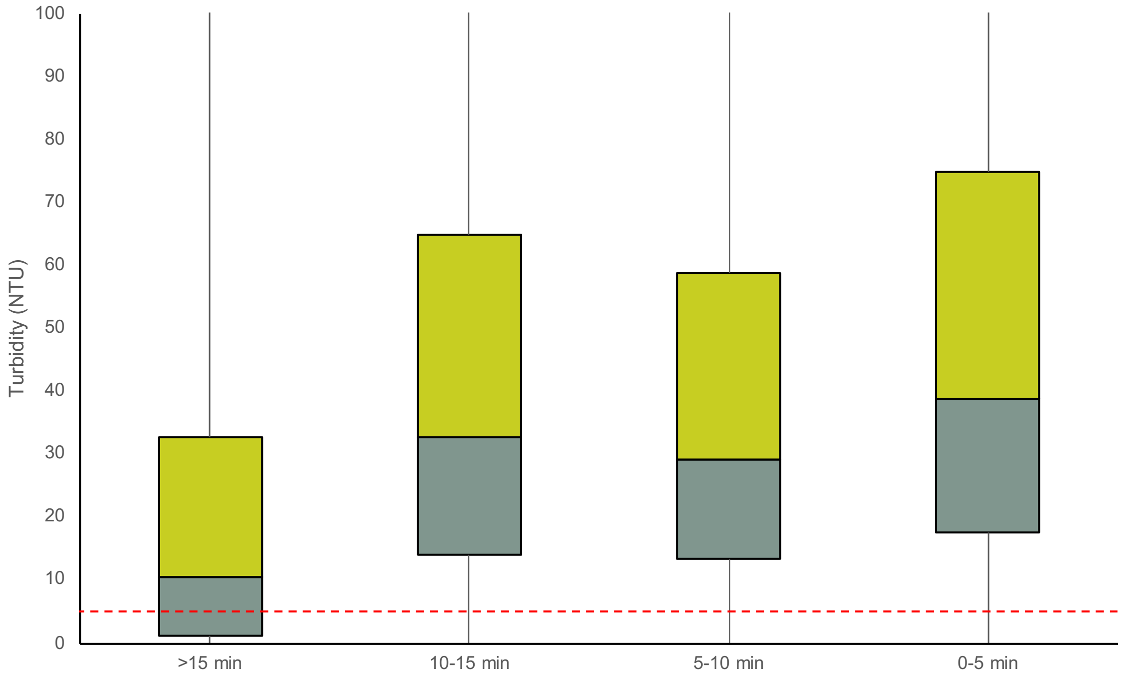

Figure 4.11 Turbidity at site L6 relative to the time since the ferry passed, and the WQO.

4.4.4 Tidal Impacts

Turbidity was correlated with tide height, with higher turbidity recorded at low tides (Figure 4.12). This correlation was significant at all sites ($p<0.05$; Appendix A), and was likely due to the interaction of waves and the bottom substrate that is more prevalent at low tide.

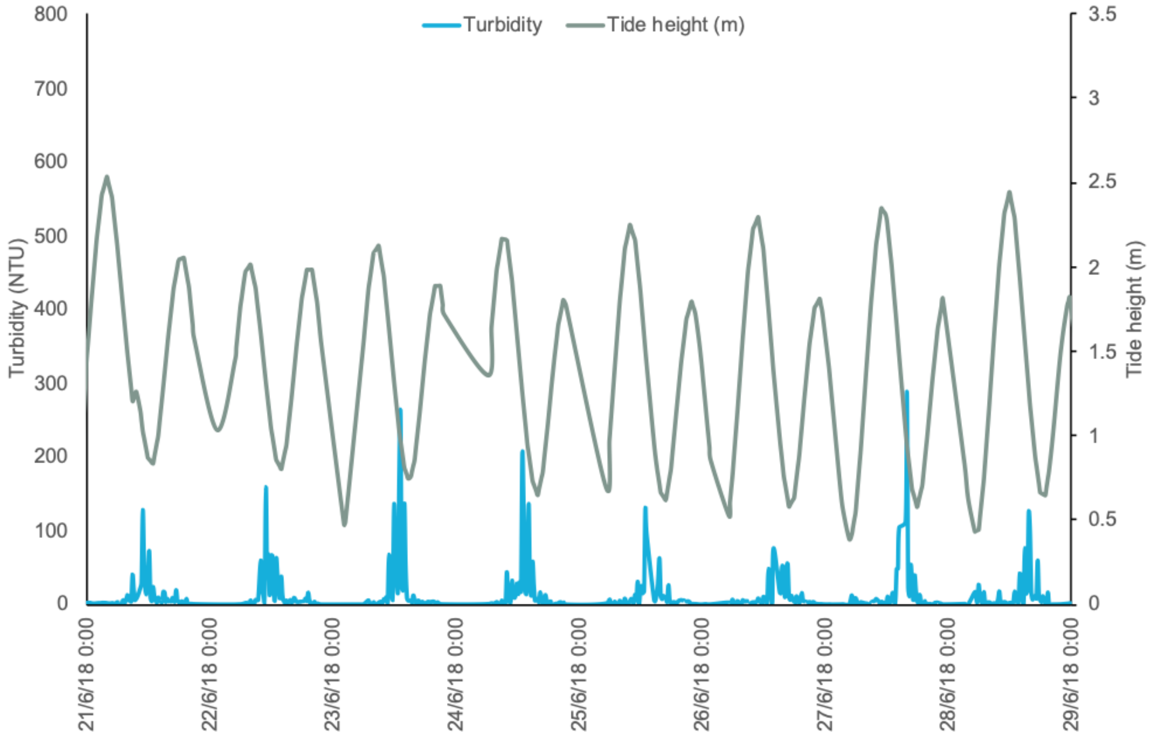

Figure 4.12 Turbidity and tide height at Site L5, 21 June 2018 to 29 June 2018.

4.4.5 Wind Direction Impacts

The dominant wind direction was divided into four wind quadrants (N, E, S, W) for the 13-month period of available wind data. For each of the prevailing wind direction subsets of data, the correlation between the speed of the maximum wind gust for the day and the turbidity values was tested at sites L2 and L6.

There was a significant relationship between wind speed in each quadrant and turbidity at site L2 ($p<0.001$; Appendix A); however, the predictive power was very low (i.e. low R^2). The exception is the wind from the south which describes around 12% of the variance in turbidity. The reason for this higher correlation with southerlies is because the wind speed range for southerlies was lower (max wind gust ~60 km/h – compared to 156 km/h from the north).

To further explore the influence of wind direction and speed on turbidity, each of the four quadrant datasets was further subset to only include turbidity observations taken in the bottom third of the tide, based on the hypothesis that wind speed and direction is the primary driver of wave action in Moreton Bay. At low tide, the water depth is less, increasing the opportunity for wave derived sediment resuspension during windy days. There was very little difference in the variance in turbidity explained by wind speed for the low tide subset data. Given the low overall correlation between turbidity and wind, the influence of wind direction and speed was not considered further.

Similarly, while there was a significant relationship between wind speed in each quadrant and turbidity at site L6 ($p<0.001$; Appendix A) predictive power was low (i.e. low R^2). Like L2, there was a higher correlation with southerlies.

4.4.6 Turbidity During Daylight Hours

The rolling two-week daytime average turbidity was consistently above the WQO at each logger (Figure 4.13 to Figure 4.17). That is, seagrass and other benthic habitat in the vicinity of the loggers is tolerant of persistently high turbidity. Average daylight turbidity was highest in the spring at L1 (32.2 NTU), L5 (45.7 NTU) and L6 (68.3 NTU), and highest in the summer at L2 (60.4 NTU) and L3 (21.4 NTU; Appendix A), with overall daylight turbidity highest at L6 (average: 57 NTU) nearest to the harbour.

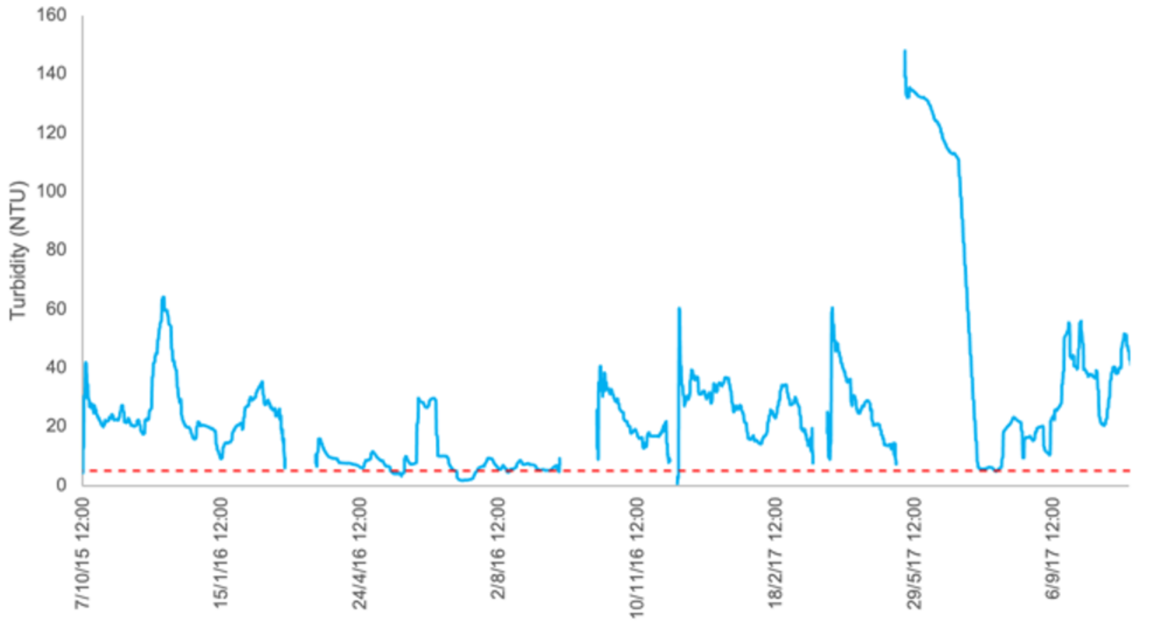

Figure 4.13 Rolling two-week average turbidity at L1: 10 July 2015 to 11 November 2017.

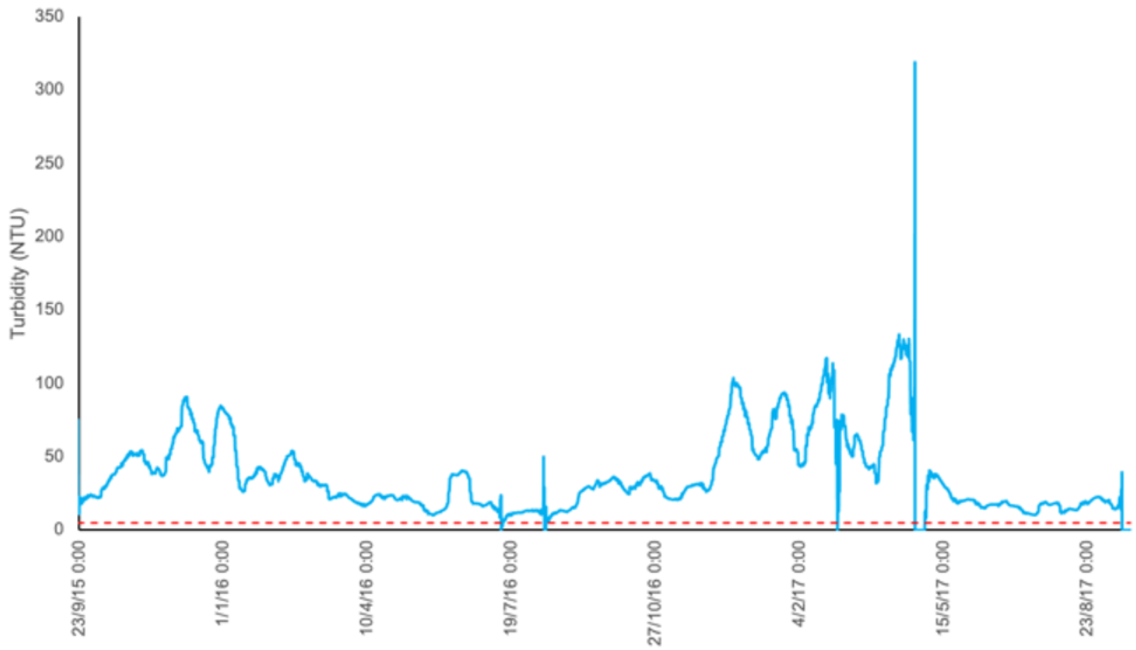

Figure 4.14 Rolling two-week average turbidity at L2: 22 September 2015 to 1 September 2017.

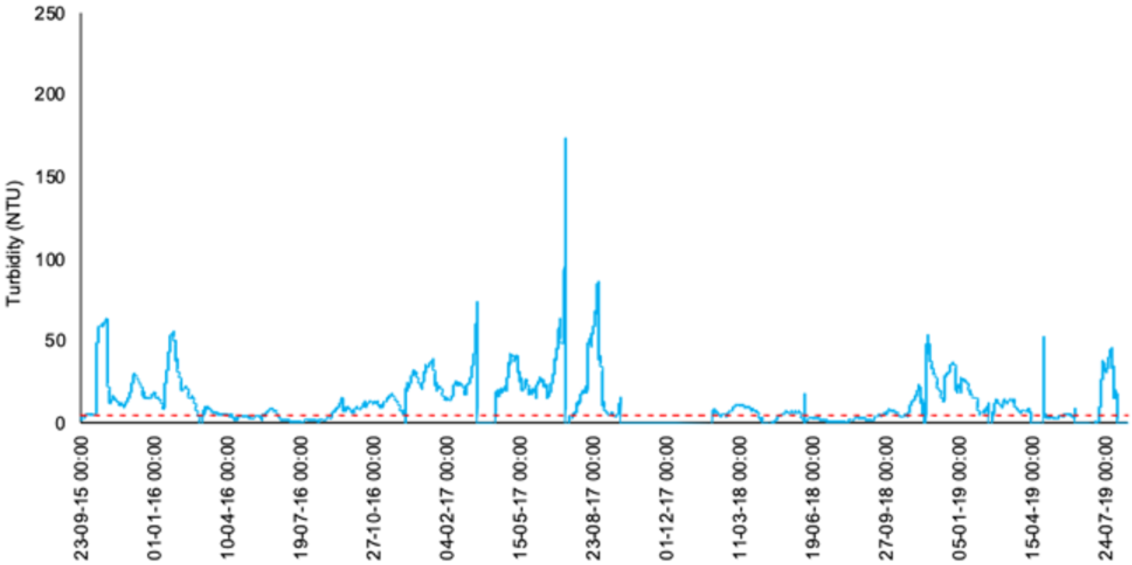

Figure 4.15 Rolling two-week average turbidity at L3: 22 September 2015 to 25 July 2019.

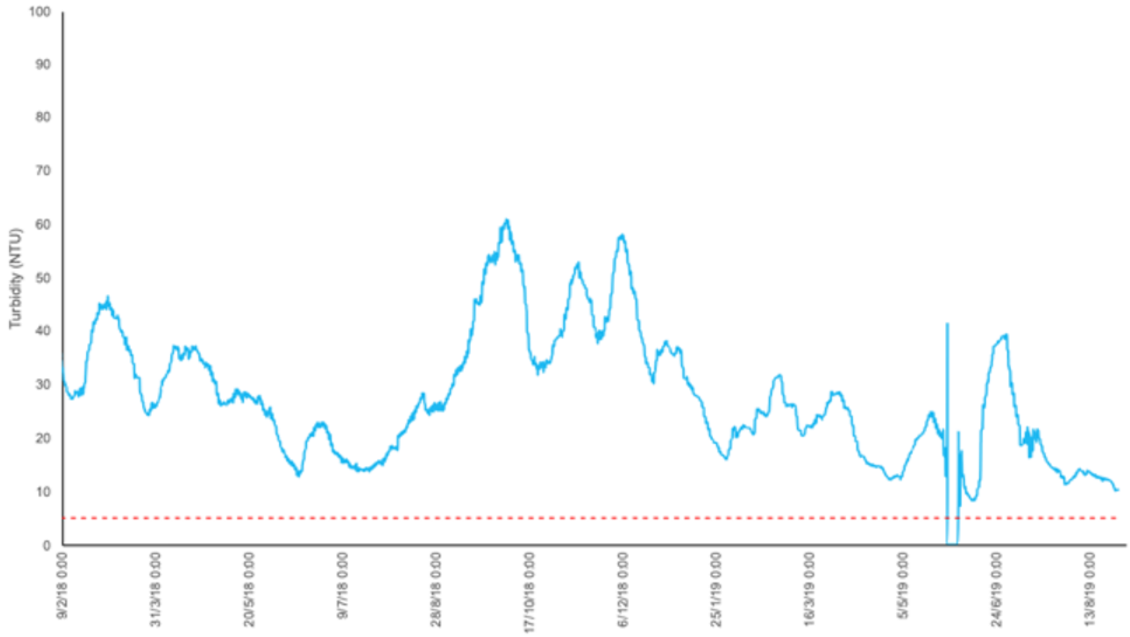

Figure 4.16 Rolling two-week average turbidity at L5: 2 February 2018 to 28 August 2019.

