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Port of Hay Point, 2019 Maintenance Dredging

Performance of Environmental Monitoring

Report No. P019_R02F1

NORTH QUEENSLAND BULK PORTS CORPORATION

Technical Report
August 2019

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Executive Summary

North Queensland Bulk Ports Corporation (NQBP) commissioned Port and Coastal Solutions (PCS) to assess the performance of the environmental monitoring undertaken before, during and following the Port of Hay Point 2019 maintenance dredging program. This report had the following aims:

- to undertake a final analysis and interpretation of the turbidity data measured pre-, during and post-maintenance dredging;
- to check whether the environmental monitoring undertaken was implemented in the manner stated in the Management Plans; and
- to provide any updates or recommendations for changes to monitoring requirements and NQBP management and monitoring plans for future dredging programs based on the analysis.

The key findings from the assessment are as follows:

- in general, the environmental monitoring undertaken as part of the Port of Hay Point 2019 maintenance dredging program has been implemented in the manner stated in the Management Plans;
- the adaptive monitoring and resultant adaptive management measures adopted were in accordance with the Management Plans. During the maintenance dredging program the turbidity at Round Top Island exceeded the 90th percentile duration exceedance, with the site entering into management zone C, respond. The subsequent investigation was in accordance with the Management Plans and despite this concluding that the elevated turbidity was due to natural conditions, adaptive management measures were implemented to ensure a precautionary approach was adopted;
- based on the monitoring undertaken as part of the 2019 maintenance dredging program a number of recommendations have been provided to update the requirements for the impact and adaptive monitoring requirements for future programs; and
- additional analysis of turbidity data was undertaken to ensure the data collected as part of the 2019 maintenance dredging program and as part of the ongoing ambient monitoring are incorporated to allow continual improvement of the procedures adopted to manage maintenance dredging. Based on the benthic and surface turbidity data collected during the maintenance dredging program updated surface turbidity intensity thresholds have been developed. In addition, the benthic turbidity intensity and duration thresholds have also been updated based on the additional two years of ambient monitoring turbidity data available.

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1. Introduction

North Queensland Bulk Ports Corporation (NQBP) commissioned Port and Coastal Solutions (PCS) to assess the performance of the environmental monitoring undertaken before, during and following the Port of Hay Point 2019 maintenance dredging program. This report is aimed at:

- undertaking a final analysis and interpretation of the turbidity data measured pre-, during and post-maintenance dredging;
- checking whether the environmental monitoring undertaken and the results from the monitoring conform with the approval conditions; and
- providing any updates or recommendations for changes to monitoring requirements for future dredging programs based on the analysis.

The Marine Park Permit (MPP 40185.1) has one condition (condition number 34) which is directly relevant to this assessment, this condition requires the following:

- within six months of completion of each dredge campaign, NQBP must publish a report on their website addressing compliance with the requirements of the Environmental Thresholds Report (RHDHV, 2018), Maintenance Dredging Environmental Management Plan (Adaptive Strategies, 2019) and the Marine Environmental Monitoring Program (NQBP, 2018), as verified by an independent audit.

This report reviews the Impact and Adaptive monitoring required by the three reports and checks whether the monitoring therefore conformed with the Marine Park Permit.

1.1. Project Overview

The Port of Hay Point is located on the central east coast of Queensland, approximately 15 km south of Mackay and close to the neighbouring communities of Louisa Creek, Salonika Beach and Half Tide Beach. It is one of the largest coal export ports in the world and consists of two separate export terminals, Dalrymple Bay Coal Terminal (DBCT) and Hay Point Coal Terminal (HPCT) which service mines in the Central Bowen Basin of Queensland. The Port includes seven berths (four at DBCT and three at HPCT), an apron and a departure path which extends approximately 11 km offshore of the berths to naturally deep water and is predominantly located within the GBRMP (Figure 1). In addition, there is an existing, designated DMPA for the Port of Hay Point with an area of 18.4 km^2 located approximately 6 km (from the centre of the apron to the centre of the DMPA) to the north of the Port.

Prior to the 2019 maintenance dredging program there had been two dredging programs undertaken at the Port of Hay Point since 2010:

- 2010 Maintenance Dredging: a total of 216,070 m^3 of sediment was removed from the Port of Hay Point by the TSHD Brisbane. However, the program was planned to return all areas back to their design depths, but due to industrial action by the dredge crew the program was stopped early and never completed; and
- 2011 Capital Dredging: 275,000 m^3 of sediment was removed to create the HPCT berth 3.

Investigations undertaken as part of the Port of Hay Point Sustainable Sediment Management (SSM) Project found that ongoing sedimentation had occurred at the Port of Hay Point since the 2010 maintenance dredging. Based on the hydrographic survey from October 2015 the current maintenance dredging requirement at the time was calculated to be 205,800 m^3, with the majority of this being in the four DBCT berths (RHDHV, 2016). In March 2017 the Mackay and Hay Point region was impacted by Tropical Cyclone (TC) Debbie and this event resulted in increased accretion in a number of areas of the Port of Hay Point (RHDHV, 2017). Additional analysis of the bathymetric surveys following TC Debbie found that the maintenance dredging requirement for the Port of Hay Point had increased to

356,553 m^3, with a requirement of approximately 240,000 m^3 at the four DBCT berths (NQBP, 2017).

To remove the sedimentation that had built up in the Port since 2010, the Port of Hay Point 2019 maintenance dredging program commenced at 07:00 on the 31st March 2019 and was completed at 15:00 on the 2nd May 2019. The dredging was undertaken by the TSHD Brisbane over a 33-day dredging program. Over the dredging program 228 dredge cycles were completed and based on the initial post-dredge surveys (final survey completed on 2nd May 2019) Maritime Safety Queensland (MSQ) calculated that 353,740 m^3 (in-situ volume) of sediment was removed from the berth pockets, apron and departure path and placed at the Port of Hay Point Dredge Material Placement Area (DMPA). Following the maintenance dredging, associated bed-levelling was undertaken until the 10th May 2019 to level out the seabed in the dredged areas and ensure there were no high spots remaining after the dredging.

1.2. Report Structure

The report herein is set out as follows:

- details of the monitoring requirements are provided in **Section 2**;
- a summary of the environmental monitoring undertaken as part of the Port of Hay Point 2019 maintenance dredging program is detailed in **Section 3**;
- analysis of the turbidity data collected during the 2019 maintenance dredging program is presented in **Section 4**;
- a summary of the conformance with the approval conditions is provided in **Section 5**;
- additional analysis of the turbidity data as part of a continual improvement process is detailed in **Section 6**; and
- a summary of the report findings is presented in **Section 7**.

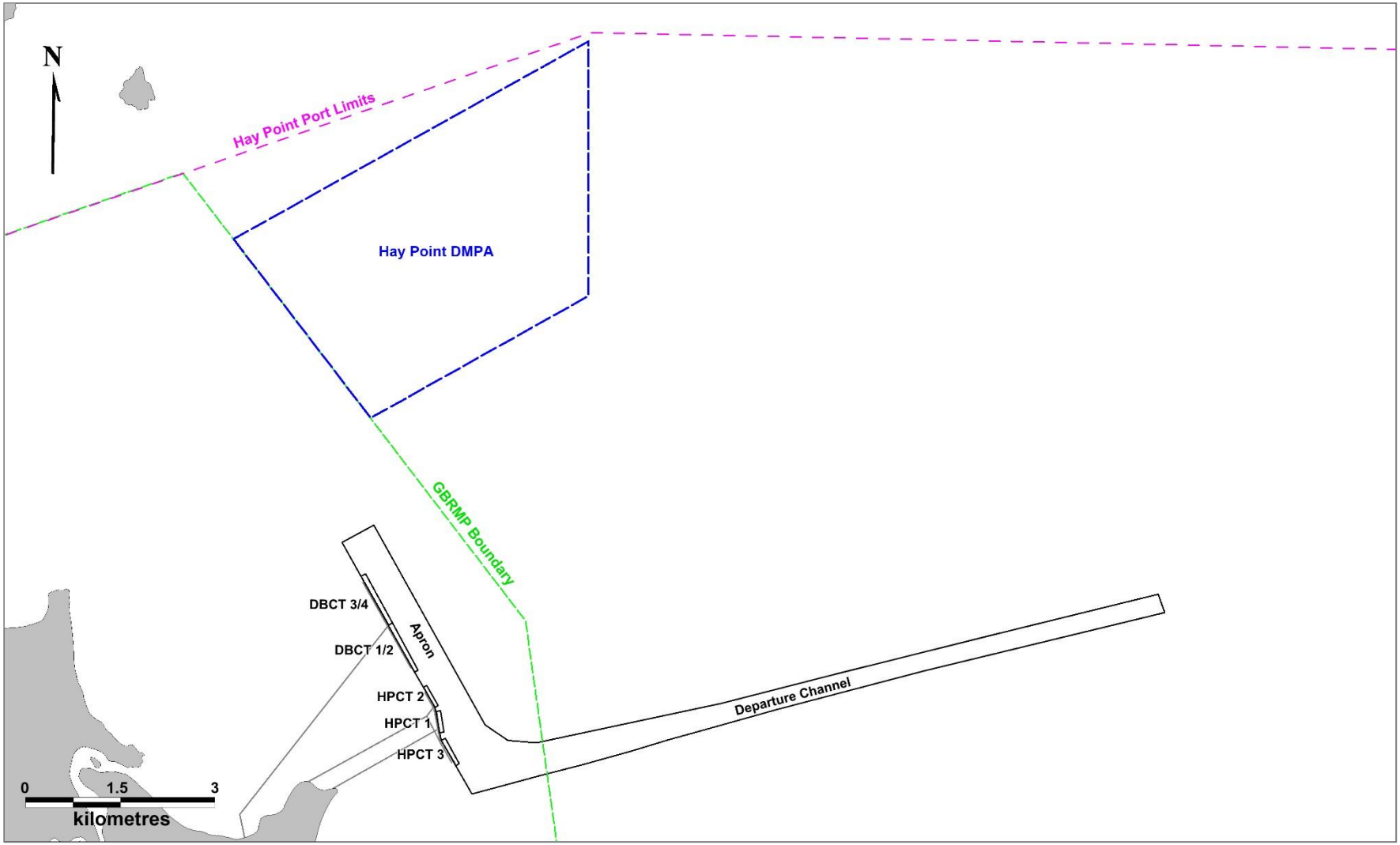

Figure 1. Layout of the Port of Hay Point.

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2. Monitoring Requirements

The Environmental Thresholds (ET) report (RHDHV, 2018), Maintenance Dredging Environmental Management Plan (EMP) (Adaptive Strategies, 2019) and the Marine Environmental Monitoring Program (MEMP) (NQBP, 2018) have all been reviewed to determine the environmental monitoring requirements.

The MEMP explains how the monitoring program has been split into three tiers:

1) Ambient monitoring: ongoing monitoring to provide a long-term baseline environmental condition;
2) Impact monitoring: undertaken before, during and after each maintenance dredging program to detect impacts; and
3) Adaptive monitoring: real-time monitoring during each maintenance dredging program to prevent incidents of serious environmental harm.

The monitoring requirements for the three tiers are summarised in Table 1. As the ambient monitoring is aimed at providing a long-term baseline environmental condition rather than monitoring related to a maintenance dredging program, it is only the performance of the impact and adaptive monitoring that must be implemented during each maintenance dredging program that are considered here. The specific requirements of these two monitoring tiers are discussed further in the following sections.

Table 1. Summary of key parameters to be measured by the Environmental Monitoring (NQBP, 2018).

Parameter	Ambient	Impact	Adaptive
Marine water quality	✓	✓	✓
Island fringing corals	✓	✓	
Seagrass and benthic habitat	✓		
Invasive marine pests	✓		
Sediment quality	✓	✓	
Marine megafauna			✓

2.1. Impact Monitoring

The impact monitoring is focused on the marine water quality and the island fringing corals as these are the receptors most likely to be adversely impacted by the dredging (NQBP, 2018). The impact monitoring is aimed at detecting any unpredicted changes in environmental condition and avoiding impacts from maintenance dredging. In addition, the marine water quality data collected can also be used to validate predictive natural and dredge plume modelling. Details of the monitoring requirements for the parameters required as part of the impact monitoring are provided in the following sections.

2.1.1. Marine Water Quality

The marine water quality impact monitoring is required at the same eight monitoring sites as the ambient water quality monitoring sites, these are shown in Figure 2 and detailed in Table 2.

As part of the marine water quality impact monitoring, the monitoring is required to commence four weeks prior to the commencement of dredging and finish four weeks post completion of the dredging. The following types of monitoring and parameters are required at the eight monitoring sites:

- Physio-chemical and nutrients: monitoring of the following parameters to be undertaken weekly during the dredging:

  - Water temperature;
  - Salinity;
  - pH;
  - Dissolved oxygen (%);
  - Turbidity;
  - Secchi disk depth (measure of optical clarity);
  - Light attenuation; and
  - Nutrients (nitrogen and phosphorus).

- Metals, chlorophyll a and pesticides/herbicides: monitoring four weeks prior and post dredging of the following parameters:
  - Ultra-trace dissolved metals including arsenic (As), cadmium (Cd), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb) and zinc (Zn);
  - Chlorophyll a; and
  - Pesticides and herbicides (Low LOR suite [EP234(A-I)]).

- Data loggers: monitoring every 10 minutes using data loggers, with the following parameters being measured:
  - Turbidity;
  - Sediment deposition;
  - Pressure;
  - Water temperature;
  - Photosynthetically Active Radiation (PAR); and
  - Current speed and direction.

Table 2. Marine water quality monitoring sites (NQBP, 2018).

