PORT OF **WEIPA**

APPENDIX B

Bathymetric analysis - part 1

Port of Weipa: Sustainable Sediment Management Assessment

Bathymetric Analysis

Report No. P007_R01F1

Technical Report
July 2018

PORT & COASTAL SOLUTIONS

Port of Weipa: Sustainable Sediment Management Assessment

Bathymetric Analysis

Report No. P007_R01F1

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North Queensland Bulk Ports Corporation Ltd

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Executive Summary

North Queensland Bulk Ports Corporation (NQBP) and Rio Tinto Alcan (RTA) commissioned Port and Coastal Solutions (PCS) who, along with its sub-consultants Water Modelling Solutions and DAMCO Consulting, are undertaking a series of studies to understand whether sedimentation can be managed at the Port of Weipa and at Amrun Port, to avoid or reduce the need for maintenance dredging. The studies form part of NQBP/RTA's Sustainable Sediment Management (SSM) assessment at the Ports, which is aimed at answering the questions regulators have regarding ongoing maintenance dredging.

Aim: The aim of this study was to analyse historic bathymetric data, quantify previous bathymetric changes at the Port of Weipa and define the natural processes which have caused the changes.

Bathymetric Analysis: The bathymetric analysis has shown that regular sedimentation has been naturally occurring in the South Channel at the Port of Weipa and in localised areas within the Inner Harbour. In addition, the analysis has found that the Albatross Bay dredge material placement area (DMPA) is partially retentive and that approximately 60% of the sediment placed there has been retained.

Local Understanding: During the aerial survey (15th May 2018), undertaken as part of the site visit, significant increased turbidity was observed along the edges of the Hey and Embley Rivers, presumably due to the resuspension of loosely consolidated fine-grained sediment on the shallow muddy sides of the river channel. There was also high natural turbidity visible within the Approach and Departure Channels during the strong ebb tidal currents. The overall turbidity in Albatross Bay was considered to be high given the relatively calm wind (<10 m/s) and wave (H_s = 0.6 m) conditions at the time of the survey. Throughout the bay there was turbidity visible even in the areas away from the nearshore influence of wave breaking.

Conceptual Sediment Transport: Conceptual sediment transport models of the erosion and accretion processes in the South Channel and Inner Harbour regions of the Port of Weipa were developed based on all available information.

In the South Channel, the conceptual model showed that the majority of the sedimentation is a result of a combination of wave and tidal current processes. Wave action resuspends natural fine-grained sediment from the seabed in Albatross Bay and then the spatial distribution of tidal currents around the South Channel, along with the trapping efficiency of the channel (i.e. depth of channel below adjacent seabed), control where the fine-grained sediment is deposited within the South Channel. High tidal current speeds occur in the South Channel within 4 km of the mouth of the Embley River, limiting the build-up of fine-grained sediment in this region. As the tidal currents reduce with distance away from the mouth of the Embley River the potential for the build-up of fine-grained sediment increases, while the elevation of the adjacent seabed remains between 2 and 6 m below LAT. As the depth of the adjacent seabed increases, sedimentation in the South Channel reduces as resuspension occurs less regularly, as larger waves are required to resuspend the fine-grained sediment from these depths.

In the Inner Harbour the conceptual model shows that there have only been localised areas of sedimentation, with the deposited sediment typically being predominantly sand. The relatively high tidal current speeds limit deposition of fine-grained sediment in most areas. The sedimentation that has occurred has typically been due to the existing shallow sand banks encroaching on the channel due to bedload transport driven by the tidal currents. The propeller wash from vessels operating in the Port results in some localised erosion in the Approach and Departure Channels, as well as at the Lorim Point berths and the adjacent tug berths. Adjacent to the areas of erosion at the berths there is localised deposition in the areas that are sheltered from the vessels' propeller wash, typically directly adjacent to the wharf and at the ends of the berths.

Sedimentation Rates: The sedimentation rates within the South Channel were determined based on the available bathymetric survey data. Sedimentation was found to be linearly correlated to the duration of time the H_s was above 2 m (i.e. the duration of large wave events). Sedimentation in the South Channel was found to predominantly occur over the wet season, with sedimentation rates ranging from 1,100 m^3/day to 3,300 m^3/day over this period, depending on the wave energy (low to high). Based on this it is expected that maintenance dredging will be required annually to ensure that the entire South Channel remains below the declared depths. Maintenance dredging within the Inner Harbour is also expected to be required, with an estimated frequency of once every 2 to 5 years.

Predictive Model: Based on the findings of this assessment, a more detailed predictive model will be developed for NQBP. This model will be designed to allow the user to adopt different metocean scenarios to predict sedimentation and associated maintenance dredging requirements at the Port of Weipa, for a range of temporal scales. The interactive model will provide a decision support tool to allow for future strategic planning of maintenance dredging activity at the Port.

1. Introduction

North Queensland Bulk Ports Corporation (NQBP) and Rio Tinto Alcan (RTA) commissioned Port and Coastal Solutions (PCS) who, along with its sub-consultants Water Modelling Solutions and DAMCO Consulting, are undertaking a series of studies to understand whether sedimentation can be managed at the Port of Weipa and at Amrun Port, to avoid or reduce the need for maintenance dredging. These studies will form part of NQBP/RTA's Sustainable Sediment Management (SSM) assessment at the Ports, which is aimed at answering the questions regulators have regarding ongoing maintenance dredging. The studies being undertaken by PCS as part of the SSM assessment are as follows:

- Bathymetric Analysis: the aim of this study is to analyse historic bathymetric data, quantify previous bathymetric changes at the ports and define the natural processes which have caused the changes;
- Sediment Budget: the aim of this study is to understand the sediment transport processes which naturally occur at the Ports. This includes understanding the source of the sediment, sediment transport pathways, processes controlling the sediment transport and the development of a quantitative sediment budget and distribution of sediment;
- Bathymetric Model: the aim of this study is to develop interactive predictive sedimentation models for the two Ports. These models will allow future sedimentation predictions to be made for the dredged areas of the Ports which will allow NQBP/RTA to understand future maintenance dredging requirements at the Ports; and
- Engineered and Technological Solutions: the aim of this study 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 Ports. The results from this study will then be used to determine whether there are feasible solutions to avoid or reduce the need for maintenance dredging at the Ports.

Each study is being undertaken for both Ports, with separate reports prepared for each of them. The present report is for the bathymetric analysis study at the Port of Weipa.

1.1. Project Overview

NQBP undertakes regular maintenance dredging of the channels and berths at the Port of Weipa to ensure there is sufficient depth for vessels to safely travel to and from the berths (further detail of the historic maintenance dredging is provided in Section 1.2). The sediment which has historically been removed by maintenance dredging, has been relocated to an offshore dredge material placement area (DMPA) located in Albatross Bay (Figure 2).

NQBP has current State and Commonwealth approvals to support maintenance dredging and at-sea placement of the dredged sediment at the Port of Weipa. The current 10-year permit was issued in 2010. Since then, 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 (GRBWHA) (TMR, 2016), which provides a framework for the sustainable, leading practise management of maintenance dredging. The MDS has provided a new benchmark in maintenance dredging planning and permitting across all port sectors and it is likely that it will set a national standard for maintenance dredging at all Australian Ports.

A particular aspect that studies are required to inform – derived from the London Protocol, which forms the basis for Australia's Sea Dumping Act 1981 – is to define whether sedimentation at ports can be managed to avoid or reduce the need for maintenance dredging. 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 (Figure 1). 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. The studies included as part of the work currently being undertaken by PCS (including the bathymetric analysis for the Port of Weipa, presented in this report) are aimed at answering the questions posed under point 1. Separate studies will be undertaken by NQBP/RTA to answer the other three questions. The findings from all these SSM studies will feed into the development of new long-term maintenance dredging strategies at the Ports of Weipa and Amrun.

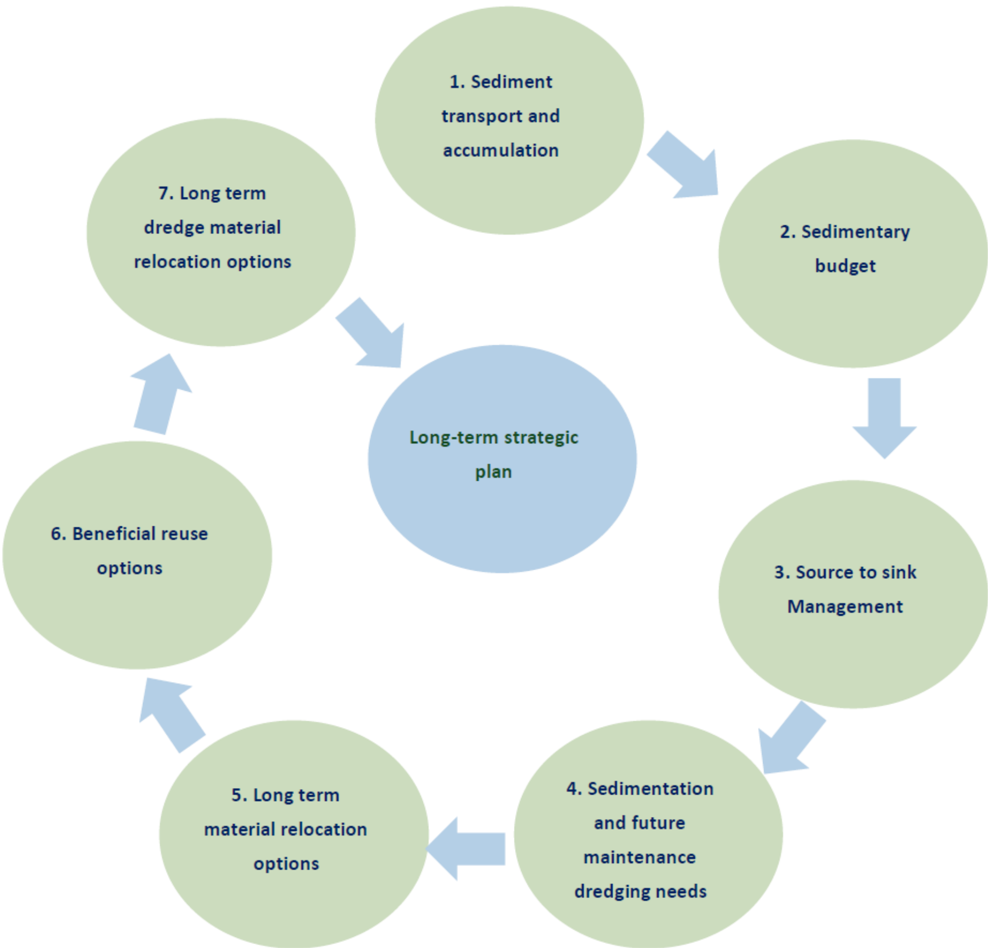

Figure 1. NQBP's SSM Assessment framework.

1.2. Port of Weipa

The Port of Weipa is located in the Gulf of Carpentaria, on the north-west coast of the Cape York Peninsula in Northern Queensland. The Port is within Albatross Bay, a large embayment, with the wharves and berths located in the Embley River (Figure 2 and Figure 3).

In the 2016/17 financial year the Port of Weipa handled approximately 36 million tonnes of commodities, including bauxite (>95%), fuel, cattle and general cargo. Rio Tinto Alcan (RTA) currently operates most of the port facilities for the export of bauxite (aluminium ore) from the nearby RTA mine.

The Port of Weipa consists of:

- a main shipping channel in Albatross Bay called South Channel (Figure 2); and
- an Inner Harbour which is within the Embley River and consists of four shipping berths (Lorim Point East and West, Humbug Wharf and Evans Landing) and the Approach and Departure Channels (Figure 3).

Several capital dredging campaigns have been undertaken at the Port of Weipa since the early 1960's, with the most recent capital works undertaken in 2012:

- 1961-63: the South Channel was first dredged across the inner half of Albatross Bay, with the natural South Channel being deepened to a depth of 8.2 m below Low Water Datum (approximately equivalent to the Lowest Astronomical Tide (LAT));
- 1980's: the South Channel was deepened and extended to a length of 14.5 km;
- 2006: the South Channel was widened and deepened (GHD, 2005). Due to variable sedimentation within the South Channel the design depth[1] was increased from the uniform depth of -12.2 m LAT in some areas (see Figure 4 for depths following capital dredging) and due to the deepening, the channel also had to be widened to ensure the batter slopes were stable; and
- 2012: the South Channel was extended by 2.4 km with a design depth of -12.2 m LAT (PaCE, 2011).

The Port has approximately 622 hectares of channels, swing basins and berths where depths are maintained by maintenance dredging. NQBP currently has a 10 year Sea Dumping Permit for the Port of Weipa which allows for an average of 1,200,000 m^3 of sediment to be removed by maintenance dredging per annum, although this includes a contingency for events such as cyclones and so is not realised on an annual basis. Since 2002 maintenance dredging at the Port has been undertaken annually by the Trailing Suction Hopper Dredge (TSHD) Brisbane, with volumes ranging from approximately 300,000 m^3 to 980,000 m^3 (although the 980,000 m^3 dredged in 2002 was because dredging had not been undertaken in 2001). Prior to 2002, maintenance dredging was typically undertaken every two years. The majority of the historic maintenance dredging at the Port of Weipa has been towards the western end of the South Channel, with limited maintenance dredging occurring in the Inner Harbour. A summary of the historic dredging works is provided in Table 1 and the average volumes removed (2012 to 2016) are detailed in Table 2.

The fact that the Port requires annual maintenance dredging indicates that regular sedimentation occurs. In addition to the regular sedimentation, it has also been observed that extreme events such as tropical cyclones (TCs) can result in significant increases in the sedimentation and therefore increased maintenance dredging requirements at the Port. To reduce the risk of increased sedimentation from a TC resulting in operational or safety issues

[1] the design or dredge depth is the depth that engineers have selected as suitable for the safe and efficient operation of the Port at all tidal levels with natural sedimentation also factored in. The declared depth is the depth designated by the harbour master and reflects the shallowest depth within the area.

at the Port, the maintenance dredging has typically been scheduled immediately after the wet season (when TCs occur) and the design depths have been adjusted over time based on the variable sedimentation which occurs in the Port (Figure 4 and Figure 5). In addition, the Dynamic Under Keel Clearance (DUKC) system, by OMC International, is in operation at the Port of Weipa to ensure safe vessel navigation and to help optimise port operations.

Table 1. Historic in-situ dredging volumes at the Port of Weipa (Advisian, 2018).

Year	Type of Dredging	Volume of in-situ Material removed (m^3)
2002	Maintenance	976,585
2003	Maintenance	463,513
2004	Maintenance	621,650
2005	Maintenance	803,098
2006	Capital and Maintenance	2,976,868
2007	Maintenance	711,000
2008	Maintenance	774,100
2009	Maintenance	553,457
2010	Maintenance	832,779
2011	Maintenance	470,820
2012	Capital and Maintenance	927,057
2013	Maintenance	644,525
2014	Maintenance	394,523
2015	Maintenance	368,384
2016	Maintenance	504,071
2017	Maintenance	297,301
2018	Maintenance	591,875

Table 2. Typical maintenance dredging volume estimate, declared depth, design depth and footprint for the dredged areas at the Port of Weipa (Advisian, 2018).

Port Area	Volume Estimate (m^3)	Declared Depth (m below LAT)	Design Depth[1] (m below LAT)	Footprint (ha)
South Channel	465,000	11.1	12.1 to 14.1	256
Approach Channel	24,000	7.3	7.3	272.5
Departure Channel	12,000	11.1	11.1 to 11.8	138.3
Evans Landing	500	9.4	9.4	0.5
Humbug	500	9.5	9.5	0.86
Lorim Point	500	12.3	12.3	2.45
Tug Berth	500	9.0	9.0[2]	2.12

[1] in some areas the design depth is variable due to natural variability in the sedimentation which occurs. The design depths are shown in Figure 4 and Figure 5.

[2] although the design depth at the Lorim Point Tug Berths is -9 m LAT it has not been dredged to that depth (currently around -5 m LAT) and due to the existing depths the TSHD Brisbane is not able to dredge the area and so bed levelling has been used to maintain the depths to -5 m LAT.

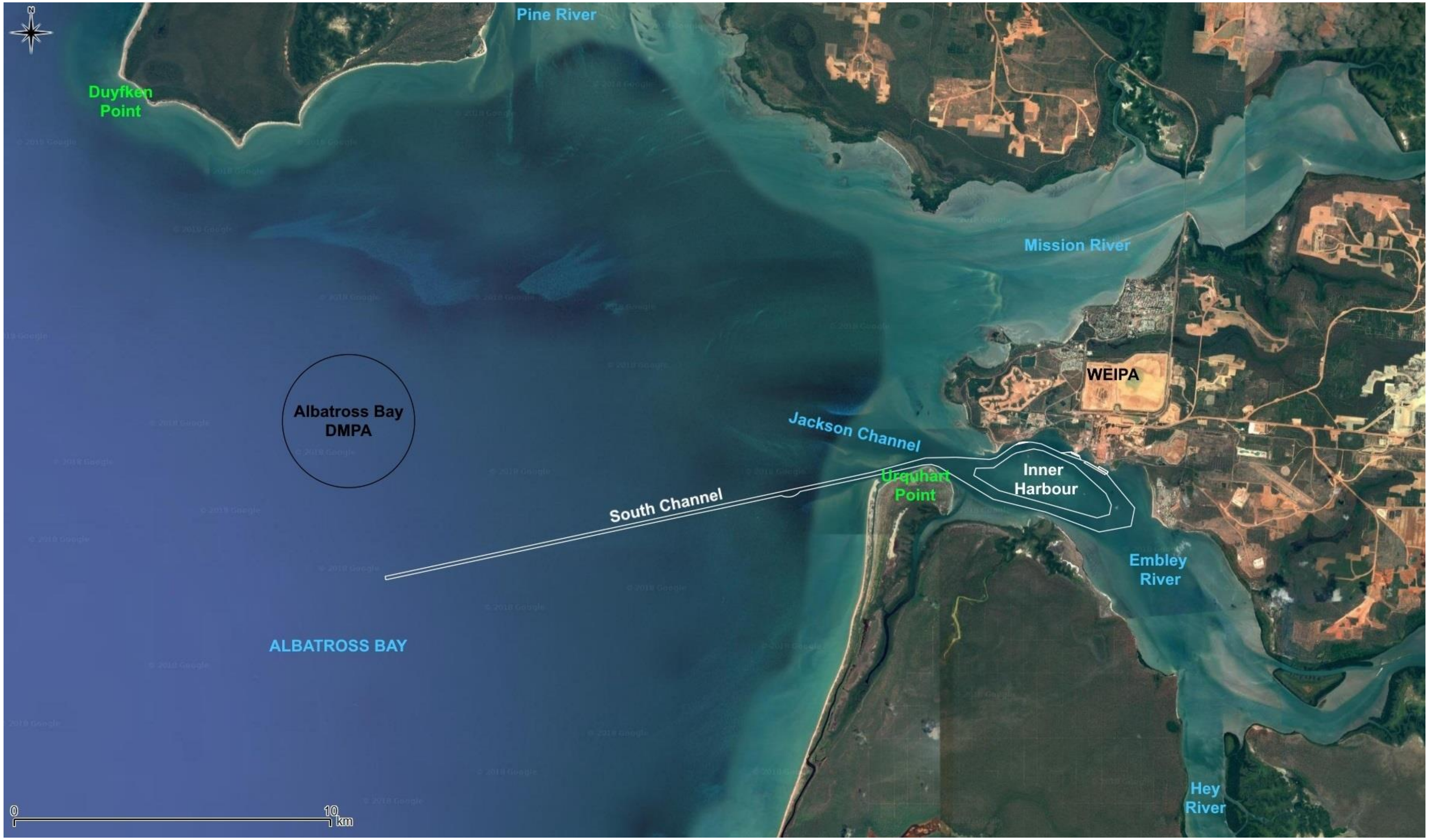

Figure 2. Location of the Port of Weipa.

Figure 3. Close up of the Port of Weipa Inner Harbour area.

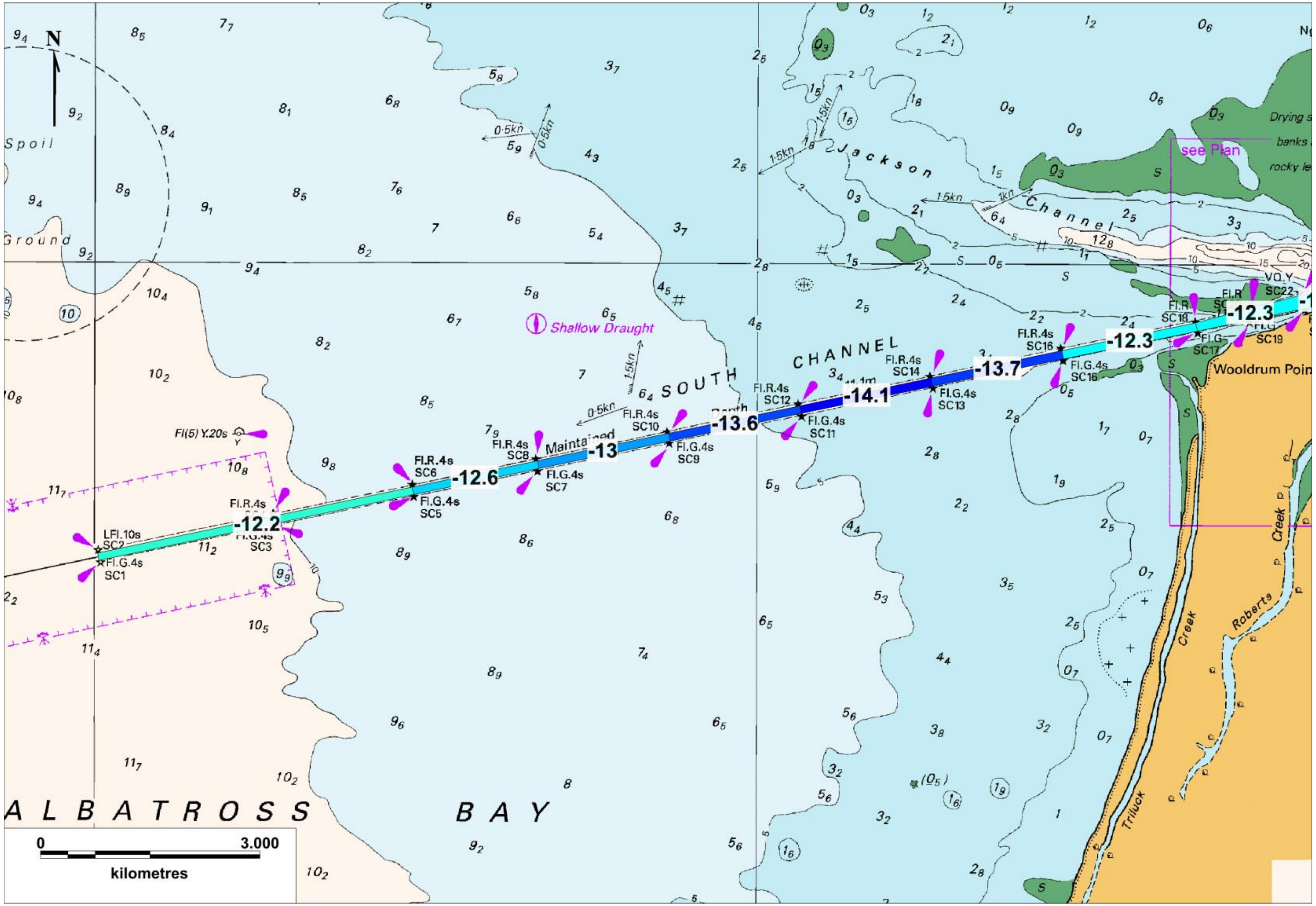

Figure 4. Variable design depths (m LAT) in the Port of Weipa South Channel.

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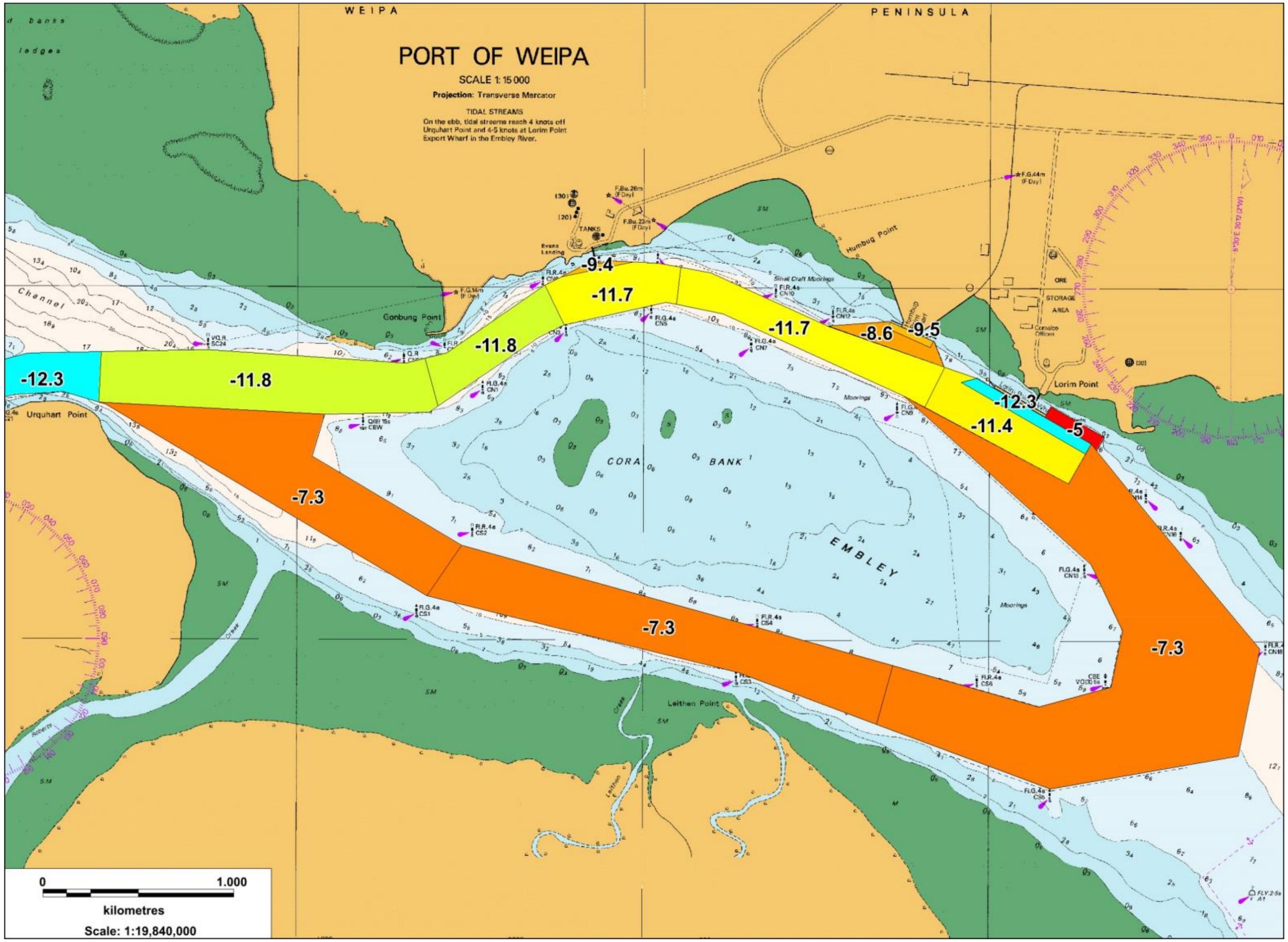


Figure 5. Variable design depths (m LAT) in the Port of Weipa Inner Harbour.

1.3. Report Structure

The report herein is set out as follows:

- a description of the local conditions at the Port of Weipa is given in **Section 2**;
- a summary of the May 2018 site visit is detailed in **Section 3**;
- a review and analysis of the bathymetric data is provided in **Section 4**;
- a discussion of the sediment transport at the Port of Weipa and a conceptual sediment transport model is presented 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 Weipa. Volumes presented throughout are *in-situ* cubic metres.

Wind and wave direction is reported as the direction the wind is 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.

2. Local Conditions

This section provides details of available hydrodynamic, meteorological, water quality and sedimentological data. A summary of the data used in the study is provided in Table 3 and their location shown in Figure 6.

Table 3. Overview of available data sources in the Weipa region (see Figure 6 for locations).

Data Type	Location	Description
Water Level	Humbug Tide Gauge	Tide gauge which is maintained by Maritime Safety Queensland (MSQ)
Meteorological	Weipa Aero	Weather station maintained by the Bureau of Meteorology (BoM)
Waves	Albatross Bay WRB	Waverider Buoy which is maintained by the Department of Science, Information Technology and Innovation (DSITI)
Currents	WQ1 ADCP & WQ2 ADCP	Bed mounted vertical ADCPs deployed by James Cook University (JCU) as part of the Weipa Ambient Water Quality Monitoring (AWQM)
	SC20 ADCP & SC24 ADCP	Mid depth mounted horizontal ADCPs deployed by MSQ. Data only available for short duration (7 to 14 days) periods.
Water Quality & Deposition	WQ1,2,4,5	SSC and deposition data at fixed position loggers by JCU for the Weipa AWQM

2.1. Water Levels

The tidal signal in the Weipa region is predominantly diurnal, with short periods of semi-diurnal tides during the neap tidal phase. The predicted water levels for Weipa (Figure 7) show how the diurnal signal dominates through the majority of the tides, with the signal transforming to a semi-diurnal signal for two to three days of neap tides during each spring neap tidal cycle. A summary of the tidal planes at Weipa (Humbug Point) relative to LAT and Australian Height Datum (AHD) is provided in Table 4, with AHD being 1.752 m above LAT.

Table 4. Tidal Planes at Weipa.

Tidal Plane	Elevation (m LAT)	Elevation (m AHD)
Highest Astronomical Tide (HAT)	3.38	1.63
Mean High High-Water (MHHW)	2.95	1.20
Mean Low High-Water (MLHW)	2.21	0.46
Mean Sea Level (MSL)	1.83	0.08
Mean High Low-Water (MHLW)	1.46	-0.29
Mean Low Low-Water (MLLW)	0.72	-1.03

Seasonal fluctuations in sea level occur within the Gulf of Carpentaria and these are primarily due to trade winds and forcing from the adjacent Arafura Sea located at the north-western entrance to the Gulf. This can be seen by the elevated predicted water levels at Weipa between November and April (wet season) compared to the levels from May to October (dry season) (Figure 8).

In addition, circulations and gyres within the Gulf can be set up by TCs that apply significant wind stress to the sea surface and result in storm surges and strong wind-induced currents. These are further discussed in Section 2.7.

Figure 6. Location of sampling stations of available data describing hydrodynamic, meteorological, water quality and sedimentological conditions in the Port of Weipa region.

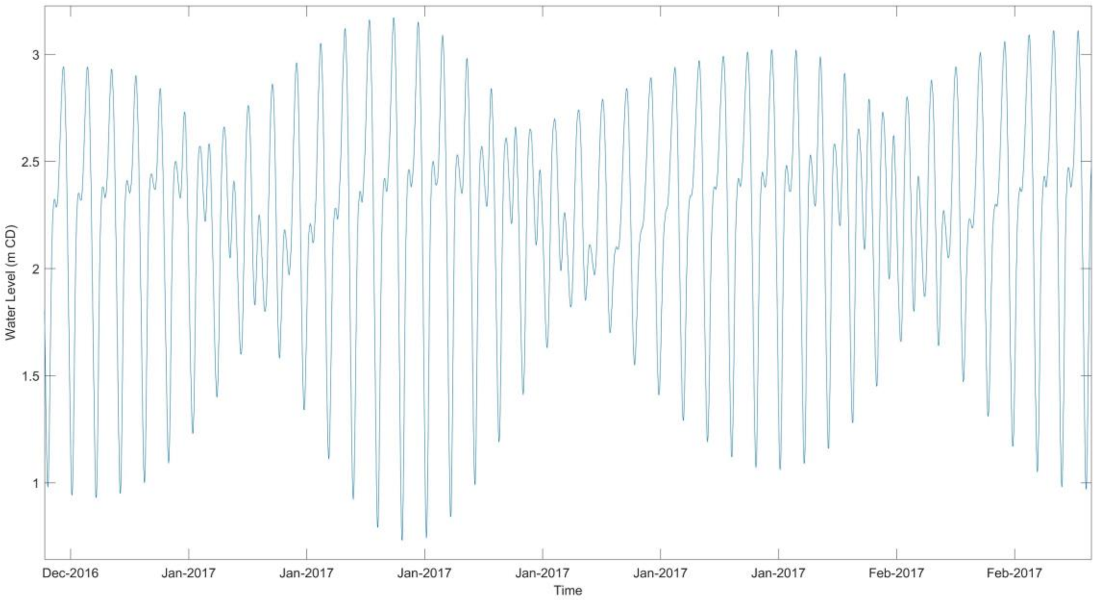


Figure 7. Predicted spring-neap water levels at Weipa.

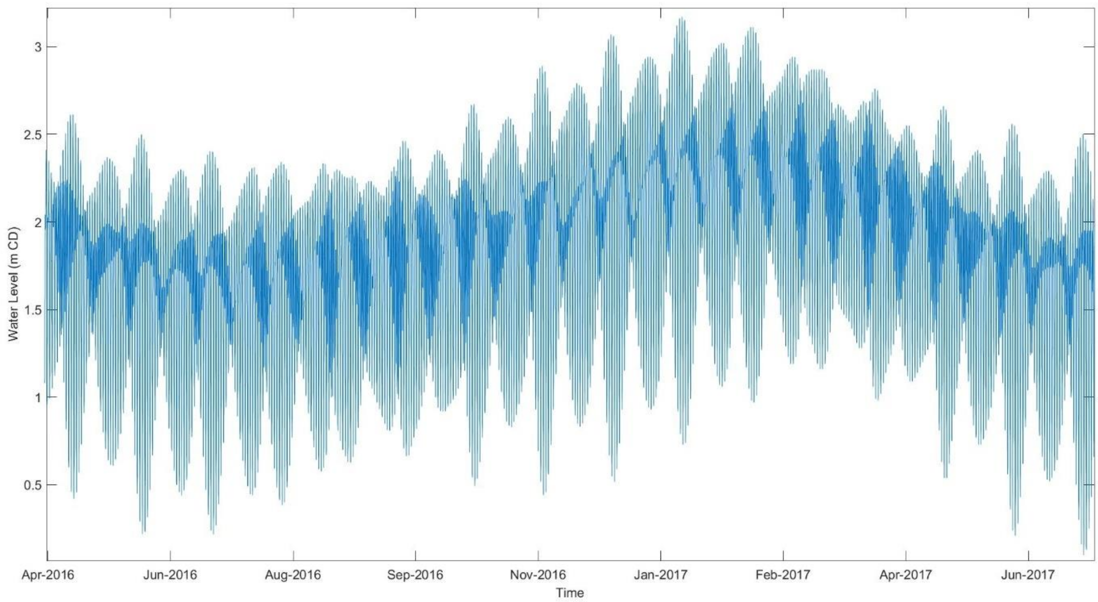


Figure 8. Predicted annual water levels for Weipa.