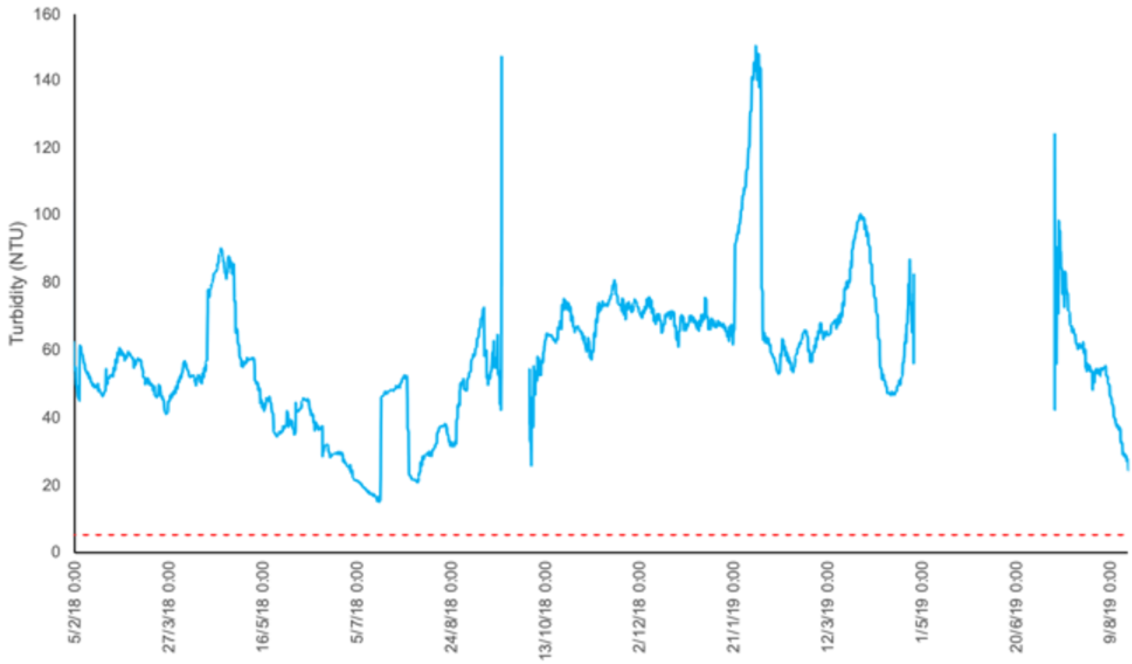

Figure 4.17 Rolling two-week average turbidity at L6: 5 February to 20 August 2019.

4.5 Key Assessment Outcomes

Water quality in the vicinity of the proposed development is highly variable and influenced by several environmental factors, including tidal state, season and wind.

Overall, turbidity was frequently higher than the WQO. Turbidity was higher in spring and summer than in autumn and winter. Turbidity was higher at the loggers around low tide, likely due to wave action in the shallow water resuspending sediment.

The concentrations of nutrients and chlorophyll a were typically above the WQO and highest in summer and lowest in winter.

5 Potential Impacts

Potential impacts to water quality from the proposed development comprise:

- changes to turbidity and sedimentation associated with dredging and reclamation
- changes to flushing rates associated with reclamation
- changes in water quality due to stormwater
- the release of contaminants from the disturbance of sediment
- the release of contaminants from the disturbance of soil and ground water
- spills of hydrocarbons and other contaminants, and
- disturbance of potential acid sulfate soils.

5.1 Background to Hydrodynamic and Coastal Process Modelling

Hydrodynamic and coastal processes of the site, as well as the quantity and quality of local catchment stormwater runoff and its subsequent deposition into the environment were modelled by BMT (BMT 2022). Specifically, the components that were numerically modelled and addressed were:

Hydrodynamic and coastal processes (including dredge plumes and climate change):

- tidal hydraulics – existing conditions and development impacts
- wave climate – existing conditions and development impacts
- marine sediment dynamics and siltation – existing conditions and development impacts
- shoreline processes – implications of development
- extreme events and storm tide – implications for development
- dredge plumes – physical impacts from dredging and disposal
- coastal hazards and risks – existing and impacts, and
- climate change considerations – impacts on processes.

Catchment surface water and receiving water quality:

- local catchment hydrology and drainage – existing conditions and development impacts
- local catchment stormwater quality – existing conditions and development impacts, and
- receiving water quality (physico-chemical) – existing conditions and development impacts (modelling only).

Two different levels of sea level rise (SLR) were superimposed to the modelled water level boundary conditions in order to represent possible future climate change scenarios:

- 0.4 metres sea level rise (likely change over the next 50 years), and
- 1.5 metres sea level rise (required by the EIS guidelines – worst case far-future scenario).

Present day bathymetry was used in the simulations; therefore the results are not completely representative of future conditions, but give an indication of relative impacts with and without the proposed development.

A detailed description of the modelling, including outcomes, is reported in full in the BMT Technical Report (BMT 2022). Modelling has been used to predict likely changes.

Outputs from this modelling include:

- spatial impact plots, and
- time series at key points of interest.

Visual representations and detailed descriptions of these outputs are in the BMT Technical Report (BMT 2022).

Outcomes of the models with respect to water quality are summarised in the sections below, and impacts to water quality assessed.

5.2 Changes to Turbidity Associated with Dredging and Reclamation

Potential impacts to turbidity associated with the first and second dredging campaigns were modelled with outputs described in BMT Technical Report (BMT 2022). The modelling took into account the configuration of the proposed development. Depth-averaged turbidity values are presented in spatial plots of percentile analysis and in time series at sensitive receptor sites (Figure 11.4).

In summary:

- Changes to turbidity due to dredging are likely to be limited to the dredge campaigns, with turbidity returning to ambient levels once dredging ceases.
- Turbidity in the vicinity of the Project Footprint is already high, prone to 'spikes' in response to wave activity, and regularly exceeding water quality objectives.
- The modelled increases in turbidity during the dredging campaigns are typically short-lived (around 20 NTU for a few hours per day immediately outside the channel) and are usually less than ambient maximums (which often exceed 100 NTU in nearshore areas).
- A combination of regional forcing and intertidal dynamics results in the net northward transport of the dredge sediment plume, particularly over the ebbing tide phase.
- In both dredging stages, the plume is advected to the east, before sweeping northward due to tidal exchange near Sandy Island.
- Significantly, from an ecological perspective, the period of high turbidity is not increased by the proposed dredging, as peaks due to dredging coincide with ambient high turbidity.

Modelling of impacts to turbidity due to the first dredging campaign indicates that:

- the dredge plume is mostly contained within the dredge envelope, with modelled changes to median turbidity outside the dredge channel less than 2 NTU, and to the 95th percentile less than 10 NTU
- typically, the eastern extent of the dredge plume reduces to very low levels before reaching Sandy Island (Figure 5.1).
- the northern transport of the dredge plume then begins with the northward flowing currents on the ebbing tide, before being cut off from the plume source in Fison Channel as the water level drops and the plume is blocked by the intertidal mudflats surrounding Cassim Island (Figure 5.2). The advected dredge plume extends to Cleveland Point, but levels are very low (predominantly less than 5 NTU above ambient).

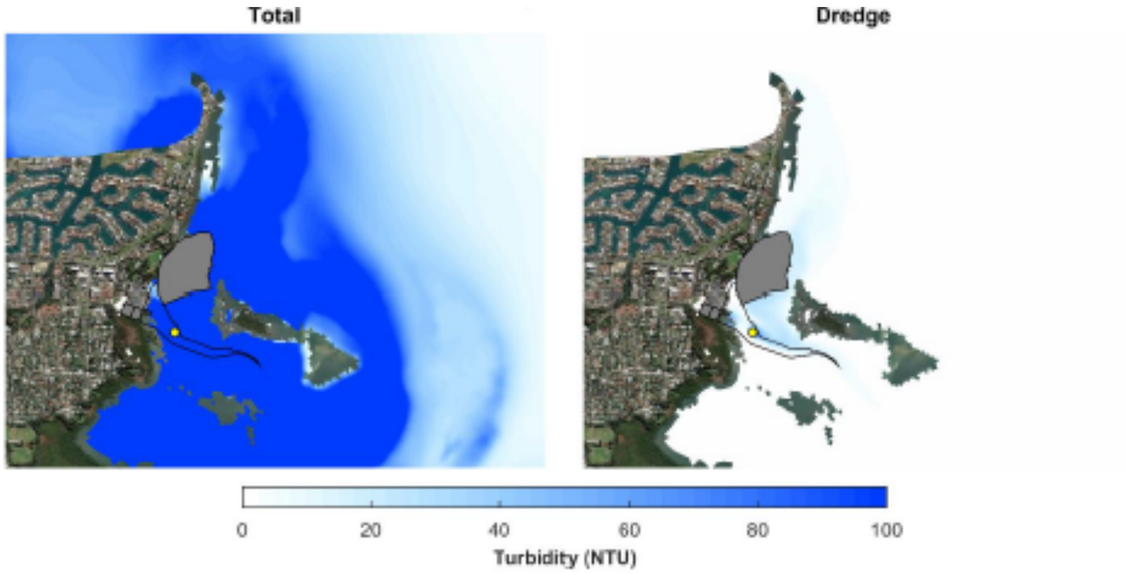

Figure 5.1 Snapshot of Stage 1 Dredging Depth-Averaged Turbidity – Depicting Eastward Advection of Dredge Plume.

Left: Total Turbidity, Right: Dredging-related Turbidity. Yellow circle indicates the position of the dredge.

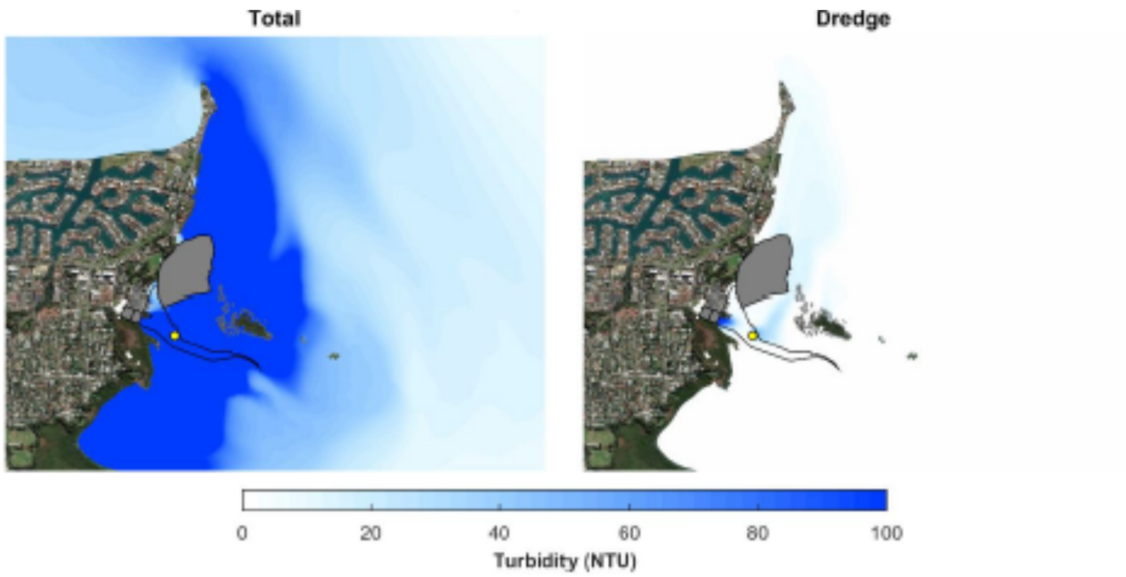

Figure 5.2 Snapshot of Stage 1 Dredging Depth-Averaged Turbidity – Depicting Northward Advection of Dredge Plume.

Left: Total Turbidity, Right: Dredging-related Turbidity. Yellow circle indicates the position of the dredge.

- this northern transport of the plume results in slight increases to the median turbidity over seagrass, coral, algal and rubble habitats (< 5 NTU, Figure 5.3)

- short term acute increases in turbidity (95th percentile) are in a slightly broader area (Figure 5.4), and
- short term acute increases in turbidity are when turbidity is already high and are associated with strong north easterly wind conditions.

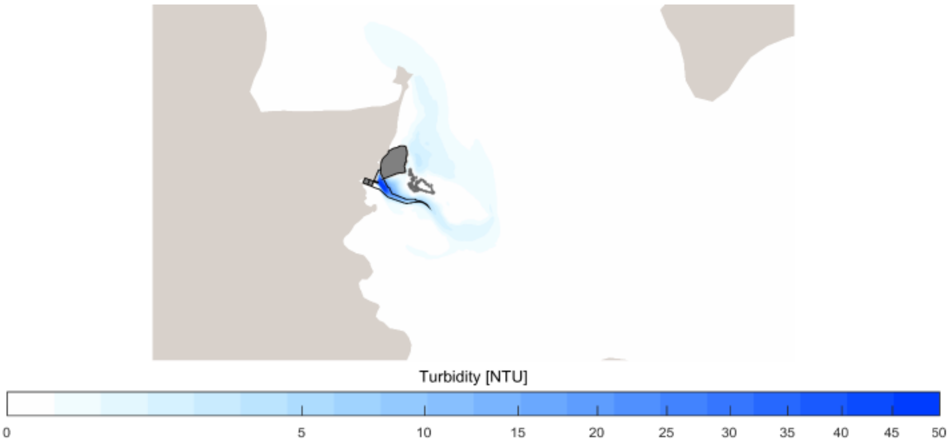

Figure 5.3 Dredge campaign 1: median increase in turbidity due to dredging.

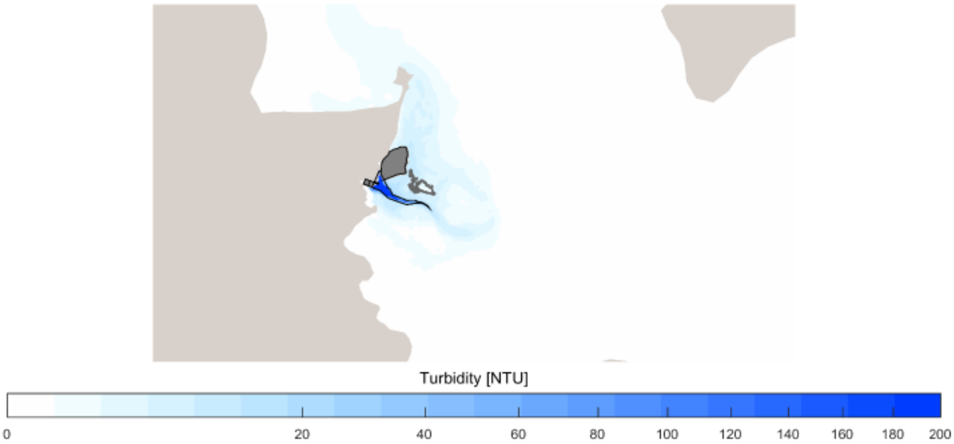

Figure 5.4 Dredge campaign 1: 95th percentile increase in turbidity due to dredging.

Modelling of impacts to turbidity due to the second dredging campaign indicates that:

- acute impacts are largely contained within the dredge channel
- there is a slightly larger spatial impact than in the stage 1 campaign
- typically, there is an eastward advection of the dredge plume along Fison Channel, particularly at the end of the ebbing tide after water levels have dropped and exposed the Cassim Island mudflats (Figure 5.5).

- The northward transport of the plume over the ebbing tide is further offshore than in the first campaign, as the plume is advected to the east of Cassim Island (Figure 5.6).

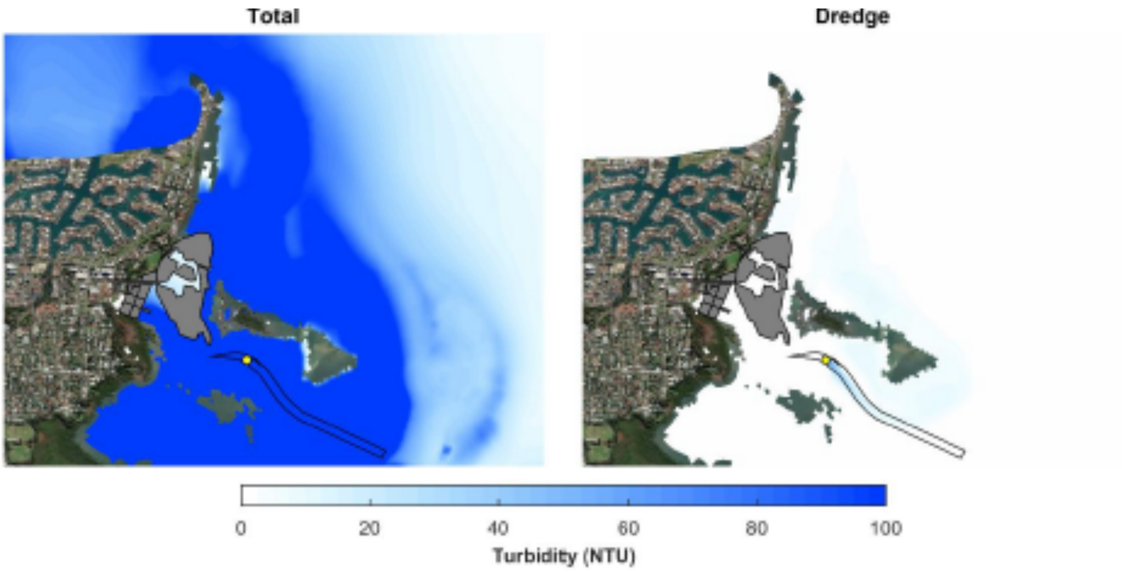

Figure 5.5 Snapshot of Stage 2 Dredging Depth-Averaged Turbidity – Depicting Eastward Advection of Dredge Plume.