Location	Site ID	Latitude	Longitude
Freshwater Point	1	-21.42	149.34
Hay Point / Reef	2	-21.26	149.30
Round Top Island	3B	-21.17	149.26
Slade Island	5	-21.09	149.24
Relocation ground	8	-21.18	149.30
Victor Island	10	-21.32	149.32
Mackay Harbour	11	-21.11	149.22
Keswick Island	12	-20.93	149.42

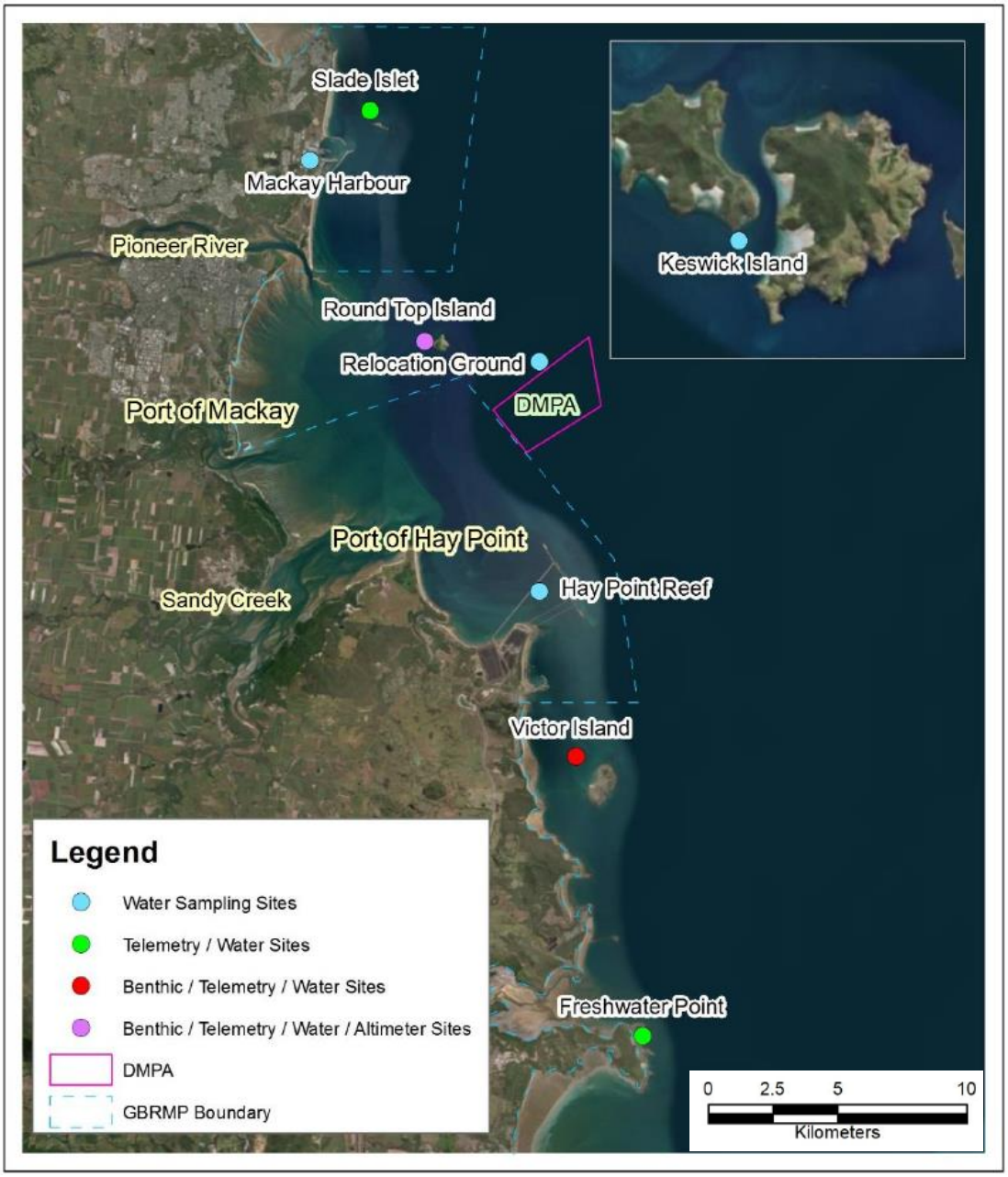


Figure 2. Water quality monitoring sites (from VE, 2019a).

2.1.2. Island Fringing Corals

The aim of the impact monitoring for corals is to quantify if coral communities in the Hay Point region have been affected by the maintenance dredging program. The monitoring is required to be undertaken four weeks prior to the commencement of maintenance dredging and four weeks following completion of the maintenance dredging.

The impact monitoring for corals is required to be undertaken at the same 24 sites (six sites at each of the following Keswick Island/St Bees Island, Slade Island, Round Top Island and Victor Island) and using the same approach as the ongoing ambient monitoring (Figure 3). The monitoring is to be undertaken along permanent benthic line transects, with four assessments along 20 m transects undertaken at each site. The following parameters relating to the coral communities are required to be measured:

- diversity and abundance of benthic communities;
- percentage coral bleaching;
- percentage coral mortality;
- sediment deposition; and
- coral recruitment.

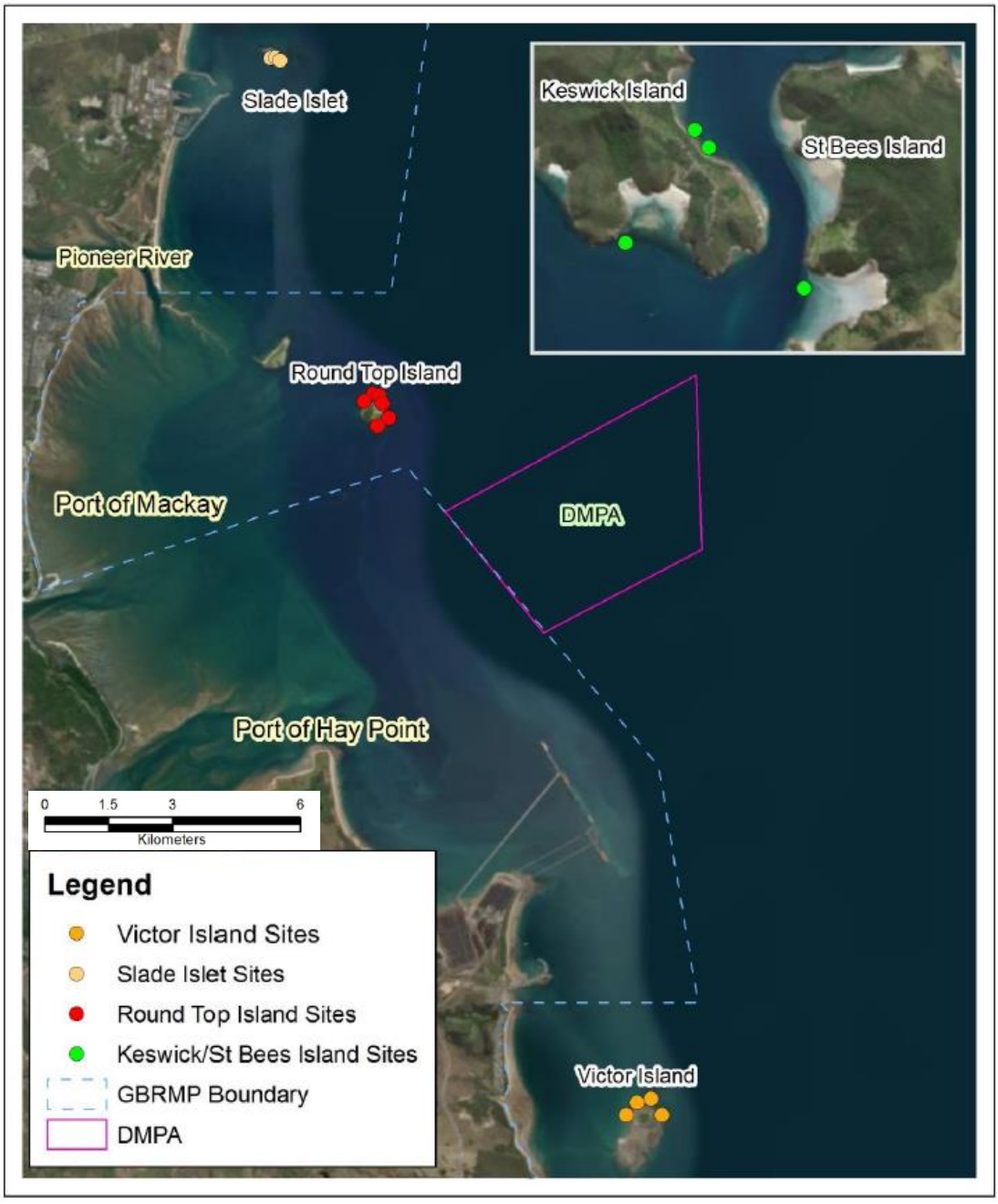


Figure 3. Coral monitoring sites (from VE, 2019b).

2.1.3. Sediment Quality

The MEMP states that sediment quality monitoring is required as part of the impact monitoring (NQBP, 2018). The monitoring is required to conform with the National Assessment Guidelines for Dredging (NAGD) (DEWHA, 2009) and therefore ensure that any sediment relocated to the Port of Hay Point DMPA is suitable for marine placement and will not result in any potential contamination impacts.

2.2. Adaptive Monitoring

The adaptive monitoring is aimed at real-time observations to detect changes in environmental condition and allow assessment as to whether the changes are natural or related to dredging and disposal activities. As part of the ET report it was concluded that turbidity should be adopted for adaptive management, while PAR and deposition were not considered to be suitable parameters for adaptive management (RHDHV, 2018). The turbidity thresholds which were developed as part of the ET report enable impact avoidance and management measures to be adopted before any potential impairment to the local ecosystem occurs. Details of the monitoring requirements for the parameters required as part of the adaptive monitoring are provided in the following sections.

2.2.1. Marine Water Quality

Four of the eight ambient water quality monitoring sites were selected as appropriate sites for adaptive monitoring of water quality:

- Round Top Island: trigger site during periods with prevailing southerly winds;
- Victor Island: trigger site during periods with prevailing northerly winds;
- Freshwater Point: control site during periods with prevailing southerly winds; and
- Slade Island: control site during periods with prevailing northerly winds.

Data loggers will be used for the adaptive monitoring with loggers providing telemetered real-time measurements every 10 minutes from four weeks prior to the dredging commencing to four weeks post completion of the dredging. The following parameters will be recorded:

- Turbidity and total suspended solids (TSS) (derived from turbidity data based on site specific correlations between turbidity and suspended solids);
- Pressure;
- Water temperature;
- Photosynthetically Active Radiation (PAR); and
- Current speed and direction.

Based on three years of measured turbidity data at each of the four adaptive monitoring sites, relative intensity and duration thresholds were adopted for the turbidity monitoring. These thresholds were developed based on the assumption that as long as the turbidity remains within the natural range where no impacts to the sensitive receptors have been observed, then the sensitive receptors should not be negatively impacted. Depending on the duration of time that the turbidity intensity thresholds are exceeded at the sites and how the trigger and associated control sites behave relative to each other (as specified in the EMP and MEMP), adaptive management measures maybe required. Four different management zones (Management Zone A to D) were defined with escalating management responses required for each subsequent management zone:

- Zone A, Normal: Normal operating conditions;
- Zone B, Investigate: Investigate to determine if increased turbidity is dredging related;

- Zone C, Respond: Investigate to determine if increased turbidity is natural or dredging related and if dredging related then instigate management actions; and
- Zone D, Stop Dredging: Instigate stop dredging and disposal measures.

In addition to the in-situ data collected by the data loggers, the MEMP also notes that daily visual analysis of satellite imagery (specifically satellite-derived turbidity) will be undertaken to compare the actual plume location with the predicted plume location from the numerical model.

The MEMP also notes that monitoring of metocean conditions will be undertaken during dredging programs, with tide, wind and weather warnings all monitored. The data are primarily to be used to inform the dredge operations.

2.2.2. Marine Megafauna

The monitoring of marine megafauna is required throughout the dredging program, with observations to commence prior to any activities commencing and will continue until all activities cease. The monitoring is to be undertaken through visual observations by personnel using binoculars from the bridge of the dredger. Megafauna includes whales, dolphin, dugong and turtles and the monitoring zone is a 300 m radius of the dredge. Management measures are to be taken if megafauna are observed within the monitoring zone, these are detailed in the EMP.

Results from the marine megafauna monitoring are required to be recorded in the Masters' log and reported daily to NQBP's Environment Manager.

3. 2019 Maintenance Dredging Program

To remove the sedimentation that had built up in the Port since 2010, the Port of Hay Point 2019 maintenance dredging program commenced at 07:00 on the 31st March 2019 and was completed at 15:00 on the 2nd May 2019. The dredging was undertaken by the TSHD Brisbane over a 33-day dredging program. Over the dredging program 228 dredge cycles were completed and based on the initial post-dredge surveys (final survey completed on 2nd May 2019) Maritime Safety Queensland (MSQ) calculated that 353,740 m^3 (in-situ volume) of sediment was removed from the berth pockets, apron and departure path and placed at the Port of Hay Point DMPA. Following the maintenance dredging, associated bed-levelling was undertaken until the 10th May 2019 to level out the seabed in the dredged areas and ensure there were no high spots remaining after the dredging.

The metocean conditions over the 2019 maintenance dredging program resulted in some downtime of the TSHD Brisbane. The most significant periods of downtime were from the 2nd to the 6th April 2019 with approximately 70 hours of downtime and from the 24th to the 25th April with 24 hours of downtime. Over the entire 2019 maintenance dredging program the TSHD Brisbane had 619 hours of productive dredging and placement hours and 170 hours of downtime (due to weather delays, vessel maintenance, bunkering etc).

Impact and adaptive monitoring were initiated as part of the 2019 maintenance dredging program, details of the monitoring undertaken are provided in the following sections. This section also details whether the impact and adaptive monitoring undertaken complies with the approval requirements.

3.1. Impact Monitoring

Impact monitoring was undertaken as part of the 2019 maintenance dredging program, with marine water quality and island fringing coral being monitored.

3.1.1. Marine Water Quality

The marine water quality monitoring which has been collected as part of the impact monitoring can be separated into two separate components:

- Vessel based sampling: the physio-chemical depth profiling and water sample collection for chlorophyll a, nutrients, metals and pesticides and herbicides were undertaken from a vessel. Due to weather constraints it was not possible to undertake the physio-chemical and nutrient sampling as frequently as specified in the MEMP. In addition, PAR was measured every 1 m through the water column and based on these measurements the vertical light attenuation coefficient and resultant euphotic depth were calculated. This provides significantly more accuracy than secchi disk measurements and so has been used in its place. Five separate sampling trips were undertaken:
  - 12/03/2019 (19 days pre-dredging): all physio-chemical, nutrients, metals, chlorophyll a and pesticide/herbicide parameters measured at all eight sites;
  - 9-10/04/2019 (10-11 days after dredging commenced): all physio-chemical, nutrients, metals, chlorophyll a and pesticide/herbicide parameters measured at all eight sites;
  - 15/04/2019 (16 days after dredging commenced): most physio-chemical parameters were monitored (excluding light attenuation) at Round Top Island and Victor Island. The sampling was undertaken as data loggers at these sites required servicing and so the sampling was opportunistic;
  - 3-4/05/2019 (1-2 days post-dredging): all physio-chemical measured at seven of the sites. Due to an engine problem with the survey vessel it was not possible to undertake the sampling at Keswick Island; and
  - 29/05/2019 (27 days post-dredging): all physio-chemical and all nutrients, metals, chlorophyll a and pesticide/herbicide parameters measured at all eight of the sites.

- Data loggers: the impact marine water quality monitoring made use of the same loggers as for the ongoing ambient water quality monitoring. As such, data collection was ongoing pre- and post-dredging and so data were collected more than four weeks pre-dredging and continued throughout the dredging and continued to be collected for over four weeks post dredging. The data loggers measured all the required parameters every 10 minutes at seven of the eight monitoring sites detailed in Table 2. There is no ambient monitoring site at Mackay Harbour and so logger data were not available for the impact monitoring at this site (as part of the ambient monitoring data are collected at eight sites, with the eighth site being Aquila Island). Individual loggers were deployed at each site and so the data capture varied between the sites depending on whether there were any issues with the instrument (either due to the instrument or external factors).

3.1.2. Island Fringing Coral

Coral impact monitoring was undertaken pre-dredging and post-dredging (VE, 2019b). Weather constraints resulting in poor water visibility meant that the monitoring could not be undertaken exactly four weeks pre- and post-dredging. The pre-dredging surveys were undertaken on the 18th to 22nd February (five weeks pre-dredging) and 13th to 15th March 2019 (two weeks pre-dredging) and the post-dredging surveys were undertaken on the 13th to 17th June 2019 (six weeks post dredging).

The monitoring technique was altered slightly from the ongoing ambient monitoring which is undertaken at the sites, to allow the monitoring to focus on techniques which would permit the detection of impacts from the maintenance dredging activities more easily. The monitoring included the following:

- photographic quadrats to accurately compare pre- and post-dredging measurements of coral species, the occurrence of coral damage (sediment deposition, bleaching or disease) and coral recruitment;
- an approach to enable objective measurements of substrate cover as opposed to field estimations;
- a rapid coral health indicator technique to determine if corals are stressed prior to physical damage being observed; and
- the use of statistical analyses to determine whether there has been a change in the coral community before and after maintenance dredging.

