Port of **Mackay**

Appendix C

Avoid and Reduce Assessment

Port of Mackay Avoid and Reduce Assessment

Long-term Dredge Management Plan

Report No. P012_R02v02

Technical Report
July 2021

PORT & COASTAL
SOLUTIONS

Port of Mackay Avoid and Reduce Assessment

Long-term Dredge Management Plan

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North Queensland Bulk Ports Corporation Ltd

Version	Details	Authorised By	Date
0.1	Draft	Andy Symonds	18/02/2021
0.2	Final	Andy Symonds	28/07/2021

Document Authorisation		Signature	Date
Project Manager	Andy Symonds		28/07/2021
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Executive Summary

North Queensland Bulk Ports Corporation (NQBP) commissioned Port and Coastal Solutions (PCS) to undertake an investigation into sedimentation at the Port of Mackay, as part of the Sustainable Sediment Management (SSM) Project at the Port.

Aim: The overall aim of the study is to better understand the natural sedimentation which occurs at the Port and to identify whether there are feasible options to avoid or reduce sediment accumulation and therefore maintenance dredging in the future.

Bathymetric Analysis: Analysis of historic bathymetric data has found that the Port of Mackay has been subject to ongoing natural sedimentation and sediment sampling indicates that the deposited sediment is predominantly made up of fine-grained silt and clay. The majority of the sedimentation has occurred in the swing basin, with on average three times more sediment deposited in the swing basin (average = 18,000 m^3/yr) compared to the berths (average = 6,000 m^3/yr).

Tropical Cyclones have the potential to result in increased sedimentation in the Port of Mackay, volumes of between 35,000 and 50,000 m^3 can be deposited during the event. In the months following a TC there is also the potential for increased sedimentation, for example, during TC Debbie just over 35,000 m^3 of sediment was deposited within the Port and over the following five months an additional 40,000 m^3 was deposited.

Based on the available surveys of the Mackay DMPA it was found that the area was partially retentive over the short-duration, with the site retaining between 55 and 75% of the sediment placed there at the end of a maintenance dredging program. Over the longer-term, the DMPA was found to be stable during typical metocean conditions and then during extreme events with large waves (e.g. Tropical Cyclones) erosion of the DMPA can occur (natural erosion of the seabed adjacent to the DMPA would also be expected during these events).

Sediment Transport Understanding: The dominant processes which result in the resuspension of sediment in the Mackay region are wave action and tidal currents. The waves have the potential to result in much higher resuspension, while the tidal currents (and wind-generated currents) will transport the suspended sediment. The local currents around Mackay Harbour result in a net import of sediment, and the low current speeds within the Harbour means that it retains much of the sediment and acts as a sediment sink.

Sedimentation Rates: The sedimentation rates within the Port of Mackay were estimated based on the available bathymetric survey data. An approximate linear relationship between the volume of sedimentation and duration of time the H_s was above 2 m (i.e. the duration of large wave events) was identified. For years with typical wave conditions, the annual sedimentation was in the order of 20,000 to 40,000 m^3/yr, while for years with high wave energy the annual sedimentation could increase up to 90,000 m^3/yr. Based on the sedimentation rates a realistic upper value for sedimentation was used to estimate future maintenance dredging volumes for the Port. It was predicted that over 10 years the maintenance dredging volume for the Port of Mackay would be 500,000 m^3.

Avoid/Reduce Sedimentation and Dredging: A range of potential solutions to avoid or reduce the natural sedimentation or the requirement for maintenance dredging at the Port of Mackay were considered. The solutions included changing the configuration of the entrance to the Harbour, trying to block sediment from entering the Harbour, trapping sediment and a range of bed agitation approaches. Based on a constraints analysis the most feasible alternative solution to undertaking maintenance dredging every three years (frequency defined based on sedimentation to maintain design depths without additional management measures), is the ongoing operation of the siltation trench (sediment trap) combined with ongoing maintenance dredging every five years and annual bed levelling/drag barring. Although the approach doesn't specifically reduce the mass of sediment requiring management, it will reduce the volume of sediment requiring maintenance dredging, as the sediment in the trap will be more consolidated (reducing the in-situ volume). The associated bed levelling/drag barring will also resuspend some of the sediment (based on bathymetry surveys approximately 1,000 m^3/day has been assumed) and the trap will also help to improve the efficiency of the maintenance dredging, with more consolidated sediment located in a small area which will reduce the dredge duration.

Future Sediment Management: The predicted dredging volumes and frequencies for maintenance dredging and the sediment trap solution are as follows:

- Maintenance Dredging: 1,000,000 m^3 relocated over 20 years, with maintenance dredging occurring every three years along with bed levelling.
    - 150,000 m^3 relocated every three years (assuming over/insurance dredging of 0.6 m this frequency should on average maintain design depths); and
    - bed levelling undertaken immediately after maintenance dredging to level out the seabed and remove any high spots.
- Sediment Trap: 880,000 m^3 relocated over 20 years, with maintenance dredging occurring every five years and bed levelling/drag barring annually.
    - 220,000 m^3 relocated by maintenance dredging every five years (assuming over/insurance dredging of 0.6 m this frequency will mean that some drag barring is required to maintain design depths in some berths); and
    - a total of six days per year of bed levelling and drag barring to move and resuspend recently deposited sediment into the trap (only from south east region of swing basin) and resuspend sediment from the berths to help maintain depths.

1. Introduction

North Queensland Bulk Ports Corporation (NQBP) commissioned Port and Coastal Solutions (PCS) to undertake an investigation into sedimentation at the Port of Mackay, as part of the Sustainable Sediment Management (SSM) Project at the Port. The overall aim of the study is to better understand the natural sedimentation which occurs at the Port and to identify whether there are feasible options to avoid or reduce sediment accumulation in the future. The key components of the study are as follows:

- Bathymetric Analysis: the aim is to analyse historic bathymetric data for the dredged areas of the Port of Mackay and at the offshore dredge material placement area (DMPA), to quantify historic bathymetric change and relate these to the natural processes; and
- Engineered and Technological Solutions: the aim is to assess the availability, practicality and feasibility of engineered or technological solutions that could be implemented to reduce sedimentation in the dredged areas of the Port. The results will then be used to determine whether there are feasible solutions to avoid or reduce the need for maintenance dredging at the Port of Mackay.

This report provides details of both components of the study, with the report set out as follows:

- an introduction and background to the study is provided in Section 1;
- description of the local conditions at the Port of Mackay is given in Section 2;
- review and analysis of the bathymetric data is provided in Section 3;
- a conceptual sediment transport understanding is presented in Section 4;
- the engineered and technological solutions assessment is included in Section 5; and
- a summary of the findings is detailed in Section 6.

Unless stated otherwise, levels are reported to Lowest Astronomical Tide (LAT). Zero metres LAT is equal to Chart Datum (CD) at the Port of Mackay. Volumes presented throughout are *in-situ* cubic metres.

Wind and wave direction are reported as the direction the wind/waves are coming from in degrees clockwise from True North. Current direction is reported as the direction the current is going to in degrees clockwise from True North.

1.1. Background

NQBP undertakes maintenance dredging, bed levelling and drag barring[1] of the channel, swing basin and berths at the Port of Mackay, to ensure there is sufficient depth for vessels to safely travel to and from the berths (further detail of previous maintenance dredging is provided in Section 1.2). The sediment which has been relocated during previous maintenance dredging has been relocated to an offshore dredge material placement area (DMPA) located approximately 3 km to the east-north-east of the Port.

NQBP has current State and Commonwealth approvals to support maintenance dredging and at-sea placement of the dredged sediment at the Port of Mackay. The current sea dumping permit will expire in January 2022. Since the previous approval was given the process to obtain new long-term sea dumping permits in Queensland has become more onerous.

A Maintenance Dredging Strategy (MDS) has been developed for the ports that are situated within the Great Barrier Reef World Heritage Area (GBRWHA) (DTMR, 2016). The MDS provides a framework for the sustainable, leading practise management of maintenance

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[1] in this report these are defined as follows: bed levelling is aimed at the removal of high spots and levelling of the seabed immediately after maintenance dredging; and drag barring is aimed at resuspending and redistributing bed sediment in the years between maintenance dredging programs to help maintain design depths.

dredging (Figure 1). It is a requirement of the MDS that each Port within the GBRWHA develop Long-term Maintenance Dredging Management Plans (LMDMPs). The 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, as well as 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.

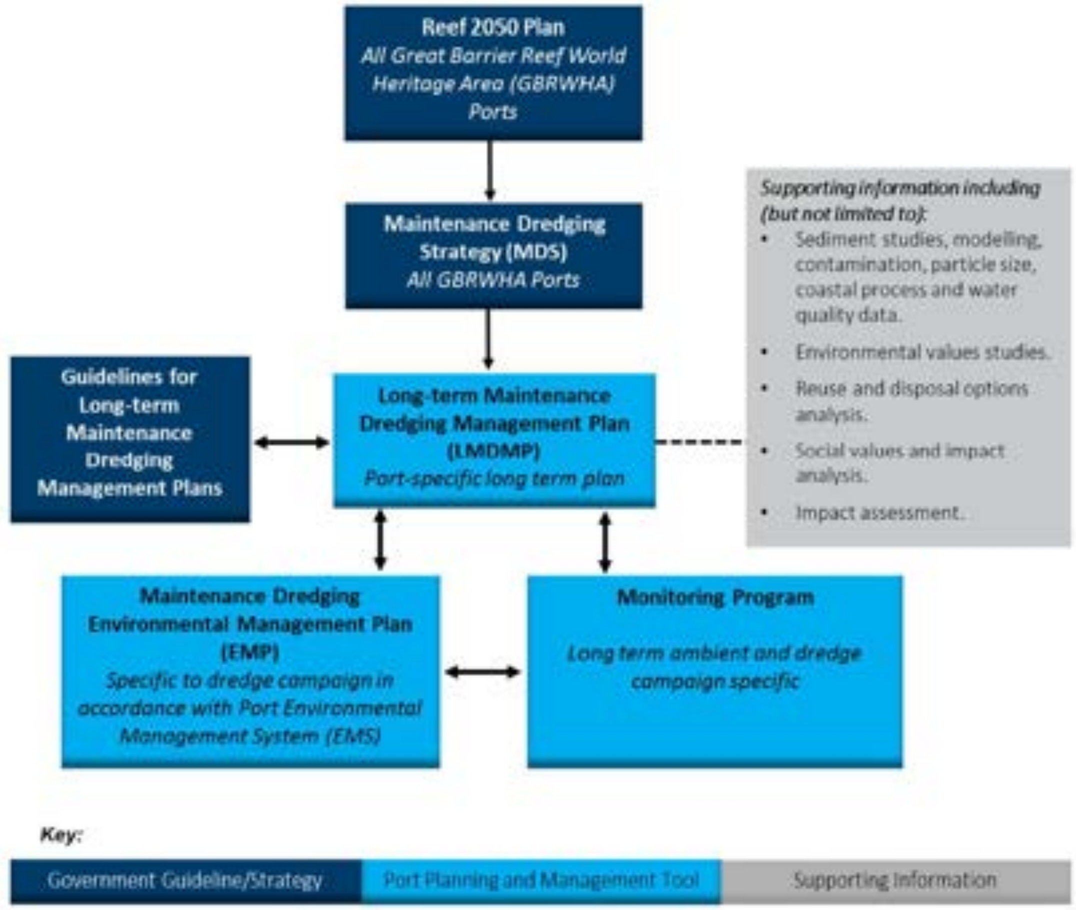


Figure 1. Planning and implementation mechanisms for maintenance dredging of ports Queensland wide (DTMR, 2018).

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, which 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 developed for the MDS, demonstrating that NQBP have been proactive at developing sound long-term maintenance dredging strategies. This investigation is aimed at answering the questions posed under point 1. Separate studies will be undertaken by NQBP to answer the other questions. The findings from this study will feed into the development of the LMDMP for 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 2).

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 with varying design depths (Figure 2 and Figure 3):

- 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 2018 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.

The 2012 to 2022 Long Term Dredge Management Plan for the Port of Mackay estimates the future maintenance dredging requirements for the Port as 120,000 m^3 every three years by the *TSHD Brisbane* and 10,000 m^3/yr by a grab dredge (e.g. *James Pearce*), giving an annual average sedimentation volume of 50,000 m^3/yr. Based on the historical maintenance dredging activity between 2004 and 2014, the Technical Supporting Document of the MDS (RHDHV, 2016a) estimated the sedimentation rates within the Port of Mackay as between 20,000 and 41,000 m^3/yr. A more accurate historical sedimentation rate will be calculated as part of this study based on the bathymetric surveys.

Table 1. Historic in-situ dredging volumes at the Port of Mackay (NQBP, 2011; RHDHV, 2016a).

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	

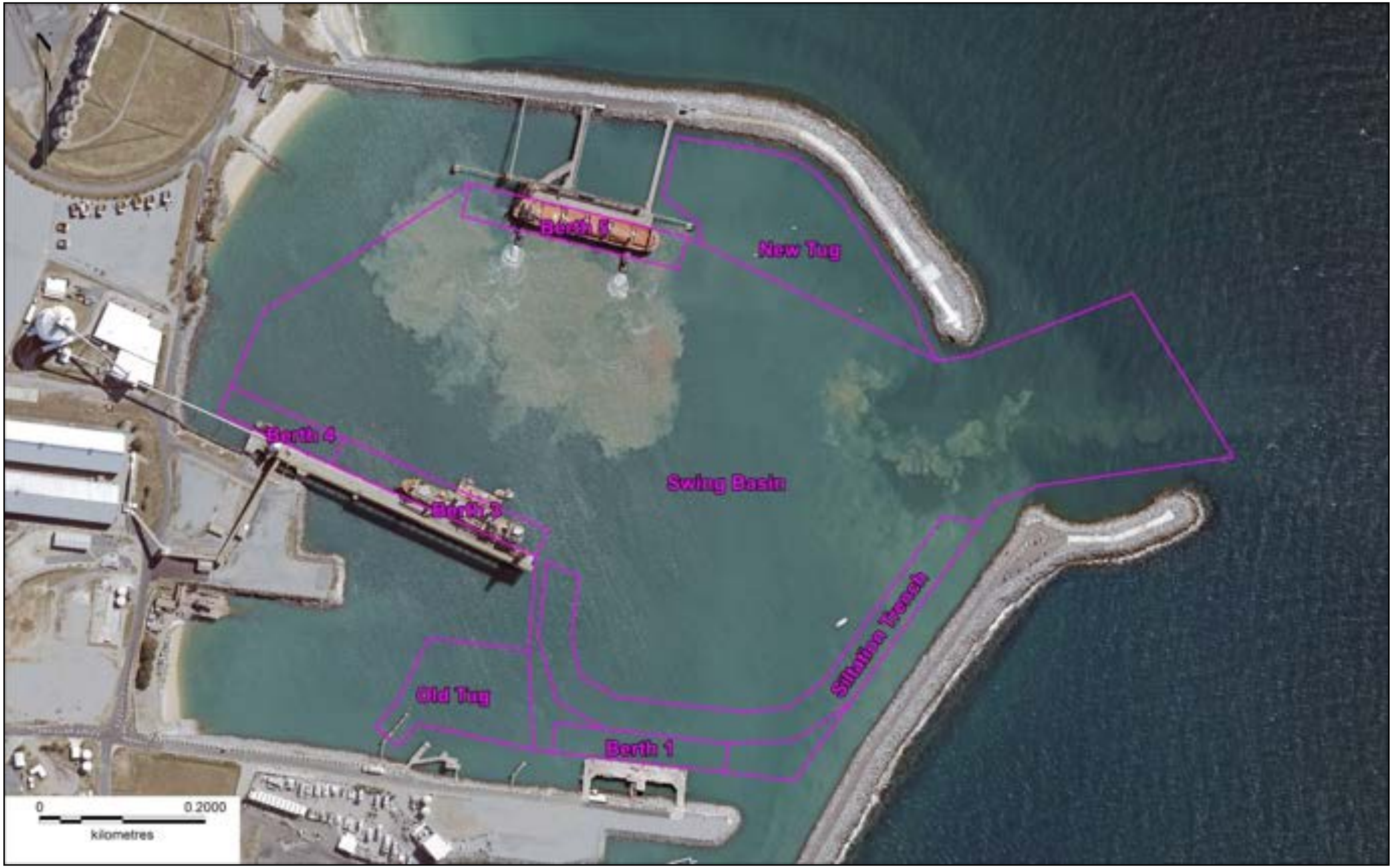


Figure 2. Port of Mackay swing basin, siltation trench, berths and location of the old and new tug bases.

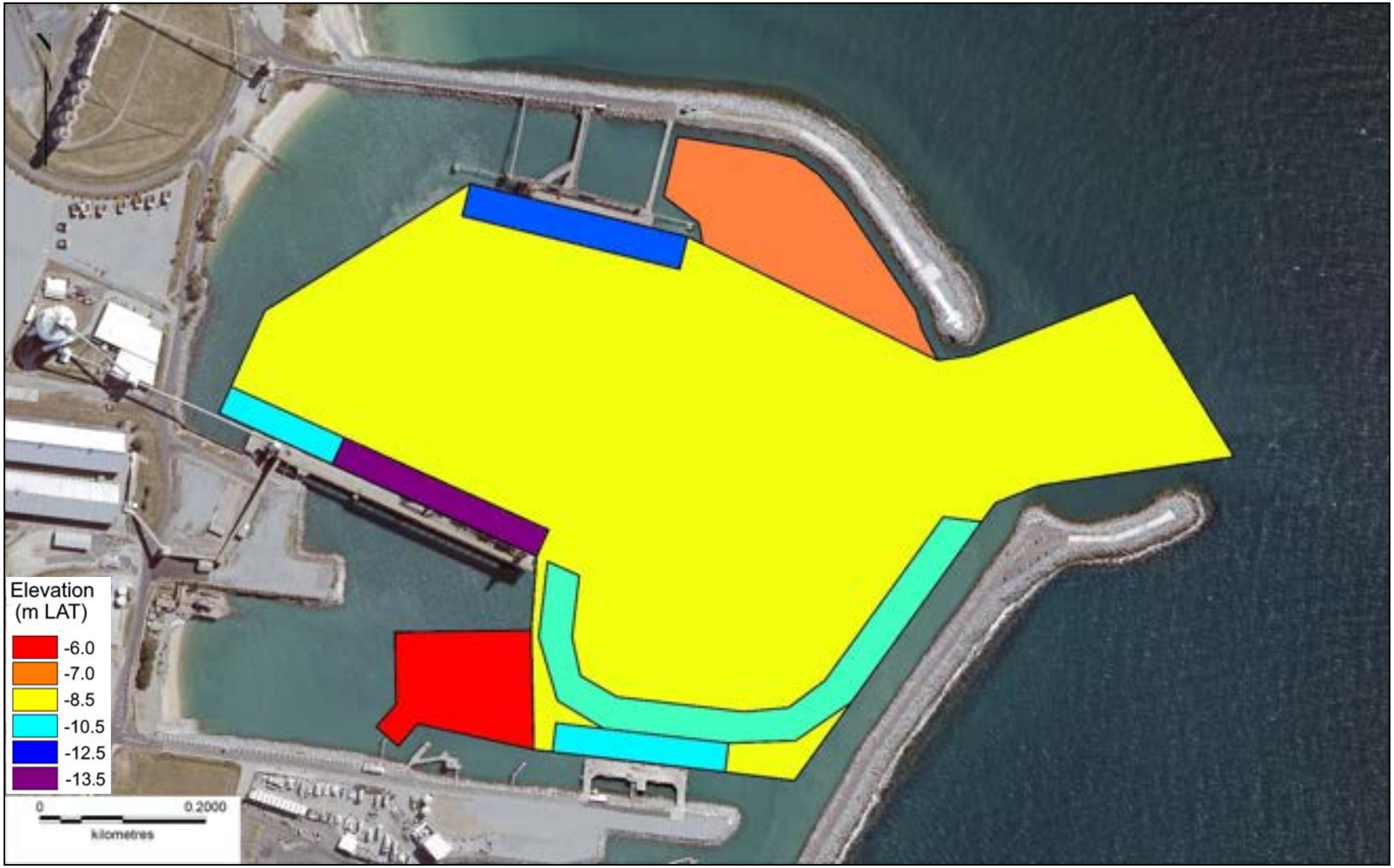


Figure 3. Design depths in the Port of Mackay.

2. Local Conditions

This section provides details and interpretation of available hydrodynamic, meteorological, water quality and sedimentological data. A summary of the data used in the study is provided in Table 2 and locations are shown in Figure 4.

Table 2. Overview of available data sources in the Mackay region (see Figure 4 for locations).

Data Type	Location	Description
Meteorological	Mackay	Bureau of Meteorology (BoM) station at Mackay Meteorological Office (MO) measuring rainfall and wind (2000 to 2021)
Water Level	Port of Mackay	Storm tide gauge managed by the Department of Environment and Science (DES), located in Mackay Harbour on Pier No.1 (1975 to 2021).
Waves	Mackay WRB, Hay Point WRB, Mackay Nearshore (MK1 & MK2)	Waverider buoys (WRB) at Mackay WRB (offshore) and Hay Point WRB (nearshore) managed by DES (1975 to 2021). Instruments were also deployed approximately 1 km to the east (MK1) and to the north (MK2) of Mackay Harbour from January to April 2017 (RHDHV, 2017a).
Currents	Mackay Nearshore (MK1)	Data collected from January to April 2017 approximately 1 km to the east of the entrance to Mackay Harbour (RHDHV, 2017a). Based on these data a numerical model was developed for the area which provides additional spatial information about the currents (RHDHV, 2017b).
Water Quality & Deposition	Mackay and Hay Point region	Data are being collected by James Cook University (JCU) as part of the ongoing ambient marine water quality monitoring (2014 to 2021). Slade Islet is the closest site to the Port of Mackay.
Sediment Properties	Port of Mackay	Information is available from the previous sediment sampling (NQBP, 2011; NQBP, 2018).

2.1. Water Levels

Mackay Harbour is located within an area of Queensland which experiences the highest tidal range, this is primarily due to local tidal amplification at Broad Sound. The tides at Mackay are categorised as mixed semi-diurnal, with a peak tidal range of 6.58 m and mean spring tidal range of 4.55 m. The tidal planes for Mackay Harbour are shown in Table 3.

Table 3. Mackay Harbour tidal planes (MSQ, 2018).

Tidal Level	Height (m LAT)	Height (m AHD)
HAT	6.58	3.64
MHWS	5.29	2.35
MHWN	4.07	1.13
MSL	3.02	0.08
AHD	2.94	0
MLWN	1.96	-0.98
MLWS	0.74	-2.20

Storm surges occur in the Mackay region with the largest typically associated with cyclonic events. When the surges coincide with high water during spring tides there is the potential for the combined tidal level and storm surge to exceed the Highest Astronomical Tide (HAT) level.

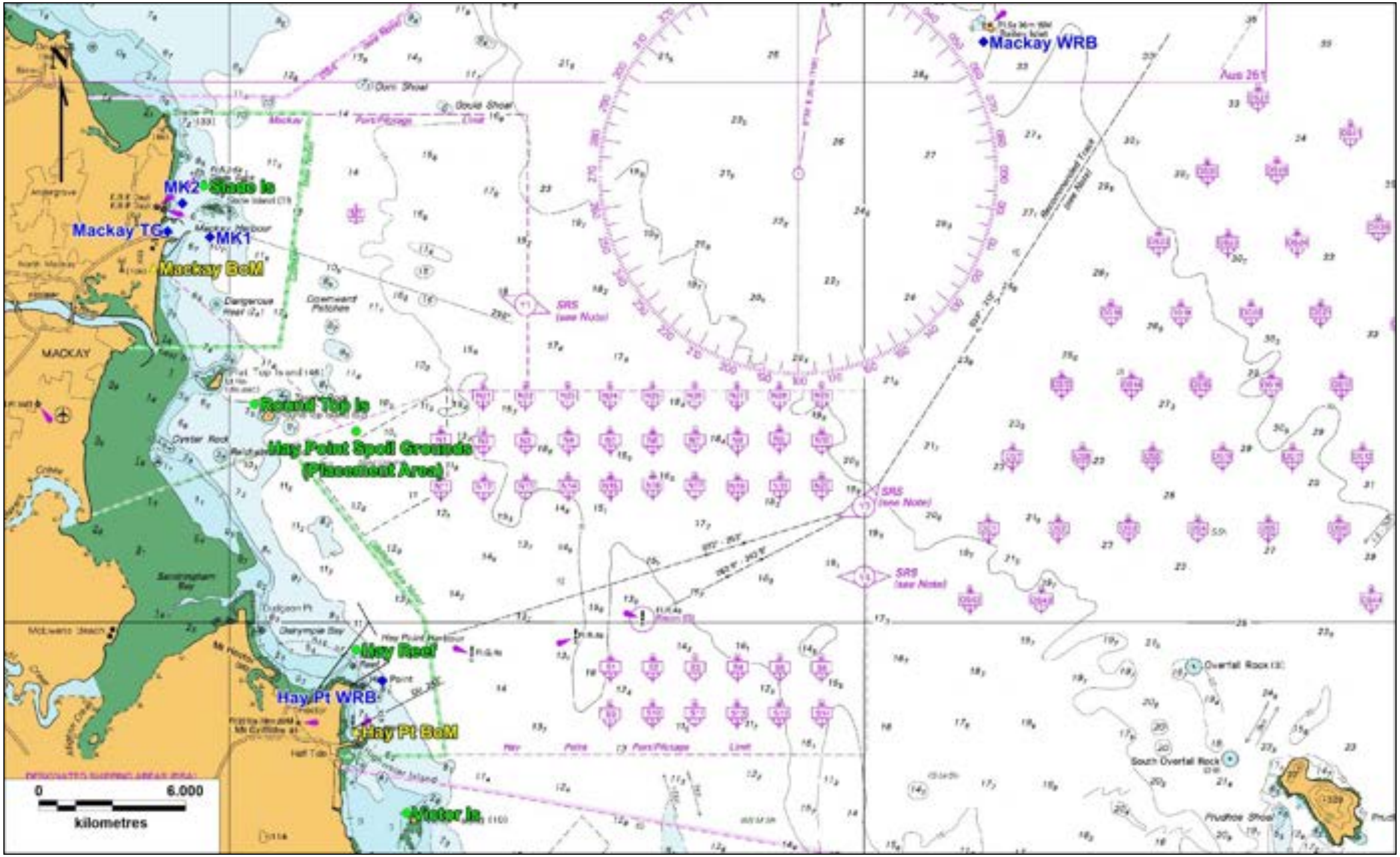


Figure 4. Location of measured metocean data in the Mackay and Hay Point region. *Note: blue = hydrodynamic and wave, green = water quality, yellow = meteorological.*

2.2. Tidal Currents

Current data were collected from January to April 2017 at MK1 which was located approximately 1 km to the east of the entrance to Mackay Harbour (see Figure 4) (RHDHV, 2017a). Mid-water column current data from MK1 are shown in Figure 5 over a spring-neap cycle for typical conditions. The plots show that at this site:

- peak tidal current speeds range from 0.3 to 0.8 m/s, with stronger currents occurring during the spring tides and weaker currents during neap tides; and
- the peak flood current direction is to the south-east and the peak ebb current direction is to the north. The reason that the flood current is to the south-east rather than the south (which would be expected given the general alignment of the shoreline) is because of the flow being deflected by Slade Islet and Mackay Harbour.

The measured current data collected at MK1 and MK2, located to the north of Mackay Harbour, were used to calibrate and validate a numerical model of the region (RHDHV, 2017b). Plots of the peak flood and peak ebb currents for the Mackay region are shown in Figure 6 and Figure 7 and for Mackay Harbour in Figure 8 and Figure 9. The plots show that the tidal currents generally flow parallel to the coastline, with the flood currents in a southerly direction and ebb currents in a northerly direction. The northerly ebb currents are generally stronger in most locations and as such a net northerly residual transport direction is expected. The currents increase around Slade Islet and adjacent to the Mackay Harbour breakwaters, with the strongest currents typically occurring between the Harbour breakwaters and Slade Islet. Within the Harbour the peak flood current speed is significantly higher than the peak ebb speed, with peak ebb speeds within the Harbour typically remaining below 0.1 m/s. This suggests that the Harbour will act as a net importer of sediment, with the low ebb current speeds being unlikely to resuspend any sediment which is deposited in the Harbour over the high water slack period.

Winds can also influence the currents which occur in the Mackay region, with the dominant south-easterly trade winds acting to further strengthen the northerly ebb currents. Very strong winds during Tropical cyclones (TC) can result in increased current speeds and also changes in current direction due to the associated strong winds, this is further discussed in Section 2.6.

As well as tide and wind induced currents, regional scale circulation currents can occur in the GBR Lagoon. These regional scale currents are dynamic and intermittent as they are primarily driven by a complex interaction between oceanic inflows caused by the North Vanuatu Jet and local wind driven circulation (Andutta et al., 2013). Although these regional scale ocean circulation processes have the potential to intermittently influence current regimes at the Port of Mackay, their impacts are considered minor relative to tidal and wind induced currents.

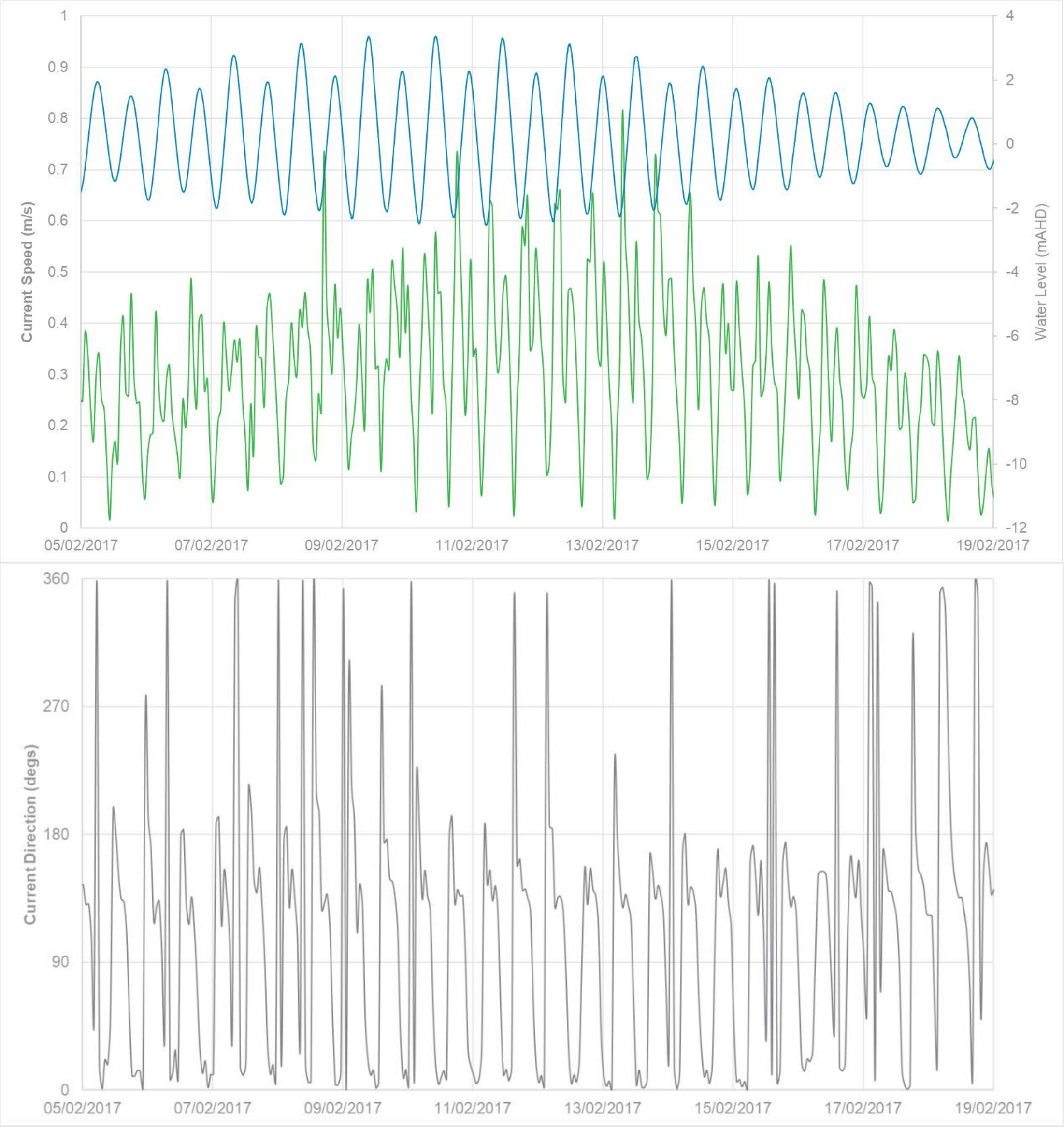


Figure 5. Measured water level (Mackay Harbour), current speed and direction (MK1) over a spring-neap cycle.

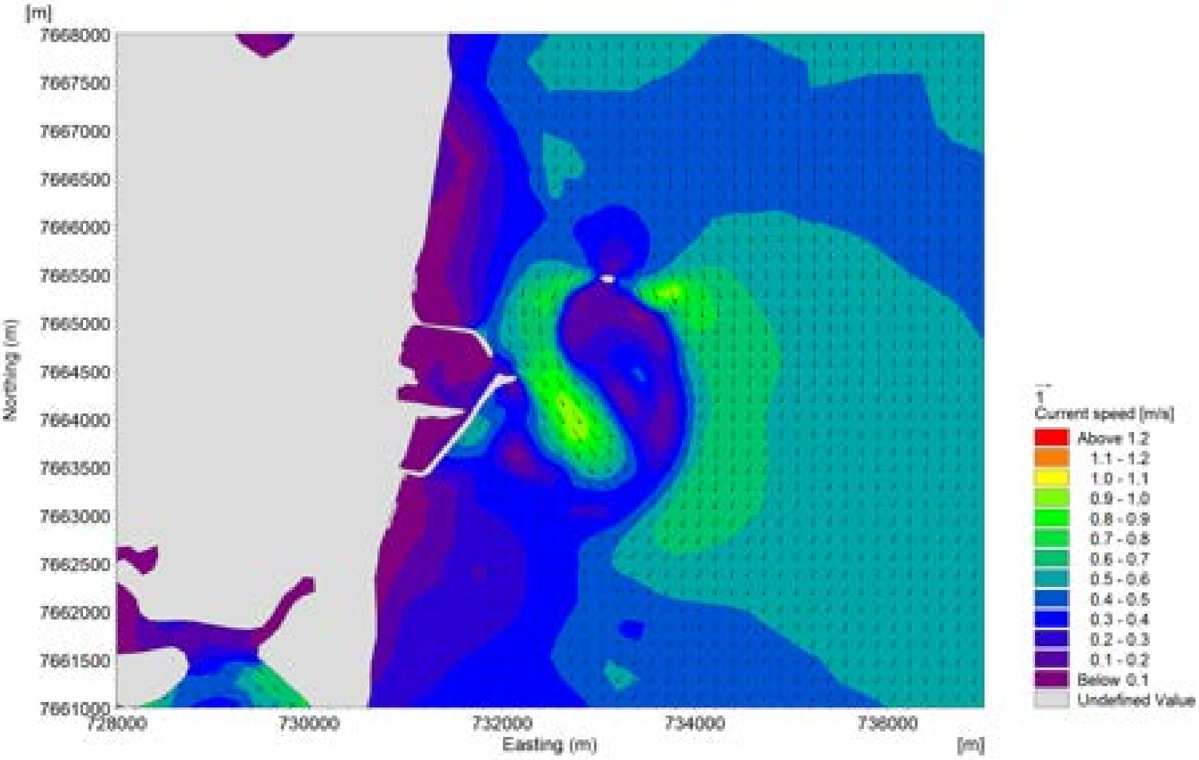


Figure 6. Modelled peak flood tidal currents around Mackay Harbour during a spring tide (RHDHV, 2017b).