2.2. Rainfall

The Weipa region has a tropical climate with a distinct monsoonal rainfall trend. Based on measured data (1990 to 2018) at the BoM Weipa Aero Automatic Weather Station (AWS) the average annual rainfall is 1918 mm. The monthly mean rainfall at the BoM Weipa Aero AWS is shown in Figure 9. The plot shows the following:

- There is a distinct wet season between November and April when over 95% of the annual rainfall occurs with a monthly average of 310 mm. During the wet season, there are on average 11 days per month with more than 1 mm of rainfall;
- During the dry season from May to October there is very little rainfall with a monthly average of less than 10 mm. During the dry season on average there is 1 day per month with more than 1 mm of rainfall;
- The highest rainfall occurs between January and March, with a monthly average of 470 mm; and
- The lowest rainfall occurs between June and September, with a monthly average of 3 mm.

It is important to note that the monsoonal climate is variable and so the start, duration and intensity of rainfall which occurs in the wet season varies between years. For example, in 2018 the monthly total rainfall in January was above the monthly mean (705 mm), while in February and March it was below the monthly mean (305 and 327 mm respectively) (Figure 10).

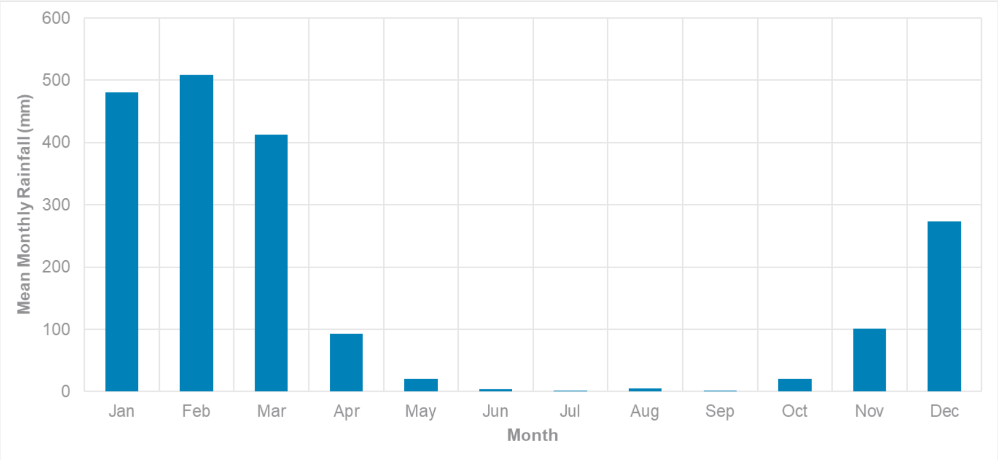
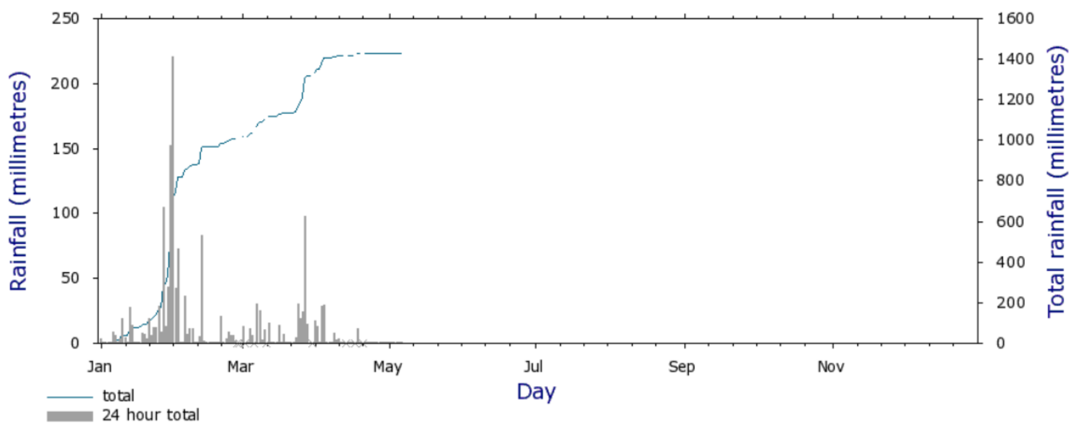


Figure 9. Mean monthly rainfall at the BoM Weipa Aero AWS (data from 1990 to 2018).



Source www.bom.gov.au

Figure 10. Summary of rainfall data for 2018 at the Weipa Aero (027045) station.

2.3. Wind

An annual wind rose of measured wind data from the BoM Weipa Aero AWS is presented in Figure 11. The plot shows that the Weipa region is dominated by winds from the east to south-east, with approximately 55% of the annual wind recorded from these sectors. Winds from the west occur for 6% of the time, with this direction being the second most frequent sector after the east to south-east.

The seasonal wind roses presented in Figure 12 highlight how the wind conditions vary between the peak of the wet and dry seasons. The plots show that:

- During the dry season winds from the east to south-east dominate. These winds are orientated offshore at Weipa and as such would not be expected to have much influence on the local currents or waves; and
- During the wet season winds are more variable, with wind directions ranging from the east south-east through north to the west. The most frequent wind directions are from the east and the west, with the strongest winds occurring from the west to north-west. During the wet season there is often a diurnal variability in the winds, with easterly winds in the morning and afternoon westerly sea breezes occurring. The westerly winds are orientated onshore at Weipa and could therefore influence local currents and result in the generation of wind waves.

Stronger winds in the Weipa region occur with the active monsoon, but strong or gale force winds normally only occur during tropical cyclones (TCs). The TC season for the Gulf of Carpentaria is from December through to April. TCs are discussed further in Section 2.7.

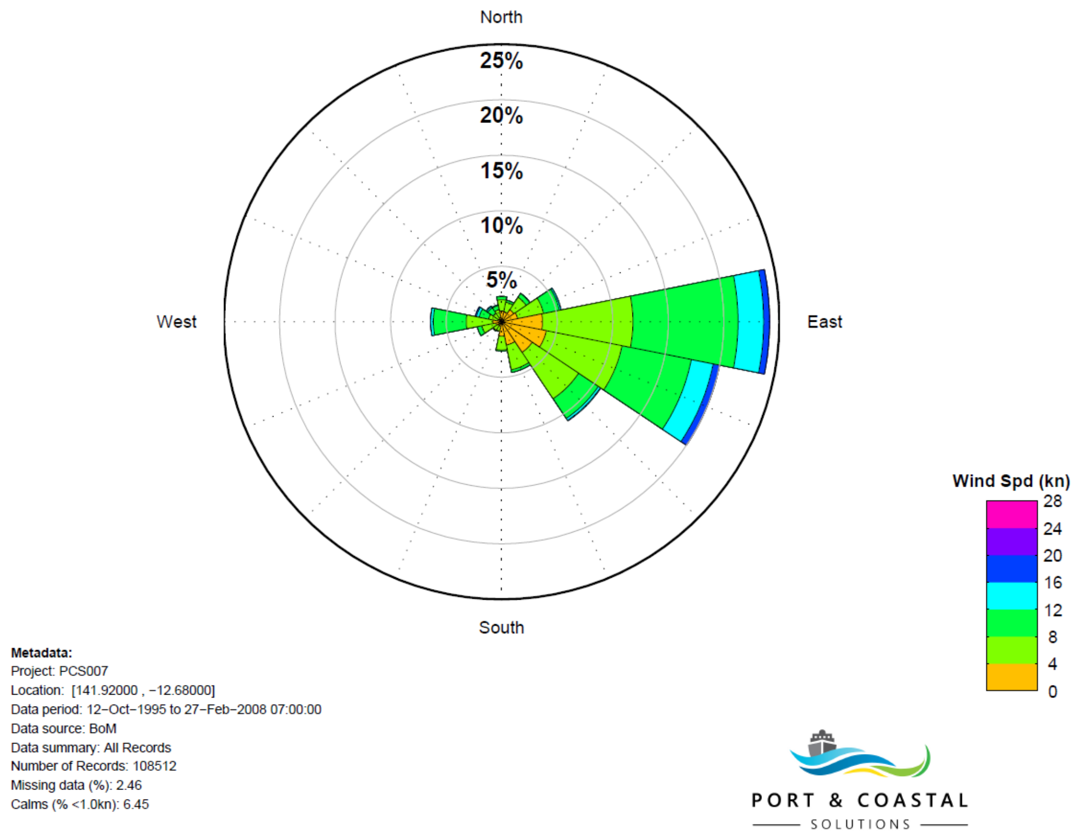
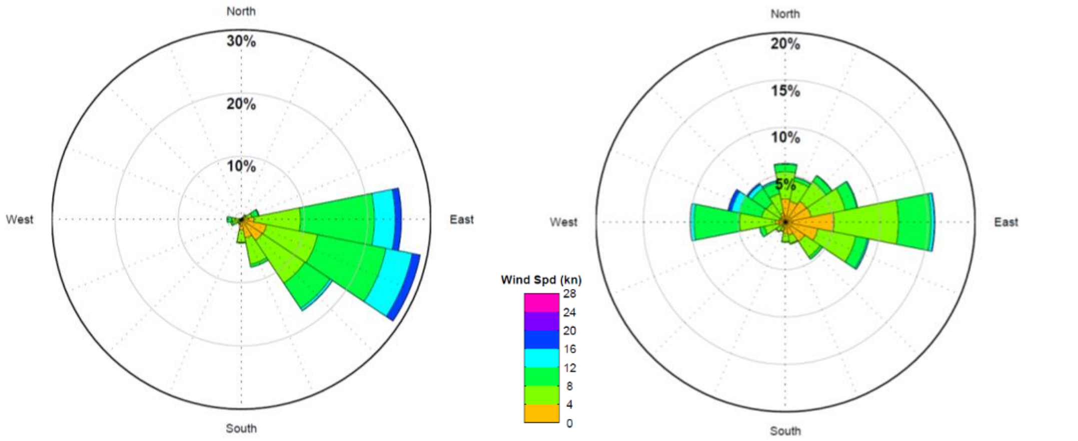


Figure 11. Annual wind rose for measured wind data at the BoM Weipa Aero AWS (1995 to 2008).



Dry Season (Jun to Aug) Wet Season (Dec to Feb)

Figure 12. Seasonal wind roses of measured wind data at the BoM Weipa Aero AWS (1995 to 2008).

2.4. Waves

DSITI have been maintaining a directional waverider buoy (WRB) in Albatross Bay measuring wave conditions since 2008. The directional wave data has been analysed and summary plots of the data are presented in Figure 13 to Figure 16. The wave climate at Weipa is strongly influenced by the wind conditions. Figure 13 and Figure 14 show that there are three dominant wave directions:

- From the east, the waves are travelling away from the Weipa shoreline and are generated by the dominant east to south-east winds;
- From the west to west north-west, the waves are travelling towards the Weipa shoreline and are generated by the onshore sea breezes and monsoonal and cyclonic winds which occur in the wet season; and
- From the south-west, the waves are travelling toward the Weipa shoreline. Unlike the other two directions the wave direction does not directly correlate to the local wind conditions. The waves are likely to be due to waves generated further south in the Gulf of Carpentaria, due to the south-easterly winds during the dry season, refracting into Albatross Bay.

The wave plots show that the wave climate at Weipa is relatively calm, with significant wave heights (H_s) of less than 0.5 m occurring for 80% of the time and with an H_s exceeding 1 m for less than 5% of the time. Wave heights are larger during the wet season compared to the dry season due to the presence of onshore winds, along with the potential for stronger winds from the monsoonal trough and cyclones. During the dry season H_s exceeds 1 m for 1% of the time, while during the wet season, H_s exceeds 1 m for 13% of the time. H_s will typically only exceed 1 m during short duration storm events (tropical lows, monsoons and TCs), which regularly occur in the wet season when the peak H_s is typically greater than 1.5 m. The largest waves are from a westerly direction, with the largest measured H_s of 4.3 m recorded during TC Nora in March 2018.

Measured wave height, period and direction at the DSITI Albatross Bay WRB over a 12 month period are shown in Figure 17. The plot highlights how the larger wave events occur during the wet season, with the H_s during the dry season generally being less than 1 m. The plots also show that during the larger wave events, the peak wave periods can reach 10 s, although 8 s is typical for smaller wave events and 2 to 4 s is typical for periods when H_s is less than 0.5 m. The wave direction shows a difference between the wet and the dry seasons, with directions during periods with larger wave heights being between from the west to west north-west during the wet season and from the south-west during the dry season.

The change in wave direction occurs in April and between October and November and is a result of the clear difference in wind conditions between the two seasons (Section 2.3).

To provide an indication of the spatial variability in wave height and direction in the Albatross Bay area, modelled wave conditions during a typical storm event (e.g. peak H_s of 1.5 m at the Albatross Bay WRB) are shown in Figure 18. The wave model has been calibrated to the measured wave data at the Albatross Bay WRB and provides a good representation of the wave conditions at this location. The plot shows how the waves refract and shoal within Albatross Bay, resulting in a reduction in wave height closer to the shoreline. The South Channel results in some localised reflection due to the sudden change in depth of the channel, causing a slight sheltering of the channel and larger waves occurring on the northern side of the channel relative to the southern side. By the entrance to the Embley River the H_s has reduced to less than 0.5 m, with limited wave energy penetrating into the Inner Harbour region of the Port of Weipa.

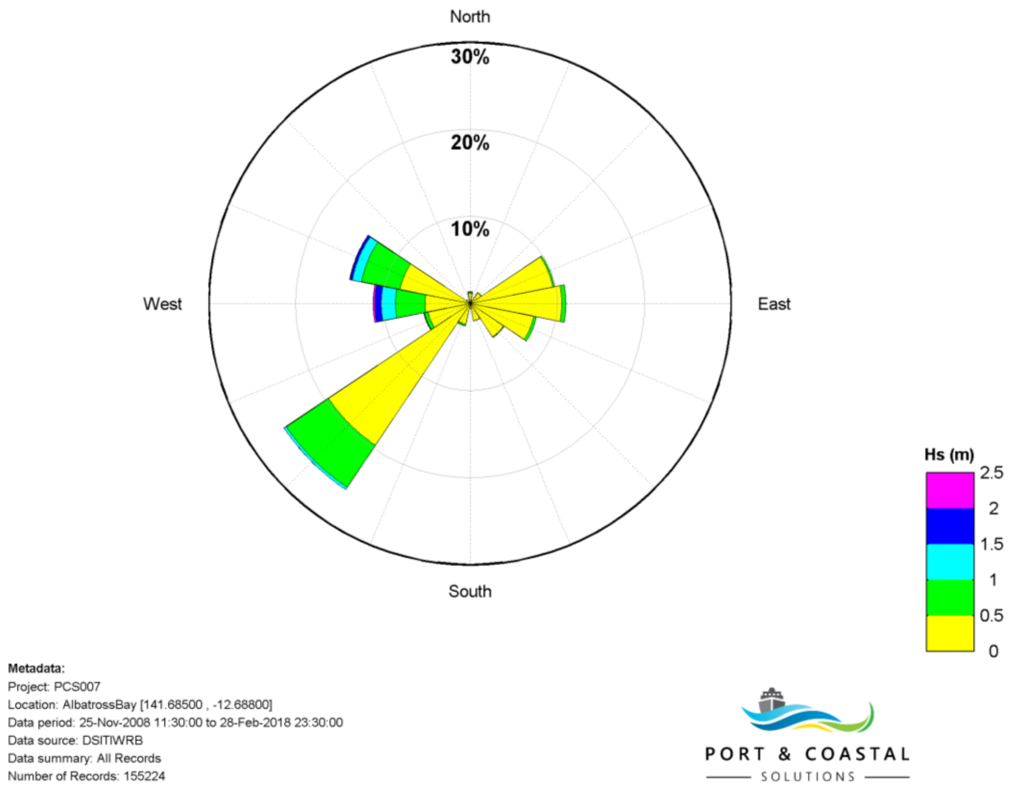


Figure 13. Annual wave rose for measured wave data at the Albatross Bay DSITI WRB (2008 to 2018).

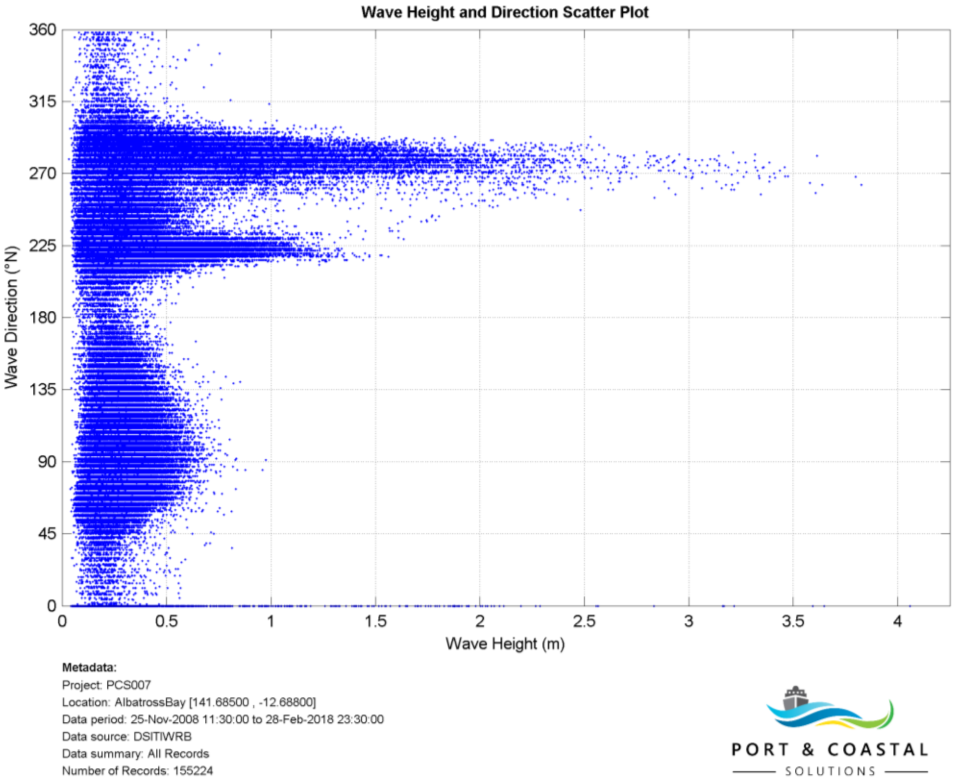


Figure 14. Wave height and wave direction scatter plot of measured wave data at the Albatross Bay DSITI WRB (2008 to 2018).

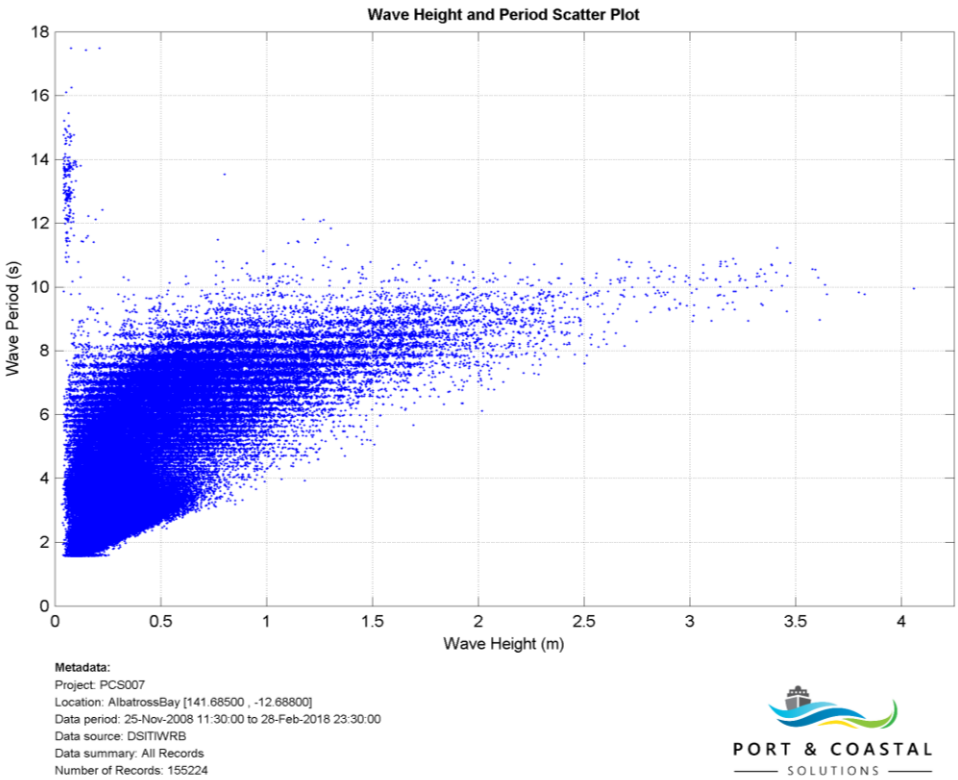


Figure 15. Wave height and peak wave period scatter plot of measured wave data at the Albatross Bay DSITI WRB (2008 to 2018).

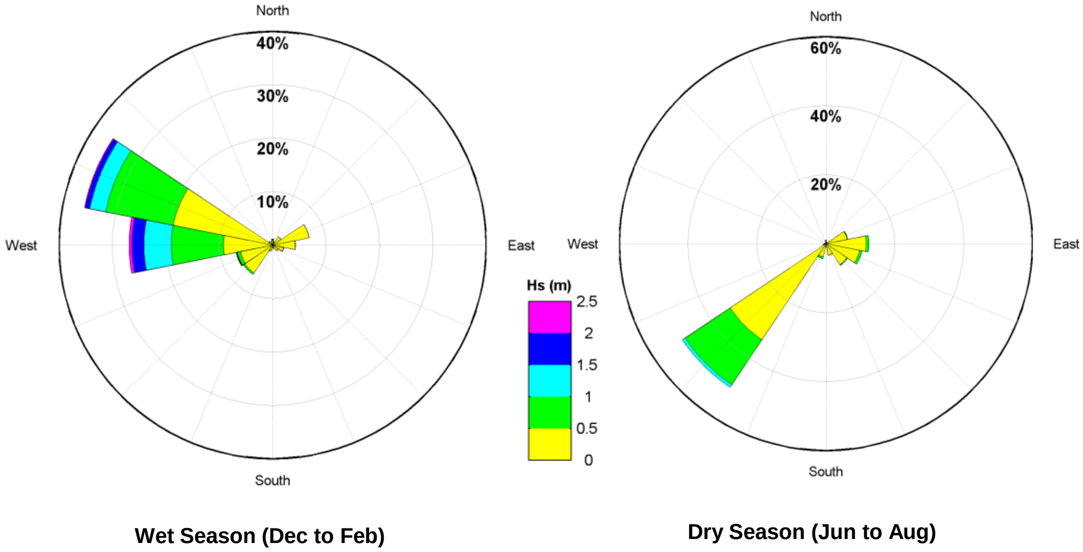


Figure 16. Seasonal wave roses of measured wave data at the Albatross Bay DSITI WRB (2008 to 2018).

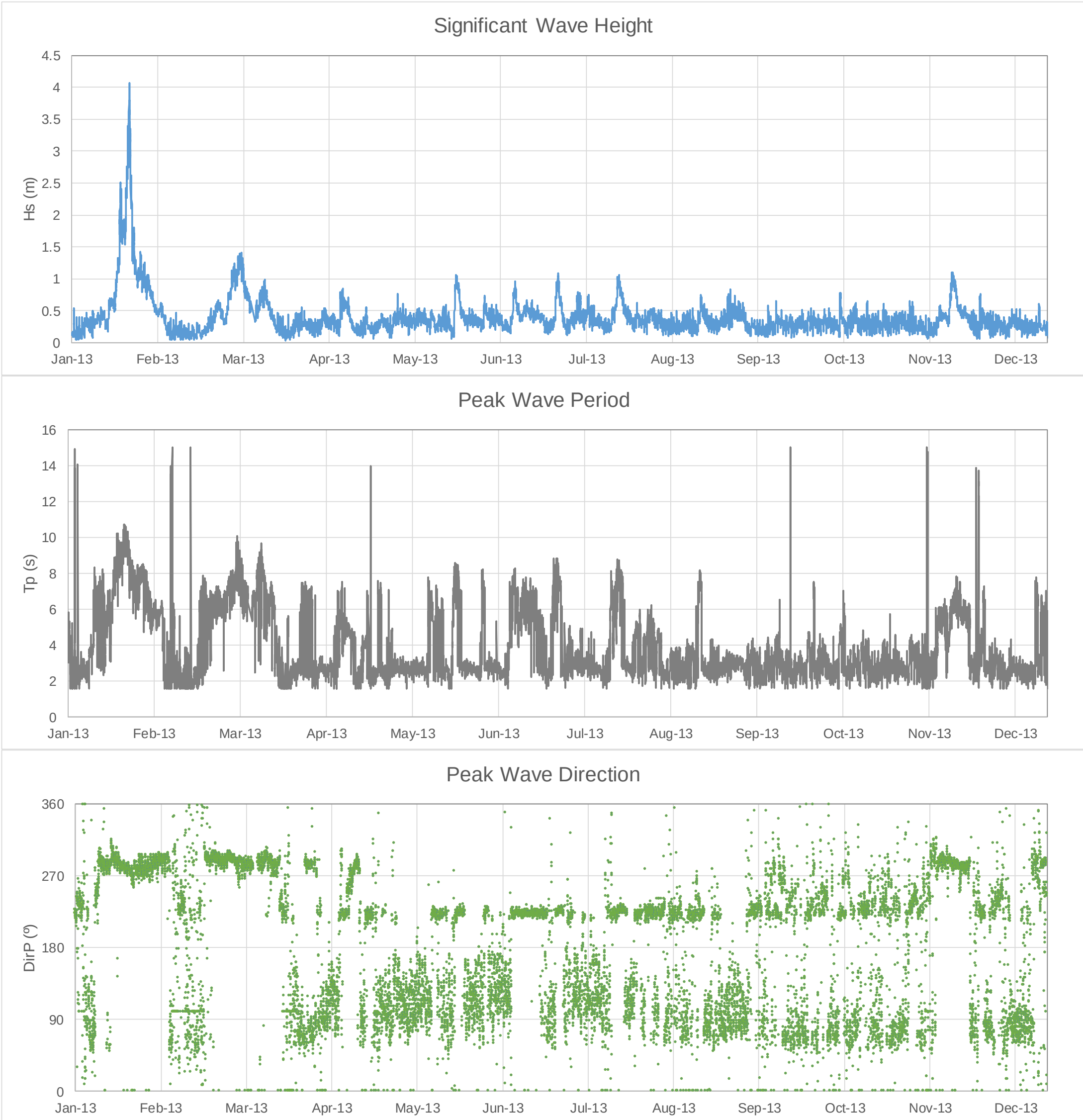


Figure 17. Measured wave conditions at the Albatross Bay DSITI WRB in 2013.

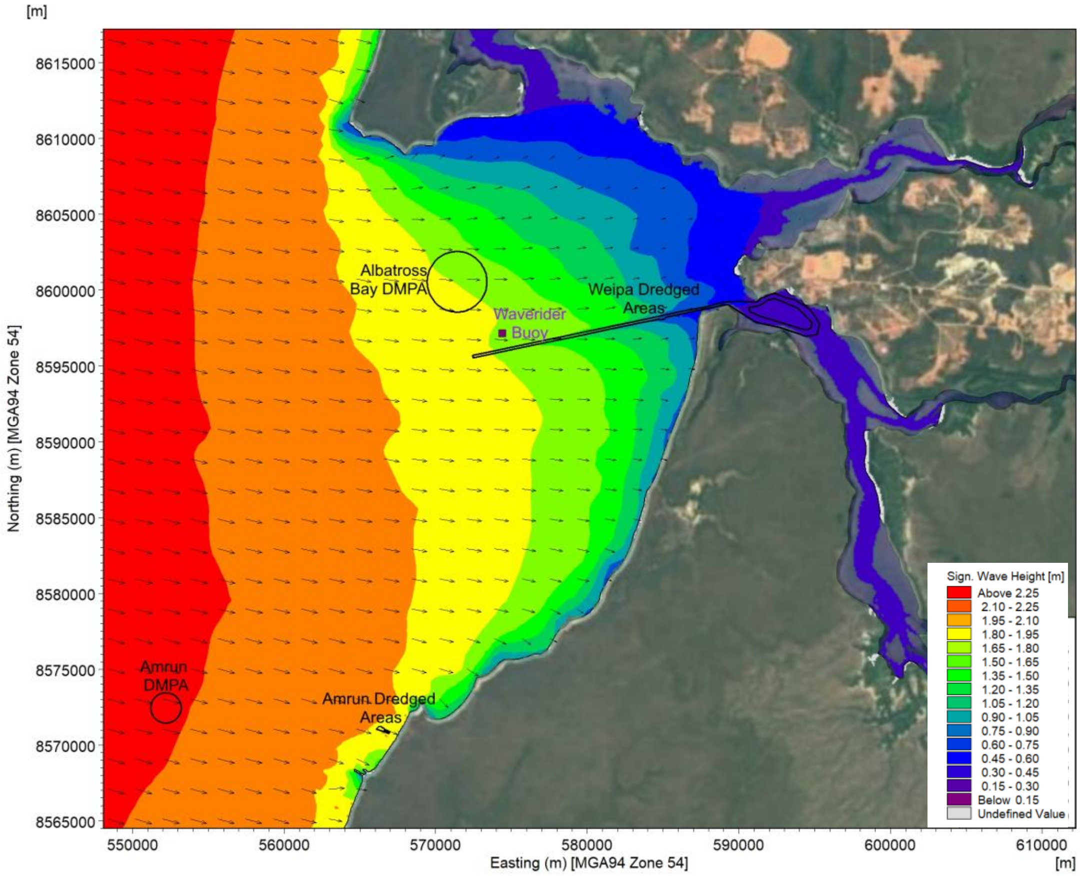


Figure 18. Modelled H_s and wave direction (vectors) for a typical storm event in Albatross Bay.

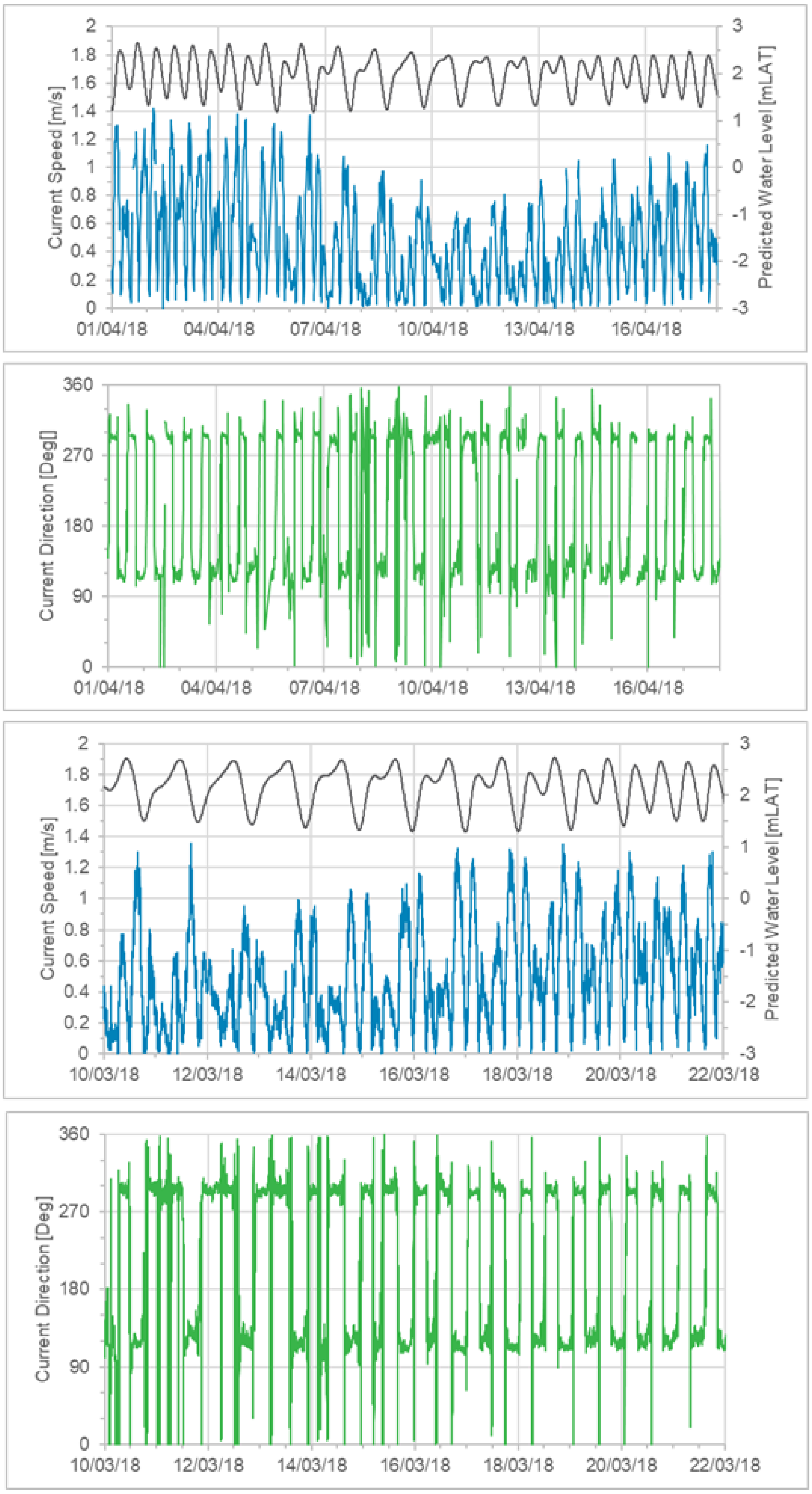
2.5. Currents

To assist with current investigation for the Port of Weipa current data were collected near beacons SC20 and SC24 which are located within the South Channel. The data were collected using horizontal Acoustic Doppler Current Profiles, thereby enabling current speed and direction information to be captured at one height within the water column. It is understood that beacons SC20 and SC24 were chosen as suitable locations to assist with obtaining data within the main navigation channels where peak flows tend to predominate. Measured current speed and direction data at beacons SC20 and SC24 are shown in Figure 19. The locations of beacons SC20 and SC24 are shown in Figure 20.

The data shows that current speeds are typically slightly lower near Beacon SC24 compared to Beacon SC20. This is likely to be due to flows being confined within the South Channel, particularly between Urquhart Point and the sandbanks to the northwest, in comparison to the less restricted geometry of Jackson Channel.

Within both the South Channel and Jackson Channel, the ebb currents are dominant with peak ebb flows of up to approximately 1.4 m/s recorded during the two data periods. Peak ebb current speeds typically range from 0.6 to 1.4 m/s. Peak flood current speeds are generally lower, ranging from 0.3 to 0.6 m/s.

Current directions recorded near Beacon SC24 align with the orientation of Jackson Channel, varying between approximately 125ºN on the flood tide and 295ºN on the ebb tide. It would be expected that the same trend be evident near Beacon SC20, with current directions aligning with the Southern Channel, however, this was not the case and MSQ have advised that the discrepancies are likely to be due to instrument error.



Note: Predicted water levels at Humbug Point, Weipa, Source: Marine Safety Queensland, 2018.

Figure 19. Measured current speeds and directions at Beacon SC20 (top two plots) and Beacon SC24 (bottom two plots) located in the South Channel at Weipa.

To provide a better understanding of the spatial variation in current speed within the Port of Weipa region, results from our numerical model of the Weipa region (see PCS (2018a) for further details of the model) have been used to supplement the measured data collected within the South Channel and the Embley River mouth.

