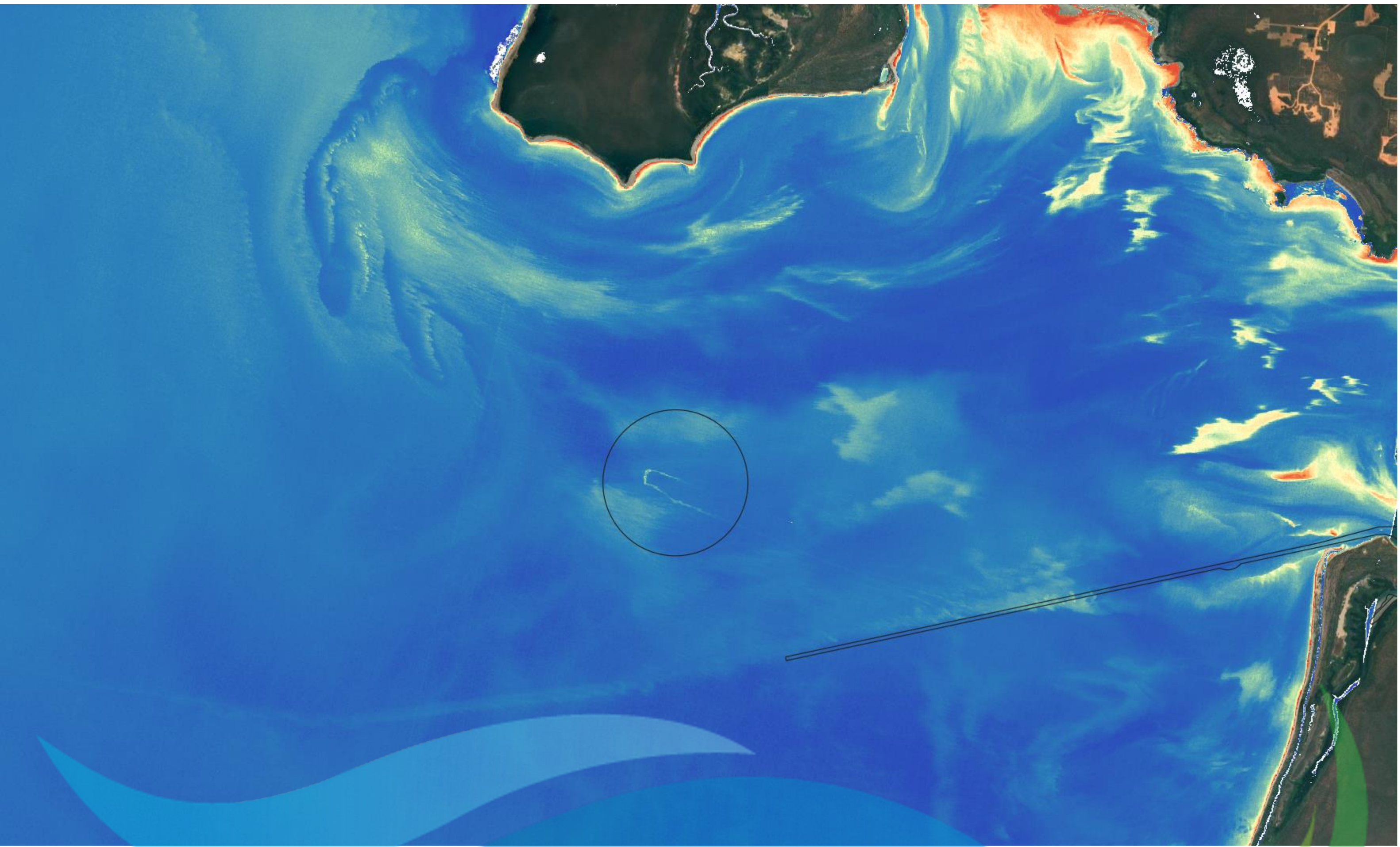
PORT & COASTAL SOLUTIONS

Port of Weipa, 2024 Maintenance Dredging

Summary of Turbidity Monitoring

Report No. P080_R02v02



NORTH QUEENSLAND BULK PORTS CORPORATION

Technical Report
December 2024

Port of Weipa, 2024 Maintenance Dredging

Summary of Turbidity Monitoring

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North Queensland Bulk Ports Corporation Ltd

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CONTENTS

FIGURES

TABLES

Executive Summary

North Queensland Bulk Ports Corporation (NQBP) commissioned Port and Coastal Solutions Pty Ltd (PCS) to undertake work to support the 2024 maintenance dredging program at the Port of Weipa (the Port). This included the following:

1) to analyse the turbidity and metocean conditions over the duration of the dredge program, including 7 days pre- and post-dredging;
2) to assess the relative contribution of the maintenance dredging and placement activities on the natural turbidity at the measurement sites;
3) to better understand the spatial extent of any plumes resulting from the maintenance dredging and placement activities based on satellite-derived total suspended matter (TSM) data; and
4) provide a technical report which presents and interprets both the in-situ benthic turbidity data and satellite-derived TSM data collected over the entire pre-, during and post-dredging periods.

The 2024 maintenance dredging program was undertaken by the Trailing Suction Hopper Dredger (TSHD) Brisbane and involved the relocation of 701,000 m^3 of sediment from the dredged areas of the Port to the Albatross Bay Dredge Material Placement Area (DMPA). The data showed that during the dredging program the turbidity around the Port of Weipa was generally driven by the natural conditions (predominantly the astronomical tide, although two wave events also resulted in elevated turbidity), with higher turbidity occurring during periods of larger range spring tides. The key findings from the turbidity data analysis are detailed below:

- the exceedance analysis of the in-situ measured benthic turbidity data showed that the duration exceedances were below the average duration exceedance at all sites during the first dredging period, while during the second dredging period they were below the average duration exceedance at WQ1 while at WQ2 and WQ4 they were well below the 90th percentile duration exceedance. The results therefore show that the turbidity over the whole period was well within the natural variability for the region;
- all of the plumes resulting from maintenance dredging (including those from both dredging and placement) and bed levelling were found to remain relatively close to where they were created. Plumes generated in the South Channel were shown to have the potential to migrate to the north of the channel and in an offshore direction. Overall, the results showed that little net residual transport occurs in the region, this was also noted during the 2019 to 2023 maintenance dredging programs and as part of the Port of Weipa Sustainable Sediment Management assessment (PCS, 2019, 2020, 2021, 2022, 2023). Based on this, it can be assumed that the majority of the sediment suspended by the maintenance dredging and bed levelling is subsequently redeposited close to where it was either dredged or placed;
- the dredging and placement activities associated with the Port of Weipa 2024 maintenance dredging program were found to result in visible plumes. Plumes were observed close to the dredger and bed leveller when operating, adjacent to the South Channel and within and adjacent to the Albatross Bay DMPA. The size and concentration of the plumes was variable depending on both the dredging and bed levelling activities;
  - the largest plume, which was due to repeat maintenance dredging loads in the South Channel, was up to 3,800 m in length and 1,000 m in width with a concentration of up to 10 mg/l, occurred adjacent to the South Channel. Satellite imagery indicated that a localised plume was regularly present around the South Channel as this was where the majority of the maintenance dredging was undertaken; and
  - plumes in the DMPA from the placement of dredged sediment were typically less than 800 m in length and only persisted for short durations (in the order of hours).

The observed plumes were consistent with placement by the TSHD Brisbane during previous annual maintenance dredging programs.

- the Port of Weipa 2024 maintenance dredging program did not influence the regional turbidity in the area. The dredging only influenced the local turbidity close to where dredging was undertaken in the Port and where placement occurred at the Albatross Bay DMPA. Natural variations in turbidity driven by the tide and wave conditions over the monitoring period were larger than the variations in turbidity due to the maintenance dredging. The satellite imagery showed that the turbidity in the area of the seagrass meadows in the Inner Harbour was predominantly controlled by natural processes over the 2024 maintenance dredging program, with no visible plumes from the dredging activity observed in the seagrass meadows; and
- the post dredging satellite imagery showed that 3.5 days after dredging ended there were no plumes from the dredging or placement activities in the South Channel, Inner Harbour or DMPA. This is in agreement with findings from previous dredge programs (2020, 2022 and 2023) where satellite imagery showed that the turbidity had returned to natural conditions within one to four days after the end of the dredging activity (PCS, 2020, 2022, 2023).

1. Introduction

North Queensland Bulk Ports Corporation (NQBP) commissioned Port and Coastal Solutions Pty Ltd (PCS) to undertake work to support the 2024 maintenance dredging program at the Port of Weipa (the Port). This included the following:

- source satellite imagery for the Port of Weipa region and process the imagery to output satellite-derived turbidity to show the spatial distribution of turbidity over the duration of the dredging program in addition to 7 days pre- and post-dredging;
- obtain metocean data for the Weipa region over the whole pre-, during and post-dredging period to help interpret the satellite-derived turbidity data;
- provide a pre-dredging technical note prior to the dredging commencing which presents the satellite-derived turbidity data and metocean conditions. The note will provide an overview of the natural turbidity and the relative influence of different drivers (e.g. waves and tidal currents) during the pre-dredging period;
- provide a during dredging technical note after 10 to 14 days of the maintenance dredging. The note will present results from the satellite-derived turbidity monitoring over this initial dredging period and discuss the potential impacts of the dredging on the turbidity in the region;
- provide a technical note after completion of the first period of the split dredge program (including the 7 days pre- and post-dredging). The note will summarise the satellite-derived TSM monitoring results from the first dredging period and discuss any visible dredge plumes resulting from the activity relative to natural plumes; and
- provide a post dredging technical report following completion of the maintenance dredging and the post monitoring period. This note will present both the satellite derived turbidity and in-situ benthic turbidity data for the pre-, during and post-dredge periods and discuss the metocean conditions, the associated natural variability in turbidity and potential impacts of the maintenance dredging to turbidity in the region.

Following completion of the 2024 maintenance dredging program and the 7 day post-dredging period, this technical report presents and discusses the metocean and turbidity data collected.

1.1. Project Overview

The Port of Weipa is located in the Gulf of Carpentaria, on the north-west coast of the Cape York Peninsula in Northern Queensland (Figure 1). The Port is within Albatross Bay, a large embayment, with the wharves and berths located in the Embley River (Figure 1 and Figure 2).

In the 2022/23 financial year, the Port of Weipa handled just over 15 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 layout of the Port of Weipa is shown in Figure 1. The Port consists of:

- a main shipping channel in Albatross Bay called South Channel; 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 2).

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 of Weipa has been undertaken annually by the Trailing Suction Hopper Dredger (TSHD) Brisbane, with volumes ranging from approximately 300,000 m^3 to 2,400,000 m^3. The sediment, which has historically been removed by maintenance dredging, has been relocated to the offshore Dredge Material Placement Area (DMPA) located in Albatross Bay (Figure 1). Following the 2020 maintenance dredging program the DMPA was moved to the west, by the distance of its radius (1.1 nautical miles), to provide additional capacity for the future. The moved DMPA was then used as the placement site for the 2021 and 2022 maintenance dredging programs.

Based on detailed bathymetric analysis by PCS (2018) it was found that the annual sedimentation at the Port was highly variable depending on the wave conditions which occurred during the wet season, with the occurrence of Tropical Cyclones (TCs) in the region being a key driver for larger waves and increased sedimentation. The analysis also found that the majority of the sedimentation occurred in the South Channel, with limited sedimentation occurring in the Inner Harbour region (see Figure 3 for locations).

Multiple tropical lows occurred in the Gulf of Carpentaria during the 2023/24 wet season, with three wave events having a peak in significant wave height of more than 2.0 m and one of these remaining above 2.0 m for 3.5 days and having a peak of 3.0 m. Based on the wave conditions since the 2023 maintenance dredging program the sedimentation was estimated to be in the order of 825,000 m^3 in the South Channel (excluding the channel batters) and in the order of 65,000 m^3 in the Inner Harbour.

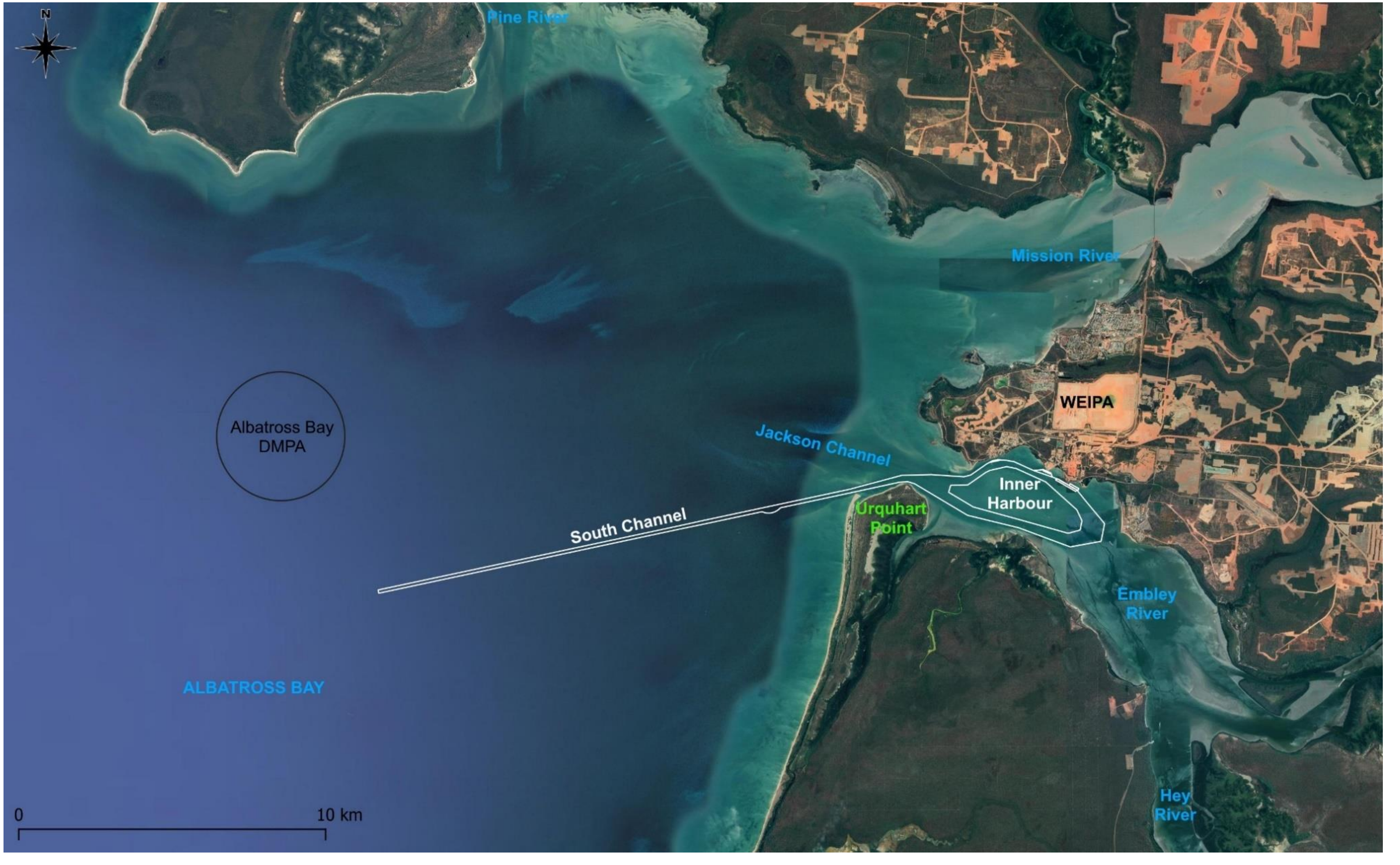

Figure 1. Layout of the Port of Weipa.

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Figure 2. Close up of the Port of Weipa Inner Harbour area.

1.2. Report Structure

The report herein is set out as follows:

- a summary of the dredge program is provided in **Section 2**;
- details of the turbidity monitoring undertaken are provided in **Section 3**;
- analysis of the in-situ turbidity and satellite-derived data is presented in **Section 4**; and
- a summary of the findings is detailed in **Section 5**.

Unless stated otherwise, levels are reported to Chart Datum (CD). Zero metres CD is equal to the Lowest Astronomical Tide (LAT) at the Port of Weipa. Volumes presented throughout are in-situ cubic metres and time is presented in 24 hour format relative to Australian Eastern Standard Time (AEST).