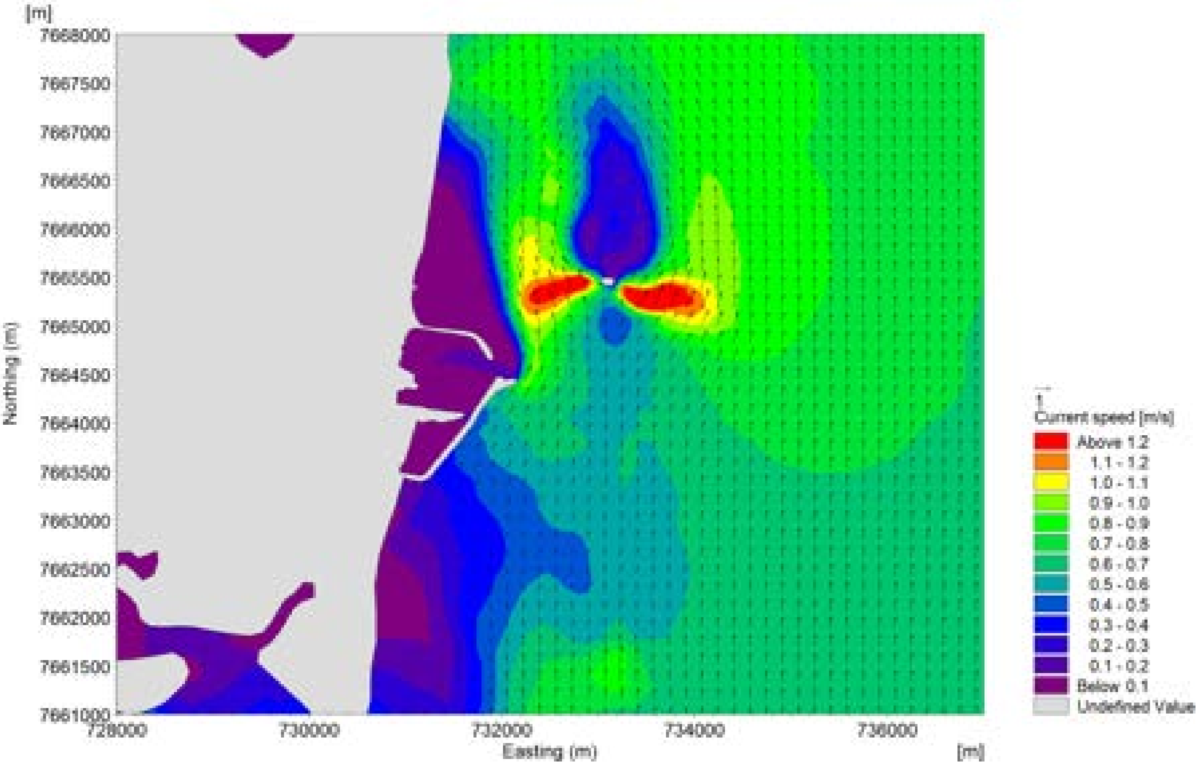


Figure 7. Modelled peak ebb tidal currents around Mackay Harbour during a spring tide (RHDHV, 2017b).

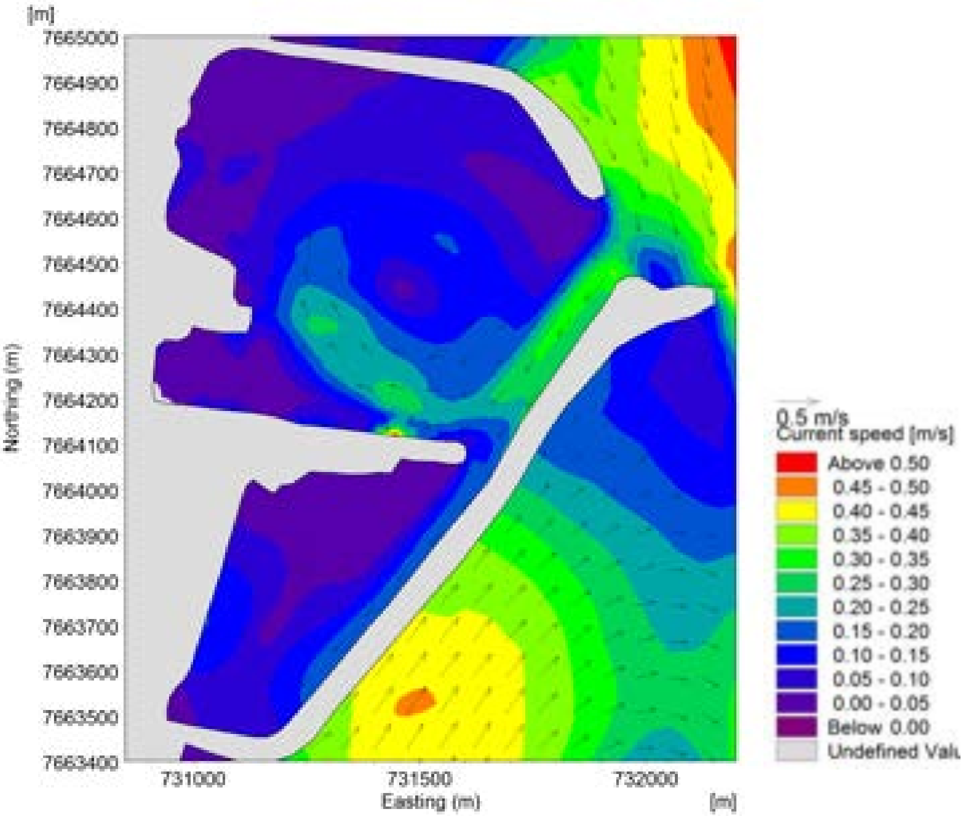


Figure 8. **Modelled peak flood tidal currents at Mackay Harbour during a spring tide (RHDHV, 2017c).**

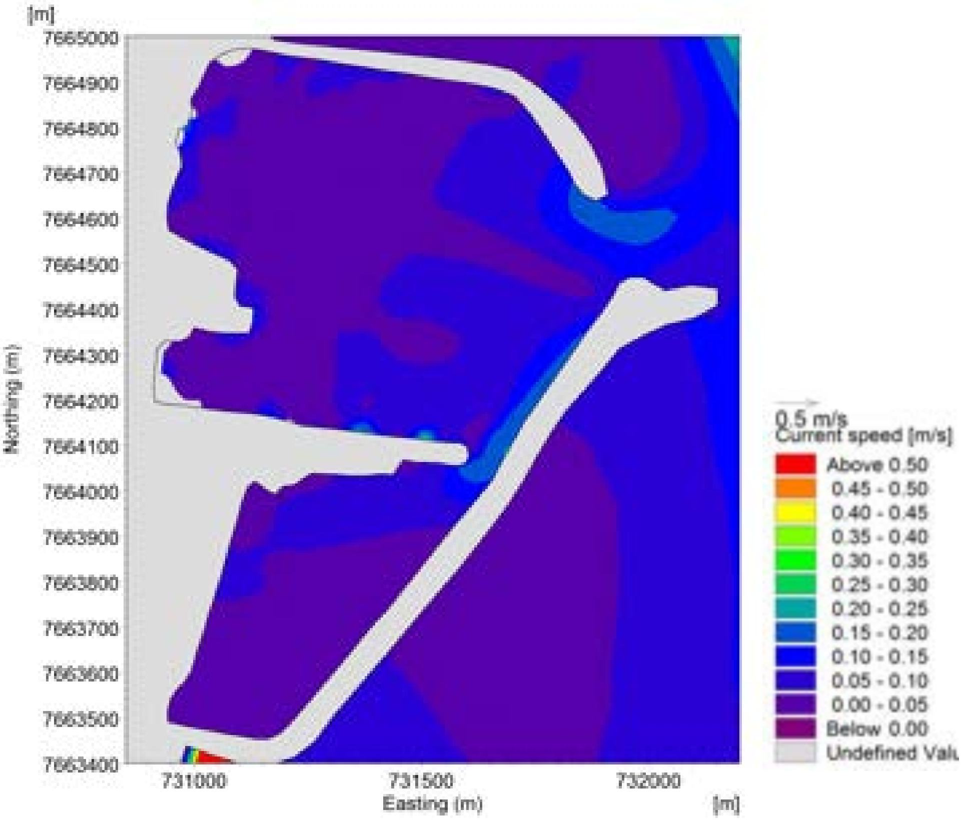


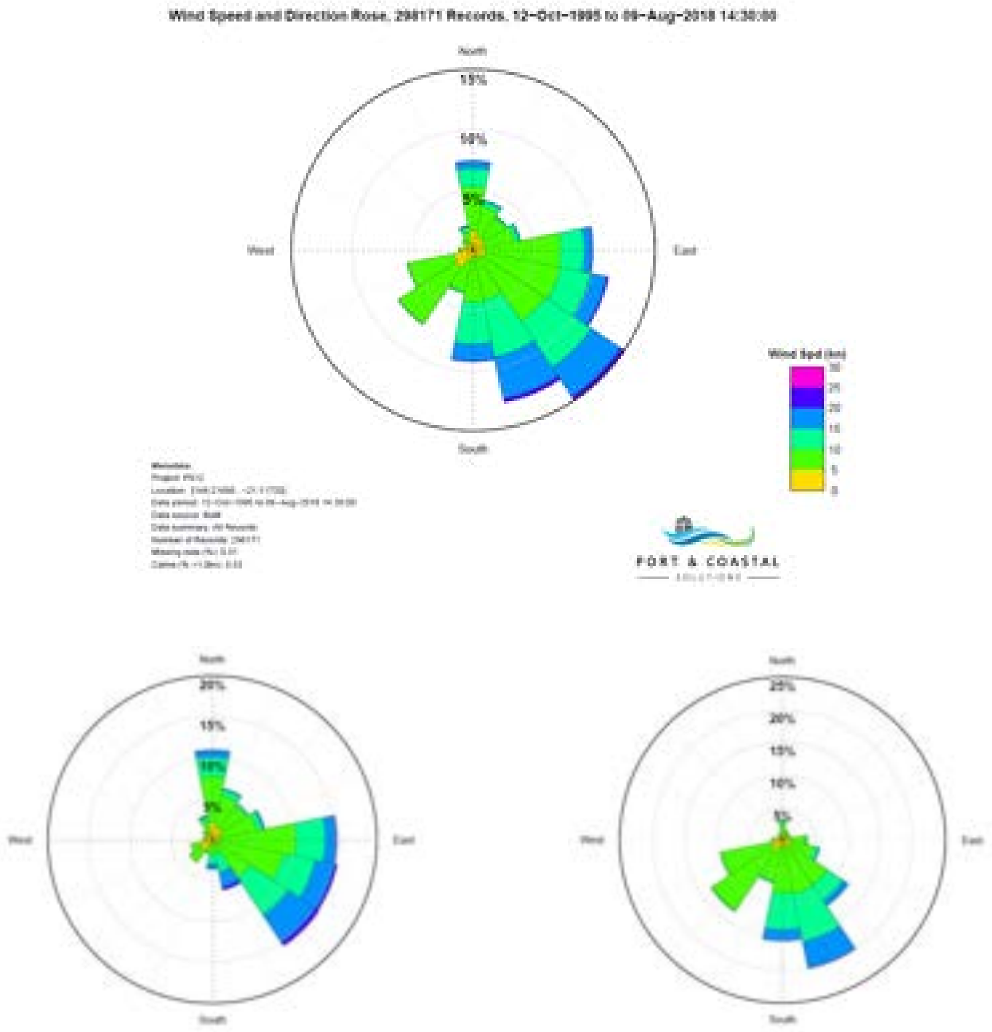
Figure 9. **Modelled peak ebb tidal currents at Mackay Harbour during a spring tide (RHDHV, 2017c).**

2.3. Wind

Mackay lies in the trade wind belt for most of the year resulting in the local wind climate being governed by easterly to southerly winds. The wind conditions measured by BoM at the Mackay MO station from 1995 to 2018 are presented in Figure 10. The plot shows the dominance of trade winds from an easterly to southerly direction, with winds from the south-east occurring most frequently. The figures also show that during the summer months the wind conditions tend to be stronger and more variable with wind directions frequently being from the north and east to south-east. During the winter months the wind speed tends to be lower and the direction less variable, with wind directions from the south-east to south-west dominating.

The highest wind speeds which occur in the Mackay region are a result of tropical cyclones which can influence the area. The associated speed and direction of these winds are a direct result of the intensity and location of the cyclones. This is further discussed in Section 2.6.

Local wind conditions are an important driver for both locally generated waves in the Mackay region as well as wind-generated currents. Wave conditions in the Mackay region are discussed further in Section 2.4.



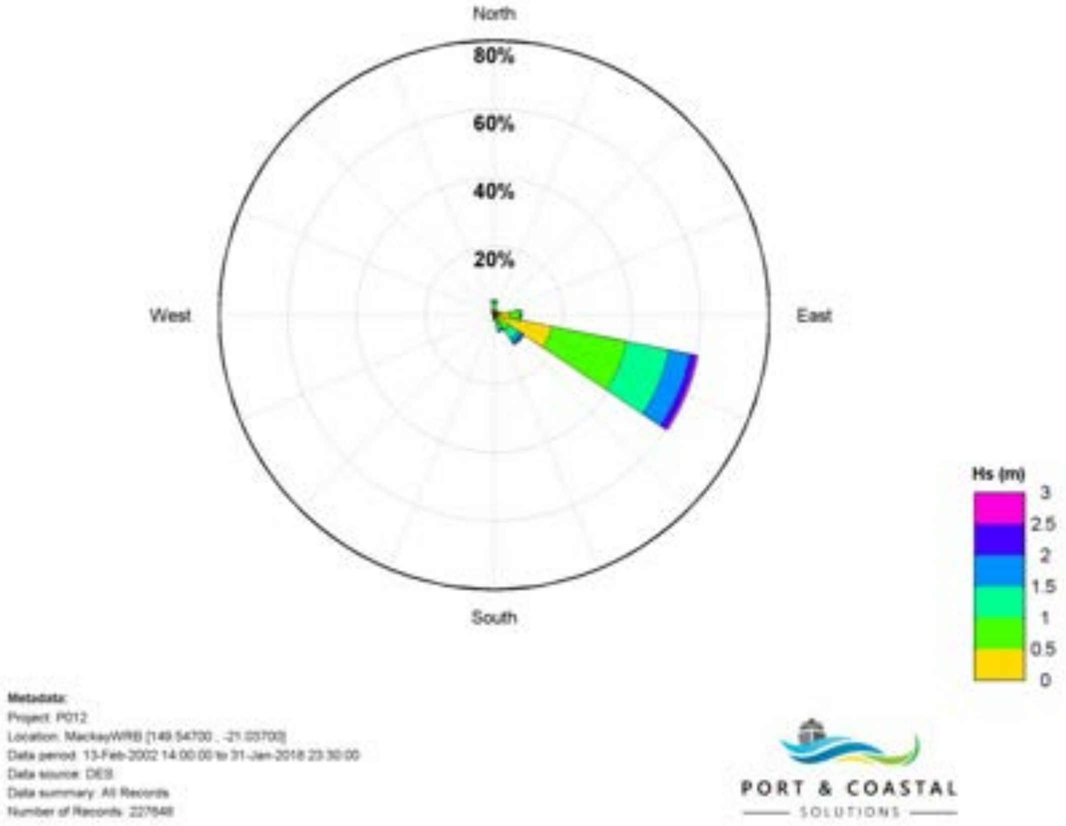
Summer Months *Winter Months*

Figure 10. Wind roses from the measured wind data from Mackay MO (1995 – 2018).

2.4. Waves

Wave data have been collected at the Mackay WRB since 1975 and at the Hay Point WRB since 1977. The Mackay WRB is located approximately 34 km to the east-north-east of Mackay Harbour in water depths of 34 m below LAT, while the Hay Pt WRB is located 20 km to the south-south-east of Mackay Harbour in water depths of 10 m below LAT (Figure 4). The Mackay WRB can be used to understand the wave conditions offshore of Mackay Harbour, while the Hay Point WRB can be used to provide an indication of the nearshore wave conditions for the region, where nearshore processes such as refraction and depth-induced wave breaking are important. Wave roses of the significant wave height (H_s) and wave direction for the Mackay WRB and the Hay Point WRB are shown in Figure 11 and Figure 12. Scatter plots of H_s, peak wave period (T_p) and wave direction are shown for the Mackay WRB in Figure 13 and Figure 14 and for the Hay Point WRB in Figure 15 and Figure 16. The figures can be used to understand the wave conditions in the Mackay region:

- Offshore wave conditions: for the majority of the time the wave direction is from the east-south-east and the H_s is less than 2.5 m. The scatter plots show that the largest H_s was over 5.5 m and for the larger wave events (e.g. $H_s > 4$ m) the wave direction is typically from the east to east-south-east. The peak wave period for these larger wave events were between 8 and 11 seconds (s); and
- Nearshore wave conditions: the nearshore wave direction is more variable than the offshore direction, with waves typically from the east but also regularly occurring from the east-north-east and east-south-east. The H_s is less than 1.5 m for the majority of the time, with the largest H_s of just below 4 m. For larger wave events (e.g. $H_s > 3$ m) the wave direction has varied between the east and north-east and the peak wave period has been between 7 and 11 s.



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Data period: 13-Feb-2002 14:00:00 to 31-Jan-2018 23:30:00
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Data summary: All Records
Number of Records: 227848

Figure 11. Wave rose showing the measured wave conditions at the Mackay WRB.

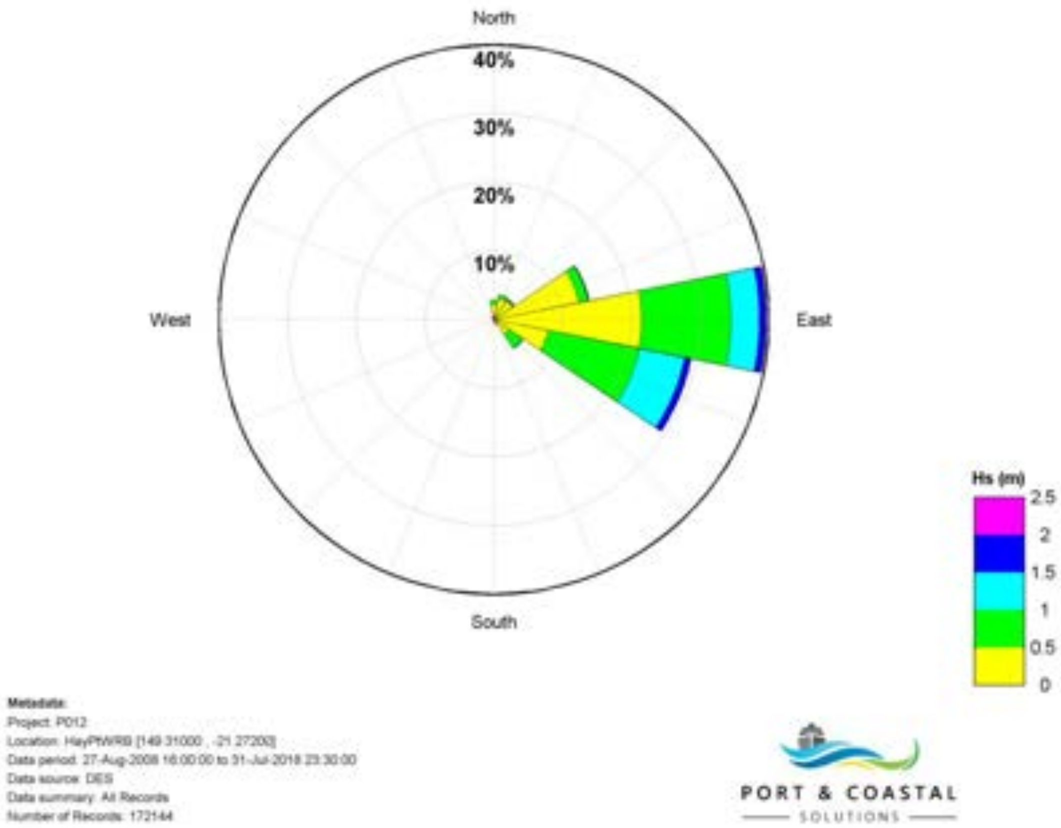

Figure 12. Wave rose showing the measured wave conditions at the Hay Point WRB.

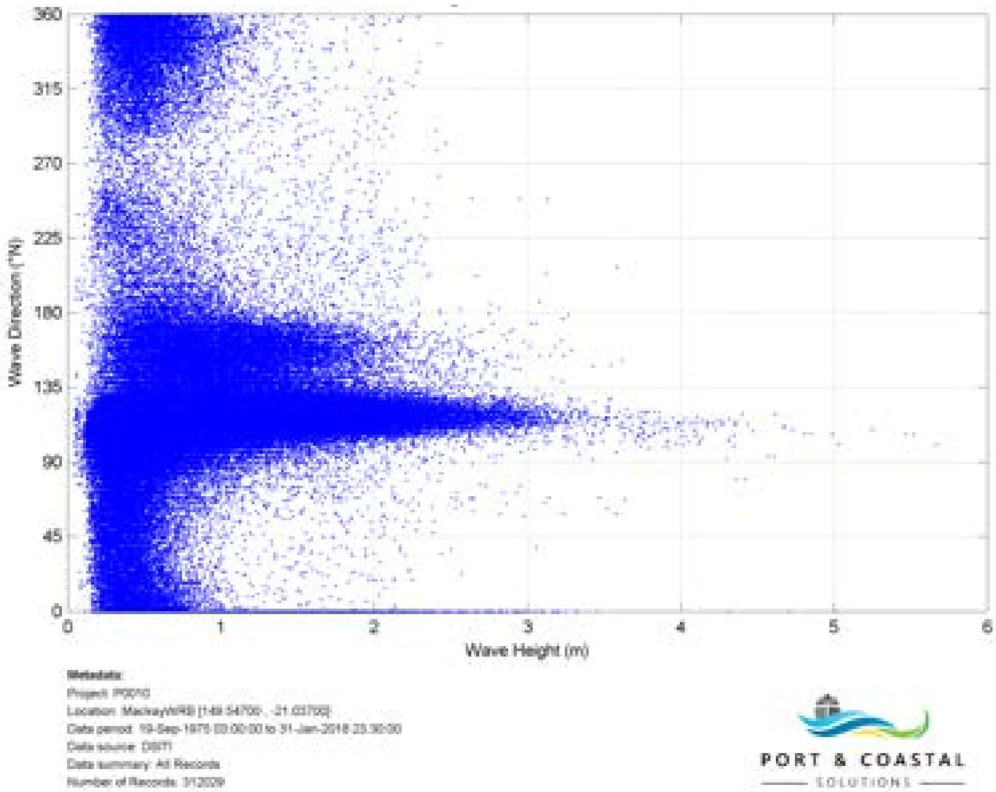

Figure 13. Significant wave height and wave direction scatter plot for Mackay WRB.

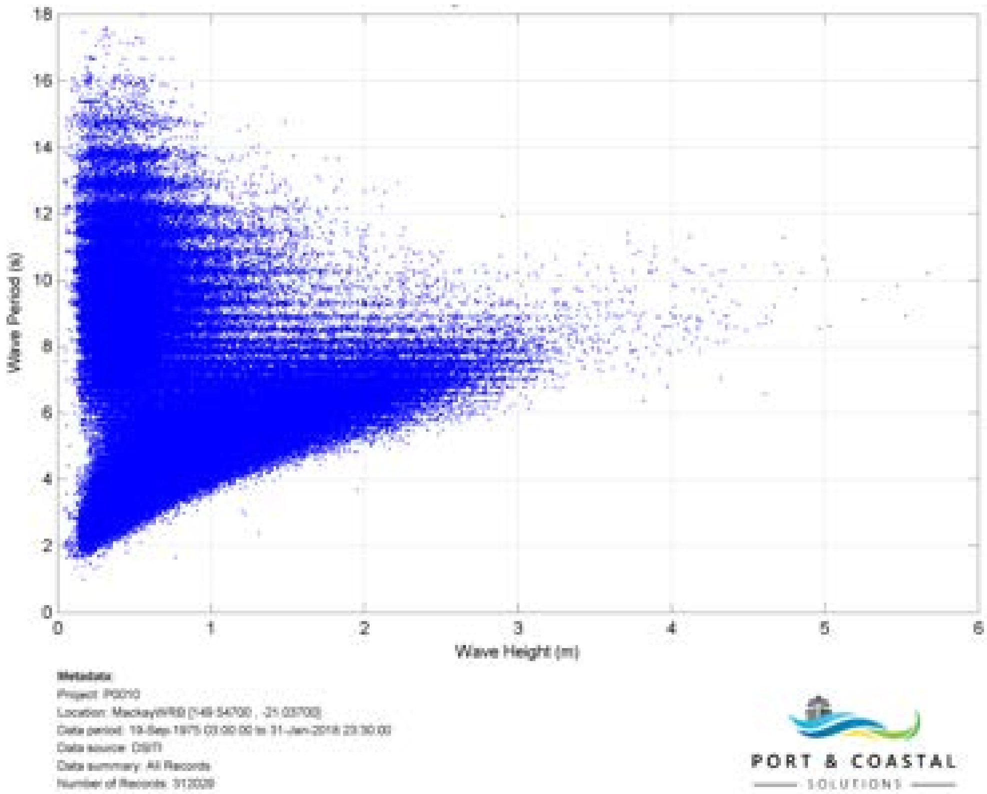

Figure 14. Significant wave height and peak wave period scatter plot for Mackay WRB.

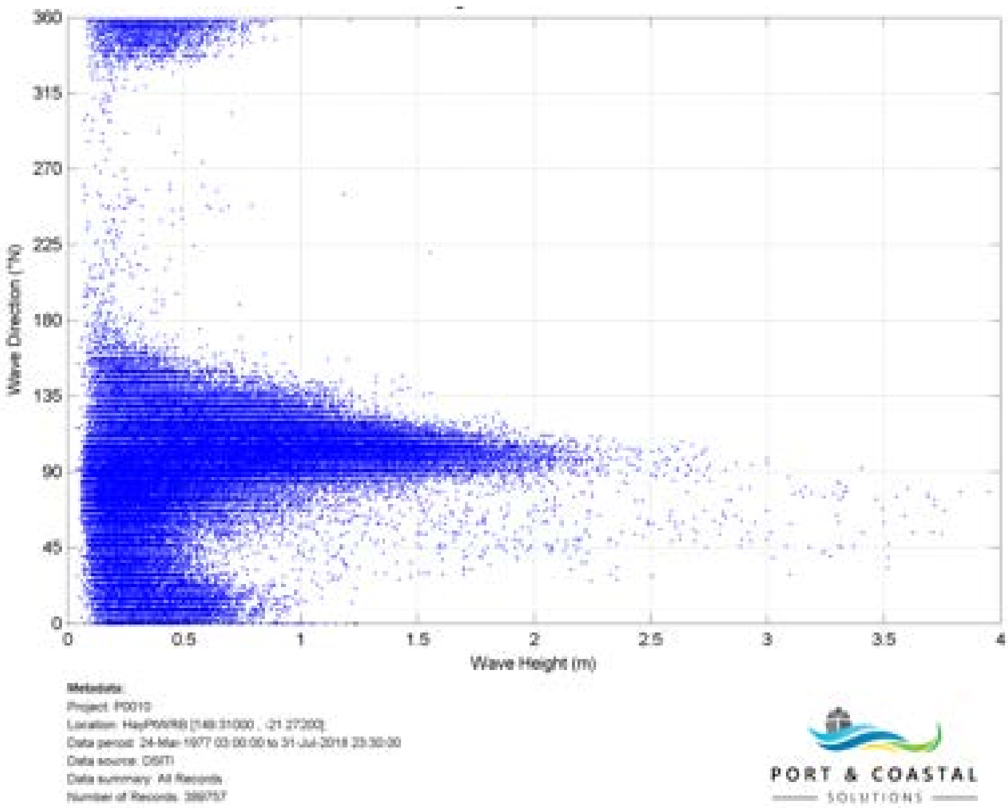

Figure 15. Significant wave height and wave direction scatter plot for Hay Point WRB.

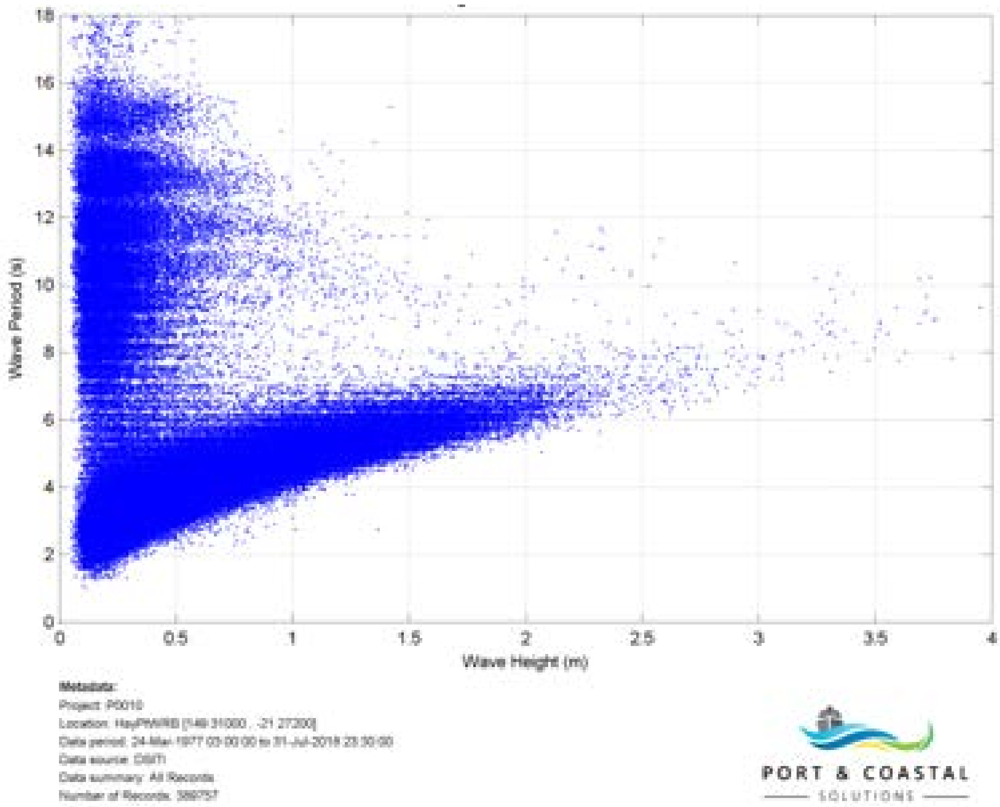

Figure 16. Significant wave height and peak wave period scatter plot for Hay Point WRB.

Measured wave data from 1975 to 2018 (Mackay WRB) and 1977 to 2018 (Hay Point WRB) were processed to determine the largest wave events which have occurred over these periods (noting that the data pre-1993 is likely to underestimate the peak H_s as the data were measured every 6-12 hours, compared to every 30 minutes after 1993). The results are presented in Table 4 and show that at both sites the largest four measured wave conditions were due to the same tropical cyclones (TCs), namely TC Ului, TC Dylan, TC Debbie and TC Justin. It is also worth noting that there is less variability between the wave heights of the events at the nearshore Hay Point WRB compared to the Mackay WRB, due to the shallow water resulting in wave attenuation (with more attenuation of larger waves) owing to processes such as refraction and wave breaking.

Table 4. Five largest H_s at the Mackay WRB and Hay Point WRB from 1975/1977 to 2018.

Mackay WRB (Offshore Conditions)			Hay Point WRB (Nearshore Conditions)		
Date	Peak H_s (m)	Notes	Date	Peak H_s (m)	Notes
20/03/2010	5.67	TC Ului	21/03/2010	3.95	TC Ului
30/01/2014	5.02	TC Dylan	30/01/2014	3.74	TC Dylan
28/03/2017	4.96[1]	TC Debbie	28/03/2017	3.63	TC Debbie
10/03/1997	4.81	TC Justin	09/03/1997	3.10	TC Justin
02/03/1979	4.02[2]	TC Kerry	31/01/2010	2.81	TC Olga

[1] the Mackay WRB malfunctioned before the peak of TC Debbie and so the H_s was larger than the 4.96 m shown.
[2] as the Mackay WRB only measured H_s every twelve hours at this time the peak H_s is expected to have exceeded the measured 4.02 m.

Wave data were measured at MK1 and MK2 as well as at the Hay Point WRB and the Mackay WRB (until it failed just prior to the peak of the event) during TC Debbie (Figure 17). Comparison of the measured wave data at the Hay Point WRB and MK1 shows that the wave heights were comparable, with the peak in wave height being slightly larger at MK1. This shows that the measured wave data at the Hay Point WRB can be used to provide a good indication of the wave conditions directly offshore of Mackay Harbour. As a result, it is possible to adopt the relationship between wind speed and H_S which was developed for the Port of Hay Point as an indication of the wave conditions at Mackay for varying wind speeds (Figure 18).

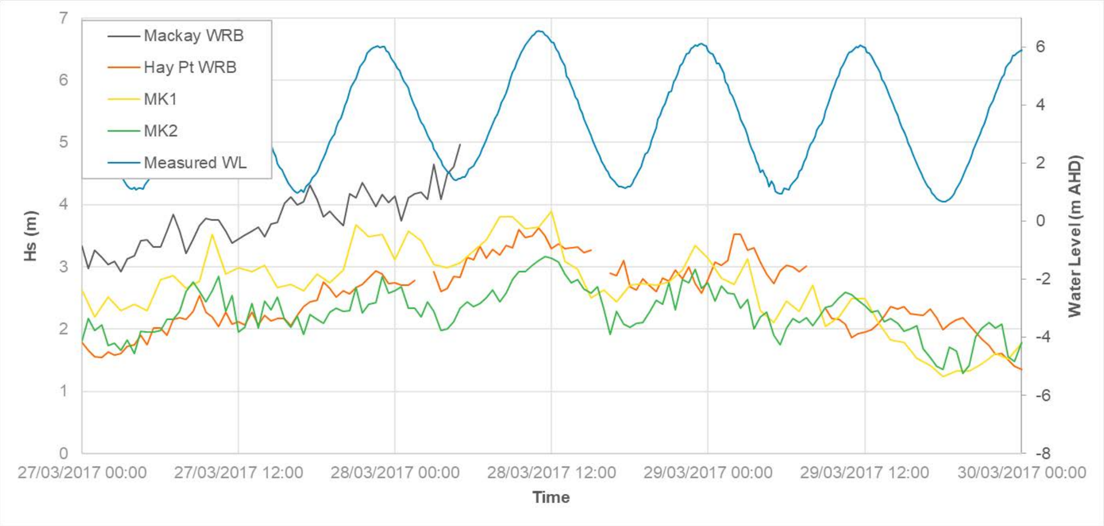

Figure 17. Measured H_S and water level (Mackay TG) during the peak of TC Debbie.