High tidal current speeds (> 1 m/s) occur in the South Channel within approximately 4 km of the mouth of the Embley River. The model results show that ebb currents are dominant in most areas including the Approach and Departure Channels, South Channel and Jackson Channel. Peak ebb current speeds at the mouth of the Embley River and along the adjacent 4 km of the South Channel range between 0.9 and 1.3 m/s (Figure 20). Peak flood current speeds in the same areas range from 0.6 to 0.8 m/s (Figure 21).

The presence of such strong ebb tidal currents at the eastern end of the South Channel and within parts of the Inner Harbour, suggest that limited deposition of fine-grained sediment would occur in these areas. The strong ebb tidal currents will regularly resuspend any recently deposited fine-grained sediment and transport them offshore, limiting the build-up of fine-grained sediment in this region. Tidal asymmetry can be used as an indicator as to whether estuaries are net importers or exporters of sediment, with ebb dominant currents indicating that estuaries are net exporters of sediment (Dronkers,1986; Winterwerp, 2011). This will be further investigated as part of the subsequent sediment budget study.

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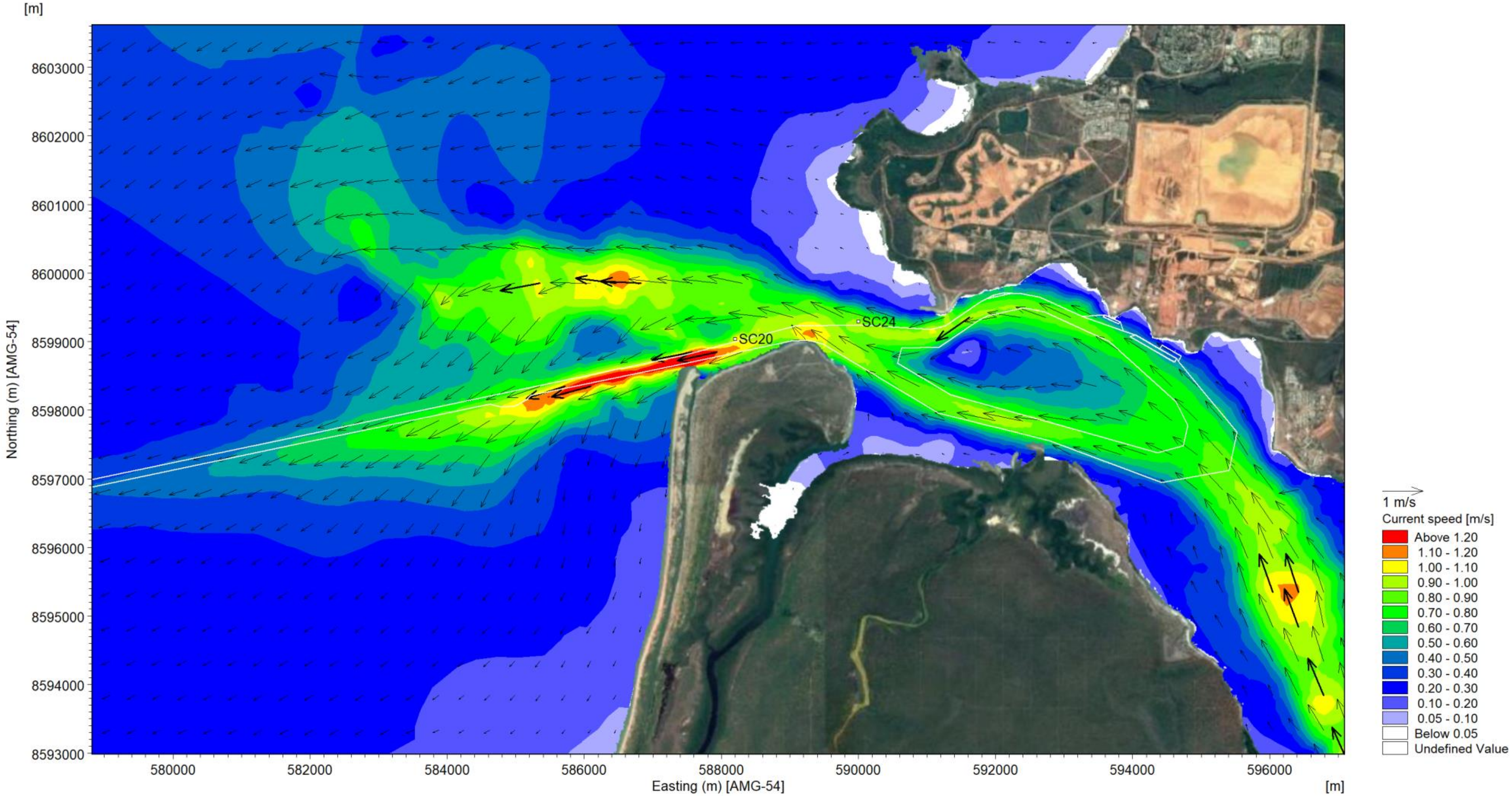

Figure 20. Modelled peak ebb tidal currents during a spring tide within the Southern Channel and Embley River.

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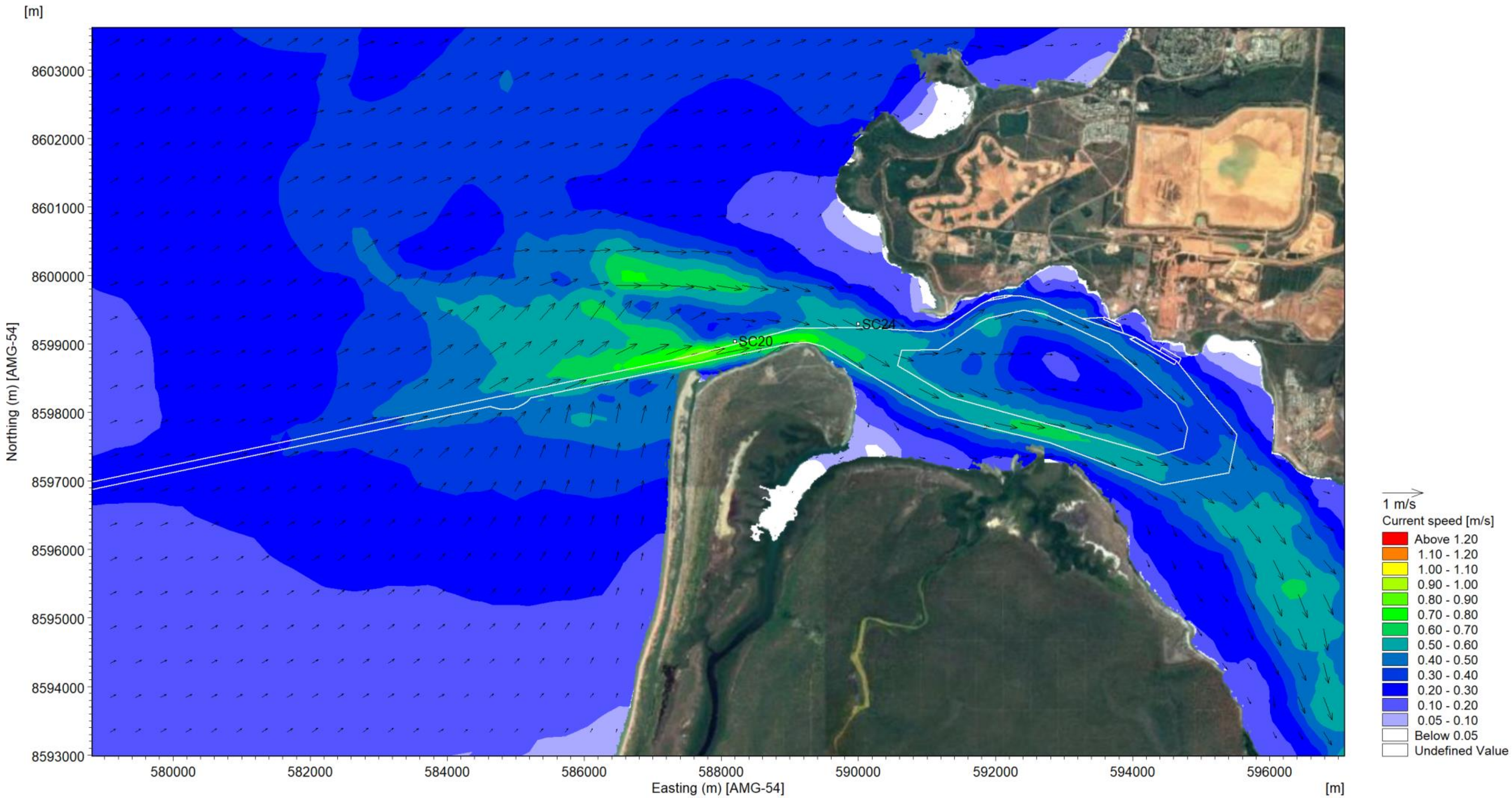


Figure 21. Modelled peak flood tidal currents during a spring tide within the Southern Channel and Embley River.

2.6. River Discharge

There are four relatively small river systems that discharge into Albatross Bay, the Pine to the north, the Mission directly to the north of Weipa and the Embley and Hey Rivers (the Hey River flows into the Embley River) which flow past the Port of Weipa (Figure 2).

A combined catchment for the Embley and Hey Rivers has been delineated by the Department of Environment and Science (DES) (2018) with a total catchment area of 1,925 km^2. A combined catchment for the Mission and Pine Rivers has also been delineated with a total area of 2,697 km^2. When these are compared to catchment areas of large rivers in the Gulf of Carpentaria such as the Norman River, which has a catchment area in excess of 50,000 km^2, it is clear that these are relatively small river systems. The size of the catchment areas combined with the relatively flat topography in the area indicates that the discharges from these rivers are likely to be small relative to the tidal discharge.

There is limited available information to define the freshwater discharge from these rivers into the system, with the most recent data being from the DES (2018). In the 1970s and 1980s there was a river gauge in the upper section of the Embley River at Kurracoo Creek (-12.816 Latitude, 142.176 Longitude). Results from this gauge showed an annual mean discharge in the order of 270,000 ML, with a clear seasonal variability that correlates with the measured rainfall (i.e. high discharge in the wet season, little to no discharge in the dry season) (Figure 22).

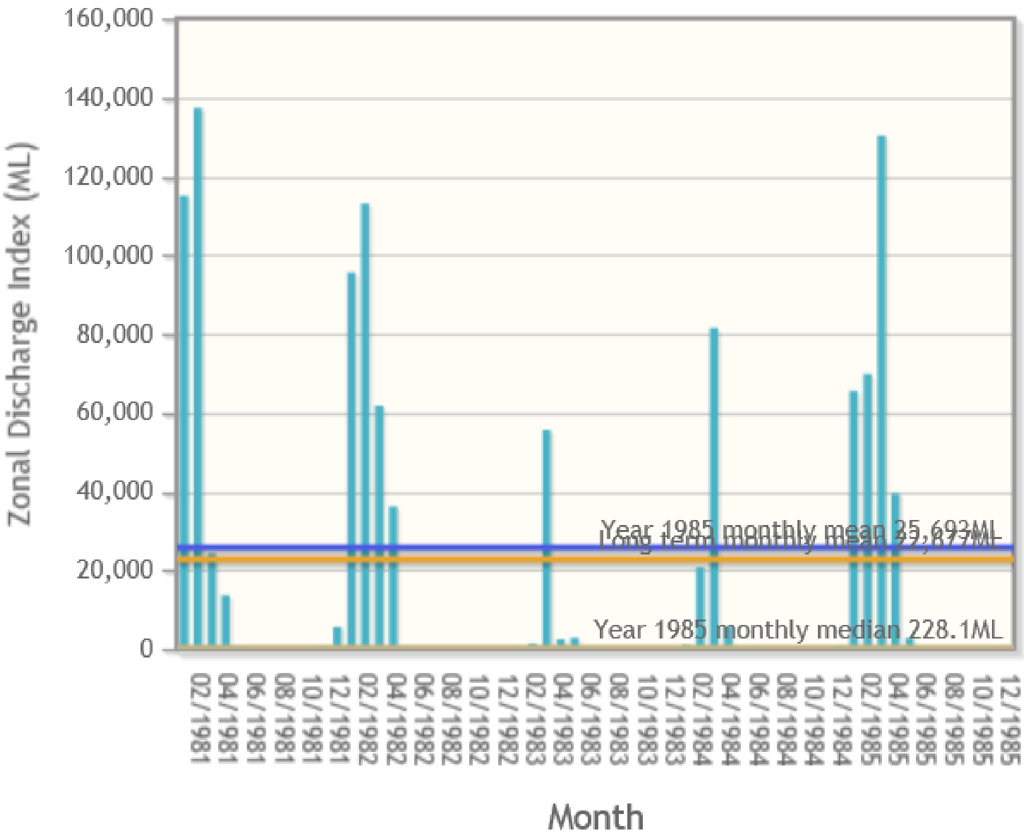


Figure 22. Measured monthly discharge for the Embley River (DES, 2018).

2.7. Tropical Cyclones

Tropical Cyclones regularly form in the Gulf of Carpentaria during the wet season and have the potential to result in strong to gale force winds and large wave heights in the Weipa region. Between 1969 and 2016 a total of 21 TCs have passed within 100 km of the Port of

Weipa and 42 TCs have passed within 200 km. Due to the clockwise wind rotation of TCs in the southern hemisphere combined with the location of Weipa in the Gulf of Carpentaria, it is typically TCs located south of Weipa that result in large waves and strong onshore winds in the vicinity of the Port of Weipa.

Recent TCs that have affected the Port include TC Nora (March 2018), TC Oswald (January 2013), TC Olga (January 2010) and TC Charlotte (2009). The largest measured significant wave heights at the DSITI WRB in Albatross Bay occurred during TC Nora with a maximum H_s of 4.3 m, while the largest measured H_{max} of 6.7 m occurred during TC Oswald. Measured time series data of the wave conditions during TC Nora and TC Oswald from the Albatross Bay WRB are shown in Figure 23 and Figure 24. The plots show that during TC Nora the H_s remained above 1.5 m for just 1 day, while for TC Oswald it was above 1.5 m for 5 days and it was above 3 m for 1 day during the peak of the event. The peak wave period during TC Nora was between 10 and 14 s, while for TC Oswald it was between 8 and 10 s during the peak of the event. During both events the wave direction during the peak of the event was from the west. The comparison highlights how even though the peak wave heights were similar for the two events, the wave conditions over the whole event were very different and could therefore result in different erosion, sediment transport and deposition occurring.

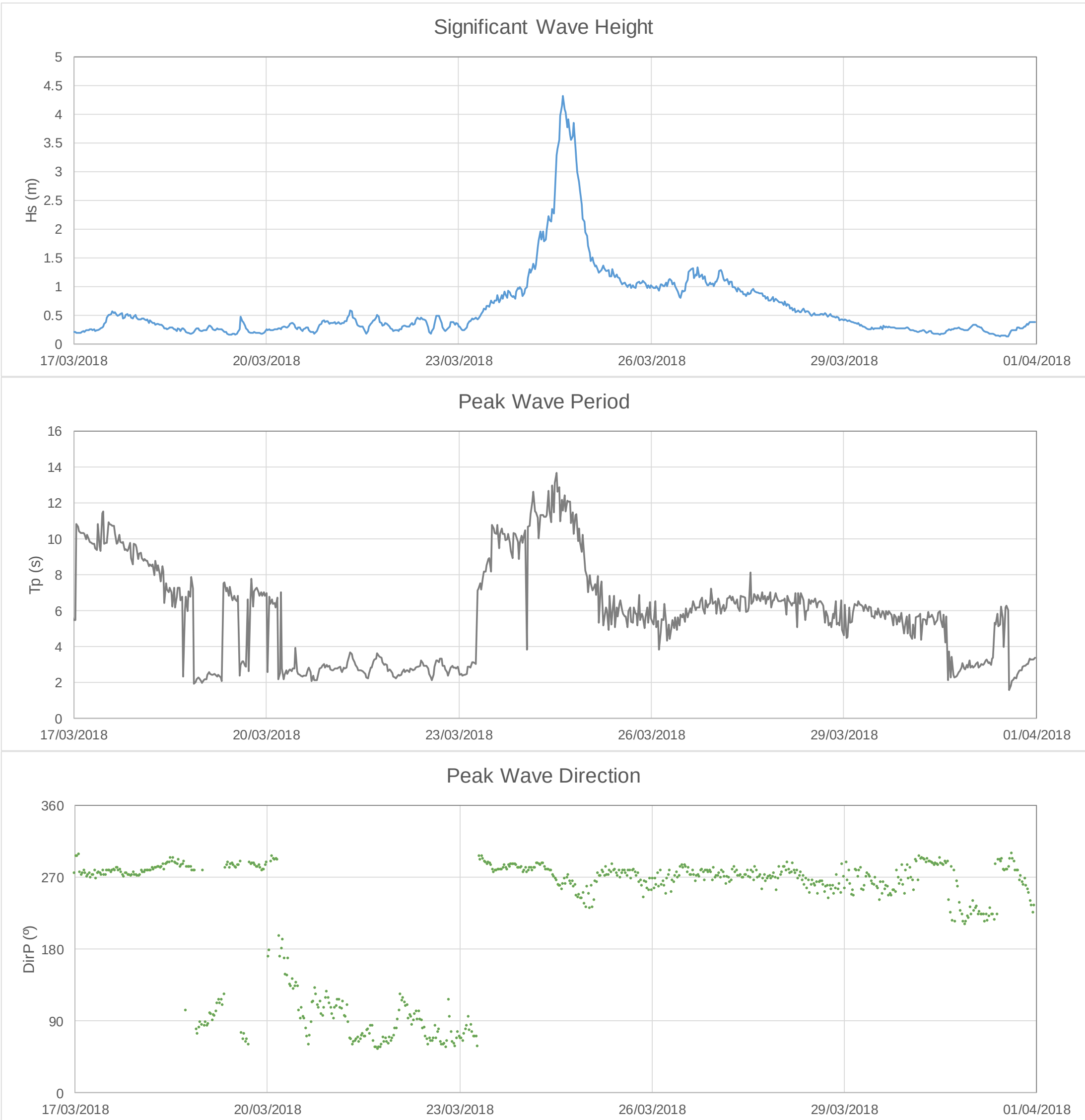


Figure 23. Measured wave conditions at the Albatross Bay DSITI WRB during TC Nora.

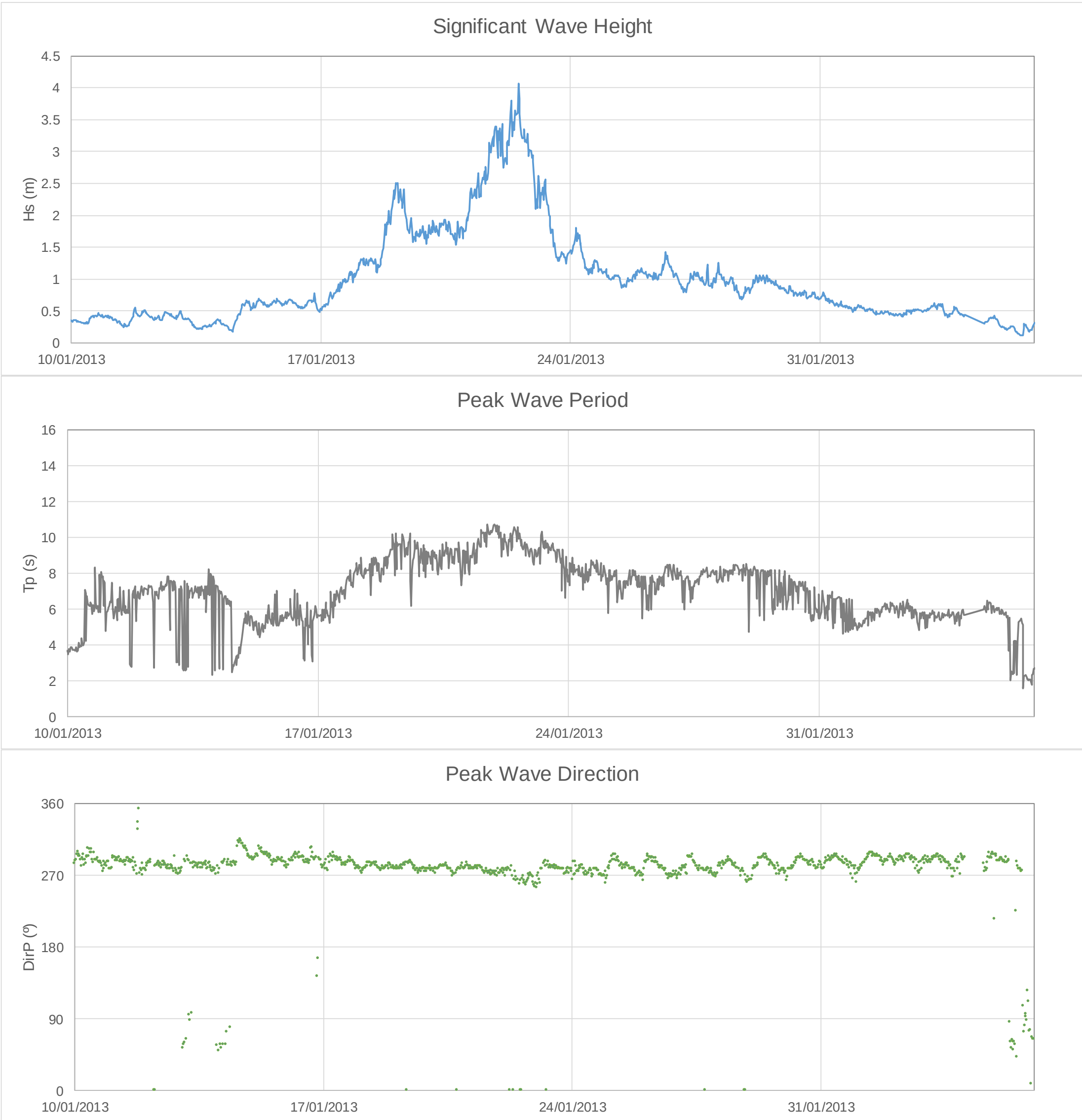


Figure 24. Measured wave conditions at the Albatross Bay DSITI WRB during TC Oswald.

The strong onshore winds during TC Oswald also resulted in a storm surge (residual) level of more than 1 m (Figure 25). The storm surge combined with the astronomical tidal level resulted in a peak storm tide water level (storm surge + astronomical tidal level) of 2.1 m AHD, which is approximately 0.5 m above HAT.

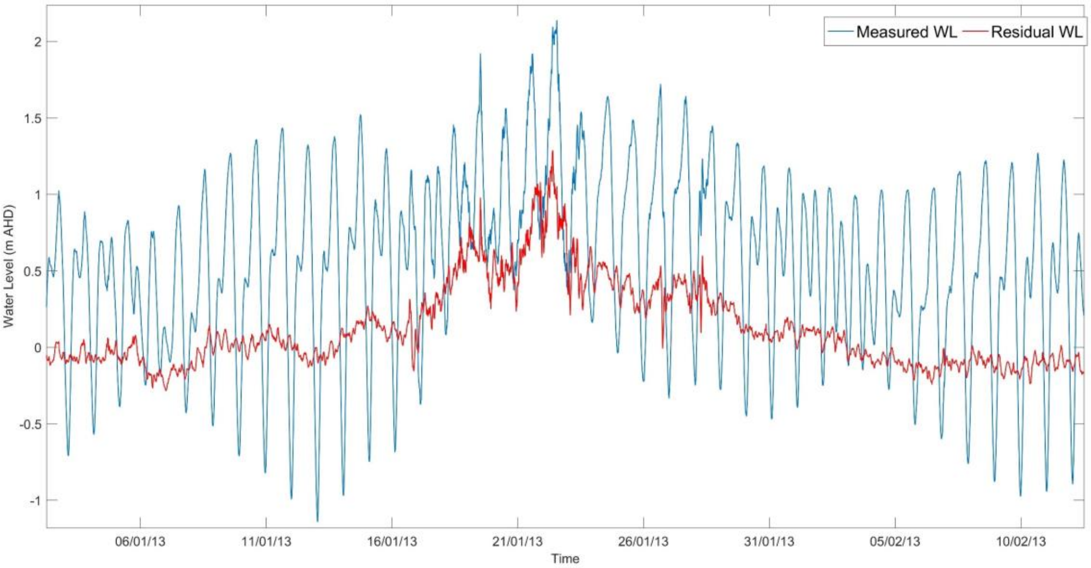


Figure 25. Measured water level (WL) and residual water level at the Weipa Tide Gauge during TC Oswald.

The strong winds and large waves from TCs have the potential to result in substantial resuspension and the resultant transport of sediment from the seabed both within Albatross Bay and in the adjacent areas of the Gulf of Carpentaria. At the Port of Hay Point analysis of bathymetric data showed that the large waves and strong winds associated with TC Dylan resulted in 0.1 to 0.2 m of erosion within the departure channel (approximately 500,000 m^3) (RHDHV, 2016). The study also highlighted the difficulty in predicting impacts from a TC as TC Ului (which was similar in intensity and track to TC Dylan) resulted in limited volumetric change within the departure channel.

2.8. Water Quality

Measured water quality (suspended sediment concentration (SSC)) data from the Port of Weipa area are shown in Figure 26 and corresponding wave heights are shown in Figure 27. The sampling locations of the three sites are shown on Figure 6 and are also described below:

- WQ1: is located on the western side of Cora Bank in the Inner Harbour, edge of the departure channel, approximately 600 m south of Evans Landing and 200 m from the edge of the Departure Channel. The water depth at the site is approximately 5 m;
- WQ4: is located approximately 250 m south of the eastern corner of the Approach Channel in the Inner Harbour. The water depth at the site is approximately 5 m; and
- WQ5: is located approximately 8 km offshore of the Embley River mouth and 600 m to the north of the South Channel. The water depth at the site is approximately 9 m.

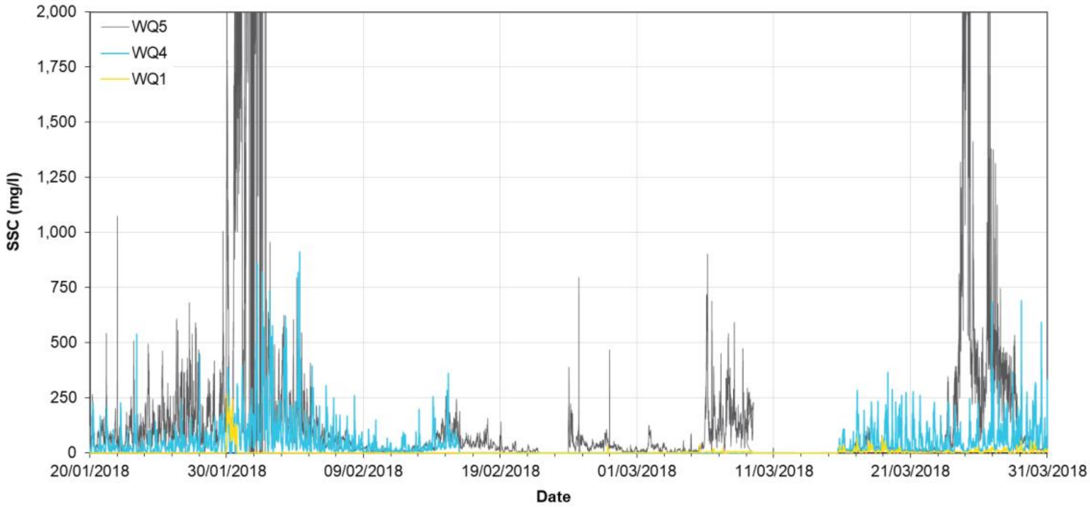
The period shown is over the wet season and included a low pressure system event which resulted in large waves in Albatross Bay (peak H_s = 2.5 m) and heavy rainfall in the Weipa region (530 mm of rainfall occurred in the last 5 days of January, which is more than the monthly average for January) and a Tropical Cyclone (TC Nora) which also resulted in large waves and heavy rainfall. Therefore, the period presented can be used to help infer the relative importance of the resuspension of sediment from within Albatross Bay by waves and the input of sediment from the local river systems during heavy rainfall events on the sediment budget. The plots show the following:

- WQ1: the SSC was consistently below 10 mg/l for the first 50 days of measurements except for a 24 hour period during the peak of the low pressure system event when the

SSC increased to 250 mg/l. During the aerial survey relatively high turbidity was visible in this area (see Section 3 and Figure 36) during a spring tide with limited wave energy in Albatross Bay and little recent rainfall, which does not appear to agree with these measurements. In addition, over this period the SSC at WQ1 does not correlate to the SSC at WQ4 which suggests the potential that the measurements at one of these sites may not be reliable (WQ1 is more likely based on the observations detailed above). In the last 15 days of measurements (from 15th March 2018 onwards) the SSC shows more variability with peaks of up to 50 mg/l occurring which coincide with some peaks at WQ4;

- WQ4: the SSC before the low pressure system event was fairly consistent and appears to correlate to the spring and neap tidal cycle (neap tides were around the 25th January 2018), with peaks in SSC of between 80 and 400 mg/l depending on the tidal range. The results indicate that natural resuspension of the bed sediment occurs within the Inner Harbour area due to the tidal currents, with more resuspension occurring during spring tides due to the stronger currents. During the low pressure system event and over the following seven days the peaks in SSC increased to between 500 and 1,000 mg/l before reducing back to peaks in the range of 80 to 400 mg/l depending on the tidal range. Interestingly, during TC Nora (end of March 2018) there was no clear peak or significant increase in SSC at WQ4 despite the high SSC in Albatross Bay but over the 5 days after the event the peaks in SSC increased above 500 mg/l. This suggests that there can be a lag in the input of SSC into the Inner Harbour from Albatross Bay and indicates that the high rainfall during the event did not result in a significant increase in SSC in the Embley River; and
- WQ5: as the wave height in Albatross Bay increased so did the SSC at WQ5, with peaks in SSC of between 500 and 800 mg/l when the peak H_s was around 1 m. When the H_s dropped below 0.5 m in Albatross Bay between the 6th and 14th February the SSC reduced to less than 25 mg/l and subsequently increased to peaks of more than 200 mg/l when the H_s subsequently increased above 0.5 m. During the two events when the H_s exceeded 2 m in Albatross Bay the SSC increased significantly, with peaks in SSC in the thousands. Based on this it can be inferred that the SSC in Albatross Bay and around the South Channel is strongly correlated to the wave conditions, with the relationship between wave height and SSC being closer to exponential than linear.

The measured SSC data therefore show that there is a strong correlation in Albatross Bay between SSC and the wave conditions, with higher SSC occurring during periods with increased wave energy. The data also indicate that although the rivers do input some sediment into the system during periods with high rainfall, the SSC from this is significantly lower than the SSC caused by large wave conditions in Albatross Bay.



Note: the peaks in SSC at WQ5 (not shown on the plot) were 10,000 (1st) and 4,000 (2nd) mg/l.

Figure 26. Measured SSC around the Port of Weipa (see Figure 6 for locations).

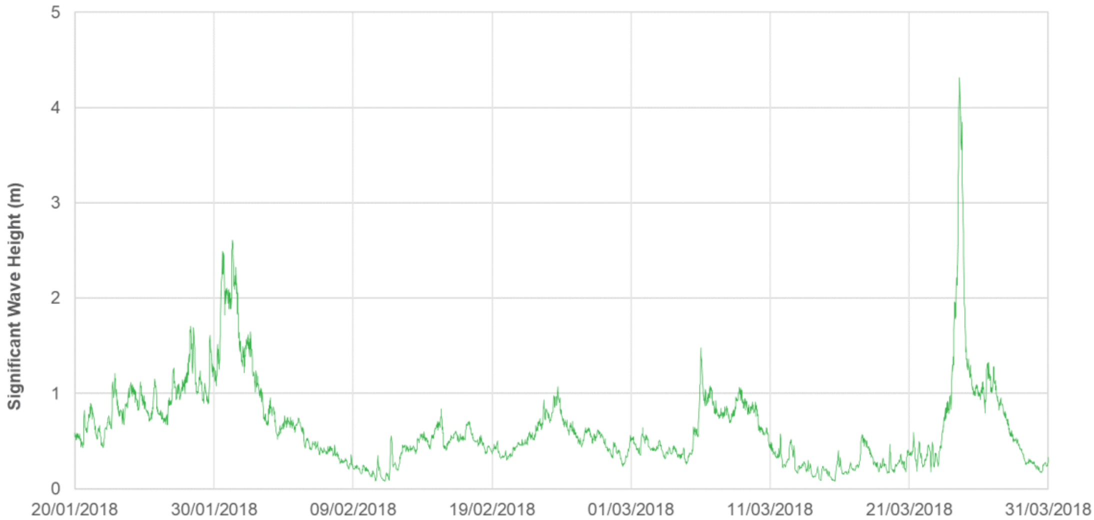


Figure 27. Measured wave height at Albatross Bay WRB over the SSC measurement period (see Figure 6 for location).

2.9. Deposition

Deposition has been measured by JCU since January 2018 at the same sites as the SSC data. The data are recorded using an optical backscatter sensor with a self-cleaning wiper (Ridd, 2001). Time series of the instantaneous deposition and corresponding SSC are shown for a site within the Inner Harbour (WQ4) and a site offshore in Albatross Bay (WQ5) in Figure 28 and Figure 29. The plots show the following:

- in the Inner Harbour there is a relationship between deposition and SSC, with higher deposition correlating to higher SSC, until 04/02/2018. After this period the deposition is consistently high irrespective of the SSC. This could either be due to the near-bed transport being higher after the low pressure system event than it was before due to the layer of loosely consolidated actively mobile sediment being thicker following the erosion caused by the event or it could be due to an issue with the measurements; and
- in Albatross Bay there is a clear relationship between deposition and SSC over the whole period shown, with higher deposition correlating to higher SSC. Until 04/02/2018 the

deposition rates in Albatross Bay (WQ5) were typically higher (peaks of up to 30 mg/cm^2 compared to 12 mg/cm^2) than those in the Inner Harbour, but over the relatively calm conditions after this date the deposition in the Inner Harbour was higher (consistent peaks of more than 10 mg/cm^{2}compared to peaks typically less than 5 mg/cm^2).

The trend that exists between SSC and deposition in Albatross Bay indicates that SSC could be used as a proxy for deposition (i.e. the sediment which is deposited in the South Channel).

It is important to also understand the limitations in the measured deposition data in terms of how useful it is in estimating sedimentation at the Port. Note: This method does not account for any erosion (through resuspension) as the sensor only measures the volume of sediment which settles on the sensor face over a particular interval (15 minutes in this case). It is therefore not possible to derive net sedimentation rates without knowing the amount of sediment eroded as well as deposited, (i.e. the instrument will record zero deposition over a period where extensive erosion has actually occurred).