2. Dredge Program

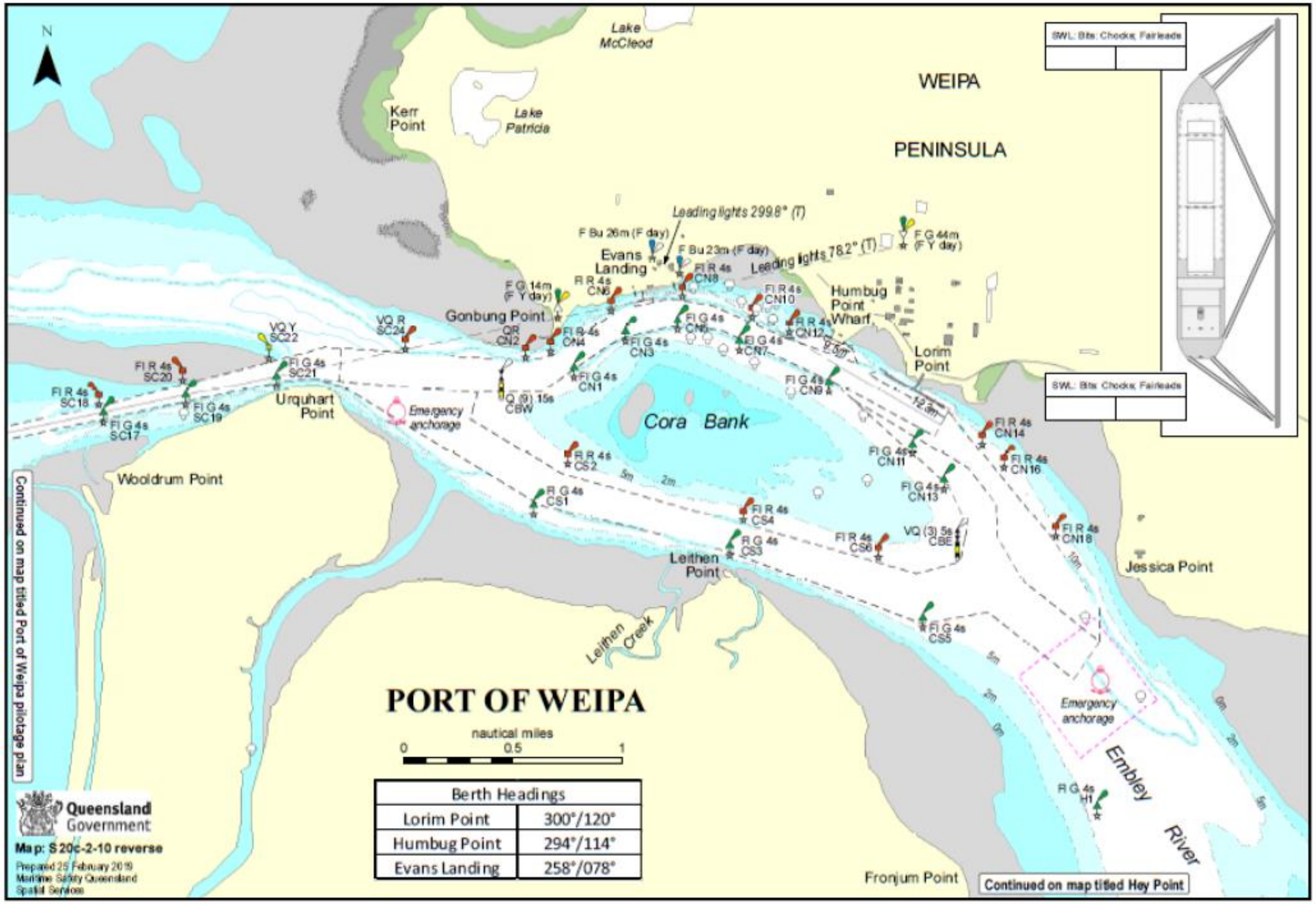
The Port of Weipa 2024 maintenance dredging program was a split program, with dredging undertaken by the Trailing Suction Hopper Dredger (TSHD) Brisbane over the following periods:

- First period: between 12th May 2024 at 14:33 Australian Eastern Standard Time (AEST) and the 6th June 2024 at 23:00 AEST. The first 2.5 days of this period were spent dredging at Amrun Port (i.e. full time dredging at the Port of Weipa commenced on 15th May 2024), with limited work undertaken at the Port of Weipa over this period.
- Second period: between 30th June 2024 at 06:45 AEST and the 18th July 2024 at 06:19 AEST.

Over the combined 43 days of dredging over both periods a total of 352 dredge hopper loads were relocated to the Albatross Bay DMPA, with an average of just under nine loads per day. The total in-situ volume of sediment removed from the dredge areas of the Port of Weipa during the program was approximately 701,000 m^3 (PCS, 2024a). The majority of the maintenance dredging was focussed in the South Channel where 626,000 m^3 was removed, and the remaining 75,000 m^3 was removed from the Inner Harbour. It is important to note that the maintenance dredging requirement within the South Channel was not uniform, with more than 75% of the dredge volume removed from between SC6 and SC14 which represents approximately 40% of the total length of the South Channel (7 km of the total 17.5 km length of the channel). Although only 11% of the dredge volume was from the Inner Harbour, extensive bed levelling was also undertaken in this area.

The dredged sediment was placed at the Albatross Bay DMPA, with the location of the placements within the DMPA being rotated between the five separate regions of the DMPA to ensure an even distribution over the DMPA. However, there was an accidental partial load release while the *TSHD Brisbane* was on route to the DMPA. The area where the release occurred was surveyed immediately after and no visible difference in the seafloor between the natural seabed level and where the release occurred was observed. This incident of an accidental partial load release outside of the DMPA was reported by NQBP in accordance with their approval conditions.

Figure 3. Location of the Port of Weipa ambient monitoring sites (WQ1, WQ2 and WQ4), DES waverider buoy (WRB) and South Channel (beacons SC2 – SC24).



Source: MSQ (2019)

Figure 4. Location of the Port of Weipa and beacons within the Inner Harbour.

2.1. Metocean Conditions

To provide an understanding of the metocean conditions over the pre-, during and post dredging periods, the following data have been sourced:

- Water Level: the predicted water level for the Port of Weipa (provided by the Bureau of Meteorology (BoM));
- Wind and Rain: measured wind and rainfall at the BoM Weipa Aero weather station (ID 027045); and
- Waves: measured wave conditions at both the Skardon River and Albatross Bay waverider buoys (WRB) (Figure 3) (provided by the Department of Environment, Science and Innovation (DESI)). Data from the Skardon River WRB (located approximately 90 km north of the Albatross Bay WRB) was used up to the 18th June 2024 as the Albatross Bay WRB was offline up to this date due to maintenance.

The metocean conditions over the entire monitoring period are shown in Figure 5, with shading indicating the two maintenance dredging periods. The figure shows the following:

- throughout the majority of the period the metocean conditions are fairly consistent and representative of calm to moderate dry season conditions;
- the winds were consistently from the east to southeast over the majority of the period. The wind speed was more variable, with peak speeds during the day varying between 8 and 23 knots while the overnight speeds were consistently lower with speeds of up to 8 knots;
- rainfall was very low throughout the whole period. There was rainfall of 4 mm over one day towards the start of the first dredge period and then no rainfall of more than 1 mm over 24 hours after that; and
- the wave direction varied between waves from the southeast (offshore) and southwest (onshore). Wave directions from the southeast typically correlated with periods of smaller significant wave heights, while directions from the southwest typically correlated with periods of larger H_s. The H_s was typically less than 0.7 m over the majority of the period except during two wave events which occurred towards the end of each dredge period, when the H_s exceeded 1 m. The wave direction during both of these were from the southwest as a result of longer period swell waves when local winds were relatively calm.

Overall, the monitoring period is considered to be relatively calm in terms of wave conditions, although resuspension of fine-grained sediment in Albatross Bay is likely to have occurred during the two wave events which occurred towards the end of each dredge period.

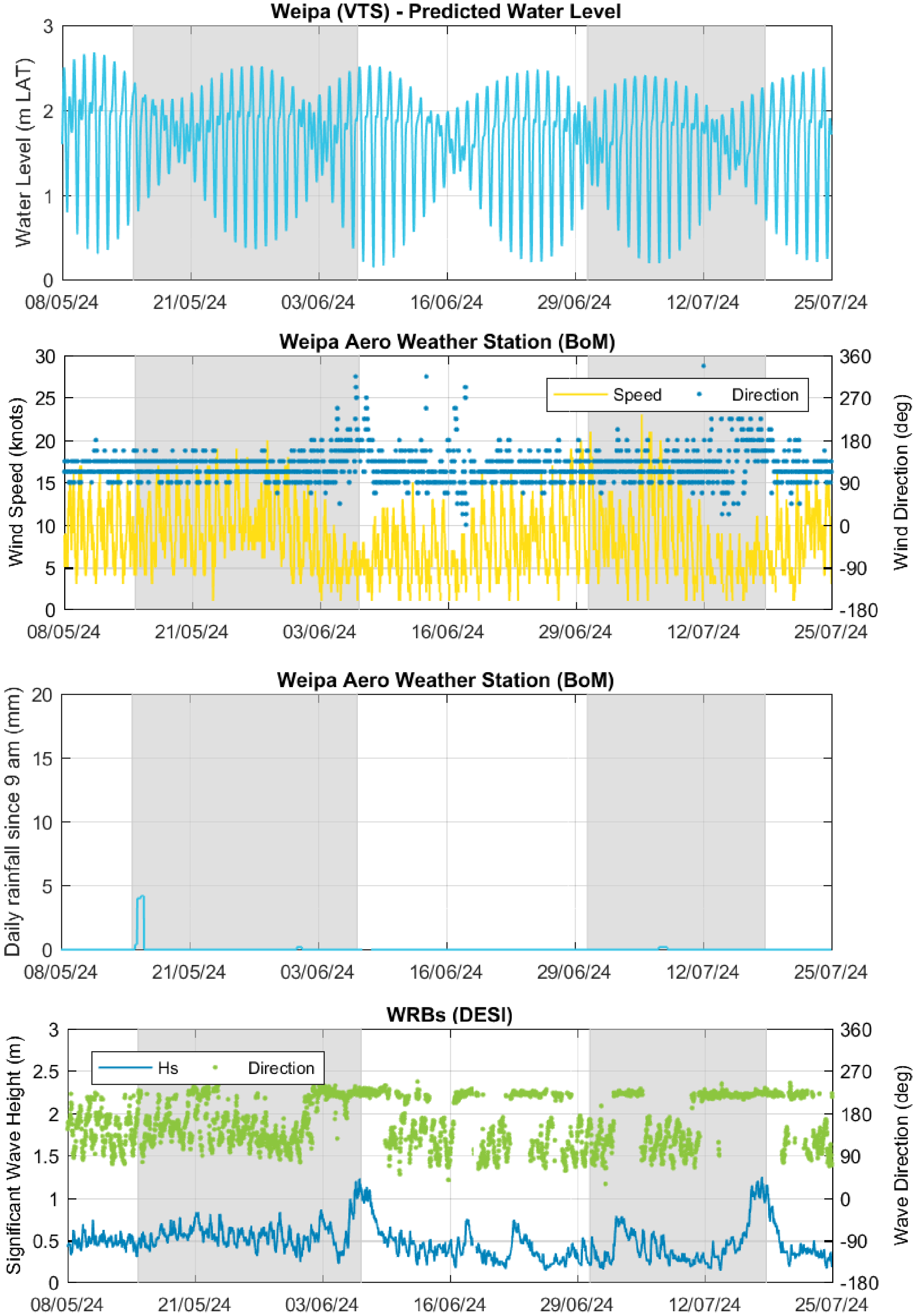


Figure 5. **Metocean conditions at Weipa over the monitoring period, with water level (upper), winds (upper middle), rainfall (lower middle) and waves (lower).**

3. Turbidity Monitoring

As part of the ongoing ambient water quality monitoring which NQBP have setup, benthic turbidity data have been collected by James Cook University (JCU) since January 2018 at monitoring sites around the Port of Weipa. The instruments measure near bed turbidity in Nephelometric Turbidity Unit equivalent (NTUe)[1]. There were originally two sites in Albatross Bay (WQ2 and WQ5), but one of these sites (WQ5) was decommissioned in July 2018 and there are currently two sites (WQ1 and WQ4) in the Inner Harbour (Figure 3). The water depth at the three monitoring sites is approximately 4.5 m (ranging from 4.4 m at WQ1 to 4.8 m at WQ4).

The instruments were serviced prior to the 2024 maintenance dredging program commencing and again between the two dredge periods and finally after completion of the maintenance dredging and the seven day post dredging period. Measured data up to the 26th September 2024 were provided by JCU.

The data return for the measured turbidity data over the 2024 maintenance dredging monitoring period, which includes 7 days pre and post dredging for each dredging period and 43 days of dredging (71 days in total), was 99% at WQ1 and WQ2 and 86.7% at WQ4. The lower data return at WQ4 was due to the measurements having a lot of spikes and some of these were removed as they failed the JCU quality control (QC) either due to the rate of change being too large or due to them being identified as spikes by JCU QC process.

3.1. Previous Analysis

Benthic turbidity data from the ongoing ambient monitoring were analysed by PCS (2020, 2021b, 2024b) to understand the natural variability in turbidity at the three monitoring sites. The analysis undertaken as part of the Environmental Thresholds component of the Port of Weipa Sustainable Sediment Management (SSM) Project recommended that the 90th percentile turbidity should be adopted as a turbidity intensity threshold as it approximately correlates with published benthic Photosynthetically Active Radiation (PAR) thresholds for the species of seagrass which are present in the Weipa region.

Monitoring during the 2023 maintenance dredging program at the Port of Weipa showed that the benthic turbidity at both WQ1 and WQ4 (the Inner Harbour sites) were naturally high which resulted in the duration exceedance at both sites being significantly higher than at WQ2 (PCS, 2023). Based on this the turbidity intensity thresholds at the three monitoring sites were updated to ensure that the thresholds were based on measured turbidity data which can be considered to represent the existing natural turbidity at the sites. It was noted that the turbidity data at WQ1 and WQ4 had increased since December 2021 and so the updated thresholds at these sites were based on measured data from December 2021 to October 2023, while at WQ2 the turbidity was not found to have increased and so the analysis was based on data from January 2018 to October 2023. Updated trigger limits were defined using the same approach as the previous trigger limits and separate values were defined for wet and dry seasons. The updated 90th and 95th percentile turbidity intensity thresholds for the dry season period at the three ambient water quality monitoring sites are shown, along with the previous values, in Table 1. The table shows that the thresholds at WQ1 and WQ4 have increased, with a significant increase at WQ4, while at WQ2 there has been a slight reduction in the threshold as a result of the updated analysis undertaken by PCS (2024b).

[1] The international turbidity standard ISO7027 defines turbidity readings in NTU for 90 degree backscatter, while the JCU instrumentation uses 180 degree backscatter. In recognition of this fact, the units are reported as NTU equivalent (NTUe).

Table 1. Dry season benthic turbidity thresholds derived by PCS (2024b) along with previous values detailed by PCS (2021b).

Location	Updated 90th Percentile Turbidity Threshold (NTUe)	Previous 90th Percentile Turbidity Threshold (NTUe)
WQ1	25	19
WQ2	19	23
WQ4	95	27

4. Data Analysis

This section presents in-situ turbidity data and satellite-derived turbidity data to provide an understanding of the variability in turbidity in the Weipa region and to determine the potential impact of the maintenance dredging activity on water quality in the region.

4.1. In-situ Turbidity Analysis

The measured benthic turbidity data at the three monitoring sites, along with the predicted water level for the Port of Weipa (calculated by BoM), the measured wave conditions in Albatross Bay (from the DESI WRBs at Skardon River and Albatross Bay) and measured wind conditions at the Weipa Aero weather station are shown in Figure 6, while individual plots for each monitoring site are shown in Figure 7. The figure shows that there is a clear tidal signal in the turbidity data at WQ1 and WQ2, while WQ4 has a tidal signal up to the start of June 2024 and after this the data becomes very noisy. At WQ1 and WQ2 the increased turbidity clearly correlated with the larger tidal range over spring tides.

The turbidity data at WQ4 is consistently higher than at the other two sites throughout the monitoring period. During the first two spring tides of the monitoring period the peaks typically just exceed 100 NTUe, while at WQ1 (the other Inner Harbour site) the peaks typically remain below 50 NTUe. After the first two spring tides the peaks in turbidity at WQ4 range between 50 and 390 NTUe, while at WQ1 the majority of the peaks remain less than 50 NTU, with occasional short durations peaks of 100 to 200 NTUe. These higher peaks in turbidity at WQ4 were observed during previous maintenance dredging programs and as a result the turbidity intensity thresholds were updated (see Section 3.1). This should ensure that despite the measured turbidity at WQ4 being much higher than at the other two sites, the exceedance duration is not higher than at the other sites unless the dredging has resulting in increased turbidity in the area.

