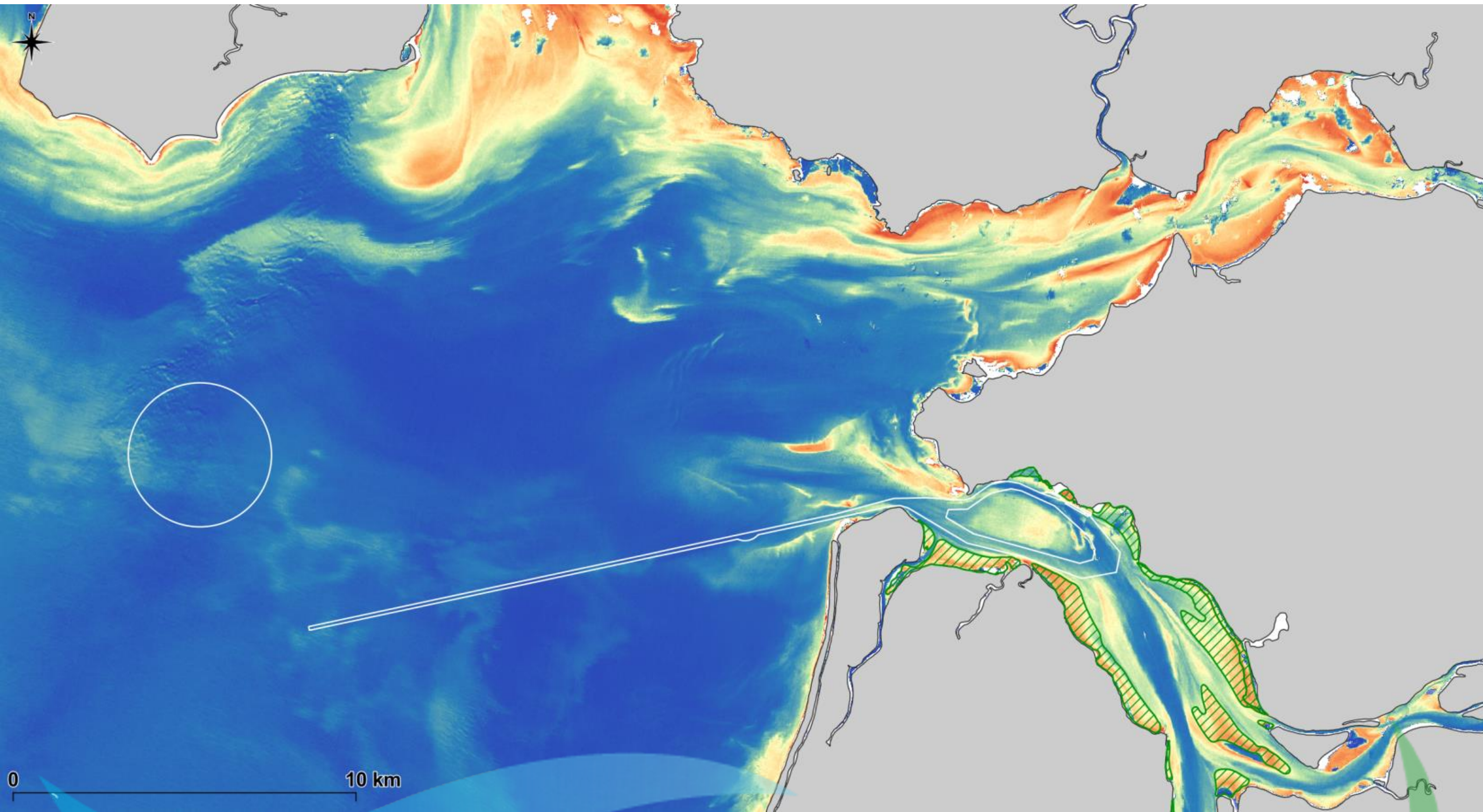
Port of Weipa, 2023 Maintenance Dredging

Summary of Turbidity Monitoring

Report No. P065_R02v02



Technical Report
October 2023

PORT & COASTAL SOLUTIONS

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North Queensland Bulk Ports Corporation Ltd

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Executive Summary

North Queensland Bulk Ports Corporation (NQBP) commissioned Port and Coastal Solutions Pty Ltd (PCS) to undertake work to support the 2023 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 2023 maintenance dredging program was undertaken by the TSHD Brisbane and involved the relocation of 782,000 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), 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 shows that the duration exceedances were below the average duration exceedance at WQ2 while at WQ1 the exceedance duration was above the average duration exceedance, but below the 90th percentile duration exceedance and at WQ4 the duration was above the 90th percentile duration but well below the maximum duration. The results therefore show that the turbidity in the Inner Harbour (i.e. at both WQ1 and WQ4) was higher than the turbidity in Albatross Bay relative to the updated turbidity intensity thresholds. Based on this it would be beneficial to undertake a further analysis and revisit updating the turbidity intensity thresholds;
- 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 2022 maintenance dredging programs and as part of the Port of Weipa Sustainable Sediment Management assessment (PCS, 2019b, 2020a, 2020b, 2021a, 2022). 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 2023 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, within the Inner Harbour channels and within the Albatross Bay DMPA. The size and concentration of the plumes was variable and depending on both the dredging and bed levelling activities and the metocean conditions (i.e. larger plumes occurred during spring tides or periods with larger waves when sediment naturally remains in suspension for longer):
  - the largest plume which was due to combined maintenance dredging and bed levelling was up to 7,500 m in length and 1,500 m in width with a concentration of up to 10 mg/l, occurring adjacent to the South Channel. Satellite imagery indicated that

  a 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 1,000 m in extent 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 2023 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 in 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 2023 maintenance dredging program, with no visible plumes from the dredging activity observed in the seagrass meadows; and
- the post dredging satellite imagery showed that a residual plume could still have been present around the South Channel 36 hours after the dredging had finished (although this could have been due to natural resuspension of recently deposited sediment suspended by the dredging), but no plume was present in the DMPA. The image captured 3.5 days after dredging ended did not show any indication of 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 and 2022) 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, 2020a, 2022).

1. Introduction

North Queensland Bulk Ports Corporation (NQBP) commissioned Port and Coastal Solutions Pty Ltd (PCS) to undertake work to support the 2023 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 21 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; 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 2023 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 2022/23 wet season, but issues with the Albatross Bay waverider buoy (WRB) meant that the wave conditions were not captured during all of the large wave events. Subsequent analysis of bathymetric data collected since the wave events estimated a sedimentation volume since completion of the 2022 maintenance dredging in the order of 900,000 m^3 in the South Channel (including batters).

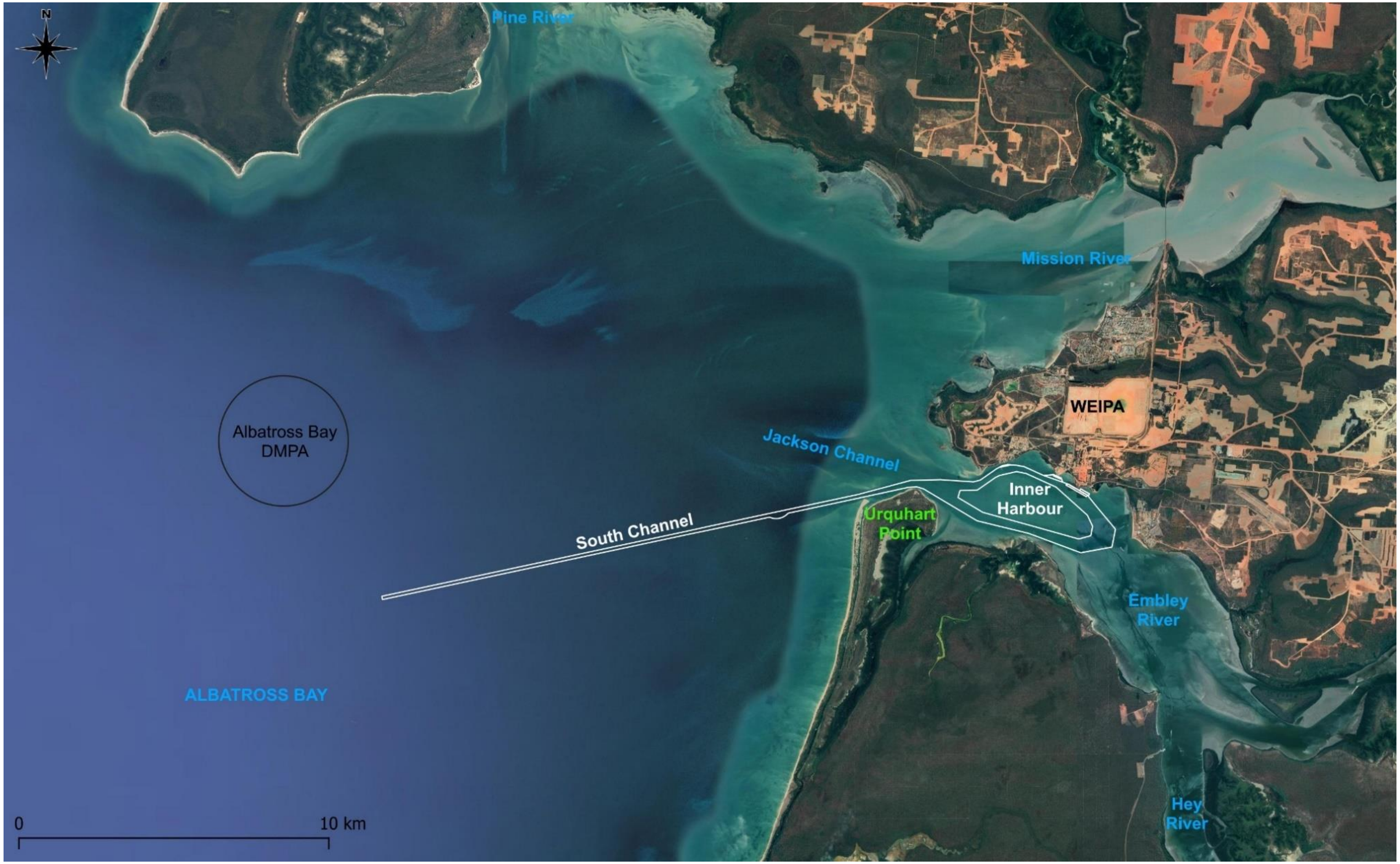


Figure 1. Layout of the Port of Weipa.

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

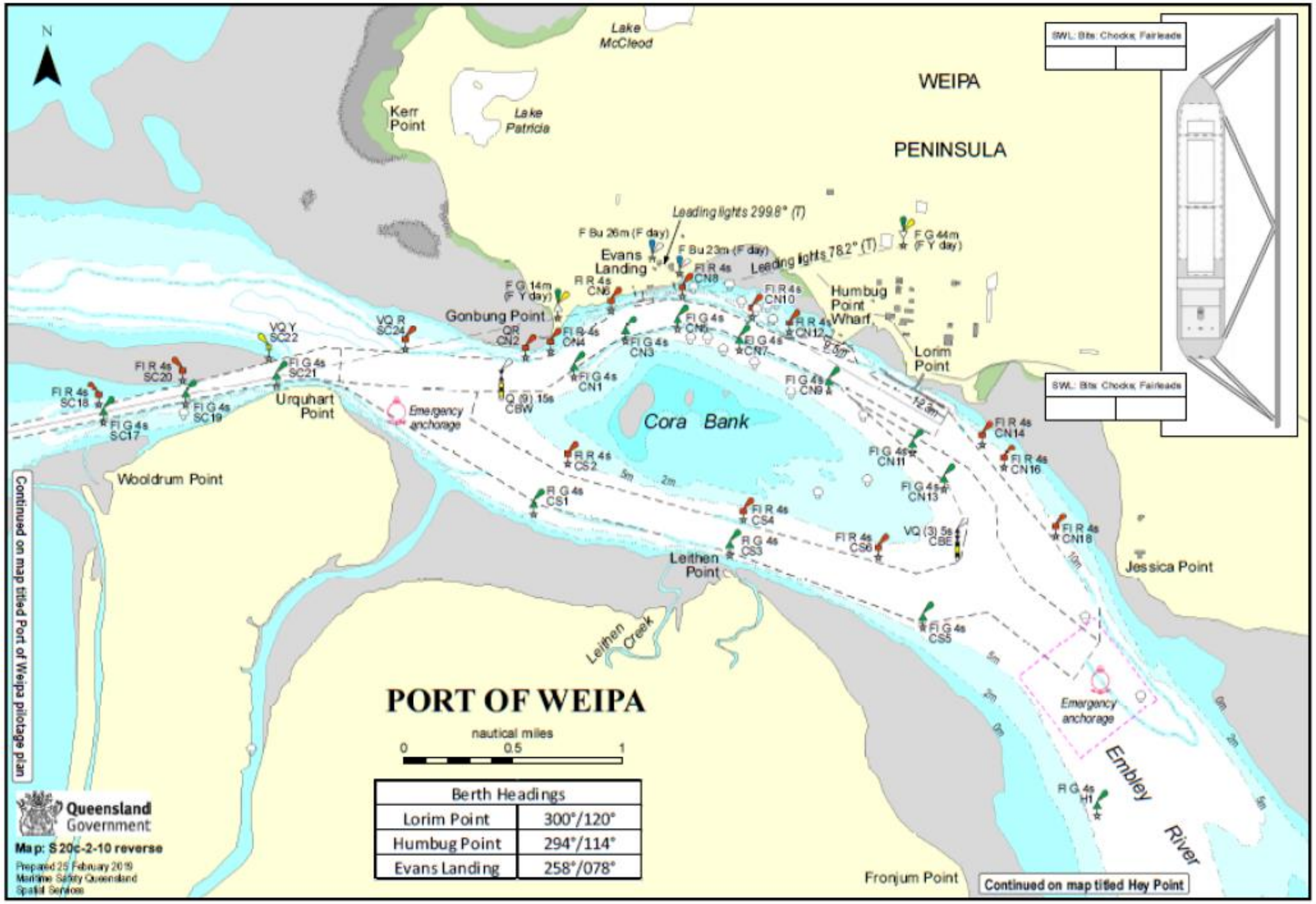
The Port of Weipa 2023 maintenance dredging program commenced at 15:55 Australian Eastern Standard Time (AEST) on the 5th May 2023 and was completed at 21:40 AEST on the 19th June 2023. Over the 45 day period a total of 410 dredge hopper loads were relocated to the Albatross Bay DMPA, with an average of just over 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 782,000 m^3 (PCS, 2023a). The majority of the maintenance dredging was focussed in the South Channel, although some maintenance dredging along with extensive bed levelling was undertaken in the Inner Harbour. It is important to note that the maintenance dredging requirement within the South Channel was not uniform, with almost 75% of the dredge loads removed from between SC6 and SC12 which represents approximately 30% of the total length of the South Channel (5.5 km of the total 17.5 km length of the channel). Although only 6% of the dredge loads were from the Inner Harbour, extensive bed levelling was also undertaken in the Inner Harbour. Bed levelling occurred from the 12th May until the end of the dredge program. For the majority of the dredge program the bed levelling targeted sedimentation in the Approach Channel adjacent to Cora Bank, along sections of the Departure Channel adjacent to Cora Bank and within the berth pockets and their approaches. Bed levelling was also undertaken in the South Channel, this was predominantly over the last week of the dredge program.

The following details the percentage of the total loads which were removed from the different port areas:

- South Channel, SC2 to SC6 (Figure 3): approximately 2% of the total number of dredge loads were removed from this area of the South Channel;
- South Channel, SC6 to SC10 (Figure 3): approximately 52% of the total number of dredge loads were removed from this area of the South Channel;
- South Channel, SC10 to SC14 (Figure 3): approximately 32% of the total number of dredge loads were removed from this area of the South Channel;
- South Channel, SC14 to SC18 (Figure 3): approximately 2% of the total number of dredge loads were removed from this area of the South Channel;
- SC18 to Urquhart Point (Figure 3): approximately 6% of the total number of dredge loads were removed from this area of the South Channel; and
- Inner Harbour (Figure 4): approximately 6% of the total number of dredge loads were removed from the Inner Harbour.

All of 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.

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).



Berth Headings	
Lorim Point	300°/120°
Humbug Point	294°/114°
Evans Landing	258°/078°

Source: MSQ (2019)

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

2.1. Metocean Conditions

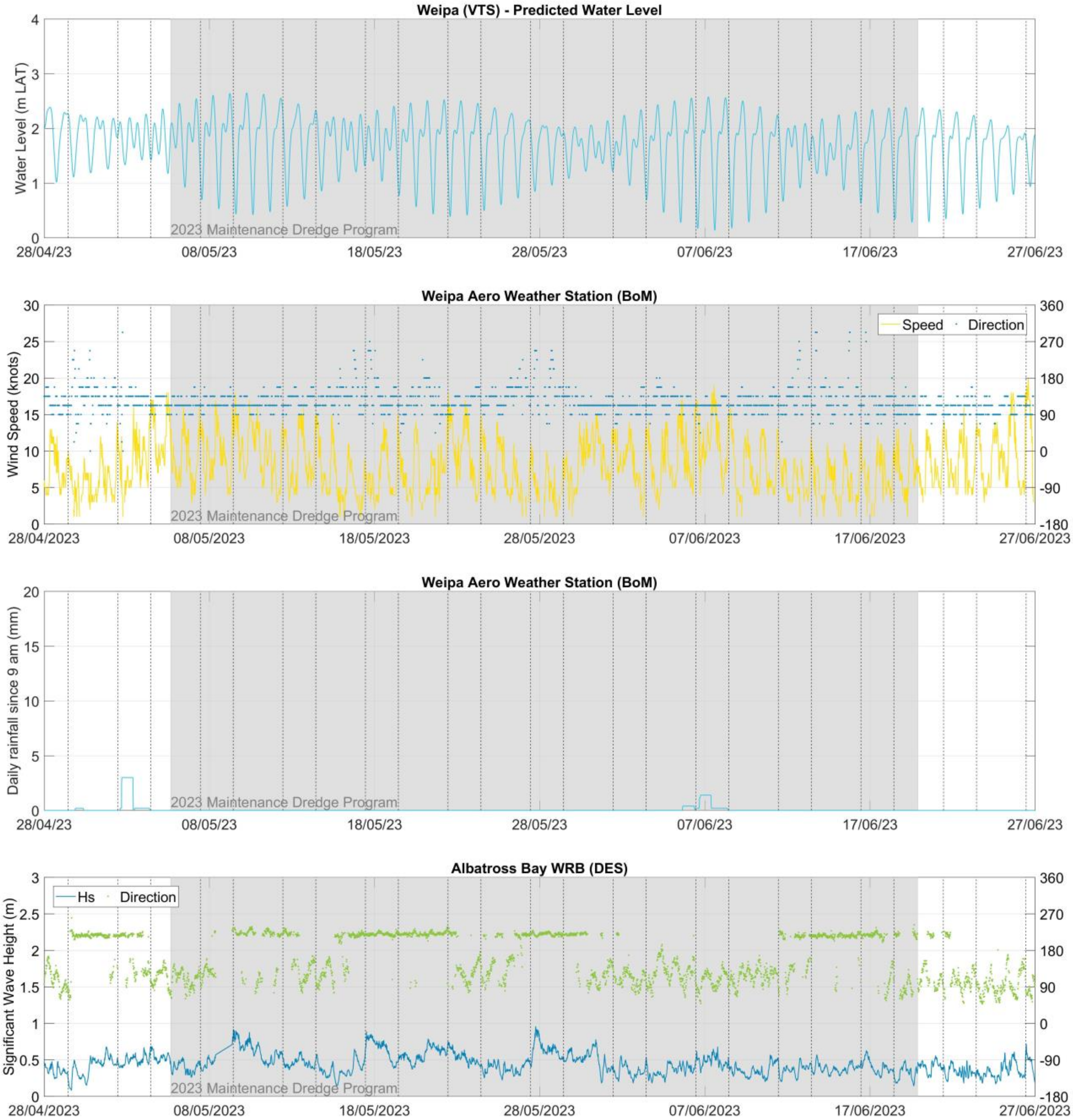
To provide an understanding of the metocean conditions over the pre-, during and post dredging periods, the following data have been sourced:

- 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 the Albatross Bay waverider buoy (WRB) (Figure 3) (provided by the Department of Environment and Science (DES)).

The metocean conditions over the entire monitoring period are shown in Figure 5, with shading indicating the period of maintenance dredging. The dashed and dotted lines indicate when high resolution satellite images were captured (refer to Section 4.2). The figure shows the following:

- the metocean conditions are fairly consistent and can be considered to generally represent calm to moderate dry season conditions;
- the winds are relatively consistent over the whole period, with peak speeds during the day of 10 to 15 knots and lighter winds overnight. Wind directions are typically from the east to south-east (i.e. from the coast at Weipa) throughout the period;
- rainfall was very low throughout the whole period. There were six days over the whole period when rain occurred and the rainfall amount was less than 2 mm for five of these days and less than 4 mm for the remaining day. For reference, the mean monthly rainfall at Weipa is 107, 21 and 4 mm for April, May and June, respectively and with 7, 2 and 0.4 days per month experiencing more than 1 mm daily of rainfall; and
- the wave conditions over the pre-, during and post dredge periods varied between the south-east (offshore) and south-west (onshore). The significant wave heights (H_s) were generally less than 0.5 m for the majority of pre- and post dredge periods. There were three wave events during dredging when the H_s increased close to 1 m, these were all with a wave direction from the south-west 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 some localised resuspension of fine-grained sediment in shallow areas of Albatross Bay could have occurred during the three wave events during the dredging when the H_s increased above 0.5 m and peaked close to 1 m.



Note: Dashed lines indicate times when satellite images were obtained and analysed, grey shaded area shows 2023 maintenance dredge program.

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 (ranges from 4.4 m at WQ1 to 4.8 m at WQ4).

The instruments were serviced prior to the 2023 maintenance dredging program commencing and again immediately after the maintenance dredging was completed (but prior to the seven day post dredging period) and finally retrieved for data download approximately two months after completion of the dredging program. Data up to the 30th June 2023 were provided by JCU.

The data return for the measured turbidity data over the 2023 maintenance dredging monitoring period, which includes 7 days pre-dredging, 45 days during dredging and 7 days post dredging (59 days in total), was 100% at WQ1 and WQ2 and 99.5% at WQ4.

3.1. Previous Analysis

Benthic turbidity data from the ongoing ambient monitoring were analysed by PCS (2019a and 2020a) to understand the natural variability in turbidity at the three monitoring sites. The analysis undertaken prior to the 2019 maintenance dredging program suggested that the 95th percentile turbidity for the dry season period could be used as a representative benthic turbidity threshold for the 2019 maintenance dredging program. The subsequent more detailed 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.

During the 2021 maintenance dredging program it was noted that the benthic turbidity threshold was exceeded significantly more at site WQ4 compared to sites WQ1 and WQ2 (PCS, 2021a). Based on the available information it was concluded that this was a result of a change in the natural turbidity at the site since the threshold was defined. Based on this, the benthic turbidity thresholds were reviewed and updated using data collected at the sites between January 2018 and August 2021. The resultant 90th and 95th percentile turbidity intensity thresholds for the dry season period at the three ambient water quality monitoring sites, which were adopted for the water quality analysis undertaken for the 2022 maintenance dredging program and have also been adopted for this assessment, are shown in Table 1. The table shows that the thresholds at all three of the monitoring sites increased as a result of the updated analysis undertaken by PCS (2021b).

[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 (2021b) along with previous values in brackets.