Left: Total Turbidity, Right: Dredging-related Turbidity. Yellow circle indicates the position of the dredge.

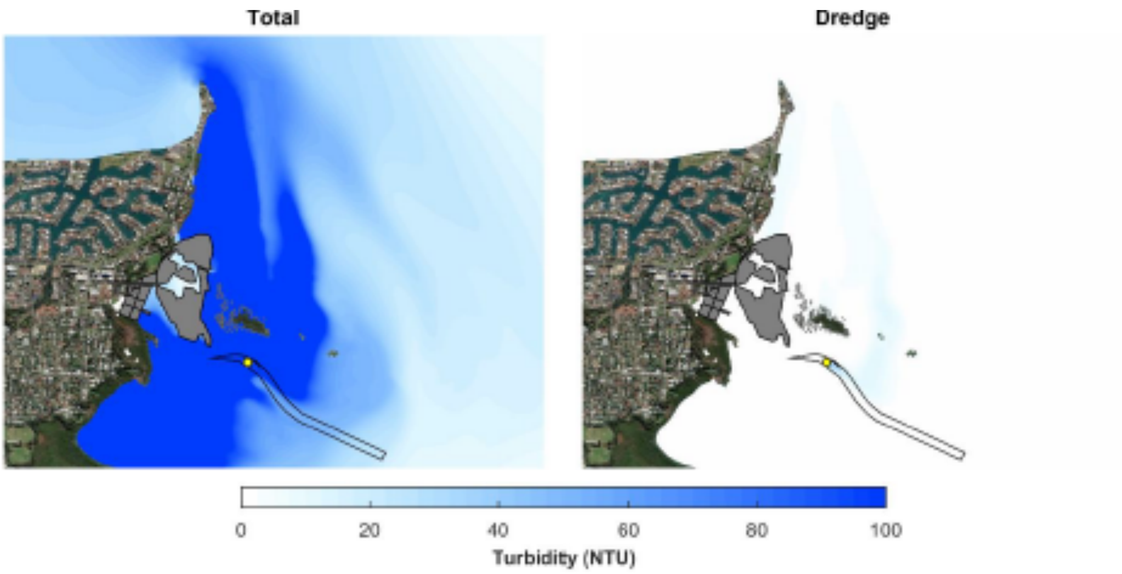

Figure 5.6 Snapshot of Stage 2 Dredging Depth-Averaged Turbidity – Depicting Northward Advection of Dredge Plume.

Left: Total Turbidity, Right: Dredging-related Turbidity. Yellow circle indicates the position of the dredge.

- increases to the median turbidity outside the dredge envelope are predominantly less than 5 NTU (Figure 5.7)
- increases to the 95th percentile turbidity are predominantly less than 10 NTU outside the dredge envelope (Figure 5.8)
- short term acute increases in turbidity are largely confined to the dredge channel, when turbidity is already high, and
- there are some small, short term acute increases (95th percentile) to turbidity north of the dredge channel, around Cassim Island and to the north of the Project Footprint, primarily over seagrass and rubble (Figure 5.8).

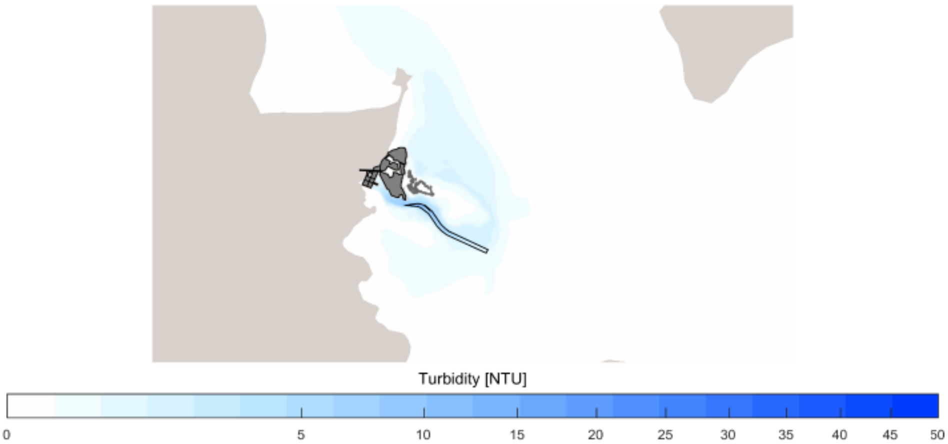

Figure 5.7 Dredge campaign 2: median increase in turbidity due to dredging.

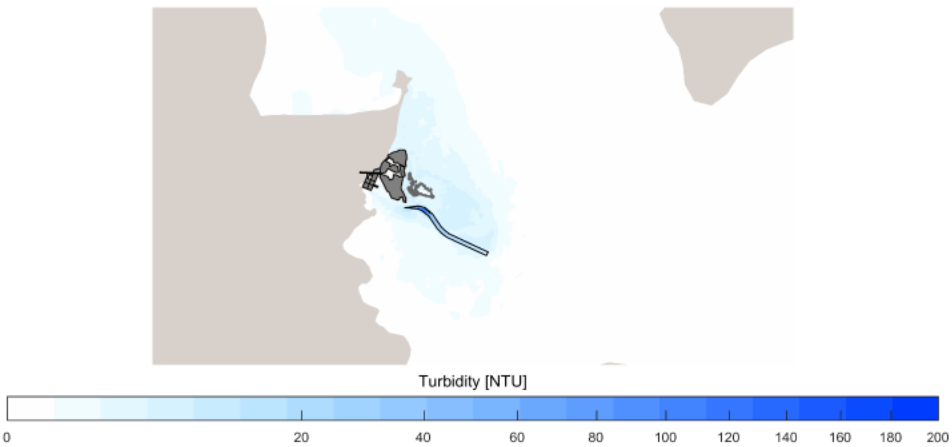

Figure 5.8 Dredge campaign 2: 95th percentile increase in turbidity due to dredging.

5.3 Changes to Flushing Rates Associated with Reclamation

Creation of the new landforms and channels may impact the turnover of water (flushing rate), in particular in the new marina basin and internal channels. This may impact water quality, with poor flushing rates sometimes resulting in eutrophic conditions.

Flushing rates were modelled using estimates of e-folding time.

The e-folding time is the time taken for the concentration of a tracer to reduce to 36.8% (1/e) of its original concentration. The e-folding time is a measure of approximately how long it takes for water within a confined area to be exchanged, and consequently is an indicator of whether water quality problems will develop due to limited exchange between a waterway and adjacent waters (Gómez et al. 2014).

e-folding times were modelled for Stage 1 Phase 3, Stage 1 Complete, and Stage 2 Complete, and also assessed with and without connections between the internal waterways and Moreton Bay (Figure 5.9).

e-folding times were also assessed for Raby Bay, a nearby canal estate built in the 1980s, with few, if any reports of poor water quality.

Modelling indicated that:

- there was little variation in e-folding times with water depth
- connections between internal waterways and the bay decreased e-folding time in the central marina and entrance channel, but increased it in the north eastern marina
- the north-eastern channel was always flushed in less than a day
- the longest e-folding times were in Stage 1 Complete and Stage 2 Complete in the central marina, where it was up to approximately six days in neap tide conditions (i.e. worst-case conditions; Figure 5.9)
- e-folding times were longer in the Raby Bay Channels than in the proposed Toondah Harbour development, with flushing rates of over 8 days in Raby Bay.

The appropriate e-folding times for water in marina developments depends on the nature of the runoff entering the marina, water quality in the marina and surrounding area, and potential impact on the receiving water and associated ecology. Short periods (e.g. less than ten days) are preferred, as this will prevent adverse impacts to water quality in the marina, such as excessive algal growth, or decreases in the concentration of dissolved oxygen (USEPA Coastal Marinas Assessment Handbook). As the e-folding times are lower than in nearby Raby Bay, a canal estate in a similar position in Moreton Bay as the proposed development, that has relatively good water quality, e-folding times in Toondah Harbour should be sufficient to maintain good water quality.

Further, phytoplankton growth and any consequent blooms and eutrophication in the marina are likely to be limited by the relatively turbid water of this area (Section 4.2 to Section 4.4), and there is consequently unlikely to be any excessive algal growth in the marina.

The flushing times are also sufficiently short to maintain high concentrations of dissolved oxygen in the water in the marina. Never the less, it is recommended the connections from internal waterway to the bay are built, to maximise turnover of water in the marina.

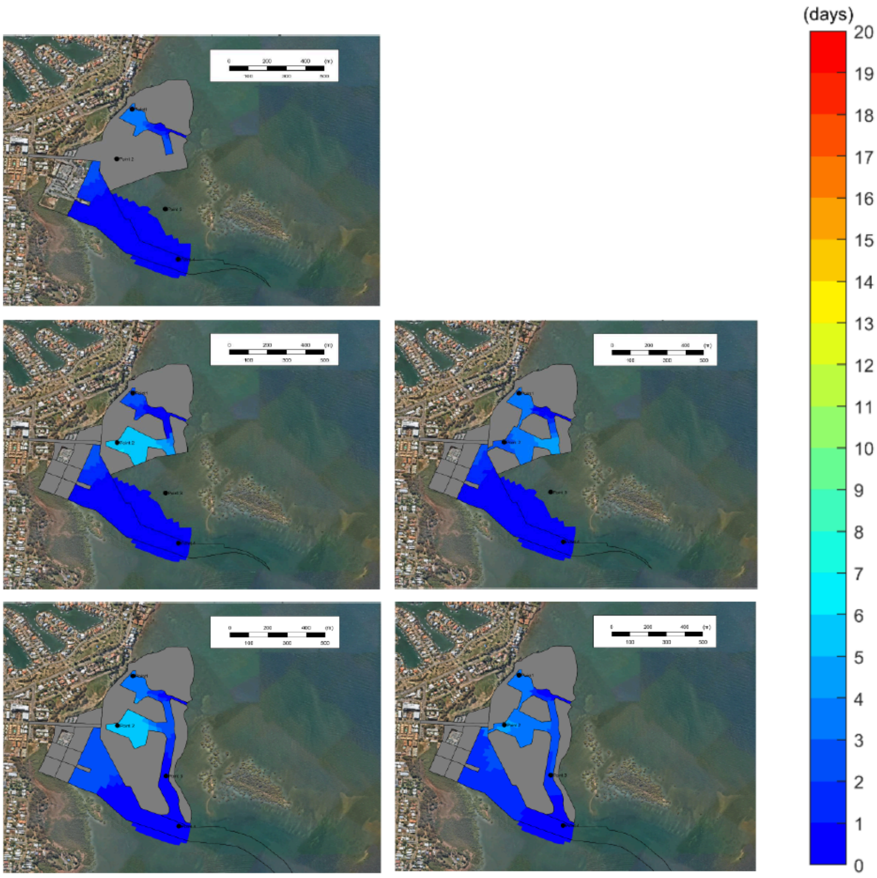

Figure 5.9 Flushing times for neap tide conditions for Stage 1 Phase 3 (top), Stage 1 Complete (middle) and Stage 2 Complete (bottom), without (left) and with (right) internal connections.

5.4 Changes in Water Quality Due to Storm Water

Creation of the new channels and landforms, and the development of infrastructure and buildings on the landforms may impact the quality and quantity of stormwater entering Moreton Bay. Stormwater flows and associated pollutant loads were modelled using MUSIC and used as input to a water quality model for the receiving environment. The concentration of total suspended solids (TSS), total nitrogen (TN) and total phosphorous (TP) from stormwater discharge were modelled. Modelled concentrations are indicative of the expected increase above background concentrations. The existing case and three treatment strategies were modelled using MUSIC:

- no mitigation
- mitigation to achieve objectives in the State Planning Policy (SPP), and
- mitigation to a higher standard than the SPP objectives.

The strategy to achieve the SPP objectives includes streetscape rain gardens (or 'at source' bioretention systems) to treat runoff from roads and carparks. Runoff from the lots will be treated in larger bioretention basins before being discharged from the site. Rain gardens will also be incorporated into the foreshore parkland area to ensure runoff from the open space areas are also treated to meet the SPP.

Additional measures to achieve a higher standard than the SPP objectives comprise rainwater harvesting and reuse, gully baskets and a small increase in the treatment performance of the streetscape and foreshore parkland bioretention systems, through an increase in the extended detention depth.

The modelling indicated that in both the scenario where SPP targets are met, and where they are exceeded, the reduction is greater than required by the SPP (Table 5.1). Further, these reductions were achieved at each of the 25 points that were modelled in each scenario. Additional reductions are anticipated where the storm water treatment devices have educational signage.

That is, where either the achieve SPP or exceed SPP targets are met, there should not be an increased risk from stormwater on the surrounding estuarine and species using the area.

Table 5.1 State Planning Policy operational performance criteria and modelled outcomes.

Pollutant	Criteria (% Reduction)	Achieve SPP (% Reduction)	Exceed SPP (% Reduction)
Total Suspended Solids	80	82	57
Total Phosphorous	60	75	80
Total Nitrogen	45	54	60
Gross Pollutants/ litter (5 mm or larger)	90	100	100

The stormwater flows and associated pollutant loads obtained from this MUSIC modelling were used in dispersion simulations to better understand the impact of stormwater flows, and in particular TSS, TN and TP on the water quality of the surrounding area. Stormwater dispersion was simulated for:

- the existing conditions
- Stage 1 complete, and
- Stage 2 complete.

For Stage 1 complete and Stage 2 each of the three management strategies used in the MUSIC model were simulated, i.e.:

- no mitigation
- mitigation to achieve objectives in the State Planning Policy (SPP), and
- mitigation to a higher standard than the SPP objectives.

Detailed results of this modelling are presented in the BMT Technical Report (BMT 2022).

In summary, modelling indicated that in the developed cases compared to the pre-development case:

- there were likely to be increases in the concentration of total suspended solids (TSS), total nitrogen (TN) and total phosphorous (TP) in the internal marinas and ferry terminal turning basin, due to confinement in these waterways, however the magnitude of the increases to TN and TP are relatively small compared to the water quality objective (WQO) and concentrations measured at nearby EHMP water quality sites
- outside of the footprint there was likely to be very little change in concentration of TSS, TN and TP, with the differences from existing conditions (80th percentiles) for:

    - TSS: always below 0.2 mg/L (Stage 1 Complete) and 0.4 mg/L (Stage 2 Complete)
    - TN: always below 2.0 µg/L, and
    - TP: always below 0.80 µg/L.
- there was likely to be an improvement in water quality in the intertidal area southwest of the ferry terminal, with the increase in treated stormwater flows mitigating the impact of the existing untreated flows
- in the intertidal area southwest of the ferry terminal, in wet weather conditions, the 80th percentile concentration of:
    - TSS is likely to decrease from 226 mg/L in the existing case to 105 mg/l in the developed cases
    - TN is likely to decrease from 1.5 mg/L in the existing case to 1.3 mg/l in the developed cases, and
    - TP is likely to decrease from 0.31 mg/L in the existing case to 0.25 to 0.26 mg/l in the developed cases.

That is, changes to stormwater runoff due to the development are unlikely to negatively impact water quality, and consequently aquatic habitats, fauna and flora, outside of the Project Footprint. Inside the Project Footprint there may be some slight increases in TSS, TN and TP, however modelling indicates that water in the internal channels of the reclamation area is likely to be flushed relatively quickly and is unlikely to result in eutrophication of these areas (BMT 2022).

Further, modelling indicated that:

- in the pre-development case the concentrations of TSS, TP and TN were likely to be higher in wet weather than in dry conditions, and there were likely to be localised areas of higher loads in the southwest and south of the ferry terminal
- in the developed cases, there was likely to be an increase in loads in the internal waterways and northern corner of the ferry terminal harbour (e.g. Figure 5.10)
- in each of the developed cases, concentrations in the internal waterways, and particularly in the central marina) were slightly higher than in the pre-developed case, which was expected due to the additional reclaimed land capturing stormwater loads in this area (e.g. Figure 5.10)
- in dry weather conditions these changes were limited to within the development footprint (e.g. Figure 5.10)

- in wet weather conditions, changes in concentrations compared to the predevelopment case extended slightly beyond the extent of the development footprint (e.g. Figure 5.10), and that
- there are likely to be both increases and decreases in the concentrations of TSS, TN and TP in a small intertidal area southwest of the ferry terminal, due to improved level of stormwater treatment and to changes in the local hydrodynamics with an overall improvement.