At WQ2 the measured turbidity data over the monitoring period typically remained below 30 NTUe, with peaks of less than 5 NTUe during neap tides and the higher peaks of up to 30 NTUe during spring tides. During the two wave events which coincided with the end of the two dredging periods the turbidity at WQ2 increased, with a peak of 150 NTUe during the first event and 600 NTUe during the second event.

Based on the benthic turbidity data at sites WQ1 and WQ2 it appears that the turbidity over both dredging periods of the 2024 maintenance dredging program was predominantly controlled by the metocean conditions, while the benthic turbidity data at WQ4 did not directly correlate with the metocean conditions it was in line with previous measurements.

To further assess any potential increase in turbidity at the sites due to maintenance dredging, the duration of time the updated benthic turbidity intensity thresholds (shown in Table 1) were exceeded is assessed in the following section.

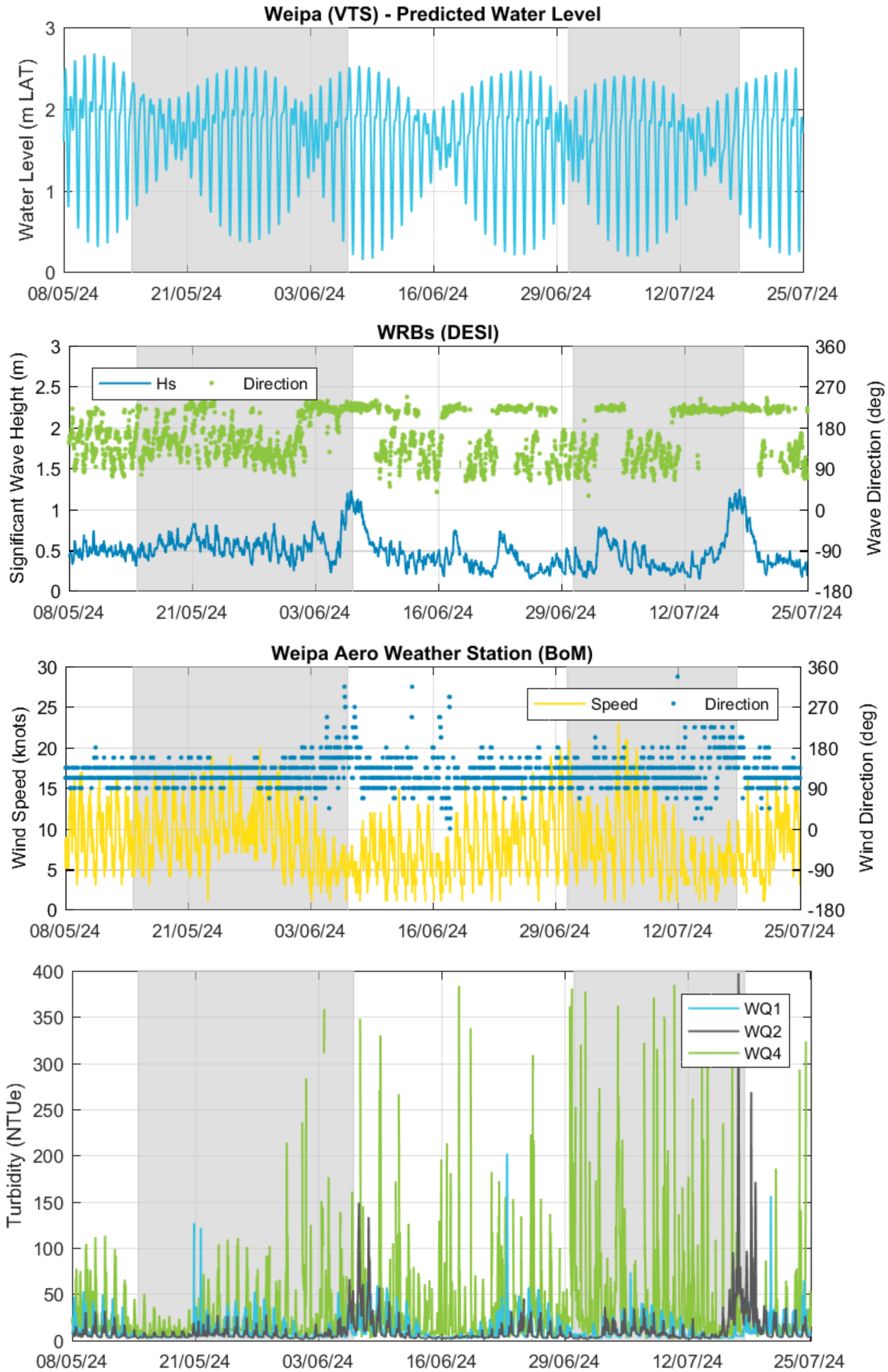
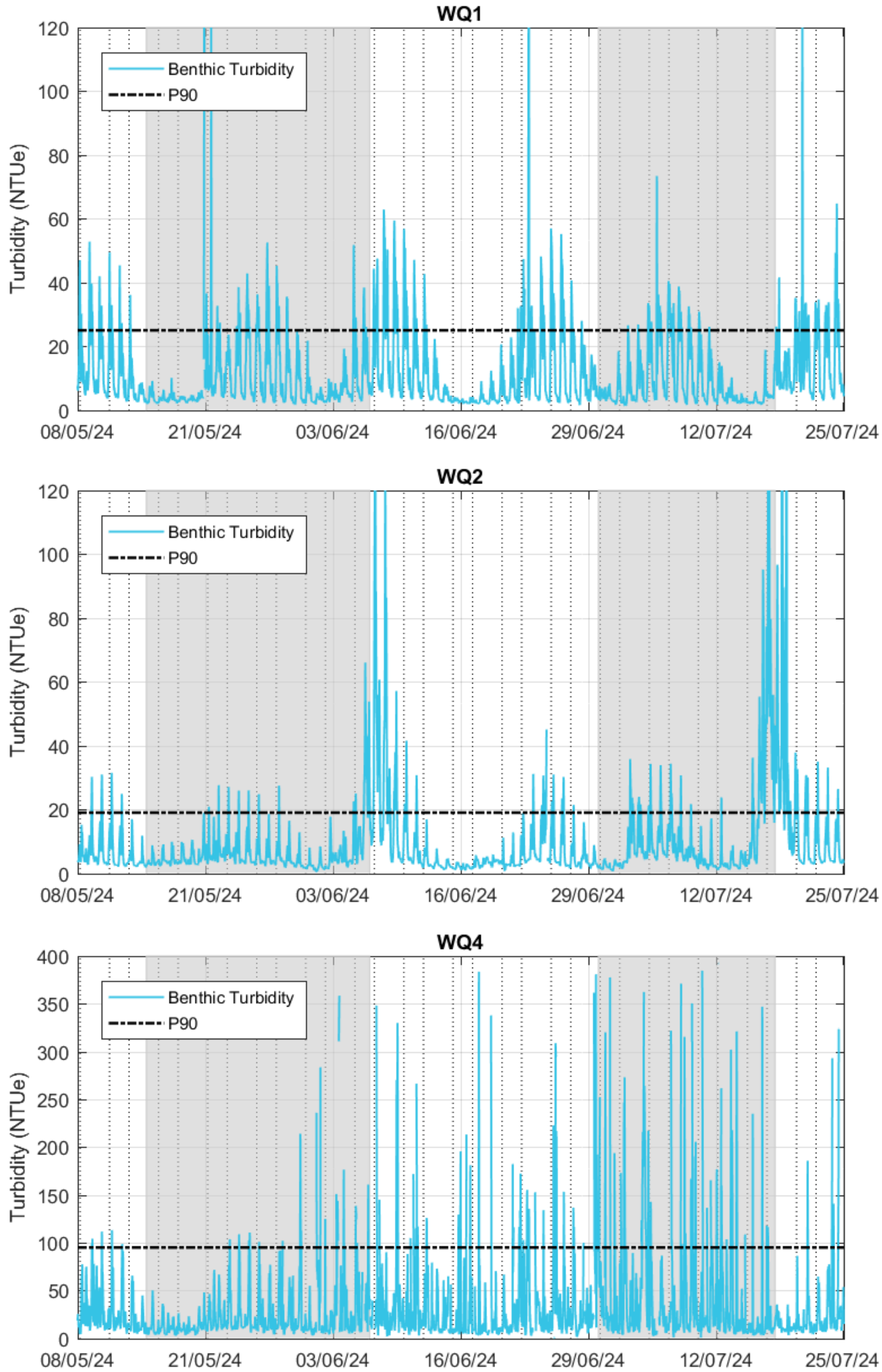


Figure 6. Metocean and turbidity conditions at Weipa over the monitoring period, with water level (upper), waves (upper middle), winds (lower middle) and turbidity at the three monitoring sites (lower).



Note: Vertical dotted lines indicate periods when Sentinel-2 satellite images were obtained and analysed, grey shaded areas show the two dredge periods.

Figure 7. Measured turbidity data and percentile thresholds at the three Weipa monitoring sites over the monitoring period, with WQ1 (upper), WQ2 (middle) and WQ4 (lower).

4.1.1. Exceedance

The duration of time that the 90th percentile benthic turbidity intensity thresholds were exceeded at the three monitoring sites was calculated over 7 days pre-dredging, the during dredging periods and 7 days post dredging for both of the dredging periods as part of the 2024 maintenance dredging program (Table 2 and Table 3). The timeseries plots presented in Figure 5 show that the metocean conditions were relatively consistent and calm throughout the majority of the period, except for the two wave events at the end of each dredge period. Therefore, the pre-dredge and during dredging periods can be considered to be relatively consistent, while the post dredge periods are considered more energetic than normal due to the two wave events.

The exceedance durations show lower exceedances during the two 7 day pre-dredge periods compared with the subsequent dredging periods, which is to be expected given the significantly shorter duration of the pre-dredge periods. However, at WQ1 and WQ2 the two 7 day post dredge periods have similar or even higher values to the preceding dredging periods. This shows how the two wave events which occurred at the start of the 7 day post dredge periods resulted in naturally higher turbidity exceedance durations at these two sites.

The suggested duration triggers for the 90th percentile turbidity intensity threshold for both 20 and 40 day dredge periods are presented in PCS (2024b). These duration triggers were suggested as possible adaptive management thresholds which could be adopted sequentially to minimise the risk of any impacts to sensitive receptors. The dry season duration triggers have been scaled to represent the durations of the two dredge periods and the durations for the two dredge periods including the 7 days pre- and post (Table 4). The table does not include the maximum duration trigger as the 90th percentile duration trigger was not exceeded at any of the sites.

The exceedance durations during the first dredge period was less than the average duration trigger of 60 hours at all three sites. During the second dredge period the exceedance duration at WQ1 was less than the average duration trigger of 43 hours, while at WQ2 and WQ4 the exceedance duration was above the average duration trigger of 43 hours but well below the 90th percentile triggers of 116 and 134 hours. When the 7 day pre- and post dredging periods are also included, the exceedance durations at WQ2 and WQ4 during the first dredge period were below the average duration trigger, while at WQ1 it was between the average and 90th percentile duration triggers. When the 7 day pre- and post dredging periods are also included for the second dredge period, both WQ1 and WQ2 were between the average and 90th percentile duration triggers, while WQ4 was below the average duration trigger.

The results therefore show that during the two dredging periods the turbidity was well within the natural variability, with the exceedance durations either below or just above the average duration triggers. Based on this no adaptive monitoring would have been implemented should real-time monitoring have been undertaken at these sites.

Table 2. Duration of exceedance of the benthic turbidity intensity thresholds over each period of the Port of Weipa 2024 maintenance dredging program.

Location	7 days Pre-Period 1 (hrs)	Dredge Period 1 – 25 days (hrs)	7 days Post Period 1 (hrs)	7 days Pre-Period 2 (hrs)	Dredge Period 2 – 18 days (hrs)	7 days Post Period 2 (hrs)
WQ1	23	41	44	30	39	38
WQ2	7	25	46	15	62	49
WQ4	3	18	12	15	49	6

Table 3. Duration of exceedance of the benthic turbidity intensity thresholds over the two combined pre-, during and post dredging periods for the Port of Weipa 2024 maintenance dredging program.

Location	Dredge Period 1 (inc. pre & post) – 39 days (hrs)	Dredge Period 2 (inc. pre & post) – 32 days (hrs)
WQ1	108	107
WQ2	78	126
WQ4	12	70

Table 4. Scaled duration triggers for the different periods of the Port of Weipa 2024 maintenance dredging program.

Location	Dredge Period 1 – 25 days (hrs)		Dredge Period 1 inc. pre and post – 39 days (hrs)		Dredge Period 2 – 18 days (hrs)		Dredge Period 2 inc. pre and post – 32 days (hrs)	
	Av. (hrs)	90^{th} (hrs)	Av. (hrs)	90^{th} (hrs)	Av. (hrs)	90^{th} (hrs)	Av. (hrs)	90^{th} (hrs)
WQ1	60	108	94	149	43	77	77	122
WQ2	60	161	94	211	43	116	77	173
WQ4	60	186	94	331	43	134	77	271

4.2. Satellite-Derived Data

Satellite-derived turbidity data are a valuable resource which can provide a reliable spatial overview of the variability in turbidity over a large area (Fearns et al., 2017). Analysis of repeat images can be used to assist in understanding how spatial variations in turbidity change over time.

To better understand the spatial extent of both the natural turbidity in the Weipa region and any plumes resulting from the maintenance dredging activity (including from the placement of dredged sediment at the Albatross Bay DMPA), satellite imagery was used. High-resolution imagery from the Sentinel-2 (10 m) sensor and low-resolution imagery (approximately 300 m) from the Sentinel-3 sensor were sourced over the 2024 maintenance dredge monitoring period.

In the Weipa region the repeat satellite coverage is high for the Sentinel-3 sensor (images captured 11 out of every 14 days) and relatively high for the Sentinel-2 sensor (images captured every 2 to 3 days). The reason the temporal coverage is relatively high for the Sentinel-2 sensor is because the area is partially covered by two separate satellite tracks, which means the entire region is not covered for each image (the Inner Harbour is only captured in every second image). The satellite data are restricted by cloud cover, and so imagery can only be used when there is little to no cloud cover in the areas of interest.

The available imagery was post processed to calculate the satellite-derived turbidity based on the approach of Brockmann et al. (2016). This approach provides an estimate of total suspended matter (TSM) and has been validated in various studies (Kyryliuk and Kratzer, 2019). An assessment of the accuracy of the satellite derived TSM against the in-situ near bed turbidity data was undertaken during the 2021 maintenance dredging program to allow a local calibration of the imagery. The results showed that the satellite derived TSM was able to provide a good representation of the benthic in-situ measured SSC data at the WQ1 and WQ2 monitoring sites (Figure 8).

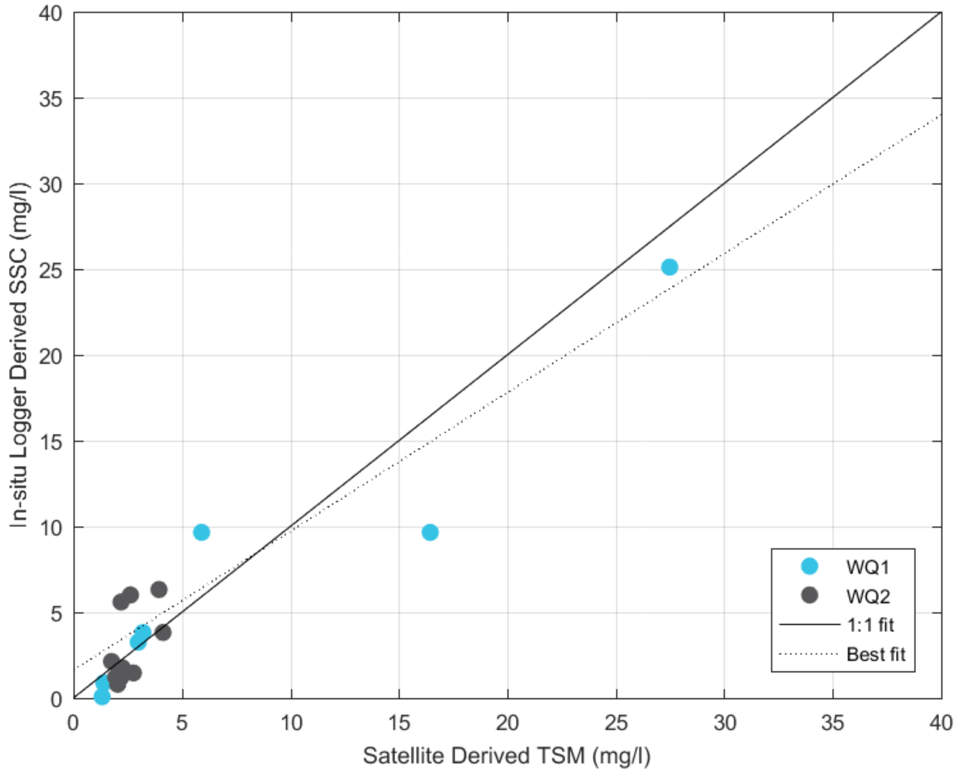


Figure 8. Correlation between satellite derived TSM from Sentinel-2 and in-situ logger derived SSC during the 2021 maintenance dredge monitoring period.