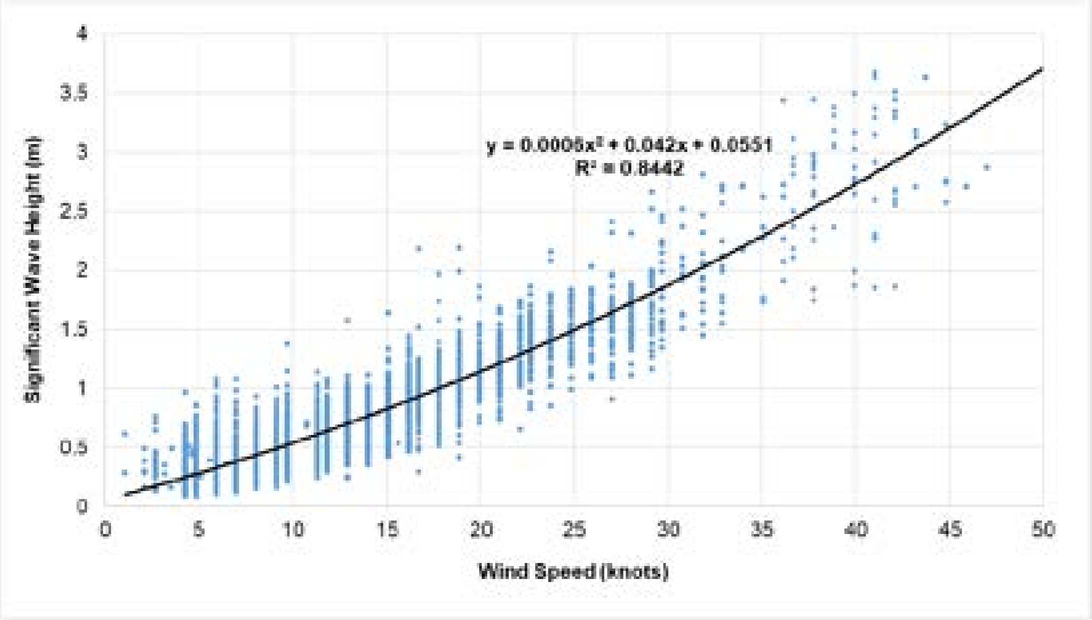

Figure 18. Relationship between H_S and wind speed at the Port of Hay Point (RHDHV, 2017d).

2.5. Rainfall

Mackay experiences a tropical climate with a distinct monsoonal rainfall trend. In this study, rainfall data recorded at the Mackay MO (1959 - 2015) has been analysed. On average Mackay receives 1,595 mm of rainfall each year. Average monthly rainfall measurements are shown in Figure 19. Rainfall in the region can be summarised as:

- the wet season is between January and March and sees a significant proportion of the annual rainfall occurring (approximately 60%);
- the dry season is between June and October with very little rainfall occurring (approximately 10%); and
- the months of April to May and November to December are the transition periods between the wet and dry seasons.

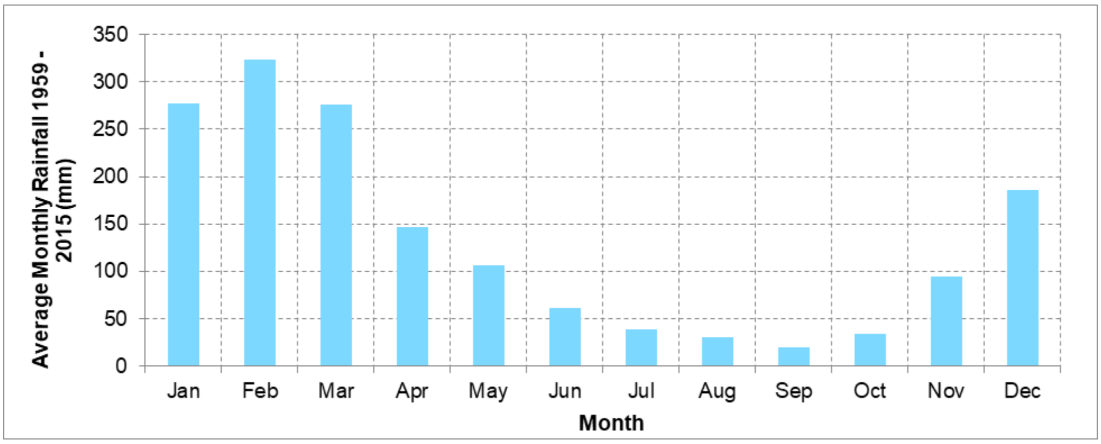

Figure 19. Mackay average monthly rainfall.

Rainfall and the associated catchment runoff is one of the key drivers responsible for the input of new terrigenous sediment to the inner shelf of the GBR. During the wet season, cyclones and periods of high rainfall can result in large volumes of sediment being input into the waters of the Great Barrier Reef (GBR) via local river systems and their associated catchment areas.

Based on the sediment budget developed for the Hay Point and Mackay regions it was found that direct deposition during wet season flood events from local catchments accounted for less than 1% of the observed sedimentation at the Port of Hay Point (AECOM, 2016). In addition, it has been estimated that the sediment load from rivers within 20 km of the Port of Mackay is approximately 140,000 tonnes/yr (BMT WBM, 2018). When this is compared to the estimated resuspension of existing seabed sediment of 6.7 million tonnes/yr for the same region (BMT WBM, 2018) it is clear that the input of sediment from the rivers represents a small amount (2%) of the total sediment transport which is occurring in the region. Based on this, the direct input of sediment from rivers in the Mackay region can be considered negligible in terms of ongoing sedimentation at the Port of Mackay.

2.6. Tropical Cyclones

Mackay is vulnerable to the effects of severe tropical cyclones during the summer months (wet season) and since 1969 a total of 29 cyclones have passed within 200 km of Mackay (www.bom.gov.au/cyclone/history/tracks). Recent notable cyclones which have affected the Port of Mackay include TC Ului (March 2010), TC Dylan (January 2014) and TC Debbie (2017). Wave and wind data collected during the passing of these cyclones are summarised in Table 5.

Table 5. Recent measured cyclonic wind (Mackay MO) and wave (Hay Pt WRB) conditions.

Cyclone	Peak 10 minute averaged wind speed (kn)	Peak H_s (m)	Peak H_{max} (m)
TC Ului (March 2010)	43	3.95	6.35
TC Dylan (January 2014)	37	3.74	7.05
TC Debbie (March 2017)	36	3.63	6.65

Tropical cyclones have the potential to cause significant sediment transport and subsequent sedimentation by generating large waves, strong currents and increased river discharge. Due to the typical east to west projection of cyclones making landfall along the GBR coastline, passing cyclones generally result in the development of strong north-westerly longshore currents as well as large waves from the south-east to north-east. These higher energy wave and current events have the potential to mobilise bed sediments in deep water areas which would not normally be subject to bed sediment mobilisation under ambient conditions. Research conducted by Carter et al (2009) showed that wave generated bed shear stresses from an intense cyclone can suspend sediments at depths of up to 30 – 60 m.

Cyclone induced waves and currents are also considered to be important in the supply of new fine-grained sediment to the inner-shelf of the GBR through the erosion and advection of sediments from the deeper mid-shelf of the GBR (Gagan et. al., 1990; and Orphin & Ridd, 2012).

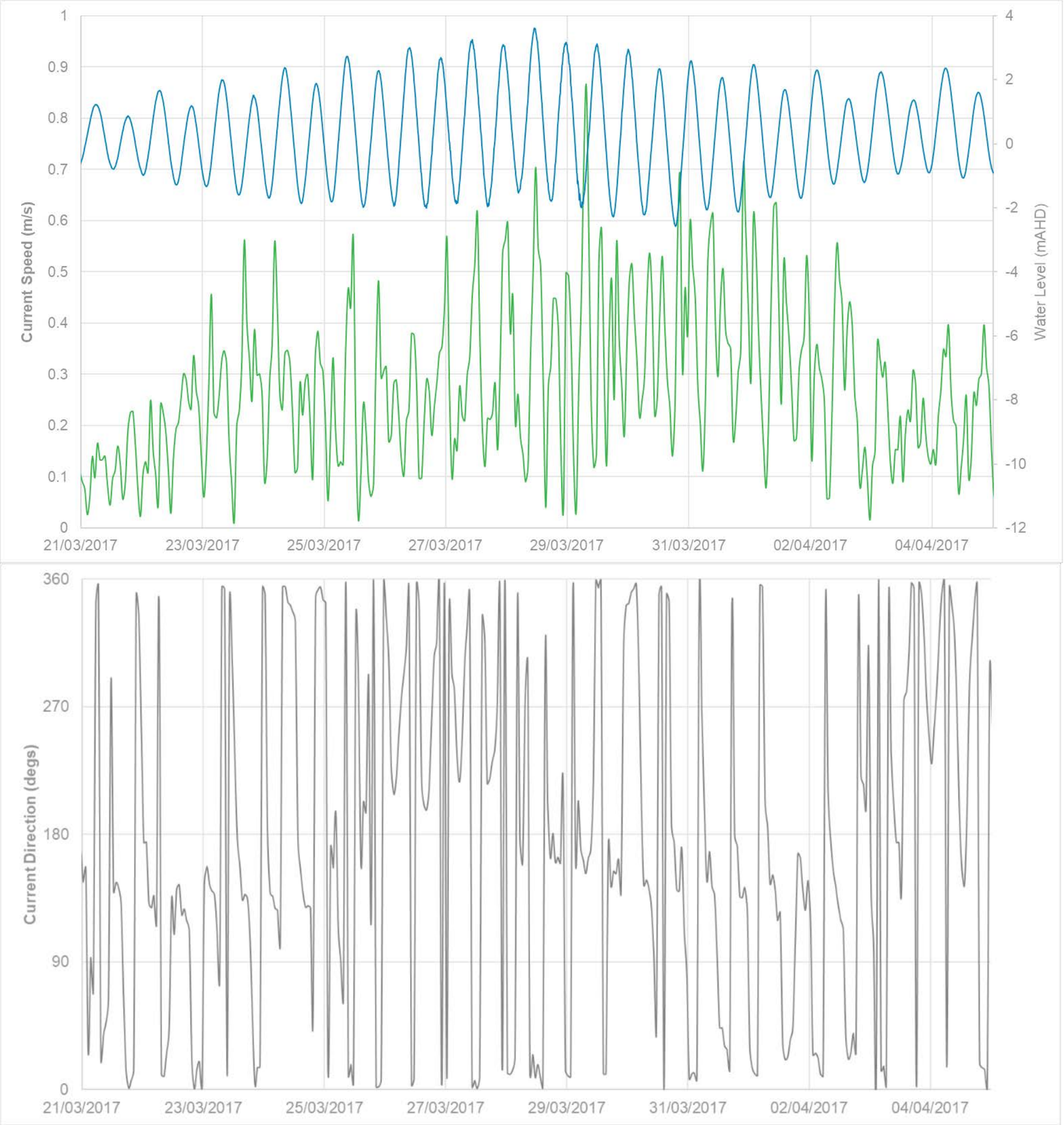

Figure 20. **Measured water level (Mackay Harbour), current speed and direction data (MK1) during TC Debbie.**

2.7. Water Quality and Deposition

Previous investigations have found that suspended sediment concentrations (SSC) in waters adjacent to Mackay are predominantly the result of existing bed sediments being resuspended by current and wave action (AECOM, 2016; RHDHV, 2016c).

An ambient water quality monitoring program was initiated for the Mackay and Hay Point region by NQBP in 2014. JCU has collected water quality and deposition data at seven sites in the Mackay and Hay Point region since 2014. The closest monitoring site to the Port of Mackay is located at Slade Islet, which based on the measured data can be considered to have similar SSC to the other nearshore monitoring sites (Hay Reef, Victor Island and Freshwater Point). Measured SSC data at Slade Islet from 2014 to 2017 has been statistically analysed to better understand the natural water quality environment: mean = 18 mg/l; 80th percentile = 23 mg/l; 90th percentile = 43 mg/l; and the 99th percentile = 208 mg/l (RHDHV, 2018). The statistics show that the SSC can be considered to typically be relatively low (less than 20 mg/l), but with the potential of becoming very high during infrequent events.

There is seasonal variability in the SSC at Slade Islet, with higher SSC during the wet season and lower SSC in the dry season (Figure 21 and Figure 22). The variable SSC during the wet season is primarily due to variable wind and wave conditions (i.e. the peaks in SSC are due to periods of increased wind/wave energy), while during the dry season the variability is due to both the spring and neap tidal cycle and the wind and wave conditions. This is due to stronger currents during spring tides resuspending more bed material than during neap tides.

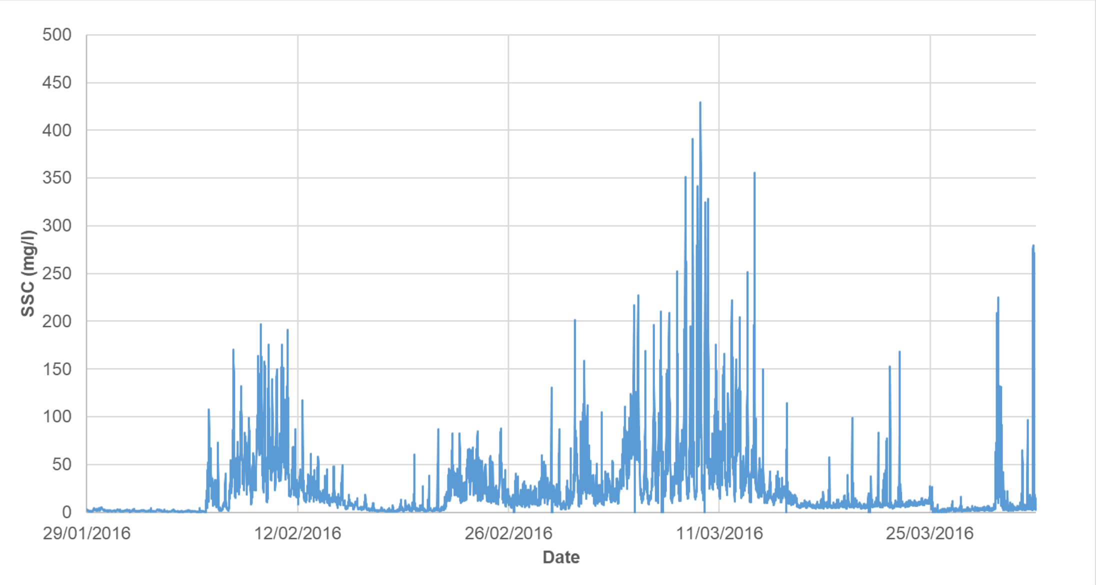

Figure 21. **Measured SSC data at Slade Islet during the wet season.**

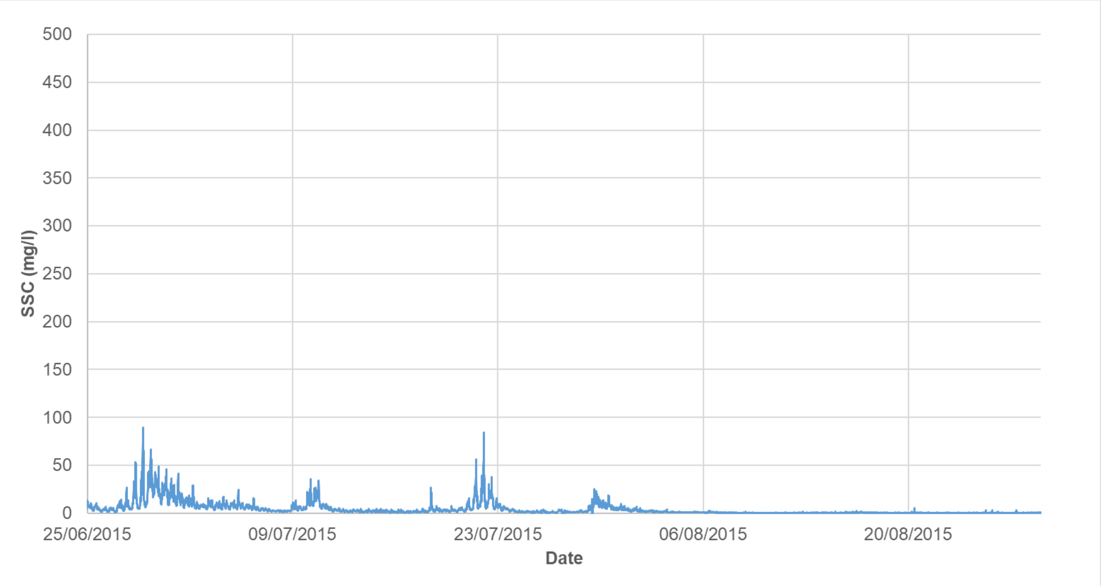

Figure 22. **Measured SSC data at Slade Islet during the dry season.**

Relationships between wind speed and SSC have been developed for Slade Islet during spring and neap tidal conditions (Figure 28 and Figure 29). The plots show that when the wind speed increases above 20 knots (equal to H_s of 1 to 1.5 m based on Figure 18) there is an approximate exponential relationship between the increase in H_s and SSC during both spring and neap tidal conditions. This suggests that when wind speeds (and the associated wave conditions) exceed this threshold a significant increase in resuspension occurs.

The measured water quality data for the Mackay and Hay Point region were used to estimate the typical annual resuspension for the Mackay region (assumed to extend 20 km north and south of the Port and out to the 15 m depth contour). It was estimated that waves and tidal currents result in resuspension of approximately 6.7 million tonnes/yr of existing fine-grained silt and clay from the seabed over an assumed 600 km^2 Mackay region (BMT WBM, 2018).

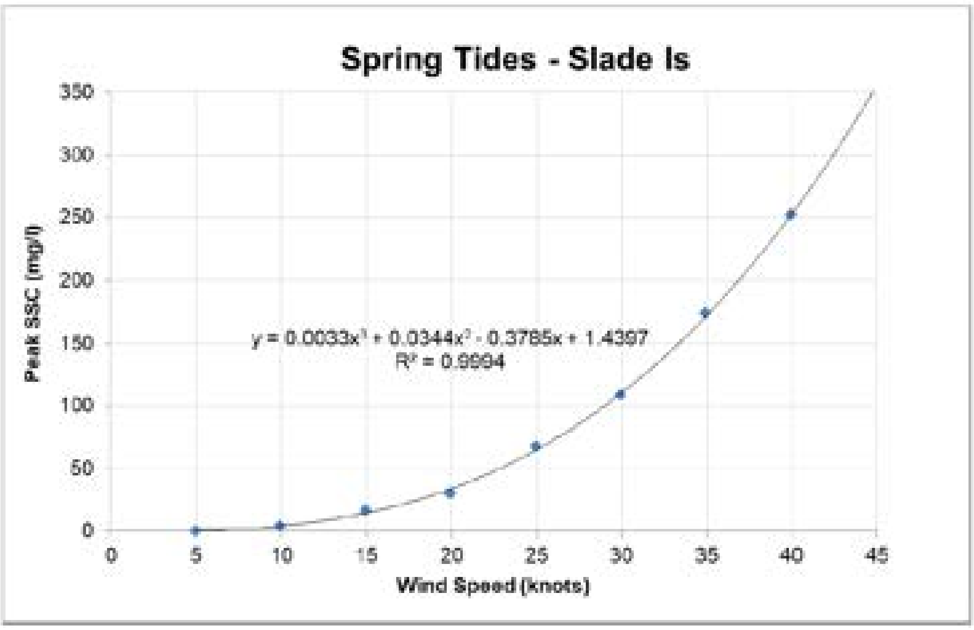

Figure 23. Relationship between wind speed and SSC at Slade Islet over spring tides (RHDHV, 2017d).

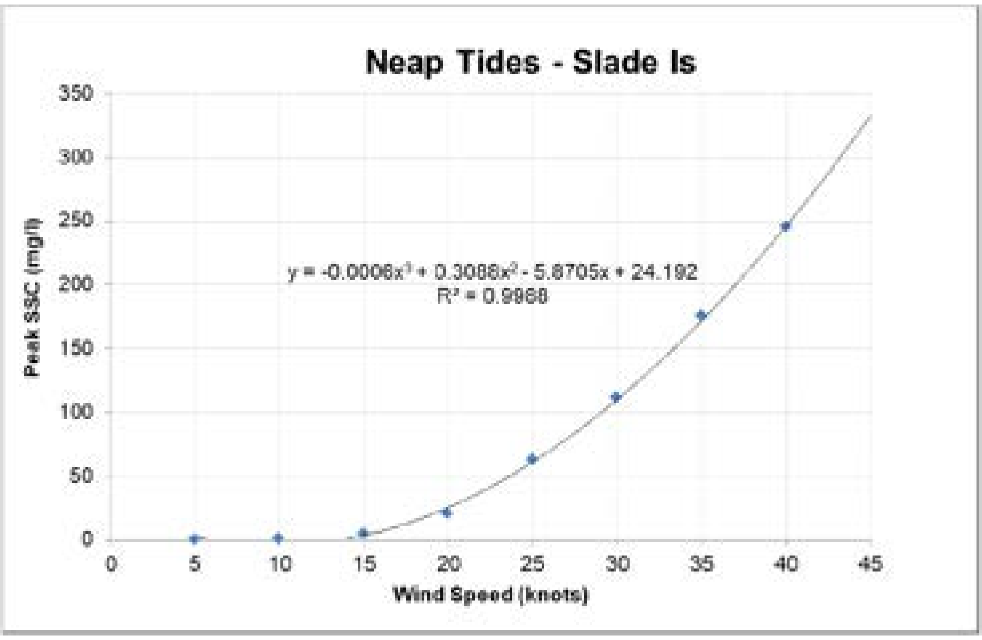

Figure 24. Relationship between wind speed and SSC at Slade Islet over neap tides (RHDHV, 2017d).

Deposition data have also been measured at the seven ambient water quality monitoring sites since 2014, with a summary of the data over the 2015 to 2016 monitoring period shown in Figure 25. The plot shows variable deposition rates at the seven sites, with Slade Islet showing the lowest deposition. Due to the high tidal current speeds which occur in the vicinity of Slade Islet (Figure 6 and Figure 7) it is not surprising that limited deposition occurs in this area. It is therefore likely that significant ongoing deposition would only occur in areas sheltered from the wave conditions and strong tidal currents (e.g. Mackay Harbour).

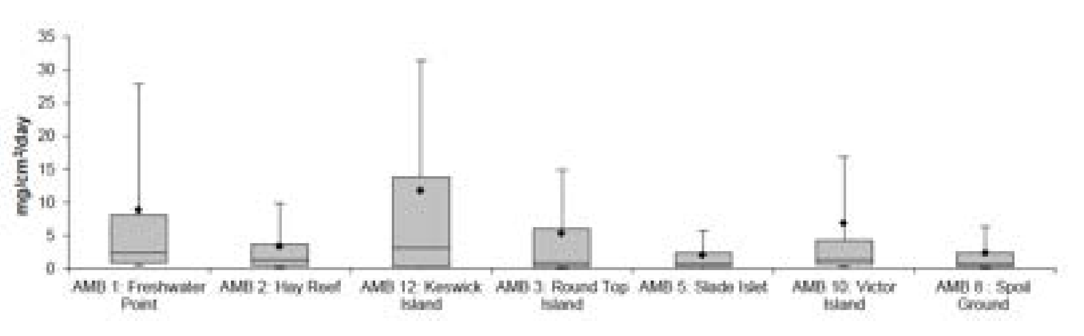

Figure 25. Summary statistics showing daily deposition at the seven Mackay and Hay Point ambient water quality sites (JCU, 2016). *Note: bottom whisker = 10th percentile, top whisker = 90th percentile, bottom box line = lower quartile, middle box line = median, top box line = upper quartile, black dot = mean.*

2.8. Sediment Properties

Based on information available from previous sediment sampling (NQBP, 2011) the sediment properties in the Port of Mackay can be considered to be relatively uniform with some spatial variability as follows:

- Harbour entrance: sandy silt made up of approximately 60% sand, 35% clay and silt and 5% gravel;
- Swing basin: clayey silt and silty clay with approximately equal proportions of clay (38%) and silt (36%) and sand making up the remainder;
- Berths: clayey silt and silty clay with the very little sand present (percentage composition information not available); and
- DMPA: sandy gravel made up of 85% sand, 10% gravel and 5% silt.

2.9. Summary

The dominant processes which result in the resuspension of sediment in the Mackay region are wave action (locally generated due to wind conditions) and tidal currents. The waves have the potential to result in much higher resuspension, while the tidal currents (and wind-generated currents) will transport the sediment when it is suspended. The currents at the entrance to Mackay Harbour are flood dominant, which indicates that the Harbour will act as a net importer of sediment and the low ebb current speed suggests that limited export of sediment from the Harbour occurs. The tidal currents in the area directly offshore of Mackay Harbour are relatively high and as a result there is expected to be limited ongoing deposition in the area. In contrast, the tidal currents within Mackay Harbour are relatively low indicating that any fine-grained sediment which is transported into the Harbour in suspension is likely to be deposited within the Harbour. The fact that the majority of the sediment within the Harbour is either clayey silt or silty clay confirms that fine-grained sediment is being deposited in the Harbour.

3. Bathymetric Analysis

Hydrographic survey data of the Port of Mackay swing basin, berths and DMPA collected by Maritime Safety Queensland (MSQ) have been made available for this study. Survey data from 2009 to 2021 have been provided to allow a thorough analysis of bathymetric changes in the dredged areas of the Port and at the DMPA.

Details of the survey data, analysis method and results are provided in this section.

3.1. Hydrographic Surveys

Details of the hydrographic survey data available are provided in Table 6. The surveys have been undertaken by MSQ with a range of different echosounders used, ranging from single-beam to multibeam. Despite the differences in echosounders, all the surveys were reported to have similar vertical uncertainties, ranging from 0.1 to 0.15 m.

The vertical uncertainty of the surveys is important to consider when analysing the hydrographic survey data and when interpreting any corresponding changes in the bathymetry. To quantify the vertical uncertainty in terms of potential volume errors we can multiply the total dredged area at the Port of Mackay (440,000 m^2) by the maximum vertical uncertainty (0.15 m), which gives a total potential volumetric error of 65,000 m^3. This is more than 50% of the typical maintenance dredging program undertaken by the *TSHD Brisbane* which represents between three and six years of sedimentation (i.e. it is significantly more than the expected annual sedimentation rate). However, it is considered unlikely for a survey to be consistently offset by the maximum vertical uncertainty and therefore, the total potential volumetric error should be lower than 65,000 m^3. The relative confidence which can be placed in the surveys will be assessed by reviewing the volumetric and sectional changes, and comparison of these with the typical trends based on the sediment management activities and the metocean conditions. By adopting this approach, it is anticipated that any erroneous results due to survey error will be identified and excluded from the analysis.

Table 6. Details of the Port of Mackay hydrographic surveys available for this assessment.

Year	Surveys	Areas
2009	Standard (Feb), Post Dredge (Apr), Post Dredge (Jul), Berth 4 (Dec)	Swing Basin & Berths
2010	Berth 4 (Jan), Post Cyclone (Mar), DMPA (Jun), Standard (Oct), Post Drag Barring (Oct)	Swing Basin & Berths, DMPA
2011	Standard + DMPA (Jul), Post Bed Levelling (Sep)	Swing Basin & Berths, DMPA
2012	Standard (Jun), Standard (Oct)	Swing Basin & Berths
2013	Standard (Mar), Pre Dredge + DMPA (Aug), Post Dredge + DMPA (Sep), Post Bed Levelling (Oct)	Swing Basin & Berths, DMPA
2014	Post Cyclone (Feb), Standard (Jun)	Swing Basin & Berths
2015	Standard (May), Standard (Oct)	Swing Basin & Berths
2016	Standard (Sep), Pre Drag Barring (Nov), Post Drag Barring (Nov)	Swing Basin & Berths
2017	Post Cyclone (Apr), Standard (Aug), Post Drag Barring (Nov)	Swing Basin & Berths
2018	Standard (Aug)	Swing Basin & Berths
2019	Post Drag Barring (Jan), Standard (Oct)	Swing Basin & Berths
2020	Standard (Apr), Pre Dredge + DMPA (Nov)	Swing Basin & Berths, DMPA
2021	Post Dredge + DMPA (Jan)	Swing Basin & Berths, DMPA

3.2. Declared Depths

The declared depth is the depth nominated by the Harbour Master and shown on navigational charts to represent the maximum legal and safe vessel draft for an area (Figure 26). Swing basins and berths can also have a design depth which is either at or below the declared depth and can include an insurance depth to allow for natural sedimentation over the period between maintenance dredging programs to allow safe navigation to continue. In addition, as dredgers are not able to dredge to an exact level, it is common for the dredger to over-dredge to ensure that the design levels have been achieved throughout, the over-dredging allowance at the Port of Mackay is an average of 0.6 m. For this assessment we have adopted the design depth as the depth for the bathymetric analysis, as this is the depth which has a direct impact on navigation in the Port.

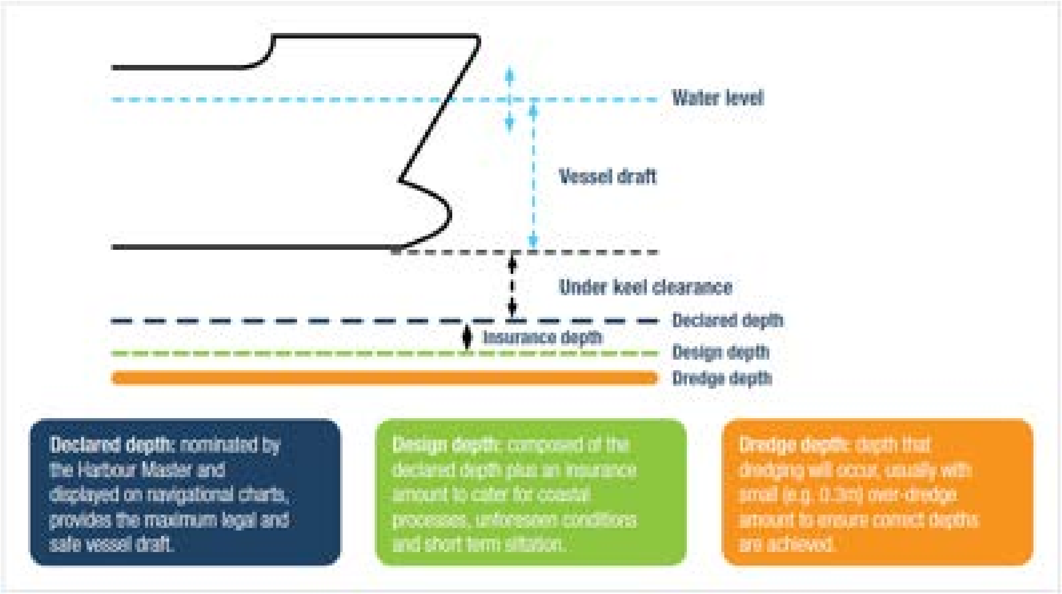

Figure 26. Schematic of depths for navigation and dredging purposes (Ports Australia, 2016).

3.3. Analysis

The hydrographic survey data were used to create high resolution (3 m for the Port and 5 m for the DMPA) gridded Digital Elevation Models (DEMs) for each of the surveys provided. The DEMs were created using a Delaunay triangulation algorithm based on the nearest neighbour input data points followed by a linear interpolation of the triangles onto a regular grid with search radii of 30 m for the Port and 60 m for the DMPA (PitneyBowes, 2009). The DEMs were analysed and processed to determine how the bathymetry has changed over time. The following has been included in the analysis:

- Spatial Maps: high resolution spatial map plots were produced showing the actual bathymetry for each survey, along with the change in bathymetry between subsequent surveys. The depth above and below the design depths was presented for the dredge areas of the Port. At the DMPA the change in bathymetry over different time periods was calculated;
- Volumetric Changes: volumetric changes were calculated to quantify the erosion or accretion which has occurred (either naturally or due to sediment management activities) between the surveys for the dredge areas and the DMPA. For the dredge areas, the volumetric changes were calculated for sub-regions within the dredge areas (Figure 27). The volumetric changes were calculated between subsequent surveys and relative to the design depth; and

- Transects: changes along set transects over time were extracted within the dredge areas of the Port. The transects help to visualise how the bathymetry has changed over time spatially within the different areas.

3.4. Results

The results from the bathymetric analyses are discussed for the Port of Mackay and the Mackay DMPA separately in the following sections.

As noted in Section 3.1, it is also important to consider the potential survey error of ± 0.15 m when analysing the results, as any bias in individual surveys may result in an apparent change that could be artificial.

3.4.1. Mackay Harbour

The bathymetry in the dredge areas of the Port of Mackay approximately 7 years after a maintenance dredging program and 2 years after the most recent bed levelling activity is shown in Figure 28. The plot shows the following:

- the bathymetry to the east of the Port is naturally deep, with bed elevations typically below -10 m LAT;
- the bathymetry suggests that natural sedimentation occurs within the swing basin of the Harbour. The areas include the natural shoal on the southern side of the entrance, the eastern half of the siltation trench and the areas to the east of Berth 1, to the north of Berth 4 and to the east of Berth 5 (some of the sedimentation in this area is from sediment removed from the adjacent new tug area by drag barring in November/December 2018). Based on the current depths in the areas it is likely that ongoing natural sedimentation could increase the depths above the design depths;
- there are deeper sections within the swing basin due to bed erosion caused by the propeller wash of vessels operating in the Port (likely to be predominantly due to tug vessels when assisting larger vessels to manoeuvre and berth);
- the berths are significantly deeper than the adjacent natural bathymetry on the opposite side to the swing basin, with differences of up to 5 m. As such, the berths are expected to act as sediment traps and be subject to natural ongoing sedimentation; and
- the Old Tug and New Tug regions (see sub-regions in Figure 27) are generally significantly shallower than the swing basin. For the Old Tug region this is because it was where the tug base used to be but is now no longer used. For the New Tug region only a small section of the region (western side) was deepened during the drag barring undertaken in 2018.