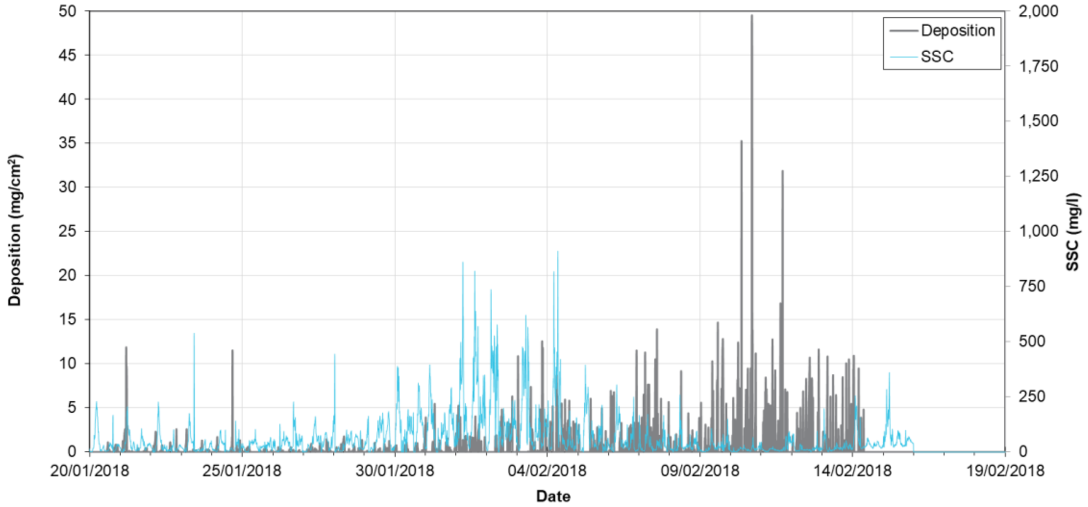


Figure 28. Measured instantaneous deposition and SSC at WQ4 (see Figure 6 for location).

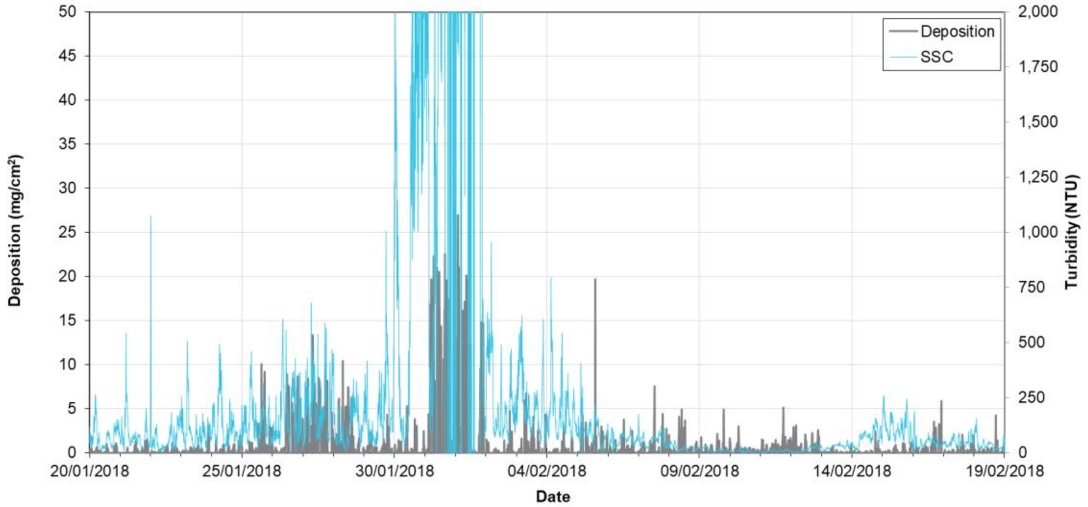


Figure 29. Measured instantaneous deposition and SSC at WQ5 (see Figure 6 for location).

2.10. Sediment Properties

NQBP periodically undertakes sediment characterisation as detailed in the Long-Term Dredge Management Plan (PaCE, 2013a) to ensure sediments remain suitable for on-going ocean placement at the Albatross Bay DMPA. Findings from the most recent two sediment characterisation assessments (2013 and 2018) have been used to inform this study (PaCE, 2013b; Advisian, 2018). The 2013 and 2018 assessments concluded that all dredge areas met the National Assessment Guidelines for Dredging (NAGD) (2009) criteria with regards to unconfined ocean disposal of maintenance dredge material.

A summary of the particle size distribution (PSD) of the sediment in each area of the Port, based on the 2018 sediment characterisation assessment, is provided in Table 5. The PSD characteristics for each area is also discussed below.

- South Channel: the sediment composition varied along the South Channel, with sand (75%) and some gravel (14%) present in the 5 km closest to the Embley River mouth. Further offshore. the sediment has higher proportions of silt (70%) and clay (20%).
- Approach Channel: the sediment composition was similar at all sample sites with the sediment dominated by sand (83%), with some clay (8%), silt (6%) and gravel (3%) also present.
- Departure Channel: the sediment composition varied between the area at the entrance to the Embley River, where the sediment was predominantly sand (54%) and gravel (44%), and the area adjacent to the berths where the sediment was predominantly sand (68%) with some clay (15%), silt (12%) and gravel (5%) present.
- Lorim Point Berths: the sediment composition was similar at the sample sites with the sediment being dominated by sand (49%) with gravel (22%), clay (18%) and silt (11%) also present.
- Humbug Point Berth: the sediment composition was similar at the sample sites with the sediment being predominantly sand (48%) and silt (31%) with some clay (16%) and gravel (4%).
- Evans Landing Berth: the sediment composition was similar at the sample sites with the sediment dominated by gravel (43%) and sand (40%) and small amounts of clay (9%) and silt (7%) also present.
- Tug Berths: the sediment in the tug berths at Lorim Point has a different composition compared to the sediment in the Lorim Point Berths. The sediment composition in the tug berths was predominantly silt (42%) and clay (35%) with some gravel (14%) and sand (9%) also present, while the sediment in the Lorim Point Berths was predominantly sand (49%).
- DMPA: the sediment composition was similar at all the sample sites with the sediment dominated by sand (65%) with some silt (18%) and clay (16%) also present.
- Reference sites: the reference sites are located in Albatross Bay approximately 2 km to the north-west of the DMPA and can be considered to be representative of the natural seabed in this area. The sediment is predominantly silt (36%) and sand (34%) with some clay (18%) and gravel (12%) present.

Table 5. Summary of the PSD for the different areas of the Port of Weipa (Advisian, 2018).

Area	Percent Composition			
	Clay (0–2µm)	Silt (2-60µm)	Sand (60-2000 µm)	Gravel (>2000µm)
South Channel Western 12 km	20	70	10	0
South Channel Eastern 5 km	6	5	75	14
Approach Channel	8	6	83	3
Departure Channel Mouth Embley River	1	1	54	44
Departure Channel Adjacent to Berths	15	12	68	5
Lorim Point Berths	18	11	49	22
Humbug Point Berth	16	31	48	5
Evans Landing Berth	9	7	40	43
Tug Berths	35	42	9	14
DMPA	16	18	65	1
Reference sites	18	36	34	12

2.11. Summary

Based on the available information the dominant processes in terms of sediment resuspension and transport are summarised below separately for the South Channel and Inner Harbour areas of the Port of Weipa:

- South Channel: wave action is considered to be the dominant driver response for the resuspension of fine-grained sediment in Albatross Bay. Sediment sampling has shown that there is fine-grained silt and clay present within the surface sediment in Albatross Bay and sampling at Amrun Port showed that there was a thin (0.05 to 0.5 m) surface layer of loosely consolidated sediment present there and a similar layer is expected to be present in most of Albatross Bay. This surface layer is regularly reworked (resuspended, transported and then deposited) by waves (resuspending the material) and currents (transporting the material). Wave action resuspends the fine-grained sediment on the seabed and then the tidal currents will transport the sediment around Albatross Bay. The majority of the sediment transport is expected to occur during the wet season when the waves are larger. During TCs (e.g. TC Nora), which result in large waves, the magnitude of sediment transport is expected to be significantly greater than during typical wet season wave events. The strong tidal currents which occur at mouth of the Embley River will prevent any build-up of fine-grained sediment in this area, with fine-grained sediment only able to build-up further offshore of the Embley River mouth where the tidal current speeds are lower.
- Inner Harbour: tidal currents are considered to be the dominant driver responsible for the mobilisation and transport of sediment in the Inner Harbour. Sediment sampling has shown that the sediment in the channels is predominantly sand and gravel, indicating that the current speeds are strong enough to prevent the build-up of fine-grained sediment in these areas. Although the tidal currents in the channels are unlikely to suspend the sand and gravel sized sediment present, they do have the potential to result in localised bedload transport. It is considered that although there is some input of suspended sediment from Albatross Bay during the flood tide (when there are large waves) and from

the river catchments (when there is heavy rainfall), it is likely that much of the suspended sediment within the Inner Harbour area is fine-grained sediment that has been resuspended from the extensive intertidal and subtidal muddy deposits present in the Hey and Embley Rivers. Due to the tidal current speeds in the Inner Harbour any fine-grained sediment in suspension will only settle in sheltered locations where the current speeds are low, such as along the side of the river and within any deeper berth pockets.

The relative importance of the information provided in this section in terms of the sediment transport processes at the Port of Weipa is further discussed as part of the conceptual understanding in Section 5.1.

3. Site Visit

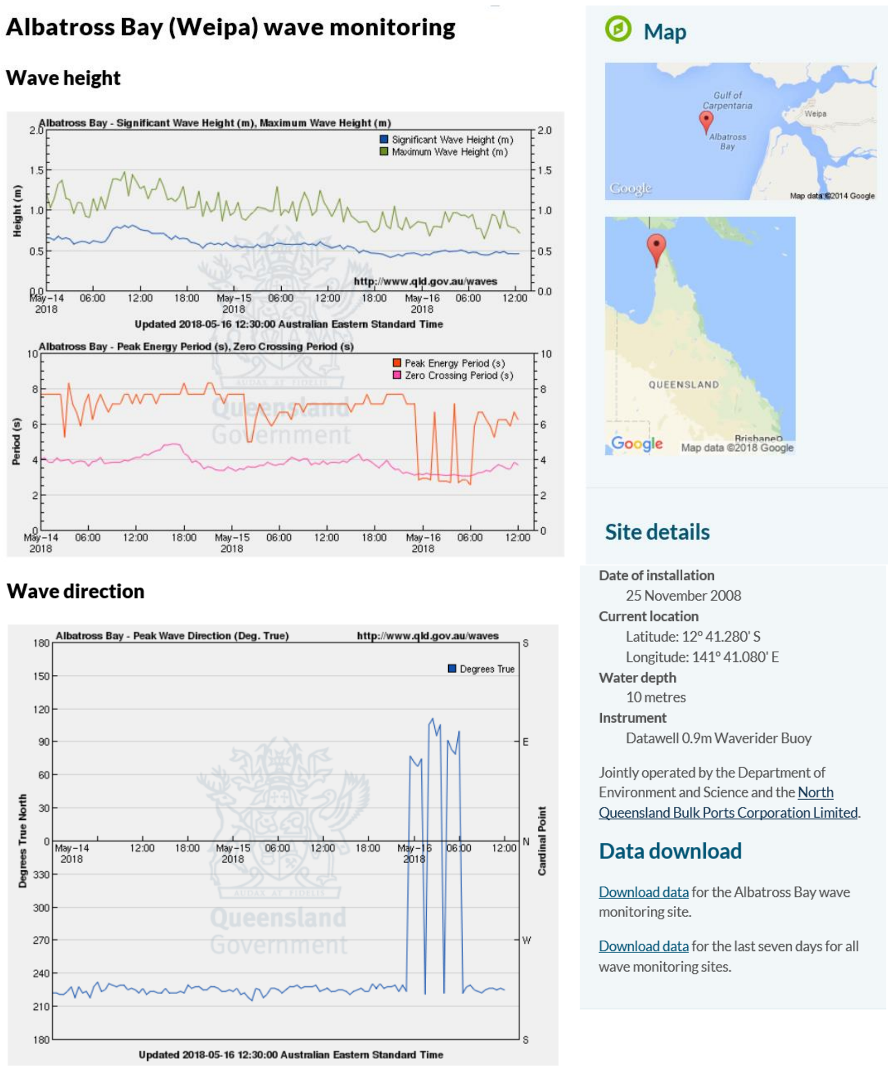
An aerial survey of the Port of Weipa coastal and estuarine areas was undertaken in May 2018 as part of a two-day site visit conducted for the Project. The aim of the survey was to better understand the natural environment and the dominant processes in terms of sediment transport. A six-seater twin-engine Aero Commander aircraft was used for the survey, which was undertaken on the 15th May 2018 from 7:30 to 9:30 am Eastern Standard Time. The survey coincided with spring tides. The tidal range was 1.4 m with the tide ebbing during the survey from a high water at 4:10 am to a low water at 11:53 am.

The conditions for the survey were good, with no cloud cover and light winds (2.5 m/s from the south-east at 7:30 am increasing to 7.8 m/s from the east south-east at 9:30 am). The offshore conditions were relatively calm (H_s = 0.6 m, T_p = 7 s and Direction = south south-west) and there had been limited rainfall over the previous month and so there was limited freshwater inflow from the rivers.

A summary of the key findings from the aerial survey relevant to the Port of Weipa, and observations during subsequent site visits by car and on foot to areas of interest, are provided below:

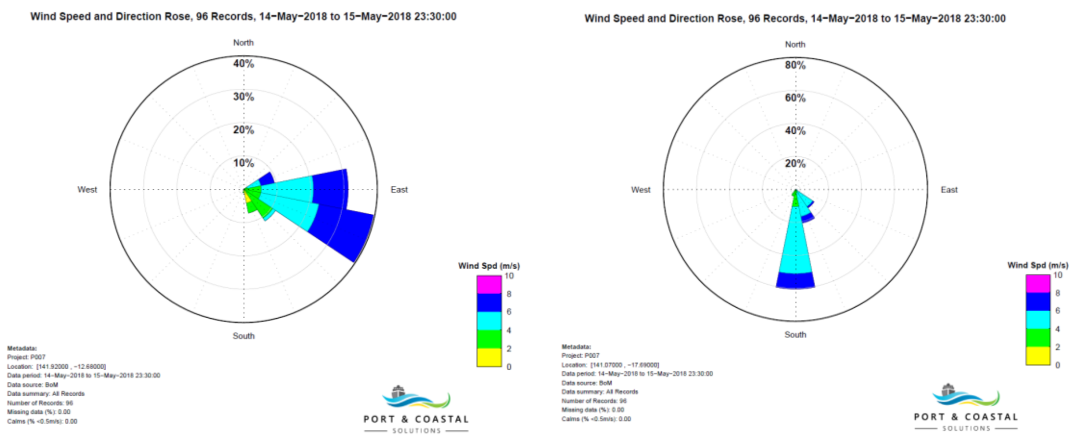
- The wind direction and wave conditions during the aerial survey did not directly correlate, with winds from the south-east (Figure 30) and waves from the south south-west (Figure 31). The waves are generated by winds further south in the Gulf of Carpentaria which are orientated from more of a southerly direction relative to the local winds in the Weipa region (Figure 30);
- Due to numerous rocky outcrops and headlands along the coastline to the south of the Embley River mouth there appears to be limited longshore transport of sand and gravel sized sediment towards the Embley River, except for the sediment present on the beach directly to the south of the Embley River. Some resuspension of fine-grained sediment was observed along this beach due to the wave conditions (Figure 33);
- There was high turbidity visible along the banks of the Embley and Hey Rivers and in areas where shallow banks were present (Figure 34). The colour of the turbidity was darker than the turbidity along the open coast beach, indicating that there is a difference in the type of sediment in suspension;
- There were strong ebb tidal currents in the Inner Harbour region that resulted in the local resuspension of fine-grained sediment around the berths and close to the mouth of the Embley River (Figure 35 to Figure 38). In addition, the Triluck Creek (mouth located to the west of Urquhart Point) was observed to be discharging relatively high turbidity into the South Channel despite it being relatively small (Figure 38);
- Increased turbidity was visible along the South Channel, with the turbidity gradually decreasing with distance offshore (Figure 39 and Figure 40);
- The overall turbidity in Albatross Bay was considered to be high given the relatively calm wind and wave conditions. Throughout the bay there was significant turbidity visible even in the areas away from the nearshore influence of wave breaking (Figure 41); and
- The highest turbidity in Albatross Bay was observed along the northern shoreline close to the Pine River which was the area most exposed to the waves from the south-west (Figure 42). The colour of the turbidity indicates that large amounts of fine-grained silt and clay have been resuspended by the waves in the nearshore shallow areas.

Aerial photographs of the Port of Weipa wharves at Evans Landing, Humbug and Lorim Point are shown in Figure 43 to Figure 45.



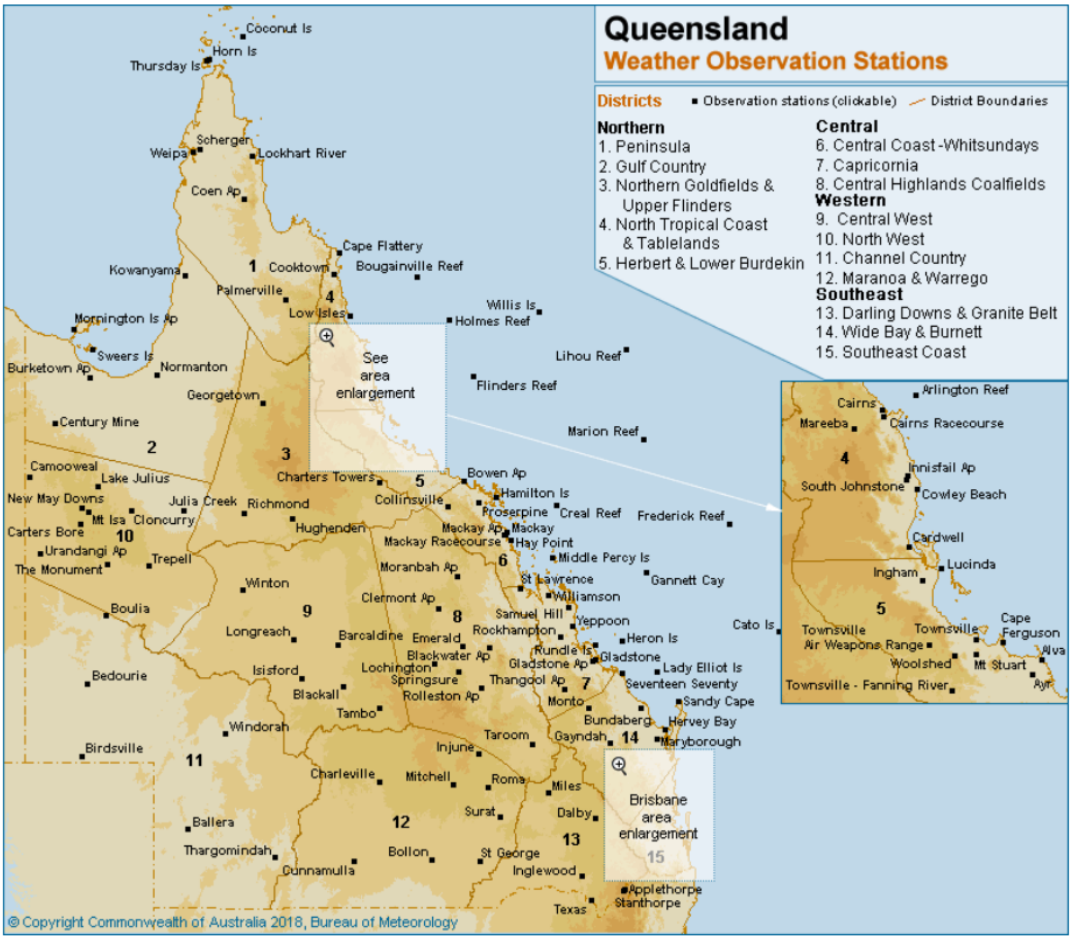
Source: https://www.qld.gov.au 16/05/2018

Figure 30. Measured wave conditions during the site visit.



Weipa Airport **Normanton Airport**

Figure 31. Wind roses for the two day site visit at Weipa and Normanton Airports (see Figure 32 for locations).



Source: http://www.bom.gov.au 16/05/2018

Figure 32. BoM weather station locations.


Figure 33. Waves and turbidity along the beach to the south of the Embley River mouth.


Figure 34. Turbidity of fine-grained sediment along the side of the Hey River channel.

Figure 35. Turbidity in the Approach and Departure Channels adjacent to Lorim Point.

Figure 36. Turbidity in the Departure Channel adjacent to Evans Landing.

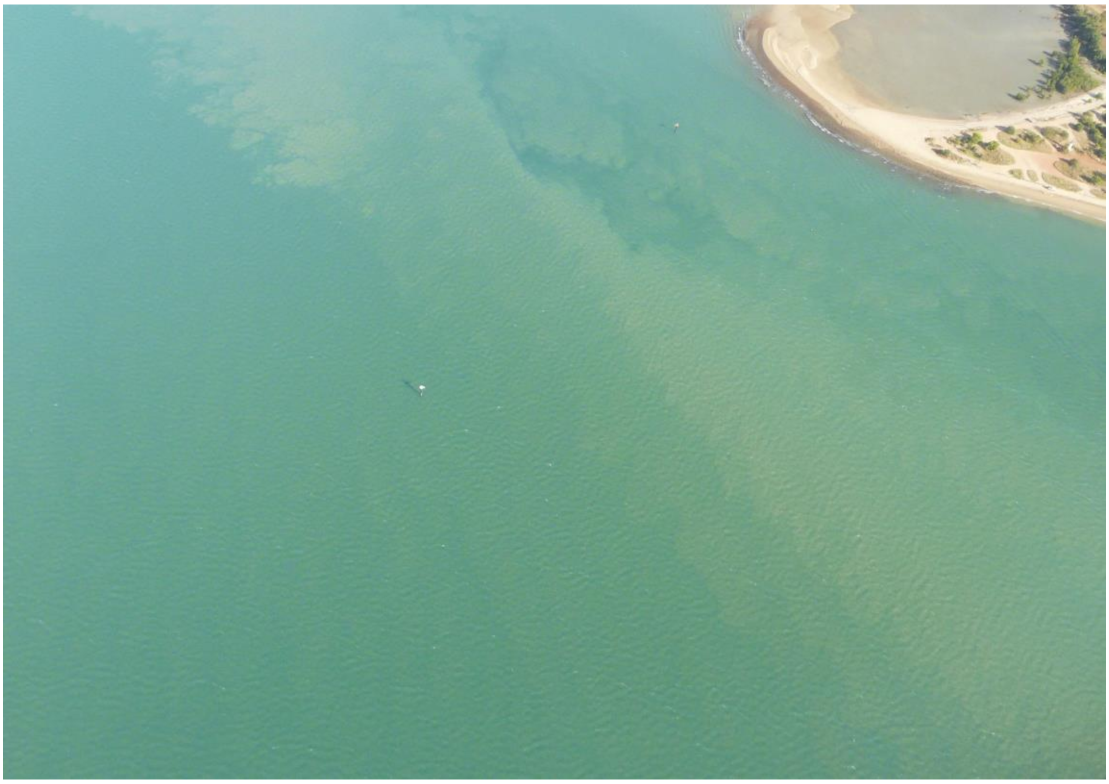


Figure 37. Turbidity at the entrance to the Embley River adjacent to the northern side of the channel.


Figure 38. Turbidity and shallow shoal in the South Channel at the entrance to the Embley River.


Figure 39. Turbidity in the South Channel, approximately 4 km from the Embley River mouth.

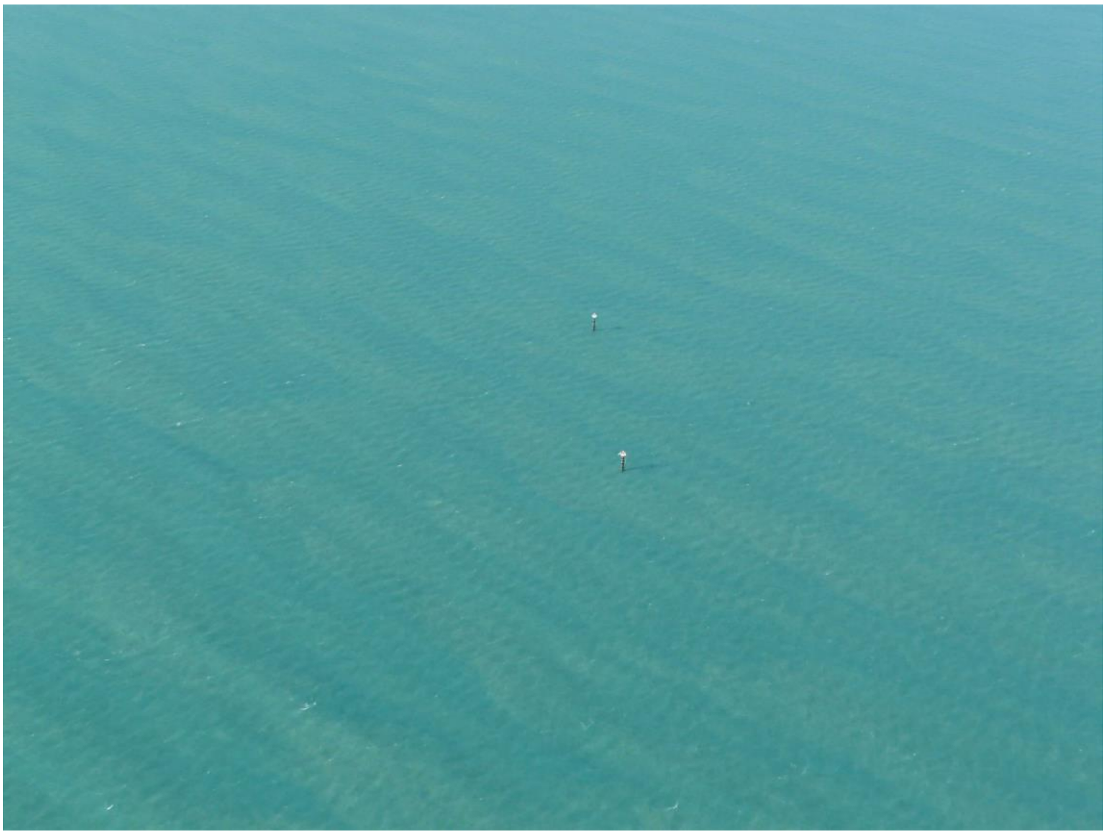


Figure 40. Turbidity in the South Channel, approximately 15 km from the Embley River mouth.

Figure 41. Turbidity in Albatross Bay away from the nearshore wave breaking areas.

Figure 42. Resuspension of fine-grained sediment adjacent to the Pine River mouth due to local wave conditions.

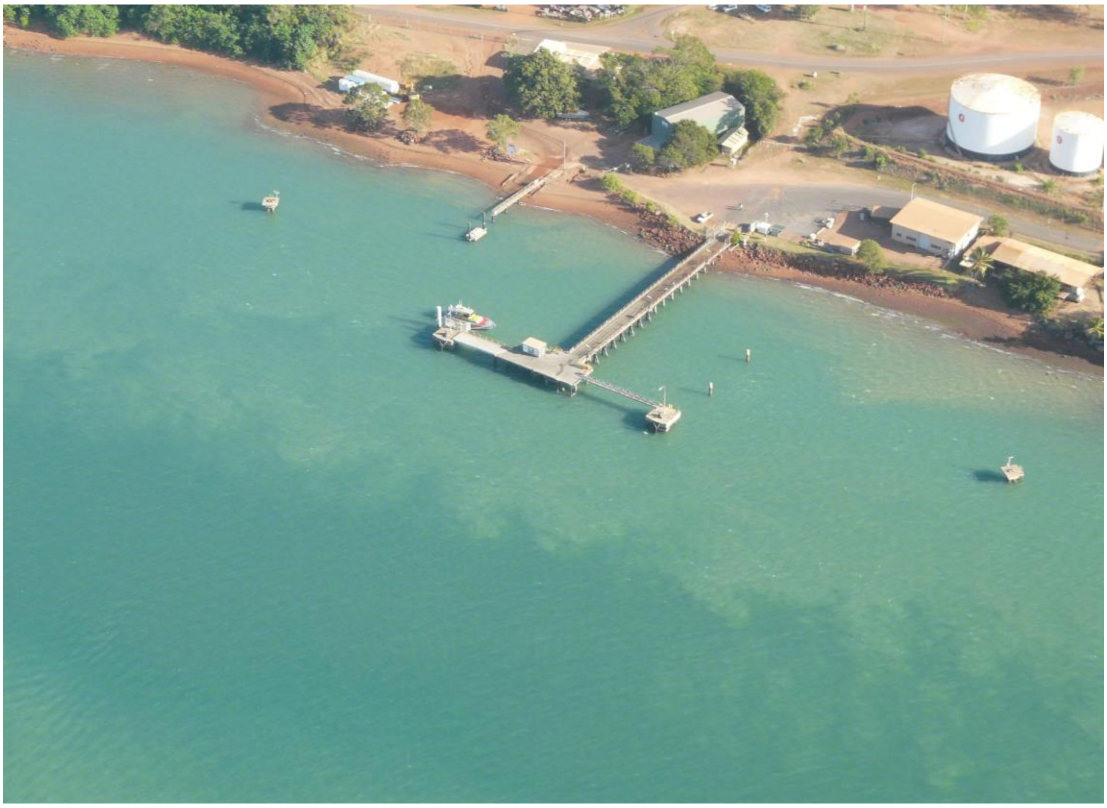


Figure 43. Evans Landing Wharf.

Figure 44. Humbug Wharf.

Figure 45. Lorim Point Wharf.

4. Bathymetric Analysis

Hydrographic survey data of the Port of Weipa channels and berths collected by Maritime Safety Queensland (MSQ) have been made available for this project. Survey data from 2002 to 2018 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.

4.1. Hydrographic Surveys

Details of the hydrographic survey data available for the analysis of the dredged areas of the Port are provided in Table 6. The surveys have mainly 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 area of the dredged areas at the Port of Weipa (6.25 Mm^2) by the vertical uncertainty (0.15 m), which gives a total potential volumetric error of 940,000 m^3. This is more than the maximum volume of sediment removed by maintenance dredging due to sedimentation over a single year from 2003 to 2018 (the volume removed in 2002 was slightly higher as this represented sedimentation over the previous two years). 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 significantly lower than 940,000 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 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 Weipa hydrographic surveys available for this assessment.

Year	Surveys	Areas
2002	Pre-Dredge, Post Dredge	South Channel, Inner Harbour
2003	Post Cyclone, Pre-Dredge, Post Dredge	South Channel
2004	Pre-Dredge, Post Dredge	South Channel
2005	Pre-Dredge, Post Dredge	South Channel, Inner Harbour
2006	Post Cyclone, Pre-Dredge, Post Dredge	South Channel, Inner Harbour, DMPA
2007	Post Cyclone, Pre-Dredge, Post Dredge	South Channel, Inner Harbour, DMPA
2008	Post Cyclone, Pre-Dredge, Post Dredge	South Channel, Inner Harbour, DMPA
2009	Post Cyclone, Pre-Dredge, Post Dredge	South Channel, Inner Harbour, DMPA
2010	Post Cyclone, Pre-Dredge, Post Dredge, Pre-Wet	South Channel, Inner Harbour, DMPA
2011	Post Wet, Pre-Dredge, Post Dredge	South Channel, Inner Harbour
2012	Post Wet, Pre-Dredge, Post Dredge	South Channel, Inner Harbour
2013	Post Cyclone, Pre-Dredge, Post Dredge	South Channel, Inner Harbour, DMPA
2014	Post Wet, Pre-Dredge, Post Dredge	South Channel, Inner Harbour, DMPA
2015	Post Wet, Pre-Dredge, Post Dredge	South Channel, Inner Harbour, DMPA
2016	Post Wet, Pre-Dredge, Post Dredge	South Channel, Inner Harbour

Year	Surveys	Areas
2017	Post Wet, Pre-Dredge, Post Dredge	South Channel, Inner Harbour, DMPA
2018	Pre-Dredge	South Channel, Inner Harbour

4.2. 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 an inverse distance weighting interpolation method (PitneyBowes, 2009) with search radii of 20 m for the Port and 50 m for the DMPA. 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 dredging) 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 46 and Figure 47). The volumetric changes were calculated between subsequent surveys and relative to the design depth;
- Long and Cross Sections: long and cross-sectional changes over time were extracted within the dredge areas at the Port and within the DMPA. The sections help to visualise how the bathymetry has changed over time spatially within the different areas.

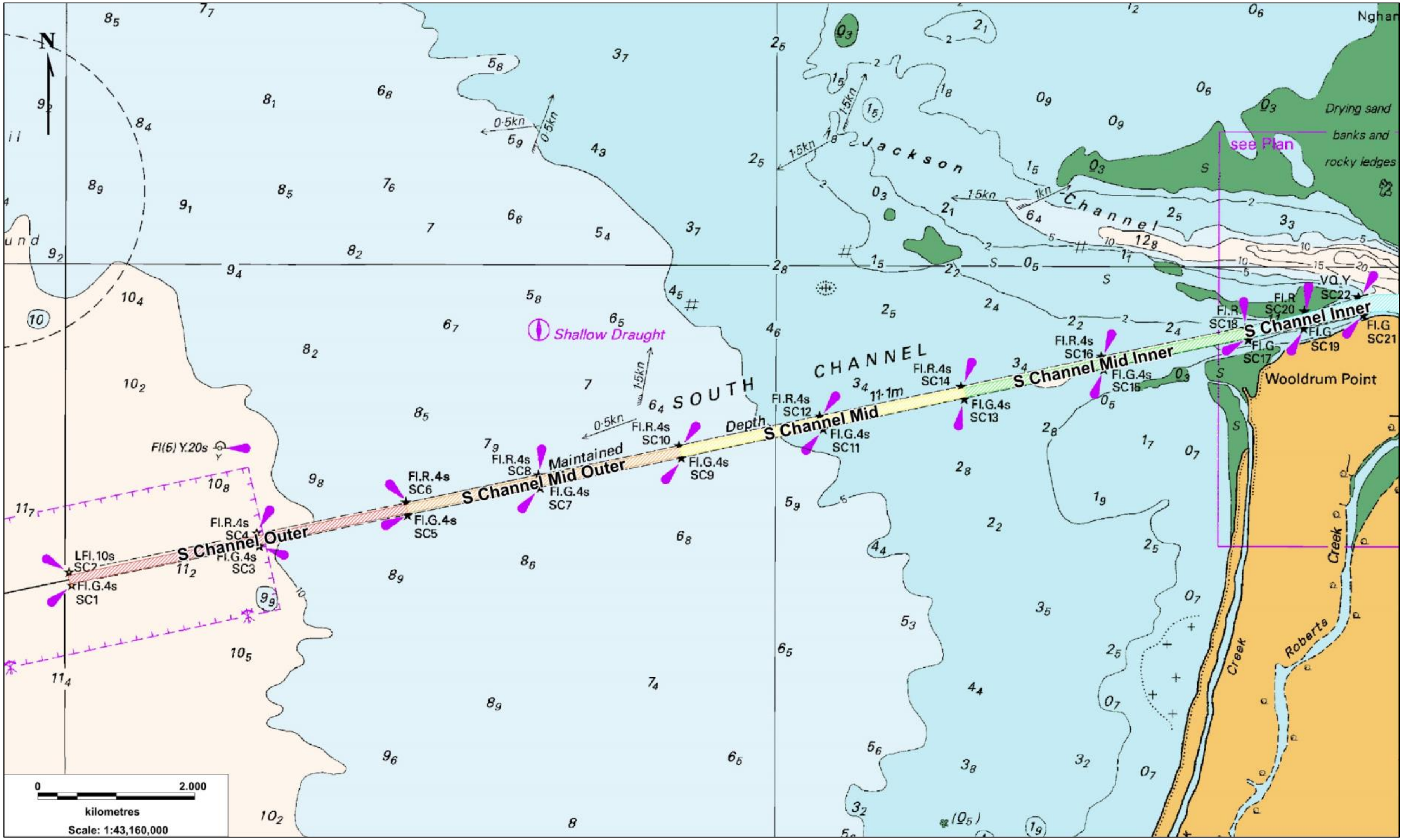


Figure 46. Sub-regions of the South Channel used in the bathymetric analysis.