To ensure continuity between the satellite-derived TSM from different sensors a comparison between the TSM images derived from the Sentinel-2 and Sentinel-3 sensors was undertaken prior to the start of the 2024 dredge program (Figure 9). Both images have similar spatial patterns in TSM and magnitudes which gives confidence that both approaches were able to provide comparable TSM values during the dredge program.

Throughout both dredge periods PCS provided NQBP with TSM from satellite imagery available from both satellite sensors to provide as much near real-time information about the natural turbidity and any plumes due to the maintenance dredging as possible. From the daily updates provided during the dredging it was noted that the plumes from the maintenance dredging were relatively small and localised and as such they could be difficult to identify from the lower resolution Sentinel-3 imagery. Based on that, the technical note provided during dredging and post the first dredge period focussed on satellite imagery from the Sentinel-2 sensor (PCS, 2024c & 2024d). This post dredging report also focusses on imagery just from the Sentinel-2 sensor.

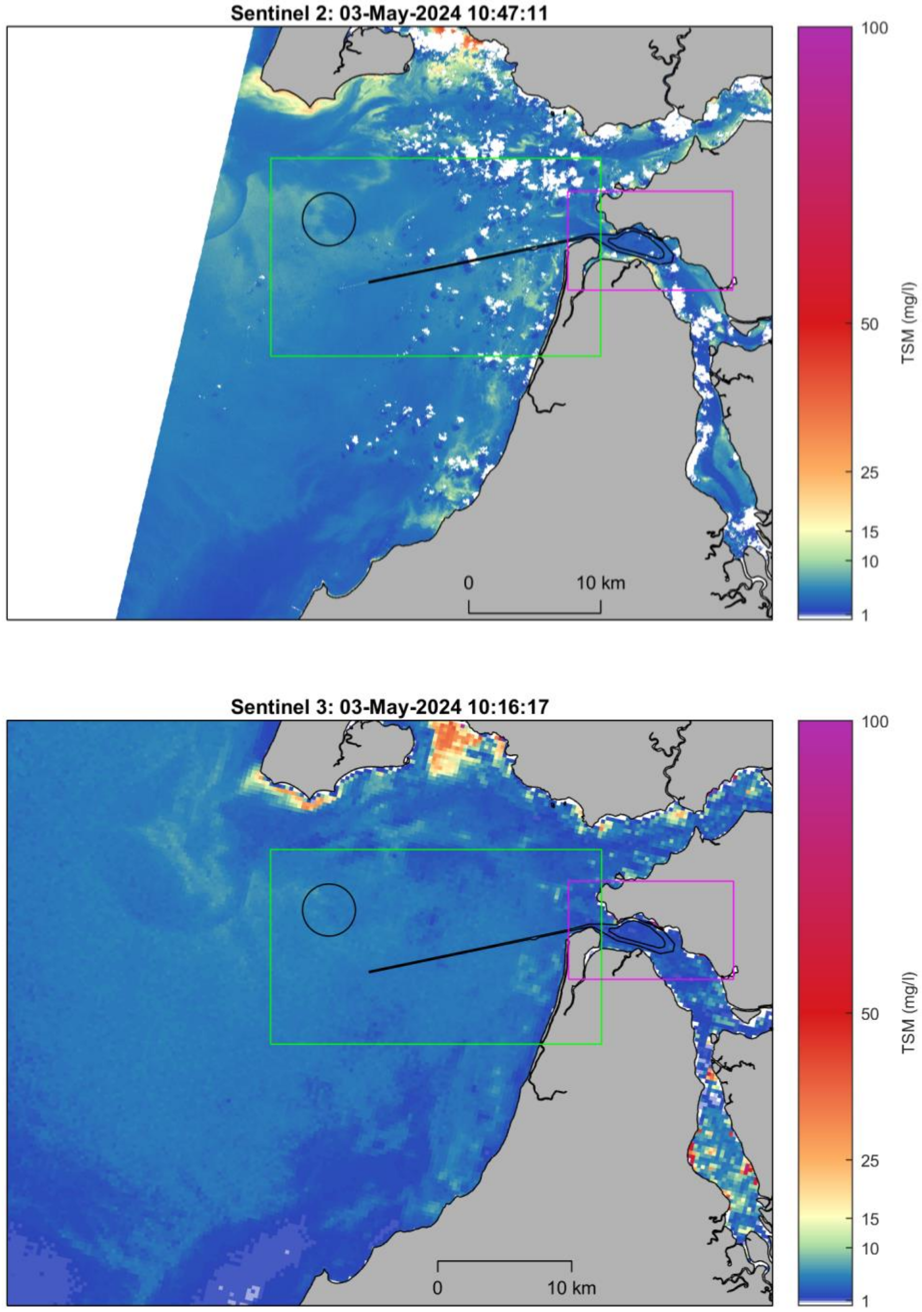


Figure 9. **Comparison between satellite-derived TSM from the Sentinel-2 (top) and Sentinel-3 (bottom) sensors for images captured approximately 30 minutes apart.**

Over the pre-, during and post-dredging monitoring period for the first dredge period a total of 15 high resolution satellite images were captured by the Sentinel-2 sensor and for the second dredge period a total of 13 high resolution satellite images were captured. As a result of high cloud cover during some of the satellite passes four of the images over the first dredge period and six images over the second dredge period were unusable.

Details of the satellite images analysed as part of this assessment are provided in Table 5 for the first dredge period and Table 6 for the second dredge period. A selection of images are presented to show the range of natural conditions and plumes observed over the period, the images which are presented in this report are highlighted as bold text in the tables while unusable images with high cloud cover are shown as grey text in the tables.

Table 5. Available satellite images over the monitoring period for the first dredge period.
Note: the images highlighted in bold are included as figures in this report.

Date and Time	Satellite Name	Details
		Pre-Dredge
08/05/2024 10:47	Sentinel-2	High cloud cover (not usable), no coverage of the Inner Harbour area.
11/05/2024 10:57	Sentinel-2	Moderate cloud cover, image excludes Inner Harbour area.
13/05/2024 10:47	**Sentinel-2**	**No cloud.**
		During Dredging
16/05/2024 10:57	Sentinel-2	Patchy cloud cover within Albatross Bay, but with most of the DMPA and South channel free of cloud, image excludes the Inner Harbour region. At this time the TSHD Brisbane was sailing back to the South Channel having finished dredging a load in the South Channel (SC6 to SC8) at 09:11 and placing the load at the DMPA at 10:00.
18/05/2024 10:47	Sentinel-2	High cloud cover throughout much of Albatross Bay, but little cloud in the Inner Harbour area. At this time the TSHD Brisbane was sailing back to the South Channel having finished dredging a load in the South Channel (SC6 to SC8) at 09:37 and placing the load at the DMPA at 10:21.
21/05/2024 10:57	**Sentinel-2**	**No cloud cover, image excludes Inner Harbour area.** **At this time the TSHD Brisbane was sailing to the Inner Harbour having finished dredging a load in the South Channel (SC10 to SC12) at 09:31 and placing the load at the DMPA at 10:34.**
23/05/2024 10:47	Sentinel-2	Patchy cloud cover around Albatross Bay and the estuaries. At this time the TSHD Brisbane was at Humbug Wharf for a crew change (from 08:55 to 14:40). The most dredging prior to the crew change had been from the South Channel (SC6 to SC8 and SC10 to SC12).
26/05/2024 10:57	Sentinel-2	High cloud cover, image excludes Inner Harbour area (not usable).
28/05/2024 10:47	Sentinel-2	High cloud cover (not usable).
31/05/2024 10:57	Sentinel-2	Patchy cloud cover, image excludes Inner Harbour area. At this time the TSHD Brisbane was on standby. The most recent dredging was in the South Channel (SC17 to SC21 and SC4 to SC6) which finished on 30/05/24 at 14:30.

Date and Time	Satellite Name	Details
02/06/2024 10:47	**Sentinel-2**	**Patchy cloud cover.** **At this time the TSHD Brisbane had just finished dredging the south channel (SC10 to SC12, finished at 10:42) and was steaming to the DMPA.**
05/06/2024 10:57	Sentinel-2	High cloud cover, image excludes Inner Harbour area. At this time the TSHD Brisbane was on standby. The most recent dredging was in the South Channel (SC10 to SC12) which finished on 02/06/24 at 17:28.
Post Dredge		
07/06/2024 10:47	Sentinel-2	High cloud cover (not usable). The TSHD Brisbane completed its final dredge load at 21:44 on 6th June from the South Channel (SC4 to SC6) and the load was placed at the DMPA at 21:54 on 6th June.
10/06/2024 10:57	**Sentinel-2**	**No cloud cover, image excludes Inner Harbour area.**
12/06/2024 10:57	Sentinel-2	No cloud cover.

Table 6. Available satellite images over the monitoring period for the second dredge period. *Note: the images highlighted in bold are included as figures in this report.*

Date and Time	Satellite Name	Details
Pre-Dredge		
25/06/2024 10:57	Sentinel-2	High cloud cover (not usable), no coverage of the Inner Harbour area.
27/06/2024 10:47	Sentinel-2	High cloud cover (not usable),
During Dredging		
30/06/2024 10:57	Sentinel-2	High cloud coverage (not usable), image excludes Inner Harbour area.
02/07/2024 10:47	**Sentinel-2**	**No cloud cover.** **At this time the TSHD Brisbane had just finished dredging in the South Channel (SC10 to SC12, finished at 10:33) and was steaming to the DMPA.**
05/07/2024 10:57	Sentinel-2	High cloud cover (not usable).
07/07/2024 10:47	Sentinel-2	High cloud cover (not usable).
10/07/2024 10:57	**Sentinel-2**	**No cloud cover, image excludes Inner Harbour area.** **At this time the TSHD Brisbane was steaming back from the DMPA having placed a load there at 10:49 from the South Channel (SC10 to SC12).**
12/07/2024 10:47	Sentinel-2	Patchy cloud cover along shoreline and in the estuaries. At this time the TSHD Brisbane was steaming to the DMPA having finished dredging a load from the South Channel (SC18 to SC22) at 10:14.
15/07/2024 10:57	Sentinel-2	Light cloud cover along majority of the area. At this time the TSHD Brisbane was dredging the South Channel (SC12 to SC14), with the dredging having commenced at 10:37.
17/07/2024 10:47	**Sentinel-2**	**No cloud cover.** **At this time the TSHD Brisbane was just about to place a load at the DMPA (placement commenced at 10:50).**

Date and Time	Satellite Name	Details
		Previous dredging of the South Channel (SC12 to SC14) had finished at 09:48.
Post Dredge		
20/07/2024 10:57	Sentinel-2	No cloud cover, image excludes Inner Harbour area. The TSHD Brisbane completed its final dredge load at 02:55 on 18th July from the South Channel (SC12 to SC14) and the load was placed at the DMPA at 04:19.
22/07/2024 10:47	**Sentinel-2**	**Patchy cloud cover over Inner Harbour area.**
25/07/2024 10:57	Sentinel-2	High cloud cover (not usable), image excludes Inner Harbour area.

4.2.1. Turbidity Analysis

To provide an understanding of natural turbidity levels within the study area and to identify the extent of potential increases in turbidity due to the 2024 maintenance dredging program, the turbidity analysis was undertaken at two different spatial scales, namely:

- regional and local (Albatross Bay and Port of Weipa); and
- dredge vessel (in close proximity to the TSHD Brisbane).

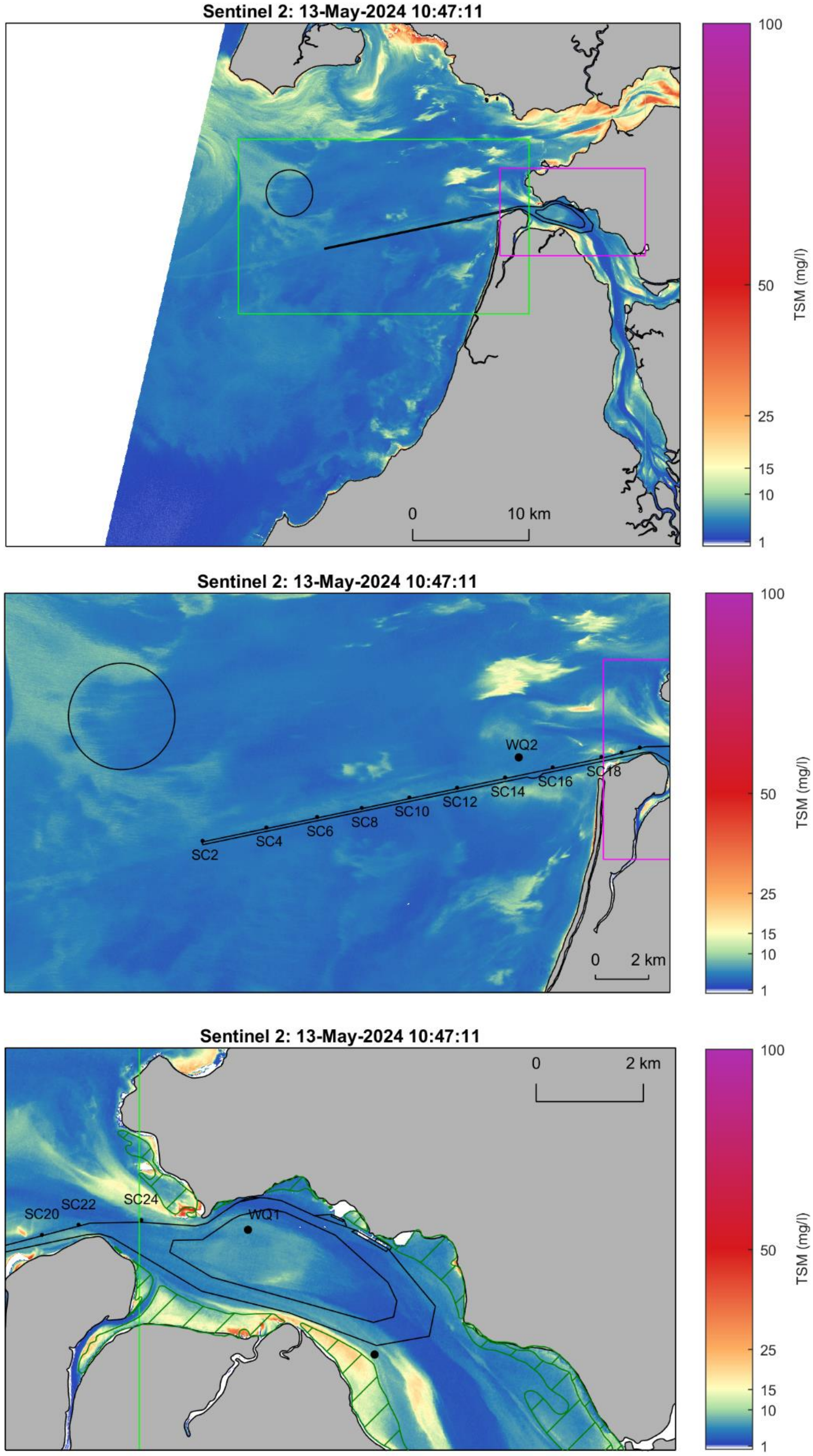
4.2.1.1. Regional and Local Scales

To provide an understanding of how the turbidity varied over the 2024 Maintenance Dredging Program, plots of the satellite-derived TSM in Albatross Bay, the South Channel/Albatross Bay DMPA and the Inner Harbour area are shown for selected satellite images over the pre-, during and post dredging periods for both dredging periods in Figure 10 to Figure 17. The plots show the following:

- the TSM in the Albatross Bay region has been variable over the period, with values typically less than 10 mg/l (approximately 7 NTU) throughout the majority of Albatross Bay, with higher TSM of 25 to 50 mg/l (approximately 18 to 35 NTU) in the shallow areas adjacent to the northern shoreline of Albatross Bay and in the estuaries. The imagery showed elevated TSM throughout much of Albatross Bay on the 10th June and 17th July 2024. The reasons for the high TSM in these images was due to larger waves occurring at the time of, or prior to, the images being captured;
- extensive natural plumes with a TSM of up to 15 mg/l (approximately 11 NTU) were present within Albatross Bay over the majority of the period. These extended up to 10's of kilometres and at times were present adjacent to the South Channel. Based on the spatial extent of the plumes, the metocean conditions and dredging activity these large scale plumes are considered to have been due to natural processes;
- the images indicate that the TSM in the area of the seagrass meadows in the Inner Harbour has been controlled by natural processes with the natural TSM typically being between 10 and 50 mg/l (approximately 7 to 35 NTU) and consistently being higher than the adjacent channel. No persistent plumes that would be expected to impact seagrass beyond what they are normally exposed to were observed as a result of the maintenance dredging program;
- none of the images captured a visible plume within the Inner Harbour, with the TSM in the deeper dredged areas of the Inner Harbour typically remaining below 10 mg/l (approximately 7 NTU) over the period; and
- plots of the satellite-derived TSM over the post dredging period are shown for the first and second dredging periods in Figure 13 and Figure 17. The plots show that the TSM was relatively high and similar in Albatross Bay during both post dredge periods as a result of the large wave events which occurred at the end of both dredging periods. The

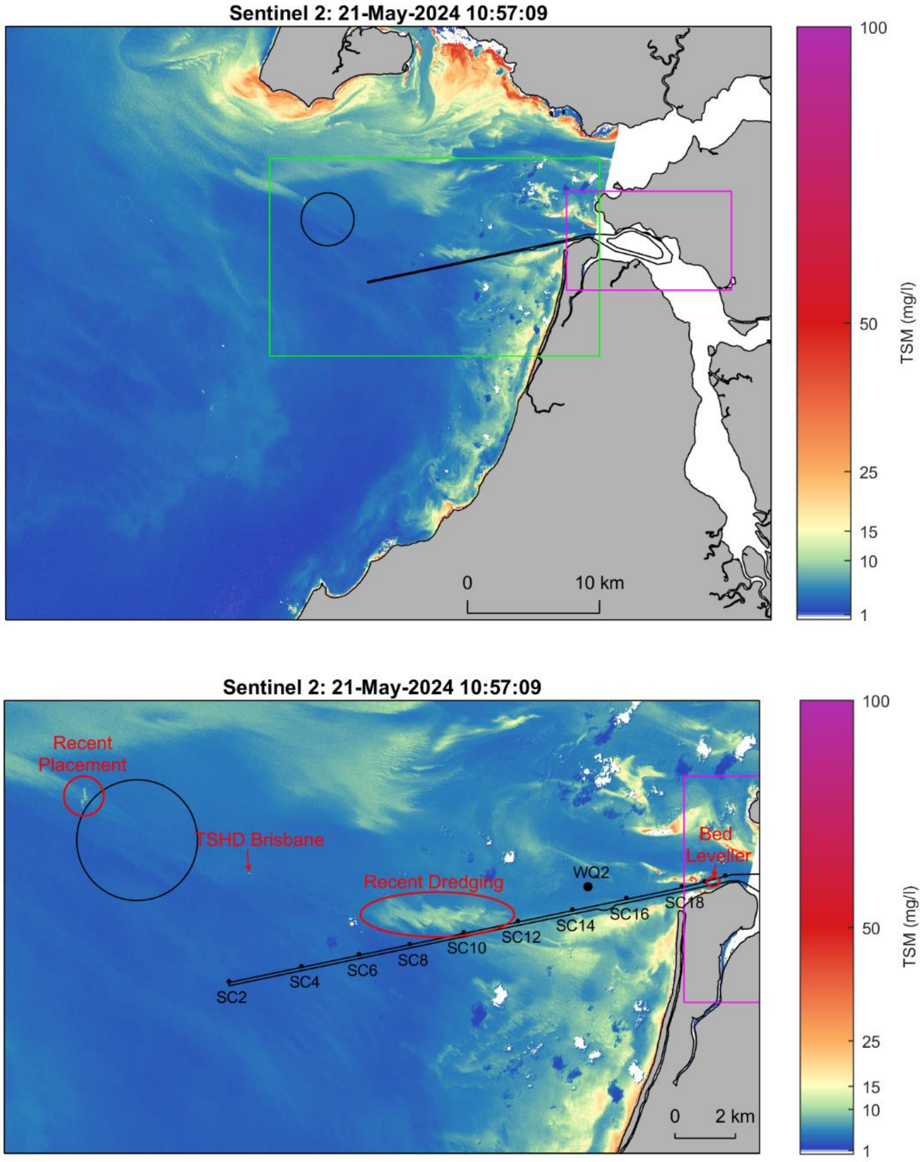
TSM was 5 to 10 mg/l around the DMPA, 5 to 25 mg/l around the South Channel and 10 to 25 mg/l in the Inner Harbour channels (only the post second dredging period included the Inner Harbour). No visible plumes are present from the maintenance dredging activity (there is a visible plume from ongoing bed levelling in the South Channel in the post second dredging period image), indicating that any plumes from the maintenance dredging activity have dispersed prior to the images being captured (approximately 3.5 and 4 days after the dredging finished).

The imagery has also shown plumes with TSM of up to 15 mg/l (approximately 11 NTU) and spatial extents of up to kilometres around the South Channel and DMPA occurred through the dredge period as a result of the dredging and bed levelling activity. These plumes are highlighted in the figures and will be further assessed in Section 4.2.1.2.



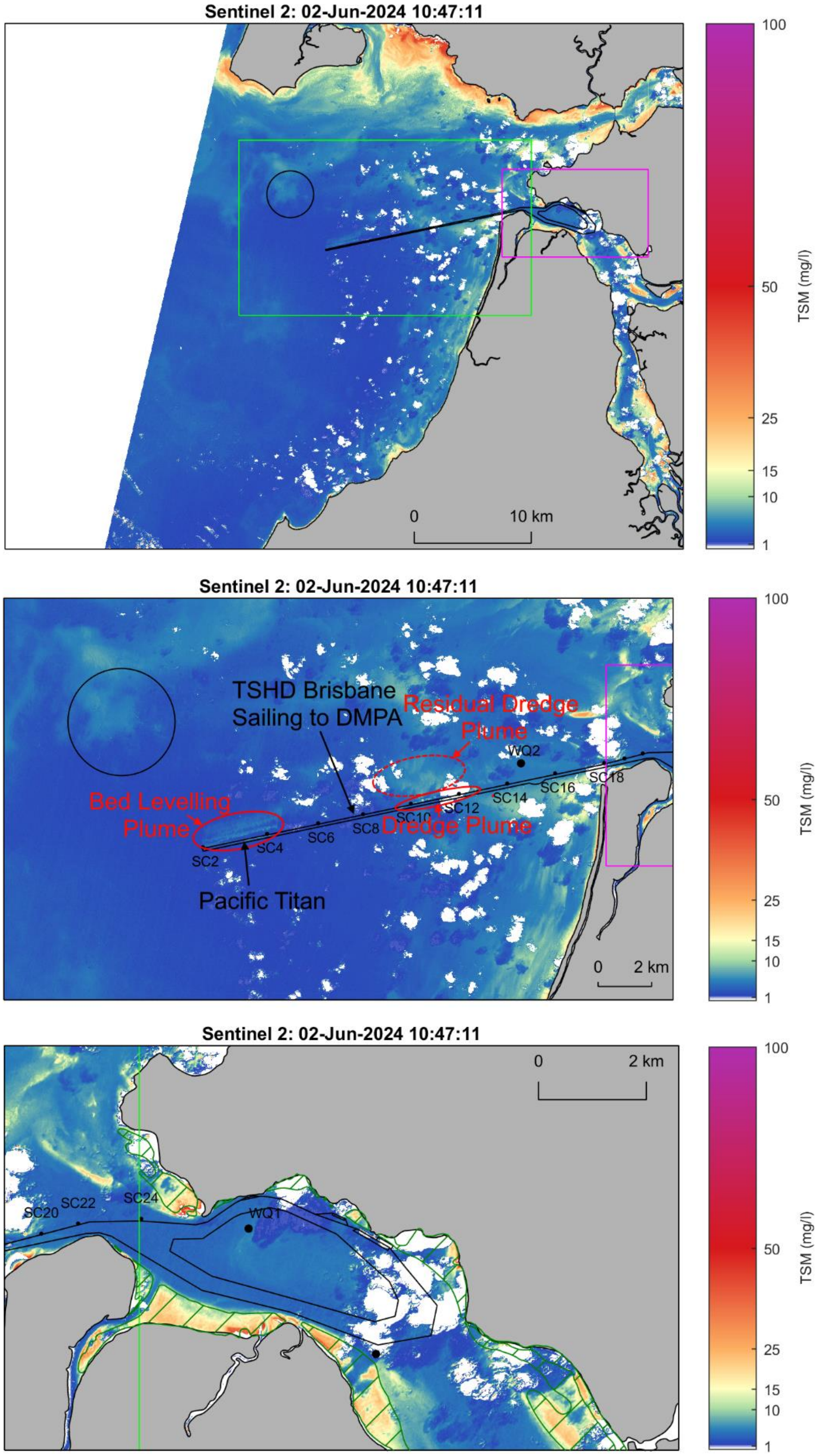
Note: the green hashed areas in the Inner Harbour represents the latest seagrass extent.

Figure 10. Satellite-derived TSM from the Sentinel-2 sensor on 13/05/2024 (pre-first dredging period).



Note: white areas represent cloud cover and red ellipses shows plumes from dredging.

Figure 11. Satellite-derived TSM from the Sentinel-2 sensor on 21/05/2024 (during first dredging period).



Note: white areas represent cloud cover, red ellipses show plumes from dredging/bed levelling and green hashed areas in the Inner Harbour represents the latest seagrass extent.

Figure 12. Satellite-derived TSM from the Sentinel-2 sensor on 02/06/2024 (during first dredging period).

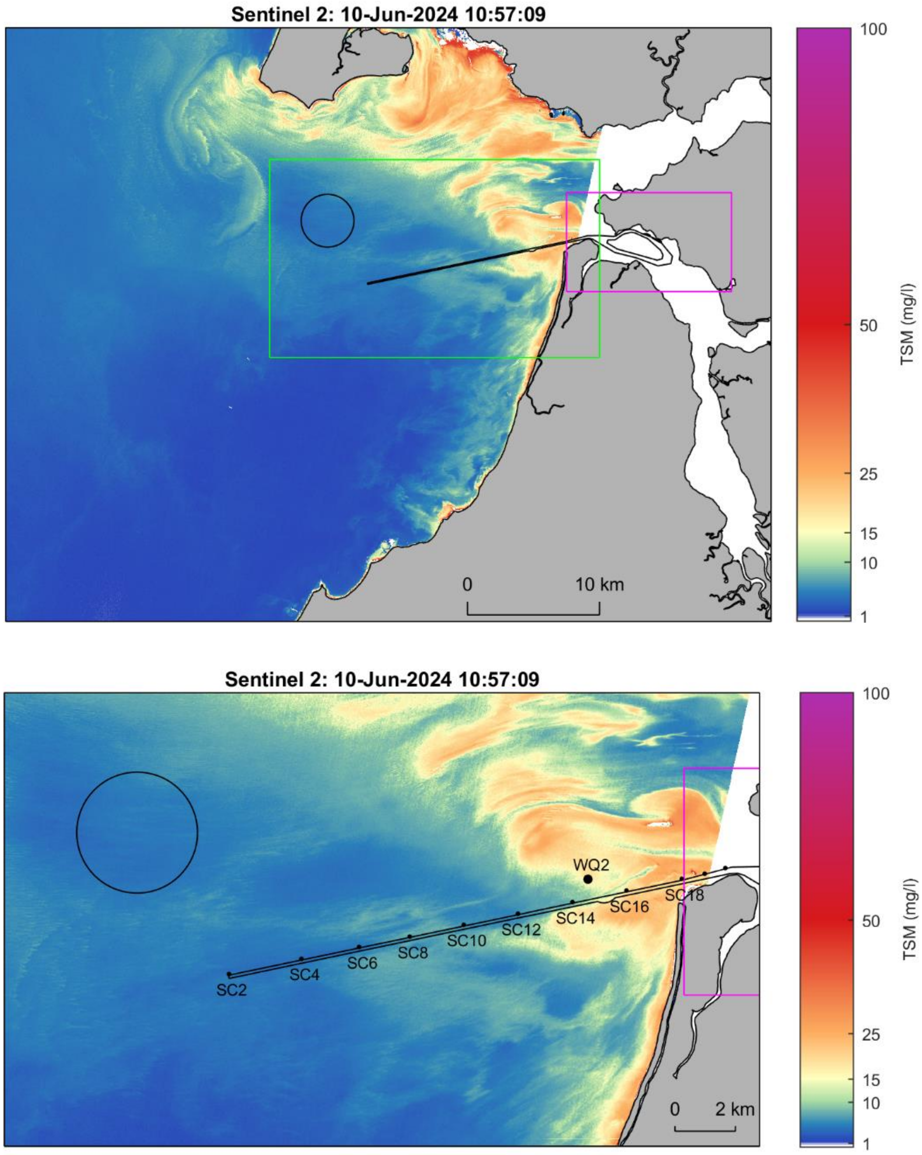
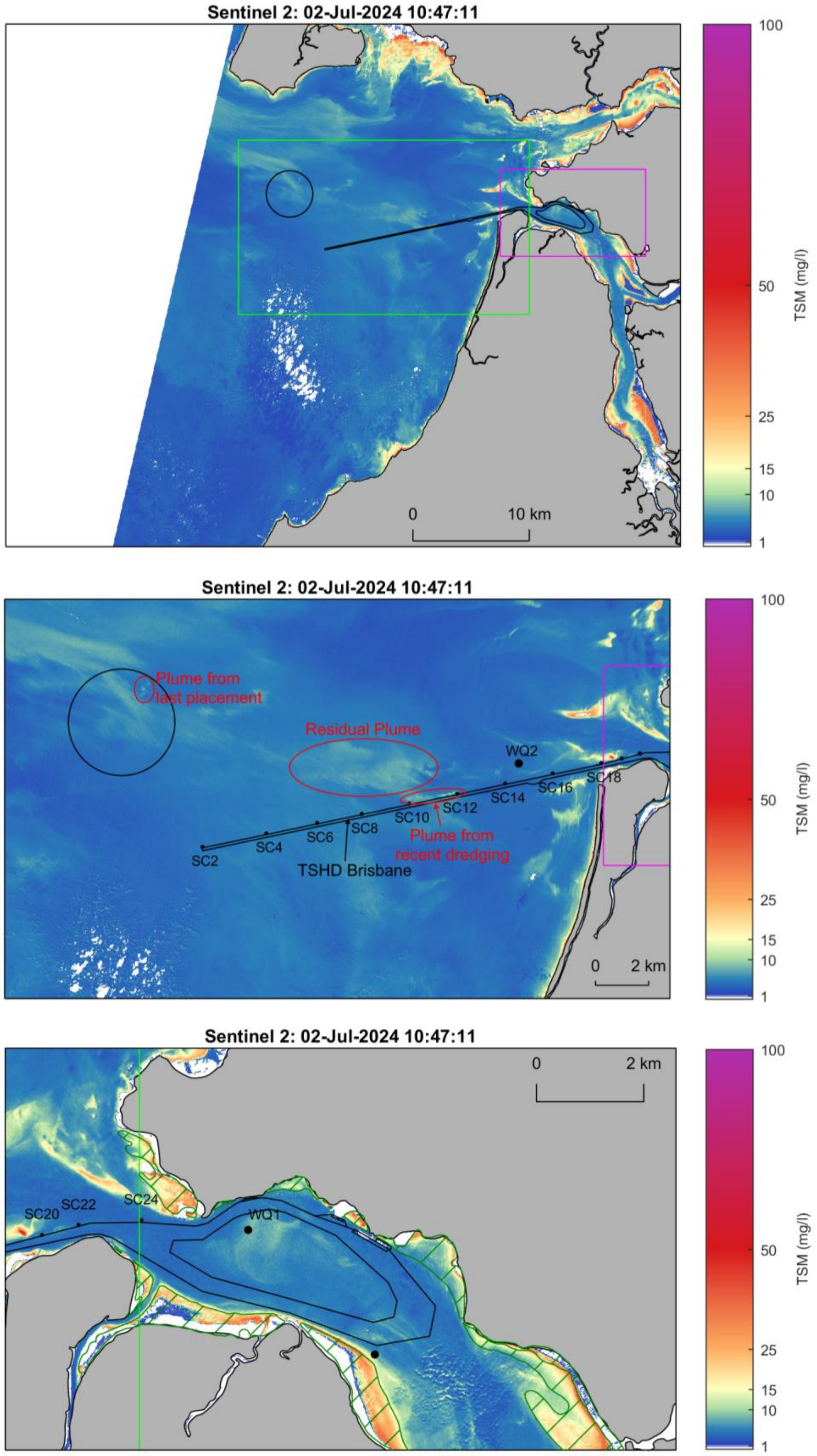
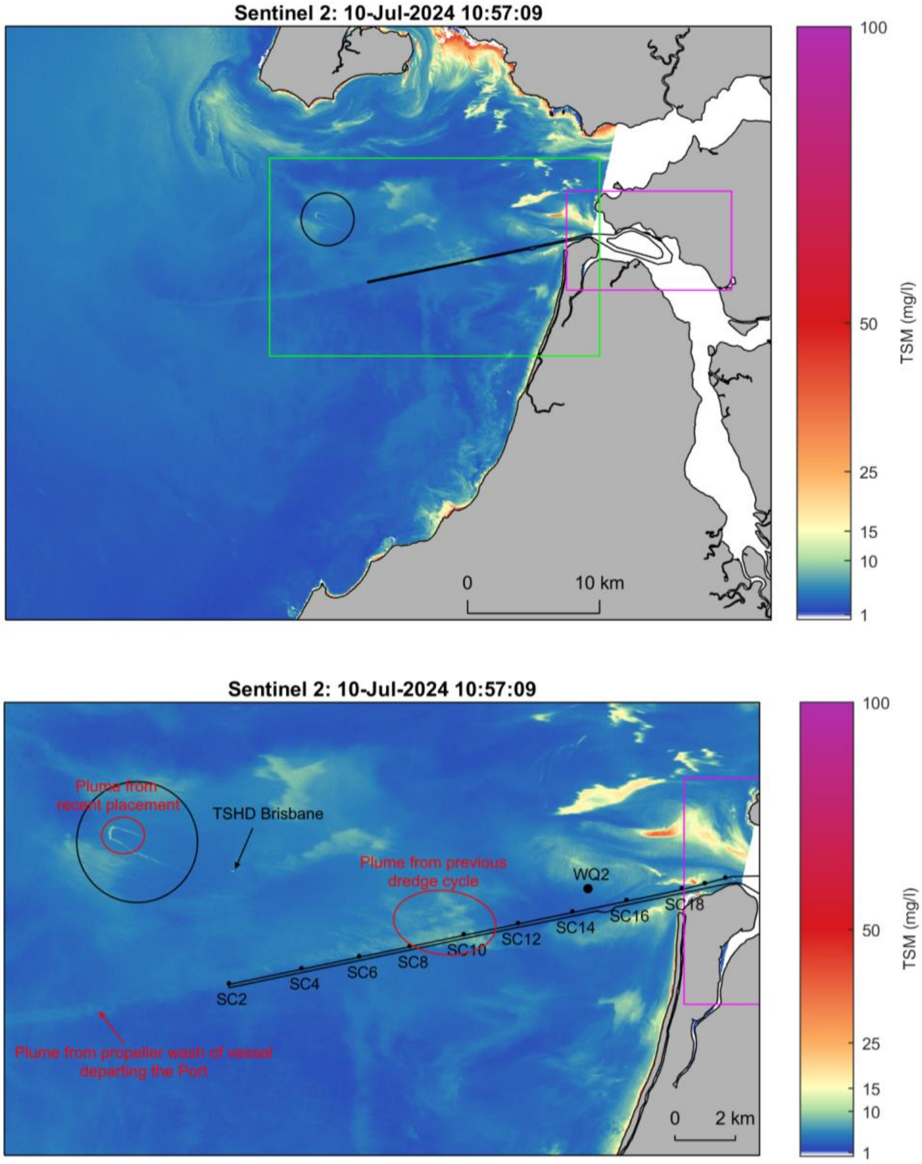