Figure 27. **Port of Mackay regions adopted for the bathymetric analysis.**

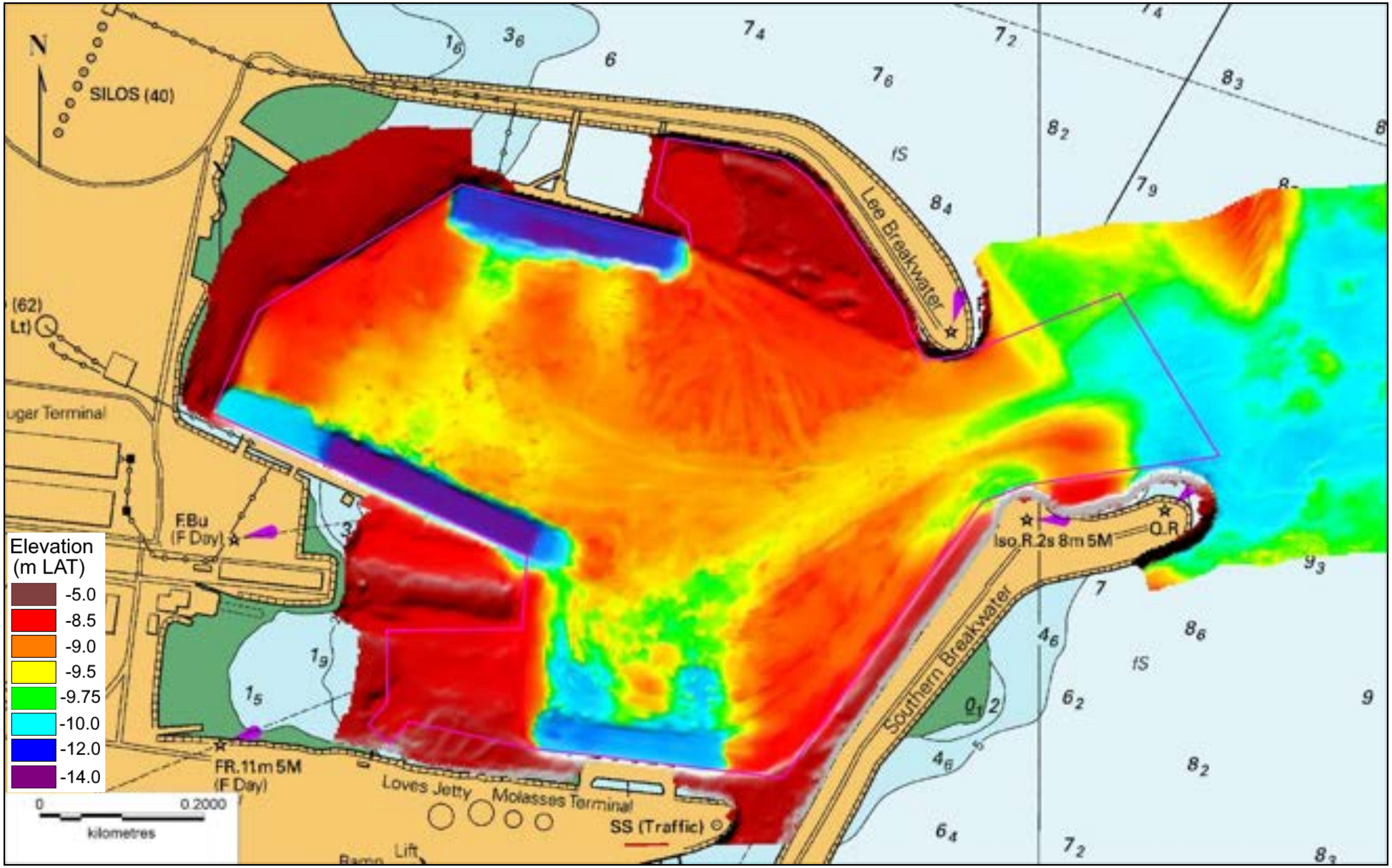

Figure 28. **Port of Mackay bathymetry in November 2020.** *Note: the pink line shows the border of the dredge areas.*

The sedimentation/erosion that has occurred within the dredge areas of the Port of Mackay each year has been determined by calculating the difference in the bathymetry between surveys. The net sedimentation/erosion that has occurred within each sub-region each year is detailed in Table 7 and a map showing the total cumulative sedimentation/erosion over the 11 years is provided in Figure 29 (both the table and the figure exclude the volume relocated during the 2013 and 2020 maintenance dredging programmes). In addition, the net change due to historical sediment management activities (i.e. maintenance dredging and drag barring) and extreme events (i.e. Tropical Cyclones) is tabulated in Table 8 and shown in Figure 30 to Figure 35. The figures and tables show the following:

- the annual total change in bathymetry has been variable over the 11-year period. The maximum change was net sedimentation of approximately 85,000 m^3 which occurred between 2013-14 and 2016-2017, coinciding with the occurrence of TC Dylan and TC Debbie. The minimum change was erosion of approximately 19,000 m^3 that occurred between 2015-2016, which coincided with a drag barring program. The overall mean change over the nine years has been sedimentation of approximately 26,500 m^3/yr;
- the majority of the sedimentation has occurred in the swing basin, with on average three times more sediment deposited in the swing basin (average = 18,000 m^3/yr) compared to the berths (average = 6,500 m^3/yr). The most sedimentation has occurred in the south-eastern region of the swing basin (South East SB and Siltation Trench) where the average sedimentation is 6,600 m^3/yr and the maximum 25,600 m^3/yr, with approximately one third of the sedimentation in the swing basin being in this region. Berths 3 and 5 have had the most sedimentation of the berths, with average sedimentation of approximately 2,000 m^3/yr in each and a maximum of up to 5,000 m^3/yr per berth;
- the maintenance dredging and bed levelling activity which was undertaken in 2009, 2013 and 2020 reduced the volume of sediment in the Port by approximately 25,000 m^3, 140,000 m^3 and 105,000 m^3 respectively. Based on the survey data it appears that the entire volume relocated in 2009 was from the swing basin, while in 2013 approximately 20% was from the berths and the remainder from the swing basin and in 2020 approximately 20% was from the berths, 20% from the New Tug region and the remainder from the swing basin;
- the individual drag barring programs between 2011 and 2017 (i.e. not the bed levelling associated with maintenance dredging) relocated between 7,000 and 10,000 m^3. Approximately 30% of this was from the berths and remainder from the swing basin. The drag barring program in 2018 relocated approximately 32,500 m^3 with 50% of this from the swing basin, 40% from the New Tug area and the remainder from the berths; and
- Tropical Cyclones have the potential to result in increased sedimentation of between 35,000 and 50,000 m^3 during the event. In the months following a TC there is also the potential for increased sedimentation, for example, during TC Debbie just over 35,000 m^3 of sediment was deposited within the Port and over the following five months an additional 40,000 m^3 was deposited. As with the typical sedimentation, during a TC the majority of the sedimentation occurs in the swing basin, with between 5 and 25% of the sedimentation in the berths.

Table 7. Net annual change in bathymetry (m^3) at the Port of Mackay from 2010 to 2020.

Notes: the years shown represent the later year (i.e. 2010 = 2010 survey - 2009 survey); +ve = sedimentation, -ve = erosion; the values exclude the volume relocated by maintenance dredging in 2013 and 2020.

Region	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total	*Annual Average*
New Tug	-	-	-10	2,174	-	-368	-	3,465	-370	2,958	-1,231	**6,618**	*1,261*
Old Tug	-1,010	2,401	-1,265	3,743	-	-277	-	3,929	857		765	**9,143**	*1,108*
Berth1	1,985	1,883	923	557	1,738	99	613	3,211	845	942	678	**13,472**	*1,314*
Berth3	3,327	3,200	137	3,129	1,846	782	1,197	4,729	1,518	2,082	1,828	**23,775**	*2,320*
Berth4	-127	1,096	-82	1,528	810	513	603	1,466	536	977	789	**8,109**	*791*
Berth5	3,400	2,841	90	2,792	2,475	612	1,037	3,577	738	1,841	1,197	**20,600**	*2,010*
Entrance SB	4,579	-2,107	762	363	4,702	-2,664	-1,418	5,306	-1,167		-1,578	**6,776**	*661*
South East SB	4,690	3,094	-843	5,928	14,996	-2,809	-3,919	10,562	1,144	4,743	-905	**36,683**	*3,579*
South West SB	1,414	1,257	-2,851	3,536	10,566	-3,530	-5,338	10,222	-1,511	4,211	-2,331	**15,645**	*1,526*
Central West SB	4,073	150	-3,802	6,160	12,677	-3,755	-4,697	12,078	-1,996	6,877	-4,987	**22,779**	*2,222*
West SB	4,289	469	-560	5,497	5,304	572	-240	6,171	25	3,404	351	**25,282**	*2,466*
North SB	3,835	2,569	-236	4,040	5,585	50	213	4,754	-741	3,957	-169	**23,857**	*2,327*
Central SB	3,816	1,420	-4,533	5,633	10,976	-4,887	-3,896	7,169	-1,676	6,435	-4,822	**15,635**	*1,525*
Siltation Trench	3,910	2,688	1,583	4,845	10,647	-1,193	-2,915	7,656	656	3,495	219	**31,592**	*3,082*
SE Corner SB	833	172	-1,600	385	1,347	64	-87	967	163	746	153	**3,144**	*307*
Total	**39,013**	**21,132**	**-12,288**	**50,312**	**83,669**	**-16,790**	**-18,846**	**85,261**	**-980**	**42,669**	**-10,042**	**263,110**	*26,500*
Total Berths	*8,585*	*9,020*	*1,067*	*8,007*	*6,869*	*2,005*	*3,451*	*12,982*	*3,637*	*4,900*	*4,492*	***65,956***	*6,435*
Total Swing Basin	*31,438*	*9,711*	*-12,080*	*36,388*	*76,800*	*-18,151*	*-22,297*	*64,886*	*-5,104*	*33,868*	*-14,068*	***181,393***	*17,697*

Table 8. Net change in bathymetry (m^3) at the Port of Mackay due to sediment management activities and extreme events from 2009 to 2020.

Note: +ve = sedimentation, -ve = erosion.

Region	Dredging 2009	Dredging & Bed Levelling 2013	Bed Levelling 2011	Bed Levelling 2016	Bed Levelling 2017	Bed Levelling 2018	Dredging 2020	TC Ului	TC Dylan	TC Debbie	5 months after TC Debbie
New Tug					-968	-12,311	-18,349				
Old Tug			-776		132	-111	-1,130				
Berth1	486	-5,783	3	-146	-313	-184	156	1,483	2,458	2,623	588
Berth3		-8,930	-692	-1,077	-2,920	-2,238	-4,939	2,837	110	3,279	1,450
Berth4	414	-3,351	-235	70	-37	-715	-8,440	-402	12	550	915
Berth5		-10,476	-1,061	-747	314	-214	-8,597	3,245	351	1,976	1,601
Entrance SB		-4,320	107	-1,565	-331	-1,325	911	5,023	3,465	3,320	1,967
South East SB	-3,307	-20,120	-394	-40	-1,313	-3,197	-13,260	3,721	11,718	3,722	6,840
South West SB	-4,449	-15,515	-1,036	148	-16	-2,517	407	1,857	8,555	5,094	5,128
Central West SB	-5,530	-17,336	-2,444	-819	-1,775	-5,836	9,862	3,564	6,601	5,057	7,021
West SB	-1,785	-8,306	-980	-2,346	278	-1,096	-23,897	3,240	2,084	2,331	3,840
North SB	-2,200	-13,300	-673	-153	350	-2,227	-14,909	2,965	2,644	1,912	2,842
Central SB	-7,807	-12,309	-1,522	-1	-1,288	1,530	2,784	4,938	5,683	3,454	3,715
Siltation Trench	-2,102	-14,496	1,426	5	46	-1,726	-25,154	2,940	8,716	2,970	4,687
SE Corner SB	-232	-3,886	-1,804	-370	-291	-384	-2,165	484	804	258	709
Total	**-26,512**	**-138,128**	**-10,081**	**-7,041**	**-8,132**	**-32,551**	**-106,720**	**35,895**	**53,201**	**36,546**	**41,303**
Total Berths	*900*	*-28,540*	*-1,985*	*-1,900*	*-2,956*	*-3,351*	*-21,820*	*7,163*	*2,931*	*8,428*	*4,554*
Total Swing Basin	*-27,412*	*-109,588*	*-7,320*	*-5,141*	*-4,340*	*-16,778*	*-65,421*	*28,732*	*50,270*	*28,118*	*36,749*

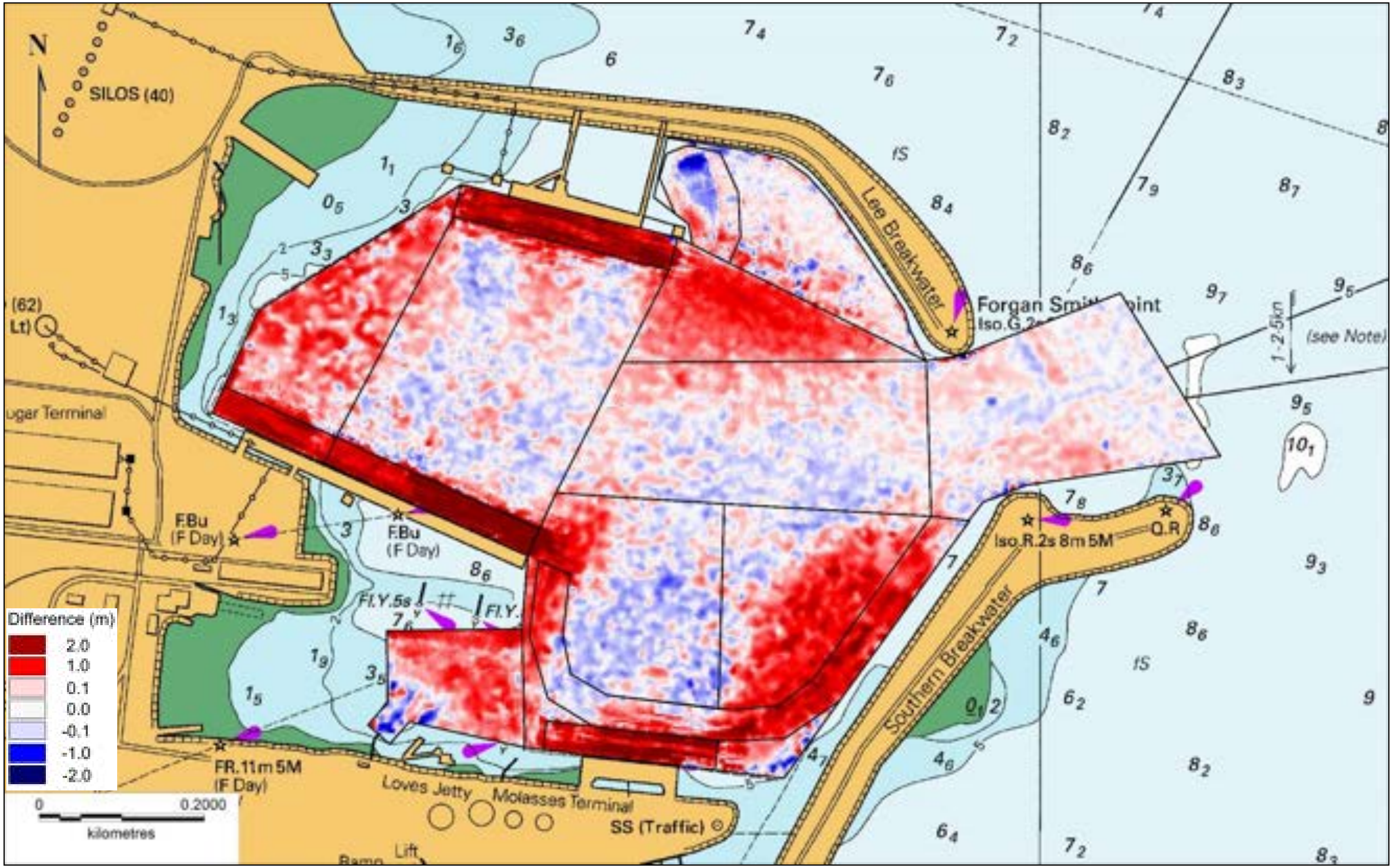

Figure 29. Cumulative sedimentation/erosion in the Port of Mackay from 2009 to 2020 (excluding the changes due to the 2013 and 2020 maintenance dredging).

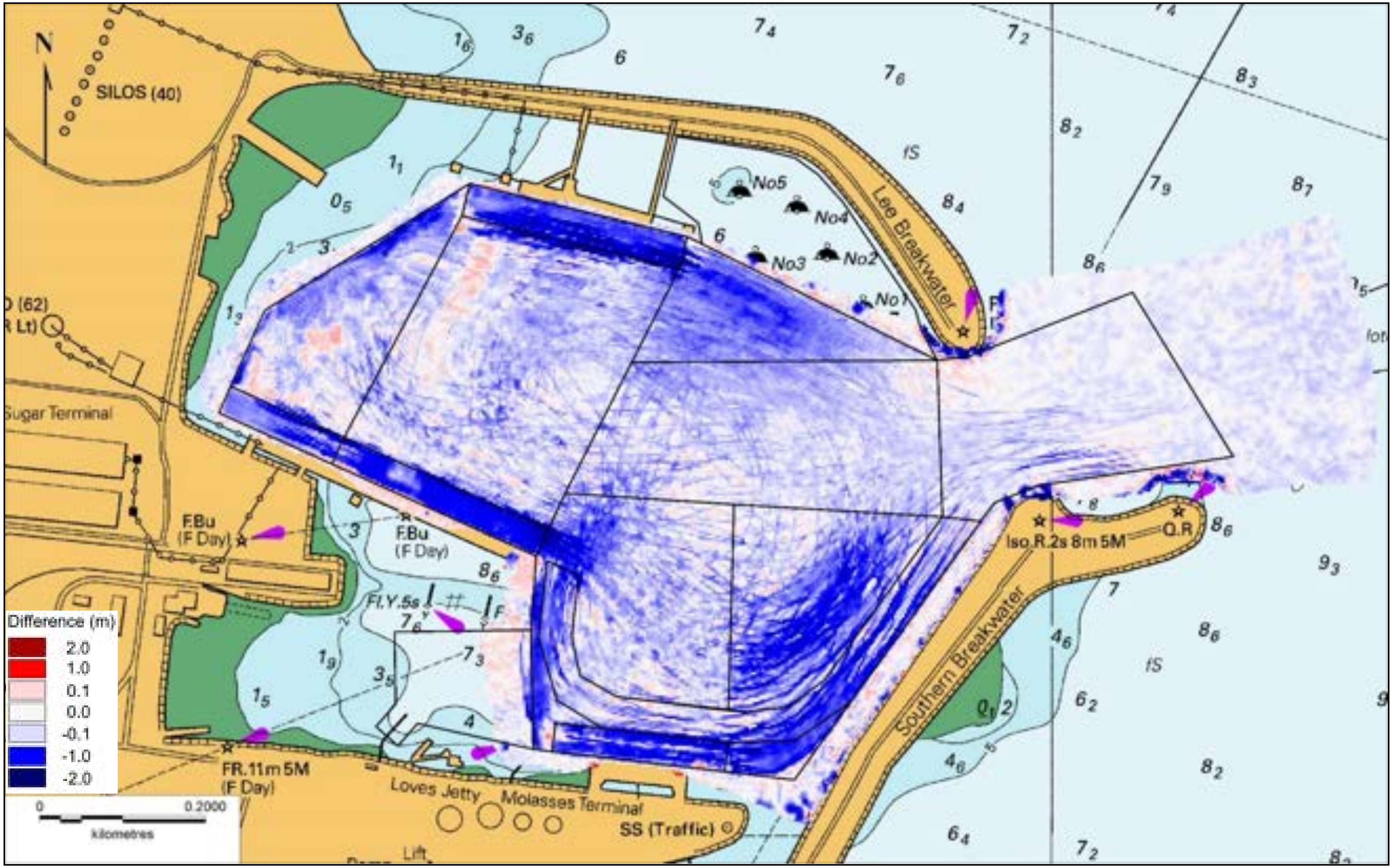

Figure 30. Change in bathymetry in the Port of Mackay due to the 2013 maintenance dredging and bed levelling (August 2013 to October 2013).

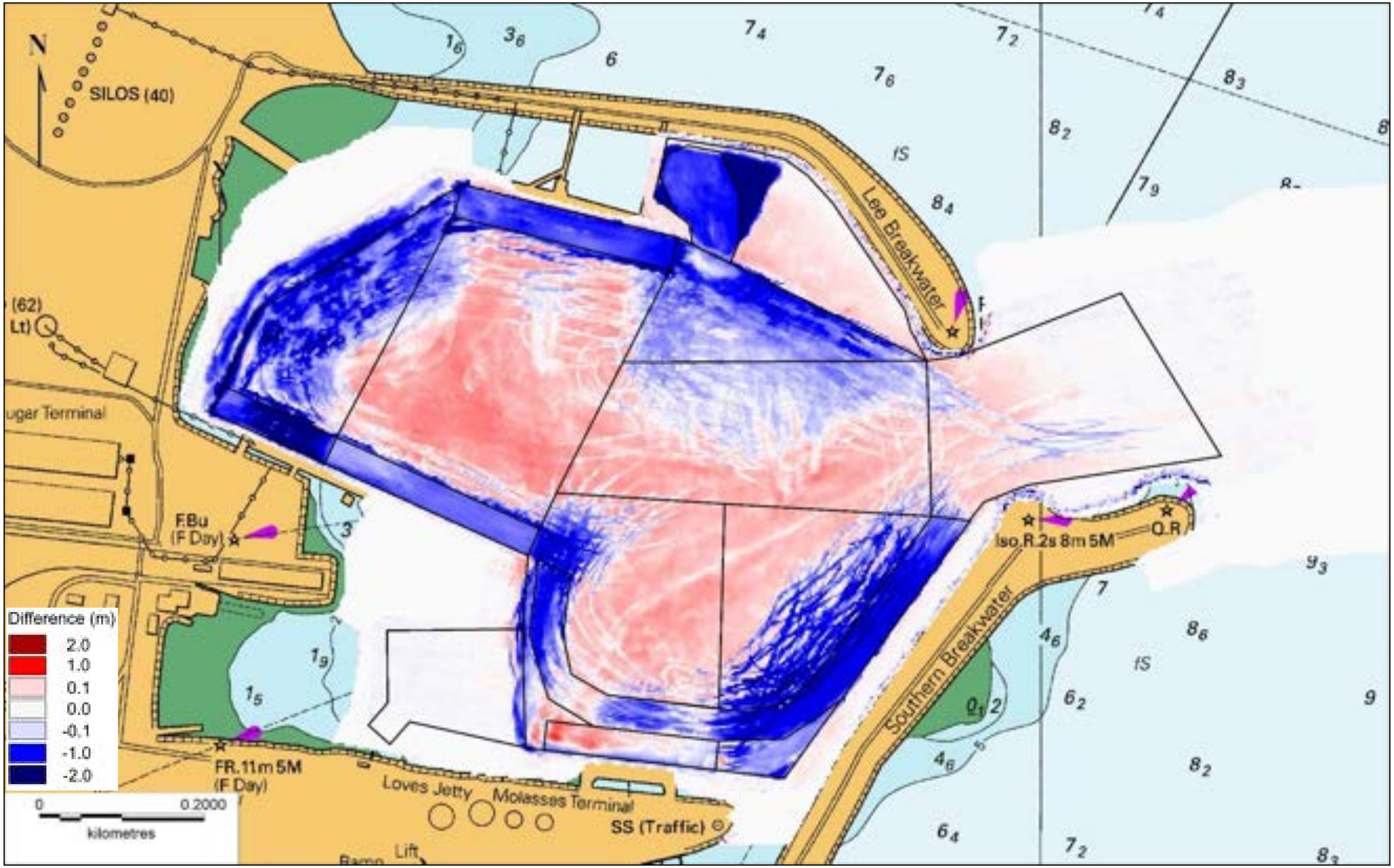

Figure 31. Change in bathymetry in the Port of Mackay due to the 2020 maintenance dredging and bed levelling (November 2020 to January 2021).

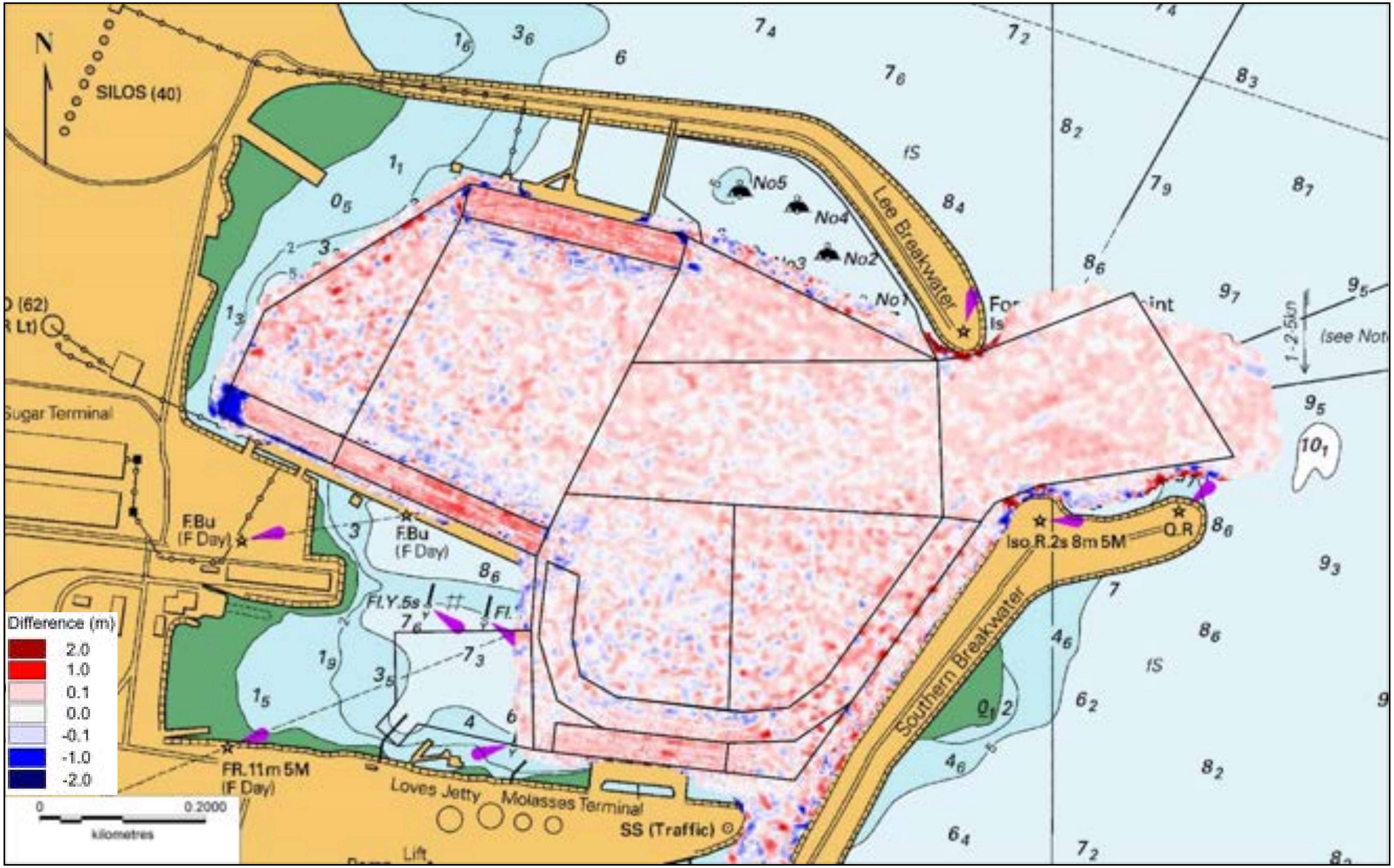

Figure 32. Change in bathymetry in the Port of Mackay due to TC Ului (July 2009 to March 2010).

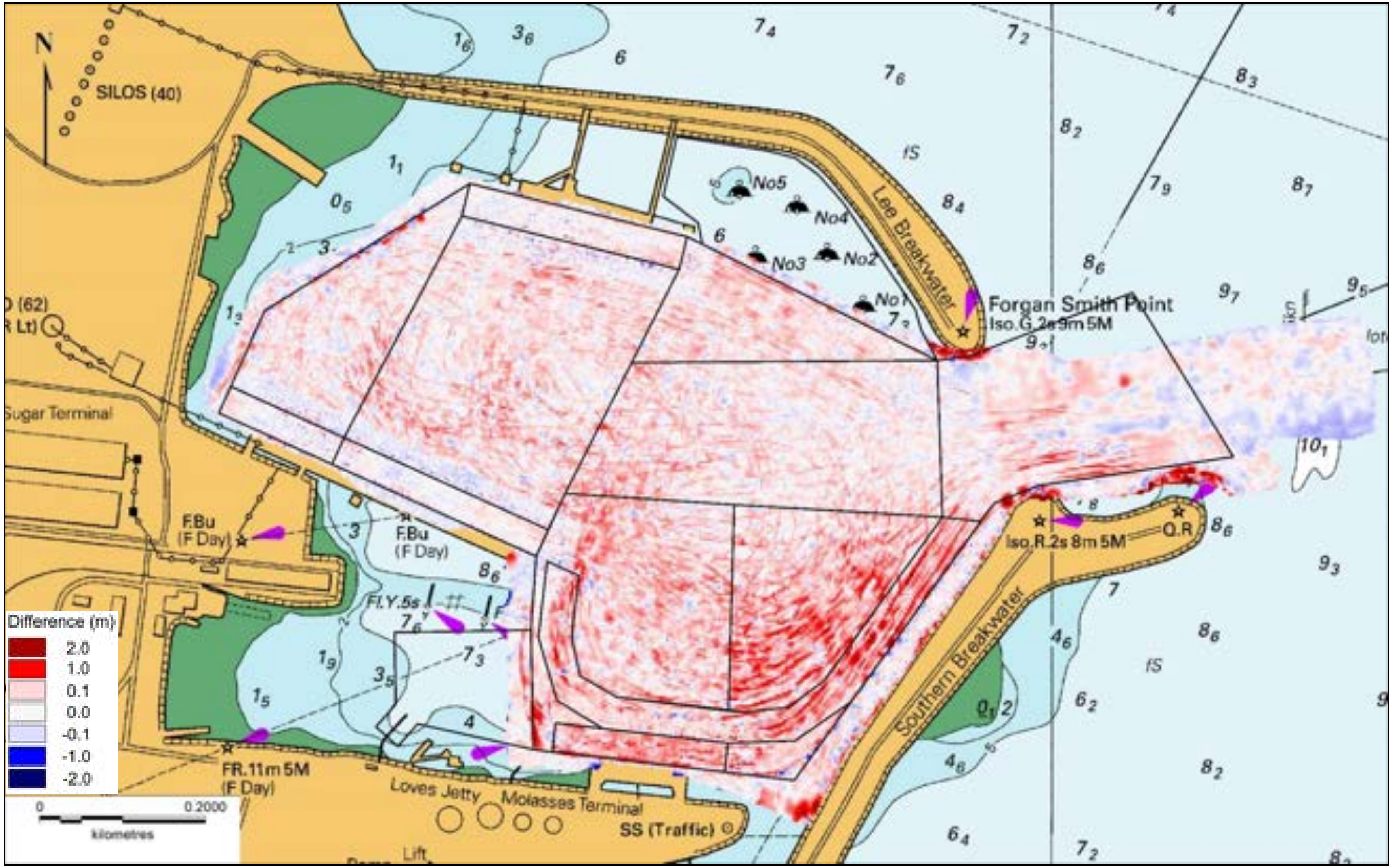

Figure 33. Change in bathymetry in the Port of Mackay due to TC Dylan (October 2013 to February 2014).

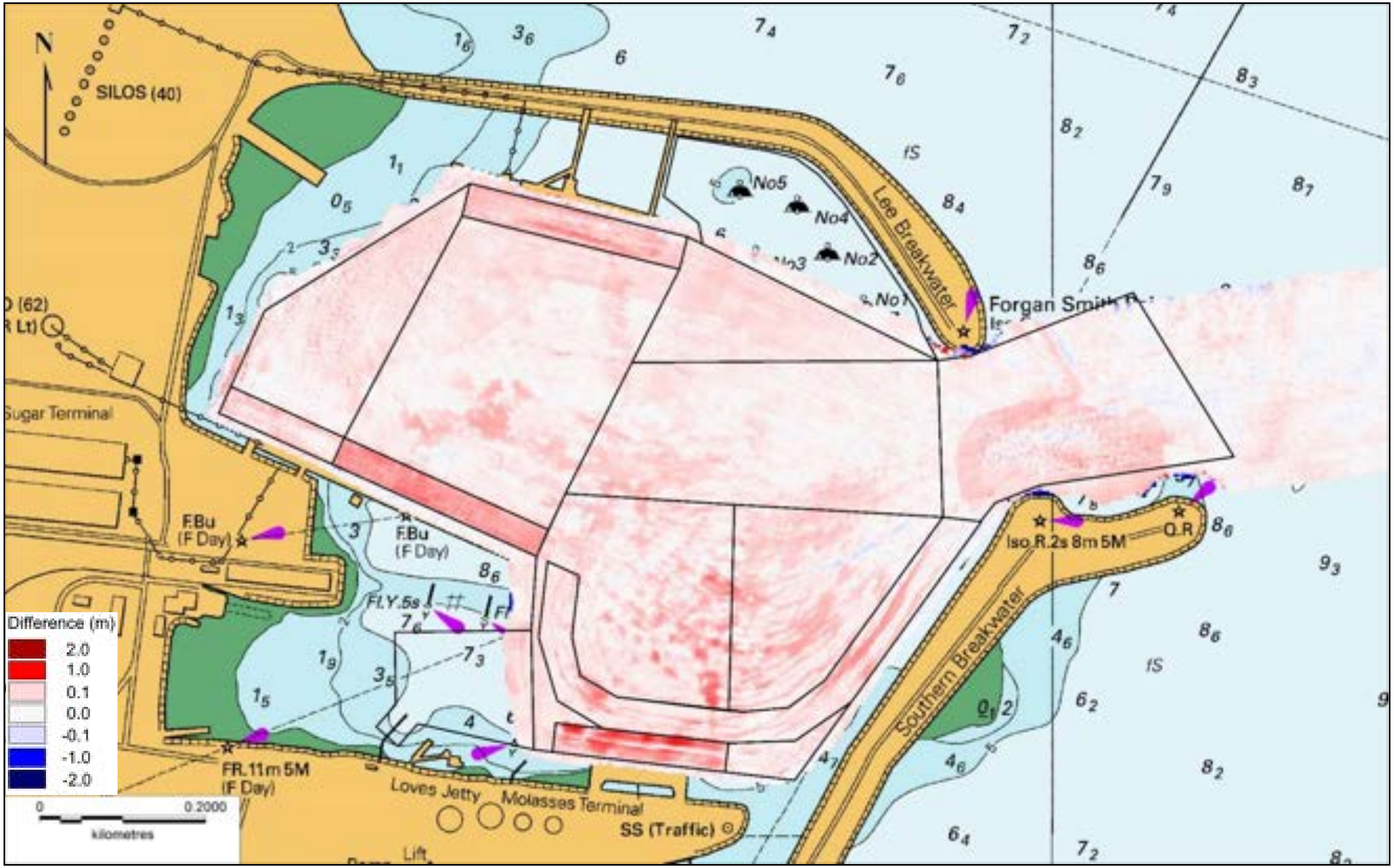

Figure 34. Change in bathymetry in the Port of Mackay due to TC Debbie (November 2016 to April 2017).