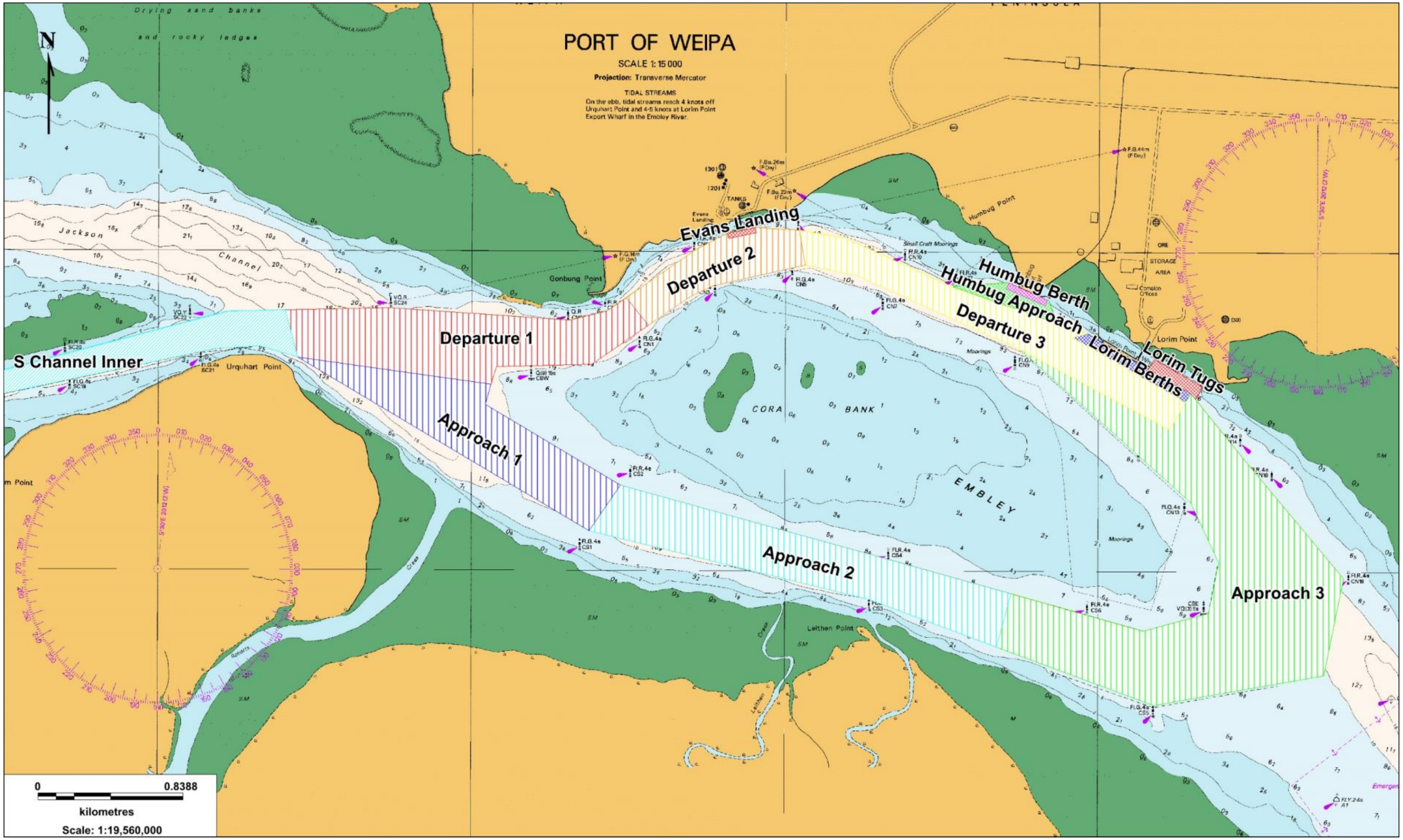


Figure 47. Sub-regions of the Inner Harbour used in the bathymetric analysis.

4.3. Results

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

As noted in Section 4.1, 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.

4.3.1. Port of Weipa

The bathymetry in the dredge areas of the Port of Weipa immediately after the maintenance dredging in 2017 is shown in Figure 48, Figure 49 and Figure 50. The plots show the following:

- there is a large difference in depth between the natural seabed and some sections of the South Channel. The largest differences occur between beacons SC16 and SC10 where the natural elevations are between -3 and -6 m LAT, while the design depths are between -13.6 and -14.1 m LAT. In contrast, towards the seaward end of the channel (i.e. seaward of beacons SC2 and SC3) the difference between the channel and natural seabed is closer to 1 m;
- throughout the majority of the South Channel there is deeper line along the centre of the channel. This will be due to erosion of the bed caused by the propeller wash of vessels navigating the channel (it is expected to be mainly from fully laden vessels departing the Port);
- the natural bathymetry between beacon SC16 and the Embley River mouth is much more variable than the rest of the South Channel, with shallow sections and deeper sections. This is due to the adjacent bathymetry (i.e. the shallow shoal between South Channel and Jackson Channel) as well as the headland at Urquhart Point and the adjacent Embley River mouth;
- sand waves are present on both the northern and southern side of the Embley River mouth entrance. The sand waves are up to 3 m in height and the bathymetric data show that at both locations the waves have been slowly migrating into the river mouth. The sand waves are located in naturally deep water and so are not expected to result in any navigational constraints;
- the bathymetry within the Inner Harbour appears to be relatively natural, with deeper areas where the flow is constrained close to the mouth and shallower areas away from the mouth on the eastern side of Cora Bank. The configuration of the maintained channels within the Inner Harbour means that the dredged areas can only be seen in a few locations:
  - the start of the Departure Channel directly south of Lorim Point where the design depth increases from -7.3 to -11.4 m LAT (see Figure 5);
  - the berths at Lorim Point; and
  - the Approach Channel and berth at Humbug Wharf.
- in the Approach Channel along the eastern side of Cora Bank there is a slightly deeper channel along the typical vessel route where propeller wash from the vessels has eroded the seabed; and
- at the Lorim Point berths, there are four deep scour holes that will have been formed by propeller wash erosion from berthed vessels or from any tugs which assist the vessels into and out of the berths.

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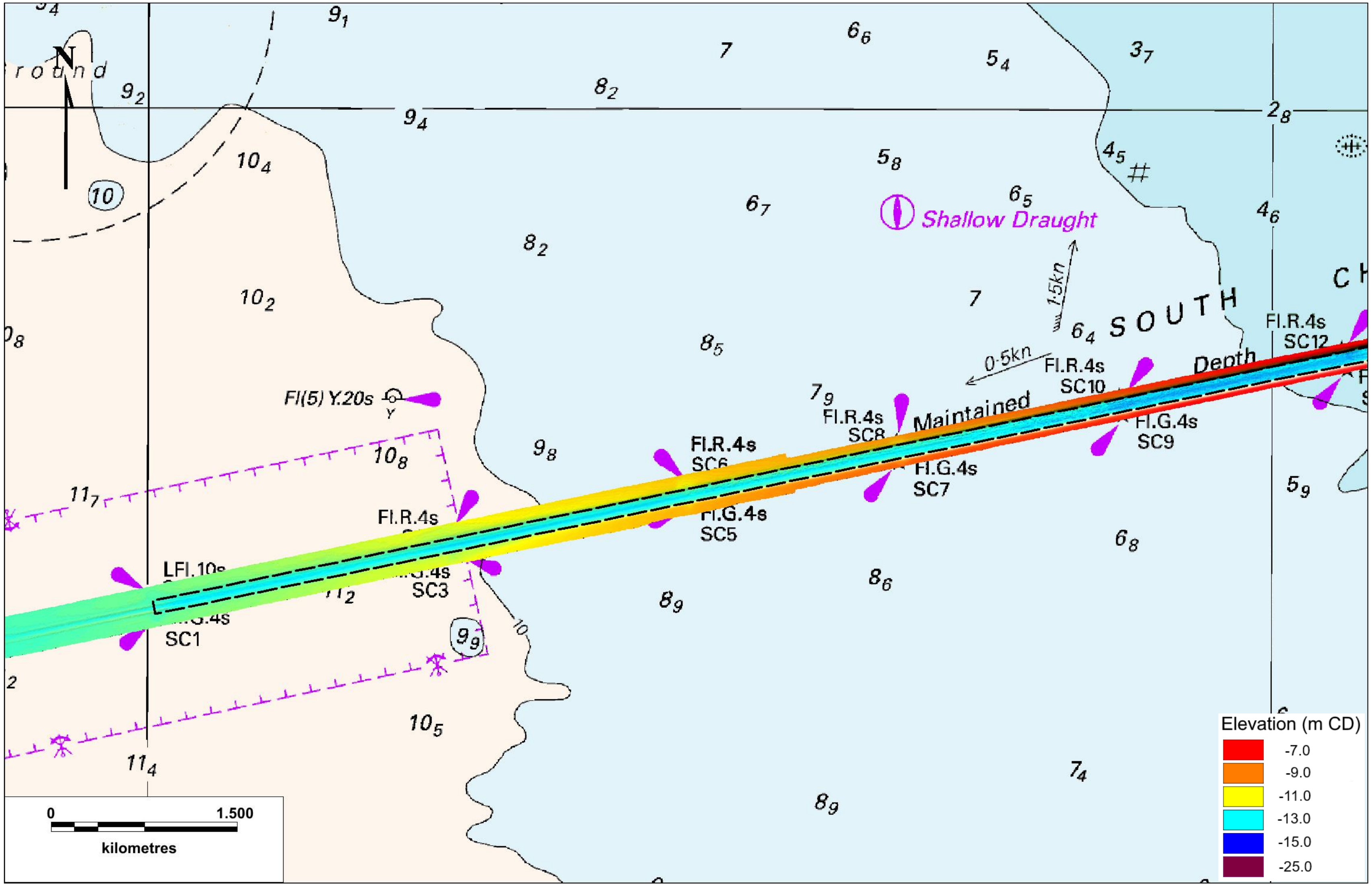

Figure 48. Outer to Mid South Channel bathymetry, post maintenance dredging 2017.

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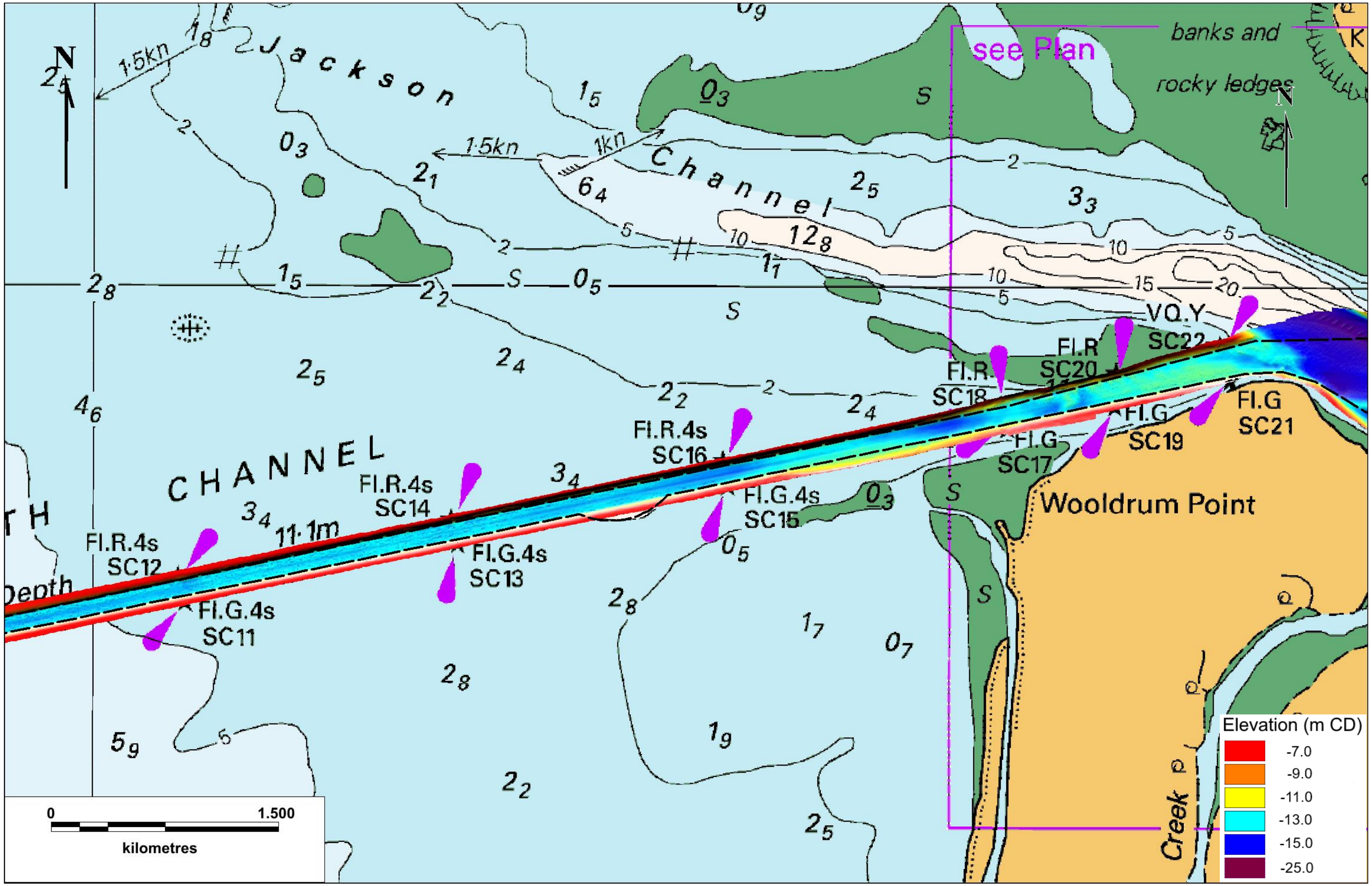

Figure 49. Mid to Inner South Channel bathymetry, post maintenance dredging 2017.

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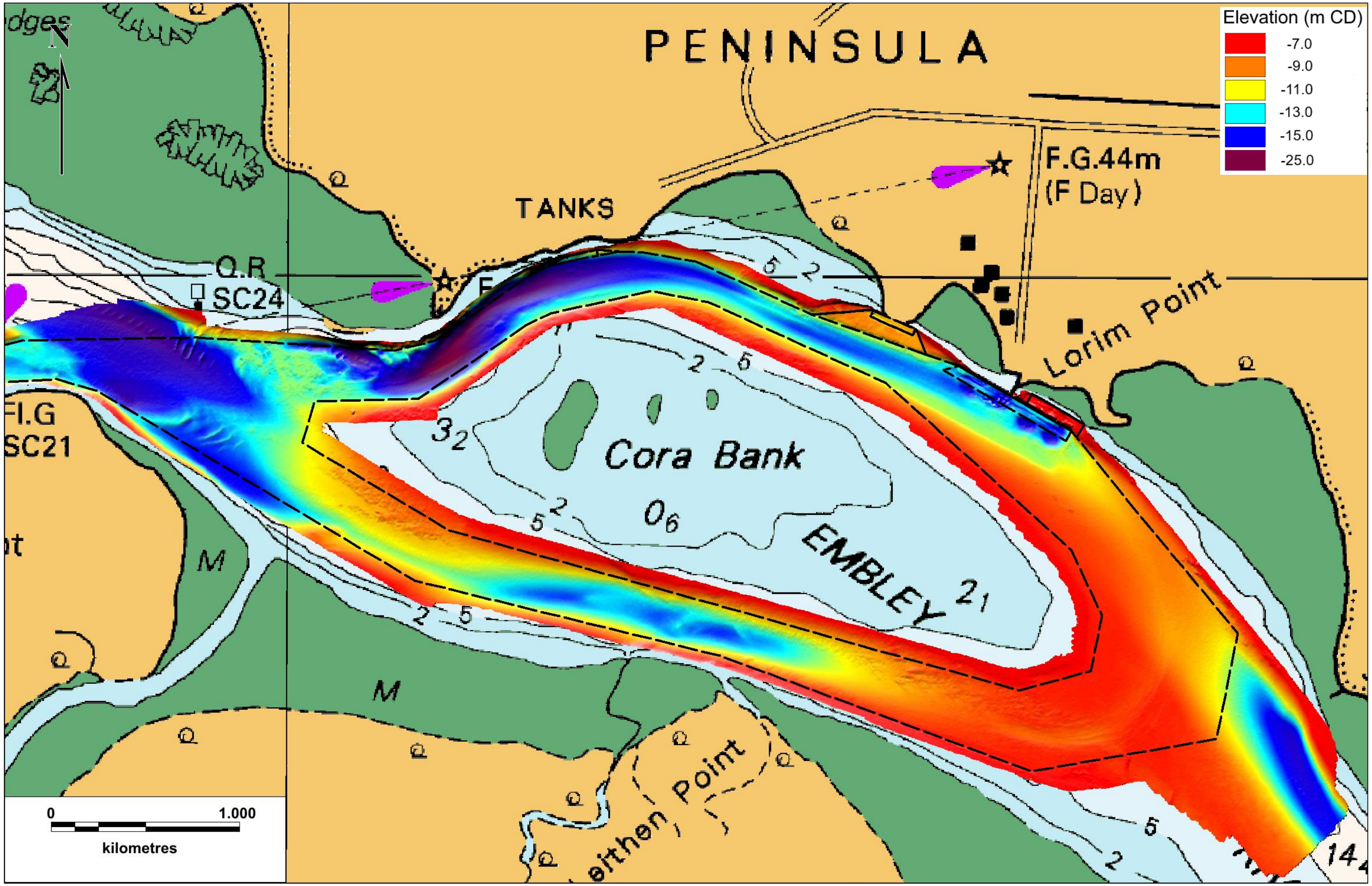

Figure 50. Inner Harbour bathymetry, post maintenance dredging 2017.

The natural sedimentation/erosion that has occurred within the dredge areas each year has been determined by calculating the difference in the bathymetry between the pre-dredge survey one year and the post dredge survey the year before (e.g. natural sedimentation/erosion = 2018 pre-dredge survey – 2017 post dredge survey). The net sedimentation/erosion that has occurred within each sub-region each year is detailed in Table 7 and Table 8 (separate tables showing the gross sedimentation and erosion are provided in Appendix A) and maps are provided in Appendix A. The net sedimentation/erosion volumes for each year were summed to create a total cumulative sedimentation/erosion map from 2002 to 2018 for the Port of Weipa (Figure 51 to Figure 54). The figures and tables show the following:

- the annual total change in bathymetry has been variable over the 16-year period. The maximum change was sedimentation of approximately 900,000 m^3 which occurred between 2005-2006 and 2007-2008. The minimum change was erosion of approximately 300,000 m^3 that occurred between 2016-2017. The overall mean change over the 16 years has been sedimentation of approximately 360,000 m^3/yr;
- the majority of the sedimentation that occurred in the dredge areas of the Port of Weipa has occurred in the South Channel, with almost 5.8 M m^3 deposited in the channel over the 16 years;
- there has been net sedimentation in all regions of the South Channel with the majority of the sedimentation occurring over an 8 km length of the 17 km long channel. This has been in the Mid region (between beacons SC10 and SC14) and Mid Outer region (between beacons SC6 and SC10) of the South Channel;
- the spatial distribution of the sedimentation in the Mid to Outer regions of the South Channel show approximately even sedimentation on both sides of the channel, with either less sedimentation or erosion in the centre of the channel due to erosion from propeller wash. Within the Mid Inner and Inner regions of the South Channel the spatial distribution is different, suggesting that the sedimentation here is due to different processes compared to the other regions of the South Channel;
- the majority of the Inner Harbour has been subject to net erosion over the past 16 years, with limited regions that were subject to net sedimentation (Approach 2, Approach 3 and the berths). The sedimentation in Approach 3 is clearly visible, with accretion occurring at the eastern end of Cora bank and along the southern edge of the channel. The accretion within the berths is predominantly along the side of the berth and at the ends of the berths as these areas will be less influenced by vessels propeller wash; and
- the sand waves at the northern and southern side of the channel at the Embley River mouth show areas of erosion and accretion as the sand waves migrated over time.

In 2010, there were sufficient bathymetric surveys of the South Channel[2] undertaken to get an indication as to whether the sedimentation is continuous over the year or if it is seasonally variable. Analysis of the sedimentation/erosion occurring between the surveys showed that there was a clear seasonal variability, with 100,000 m^3 of erosion over the dry season and 650,000 m^3 of sedimentation over the wet season. There was a TC during the wet season (TC Olga), but regardless of that the lack of sedimentation during the dry season shows that during years without a TC, seasonal variability would still be expected due to the difference in wind and wave conditions between the seasons.

[2] only the pre- and post-dredge surveys covered the Inner Harbour area, so it was not possible to investigate this area.

Table 7. Annual change in bathymetry (m³) at the Port of Weipa from 2002 to 2018 (table 1 of 2).

Notes: the years shown represent the year of the pre-dredge survey; +ve = sedimentation, -ve = erosion

Region	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
S Channel Outer	1,704	62,726	12,273	64,830	19,202	45,725	12,328	15,198	-5,228	60,291
S Channel Mid Outer	79,753	148,627	51,277	158,639	172,439	258,669	59,251	149,324	52,683	192,671
S Channel Mid	72,943	210,725	173,415	339,481	329,345	439,226	177,182	223,942	129,216	198,663
S Channel Mid Inner	-62,897	30,101	43,505	50,315	87,913	56,324	-16,034	76,684	18,417	33,921
S Channel Inner	-51,381	34,251	26,711	26,939	31,409	38,770	33,618	55,551	40,898	21,764
Approach 1				23,016	-10,144	-21,074	-63,228	42,476	-10,413	4,921
Approach 2				58,916	-31,849	-2,979	-14,208	8,820	-3,895	4,291
Approach 3				121,452	-128,336	74,632	-9,726	31,480	35,561	46,430
Departure 1				14,098	-48,334	-6,809	-73,866	49,331	1,812	-6,615
Departure 2				17,227	-2,934	-7,856	-34,060	11,263	5,015	666
Departure 3				29,890	-44,516	16,091	-40,696	9,879	582	210
Evans Landing				2,722	-1,801	-12	-49	-101	-3	368
Humbug Approach				1,721	-6,714	-581	-1,428	854	-1,899	1,693
Lorim Berths				1,866	-3,571	107	-2,708	157	3,105	3,681
Humbug Berth				419	-630	19	-344	-45	-52	1,016
Lorim Tugs				2,061	-4,460	2,124	-2,297	1,735	1,052	3,968
Total	**40,121**	**486,430**	**307,181**	**913,592**	**357,020**	**892,374**	**23,735**	**676,548**	**266,849**	**567,939**
Sub-Total South Channel	*40,121*	*486,430*	*307,181*	*640,204*	*640,308*	*838,712*	*266,345*	*520,698*	*235,985*	*507,310*
Sub-Total Approach Channel				*203,385*	*-170,329*	*50,579*	*-87,162*	*82,776*	*21,253*	*55,643*
Sub-Total Departure Channel				*61,215*	*-95,784*	*1,425*	*-148,622*	*70,473*	*7,409*	*-5,739*
Sub-Total Berths & Approaches				*8,788*	*-17,176*	*1,657*	*-6,826*	*2,600*	*2,202*	*10,725*

Table 8. Annual change in bathymetry (m^3) at the Port of Weipa from 2002 to 2018 (table 2 of 2).

Notes: the years shown represent the year of the pre-dredge survey; +ve = sedimentation, -ve = erosion

Region	2013	2014	2015	2016	2017	2018	Total	*% of Total*	*Mean*	*Max*
S Channel Outer	-8,735	-41,029	-113,998	24,072	-47,647	154,816	**256,527**	*4.5%*	*16,033*	*154,816*
S Channel Mid Outer	140,989	40,806	-23,654	66,671	-35,116	122,217	**1,635,245**	*28.4%*	*102,203*	*258,669*
S Channel Mid	328,021	84,348	63,795	223,368	-7,111	184,677	**3,171,235**	*55.0%*	*198,202*	*439,226*
S Channel Mid Inner	46,141	-17,760	-35,980	44,085	-27,413	29,455	**356,776**	*6.2%*	*22,298*	*87,913*
S Channel Inner	22,158	46,357	8,084	16,449	4,780	-3,653	**352,705**	*6.1%*	*22,044*	*55,551*
Approach 1	576	8,707	-7,820	5,341	-16,663	1,199	**-43,105**	*-0.7%*	*-3,316*	*42,476*
Approach 2	-121	2,679	-7,087	13,831	-16,286	2,114	**14,226**	*0.2%*	*1,094*	*58,916*
Approach 3	11,744	11,522	-7,080	83,308	-77,492	67,099	**260,596**	*4.5%*	*20,046*	*121,452*
Departure 1	-11,005	26,287	-15,874	-8,437	-21,103	-24,382	**-124,898**	*-2.2%*	*-9,608*	*49,331*
Departure 2	-20,367	-4,806	-2,978	9,866	-5,561	-2,471	**-36,996**	*-0.6%*	*-2,846*	*17,227*
Departure 3	-27,200	-9,553	-2,187	13,773	-28,086	8,468	**-73,344**	*-1.3%*	*-5,642*	*29,890*
Evans Landing	-513	19	38	16	7	40	**731**	*0.0%*	*56*	*2,722*
Humbug Approach	-1,053	681	-370	1,886	-2,319	492	**-7,039**	*-0.1%*	*-541*	*1,886*
Lorim Berths	-1,261	-664	-4,767	952	-1,304	4,809	**401**	*0.0%*	*31*	*4,809*
Humbug Berth	120	-18	-38	997	-571	-27	**846**	*0.0%*	*65*	*1,016*
Lorim Tugs	-2,211	-503	-1,158	-196	-3,709	3,157	**-437**	*0.0%*	*-34*	*3,968*
Total	**477,282**	**147,073**	**-151,074**	**495,982**	**-285,593**	**548,010**	**5,763,468**	***100.0%***	***360,217***	**913,592**
Sub-Total South Channel	*528,573*	*112,722*	*-101,754*	*374,645*	*-112,506*	*487,511*	***5,772,487***	*100.2%*	*360,780*	*838,712*
Sub-Total Approach Channel	*12,199*	*22,909*	*-21,987*	*102,480*	*-110,441*	*70,412*	***231,717***	*4.0%*	*17,824*	*203,385*
Sub-Total Departure Channel	*-58,571*	*11,928*	*-21,039*	*15,201*	*-54,750*	*-18,384*	***-235,238***	*-4.1%*	*-18,095*	*70,473*
Sub-Total Berths & Approaches	*-4,919*	*-486*	*-6,295*	*3,655*	*-7,896*	*8,470*	***-5,498***	*-0.1%*	*-423*	*10,725*

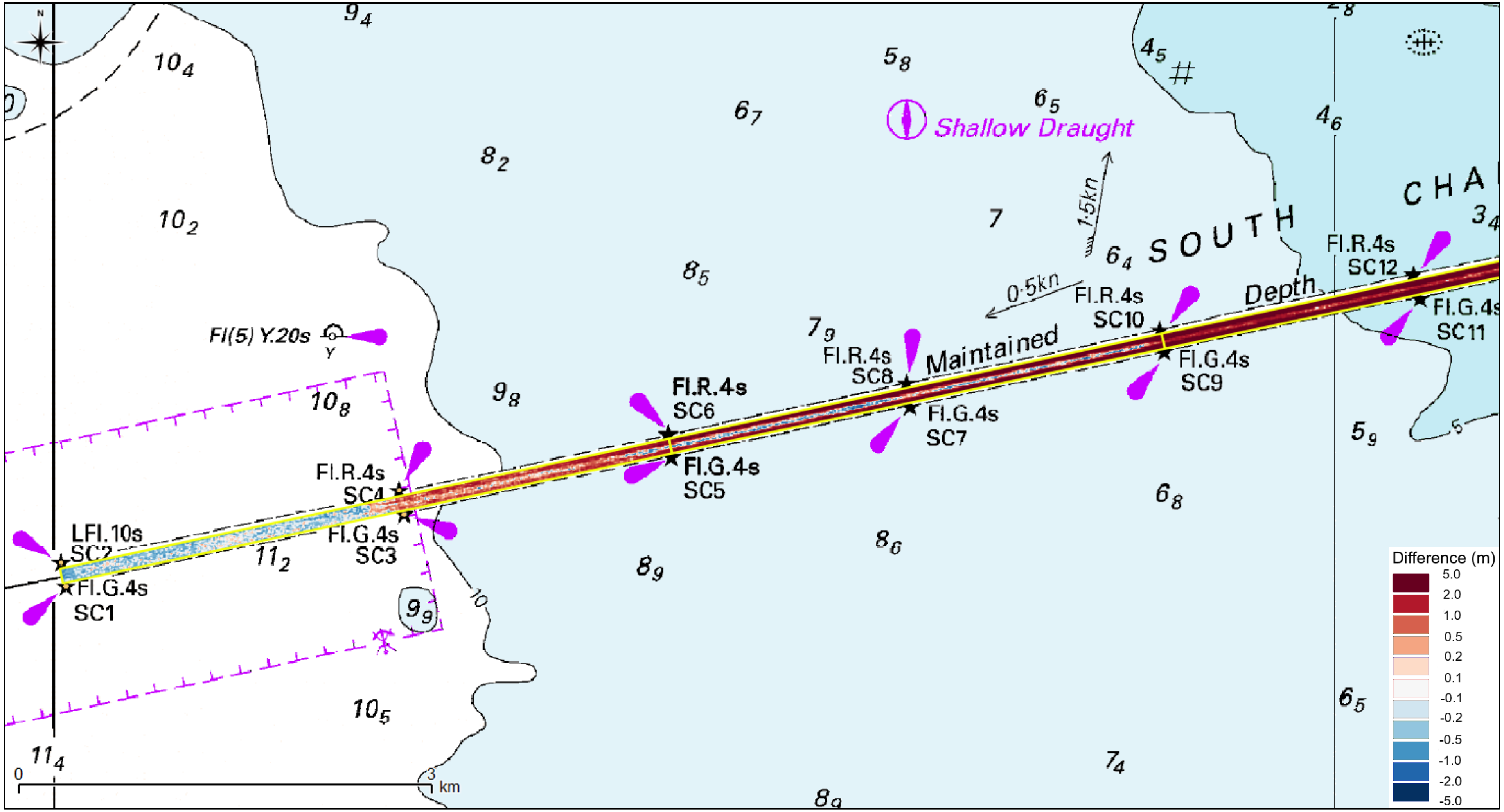

Figure 51. Cumulative sedimentation/erosion from 2002 to 2018 in the Outer to Mid South Channel, showing erosion in blue, accretion in red and volume calculation regions outlined in yellow.

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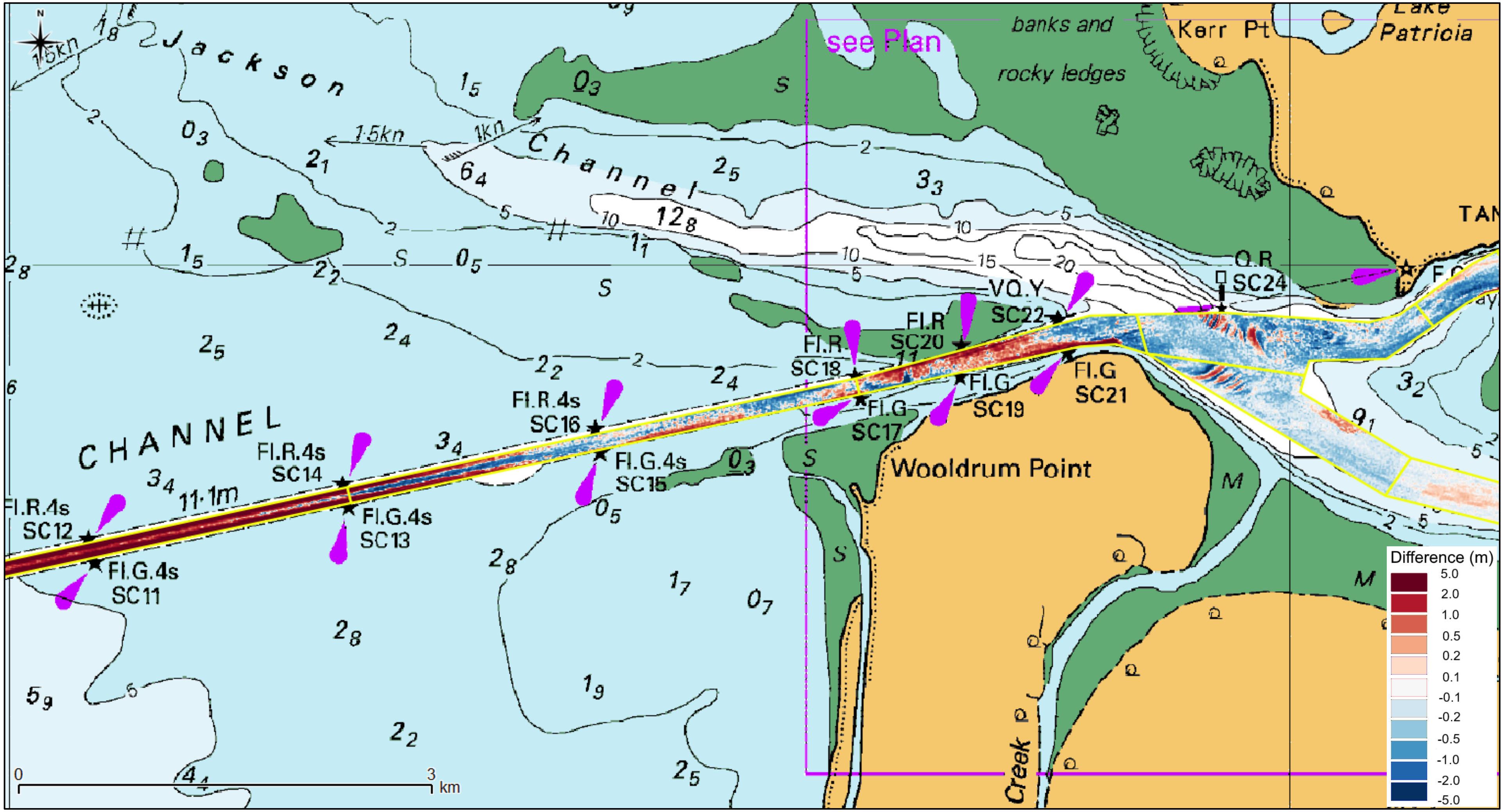

Figure 52. Cumulative sedimentation/erosion from 2002 to 2018 in the Mid to Inner South Channel, showing erosion in blue, accretion in red and volume calculation regions outlined in yellow.

