Port of **Mackay**

Environmental Thresholds Report

Port of Mackay: Sustainable Sediment Management Assessment

Environmental Thresholds

Report No. P033_R01v02

Technical Report
August 2021

PORT & COASTAL SOLUTIONS

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North Queensland Bulk Ports Corporation Ltd

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CONTENTS

FIGURES

TABLES

Executive Summary

North Queensland Bulk Ports Corporation (NQBP) commissioned Port and Coastal Solutions (PCS) to undertake an assessment into ambient water quality conditions and environmental thresholds at the Port of Mackay. The aim of this assessment was to better understand the natural water quality and deposition conditions and to relate these to published environmental thresholds to define relevant, site specific thresholds, which can be used to inform the management of maintenance dredging activities at the Port of Mackay.

Based on a review of information in the literature and an analysis of measured data, relevant ecological thresholds have been defined. The data analysis applied an intensity, duration and frequency (IDF) approach to define the water quality and deposition conditions and to enable the recommendation of appropriate water quality triggers that can be considered for use in future adaptive monitoring.

The analysis was undertaken using 7 years of measured data around the coastal waters in the Mackay and Hay Point region. The analysis showed that the local metocean conditions control the turbidity which in turn means that they also have a strong influence on the benthic photosynthetically active radiation (PAR) and sediment deposition. The metocean conditions vary seasonally, with the potential for larger waves and stronger winds in the wet season, which also results in seasonal variability in the turbidity, benthic PAR and deposition.

Based on monitoring and numerical modelling of the 2020 Port of Mackay maintenance dredging program, it was noted that the only monitoring site where measurable elevated turbidity due to maintenance dredging at the Port of Mackay and placement at the Mackay dredge material placement area (DMPA) was at Slade Islet. The potential for elevated turbidity at this site was due to elevated turbidity occurring within Mackay Harbour as a result of the dredge activity and then during the ebb stage of the tide the water from Mackay Harbour with elevated turbidity was exported from the Harbour and transported to the north by the northerly ebb tidal currents. Based on this the site at Slade Islet has been selected as a potential trigger monitoring site and the site at Round Top Island (as this is the next closest to the Port of Mackay) has been selected as a potential control monitoring site if adaptive management is required during dredging at the Port.

Based on information regarding relevant ecological thresholds for coral and seagrass in the Mackay region along with the analysis of the measured water quality and deposition data, it was concluded that turbidity was the most suitable parameter for monitoring in real-time as part of any future adaptive management required. However, it was also recommended that monitoring of both benthic PAR and deposition continues to better understand the relationship between these parameters and the receptors present in the region.

Analysis of the measured turbidity data indicated that a single turbidity intensity threshold value across all sites and both seasons (wet and dry) would not be applicable as would not represent the spatial and temporal variations in turbidity which occur in the region. Percentiles from the turbidity data were adopted as these enabled a comparable interpretation of turbidity at the different sites and allowed for the different conditions during the two seasons. Based on the results from the percentile analysis and the relevant turbidity thresholds published in the literature, the 91st and 97th percentile turbidity was adopted for the wet and dry seasons respectively. As these thresholds are only naturally exceeded for 9% and 3% of the time, they can be considered to be representative of a threshold for short duration acute impacts due to high turbidity, as opposed to longer duration chronic impacts due to prolonged periods of lower turbidity.

The IDF analysis was applied for periods of 6 days, 12 days and 20 days to account for a potential range of maintenance dredge program durations and so the results could be directly compared to previous analysis at the Port of Hay Point (for which a 20 day duration was adopted). The results from the analysis are shown in Table E1 to Table E3 and define the

natural conditions in terms of both the intensity and duration, and therefore provide the basis for potential trigger limits if adaptive monitoring is required during future maintenance dredging programs. These trigger limits will be further tested using results from the dredge plume modelling being undertaken as part of the Port of Mackay SSM Project.

Table E1. Suggested SSC/NTUe intensity and duration triggers at the two water quality monitoring sites around the Port of Mackay, based on a 6 day period.

Site	Intensity (mg/l)	Intensity (NTUe)	Average Duration (hours)	90th Percentile Duration (hours)	Maximum Duration (hours)
Wet Season (91st percentile data)					
Round Top Island	15	11	3	47	153
Slade Islet	53	45	3	46	177
Dry Season (97th percentile data)					
Round Top Island	16	12	2	11	73
Slade Islet	41	34	2	12	93

Table E2. Suggested SSC/NTUe intensity and duration triggers at the two water quality monitoring sites around the Port of Mackay, based on a 12 day period.

Site	Intensity (mg/l)	Intensity (NTUe)	Average Duration (hours)	90th Percentile Duration (hours)	Maximum Duration (hours)
Wet Season (91st percentile data)					
Round Top Island	15	11	26	88	241
Slade Islet	53	45	26	87	228
Dry Season (97th percentile data)					
Round Top Island	16	12	9	29	99
Slade Islet	41	34	9	33	95

Table E3. Suggested SSC/NTUe intensity and duration triggers at the two water quality monitoring sites around the Port of Mackay, based on a 20 day period.

Site	Intensity (mg/l)	Intensity (NTUe)	Average Duration (hours)	90th Percentile Duration (hours)	Maximum Duration (hours)
Wet Season (91st percentile data)					
Round Top Island	15	11	43	138	298
Slade Islet	53	45	43	120	248
Dry Season (97th percentile data)					
Round Top Island	16	12	14	51	103
Slade Islet	41	34	14	45	98

1. Introduction

North Queensland Bulk Ports Corporation (NQBP) commissioned Port and Coastal Solutions (PCS) to undertake a series of studies as part of NQBP's long-term Sustainable Sediment Management (SSM) assessments at the Port of Mackay. The scope of work for the studies being undertaken by PCS are as follows:

- Environmental Thresholds Analysis: the turbidity, deposition and benthic photosynthetically active radiation (PAR) data collected as part of the ambient water quality monitoring at the Port of Mackay and adjacent Port of Hay Point will be analysed to understand the natural variability of these parameters in the environment. Based on this and information available from the literature, relevant thresholds (using an intensity, duration and frequency approach) will be defined for the long-term monitoring sites closest to the Port of Mackay;
- Avoid and Reduce Assessment Update: the aim of this component of the work is to update the necessary sections of the previous Avoid and Reduce assessment so that it is up to date and corresponds with the other information supporting the Long Term Dredge Management Plan;
- Sediment transport and dredge plume modelling: the aim of this study is to undertake natural sediment transport and dredge plume modelling specific to the Port of Mackay SSM project to better understand potential impacts from dredging. It is also possible that the simulation of a number of additional plume modelling scenarios (e.g. reclamation failure, onshore pond tailwater discharge, alternative offshore placement site etc) may be required to support the Comparative Analysis component of the SSM, as to date these have been based on the modelling results from the Port of Hay Point SSM; and
- Resuspension Assessment: the aim of this study is to estimate the mass of sediment naturally resuspended in the Port of Mackay region and to develop a relationship between the natural SSC and the wind speed and compare this to the SSC resulting from maintenance dredging.

This report details the environmental thresholds analysis for the Port of Mackay. The overall aims of this assessment are to:

- review and summarise knowledge on relevant environmental thresholds at the Port of Mackay based on published literature;
- undertake statistical analysis of observational data using the intensity, duration and frequency (IDF) approach to define the water quality conditions at the Port of Mackay; and
- recommend appropriate water quality triggers that can be considered for use in adaptive monitoring and management plans.

1.1. Project Background

Regular but infrequent maintenance dredging has been required at the Port of Mackay to ensure there is sufficient depth for vessels to safely travel to and from the berths. Since 2010 maintenance dredging within the Port has been undertaken twice, with approximately 100,000 m^3 of sediment dredging in 2013 and approximately 120,000 m^3 of sediment dredged in 2020. The dredged sediment has been relocated to the approved dredge material placement area (DMPA) located approximately 3.5 km offshore and to the east north-east of Mackay Harbour (Figure 1).

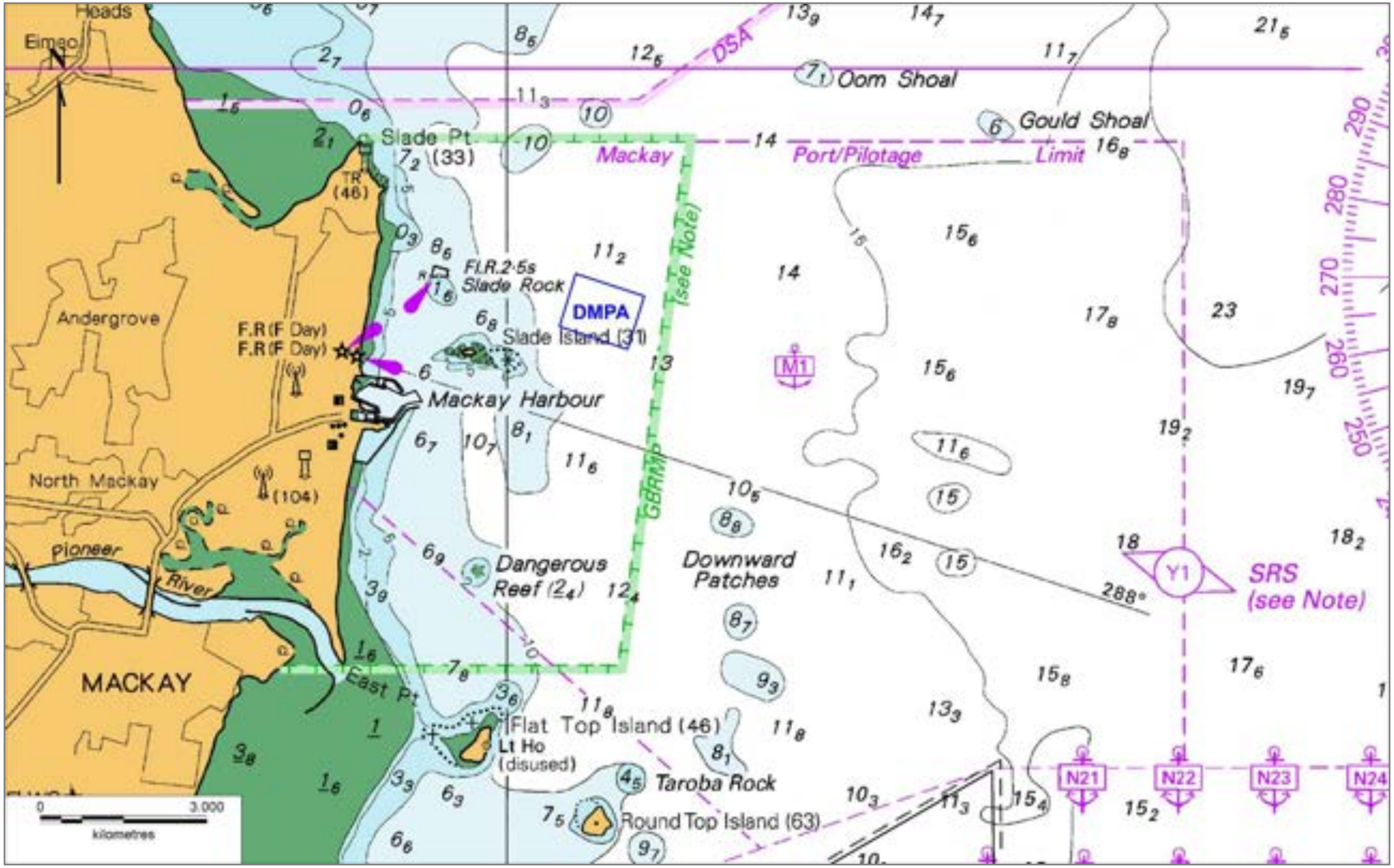


Figure 1. Location of the Port of Mackay DMPA.

In 2016, a Maintenance Dredging Strategy (MDS) was developed for the ports that are situated within the Great Barrier Reef World Heritage Area (GBRWHA) (DTMR, 2016). This MDS (which supports the wider Reef 2015 Plan) provides a framework for the sustainable, leading practise management of maintenance dredging in the GBR (Figure 2). It is a requirement of the MDS that each Port within the GBRWHA develops Long-term Maintenance Dredging Management Plans (LMDMPs). Such LMDMPs are aimed at creating a framework for continual improvement in environmental performance. DTMR have provided guidelines to assist in the development of the LMDMPs (DTMR, 2018). The guidelines note that they should include, among other aspects, the following:

- an understanding of port-specific sedimentation conditions and processes;
- management approaches (including dredge avoidance and reduction); and
- long-term dredging requirements based on sedimentation rates, port safety and port efficiency needs.