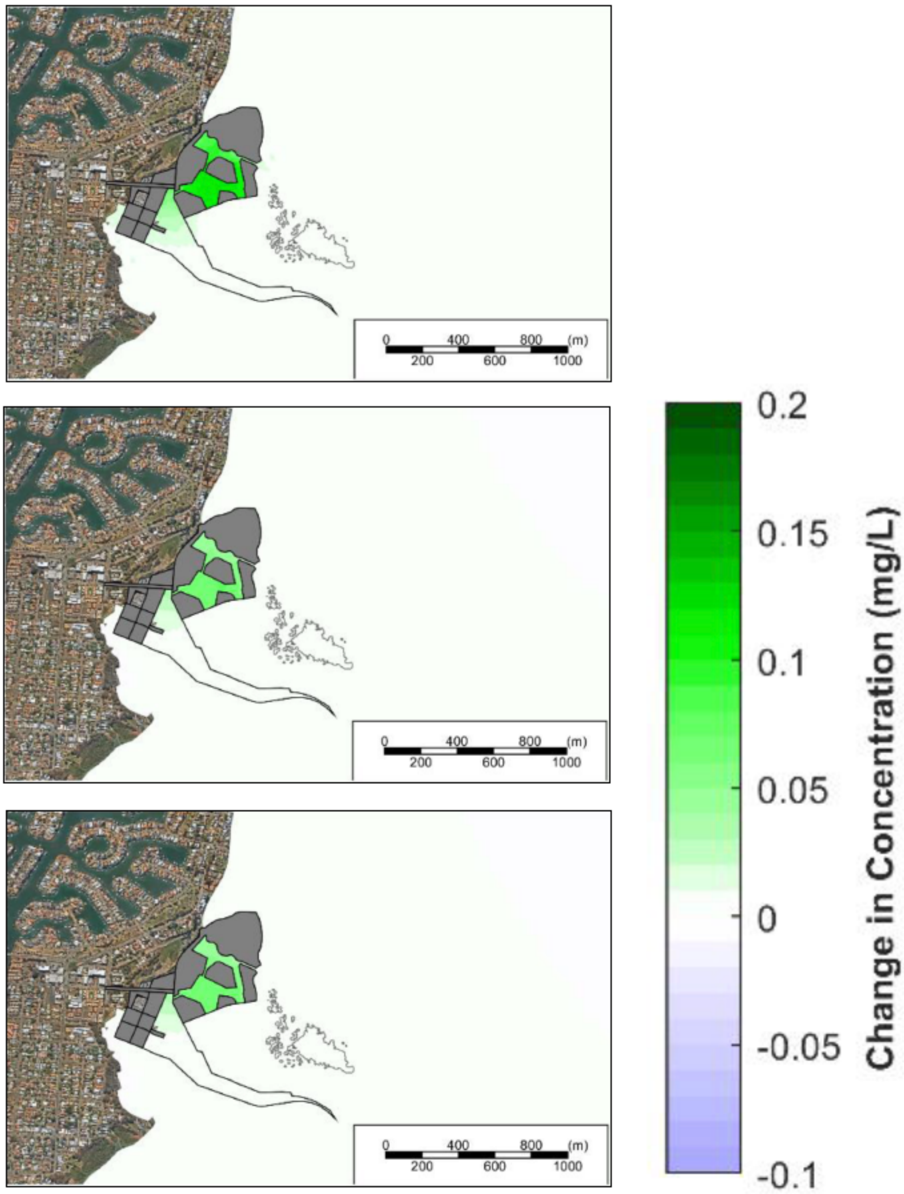

Figure 5.10 Difference in TSS concentrations in dry weather conditions (50th percentiles) in Stage 1 Complete Scenario, between existing case and BAU (top), ASSP (middle), and BBP (bottom)

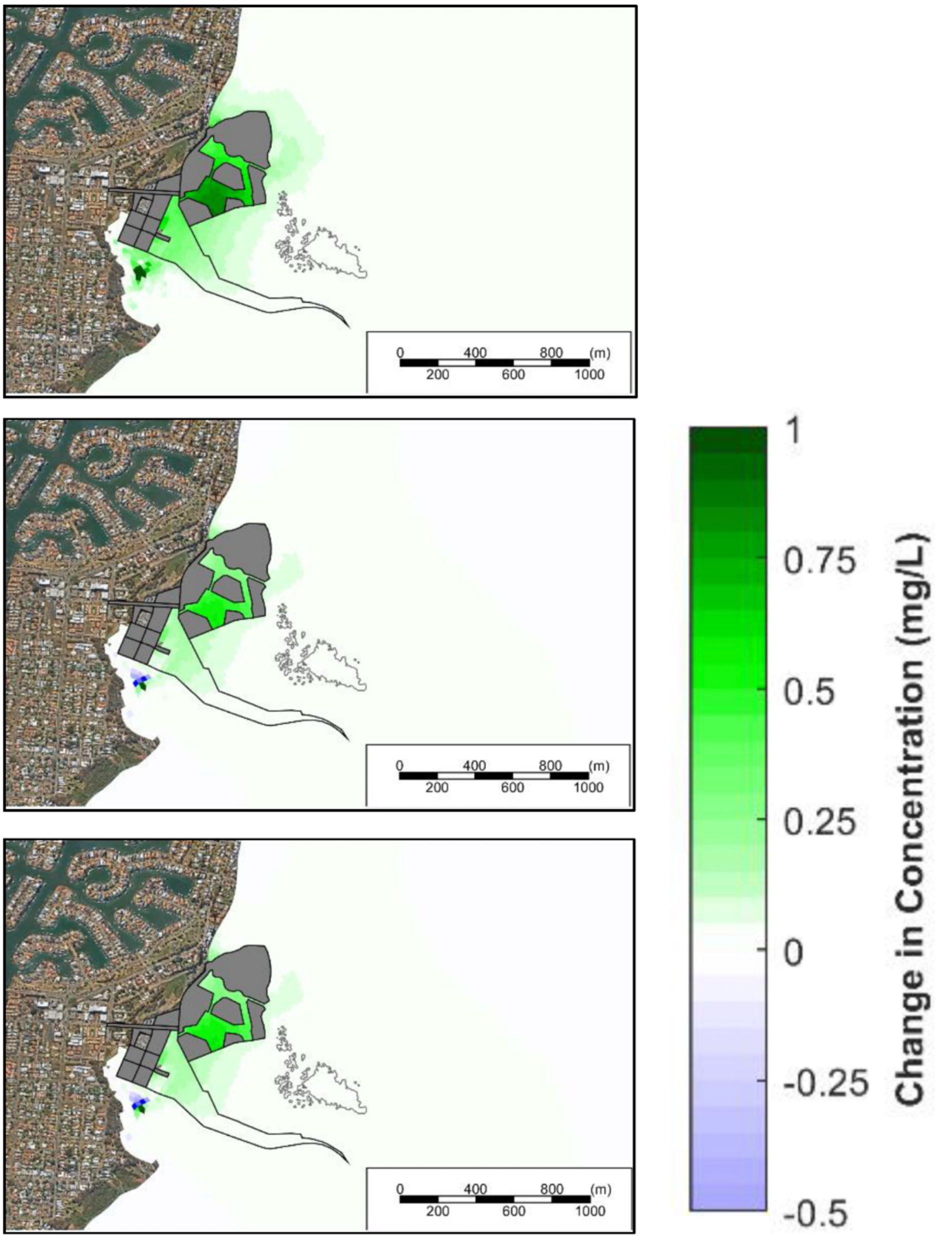

Figure 5.11 Difference in TSS concentrations in wet weather conditions (80th percentiles) in Stage 1 Complete Scenario, between existing case and BAU (top), ASSP (middle), and BBP (bottom) (BMT 2022)

Overall, in the developed cases compared to the pre-development case:

- there were likely to be slight increases in the concentration of TSS, TN and TP in the internal marinas and ferry terminal turning basin, due to confinement in these waterways (BMT 2022), however the magnitude of the increases to TN and TP are relatively small compared to the WQO and concentrations measured at EHMP sites (Table 5.2 and Table 5.3). For example, the WQO and 50th percentile of the EHMP sites in the vicinity of the proposed development for TN is 160 µg/L, and the predicted increase in the central marina is <0.8 µg/L
- outside the footprint there was very little change in concentration
- there was likely to be an improvement in water quality in the intertidal area southwest of the ferry terminal in wet weather conditions, with the increase in treated stormwater flows mitigating the impact of the existing untreated flow, with:
  - TSS likely decreasing from 226 mg/L in the existing case to 105 mg/l in the developed cases
  - TN is likely decreasing from 1.5 mg/L in the existing case to 1.3 mg/l in the developed cases, and
  - TP is likely decreasing from 0.31 mg/L in the existing case to 0.25 to 0.26 mg/l in the developed cases.

Table 5.2 Stage 2 Complete: modelled increases in the concentration of the 50th percentile of TN and TP in the central marina, with WQO for Area C2 and background conditions at nearby EHMP sites.

Parameter (µg/L)	Modelled Increase	WQO	Sites in Area C2[1]	Site E01201	Site E04500	All Sites[2]
Total nitrogen	<0.8	<160	150	150	220	160
Total phosphorous	<0.14	<20	15	19	39	20

[1] 50th percentile of Sites E0309, E0500 and E0501 in Area C2
[2] 50th percentile of Sites E0309, E0500 and E0501, EO1201 and E04500
* indicates differences with respect to existing concentrations

Table 5.3 Modelled increases in the concentration of the 80th percentile of TN and TP in the central marina, background conditions at EHMP sites and the WQO for Area C2.

Parameter (µg/L)	Modelled Increase	WQO	Sites in Area C2[1]	Site E01201	Site E04500	All Sites[2]
Total nitrogen	<7	<160	182	190	340	240
Total phosphorous	<1.3	<20	23	29	82	36

[1] 80th percentile of Sites E0309, E0500 and E0501 in Area C2
[2] 80th percentile of Sites E0309, E0500 and E0501, EO1201 and E04500
* indicates differences with respect to existing concentrations

In summary, modelling indicates changes to the stormwater discharge and treatment associated with the project is likely to result in:

- no change in water quality in the Area HEVa1284, the nearby HEV Area
- very minor increases in concentrations within the project footprint, and an
- overall decrease in concentrations in the intertidal area to the southwest of the ferry terminal, i.e. excluding the project footprint, an overall improvement in water quality in Area C2 (a moderately disturbed area).

As such, stormwater modelling indicates that the project will not significantly negatively impact the management intent of Area C2, nor the nearby HEV waters in Area HEVa1284.

Potential impacts to aquatic ecological communities from these changes to water quality and sedimentation are discussed in the EIS Chapter: Marine Ecology.

5.5 Release of Contaminants from the Disturbance of Sediment

The disturbance of sediment can result in the release of contaminants. Sediment in the Proposed Channel was assessed according to the National Assessment Guidelines for Dredging 2009 (NAGD; DEWHA 2009) and summarised in the EIS Chapter: Sediment Sampling and Analysis.

It was also assessed using the National Environment Protection (Assessment of Site Contamination) Measure 1999 (ASC NEPM; Australian Government 2013), and summarised in EIS Chapter: Contaminated Land Sampling and Analysis 2019 (Sediment).

NAGD

The NAGD were developed to determine whether there are any contaminants in the sediment, and consequently whether it is suitable for disposal at sea. As the sediment is being used in the Reclamation Areas, any contaminants in the sediment would only cause an impact during the dredging process, and if contaminants were dissolved in the seawater. The concentration of potential contaminants in the sediment from the dredging area were low (below the available NAGD Screening Levels, and predominantly below the laboratory's detection limits), and consequently the risk of release of contaminants from the dredged sediment is considered to be negligible.

In the proposed reclamation area, the 95% UCL for arsenic, chromium, lead, and nickel exceeded the NAGD Screening Levels, but were less than the High Trigger Values. These concentrations were similar, or within the range of previously recorded concentrations in the channel, and are most likely a result of the local geology, with high concentrations of metals in the laterite dominated intertidal rock platforms in the area.

ASC NEPM

The mean, 95% UCL and maximum of all parameters in the proposed dredge area and reclamation area were below (and complied with) the ASC NEPM HIL, HSL, ESL and ML (where available) and in many instances were below the laboratory's detection limits. Of the parameters that do not have an ASC NEPM investigation or screening levels, and that were above the LOR, the concentration was similar to previously recorded and are unlikely to be of concern. In accordance with the flowchart for the assessment of site contamination, no further action is required.

The sediment in the proposed dredge and reclamation areas is not considered to be contaminated and is of low risk to human and ecological health. That is, there is not a significant risk of release of contaminants to the water column by the suspension of the sediment in the water column due to dredging or other proposed activities.

As the proposed reclamation area will be bunded during works, the risk of sediment mixing with the surrounding water is low.

This issue is not discussed further in this report, as there is not an impact to water quality from contaminants in the dredge material.

5.6 Release of Contaminants from the Disturbance of Soil and Groundwater

The potential for contamination associated with current and former land use of the site, including GJ Walter Park and the current Toondah Harbour on Emmett Drive, Cleveland was investigated (EIS Chapter: Contaminated Land). No risks to human health or to the environment were identified, that could not be managed on site. However, it was noted that further investigations were required in the early planning stages.

Impacts to groundwater of the proposed development were also assessed (EIS Chapter: Groundwater). Potential impacts were expected to be of low risk to the groundwater regime and sensitive receptors, as they are short to medium term and localised within the PDA area. Any risks will be further mitigated through ongoing monitoring and management, to ensure the risk to surrounding areas, including Moreton Bay is very low.

5.7 Spills of Hydrocarbons and Other Contaminants

This issue is addressed in the EIS Chapter: Marine Ecology.

5.8 Disturbance of Acid Sulfate Soils

This issue is addressed in the EIS Chapter: Marine Ecology.

6 Management Measures

Stormwater management, dredging activities and reclamation works have been designed to minimise impacts to water quality. The proposed works will also be subject to an Environmental Management Plan that ensures detrimental impacts to water quality are minimised by using appropriate:

- erosion and sediment controls
- management of potential acid sulfate sediments, and
- chemical (including fuel) management and containment.

The detailed management framework for the proposed works are discussed in a separate Chapter.

The ability to adequately manage potential impacts on water quality during construction is principally dependent on the control of turbidity plumes, stormwater runoff and controlling any release of water from the reclamation areas. Measures proposed to manage potential impacts include:

- using sheet piling and geofabric lining to prevent the movement of fine sediment through the rock walls
- using silt nets where possible to limit the spread of any plumes
- providing adequate reclamation area and arrangement to avoid tailwater discharge including re-use of water onsite for dust suppression
- using erosion and sediment control devices on land works where appropriate
- using sediment fences where appropriate to limit sediment from moving outside of the reclamation footprint
- using a Back-Hoe Dredge which limits the resuspension of sediment and extent of turbidity generation.

Operational water quality will be managed through the implementation of beyond best practice stormwater treatment controls that will result in reductions above those required by the relevant water quality objectives. Other measures that would be put in place to manage potential impacts to water quality during operations include:

- using breakaway couplings at bowsers, emergency shut offs and similar equipment for the re-fuelling area
- keeping spill kits on site and provide training to staff members on how to use them

- providing pump-out facilities on-site for vessel wastewater treatment
- providing pamphlets, signs etc. to educate users on facilities such as the pump-out system and spill kits
- providing waste oil and fuel collection facilities
- regular inspections of facilities by marina management.

These measures have been addressed in the management framework and would be updated and finalised prior to the commencement of operations and approval from state government.

7 Water Quality Monitoring Program

Potential impacts to water quality and marine ecology will be managed through an overall trigger action response plan (TARP). In this plan key sensitive receptors will be protected by:

- using baseline data and modelling to develop trigger levels for a suite of parameters that provide an early warning of potential damage
- monitoring these parameters
- providing actions in response to these triggers being met.

All monitoring will be in accordance with methods prescribed in the latest edition of the Monitoring and Sampling Manual (Monitoring and Sampling Manual 2009 Environmental Water (Policy) DES 2018), and a project-specific Standard Operating Procedure that addresses the management of data quality and integrity, including effective calibration and maintenance of water quality meters in accordance with their specifications and the Monitoring and Sampling Manual. Samples will be analysed by a NATA accredited laboratory, with appropriate Practical Quantitation Limits (PQL) so that data can be compared to the WQO for Area C2. The results of water quality monitoring will be publicly available, as close to real time as possible.

Where water quality parameters exceed predefined trigger levels, further investigation will be required. Where this investigation indicates there may be an adverse impact to key sensitive habitats, a management response will be implemented.

The water quality monitoring program has been designed to specifically address changes to water quality:

- from potential plumes from dredging and reclamation, and
- within the marina.

Overall impacts from the Project on sentinel key sensitive habitats in the surrounding area will also be monitored. This will include monitoring water quality, benthic photosynthetically active radiation (BPAR), and habitat condition (monitoring of habitat condition is addressed in the EIS Chapter on Marine Ecology).

7.1 Potential Plumes from Dredging and Reclamation

This component of the water quality monitoring program addresses monitoring of potential plumes from dredging and reclamation activities. The risk from contaminants and nutrient release during dredging and reclamation is considered to be low (Section 5.5), and consequently this part of the monitoring program focusses on changes to turbidity (associated with a potential increase in suspended solids), dissolved oxygen and pH. While the water body is generally well mixed, in the short term these parameters may vary with depth, and so will be measured throughout the water column.

Water quality will be measured up and down current of any active dredging and of any activities from the reclamation works (e.g. construction of bund walls) that may negatively impact water quality[8]. The scope and extent of any plumes from activities will be assessed visually (including the use of drones) throughout the construction phase.