Difficulties were encountered locating the marker stakes at the ambient coral monitoring sites and so it was decided that all new transects would be established at sites adjacent to the ambient monitoring transects. Due to weather conditions, poor water visibility and the requirement to establish new transects at all sites, a reduced number of transect surveys were completed. The monitoring was undertaken at between three and six individual sites at each of the four monitoring locations (a total of 17 sites at Keswick Island/St Bees Island (four sites), Slade Island (three sites), Round Top Island (six sites) and Victor Island (four sites)). At each site between three and four transects were undertaken, with a total of 52 transects monitored as part of the pre- and post-dredging surveys. The surveys measured the parameters required in accordance with the MEMP (diversity and abundance of benthic communities, percentage coral bleaching, percentage coral mortality, sediment deposition and coral recruitment).

The coral monitoring found that coral coverage remained similar during the pre-dredging and post-dredging surveys, with the overall conclusion that there was no apparent impact from maintenance dredging activities on the monitored coral parameters. Based on this, results from the monitoring are also considered to have complied with the requirements specified in the Environmental Permit (EPPR01742813), that coral mortality does not exceed 5% at Round Top Island and Victor Island in any one dredge program.

3.1.3. Sediment Quality

Sediment characterisation results for the approved sediment Sampling and Analysis Plan (SAP) are detailed by Advisian (2018). Based on a total of 42 samples analysed it was concluded that the sediments to be dredged from the Port of Hay Point navigational areas outlined in this report are suitable for unconfined placement at sea at the approved Hay Point DMPA. The results from this assessment were in accordance with the National Assessment Guidelines for Dredging (2009) assessment framework and should be valid until the 14th March 2023.

3.2. Adaptive Monitoring

Adaptive monitoring was undertaken as part of the 2019 maintenance dredging program, with marine water quality and marine megafauna being monitored. In addition, the Adaptive Management Reference Group (MRG) were provided weekly updates of the maintenance dredging program. This included updates on operational progress, water quality monitoring results, environmental incidents and an overview of the proposed future works.

3.2.1. Marine Water Quality

Marine water quality monitoring has been collected as part of the adaptive monitoring at the four sites specified in the MEMP from 17-18/02/2019 (approximately six weeks pre-dredging) to 30/05/2019 (four weeks post-dredging). The monitoring was undertaken using dual YSI EXO3 sondes which were deployed at the surface (approximately 0.75 m below the water surface) and telemetered to provide real-time measurements every 10 minutes. The instruments provided measurements of the turbidity, water temperature, conductivity (salinity), pH and dissolved oxygen (% saturation). Real-time surface turbidity monitoring was undertaken, as opposed to real-time benthic turbidity monitoring, as this method was considered to reduce the risk of data loss and increase the confidence in the data. The following conditions within the Hay Point region were taken into consideration to determine the water quality monitoring approach:

- due to the large tidal range and strong tidal currents in the Hay Point region there is a high probability of ongoing data loss when trying to transmit real-time benthic data. This is because a cable is required to connect the instrument at the seabed to the modem on the surface buoy, but due to the metocean conditions there is a risk that the cable could become entangled or damaged;
- the risk of data loss when using a near-surface logger is low, as both the instrument and modem are located on the same buoy and so there are no long cables required; and
- in the Hay Point region the large tidal range and strong tidal currents result in the turbidity being relatively well mixed through the water column.

In addition to the real-time surface turbidity monitoring, benthic turbidity data were also concurrently collected by using self-logging instruments at the two trigger sites (Round Top Island and Victor Island). The benthic loggers were located approximately 0.75 m above the seabed and were the same dual sondes as the surface loggers providing the same measurements every 10 minutes as well as pressure (water depth). In addition, at the Round Top Island site dual benthic altimeters were also deployed to monitor the sedimentation rates. The benthic loggers were deployed from 19/02/2019 to 30/05/2019, with data downloaded six times over the duration of the adaptive monitoring. These data were collected as the turbidity thresholds were calculated using the long-term ambient turbidity data which was all benthic data and so the concurrent surface and benthic turbidity data were used to allow the difference between the benthic turbidity and surface turbidity data to be checked. This was undertaken to ensure the real-time surface turbidity data and the associated surface turbidity intensity threshold were providing a realistic representation of the duration that the benthic turbidity intensity threshold was being exceeded.

Metocean conditions were monitored over the duration of the adaptive monitoring period. This included real-time wind data at Half Tide Tug Harbour (from the Bureau of Meteorology (BoM)), predicted water levels for the Port of Hay Point (from the Queensland Government, Transport and Main Roads), real-time wave data at the Hay Point waverider buoy (from the Department of Environment and Science) and weather forecasts/warnings provided by the BoM.

Satellite-derived turbidity data were also sourced from EOMAP from 17/03/2019 to 22/05/2019, with a combination of lower resolution (300 m) daily data from the Sentinel 3 sensor and twice weekly higher resolution (10 – 30 m) data from the Sentinel 2 and Landsat sensors.

3.2.2. Marine Megafauna

Marine megafauna monitoring was undertaken throughout the duration of the maintenance dredging (excluding periods of downtime when the dredger was in Mackay Harbour). The monitoring was undertaken through visual observations by personnel using binoculars from the bridge of the TSHD Brisbane. Results from the observations were included in the dredge log along with details of the personnel who undertook the monitoring. No marine megafauna were observed during the duration of the maintenance dredging.

4. Turbidity Analysis

Turbidity was determined to be the most appropriate parameter to identify potential impacts to sensitive receptors resulting from the 2019 maintenance dredging program, as this parameter was adopted for the real-time adaptive monitoring with specific management measures required when certain thresholds were exceeded.

This section analyses the turbidity data collected as part of the adaptive monitoring and calculates the duration of time that the turbidity intensity thresholds were exceeded.

4.1. Quality Assurance

A quality assurance and quality control (QA/QC) check was undertaken in real-time on the surface turbidity data and following each download on the benthic turbidity data. Where the QA/QC showed that data from both sondes were reliable the data were averaged and when data from one sonde were considered unreliable just the data from the sonde considered to be providing reliable data were adopted.

PCS has also undertaken a quality check of the surface and benthic turbidity data. The check involved comparing all benthic (impact and adaptive monitoring) and surface turbidity data available to ensure continuity. It was generally found that the surface and benthic data showed similar temporal patterns, with similar turbidity magnitudes during calm periods and higher benthic turbidity magnitudes during periods with elevated turbidity. As part of the quality check an offset was identified between the benthic adaptive monitoring and benthic ambient/impact monitoring data at Round Top Island between the 27th March and the 10th April 2019 (Figure 4). The offset gradually increased up to approximately 10 NTU where it remained from the 30th March up to the 10th April 2019 when the loggers were changed during a servicing trip and the offset disappeared. Over this period only one of the adaptive monitoring benthic loggers was measuring data as the other logger had a technical issue. Based on the water column profile data collected over this period along with the other turbidity data collected pre-, during and post this period, the adaptive monitoring benthic data were offset to remove the positive turbidity offset which occurred, with a maximum reduction of 10 NTU applied to the data. Figure 4 shows the improved agreement between the impact and adaptive monitoring benthic data after the offset was applied.

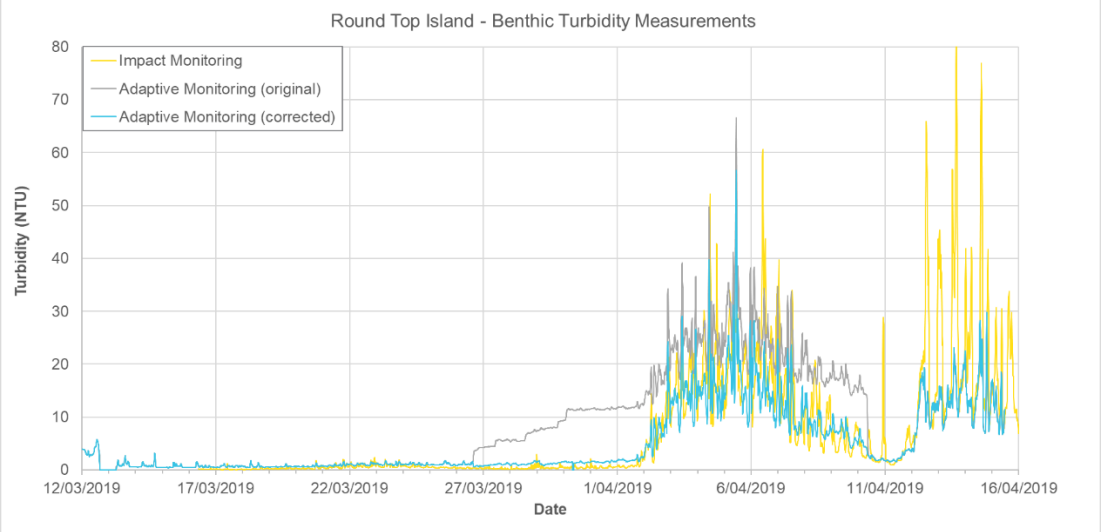


Figure 4. Measured benthic data at Round Top Island.

4.2. Turbidity Thresholds

Turbidity thresholds were calculated at the four adaptive management sites based on three years of benthic turbidity data collected as part of the long-term ambient water quality monitoring undertaken by JCU (RHDHV, 2018). The thresholds were determined using an hourly rolling average benthic turbidity and include a benthic turbidity intensity threshold and a duration of time the intensity threshold has been exceeded over a set period of time. These thresholds were adopted as part of the adaptive management for the Port of Hay Point 2019 maintenance dredging program. However, to allow the benthic turbidity thresholds to be applied to surface turbidity data it was necessary to correlate the concurrent benthic and surface turbidity data. This was undertaken prior to the commencement of the maintenance dredging based on concurrent benthic and surface turbidity data at each of the four sites in September and October 2018 (eight weeks of data) and over the pre-dredging period in 2019 (four weeks of data). The benthic to surface turbidity correlations were subsequently checked as required throughout the dredging program (PCS, 2019b; and PCS, 2019c). The benthic and correlated surface turbidity intensity thresholds are provided in Table 3, with the table showing the surface turbidity intensity thresholds developed based on the pre-dredging data which were adopted for the dredging program (in brackets) and the updated thresholds based on data collected during the dredging program. The benthic intensity and duration thresholds which were applied for the 2019 maintenance dredging program are shown in Table 4. The surface intensity thresholds detailed in Table 3 were applied along with the duration thresholds shown in Table 4 to allow the real-time surface turbidity data to be used to inform adaptive management activities in the periods between when data from the benthic loggers were available.

Table 3. Benthic and surface turbidity intensity thresholds for the trigger and control sites (RHDHV, 2018; and PCS, 2019c).

Location	Benthic Turbidity Intensity Threshold (NTU)	Surface Turbidity Intensity Threshold (NTU)
Slade Islet (control)	43	7.7 (8.9)
Round Top Island (trigger)	11	5.0 (8.1)
Victor Island (trigger)	32	11.0 (13.7)
Freshwater Point (control)	104	32.3 (24.3)

Note: the surface turbidity intensity threshold values in brackets represent the thresholds adopted for the maintenance dredging period based on a total of 12 weeks of pre-dredging surface and benthic data.

Table 4. Turbidity intensity and duration thresholds for the four adaptive monitoring sites based on a 40 day period (RHDHV, 2018).

Location	Intensity Threshold (NTU)	Average Duration (hrs)	90th Percentile Duration (hrs)	Maximum Duration (hrs)
Slade Islet (control)	43	77	194	278
Round Top Island (trigger)	11	77	164	300
Victor Island (trigger)	32	77	241	291
Freshwater Point (control)	104	77	166	333

4.3. Results

Results from the turbidity monitoring undertaken as part of the adaptive monitoring for the 2019 maintenance dredging program are presented in the following sections along with metocean data.

4.3.1. Metocean Conditions

The metocean conditions over the 2019 maintenance dredging impact and adaptive monitoring period are shown in Figure 5. The plots show that over the majority of the pre-dredge period the wind and wave conditions were relatively calm (wind speed typically below 15 knots and significant wave height (H_s) typically below 1 m). In contrast, over the duration of the maintenance dredging program and the post dredging period, higher energy wind and wave conditions dominated (wind speed consistently above 15 knots and H_s often above 1 m). In addition, the only rainfall event which resulted in a significant river discharge (from the Pioneer River) occurred during the 2019 maintenance dredging program (rainfall from 23-25/04/19 and peak discharge on 24/04/19).

4.3.2. Turbidity Conditions

The quality checked measured benthic and surface turbidity data over the 2019 maintenance dredging impact and adaptive monitoring period are shown in Figure 6 to Figure 9 at the four adaptive monitoring sites. The variation in turbidity at the four sites generally corresponds to the metocean conditions:

- from the 3rd March to the 10th March the turbidity was elevated at all four sites with the benthic and surface intensity thresholds exceeded at most sites. This coincided with a period of increased wind and wave energy from the 3rd to the 6th March (wind speed of 15 – 25 knots and H_s of 1 – 1.5 m). The elevated turbidity continued for longer than the elevated wind and wave conditions due to the lag in the turbidity in responding to the metocean conditions as the resuspended sediment is gradually deposited over time;
- between the 10th March and the 1st April the turbidity was low at all four sites. Although large spring tides occurred over this period (full moon on 21st March), the wind and wave conditions were generally calm with wind speeds of less than 15 knots and H_s of less than 0.5 m for the majority of the period;
- from the 1st April to the 5th May turbidity levels were generally elevated at all four sites, with a number of periods of increased turbidity occurring. Periods of increased wind and wave energy over this period typically correlate with the increased turbidity, with increased turbidity generally occurring when wind speeds of more than 15 knots and H_s greater than 1 m occur. Previous work identified both of these as thresholds above which there is likely to be a significant increase in turbidity in the Hay Point region due to increased natural resuspension of sediment from the seabed (RHDHV, 2016; and RHDHV, 2017). The exception to this is the increased benthic turbidity recorded at Slade Islet between the 25th April and the 2nd May 2019. The increase in turbidity over this period was not measured at the other monitoring sites and as a result it is likely that this period of increased turbidity was due to increased discharge from the Pioneer River which occurred at this time. The dominant south-easterly winds over this period would result in the high turbidity water being discharged from the river predominantly influencing areas located to the north of the river mouth. As the mouth is located between Slade Islet and Round Top Island, this would explain why Slade Islet was the only site to experience a significant increase in turbidity over this period; and
- between the 5th and the 12th May the turbidity was low at all four sites. Although the start of this period coincided with spring tides (new moon on 5th May), the wind and wave conditions were generally calm with wind speeds of less than 15 knots and H_s of less than 1 m for the majority of the period;
- between the 12th and 25th May elevated turbidity occurred at all four sites. The surface and benthic turbidity intensity thresholds were exceeded at Round Top Island and Slade Islet, but not at Victor Island or Freshwater Point. This period of increased turbidity coincided with a period of increased wind and wave energy with wind speeds generally of 15 – 25 knots and H_s typically between 1 – 1.5 m; and

- from the 25th to the 30th May the turbidity was low at all four sites. The wind and wave conditions were calm over this period, with wind speeds of less than 15 knots and H_s typically less than 0.5 m.

Although the measured data show that the turbidity increased soon after the 2019 maintenance dredging program commenced and that the turbidity remained high for the majority of the dredging program, numerical modelling undertaken as part of the model validation exercise showed that this was coincidental as the increased turbidity was predominantly due to the natural resuspension of bed sediment due to the wind and wave conditions (PCS, 2019d). Based on the 10 years of wave monitoring at Hay Point, the 2018-19 period (period taken to be from 1st May 2018 to 30th April 2019 to ensure full wet season is captured in a single year) had the second largest duration with H_s greater than 1 m and the largest since the ambient monitoring program began in 2014. In addition, over the duration of the maintenance dredging (33 days) the H_s exceeded 1 m for approximately 12 days (288 hours in total) which is approximately 36% of the time. On average, wave heights of this size are expected to occur for less than 15% of the time, and therefore, this period is considered to be more energetic than normal in terms of the wave conditions.