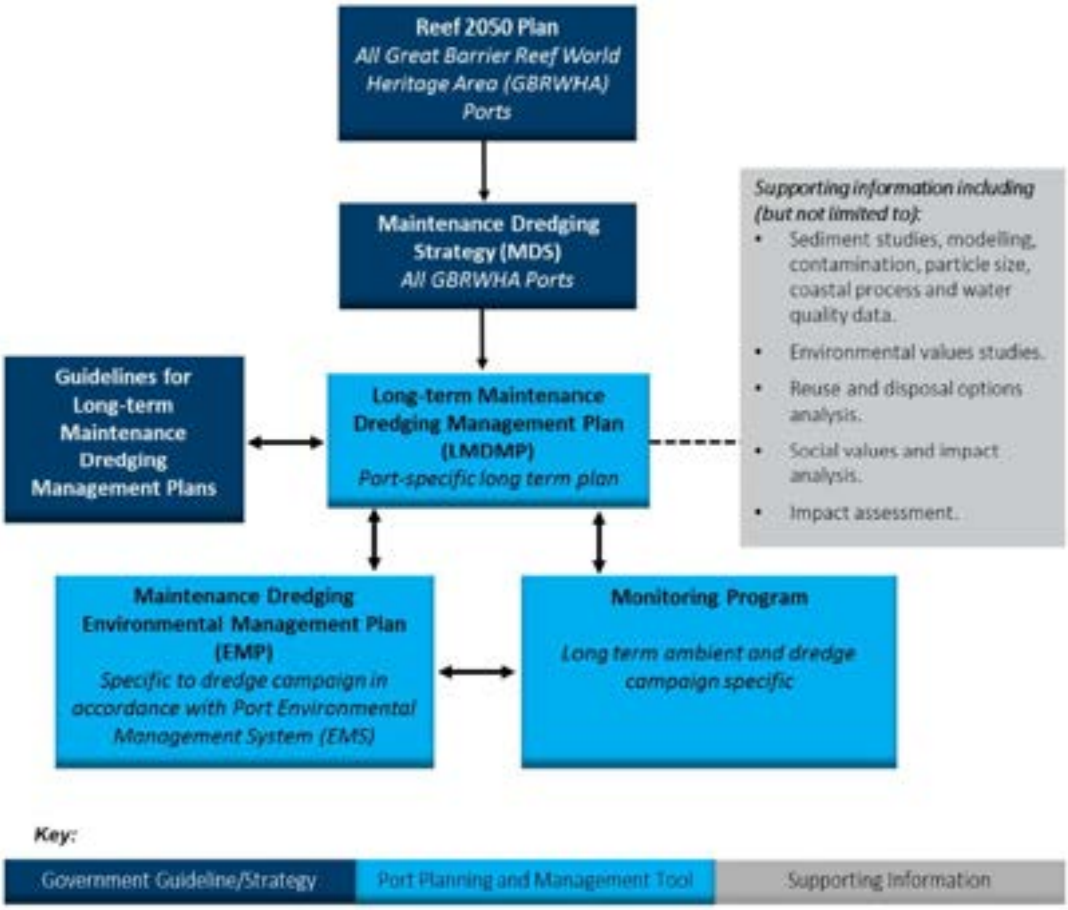


Figure 2. Planning and implementation mechanisms for maintenance dredging of Queensland Ports (DTMR, 2018).

The requirement to investigate whether sedimentation at ports can be managed to avoid or reduce the need for maintenance dredging is derived from the London Protocol, which forms the basis for Australia's Sea Dumping Act 1981. Based on this, the environmental regulators are particularly focused on the following questions:

1. Can sedimentation be managed at the Port to avoid or reduce the need for maintenance dredging?
   – Where do sediments accumulate in the Port and at what volumes and rates?

- What causes sedimentation in the Port?
- Does sedimentation at the Port pose a risk to port operations and safety?
- Why does the Port need to undertake maintenance dredging?

2. If maintenance dredging must occur, has there been a comprehensive assessment of whether the material can be beneficially reused?

3. If no beneficial reuse options are available, what would be the most suitable and feasible disposal or placement options?

4. Has a comparative analysis of options been undertaken, that considers human health, social values, environmental impacts and disproportionate costs?

To answer these questions, NQBP developed a framework as part of the SSM assessment at the Port of Hay Point. This framework was subsequently used to inform the framework that has been adopted at the Port of Mackay as well as the framework developed for the MDS, demonstrating that NQBP have been proactive at developing sound long-term maintenance dredging strategies. The findings from all the SSM studies being undertaken will feed into the development of a new LMDMP at the Port of Mackay.

1.2. Port of Mackay

NQBP manages the Port of Mackay which is located on the central Queensland coast near the city of Mackay. The Port is located within Mackay Harbour which is positioned on Harbour Beach, approximately 4 km to the north of the mouth of the Pioneer River. The Harbour is enclosed by rock breakwaters with a 180 m wide entrance channel (Figure 3).

The key export trade through the Port is sugar (raw and refined). Fuel for agriculture and the mining industry is the dominant import, although the Port also provides for the import of a diverse range of other products. In the 2019-20 financial year the Port had a total throughput of approximately 3.2 million tonnes.

The Port of Mackay consists of a swing basin, a siltation trench and four berths (Figure 3) with varying design depths as follows:

- Swing Basin: area = 352,500 m^2, design depth = -8.6 m LAT;
- Siltation Trench: area = 29,700 m^2, design depth = -10.0 m LAT;
- Berth 1: area = 7,560 m^2, design depth = -10.6 m LAT;
- Berth 3: area = 9,720 m^2, design depth = -13.5 m LAT;
- Berth 4: area = 5,400 m^2, design depth = -10.6 m LAT; and
- Berth 5: area = 10,800 m^2, design depth = -12.5 m LAT.

Since 2004 the Trailing Suction Hopper Dredge (TSHD) *Brisbane* has undertaken the majority of the maintenance dredging at the Port of Mackay. Between 2004 and 2021 the dredge has undertaken four programs, in 2004, 2007, 2013 and 2020. Prior to 2004 the Port's grab bucket dredge *James Pearce* undertook the maintenance dredging, with an average annual volume of 40,000 m^3 dredged. Between 2004 and 2012 the *James Pearce* continued to undertake infrequent dredging of sedimentation in the berth pockets and the removal of high spots within the swing basin. The *James Pearce* was decommissioned in 2013 and the only maintenance dredging undertaken since then has been by the *TSHD Brisbane*. Details of the historical maintenance dredging undertaken at the Port since 2000 is detailed in Table 1.

In addition to maintenance dredging, bed levelling and drag barring has been undertaken at the Port to help manage the sedimentation in the berths and swing basin and maintain design depths. Historical drag barring was undertaken in 2010, 2011, 2016, 2017 and 2018 while bed levelling was undertaken along with the maintenance dredging in 2013 and 2020. Typically, drag barring programs have been up to a week in duration and have been focused in the berths. Drag barring of the berths has been found to be most effective for short duration programs (e.g. 1 day), after this the loosely consolidated surface sediment in the berth fluidises and cannot be dragged up the batter slopes or resuspended.

Table 1. Historic in-situ dredging volumes at the Port of Mackay (PCS, 2021a).

Year	Grab *James Pearce* (m^3)	TSHD *Brisbane* (m^3)	Drag Barring
2000	47,872	-	
2001	44,200	-	
2002	44,098	-	
2003	46,736	-	
2004	4,760	118,000	
2005	-	-	
2006	520	-	
2007	-	106,000	
2008	3,406	-	
2009	-	-	
2010	-	-	✓
2011	-	-	✓
2012	-	-	
2013	-	98,381	
2014	-	-	
2015	-	-	
2016	-	-	✓
2017	-	-	✓
2018	-	-	✓
2019	-	-	
2020	-	122,338	

Previous investigations by PCS (2021a) found that the majority of the sedimentation which occurs within the Port of Mackay is due to fine-grained sediment being suspended by wave action offshore of the Harbour and then being imported into the Harbour in suspension during the flood stage of the tide. Tropical Cyclones were found to have the potential to result in increased sedimentation in the Port due to their potential to result in increased wave activity and therefore increased resuspension of sediment offshore of the Harbour.

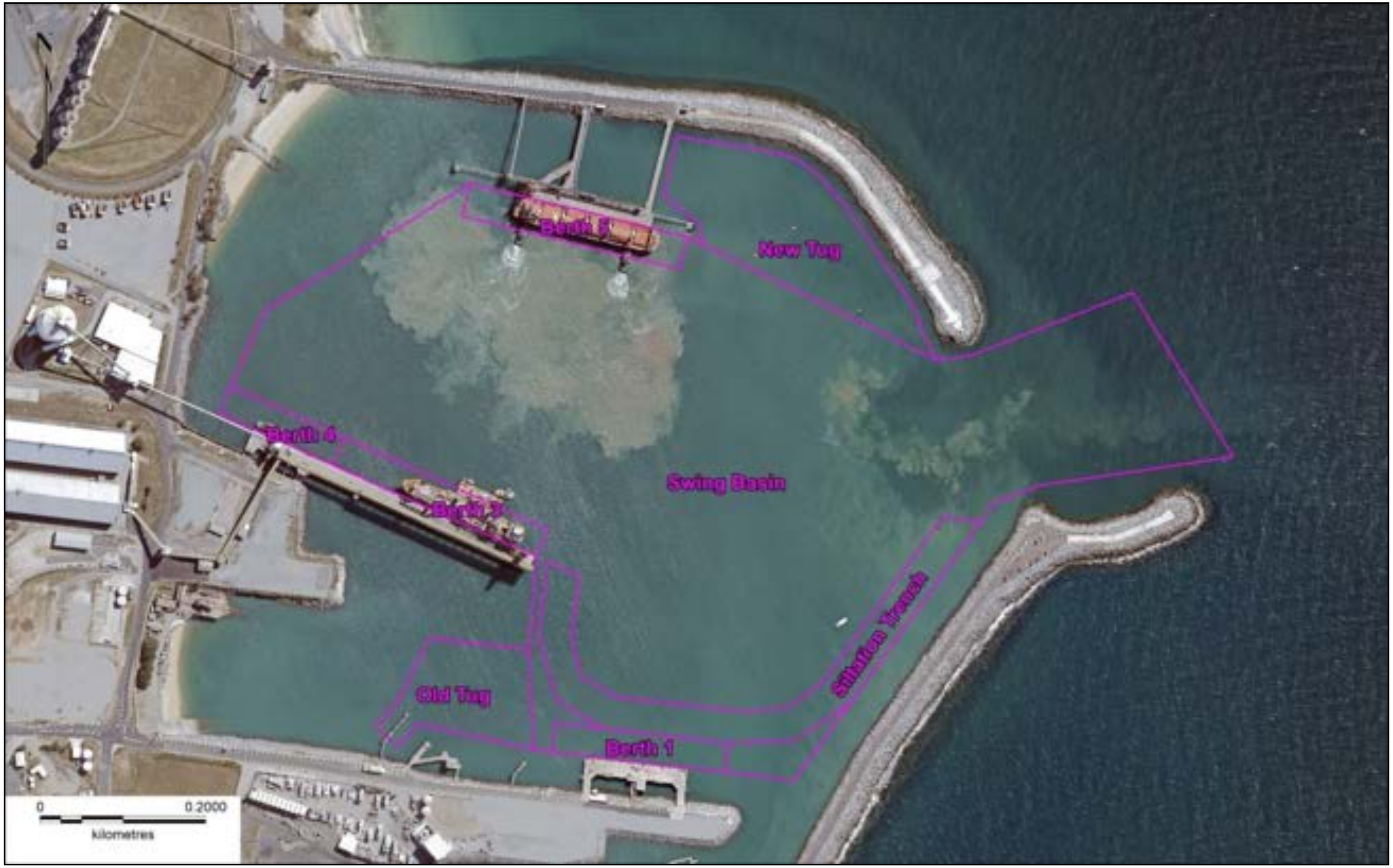


Figure 3. Dredged areas within the Port of Mackay.

1.3. Report Structure

The report herein is set out as follows:

- an introduction to the study is provided in **Section 1**;
- an overview of the measured water quality data and the data processing and analysis methods are provided in **Section 2**;
- the literature review on environmental thresholds and the results of the IDF analysis are presented in **Section 3**; and
- a summary of the key findings of the report are given in **Section 4**.

2. Water Quality Data

2.1. Introduction

To develop suitable water quality triggers, high quality site-specific baseline data are required. Data collected between July 2014 and May 2021 by James Cook University (JCU) were available at multiple sites (although not all sites collected data for the full duration) around the Port of Mackay (and Hay Point) (Figure 4). The ambient marine water quality monitoring program collected baseline water quality measurements using multiparameter instrumentation manufactured by JCU.

The following parameters were measured and have been analysed as part of this assessment:

- near bed turbidity;
- benthic light availability/ Photosynthetically Active Radiation (PAR); and
- deposition rates.

Additional information on the instrumentation and the measurements obtained are provided in Waltham *et al.* (2016).

2.2. Data Sources

JCU has been carrying out NQBP's ongoing ambient marine water quality monitoring around the coastal waters of the Port of Mackay and nearby Port of Hay Point since July 2014. As part of the program, water quality sensors were deployed at seven locations (see Figure 4 and Table 1), with each sensor returning data on turbidity, benthic light and deposition at a ten-minute temporal resolution. Two of these measurement locations provide data which can be used to characterise the water quality in the local area of the Port of Mackay (Slade Islet and Round Top Island), while the other locations provide data to characterise the water quality around the Port of Hay Point and at sensitive receptors in the region. The focus of this report is on the data collected at the two sites closest to the Port of Mackay, although some high-level statistic analysis of the data collected at the other sites are included for reference.