Monitoring sites will comprise sites up and down-current of dredging and other earthworks activities, as well as sites in nearby sensitive habitats that may be impacted by changes in water quality. As in previous dredge campaigns at Toondah Harbour, to assist in correctly attributing the cause of any changes in turbidity, an up-current control site will be monitored, in addition to down-current sites at set distances from the current dredging activities. As the dredge moves throughout the campaign, and the position on any one day cannot currently be predicted, and as the direction of up and down current changes with the tide, it is not possible to map all possible monitoring locations. As an example, water quality monitoring sites in the last dredge campaign at Toondah Harbour are presented in Map 11.3.

Water quality depth profiles of turbidity, percent saturation of dissolved oxygen and pH will be collected at sites:

- 50 -100 m up-current of activities that result in the disturbance of sediment or water quality
- ≤ 350 m down-current of activities, and
- 500 m down-current of activities and continuing every 250 m to the maximum distance of any visible plume.

Water quality depth profiles will be collected:

- every day for four days at the commencement of each dredge campaign

[8] Noting that with the current design there are no discharges from the reclamation area, so ambient monitoring during standard reclamation activities would not be required.

- every day for four days prior to any reclamation activity that would result in a discharge[10]
- every day for four days following any exceedance, and
- once a week throughout standard dredging activity, and any reclamation activity that would result in a discharge[10].

Further:

- Each time water quality data is collected, Global Position System coordinates will be recorded for the up-current control site(s), location(s) of the activity, and downstream monitoring point(s).
- Data will be collected in depth profiles, with measurements at 2m depth intervals where overall depth is >10m, or I m depth intervals where the overall depth is <10m, with the deepest reading taken at least 1 m above the substrate.
- Water quality measurements will only be collected during tidal flows and will be at least one hour either side of the slack tide.
- All monitoring will be of samples that are representative of the effects of the dredging activity.

Background values (BV) will be calculated as the average of the readings collected from depth profiles at the up-current point.

Triggers for investigation will be based on the comparison of BV to the value ≤ 350 m down-current of activities. The following investigation triggers are nominally recommended:

- where the BV for turbidity is less than 100 NTU, then the trigger for investigation is defined as 10 NTU or more above the BV, and
- where the BV is more than 100 NTU, then the trigger for investigation is defined as 10% or more above the BV.

These triggers were used previously to monitor dredge activities in Toondah Harbour (Section 4.3).

The pH at the monitoring point/s 350 m downstream of activities will also be compared to the prescribed minimum and maximum WQO for Area C2, and to the BV.

When an investigation trigger is reached or exceeded, the likely cause will be investigated and determined. The length of the plume will be recorded, and data will be collected and analysed from the nearby sensitive habitats (Section 7.3) to determine whether pH complies with the WQO, whether there is a corresponding peak in turbidity or decrease in BPAR that may be due to the dredge or reclamation activities. Where other current data is available (e.g. data from the EHMP) it will also be used in this assessment.

Where the activities result in a plume that may negatively impact nearby sensitive habitats, management measures (including modifying or ceasing dredging) will be implemented to rectify the issue. Specific measures may include:

- moving the position of the dredge away from the sensitive habitat
- stopping dredging to allow turbidity levels to drop or currents to reverse, and
- use of or other management measures to reduce turbidity, such as silt curtains or modifying the dredge technique, should the investigation triggers be reached frequently.

7.2 Water Quality Within the Marina

Modelling indicates that the marina flushing times are sufficiently short to maintain water quality, including high concentrations of dissolved oxygen in the marina (Section 5.3).

On connection of the interior waterways to the bay, the site will be inspected daily for visual and olfactory signs of poor water quality, including:

- floating scums of algae
- slicks (oil, chemical)
- litter
- excessive growth of algae, and
- unpleasant odours.

Water quality will also be monitored monthly for the first twelve months in areas of the marina with the longest flushing times (i.e. the north-western section of the internal waterway, the central marina, the middle entrance channel and at two background (control) points to the north and south of the project). Turbidity, pH, conductivity and the percent saturation of dissolved oxygen will be measured in situ in surface water, and 1 m from the bottom. In addition, surface samples will be collected and analysed for the concentration of total nitrogen, oxides of nitrogen, ammonia, oxidised nitrogen, total phosphorus, filterable reactive phosphorus, chlorophyll a, and enterococci.

These water quality parameters will also be measured at these sites following two rainfall events each year (nominally > 20 mm within a 24 hour period) and where visual assessment indicates a deterioration in water quality.

7.2.1 Management Trigger: Dissolved Oxygen

After each monitoring event, the percent saturation of dissolved oxygen at each site within the marina will be compared to data from the control sites and to the water quality objectives (WQO).

Where the percent saturation of dissolved oxygen is within WQO (95 to 105%[9]) at the control sites, but is not within the WQO at a site within the marina:

- monitoring of dissolved oxygen will be increased to daily, until levels return to an acceptable level
- the cause will be investigated by a suitably qualified water quality scientist or engineer, and
- the waterway will be managed to prevent the percent saturation of dissolved oxygen decreasing to less than 85%. Management measures may include aeration, and re-evaluation of stormwater management.

7.2.2 Management Trigger: Nutrients, Chlorophyll a, and Enterococci

The annual median of the monthly concentration of nutrients, chlorophyll a, and enterococci from each site within the marina will be compared to the median from the control sites.

Where the median from each site within the marina is higher than the control sites, the medians from the marina will be compared to the WQO.

Indicative triggers for investigation based on this approach, and using background concentrations in Area C2 as a guide for likely median concentrations for the control sites, are presented in Table 7.1.

[9] Noting that in Area C2, the median of water quality parameters should comply with the WQO, not individual readings. Thus this will be an early alert.

Table 7.1 Indicative triggers for investigation within the marina

Parameter (µg/L)	Modelled Increase*	Median in Area C2[1]	WQO	Trigger for Investigation
Total nitrogen	<7	150	<160	160
Total phosphorous	<1.3	15	<20	20

[1] 50th percentile of Sites E0309, E0500 and E0501 in Area C2
* indicates differences with respect to existing concentrations

Where a median from within the marina is higher than the median from the control sites and exceeds the WQO, the cause and impacts will be investigated, and where necessary management actions implemented to rectify this (e.g. aeration, re-evaluation of stormwater management) implemented to improve it.

If after 12 months water quality does not comply with the expectations of the models, is significantly poorer than historical water quality, and/ or is poorer than at the control sites, water quality data will continue to be collected each month, until such time as these expectations are met.

If, after twelve months, water quality in the channels and marina complies with the expectation of the models, or is not significantly different to historical data or to water quality at the control sites, water quality data will only be collected after significant rainfall events (i.e. > 20 mm within a 24 hour period) for three years.

7.2.3 Ongoing Use and Operations

After the completion of works comprising the establishment of the development footprint and the completion of dredging, monitoring of the marina will be required to assess any changes in water quality due to runoff and altered hydrodynamics. Water quality will be measured in the marina and ferry port harbour, Fison Channel and two background 9(control) locations, quarterly over two years for:

- physico-chemical parameters measured in situ (i.e. dissolved oxygen, pH, salinity and turbidity);
- nutrients (e.g. total nitrogen, total phosphorous, oxides of nitrogen, organic nitrogen, filtered reactive phosphorous, ammonia)
- total suspended solids, and
- chlorophyll a.

Where the median concentration of nutrients, chlorophyll a, or enterococci is higher than the background (control) conditions and exceeds the WQO, the cause and impacts will be investigated, and where necessary management actions implemented to rectify this.

7.3 Monitoring Water Quality and BPAR at Key Habitats

In addition, to determine and manage any adverse impacts to nearby sensitive habitats, turbidity, pH, and benthic photosynthetically active radiation (BPAR) will be monitored at the sites where the ecological condition of key habitat is monitored (Map EIS Chapter: Marine Ecology; Map 11.6):

1. the closest coral communities near Jercuruba (Peel Island)
2. the closest coral communities near Coochiemudlo Island
3. coral communities on the north-east edge of the Cassim Island sandbar
4. a coral control site east of Wellington Point
5. seagrass bed north of Oyster Point
6. seagrass bed north of the proposed development
7. seagrass control site north of Point Halloran, and a
8. seagrass control site at Wellington Point.

These sites will be surveyed prior to monitoring commencing to ensure they still support these habitats, and varied as appropriate if habitat distribution has changed.

7.3.1 Water Quality

Turbidity, conductivity, Secchi depth, temperature and percent saturation of dissolved oxygen in surface waters will be monitored at each site. Each site will be monitored:

- immediately prior to, and each month during dredging and reclamation activities
- each quarter for two years once the final development footprint is established.

This data will be assessed together with the results of the marine ecological assessments at each site (EIS Marine Ecology Chapter). Where there are significant changes to habitats at potentially impacted coral or seagrass habitats but not at the control sites, the reasons for these changes, including changes to water quality, will be investigated, and appropriate management actions applied.

7.3.2 BPAR

A variety of factors, including genetics, temperature, nutrient and sediment conditions may influence light thresholds (Collier et al. 2016). Light thresholds for the management of acute impacts have been developed for all the seagrasses species that occur in the MIA, including the dominant species *Zostera muelleri* and *Halophila ovalis* (Collier et al. 2016, Pearson et al. 2020, Table 7.2). These thresholds are conservative as they are higher than the maximum biological thresholds (Collier et al. 2016). As they are conservative they provide an early warning of potential impact, and an opportunity to investigate and instigate appropriate management actions to prevent impacts.

Table 7.2 Seagrass light thresholds for species in the MIA.

Species	Classification	Suggested Management Threshold (Mol m^{-2} d^{-1})	Integration Time (days)*	Time to Impact (days)**	Confidence Score+	Application Area
Cymodocea serrulata	opportunistic	5	14	50	4	GBRWHA
Halophila decipiens	colonising	2	1	14	3	GBRWHA
Halophila ovalis^	colonising	2	7	14	3	GBRWHA
Halophila ovalis^	colonising	6	7	28	3	GBRWHA
Halodule uninervis	colonising / opportunistic	5	14	40	3	GBRWHA
Zostera muelleri	colonising / opportunistic	6	14	28	2	GBRWHA
Zostera muelleri	colonising / opportunistic	4.5	14			Gold Coast

*Averaging time used to describe light history and as first signal to trigger management plan

**Time to impact expected and a management plan should be implemented before this time

^Two thresholds are recommended for this species as it occupies diverse habitats (with a broad range in light levels) and is highly sensitive to disturbance. Both levels should be complied with.

+ A confidence score of 2 indicates a relatively high level of confidence, but based on studies from limited locations, 3 indicates somewhat confident, 4 indicates low confidence.

The suggested management threshold for the dominant seagrass in the MIA (*Z. muelleri*) is a rolling average of 6 mol m^{-2} d^{-1} with an expected time to impact after 28 days (Collier et al. 2016).

The threshold of 6 mol m^{-2} d^{-1} with an expected time to impact after 28 days developed for the GBRWHA for *Z. muelleri* is based on a broad geographical range of data, from Port Hacking in NSW to Gladstone, including data from Moreton Bay, and is within the margin of error developed for the lower threshold of 4.5 mol m^{-2} d^{-1} developed for this species for the Gold Coast (Collier et al. 2016, Pearson et al. 2020). It is considered likely that the appropriate management threshold for the MIA is likely to be in the vicinity of these two values. This threshold will be refined for use in the MIA by some site specific studies, including logging of BPAR and assessment of seagrass biomass, density and length.

BPAR will be logged at deepest end of the *Z. muelleri* meadow at each of the four seagrass sites for 14 months prior to works commencing, and throughout the dredging and reclamation campaigns. Two autonomous 2π loggers (OdysseyTM or similar) with wiper units to keep sensors clean will be used to measure BPAR at each site. Light will be recorded as instantaneous light (μmol m-2 s-1) every 15 – 30 minutes, and will be summed to daily light (mol m-2 d-1), which integrates daily light exposure (Bryant et al. 2014, McKenzie et al. 2016). Daily light will then be reported as a rolling average of the previous 14 days.

Seagrass biomass, average leaf length and density will also be measured in 5 replicate quadrates each month at each site at the deepest edge of the *Z. muelleri* meadow, for 14 months prior to works commencing.

This data will be compared to data from existing studies to determine a conservative threshold to be used in combination with the water quality monitoring (Section 7.1) to manage dredging and reclamation activities.

The light threshold will be used to supplement the triggers and dredge management described in section 7.1m. Where BPAR is below the threshold at the potentially impacted sites for 14 days, an investigation of data will be triggered (including water quality, habitat, BPAR, weather and other relevant data) and possible causes identified.

Where investigation indicates the low BPAR is likely due to dredging or reclamation activities, measures (including modifying or ceasing dredging) will be implemented to rectify the issue.

8 Conclusions

Modelling of potential impacts to water quality indicates that:

- the internal waterways created by the proposed development are likely to be well flushed, and it is unlikely there will be phytoplankton blooms or eutrophication within these waterways
- while there may be slight increases in the concentration of total nitrogen and phosphorous in the internal waterways, these increases are very small compared to current concentrations
- in wet weather conditions there is likely to be a reduction in the concentration of total suspended solids, total nitrogen and total nutrients in the intertidal area southwest of the ferry port due to an increase in the proportion of treated stormwater flows
- stormwater from the project will not significantly negatively impact the management intent of Area C2, nor the nearby High Ecological Value waters in Area HEVa1284
- during both dredging campaigns most of the increases to turbidity are confined to the channel
- changes to turbidity due to dredging are likely to be limited to the dredge campaigns, with turbidity returning to ambient levels once dredging ceases
- turbidity in the vicinity of the Project Footprint is already high, prone to 'spikes' in response to wave activity, and regularly exceeding water quality objectives
- the modelled increases in turbidity during the dredging campaigns are typically short-lived (around 20 NTU for a few hours per day immediately outside the channel) and are usually less than ambient maximums (which often exceed 100 NTU in nearshore areas)
- a combination of regional forcing and intertidal dynamics results in the net northward transport of the dredge sediment plume, particularly over the ebbing tide phase
- in both dredging stages, the plume is advected to the east, before sweeping northward due to tidal exchange near Sandy Island, and
- significantly, from an ecological perspective, the period of high turbidity is not increased by the proposed dredging, as peaks due to dredging coincide with ambient high turbidity.

A comprehensive water quality monitoring plan is proposed, with reactive management if investigations indicate there is likely to be a negative impact on nearby sensitive habitats.

Stormwater management, dredging activities and reclamation works have been designed to minimise impacts to water quality. The proposed works will also be subject to an Environmental Management Plan that ensures detrimental impacts to water quality are minimised by using appropriate:

- erosion and sediment controls
- management of potential acid sulfate sediments, and
- chemical (including fuel) management and containment.

Based on the modelling of potential impacts, and where monitoring and these management plans are effectively implemented, there is likely to be little long-term significant negative impact to water quality as a result of the Project.

9 References

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10 Glossary, Abbreviations and Units

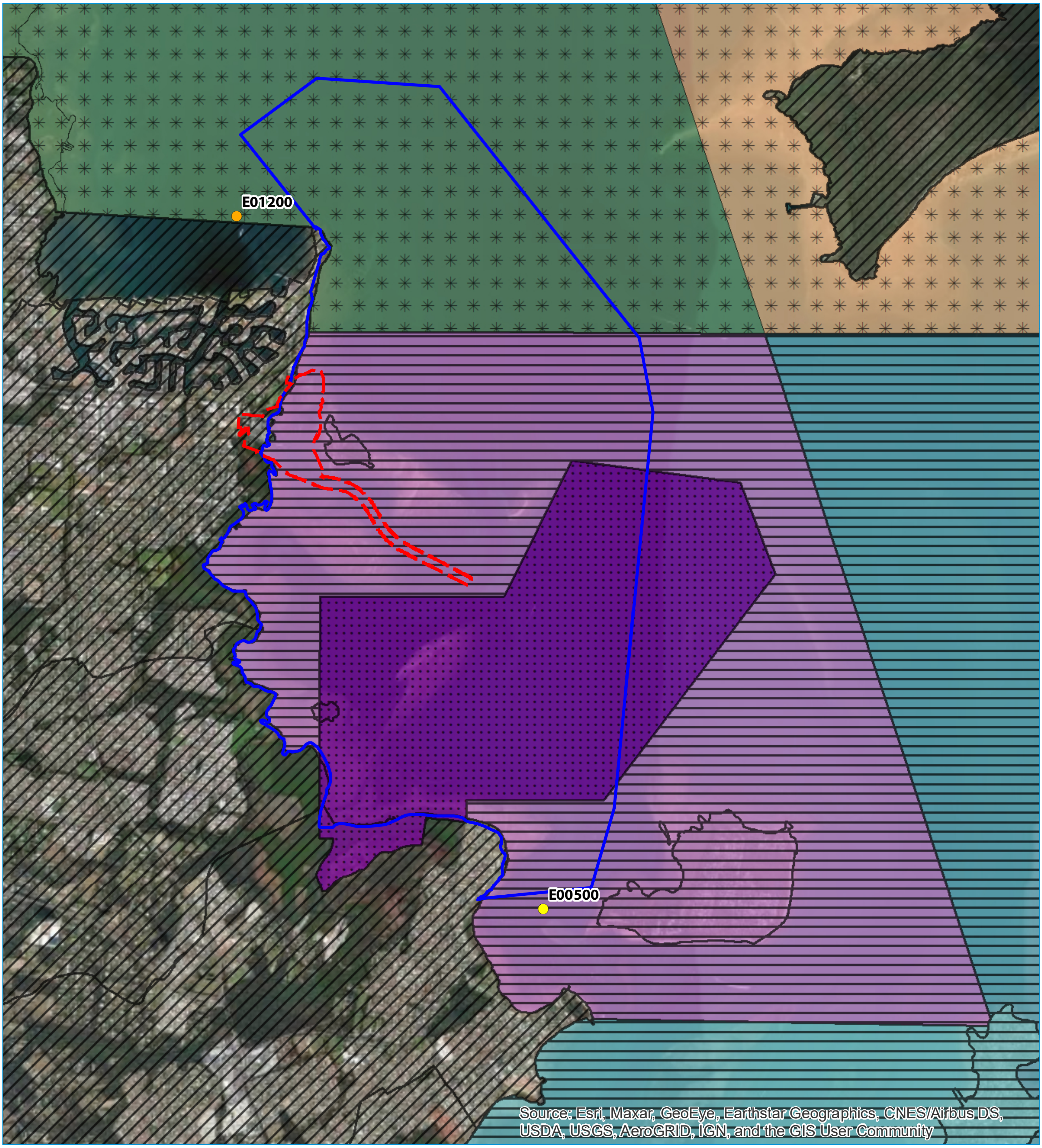
AHD	Australian Height Datum
ANZG	Australian & New Zealand Guidelines for Fresh and Marine Water Quality
DERM	Department of Environment and Resource Management
EA	Environmental Authority. In Queensland an EA is required for environmentally relevant activities (ERA).
e-folding time	The time for a quantity to decrease to 1/e of it previous value, i.e. the amount of time required to remove 63% of material from a system, which represents the average time to flush the material out of the system (Honghai 2010).
EHMP	Ecosystem health monitoring program
EIS	Environmental impact statement
EP Act	*Environmental Protection Act 1994* (Qld)
EPBC ACT	*Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth)
EPP Water and Wetland	Environmental Protection (Water and Wetland Biodiversity) Policy 2019 (Qld)
EPR	Environmental Protection Regulation 2019 (Qld)
ERA	Environmentally relevant activity, an activity specified under the Qld Environmental Protection Regulation that may cause environmental harm.
EV	Environmental value defined under the EEPP Water and Wetlands. The qualities that make it suitable for supporting aquatic ecosystems and human uses of water.
Flushing time	The amount of time to replace a water mass (also known as turnover time)
FRP	filterable reactive phosphorus
HEV	High ecological value
HEVa	High ecological value (achieve)
HEVm	High ecological value (maintain)
HLW	Healthy Land and Water
MNES	Matter of national environmental significance
MSES	Matter of state environmental significance