Location	90th Percentile Turbidity Threshold (NTUe)	95th Percentile Turbidity Threshold (NTUe)
WQ1	19 (17)	29 (21)
WQ2	23 (15)	47 (25)
WQ4	27 (18)	44 (28)

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

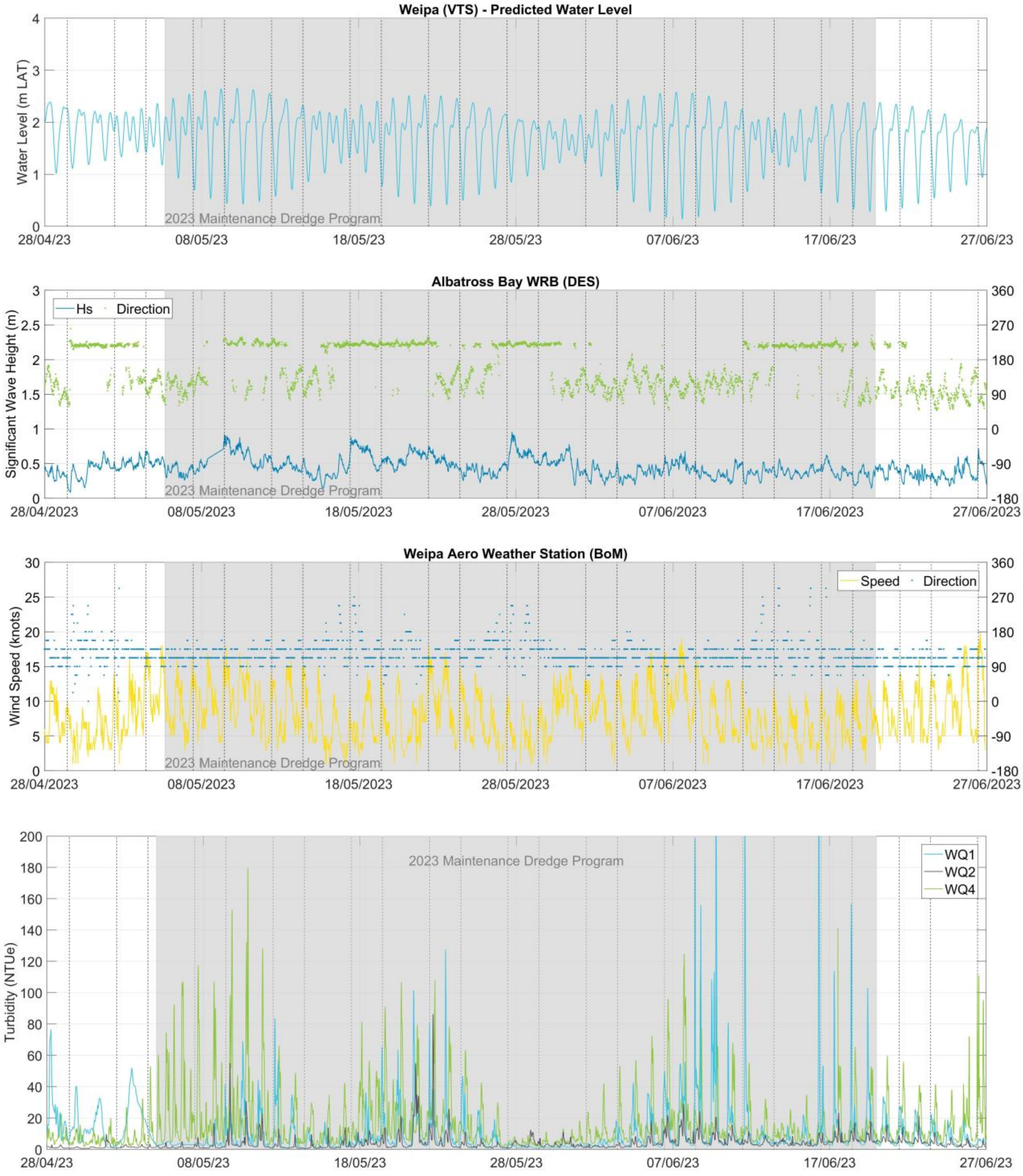
The measured benthic turbidity data at the three monitoring sites, along with the predicted water level for the Port of Weipa (calculated by BoM) and the measured wave conditions in Albatross Bay (from the DES WRB in Albatross Bay) are shown in Figure 6, while individual plots for each monitoring site are shown in Figure 7. The figure shows that there is a clear tidal signal in the turbidity data at the three sites (during the pre-, during and post dredge periods), with increased turbidity correlating with the larger tidal range over spring tides.

The turbidity data at WQ4 has regular peaks in turbidity which are typically higher than at the other two sites throughout most of the monitoring period. These peaks typically exceed 80 NTUe during the larger spring tidal ranges, while at WQ1 (the other Inner Harbour site) the peaks typically remained below 80 NTUe except over the last 10 days of the dredge program when the peaks in turbidity at WQ1 were typically higher than at WQ4 (and exceeded 100 NTUe on multiple occasions). The higher peaks in turbidity at WQ4 were observed during the 2021 and 2022 maintenance dredging programs and as a result the turbidity intensity thresholds were updated (see Section 3.1). Based on this, the exceedance durations at WQ4 should be more in line with the durations at the other two sites.

At WQ1 the measured turbidity data over the 7 day pre-dredging period was significantly higher than at the other two sites, and the data also did not show the typical pattern with a peak during the flood/ebb stage of the tide followed by a period of very low turbidity during slack water. The data over this period were not flagged by the JCU quality check procedure, but nevertheless the data appear to be erroneous.

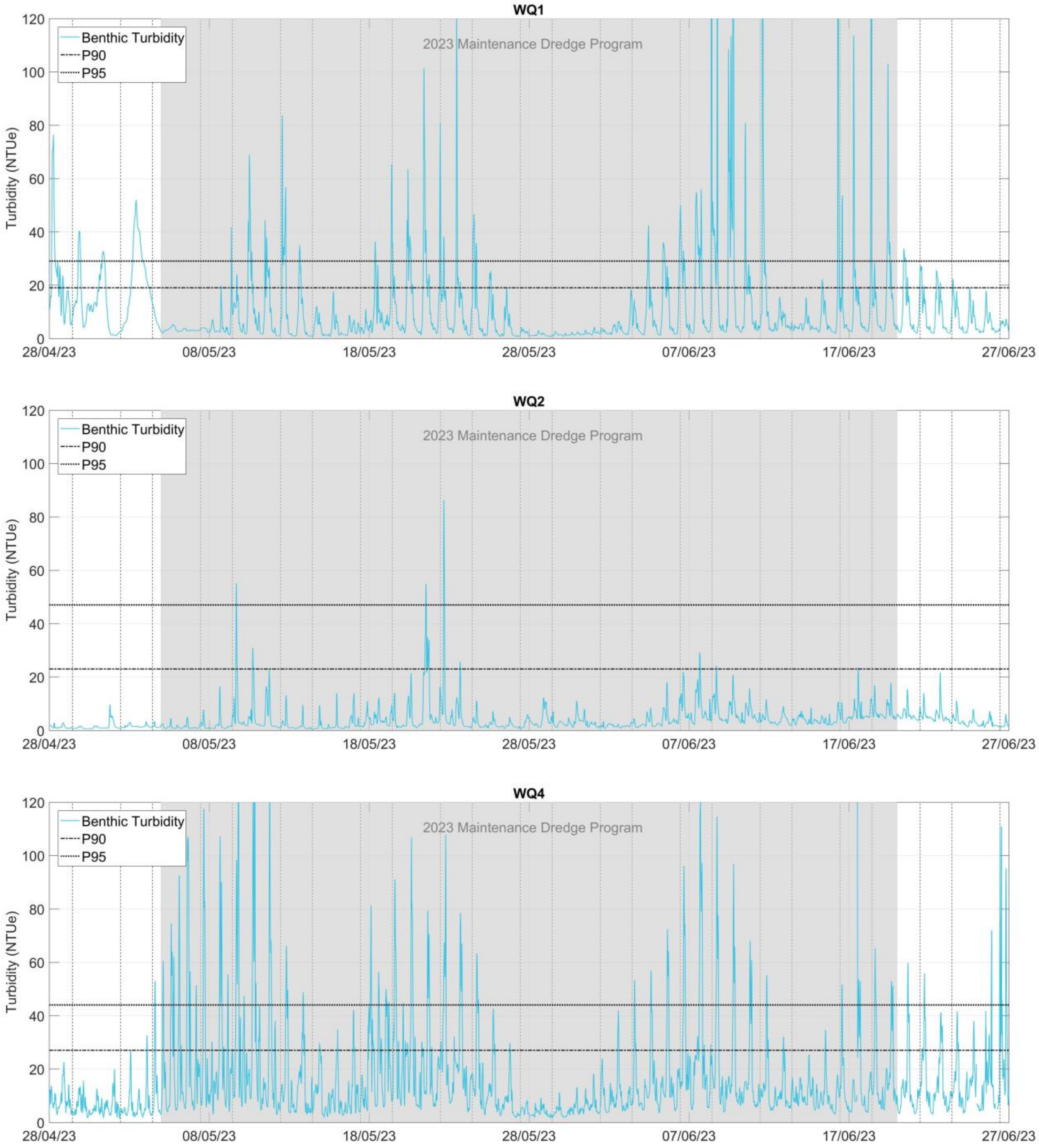
Based on the benthic turbidity data at the sites it appears that the turbidity over the pre-, during and post dredging periods of the 2023 maintenance dredging program was predominantly controlled by the metocean conditions. With the turbidity at all three monitoring sites increasing during spring tides and reducing during neap tides.

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 were exceeded is shown in Table 1 and analysed in the following section.



Note: Dashed lines indicate periods when Sentinel-2 satellite images were obtained and analysed, grey shaded area shows dredge period.

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 dashed lines indicate periods when Sentinel-2 satellite images were obtained and analysed, grey shaded area shows dredge period.

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 both the 90th and 95th percentile benthic turbidity intensity thresholds were exceeded at the three monitoring sites was calculated over 7 days pre-dredging, the 45 days during dredging and 7 days post dredging for the 2023 maintenance dredging program (Table 2). The timeseries plots presented in Figure 5 show that the metocean conditions were relatively consistent and calm throughout the pre-, during and post-dredging periods.

However, the plots also show that the 7 day pre-dredge period coincided with smaller range tides (mainly neaps), light winds (less than 10 knots for the majority of the time) and small wave heights (H_s of less than 0.6 m) compared to the conditions during and post dredging. As previously noted in Section 4.1, the measured turbidity at WQ1 over the 7 day pre-dredging period was significantly higher than at the other two sites and the data did not show the typical pattern and so the data are considered erroneous, meaning that the exceedance duration at WQ1 over this period also considered to be erroneous.

The suggested duration triggers for the 90th percentile turbidity intensity threshold for a 40 day dredge period are presented in PCS (2021b). 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. If the dry season thresholds are scaled up to represent a 45 day period, then the exceedance durations during the dredging are less than the average duration of exceedance at WQ2 (108 hours), while at WQ1 they are more than the average duration (108 hours) but below the 90th percentile duration (170 hours) and at WQ4 they are above the 90th percentile duration but well below the maximum duration (338 hours). At WQ2 where the average duration was not exceeded, the turbidity during the dredging period was well within the range of natural variability and as such no adaptive monitoring would have been implemented should real time monitoring have been undertaken at these sites. At WQ1 where the average duration was exceeded but the 90th percentile duration was not exceeded, an investigation into the cause of the elevated turbidity would have been required should real time monitoring have been undertaken at these sites. At WQ4 where both the average duration and 90th percentile duration were exceeded, an investigation into the cause of the elevated turbidity would have been required and mitigation measures may have also been required, if found to be the result of maintenance dredging activities.

Table 2. Duration of exceedance of the previously derived benthic turbidity intensity thresholds over the Port of Weipa 2023 maintenance dredging program.

Location	7 days Pre-Dredging (hrs)		45 days During Dredging (hrs)		7 days Post-Dredging (hrs)	
	90th %ile	95th %ile	90th %ile	95th %ile	90th %ile	95th %ile
WQ1	58.2[1]	27.8[1]	154.3	91.2	13.7	3.2
WQ2	0	0	15.0	3.2	0	0
WQ4	2.7	1.0	182.8	93.7	24.8	6.8

[1] the measured turbidity data over this period appears to be erroneous and so the exceedance durations are not considered to provide a reliable representation of the conditions at this site (which are likely to have been closer to the conditions at WQ4 (i.e. very low exceedance durations).

The exceedance results show that the turbidity at WQ1 and WQ4 was significantly higher than the turbidity at WQ2 relative to the updated turbidity intensity thresholds both during the dredging and over the 7 days post dredging. This suggests that either the dredging activity resulted in a significant increase in turbidity at these two sites in the Inner Harbour during and after the dredging (despite the majority of the dredging being in the South Channel) or that the updated thresholds do not accurately represent the existing natural turbidity at these two sites. The satellite-derived data presented in the following section will be used to help determine the cause. The updated thresholds were based on measured turbidity data from January 2018 to August 2021. However, the natural turbidity at WQ1 and WQ4 has remained higher since November 2020 and so the updated analysis is based on a combination of lower and higher turbidity data. Based on this it would be beneficial to undertake a further analysis and revisit updating the turbidity intensity thresholds just using measured data which can be considered to represent the existing natural turbidity at the sites (i.e. since November 2020).

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 2023 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.

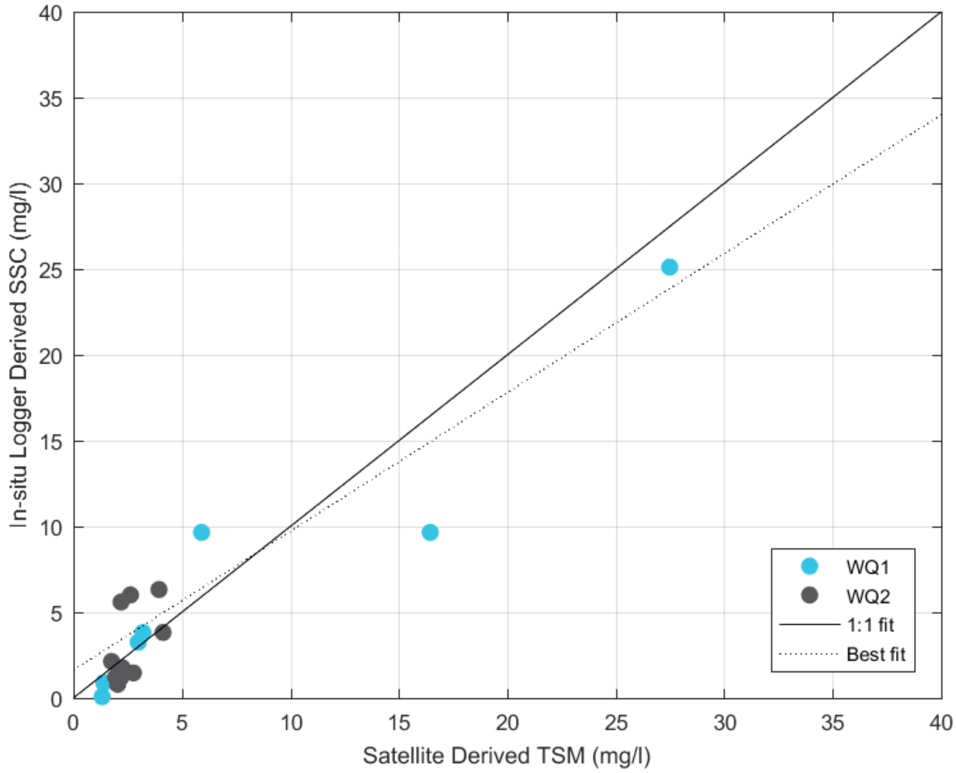


Figure 8. **Correlation between satellite derived TSM from Sentinel-2 and in-situ logger derived SSC during the 2021 maintenance dredge monitoring period.**

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 2023 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 the dredge period 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 can be difficult to identify from the lower resolution Sentinel-3 imagery. Based on that, the technical note provided during dredging focussed on satellite imagery from the Sentinel-2 sensor (PCS, 2023b). This post dredging report also focusses on imagery from the Sentine-2 sensor.

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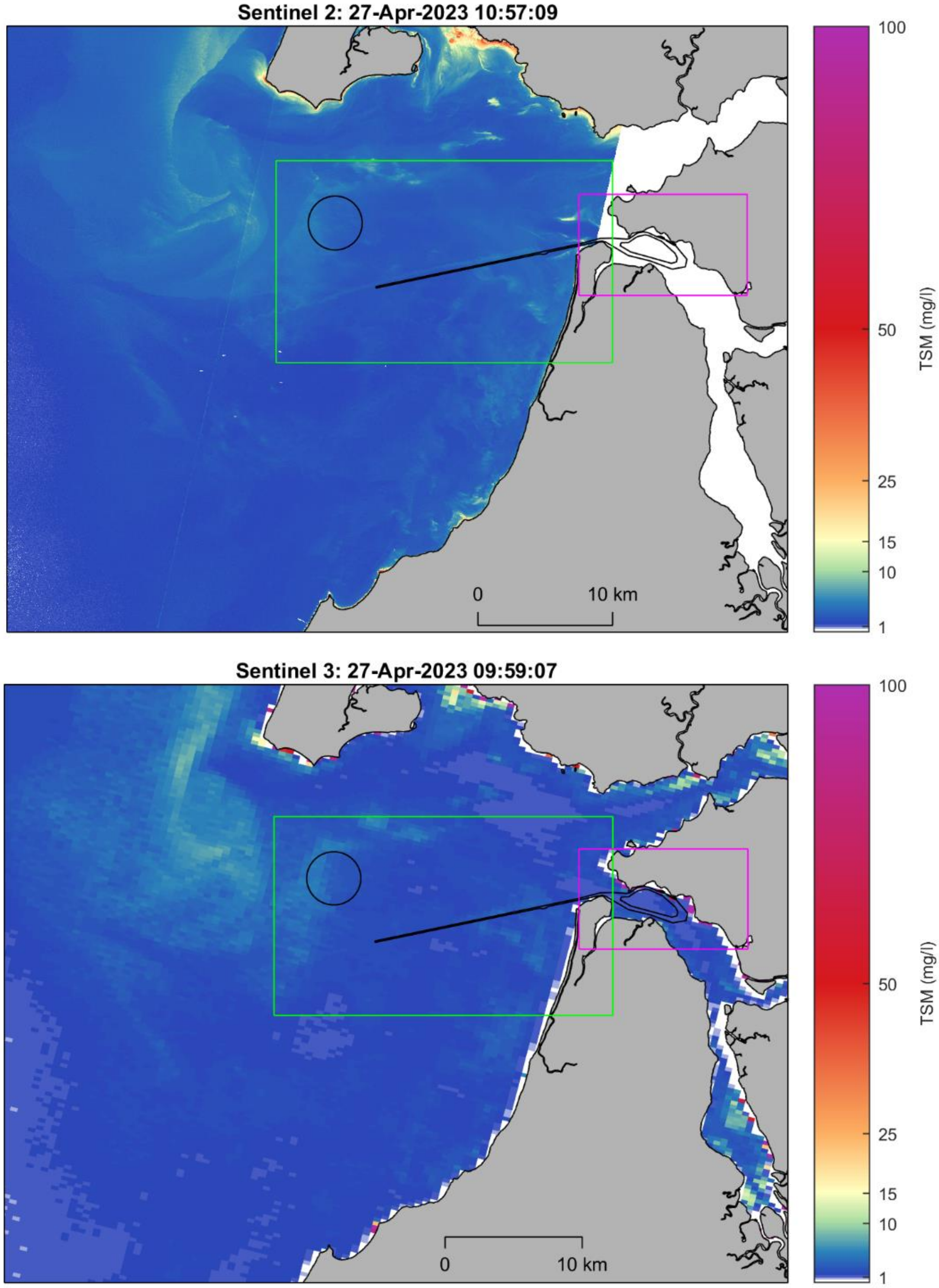


Figure 9. Comparison between satellite-derived TSM from the Sentinel-2 (top) and Sentinel-3 (bottom) sensors for images captured within 1 hour of each other.

Over the pre-, during and post-dredging monitoring periods a total of 23 high resolution satellite images were captured by the Sentinel-2 sensor. As a result of high cloud cover during some of the satellite passes four of the images were unusable (one during the pre-dredge, two during dredging and one post dredge), further the Inner Harbour region was only covered by ten of the Sentinel-2 images (some of these had cloud cover over the Inner Harbour and so did not show conditions anyway).

Details of the satellite images analysed as part of this assessment are provided in Table 3 for the pre-dredging monitoring period, Table 4 during dredging and Table 5 for the post-dredging monitoring period. Images presented are detailed in black text while other images are detailed in grey.

Table 3. Available satellite images for the pre-dredging monitoring period.

Date and Time	Satellite Name	Details
27/04/2023 10:57	Sentinel-2	No cloud, no coverage of the Inner Harbour area.
29/04/2023 10:47	Sentinel-2	No cloud.
02/05/2023 10:57	Sentinel-2	No cloud, no coverage of the Inner Harbour area.
04/05/2023 10:47	Sentinel-2	High cloud coverage (not usable).

Table 4. Available satellite images during dredging.

Date and Time	Satellite Name	Details
07/05/2023 10:57	Sentinel-2	High cloud coverage (not usable), image excludes Inner Harbour area.
09/05/2023 10:47	Sentinel-2	Generally clear with some cloud cover along the shoreline and over the Inner Harbour region. At this time the TSHD Brisbane was dredging at Amrun Port at this time, with dredging of the South Channel (SC6 to SC8) completed at 03:58 and the load placed at the DMPA at 04:05.
12/05/2023 10:57	Sentinel-2	No cloud cover, image excludes Inner Harbour area. At this time the TSHD Brisbane was steaming to the DMPA, having completed a load from the South Channel (SC10 to SC12) at 10:36.
14/05/2023 10:47	Sentinel-2	High cloud cover (not usable).
17/05/2023 10:57	Sentinel-2	Patchy cloud cover along the shoreline, image excludes Inner Harbour area. At this time the TSHD Brisbane was steaming back from the DMPA having placed a load there at 09:21 from the South Channel (SC8 to SC10).
19/05/2023 10:47	Sentinel-2	Patchy cloud cover along shoreline and in the estuaries. At this time the TSHD Brisbane was dredging the Inner Harbour (CS3 to CS5), having commenced dredging at 10:00. The most recent load was placed at the DMPA at 08:29.
22/05/2023 10:57	Sentinel-2	Cloud cover along the northern shoreline of Albatross Bay, image excludes Inner Harbour area. At this time the TSHD Brisbane was steaming back from the DMPA having placed a load at 10:05 from dredging the South Channel (SC12 to SC14) which finished at 09:04.
24/05/2023 10:47	Sentinel-2	No cloud cover. At this time the TSHD Brisbane was not operating, the most recent dredge load was from the South Channel (SC8 to SC10) and was finished at 05:54 and placement at the DMPA was at 06:43.

Date and Time	Satellite Name	Details
27/05/2023 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 at 10:26 from dredging the South Channel (SC10 to SC12) which finished at 09:37.
29/05/2023 10:47	Sentinel-2	No cloud cover. At this time the TSHD Brisbane was steaming back from the DMPA having placed a load at 10:39 from dredging the South Channel (SC12 to SC14) which finished at 09:50.
01/06/2023 10:57	Sentinel-2	Patchy cloud cover along shoreline, image excludes Inner Harbour area. At this time the TSHD Brisbane was just finishing dredging at Lorim Point Wharf, and the most recent placement at the DMPA was at 08:16 from dredging the South Channel (SC10 to SC12).
03/06/2023 10:47	Sentinel-2	High cloud cover along northern end of Albatross Bay including the DMPA. At this time the TSHD Brisbane was steaming back from the DMPA having placed a load at 10:25 from dredging the South Channel (SC6 to SC8) which finished at 09:55.
06/06/2023 10:57	Sentinel-2	High cloud cover (not usable), image excludes Inner Harbour area.
08/06/2023 10:47	Sentinel-2	Light cloud cover over the estuaries. At this time there was a crew change for the TSHD Brisbane. The most recent dredging was completed in the South Channel (SC6 to SC8) at 04:57 and it was placed at the DMPA at 05:26.
11/06/2023 10:57	Sentinel-2	No cloud cover, image excludes Inner Harbour area. At this time the TSHD Brisbane was midway through dredging a load from the South Channel (SC18 to SC22, northside), the dredging commenced at 10:18. The most recent placement at the DMPA was at 09:12 with a load from the South Channel (SC8 to SC10).
13/06/2023 10:47	Sentinel-2	Light cloud cover over the upper areas of the estuaries. At this time the TSHD Brisbane had just commenced (at 10:40) dredging in the South Channel (SC10 to SC12), the most recent load was placed at the DMPA at 09:57.
16/06/2023 10:57	Sentinel-2	No cloud cover, image excludes Inner Harbour area. At this time the TSHD Brisbane had just placed a load at the DMPA (10:49) from the South Channel (SC8 to SC10) which finished at 09:56.
18/06/2023 10:47	Sentinel-2	No cloud cover. At this time the TSHD Brisbane was steaming back to the South Channel having placed a load at the DMPA at 10:27 from the South Channel (SC6 to SC8) which finished at 09:43.

Table 5. Available satellite images for the post-dredging monitoring period.

Date and Time	Satellite Name	Details
21/06/2023 10:57	Sentinel-2	Isolated clouds adjacent to the shoreline in some areas, image excludes Inner Harbour area. The TSHD Brisbane completed its final dredge load at 19:28 on 19th June from the South Channel (SC8 to SC10) and the load was placed at the DMPA at 20:36 on 19th June.
23/06/2023 10:47	Sentinel-2	Patchy cloud cover in Albatross Bay and Inner Harbour.

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 2023 maintenance dredging program, the turbidity analysis was undertaken at three different spatial scales, namely:

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

4.2.1.1. Regional Scale

To provide an understanding of how the turbidity in Albatross Bay varied over the 2023 Maintenance Dredging Program, plots of the satellite-derived TSM in the Albatross Bay region for the usable satellite images are shown in Figure 10 to Figure 29. The plots show the following:

- Pre-Dredging: the pre-dredging images (Figure 10 to Figure 12) show that TSM throughout the majority of Albatross Bay was relatively low (less than 10 mg/l, equivalent to approximately 7 NTU), which corresponds to the calm metocean conditions over this period. Isolated patches of TSM of up to 15 mg/l (approximately 11 NTU) were observed in Albatross Bay, including areas adjacent to the DMPA and the South Channel. In the South Channel these may be partially attributed to resuspension of the seabed by propellor wash from vessels entering or leaving the Port (as visible in all three images). There are no specific reasons for the areas of elevated TSM elsewhere in Albatross Bay in terms of the metocean conditions over the pre-dredge period. This shows that Albatross Bay can experience variable natural plumes of up to 15 mg/l without significant changes in metocean conditions;
- During Dredging: the TSM in the Albatross Bay region was variable, with periods of relatively low TSM when the northern half of the bay was predominantly below 10 mg/l (approximately 7 NTU) and periods of higher TSM when it was predominantly above 10 mg/l. High TSM of 25 to 50 mg/l (approximately 18 to 35 NTU) also regularly occurred in the shallow areas adjacent to the northern shoreline of Albatross Bay and in the estuaries. For example, elevated TSM was widely visible in the shallow areas of the estuaries and adjacent to their mouths on the 19th and 22nd May 2023 (Figure 16 and Figure 17). The TSHD Brisbane had dredged multiple loads from the South Channel region prior to the images being captured and so some localised plumes adjacent to the South Channel and DMPA could be due to the dredging, but the majority of the TSM in Albatross Bay was natural. These images were captured on the ebb stage of a large spring tide when there was also wave heights above 0.5 m from the south-west and it is therefore likely that the strong tidal currents naturally resuspended sediments within the estuaries and in shallower areas of Albatross Bay the combined strong tidal currents and waves also resulted in some natural resuspension.