Data from 2014 to 2017 was previously quality checked for use in an assessment of environmental thresholds for the Port of Hay Point (Royal HaskoningDHV, 2018), while data from 2017 to 2019 was quality checked for use in an extension to this assessment following the 2019 maintenance dredging at Hay Point (PCS, 2019a). During the initial study it was found that the IDF results differed between sites depending on whether data were captured during TC Debbie. Therefore, to ensure continuity between the sites any data gaps at sites over this period were filled using modelled SSC/turbidity from a numerical model which was calibrated for this event (Royal HaskoningDHV, 2018). The data collected pre July 2019 is based on the dataset (including any modelled values) used by PCS (2019a) for consistency with these earlier studies. The present study extends the period of data analysis to April 2021. A summary of the water quality data sites and periods of data availability is given in Table 1.

The data return for each instrument has been calculated and the results are presented in Table 2 and the periods of data return for turbidity are also shown graphically in Figure 5. The data return for turbidity at individual sites was between 32 and 72% during the wet season (November to April inclusive) and 54 to 78% during the dry season (May to October inclusive). The longest duration dataset is available at Victor Island, with a 72% turbidity data return in the wet season and a 78% data return in the dry season. The data returns at Slade Islet and Round Top Island are lower, with returns of 59% and 69% during the wet and dry seasons at Slade Islet and 47% and 68% during the wet and dry seasons at Round Top Island. Based on these data returns there is a significant amount of data available for site characterisation with 1,583 days of data at Slade Islet and 1,420 days of data at Round Top Island. The data returns for bPAR and deposition also varied with site, with the data return for bPAR generally slightly higher than the data return for turbidity, while the data return for deposition was generally slightly lower.

Table 1. Summary of water quality data used in this study.

Site Name	TropWater Site ID	Latitude	Longitude	Period
Freshwater Point	AMB1	-21.42	149.34	Jul 2014 to Mar 2021
Hay Point/Reef	AMB2	-21.26	149.30	Jul 2014 to Sep 2020
Round Top Island	AMB3	-21.17	149.26	Jul 2014 to Apr 2021
Slade Islet	AMB5	-21.09	149.24	Jul 2014 to Mar 2021
Spoil Grounds	AMB8	-21.18	149.30	Jul 2015 to Jan 2021
Victor Island	AMB10	-21.32	149.32	Jul 2014 to Mar 2021
Keswick Island	AMB12	-20.93	149.42	Oct 2014 to Sep 2020

Table 2. Summary of data return at water quality monitoring stations.

Site ID	Turbidity				bPAR		Deposition Rates	
	Days of data		Percentage return*		Percentage return		Percentage return	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
AMB1	880	933	70	76	82	83	64	63
AMB2	401	764	32	62	31	62	38	54
AMB3	590	830	47	68	61	70	55	69
AMB5	743	840	59	69	70	78	59	67
AMB8	632	660	50	54	57	56	45	54
AMB10	901	952	72	78	80	77	67	66
AMB12	856	700	68	57	65	68	64	56

* Percentage return quantified as the percentage of time readings were obtained between 5 July 2014 to 13 April 2021, which is 1,251 wet season days and 1,223 dry season days.

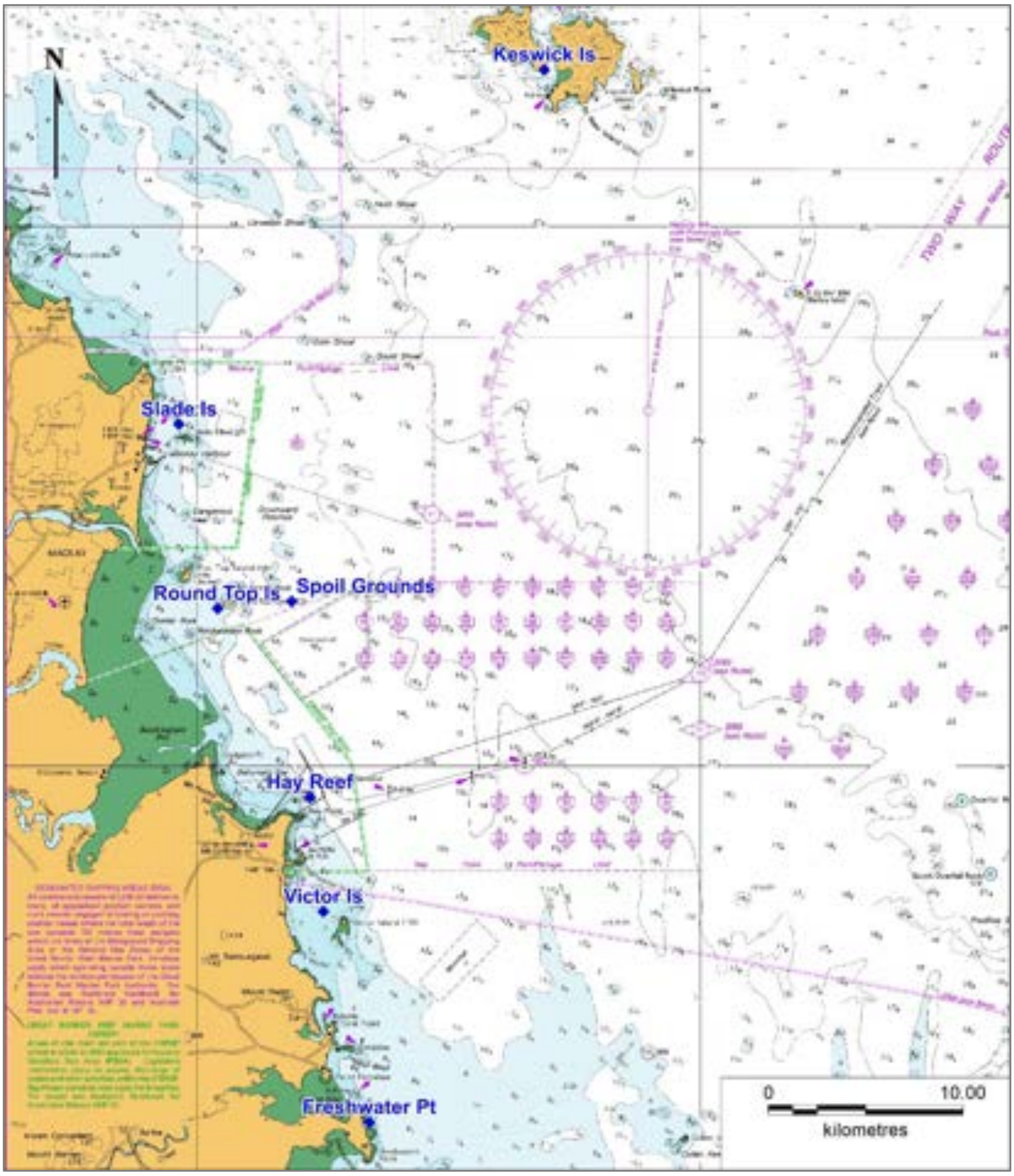


Figure 4. Location map of the water quality monitoring sites.

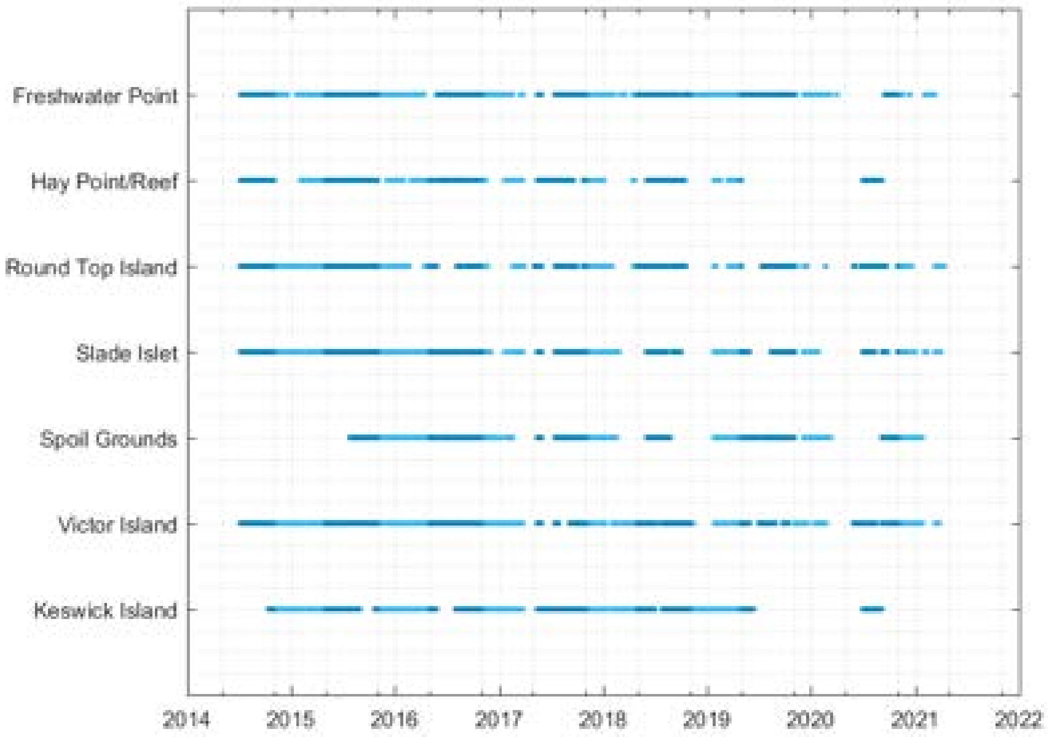


Figure 5. **Periods of data return for Turbidity (wet season shown as lighter colour, dry season as darker colour).**

2.3. Data Processing

The JCU turbidity loggers use 180 degree backscatter to measure turbidity. The international turbidity standard ISO7027 defines turbidity readings in Nephelometric Turbidity Unit (NTU) only for 90 degree scatter. However, the JCU instrumentation uses 180 degree backscatter as it allows for much more effective cleaning (critical to avoid issues with bio-fouling during long deployment periods). Because particle size influences the angular scattering functions of incident light (Ludwig and Hanes 1990; Conner and De Visser 1992; Wolanski *et al.*, 1994; Bunt *et al.*, 1999) instruments using different scattering angles can give different measurements of turbidity (in NTU). In acknowledgement of this fact, the readings obtained in this study are referred to in units of NTU equivalent (NTUe).

Methods used for real-time monitoring during dredging activity may differ from the instrumentation deployed by JCU and so it is important that differences in data analysed to develop thresholds and triggers and real-time monitoring data are understood and accounted for. During the 2019 maintenance dredging program at the Port of Hay Point two different types of benthic turbidity logger were deployed at the same benthic sites (180 degree and 90 degree backscatter loggers). The data measured by the two different loggers were shown to have similar temporal patterns and turbidity magnitudes, with the 180 degree backscatter loggers measuring slightly high peaks in turbidity compared to the 90 degree backscatter loggers (PCS, 2019b).

The turbidity data were processed using an hourly rolling average (data were captured at a temporal resolution of 10 minutes) to smooth the data and remove any spikes/noise which can occur when measuring turbidity. To ensure that the management triggers are representative of the natural conditions that sensitive receptors can tolerate, the following periods were removed from the data and excluded from the analysis:

- periods when natural conditions resulted in impacts to sensitive receptors. Waltham *et al.* (2017) indicated that conditions during TC Debbie were intolerable to the local flora and fauna and as such the turbidity data collected during the period 26h March 2017 to 15th May 2017 inclusive were removed from the dataset at all sites. Coral monitoring after TC Debbie indicated a decrease in hard coral cover at Round Top Island, Victor Islet and Slade Islet (Ayling *et al.*, 2019). While other TC's occurred during the data collection period including TC Marcia in February 2016, TC Iris in April 2018, TC Owen in December 2018 and TC Penny in January 2019, monitoring reports on the water quality by JCU for these years did not note the occurrence of intolerable conditions resulting from these events and as such no data have been removed for these periods; and

- periods when conditions were modified by anthropogenic activities such as maintenance dredging. Only two periods of dredging have occurred locally in the vicinity of the monitoring sites since 2014:
  - Port of Mackay 2020 maintenance dredge program (13th December 2020 to 24th December 2020). Data collected at Slade Islet were removed for the period of the dredging as monitoring indicated that dredging could have resulted in some increase in turbidity (PCS, 2021b). Data were not removed following the completion of the dredge, since the turbidity analysis indicated that the turbidity at Slade Islet was only potentially affected by the dredging during the initial few days of the dredging which coincided with spring tides; and
  - Port of Hay Point 2019 maintenance dredge program (31st March 2019 to 2nd May 2019). No data were removed for this period since it was concluded that the turbidity variations occurring during the dredge program were predominantly natural (PCS, 2019c).

The data returns presented in Table 2 and Figure 5 already have these data removed.