NATA	National Association of Testing Authorities. NATA provides assessment, accreditation and training services to laboratories and technical facilities. NATA accreditation is a formal recognition that an organisation is competent to perform an assessment activity. https://www.nata.com.au/about-nata/about-accreditation
PQL	Practical quantitation limit, the minimum concentration of an analyte (substance) that can be measured with a high degree of confidence that the analyte is present at or above that concentration.
PDA	Priority Development Area
WQG	Water quality guideline, EPP Water and Wetlands. Numerical concentrations for key indicators (e.g., total concentration of nitrogen) that protect an EV.
WQO	Water quality objectives defined under the EPP Water and Wetlands. Long term goals for water quality management.
Units	
℃	degrees Celsius
cm	centimetres
g	grams
L	litres
µg	micrograms
m	metres
mg	milligrams
mS	millisiemens
NTU	nephelometric turbidity units, a measure of the propensity of particles to scatter a light beam focused on them.
Siemen	Conductivity (or specific conductance) of an electrolyte solution is a measure of its ability to conduct electricity. The SI unit of conductivity is Siemens per meter (S/m).

11 Maps

All maps are provided by Saunders Havill Group.

Figure 11-1/2: EPP Water and Wetland Status and EHMP Water Quality Sites



Toondah Harbour EIS

Legend

Project Footprint

Marine Investigation Area

EHMP Sites

Current water quality site

Historic water quality site

Management intent

HEV (achieve) marine

HEV (maintain) marine

Moderately Disturbed

Moderately Disturbed marine

Central Bay : EHMP zone (part)

Eastern Bay (south) : EHMP zone (part)

Marine Parks (Moreton Bay) Zoning Plan 2008: Marine National Park zone

Moreton Bay : Central Bay enclosed coastal

Moreton Bay: Eastern Bay and Banks Open coastal waters - oceanic and estuarine influence

N 0 500 1,000 1,500 2,000 Meters

GDA 1994 MGA zone 56

Scale (A4): 1:55,000

TOONDAH HARBOUR

walker

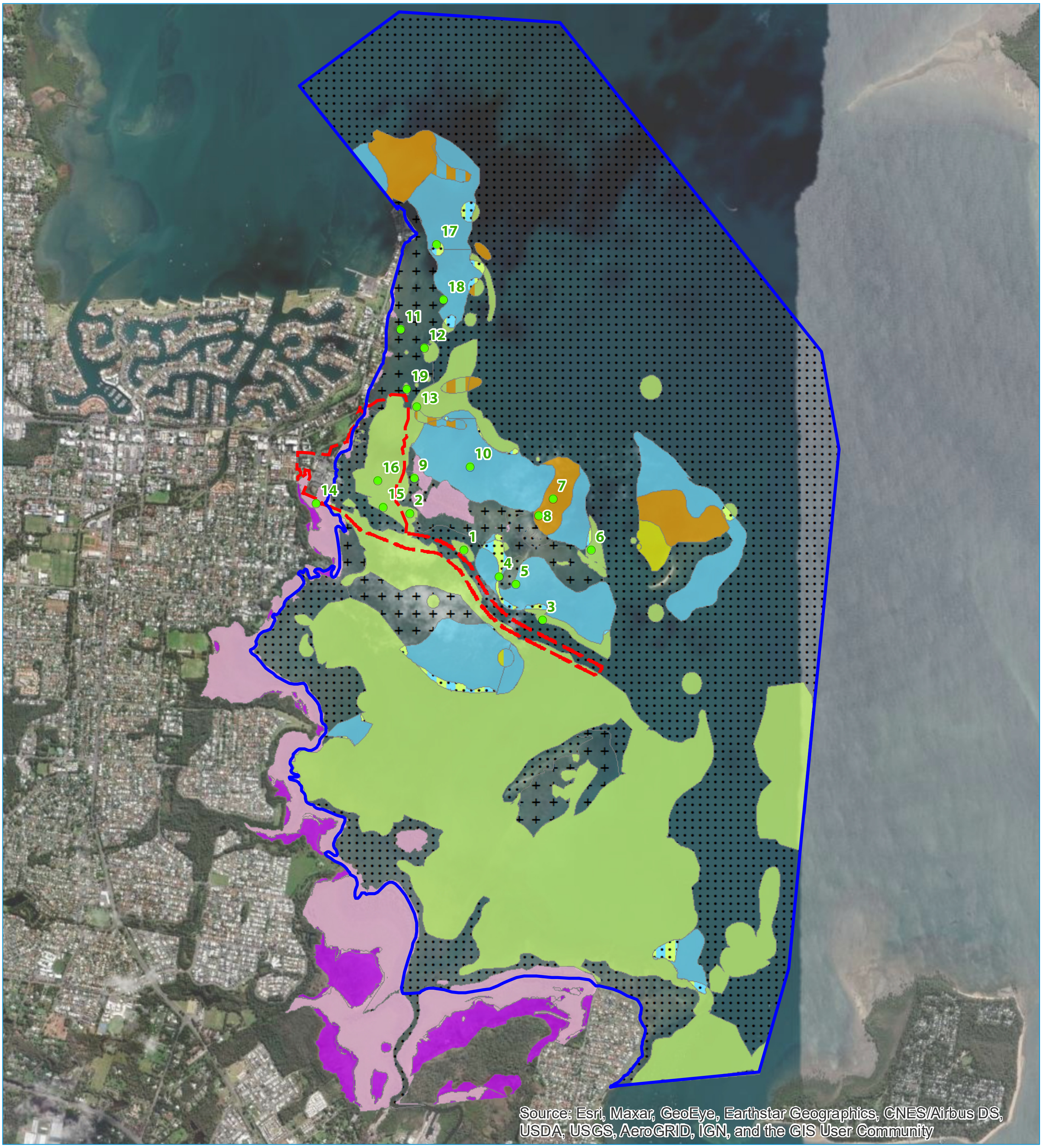
Layer Source: © State of Queensland Datasets (Department of Resources 2022), Aerial (Nearmap 2020)

DATE 18/07/2022 FILE REF. 9858 E Figure 9 1 EPP Water Wetland Status EHMP A

Figure 11.3 Position of the barge and up and downstream monitoring sites during the 2019 dredging campaign

	Barge Position		**Up Current Position**		**Down Current Position**	
Date	**Latitude / Easting**	**Longitude / Northing**	**Latitude / Easting**	**Longitude / Northing**	**Latitude / Easting**	**Longitude / Northing**
Tuesday, 7 May 2019	-27.52959302	153.285295	-27.52910603	153.284776	-27.531747	153.287866
Thursday, 9 May 2019	-27.52942898	153.28564	-27.52981899	153.28618	-27.52737299	153.284855
Friday, 10 May 2019	-27.52962998	153.284913	-27.53000599	153.286239	-27.527369	153.284922
Saturday, 11 May 2019	-27.52945597	153.285099	-27.52908499	153.284718	-27.53130804	153.287877
Monday, 13 May 2019	-27.52923997	153.285039	-27.52951096	153.285545	-27.52712497	153.284846
Tuesday, 14 May 2019	-27.52817103	153.285271	-27.52797799	153.284811	-27.53083999	153.287201
Thursday, 16 May 2019	-27.52804102	153.28489	-27.52854402	153.285299	-27.52748799	153.28486
Thursday, 16 May 2019	-27.52804102	153.28489	-27.52854402	153.285299	-27.52650797	153.287894
Saturday, 18 May 2019	-27.52943	153.2859	-27.52976	153.28632	-27.52621	153.28591
Monday, 20 May 2019	-27.52836407	153.2850907	-27.52767833	153.2849067	-27.53074289	153.2872944
Tuesday, 21 May 2019	-27.52880087	153.2854351	-27.52795334	153.2849063	-27.53126126	153.287477
Wednesday, 22 May 2019	-27.52821	153.28499	-27.52893	153.28555	-27.52654	153.28505
Thursday, 23 May 2019	-27.5287	153.2855	-27.52839	153.28526	-27.52065	153.2874
Tuesday, 28 May 2019	-27.52806	153.28499	0528101	6954937	0528142	6955032
Monday, 3 June 2019	0528135	6955043	0528126	6955138	0528135	6955043
Tuesday, 11 June 2019	529351	6954022	530195	6953765	529365	6954022
Friday, 14 June 2019	0528123	6955112	0528124	6955159	0528337	6954837
Wednesday, 19 June 2019	528145	6955161	0528099	6955113	0528303	6955161
Wednesday, 19 June 2019	528473	6954652	0528381	6954695	529670	6953868
Wednesday, 26 June 2019	528137	6955046	528123	6955121	528378	6954903
Wednesday, 26 June 2019	529072	6954468	529030	6954505	529929	6953900
Wednesday, 10 July 2019	528152	6955009	0528463	6954774	0528407	6954772
Wednesday, 17 July 2019	528153	6954972	528164	6955050	528058	6954759

Figure 11-4: Distribution of Habitats in the Project Footprint and MIA



Toondah Harbour EIS

Legend

- Project Footprint
- Marine Investigation Area
- Reporting Locations
- Mangrove and Saltmarsh
- Mangrove
- Saltmarsh
- Rubble
- Bare Sand/Mud
- Seagrass and Macroalgae
- Macroalgae and Hard Coral
- Macroalgae
- Hard Coral
- Seagrass and Hard Coral
- Seagrass and Soft Coral
- Seagrass
- Macroalgae and Soft Coral
- Soft Coral

0 500 1,000 1,500 2,000 Meters

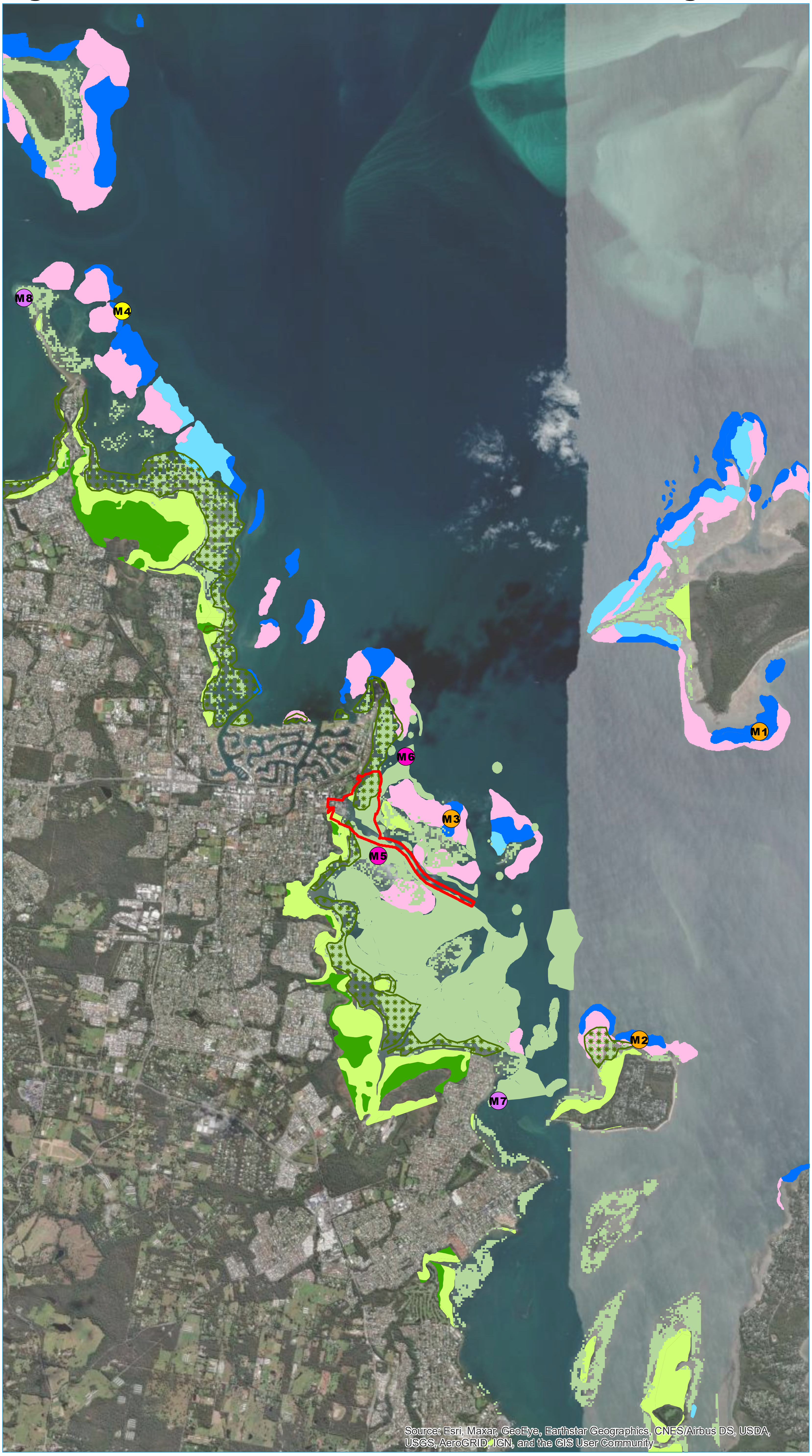
GDA 1994 MGA zone 56

Scale (A4): 1:42,000

TOONDAH HARBOUR

walker

Figure 11-5: Draft Marine Habitat Monitoring Sites



Legend

- Project Footprint
- Mangrove
- Saltmarsh
- Mud Flat
- Seagrass
- Algae on Sand Rubble
- Coral on Reef Matrix
- Soft Coral Algae Sand Rubble
- M1 Coral impact sites
- M1 Coral control sites
- M1 Seagrass impact sites
- M1 Seagrass control sites

TOONDAH HARBOUR

walker

0 1 2 3 km

GDA 1994 MGA zone 56

Scale (A3): 1:60,000

N

DATE: 29/06/2022

Layer Source: © State of Queensland Datasets (Department of Resources 2022), Aerial Imagery (Nearmap.com 2022)

FILE REF. 9858 E Figure 16 10 Marine Habitat Monitoring Sites A

Appendix A Comparison with WQO and Statistical Analyses

Table A.1: Comparison of water quality data to WQO for site E01200 in the HEV Area C1.

Parameters	**WQO[1]**	**Site: E01200**			**75% Confidence Interval ranges**					
	20th – 50th – 80th	**20th**	**50th**	**80th**	**20th percentile**		**50th percentile**		**80th percentile**	
Turbidity (NTU)	<1 – 1 – 5	2	3	6	1	2	3	3	6	7
Chl *a* (µg/L)	0.5 – 0.8 – 1	0.4	0.9	1.8	0.4	0.5	0.9	1.0	1.7	1.9
Total nitrogen (µg/L)	110 – 130 – 160	120	150	190	120	120	150	150	180	190
Oxidised N (µg/L)	2 – 2 – 2	1	1	3	1	1	1	1	3	4
Ammonia N (µg/L)	2 – 3 – 5	1	2	4	1	1	2	2	4	5
Organic N (µg/L)	100 – 120 – 150	114	144	176	112	115	146	146	176	182
Total phosphorus (µg/L)	12 – 15 – 20	9	14	19	9	10	14	14	19	20
Filterable reactive phosphorus (FRP) (µg/L)	3 – 5 – 8	3	5	8	3	3	5	5	8	8
Dissolved oxygen (% saturation)	95 – 100 – 105	95	99	103	95	96	99	99	103	104
pH	8.2 – 8.2 – 8.4	8.1	8.1	8.3	8.1	8.1	8.1	8.2	8.3	8.3
Secchi depth (m)	2.7 – 4.5 – 6	1.3	1.9	2.8	1.3	1.4	1.8	2.0	2.8	2.9

[1] WQO in this table are for Area C1 – Central Bay (Table 2).