  The imagery has also shown plumes with TSM of up to 20 mg/l (approximately 15 NTU) and spatial extents of up to kilometres around the South Channel and DMPA occurred through the dredge period. Based on the spatial extent of the plumes, the dredge activity and the metocean conditions it is considered likely that the plumes were a result of the dredging activity. This will be further assessed in Section 4.2.1.2; and

- Post-Dredging: the post dredging images (Figure 28 and Figure 29) show that TSM in the broader Albatross Bay region during the post dredging period was similar to within the dredging period. The TSM was up to 10 mg/l (approximately 7 NTU) in the deeper areas of the bay and up to 50 mg/l (approximately 35 NTU) in the shallower areas and within the estuaries. The image from the 21st June 2023 shows a localised plume of less than 10 mg/l (approximately 7 NTU) present adjacent to the South Channel. The image captured on the 23rd June 2023 does not show any indication of plumes from the dredging activity. The higher TSM throughout Albatross Bay on the 21st June 2023 compared to the 23rd June 2023 is a result of the metocean conditions, with the image on the 21st June coinciding with large spring tides while the tidal range had reduced slightly by the 23rd June.

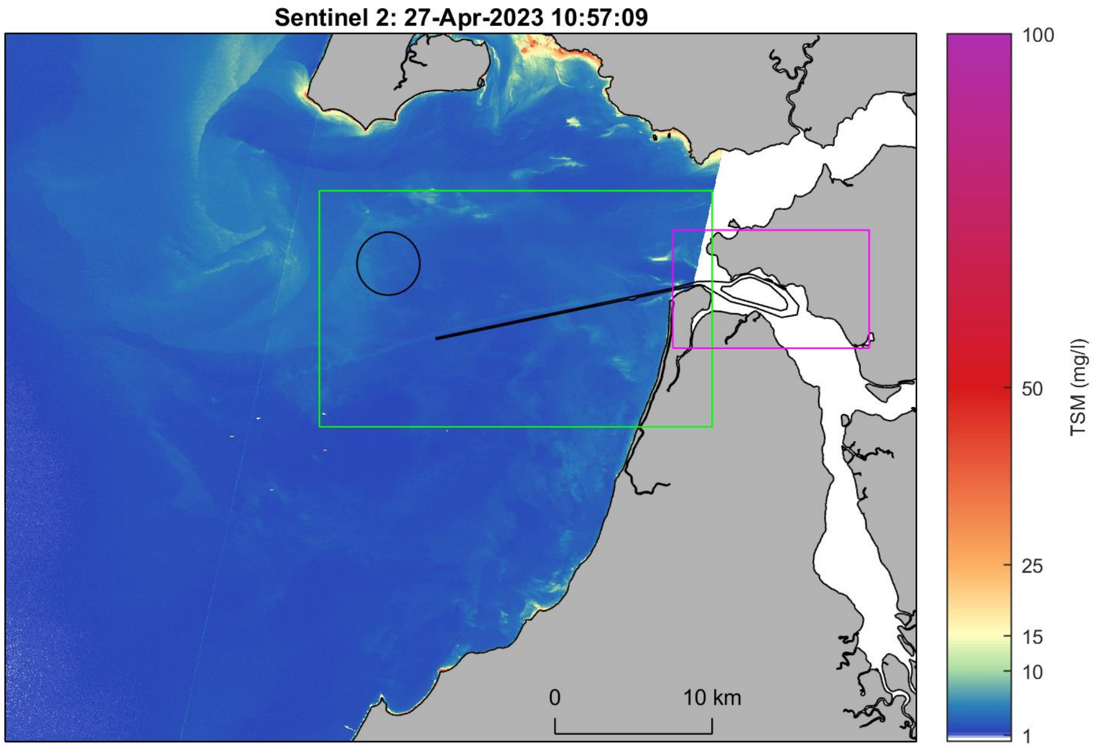


Figure 10. Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 27/04/2023 at 10:57 AEST (pre-dredging).

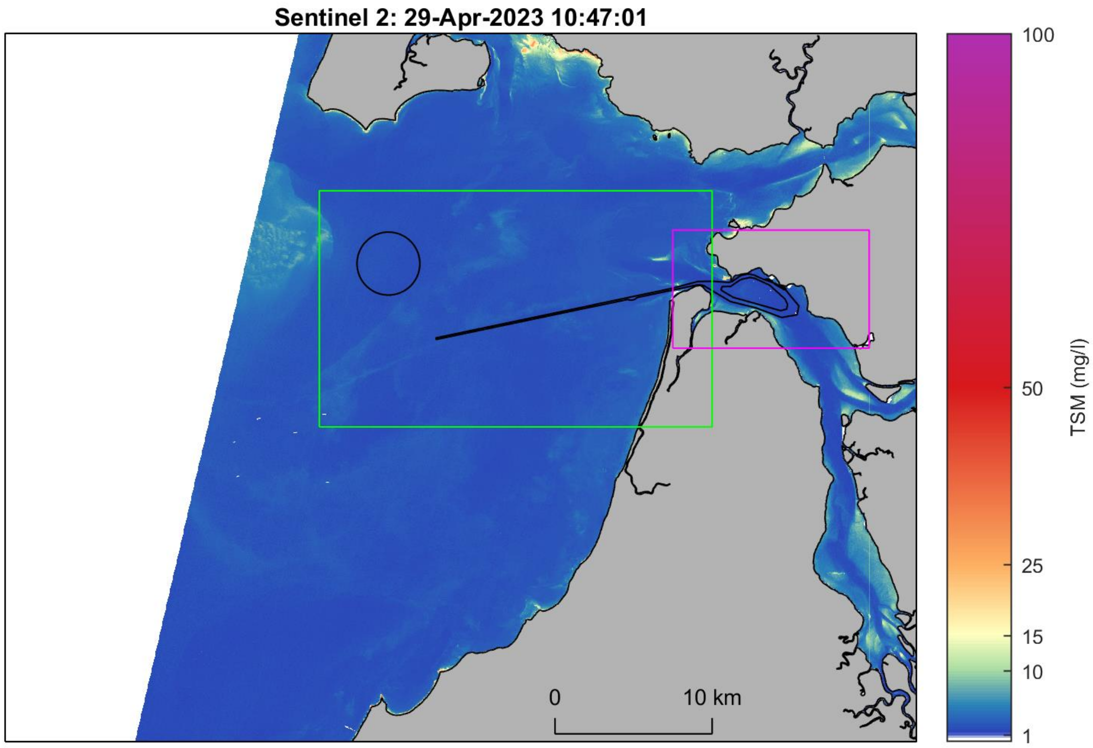


Figure 11. Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 29/04/2023 at 10:47 AEST (pre-dredging).

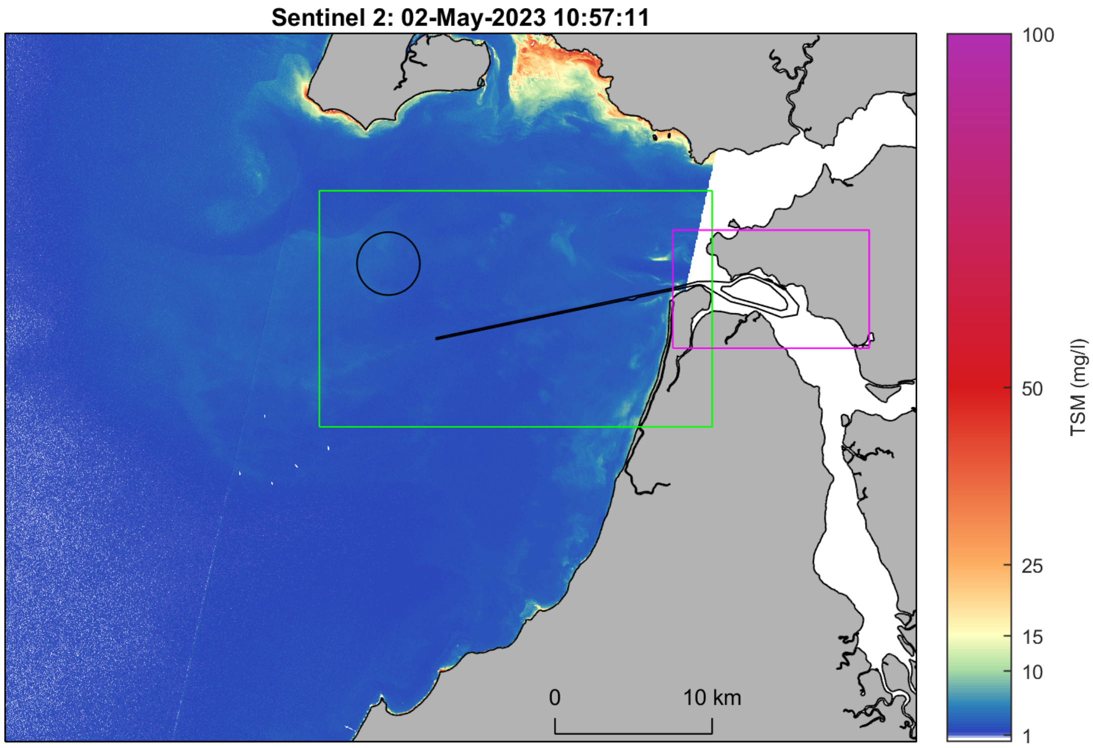
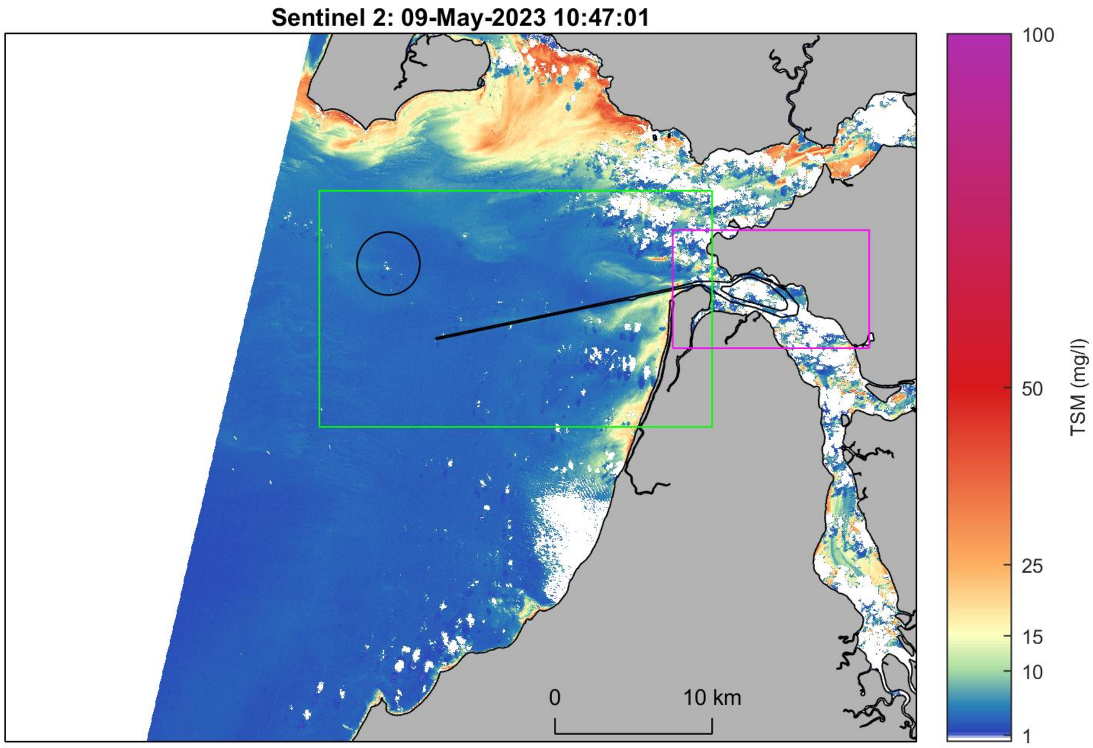


Figure 12. Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 02/05/2023 at 10:57 AEST (pre-dredging).



Note: the white areas represent cloud cover and adjacent blue areas the shadow from the cloud.

Figure 13. Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 09/05/2023 at 10:47 AEST (dredging).

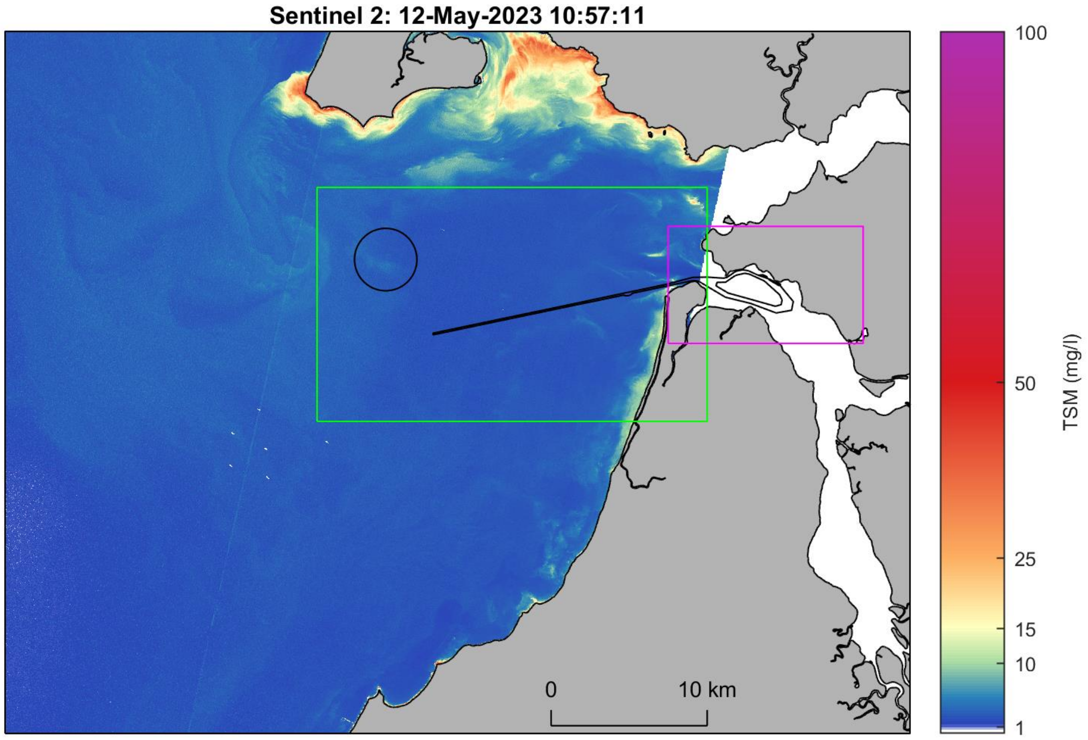
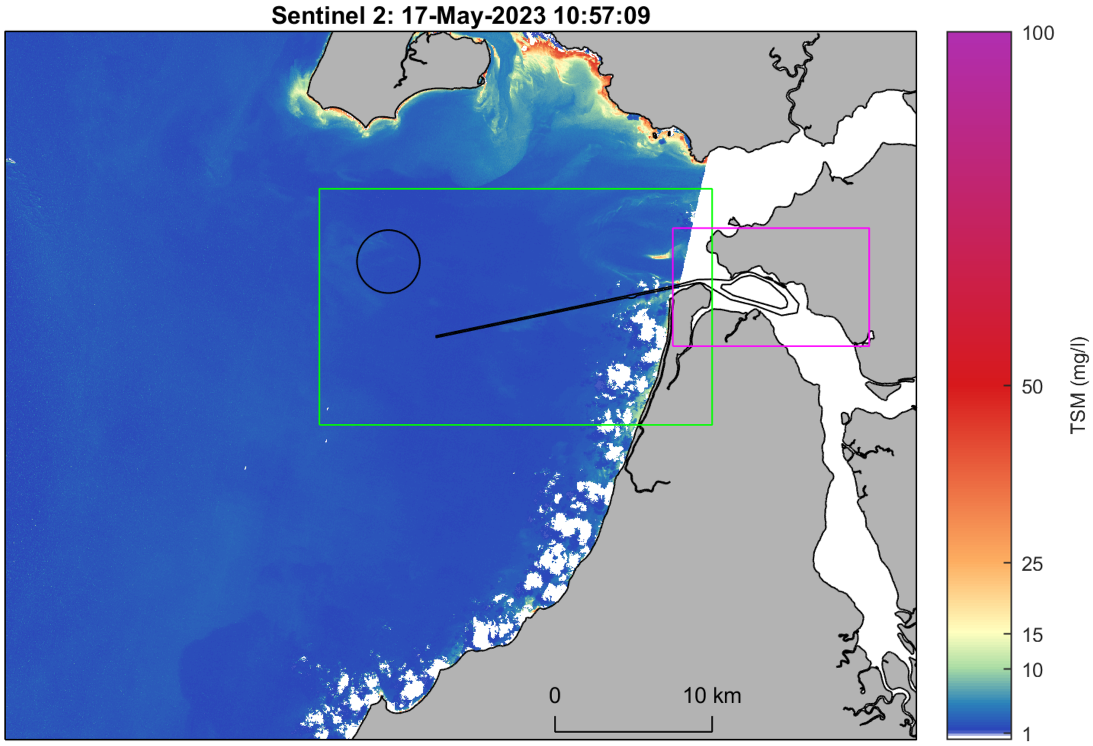
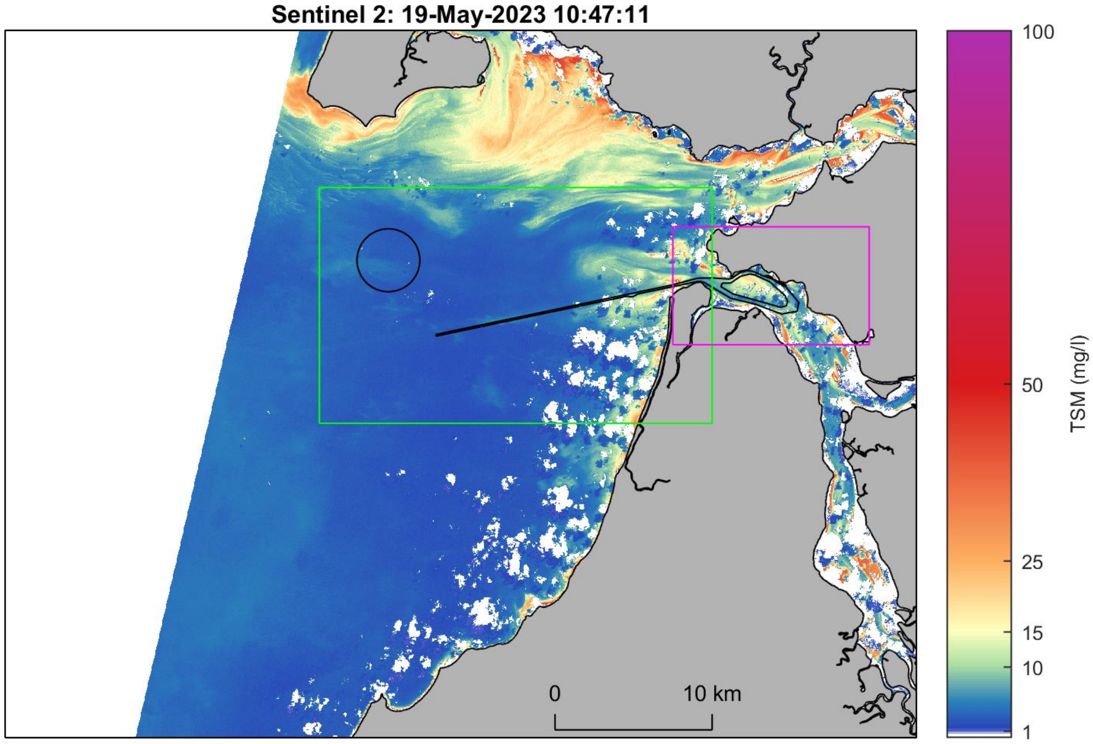


Figure 14. Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 12/05/2023 at 10:57 AEST (dredging).



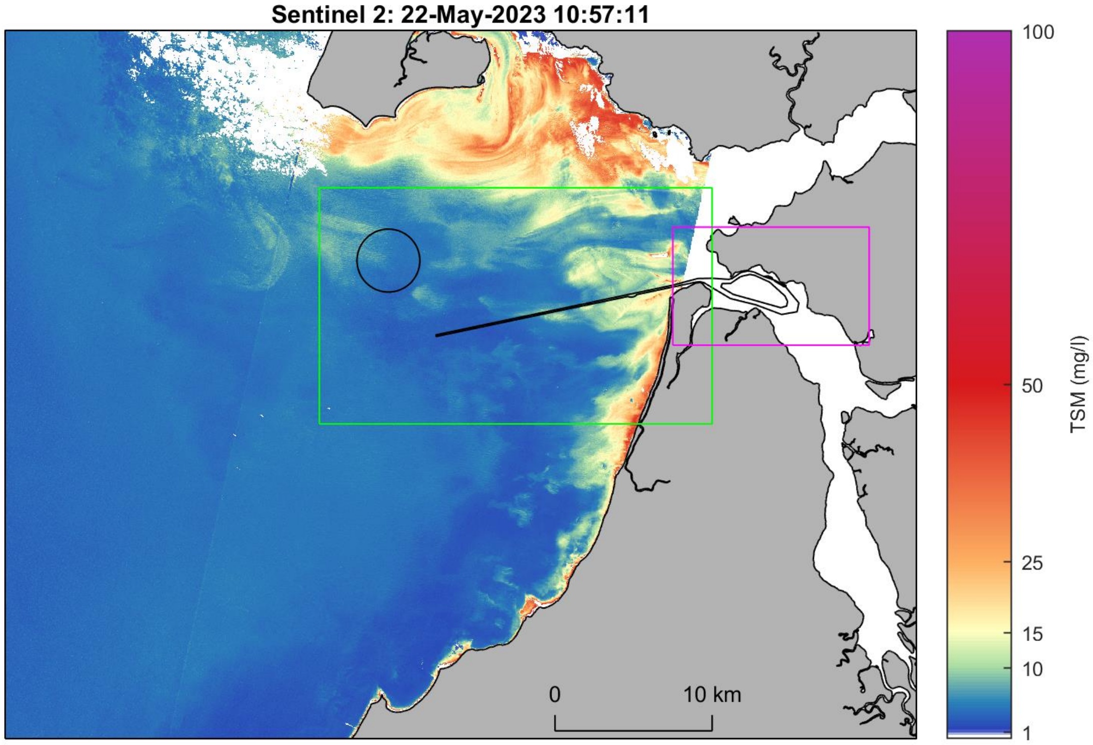
Note: the white areas represent cloud cover and adjacent blue areas the shadow from the cloud.

Figure 15. Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 17/05/2023 at 10:57 AEST (dredging).



Note: the white areas represent cloud cover and adjacent blue areas the shadow from the cloud.

Figure 16. Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 19/05/2023 at 10:47 AEST (dredging).



Note: the white areas represent cloud cover.

Figure 17. Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 22/05/2023 at 10:57 AEST (dredging).