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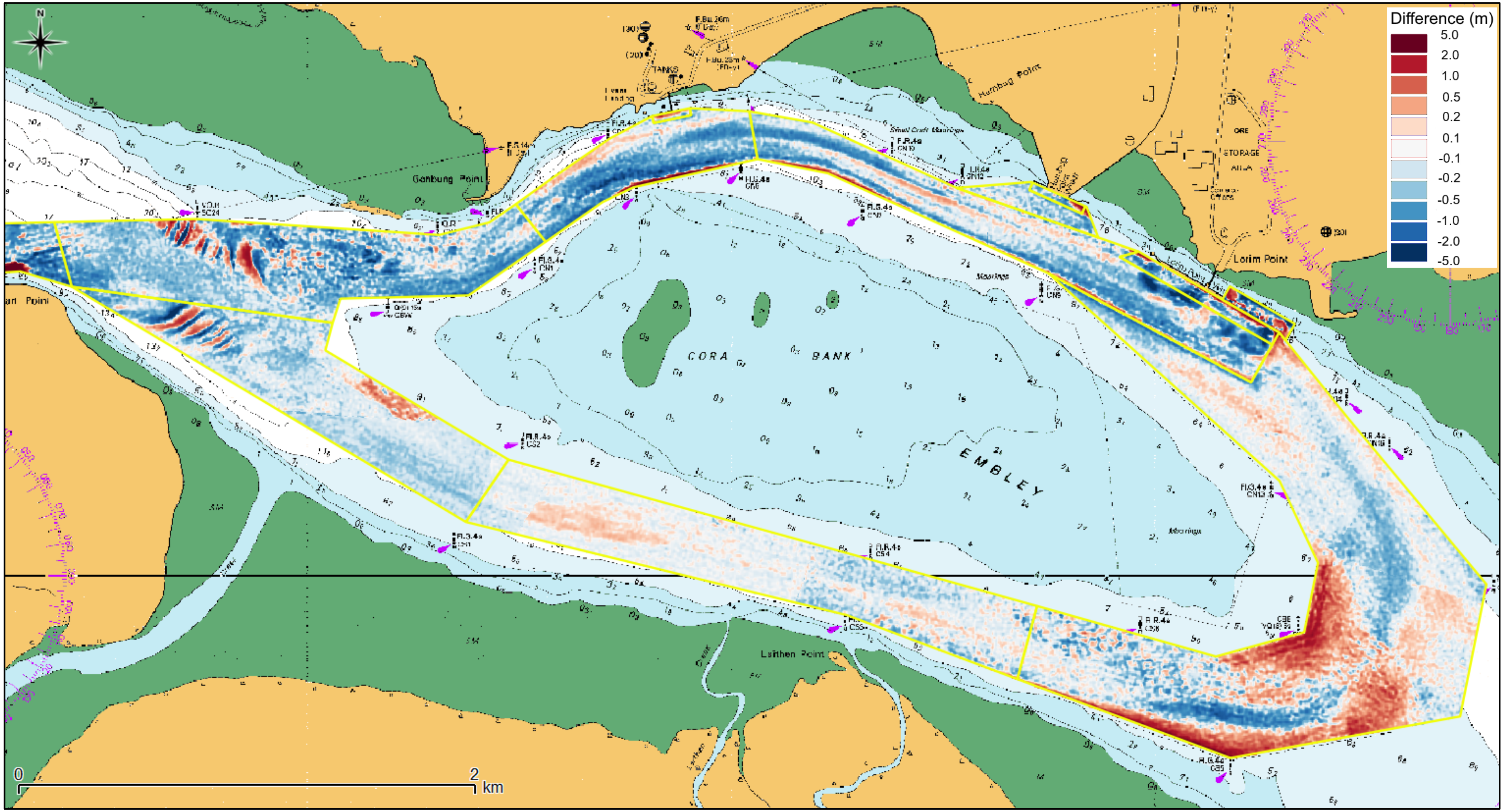

Figure 53. Cumulative sedimentation/erosion from 2002 to 2018 in the Inner Harbour, showing erosion in blue, accretion in red and volume calculation regions outlined in yellow.

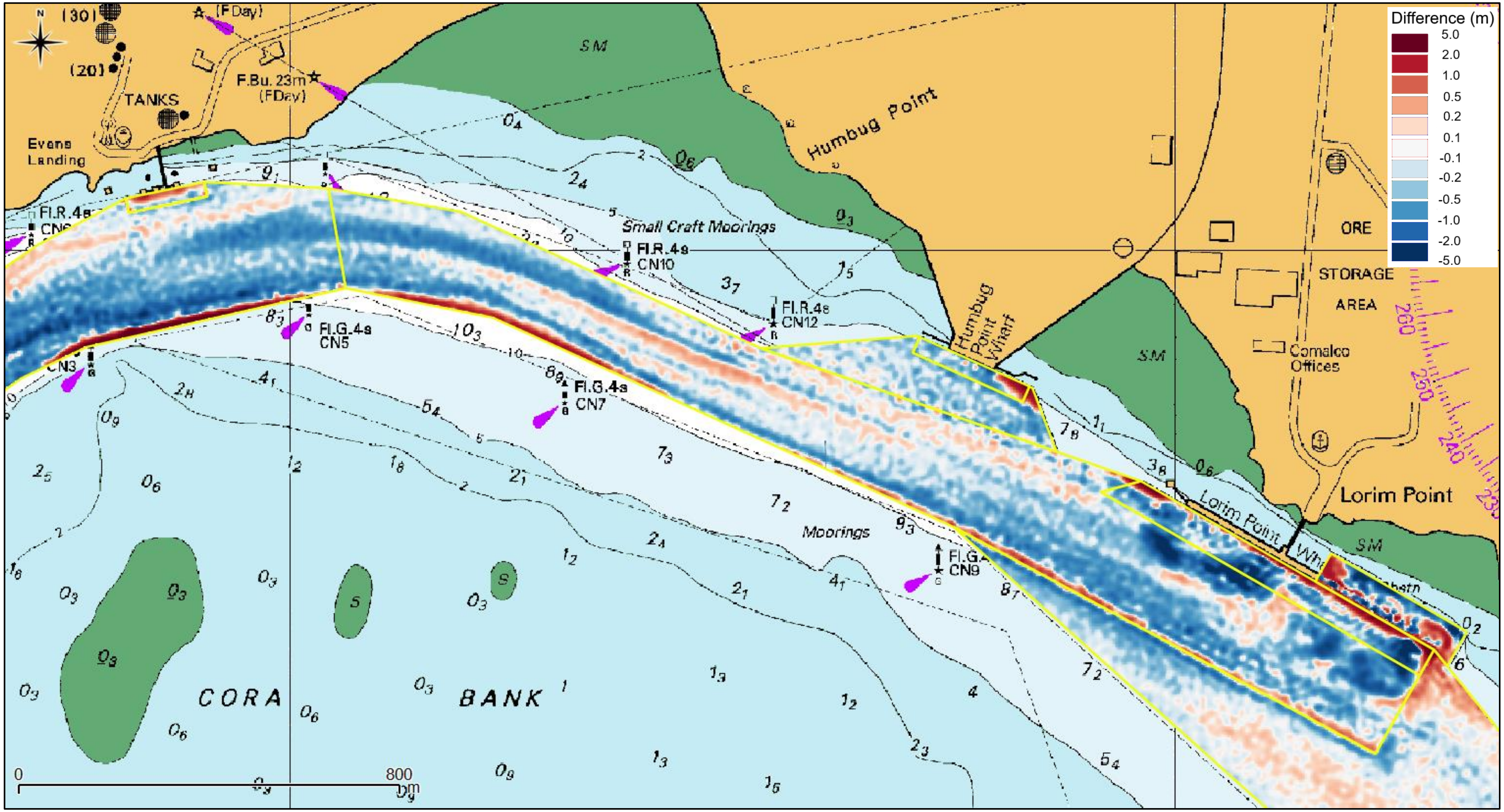

Figure 54. Cumulative sedimentation/erosion from 2002 to 2018 at the Inner Harbour berths, showing erosion in blue, accretion in red and volume calculation regions outlined in yellow.

To better understand how the changes in bathymetry influence the maintenance dredging requirements at the Port of Weipa, the pre-dredge bathymetric surveys for each year between 2007[3] and 2018 were compared to the design depths at the Port (see Figure 4 and Figure 5). The volume of sediment above the design depths within each sub-region of the Port for each survey is detailed in Table 9. The table shows that the largest volume above the design depths was in 2008, which was also one of the two years when the most sedimentation occurred. In 2008, the volume above the design depths was approximately 1.15 M m^3, which was 350,000 m^3 more than in the previous year (2007). 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 post maintenance dredging survey in 2007 and the pre-maintenance dredging survey in 2008 in Figure 55 to Figure 60. The difference between the two surveys shows where the natural sedimentation has significantly increased the maintenance dredging requirement. Results from the comparison of the two surveys along with the tabulated results can be summarised as follows:

- the volume of sediment above the design depths was largest in 2008 with approximately 1.15 M m^3 above, and smallest in 2017 with approximately 415,000 m^3 above. The vast majority of the volume above the design depths (i.e. the maintenance dredging requirement) was in the South Channel, with limited areas above the design depths in the Inner Harbour;
- the Mid and Mid Outer regions of the South Channel are where the majority of the maintenance dredging requirement was in 2008, due to sedimentation between 2007 and 2008. However, after the maintenance dredging in 2007 there were areas of these regions that were still above the design depths (i.e. not all of the volume above the design depth was due to sedimentation over the previous year). In all years, the Mid region of the South Channel had the largest volume above the design depths, but in some years the Mid Inner had a larger volume than the Mid Outer; and
- most of the areas above the design depths in the Inner Harbour in the 2008 pre-dredge survey were also above the design depth in the 2007 post dredge survey. This shows that these areas were not dredged the previous years and so the sedimentation, which has resulted in them being above the design depths, could have been over multiple years or longer. The only area in the Inner Harbour where sedimentation between 2007 and 2008 resulted in a potential increase in the volume at or above the design depth, was the south-eastern corner of the Approach Channel, where sedimentation has occurred along the edge of the channel.

[3] Surveys before 2007 were not included as the capital dredging in 2006 deepened the design depths significantly in some areas of the South Channel and so the volumes are not comparable.

Table 9. Volume (m^3) of sediment above the design depth at the Port of Weipa from 2007 to 2018

Region	2007	2008	2009	2010	2011	2012[1]	2013	2014	2015	2016	2017	2018
S Channel Outer	27,100	107,961	117,285	119,933	92,170	110,498	9,119	5,654	471	4,489	311	1,260
S Channel Mid Outer	172,440	346,586	251,706	294,675	112,757	221,490	209,474	124,867	68,451	100,953	55,638	107,358
S Channel Mid	329,515	547,971	426,509	464,716	288,843	407,600	582,398	381,737	328,942	429,058	278,790	397,433
S Channel Mid Inner	97,500	75,176	54,412	100,624	79,814	107,463	135,205	90,104	82,586	115,650	66,500	81,867
S Channel Inner	48,309	39,048	41,327	43,773	32,738	30,865	6,067	5,522	3,569	3,036	6,799	7,423
Approach 1	13,735	0	0	0	0	0	0	0	0	0	0	0
Approach 2	10,040	0	38	0	39	11	27	11	3	21	10	33
Approach 3	26,105	2,119	4,668	2,052	4,496	3,557	801	1,249	453	4,399	2,914	6,316
Departure 1	23,563	10,747	6,571	10,044	6,385	2,823	115	140	337	331	171	75
Departure 2	20,440	4,664	5,362	5,431	5,772	4,513	1,727	331	268	177	454	740
Departure 3	6,546	11,576	7,208	8,629	12,073	10,666	870	1,062	1,299	1,485	1,168	1,540
Evans Landing	0	0	0	0	0	1	0	0	0	0	0	0
Humbug Approach	254	0	0	5	3	42	15	7	13	88	8	26
Lorim Berths	1,465	0	29	46	80	1,169	26	72	16	36	111	308
Humbug Berth	275	0	5	22	19	160	45	45	143	524	4	209
Lorim Tugs	3,188	1,216	699	1,142	956	1,866	1,024	1,195	892	582	498	888
Total	**780,474**	**1,147,064**	**915,818**	**1,051,093**	**636,146**	**902,723**	**946,912**	**611,994**	**487,444**	**660,830**	**413,378**	**605,476**
Sub-Total South Channel	*674,863*	1,116,742	*891,237*	*1,023,721*	*606,322*	*877,916*	*942,262*	*607,883*	*484,018*	*653,187*	*408,039*	*595,341*
Sub-Total Approach Channel	*49,880*	2,119	*4,706*	*2,052*	*4,535*	*3,568*	*827*	*1,260*	*457*	*4,420*	*2,925*	*6,349*
Sub-Total Departure Channel	*50,549*	26,988	*19,141*	*24,105*	*24,230*	*18,002*	*2,712*	*1,532*	*1,905*	*1,993*	*1,794*	*2,354*
Sub-Total Berths & Approaches	*5,182*	1,216	*734*	*1,215*	*1,059*	*3,238*	*1,110*	*1,319*	*1,064*	*1,231*	*621*	*1,432*

[1] *Note: volumes shown up to and including 2012 are all pre-capital dredging of the South Channel extension and 2013 onwards is post capital dredging.*

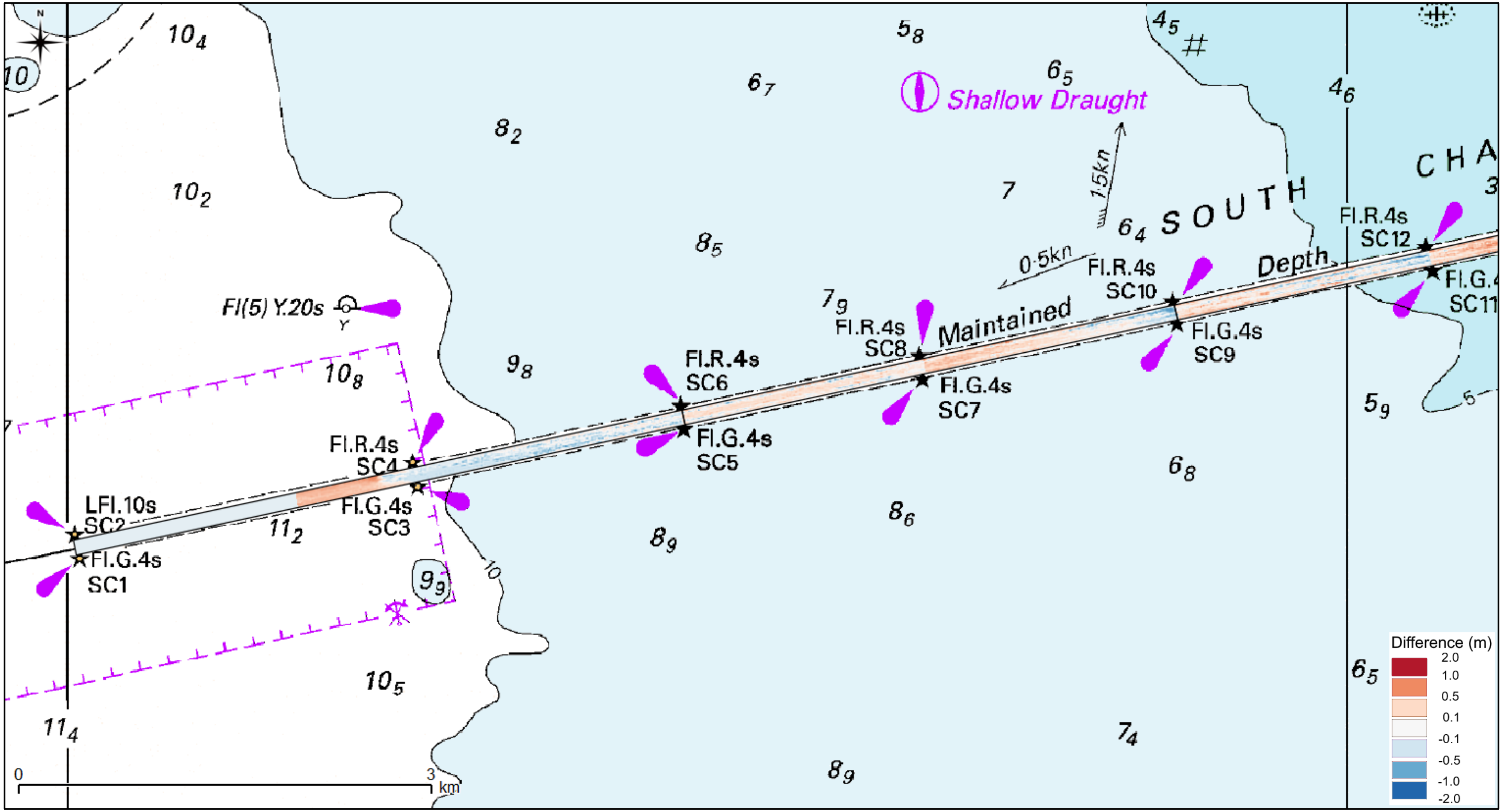

Figure 55. Depths above (red) and below (blue) design depths in the 2007 post dredge survey for the Outer to Mid South Channel. Volume calculation regions outlined in black.

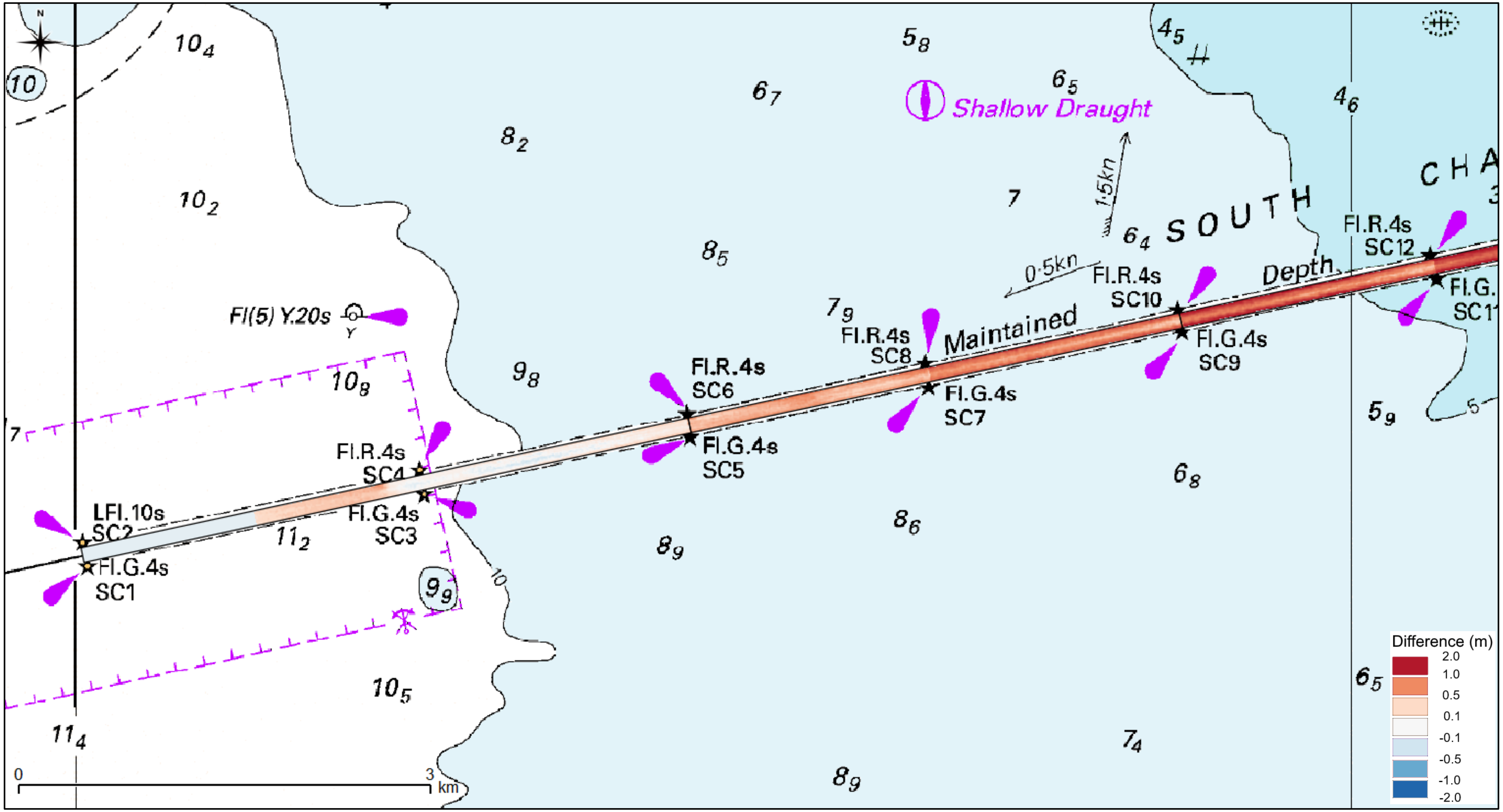

Figure 56. Depths above (red) and below (blue) design depths in the 2008 pre-dredge survey for the Outer to Mid South Channel. Volume calculation regions outlined in black.

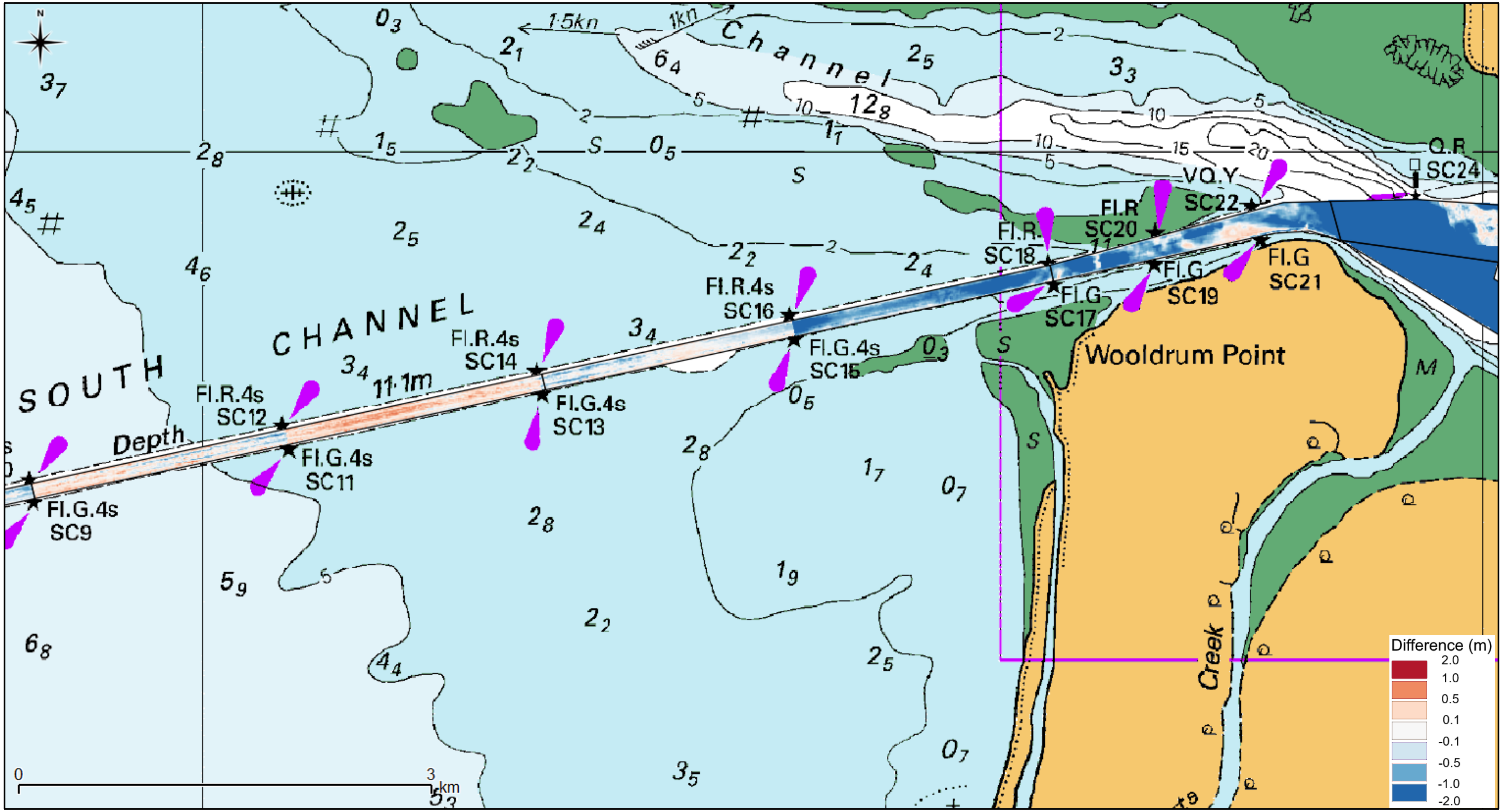

Figure 57. Depths above (red) and below (blue) design depths in the 2007 post dredge survey for the Mid to Inner South Channel. Volume calculation regions outlined in black.

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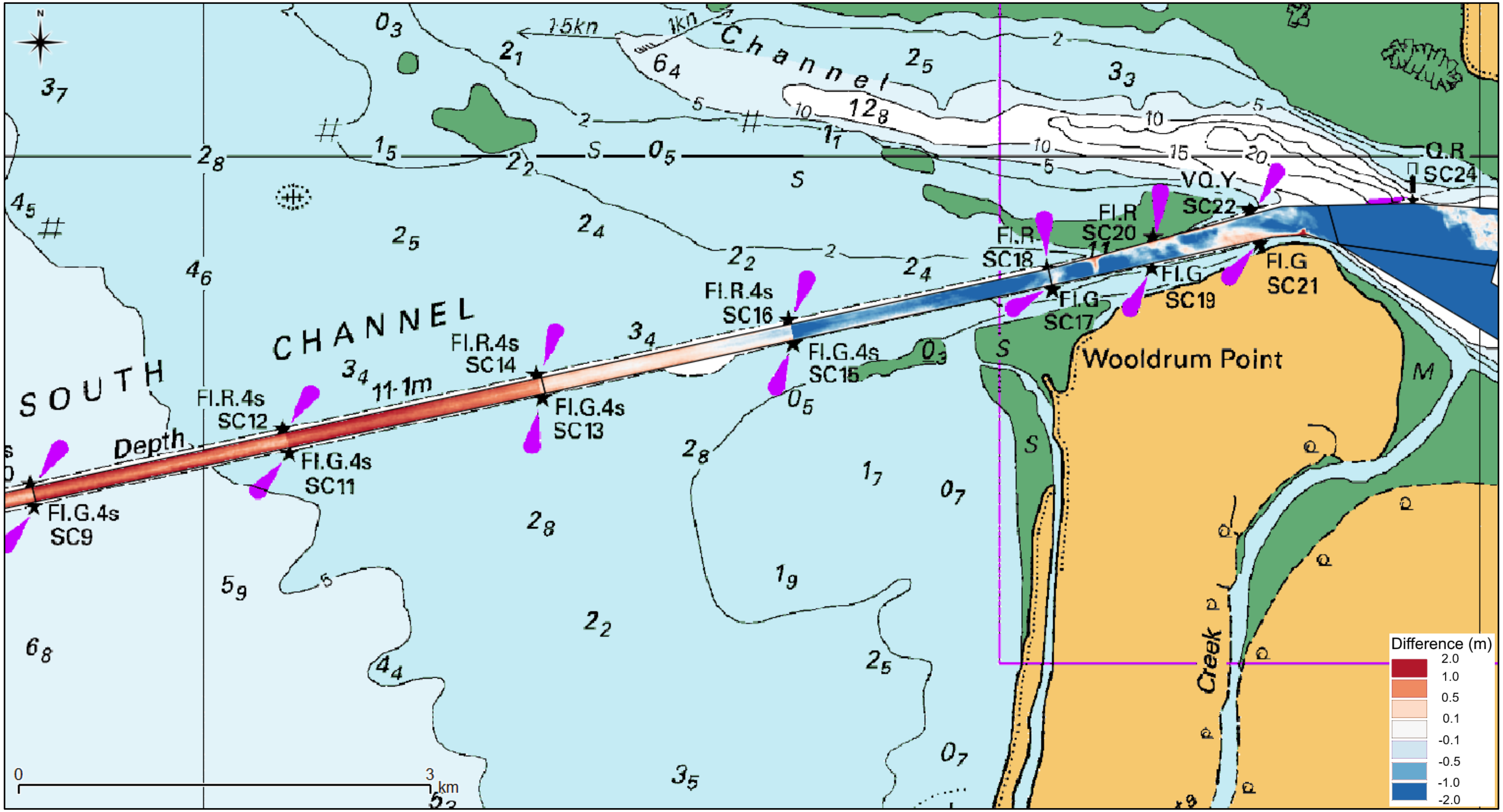


Figure 58. Depths above (red) and below (blue) design depths in the 2008 pre-dredge survey for the Mid to Inner South Channel. Volume calculation regions outlined in black.

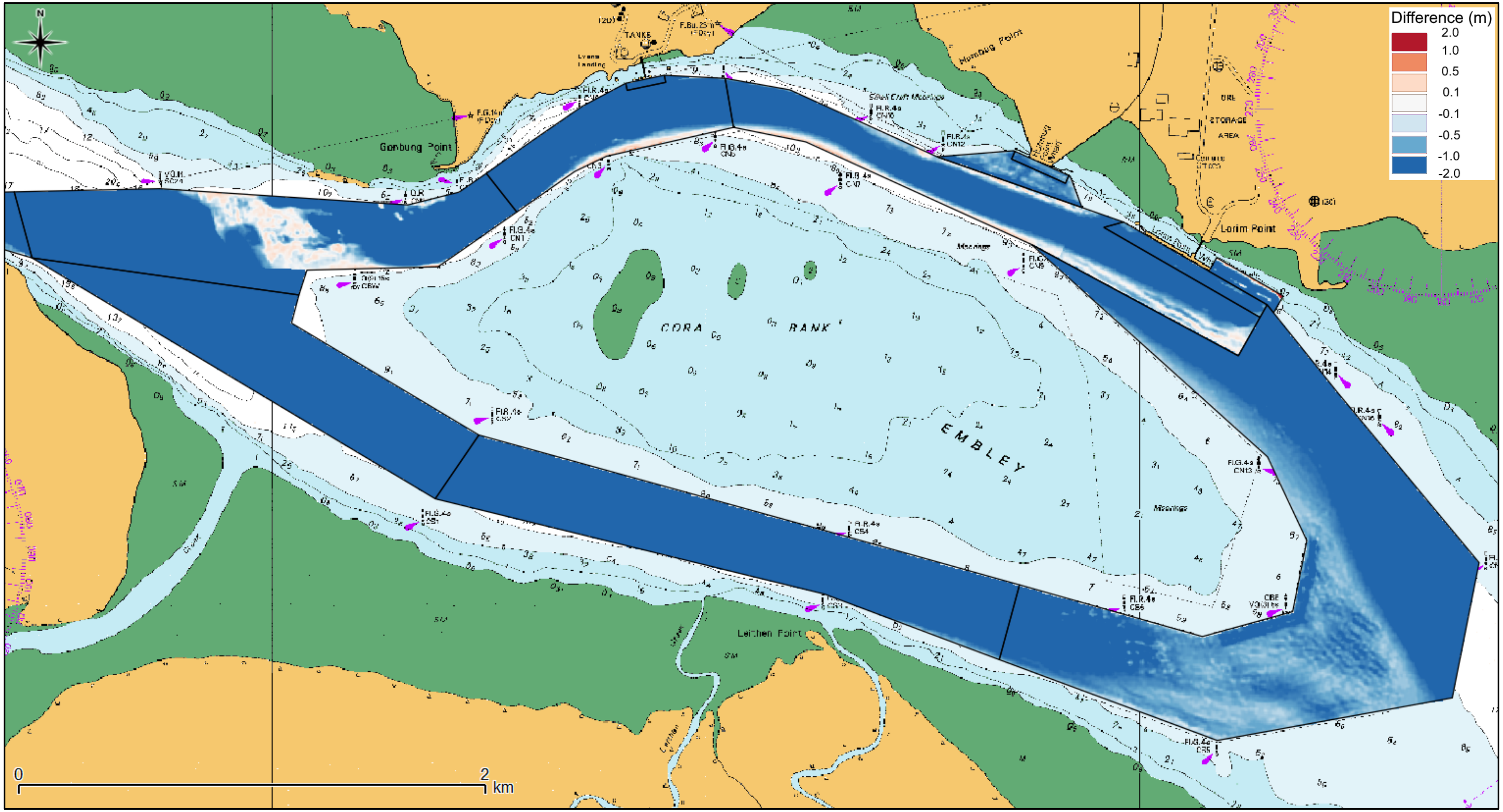
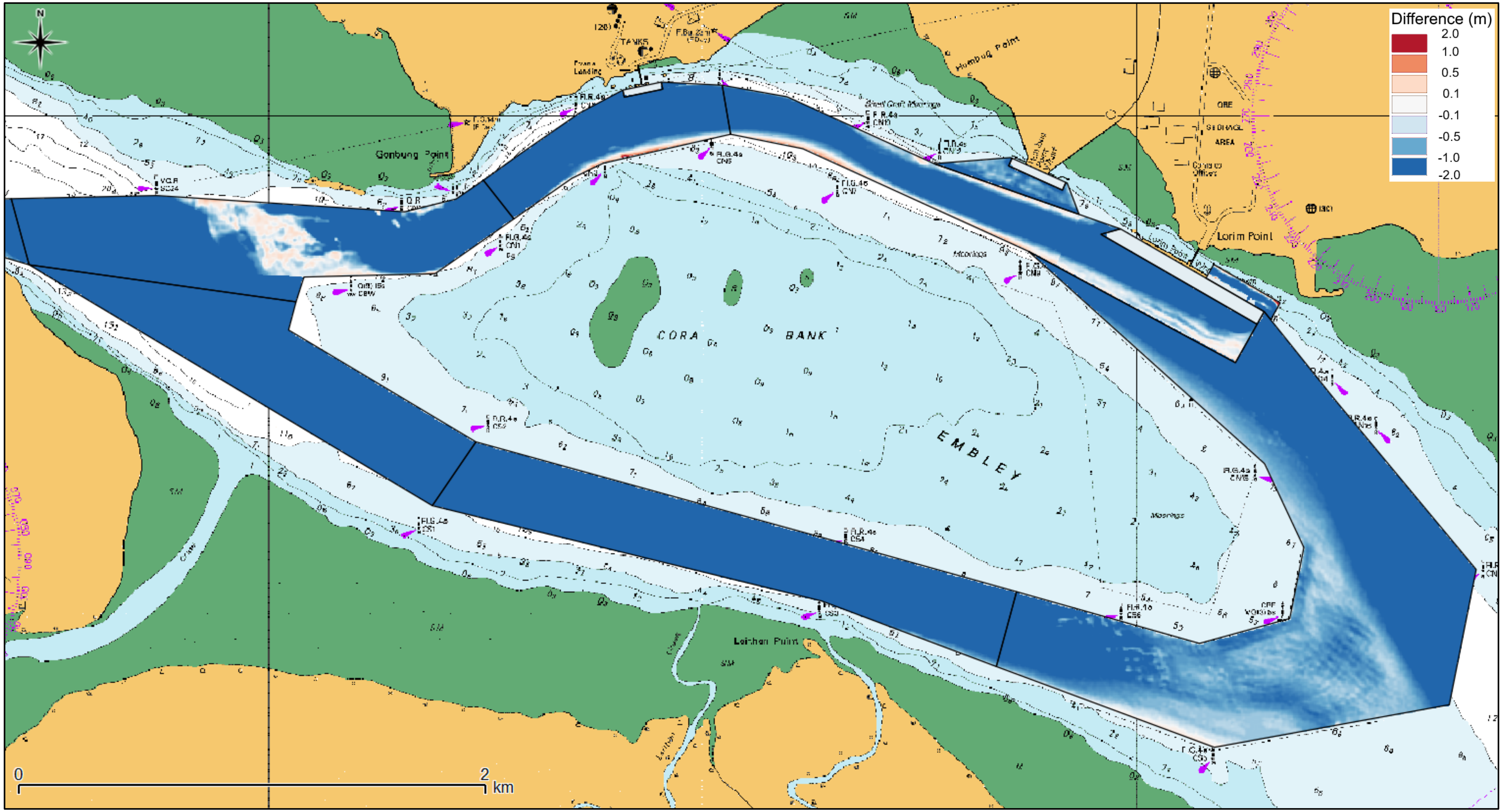


Figure 59. Depths above (red) and below (blue) design depths in the 2007 post dredge survey for the Inner Harbour. Volume calculation regions outlined in black.