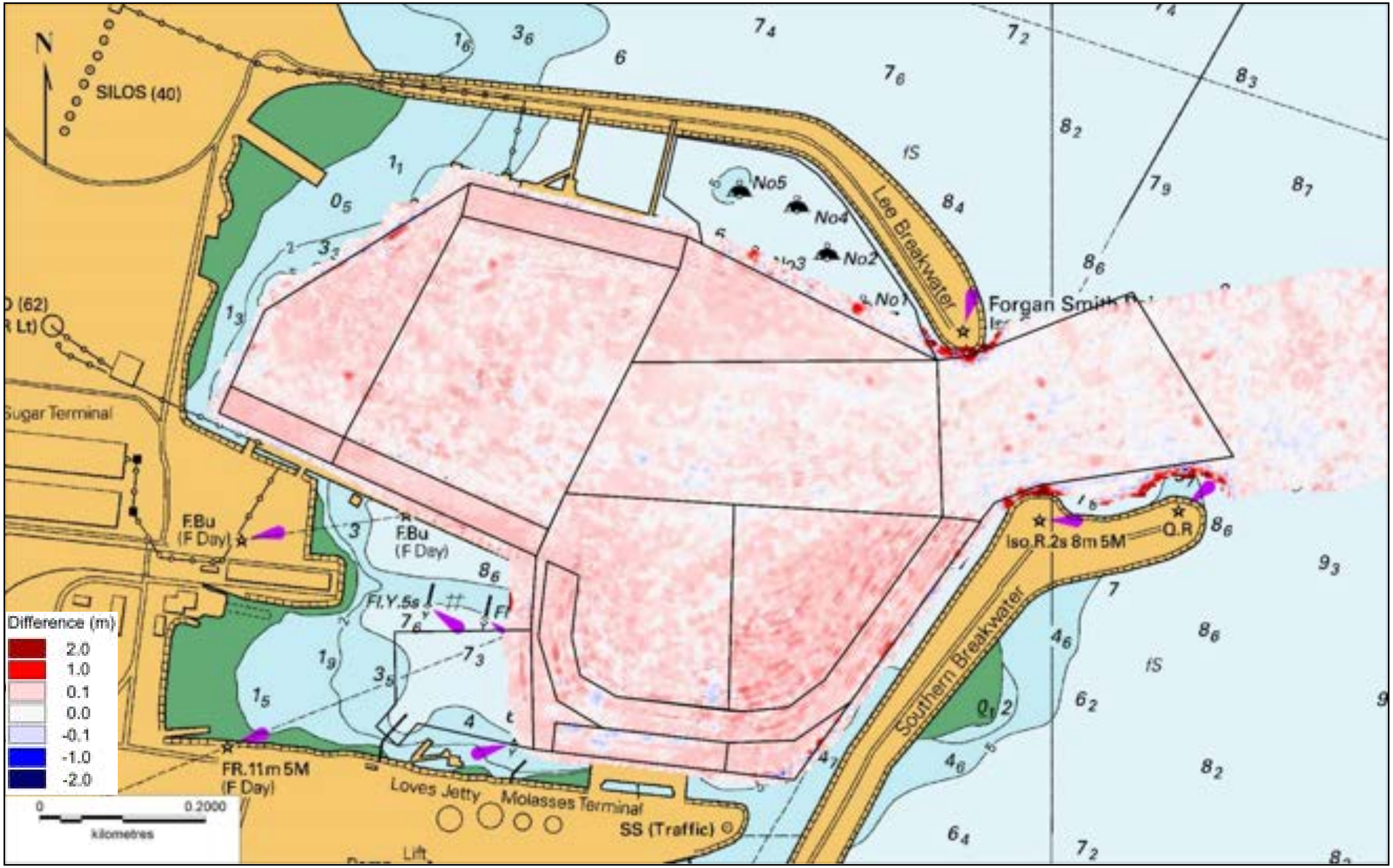

Figure 35. Change in bathymetry in the Port of Mackay over the 5 months following TC Debbie (April 2017 to August 2017).

To better understand how the changes in bathymetry have the potential to influence navigation, port operations and therefore the maintenance dredging requirements at the Port of Mackay, surveys for each year between 2009 and 2020 were compared to the design depths at the Port (see Section 1.2 for the design depths). Based on advice from NQBP, design depths of -7.0 m and -6.8 m LAT have been assumed for the New Tug and Old Tug regions, respectively. The volume of sediment relative to the design depths was calculated for the November 2020 (i.e. prior to the 2020 maintenance dredging program) bathymetric survey (Table 9). The volume above the design depths within each sub-region of the Port was calculated for a representative annual survey and then the change in volume above design depth was calculated between years (Table 10). Table 10 therefore shows the sedimentation and erosion of only the sediment above the design depths. To assess the spatial distribution of the maintenance dredging requirement (i.e. sediment above the design depths), plots of the depth above/below design depth are shown for the most recent pre dredging survey (November 2020) as well as post 2020 maintenance dredging and post TC Debbie in Figure 36 to Figure 38. Results from the analysis relative to design depths are summarised below:

- the spatial plots show that sedimentation above design depth occurs most commonly in Berths 3 and 5 and in the South East, South West, North and West regions of the swing basin as well as in the eastern half of the Siltation Trench. There is also the potential for sedimentation to result in small areas to be at or above the design depth in the other two berths and in the other regions of the swing basin. The results suggest that the Old Tug and New Tug regions have large areas above the design depth, but this is because the depths in these regions are not maintained and so the depths are more representative of the natural depths rather than the assumed design depths;
- the largest annual increase in volume above the design depths was approximately 16,000 m^3/yr which occurred between 2016 and 2017 and the second largest was just under 14,000 m^3/yr which occurred between 2012 and 2013. Both increases coincided with periods when maintenance dredging had not been undertaken for at least four years, resulting in the bed levels being closer to the design depths due to natural sedimentation over the four years;
- the annual change in volume above design depth does not directly correlate with the annual sedimentation rates. This is due to insurance and over dredging undertaken as part of the maintenance dredging activity meaning that the bed elevation immediately after maintenance dredging programs is lower than the design depths (this is further discussed as part of the following transect analysis). Therefore, when high sedimentation occurs immediately after maintenance dredging (e.g. in 2013 - 2014) the increase in volume above the design depth is low compared to when moderate sedimentation occurs when there hasn’t been any maintenance dredging for four years (e.g. in 2012 - 2013); and
- the largest increase in volume above design depth has occurred in Berth 3, with all of the spatial plots showing that the majority of this berth was above the design depth. The pre-maintenance dredging and post TC Debbie spatial plots (Figure 36 and Figure 38) show that the entire berth was above the design depth with a relatively flat sedimentation pattern.

Table 9. Volume (m^3) of sediment relative to the design depth in the Port of Mackay based on the November 2020 bathymetric survey.

Region	Above Design depth (m^3)	Below Design depth (m^3)	Net relative to Design depth (m^3)
New Tug	52,246	-2,576	49,670
Old Tug	9,662	-6,015	3,647
Berth1	57	-3,074	-3,017
Berth3	7,702	-0	7,702
Berth4	990	-719	270
Berth5	1,467	-352	1,115
Entrance SB	145	-56,118	-55,973
South East SB	3	-19,342	-19,339
South West SB	253	-46,205	-45,952
Central West SB	3	-69,324	-69,321
West SB	2,219	-9,489	-7,271
North SB	205	-5,142	-4,937
Central SB	3	-31,409	-31,407
Siltation Trench	21,156	-2,387	18,769
SE Corner SB	1,339	-1,116	223
Total (m^3)	**97,450**	**-253,268**	**-155,821**
Total Berths	*10,216*	*-4,145*	*6,070*
Total Swing Basin	*25,326*	*-240,532*	*-215,208*

Table 10. Change in volume (m^3) of sediment above the design depth at the Port of Mackay from 2009 to 2020.

Notes: the years shown represent the later year (i.e. 2010 = 2010 above design depth - 2009 above design depth); +ve = increase in volume above design depth, -ve = reduction in volume above design depth; the number of days that the sedimentation represents is shown in brackets after the year; the values exclude volumes relocated by maintenance dredging in 2013 and 2020.

Region	2010 (457 days)	2011 (273 days)	2012 (336 days)	2013 (426 days)	2014 (243 days)	2015 (487 days)	2016 (397 days)	2017 (273 days)	2018 (273 days)	2019 (273 days)	2020 (397 days)	Total
New Tug			84	1,692				2,853	-261	2,774	-931	**6,212**
Old Tug			-650	1,175		-373		1,186	201	119	212	**1,869**
Berth1	5	22	19	-23	3	0	3	4	12	11	46	**102**
Berth3	1,263	2,871	132	3,130	119	720	1,195	4,728	1,518	2,082	1,828	**19,586**
Berth4	-152	13	-2	105	-84	47	65	109	101	209	628	**1,037**
Berth5	19	681	-410	860	-15	103	137	149	239	504	785	**3,053**
Entrance SB	120	-58	-7	49	273	-188	-69	182	9	283	-138	**262**
South East SB	11	1	3	75	1	0	-1	0	0	1	1	**91**
South West SB	64	-75	-254	411	13	-5	-13	34	17	81	43	**317**
Central West SB	3	-2	0	0	2	0	-3	1	0	49	-49	**1**
West SB	793	-67	-211	1,107	527	10	36	526	-45	557	227	**3,461**
North SB	13	26	-9	548	132	-39	-31	272	-219	163	-62	**795**
Central SB	0	1	0	0	1	0	-1	0	0	7	-7	**1**
Siltation Trench	2,341	2	1,317	4,399	2	-995	-2,384	5,797	601	2,962	521	**14,561**
SE Corner SB	552	3	-1,628	450	3	-34	-183	174	24	274	57	**-308**
Total (m^3)	**5,032**	**3,418**	**-1,616**	**13,978**	**977**	**-754**	**-1,249**	**16,015**	**2,197**	**10,076**	**3,161**	**51,040**
Total Berths	*1,135*	*3,587*	*-261*	*4,072*	*23*	*870*	*1,400*	*4,990*	*1,870*	*2,806*	*3,287*	***23,778***
Total Swing Basin	*3,897*	*-169*	*-789*	*7,039*	*954*	*-1,251*	*-2,649*	*6,986*	*387*	*4,377*	*593*	***19,181***
Total per year (m^3/yr)	*4,019*	*4,569*	*-1,758*	*11,977*	*1,468*	*-564*	*-1,148*	*21,411*	*2,938*	*13,208*	*2,908*	***5,366[1]***

[1] *This value represents the average sedimentation rate per year.*

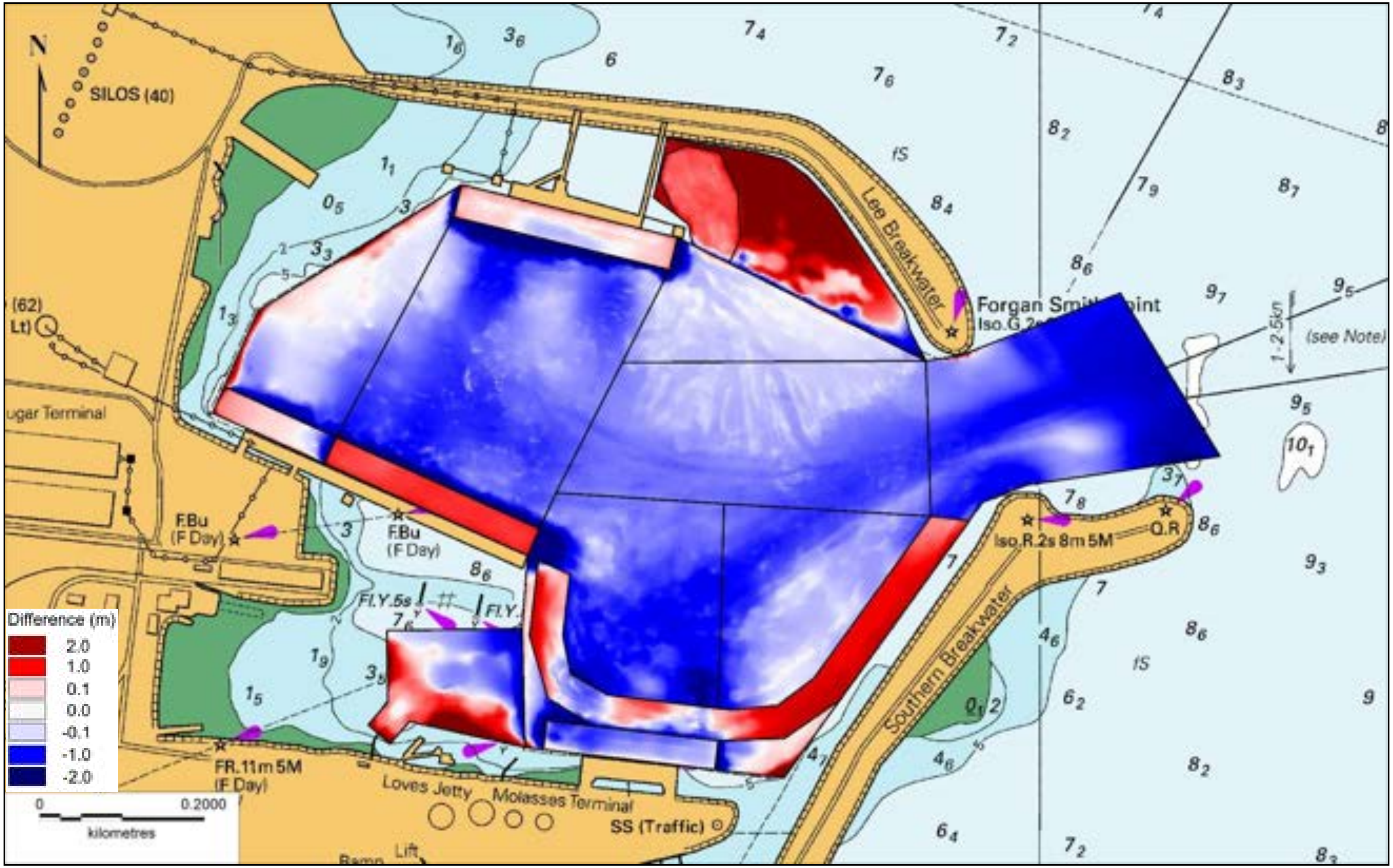

Figure 36. Depths above (red) and below (blue) design depths for the pre-maintenance dredging (November 2020) bathymetric survey of the Port of Mackay.

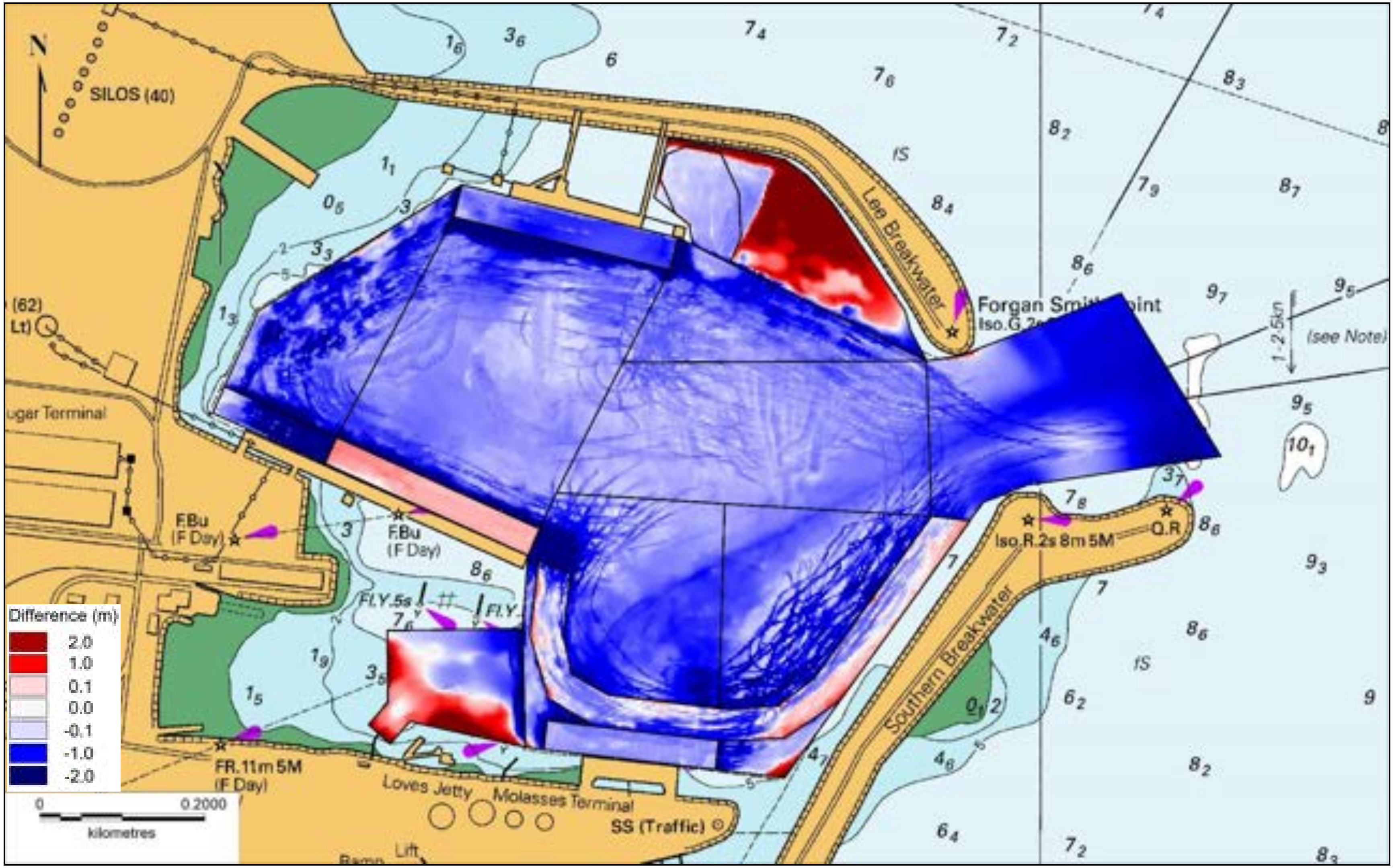

Figure 37. Depths above (red) and below (blue) design depths for the post maintenance dredging and bed levelling (January 2021) bathymetric survey of the Port of Mackay.

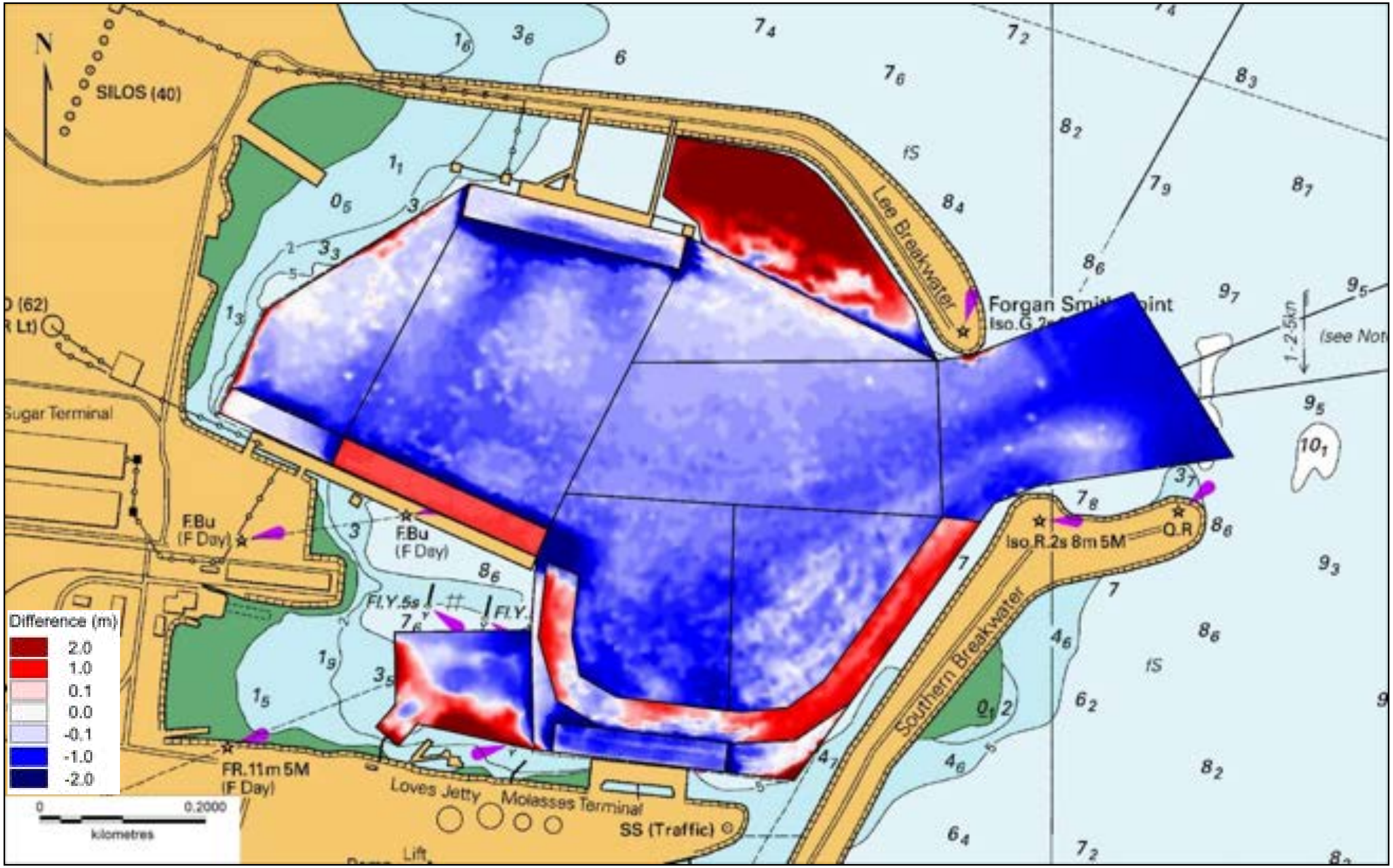

Figure 38. Depths above (red) and below (blue) design depths for the Port of Mackay five months after TC Debbie (August 2017).

To clearly show how the bed elevation in the dredge areas can naturally change, a series of transects were extracted from the DEMs at specific locations. The locations of the transects are shown in Figure 39 and plots of all the transects are shown in Figure 40 to Figure 46. The plots show the following:

- Entrance: the shoal at the entrance to Mackay Harbour has typically remained below the design depth with limited change in the bathymetry since November 2016. The survey from June 2014 shows that a small area was above the design depth, based on the morphology of the shoal it is likely that this was from debris as opposed to natural sedimentation of the shoal. It is possible that this was a rock from the breakwater which was displaced during TC Dylan (January 2014). In January 2021 (following maintenance dredging) the shallowest part of the shoal was approximately **0.2 m below the design depth**;
- South East: the south east region of the swing basin was at or above the design depth of the siltation trench between June 2014 and November 2020. The data suggest that there was some erosion between 2014 and 2016, this could have been a result of localised erosion due to propeller wash from vessels as no sediment management activities were undertaken over this time. Between November 2016 and November 2020 there was ongoing sedimentation, with deposition of up to around 1 m occurring in some locations (0.25 m/yr). The January 2021 survey shows that the 2020 maintenance dredging program reinstated the design depths for some of the siltation trench with depths varying **between 0.5 above and 0.6 m below the design depth**;
- Berth 1: following the 2013 maintenance dredging (refer to June 2014 transect), Berth 1 was 1 to 2 m below the design depth. Since the 2013 dredging there has been ongoing sedimentation on average of 0.2 m/yr (between 0.4 and 0.8 m/yr between 2016 and 2017 due to TC Debbie (2017)). The November 2020 survey shows that the depth of the transect across the berth was below the design depth and so no dredging was undertaken in this area as part of the 2020 dredging program. The infilling at the western side of the berth was due to some drag barring which was undertaken along the southern end of the berth redistributing sediment in the berth and resulting in some localised sedimentation. In January 2021 the depths in the berth were typically **between 0.2 and 0.5 m below the design depth**;
- Berths 3 and 4: following the 2013 maintenance dredging (refer to June 2014 transect), Berth 3 was up to 0.5 m above the design depth, while Berth 4 was 0.5 to 1.5 m below the design depth. Since 2014 there has been ongoing sedimentation of 0.2 m/yr on average (up to 0.4 m/yr in Berth 3 and 0.8 m/yr in Berth 4 due to TC Dylan and TC Debbie), with Berth 3 being around 1 m above design depth and Berth 4 being up to 0.5 m above design depth in November 2020. The 2020 maintenance dredging program deepened both berths and as a result in January 2021 **Berth 3 was between 0.3 and 0.5 m above the design depth** while **Berth 4 was between 0.5 and 2.0 m**[2] **below the design depth**;
- Berth 5: following the 2013 maintenance dredging (refer to June 2014 transect), Berth 5 was 0.5 to 1.5 m below the design depth. Since 2014 dredging there has been ongoing sedimentation of 0.2 m/yr on average (up to 0.4 m/yr due to TC Dylan and TC Debbie) which resulted in both the western and eastern ends of the berth being above design depths in November 2020. The 2020 maintenance dredging program deepened the entire berth and as a result in January 2021 the berth was **between 0.5 and 1 m below the design depth**;
- North: following the 2013 maintenance dredging (refer to June 2014 transect), the north region of the swing basin was on average 0.4 to 0.9 m below the design depth. Since the dredging there has been ongoing sedimentation of around 0.1 m/yr on average (up to 0.4 m/yr due to TC Dylan and TC Debbie). In November 2020 the sedimentation had resulted in depths being at the design depth. The 2020 maintenance dredging program removed

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[2] It was not possible to deepen Berth 3 without also dredging the eastern half of Berth 4 as the sediment from Berth 4 kept collapsing/flowing into Berth 3 due to the sediment properties.

sediment from the area resulting in depths in January 2021 being **between 0.6 and 1.3 m below the design depth**; and

- New Tug: as the depths in this area had not been maintained before the drag barring campaign at the end of 2018, the dates of the bathymetric surveys presented for the transect differs from the other transects. The data show that in August 2018 the entire area was approximately 2 m above the design depth. The drag barring campaign at the end of 2018 resulted in a 90 m wide area being deepened to around 0.5 m above the design depth. Between January 2019 and November 2020 there was on average around 0.15 m of deposition, providing an indication of the ongoing natural sedimentation rate in the new tug area. The sedimentation volume over this 21 month period for just the deepened area of the New Tug region (black outline is shown in Figure 39) was calculated to be approximately 1,000 m^3. Additional drag barring was undertaken as part of the 2020 maintenance dredging program which resulted in the deepened area being widened by 20 m (the sedimentation over this larger area is predicted to be around 1,800 m^3 over the 21 months which is approximately 1,000 m^3/yr) and the depths in January 2021 being **below the design depth by between 0.1 and 0.4 m** in the deepened area.

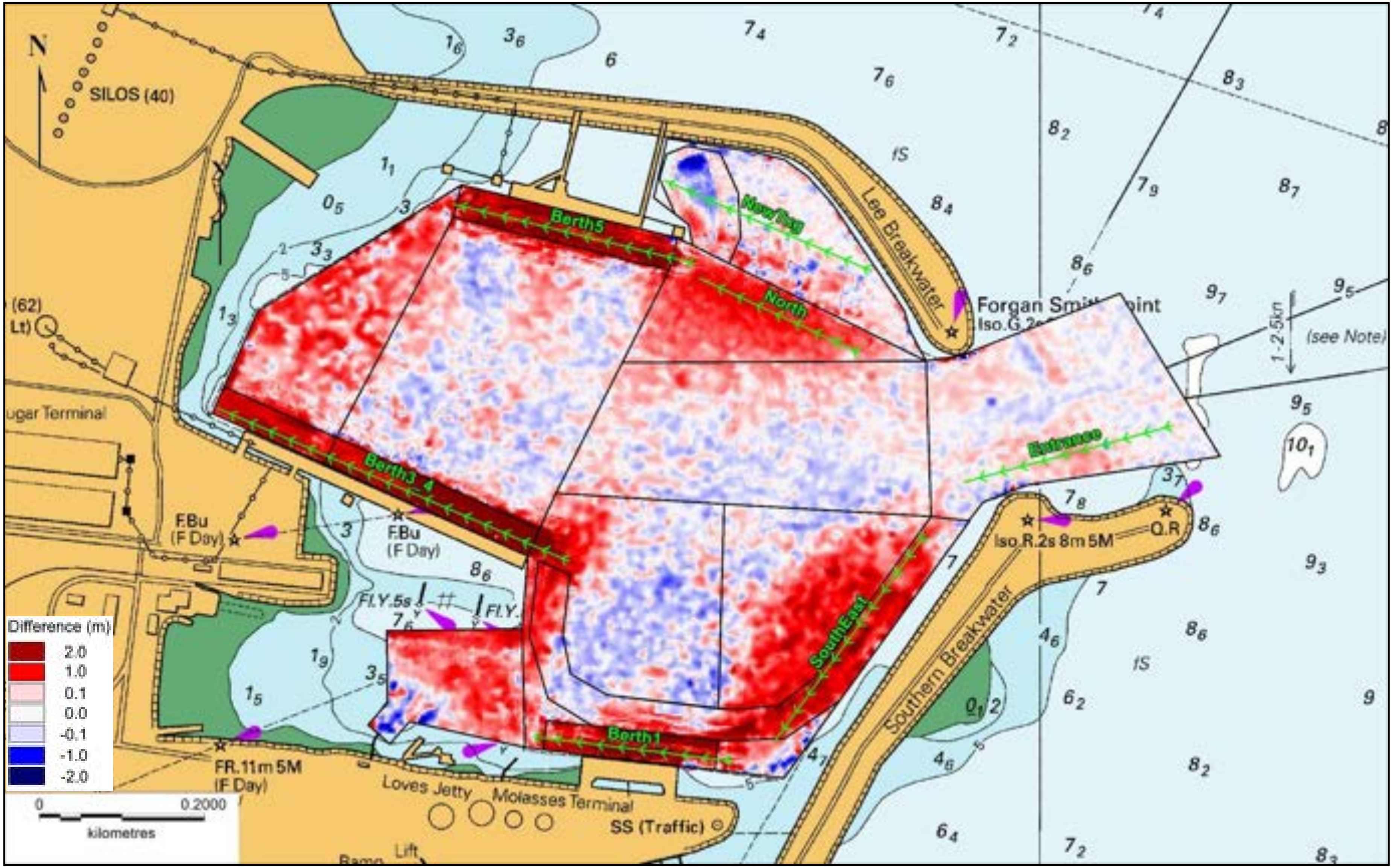

Figure 39. Transect locations and directions with cumulative sedimentation/erosion for 2009 to 2020 also shown.

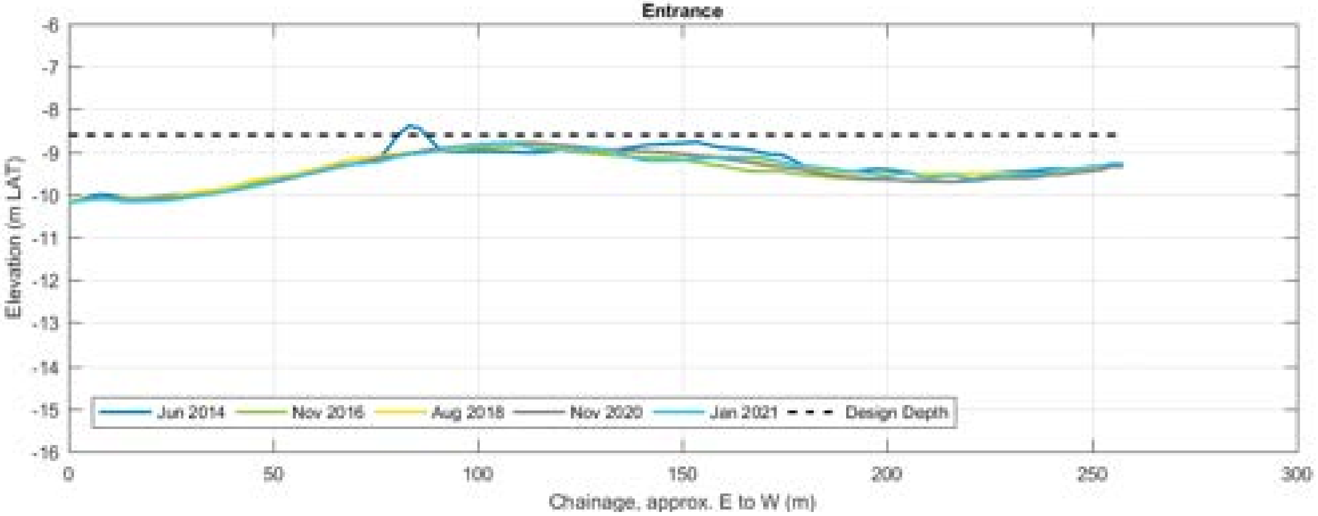

Figure 40. Change in bed elevation within the Port of Mackay at the Entrance transect.

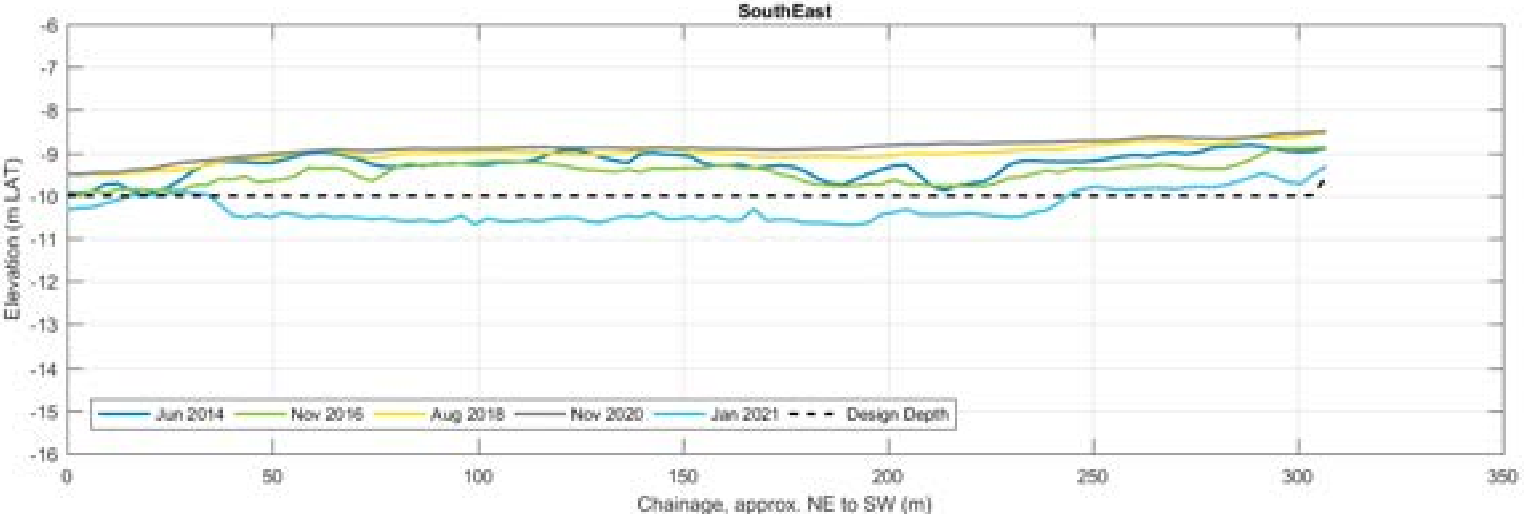

Figure 41. Change in bed elevation within the Port of Mackay at the South East transect.

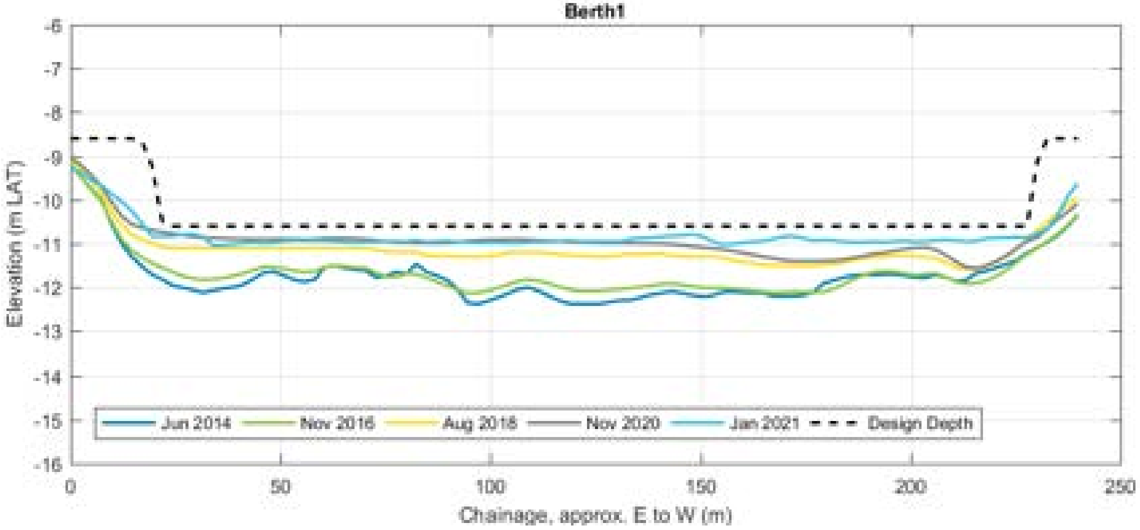

Figure 42. Change in bed elevation within the Port of Mackay at the Berth 1 transect.