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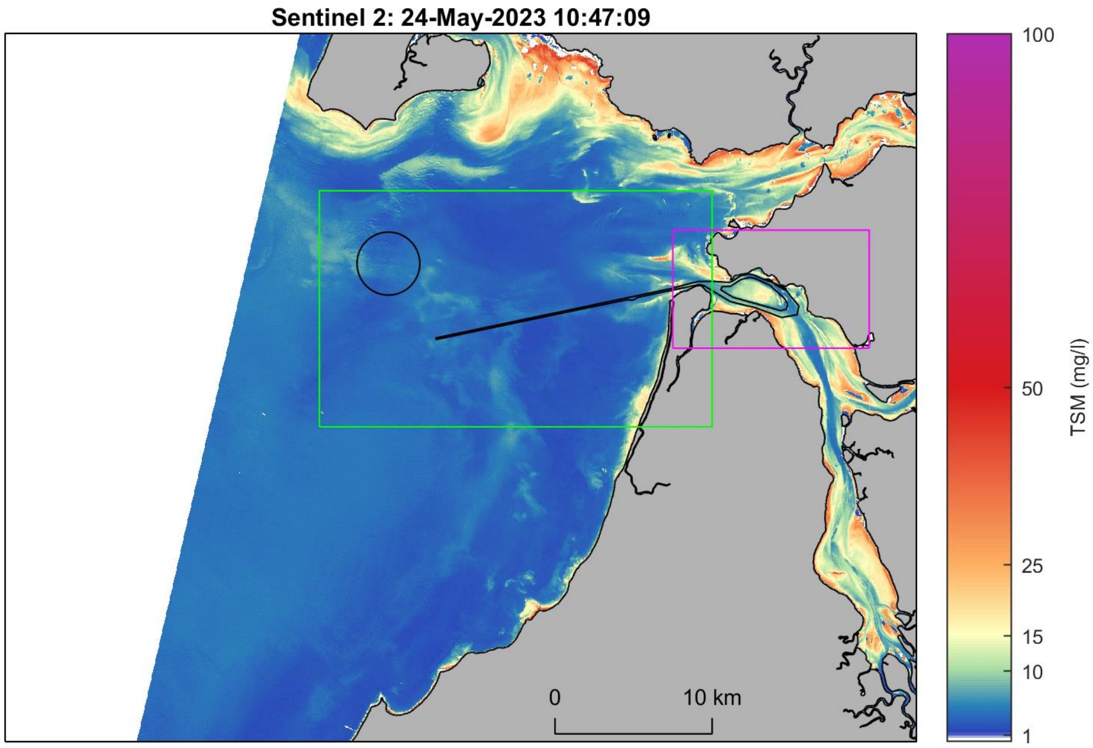


Figure 18. **Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 24/05/2023 at 10:47 AEST (dredging).**

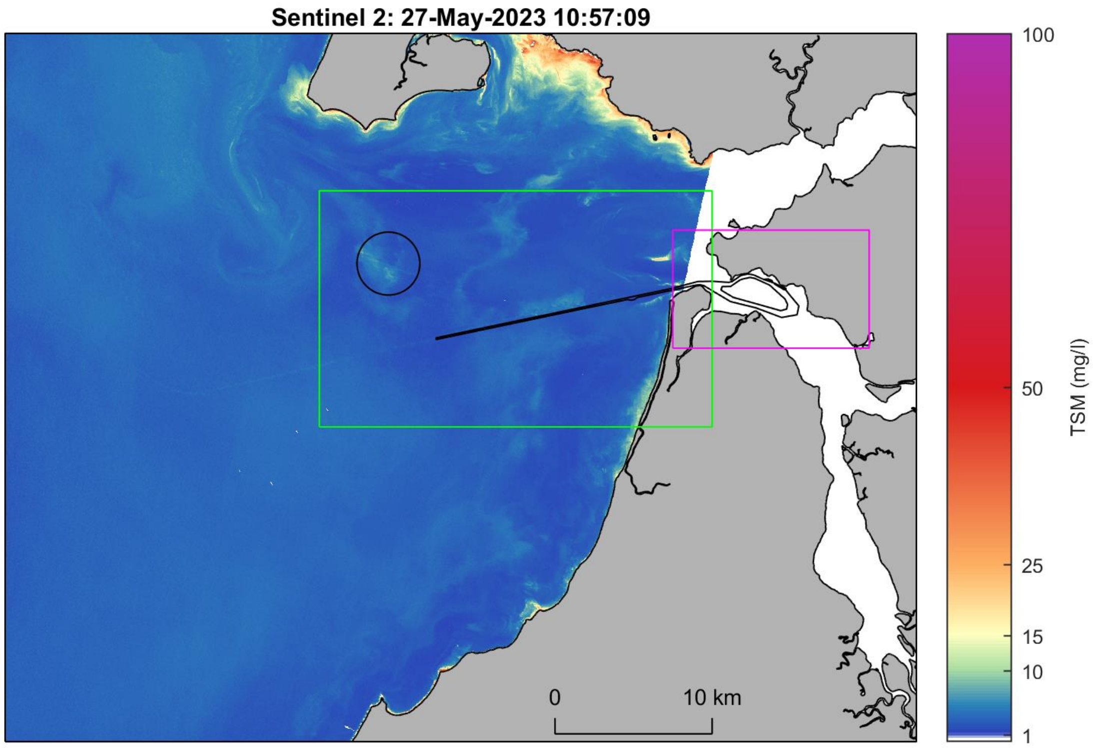


Figure 19. **Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 27/05/2023 at 10:57 AEST (dredging).**

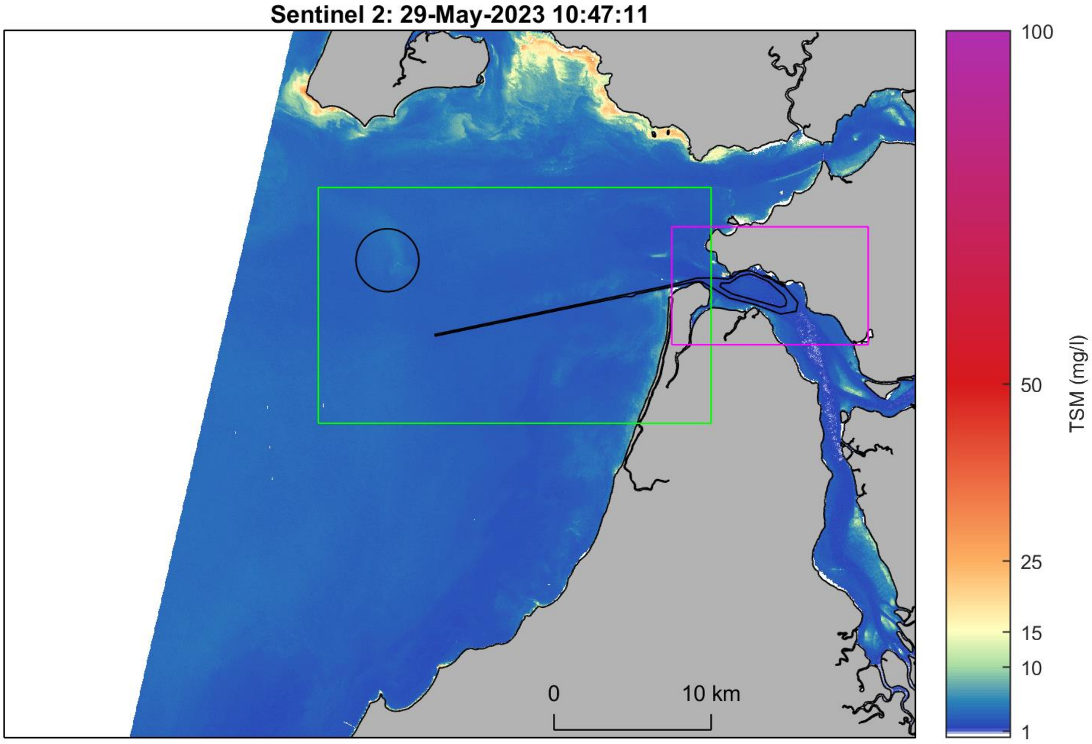
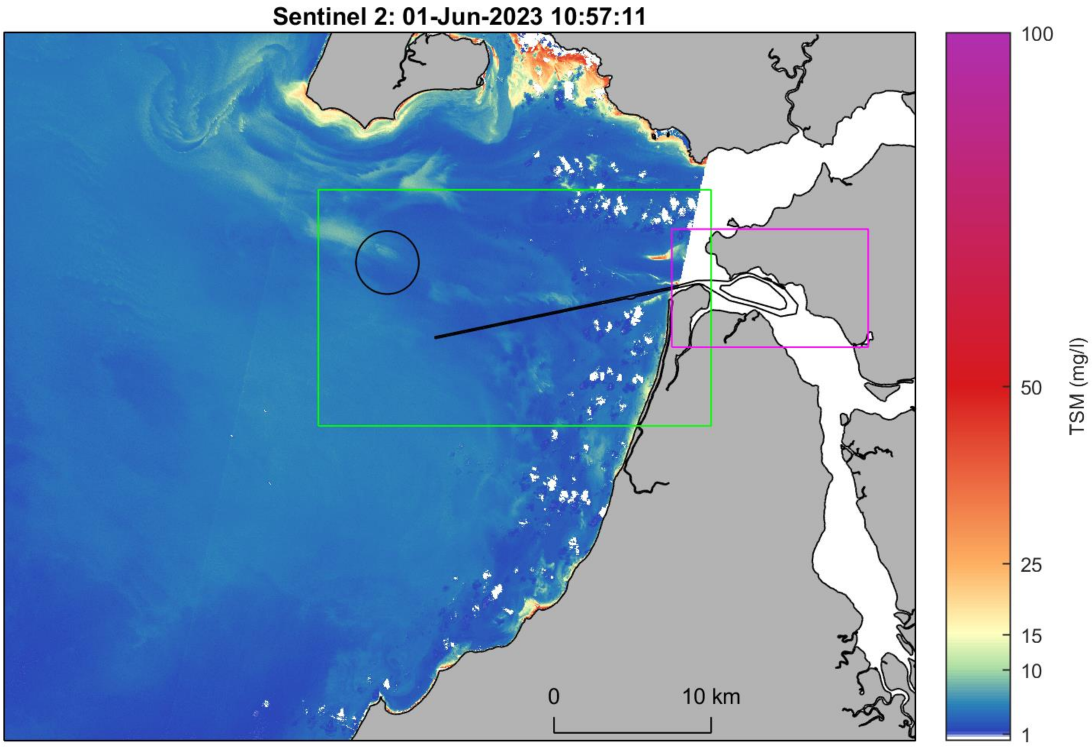
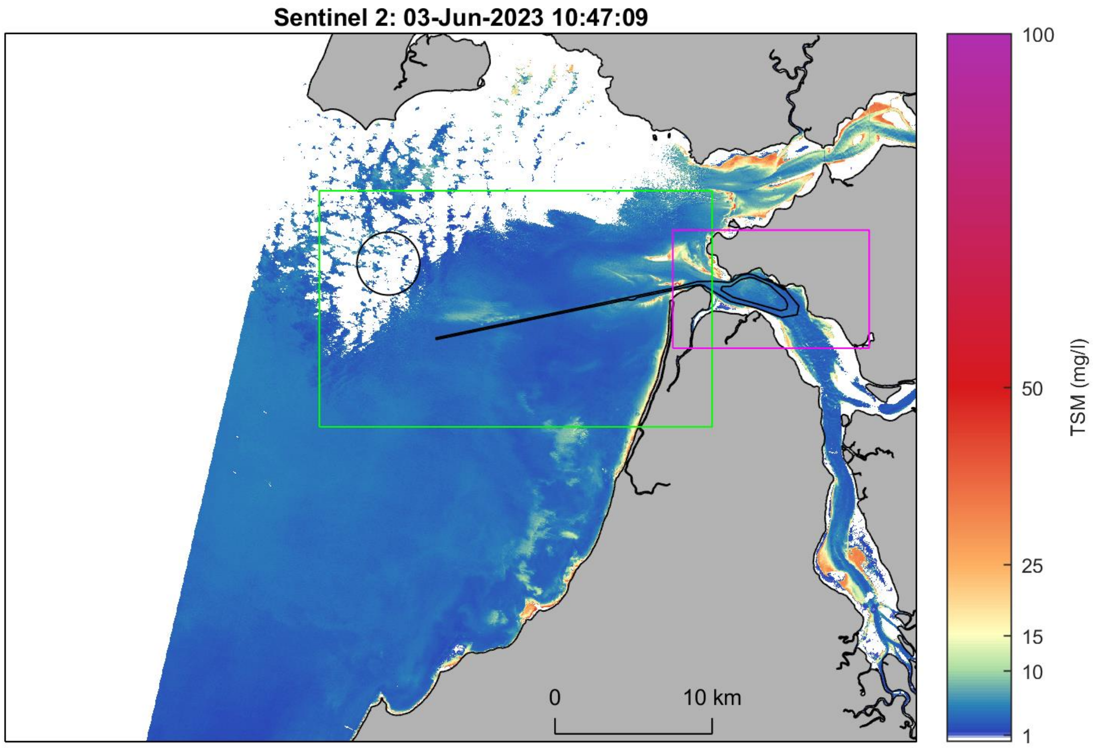


Figure 20. Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 29/05/2023 at 10:47 AEST (dredging).



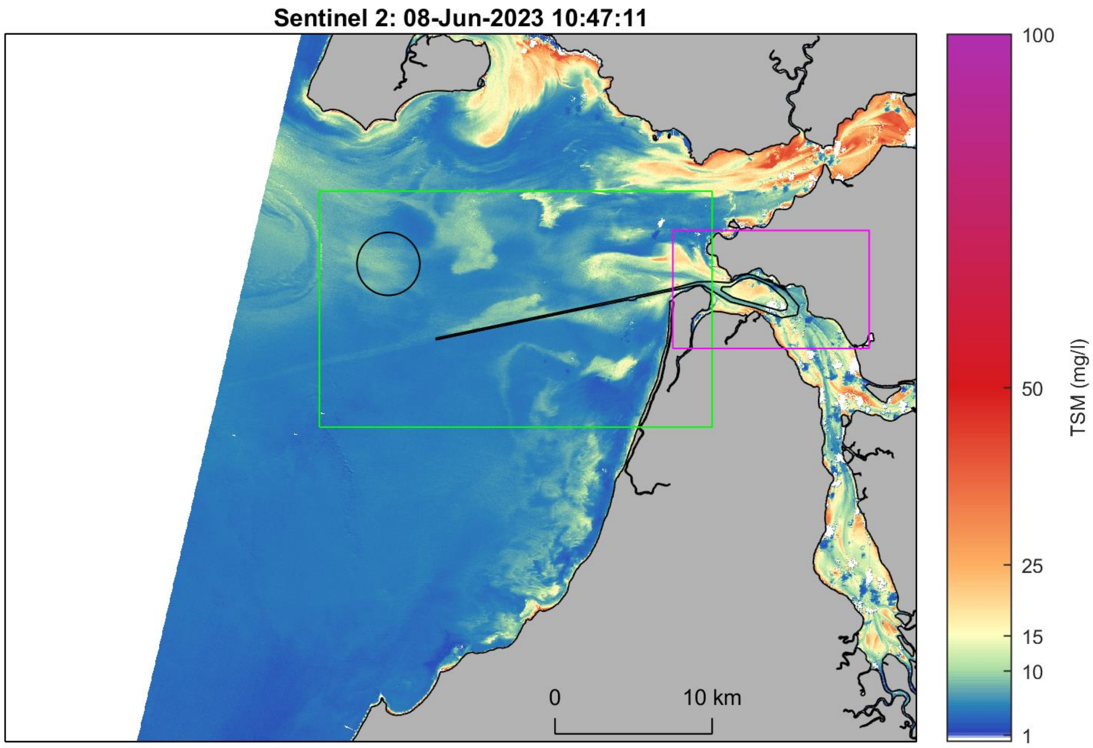
Note: the white areas represent cloud cover and adjacent blue areas the shadow from the cloud.

Figure 21. Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 01/06/2023 at 10:57 AEST (dredging).



Note: the white areas represent cloud cover and adjacent blue areas the shadow from the cloud.

Figure 22. Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 03/06/2023 at 10:47 AEST (dredging).



Note: the white areas represent cloud cover and adjacent blue areas the shadow from the cloud.

Figure 23. Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 08/06/2023 at 10:47 AEST (dredging).

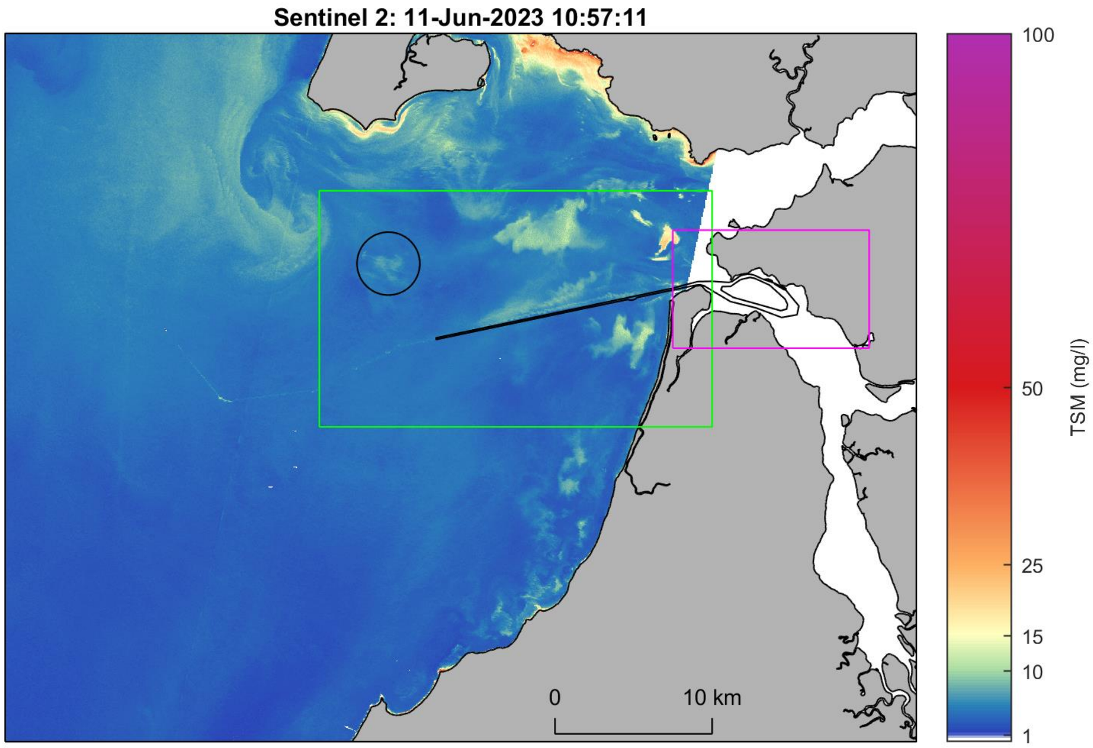
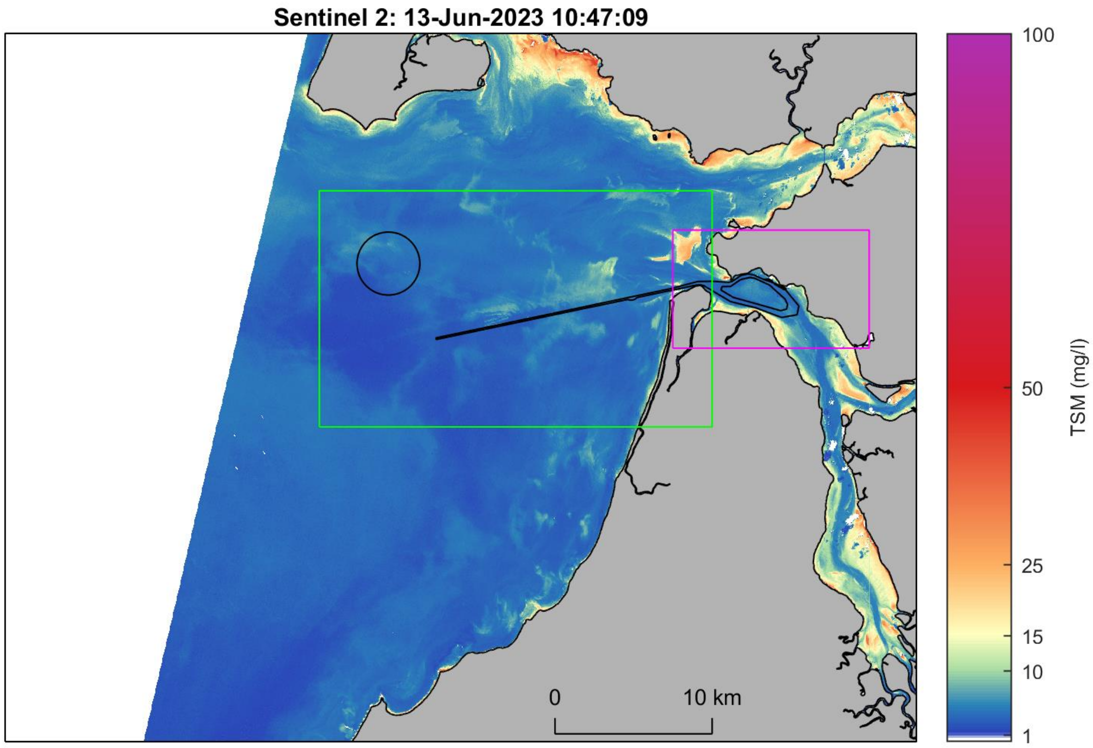


Figure 24. Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 11/06/2023 at 10:57 AEST (dredging).



Note: the white areas represent cloud cover and adjacent blue areas the shadow from the cloud.

Figure 25. Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 13/06/2023 at 10:47 AEST (dredging).

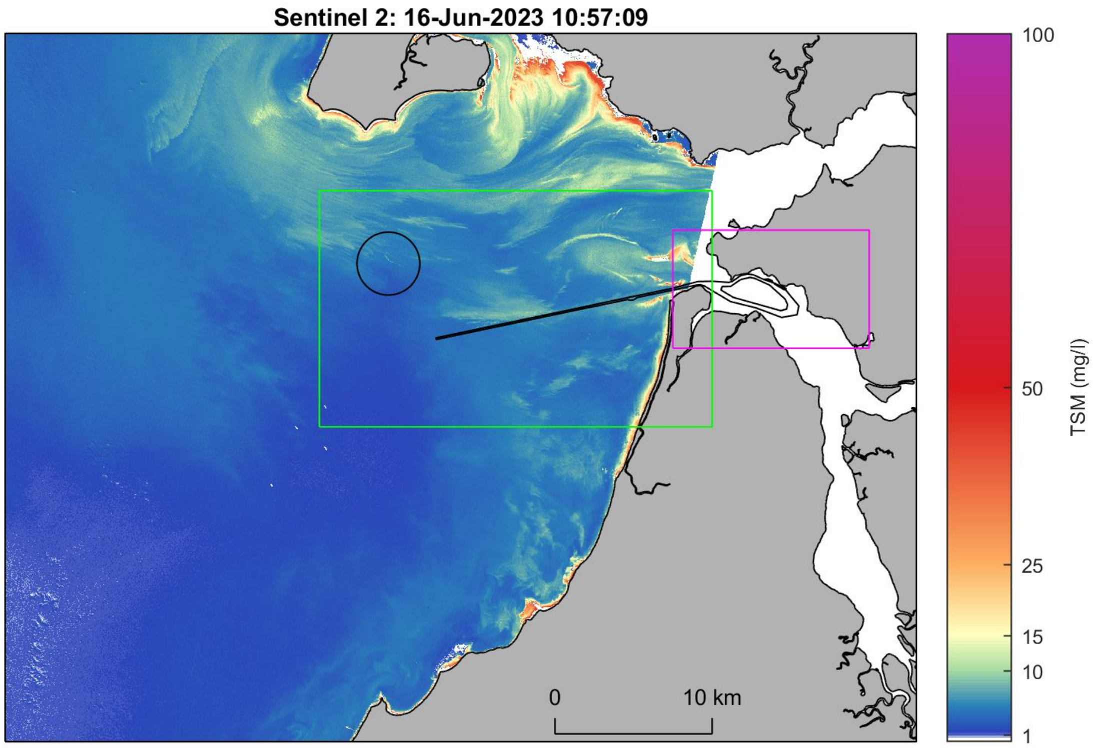


Figure 26. Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 16/06/2023 at 10:57 AEST (dredging).

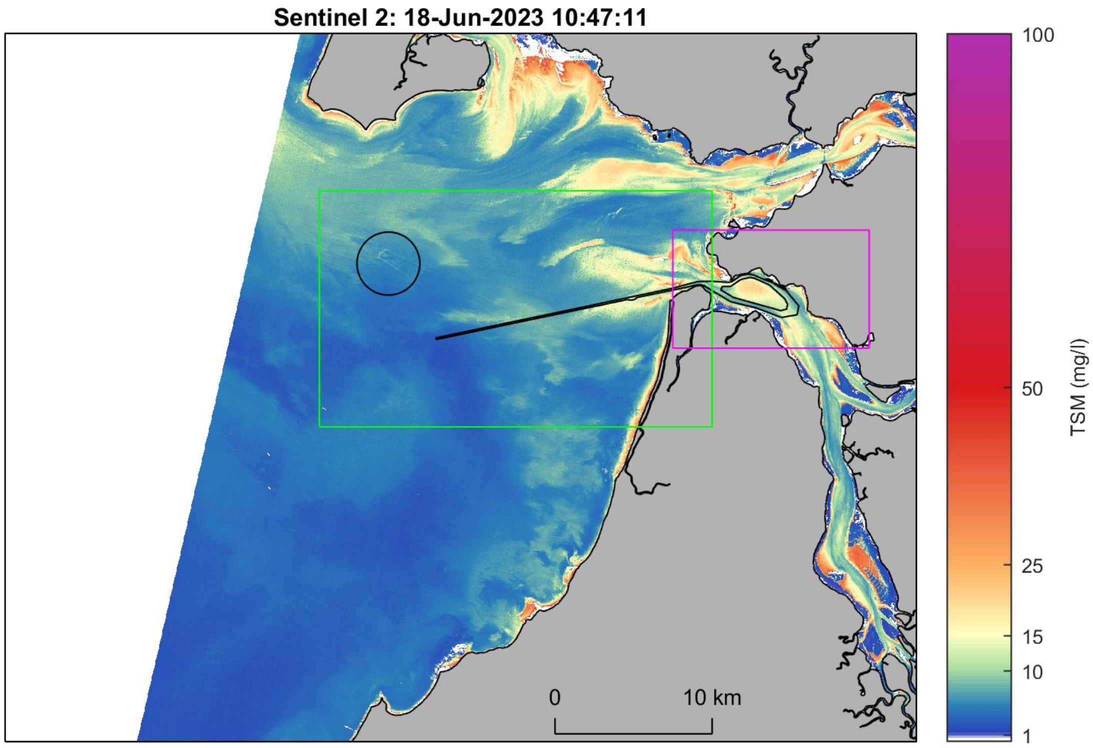


Figure 27. Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 18/06/2023 at 10:47 AEST (dredging).