HEV: High environmental value. For HEV waters the 75% confidence interval the 20th, 50th and 80th percentile is calculated resulting in a range. Where the WQO is not within this range, the parameter does not comply.

Red letters indicate the confidence interval range was higher than the WQO

Blue letters indicate the confidence interval range was lower than the WQO

Table A.2: Site E01201 in the HEV Moreton Bay Area HEVa1284: compliance of water quality with WQO.

Parameters	WQO[1]	Site: E01201			75% Confidence Interval ranges					
	20th – 50th – 80th	20th	50th	80th	20th percentile		50th percentile		80th percentile	
Turbidity (NTU)	2 – 4 – 6	4	8	15	3	4	7	8	14	17
Chl *a* (µg/L)	0.5 – 1 – 2	0.5	1	1.9	0.5	0.5	1	1.1	1.8	2
Total nitrogen (µg/L)	120 – 150 – 200	120	150	190	120	130	150	160	190	200
Oxidised N (µg/L)	2 – 2 – 2	1	1	1	1	1	1	1	1	2
Ammonia N (µg/L)	2 – 3 – 5	1	1	3	1	1	1	1	3	3
Organic N (µg/L)	110 – 150 – 190	116	146	186	116	123	146	152	185	186
Total phosphorus (µg/L)	15 – 22 – 30	13	19	29	13	13	19	20	27	29
Filterable reactive phosphorus (FRP) (µg/L)	6 – 10 – 14	3	6	8	3	4	5	6	8	8
Dissolved oxygen (% saturation)	95 – 100 – 105	100	105	110	99	100	105	105	109	110
pH	8.1 – 8.2 – 8.4	8.1	8.2	8.3	8.1	8.2	8.2	8.2	8.3	8.4
Secchi depth (m)	1.3 – 2 – 3	0.7	1.1	1.8	0.7	0.8	1.0	1.2	1.8	1.9

[1] WQO in this table are for Area HEVa1284 – Central Bay (Table 2).

HEV: High environmental value. For HEV waters the 75% confidence interval the 20th, 50th and 80th percentile is calculated resulting in a range. Where the WQO does not fall within this range, the parameter does not comply.

Red letters indicate the confidence interval range was higher than the WQO

Blue letters indicate the confidence interval range was lower than the WQO

Table A.3: Site E04500 in the HEV Moreton Bay Area HEVa1284 compliance of water quality with WQO.

Parameters	WQO[1]	Site: E04500			75% Confidence Interval ranges					
	20th – 50th – 80th	20th	50th	80th	20th percentile		50th percentile		80th percentile	
Turbidity (NTU)	2 – 4 – 6	5	7	11	5	5	7	8	11	11
Chl *a* (µg/L)	0.5 – 1 – 2	0.6	1.3	2.7	0.6	0.7	1.2	1.3	2.5	2.8
Total nitrogen (µg/L)	120 – 150 – 200	160	220	340	160	170	210	240	330	340
oxidised N (µg/L)	2 – 2 – 2	1	4	21	1	1	3	4	18	24
ammonia N (µg/L)	2 – 3 – 5	2	5	16	2	2	4	5	14	17
Organic N (µg/L)	110 – 150 – 190	156	201	284	155	156	194	209	280	291
Total phosphorus (µg/L)	15 – 22 – 30	24	39	82	22	25	38	40	79	98
filterable reactive phosphorus (FRP) (µg/L)	6 – 10 – 14	9	18	56	8	9	16	19	53	65
Dissolved oxygen (% saturation)	95 – 100 – 105	84.36	90.6	104	84	85	90	92	103	106
pH	8.1 – 8.2 – 8.4	7.9	8.0	8.2	7.9	7.9	8.0	8.0	8.1	8.2
Secchi depth (m)	1.3 – 2 – 3	0.8	1	1.3	0.7	0.8	1.0	1.0	1.3	1.3

[1] WQO in this table are for Area HEVa1284 – Central Bay (Table 2).

HEV: High environmental value, For HEV waters the 75% confidence interval for the 20th, 50th and 80th percentile is calculated resulting in a range. Where the WQO does not fall within this range, the parameter does not comply.

Grey shading indicates percentile ranges that do not include the respective WQO

Red letters indicate the confidence interval range was higher than the WQO

Blue letters indicate the confidence interval range was lower than the WQO

Table A.4: Site E04503 in the HEV Moreton Bay Area HEVa1284 compliance of water quality with WQO.

Parameters	WQO[1]	Site: E04503			75% Confidence Interval ranges					
	20th – 50th – 80th	20th	50th	80th	20th percentile		50th percentile		80th percentile	
Turbidity (NTU)	2 – 4 – 6	9	11	15	8	9	10	11	14	16
Chl *a* (µg/L)	0.5 – 1 – 2	1.6	2.4	4.3	1.2	1.6	2.3	2.7	3.9	4.5
Total nitrogen (µg/L)	120 – 150 – 200	336	430	506	310	360	400	430	500	540
Oxidised N (µg/L)	2 – 2 – 2	11	58	96	1	15	52	59	88	100
Ammonia N (µg/L)	2 – 3 – 5	3.6	27	41	2	6	11	27	36	47
Organic N (µg/L)	110 – 150 – 190	299	325	406	240	303	322	338	404	415
Total phosphorus (µg/L)	15 – 22 – 30	5	45	70	5	5	36	45	66	76
Filterable reactive phosphorus (FRP) (µg/L)	6 – 10 – 14	1	3	30	1	1	2	5	11	38
Dissolved oxygen (% saturation)	95 – 100 – 105	85	88	95	79	85	86	90	93	99
pH	8.1 – 8.2 – 8.4	7.7	7.8	7.9	7.6	7.7	7.8	7.9	7.9	8.0
Secchi depth (m)	1.3 – 2 – 3	0.6	0.7	0.8	0.5	0.6	0.7	0.7	0.8	0.9

[1] WQO in this table are for Area HEVa1284 – Central Bay (Table 2).

HEV: High environmental value. For HEV waters the 75% confidence interval for the 20th, 50th and 80th percentile is calculated resulting in a range. Where the WQO does not fall within this range, the parameter does not comply.

Grey shading indicates percentile ranges which do not include the respective WQO

Red letters indicate the confidence interval range was higher than the WQO

Blue letters indicate the confidence interval range was lower than the WQO

Table A.5: Sites in Moreton Bay Area C2: compliance of water quality with WQO.

Parameters	WQO[1]	E00309			E00500			E00501		
		20th	50th	80th	20th	50th	80th	20th	50th	80th
Turbidity (NTU)	< 5	2	4	7	2	5	9	0.8	2	3.2
Chl *a* (µg/L)	< 1.0	0.5	1.1	2	0.4	0.9	2	0.3	0.5	0.9
Total nitrogen (µg/L)	< 160	120	150	180	120	150	190	140	160	198
Oxidised N (µg/L)	< 2	1	1	1	1	1	1	1	1	2
ammonia N (µg/L)	< 5	1	1	3	1	1	2	2	2	2
Organic N (µg/L)	< 150	113	136	176	115.8	142	177	135	156	194
Total phosphorus (µg/L)	< 20	11	15	23	11	16	23	5	5	5
Filterable reactive phosphorus (FRP) (µg/L)	< 8	3	5	7	3	5	8	1	1	3.8
Dissolved oxygen (% saturation)	95-105	99	103	109	99	104	108	94	96	99
pH	8.2 - 8.4	8.2	8.2	8.3	8.13	8.2	8.3	8.0	8.1	8.2
Secchi depth (m)	> 2.7	1.3	2	3.2	0.9	1.5	2.4	1.9	2.7	3.5

[1] WQO in this table are for Area C2 – Central Bay (Table 2), only medians are compared to the WQO for this water type..
Red letters indicate the water quality data was higher than the WQO
Blue letters indicate the water quality data was lower than the WQO

Table A.6: Sites in the Redland Creek mid-estuary Area S2: compliance of water quality with WQOs.

Parameters	WQO[1]	E04501			E04502		
		20th	50th	80th	20th	50th	80th
Turbidity (NTU)	<8	9	11	15	7	9	15
Chl *a* (µg/L)	<4	2	3	10	1	3	6
Total nitrogen (µg/L)	<300	622	690	786	764	820	904
Oxidised N (µg/L)	<10	85	140	242	107	210	266
Ammonia N (µg/L)	<10	9.4	71	116	39	100	168
Organic N (µg/L)	<280	385	434	543	408	480	615
Total phosphorus (µg/L)	<25	65	77	128	82	120	220
Filterable reactive phosphorus (FRP) (µg/L)	<6	26	34	74	41	53	134
Dissolved oxygen (% saturation)	85-105	70	77	93	55	63	78
pH	7.0-8.4	7.4	7.6	7.75	7.1	7.2	7.5
Secchi depth (m)	>1	0.5	0.7	0.8	0.5	0.7	0.8

[1] WQO in this table are for Area S2 – Mid Estuary (Table 2), only medians are compared to the WQO for this water type.
Grey shading indicates values that did not comply with the WQO
Red letters indicate the water quality data was higher than the WQO
Blue letters indicate the water quality data was lower than the WQO

Table A.7: Seasonal water quality data summary for Site E01201

Moreton Bay Area HEVa1284	HEV waters	Spring			Summer			Autumn			Winter		
Parameter	**WQO[1] 20th – 50th – 80th**	**20th**	**50th**	**80th**	**20th**	**50th**	**80th**	**20th**	**50th**	**80th**	**20th**	**50th**	**80th**
Turbidity (NTU)	2 – 4 – 6	5	9	14	7	12	21	4	7.2	16	2	3	5
Chl a (µg/L)	0.5 – 1 – 2	0.5	1.0	1.6	1.2	1.9	2.9	0.8	1.2	2.0	0.3	0.5	0.6
Total nitrogen (µg/L)	120 – 150 – 200	130	155	198	150	190	216	130	160	190	110	130	150
oxidised N (µg/L)	2 – 2 – 2	1	1	1	1	1	2	1	1	2	1	1	1
ammonia N (µg/L)	2 – 3 – 5	1	1	5	1	1	5	1	1	4	1	1	2
Organic N (µg/L)	110 – 150 – 190	118	151	189	146	176	208	126	154	178	106	125	146
Total phosphorus (µg/L)	15 – 22 – 30	14	19	24	18	27	37	16	20	29	12	13	19
filterable reactive phosphorus (FRP) (µg/L)	6 – 10 – 14	3	5	7	3	5	9	5	7	9	4	5	6
Dissolved oxygen (%)	95 – 100 – 105	103	106	109	97	104	110	100	105	112	101	105	109
pH	8.1 – 8.2 – 8.4	8.1	8.2	8.3	8.1	8.2	8.3	8.2	8.2	8.3	8.2	8.3	8.4
Secchi depth (m)	1.3 – 2 – 3	0.8	1.0	1.5	0.6	0.8	1.2	0.7	1.2	1.8	1.4	1.9	2.4

1 Guidelines presented in this table are Moreton Bay water quality objectives for Area C2 – Central Bay (Table 2).
Red letters indicate the water quality data was higher than the WQO

Table A.8: Seasonal water quality data summary for Site E04500

Moreton Bay Area HEVa1284	HEV waters	Spring			Summer			Autumn			Winter		
Parameter	**WQO[1] 20th – 50th – 80th**	**20th**	**50th**	**80th**	**20th**	**50th**	**80th**	**20th**	**50th**	**80th**	**20th**	**50th**	**80th**
Turbidity (NTU)	2 – 4 – 6	5	8	13	6	9	16	5	7	11	3	5	10
Chl a (ug/L)	0.5 – 1 – 2	0.8	1.2	2.1	1.1	2.2	3.8	1.0	1.7	3.0	0.5	0.7	1.2
Total nitrogen (ug/L)	120 – 150 – 200	160	200	322	190	255	340	170	230	392	150	200	290
oxidised N (ug/L)	2 – 2 – 2	1	3	17	1	2	6	1	4	43	2	6	37
ammonia N (ug/L)	2 – 3 – 5	2	4	14	2	4	9	2	6	20	3	6	21
Organic N (ug/L)	110 – 150 – 190	155	196	275	176	248	325	165	195	316	140	179	235
Total phosphorus (ug/L)	15 – 22 – 30	19	34	61	25	41	55	28	39	110	29	46	110
filterable reactive phosphorus (FRP) ug/L	6 – 10 – 14	7	14	44	9	14	28	10	18	64	11	29	83
Dissolved oxygen (%)	95 – 100 – 105	85	92	102	83	92	102	82	89	97	86	94	109
pH	8.1 – 8.2 – 8.4	7.9	8.0	8.1	7.9	8.0	8.2	7.8	8.0	8.1	7.9	8.0	8.1
Secchi depth (m)	1.3 – 2 – 3	0.7	1.0	1.2	0.6	0.9	1.2	0.8	1.1	1.3	1.0	1.3	1.5

1 Guidelines presented in this table are Moreton Bay water quality objectives for Area C2 – Central Bay (Table 2).

Table A.9: Seasonal water quality data summary for Site E00500

Moreton Bay Area C2	HEV waters	Spring			Summer			Autumn			Winter		
Parameter	WQO[1]	20th	50th	80th	20th	50th	80th	20th	50th	80th	20th	50th	80th
Turbidity (NTU)	< 5	3	5	7	5	9	15	3	5	10	1	2	2
Chl a (ug/L)	< 1.0	0.6	0.9	1.5	1.3	1.9	3.3	0.8	1.3	2.4	0.3	0.4	0.5
Total nitrogen (ug/L)	< 160	120	140	180	142	170	226	130	150	184	100	120	164
oxidised N (ug/L)	< 2	1	1	1	1	1	2	1	1	1	1	1	1
ammonia N (ug/L)	< 5	1	1	2	1	1	5	1	1	2	1	1	2
Organic N (ug/L)	< 150	116	126	176	136	166	222	126	146	176	96	115	160
Total phosphorus (ug/L)	< 20	12	15	19	17	22	31	13	19	25	9	11	14
filterable reactive phosphorus (FRP) ug/L	< 8	3	4	6	3	6	8	4	6	8	3	4	7
Dissolved oxygen (%)	95-105	101	105	107	96	103	109	99	102	107	101	104	107
pH	8.2 - 8.4	8.1	8.2	8.3	8.1	8.2	8.3	8.1	8.2	8.3	8.2	8.3	8.4
Secchi depth (m)	> 2.7	1.3	1.6	2.3	0.7	1.1	1.5	0.9	1.4	2.0	2.4	3.4	3.8

1 Guidelines presented in this table are Moreton Bay water quality objectives for Area C2 – Central Bay (Table 2).

2 Red letters indicate values that are above WQO

Table A.10: Summary statistics of turbidity at site L1 from October 2015 to October 2017.

Year / Season	Month	n	Mean	Standard Error	Min	10th %ile	20th %ile	50th %ile	80th %ile	90th %ile	Max
2015	10	2310	27.54	0.98	1.6	4.4	5.8	13.1	36.3	89	795
2015	11	2862	41.68	1.21	0.3	5.6	9.4	22.5	61.4	133	1406
2015	12	2954	31.41	1.27	0.9	5.7	7.6	15.5	37.4	92	1209
2016	1	2969	20.76	0.61	0.6	3.4	4.5	10.2	28	81	1080
2016	2	1479	29.15	0.64	2.8	7.2	9.7	19.2	48.3	80	127
2016	3	799	18.27	0.88	2.5	4.4	5	10.3	24.3	56	211
2016	4	2259	9.93	0.28	0	3.7	4.7	7.1	11.1	22	218
2016	5	1991	8.13	0.38	0	0.9	1.5	4	9.7	21	194
2016	6	2871	12.83	0.90	0	1.1	1.6	3.4	10.8	44	1240
2016	7	2846	5.85	0.33	0	0.3	0.8	2.1	5.4	22	334
2016	8	2922	5.63	0.13	0	1	1.7	3.4	7.6	19	101
2016	9	66	4.11	0.34	0.8	1.8	2	2.8	6.4	10	12
2016	10	1868	27.75	0.65	0.5	4.7	7.5	20	41.7	78	292
2016	11	1156	17.58	0.68	2	4.2	5.3	9.4	25.3	53	354
2016	12	2041	34.89	0.90	0	3.3	7	21.6	56	113	637

Year / Season	Month	n	Mean	Standard Error	Min	10th %ile	20th %ile	50th %ile	80th %ile	90th %ile	Max
2017	1	2658	31.00	0.63	1.5	5	7.4	20	47.8	100	297
2017	2	2683	29.50	0.53	1.6	5.2	7.2	21.6	47.7	81	376
2017	3	637	52.09	5.58	2.9	4.8	6.12	12.2	46	192	1411
2017	4	2856	24.59	0.80	1.5	5	6.4	13.6	35	68	1268
2017	5	1034	115.93	1.28	3.4	9.43	126.9	128.5	132.5	140	227
2017	6	2874	114.46	0.42	1	105.5	106.4	111.5	126.2	133	812
2017	7	2970	8.37	0.39	0	1.1	1.7	3.6	8.2	31	433
2017	8	2964	17.29	0.75	0.1	1.8	2.9	7.1	17	57	1170
2017	9	2820	44.73	1.76	0.9	3.5	5.4	16.1	58.9	179	2029
2017	10	2918	38.81	1.00	0	4.3	7.24	25.6	62.2	104	1250
Seasonal Statistics											
Spring		14000	35.34	0.52	0	4.3	6.4	18.3	51.2	114	2029
Summer		14784	29.11	0.35	0	4.7	6.7	16.7	43.9	91	1209
Autumn		9576	28.87	0.58	0	3.1	4.5	9	33.8	130	1411
Winter		17447	27.23	0.37	0	1.1	1.8	4.7	35.7	125	1239
All Data											
		55807	30.04	0.22	0	2.2	3.9	11.2	44.1	125	2029

1 red letters indicate values that are above WQO

Table A.11: Summary statistics of turbidity at site L2 from September 2015 to September 2017.