PORT & COASTAL SOLUTIONS



Note: the berths were not included in the 2008 pre-dredge survey and so they all show a value of 0. It is expected that they should show a similar pattern to Figure 59.

Figure 60. Depths above (red) and below (blue) design depths in the 2008 pre-dredge survey for the Inner Harbour. Volume calculation regions outlined in black.

To clearly show how the bed elevation in the dredge areas can naturally change, a series of sections (long and cross) were extracted from the DEMs at specific locations. Maps of the section locations along with plots of all the sections are included in Appendix B. As the main area where regular sedimentation has occurred has been the South Channel the three long sections along the South Channel, as shown in Figure 61, are presented here in Figure 62 to Figure 64. The plots show the design depths (post 2006 capital dredging) and measured bathymetry (2018 pre-dredge) on the left y-axis and on the right y-axis they show the change in depth for example years to represent the maximum sedimentation (2006), typical sedimentation (2018) and minimum sedimentation (2017). The plots show the following:

- the highest sedimentation has occurred between 8,000 m (Beacon SC10) and 12,000 m (Beacon SC14), with the annual sedimentation exceeding 1 m in this area;
- there is generally more sedimentation along the sides of the channel compared to the centre of the channel. This will be due to erosion of the centre of the channel by the propeller wash of the vessels, indicating that the typical route for the vessels is along the centre of the channel;
- the year representing the maximum sedimentation actually shows less sedimentation in the centre of the channel relative to the typical year. This is particularly noticeable from chainage 0 m (Beacon SC2) to chainage 6,000 m (Beacon SC8), with approximately 0.5 m of sedimentation in the typical year and less than 0.25 m in the maximum year. This is likely to be due to two reasons:
  - the maximum sedimentation example year (2005-2006) was before the capital dredging, which deepened and widened the South Channel (2006), and before the capital dredging, which lengthened the South Channel (2012). Both of these capital dredging campaigns would act to increase the trapping efficiency of the channel; and
  - the year selected to represent the typical conditions (2017-2018) coincided with TC Nora which resulted in the largest waves recorded by the Weipa WRB. As such, more sediment transport would have occurred in the deeper areas towards the western end of the channel, potentially increasing the likelihood for sediment to be deposited into the channel.
- the sedimentation which occurs close to the mouth of the Embley River (chainage 15,000 m to 17,500 m) is mainly on the north and south sides of the channel. The sedimentation is very localised, indicating it is associated with local bedforms/bathymetry; and
- over the year with the minimum sedimentation (2016-2017), there was actually erosion along the centre of the South Channel of up to 0.75 m. Sedimentation did occur along the sides of the channel but this was generally less than 0.5 m.

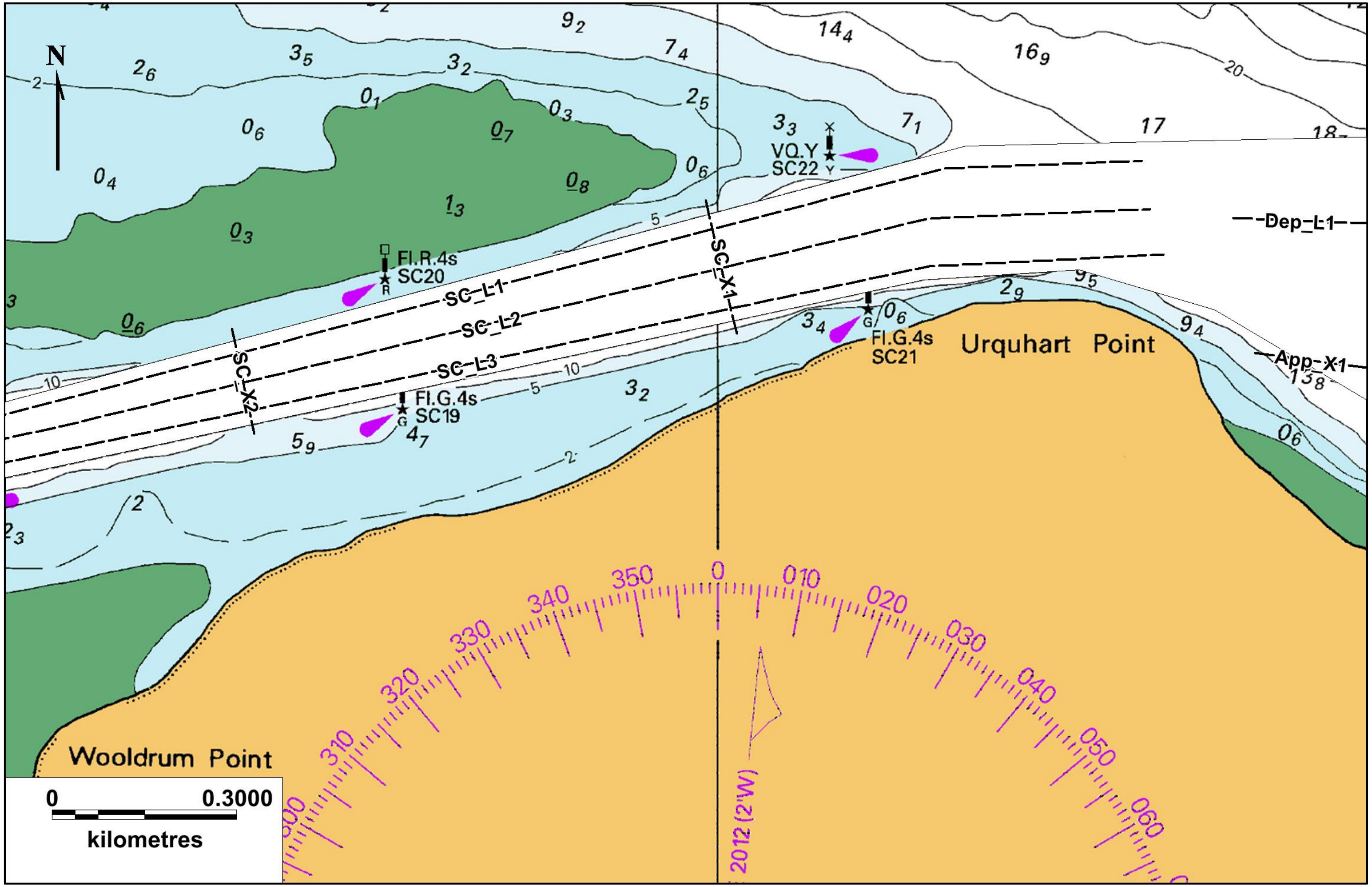


Figure 61. Location of the South Channel long-sections at the eastern end of the sections. The sections extend to the western end of the channel.

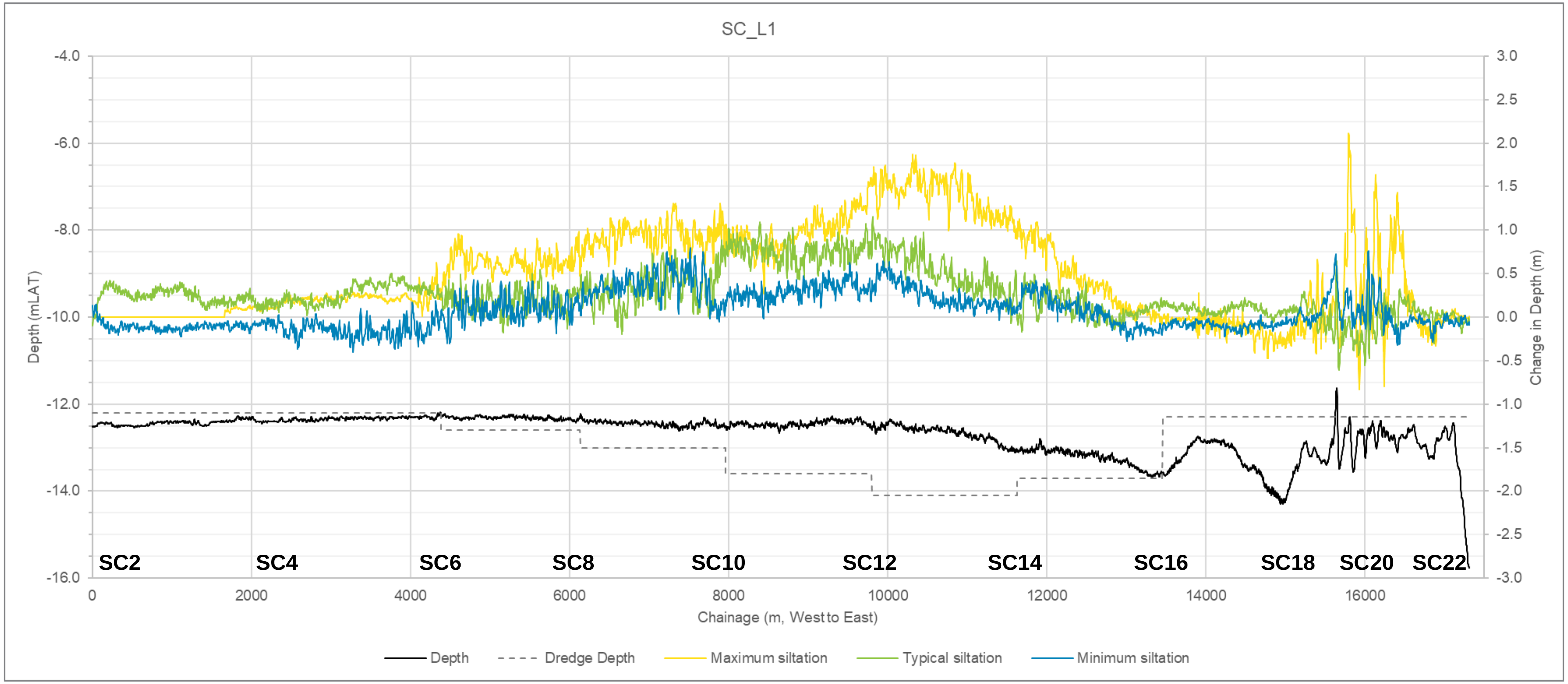


Figure 62. Long Section along the northern side of the South Channel (SC_L1), with channel beacon locations shown above the x-axis.

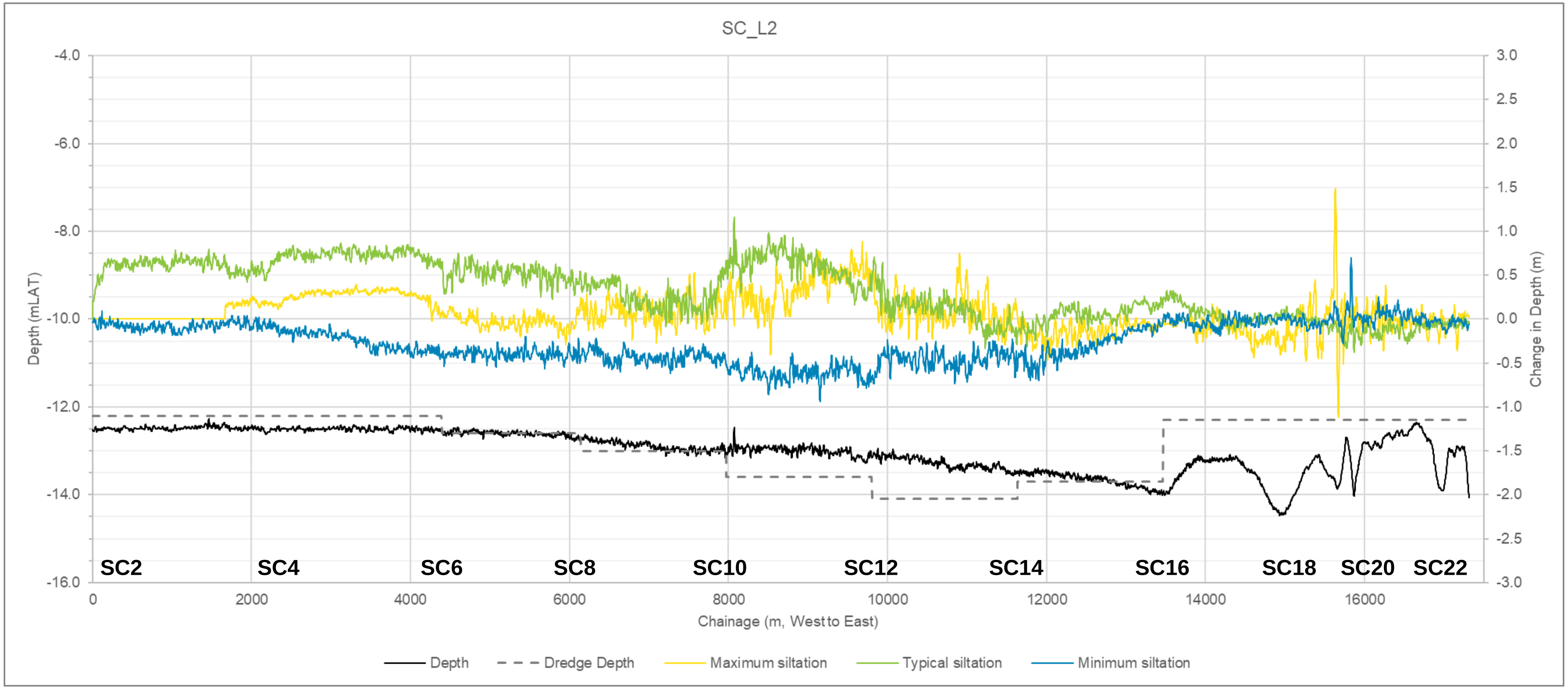


Figure 63. Long Section along the centre of the South Channel (SC_L2), with channel beacon locations shown above the x-axis.

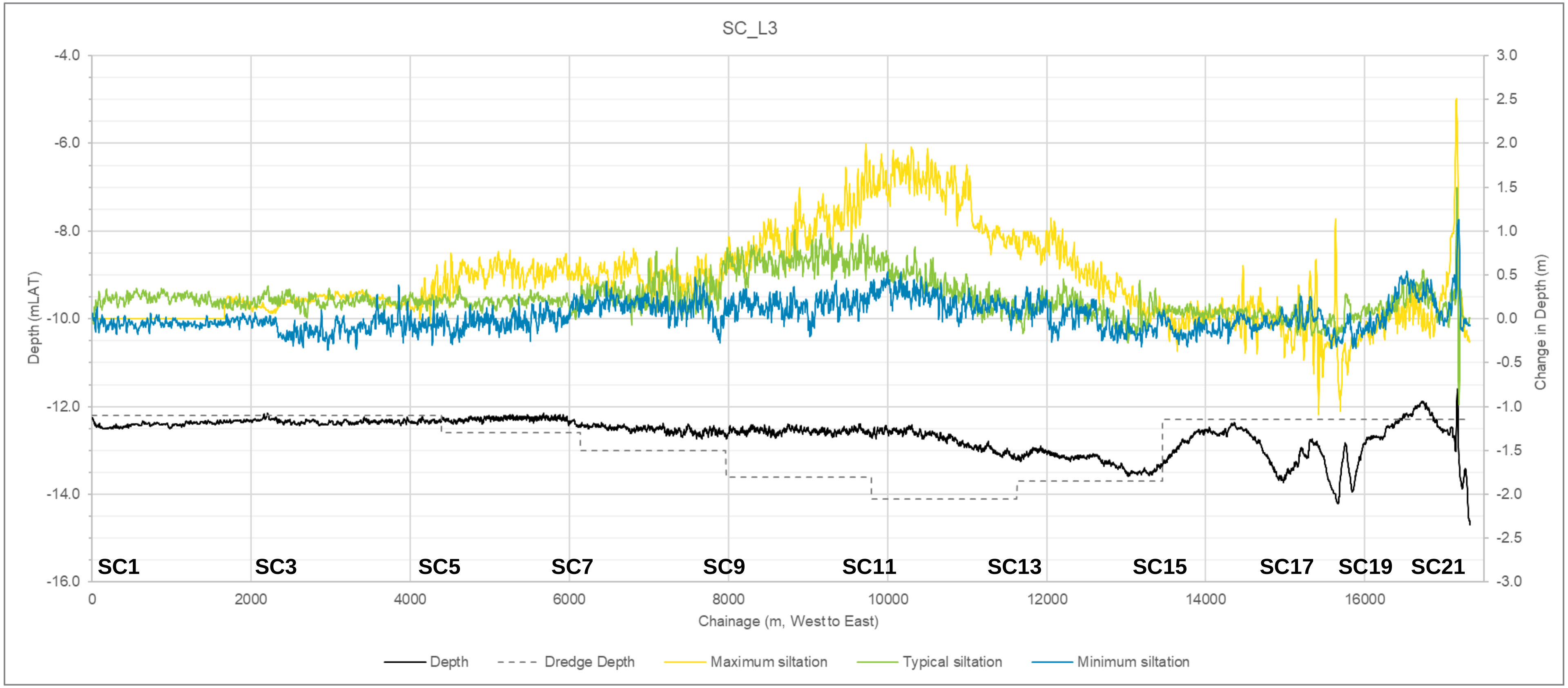


Figure 64. Long Section along the southern side of the South Channel (SC_L3), with channel beacon locations shown above the x-axis.

4.3.2. Albatross Bay DMPA

Sediment has been regularly placed in the Albatross Bay DMPA from the annual maintenance dredging campaigns undertaken at the Port of Weipa. The volumes of sediment placed during the annual maintenance dredging campaigns (which have been undertaken since 2002), excluding campaigns with any capital dredging, range from approximately 300,000 m^3 to 830,000 m^3. In addition to the maintenance dredging sediment, sediment has also been placed at the Albatross Bay DMPA from capital dredging. Since 2002 there have been three capital dredging campaigns:

- 2006: both maintenance dredging and capital dredging were undertaken with a combined volume of sediment of approximately 3 M m^3 of sediment placed at the DMPA. The capital dredging involved deepening and widening the South Channel;
- 2012: both maintenance dredging and capital dredging were undertaken with a combined volume of sediment of approximately 930,000 m^3 of sediment placed at the DMPA. The capital dredging involved extending the South Channel; and
- 2016: capital dredging for the Humbug RORO and Hey River Facility was undertaken as part of the Amrun Project (see PCS (2018b) for further details). A total of just under 50,000 m^3 was placed at the DMPA.

The earliest bathymetric survey of the DMPA available for this assessment was May 2006. A total of approximately 9.5 M m^3 (in-situ volume) of sediment has been dredged between 2006 and 2017. It is expected that on average 10% of this sediment would have been lost during the dredging activity itself, so the actual volume placed at the Albatross Bay DMPA is likely to be closer to 8.5 M m^3 (in-situ volume). The density of the sediment placed at the DMPA will have been variable between the sediment from the capital dredging (higher density) and that from the maintenance dredging. As such, if all of the sediment placed at the DMPA remained there and consolidated, then the total in-situ volume at the DMPA might be closer to 6 M m^3 (assuming a 50% reduction in volume of sediment from maintenance dredging due to consolidation, based on Van Rijn (2015)).

The bathymetry before (May 2006), immediately after the 2006 capital dredging (August 2006) and eleven years later (June 2017) are shown in Figure 65, Figure 66 and Figure 67, respectively. The plots show the following:

- before the capital dredging, the depths were shallower along the north-eastern side of the DMPA, sloping to the deepest areas along the south-western side of the DMPA;
- immediately after the capital dredging, the deepest area of the DMPA in the south-western quarter has shallowed significantly, with some shallower mounds present from the placement of the dredge material; and
- the shallower areas can still be seen more than 10 years later, although they are less well defined indicating that some erosion has occurred to the peaks of the mounds. In addition, the remainder of the DMPA appears on average to have shallowed. The shallowing can be seen to have resulted in three clear mounds that have become clearly defined (from north-west of DMPA, centre of DMPA and south-east of DMPA). These correlate with the dredge sediment placement approach adopted at the DMPA. During dredging, the DMPA was split into five zones (north-east, south-east, south-west, north-west and centre) and the placement of sediment by the dredger rotated between the different zones in each day of the campaign. Overall, the bathymetry indicates that the DMPA has been at least partially retentive for some of the maintenance dredging sediment that was placed there.

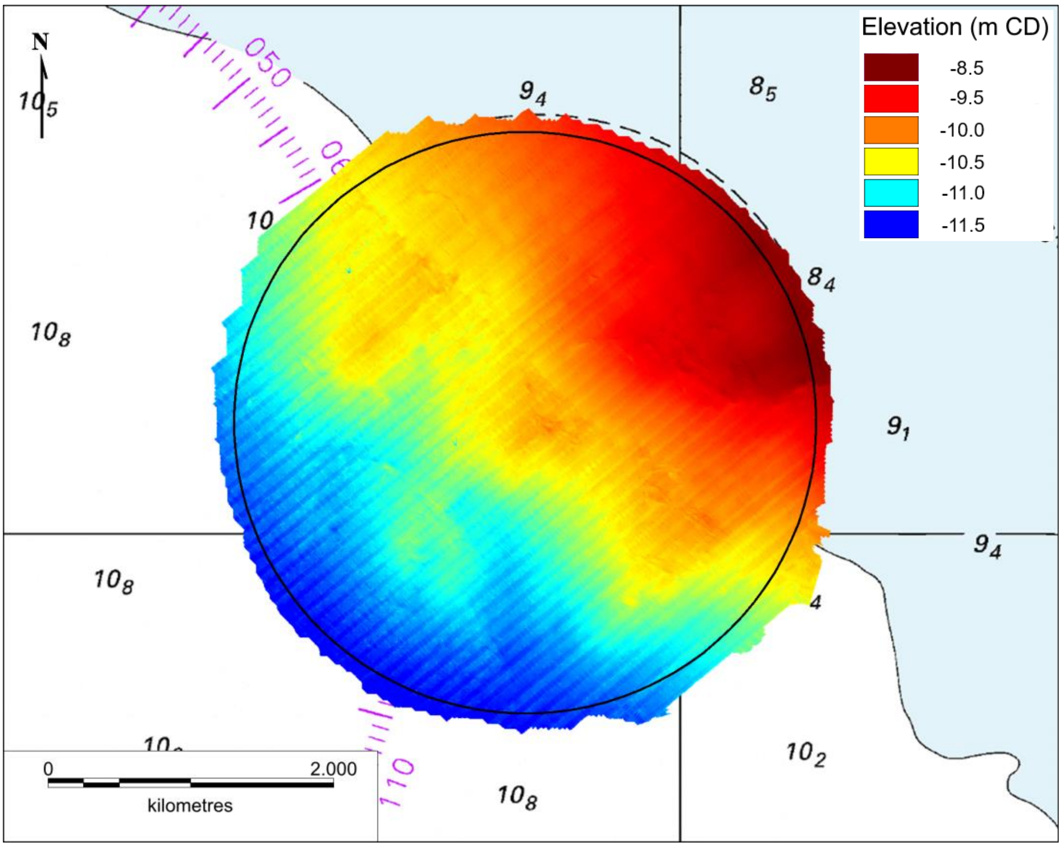


Figure 65. Albatross Bay DMPA bathymetry, pre-capital dredging (May 2006).

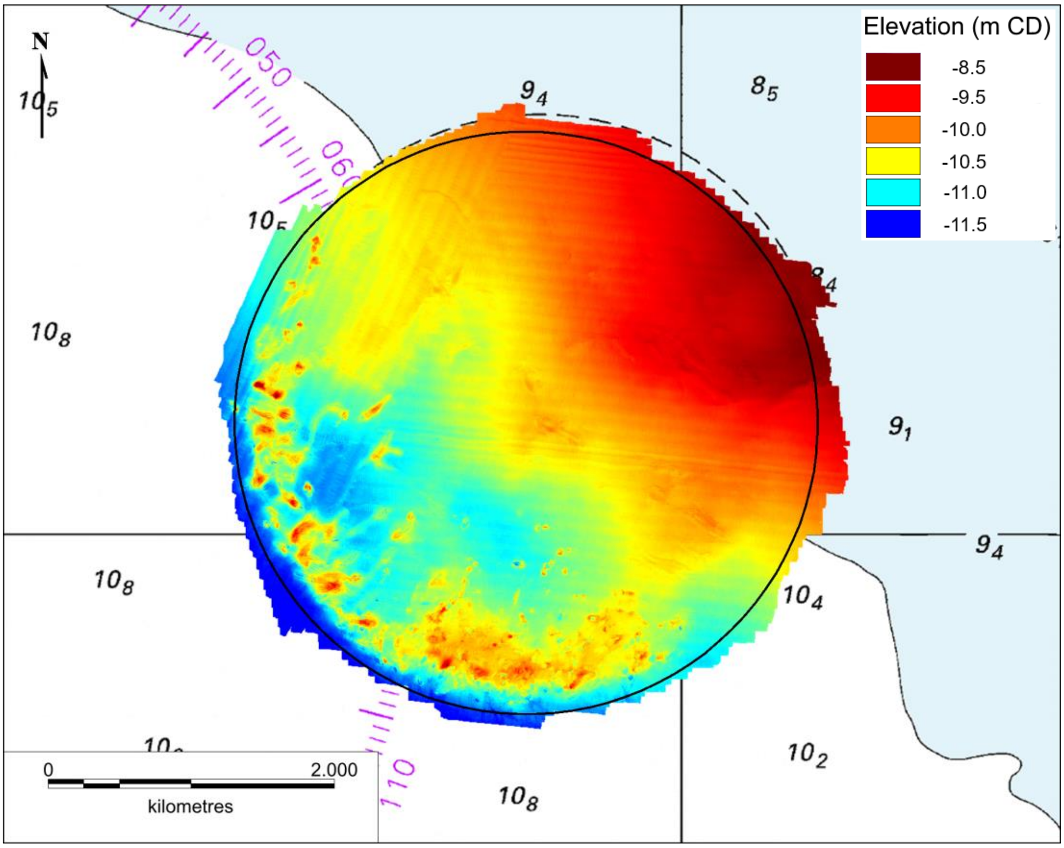


Figure 66. Albatross Bay DMPA bathymetry, post-capital dredging (August 2006).

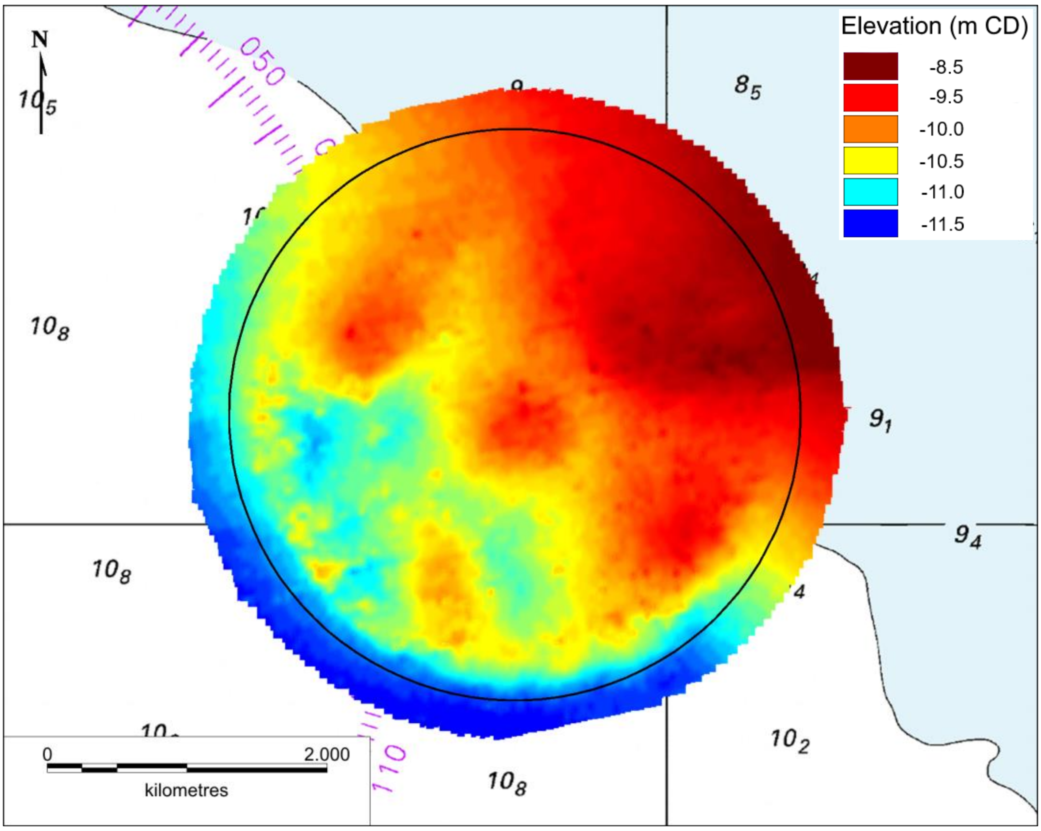


Figure 67. Albatross Bay DMPA bathymetry, most recent available survey (June 2017).

Spatial maps of the change in the bathymetry and the in-situ volume changes between the available DMPA surveys are shown in Figure 68 to Figure 70 and in Table 10. The figures and table show the following:

- the 2006 capital dredging resulted in a significant increase in the volume of sediment in the southern and south-western region of the DMPA. The increase in volume in the DMPA due to the dredging was approximately 1.5 M m^3, which is around half the volume that was reported to have been dredged. This is thought to have been due to a minor datum offset between the surveys as the comparison shows erosion of 520,000 m^3 in the areas of the DMPA where no placement occurred over the four-month period, which is considered unlikely given the relatively calm wave conditions over the dry season. The fact that the increase in volume the following year was close to double the volume of dredging undertaken further indicates that the increase in volume of the DMPA in 2006 is underestimated and that the actual volume increase was likely to have been over 2 M m^3;
- there has been erosion of the higher mounds of sediment placed during the 2006 capital dredging. This can be seen by the reduction in depth in Figure 70. Given the bed elevation in this area is around 10 m below LAT, it is expected that the erosion has occurred predominantly during large wave events;
- there has been an overall increase in volume throughout the DMPA between 2006 (pre-capital dredging) and 2017, with a total increase in sediment of 6.25 M m^3 and total loss of sediment of 2.5 M m^3, resulting in an overall net increase in volume of approximately 3.7 M m^3. If we assume that the majority of the increase in volume at the DMPA is due to the dredged sediment placed there as opposed to natural sedimentation (based on the spatial changes at the DMPA this assumptions seems reasonable), then it can be calculated that the Albatross Bay DMPA has retained approximately 60% of the sediment placed at the site, with 40% of the sediment lost (although some of this loss could be due to natural consolidation of the sediment). As such, the Albatross Bay DMPA is considered to be a partially retentive DMPA.

Table 10. Volumetric change between surveys at Albatross Bay DMPA (+ve = accretion, -ve = erosion).

Comparison	Change in Volume (m^3)		Total (m^3)
	+ve (m^3)	-ve (m^3)	
Aug 2006 – May 2006	1,546,399	-520,163	1,026,236
Sep 2007 – Aug 2006	1,320,183	-122,351	1,197,832
Sep 2008 – Sep 2007	1,024,032	-56,033	967,999
Sep 2009 – Sep 2008	560,072	-68,028	492,044
Aug 2010 – Sep 2009	154,140	-574,292	-420,152
Jul 2013 – Aug 2010	426,150	-490,905	-64,755
Aug 2014 – Jul 2013	312,177	-237,260	74,917
Aug 2015 – Aug 2014	286,381	-270,603	15,777
Jun 2017 – Aug 2015	619,364	-200,594	418,770
Total	**6,248,897**	**-2,540,229**	**3,708,668**
Jun 2017 – May 2006	*3,755,717*	*-45,844*	*3,709,873*
Jun 2017 – Aug 2006	*3,029,754*	*-346,352*	*2,683,402*

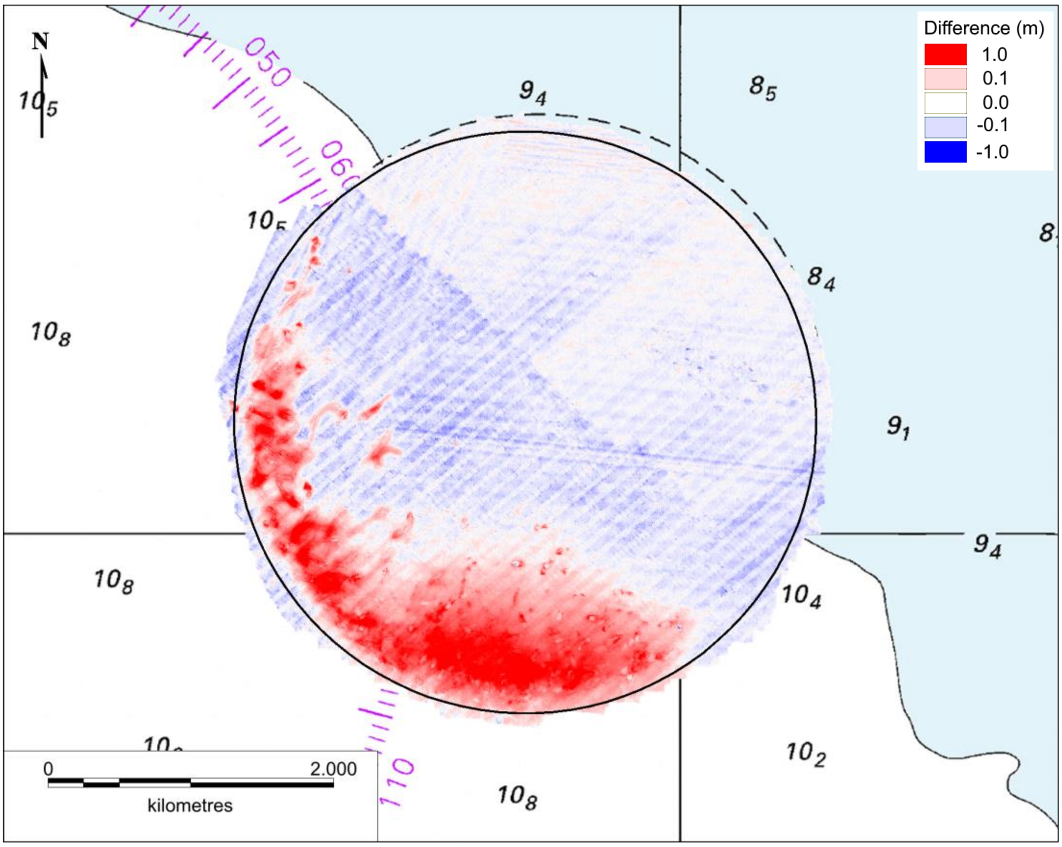


Figure 68. Bathymetric change due to capital dredging at Albatross Bay DMPA, May 2006 to August 2006, showing erosion in blue and accretion in red.