The IDF analysis has been performed directly on the turbidity data measured in NTUe. To enable comparison of management triggers relative to published thresholds which are typically given in Suspended Sediment Concentration (SSC), conversion factors have been applied. The conversion factors vary between the sites and were calculated based on concurrent in-situ water sampling and turbidity measurements by JCU at each monitoring site. The conversions applicable at each site are provided in Table 3.

Table 3. Conversion factors between turbidity and SSC at each site.

Site Name	Conversion Factor (NTUe to mg/l)
Freshwater Point	0.8
Hay Point/Reef	1.24
Round Top Island	**1.32**
Slade Islet	**1.20**
Spoil Grounds	2.03
Victor Island	1.46
Keswick Island	1.49

The relationship between NTUe and SSC can vary and change during dredging operations due to the different sediment properties of the suspended sediment resulting from the dredging activities (Thackston and Palermo, 2000). In the case of maintenance dredging, when the sediment to be removed is natural sediment which has been recently deposited in the dredged areas, the properties of the sediment in suspension due to dredging compared to the sediment naturally in suspension is not expected to differ significantly. As such, the NTUe to SSC relationship is not expected to change significantly during periods of maintenance dredging.

Light intensity was measured at the monitoring stations at ten minute intervals using a PAR sensor, which was positioned on the horizontal surface of the water quality logging instrument. The instantaneous values recorded at each ten minute interval have been multiplied by 600 and summed for each day to provide total daily PAR in mol photons/m^2/day. The IDF analysis was performed on these derived daily PAR values.

As with turbidity, PAR data collected during TC Debbie were removed from the dataset prior to analysis. Daily light levels were affected for a much longer period than turbidity data, being close to zero for around a month during and after TC Debbie at all sites except Keswick Island, which was unaffected. Benthic PAR data collected during the period 25th March 2017 to 30th April 2017 were therefore removed from the dataset at all sites except Keswick Island. PAR data collected during the maintenance dredge programs at the Port of Hay Point and the Port of Makay were also removed from the dataset (at the sites closest to the dredge locations) prior to analysis.

Sediment deposition was measured using optical backscatter sensors which determine deposition based on the backscatter of light detected by the sensor (Waltham *et al.*, 2016). During deployment, the sensor is wiped clean every 2 hours to prevent the deposition from becoming too thick for the sensor to measure. The instruments can therefore accurately measure deposition over time, but they can only measure erosion of any sediment which has been deposited over the previous 2 hours. For example, a period of consistent erosion would only be shown as zero deposition by the sensor. As such, the instruments are not able to define the net deposition/erosion which has occurred over time, but can define the gross deposition over time.

Deposition data were provided as a measurement of deposited sediment in mg/cm^2. The deposition rate was calculated over the two hour interval between sensor wipes and averaged over the day to derive daily deposition rates in mg/cm^2/day. Data collected during TC Debbie (at all sites except Keswick Island) and coinciding with maintenance dredge programs (at the sites closest to the dredge locations) were removed and the IDF analysis was applied to the average daily deposition rates.

2.4. IDF Analysis Method

The IDF analysis has the following aims:

- to describe the water quality of the natural environment and its temporal and spatial variability in and around the Port of Mackay;
- to assist in defining relevant thresholds which could be used for adaptive management of future maintenance dredging activities at the Port of Mackay; and
- to assist in defining thresholds that can be adopted for processing plume modelling results for the maintenance dredging activities.

The results from the site-specific IDF analysis can be used to inform the magnitude (intensity) and associated duration of naturally occurring water quality changes and to provide site specific context to the discussion around intensity threshold values from the literature.

Measured data obtained as part of the ambient water quality monitoring program at the Port of Mackay were analysed to calculate intensity (percentiles) of turbidity, daily light and daily deposition rates and the associated duration and frequency of exceedances for the calculated intensities (i.e. IDF analysis).

The IDF analysis calculated the following, using the Fox (2016) approach:

- Calculation of **intensity** percentiles (1st to 99th percentile) for turbidity, daily light and daily deposition;

- Calculation of average **duration** and **frequency** for a range of intensity percentile exceedances; and
- Presentation of a range of percentiles to show natural variability of conditions.

To try and capture the seasonal variability in the metocean and water quality conditions, the IDF analysis was undertaken for two separate periods:

- the wet season (taken to be November to April inclusive); and
- the dry season (taken to be May to October inclusive).

This allowed the water quality conditions resulting from the differing metocean conditions which occur during these two periods to be considered.

The site specific triggers are defined based on the intensity of the water quality parameters and the total cumulative duration that the intensity was exceeded over durations relevant to the maintenance dredging at the Port of Mackay. The frequency of occurrence of events has been undertaken over three different duration periods:

- **6 days**: this is representative of the duration of a typical low volume maintenance dredging program at the Port of Mackay (with a volume of 60,000 m^3);
- **12 days**: this is representative of the duration of a typical high volume maintenance dredging program at the Port of Mackay (with a volume of 120,000 m^3); and
- **20 days**: this duration is approximately representative of the duration of a very large maintenance dredging program at the Port of Mackay with a volume of 200,000 m^3. In addition, this volume is also representative of a 200,000 m^3 maintenance dredging campaign at the Port of Hay Point, which was one of the volumes and dredge durations adopted for the Port of Hay Point thresholds analysis and so allows direct comparison of the results.

The analysis is focussed on the two sites closest to the Port of Mackay, namely Slade Islet and Round Top Island. Analysis of data collected at the other sites is reported in the Port of Hay Point environmental thresholds report (PCS, in prep.).

3. Ecological Thresholds

3.1. Introduction

Ecological thresholds refer to the point at which changes or disturbance in external conditions can cause a rapid change in an organism or habitat, noted as tolerance limits of a particular receptor. When these points of tolerance have been exceeded, potentially irreversible impacts can occur. In the marine environment, where activities such as dredging or disposal can cause changes to water quality parameters, thresholds are generally expressed as concentrations, levels or rates, or calculated as an intensity, duration and frequency over relative periods of time.

Ecological thresholds can be determined for any sensitive receptors present in the environment which could potentially be impacted. Seagrass beds and coral communities are the primary sensitive receptors located in the area surrounding the Port of Mackay.

Coral monitoring at Round Top Island and Slade Islet undertaken as part of an ambient monitoring program for the Ports of Mackay and Hay Point (Ayling *et al.*, 2020) indicated that corals at Round Top Island are dominated by *Turbinaria* corals, with siderastreids, favids and *Montipora* also important, while at Slade Islet *Montipora* corals are dominant.

Rasheed *et al.* (2001) undertook an extensive survey to map seagrass, algae and benthic macro-invertebrate communities in the Port of Mackay port limit area. Three seagrass species (from two families) were found in the survey area including *Halodule uninervis, Halophila ovalis* and *Halophila decipiens* confined to three meadows, two of which were *Halophila decipiens* meadows approximately 7 km and 12 km east of the harbour and a small coastal *Halodule uninervis/ Halophila ovalis* meadow adjacent to the north-western shore of Round Top Island.

To assist in ensuring that ecological thresholds are not exceeded during dredging operations, water quality management triggers can be adopted. Trigger values are typically defined at a precautionary level below ecological thresholds to account for the potential delay between exceedance occurring and response (i.e. implementation of management measures), thus reducing the risk to habitats arising from a degradation of water quality conditions.

Royal HaskoningDHV (RHDHV, 2018) reviewed existing literature to provide an overview of threshold values relevant to the receptors at the Port of Hay Point. Given the proximity of Hay Point to the Port of Mackay the receptors for the two port areas are the same, so this process has not been duplicated here (although a brief summary of the key studies is included for reference). The following review instead focuses on the threshold values applied in previous dredge programs at the Port of Hay Point and any recommendations on how these should be adapted following application.

Following this review, the measured water quality data for the Mackay region has been analysed to assess the relevance of the most up to date recommended threshold values (and how these compare with literature based thresholds). Based on this assessment, recommendations for modified site-specific trigger values have been provided.

3.2. Turbidity Thresholds

The GBRMPA (2010) water quality guidelines specify that an annual mean SSC of less than 15 mg/l would have no effect, while more than 15 mg/l may cause stress to coral communities in the enclosed coastal areas of the Central Coast Region of the Great Barrier Reef Marine Park. These guidelines do not take account of the specific coral species present within the study area and a review by RHDHV (2018) indicated that the adoption of these guidelines in and around the study area is likely to be overly conservative, with natural turbidity regularly exceeding this value. Further, these guidelines do not consider the fact that some short-term exposure to increased SSC could be tolerated. For example, Flores *et* *al.* (2012) indicates that corals (including *Montipora*, which is one of the four dominant species at Round Top Island) are able to withstand moderate levels of turbidity for durations of weeks to months, owing to their ability to access lipid fat reserves.

Erftemeijer *et al.* (2012) developed a species specific response matrix. For the types of coral present in the Mackay area the following thresholds for turbidity (in terms of SSC) are relevant:

- no impacts at a continuous SSC of less than 20 mg/l (equivalent to 15.2 NTUe at Round Top Island and 16.7 NTUe at Slade Islet);
- at a continuous SSC of 20-40 mg/l possible minor sublethal effects could occur;
- at a continuous SSC of 40-100 mg/l possible lethal and major /minor sublethal impacts could occur; and
- at a continuous SSC of more than 100 mg/l lethal (partial mortality) and major lethal (mass mortality) effects could occur.

Given the short duration of dredge activities at the Port of Mackay (for example the 2020 maintenance dredge program lasted 12 days), the risk of longer duration chronic impacts from elevated SSC due to the dredging is low. As such, the adoption of management trigger values for acute impacts, as opposed to chronic impacts, is considered suitable.

Prior to the commencement of the water quality monitoring program in 2014, the water quality trigger[1] values (in NTU) adopted for previous dredging and placement projects at the Port of Hay Point were as follows:

- Port of Hay Point Apron Areas and Departure Path Capital Dredging Project (dredging of 8.6 Mm^3): Trigger values were set at 100 NTU over a continuous period of six hours at two fringing reefs); and
- Hay Point Coal Terminal Expansion Phase 3 (dredging of 260,000 m^3): Trigger value of 110 NTU, 6 hour daily median during daylight hours.

These previous trigger values applied at the Port of Hay Point were developed based on the natural turbidity conditions at Hay Reef. It is important to note that Hay Reef is typically a more turbid site compared to other sensitive receptors in the region such as Round Top Island.

RHDHV (2018) developed a set of water quality threshold values using three years of measured water quality data available at the time. Benthic turbidity intensity thresholds were developed using the turbidity percentile at Round Top Island that was equal to the GBRMPA water quality guideline value of 15 mg/l (equivalent to 11 NTU at this site), which was the 92nd percentile value during the wet season and the 95th percentile during the dry season. The developed threshold values were adopted for adaptive management during the 2019 maintenance dredge program at the Port of Hay Point (PCS, 2019a). However, the adaptive management required real-time monitoring of turbidity which meant that surface loggers had to be adopted and therefore the benthic turbidity intensity thresholds required scaling to represent the surface turbidity. Details of the benthic and surface turbidity thresholds recommended based on all the data collected as part of the Port of Hay Point 2019 maintenance dredging are detailed in Table 4. The table shows that the scaling factors range from 1.8 at Round Top Island to 5.6 at Slade Islet, the large range 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.

[1] For the purposes of this report the term trigger has been adopted to refer to a value adopted for management practices, which when exceeded management measures would be implemented. The term threshold has been adopted to refer to a value which has ecological implications and so when a threshold is exceeded there is a risk of ecological impacts (these can also be used for management practices).

Table 4. Turbidity intensity threshold values used in the 2019 maintenance dredge program at Hay Point developed by RHDHV (2018) for use in the wet season.

Location	Benthic Turbidity Intensity Threshold (NTU)	Surface Turbidity Intensity Threshold (NTU)	Surface to Benthic Scaling Factor
Slade Islet (control)	43	7.7	5.6
Round Top Island (trigger)	11	5.0	1.8
Victor Island (trigger)	32	11.0	2.7
Freshwater Point (control)	104	32.3	3.2

The RHDHV threshold values were reviewed by PCS (2019a) as part of the post dredging assessment of environmental compliance. The exceedance duration above these threshold values was found to be significantly higher at Round Top Island compared to the other three sites for the pre-, during- and post-dredge periods considered, suggesting that the natural turbidity at Round Top Island was high relative to the turbidity intensity threshold compared to the other three sites. The updated analysis indicated that the 15 mg/l intensity threshold value was actually equivalent to the 91st percentile benthic turbidity in the wet season and the 96th percentile benthic turbidity in the dry season. PCS (2019a) subsequently developed an updated set of benthic and surface turbidity threshold values using these updated percentiles, the extended dataset and the scaling factors noted in Table 4 (Table 5).

Table 5. Updated turbidity intensity threshold values for the wet season developed after the 2019 maintenance dredge at Hay Point (PCS, 2019a).