Figure 13. Satellite-derived TSM from the Sentinel-2 sensor on 10/06/2024 (post first dredging period).



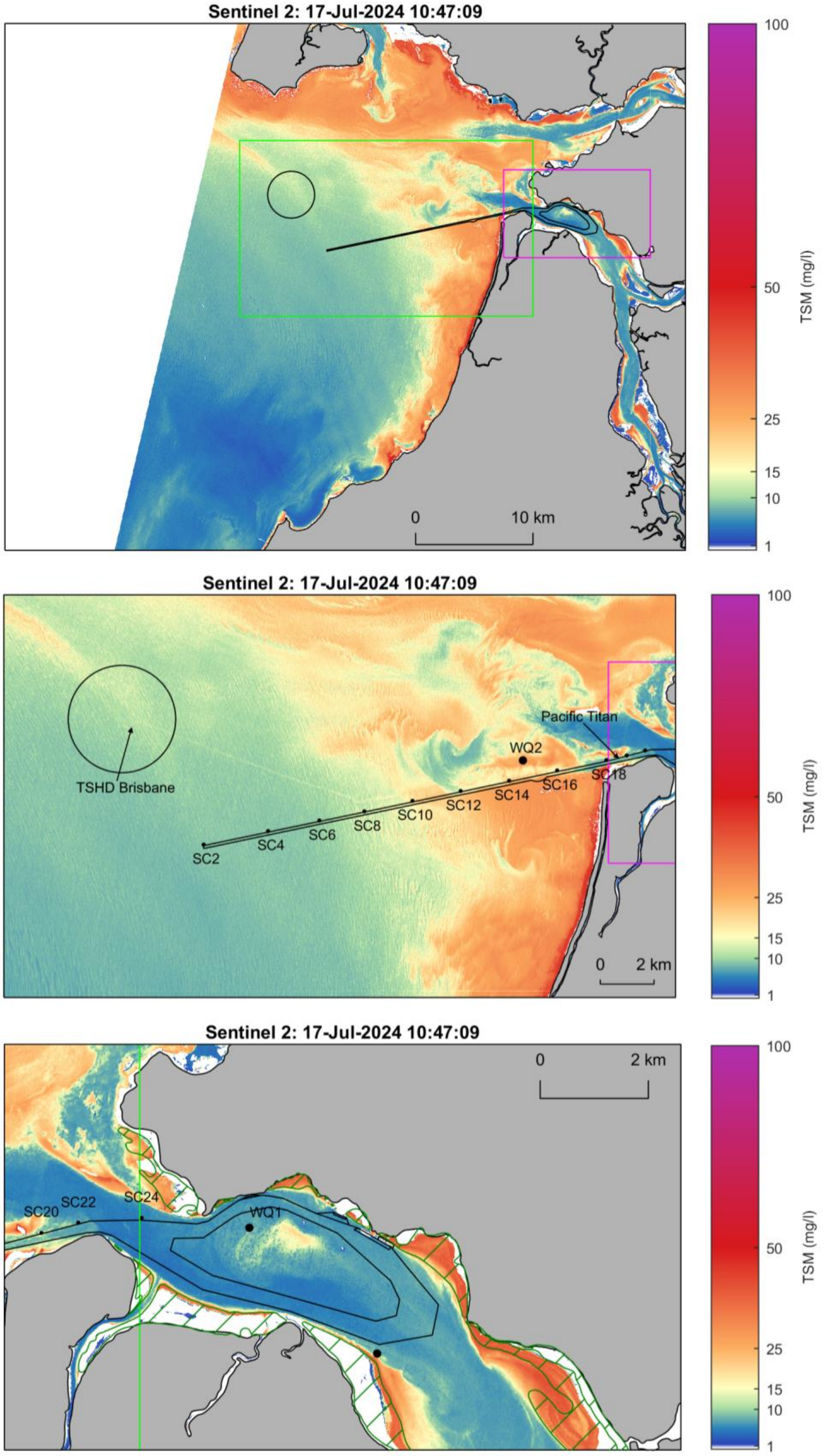
Note: white areas represent cloud cover, red ellipses show plumes and green hashed areas in the Inner Harbour represents the latest seagrass extent.

Figure 14. Satellite-derived TSM from the Sentinel-2 sensor on 02/07/2024 (during second dredging period).



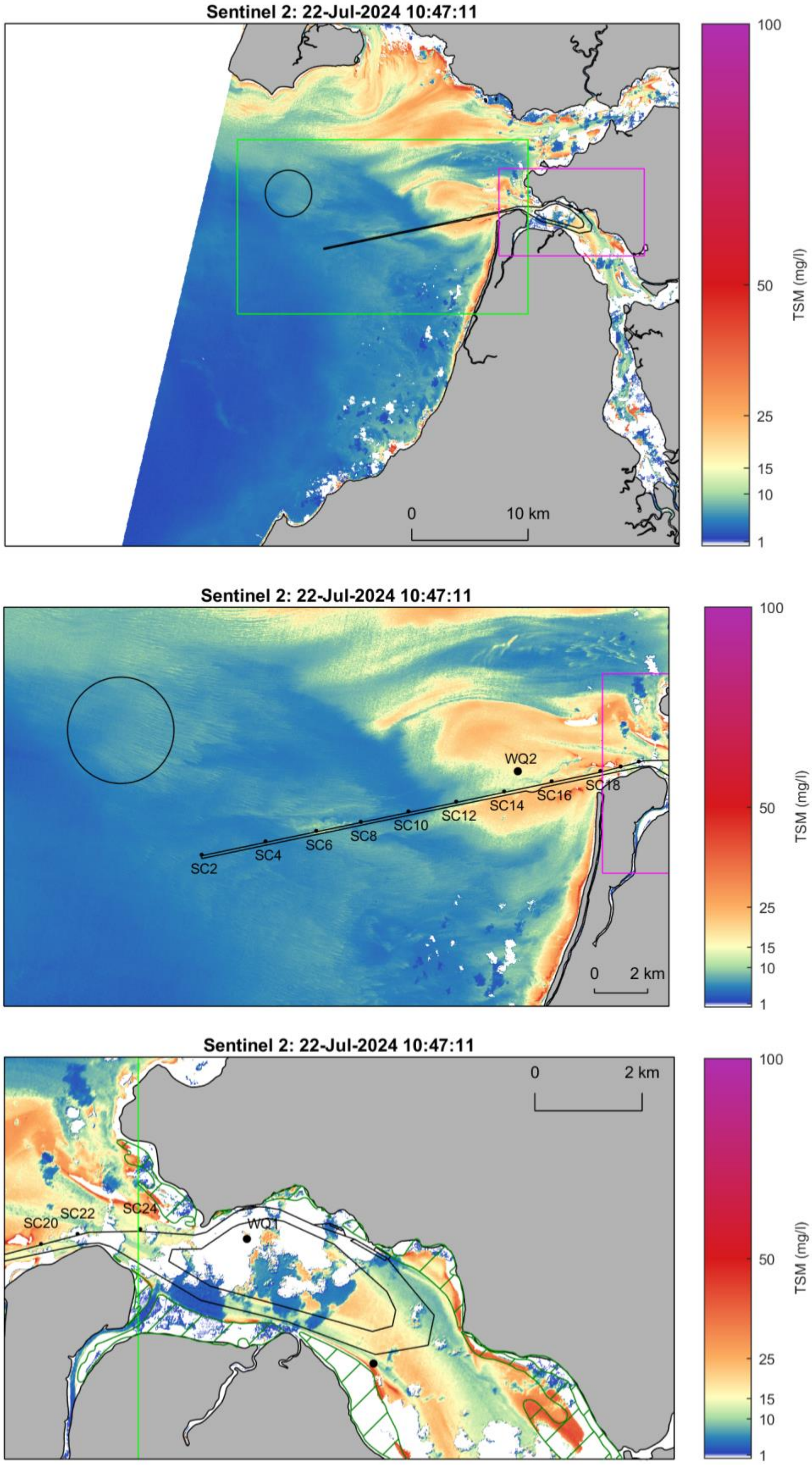
Note: red ellipses show plumes from dredging.

Figure 15. Satellite-derived TSM from the Sentinel-2 sensor on 10/07/2024 (during second dredging period).



Note: green hashed areas in the Inner Harbour represents the latest seagrass extent.

Figure 16. Satellite-derived TSM from the Sentinel-2 sensor on 17/07/2024 (during second dredging period).



Note: white areas represent cloud cover, red ellipses show plumes and green hashed areas in the Inner Harbour represents the latest seagrass extent.

Figure 17. Satellite-derived TSM from the Sentinel-2 sensor on 22/07/2024 (post second dredging period).

4.2.1.2. Dredge Vessel Scale

To further analyse the satellite-derived TSM for increases in TSM due to the maintenance dredging and bed levelling activity, zoomed in plots of the plume shown by Sentinel-2 imagery during periods with visible plumes are shown in Figure 18 to Figure 26.

The plots show how the plume varies depending on the time after the maintenance dredging activity finished:

- up to 15 minutes after dredging finished (Figure 21 and Figure 23): the TSHD Brisbane had just finished dredging a hopper load of silt from the South Channel in the two images. The plots show a higher concentration plume of up to 15 mg/l is present along the track where the vessel dredged (up to 3,000 m in length), but with the plume width being in the order of 150 m and with the plume either remaining within or directly adjacent to the South Channel; and
- 1 to 1.5 hours after dredging finished (Figure 18 and Figure 25): between 1 and 1.5 hours after the TSHD Brisbane finished dredging a hopper load of silt from the South Channel the resultant plumes can be seen to have reduced in concentration to less than 10 mg/l, while the plume extent has significantly increased, with a length of up to 3,800 m and the width varying from 600 to 1,000 m.

The plots show how the maintenance dredging activity can result in a localised plume in the area where the dredging was undertaken with a concentration of up to 15 mg/l immediately after completion of the dredge load. Plots of the residual plume from the maintenance dredging 1 to 1.5 hours after the dredging activity finished show that the residual plume has a concentration of less than 10 mg/l and can extend up to 4,000 m in length and up to 1,000 m in width. In both cases the plume had migrated to the north of the South Channel and had also been advected in an offshore direction.

The satellite imagery has also shown plumes resulting from the bed levelling undertaken by the Pacific Titan. Plumes when the Pacific Titan is actively bed levelling are shown in Figure 20 and Figure 22. The plots show that a small, localised plume of up to 15 mg/l can result from the bed levelling, with a plume width of up to 100 m close to the vessel. The plots indicate that a residual plume can result from repeat bed levelling within a section of the South Channel, with the plume migrating to the north of the channel. The plots indicate a residual plume with a concentration of less than 10 mg/l extending up to 3,000 m in length and 1,000 m in width.

To better understand the increases in TSM at the Albatross Bay DMPA, plots of the plume shown by Sentinel-2 imagery after the TSHD Brisbane had placed sediment there are shown for the following:

- 10 minutes after placement (Figure 26): a plume of up to 15 mg/l with a length of 500 m and a width of 100 m is clearly visible in the DMPA. The plume is in a semi-circular shape as the dredger turns during placement to ensure the sediment is placed where intended and the hopper is completely emptied. There is no residual plume present from the previous placement, which occurred 2 hours 10 minutes prior to the image being captured;
- 25 minutes after placement (Figure 19): a plume of up to 15 mg/l with a length of 750 m and a width of 150 m is clearly visible at the western boundary to the DMPA. The reason for the plume being partially outside of the DMPA is that the ebb tidal current has transported the plume to the west since placement (original placement was within the DMPA). There are no residual plumes present in the DMPA from previous loads, with the previous placement having been 3 hours prior to the image being captured; and
- 1 hour 10 minutes after placement (Figure 24): a plume of up to 10 mg/l with a length of 600 m and a width of 200 m is clearly visible in the northeastern quadrant of the DMPA. There are no obvious residual plumes present in the DMPA from previous loads, with the previous placement having been 3 hours 15 minutes prior to the image being captured.

The plumes resulting from the placement of dredged sediment within the DMPA show how quickly the TSM of the plume reduces following placement, while the extent of the plume increases due to the advection and dispersion of the plume. Plumes from placements more than 2 hours before the satellite image was captured cannot be clearly distinguished from the natural background TSM in the region.