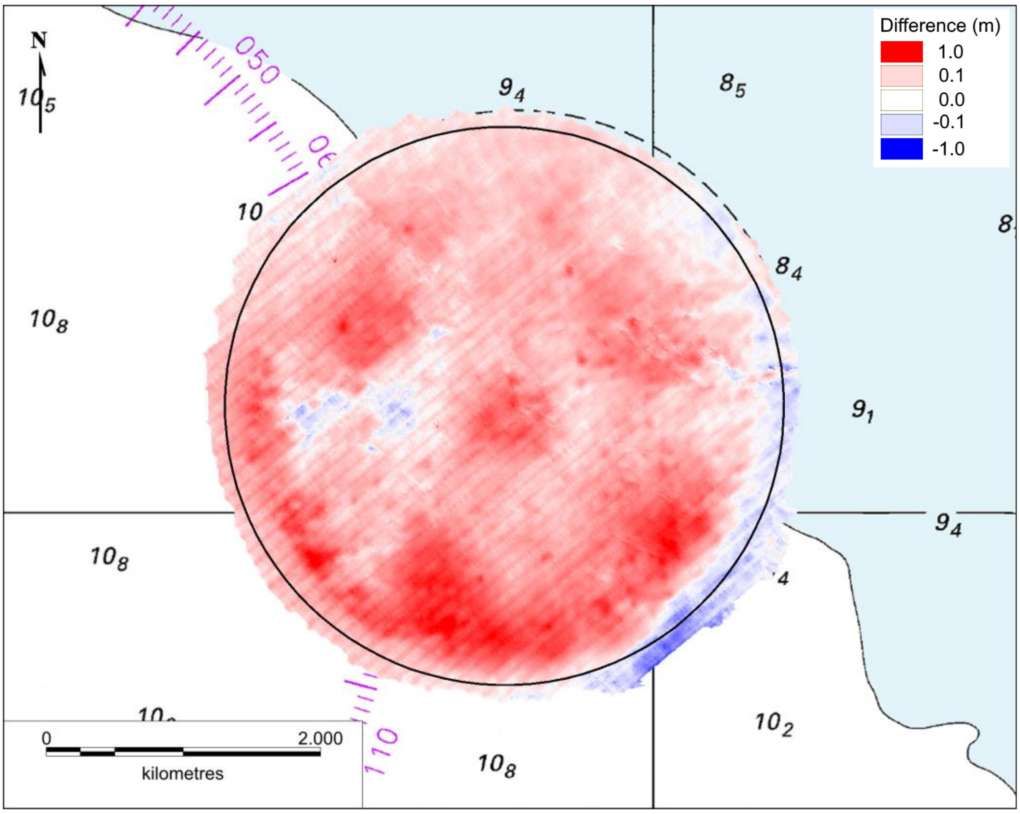


Figure 69. Bathymetric change from pre-capital dredging (May 2006) to the most recent available survey (June 2017) at Albatross Bay DMPA, showing erosion in blue and accretion in red.

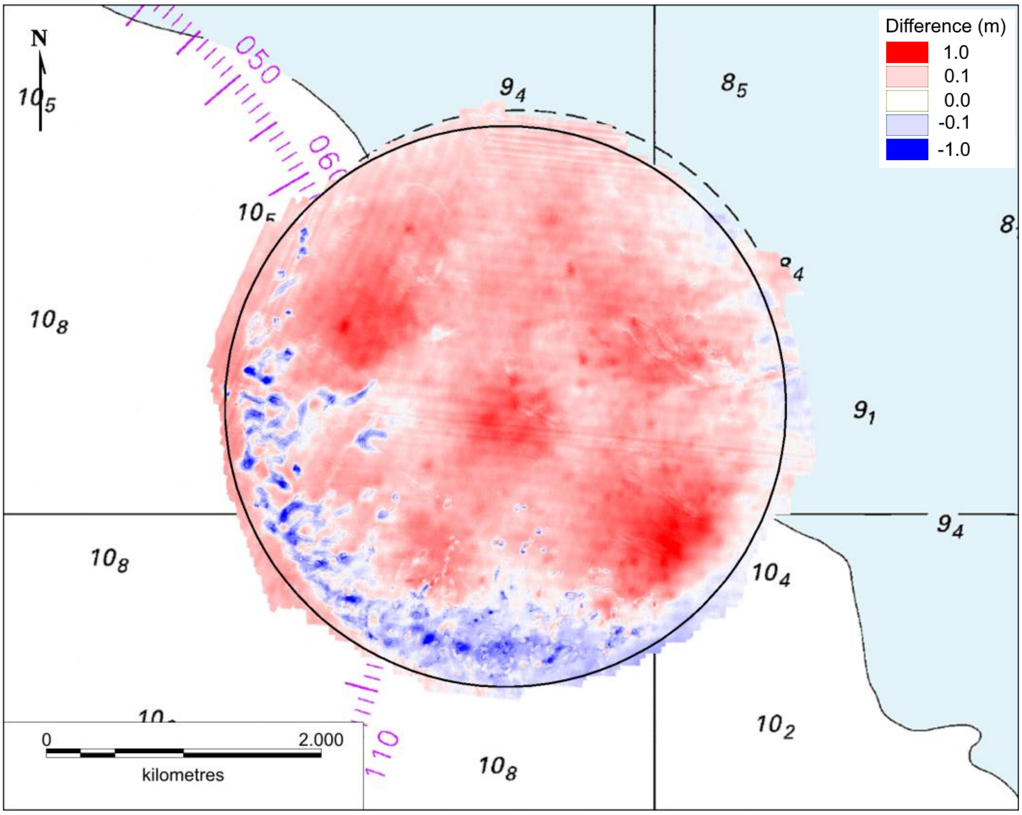


Figure 70. Bathymetric change from post-capital dredging (August 2006) to the most recent available survey (June 2017) at Albatross Bay DMPA, showing erosion in blue and accretion in red.

To further show how the bed elevation has changed since May 2006, two cross-sections have been extracted from the May 2006, August 2006 and June 2017 DEMs at specific locations as shown in Figure 71. The sections are shown in Figure 72 and Figure 73. The plots show that along DMPA1 there was little change in the bathymetry due to the 2006 capital dredging, while the southern end of DMPA2 shows that a 1 m high mound was created by the placement of dredged sediment. More than 10 years after the capital dredging the high mound at the southern end of DMPA2 is still visible, although it is likely that the placement of sediment from maintenance dredging has also helped to further retain the mound. The maintenance dredging and additional capital dredging that occurred between 2006 and 2017 resulted in the formation of five clear mounds, located in each of the five placement mounds used by the dredger. The mounds are between 0.25 and 0.5 m higher than they were in the 2006 pre-capital dredging survey.

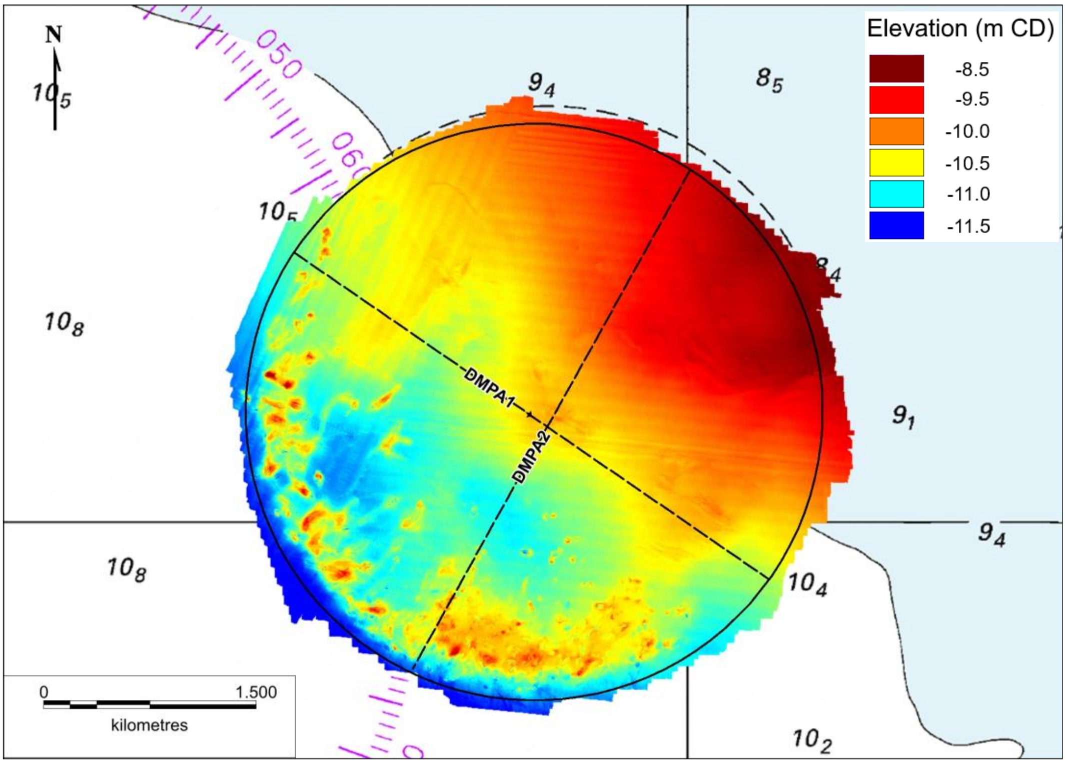


Figure 71. Sections adopted for the Albatross Bay DMPA with bathymetry from August 2006 (post-capital dredging) shown.

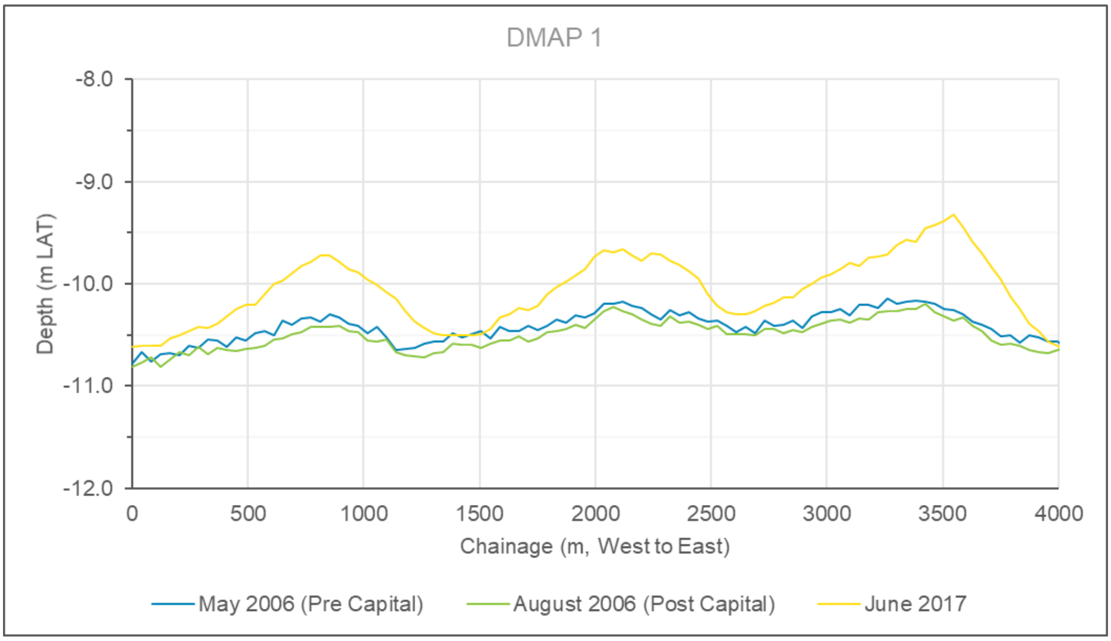


Figure 72. Plot of the cross section through the Albatross Bay DMPA at DMPA1.

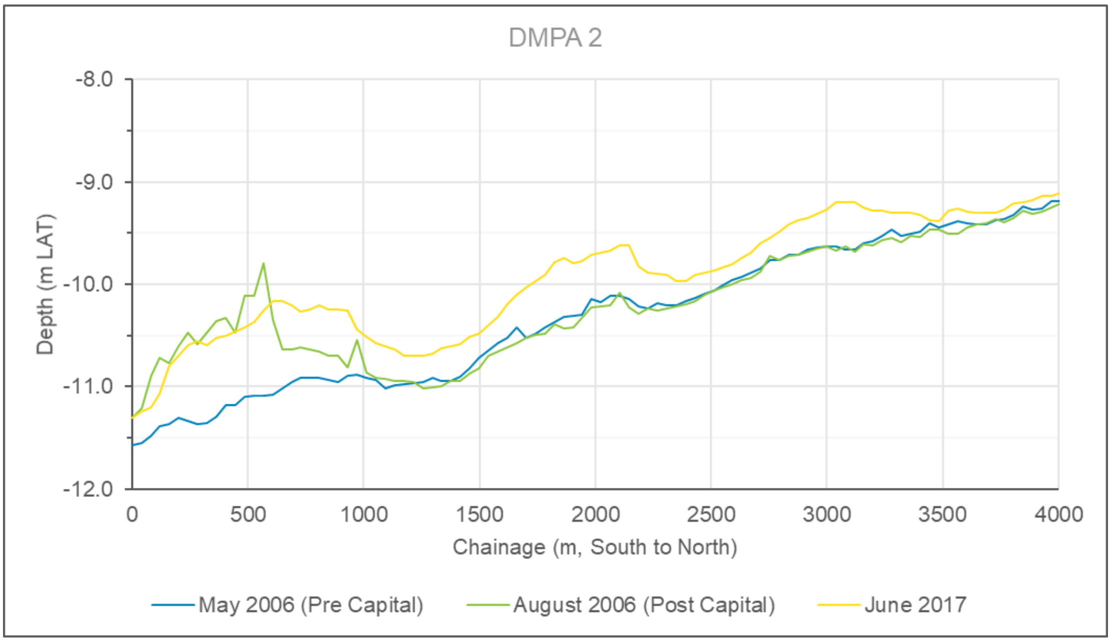


Figure 73. Plot of the cross section through the Albatross Bay DMPA at DMPA2.

5. Sediment Transport

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

Relationships between sedimentation rates observed in the dredged areas of the Port and the key sediment transport drivers are investigated. How the relationships and their associated uncertainty influence the development of a predictive model is also outlined and an overview of the proposed model development based on the results of this study is provided.

5.1. Conceptual Understanding

The bathymetric analysis has shown that the majority of the historical sedimentation at the Port of Weipa has occurred in the South Channel and that limited sedimentation has occurred in the Inner Harbour. The sedimentation within the South Channel is variable, with higher rates of sedimentation occurring in the Mid and Mid Outer regions, which are located between Beacons SC14 and SC10. Sediment sampling in the South Channel correlates well with the findings of the bathymetric analysis, with the sediment composition changing from predominantly sand and gravel close to the mouth of the Embley River (where limited regular sedimentation has occurred), to predominantly silt and clay between SC16 and SC14 (where regular sedimentation has occurred). These findings also correlate with the spatial distribution of tidal currents predicted by the numerical model (see Section 2.5) that show this area is where the current speeds have reduced away from the entrance to the Embley River, potentially allowing fine-grained sediment to be deposited and not be resuspended on the subsequent tide.

It was previously noted in Section 2 that waves were thought to be the dominant driver for sediment resuspension and therefore are also expected to the dominant driver for sedimentation in the dredge areas of the Port. To further test this, Figure 74 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) when the H_s was above 2 and 3 m, as well as the total rainfall over the period. The plot clearly shows that there is no correlation between rainfall and sedimentation, either in the South Channel or the Inner Harbour as the year with the highest rainfall corresponds with relatively low sedimentation in the South Channel and approximately average conditions at the Inner Harbour. In contrast, there is some correlation between the H_s and the sedimentation, with the three years when the H_s was above 2 m for the most time, corresponding with the three years when the most sedimentation was observed in the South Channel. In addition, the year when most erosion occurred in the South Channel corresponded with the only year when the H_s was never above 2 m.

Based on the findings from the bathymetric analysis, along with an understanding of the existing processes that was developed using all available information, conceptual sediment transport models for the South Channel and Inner Harbour regions of the Port of Weipa have been developed (Figure 75 and Figure 76). A summary of the conceptual models for the two regions is provided below:

- South Channel: the majority of the sedimentation which occurs along the South Channel is a result of a combination of wave and tidal current processes. Wave action resuspends natural fine-grained sediment from the seabed in Albatross Bay and then the spatial distribution of tidal currents around the South Channel, along with the trapping efficiency of the channel (i.e. depth of channel below adjacent seabed), control where in the South Channel the fine-grained sediment are deposited. High tidal current speeds occur in the South Channel within 4 km of the mouth of the Embley River, limiting the build-up of fine-grained sediment in this region. As the currents reduce with distance away from the mouth of the Embley River the potential for the build-up of fine-grained sediment increases, while the elevation of the adjacent seabed remains between 2 and 6 m below LAT. As the depth of the adjacent seabed increases, sedimentation in the South Channel reduces, due to resuspension occurring less regularly as larger waves are required to resuspend the fine-grained sediment.

- Inner Harbour: there are only localised areas of sedimentation in the Inner Harbour, with the sediment that is typically deposited being predominantly composed of sand. The relatively high tidal current speeds limit deposition of fine-grained sediment in most areas. In general, sedimentation within the area of interest is due to the existing shallow sand banks encroaching on the channel, as a result of bedload transport being driven by tidal currents. Propeller wash from vessels operating in the Port results in some localised erosion in the Approach and Departure Channels, as well as at the Lorim Point berths and adjacent tug berths. Adjacent to the areas of erosion at the berths there is localised deposition in the areas which are sheltered from the vessels propeller wash, typically directly adjacent to the wharf and at the ends of the berths.

Figure 74. Plots showing the sedimentation/erosion, time Hs was above 2 m and total rainfall (May to April) for 2009 to 2018.

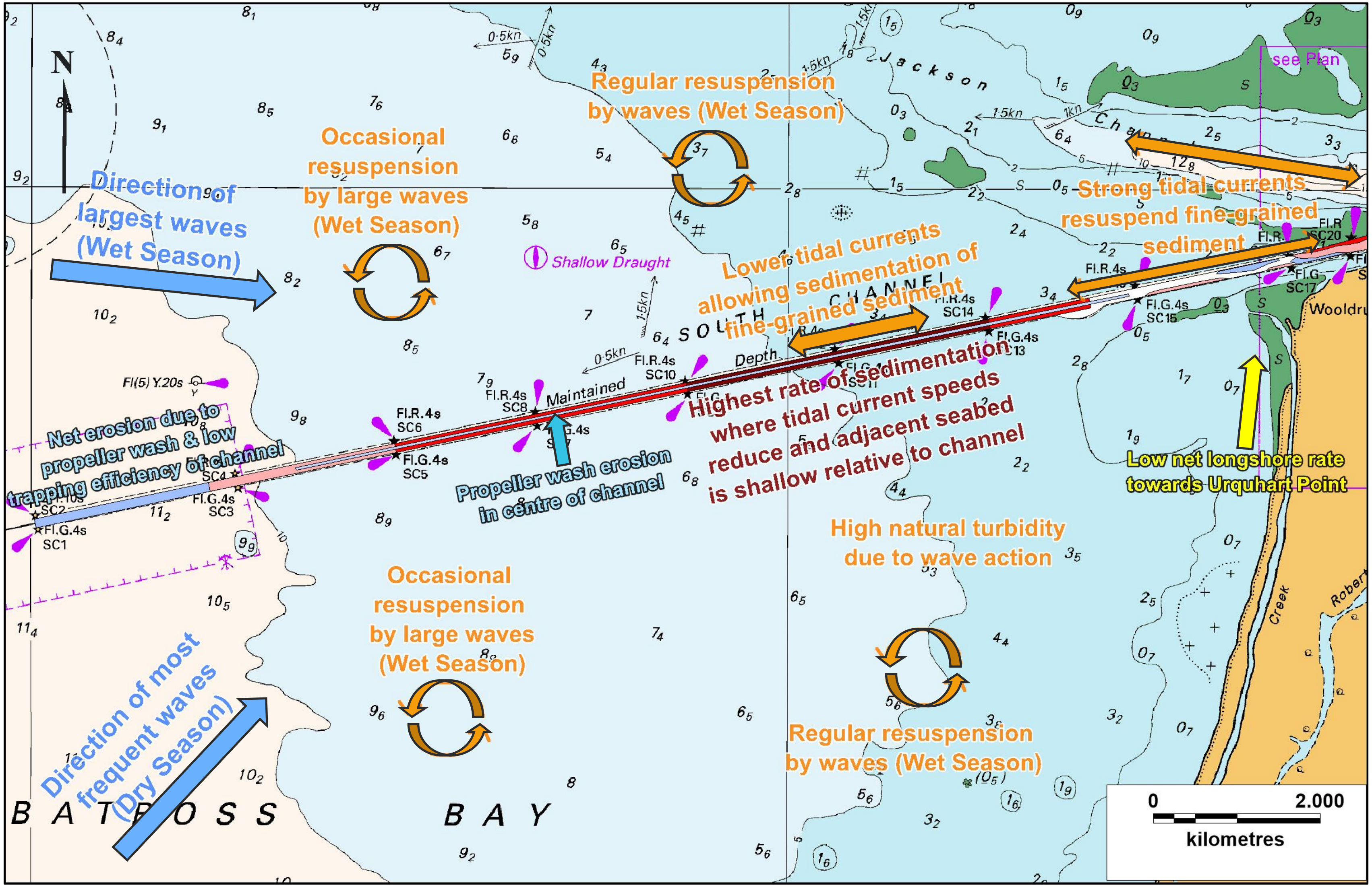


Figure 75. Conceptual sediment transport model of the South Channel at the Port of Weipa.

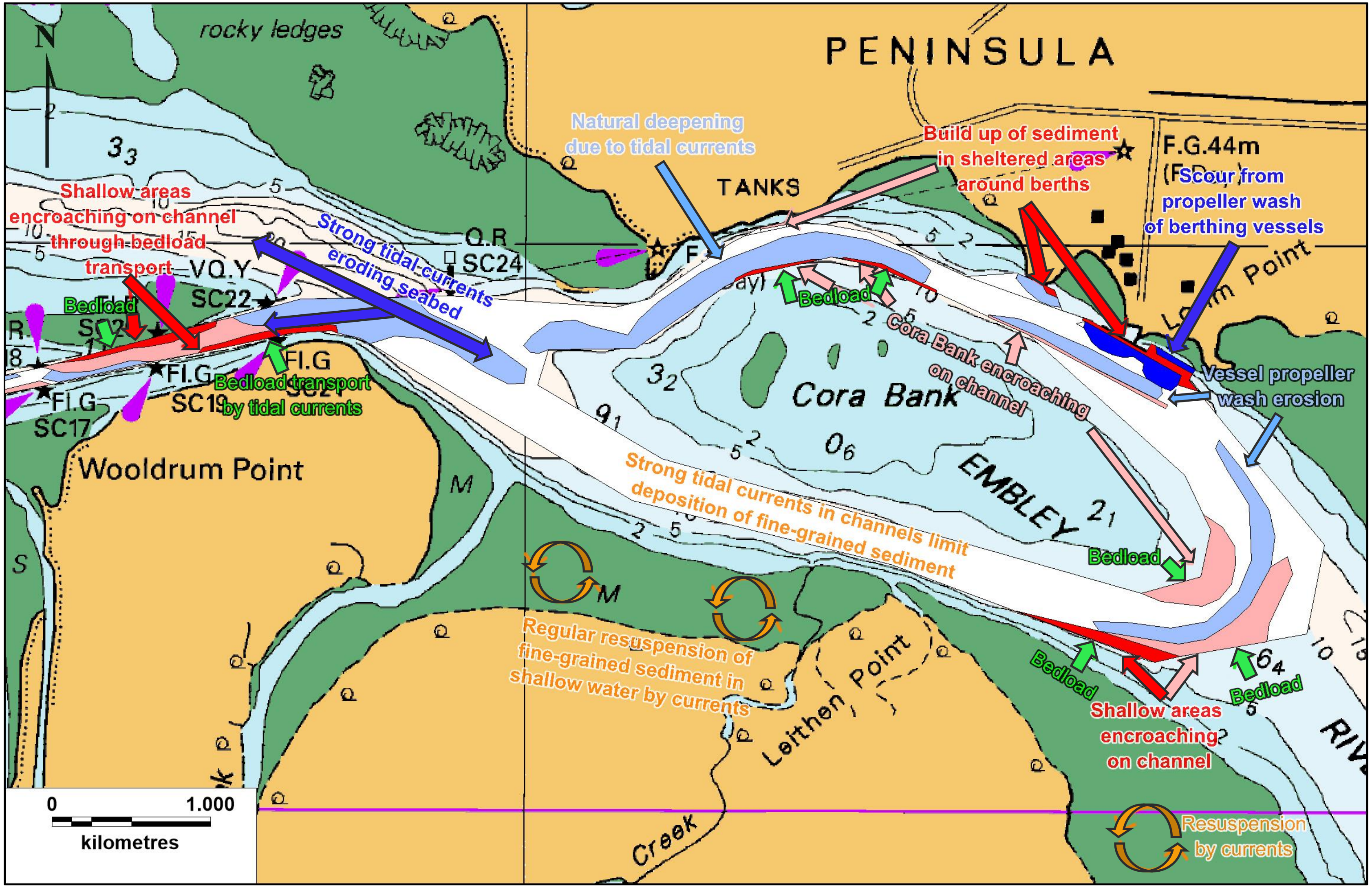


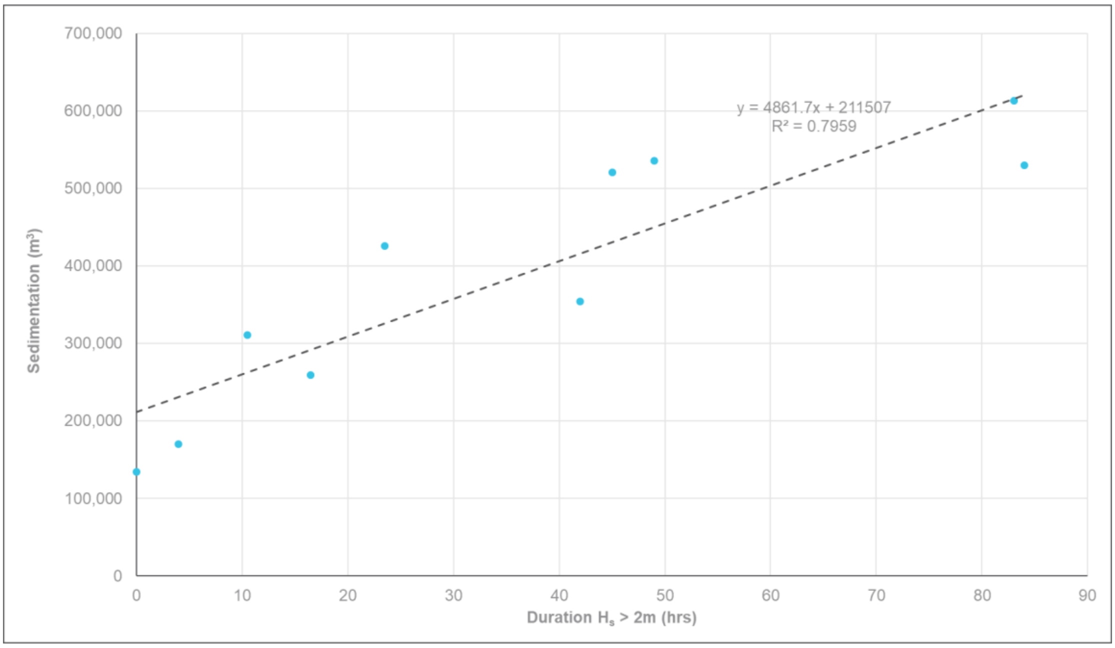
Figure 76. Conceptual sediment transport model of the Inner Harbour at the Port of Weipa.

5.2. Sedimentation Rate Analysis

The analysis has shown that the majority of the sedimentation that has historically occurred at the Port of Weipa is in the South Channel. As such, the sedimentation rate analysis focused on sedimentation in the South Channel.

The relationship between the duration of time that the H_s was above 2 m and the gross sedimentation within the South Channel (i.e. without any erosion subtracted) is shown in Figure 77. The plot shows a reasonable linear correlation (R^2 = 0.8) between the duration of time H_s is greater than 2 m and gross annual sedimentation. The correlation shows that in years with no large wave events there would typically be approximately 200,000 m³ of sedimentation in the South Channel, while in a year with large waves the sedimentation in the channel could increase up to 600,000 m³. The analysis in Section 4.3.1 found that the majority of the sedimentation occurs during the wet season due to the increased wave activity 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 would be as follows:

- Low wave activity: sedimentation of 200,000 m³ = 1,100 m³/day over the wet season;
- Typical wave activity: sedimentation of 400,000 m³ (similar to the mean sedimentation of 360,000 m³ over the 16 years of data) = 2,200 m³/day over the wet season; and
- High wave activity: sedimentation of 600,000 m³ = 3,300 m³/day over the wet season.



Note: to represent the increased sedimentation when H_s > 3 m the durations were doubled. This was to account for the non-linear relationship between H_s and SSC (see Section 2.8).

Figure 77. Correlation between wave conditions and sedimentation in the South Channel.

5.3. Sedimentation Predictions

Based on the sedimentation rates detailed in the previous section along with the calculated volume of sediment above the design depth, a prediction of the future sedimentation at the Port of Weipa is made below:

- South Channel: annual sedimentation typically ranges from 200,000 to 600,000 m³, with the majority of this being above the design depths. The majority of the sediment is deposited in the middle 8 km of the 17 km long channel and on the sides of the channel (approximately 70 m of the 100 m wide channel). As such, the depth of the sedimentation, if assumed to be uniform over the length, would be between 0.35 and 1.05 m. However, as shown in Figure 72 to Figure 74, the sedimentation pattern is not uniform and so as a conservative estimate it is assumed that sedimentation depths could be up to double the average in some places, meaning that peak sedimentation depths of 0.7 to 2.1 m are assumed. Based on these maximum sedimentation depths and the current design depths (average of -13.5 m LAT for the region where the most sedimentation occurs), the South Channel is likely to require annual maintenance dredging to ensure that none of the channel exceeds the declared depth of -11.1 m LAT. The only scenarios which would allow less frequent maintenance dredging would be either if multiple years of low wave energy occurred, or If a low wave energy year was followed by a typical wave energy year. However, there would be significant risk to Port operations if maintenance dredging was not undertaken annually in case the subsequent year was a high wave energy year; and

- Inner Harbour: the annual average volume of sediment above the design depths in the Inner Harbour is just under 25,000 m^3 with an annual minimum of 3,500 m^3 and an annual maximum of 105,000 m^3. Of the average sedimentation of just under 25,000 m^3, approximately 15,000 m^3 is in the Departure Channel, 7,000 m^3 in the Approach Channel and 2,000 m^3 in the berths. As much of the sediment that is above the design depths is not in a location that is considered an issue for vessel navigation and operation (i.e. directly adjacent to the sides of the channel or adjacent to the wharves) the historic maintenance dredging hasn't always removed the sediment immediately. Due to the relatively low sedimentation rates in the Inner Harbour region, along with the location of the sedimentation, a maintenance dredging frequency of every 2-5 years is estimated.

Further detailed sedimentation predictions will be made for each of the sub-regions of the dredge areas as part of the predictive model development, which is outlined in the following section.

5.4. Predictive Model

An interactive sedimentation prediction model will be developed for the dredge areas at the Port of Weipa. This interactive model will be used to better understand future sedimentation and therefore maintenance dredging requirements, to determine whether sedimentation at the Port poses a risk to port operations and safety, and to demonstrate why the Port needs to undertake maintenance dredging and bed levelling.

The model development will be discussed further and confirmed during the Bathymetric Model stage of the Project. At this stage it is proposed that the model will be developed in Microsoft Excel, which will mean that it can be easily run on any machine without the requirement for additional software installation (assuming the machine has Microsoft Office installed). The interactive dashboard model will be setup with a number of user input boxes and when data is put into these, a series of plots and summary tables will automatically be produced. The model will allow the user to specify the following:

- duration of time for the sedimentation/erosion predictions (months to > 20 years);
- number of cyclones assumed to have occurred within the prediction period;
- the volume and frequency of maintenance dredging over the prediction period; and
- the initial bed elevation to be assumed for the model (design depth or latest bathymetric survey).

The output of the model will provide details on any sedimentation which is predicted to occur within the Port of Weipa, along with a predicted maximum bed elevation and whether the bed elevation is above or below the declared depths.

6. Summary

The bathymetric analysis has shown that regular sedimentation has been naturally occurring in the South Channel at the Port of Weipa and in localised areas within the Inner Harbour. In addition, the analysis has found that the Albatross Bay DMPA is partially retentive and that approximately 60% of the sediment placed there has been retained.

During the aerial survey (15th May 2018), undertaken as part of the site visit, significant increased turbidity was observed along the edges of the Hey and Embley Rivers, presumably due to the resuspension of loosely consolidated fine-grained sediment on the shallow muddy sides of the river channel. There was also high natural turbidity visible within the Approach and Departure Channels during the strong ebb tidal currents. The overall turbidity in Albatross Bay was considered to be high given the relatively calm wind (<10 m/s) and wave (H_s = 0.6 m) conditions at the time of the survey. Throughout the bay there was turbidity visible even in the areas away from the nearshore influence of wave breaking.

Conceptual sediment transport models of the erosion and accretion processes in the South Channel and Inner Harbour regions of the Port of Weipa were developed based on all available information.

In the South Channel, the conceptual model showed that the majority of the sedimentation is a result of a combination of wave and tidal current processes. Wave action resuspends natural fine-grained sediment from the seabed in Albatross Bay and then the spatial distribution of tidal currents around the South Channel, along with the trapping efficiency of the channel (i.e. depth of channel below adjacent seabed), control where the fine-grained sediment is deposited within the South Channel. High tidal current speeds occur in the South Channel within 4 km of the mouth of the Embley River, limiting the build-up of fine-grained sediment in this region. As the tidal currents reduce with distance away from the mouth of the Embley River the potential for the build-up of fine-grained sediment increases, while the elevation of the adjacent seabed remains between 2 and 6 m below LAT. As the depth of the adjacent seabed increases, sedimentation in the South Channel reduces as resuspension occurs less regularly, as larger waves are required to resuspend the fine-grained sediment from these depths.

In the Inner Harbour the conceptual model shows that there have only been localised areas of sedimentation, with the deposited sediment typically being predominantly sand. The relatively high tidal current speeds limit deposition of fine-grained sediment in most areas. The sedimentation that has occurred has typically been due to the existing shallow sand banks encroaching on the channel due to bedload transport driven by the tidal currents. The propeller wash from vessels operating in the Port results in some localised erosion in the Approach and Departure Channels, as well as at the Lorim Point berths and the adjacent tug berths. Adjacent to the areas of erosion at the berths there is localised deposition in the areas that are sheltered from the vessels' propeller wash, typically directly adjacent to the wharf and at the ends of the berths.

The sedimentation rates within the South Channel were determined based on the available bathymetric survey data. Sedimentation was found to be linearly correlated to the duration of time the H_s was above 2 m (i.e. the duration of large wave events). Sedimentation in the South Channel was found to predominantly occur over the wet season, with sedimentation rates ranging from 1,100 m^3/day to 3,300 m^3/day over this period, depending on the wave energy (low to high). Based on this it is expected that maintenance dredging will be required annually to ensure that the entire South Channel remains below the declared depths. Maintenance dredging within the Inner Harbour is also expected to be required, with an estimated frequency of once every 2 to 5 years.

Based on the findings of this assessment, a more detailed predictive model will be developed for NQBP. This model will be designed to allow the user to adopt different metocean scenarios to predict sedimentation and associated maintenance dredging requirements at the Port of Weipa, for a range of temporal scales. The interactive model will provide a decision support tool to allow for future strategic planning of maintenance dredging activity at the Port.

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