Location	Benthic Turbidity Intensity Threshold (NTU)	Surface Turbidity Intensity Threshold (NTU)
Slade Islet (control)	50	8.9
Round Top Island (trigger)	11	6.1
Victor Island (trigger)	41	15.2
Freshwater Point (control)	70	21.9

3.2.1. Turbidity Local Context

A time series plot of turbidity at the Port of Mackay monitoring locations is shown in Figure 6 for the whole data series. To help identify how turbidity varies with the metocean conditions, the plots are also shown for a one month period in November 2020 in Figure 7. The one month plot shows that over this period the wave conditions are the dominant driver for increased turbidity, but over separate periods with calm wave conditions elevated turbidity can also occur during spring tides.

Turbidity percentiles in NTUe for the monitoring sites around the Port of Mackay and the Port of Hay Point are provided in Table 6, with results presented separately for the wet and dry seasons and for all data. All measured data are included in the analysis, except for the periods noted in Section 2.3 when either environmental impacts to local receptors or anthropogenic changes to turbidity (i.e. dredging) occurred.

Consistent with earlier studies, the results show that the turbidity is generally higher at the nearshore site of Slade Islet (and other nearshore sites), compared to the site at Round Top Island (and Keswick Island, also located offshore). At Slade Islet the 80th percentile turbidity is above the equivalent 15 mg/l threshold during the dry season and as such 15 mg/l is probably too low to be a threshold.

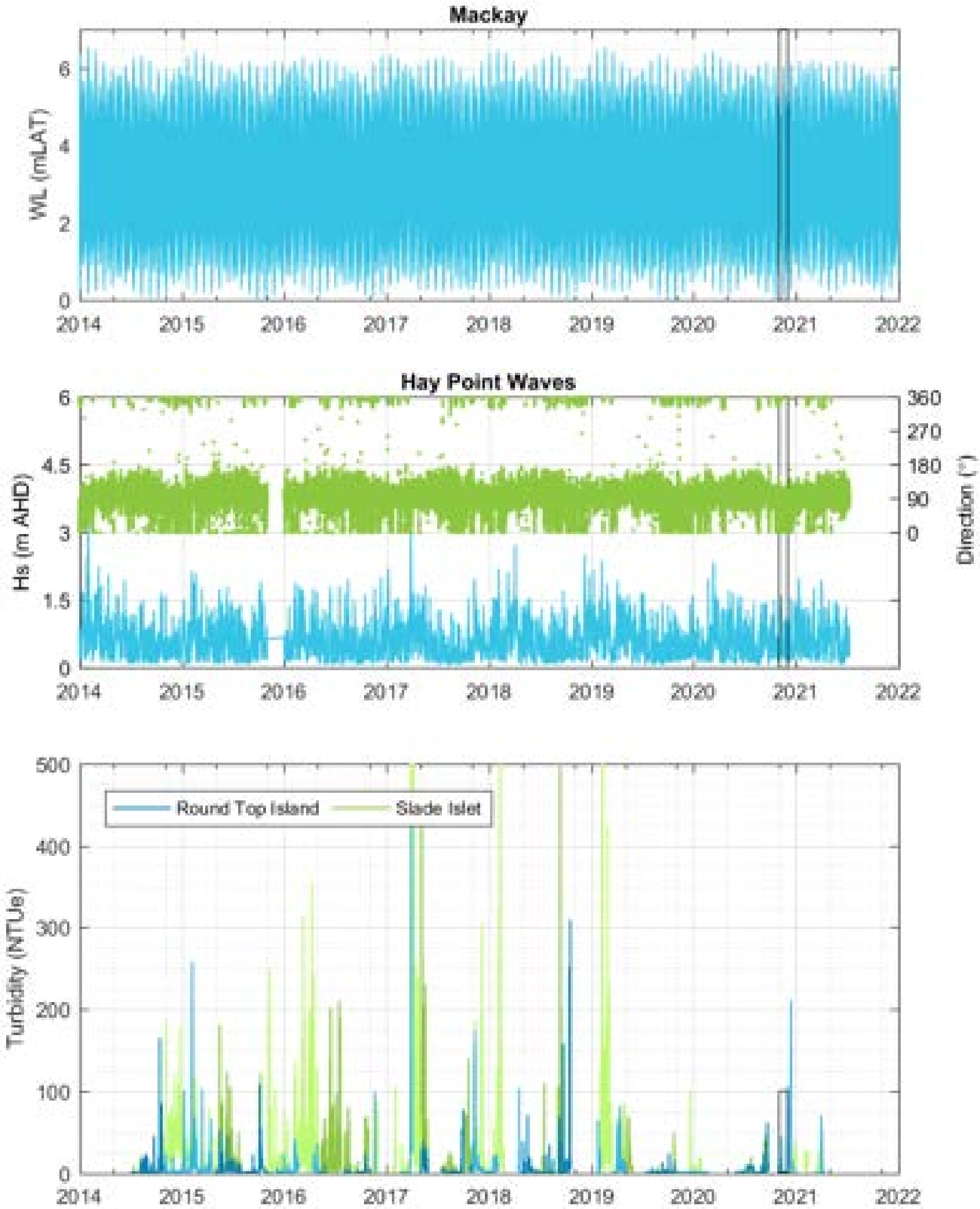
Table 6. Turbidity percentiles for the Ports of Mackay and Hay Point monitoring sites.

Site	Percentile Turbidity Intensity (NTUe)					Data Duration (days)	15 mg/l in NTU
	50th	80th	90th	95th	99th		
Dry Season							
Freshwater Point	2.3	10.4	21.7	37.3	95.1	933.4	18.8
Hay Point/Reef	2	6.8	13.9	22.7	52.4	764.3	12.1
Round Top Island	0.7	2.1	4.7	8.5	23.2	829.9	11.4
Slade Islet	1.1	5.3	13.6	24.7	57.2	840	12.5
Spoil Grounds	0.8	2.5	5.2	9.5	72.3	659.7	7.4
Victor Island	1.9	6.2	12.2	20.3	50.9	951.7	10.3
Keswick Island	0.6	1.2	1.9	3.6	24.4	699.5	10.1
Wet Season							
Freshwater Point	7.5	34.1	60.9	95.1	226.7	879.5	18.8
Hay Point/Reef	4.5	17.2	33.3	55.4	130.1	401	12.1
Round Top Island	0.9	4.5	10	17.4	47	590.3	11.4
Slade Islet	4.8	24.5	41.8	66.2	174.8	743	12.5
Spoil Grounds	1.4	6.9	18.3	49.1	175.4	631.6	7.4
Victor Island	3.9	19.1	33.6	52.3	133.3	901.1	10.3
Keswick Island	0.8	1.9	5.2	32.1	198.5	855.7	10.1
All Data							
Freshwater Point	3.9	20.9	41.6	68.8	166.3	1813	18.8
Hay Point/Reef	2.5	10.1	20	34.2	87.5	1165.3	12.1
Round Top Island	0.8	2.9	6.6	12.3	33.1	1420.2	11.4
Slade Islet	2.1	13.2	28.9	45.3	117.3	1583	12.5
Spoil Grounds	1	4.2	9.7	25.7	133.1	1291.3	7.4
Victor Island	2.6	11.2	23.5	37.3	101.2	1852.8	10.3
Keswick Island	0.7	1.5	3.1	10.9	142.5	1555.2	10.1

A comparison of turbidity percentiles based on three years of data (RHDHV, 2018), five years of data (PCS, 2019a) and seven years of data at the sites is given in Table 7. This is included to give context for how any thresholds developed as part of the present study at the Port of Mackay may differ from previously developed thresholds at the Port of Hay Point. Results are shown for the four sites identified as suitable adaptive monitoring sites for dredging activity at the Port of Hay Point. The results show that the percentiles are broadly similar but with a general reduction in turbidity as the record duration increases. This reduction is most notable at Freshwater Point where the 90th, 95th and 99th percentiles were reduced by approximately a third when the dataset was extended from 3 to 5 years. Changes in turbidity statistics were less notable for the extension of the dataset from 5 to 7 years, with reductions of the order of 5 to 10%.

Table 7. Comparison between benthic turbidity percentiles based on three, five and seven years of data.

Site	Turbidity Statistic (NTU)					Data Duration (days)
	Median	80th	90th	95th	99th	
RHDHV (2018) 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
PCS (2019a) 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
Updated analysis (July 2014 to April 2021)						
Slade Islet	2.1	13.2	28.9	45.3	117.3	1583
Round Top Island	0.8	2.9	6.6	12.3	33.1	1420
Victor Island	2.6	11.2	23.5	37.3	101.2	1853
Freshwater Point	3.9	20.9	41.6	68.8	166.3	1813



Note: for turbidity, data for the wet season are shown as a lighter colour and data for the dry season are shown as a darker colour.

Figure 6. Predicted water level (top), measured waves (middle) and benthic turbidity (bottom) at the Port of Mackay.

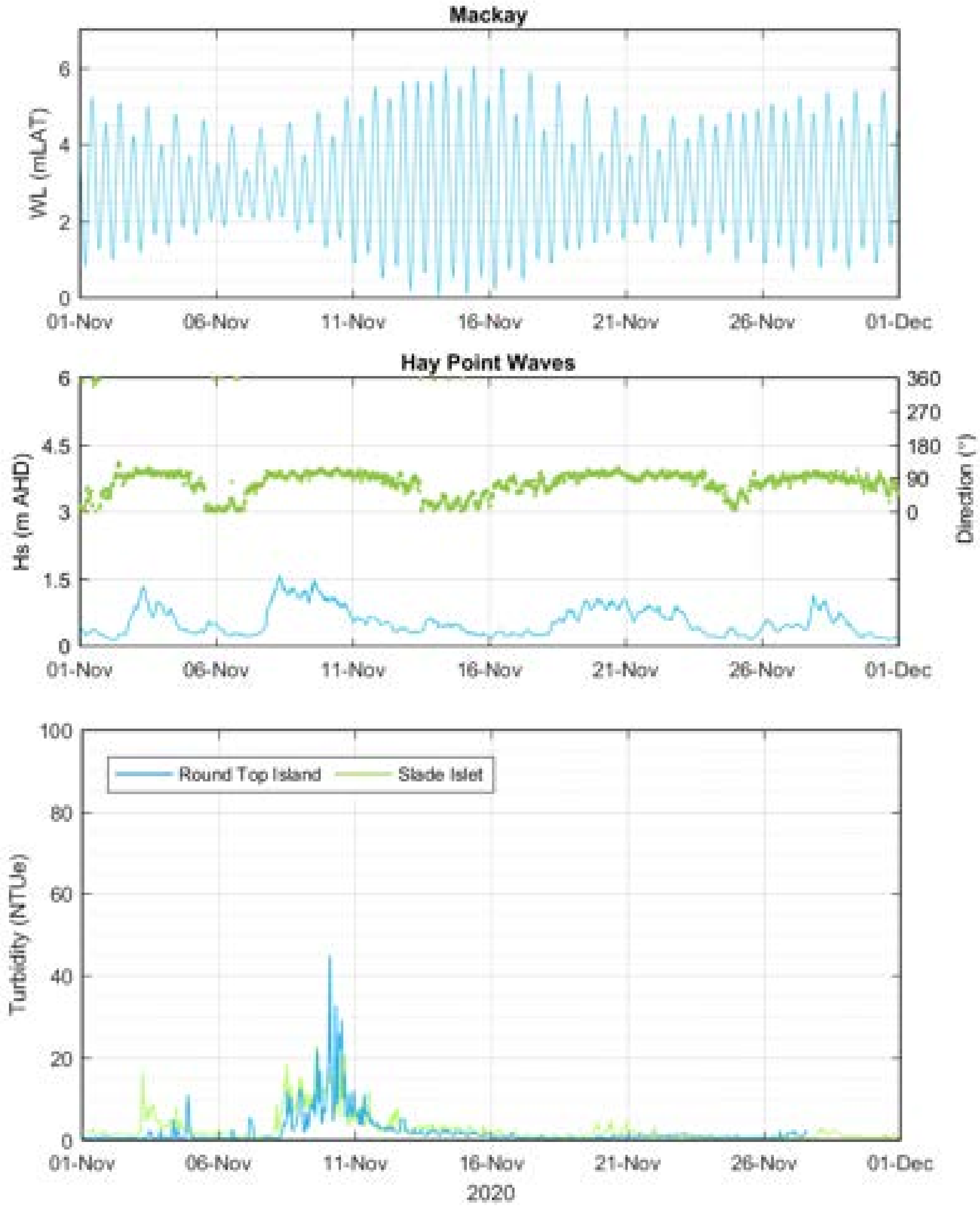


Figure 7. **Predicted water level (top), measured waves (middle) and benthic turbidity (bottom) at the Port of Mackay for a one month period.**

To investigate the suitability (or otherwise) of the 15 mg/l threshold at the monitoring sites, the frequency and average duration that the intensity limit of 15 mg/l has been exceeded naturally has been calculated, along with the percentile at each site which is equal to 15 mg/l, using the full seven year data set available. These statistics are presented separately for the wet and dry season, as well as for all data in Table 8. The results confirm that the 15 mg/l threshold is not a suitable value to be applied at all sites, with the site at Slade Islet naturally exceeding the threshold much more frequently than the site at Round Top Island.