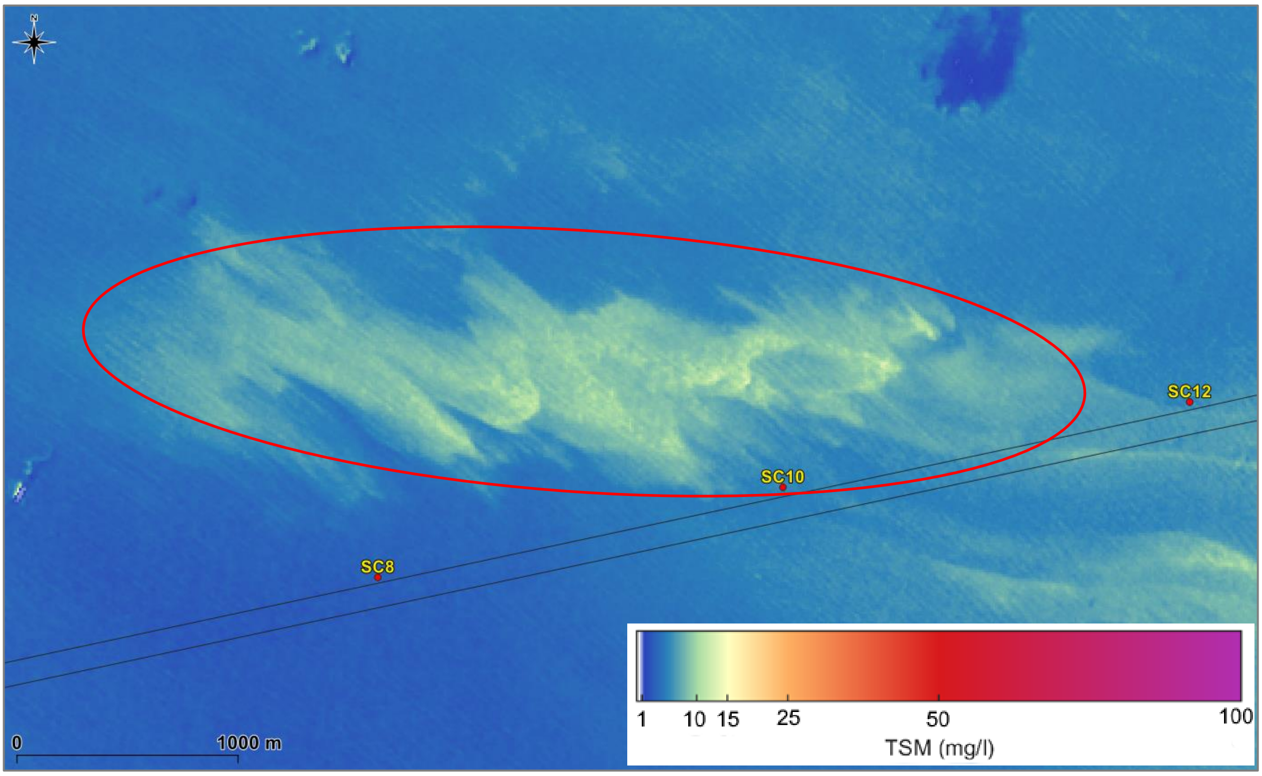


Figure 18. Satellite-derived TSM of South Channel showing a plume from the TSHD Brisbane approximately 1 hour 30 minutes after it finished dredging between SC10 and SC12 on 21/05/2024 at 10:57 AEST.

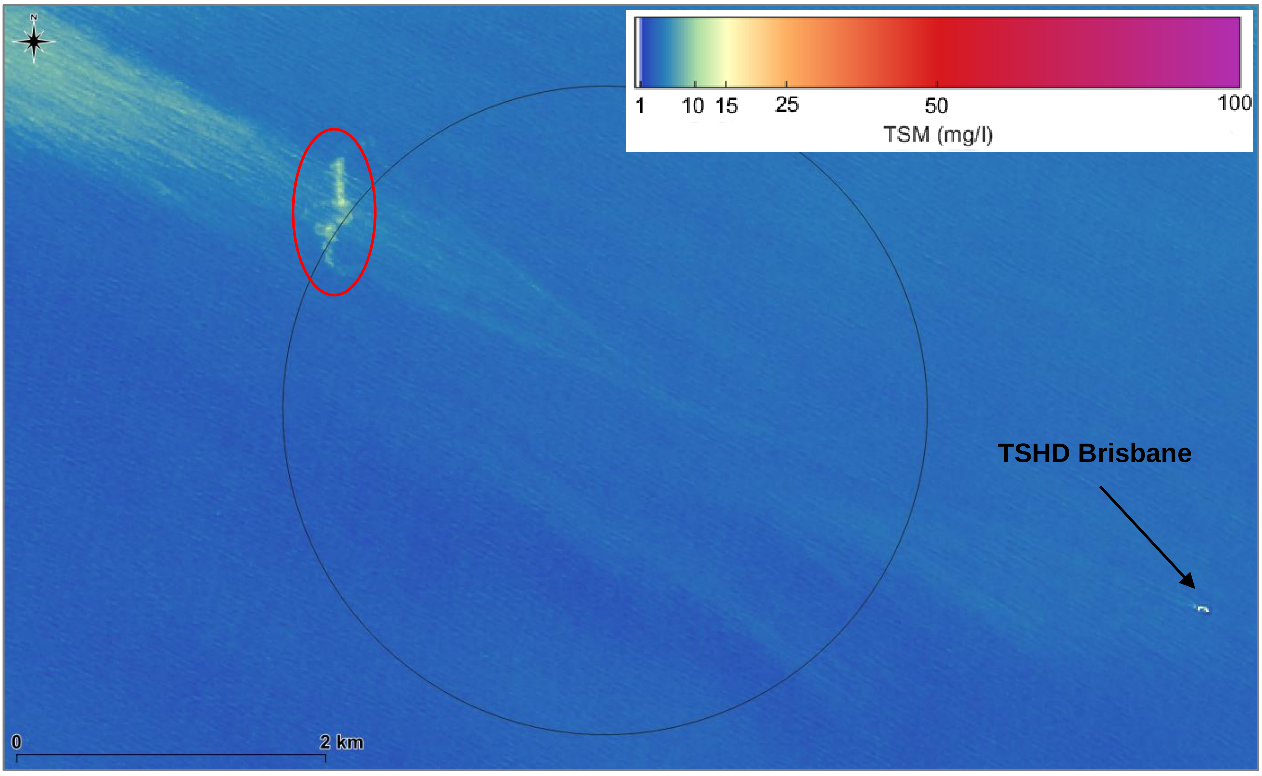


Figure 19. Satellite-derived TSM of the DMPA showing the plume from the TSHD Brisbane 25 minutes after placing at the DMPA on 21/05/2024 at 10:57 AEST.

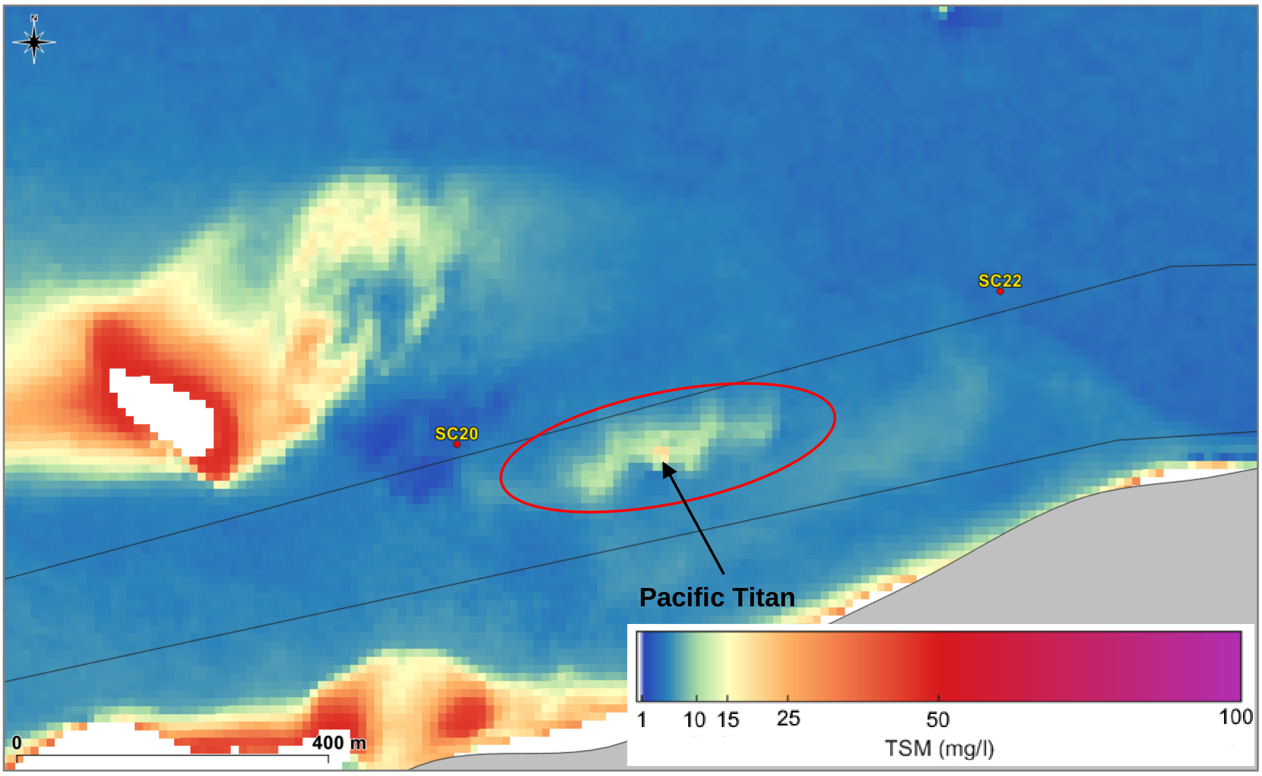


Figure 20. Satellite-derived TSM of South Channel showing a plume from the Pacific Titan while bed levelling on 21/05/2024 at 10:57 AEST.

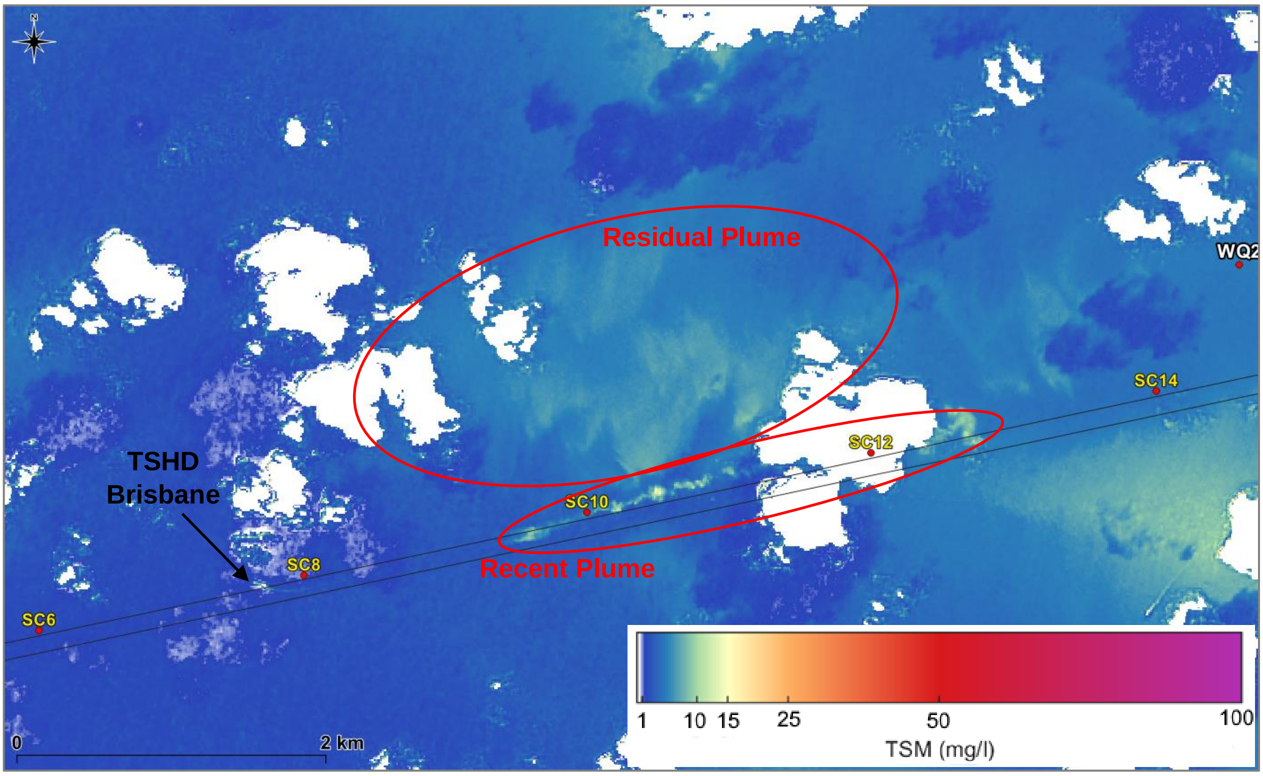


Figure 21. Satellite-derived TSM of South Channel showing a plume from the TSHD Brisbane approximately 5 minutes after it finished dredging between SC10 and SC12 on 02/06/2024 at 10:47 AEST.

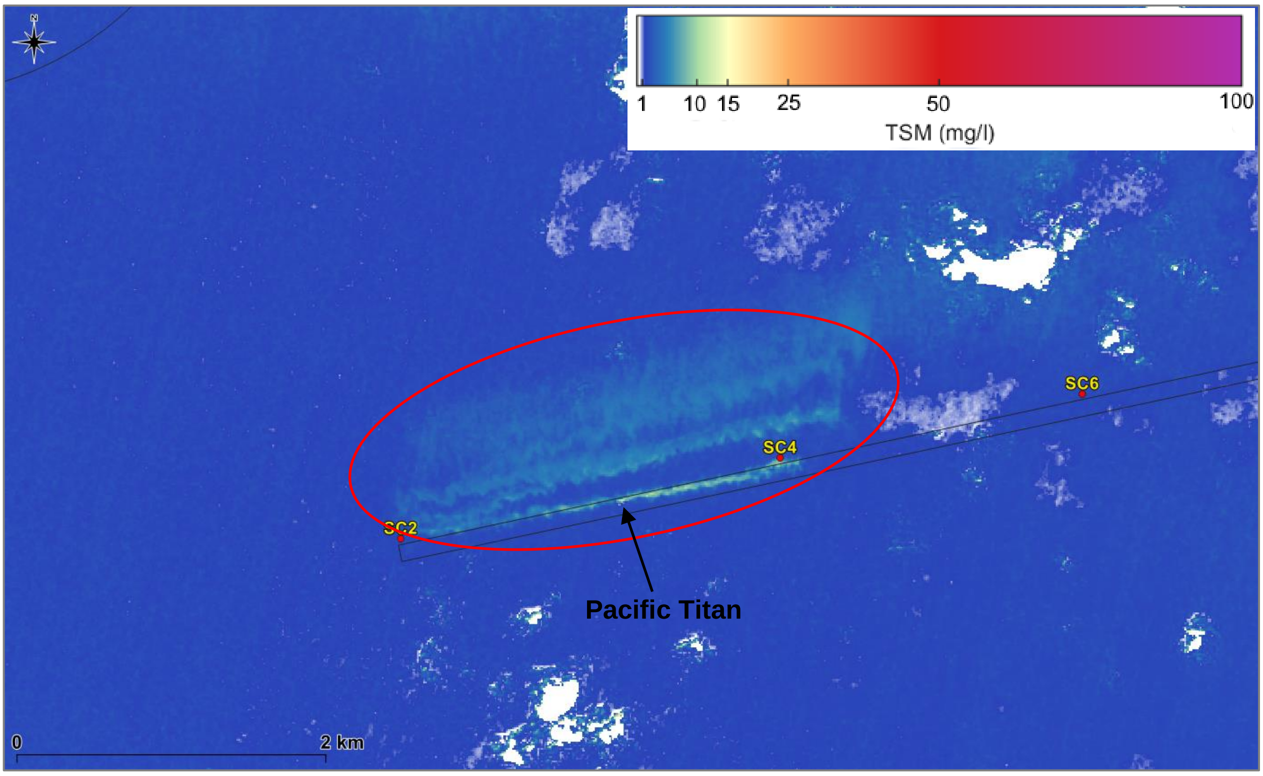


Figure 22. Satellite-derived TSM of the outer reach of the South Channel showing a plume from the Pacific Titan while bed levelling on 02/06/2024 at 10:47 AEST.