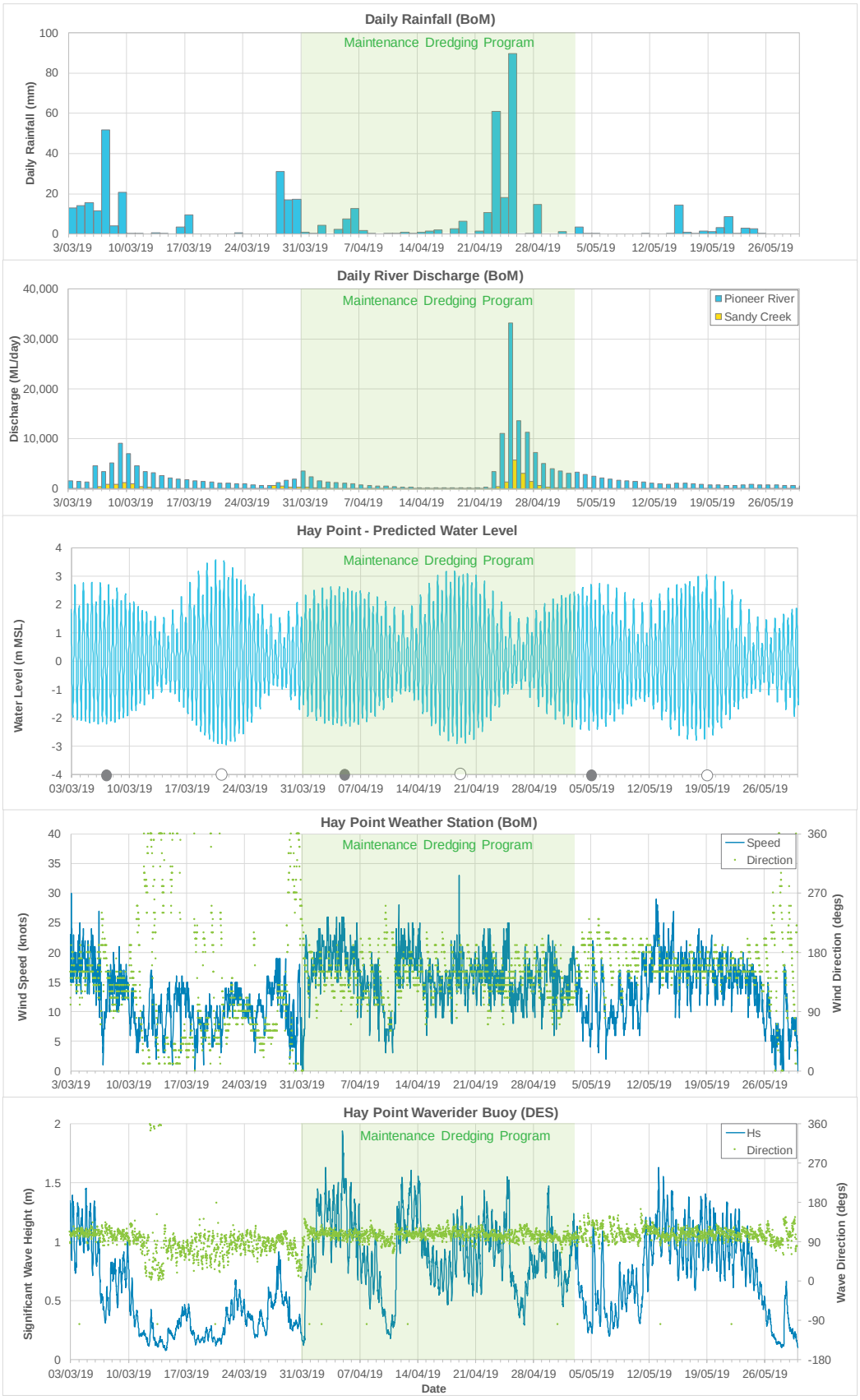


Figure 5. Metocean conditions over the 2019 maintenance dredging impact and adaptive monitoring period.

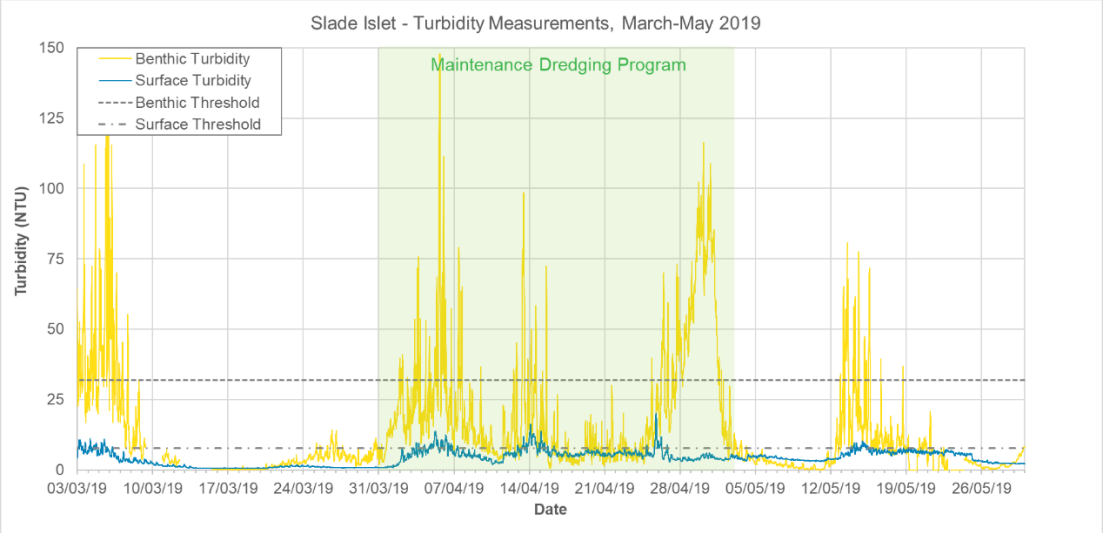


Figure 6. Hourly rolling average surface and benthic turbidity and turbidity intensity thresholds at Slade Islet over the 2019 maintenance dredging impact and adaptive monitoring period.

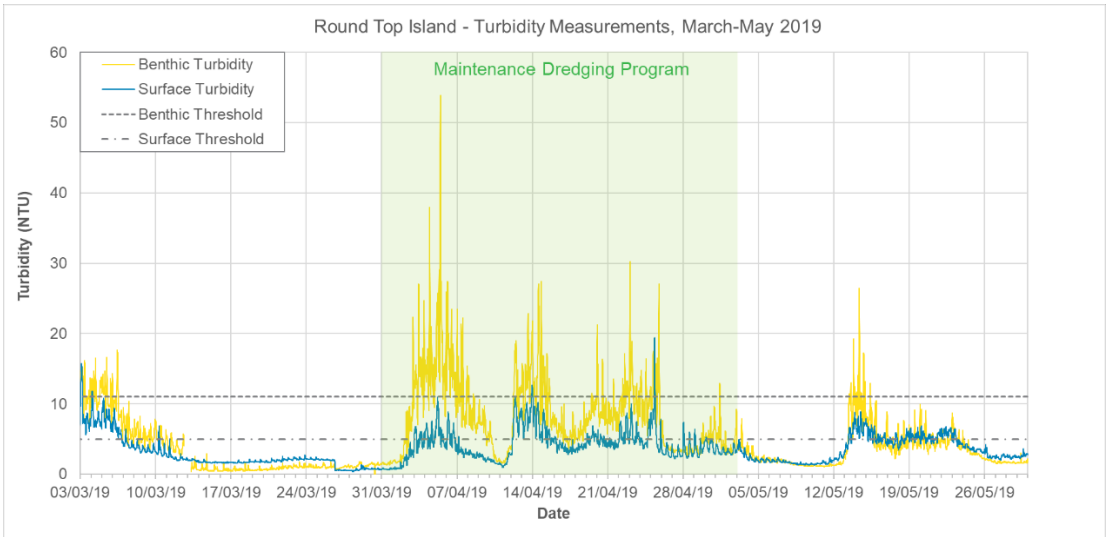


Figure 7. Hourly rolling average surface and benthic turbidity and turbidity intensity thresholds at Round Top Island over the 2019 maintenance dredging impact and adaptive monitoring period.

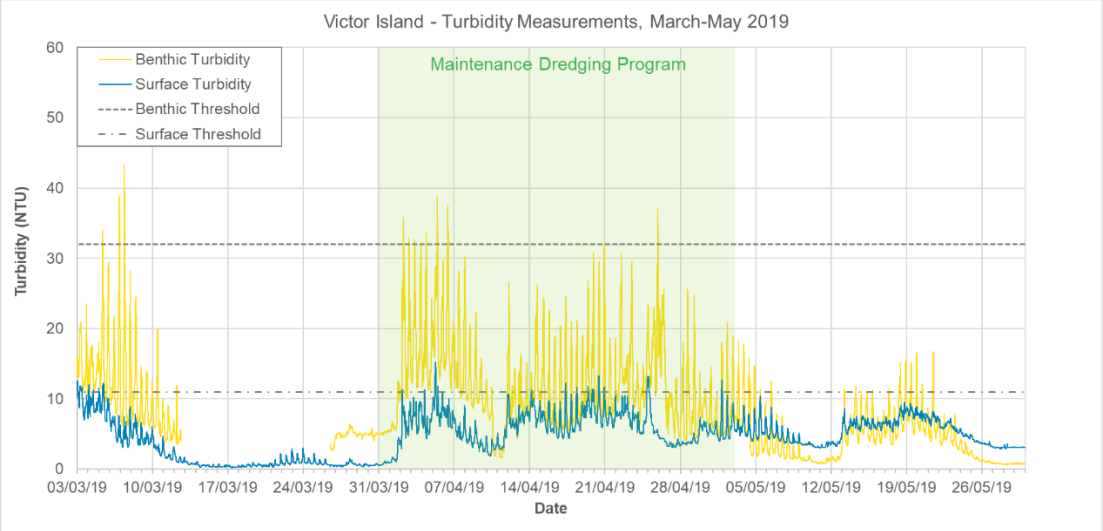


Figure 8. Hourly rolling average surface and benthic turbidity and turbidity intensity thresholds at Victor Island over the 2019 maintenance dredging impact and adaptive monitoring period.

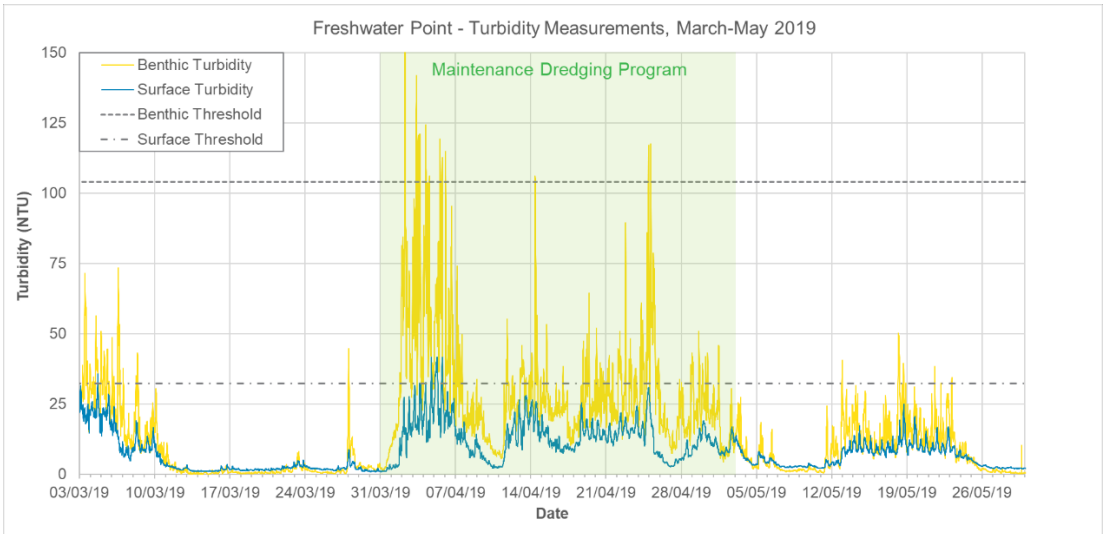


Figure 9. Hourly rolling average surface and benthic turbidity and turbidity intensity thresholds at Freshwater Point over the 2019 maintenance dredging impact and adaptive monitoring period.

4.3.3. Water Column Profiling

Water column profile measurements of turbidity were undertaken as part of the vessel based impact monitoring. As the measurements were vessel based there were limitations as to when measurements could be undertaken. As a result, the profile turbidity data are generally representative of calmer wind and wave conditions and as a result the turbidity was generally low.

Water column profiles of turbidity are shown in Figure 10 and Figure 11 during calm conditions at the eight impact monitoring sites. The plots show that at most of the sites the turbidity is relatively uniform through the water column during calm periods with low turbidity. The exception to this was at Hay Reef where the benthic turbidity was close to eight times higher than the surface turbidity. This indicates that localised sediment transport occurs around Hay Reef even during relatively calm wind and wave conditions. The turbidity profiles through the water column during the sampling period when the highest turbidity was

measured are shown for the two trigger sites in Figure 12. These plots show that during periods with slightly elevated turbidity there is a clear difference between the benthic and surface turbidity, with it being up to 1.5 to 2 times higher near the bed than near the surface.