Year / Season	Month	n	Mean	Standard Error	Min	10th %ile	20th %ile	50th %ile	80th %ile	90th %ile	Max
2015	9	813	14.91	0.97	0	0	0.3	4.5	23	68	299
2015	10	2899	34.37	1.20	0	2.3	5.1	14.7	47.1	131	1540
2015	11	2847	48.45	1.49	2.4	7.3	10.5	23.4	66.1	166	1172
2015	12	2880	60.77	2.34	3.2	8.7	11.8	27.8	69.3	205	1285
2016	1	2937	28.88	0.94	0	2.8	4.5	12.1	39.6	105	657
2016	2	2647	39.96	1.42	0	6.5	9.2	19.2	52.4	145	1290
2016	3	2716	15.39	0.48	0.1	2.2	3.7	7.1	18.6	59	332
2016	4	2868	15.90	0.87	0	0	1.3	6.8	19.46	62	1488
2016	5	2946	9.70	0.55	0	0.6	1	3	10.4	40	956
2016	6	2531	23.31	1.02	1.7	2.7	3.4	7	25.8	108	850
2016	7	1426	7.58	0.38	0.2	0.7	1	2.6	10.1	30	244
2016	8	1790	12.05	0.74	0	1.5	2.1	3.9	14.5	49	862
2016	9	2838	25.21	0.73	0.9	4	5.3	11.9	34	92	641
2016	10	2912	24.67	1.14	0	3.2	4.7	11.7	29.5	81	1261
2016	11	2824	21.61	0.57	0	3.2	4.9	11.9	30.5	74	474
2016	12	2799	65.93	1.58	0	5.7	14.7	44.1	98.8	197	1332

Year / Season	Month	n	Mean	Standard Error	Min	10th %ile	20th %ile	50th %ile	80th %ile	90th %ile	Max
2017	1	2644	60.31	1.53	0	8.3	13.4	33.8	86.4	221	1232
2017	2	1459	72.65	2.91	3.4	12	16.7	35.2	91.4	285	1264
2017	3	2725	49.17	1.58	1	3.6	5.7	17.1	77.2	187	1293
2017	4	977	82.05	2.95	0	8.6	16.8	58.6	125.1	265	1269
2017	5	2798	15.75	0.59	0	2.1	3.1	6.3	18.6	64	708
2017	6	2864	10.73	0.43	0	0.6	1	3.6	14.4	43	550
2017	7	2948	8.05	0.47	0	0	0	0.7	8.7	36	646
2017	8	2962	11.58	0.46	0	0	0.3	2.9	15.4	53	319
2017	9	51	10.98	2.10	1.3	1.7	1.9	4.9	16.7	37	80
Seasonal Statistics											
Spring		6611	37.86	0.85	0	2.6	5.9	17.1	52.4	141	1540
Summer		15366	53.08	0.73	0	6	9.8	26.4	72.8	183	1332
Autumn		15030	24.90	0.45	0	1.2	2.6	7.5	29.2	106	1488
Winter		23094	16.65	0.25	0	0.4	1.7	6.2	21.3	64	1261
All Data											
		60101	30.36	0.26	0	1.2	3.1	10.9	39.9	1120	1540

Table A.12: Summary statistics of turbidity at site L3 from September 2015 to July 2017.

Year / Season	Month	n	Mean	Standard Error	Min	10th %ile	20th %ile	50th %ile	80th %ile	90th %ile	Max
2015	9	820	5.71	0.19	1.4	2.3	2.8	4.2	7.5	11	58
2015	10	2888	32.54	2.67	0	0	1.8	5.9	15.9	31	1594
2015	11	2858	20.87	0.58	2.3	6.17	7.9	13.9	28.8	42	1006
2015	12	2969	25.64	1.73	3.4	7.2	8.4	12.2	23.3	35	1213
2016	1	2958	30.82	1.50	1.6	5.3	6.5	12.4	30.3	58	1317
2016	2	1442	19.93	0.60	0	5.9	8.3	14.2	25	43	452
2016	3	2230	6.98	0.11	0.9	3.29	4	5.8	9	12	110
2016	4	1838	4.84	0.12	0	1.2	1.8	3.3	6.5	10	49
2016	5	1984	7.56	1.22	0.4	1.3	1.7	2.8	5.3	9	1572
2016	6	2875	3.79	0.13	0	0.4	0.7	1.6	4.1	9	107
2016	7	2969	1.37	0.04	0	0.3	0.4	0.9	1.8	3	39
2016	8	2774	3.85	0.20	0	0.7	1.2	2.3	4.2	6	282
2016	9	1911	9.49	0.37	1	2.1	2.6	4.7	11.1	20	257
2016	10	2923	13.16	0.68	1.6	3.5	4.6	7.9	14.1	22	1230
2016	11	2120	14.54	0.29	2	4.5	5.6	10.3	20	30	97

Year / Season	Month	n	Mean	Standard Error	Min	10th %ile	20th %ile	50th %ile	80th %ile	90th %ile	Max
2016	12	2142	25.26	0.78	1.9	6.5	9	20	33.9	45	1243
2017	1	2643	24.11	1.10	2.4	7.3	9.5	15.3	29.6	42	1256
2017	2	2668	21.78	0.63	2.5	6.5	8.7	16.1	29	40	1262
2017	3	218	38.60	7.74	3.9	8.4	11.2	15.6	26.2	50	1253
2017	4	1886	33.82	2.39	2.2	7.3	9	14.2	24.4	39	1430
2017	5	2409	23.28	2.12	0	3.5	5.3	9	15.3	23	1409
2017	6	2338	23.04	1.78	0	1.9	3	7.8	18.9	31	1438
2017	7	1092	10.23	1.59	0.5	1.8	2.5	4	7.7	14	1426
2017	8	2037	31.16	2.80	0.2	1.9	3	7.4	22.7	43	1544
2017	9	1161	6.73	0.29	0	0.7	1.5	3.4	9	16	75
2018	2	2523	6.91	0.12	0.2	2.1	2.8	5.1	9.5	14	60
2018	3	2438	9.11	0.21	1.3	3.4	4.5	7.3	11.1	15	254
2018	4	720	3.20	0.21	0	0	0.1	1.5	4.8	7	48
2018	5	2048	7.93	0.28	0	2.1	3.2	6	9.8	13	235
2018	6	2355	2.47	0.09	0	0.6	0.8	1.6	3.1	5	96
2018	7	2972	1.40	0.04	0	0.1	0.4	0.9	1.8	3	39

Year / Season	Month	n	Mean	Standard Error	Min	10th %ile	20th %ile	50th %ile	80th %ile	90th %ile	Max
2018	8	2934	3.18	0.15	0	0.5	0.8	1.6	3.3	5	177
2018	9	2445	6.86	0.25	0	0	0.4	3.2	8.6	17	203
2018	10	2943	10.35	0.73	0	1.5	2.1	3.8	9	17	1227
2018	11	1234	23.97	1.61	0.6	4.3	5.9	13.7	33.1	47	1260
2018	12	2916	20.24	1.17	0.3	3.2	4.8	10.2	23.1	35	1292
2019	1	1914	15.31	1.55	0	1.7	2.8	6.1	15.2	26	1337
2019	2	990	11.37	0.36	0	2.19	3.3	7.7	17.5	26	78
2019	3	2713	10.98	0.69	0.6	3.1	3.9	6.4	12.6	20	1266
2019	4	138	3.26	0.45	0	0.1	0.5	2.2	4.3	6	52
2019	5	2521	4.06	0.11	0	1	1.7	2.9	4.8	7	83
2019	6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2019	7	1406	27.66	1.56	0	0.2	0.4	4.3	38.5	83	647
Seasonal Statistics											
Spring		21303	15.51	0.41	0	1.8	2.8	6.7	16.6	28	1594
Summer		23165	21.11	0.39	0	3.7	5.7	11.7	25	37	1337
Autumn		21143	11.78	0.37	0	1.8	2.8	5.7	11.4	17	1572

Year / Season	Month	n	Mean	Standard Error	Min	10th %ile	20th %ile	50th %ile	80th %ile	90th %ile	Max
Winter		23752	8.94	0.33	0	0.4	0.7	1.9	6	14	1544
All Data											
		89363	14.33	0.19	0	1	2	6	15.4	26	1594

Table A.13: Summary statistics of turbidity at site L5 from February 2018 to August 2019.

Year / Season	Month	n	Mean	Standard Error	Min	10th %ile	20th %ile	50th %ile	80th %ile	90th %ile	Max
2018	2	2489	28.64	0.80	1.8	5.8	7.9	17.1	38.6	60	735
2018	3	2894	24.81	0.54	0	4.2	6.8	16.1	36.8	52	402
2018	4	2857	25.34	0.52	0.8	4.8	6.8	18.9	35.3	50	347
2018	5	2942	18.53	0.55	0	1.7	2.9	8.1	24.5	46	431
2018	6	2464	11.42	0.47	0	0.8	1.4	3.8	13.4	29	287
2018	7	2840	10.36	0.32	0	1.7	2.3	4.8	12.2	24	225
2018	8	2842	16.89	0.55	0	2.5	3.4	7.8	20.3	36	459
2018	9	2656	34.68	0.82	0	5.4	8.1	21.1	50.3	79	600
2018	10	2850	30.20	0.69	0.1	5.1	7.9	19.4	41.8	63	459
2018	11	2753	39.89	0.85	0	6.9	10.3	27.1	58.96	83	588
2018	12	2815	31.66	0.60	0.9	6.6	10.4	23.9	45.1	63	413
2019	1	2054	18.96	0.47	0.7	4.1	5.7	12.8	27.1	39	300
2019	2	2647	21.77	0.41	0	4.8	7.3	15.3	30.8	49	293
2019	3	2892	18.90	0.37	0	4.2	6.1	13	27.6	38	293
2019	4	2810	10.84	0.22	0	1.7	2.9	7.8	16	23	254

Year / Season	Month	n	Mean	Standard Error	Min	10th %ile	20th %ile	50th %ile	80th %ile	90th %ile	Max
2019	5	1198	14.71	0.56	1.4	2.8	3.4	7.8	20.5	33	186
2019	6	1887	20.59	0.90	0	0.9	2.1	9.3	26.6	46	596
2019	7	2054	9.32	0.29	0.6	1.5	2.1	5.2	12.1	21	163
2019	8	2572	8.34	0.20	0	1.8	2.3	5.1	11.2	19	119
Seasonal Statistics											
Spring		8259	34.87	0.46	0	5.7	8.7	22.3	50	76	600
Summer		10005	25.69	0.30	0	5.3	7.68	17	36.6	54	735
Autumn		15593	19.33	0.20	0	2.8	4.5	11.5	28.3	42	431
Winter		14659	12.62	0.20	0	1.5	2.3	5.5	15.6	28	596
All Data											
		48516	21.26	0.14	0	2.5	4.2	11.5	30.7	49	753

Table A.14: Summary statistics of turbidity at site L6 from February 2018 to August 2019.

Year / Season	Month	n	Mean	Standard Error	Min	10th %ile	20th %ile	50th %ile	80th %ile	90th %ile	Max
2018	2	2526	40.93	1.01	2	7.9	10.8	27.3	57	85	1043
2018	3	2956	37.48	0.73	0	4.15	7.9	24.6	57.9	87	375
2018	4	2866	61.78	1.71	0	5.4	12.1	36	82.5	131	1315
2018	5	2847	29.70	0.89	0	2.1	3.7	12.4	46.7	79	1003
2018	6	2729	22.47	1.19	0	0.6	1.7	9.5	32.1	46	1220
2018	7	2673	21.67	1.43	0	0	0.9	4.8	21.6	41	1384
2018	8	2871	32.62	1.42	0	1.6	3.1	10.4	37	71	1270
2018	9	432	45.00	2.97	1.2	6.1	8.4	27.4	67.4	93	698
2018	10	2598	48.52	1.17	0	6.7	10	29.9	71.4	108	644
2018	11	2839	58.95	1.24	0	9.38	13.7	39.6	90.2	130	931
2018	12	2932	55.89	1.15	2	9.9	14.4	36.8	82.6	125	740
2019	1	2096	66.18	2.82	3.7	11.5	15.8	30.9	76.7	128	2109
2019	2	2680	45.51	0.97	0	6.1	9.8	26.8	72.3	113	416
2019	3	2940	68.56	1.27	4.5	18.2	24.5	55.3	89.4	126	944
2019	4	1089	33.62	1.16	2.3	4.8	7.9	20.7	52.1	77	416

Year / Season	Month	n	Mean	Standard Error	Min	10th %ile	20th %ile	50th %ile	80th %ile	90th %ile	Max
2019	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2019	6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2019	7	2049	36.54	1.49	0	4.1	6.1	14.4	47.7	84	1028
2019	8	2594	16.31	0.68	0	0.7	1.7	6.1	22.3	38	969
Seasonal Statistics											
Spring		5869	53.31	0.82	0	7.5	11.7	33.7	80	121	931
Summer		10235	51.58	0.76	0	8.5	12.3	30.4	72.3	111	2109
Autumn		12697	48.09	0.58	0	4.3	8.6	29.3	71.48	103	1315
Winter		12916	25.56	0.57	0	0.7	2	8.4	31	54	1384
All Data											
		41717	42.70	0.34	0	2.8	6.4	22.2	62.4	97	2109

Table A.15: Results of Pearson correlation between turbidity and season.

Site	R coefficient	p value
L1	-0.032	<0.001
L2	-0.191	<0.001
L3	-0.059	<0.001
L5	0.037	<0.001
L6	-0.147	<0.001

Table A.16 ANOVA results of turbidity affected by ferry activity.

Site	Source of variation	Degrees of freedom	Mean Square	F value	p value
L1	Between groups	3	25874	9.44	<0.001
	Within groups	52885	2739		
	Total	52888			
L2	Between groups	3	822099	201	<0.001
	Within groups	60097	4099		
	Total	60100			
L3	Between groups	3	6985	2.19	0.086
	Within groups	89359	3181		
	Total	89362			
L5	Between groups	3	351529	394	<0.001
	Within groups	48512	891		
	Total	48515			
L6	Between groups	3	1669179	360	<0.001
	Within groups	41713	4634		
	Total	41716			

Table A.17 Pearson correlation between turbidity and tidal state (low versus high).

Site	R coefficient	p value
L1	0.011	0.026
L2	-0.188	<0.001
L3	-0.010	0.002
L5	-0.183	<0.001
L6	-0.132	<0.001

Table A.18 L2 wind quadrant analysis summary.

Wind quadrant	R2 coefficient	p value
North	0.0264	<0.001
East	0.0127	<0.001
South	0.1245	<0.001
West	0.0308	<0.001

Table A.19 L6 wind quadrant analysis summary.

Wind quadrant	R2 coefficient	p value
North	0.0458	<0.001
East	0.0447	<0.001
South	0.0678	<0.001
West	0.0024	<0.001

Table A.20 Daylight turbidity (NTU) summary statistics at each logger in each season.

Logger	Season	Average	20th Percentile	50th Percentile	80th Percentile
L1	Spring	32.22	5.9	17.2	45.8
	Summer	25.77	6.2	15.9	40.0
	Autumn	27.04	4.7	8.6	31.6
	Winter	27.83	1.9	4.8	35.3
L2	Spring	45.56	8.9	22.9	66.3
	Summer	60.36	12.1	31.1	86.1
	Autumn	33.36	4.4	11.2	46.1
	Winter	22.61	3.5	10.1	30.7
L3	Spring	14.94	2.9	6.7	16.1
	Summer	21.41	5.8	11.6	24.9
	Autumn	11.26	2.8	5.7	11.1
	Winter	11.03	0.8	2.0	6.4
L5	Spring	45.72	16.4	30.8	63.3
	Summer	31.71	12.0	22.5	44.2
	Autumn	25.69	8.1	17.2	36.0
	Winter	18.58	4.1	9.1	24.4
L6	Spring	68.30	21.9	47.6	96.9
	Summer	66.29	21.9	44.4	91.7
	Autumn	59.20	15.6	41.9	84.7
	Winter	36.95	5.6	16.7	44.0