Noting that 15 mg/l (equivalent to 11 NTUe at Round Top Island) is a conservative management trigger for corals in view of the local corals present, the approach taken in this study is to use the equivalent percentile turbidity at Round Top Island as a percentile to apply for the site at Slade Islet (consistent with the approach adopted by RHDHV (2018) and PCS

(2019a) to develop thresholds at the nearby Port of Hay Point). The 91st percentile during the wet season and the 97th percentile during the dry season represent the 15 mg/l threshold at Round Top Island[2].

These percentiles have subsequently been used to determine the benthic turbidity intensity thresholds at Slade Islet. Based on these updated benthic turbidity intensity thresholds, updated average, 90th percentile and maximum exceedance durations were calculated for the two monitoring sites local to the Port of Mackay based on 6, 12 and 20 day periods.

Table 8. Duration and frequency analysis of data at the Port of Mackay using a threshold of 15 mg/l.

Site	15 mg/l as percentile	Average Duration (hrs)	Maximum Duration (hrs)	Frequency (times/season)
Wet Season				
Round Top Island	91	4	123	142
Slade Islet	68	8	1192	398
Dry Season				
Round Top Island	97	3	47	156
Slade Islet	89	5	179	310
All Data				
Round Top Island	94	3	123	79
Slade Islet	79	7	1192	247

3.2.2. Defining Intensity Thresholds

Consistently applying set percentile values for the wet and dry season across the monitoring sites enables a comparable interpretation of natural NTUe and dredge related changes in intensity and duration.

Taking account of the results from the percentile analysis (Table 6 and Table 8) a 91st percentile turbidity has been adopted as a turbidity intensity threshold for the wet season and a 97th percentile turbidity has been adopted as a turbidity intensity threshold for the dry season. These percentiles have been used to define site specific turbidity intensity and duration triggers which can be adopted if required for future maintenance dredging programs to ensure the turbidity remains within the natural range.

As the proposed 91st and 97th percentile turbidity/SSC thresholds are on average only naturally exceeded for 9% and 3% of the time, they can be considered to be representative of a threshold for short duration acute impacts due to high turbidity/SSC, as opposed to longer duration chronic impacts due to prolonged periods of lower SSC.

Correlations between the benthic turbidity and surface turbidity were developed by PCS (2019a) based on concurrent surface and benthic turbidity data measured at each site. Applying these correlations yields equivalent surface turbidity thresholds as given in Table 9.

Table 9. Benthic and surface turbidity thresholds at the two water quality monitoring sites.

Location	Benthic Turbidity Intensity Threshold (NTUe)	Surface Turbidity Intensity Threshold (NTUe)
Round Top Island	11	6.1
Slade Islet	45	8.0

[2] RHDHV (2018) found the 15 mg/l threshold to represent the 90th percentile in the wet season and the 94th percentile in the dry season using three years of data while PCS (2019a) found it to represent the 91st percentile in the wet season and 96th percentile in the dry season using five years of data.

3.2.3. Defining Duration Thresholds

The threshold development approach is based around the assumption that as long as the turbidity remains within the natural range during periods when no impacts to sensitive receptors have occurred, then the dredging will not have contributed to potential impacts. The IDF results presented in Table 8 were based on data collected over the whole of the dry and wet season periods. To allow adaptive management to be effective, it is important to define a range of thresholds based on IDF analysis over discrete periods of time (6 days, 12 days and 20 days in this case). This gives an understanding of the typical natural conditions over the likely range of possible durations for future dredging programs. It is therefore important to understand the range of natural conditions which can occur and to factor this into any adaptive management approaches.

Different duration triggers are required to represent the limits when different management actions would be adopted. The duration triggers have been defined assuming the different percentile turbidity intensities for the wet and dry seasons. The different duration triggers adopted are described below assuming an example 91st percentile turbidity intensity:

- average cumulative duration (as time in hours) that conditions exceed the 91st percentile turbidity (i.e. 9% of the time) over the dredge durations considered (6 days, 12 days and 20 days);
- the 90th percentile of all the cumulative durations (as time in hours) that conditions exceed the 91st percentile turbidity for both the wet and dry seasons, over typical periods equivalent to the dredge durations considered (6 days, 12 days and 20 days). This provides an indication of a known duration that intensity limits have naturally exceeded over a period of time without resulting in known impacts to local receptors; and
- the maximum cumulative duration (as time in hours) that conditions exceed the 91st percentile turbidity for both the wet and dry seasons, over typical periods equivalent to the dredge durations considered (6 days, 12 days and 20 days). This provides an indication of the maximum duration that intensity limits have naturally been exceeded over a period of time without resulting in known impacts to local receptors. Therefore, if these conditions are exceeded there is a potential that impacts to coral could occur.

Intensity and duration values are suggested which consider both the intensity and duration of the natural conditions and events. The values provide the basis for potential trigger limits if adaptive monitoring is required and have been defined over a 6 day, 12 day and 20 day period (relevant to potential dredging program durations). The calculated IDF parameters for the NTUe (and SSC) data measured at the two ambient water quality monitoring sites for the wet and dry seasons are presented in Table 10 to Table 12.

Table 10. Suggested SSC/NTUe intensity and duration triggers at the two water quality monitoring sites around the Port of Mackay, based on a 6 day period.

Site	Intensity (mg/l)	Intensity (NTUe)	Average Duration (hours)	90th Percentile Duration (hours)	Maximum Duration (hours)
Wet Season (91st percentile data)					
Round Top Island	15	11	3	47	153
Slade Islet	53	45	3	46	177
Dry Season (97th percentile data)					
Round Top Island	16	12	2	11	73
Slade Islet	41	34	2	12	93

Table 11. **Suggested SSC/NTUe intensity and duration triggers at the two water quality monitoring sites around the Port of Mackay, based on a 12 day period.**

Site	Intensity (mg/l)	Intensity (NTUe)	Average Duration (hours)	90th Percentile Duration (hours)	Maximum Duration (hours)
Wet Season (91st percentile data)					
Round Top Island	15	11	26	88	241
Slade Islet	53	45	26	87	228
Dry Season (97th percentile data)					
Round Top Island	16	12	9	29	99
Slade Islet	41	34	9	33	95

Table 12. **Suggested SSC/NTUe intensity and duration triggers at the two water quality monitoring sites around the Port of Mackay, based on a 20 day period.**

Site	Intensity (mg/l)	Intensity (NTUe)	Average Duration (hours)	90th Percentile Duration (hours)	Maximum Duration (hours)
Wet Season (91st percentile data)					
Round Top Island	15	11	43	138	298
Slade Islet	53	45	43	120	248
Dry Season (97th percentile data)					
Round Top Island	16	12	14	51	103
Slade Islet	41	34	14	45	98

Comparison of the IDF values with those presented in PCS (2019a) based on five years of data indicates that the extended duration of data has not made a significant difference to the derived thresholds, with only a small reduction in the 90th percentile duration of exceedance. For example, at Slade Islet the 90th percentile duration above the threshold value during the wet season when all seven years of data is included is 120 hours, while previously based on five years this was 124 hours (while at Round Top Island this is 138 hours based on seven years of data and 144 hours based on five years of data).

Table 13. **Updated benthic turbidity intensity and duration thresholds based on five years of data and a 20 day period from PCS (2019a).**

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
Slade Islet	50	43	124	228
Dry Season (96th percentile data)				
Round Top Island	11	19	69	113
Slade Islet	32	19	76	97

3.2.4. Applying IDF Results for Adaptive Management

Monitoring from the 2020 Port of Mackay maintenance dredge program indicated that the closest monitoring site at Slade Islet had the potential to experience increased turbidity as a result of the dredging activity (PCS, 2021b). There were no data returned at the next closest monitoring site (Round Top Island), however satellite derived turbidity data indicated that it is unlikely that the maintenance dredging resulted in an increase in turbidity at this site. In addition, numerical modelling undertaken as part of the SSM Project predicted that any increases in turbidity at Round Top Island due to maintenance dredging at the Port of Mackay would not be measurable (less than 0.5 NTUe) (PCS, 2021c). The modelling also showed that elevated turbidity occurring within Mackay Harbour over the duration of the dredging program and that plumes with elevated turbidity were consistently transported to the north of Mackay Harbour (towards Slade Islet) due to the ebb tidal currents being in a northerly direction. Therefore, the only conditions when a plume from the maintenance dredging could be transported to Round Top Island would be during a period of strong northerly winds, but during these conditions it would be unlikely that offshore placement at the DMPA could be undertaken and so it is likely that dredging would have to be put on hold. Based on the above, Slade Islet is considered to be the most suitable location for a trigger monitoring site for the Port of Mackay and Round Top Island would be a suitable location for a control monitoring site.

It is important that the variability of the natural environment shown by the IDF analysis be considered as part of any adaptive management approaches. Understanding the variability of the natural environment relevant to SSC/NTUe will help to ensure that:

- any increases in SSC/NTUe due to maintenance dredging are managed and do not result in SSC/NTUe conditions which could result in impacts to the natural receptors; and
- any natural fluctuations in SSC are not misinterpreted as impacts due to dredging.

To further test the proposed triggers, near bed turbidity data collected during the 2020 maintenance dredge program were analysed and the total duration above the triggers defined by this assessment was quantified. During the 12 day dredge period the turbidity at Slade Islet was above the threshold value of 45 NTUe for a total of just under two hours, less than 1% of the dredge duration. The exceedance during the dredge program was much less than the expected natural exceedance (which on average would be 26 hours during a 12 day period for the 91st percentile) despite the potential that low concentration increases in turbidity at Slade Islet occurred due elevated turbidity from the maintenance dredging activity in the Harbour being transported to the north during the ebb stage of the tide. This is consistent with the findings of the report on the turbidity monitoring during the dredging program which noted that the turbidity at Slade Islet remained below typical turbidity values for the wet season (PCS, 2021b). This test suggests that the proposed triggers at Slade Islet are suitable for future maintenance dredging programs with the potential low concentration increases in turbidity at Slade Islet not resulting in any triggers being exceeded. The triggers will be further tested as part of the dredge plume modelling being undertaken as part of the Port of Mackay SSM Project.

3.3. PAR Thresholds

As seagrass and coral rely on sunlight to photosynthesise, grow and reproduce, the amount of PAR which reaches photosynthetic benthic communities is very important. The amount of PAR which reaches the seabed is influenced by the concentrations of particles in the water column in which the light passes. Suspended solids in the water column will reduce the amount of light reaching the seabed by the processes of absorption or reflection (Kirk, 1994).

There is a considerable range of values reported in the literature for the minimum light requirements of seagrasses, varying between different seagrass species as well as within a single seagrass species. In addition to varying requirements for minimum light levels, the length of time that different species can survive at low levels is also highly variable between species (Erftemeijer and Lewis, 2006, Collier *et al.,* 2016, Statton *et al.,* 2017).

Variability between different seagrass species in their ability to endure and recover from periods of reduced light is related to their differing morphological and physiological characteristics (Chesire *et al.,* 2002). These characteristics represent different strategies for survival in the face of stress or disturbance. Smaller fast growing (short-lived) species such as those present in the study area, including *Halophila ovalis*, do not endure long once environmental conditions are beyond that to which they can adapt, but they tend to recolonise quickly following an impact.

The effects of sub-optimal levels of light between species varies depending on the period of time the conditions persist and this should be considered during threshold development (Statton *et al*., 2017). For example, for *Halophila ovalis* thresholds of between 0.9 mol/m^2/day and 2.3 mol/m^2/day were recommended for periods of 3 weeks and 9 weeks, respectively (Statton *et al.,* 2017). Similarly, for *Halodule uninervis* thresholds of between 5 mol/m^2/day and 13 mol/m^2/day were recommended for periods of 6 weeks and 12 weeks, respectively.

As noted by Collier *et al*. (2016), in some locations, investments into research and monitoring has enabled the development of site-specific compliance standards for adaptive management. For example, McKenna *et al*. (2015) recommended the following thresholds for application at Abbot Point where *Halophila ovalis, Halophila decipiens* and *Halodule uninervis* were among the seagrass species present:

- For the offshore areas of deepwater *Halophila* species, the threshold is 1.5 mol/m^2/day over a rolling 7 day average; and
- For the shallow inshore areas dominated by *Halodule uninervis*, the threshold is 3.5 mol/m^2/day over a rolling 14 day average.

Site specific light thresholds for the deep-water seagrass species which occur in the Mackay and Hay Point region were developed by TropWATER through detailed field and laboratory investigations between 2012 and 2016. The results showed that *Halophila decipiens* has a minimum benthic light requirement of greater than 1.1 mol/m^2/day to maintain growth during the growing season and 1.5 to 2 mol/m^2/day to germinate and produce seeds to replenish seed banks (McCormack *et al*., 2015). If the benthic light falls below these levels for greater than a consecutive 7-day period during the growing season (July to December) then it could impact the ability of the species to reproduce and replenish seed banks (McKenna *et al.*, 2016).