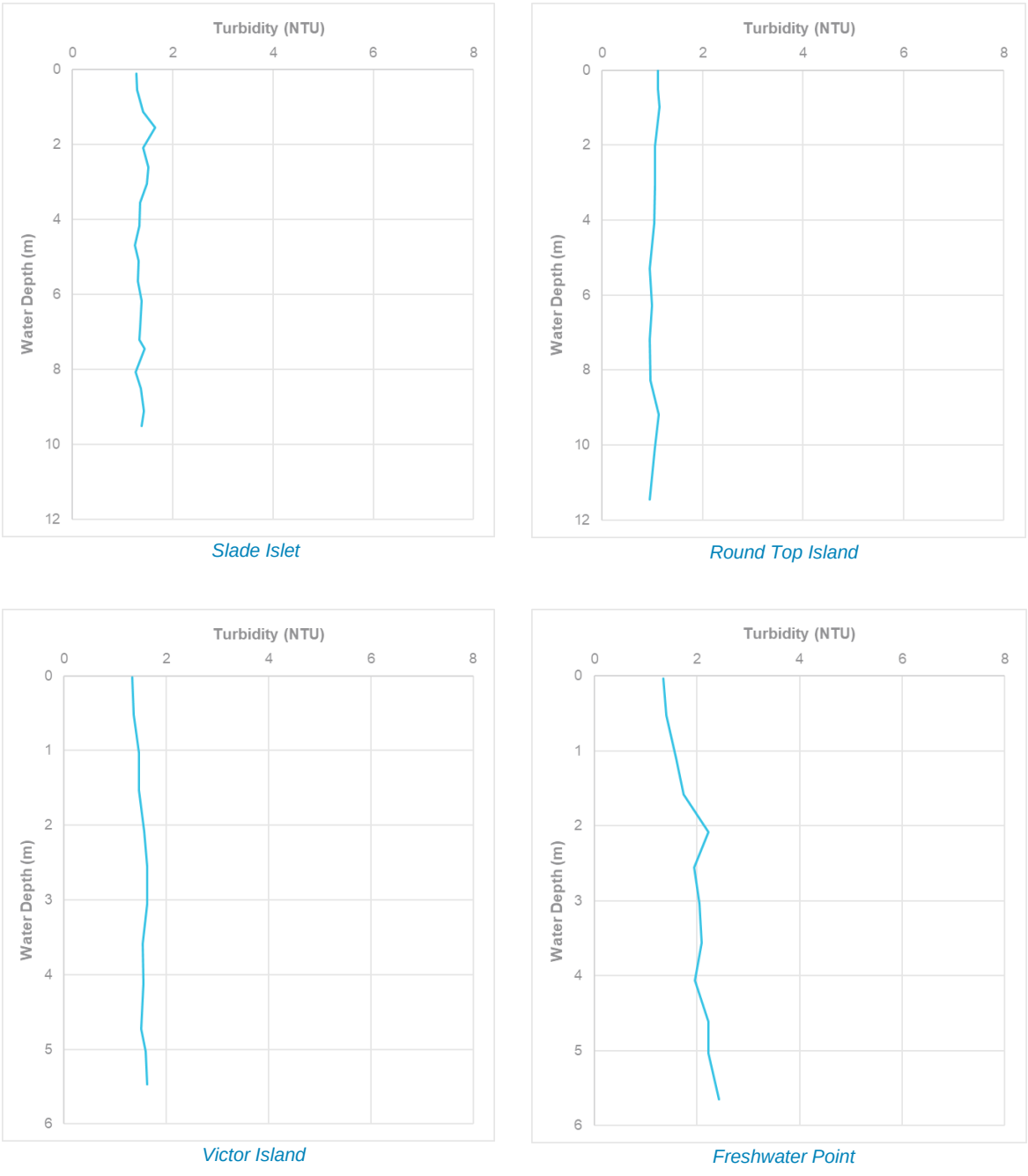
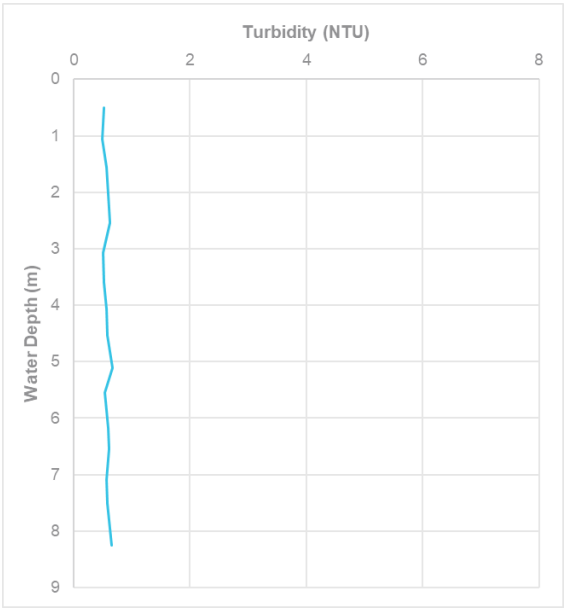
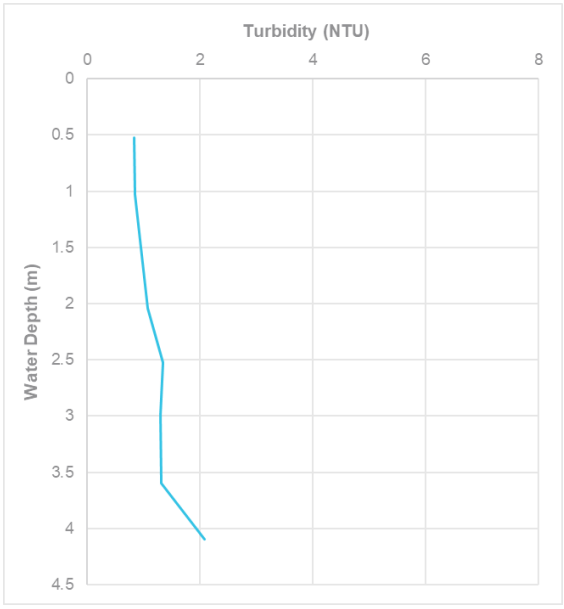


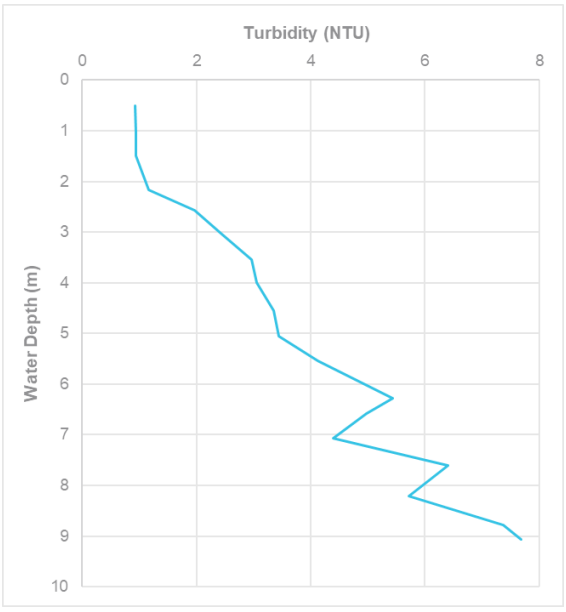
Figure 10. Measured turbidity profiles through the water column on 12/03/2019 at the four adaptive monitoring sites.



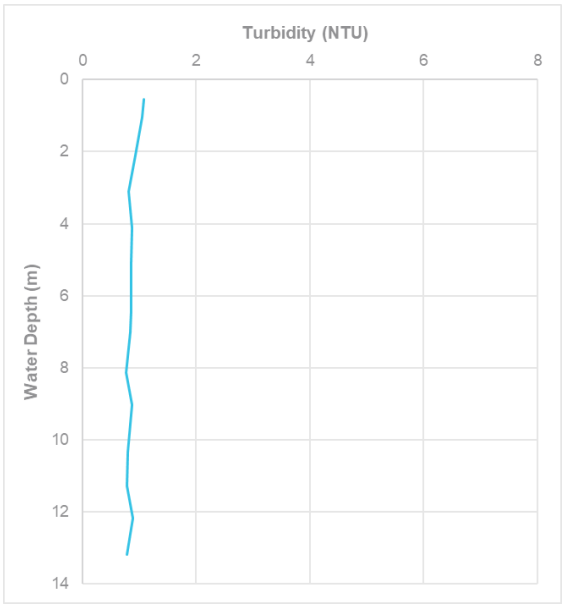
Keswick Island



Mackay Harbour

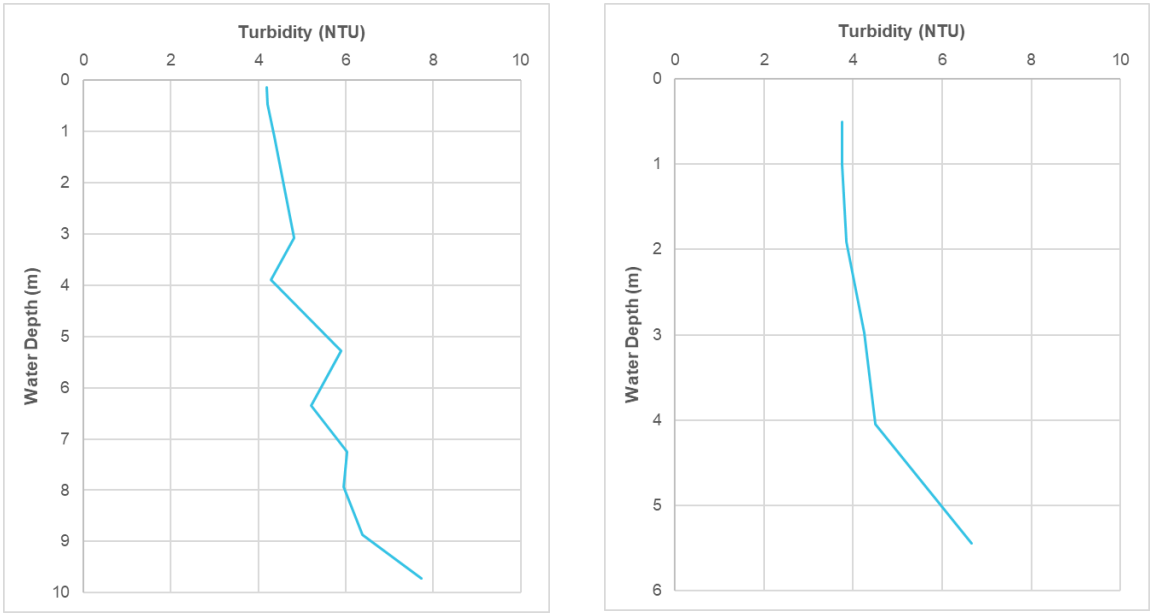


Hay Point Reef



Hay Point DMPA

Figure 11. Measured turbidity profiles through the water column on 12/03/2019 at four of the impact monitoring sites.



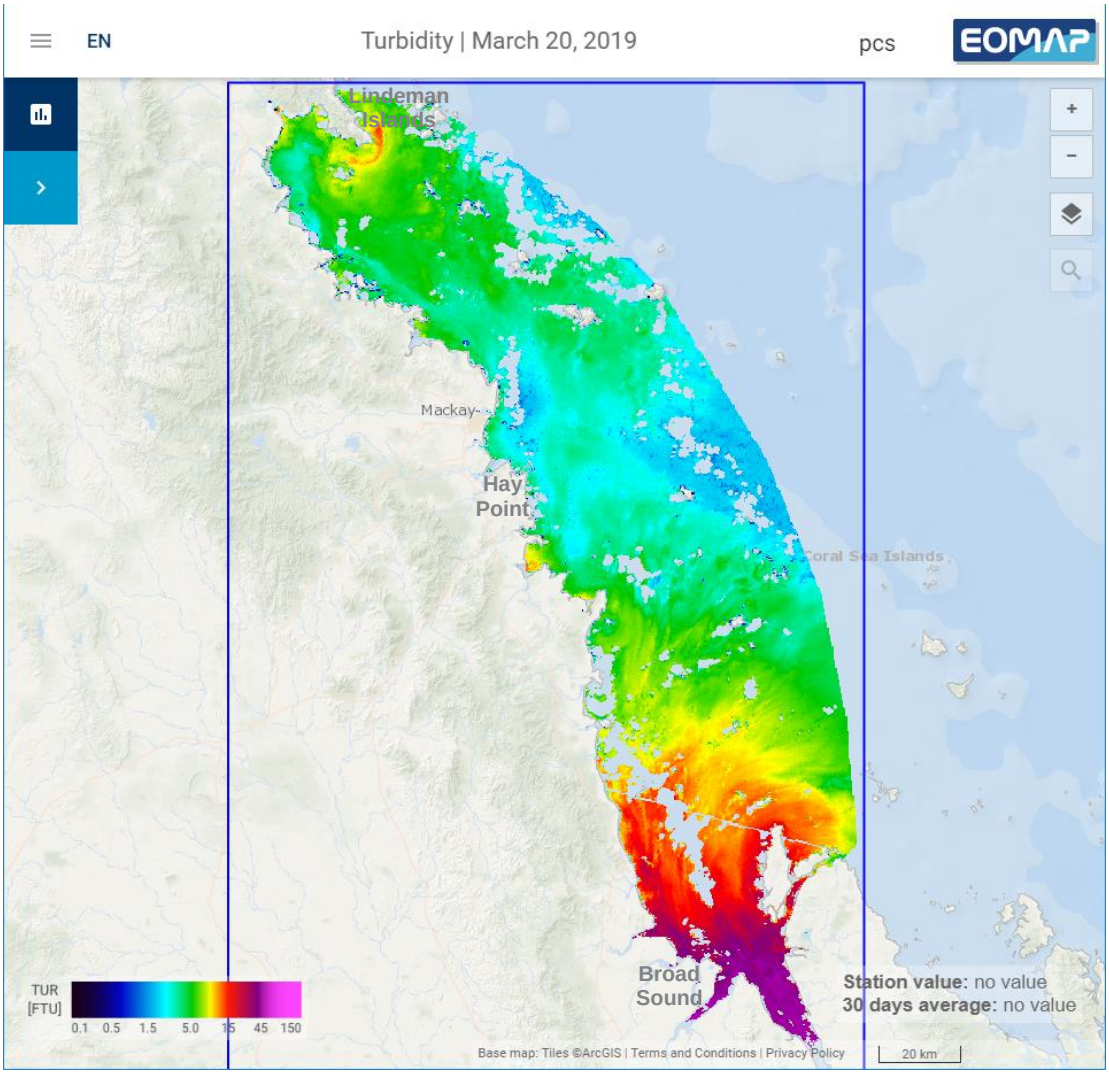
Round Top Island *Victor Island*

Figure 12. Measured turbidity profiles through the water column on 15/04/2019 at the two trigger sites.

4.3.4. Satellite-Derived Turbidity

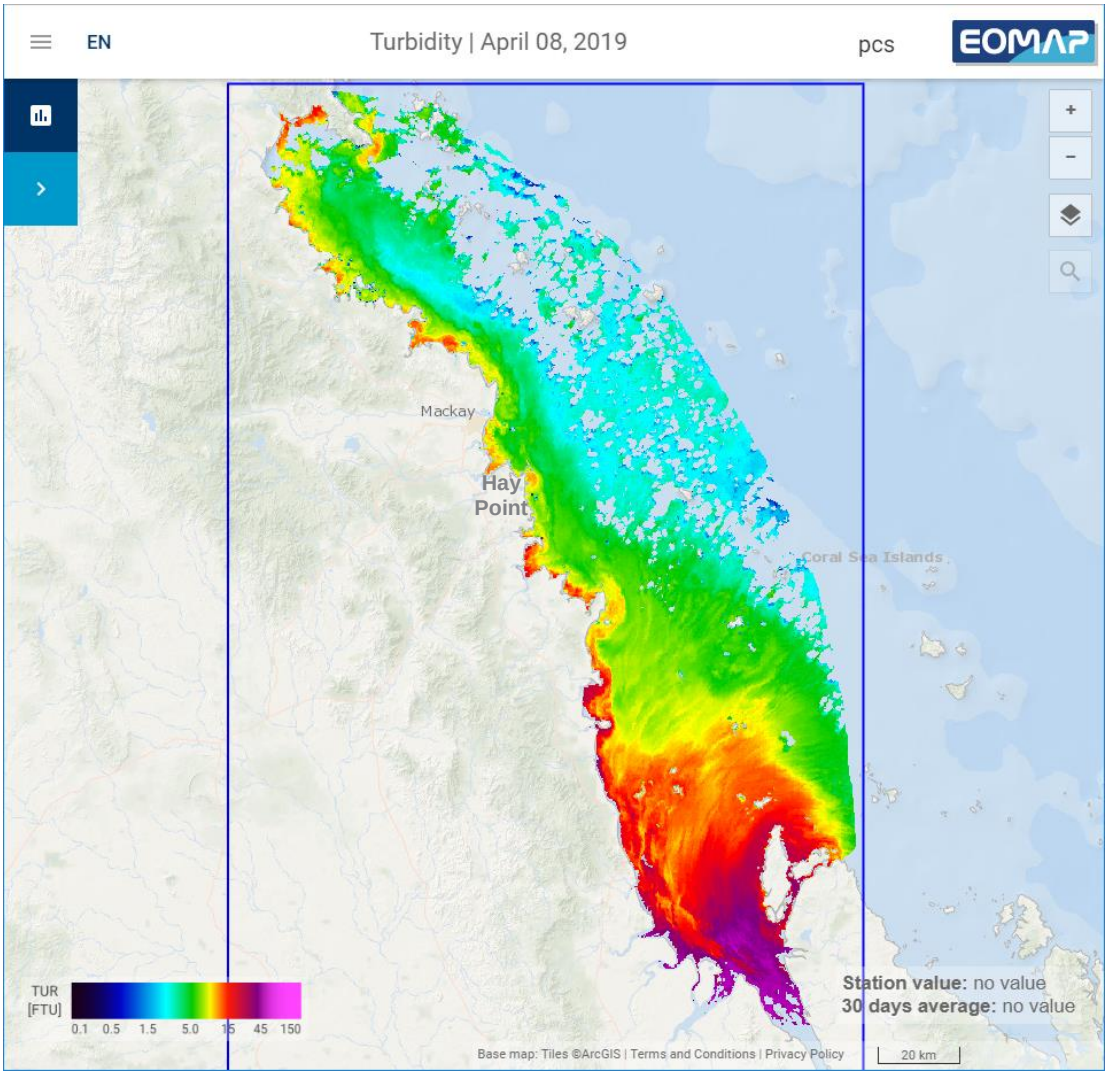
To better understand how the turbidity has varied spatially during the 2019 maintenance dredging program the satellite-derived turbidity data obtained as part of the adaptive monitoring have been analysed. Satellite-derived turbidity data is a valuable resource which can provide a reliable spatial overview of the variability in turbidity (Fearns et al., 2017). This type of data can greatly assist the interpretation of in-situ data sets, especially when attempting to gain a better understanding of the spatial variability in turbidity over a large area, such as the Hay Point region. A combination of low-resolution (300 m cells) and high-resolution (10 – 30 m cells), satellite-derived turbidity data have been sourced over the pre-, during and post-maintenance dredging periods. The satellite data are restricted by cloud cover and over much of the maintenance dredging program period the unsettled weather conditions have resulted in high cloud cover. However, the satellite data are still able to provide useful information relating to the regional and local turbidity.