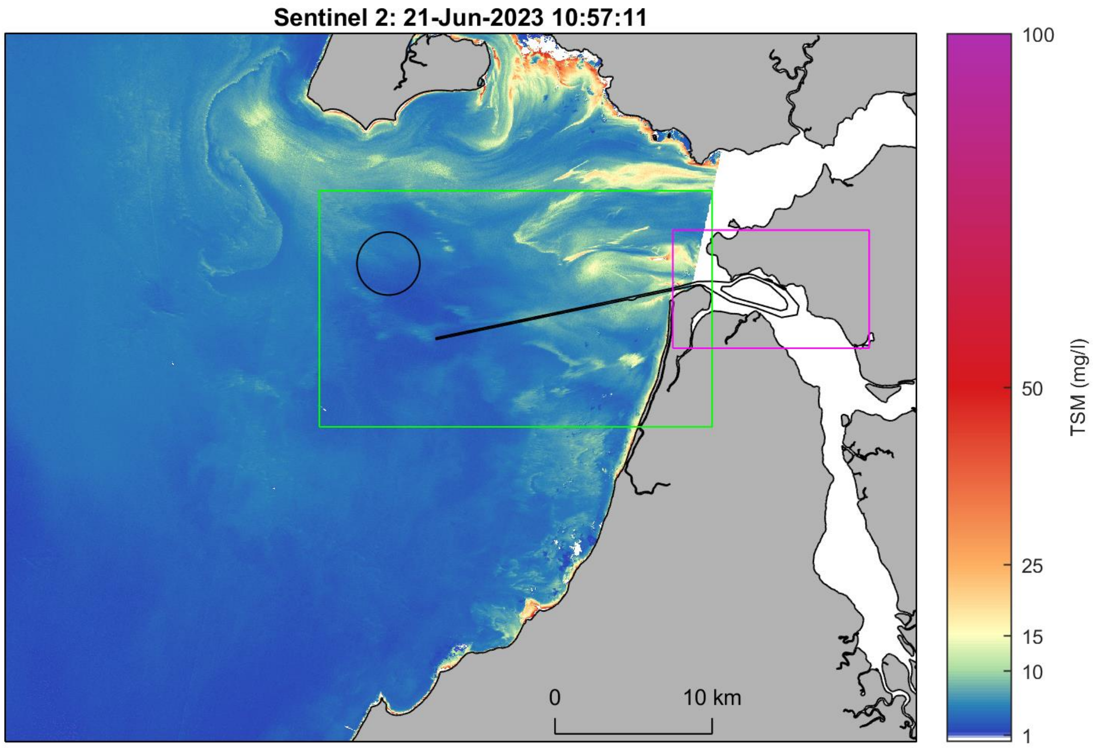
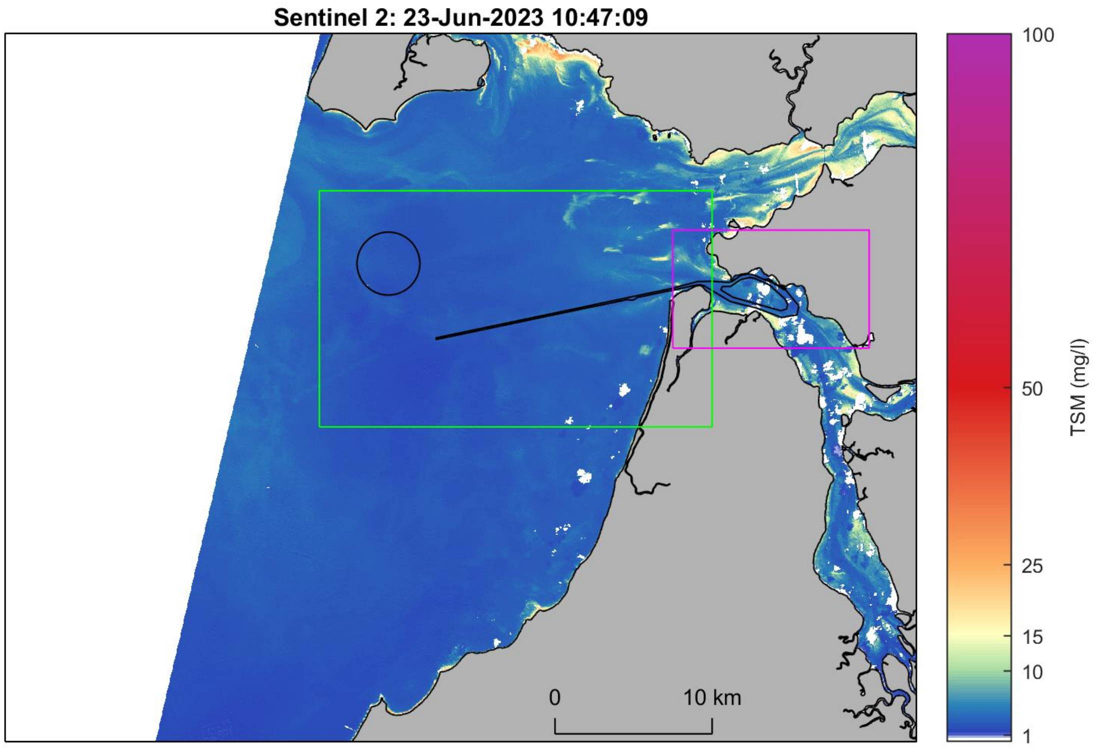


Figure 28. Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 21/06/2023 at 10:57 AEST (post-dredging).



Note: the white areas represent cloud cover and adjacent blue areas the shadow from the cloud.

Figure 29. Satellite-derived TSM from the Sentinel-2 sensor for Albatross Bay on 23/06/2023 at 10:47 AEST (post-dredging).

4.2.1.2. Local Scale

To show how the local turbidity around the Port of Weipa varied over the 2023 Maintenance Dredging program, plots of the satellite-derived TSM covering the South Channel and Albatross Bay DMPA and the Inner Harbour area are shown for the pre-, during and post-dredging periods in Figure 30 to Figure 49. The plots show the following:

- Pre-Dredging: the imagery from the pre-dredging period shows generally low TSM (less than 10 mg/l equivalent to approximately 7 NTU) across the South Channel and DMPA (Figure 30 to Figure 32). The image from the 27th April 2023 shows isolated plumes of up to 10 mg/l with spatial extents of multiple kilometres present close to the South Channel, and plumes of multiple kilometres in size and of up to 15 mg/l (approximately 11 NTU) close to the DMPA. The TSM in the Inner Harbour is low, with values in the channel of less than 5 mg/l (approximately 4 NTU) and higher values along the shallow coastal areas (5 to 15 mg/l, approximately 4 to 11 NTU);
- During Dredging: the available images during the maintenance dredging program show localised plumes adjacent to the South Channel (mainly between SC6 and SC12), which are likely to be residual plumes predominantly due to the maintenance dredging and bed levelling activity (visible in Figure 36 to Figure 47). Localised plumes were also visible within the Albatross Bay DMPA due to the recent placement of sediment within the DMPA. The plumes identified in the images attributed to dredging and placement activity remained close to where the placement or dredging activity occurred, showing that very little residual transport of the plumes away from where they were generated occurs. Visible plumes were observed within the Inner Harbour in two of the satellite images, with one plume due to the TSHD Brisbane and two plumes due to bed leveller by the Pacific Titan. The satellite images also did not show any visible plumes from maintenance dredging or bed levelling activities present at any of the three monitoring sites (WQ1, WQ2 and WQ4), indicating limited influence of the activities on the turbidity measurements at these sites. Further details of the observed plumes are provided below:
  - during dredging, up to 1 hour after dredging and within 30 minutes of placement at the DMPA, higher concentration plumes of 10 to 20 mg/l (approximately 7 to 14 NTU) were observed. The plumes of this concentration either remained within the South Channel, Inner Harbour channels or the DMPA where they were generated;
  - lower concentration residual plumes of up to 10 mg/l (approximately 7 NTU) were observed adjacent to the South Channel for more than 6 hours after dredging (following repeat dredging in one location) and within/adjacent to the DMPA for up to 4 hours after placement. Natural advection and dispersion of the plumes resulted in them being transported beyond the boundaries of the South Channel/DMPA, but these processes also acted to reduce the TSM of the plumes. Lower concentration plumes from the dredging of up to 7,500 m in length and 1,500 m in width were observed adjacent to the South Channel towards the end of the dredge program when both the TSHD Brisbane and the Pacific Titan were operating in the South Channel, while in the DMPA the lower concentration plumes were observed to be up to 600 m in diameter;
  - localised plumes in the Inner Harbour due to the maintenance dredging and bed levelling were observed. The plume from the TSHD Brisbane was up to 20 mg/l and extended approximately 1,000 m in length by 200 m in width. The plumes from the Pacific Titan were also up to 20 mg/l and extended up to 1,800 m from the vessel, with a plume width of up to 160 m. The plumes were predominantly constrained within the channels and the available images did not show the plumes extending into areas with seagrass;
  - the images indicate that the TSM in the area of the seagrass meadows in the Inner Harbour has been predominantly controlled by natural processes, with the natural TSM varying between 5 mg/l (along the northern shoreline, approximately 4 NTU) and 25 mg/l (along the southern shoreline, approximately 18 NTU) and remaining

relatively consistent throughout the images. No persistent plumes that would be expected to impact seagrass beyond what they are normally exposed to have been observed as a result of the maintenance dredging program; and

– the propeller wash from bulk carriers departing the Port resulted in plumes extending the majority of the length of the South Channel and offshore to the west. A plume which was generated by a vessel departing the Port approximately 2 hours prior had a plume of up to 5 mg/l (approximately 4 NTU) and approximately 200 m in width.

- Post-Dredging: the first post dredging image was captured approximately 36 hours after the dredging ceased and the second was approximately 3.5 days after the dredging ceased (Figure 48 and Figure 49). The image from the 21st June 2023 shows relatively high TSM in Albatross Bay, with multiple natural plumes of up to 25 mg/l (approximately 18 NTU) close to the DMPA and South Channel. There is no evidence of any residual plumes from the placement of dredged sediment around the DMPA, but in the South Channel there is a plume adjacent to the channel between SC6 and SC10 of 5 to 10 mg/l (approximately 4 to 7 NTU). This could be a residual plume from the dredging, but it is more likely to be a result of natural processes (e.g. strong tidal currents) resuspending surface sediment which had been recently disturbed or deposited as a result of the dredging. The image captured on the 23rd June 2023 shows much lower natural TSM in Albatross Bay, with a TSM of less than 5 mg/l adjacent to the South Channel and DMPA and no indication of plumes from the dredging or placement activity. These images therefore indicate that 36 hours after dredging ended most if not all of the sediment suspended during the dredging had been deposited, and 3.5 days after dredging ended there were no residual plumes remaining.

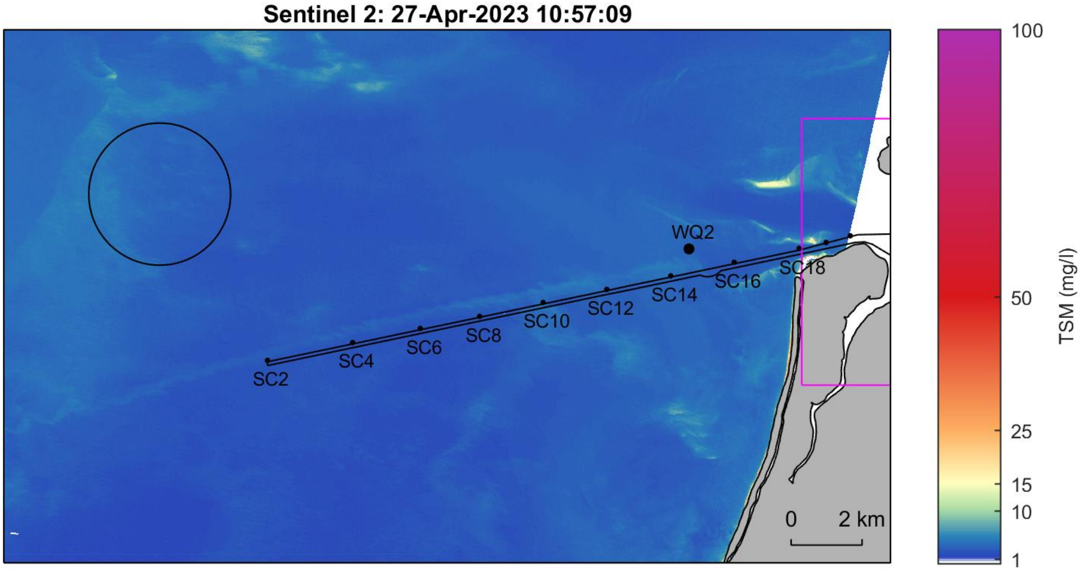


Figure 30. Satellite-derived TSM from the Sentinel-2 sensor for South Channel on 27/04/2023 at 10:57 AEST (pre-dredging).

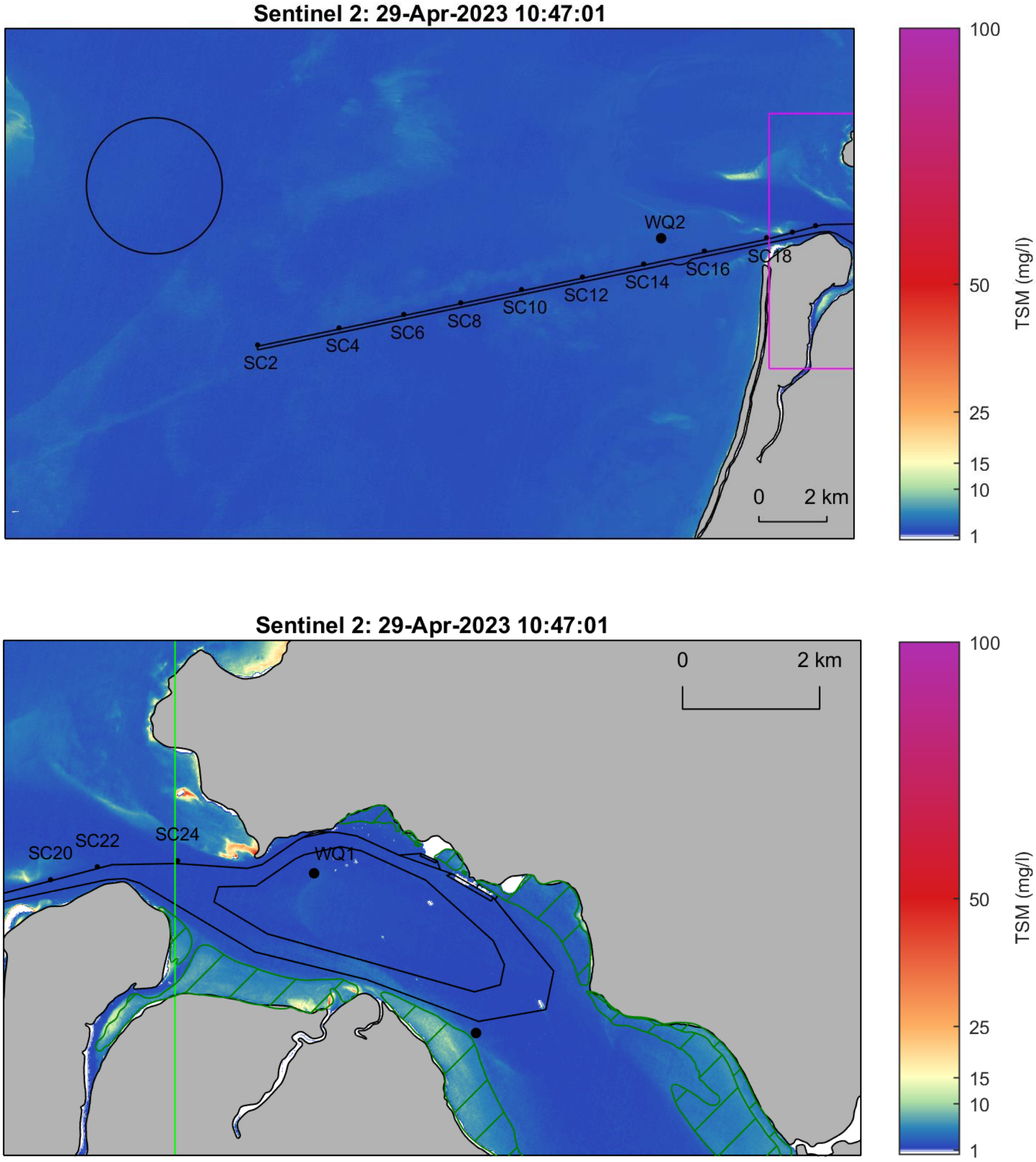


Figure 31. Satellite-derived TSM from the Sentinel-2 sensor for South Channel (top) and Inner Harbour (bottom) on 29/04/2023 at 10:47 AEST (pre-dredging).

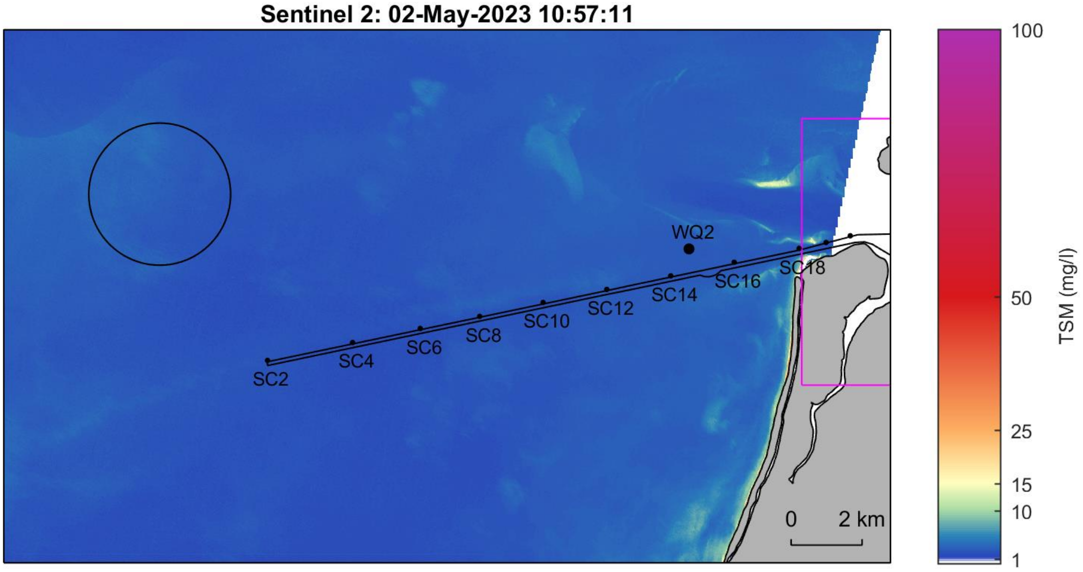
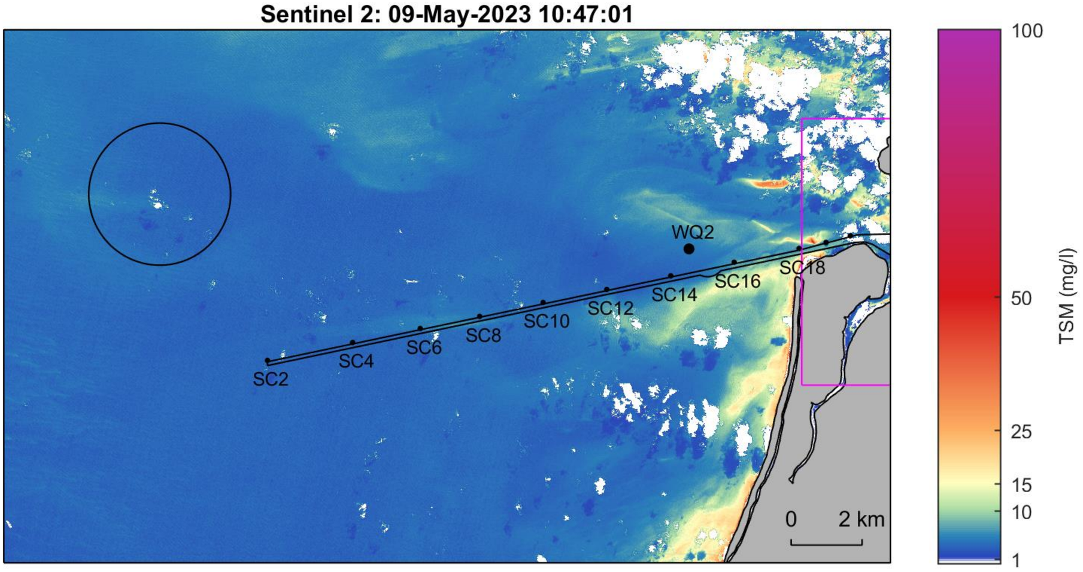


Figure 32. **Satellite-derived TSM from the Sentinel-2 sensor for South Channel (top) and Inner Harbour (bottom) on 02/05/2023 at 10:57 AEST (pre-dredging).**



Note: the white areas represent cloud cover and adjacent blue areas the shadow from the cloud.