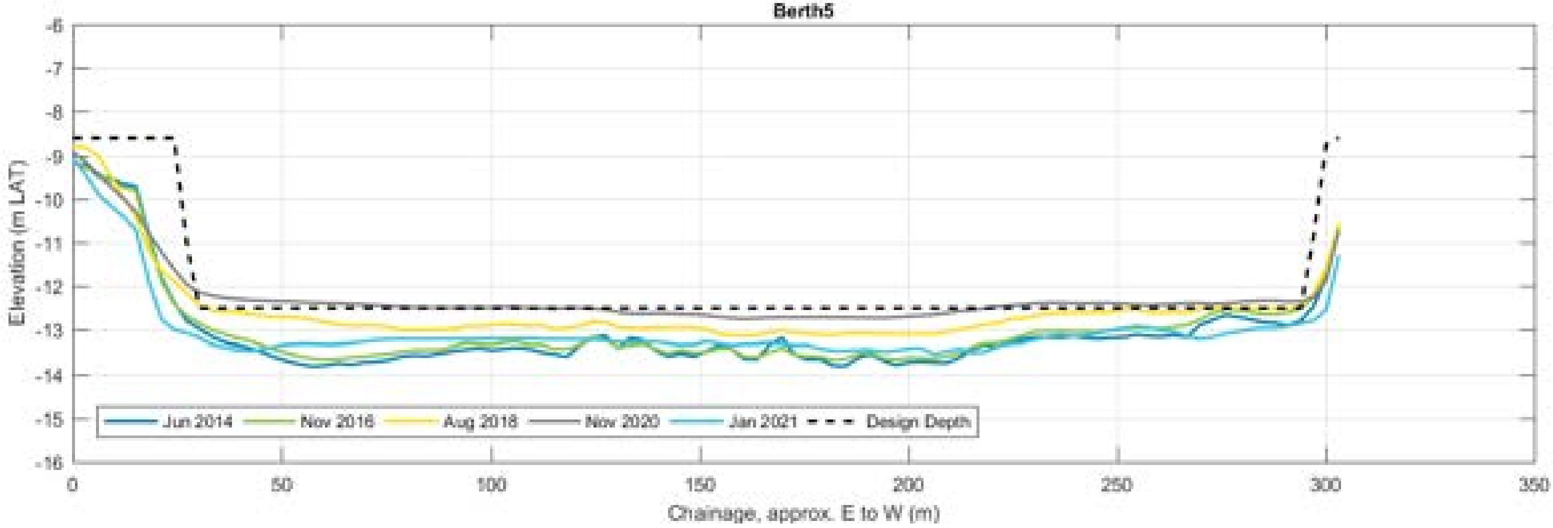

Figure 43. Change in bed elevation within the Port of Mackay at the Berth 5 transect.

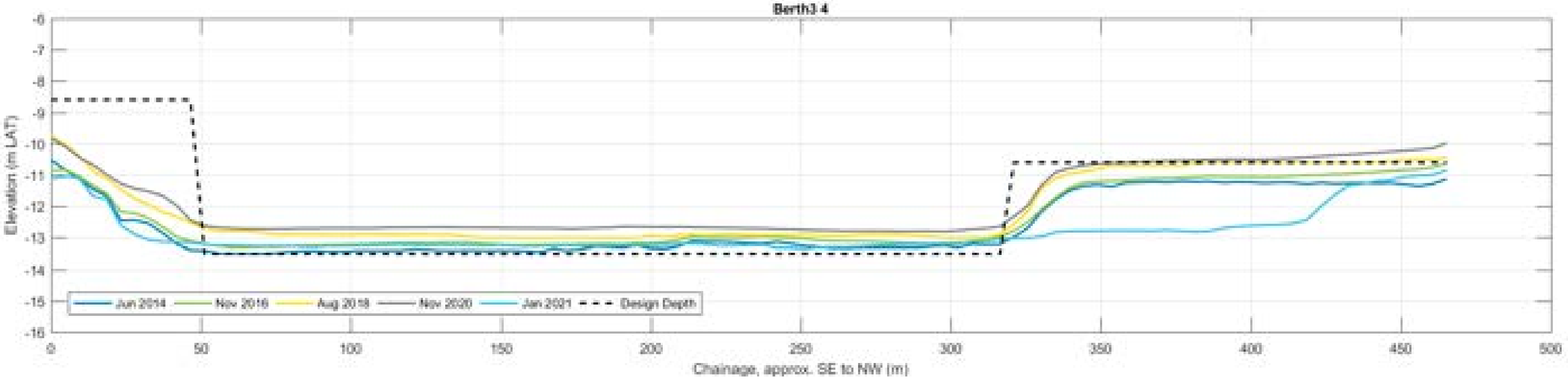

Figure 44. Change in bed elevation within the Port of Mackay at the Berth 3 and 4 transect.

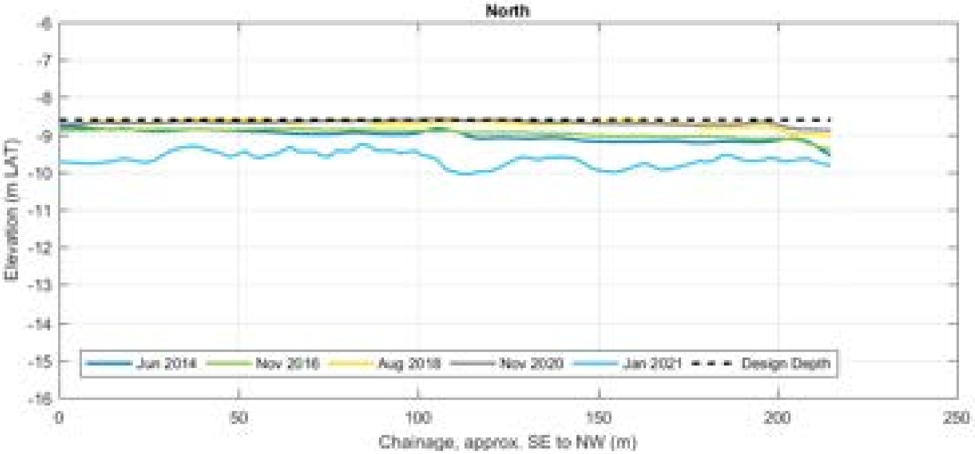

Figure 45. Change in bed elevation within the Port of Mackay at the North transect.

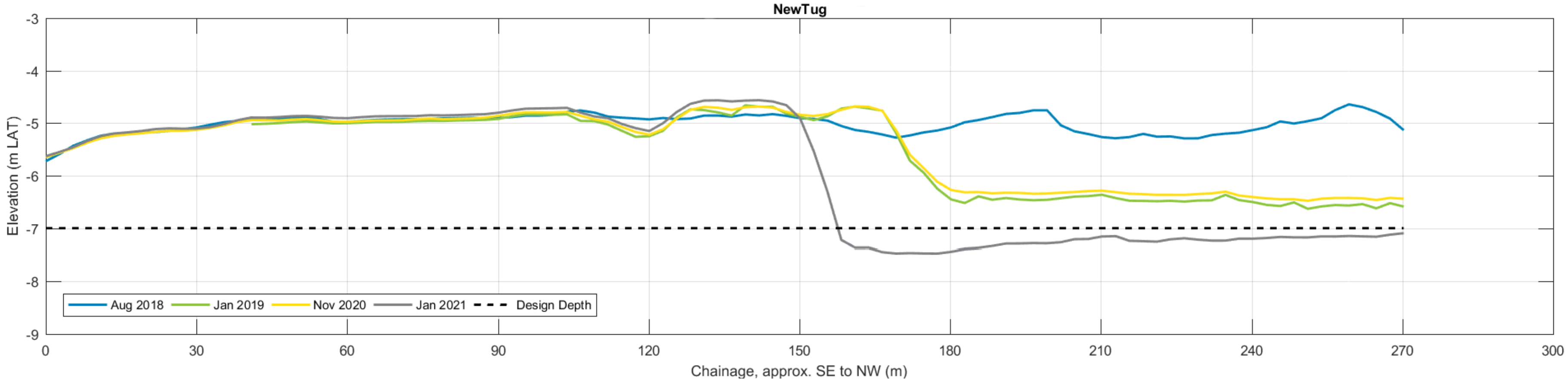

Figure 46. Change in bed elevation within the Port of Mackay at the New Tug transect.

3.4.2. Mackay DMPA

Sediment has historically been placed at the Mackay DMPA from maintenance dredging programs undertaken at the Port of Mackay. Bathymetric survey data for the Mackay DMPA are available for June 2010, July 2011, August 2013, September 2013, November 2020 and January 2021. Over this period two maintenance dredging programmes were undertaken by the *TSHD Brisbane,* with just under 100,000 m^3 (in-situ volume) was placed at the DMPA in August 2013 and just over 120,000 m^3 placed at the DMPA in December 2020.

The latest bathymetric survey for the Mackay DMPA is shown in Figure 47. The plot shows how the bathymetry is shallowest at the western side of the DMPA and deepest at the eastern side. There are large shore normal undulations (ridges/mega ripples) present in the DMPA with elevations of approximately 2 to 3 m. The 'pockmarks' visible in the DMPA were not visible in the 2020 pre-dredge survey and so are assumed to be a result of the dynamic descent of the sediment from the dredge hopper hitting loosely consolidated surface sediment on the seafloor and creating a crater.

The bathymetric data were analysed to calculate the change in volume over time from June 2010 to January 2021. Based on the analysis there is a lack of confidence in the June 2010 bathymetric data, as the data show a consistent offset of approximately +0.1 m in the bathymetry which is not considered realistic. As such, the data from the June 2010 survey have not been considered further in the analysis.

Results from the bathymetric analysis for the Mackay DMPA are detailed in Table 11 and differences between surveys are shown for three of the periods in Figure 48 to Figure 50. When the differences between the June 2010 and July 2011 survey are ignored, the results suggest that there are periods when the Mackay DMPA is relatively stable over time (e.g. July 2011 to August 2013) and periods when natural erosion can occur (e.g. September 2013 to November 2020). The reason for the loss of sediment from the DMPA between 2013 and 2020 is likely to be due to two Tropical Cyclones resulting in large waves and strong winds in the Mackay region over this period (TC Dylan in January 2014 and TC Debbie in March 2017) which appear to have resulted in erosion of just under 250,000 m^3 of sediment from the DMPA.

The results can also be interpreted to provide an indication of the short-term retention of maintenance dredge sediment at the DMPA. It is necessary to make a number of assumptions regarding the change in density of the sediment due to the dredging (in-situ density reducing from 1,250 kg/m^3 pre dredging to 1,100 kg/m^3 post dredging) and losses of sediment during the dredging activity (on average 10% of the sediment dredged by the *TSHD Brisbane* during maintenance dredging is lost when dredging (BMT WBM, 2013)). If we assume that the positive change of the DMPA over the dredge program provides the best representation of the sediment retained by the DMPA over the duration of the dredging, then it can be estimated that between 55 and 75% of the sediment placed at the DMPA was retained following the maintenance dredging program.

Based on this analysis it can be determined that over the short-term the Mackay DMPA can be considered to be partially retentive. Over the longer-term the Mackay DMPA can be considered to be stable during typical metocean conditions and then during extreme events with large waves (e.g. Tropical Cyclones) erosion of the DMPA can occur (natural erosion of the seabed adjacent to the DMPA would also be expected during these events).

Table 11. **Change in volume (m^3) at the Mackay DMPA over time.**

Note: the values in red highlight when there is uncertainty with the bathymetric data.

Period	Positive Change (m^3)	Negative Change (m^3)	Net Change (m^3)
June 2010 – July 2011	9,021	-155,914	-146,893
July 2011 – Aug 2013	34,341	-33,101	1,240
Aug 2013 – Sep 2013	55,336	-14,419	40,917
Sep 2013 – Nov 2020	11	-232,793	-232,782
Nov 2020 – Jan 2021	90,345	-1,742	88,603
July 2011 – Jan 2021	**12,394**	**-114,415**	**-102,021**

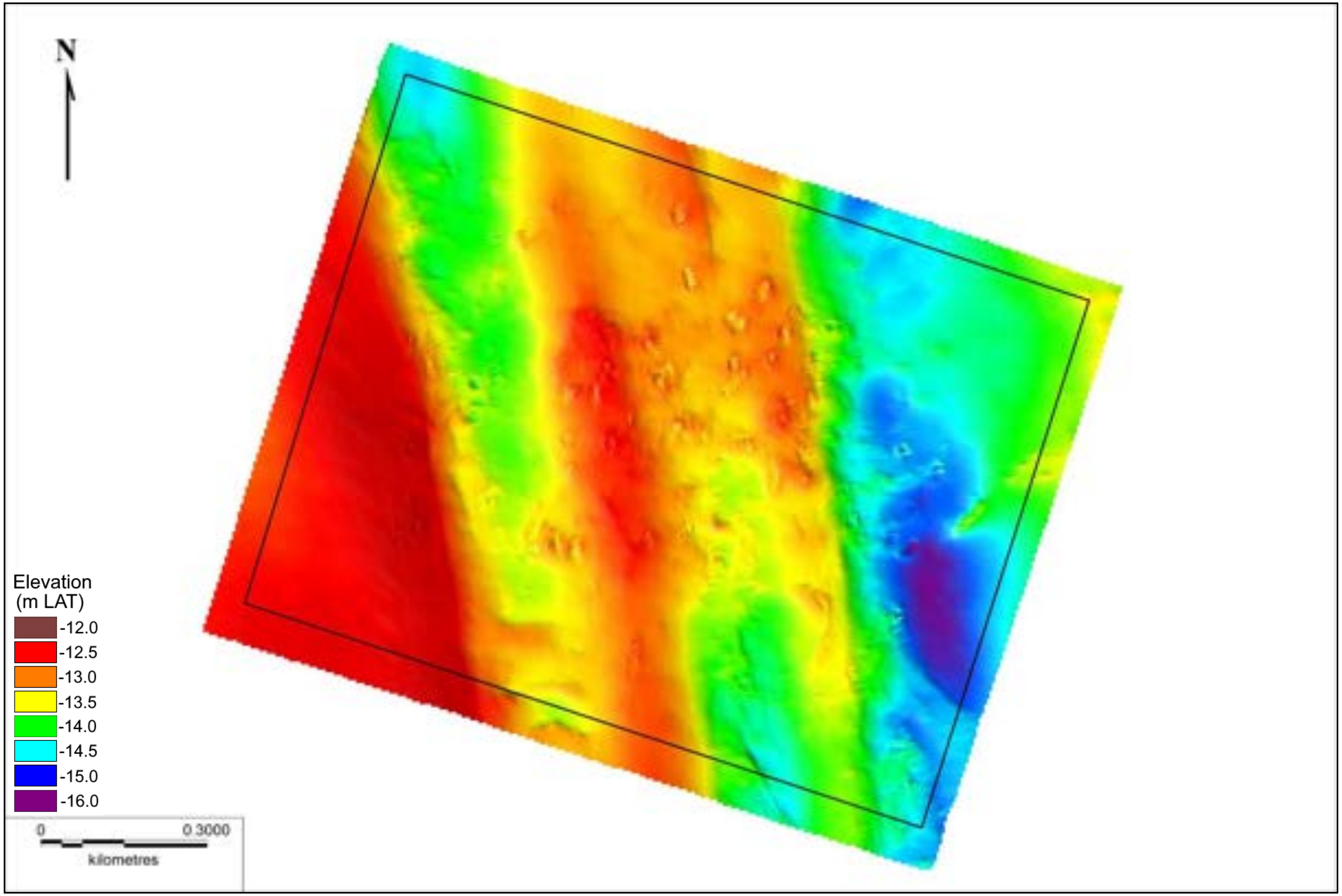

Figure 47. Bathymetry at the Mackay DMPA in January 2021.

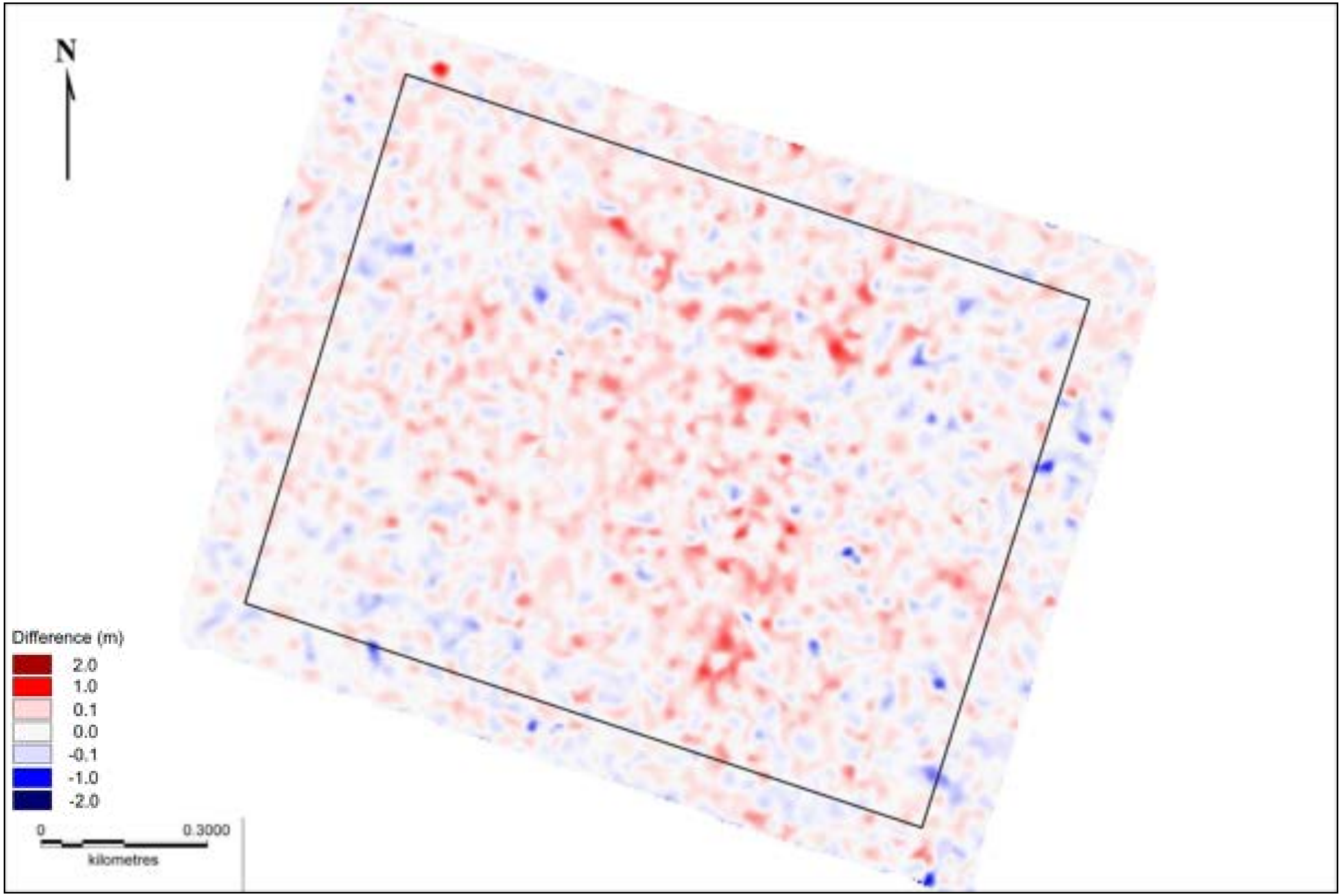

Figure 48. Change in bathymetry at the Mackay DMPA from August 2013 to September 2013.

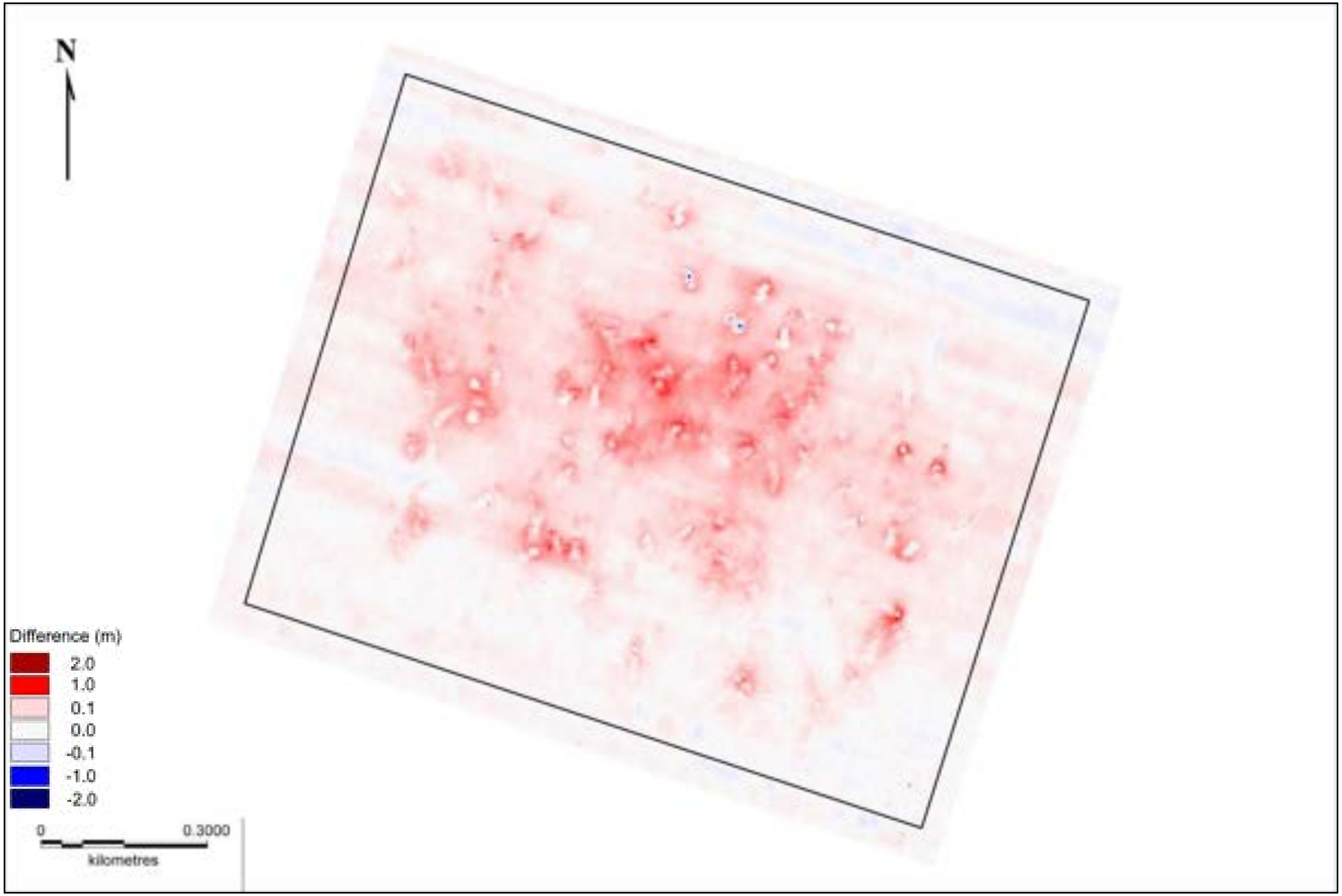

Figure 49. Change in bathymetry at the Mackay DMPA from November 2020 to January 2021.

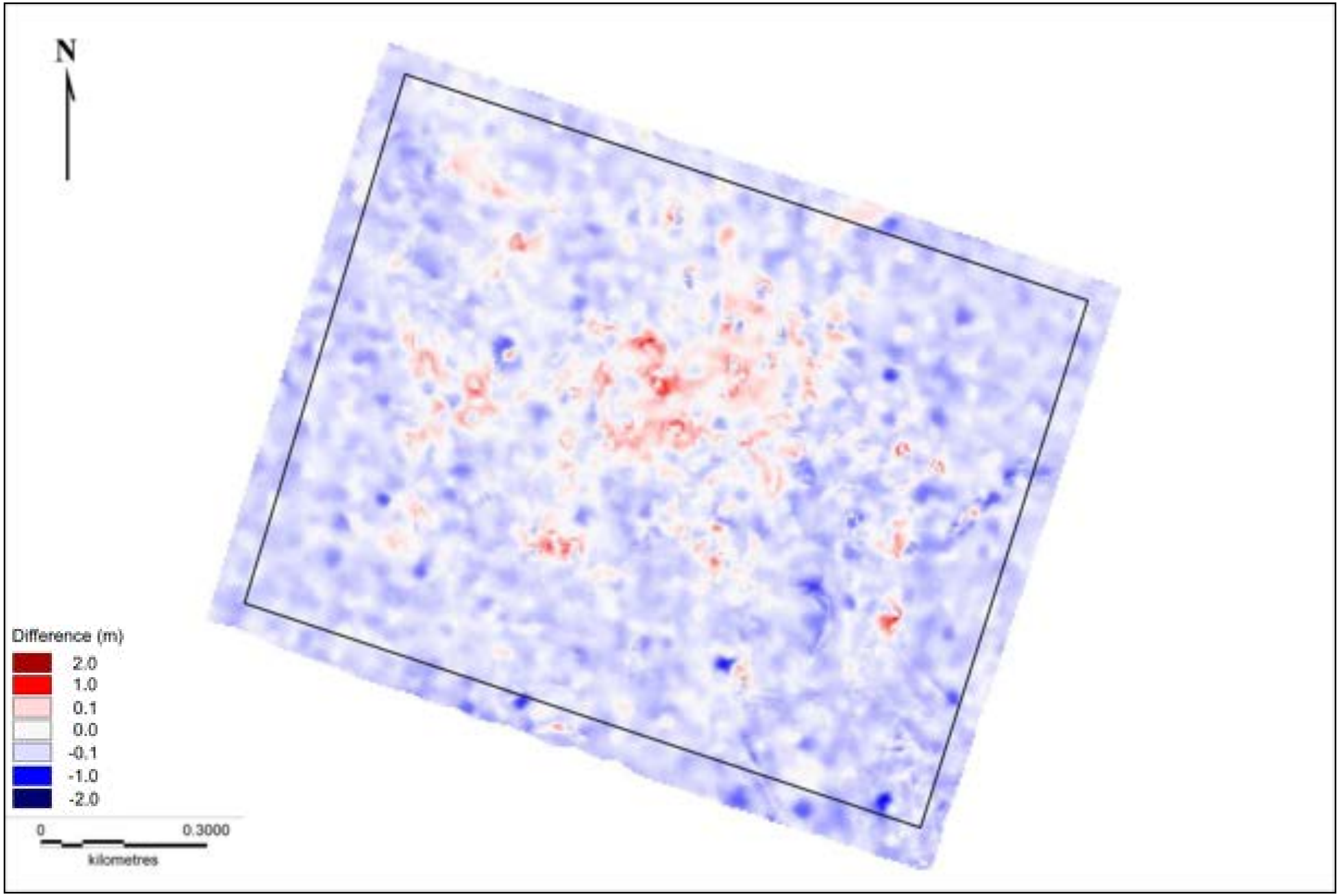

Figure 50. Change in bathymetry at the Mackay DMPA from July 2011 to January 2021.

4. Sedimentation

This section provides details of the conceptual understanding of the processes which influence sediment transport at the Port of Mackay based on all available information. The relative influence of the different processes on the supply, resuspension, transport and deposition of sediment within the dredged areas of the Port of Mackay is discussed.

4.1. Conceptual Understanding

The bathymetric analysis has shown that the largest volume of historical sedimentation at the Port of Mackay occurred in the swing basin, but that the majority of the sedimentation above design depths was in the berths. Sediment sampling has shown that the majority of the sediment within the Port of Mackay is silt and clay. Consequently, it is expected that, in most locations, the sedimentation will predominantly be fine-grained sediment. The only exception to this is the shoal at the entrance to the Harbour, where it is likely that sand sized sediment has historically accumulated in the form of an ebb bar.

The majority of the sedimentation which occurs within the Port of Mackay is due to fine-grained sediment being imported into the Harbour as suspended load during the flood tide. This is natural sediment which has been resuspended from the seabed within the adjacent nearshore coastal region around Mackay due to wave action and tidal currents (AECOM, 2016). The suspended sediment is then transported by tidal currents until the wave and tidal energy reduce sufficiently to allow the sediment to start to settle to the seabed and be deposited. The tidal currents in the area result in some of the suspended sediment from the adjacent coastal region being transported into the Harbour during the flood tide. Due to the relatively low ebb tidal currents in the Harbour and at the entrance to the Harbour, combined with the fact the Harbour is sheltered from wave action, it is expected that much of the suspended sediment transported into the Harbour will settle out and be deposited. The metocean conditions within the Harbour suggest that it is unlikely for any sediment which has been deposited to subsequently be resuspended by natural conditions. The spatial distribution of the sedimentation within the Harbour will be controlled by a combination of the local bathymetry (i.e. more sedimentation in areas with high trapping efficiency such as berths), the vessel routes (i.e. high traffic routes will have more propeller wash which will limit sedimentation) and the local metocean conditions (i.e. the higher current speeds and larger waves at the entrance to the Harbour will limit the deposition of fine-grained sediment).

As detailed above, wave action is the dominant driver for the resuspension of fine-grained sediment in the Mackay region. Consequently, waves are indirectly also expected to be the dominant driver for sedimentation in the dredged areas of the Port. To further test this, Figure 51 shows the annual sedimentation/erosion results, along with the total time over each dredging year (taken to be from May one year to April the following year, to include the full wet season) when the nearshore H_s (at the Hay Point WRB) was above 1.5 and 2 m, as well as the total rainfall over the dredging period. The plot shows that there is no correlation between rainfall and sedimentation, with the year with the third lowest rainfall coinciding the year when the sedimentation in the Port was highest. In contrast, there is some correlation between H_s and sedimentation, with the two years when the H_s was above 2 m for the most time, corresponding with the two years when the most sedimentation occurred in the Port. In addition, the years when the H_s was above 2 m for less than 10 hours (2012, 2015, 2016 and 2018) all correspond to the years when net erosion of sediment occurred within the Port. The erosion was likely due to propeller wash erosion caused by vessel operations. There are some anomalies with the correlation between H_s and sedimentation/erosion. The duration of time H_s was above 2 m was similar in 2018, 2019 and 2020 but the sedimentation/erosion varied from approximately no change in 2018 to net sedimentation of around 43,000 m^3 in 2019 and then to net erosion of 10,000 m^3 in 2020. This variability will be further investigated in the following sections.

Based on the findings from the bathymetric analysis, along with an understanding of the existing processes that was developed using all available information, a conceptual sediment transport model for the Port of Mackay has been developed to schematically explain the key processes influencing sedimentation (Figure 52).

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Figure 51. Plots showing the sedimentation/erosion, duration H_s was above 1.5 and 2 m and total rainfall (May to April) for 2010 to 2020.

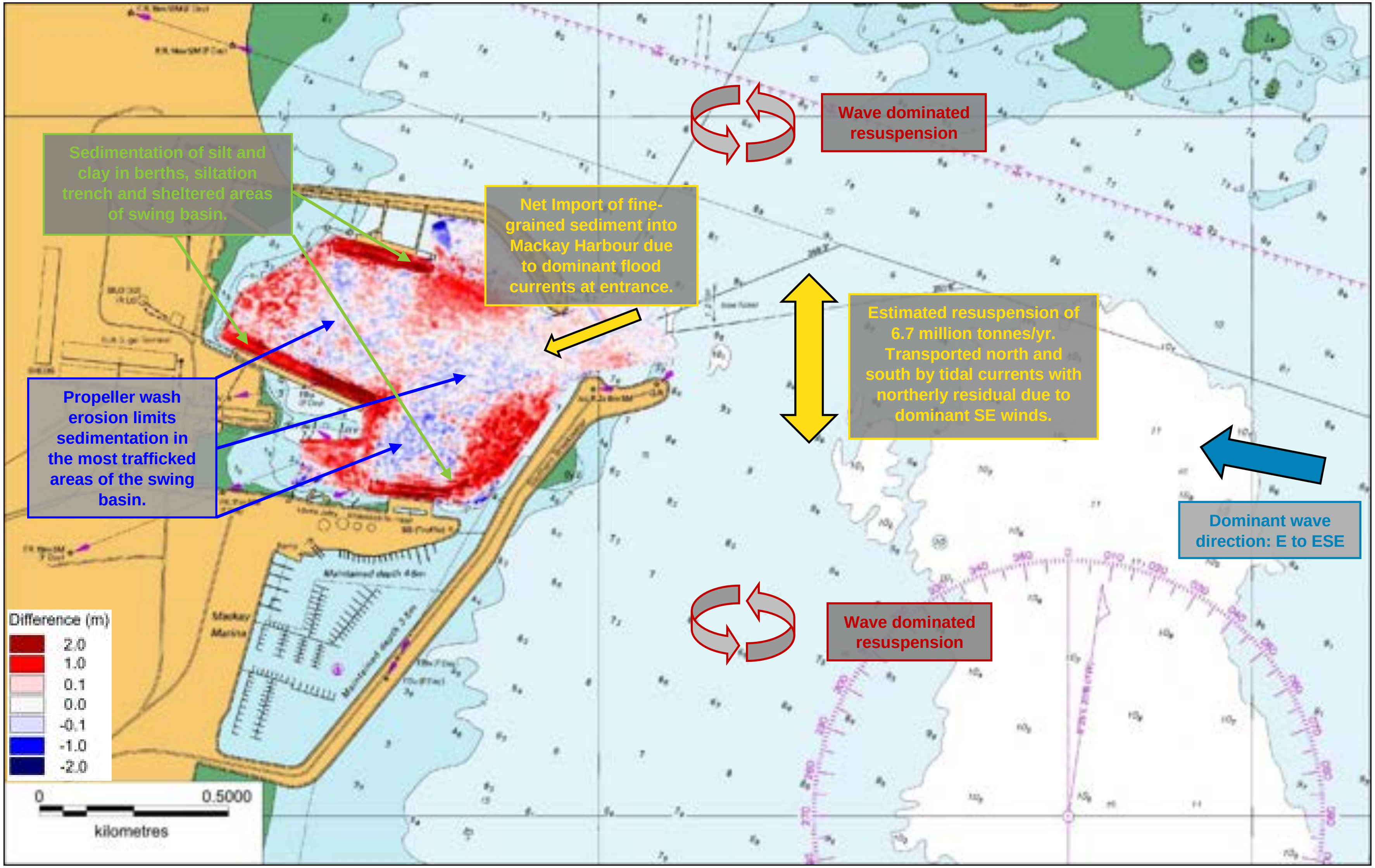


Figure 52. Conceptual model of sediment transport at the Port of Mackay.