Low-resolution satellite derived turbidity data were sourced from EOMAP over a 300 km length of coastline, from Broad Sound to the south to the Lindeman Islands to the north (area of approximately 15,000 km^2). These data can be used to understand the regional scale processes which influence turbidity and to assess whether the Port of Hay Point maintenance dredging program has the potential to impact upon the regional turbidity. Plots of the satellite derived turbidity over the regional area are shown for pre, during and post maintenance dredging periods (with variable metocean conditions) in Figure 13 to Figure 15. The plots show that very high turbidity occurs to the south in Broad Sound, this is a result of the high tidal currents in this area resulting from the tidal amplification in Broad Sound. The turbidity reduces north of Broad Sound, with Hay Point being the approximate northern limit where increased turbidity occurs. Elevated turbidity also tends to occur around the headlands along the entire coastline due to increased current speeds and relatively shallow water in these areas. The plots also indicate that moderate wind and wave conditions can result in increased turbidity along the coastlines and specifically adjacent to the headlands. These plots along with other low-resolution satellite derived turbidity data obtained as part of the project, indicate that the 2019 maintenance dredging program at the Port of Hay Point did not directly influence the regional scale turbidity, with this being predominantly controlled by tidal currents and wind/wave conditions.



Note: The gaps in the data are due to cloud cover.

Figure 13. Low-resolution satellite turbidity data for the regional area at 09:20 on 20/03/2019 (large spring tide, low wind and wave energy, pre-dredging program).



Note: The gaps in the data are due to cloud cover.

Figure 14. Low-resolution satellite turbidity data for the regional area at 09:30 on 08/04/2019 (average spring tide, moderate wind and wave energy, during dredging program).

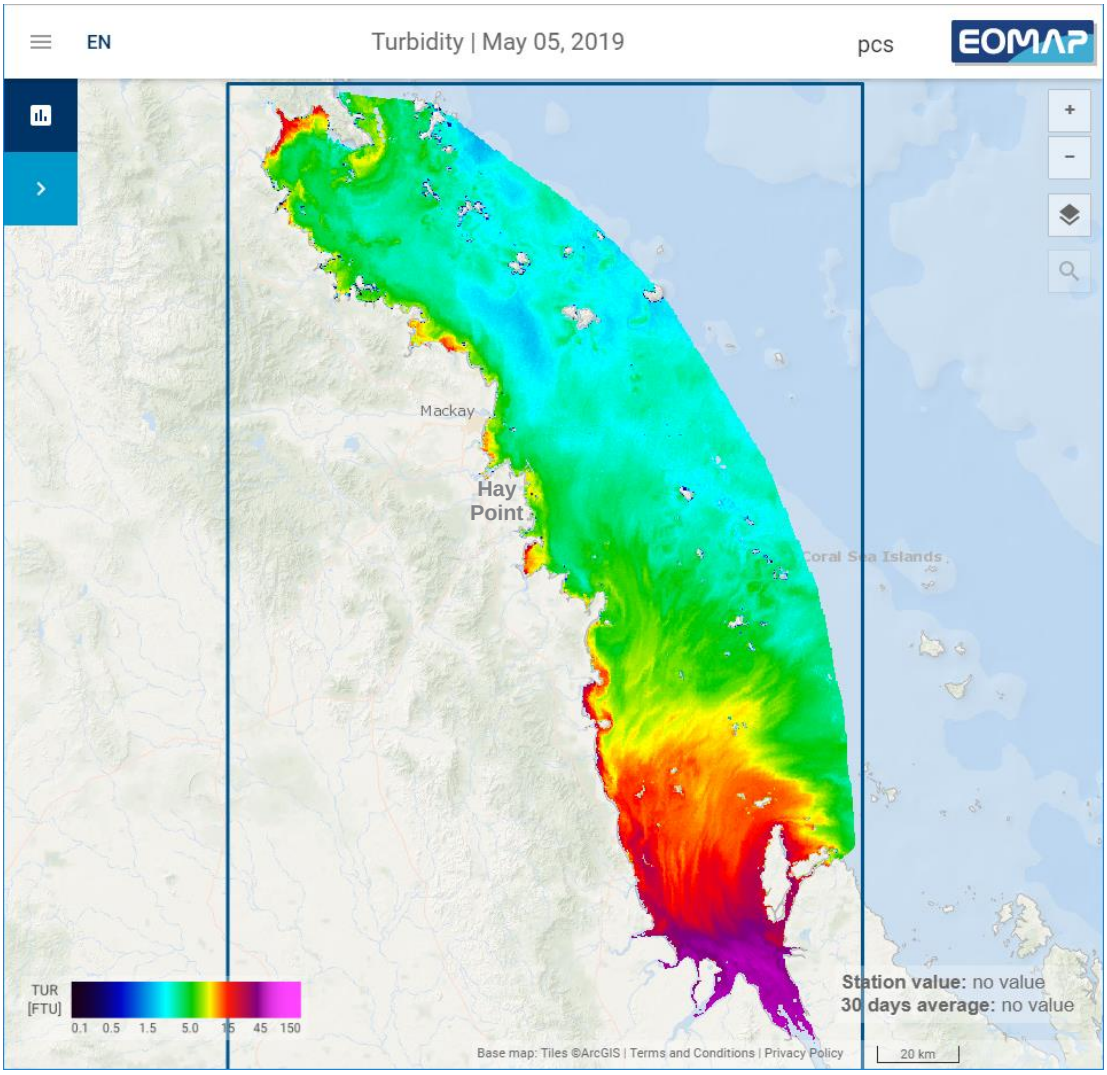
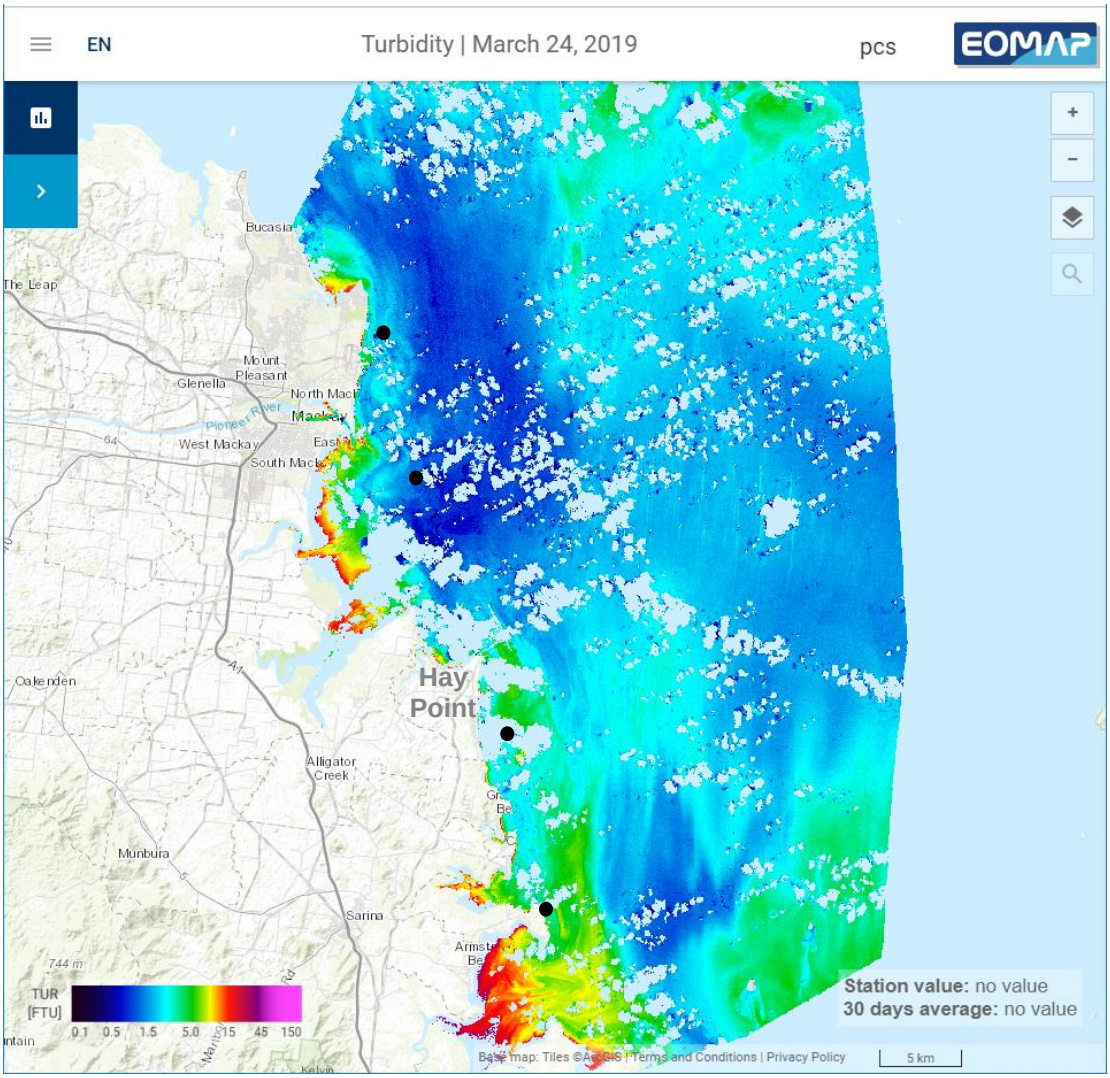


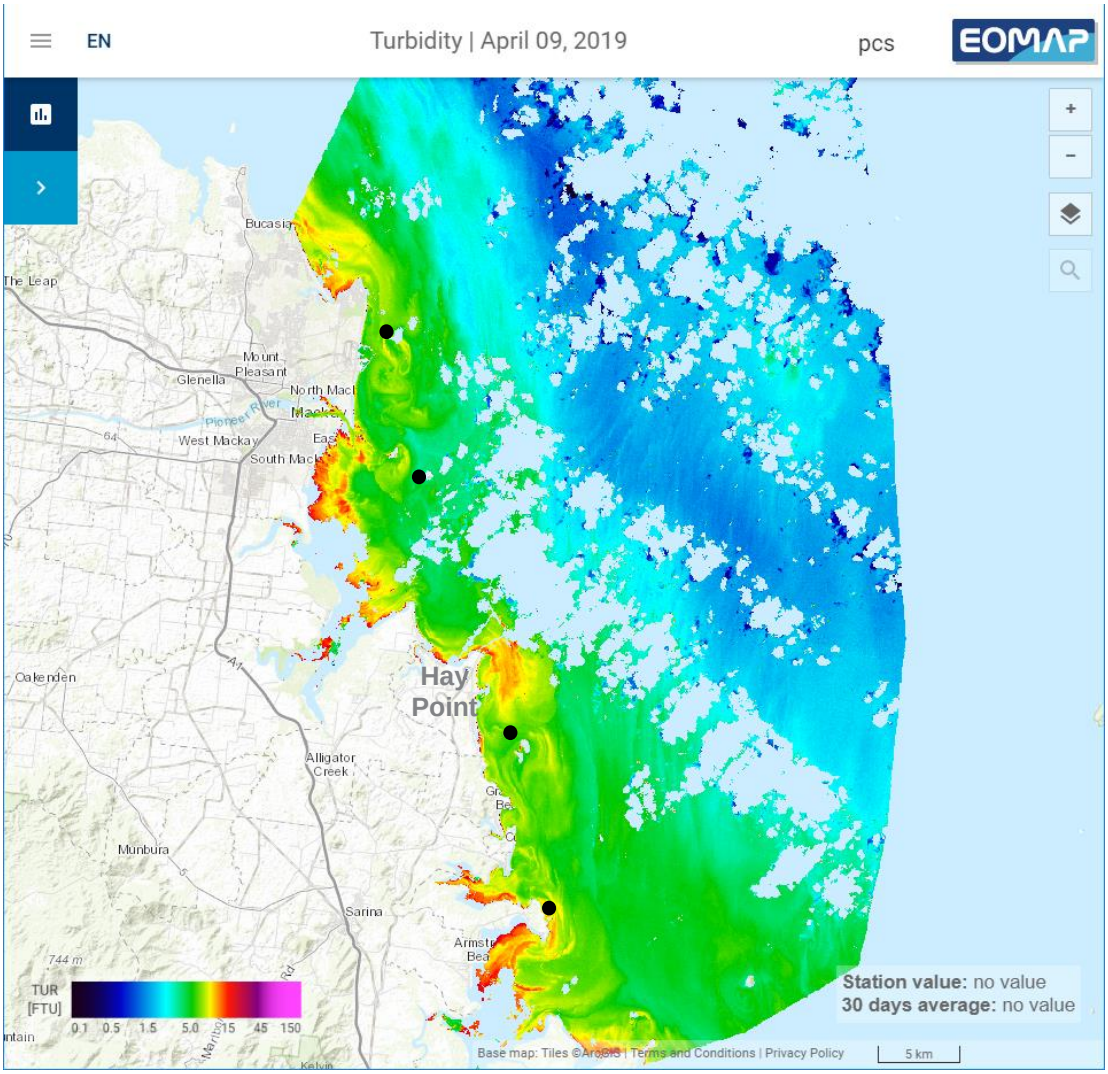
Figure 15. Low-resolution satellite turbidity data for the regional area at 09:30 on 05/05/2019 (large spring tide, low wind and wave energy, post dredging program).