Figure 33. **Satellite-derived TSM from the Sentinel-2 sensor for South Channel on 09/05/2023 at 10:47 AEST (dredging).**

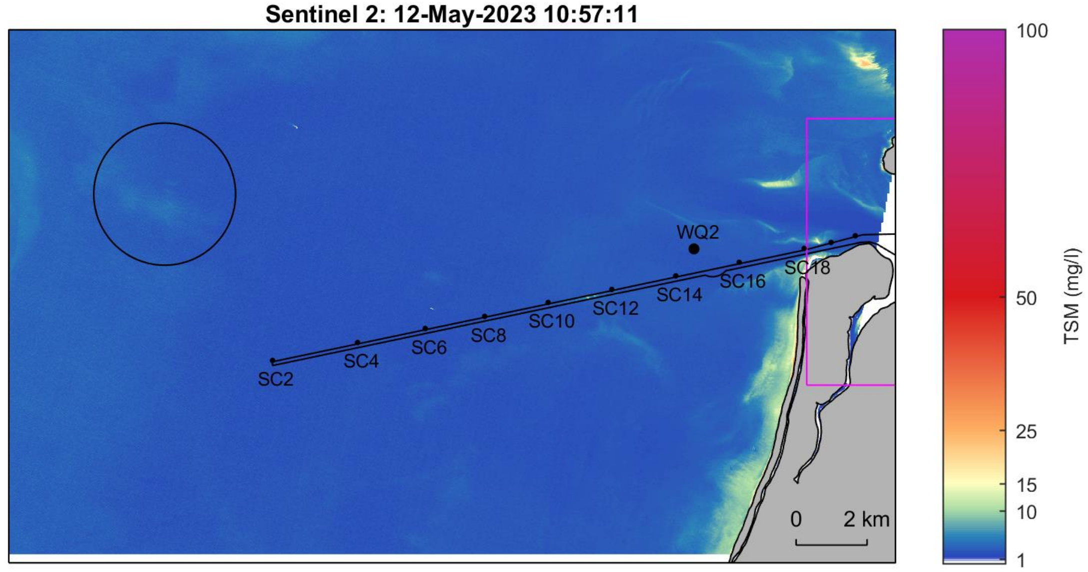
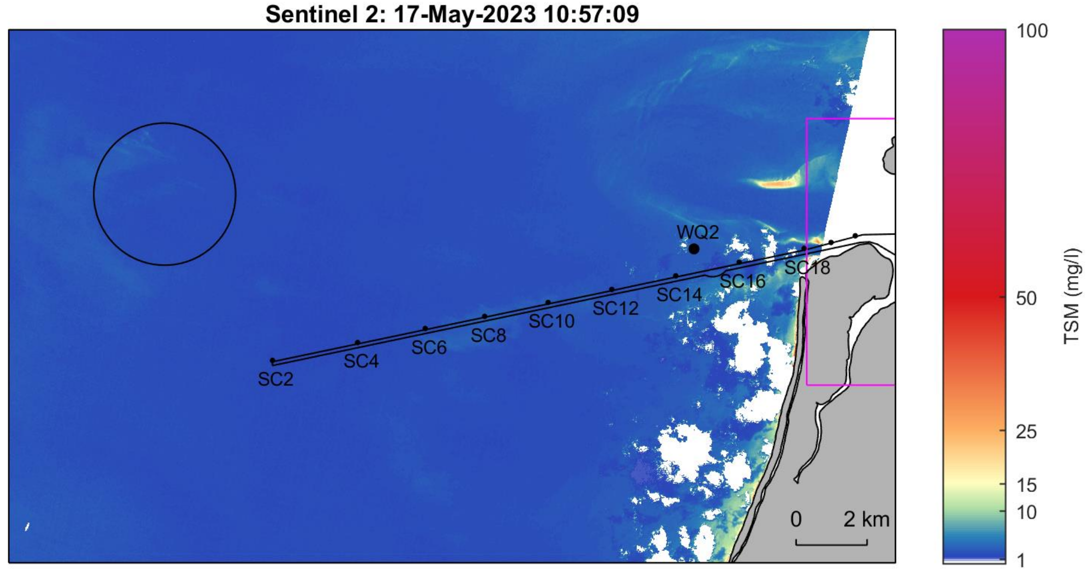
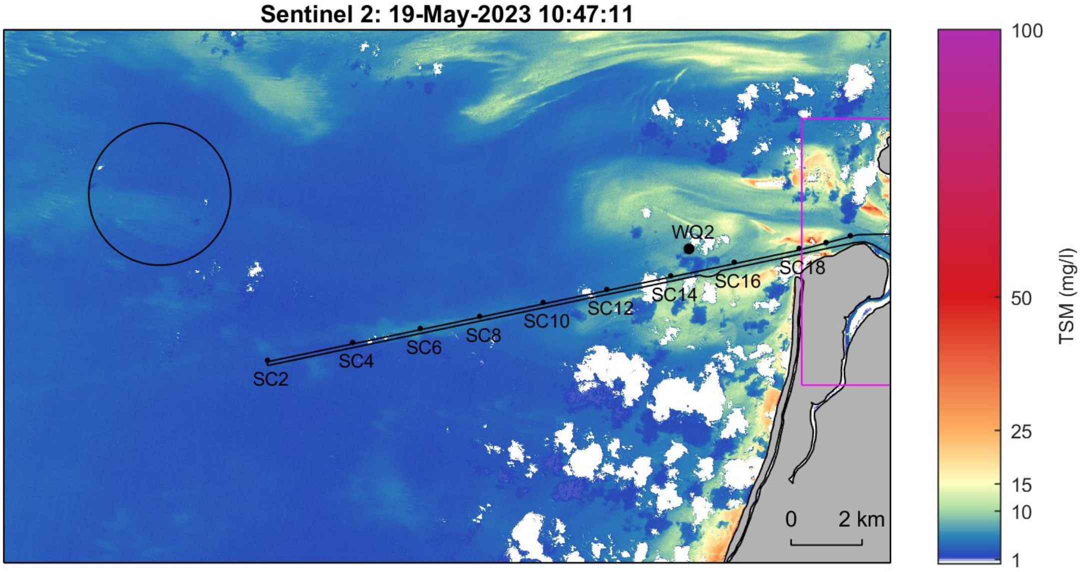


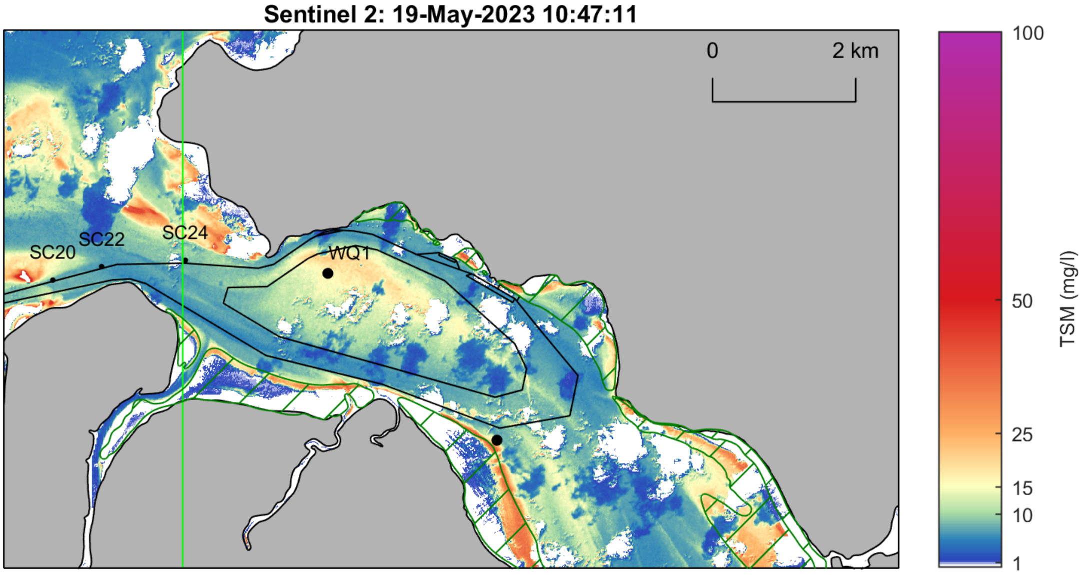
Figure 34. Satellite-derived TSM from the Sentinel-2 sensor for South Channel on 12/05/2023 at 10:57 AEST (dredging).



Note: the white areas represent cloud cover.

Figure 35. Satellite-derived TSM from the Sentinel-2 sensor for South Channel (top) and Inner Harbour (bottom) on 17/05/2023 at 10:57 AEST (dredging).





Note: the white areas represent cloud cover and adjacent blue areas the shadow from the cloud.

Figure 36. Satellite-derived TSM from the Sentinel-2 sensor for South Channel (top) and Inner Harbour (bottom) on 19/05/2023 at 10:47 AEST (dredging).

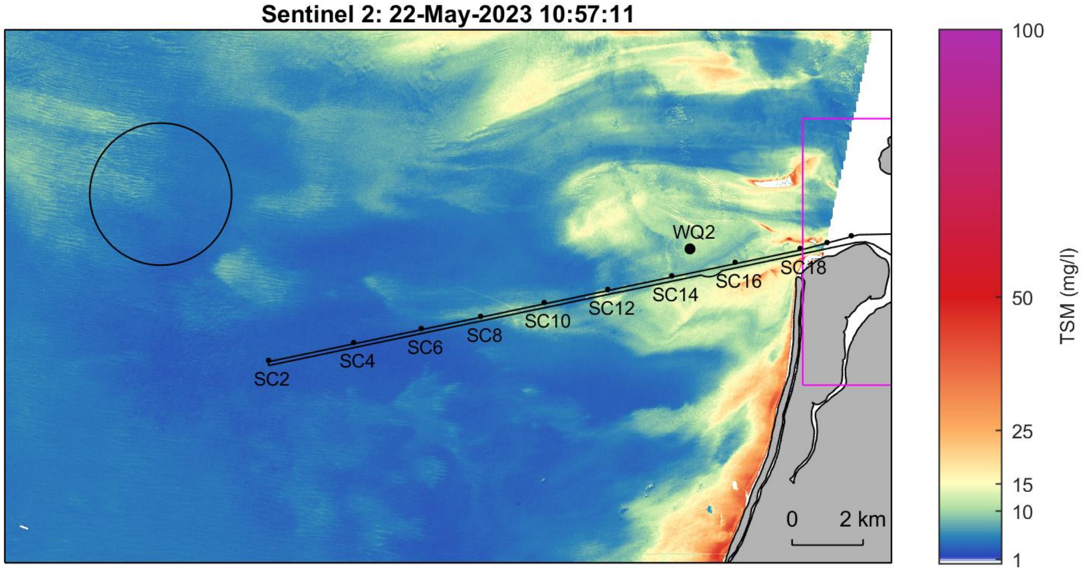


Figure 37. Satellite-derived TSM from the Sentinel-2 sensor for South Channel on 22/05/2023 at 10:57 AEST (dredging).

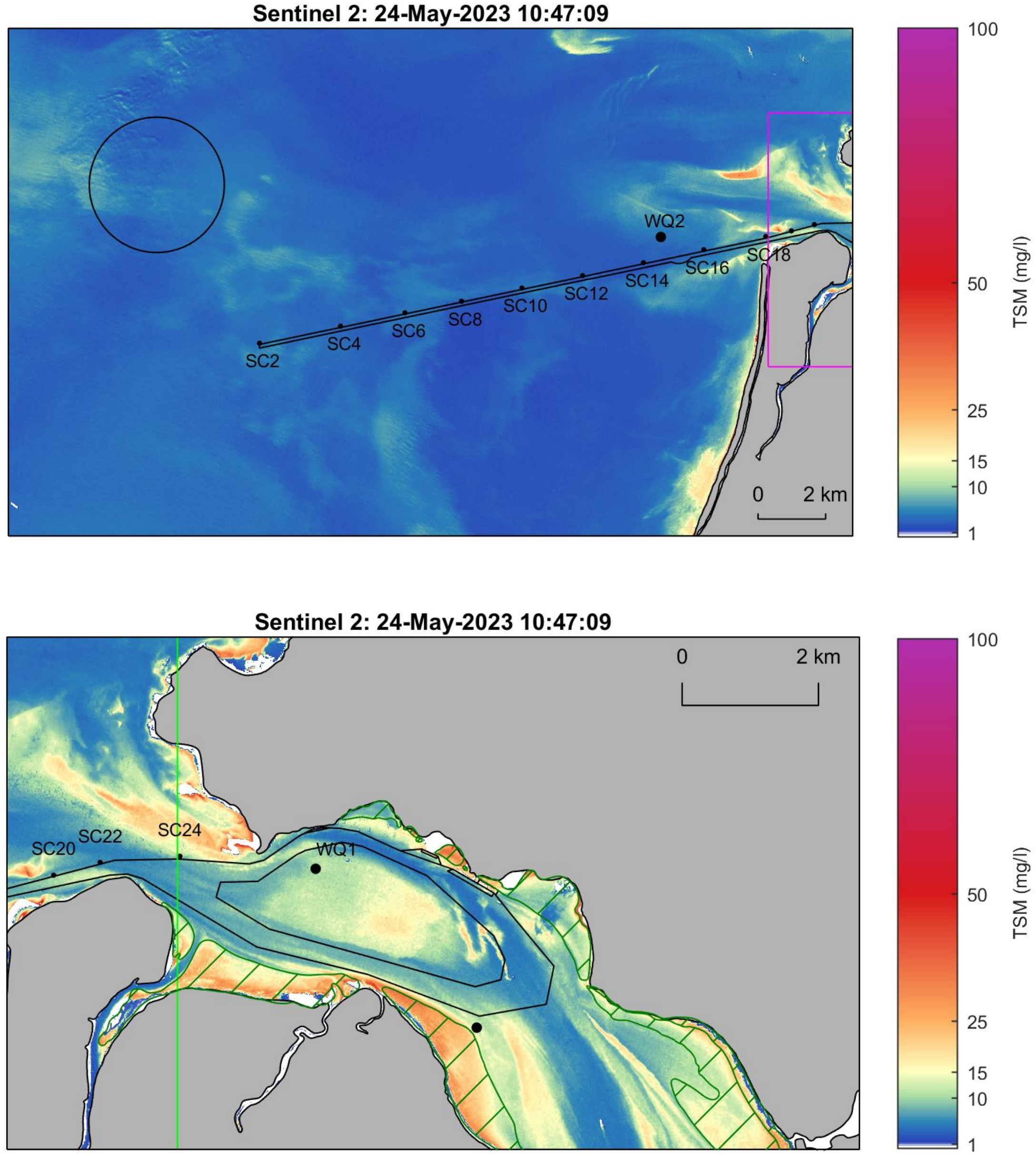


Figure 38. Satellite-derived TSM from the Sentinel-2 sensor for South Channel (top) and Inner Harbour (bottom) on 24/05/2023 at 10:47 AEST (dredging).

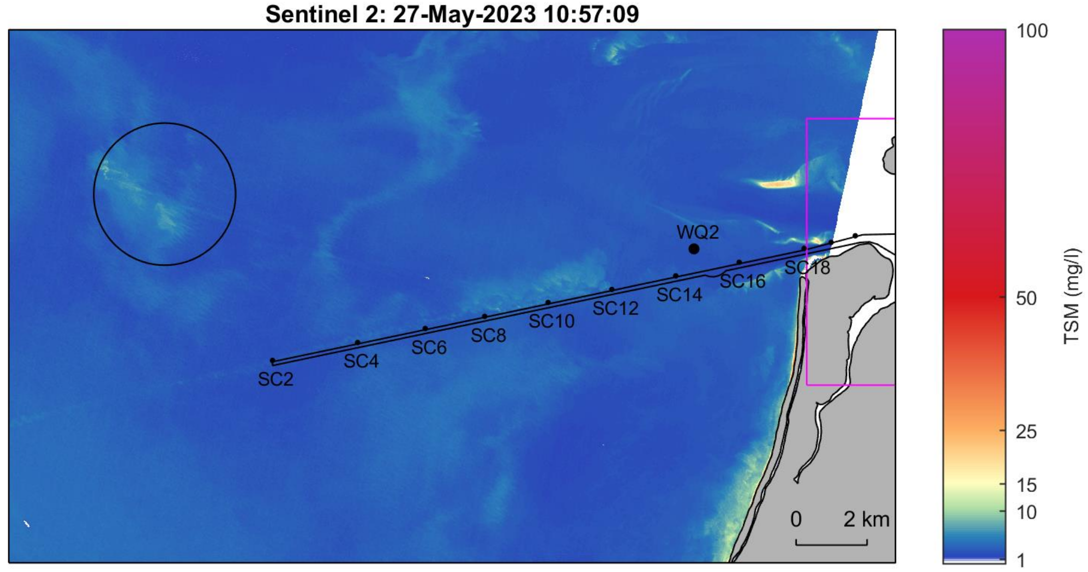
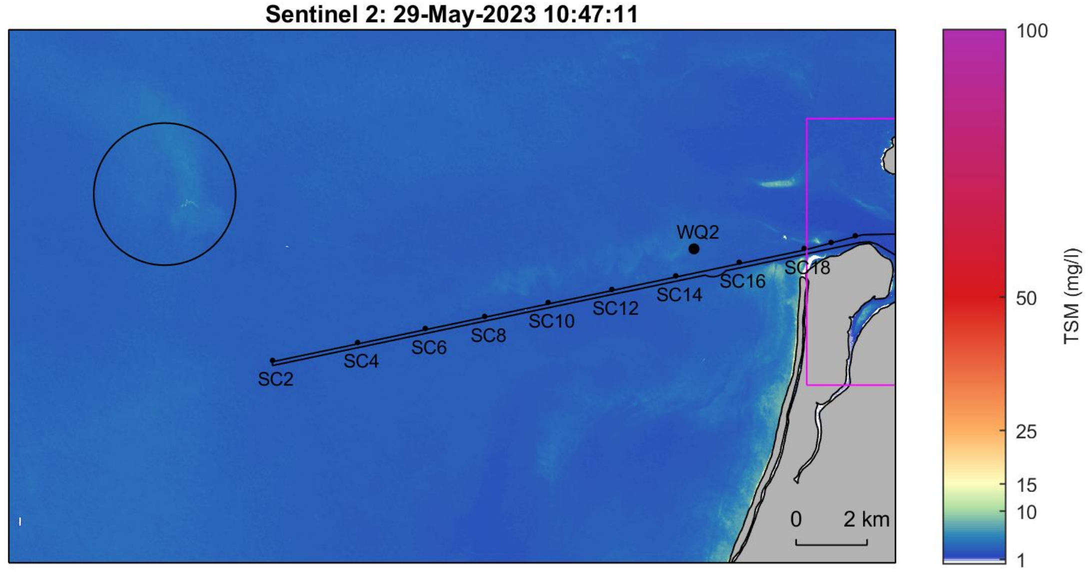


Figure 39. Satellite-derived TSM from the Sentinel-2 sensor for South Channel on 27/05/2023 at 10:57 AEST (dredging).



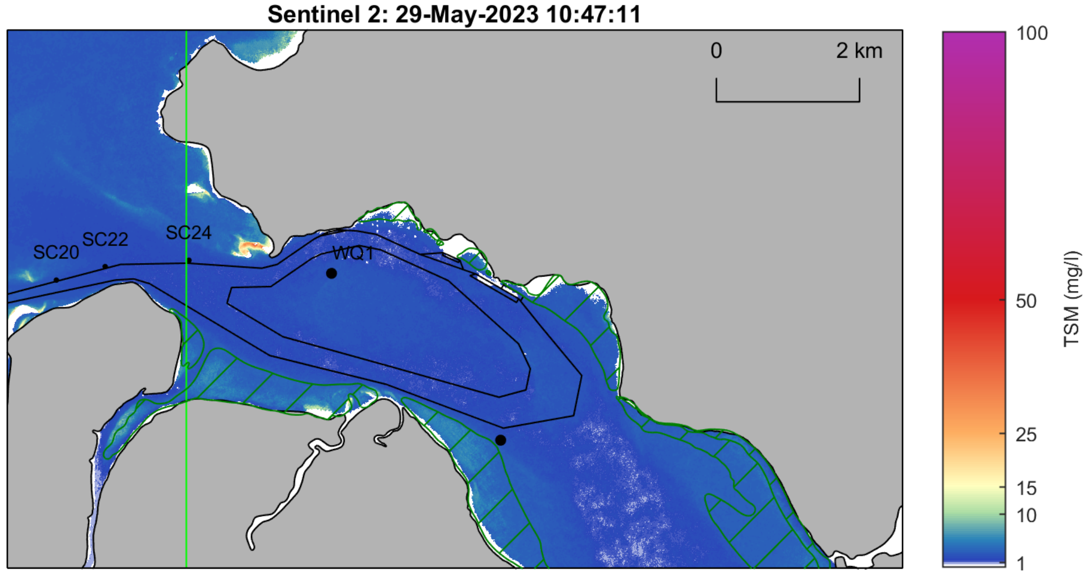
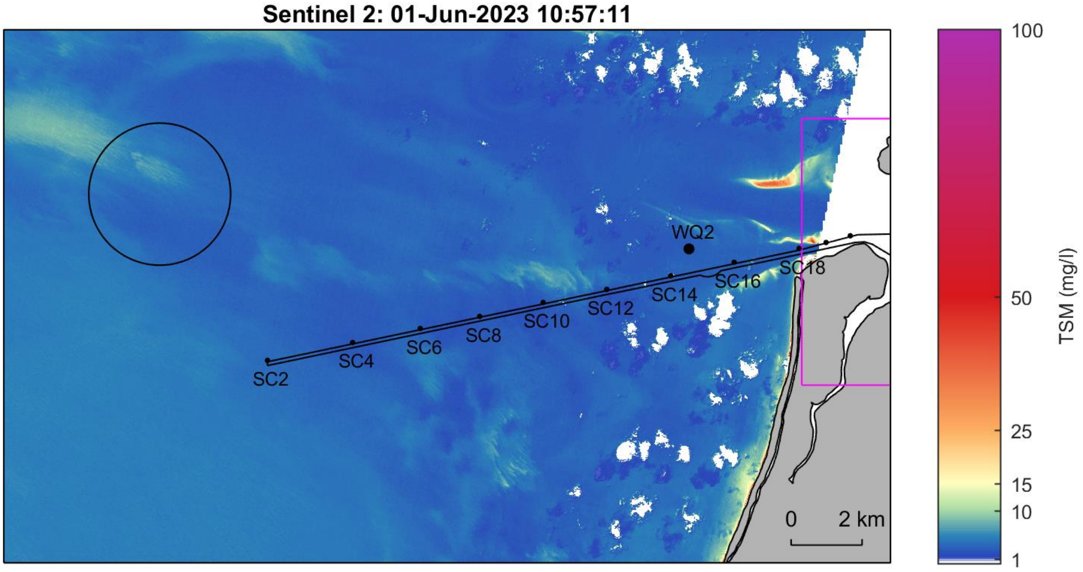
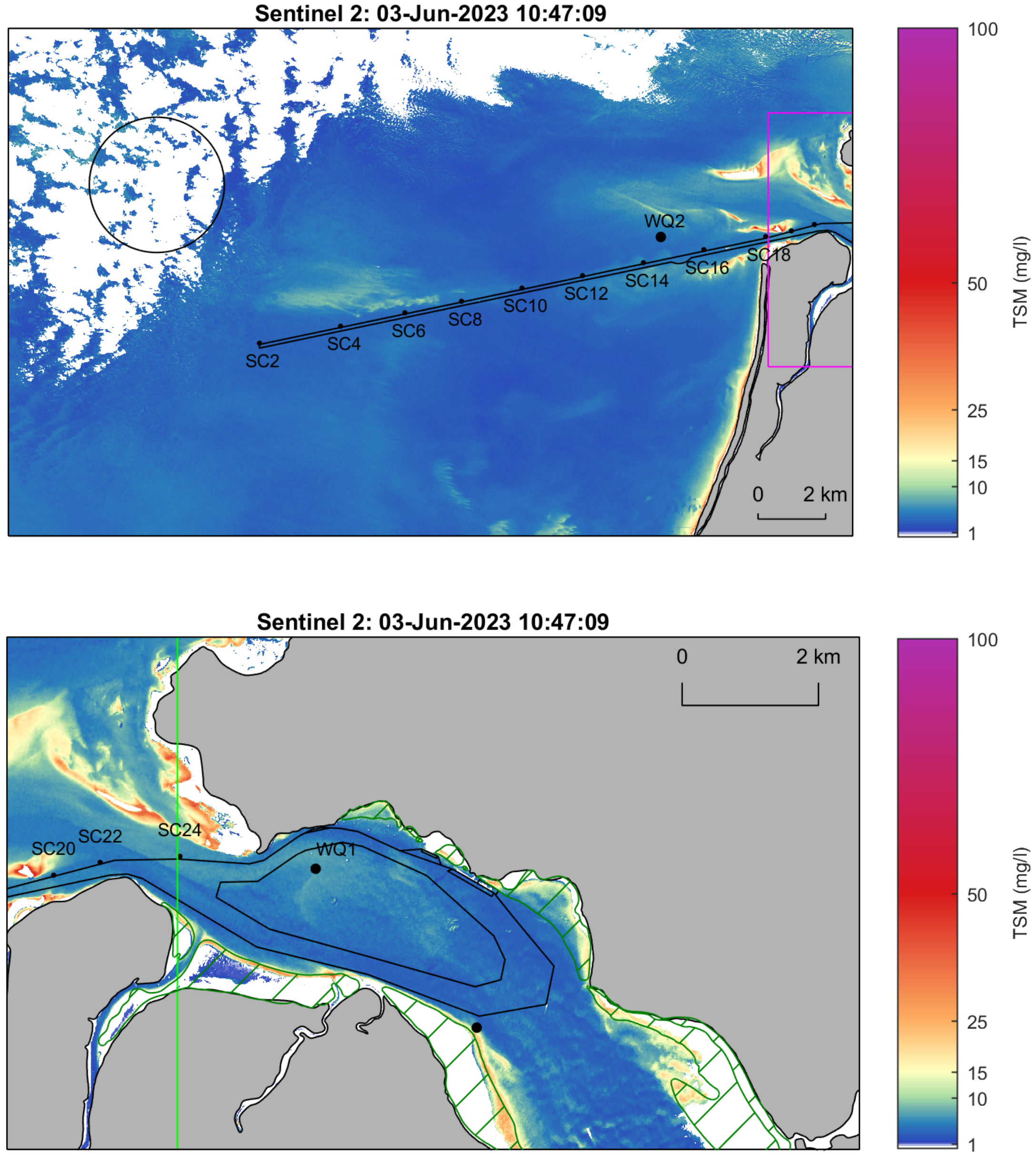


Figure 40. Satellite-derived TSM from the Sentinel-2 sensor for South Channel (top) and Inner Harbour (bottom) on 29/05/2023 at 10:47 AEST (dredging).



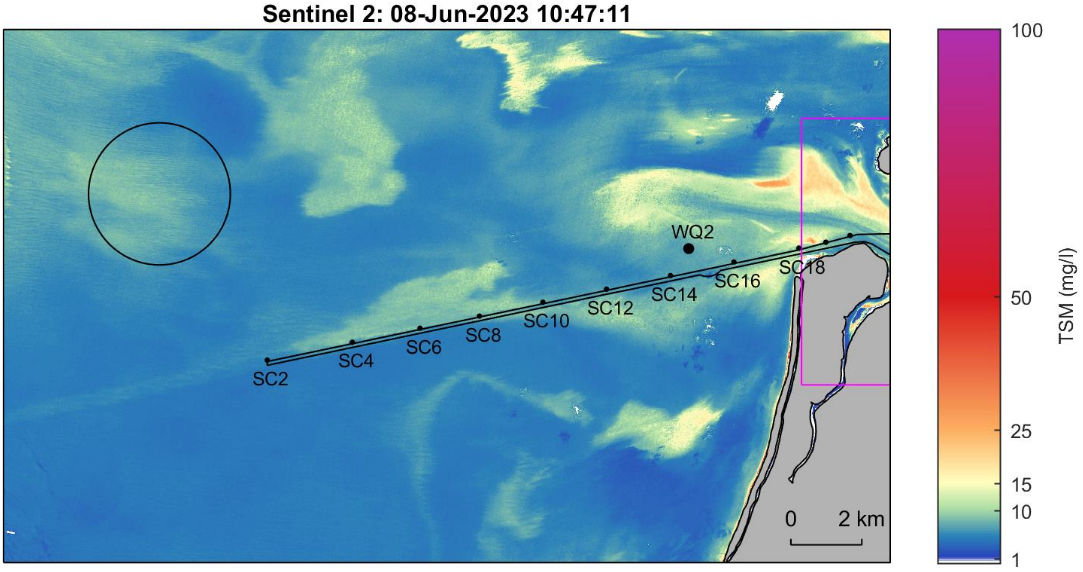
Note: the white areas represent cloud cover and adjacent blue areas the shadow from the cloud.