4.2. Sedimentation Predictions

The relationship between the duration of time that the H_s was above 2 m and the net sedimentation/erosion within the Port of Mackay is shown in Figure 53. The plot shows a reasonable linear correlation ($R^2 = 0.7$) between the duration of time H_s is greater than 2 m and net annual sedimentation/erosion. The correlation shows that in years with no large wave events (i.e. duration H_s is above 2 m of less than 10 hours) there would typically be net erosion in the Port (due to drag barring and propeller wash rather than natural processes); while in a year with large waves (i.e. duration H_s is above 2 m of more than 60 hours) sedimentation in the Port of up to 90,000 m^3 could occur. When the duration that the H_s is above 2 m is between 10 hours and 30 hours there is more variability in the sedimentation rates, with values ranging from -10,000 m^3 (2020) to 43,000 m^3 (2019) when both years had 17 hours with the H_s above 2 m. The correlation line suggests that the high sedimentation rate in 2019 (and the high rate in 2013) are the anomalies as the correlation would be improved if these two points were removed. The following section will further investigate this relatively high sedimentation compared to the wave conditions.

It is likely that the majority of the sedimentation occurs during the wet season, due to the increased wave activity and associated increased SSC relative to the dry season. Therefore, if we assume that the sedimentation occurs over the full six months of the wet season the daily sedimentation rates can be estimated as follows:

- Low wave activity: no net sedimentation and likely net erosion;
- Typical wave activity: sedimentation in the order of 10,000 to 40,000 m^3 (similar to the mean sedimentation of 25,000 m^3 over the 9 years of data) = 60 – 220 m^3/day over the wet season; and
- High wave activity (i.e. year with a TC): sedimentation in the order of 90,000 m^3 = 500 m^3/day over the wet season.

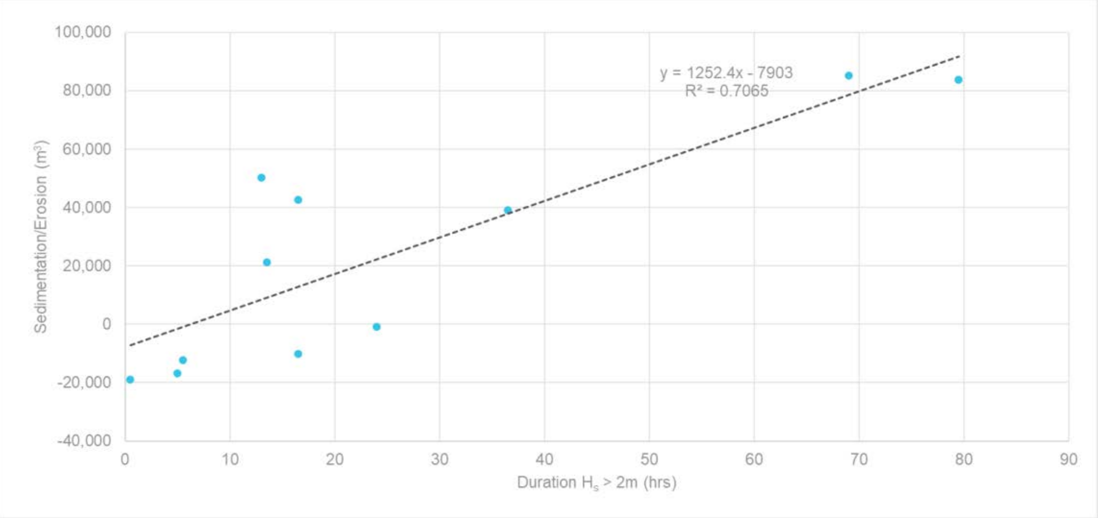


Figure 53. Correlation between wave conditions and sedimentation in the Port of Mackay.

4.3. Sedimentation Variability

As noted in the previous sections, although the duration of time the H_s was above 2 m does approximately correlate to sedimentation at the Port of Mackay, there are years when the sedimentation was much higher or lower than the correlation predicts. Years when sedimentation is lower than expected is not a major concern to the Port of Mackay as it will not influence the operability of the Port, but years when sedimentation is higher than expected could result in operability issues at the Port. Therefore, this section investigates potential drivers for the increase in sedimentation in the dredged areas of the Port observed to occur in 2019. The investigation includes an analysis of metocean conditions over the past eleven years (2010 to 2020 inclusive) to further consider if the sedimentation was due to natural processes and an assessment of changes in shipping movements over the past 3 years (2018 to 2020 inclusive) to identify if the change could be anthropogenically driven.

4.3.1. Metocean Drivers

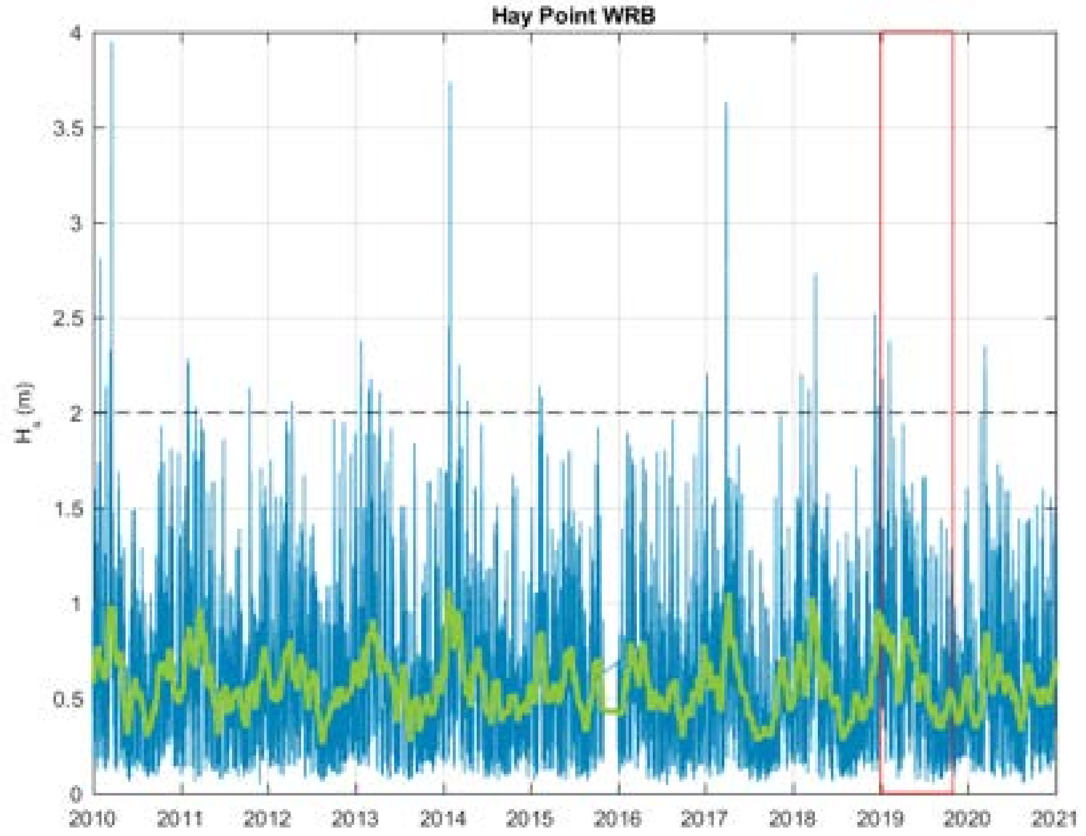
As noted in the previous sections, there is a correlation between net sedimentation/erosion in the Port and the wave climate (in particular the time that H_s measured at the Hay Point WRB exceeded 2 m). Using the trend line shown in Figure 53 and the number of hours that H_s was above 2 m during 2019 (which covered the period of increased sedimentation), just under 13,000 m^3 of sedimentation is predicted, while the actual volume from the bathymetric analysis was over three times this.

Further analysis of the wave conditions shows that while the H_s at the Hay Point WRB only exceeded 2 m for a relatively short duration in 2019, the wave climate over the 2018/19 wet season was characterized by a relatively extended period of elevated wave conditions (Figure 54). In addition, the median monthly H_s for 2019 was higher than any of the other years since 2010 for three months between January and May and the median H_s over the entire wet season was also notably higher than for other years (being 0.71 m while the next highest was 0.58 m) (Table 12).

Analysis of turbidity data collected at Slade Islet over five wet season periods (2015 to 2019 inclusive) shows a similar pattern to the wave data (Figure 55). The data indicates that while the extremes in turbidity in 2019 were not the largest measured, the 2018/19 wet season exhibited a small increase in median values relative to other years (Table 13 and Figure 56).

Table 12. Median significant wave height from Hay Point WRB. *Note: the red values represent the highest median over all years.*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Wet Season**
2010	0.70	0.50	0.79	0.67	0.35	0.48	0.51	0.28	0.38	0.61	0.67	0.40	**0.55**
2011	0.46	0.64	0.61	0.80	0.38	0.31	0.39	0.44	0.40	0.39	0.49	0.67	**0.58**
2012	0.44	0.51	0.67	0.50	0.72	0.39	0.58	0.20	0.37	0.44	0.41	0.46	**0.53**
2013	0.46	0.62	0.78	0.58	0.63	0.38	0.65	0.23	0.34	0.37	0.34	0.49	**0.53**
2014	0.71	0.69	0.75	0.55	0.60	0.53	0.32	0.50	0.33	0.38	0.37	0.39	**0.55**
2015	0.38	0.86	0.40	0.56	0.48	0.75	0.44	0.28	0.44	0.68	-	-	**0.43**
2016	0.37	0.49	0.59	0.76	0.42	0.38	0.39	0.44	0.28	0.40	0.43	0.39	**0.54**
2017	0.49	0.58	0.44	0.76	0.56	0.47	0.30	0.24	0.25	0.33	0.61	0.37	**0.52**
2018	0.59	0.35	0.78	0.67	0.62	0.46	0.33	0.26	0.37	0.34	0.38	0.86	**0.55**
2019	0.80	0.77	0.38	0.92	0.73	0.54	0.34	0.39	0.24	0.50	0.34	0.46	**0.71**
2020	0.39	0.30	0.74	0.47	0.59	0.57	0.46	0.29	0.60	0.43	0.45	0.46	**0.41**



Note: Red box indicates the period of increased sedimentation (January to October 2019) and the green line shows the median monthly H_s.

Figure 54. Time series of significant wave height at the Hay Point WRB.

Table 13. Median turbidity (NTU) at Slade Islet.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Wet Season[1]**
2014							0.2	0.7	0.6	1.2	12.5	32.4	
2015	10.1	30.0	2.0	2.4	3.2	6.7	2.9	0.3	0.5	3.1	2.5	1.2	**3.8**
2016	2.2	9.5	10.3	11.8	3.2	2.4	5.2	2.3	0.9	1.3	3.6	0.3	**7.9**
2017	1.7	2.6	3.2	39.3	9.8		1.9	0.5	0.4	3.0	3.4	1.5	**6.4**
2018	2.3	14.5				0.9	0.3	0.3	1.7				**9.3**
2019	1.2	33.4	17.5	11.1	4.2			0.2	0.4	1.3	0.4	0.8	**15.1**

[1] *taken to be Jan to April due periods with no data in Nov and Dec 2018*

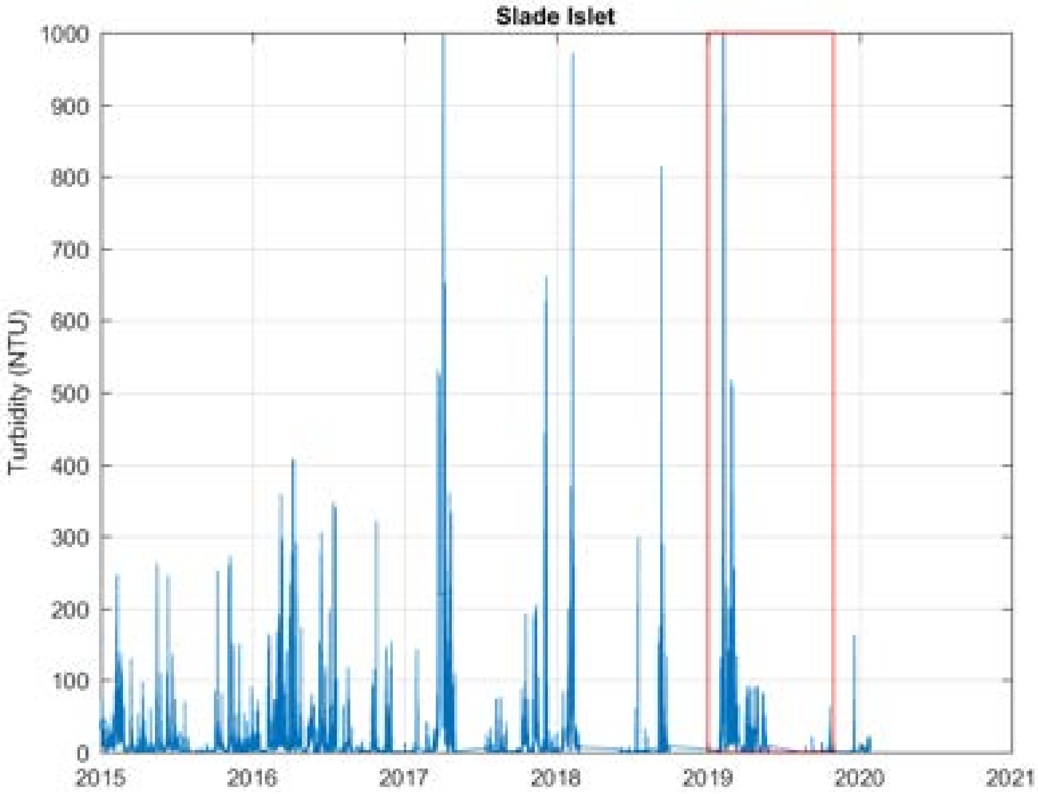


Figure 55. Time series of measured turbidity at Slade Islet.

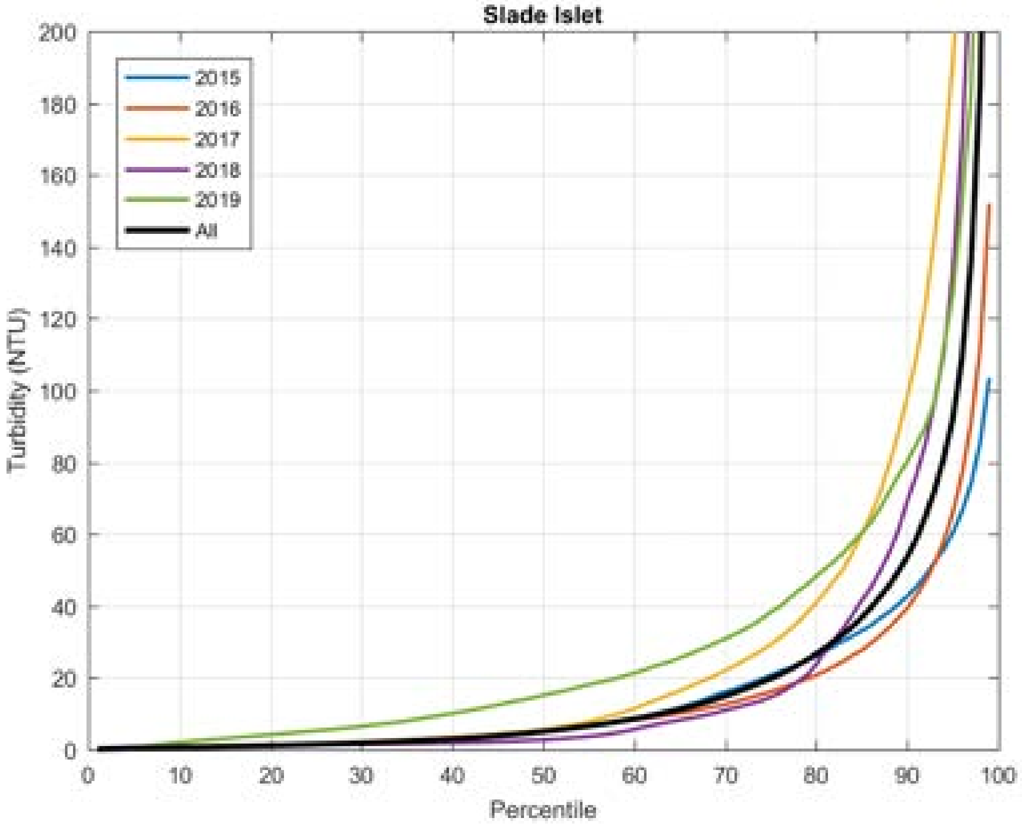


Figure 56. Wet season measured turbidity percentile plot at Slade Islet.

The correlation between the wave conditions and the turbidity provides confidence that these results indicate a true increase in wave energy and turbidity and are not just due to any changes in instrumentation or instrument error over the period.

As noted in Section 2.6, TC's have the potential to increase sedimentation in the Port due to the large waves and wind-induced currents which they can generate. The number of TC's which passed within 200 km of Mackay for each wet season since 2010 is detailed in Table 14. The relationship between TC's and sedimentation is not straightforward and its relative influence on sediment transport and sedimentation at the Port will be dependent on the strength of the TC, its track and duration. However, it is interesting to note that all years without ant TC's tracking within 200 km of the Port show a net reduction in sedimentation in the Port. There is also a net reduction in sedimentation in the Port in 2015 despite the occurrence of TC Marcia. This is likely to be a result of the TC tracking further south compared to the other TCs and it being the only TC to make landfall to the south of Mackay (meaning the strongest winds at Mackay due to the TC would have been in an offshore direction which would not have resulted in large waves).

The highest sedimentation occurred in 2017 following TC Debbie and in 2014 following three TC's over the 2013/14 wet season, with TC Dylan resulting in the largest waves. In the 2019 wet season two TC's passed within 200 km of Mackay, one in December 2018 (TC Owen) and one in January 2019 (TC Penny).

Table 14. Sedimentation and erosion rates in the Port of Mackay and number of TC's.

Year	Sedimentation/Erosion (m^3)	TC's passing with 200 km of Mackay
2010	39,011	1 (TC Ului)
2011	21,135	1 (TC Anthony)
2012	-12,284	0
2013	50,313	2 (TC Oswald and TC Tim)
2014	83,658	3 (TC Dylan, TC Edna and TC Ita)
2015	-16,780	1 (TC Marcia)
2016	-18,838	0
2017	85,256	1 (TC Debbie)
2018	-982	0
2019	42,669	2 (TC Owen and TC Penny)
2020	-10,042	0

4.3.2. Vessel Disturbance

Vessel movements are known to disturb sediment from the seabed in the Port area, with plumes resulting from the propeller wash of the bulk carriers and tugs often visible during and after berthing. Satellite imagery has been sourced and processed to show some example plumes from vessels moving within the Port (Figure 57 to Figure 59). The figures show that plumes with concentrations of 10 to 25 mg/l which take up approximately half of the dredged areas of the Port can be generated during the berthing of a vessel. The satellite imagery shows that one day after berthing there is no clear visible plume in the harbour, although the background SSC in the harbour is potentially still slightly higher than the SSC offshore of the harbour.

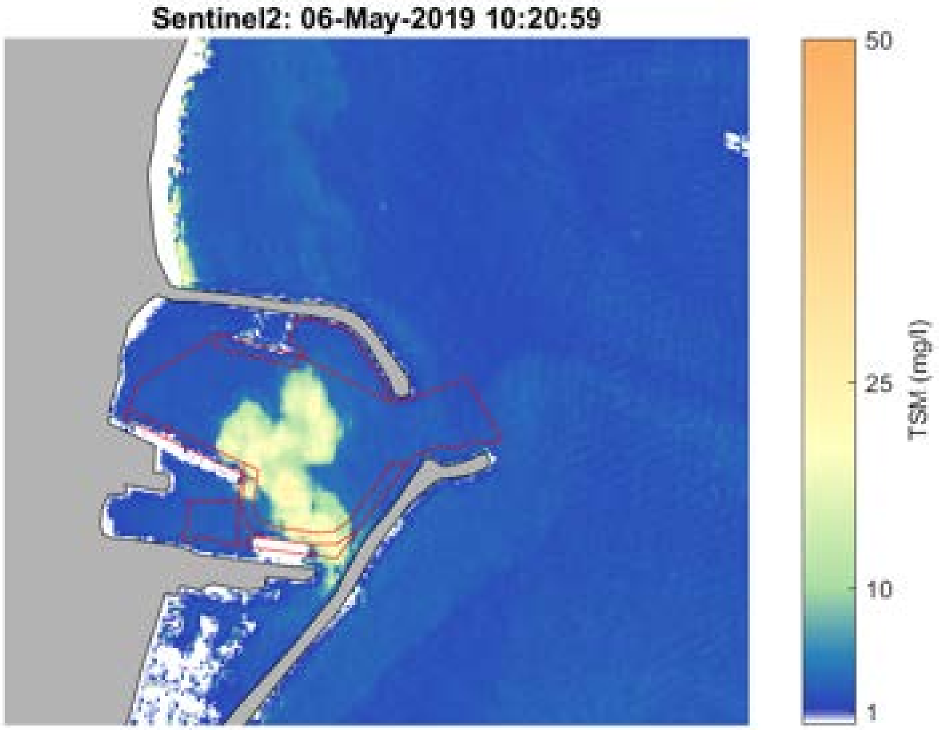


Figure 57. Satellite derived turbidity from Sentinel 2 showing a sediment plume from a Tanker (the Lindanger) berthing on berth 1.

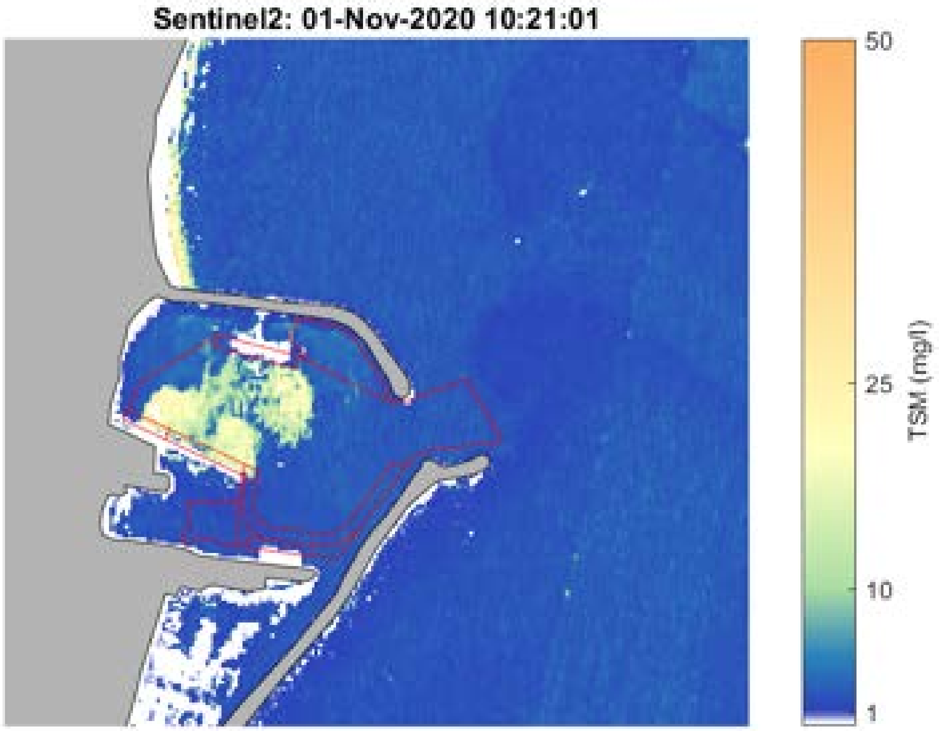


Figure 58. Satellite derived turbidity from Sentinel 2 showing a sediment from a Tanker (the Leikanger) berthing on berth 5.

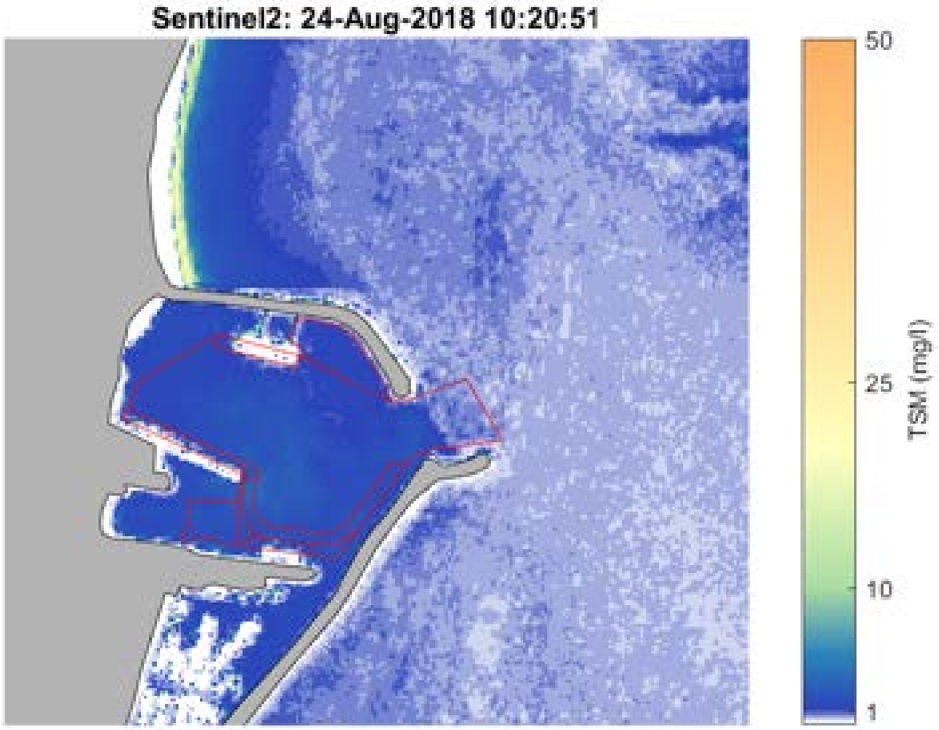


Figure 59. Satellite derived turbidity from Sentinel 2 showing a small increase in turbidity one day after the berthing of a car carrier (the Viking Destiny) on berth 4.

To understand whether operations within the Port could have led to an increase in the sedimentation observed in 2019, an assessment of the shipping movements during the three years from 2018 to 2020 was undertaken using vessel movement logs provided by NQBP.

The analysis is summarised in Table 15 and Table 16 and indicates the following:

- the total number of vessel movements within the Port did not vary significantly between years. However, there was a shift in the use of the berths within the Port with a notable reduction in the use of berth 1 and an equivalent increase in the use of berth 3 in 2019 and 2020 relative to 2018;
- the sum of the Dead Weight Tonnage (DWT) of ships using the Port did not vary significantly between years, although as with the number of ships, the use of different berths within the Port did vary; and
- the number of vehicle carriers calling at the Port increased from just two in 2018 (one in August and one in October) to eleven in 2019 and nine in 2020. All vehicle carriers used berth 3 or 4.

It is possible that these changes in vessel type and berth uses contributed to the increase in sedimentation which occurred between January and October 2019. In particular, operational changes in the way in which vessels are berthed (including orientation, use of bow thrusters, tugs and tidal state) and changes in vessel characteristics (draught, width, maneuverability) could result in an increase in propeller wash in regions not previously affected (for example along the batter slopes around the berths, which would be outside the area included in the bathymetric analysis volumes). Sediment from these areas could be eroded from the bed and re-deposited in other areas within the Port. If shipping movements did contribute to the increased sedimentation between January and October 2019, given that the trend for increased sedimentation did not continue post October 2019 and that shipping movements in 2020 were similar to those in 2019, it would appear that the seabed in the region has reached a new equilibrium in response to the changes in vessel movements/frequency.

Table 15. Number of vessel movements by year and berth.

Year	Berth 1	Berth 3	Berth 4	Berth 5	Total
2018	108	20	23	39	**190**
2019	91	34	20	43	**188**
2020	99	38	14	40	**191**

Table 16. Total DWT (million tonnes) by year and berth.

Year	Berth 1	Berth 3	Berth 4	Berth 5	Total
2018	4.2	0.8	0.4	1.7	**7.2**
2019	3.5	1.4	0.4	1.9	**7.1**
2020	3.7	1.5	0.3	1.6	**7.1**

4.3.3. Summary

This assessment has shown that the wave conditions over the 2018/19 wet season were more energetic than other years since 2010, despite the duration that the H_s was above 2 m not being as high as other years. In addition, the turbidity at Slade Islet (the closest long term monitoring site to the Port) over the 2018/19 wet season was significantly higher than during other years since 2015. These results show that the 2018/19 wet season was naturally more energetic than other wet seasons and as a result the turbidity/SSC was higher. This suggests that although the duration of time that the H_s was above 2 m can be used to determine the sedimentation during some years, it is important to also consider the duration of time that the H_s exceeds lower thresholds as elevated turbidity/SSC can still occur during these conditions. Based on this, a weighted duration approach has been adopted which encompasses the duration of time the H_s was above 1 m, 2 m and 2.5 m (Figure 60). Although the sedimentation still does not correlate perfectly with the weighted duration, it provides a better correlation than when just the 2 m H_s threshold is adopted. The correlation plot between the sedimentation and the weighted duration in Figure 61 shows that the correlation has improved, with the R^2 increasing from 0.7 to 0.8.

The analysis has also assessed the potential that changes to vessel movements in the Port could have contributed to the increased sediment experienced in 2019. While the assessment found that there was a change in vessel movements between 2018 and 2019, the movements in 2019 and 2020 have been similar. Therefore, although it is possible that the change in vessel movements between 2018 and 2019 could have resulted in increased sedimentation as areas not previously subject to propeller wash could have been eroded, it is considered unlikely that this was a major contributor as the vessel movements were similar in 2020 when net erosion occurred in the Port.

Based on the analysis undertaken, it is considered most likely that the elevated sedimentation which occurred in 2019 was due to a more sustained energetic period during the 2018/19 wet season, resulting in higher natural turbidity/SSC and therefore more suspended sediment being transported into the harbour and deposited in the dredged areas of the Port.

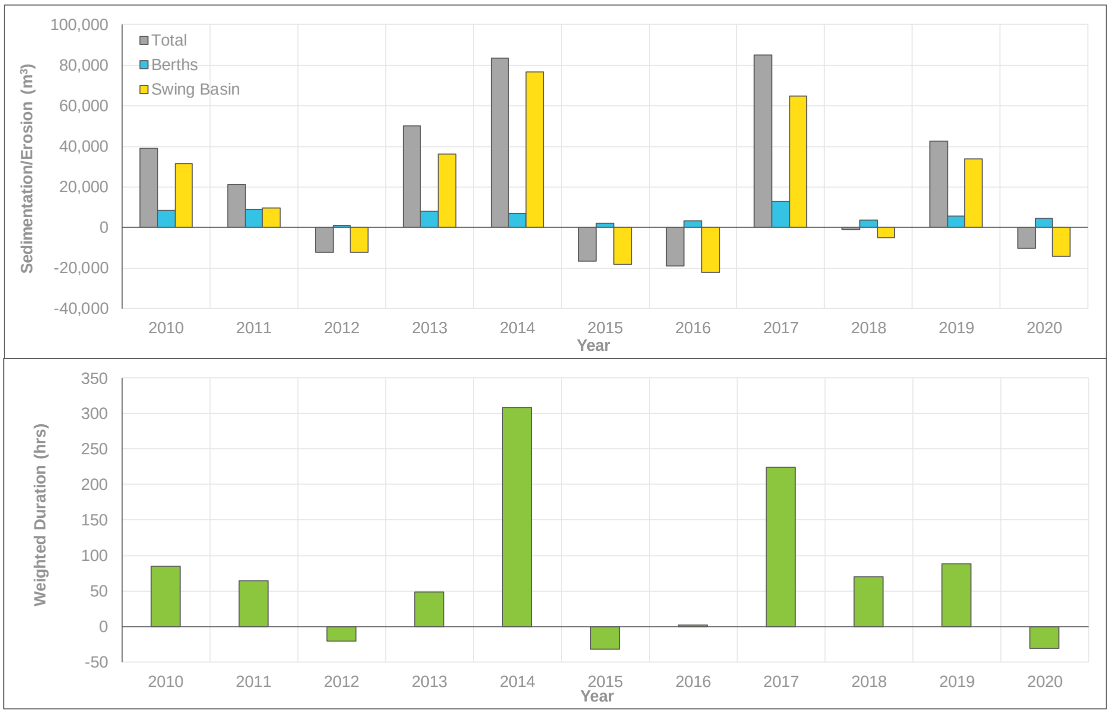


Figure 60. Plots showing the sedimentation/erosion and the weighted wave duration for 2010 to 2020.

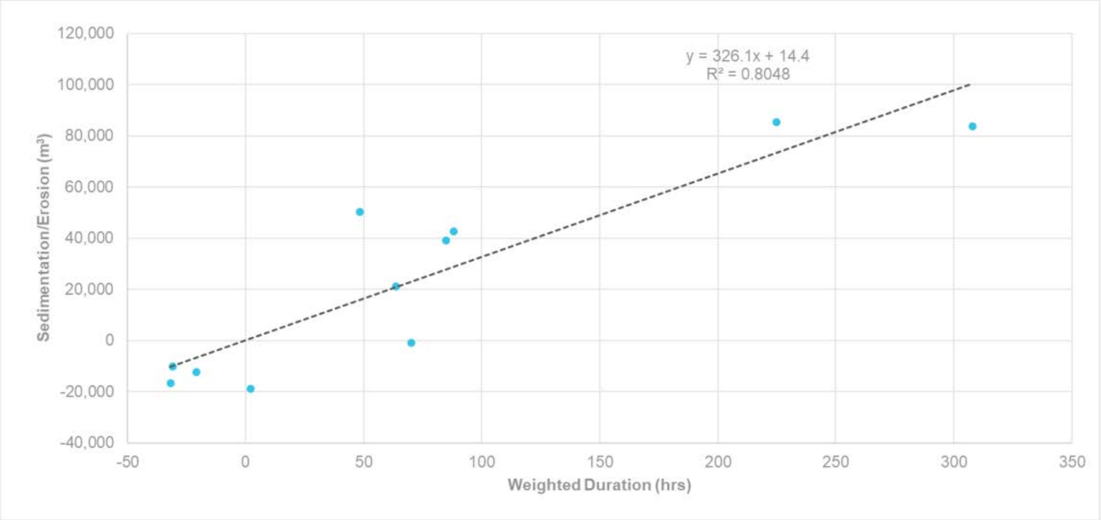


Figure 61. Correlation between weighted wave duration and sedimentation in the Port of Mackay.

4.4. Future Maintenance Dredging Volumes

The sedimentation predictions detailed in this section of the report can be used to estimate future maintenance dredging volume requirements for the Port of Mackay. The volume requirement will be used to inform the future maintenance dredging volume in the LMDMP, which includes the future maintenance dredging volume over a 10 year period. As the value specified will represent the maximum volume of sediment allowed to be removed by maintenance dredging over a 10 year period, it is important to ensure that it represents a realistic upper value for future sedimentation as opposed to an average value. Therefore, to define the future sedimentation requiring maintenance dredging at the Port of Mackay it has been assumed that a 10 year period would be made up of eight years with typical wave activity and two years with high wave activity. The sedimentation requiring maintenance dredging for these years have been assumed to be the upper range of the values presented in Section 4.2, resulting in the following volumes:

- eight typical wave activity years: an annual maintenance dredging requirement of 40,000 m^3/yr, resulting in a total maintenance dredging volume over the eight years of 320,000 m^3; and
- two high wave activity years: an annual maintenance dredging requirement of 90,000 m^3/yr, resulting in a total maintenance dredging volume over the two years of 180,000 m^3.

This gives a total predicted future maintenance dredging volume over 10 years for the Port of Mackay of 500,000 m^3. This value does not include any allowance for over dredging which should also be included. Based on the historic maintenance dredging detailed in Table 1, which shows that approximately 415,000 m^3 of sediment was removed by maintenance dredging between 2000 and 2008, this volume is considered to provide a realistic upper value for future maintenance dredging.