High-resolution satellite derived turbidity data were sourced from EOMAP to cover the area where the four water quality monitoring sites were setup (these are represented by black dots in Figure 16 to Figure 19), as well as the waters surrounding Keswick and St Bees Islands (area of approximately 2,000 km^2). These data can be used to understand the local processes which influence turbidity and have the potential to identify specific plumes resulting from the 2019 maintenance dredging program. Plots of the satellite derived turbidity over the local Hay Point region are shown for pre-, during and post-maintenance dredging periods (with variable metocean conditions) in Figure 16 to Figure 19. The plots show that elevated turbidity can occur within 5 to 15 km of the coastline, with the highest turbidity occurring in shallow areas and adjacent to headlands. The area to the south of the Port of Hay Point experiences elevated turbidity compared to the surrounding areas and this occurs during calm and moderate wind/wave conditions. Similar to the regional scale turbidity, the satellite derived turbidity data show that the turbidity over the area pre-, during and post-maintenance dredging is predominantly controlled by tidal currents and wind/wave conditions. It has not been possible to identify any sediment plumes directly resulting from the maintenance dredging and placement activities. It is expected that this has been partially due to the extensive cloud cover over much of the dredging period (i.e. some localised plumes would have occurred).



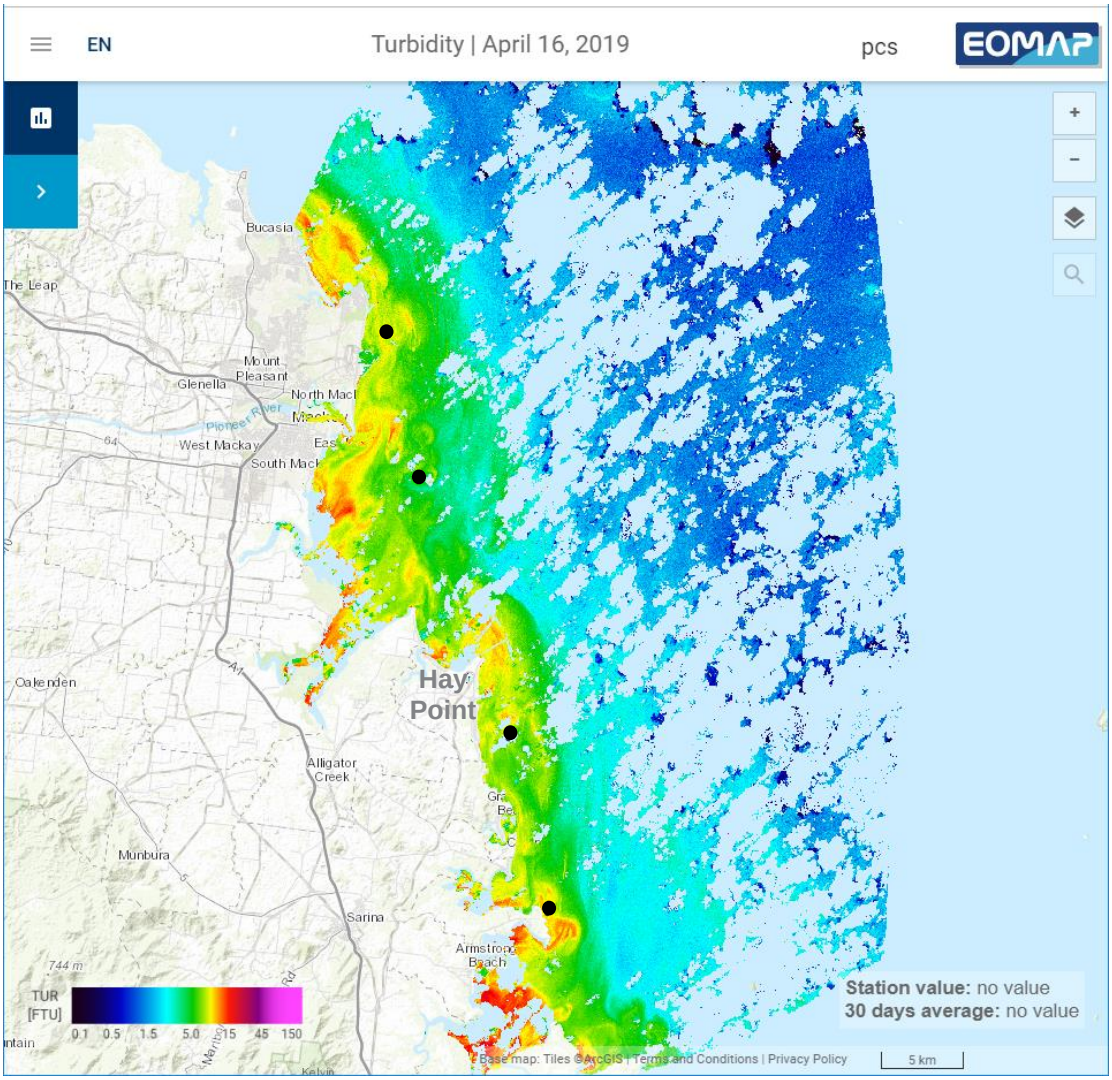
Note: The gaps in the data are due to cloud cover and the grey dots represent the location of the four monitoring sites.

Figure 16. High-resolution satellite turbidity data for the Hay Point region at 10:04 on 24/03/2019 (large spring tide, low wind and wave energy, pre-dredging program).



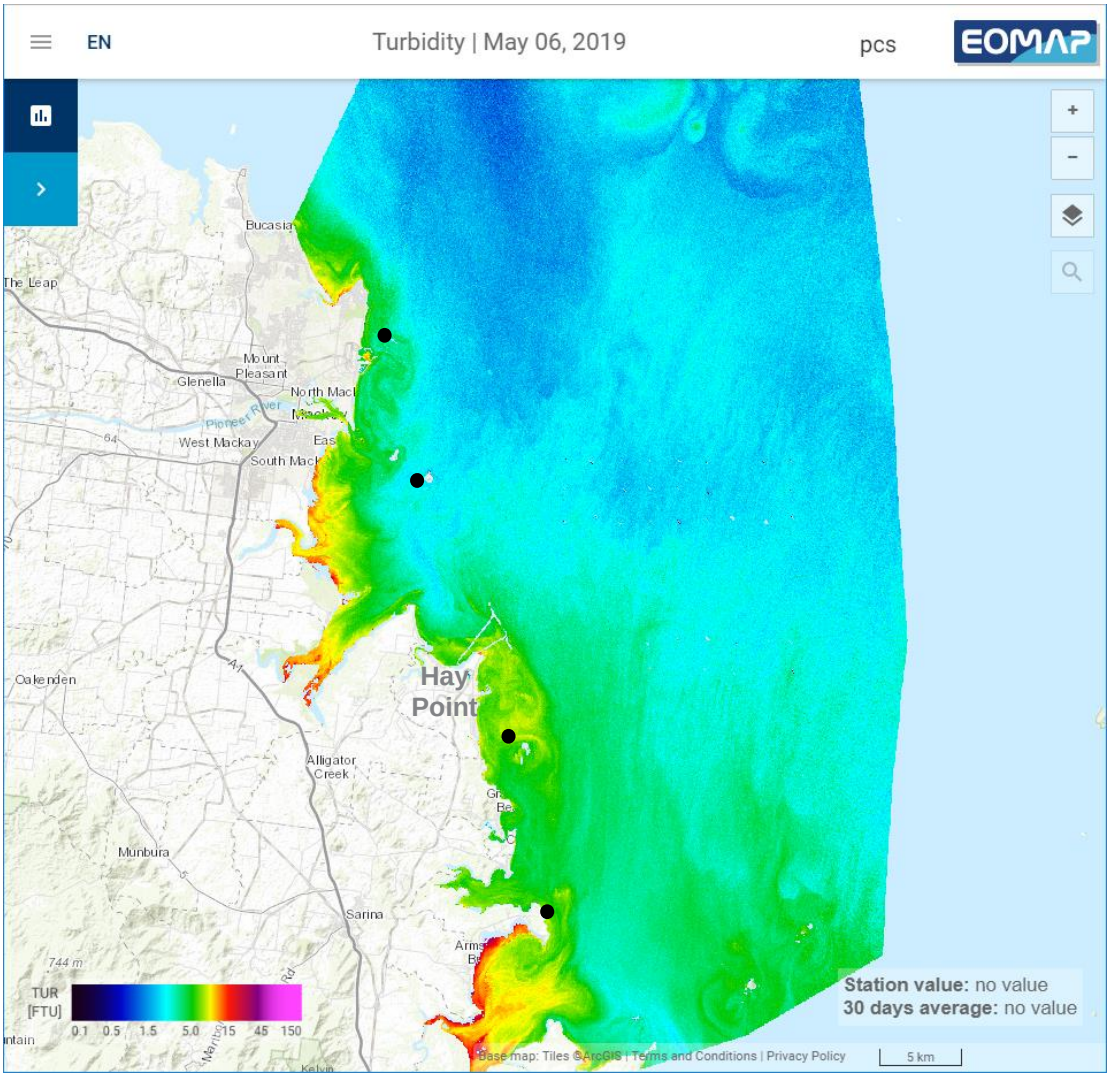
Note: The gaps in the data are due to cloud cover and the grey dots represent the location of the four monitoring sites.

Figure 17. High-resolution satellite turbidity data for the Hay Point region at 10:04 on 09/04/2019 (average tide, moderate wind and wave energy, during dredging program).



Note: The gaps in the data are due to cloud cover and the grey dots represent the location of the four monitoring sites.

Figure 18. High-resolution satellite turbidity data for the Hay Point region at 10:22 on 16/04/2019 (average spring tide, moderate wind and wave energy, during dredging program).



Note: The grey dots represent the location of the four monitoring sites.

Figure 19. High-resolution satellite turbidity data for the Hay Point region at 10:22 on 06/05/2019 (large spring tide, low wind and wave energy, post dredging program).

4.3.5. Threshold Exceedance

The benthic and surface turbidity measured at the four adaptive monitoring sites have been analysed to calculate the duration that the benthic and surface turbidity intensity thresholds were exceeded over the pre-, during and post-maintenance dredging periods (Table 5). The table shows that the longest duration that the turbidity intensity thresholds were exceeded at all four sites occurred during the maintenance dredging program. This correlates with the metocean conditions over the different periods, with the wind and wave conditions being consistently higher energy over this maintenance dredging program relative to the pre- and post-dredging periods.

During all three periods the exceedance duration was significantly higher at Round Top Island compared to the other three sites. As this was the case during the pre-dredge period, as well as the during and post-dredge periods, it suggests that the natural turbidity at Round Top Island was high relative to the turbidity intensity threshold compared to at the other three sites. This could be a result of a natural change in the turbidity at Round Top Island, this will be further considered in Section 6.2 where the turbidity intensity threshold will be recalculated using the additional two years of ambient monitoring turbidity data.

At Victor Island the benthic exceedance over the period was calculated to be seven hours using the adaptive monitoring benthic turbidity data, but up to 22 hours using the impact monitoring benthic turbidity data. Reliable impact monitoring turbidity data were only available at Victor Island for the second half of the dredging period (16/04/2019 to 02/05/2019) and over this period there were 29 hours of benthic threshold exceedance at Round Top Island (based on the impact monitoring data). Based on this and that the impact monitoring benthic turbidity data consistently measured higher peaks in turbidity compared to the adaptive monitoring benthic data at Victor Island, it is expected that if reliable impact monitoring benthic turbidity data were available at Victor Island over the entire dredge period the duration of exceedance would have been significantly higher than 22 hours.

During the maintenance dredging the duration exceedance between the surface and benthic loggers were very similar at the four sites, this was because the benthic to surface correlation adopted was determined over this period. There was much more variability over the pre- and post-dredging periods, with the largest variations occurring at Round Top Island over the post-dredge period when the surface exceedance was ten times higher than the benthic exceedance. This suggests that the correlation between the benthic and surface turbidity is variable depending on the metocean conditions. This will be further considered in Section 6.1, where data over the entire pre-, during and post-dredge periods will be used to update the benthic to surface turbidity correlation and determine if the surface turbidity intensity thresholds should be updated.

Table 5. Benthic and surface turbidity intensity threshold exceedances from 03/03/2019 to 30/05/2019.

Location	Pre-Dredging (hrs)		During Dredging (hrs)		Post-Dredging (hrs)	
	Surface	Benthic	Surface	Benthic	Surface	Benthic
Slade Islet	29	39[1]	115	117[1]	25	16[1]
Round Top Island	96	45	219	217	161	16
Victor Island	13	3	21	7[2]	0	0
Freshwater Point	1	0[1]	11	11[1]	0	0[1]

[1] turbidity data collected as part of the impact monitoring were used to calculate the benthic exceedance duration at Slade Islet and Freshwater Point.

[2] benthic turbidity data collected as part of the impact monitoring were also used to calculate the duration exceedance, with 22 hours of exceedance from 16/04/2019 to 02/05/2019 (there was an issue with the instrument prior to 16/04/2019 and so no reliable data were measured).

During the 2019 maintenance dredging program the duration of surface turbidity threshold exceedance was calculated in real-time at all four adaptive monitoring sites. In addition, the duration of benthic turbidity threshold exceedance was calculated at Round Top Island and Victor Island during the maintenance dredging program each time the benthic turbidity data were downloaded from the loggers (every 1 to 2 weeks). On the 18th April 2019 the benthic turbidity data showed that Round Top Island had exceeded the 90th percentile duration of 164 hours and as a result the management zone increased from Zone B to Zone C (see Section 2.2.1). This meant that the management zone had changed from investigate to respond, requiring investigation to determine if the turbidity levels are natural or dredging related and if they are dredging related then management actions should be instigated. The investigation found that the elevated turbidity was predominantly due to natural conditions (PCS, 2019b), despite this NQBP adopted a precautionary approach and the following adaptive management measures were implemented for the remainder of the dredging program:

- dredge material to be placed within the southern extent of the DMPA, with a focus on the south-eastern corner; and
- dredger to drift at a slow speed during placement runs within the DMPA.

The MRG were informed of the change in management zone and subsequent approved adaptive measures put in place as part of a weekly update. At the end of the 2019 maintenance dredging program Round Top Island remained in management zone C (exceedance of between 164 and 300 hours), while Victor Island remained in management

zone A throughout (exceedance of less than 96 hours, resulting in normal operating conditions).

The State Environmental Permit (EPPR01742813) conditions specify that total suspended solids do not exceed 100 mg/l calculated as a six-hour rolling mean. Based on the turbidity to total suspended solids relationships in the Environmental Thresholds report (RHDHV, 2018), site specific turbidity thresholds were calculated. The six-hour rolling mean surface turbidity was monitored during and post maintenance dredging at the four monitoring sites as part of the real-time adaptive management. The six-hour rolling mean surface turbidity remained below the 100 mg/l threshold specified throughout the monitoring period (Table 6). In addition, the maximum hourly rolling mean benthic turbidity measured at the Round Top Island and Victor Island were 54 NTU and 39 NTU (Figure 7 and Figure 8), which are both below the six-hour rolling mean turbidity values. Therefore, the benthic turbidity data at the two trigger sites during the dredging and post-dredging periods remained below the 100 mg/l six-hour rolling mean (noting that a six-hourly rolling mean would reduce the maximum turbidity compared to the hourly rolling mean presented in this report). Therefore, the water quality monitoring results show that both the surface and benthic turbidity did not exceed the trigger value of 100 mg/l specified in the State Environmental Permit during the 2019 dredging program.

Table 6. Surface turbidity six-hour rolling mean values during dredging along with State compliance thresholds (VE, 2019a).

Location	Surface turbidity 6 hr rolling average range (NTU)	State Compliance Turbidity (NTU)
Slade Islet (control)	<1 – 12	83.3
Round Top Island (trigger)	<1 – 12	73.5
Victor Island (trigger)	<1 – 14	68
Freshwater Point (control)	1 – 38	125

5. Implementation

This section provides a summary of how the monitoring undertaken and the results of the monitoring and associated actions adopted performed relative to the requirements of the approval conditions.