3.3.1. Local Context

A time series of benthic PAR at the monitoring sites close to the Port of Mackay is shown in Figure 8. There is an inverse relationship between benthic PAR and NTUe, with periods of high NTUe corresponding to periods of low benthic PAR (with suspended solids in the water column reducing the amount of light reaching the seabed by the process of absorption or reflection). Therefore, lower percentile values represent the higher light conditions.

Benthic PAR percentiles have been calculated for the wet and dry season (and for all data) and results are presented in Table 14. For benthic PAR the lower percentiles represent the higher light conditions at the seabed, with the amount of light reducing as the percentile increases. For example, the 20th percentile value of 2.9 mol photons/m^2/day at Round Top Island shows that for 20% of the time benthic PAR is above this value (i.e. there is more light than this) and for 80% of the time benthic PAR is below this (i.e. there is less light than this). Lower percentile values have been included to show the higher benthic PAR values which relate to thresholds detailed in the published literature.

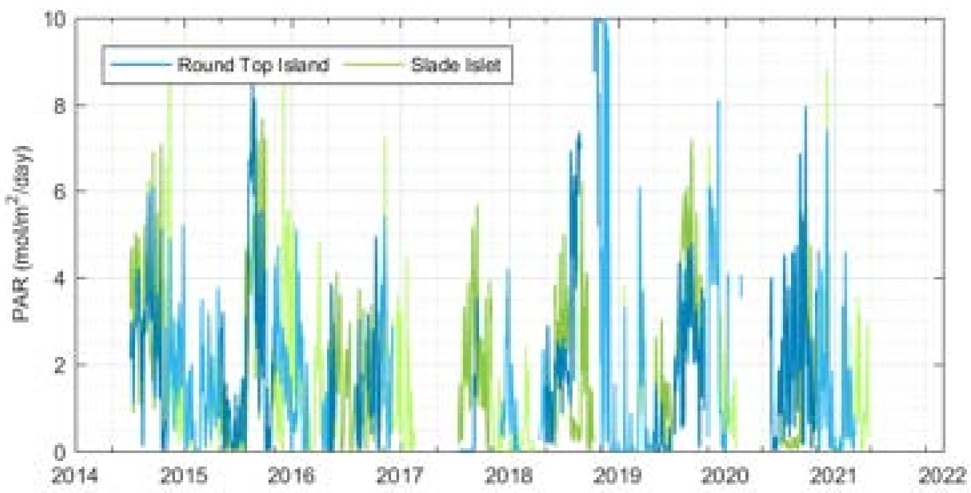


Figure 8. Time series of PAR data (wet season data shown as lighter colour, dry season data as darker colour).

Table 14. PAR percentiles for the Port of Mackay monitoring sites.

Site	Percentile PAR Intensity (mol photons/m^2/day)						Data Duration (days)
	1st	5th	10th	20th	50th	80th	
Wet Season							
Round Top Island	9.5	5.1	4.2	2.9	1.1	0.1	768
Slade Islet	6.7	4.8	3.4	2.3	0.8	0	874
Spoil Grounds	4.2	2.7	2.1	1.3	0.4	0	708
Dry Season							
Round Top Island	12.6	6.7	4.9	3.7	1.9	0.5	861
Slade Islet	6.8	5.3	4.6	3.7	1.5	0.2	959
Spoil Grounds	8.3	4.3	3.3	2	0.7	0.2	684
All Data							
Round Top Island	9.9	6	4.5	3.4	1.6	0.3	1629
Slade Islet	6.7	5	4.2	3.1	1.1	0.1	1833
Spoil Grounds	7.1	3.7	2.6	1.6	0.6	0.1	1392

In context of the published light thresholds for the deep water seagrass species in the Mackay region (required light levels above 1.1 to 2.0 mol photons/m^2/day), the range of PAR in the Mackay region shows that the PAR is only above the required light levels for 20 to 50% of the time with highest light levels at the less turbid offshore site of Round Top Island.

NQBP's ambient seagrass monitoring program has shown seagrass regularly occurs near the spoil ground monitoring site (adjacent to the Hay Point DMPA), with the deeper water *Halophila* species being dominant in the area. The benthic PAR is only above the minimum benthic light requirements in the literature (1.1 to 2.0 mol photons/m^2/day) for between 20% and 10% of the time (see Table 14).

To further investigate this, the IDF analysis was undertaken on the benthic PAR data using the 1.5 mol photons/m^2/day threshold (Table 15). The table shows that the benthic PAR at the monitoring sites can be below the intensity threshold for up to 18 days at the Spoil Grounds, which is significantly longer than the 7 day duration noted in the literature. This indicates that if the benthic light threshold is correct, then the seagrass in this area will frequently experience low levels of light which would limit their potential to germinate and produce seeds to replenish seed banks, suggesting that a meadow would not be expected to be present over the longer term.

Table 15. Duration and frequency analysis of PAR data at the Port of Mackay using a threshold of 1.5 mol/m²/day.

Site	1.5 mol/m²/day as percentile	Average Duration (days)	Maximum Duration (days)	Frequency (times/season)
Wet Season				
Round Top Island	42	7	35	37
Slade Islet	32	9	43	48
Spoil Grounds	16	13	84	25
Dry Season				
Round Top Island	61	6	54	38
Slade Islet	51	8	74	45
Spoil Grounds	27	12	72	22
All Data				
Round Top Island	52	7	54	23
Slade Islet	42	11	218	34
Spoil Grounds	22	18	207	14

3.3.2. Applying IDF Results for Adaptive Management

The analysis in this report indicates that the threshold values for benthic PAR as recommended in the literature are not suitable for the adaptive management of dredging activities at the Port of Mackay for areas where seagrass can occur. This is because the threshold values are regularly exceeded naturally (that is to say the light levels are too low). It is important to note that the water depths at the monitoring sites may be deeper than at the exact locations where seagrass is present (since monitoring sites have been selected to be adjacent to sensitive receptors but not directly on them to avoid impacts to them) and consequently benthic PAR at the monitoring locations are likely to be lower than at the adjacent seagrass beds. This difference may partially account for the presence of seagrass beds at locations around the Port of Mackay, despite the measured data showing conditions regularly being below benthic PAR thresholds defined in the published literature (sometimes for periods of several weeks at a time).

Since benthic PAR levels are lower than the defined PAR thresholds and for relatively long durations (comparable or longer than dredge campaigns at the Port of Mackay) and given the relative uncertainty that still exists in relation to predicting the effects of varying light levels on seagrasses (Lavery *et al.*, 2017) we do not recommend the use of benthic PAR as a trigger for the adaptive management of maintenance dredging at the Port of Mackay. Practical limitation associated with obtaining benthic PAR readings in real time during dredging operations also limit the suitability of this variable for use in adaptive management strategies.

It is proposed that ongoing ambient monitoring of benthic PAR should continue, along with the annual seagrass surveys, to better understand the relationship between the seagrass in this area and the benthic light in the Mackay area.

3.4. Sedimentation Rate Thresholds

High sedimentation rates from dredging activities is generally concentrated to areas within the boundary of, and immediately surrounding, the DMPA. The dominant coral families in the Mackay region have intermediate (massive or dome shaped) tolerance to elevated sedimentation rates (Erftemeijer *et al.*, 2012). Extended periods of sedimentation values of 10 mg/cm²/day may have sub-lethal impacts on corals of these growth forms. Lethal impacts may not occur until these colonies are exposed to extended periods of sedimentation (up to 2 weeks) of more than 50 mg/cm²/day.

The Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA 2010) provide two different threshold sedimentation rates based on the annual average daily rate (3 mg/cm^2) and maximum daily rate (15 mg/cm^2).

Vermaat *et al.* (1997) provided threshold annual sedimentation rates for different seagrass species including *Halophila ovalis*, which was quoted as being 2 cm/yr. This is equivalent to an average rate of 1.6 mg/cm^2/day at a bed density of 300 kg/m^3.

3.4.1. Local Context

Deposition has been measured in the Mackay region over the last seven years using optical backscatter sensors which determine deposition based on the backscatter of light detected by the sensor (Waltham *et al.,* 2018). During deployment, the sensor is wiped clean every 2 hours to prevent the deposition from becoming too thick for the sensor to measure. The instruments can therefore accurately measure deposition over time, but they can only measure erosion of any sediment which has been deposited over the previous 2 hours. For example, a period of consistent erosion would only be shown as zero deposition by the sensor. As such, the instruments are not able to define the net deposition/erosion which has occurred over time, but they do measure the gross deposition over time. On this basis, the deposition rates derived from the instrumentation are not directly comparable to (and are expected to be higher than) the threshold values defined in the literature, which consider a net deposition rate. This is a limitation of most instruments which can accurately measure deposition and remotely log it over time (Royal HaskoningDHV, 2018).

A time series of deposition rates at the two monitoring locations is shown in Figure 9. Daily deposition rates are typically in the order of tens of mg/cm^2/day but with many spikes with much higher daily deposition rates (in hundreds of mg/cm^2/day).

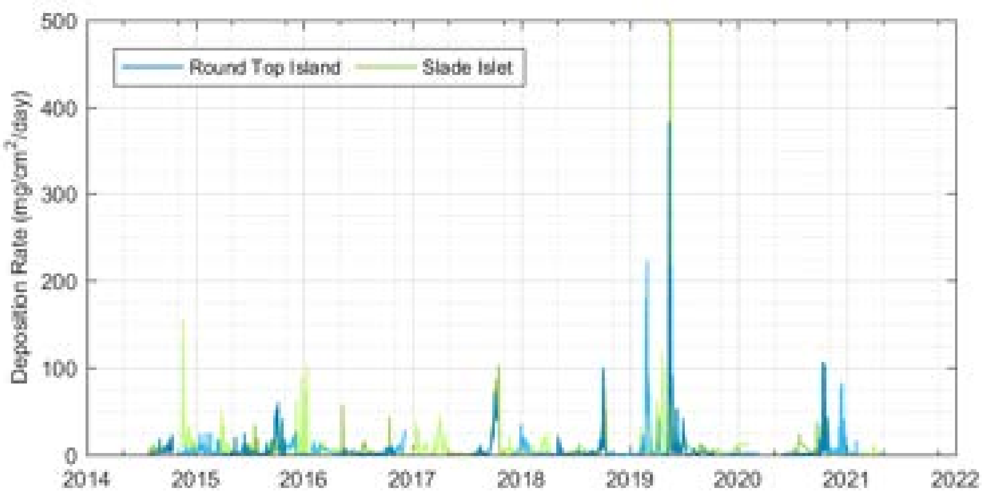


Figure 9. Time series of deposition rate data (wet season data shown as lighter colour, dry season data as darker colour).

To provide further quantification of the daily deposition data, percentile values are presented in Table 16. The median (50th percentile) sedimentation rates at the sites were as follows:

- at Slade Islet 1.9 mg/cm^2/day during the wet season and 1.8 mg/cm^2/day during the dry season; and
- at Round Top Island 0.9 mg/cm^2/day during the wet season and 0.8 mg/cm^2/day during the dry season.

These median values are lower than the annual average sedimentation rates from the Water Quality guidelines (3 mg/cm²/day), however the 95th percentiles range from 21.1 to 38.5 mg/cm²/day which are above the maximum daily sedimentation rate of 15 mg/cm²/day.

Table 16. Deposition rate percentiles for the Port of Mackay monitoring sites.

Site	Percentile Deposition rate Intensity (mg/cm²/day)					Data Duration (days)
	50th	80th	90th	95th	99th	
Wet Season						
Round Top Island	0.9	6	13.2	21.1	80.4	685
Slade Islet	1.9	8	15.3	30.2	78.6	740
Dry Season						
Round Top Island	0.8	4.5	15.3	38.5	102.7	842
Slade Islet	1.8	7.1	14.9	35	90.5	817
All Data						
Round Top Island	0.9	5.3	14	27.3	92.8	1527
Slade Islet	1.8	7.6	15.2	34.1	88.9	1557

An example time series of concurrent deposition, turbidity and wave data is presented in Figure 10 using data from 2020 to 2021. The plots show that there is a notable trend between wave activity, SSC and deposition. During periods of higher wave energy, wave induced bed shear stresses act to suspend sediment and in turn increase the turbidity. It is during these periods of elevated turbidity that peaks in deposition also occur. The peak in deposition will occur during periods of slack water when suspended sediments have the opportunity to settle out of the water column. The correlation between SSC and deposition indicates that SSC can be used as a proxy for sedimentation.