5. Sedimentation Reduction

This section investigates possible engineering or technical solutions to avoid or reduce sediment accumulation and therefore maintenance dredging within the Port of Mackay. The Guidelines for Long-term Maintenance Dredging Management Plans note that consideration should be given to actions that reduce dredging and disposal volumes and frequency (i.e. not just the volume) (DTMR, 2018).

The study includes an assessment of the feasibility of solutions based on the local environment and Port configuration, a constraints analysis of potentially feasible solutions relative to maintenance dredging and consideration of the impact of any feasible solutions to future maintenance dredging volumes.

5.1. Existing Sedimentation Management

The following three sediment management approaches have historically been used and are currently adopted at the Port of Mackay:

- Maintenance dredging: this has been the main approach to remove sediment and maintain design depths in the Port of Mackay. Since 2004 the *TSHD Brisbane* has undertaken the majority of the maintenance dredging at the Port, with approximately 325,000 m^3 relocated during three separate programs between 2004 and 2018 (i.e. approximately 100,000 m^3 relocated every four to five years). This type of vessel has a high production rate (approximately 16,500 m^3/day for the Port of Mackay), can operate in offshore areas and heavily trafficked areas, has a hopper allowing offshore placement and is well suited to dredging soft unconsolidated sediment typically associated with maintenance material (it was built specifically for undertaking maintenance dredging at the Queensland Ports);
- Siltation trench: the siltation trench in the swing basin was designed to act as a sediment trap with a design depth 1.4 m deeper than the surrounding swing basin. The location of the trench was selected as the highest sedimentation rates in the swing basin occur in this area. The trench location also means that any sedimentation in that area of the swing basin which wasn't directly in the trench could be moved by bed levelling/drag barring into the deeper siltation trench. This has assisted to ensure that the design depths have been maintained in the swing basin for a longer period of time and also that ongoing sedimentation in the area has been focused in one area, which acts to promote consolidation of the sediment. As such, the frequency and in-situ volume (due to consolidation) for maintenance dredging is likely to have been reduced due to the trench, and the dredging required will have been more efficient and the dredge duration shorter as the majority of the sediment has been concentrated in one location; and
- Bed levelling and drag barring: bed levelling has routinely been undertaken following maintenance dredging to redistribute the sediment on the bed and remove any high spots. In addition, drag barring has been undertaken in the Port to try and resuspend and redistribute bed sediment in the years between maintenance dredging programs to help maintain design depths. Based on information provided by NQBP, we understand that the historic drag barring programs have typically been up to one week in duration and the bathymetric analysis has shown that between 7,000 and 10,000 m^3 has been relocated over this duration. Based on this information, the rate that loosely consolidated sediment can be resuspended from the Port of Mackay by drag barring is between 1,000 and 1,400 m^3/day (i.e. at least an order of magnitude less than the *TSHD Brisbane*). It is also important to note that during previous drag barring programs it was found that in berths with recently deposited sediment the approach was only effective for short programs (e.g. 1 day or approximately 0.1 m in depth) due to the drag bar fluidising the loosely consolidated surface sediment in the berths which then makes the sediment difficult to relocate. As such, although bed levelling provides a good interim measure to help manage sedimentation in the Port of Mackay, there is uncertainty as to whether it can be used in place of maintenance dredging.

Based on the bathymetric analysis the future sediment management requirements at the Port of Mackay were estimated in Section 4.4, with a total volume over ten years predicted to be 500,000 m^3. Over/insurance dredging is currently adopted at the Port to ensure that the design depths are achieved based on the dredging tolerance and to ensure that natural sedimentation does not result in the seabed becoming shallower than the design depths soon after the dredging. However, if we assume that the existing bed level in the Port is the design depth, (which would be the case in areas where ongoing sedimentation occurs if no ongoing sediment management was adopted), then the future sedimentation which would require management would be as follows:

- Swing basin: annual average sedimentation of 42,000 m^3;
- Berths: annual average sedimentation of 7,000 m^3; and
- Proposed new tug area: based on bathymetric surveys since the new tug area was deepened, the annual average sedimentation is predicted to be in the order of 1,000 m^3.

Based on the above, the annual average sedimentation requiring management within the Port is expected to be 50,000 m^3/yr. Therefore, the sedimentation over 5 years is predicted to be 250,000 m^3, over 10 years it is 500,000 m^3 and over 20 years it is 1,000,000 m^3.

For the comparative analysis it will be assumed that 150,000 m^3 of sediment will be relocated by maintenance dredging every three years, with bed levelling only required immediately after the dredging (i.e. no requirement for drag barring between maintenance dredging programs).

5.2. Overview of Solutions

Significant research has been undertaken globally into solutions to reduce sedimentation in Ports and Harbours due to the ongoing economic and operational impacts. Best practise guidelines have been developed by PIANC and the United States Army Corps of Engineers (USACE) for approaches to minimise harbour and channel sedimentation based on port specific experience (USACE, 2003; PIANC, 2008). Both guidelines note that port specific investigations, such as this, are required to assess the applicability of the approaches on a case by case basis, as the suitability is dependent on the port configuration, sediment type, natural environment and processes. These guidelines are summarised in the Maintenance Dredging Strategy, Technical Supporting Document (RHDHV, 2016a) where it is noted that three broad strategies can be implemented to reduce sedimentation:

- Keep Sediment Out: keeping sediment out of the Port that might otherwise enter and deposit;
- Keep Sediment Moving: increase current speeds in quiescent areas to prevent sediment from settling as it passes through the Port; and
- Keep Sediment Navigable: applicable to sites characterised by high turbidity near-bottom sediment regimes where navigability of fluid mud zones is permitted, thereby reducing the required dredged depth.

An overview of the various approaches available for each strategy is provided in Table 17.

Table 17. Summary of strategies to reduce future sedimentation (RHDHV, 2016a).

Strategy	Approach	Example
Keep Sediment Out	Stabilise sediment sources	Reduce sediment input through better catchment management.
	Diverting sediment-laden flows	Diverting river sediment inputs away from port.
	Trapping sediment before it enters port	Sediment traps and insurance trenches.
	Blocking sediment entry	Pneumatic barrier, silt screen, barrier curtain.
	Habitat creation	Seagrass, saltmarsh, mangroves to stabilise sediment and promote accretion.
Keep Sediment Moving	Structural solutions to train natural flows	Training walls/dikes to divert flow and prevent local deposition of sediment.
	Devices to increase bed shear stresses	Hydraulic jets, vortex foil arrays, mechanical agitators (e.g. spider dredging system).
	Methods to reduce sediment flocculation	Adopting designs which reduce turbulence and therefore flocculation (e.g. solid wharf walls instead of piling supported wharfs).
Keep Sediment Navigable	Adopt a 'nautical depth' navigation approach which includes fluid mud	Nautical depth is the distance from the water surface to a given wet density, typically in the range of 1100 to 1300 kg/m^3.

5.3. Initial Feasibility

When considering the potential feasibility of solutions, it is important to take into account that the sedimentation in the Port of Mackay is relatively low. This means that for any solution to be potentially feasible, as well as having the potential to reduce sedimentation/dredging and having a medium to high probability of being effective, the solution would also need to be cost effective (i.e. not more than five times the cost of maintenance dredging) relative to the reduction in sedimentation it provides compared to ongoing maintenance dredging. These three criteria have been adopted to assess the potential feasibility of the sedimentation reduction approaches detailed in Table 17.

A summary of the feasibility of the broad approaches detailed in Table 17 based on the three criteria is shown in Table 18. The solutions which have the potential to reduce sedimentation are discussed in more detail below:

- Diverting sediment-laden flows: based on numerical modelling results the flood current speeds within the Harbour are higher than the ebb current speeds. This is thought to be partially due to the entrance configuration of the Harbour being more aligned to the offshore flood currents than the ebb currents, therefore allowing higher flood flows into the Harbour. There is the potential that changing the entrance configuration could reduce the flood current speeds and increase the ebb current speeds, which in turn could reduce the mass of sediment being transported into the Harbour. However, detailed investigations would be required to test if changing the configuration results in any change to the sedimentation. In addition, the costs to change the entrance configuration of the Harbour would be in excess of $10M and so the cost combined with the low to medium confidence in the effectiveness, mean that it is not considered a realistic option for reducing sedimentation. However, if any changes to the entrance configuration are planned as part of future projects, then it would be beneficial to try and optimise the configuration to reduce sedimentation in the Port;

- Trapping sediment: as noted in Section 5.1, the siltation trench in the Port of Mackay was designed to act as a sediment trap to reduce the duration and frequency of maintenance dredging. Although this approach is currently adopted at the Port, its feasibility will be considered as a potential ongoing sediment management approach and therefore the approach will be taken forward to the constraints analysis detailed in the next section;
- Blocking sediment entry: for harbours with single entrances it can be possible to block sediment from entering the harbour. The most successful solution for this approach is a pneumatic barrier at the harbour entrance, which is closed during periods when high turbidity is present in the adjacent water body. This approach would not only have very high capital and maintenance costs, but would also have significant operational issues at the Port of Mackay and so is not considered to be feasible. In some locations air-bubble screens have been adopted with the air bubbles forming a screen at the entrance to the harbour. The aim of the air bubbles is to promote the generation of currents away from the bubbles, thereby reducing the input of water with high SSC from the adjacent water body. However, research has found that the air-bubbles are typically only suitable in areas with calm conditions and low wind speeds (Cutroneo et al, 2014). Given the local metocean conditions at the Port of Mackay this approach is considered unlikely to be effective in reducing sedimentation; and
- Devices to increase bed shear stresses: there are a range of solutions which can be adopted to increase bed shear stresses including fixed position jet arrays, bed levelling/drag barring and propeller wash agitation. Due to high capital and maintenance costs, fixed position jet arrays have only been adopted in berths where very high sedimentation occurs (> 3 m/yr). They were considered as part of the Avoid and Reduce assessment at the Port of Hay Point and it was found that over a 20 year period the costs for the jet array were more than 10 times higher than the costs for ongoing maintenance dredging and so the option was discounted (RHDHV, 2016b). Given that the average annual sedimentation in the berths at the Port of Mackay are in the order of 0.2 m/yr, the solution of fixed jet arrays for the berths are not considered to be feasible due to their high cost compared to maintenance dredging. Based on historical evidence, other solutions of bed agitation such as drag barring and propeller wash agitation are considered to be feasible and will be taken forward to the constraints analysis detailed in the next section.

Table 18. Initial feasibility assessment of approaches to reduce future maintenance dredging volumes.

Approach	Potential Reduction in Sedimentation / Dredging	Probability of Effectiveness	Cost Effective	Potentially Feasible
Stabilise sediment sources	No	Low	No	No
Diverting sediment-laden flows	Yes	Low/Medium	No	No
Trapping sediment	Yes	High	Yes	**Yes**
Blocking sediment entry	Yes	Low	No	No
Habitat creation	No	Low	No	No
Structural solutions to train natural flows	No	Low	No	No
Devices to increase bed shear stresses	Yes	High	Some	**Yes**
Methods to reduce sediment flocculation	No	Low	No	No
Adopt a 'nautical depth' navigation approach which includes fluid mud	No	Medium	Yes	No

5.4. Constraints Analysis

Based on the initial feasibility assessment detailed in the previous section, two potentially feasible solutions to reduce sedimentation/dredging were identified as trapping sediment and increasing bed shear stresses. The solutions identified for these approaches were the ongoing operation of the sediment trap within the swing basin and either using drag barring or propeller wash agitation to increase bed shear stresses and promote resuspension of bed sediment. A comparative constraints analysis of these solutions relative to ongoing maintenance dredging is provided in the following sections. Costs and greenhouse gas emissions have been calculated assuming a representative duration of 20 years.

5.4.1. Environmental Impacts

Based on the solutions being considered, potential environmental impacts would be indirect resulting from changes to the turbidity, light availability and deposition due to the solution. Both solutions would result in the potential for indirect impacts due to sediment suspended during the dredging, placement and bed agitation activity. Based on previous monitoring of the *TSHD Brisbane* during maintenance dredging the impacts are expected to be low (BMT WBM, 2013). The impacts from bed agitation (either by drag barring or propeller wash) are likely to be comparable or less than dredging as the production rate would be lower. As such, the potential environmental impacts of the solutions are considered to be low.

5.4.2. Operational Impacts

To assess the potential operational impacts of the solutions we have made the following assumptions:

- the *TSHD Brisbane* has a daily production rate of 16,500 m^3 (this is the rate of the 2013 program). This rate has been adopted for maintenance dredging and capital dredging (i.e. the sediment trap);
- the drag barring has a daily production rate of 1,000 m^3 (based on the historic drag barring which has been undertaken at the Port); and

- it is difficult to accurately define the production rate resulting from propeller wash agitation, a specific detailed investigation would be required to better understand this. For this case it has been assumed that regular agitation would be required to limit ongoing sedimentation, with the tugs working for six hours per week on the ebbing tide to resuspend recently deposited sediment.

Details of the operational impacts of the solutions are provided below:

- Maintenance Dredging: to limit the requirement for drag barring between programs, if the maintenance dredging is undertaken every three years[3], then the dredge program will be approximately 10 days. Bed levelling would typically be undertaken along with the dredging, so there is the potential that both activities could be undertaken over a 10 day period every three years. Based on this there would be limited impact to Port operations.
- Sediment Trap: the existing siltation trench has a capacity of just over 40,000 m^3 (equivalent to 5 years of sedimentation in the southern swing basin area). With the sediment trap as well as annual bed levelling/drag barring, the frequency of maintenance dredging could be reduced to every five years (220,000 m^3 per program[4]) with the program being approximately 15 days in duration and with annual bed levelling/drag barring of approximately 6 days per year. Based on this there would be limited impact to Port operations.
- Drag Barring: if it is assumed that all of the sedimentation in the Port is managed by drag barring then approximately 50 days of work would be required each year, with this likely being undertaken during two separate programs through the year to limit fluidisation of sediment in the berths. This could result in a moderate impact to Port operations.
- Propeller Wash Agitation: as noted previously it has been assumed that regular propeller wash agitation would be required by the tug vessels if it is to be adopted to manage sedimentation, with 12 hours per week assumed. This is the equivalent of 26 days per year and as the work is required to be undertaken by a tug vessel (meaning one tug is not available for other work) it is considered that this could result in a moderate impact to Port operations.

5.4.3. Ongoing Maintenance

The ongoing maintenance associated with the equipment required for the solutions is similar in all cases. All solutions require the ongoing maintenance of the vessels, in all cases the vessel contractor is responsible for the ongoing maintenance and so there would be no maintenance requirement for NQBP.

5.4.4. Effectiveness

The effectiveness of the solutions in managing the sedimentation is detailed below:

- Maintenance Dredging: based on previous experience at the Port of Mackay there is a high level of confidence that this approach would be successful.
- Sediment Trap: as the siltation trench is currently used at the Port there is a high level of confidence that the approach would be successful. It is possible that its effectiveness could be further improved by additional bed levelling and drag barring to move more sediment into the trap which would help maintain design depths in the adjacent areas of the swing basin.
- Drag Barring: based on previous experience at the Port of Mackay there is a moderate level of confidence that this approach would be successful. During previous programs it was found that drag barring in the berths has only been effective for short programs (e.g.

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[3] assuming that over/insurance dredging of 0.6 m is permitted then this frequency should allow design depths to be maintained given the highest average sedimentation rate is 0.2 m/yr in some berths.

[4] this assumes that the bed levelling/drag barring resuspends 1,000 m^3/day, reducing the annual sedimentation requiring maintenance dredging from 50,000 m^3/yr to 44,000 m^3/yr.

1 day or approximately 0.1 m in depth) due to the drag bar fluidising the loosely consolidated surface sediment in the berths which then makes the sediment difficult to relocate. To try and mitigate this risk it is assumed that the drag barring would be undertaken twice a year, as the typical sedimentation rate in the berths where sedimentation is highest is 0.2 m/yr (i.e. each drag barring program could remove 0.1 m of sediment deposited over the previous six months) and so this approach would give time between programs for the sediment to consolidate slightly and mean the drag barring would be effective again. In addition, historical drag barring has only been for small volumes and has never been used to manage the full volume of sedimentation in the Port. Given the relatively low ebb tidal currents it is likely that the majority of the sediment resuspended and relocated by drag barring would remain within the Harbour. As such, there is a risk that by adopting this approach without maintenance dredging would result in increased sedimentation rates over time due to the majority of the sediment which is resuspended by the drag barring remaining in the Harbour and potentially redepositing in the dredged areas. Therefore, there is a moderate risk that drag barring would not be able to manage the long-term sedimentation in the Port and that other approaches such as maintenance dredging would be required.

- Propeller Wash Agitation: the analysis of historical bathymetric data has shown that erosion due to propeller wash from the tugs has occurred. However, the main areas of erosion have been adjacent to where the tugs assist vessels in manoeuvring into and out of berths and it might not be possible for the tugs to have the same impact when they are not assisting vessels in manoeuvring. As with drag barring there is also the risk that over time the majority of the resuspended sediment remains within the Harbour and could be redeposited in the dredged areas. As such, there is a low degree of confidence as to the effectiveness of this approach.

5.4.5. Legal Considerations

The ongoing legal considerations required for the solutions in managing the sedimentation are detailed below:

- Maintenance Dredging: there are ongoing approval requirements for maintenance dredging, but the approval requirements are well known and historically this has not caused an issue at the Port of Mackay. The risk implications of the approval requirements are considered to be low.
- Sediment Trap: as the siltation trench has already been created and the trench has recognised design depths of 10 m below LAT, no additional approval requirements in addition to those required for maintenance dredging are necessary.
- Drag Barring: no approval is required.
- Propeller Wash Agitation: no approval is required.

5.4.6. Comparative Costs

In order to develop comparative costs for the solutions a number of assumptions have had to be made:

- a daily rate of $105,000 has been assumed for the *TSHD Brisbane*, which when considered along with the weekly production rate of 115,000 m^3 (daily rate of 16,400 m^3) gives a cost of $6.39 per m^3 of sediment dredged;
- a day of time allowed for the mobilisation and demobilisation of the *TSHD Brisbane* (i.e. $105,000) per dredge program;
- a daily rate of $9,000 has been assumed for bed levelling and drag barring (based on the *Pacific Conquest* rate), along with a combined mobilisation and demobilisation cost of $10,000 per visit; and
- an hourly rate for a tug vessel of $1,000 has been assumed.

Based on these assumptions comparative cost estimates have been made for the solutions assuming a 20-year period:

- Maintenance Dredging: the costs assume maintenance dredging of 150,000 m^3 every three years, along with 10 days of bed levelling to even out the bed following the dredging. The total cost over 20 years is estimated to be $8.0 million (including the cost for the final dredging program representing 100,000 m^3 so that the value truly represents 20 years of sedimentation).
- Sediment Trap: the costs assume maintenance dredging of 220,000 m^3 every five years and six days of bed levelling/drag barring every year. The total cost over 20 years is estimated to be $7.3 million.
- Drag Barring: the costs assume 50 days of drag barring each year over the 20 years. The total cost over 20 years is estimated to be $9.2 million.
- Propeller Wash Agitation: the costs assume 12 hours of propeller wash agitation by tug vessels every week over the 20 years. The total cost over 20 years is estimated to be $12.4 million.

5.4.7. Greenhouse Gas Emissions

An estimate of the Greenhouse Gas (GHG) emissions from the operation of the vessels associated with the solutions has been made. Details of the approach adopted are provided in Appendix A. For all solutions the GHG emissions are due to Scope 1 emissions which are direct emissions associated with fossil fuel consumption by vessels during movement and dredging activity. As with the cost estimates, the GHG estimates have been made over a 20-year period:

- Maintenance Dredging: the estimate has included GHG emissions associated with the travel of the vessels (*TSHD Brisbane* and bed levelling vessel (*Pacific Conquest*)) to Mackay and the dredging/bed levelling activity. The total GHG emissions over 20 years is estimated to be 7,950 tonnes.
- Sediment Trap: the estimate has included GHG emissions associated with the travel of the vessels (*TSHD Brisbane* and bed levelling/drag barring vessel (*Pacific Conquest*)) to Mackay and the dredging/bed levelling/drag barring activity. It has been assumed that the sediment can be placed offshore, additional GHG emissions would be created if the sediment was placed on land. The total GHG emissions over 20 years is estimated to be 9,380 tonnes.
- Drag Barring: the estimate has included GHG emissions associated with the travel of the drag barring vessel (*Pacific Conquest*) to Mackay and the drag barring activity. The total GHG emissions over 20 years is estimated to be 30,530 tonnes.
- Propeller Wash Agitation: the estimate has included GHG emissions associated with the operation of the tug vessel during the propeller wash agitation (no allowance was made for travel as it is assumed the tug is based at the Port of Mackay). The total GHG emissions over 20 years is estimated to be 26,160 tonnes.

5.5. Summary and Implications

A summary of the comparative constraints analysis for the potentially feasible solutions is provided in Table 19. The table shows the following:

- maintenance dredging every three years with no drag barring between dredging programs is one of the preferred approaches based on the constraints analysis. This approach results in the lowest GHG emissions and the second lowest costs over the 20-year period along with a high confidence in its effectiveness and low environmental and operational impacts and a low level of legal risk;
- ongoing use of the existing sediment trap in the south east area of the swing basin is one of the preferred approaches based on the constraints analysis. Compared to

maintenance dredging every three years with no annual drag barring it is predicted to result in a lower cost (10% reduction compared to maintenance dredging) but higher GHG emissions (additional 20% compared to maintenance dredging);

- based on the constraints analysis drag barring is not considered to be a realistic solution to manage all of the ongoing sedimentation in the Port of Mackay. The option is predicted to result in four times more GHG emissions than maintenance dredging and there is a risk that the approach might not be able to manage the sedimentation to maintain design depths over the long term. However, this approach could continue to be adopted for assisting with the sediment management of small volumes of sedimentation between maintenance dredging programs to help maintain design depths; and
- as with drag barring, propeller wash agitation is not considered to be a realistic solution to manage all of the ongoing sedimentation in the Port of Mackay. The solution is predicted to be the most expensive and results in three times more GHG emissions than maintenance dredging. There is also a low confidence in the effectiveness of the approach.

Table 19. Summary of the constraints analysis.

Approach	Environmental Impacts	Operational Impacts	Ongoing Maintenance	Effectiveness	Legal Risk	Cost	GHG (CO_2e tonnes)
Maintenance Dredging	Low	Low	No	High	Low	$8.0M	7,950
Sediment Trap	Low	Low	No	High	Low	$7.3M	9,380
Drag Barring	Low	Moderate	No	Medium	No	$9.2M	30,530
Propeller Wash Agitation	Low	Moderate	No	Low	No	$12.4M	26,160

The most feasible alternative solution to undertaking maintenance dredging every three years, which also has the potential of reducing the requirement for maintenance dredging at the Port of Mackay, is the active use of the existing siltation trench which would result in ongoing maintenance dredging every five years and annual bed levelling/drag barring[5]. Although the approach doesn't specifically reduce the mass of sediment requiring management it will reduce the volume of sediment requiring maintenance dredging as the sediment in the trap will be more consolidated (reducing the in-situ volume), the bed levelling/drag barring will resuspend some of the sediment (based on bathymetry surveys approximately 1,000 m^3/day has been assumed) and the trap will also improve the efficiency of the maintenance dredging with more consolidated sediment located in a small area which will result in a reduction in the dredge duration.

The predicted dredge volumes and frequencies for maintenance dredging and the sediment trap solution are as follows:

- Maintenance Dredging: 1,000,000 m^3 relocated over 20 years, with maintenance dredging occurring every three years along with bed levelling.
  - 150,000 m^3 relocated every three years (assuming over/insurance dredging of 0.6 m this frequency should on average maintain design depths); and
  - bed levelling undertaken immediately after maintenance dredging to level out the seabed and remove any high spots.
- Sediment Trap: 880,000 m^3 relocated over 20 years, with maintenance dredging occurring every five years and bed levelling/drag barring annually.

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[5] The frequency of the bed levelling/drag barring could be refined over time based on the sedimentation rates and depths of the adjacent swing basin. It is likely that a reduction in frequency to biennial or less could be possible.

  - 220,000 m^3 relocated by maintenance dredging every five years (assuming over/insurance dredging of 0.6 m this frequency will mean that some drag barring is required to maintain design depths in some berths); and
  - a total of six days per year of bed levelling and drag barring to move and resuspend recently deposited sediment into the trap (only from south east region of swing basin) and resuspend sediment from the berths to help maintain depths.

6. Summary

This report has described the natural sedimentation which has historically occurred at the Port of Mackay and assessed whether there are feasible options to avoid or reduce sediment accumulation and future dredging.

The dominant processes which result in the resuspension of sediment in the Mackay region are wave action and tidal currents. The waves have the potential to result in much higher resuspension, while the tidal currents (and wind-generated currents) will transport the suspended sediment. The local currents around Mackay Harbour result in a net import of sediment, and the low current speeds within the Harbour means that it retains much of the sediment and acts as a sediment sink.

Analysis of historic bathymetric data has found that the Port of Mackay has been subject to ongoing natural sedimentation and sediment sampling indicates that the deposited sediment is predominantly made up of fine-grained silt and clay. The majority of the sedimentation has occurred in the swing basin, with on average three times more sediment deposited in the swing basin (average = 18,000 m^3/yr) compared to the berths (average = 6,000 m^3/yr).

Tropical Cyclones have the potential to result in increased sedimentation in the Port of Mackay, volumes of between 35,000 and 50,000 m^3 can be deposited during the event. In the months following a TC there is also the potential for increased sedimentation, for example, during TC Debbie just over 35,000 m^3 of sediment was deposited within the Port and over the following five months an additional 40,000 m^3 was deposited.

The sedimentation rates within the Port of Mackay were estimated based on the available bathymetric survey data. An approximate linear relationship between the volume of sedimentation and the offshore wave height was identified. For years with typical wave conditions the annual sedimentation was in the order of 10,000 to 40,000 m^3/yr (average = 25,000 m^3/yr), while for years with high wave energy the annual sedimentation could increase up to 90,000 m^3/yr. Based on the sedimentation rates a realistic upper value for sedimentation was used to estimate future maintenance dredging volumes for the Port. It was predicted that over 10 years the maintenance dredging volume for the Port of Mackay would be 500,000 m^3.

Based on the available surveys of the Mackay DMPA it was found that the area was partially retentive over the short-duration, with the site retaining between 55 and 75% of the sediment placed there at the end of a maintenance dredging program. Over the longer-term, the DMPA was found to be stable during typical metocean conditions and then during extreme events with large waves (e.g. Tropical Cyclones) erosion of the DMPA can occur (natural erosion of the seabed adjacent to the DMPA would also be expected during these events).

A range of potential solutions to avoid or reduce the natural sedimentation or the requirement for maintenance dredging at the Port of Mackay were considered. The solutions included changing the configuration of the entrance to the Harbour, trying to block sediment from entering the Harbour, trapping sediment and a range of bed agitation approaches. Based on a constraints analysis the most feasible alternative solution to undertaking maintenance dredging every three years (frequency defined based on sedimentation to maintain design depths without additional management measures), is the ongoing operation of the siltation trench (sediment trap) combined with ongoing maintenance dredging every five years and annual bed levelling/drag barring. Although the approach doesn't specifically reduce the mass of sediment requiring management, it will reduce the volume of sediment requiring maintenance dredging, as the sediment in the trap will be more consolidated (reducing the in-situ volume). The associated bed levelling/drag barring will also resuspend some of the sediment (based on bathymetry surveys approximately 1,000 m^3/day has been assumed) and the trap will also help to improve the efficiency of the maintenance dredging, with more consolidated sediment located in a small area which will reduce the dredge duration.

The predicted dredging volumes and frequencies for maintenance dredging and the sediment trap solution are as follows:

- Maintenance Dredging: 1,000,000 m^3 relocated over 20 years, with maintenance dredging occurring every three years along with bed levelling.
    - 150,000 m^3 relocated every three years (assuming over/insurance dredging of 0.6 m this frequency should on average maintain design depths); and
    - bed levelling undertaken immediately after maintenance dredging to level out the seabed and remove any high spots.
- Sediment Trap: 880,000 m^3 relocated over 20 years, with maintenance dredging occurring every five years and bed levelling/drag barring annually.
    - 220,000 m^3 relocated by maintenance dredging every five years (assuming over/insurance dredging of 0.6 m this frequency will mean that some drag barring is required to maintain design depths in some berths); and
    - a total of six days per year of bed levelling and drag barring to move and resuspend recently deposited sediment into the trap (only from south east region of swing basin) and resuspend sediment from the berths to help maintain depths.

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Appendices

Appendix A – GHG Assessment

A 1 GHG Assessment Approach

The aim of this Greenhouse Gas (GHG) emissions assessment is to estimate GHG emissions, to allow a comparative assessment between the four sediment management options to be undertaken. The assessment has been undertaken in accordance with the internationally recognised methodology outlined in the GHG Protocol[6]. The GHG Protocol defines three groups of GHG emissions that arise from an organisation's operational entity:

- **Scope 1 emissions**: "direct" GHG emissions arising from each of the options, such as those associated with fossil fuel consumption by marine vessels in movements and dredging activity;
- **Scope 2 emissions**: account for "indirect" GHG emissions from the production of electricity and gas (i.e. off site and usually by third parties) consumed by plant and equipment as part of the options; and
- **Scope 3 emissions**: are indirect emissions arising from supporting activities (e.g. work upstream and/or downstream, the activities of sub-contractors and ancillary travel associated with a project) associated with the options. Scope 3 emissions are voluntary and an organisation can take a decision on the materiality of such activities before deciding to spend effort on calculating them for inclusion in a GHG footprint, or excluding them.

This GHG assessment considered only Scope 1 emissions from each of the four options assessed, to manage ongoing sedimentation at the Port of Mackay over a 20 year period.

A 1.1 Options

A 1.1.1 Maintenance Dredging

It has been assumed that the trailing suction hopper dredger (TSHD) Brisbane would be used to undertake the maintenance dredging at the Port of Mackay. It has also been assumed that the TSHD Brisbane would be travelling from the Port of Gladstone to the Port of Mackay and then on to the Port of Townsville for each visit, with half of this overall travel distance included in the GHG emission calculations. As noted in the main report, the dredger has been assumed to be working for ten days every three years to relocate sediment from the berths and swing basin to the offshore material placement site and the Pacific Conquest would also be undertaking ten days of bed levelling every three years. During this maintenance dredging program, the following assumptions were made:

- 65% of the time the vessel is dredging, 35% of the time the vessel is transiting to and from the material placement site;
- during cruising periods, including travelling to the Port of Mackay and to the placement site, the TSHD Brisbane was assumed to operate engines at 80% power; and
- when dredging it was assumed that the engines operated at 50% power and the pumps operate at full capacity.

A 1.1.2 Sediment Trap

For the ongoing maintenance dredging required for the sediment trap option, it has been assumed that the TSHD Brisbane would be used. It has also been assumed that 15 days of maintenance dredging of the trap would be required every 5 years. Every year it has been assumed that 6 days of bed levelling/drag barring will be undertaken using the Pacific Conquest, to push sediment into the sediment trap and to help maintain depths in the berths. The Pacific Conquest would travel to the site from the Port of Gladstone, approximately 450 km to the south. When sailing to and from the Port of Mackay, it was assumed that the

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[6] World Resources Institute and World Business Council on Sustainable Development (2015), Greenhouse Gas Protocol, available at URL: http://www.ghgprotocol.org/

vessel engines would operate at 80% power. During the drag barring activity, the Pacific Conquest engines would operate at full power.

A 1.1.3 Drag Barring

It has been assumed that every year 50 days of drag barring would be required in the berths and swing basin by the Pacific Conquest. The bed levelling would be undertaken during two separate programs each year. The Pacific Conquest would travel to the site from the Port of Gladstone, approximately 450 km to the south. When sailing to and from the Port of Mackay, it was assumed that the vessel engines would operate at 80% power. During the drag barring activity, the Pacific Conquest engines would operate at full power.

A 1.1.4 Propeller Wash Agitation

It has been assumed that a tugboat from the Port of Mackay would be used to agitate the bed through the effects of propeller wash. It was assumed that the propeller wash approach would be undertaken for a total duration of 26 days each year, with the tugs operating weekly. The vessel specifications for the tugboat that would be utilised were based upon a 50 – 60 tonne Tug, which is similar to the tugboats which currently service the Port of Mackay. It was assumed that the tugboat would operate its engines at full power during the propeller wash agitation process.

A 1.2 Assumptions

The following assumptions were used in the assessment of GHG emissions:

- low sulphur diesel fuel is used in all of the marine vessels;
- fuel for the vessels should be considered to be supplied by the Port of Mackay, as they would be commissioning the vessel and therefore they were considered to be Scope 1 direct GHG emissions in line with the GHG Protocol;
- for each marine vessel it was assumed that one generator with a total power of 800 kW was operated at full capacity to supply power for the onboard facilities; and
- GHG emissions were calculated over a 20 year operating period for each option in the GHG assessment. It was assumed that the same equipment, available today, is used with no technology improvements.

A 1.3 Emission Factors and Calculations

A 1.3.1 Scope 1 GHG Emissions Calculations

GHG emissions from the consumption of bunker fuel during the operation of marine vessels were calculated using guidance from the Environmental Protection Agency (USEPA) methodology '*Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories*'.[7] The emission parameters and emission rates used were derived using the USEPA methodology. The vessel parameters were determined from the marine vessel specifications to be used in each option.

Emissions per ship call and mode can be determined from Equation 1:

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[7] USEPA (2009); Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories, Final Report, April 2009

$$E = P\ x\ LF\ x\ A\ x\ EF \qquad [1]$$

where:

E = Emissions (grams (g))
P = Engine Power (kilowatts (kW))
LF = Load Factor (percent of vessel's total power)
A = Activity (hours (h))
EF = Emission Factor (grams per kilowatt-hour (g/kWh)).

GHG emissions were calculated based on fuel consumption associated with the travel of the vessels to the Port of Mackay, and throughout the duration of the activity. Emissions of carbon dioxide (CO_2), methane (CH_4) and Nitrous Oxide (N_2O) were determined for each option.

The marine vessel parameters and emission factors utilised to calculate GHG emissions are detailed in Table 20**.**

Table 20. Marine Vessel Emission Parameters & Factors Utilised in the GHG Assessment.

Option	Marine Vessel	Engine Power (kW)	Load Factor[1]	CO_2 Emission Factor[1] (g/kWh)	CH_4 Emission Factor[1] (g/kWh)	N_2O Emission Factor[1] (g/kWh)
Maintenance Dredging	THSD Brisbane	3,700	0.69	690	0.09	0.02
Drag Barring / Bed Levelling	Pacific Conquest	1,322	0.69	690	0.09	0.02
Propeller Wash	50 – 60 tonne Tug	3,600	0.68	690	0.09	0.02

[1] Obtained from (USEPA) methodology 'Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories'.

A 2 Results

The predicted comparative GHG emissions associated with each option over a 20 year period are detailed in Table 21. The results show that maintenance dredging would produce the lowest quantity of GHG emissions over the 20 years. The predicted GHG emissions associated with the drag barring and propeller wash options are the highest as they require significantly more vessel operation time.

Table 21. Predicted GHG Emissions from Each SSM Project Option.

Option	Scope 1 CO_2e Emissions over 20 Year Operational Period (Tonnes)
Option 1 – Maintenance Dredging	7,950
Option 2 – Sediment Trap	9,380
Option 3 – Drag Barring	30,530
Option 4 – Propeller Wash	26,160