5.1. Implementation Summary

In general, the environmental monitoring undertaken as part of the Port of Hay Point 2019 maintenance dredging program has been implemented in the manner stated in the Maintenance Dredging EMP, the MEMP and the ET report. The scale and frequency of impact monitoring implemented was affected by weather conditions and water visibility. A summary of the environmental monitoring is presented below:

- Impact Monitoring:
  - Marine Water Quality Monitoring: monitoring undertaken using the data loggers was in accordance with the specified requirements except that sampling was only undertaken at seven of the eight sites, with no logger data collected in Mackay Harbour as this ambient monitoring site was moved to Aquila Island. The sampling for metals, chlorophyll a and pesticides/herbicides was all been in accordance with the specified requirements (with additional sampling undertaken during dredging). The vessel-based physio-chemical profiling was undertaken on average every three weeks rather than every week over the period, this was mainly due to limitations regarding the weather conditions. The water sampling and subsequent analysis for nutrients was only undertaken three times over the monitoring period (pre-, during and post-dredging) rather than the weekly sampling suggested in the MEMP. The frequency of the sampling specified in the MEMP was considered to be unrealistic (given weather constraints) and more frequent than necessary to determine any potential changes due to the maintenance dredging.
  - Island Fringing Coral: coral monitoring was undertaken pre- and post-dredging with the monitored parameters being in accordance with the specified requirements. The timing of the monitoring activities was not exactly four weeks pre- and post-dredging and the number of sites adopted and the transects undertaken at each site were less than those stated in the MEMP. This was due to a combination of unfavourable weather conditions, poor water visibility and the requirement to establish new transects at all sites.
  - Sediment Quality: sediment sampling was undertaken prior to dredging in accordance with the NAGD and this showed that the sediment was suitable for placement in the marine environment. The sediment sampling therefore conformed with the MEMP.
- Adaptive Monitoring:
  - Marine Water Quality Monitoring: the monitoring was generally undertaken in accordance with the specified requirements. The exceptions to this were as follows:
    - turbidity was monitored but the TSS was not measured as this would have required regular water sampling to provide confidence that the correlation between turbidity and TSS was representative;
    - PAR was not monitored as it wasn't considered a suitable parameter to inform adaptive management activities (RHDHV, 2018) and due to the site conditions, it was not realistic to telemeter benthic data (see Section 3.2.1). In addition, benthic PAR was already being monitored at each of the eight impact monitoring sites;
    - current speed and direction were not monitored as part of the adaptive monitoring as the data are not required to inform the adaptive management activities. In addition, the current speed and direction were already being monitored at each of the eight impact monitoring sites; and

  - pressure was only monitored at the two trigger sites where benthic data loggers were deployed as monitoring pressure (which is post-processed to determine water depth) at the real-time surface loggers is not of benefit. Pressure was monitored at all sites as part of the impact monitoring.
- Marine Megafauna: this monitoring was undertaken in accordance with the specified requirements.

- Turbidity Thresholds:
  - the adaptive monitoring and management was implemented in the manner stated in the Maintenance Dredging EMP, the MEMP and the ET report. During the maintenance dredging program the benthic turbidity data showed that the monitoring site at Round Top Island had exceeded the 90th percentile duration of 164 hours and so the management zone increased to Zone C. As noted in the Maintenance Dredging EMP, this meant that the management zone had changed from investigate to respond, requiring investigation to determine if the turbidity levels are natural or dredging related and if they are dredging related then management actions should be instigated. The investigation found that the elevated turbidity was predominantly due to natural conditions (PCS, 2019b), despite this NQBP adopted a precautionary approach and the following adaptive management measures were implemented for the remainder of the dredging program. At the end of the 2019 maintenance dredging program, Round Top Island remained in management zone C (exceedance of between 164 and 300 hours), while Victor Island remained in management zone A throughout (exceedance of less than 96 hours, resulting in normal operating conditions).

5.2. Recommendations

It is recommended that the following be considered for environmental monitoring required as part of future maintenance dredging programs at the Port of Hay Point:

- Impact Monitoring:
  - the locations of the data loggers required as part of the impact monitoring should match the data loggers as part of the ongoing ambient monitoring and as such the MEMP should be updated to replace Mackay Harbour with Aquila Island;
  - undertaking vessel based physio-chemical monitoring at all eight monitoring sites weekly over the pre-, during and post-dredging periods is unrealistic given the exposed nature of the sites and the distances between sites. It is suggested that monthly sampling should be undertaken at all sites, and fortnightly sampling at the trigger and control sites would be more realistic while still providing sufficient data;
  - the requirement for weekly nutrient sampling and analysis is considered unnecessary. It is recommended that the sampling frequency be changed so that it is in line with the sampling required for metals, chlorophyll a and pesticides/herbicides (four weeks prior to and four weeks after dredging); and
  - it is unnecessary to undertake measurements of secchi disk depth when PAR measurements through the water column are undertaken as these can be used to provide a more accurate measure of the light attenuation coefficient.

- Adaptive Monitoring:
  - the requirement to monitor turbidity and TSS is unnecessary as this is not required to inform adaptive management and this is already being monitored as part of the impact monitoring;
  - it is unnecessary to measure current speed and direction, benthic PAR and pressure as part of the adaptive monitoring, as these data are not required to inform adaptive management and they are already being monitored as part of the impact monitoring; and
  - for future programs it is recommended that only telemetered surface loggers are deployed at the trigger and control sites as part of the adaptive monitoring (i.e. the

benthic loggers at the trigger sites are not deployed). The benthic data being collected as part of the impact monitoring should be retrieved fortnightly (weather permitting) at the trigger and control sites to allow the correlation between the benthic and surface data to be confirmed and to check the benthic threshold exceedance relative to the surface threshold exceedance.

6. Continual Improvement

As part of the continual improvement of the environmental monitoring associated with maintenance dredging at the Port of Hay Point, this section presents additional analysis of the measured turbidity data.

6.1. Surface to Benthic Turbidity Correlation

As previously noted in Section 4.3.5, there was variability in the duration of time the benthic and surface turbidity thresholds were exceeded over the pre- and post-dredging periods. This suggests that the correlation between the benthic and surface turbidity is variable depending on other variables such as the metocean conditions. To further investigate this, the turbidity data at the four adaptive monitoring sites over the entire pre-, during and post-dredge periods have been analysed to determine the surface turbidity intensity thresholds required for the duration exceedances to match the benthic turbidity data over the entire monitoring period (Table 7). The table shows that the surface to benthic scaling factor varies between the sites, with values ranging from 1.8 to 5.6. This suggests that site specific factors such as water depth, local metocean conditions and local sediment properties could all influence how the turbidity varies through the water column. For future monitoring programs it is also important to consider instrument accuracy when determining the surface turbidity intensity threshold which should be adopted for the adaptive management.

Table 7. Benthic and surface turbidity intensity thresholds and resultant exceedance durations for the entire pre-, during and post-dredging period (03/03/2019 to 30/05/2019).

Location	Benthic Turbidity		Surface Turbidity		Surface to Benthic Scaling Factor
	Intensity (NTU)	Total Duration (hrs)	Intensity (NTU)	Total Duration (hrs)	
Slade Islet	43	172	7.7	169	5.6
Round Top Island	11	278	6	279	1.8
Victor Island	32	10	12	11	2.7
Freshwater Point	104	11	33	11	3.2

6.2. Benthic Turbidity Thresholds Update

Analysis of ambient benthic turbidity data collected between July 2014 and July 2017 informed the benthic turbidity intensity thresholds adopted for the adaptive management of the 2019 maintenance dredging program (RHDHV, 2018). Following completion of the 2019 maintenance dredging program there is an additional two years of measured turbidity data available, extending the ambient benthic turbidity data to July 2019 and the total duration available from three years to five years.

Additional analysis of the benthic turbidity data at the four adaptive monitoring sites has been undertaken using all five years of available data. The data were quality checked and any erroneous data were removed, as a result it is possible that the data included in the analysis for the July 2014 to July 2017 period are not identical to the data used in the previous analysis undertaken by RHDHV (2018).

The analysis undertaken has excluded turbidity data from any periods where the natural turbidity resulted in measurable impacts to any sensitive receptors. As a result, turbidity data from during and following TC Debbie were excluded from the analysis as this event resulted in an average reduction in coral cover at Round Top Island, Slade Islet and Victor Island of 27% (RHDHV, 2018). The model validation concluded that the turbidity over the 2019 maintenance dredging program was predominantly natural, with an increase in the duration the benthic threshold was exceeded of less than 3% (PCS, 2019d). As a result, the period of the 2019 maintenance dredging program has been included in this analysis.

A comparison between the turbidity percentiles based on three years of data and five years of data is shown in Table 8. The table shows that although the percentiles are similar at Slade Islet, Round Top Island and Victor Island, the longer duration of data has resulted in a slight reduction in turbidity. At Freshwater Point the longer duration of data resulted in a larger reduction in the turbidity statistics, with the 90th, 95th and 99th percentiles being reduced by approximately a third.

Table 8. Comparison between benthic turbidity percentiles based on three and five years of data.

Site	Turbidity Statistic (NTU)					Data Duration (days)
	Median	80th	90th	95th	99th	
Previous Analysis (July 2014 to July 2017)						
Slade Islet	3.8	19.3	35.4	55.5	173.6	953
Round Top Island	0.9	3.9	9.2	15.3	38.0	802
Victor Island	3.4	14.0	27.7	45.5	142.7	957
Freshwater Point	4.4	26.6	60.8	112.0	272.9	973
Updated Analysis (July 2014 to July 2019)						
Slade Islet	2.6	17.0	32.9	50.7	130.9	1247
Round Top Island	0.8	3.3	7.4	12.8	33.8	1058
Victor Island	3.0	13.7	27.0	42.2	110.9	1408
Freshwater Point	3.9	22.3	44.3	72.9	174.0	1498

The benthic turbidity intensity thresholds defined in the ET report were developed based on the turbidity percentile at Round Top Island that was equal to the GBRMPA water quality guideline value of 15 mg/l (RHDHV, 2018). The turbidity intensity threshold of 15 mg/l (or 11 NTU) at Round Top Island was equivalent to the 92nd percentile benthic turbidity in the wet season and the 95th percentile benthic turbidity in the dry season.

With the additional two years of benthic turbidity data, the 15 mg/l (or 11 NTU) intensity threshold at Round Top Island is now equivalent to the 91st percentile benthic turbidity in the wet season and the 96th percentile benthic turbidity in the dry season. These percentiles have subsequently been used to determine the benthic turbidity intensity thresholds at the other three adaptive monitoring sites. Based on these updated benthic turbidity intensity thresholds, updated average, 90th percentile and maximum exceedance durations were calculated for the four adaptive monitoring sites based on 20 and 40 day periods. The previous benthic turbidity intensity and duration thresholds are shown in Table 9 and Table 11 and the updated benthic thresholds incorporating the additional two years of data are shown in Table 10 and Table 12. The updated benthic turbidity intensity thresholds are generally similar to the previous thresholds, with the largest change being at Freshwater Point where the threshold has reduced by approximately 30%. The updated analysis has also shown the potential for higher maximum duration exceedances at Freshwater Point with more than a 100 hour duration increase for both the wet and dry seasons over the 40 day period.

There were no deviations from the ET report during the 2019 maintenance dredging program. As part of this report the Intensity-Frequency-Duration (IFD) values have been updated based on an additional two-years (now five years in total) of ambient water quality data. It is recommended that these IFD values are updated again prior to the next maintenance dredging program at the Port of Hay Point.

Table 9. Previous benthic SSC/NTU intensity and duration thresholds based on three years of data and a 20 day period (RHDHV, 2018).

Site	Intensity (mg/L)	Intensity (NTU)	Average Duration (hrs)	90th Percentile Duration (hrs)	Maximum Duration (hrs)
Wet Season (92nd percentile data)					
Round Top Island	15	11	38	74	265
Freshwater Point	83	104	38	87	223
Victor Island	47	32	38	129	232
Slade Islet	52	43	38	15	189
Dry Season (95th percentile data)					
Round Top Island	15	11	24	58	109
Freshwater Point	38	48	24	59	87
Victor Island	49	34	24	62	102
Slade Islet	37	31	24	80	106

Table 10. Updated benthic turbidity intensity and duration thresholds based on five years of data and a 20 day period.

Site	Intensity (NTU)	Average Duration (hrs)	90th Percentile Duration (hrs)	Maximum Duration (hrs)
Wet Season (91st percentile data)				
Round Top Island	11	43	144	275
Freshwater Point	70	43	122	279
Victor Island	41	43	146	231
Slade Islet	50	43	124	228
Dry Season (96th percentile data)				
Round Top Island	11	19	69	113
Freshwater Point	46	19	61	289
Victor Island	26	19	75	113
Slade Islet	32	19	76	97

Table 11. Previous benthic SSC/NTU intensity and duration thresholds based on three years of data and a 40 day period (RHDHV, 2018).

Site	Intensity (mg/L)	Intensity (NTU)	Average Duration (hrs)	90th Percentile Duration (hrs)	Maximum Duration (hrs)
Wet Season (92nd percentile data)					
Round Top Island	15	11	77	164	300
Freshwater Point	83	104	77	166	333
Victor Island	47	32	77	241	291
Slade Islet	52	43	77	194	278
Dry Season (95th percentile data)					
Round Top Island	15	11	48	82	115
Freshwater Point	38	48	48	80	145
Victor Island	49	34	48	94	150
Slade Islet	37	31	48	98	197

Table 12. Updated benthic turbidity intensity and duration thresholds based on five years of data and a 40 day period.

Site	Intensity (NTU)	Average Duration (hrs)	90th Percentile Duration (hrs)	Maximum Duration (hrs)
Wet Season (91st percentile data)				
Round Top Island	11	86	173	311
Freshwater Point	70	86	171	438
Victor Island	41	86	214	357
Slade Islet	50	86	157	302
Dry Season (96th percentile data)				
Round Top Island	11	38	81	119
Freshwater Point	46	38	89	294
Victor Island	26	38	84	203
Slade Islet	32	38	80	176

7. Summary

This report has presented a final analysis and interpretation of the turbidity data measured as part of the Port of Hay Point 2019 maintenance dredging program. The report has reviewed whether the environmental monitoring undertaken as part of the maintenance dredging program has been implemented in the manner stated in the Management Plans. In addition, based on the monitoring undertaken as part of the 2019 program the report provides recommendations for updates to the monitoring requirements for future dredging programs.

A summary of the key findings of the assessment are provided below:

- in general, the environmental monitoring undertaken as part of the Port of Hay Point 2019 maintenance dredging program has been implemented in the manner stated in the Management Plans;
- the adaptive monitoring and resultant adaptive management measures adopted were in accordance with the Management Plans. During the maintenance dredging program the turbidity at Round Top Island exceeded the 90th percentile duration exceedance, with the site entering into management zone C, respond. The subsequent investigation was in accordance with the Management Plans and despite this concluding that the elevated turbidity was due to natural conditions, adaptive management measures were implemented to ensure a precautionary approach was adopted;
- based on the monitoring undertaken as part of the 2019 maintenance dredging program a number of recommendations have been provided to update the requirements for the impact and adaptive monitoring requirements for future programs; and
- additional analysis of turbidity data was undertaken to ensure the data collected as part of the 2019 maintenance dredging program and as part of the ongoing ambient monitoring are incorporated to allow continual improvement of the procedures adopted to manage maintenance dredging. Based on the benthic and surface turbidity data collected during the maintenance dredging program updated surface turbidity intensity thresholds have been developed. In addition, the benthic turbidity intensity and duration thresholds have also been updated based on the additional two years of ambient monitoring turbidity data available.

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