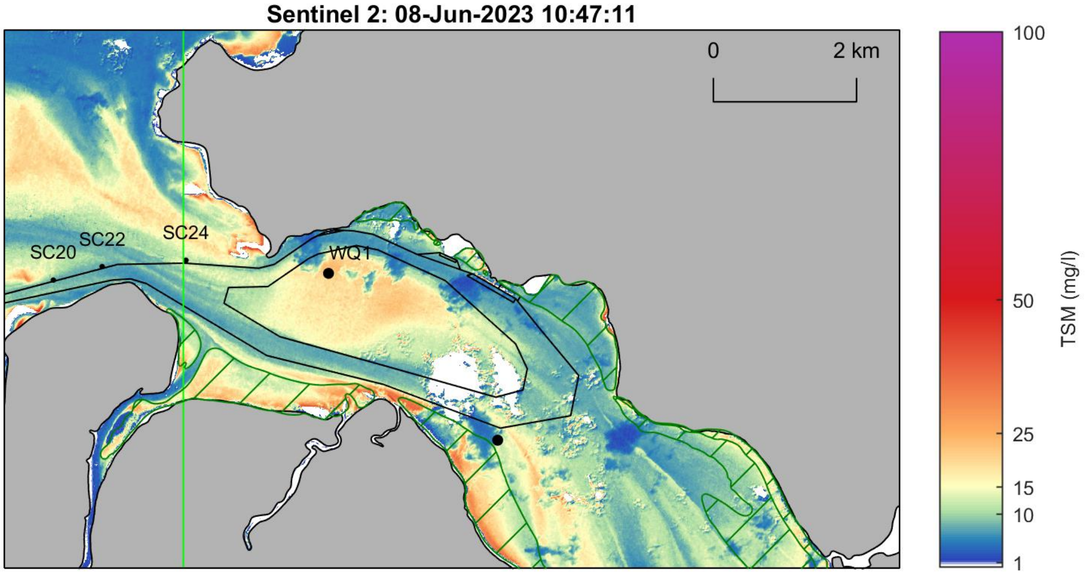
Figure 41. Satellite-derived TSM from the Sentinel-2 sensor for South Channel on 01/06/2023 at 10:57 AEST (dredging).



Note: the white areas represent cloud cover and adjacent blue areas the shadow from the cloud.

Figure 42. Satellite-derived TSM from the Sentinel-2 sensor for South Channel (top) and Inner Harbour (bottom) on 03/06/2023 at 10:47 AEST (dredging).





Note: the white areas represent cloud cover and adjacent blue areas the shadow from the cloud.

Figure 43. Satellite-derived TSM from the Sentinel-2 sensor for South Channel (top) and Inner Harbour (bottom) on 08/06/2023 at 10:47 AEST (dredging).

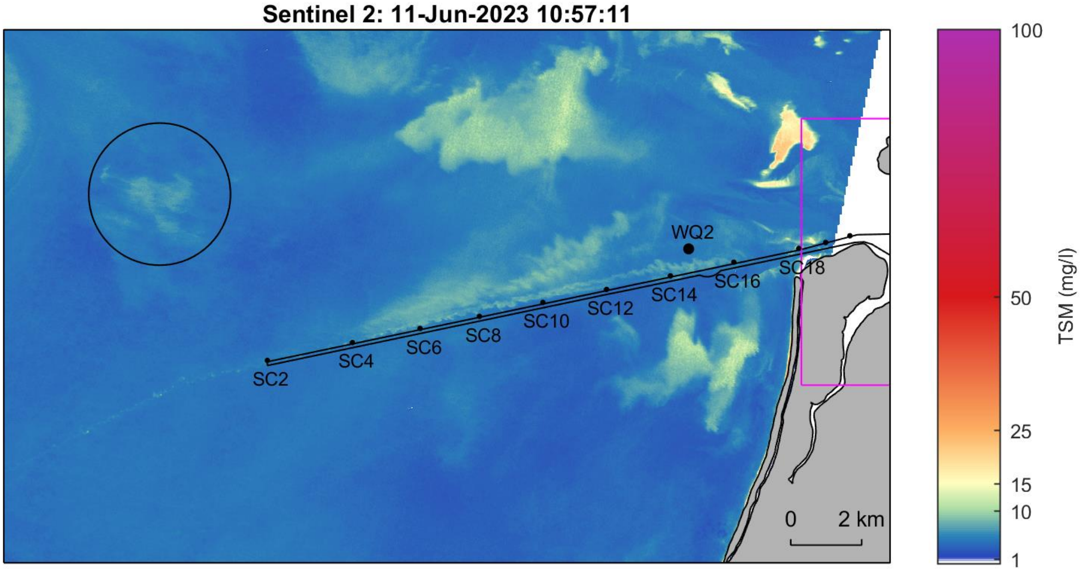


Figure 44. Satellite-derived TSM from the Sentinel-2 sensor for South Channel on 11/06/2023 at 10:57 AEST (dredging).

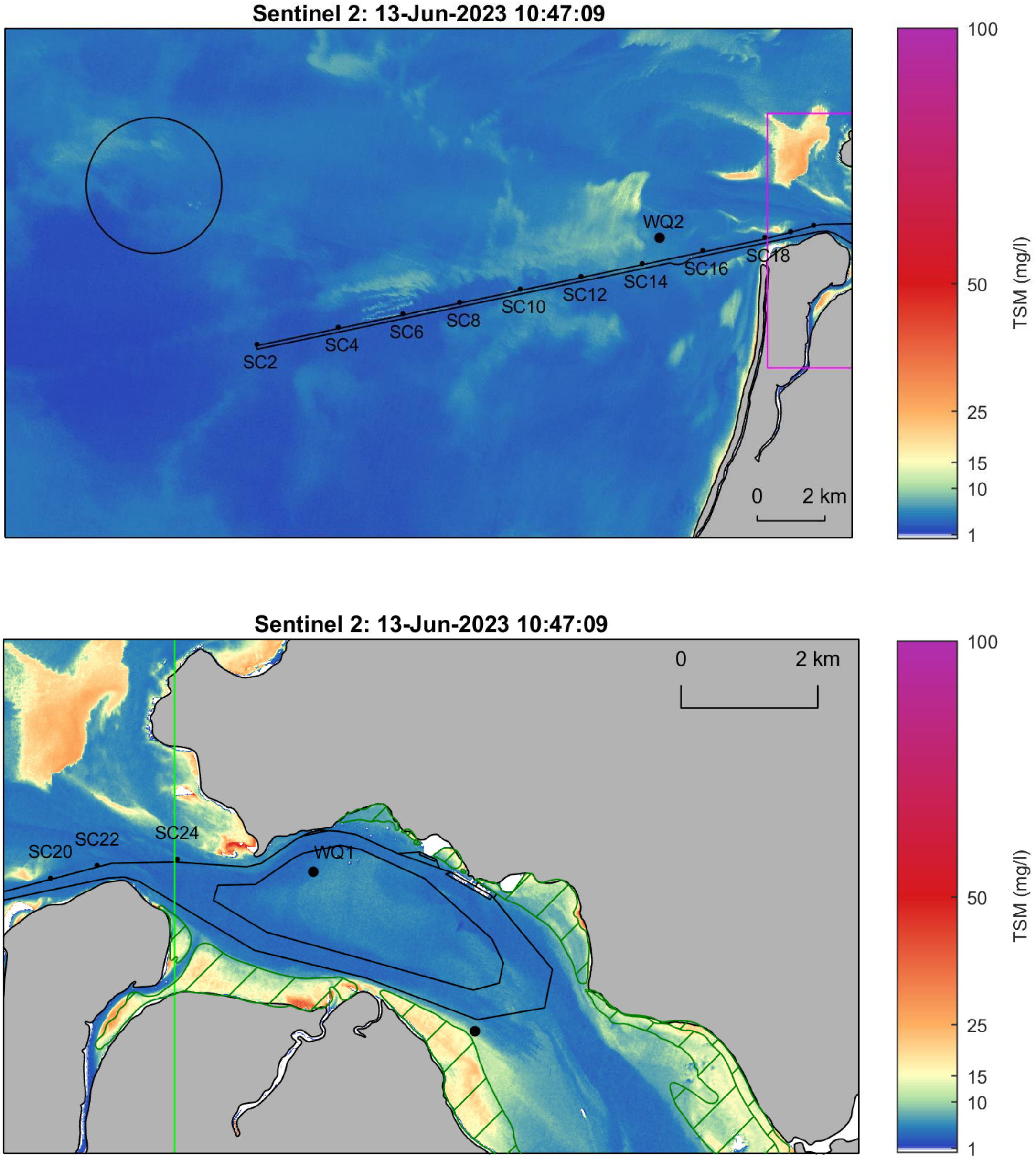


Figure 45. Satellite-derived TSM from the Sentinel-2 sensor for South Channel (top) and Inner Harbour (bottom) on 13/06/2023 at 10:47 AEST (dredging).

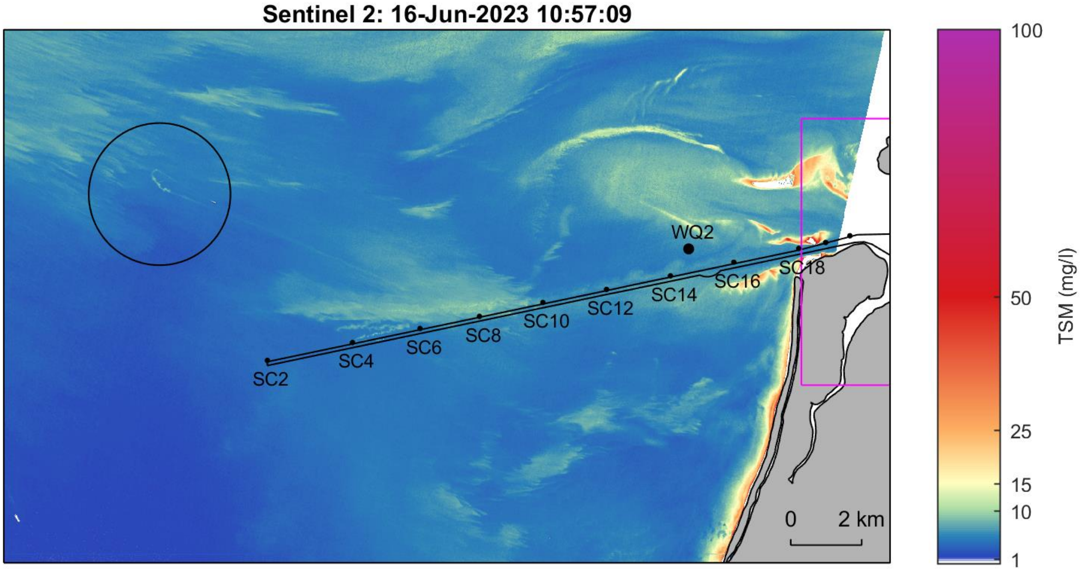
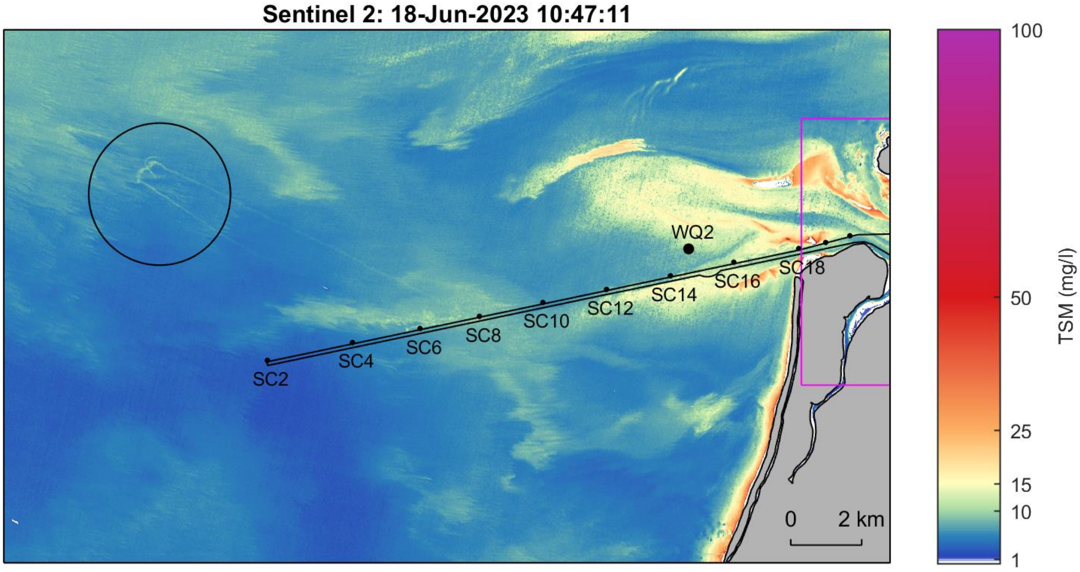


Figure 46. Satellite-derived TSM from the Sentinel-2 sensor for South Channel on 16/06/2023 at 10:57 AEST (dredging).



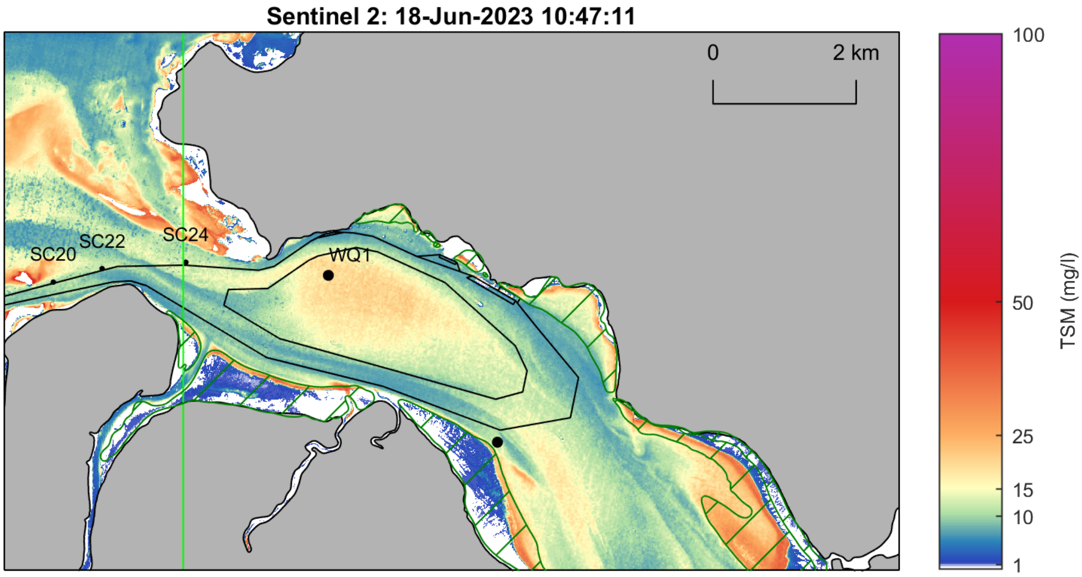


Figure 47. **Satellite-derived TSM from the Sentinel-2 sensor for South Channel (top) and Inner Harbour (bottom) on 18/06/2023 at 10:47 AEST (dredging).**

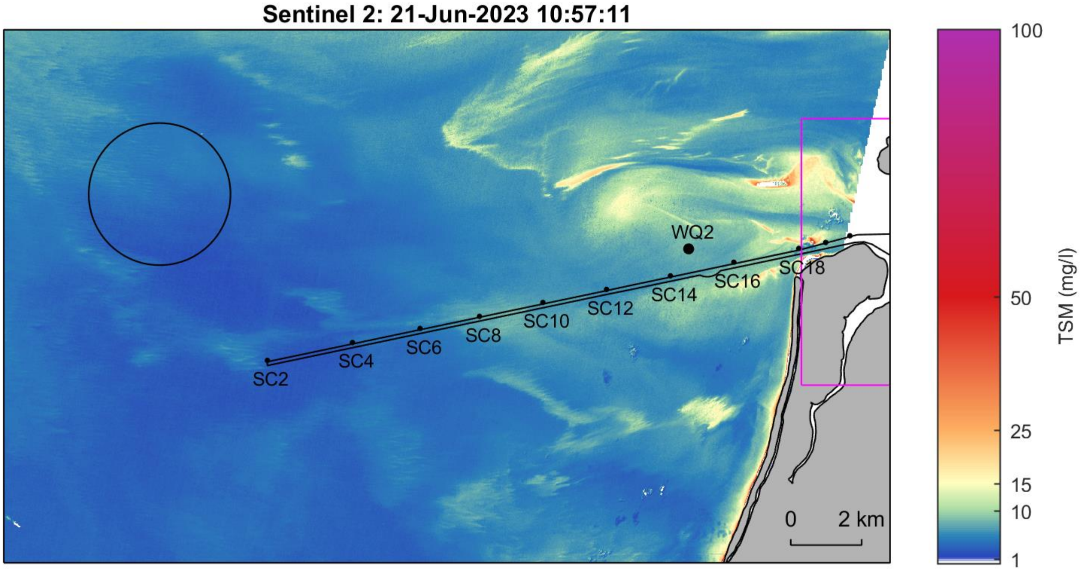
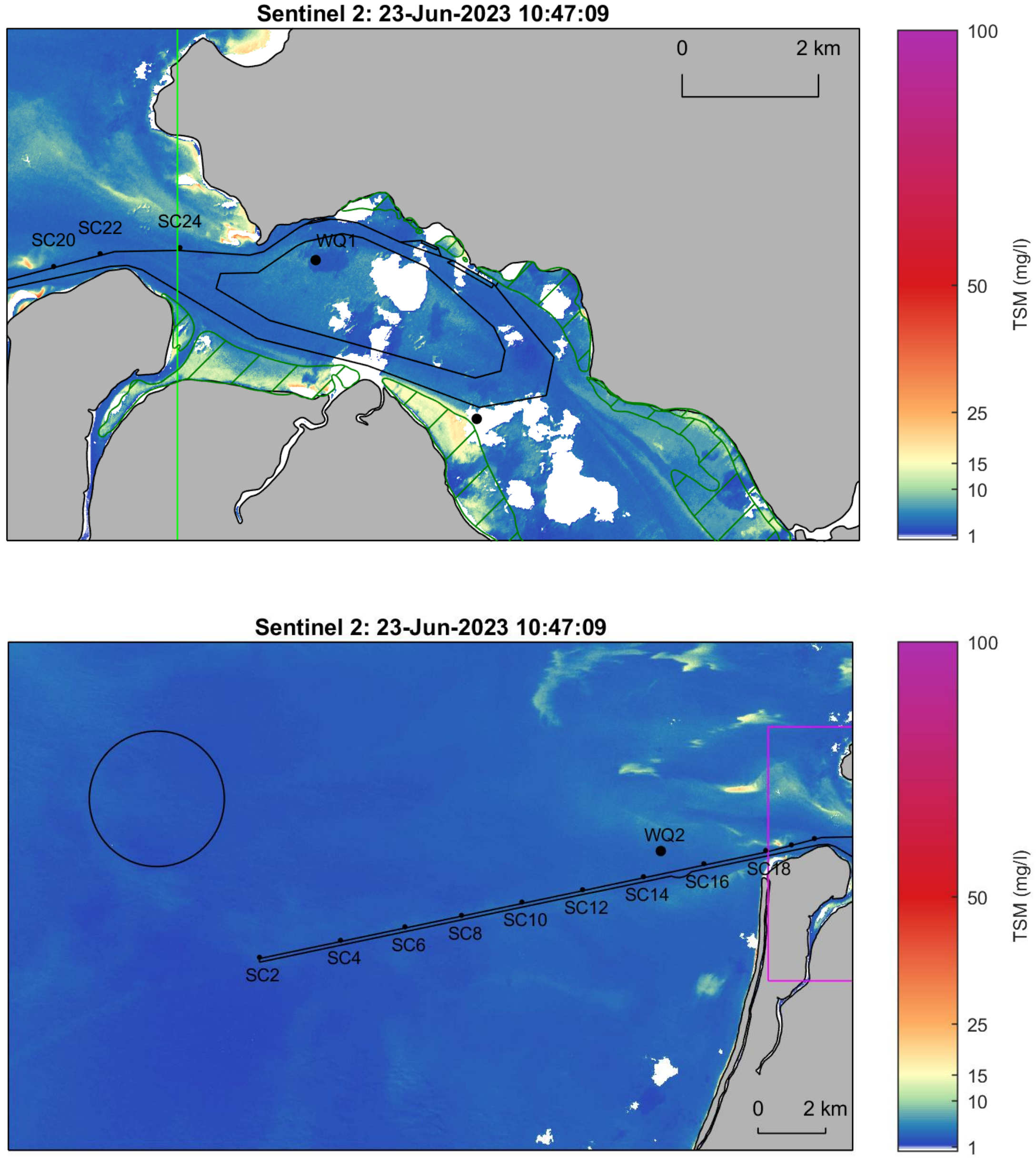


Figure 48. **Satellite-derived TSM from the Sentinel-2 sensor for South Channel on 21/06/2023 at 10:57 AEST (post-dredging).**



Note: the white areas represent cloud cover and adjacent blue areas the shadow from the cloud.

Figure 49. Satellite-derived TSM from the Sentinel-2 sensor for South Channel (top) and Inner Harbour (bottom) on 23/06/2023 at 10:47 AEST (post-dredging).

4.2.1.3. Dredge Vessel Scale

To further analyse the satellite-derived TSM for increases in TSM due to the maintenance dredging activity, zoomed in plots of the plume shown by Sentinel-2 imagery during periods when or soon after the TSHD Brisbane was dredging are shown for the following:

- at the start of dredging (Figure 50): the TSHD Brisbane had just started dredging silt from the South Channel in the image (i.e. no overflow from the hopper). The plot shows a higher concentration plume of up to 15 mg/l is present immediately behind the dredger (up to 650 m) which remains predominantly constrained within the South Channel (width of up to 100 m);
- during dredging (Figure 51): the TSHD Brisbane had been dredging predominantly sandy sediment from the Inner Harbour Approach Channel for 45 minutes when the image was captured (i.e. overflow from the hopper). This plot shows a plume of up to 20 mg/l is present predominantly within the Approach Channel (width of up to 200 m) over a 1,000 m length of the channel; and
- straight after dredging (Figure 52): the plot shows the plume 20 minutes after the TSHD Brisbane had finished dredging silt from the South Channel. The plume is up to 10 mg/l and extends approximately 1,500 m and is predominantly constrained within the South Channel with a width of 180 m.

The plots show how the maintenance dredging activity can result in a localised plume in the location where the dredging is being undertaken with a concentration of up to 15 mg/l prior to hopper overflow and up to 20 mg/l during overflow. Although the plots show that some advection and dispersion of the plume occurs resulting in the plume extent increasing, the plume still remains predominantly within the dredged channel with the width increasing to up to 180 m immediately after dredging finished. Plots of the residual plume from the maintenance dredging 1 to 2 hours after the dredging activity finished are shown in Figure 53 and Figure 55. The plots show that the residual plume has a concentration of less than 10 mg/l and can extend up to 6,000 m in length and up to 1,500 m in width. In both cases the plume has migrated to the north of the South Channel and has 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 51, Figure 53, Figure 54 and Figure 56. The plots show that a small, localised plume of up to 20 mg/l can result from the bed levelling, with a plume width of around 50 m close to the vessel. The plots indicate show that a residual plume can result from the bed levelling in the South Channel, with the plume migrating to the north of the channel and in an offshore direction. The plots indicate a residual plume with a concentration of less than 10 mg/l extending 3,500 m in length and 1,200 m in width.

The largest residual plume observed adjacent to the South Channel due to the maintenance dredging and bed levelling was towards the end of the dredge program when both the TSHD Brisbane and the Pacific Titan were operating in adjacent reaches of the channel for prolonged periods (Figure 56). The residual plume was located directly to the north of the South Channel with a concentration of up to 10 mg/l and an extent of 7,500 m in length and 1,500 m in width.

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

- 10 minutes after placement (Figure 56): a plume of up to 10 mg/l with a length of 900 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 was silt from the South Channel placed 2 hours 15 minutes prior to the image being captured; and

- 30 minutes after placement (Figure 55): a plume of up to 10 mg/l with a length of 600 m and a width of 350 m is clearly visible in the DMPA. There is also a second residual plume present towards the centre of the DMPA from the previous load placed there, this was silt from the South Channel which was placed 2 hours 45 minutes prior to the image being captured. The plume has a concentration of less than 7 mg/l and an extent of 1,000 m by 600 m.

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. The results show that for some cases the plume is not visible just over 2 hours after placement, while in other cases it is still visible almost 3 hours after placement. The metocean conditions and type of sediment placed was fairly similar for both cases shown, with the main difference being slightly larger waves (H_s > 0.5 m) present when the residual plume remained for longer.