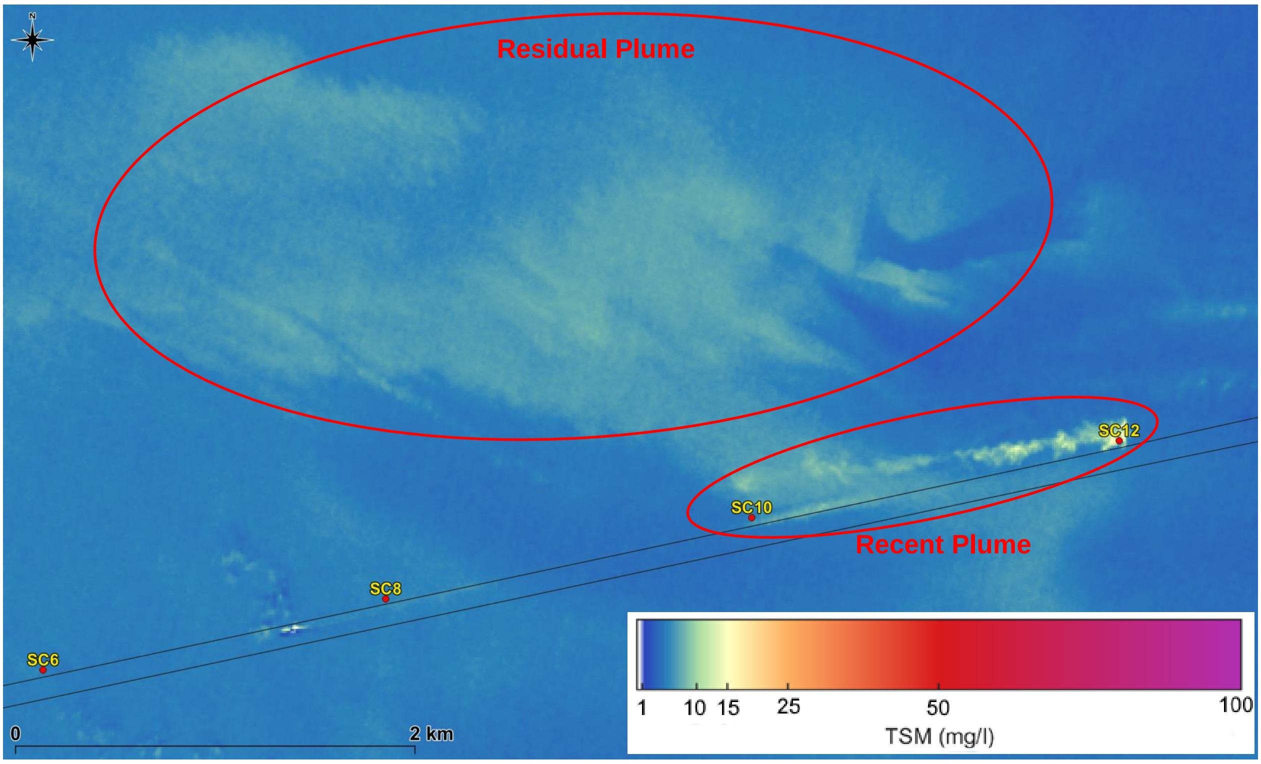


Figure 23. Satellite-derived TSM of South Channel showing a plume from the TSHD Brisbane approximately 15 minutes after it finished dredging between SC10 and SC12 on 02/07/2024 at 10:47 AEST.

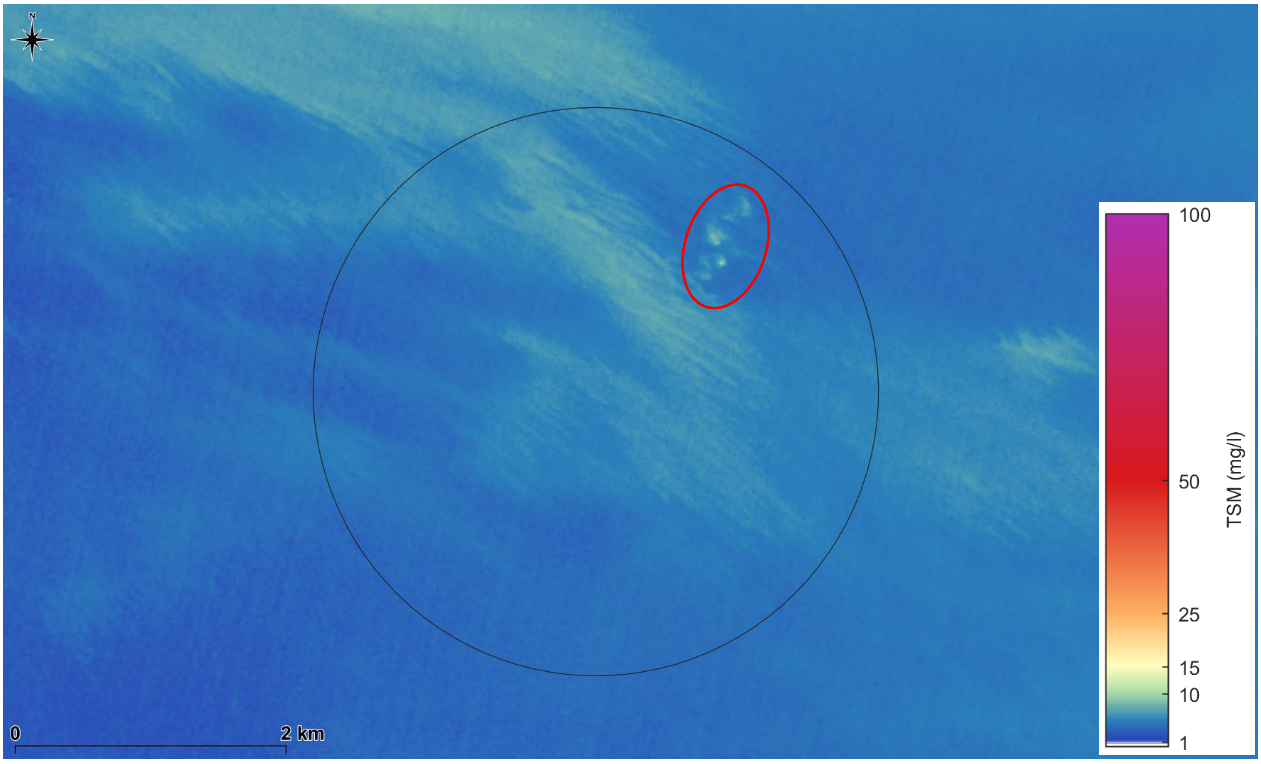


Figure 24. Satellite-derived TSM of DMPA showing the plume from the TSHD Brisbane 1 hour 10 minutes after placing at the DMPA on 02/07/2024 at 10:47 AEST.

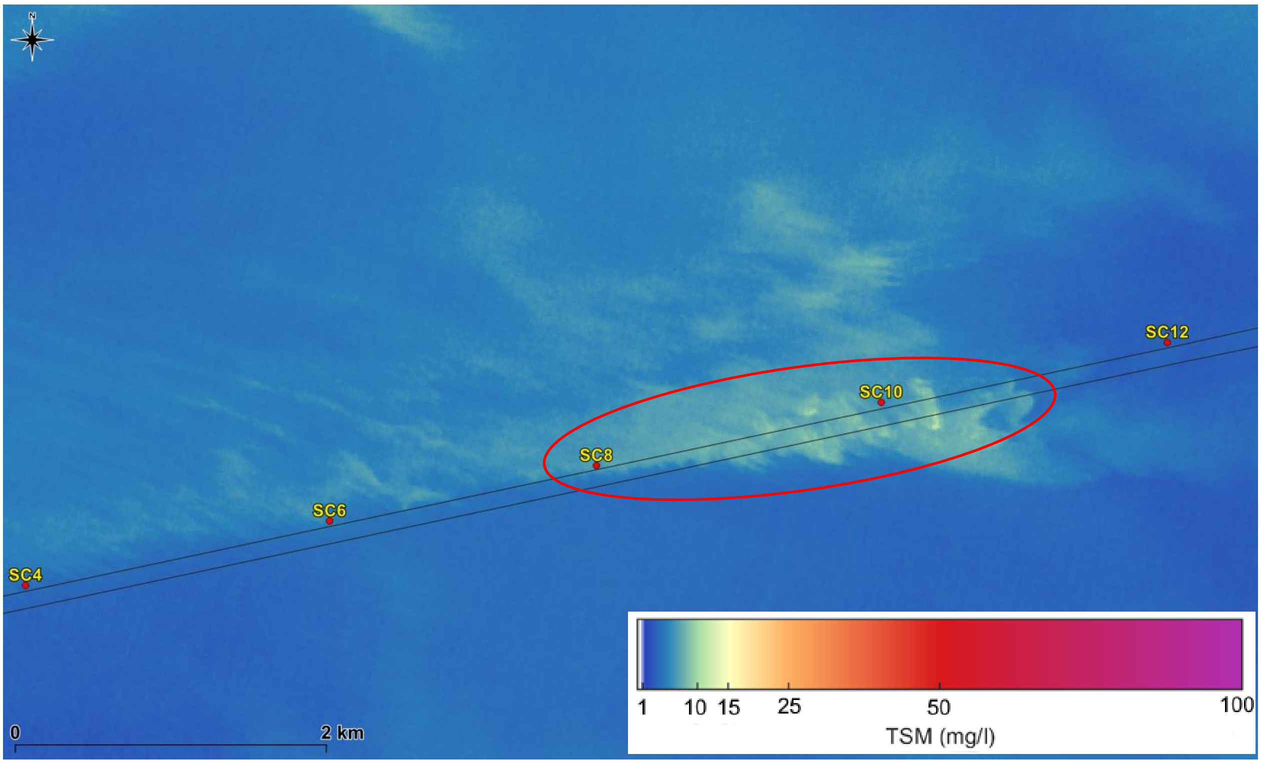


Figure 25. Satellite-derived TSM of South Channel showing a plume from the TSHD Brisbane approximately 1 hour 10 minutes after it finished dredging between SC10 and SC12 on 10/07/2024 at 10:57 AEST.

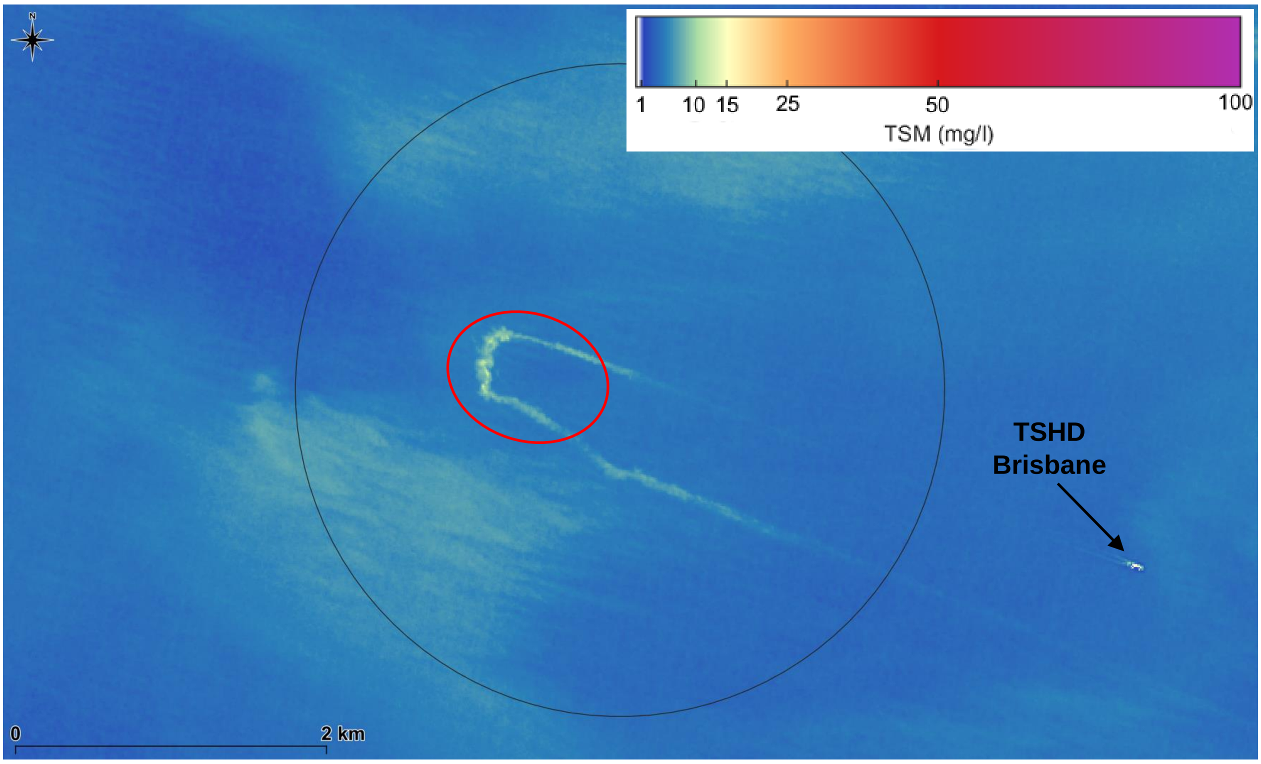


Figure 26. Satellite-derived TSM of DMPA showing the plume from the TSHD Brisbane 10 minutes after placing at the DMPA on 10/07/2024 at 10:57 AEST.

5. Summary

This report has analysed and interpreted turbidity data collected pre-, during and post the two periods of the Port of Weipa 2024 maintenance dredging split program. The 2024 maintenance dredging program was undertaken by the TSHD Brisbane and involved the relocation of 701,000 m^3 of sediment from the dredged areas of the Port to the Albatross Bay DMPA. The data showed that during the dredging program the turbidity around the Port of Weipa was generally driven by the natural conditions (predominantly the astronomical tide, although two wave events also resulted in elevated turbidity), with higher turbidity occurring during periods of larger range spring tides. The key findings from the turbidity data analysis are detailed below:

- the exceedance analysis of the in-situ measured benthic turbidity data showed that the duration exceedances were below the average duration exceedance at all sites during the first dredging period, while during the second dredging period they were below the average duration exceedance at WQ1 while at WQ2 and WQ4 they were well below the 90^{th} percentile duration exceedance. The results therefore show that the turbidity over the whole period was well within the natural variability for the region;
- all of the plumes resulting from maintenance dredging (including those from both dredging and placement) and bed levelling were found to remain relatively close to where they were created. Plumes generated in the South Channel were shown to have the potential to migrate to the north of the channel and in an offshore direction. Overall, the results showed that little net residual transport occurs in the region, this was also noted during the 2019 to 2023 maintenance dredging programs and as part of the Port of Weipa Sustainable Sediment Management assessment (PCS, 2019, 2020, 2021, 2022, 2023). Based on this, it can be assumed that the majority of the sediment suspended by the maintenance dredging and bed levelling is subsequently redeposited close to where it was either dredged or placed;
- the dredging and placement activities associated with the Port of Weipa 2024 maintenance dredging program were found to result in visible plumes. Plumes were observed close to the dredger and bed leveller when operating, adjacent to the South Channel and within and adjacent to the Albatross Bay DMPA. The size and concentration of the plumes was variable depending on both the dredging and bed levelling activities;
  - the largest plume, which was due to repeat maintenance dredging loads in the South Channel, was up to 3,800 m in length and 1,000 m in width with a concentration of up to 10 mg/l, occurred adjacent to the South Channel. Satellite imagery indicated that a localised plume was regularly present around the South Channel as this was where the majority of the maintenance dredging was undertaken; and
  - plumes in the DMPA from the placement of dredged sediment were typically less than 800 m in length and only persisted for short durations (in the order of hours). The observed plumes were consistent with placement by the TSHD Brisbane during previous annual maintenance dredging programs.
- the Port of Weipa 2024 maintenance dredging program did not influence the regional turbidity in the area. The dredging only influenced the local turbidity close to where dredging was undertaken in the Port and where placement occurred at the Albatross Bay DMPA. Natural variations in turbidity driven by the tide and wave conditions over the monitoring period were larger than the variations in turbidity due to the maintenance dredging. The satellite imagery showed that the turbidity in the area of the seagrass meadows in the Inner Harbour was predominantly controlled by natural processes over the 2024 maintenance dredging program, with no visible plumes from the dredging activity observed in the seagrass meadows; and
- the post dredging satellite imagery showed that 3.5 days after dredging ended there were no plumes from the dredging or placement activities in the South Channel, Inner Harbour or DMPA. This is in agreement with findings from previous dredge programs (2020, 2022

and 2023) where satellite imagery showed that the turbidity had returned to natural conditions within one to four days after the end of the dredging activity (PCS, 2020, 2022, 2023).

6. References

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