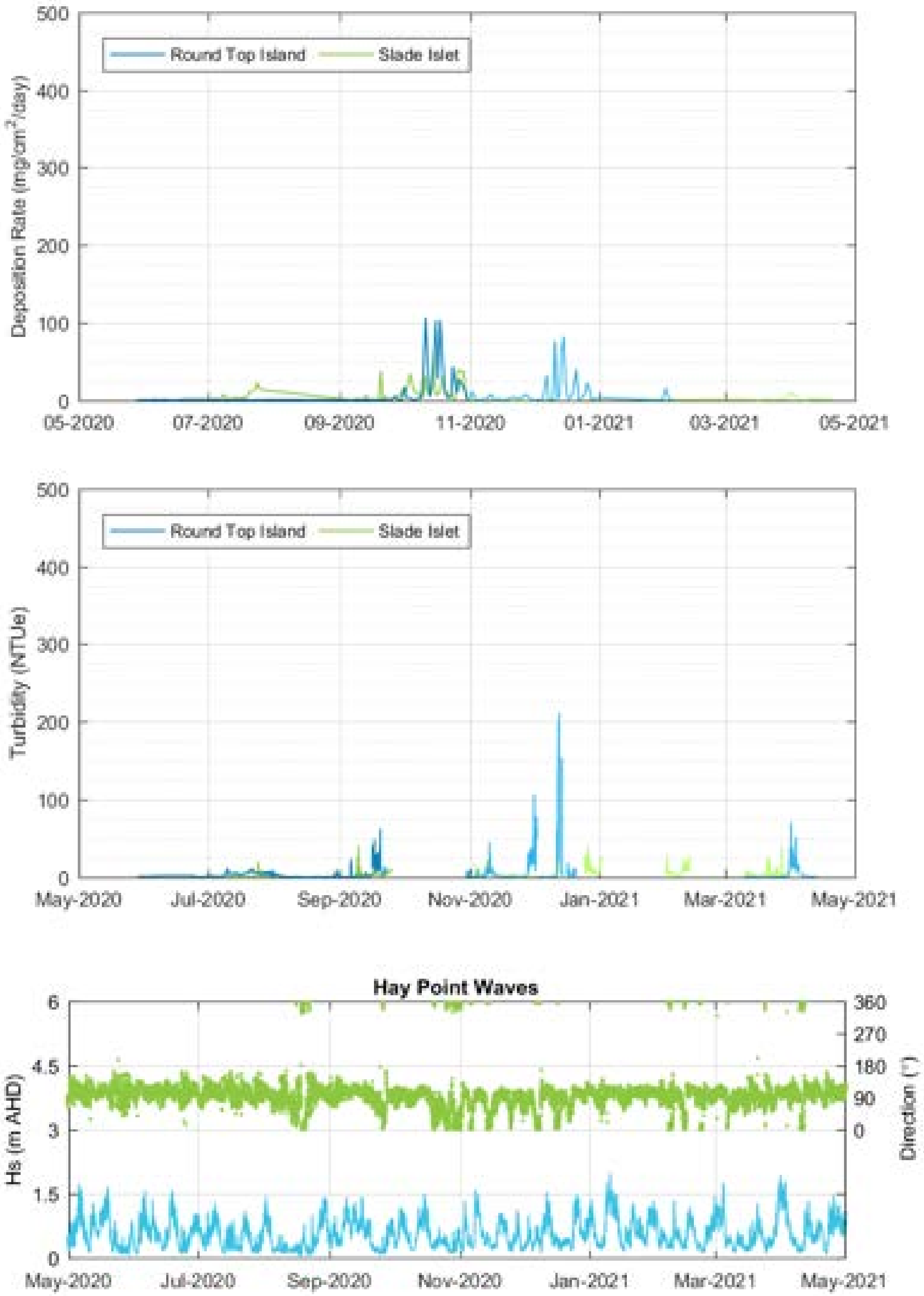


Figure 10. Time series of deposition rate data (top), benthic turbidity data (middle) and measured waves (bottom) at Slade Islet.

3.4.2. Applying IDF Results for Adaptive Management

Considerable research has highlighted that existing methods for monitoring of deposition using in-situ benthic instruments are inherently unreliable and not suitable for adaptive management monitoring. Research has demonstrated that sediment deposition rates are sometimes over-estimated by an order of magnitude when using conventional techniques (e.g. sediment traps) for sampling (Whinney *et al.,* 2017).

In addition to concerns over the accuracy of measured deposition rates and the inability to accurately measure net deposition/erosion, consideration should be given to the lack of suitable adaptive management responses available if deposition thresholds are exceeded. As an example, if a deposition trigger was reached (set against a defined threshold), and the management response was to stop dredging, clarity around when dredging could safely resume cannot be easily defined as the deposited sediment would potentially remain in location and most instruments cannot show when erosion has occurred.

While deposition data are of limited use for adaptive monitoring purposes, they are considered relevant to providing context to the interpretation of impacts to marine habitats and organisms following dredging (Whinney *et al.,* 2017). This aligns with the recommendations of SKM (2013) who suggested that deposition should be included as part of ongoing water quality investigations, rather than being linked to operational management responses. Based on this, along with the measured deposition data at the monitoring sites showing high rates relative to the thresholds for coral and seagrass in the literature, it is recommended that deposition rates continue to be monitored as part of the ongoing ambient monitoring program but that they are not adopted for any adaptive management monitoring.

3.5. Recommended Monitoring Approach

The IDF results indicate that turbidity data is the most appropriate parameter for real-time monitoring during dredging operations as part of an adaptive management approach. However, it is recommended that monitoring of both benthic PAR and deposition continues to better understand the relationship between these parameters and the receptors present at and around the Port of Mackay and to provide context to the interpretation of impacts to marine habitats and organisms following dredging and natural events.

As noted in Section 3.2.4, the monitoring site at Slade Islet is the most suitable location for a trigger monitoring site and Round Top Island would be a suitable location for a control monitoring site. Based on turbidity intensity thresholds relevant to the sensitive receptors in the region, duration triggers are detailed for three different dredge durations (6 days, 12 days and 20 days) in Table 10 to Table 12. These duration triggers can be used as limits between different management zones as part of an adaptive management approach. An example plot showing how the various duration triggers could fit into different adaptive management zones (as applied previously at the Port of Hay Point) is shown in Figure 11. While the cumulative duration remains below the average duration the water quality conditions would fall within Management Zone A, which allows dredging to operate as normal. If the cumulative hourly count increases above the average, 90th percentile or maximum duration triggers then pre-defined management actions would be initiated as part of the adaptive management process. These would initially involve investigating the cause for the threshold exceedance to determine if it was natural or dredging related and then potentially responding to the elevated turbidity by implementing adaptive management measures.

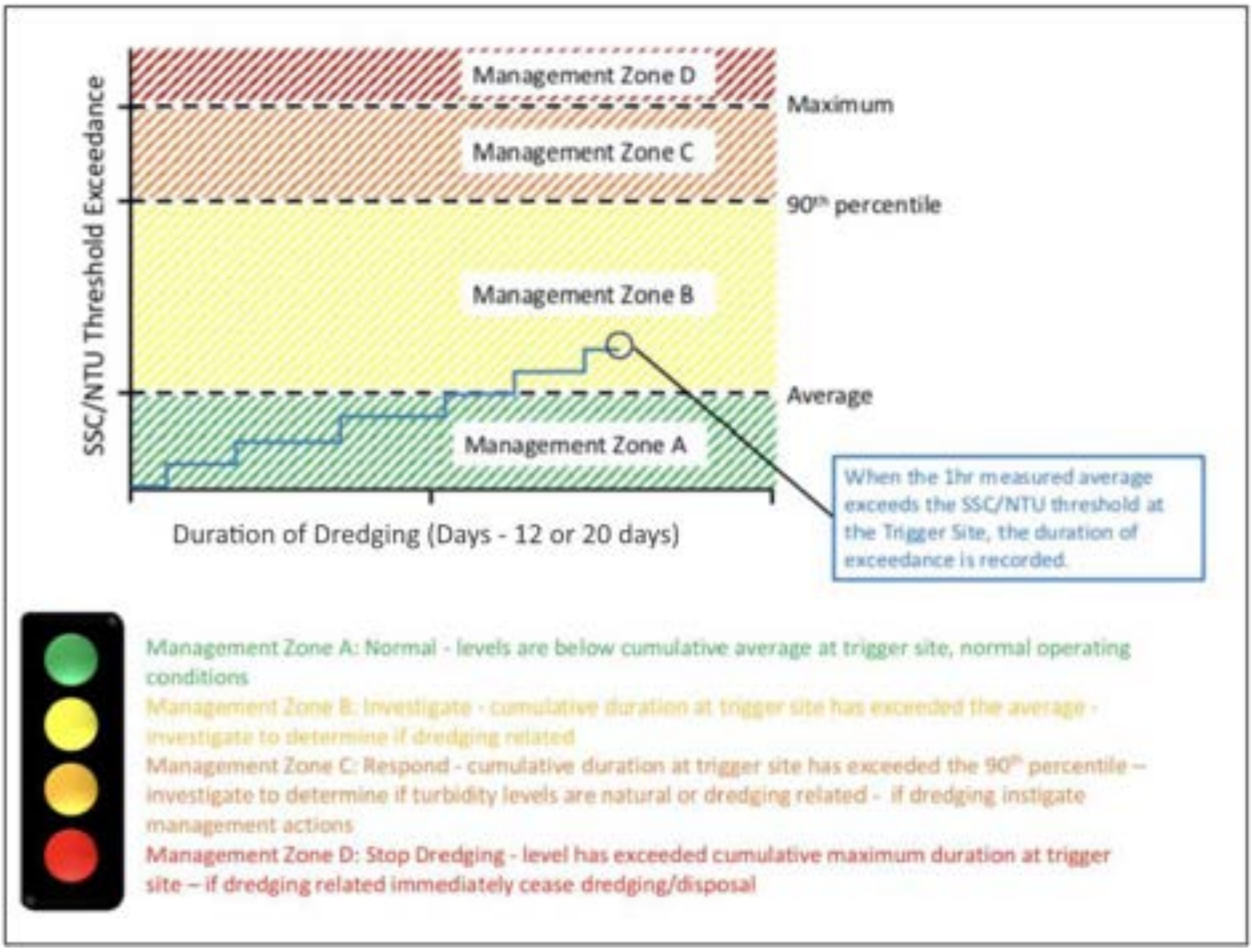


Figure 11. Example plot showing potential intensity and duration trigger limits which could be implemented for adaptive management responses (adapted from NQBP (2018)).

4. Summary

This report had the aim of understanding the natural variability of turbidity, benthic PAR and deposition in the Port of Mackay region. Based on a review of information in the literature and an analysis of measured data, relevant ecological thresholds have been defined. The data analysis applied an intensity, duration and frequency (IDF) approach to define the water quality and deposition conditions and to enable the recommendation of appropriate water quality triggers that can be considered for use in future adaptive monitoring.

The analysis was undertaken using 7 years of measured data around the coastal waters in the Mackay and Hay Point region. The analysis showed that the local metocean conditions control the turbidity which in turn means that they also have a strong influence on the benthic PAR and sediment deposition. The metocean conditions vary seasonally, with the potential for larger waves and stronger winds in the wet season, which also results in seasonal variability in the turbidity, benthic PAR and deposition.

Based on monitoring and numerical modelling of the 2020 Port of Mackay maintenance dredging program, it was noted that the only monitoring site where measurable elevated turbidity due to maintenance dredging at the Port of Mackay and placement at the Mackay DMPA was at Slade Islet. The potential for elevated turbidity at this site was due to elevated turbidity occurring within Mackay Harbour as a result of the dredge activity and then during the ebb stage of the tide the water from Mackay Harbour with elevated turbidity was exported from the Harbour and transported to the north by the northerly ebb tidal currents. Based on this the site at Slade Islet has been selected as a potential trigger monitoring site and the site at Round Top Island (as this is the next closest to the Port of Mackay) has been selected as a potential control monitoring site if adaptive management is required during dredging at the Port.

Based on information regarding relevant ecological thresholds for coral and seagrass in the Mackay region along with the analysis of the measured water quality and deposition data, it was concluded that turbidity was the most suitable parameter for monitoring in real-time as part of any future adaptive management required. However, it was also recommended that monitoring of both benthic PAR and deposition continues to better understand the relationship between these parameters and the receptors present in the region.

Analysis of the measured turbidity data indicated that a single turbidity intensity threshold value across all sites and both seasons (wet and dry) would not be applicable as would not represent the spatial and temporal variations in turbidity which occur in the region. Percentiles from the turbidity data were adopted as these enabled a comparable interpretation of turbidity at the different sites and allowed for the different conditions during the two seasons. Based on the results from the percentile analysis and the relevant turbidity thresholds published in the literature, the 91st and 97th percentile turbidity was adopted for the wet and dry seasons respectively. As these thresholds are only naturally exceeded for 9% and 3% of the time, they can be considered to be representative of a threshold for short duration acute impacts due to high turbidity, as opposed to longer duration chronic impacts due to prolonged periods of lower turbidity.

The IDF analysis was applied for periods of 6 days, 12 days and 20 days to account for a potential range of maintenance dredge program durations and so the results could be directly compared to previous analysis at the Port of Hay Point (for which a 20 day duration was adopted). The results from the analysis are shown in Table 10 to Table 12 and define the natural conditions in terms of both the intensity and duration, and therefore provide the basis for potential trigger limits if adaptive monitoring is required during future maintenance dredging programs. These trigger limits will be further tested using results from the dredge plume modelling being undertaken as part of the Port of Mackay SSM Project.

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