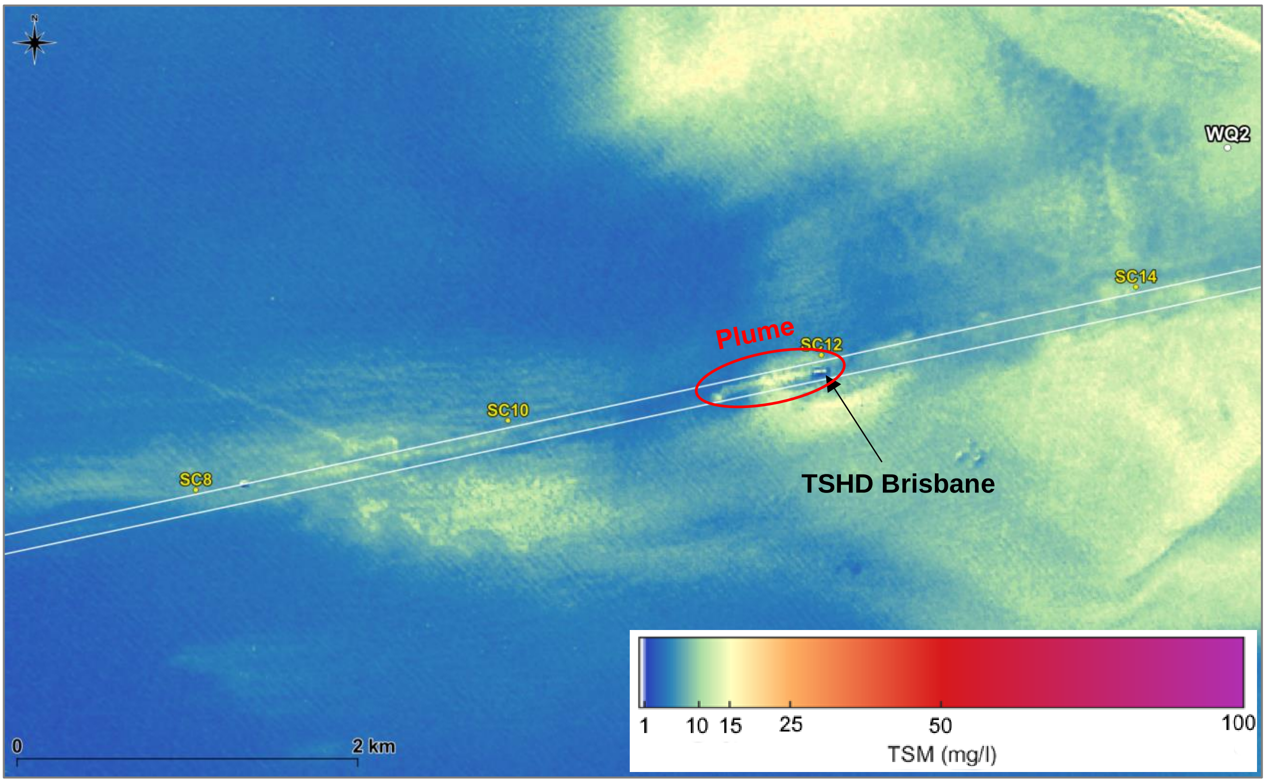


Figure 50. Satellite-derived TSM from the Sentinel-2 sensor showing the plume from the TSHD Brisbane just as it started dredging on 22/05/2023 at 10:57 AEST.

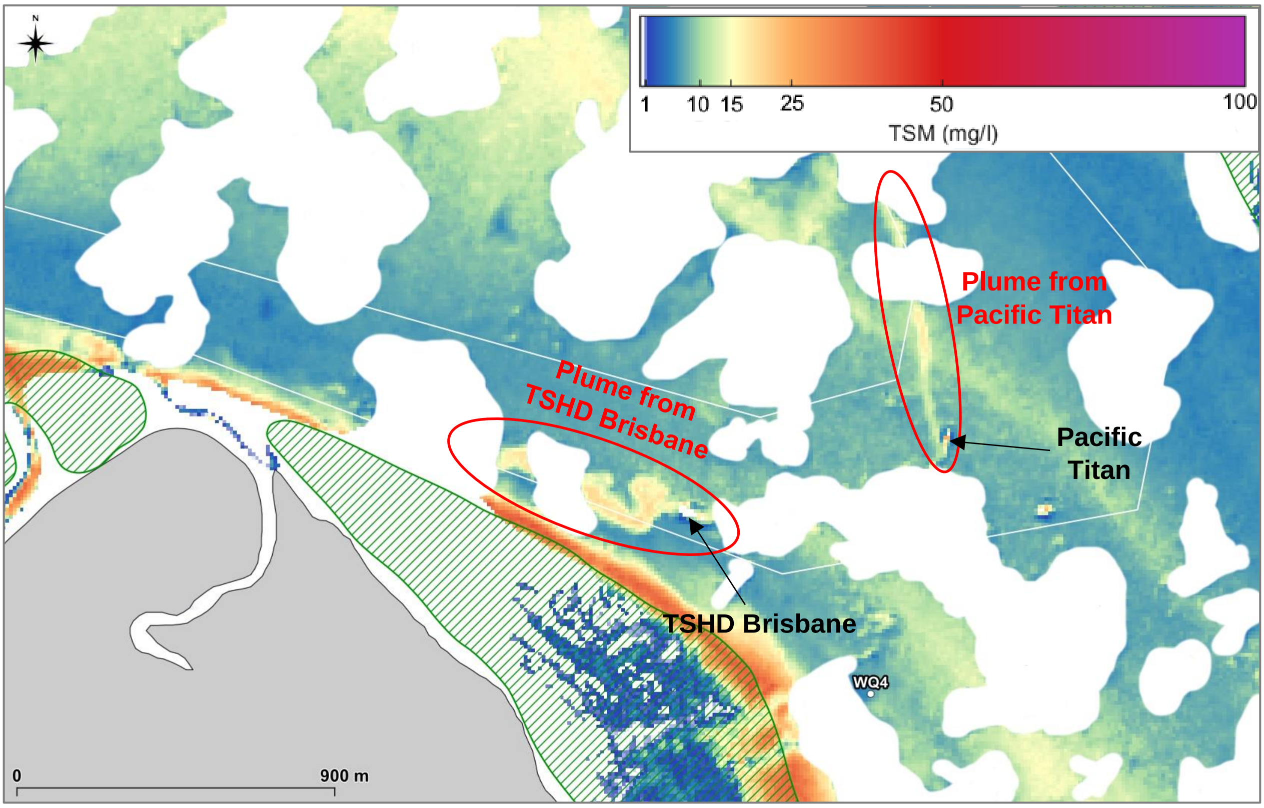


Figure 51. Satellite-derived TSM from the Sentinel-2 sensor showing the plume from the TSHD Brisbane 45 minutes after it started dredging and the plume from the Pacific Titan while bed levelling on 19/05/2023 at 10:47 AEST.

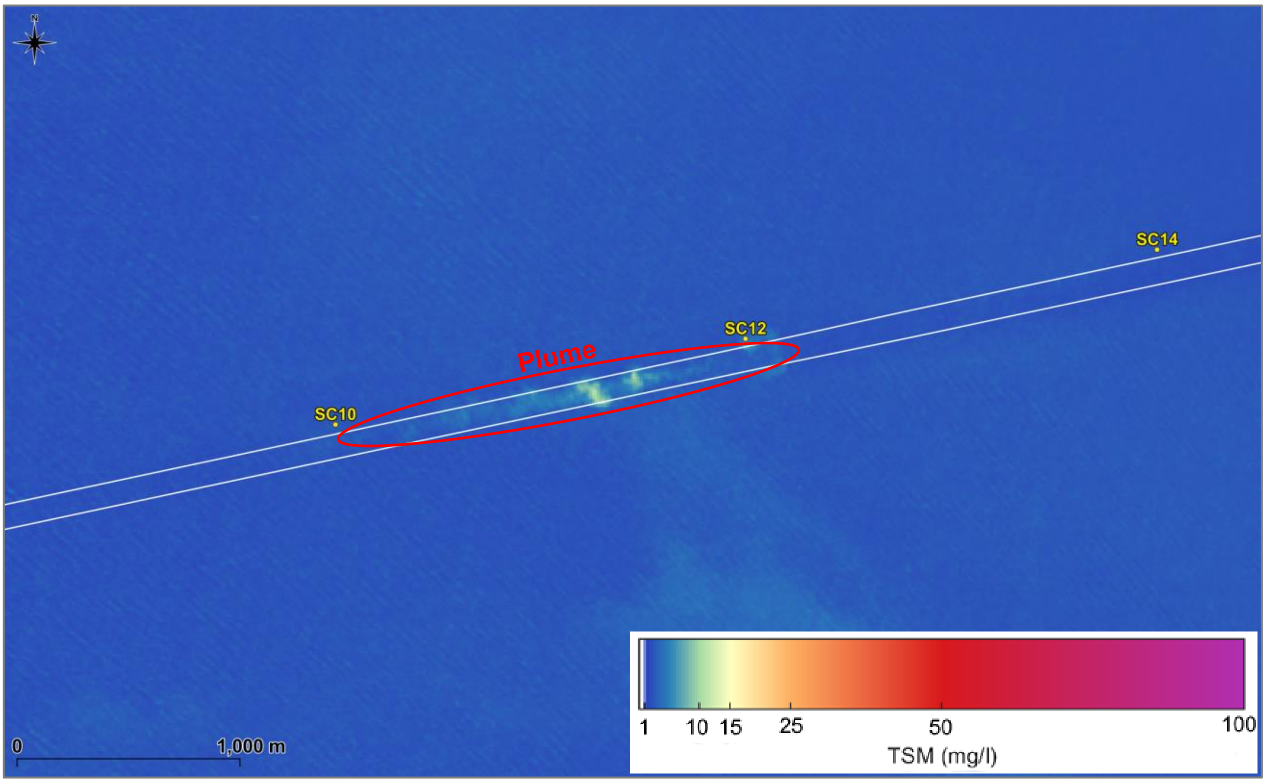


Figure 52. Satellite-derived TSM from the Sentinel-2 sensor showing the plume from the TSHD Brisbane 20 minutes after it finished dredging between SC10 and SC12 on 12/05/2023 at 10:57 AEST.

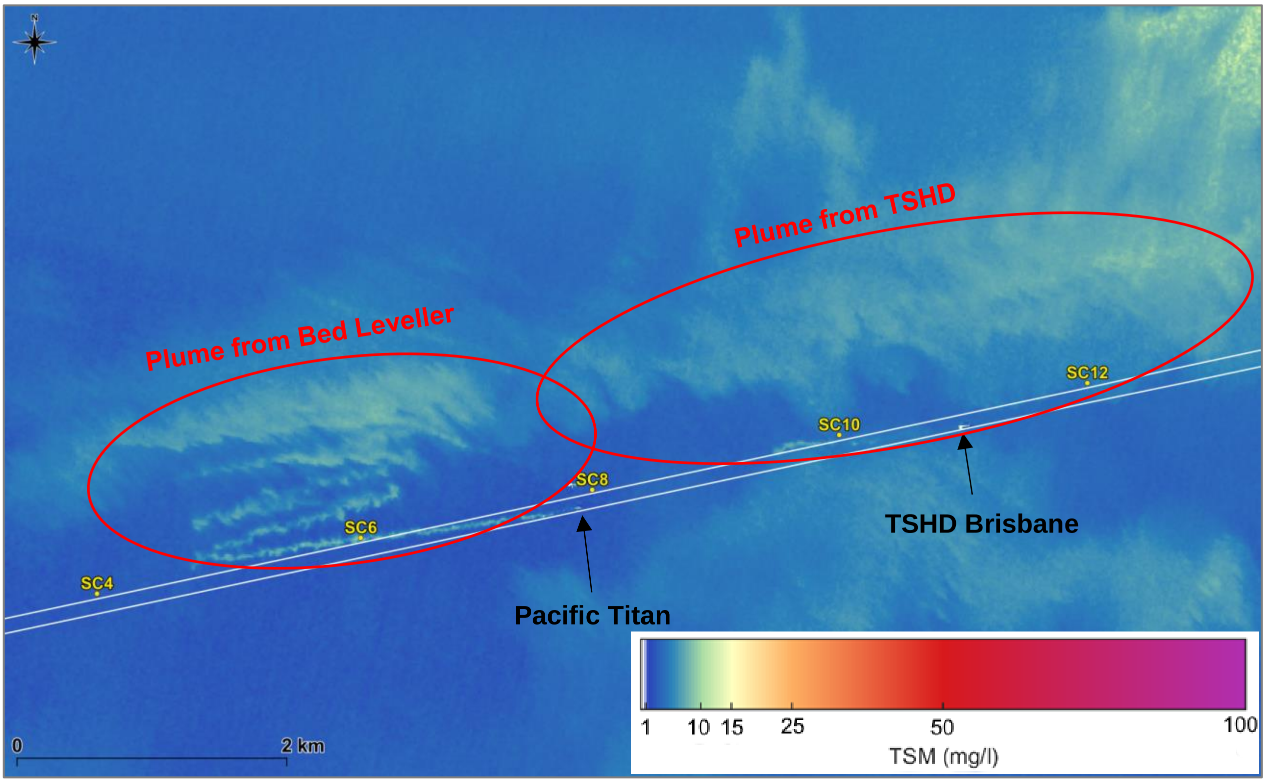


Figure 53. Satellite-derived TSM from the Sentinel-2 sensor showing the plume from the TSHD Brisbane 7 minutes after starting dredging (1 hour 45 minutes since previous dredging from SC10 to SC12 finished) between SC10 and SC12 and the Pacific Titan after ongoing bed levelling between SC6 and SC8 on 13/06/2023 at 10:47 AEST.

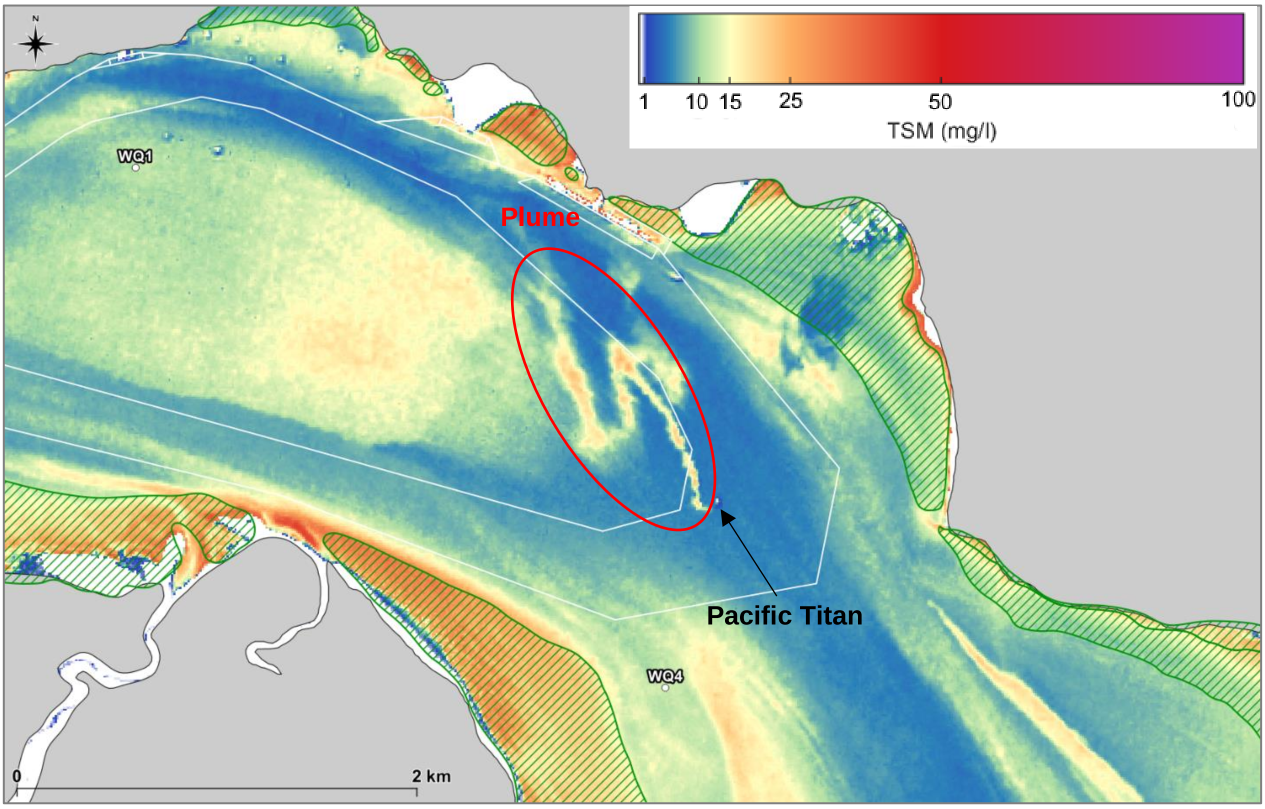


Figure 54. Satellite-derived TSM from the Sentinel-2 sensor showing the plume from the Pacific Titan while bed levelling in the Approach Channel of the Inner Harbour on 24/05/2023 at 10:47 AEST.

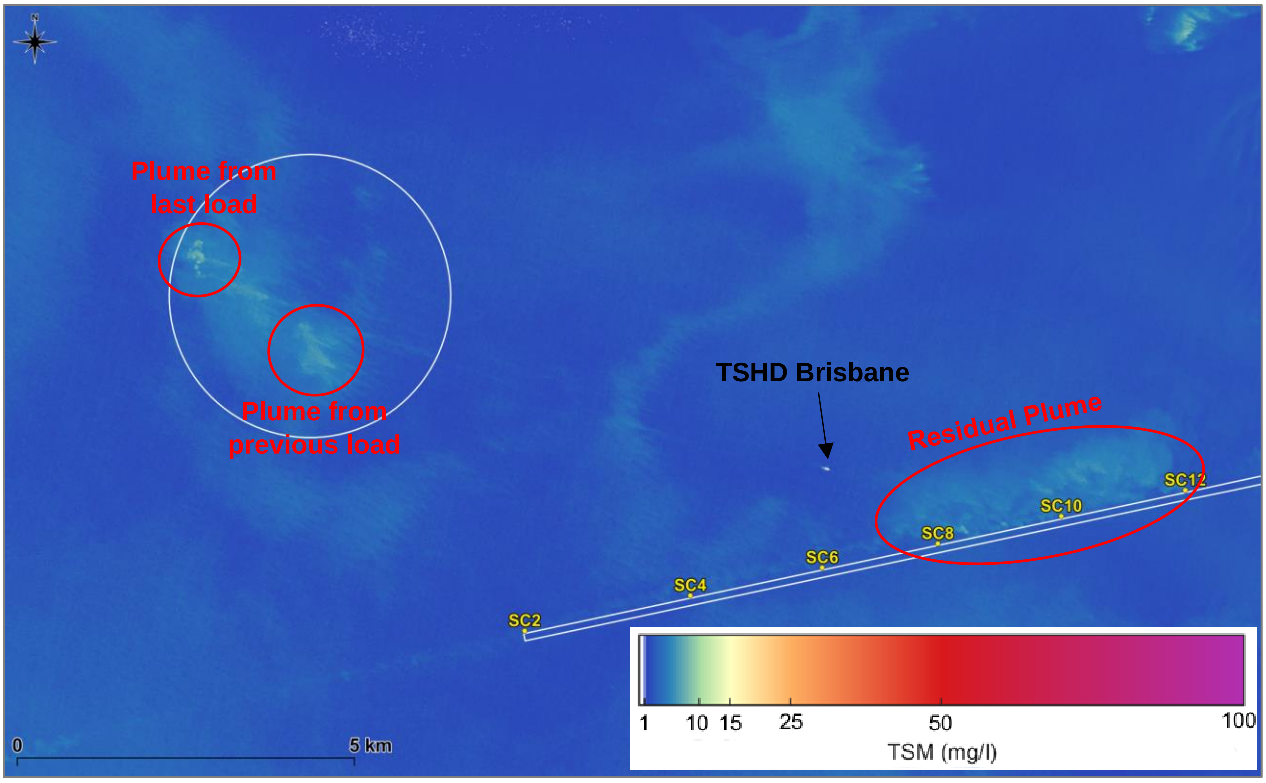


Figure 55. Satellite-derived TSM from the Sentinel-2 sensor showing the plume from the TSHD Brisbane 30 minutes after placing at the DMPA and 1 hour 20 minutes after finishing dredging between SC10 and SC12 on 27/05/2023 at 10:57 AEST.

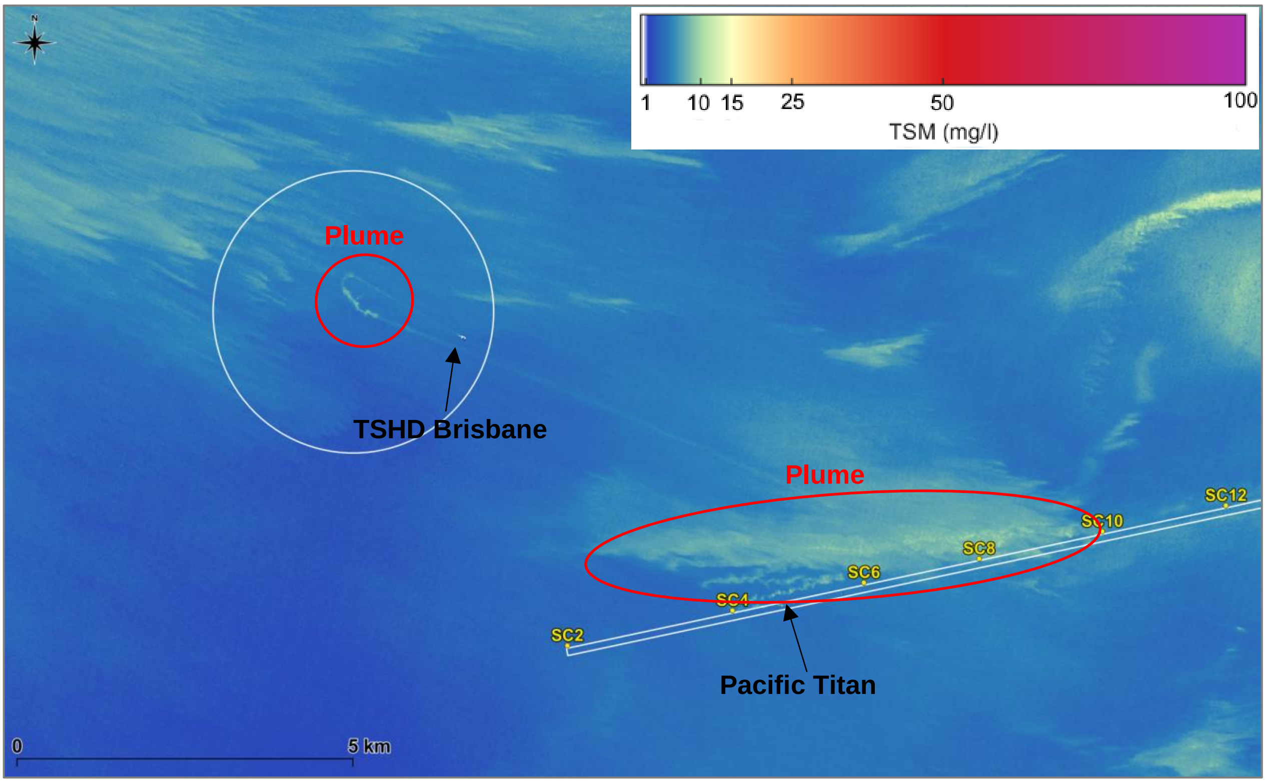


Figure 56. Satellite-derived TSM from the Sentinel-2 sensor showing the plume from the TSHD Brisbane 10 minutes after placing at the DMPA and 1 hour after finishing dredging between SC8 and SC10 on 16/06/2023 at 10:57 AEST.

5. Summary

This report has analysed and interpreted turbidity data collected pre-, during and post the Port of Weipa 2023 maintenance dredging program. The 2023 maintenance dredging program was undertaken by the TSHD Brisbane and involved the relocation of 782,000 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), 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 shows that the duration exceedances were below the average duration exceedance at WQ2 while at WQ1 the exceedance duration was above the average duration exceedance, but below the 90th percentile duration exceedance and at WQ4 the duration was above the 90th percentile duration but well below the maximum duration. The results therefore show that the turbidity in the Inner Harbour (i.e. at both WQ1 and WQ4) was higher than the turbidity in Albatross Bay relative to the updated turbidity intensity thresholds. Based on this it would be beneficial to undertake a further analysis and revisit updating the turbidity intensity thresholds;
- 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 2022 maintenance dredging programs and as part of the Port of Weipa Sustainable Sediment Management assessment (PCS, 2019b, 2020a, 2020b, 2021a, 2022). 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 2023 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, within the Inner Harbour channels and within the Albatross Bay DMPA. The size and concentration of the plumes was variable depending on both the dredging and bed levelling activities and the metocean conditions (i.e. larger plumes occurred during spring tides or periods with larger waves when sediment naturally remains in suspension for longer);
  - the largest plume which was due to combined maintenance dredging and bed levelling was up to 7,500 m in length and 1,500 m in width with a concentration of up to 10 mg/l, occurring adjacent to the South Channel. Satellite imagery indicated that a 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 1,000 m in extent 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 2023 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 in 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 2023 maintenance dredging

program, with no visible plumes from the dredging activity observed in the seagrass meadows; and

- the post dredging satellite imagery showed that a residual plume could still have been present around the South Channel 36 hours after the dredging had finished (although this could have been due to natural resuspension of recently deposited sediment suspended by the dredging), but no plume was present in the DMPA. The image captured 3.5 days after dredging ended did not show any indication of 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 and 2022) 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, 2020a, 2022).

6. References

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