PORT OF **WEIPA**

SUMMARY

2020 Turbidity Monitoring

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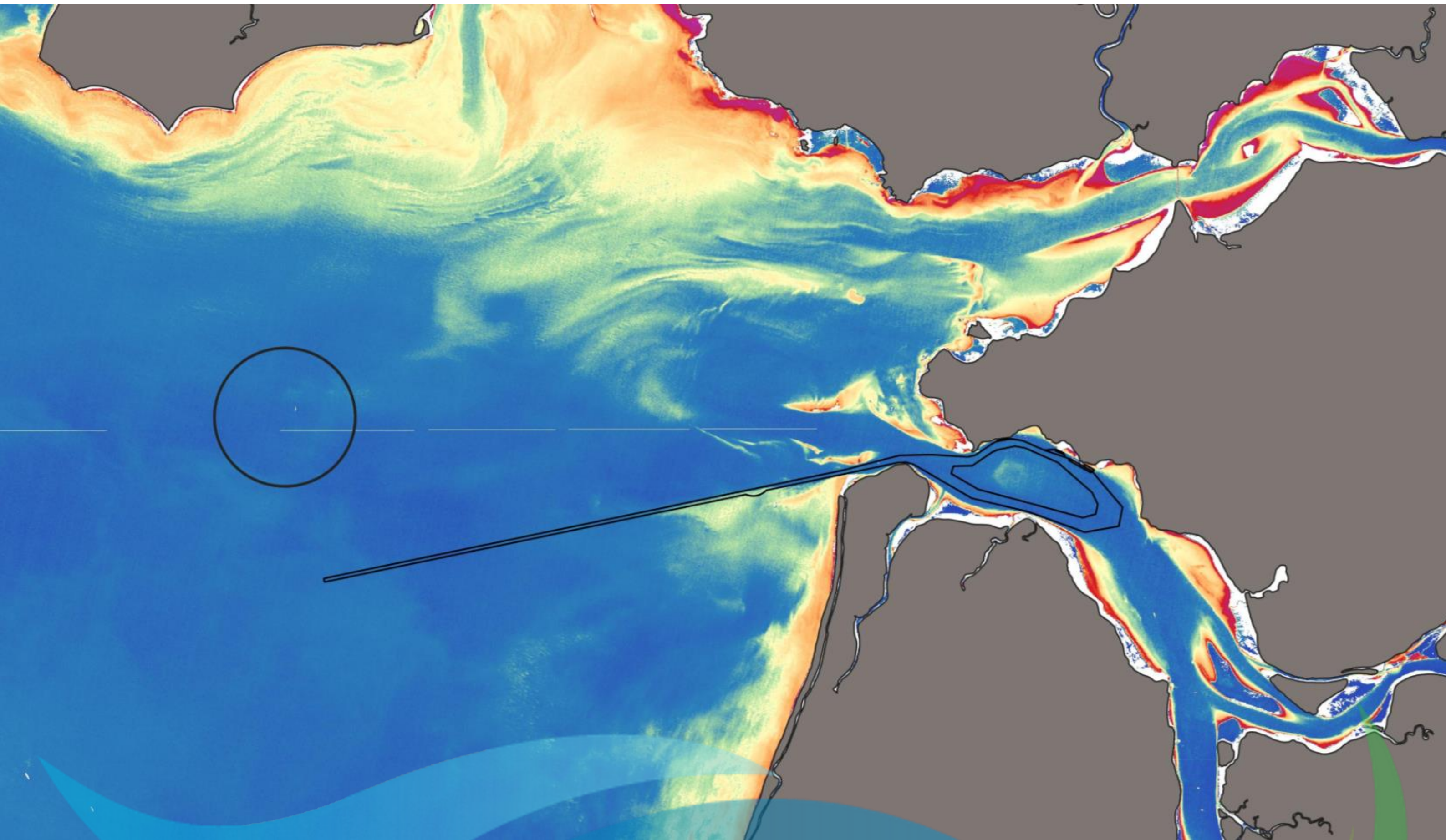
Port of Weipa, 2020 Maintenance Dredging

Summary of Turbidity Monitoring

Report No. P028_R2v02



Technical Report
June 2020

Port of Weipa, 2020 Maintenance Dredging

Summary of Turbidity Monitoring

Report No. P028_R2v02

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North Queensland Bulk Ports Corporation Ltd

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Note: if this report is printed it is possible that some of the detail in the satellite imagery, such as low concentration plumes, may not be visible. Figure 21 should be compared between any printed versions and the digital version of the report to determine how well the printed version represents the lower concentration plumes.

TABLES

Executive Summary

North Queensland Bulk Ports Corporation (NQBP) commissioned Port and Coastal Solutions Pty Ltd (PCS) to undertake work to support the 2020 maintenance dredging program at the Port of Weipa. This included the following:

1) to analyse the turbidity and metocean conditions over the duration of the dredge program, including 12 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 turbidity data; and
4) provide a technical report which presents and interprets both the in-situ benthic turbidity data and satellite-derived turbidity data collected over the entire pre-, during and post-dredging periods.

The 2020 maintenance dredging program was undertaken by the Trailing Suction Hopper Dredger (TSHD) Brisbane and involved the relocation of approximately 300,000 m^3 (excluding 13 dredge trips in the Inner Harbour) of sediment from the dredged areas of the Port to the Albatross Bay Dredge Material Placement Area (DMPA). PCS analysed and interpreted satellite-derived turbidity data collected during the Port of Weipa 2020 maintenance dredging program. The data showed that during the dredging program the turbidity around the Port of Weipa was generally driven by the natural conditions (predominantly the wave conditions), with higher turbidity occurring during periods with larger waves. The key findings from the turbidity data analysis are as follows:

- based on the measured benthic turbidity data the turbidity during the pre-, during and post-dredging periods of the 2020 maintenance dredging program appears to have been predominantly controlled by the metocean conditions;
- exceedance analysis of the in-situ measured benthic turbidity data shows increased duration exceedances over the 2020 maintenance dredging program. However, based on the available information this is expected to mainly be related to the metocean conditions as opposed to increased turbidity from maintenance dredging;
- the dredging and placement activities associated with the 2020 maintenance dredging program have been found to result in visible plumes. Plumes were observed close to the dredger when dredging, adjacent to the South Channel and within the Albatross Bay DMPA. The size and concentration of the plumes varied, the largest plume was up to 2 km in length, 300 m in width with a concentration of approximately 25 mg/l, occurring adjacent to the South Channel due to ongoing dredging in the area;
- all of the plumes resulting from maintenance dredging (including those from both dredging and placement) were found to remain close to where they were created. This shows that little net residual transport occurs in the region, this was also noted during the 2019 maintenance dredging program and as part of the Port of Weipa Sustainable Sediment Management assessment (PCS, 2018b and 2019c). Based on this, it can be assumed that the majority of the sediment suspended by the maintenance dredging is subsequently redeposited close to where it was either dredged or placed;
- the Port of Weipa 2020 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 wave conditions over the monitoring period were significantly larger than the variations in turbidity due to the maintenance dredging; and
- the satellite imagery showed that following completion of the 2020 maintenance dredging program, the turbidity quickly (between one and four days) returned to natural conditions

with no remaining areas with elevated turbidity due to the maintenance dredging and placement activities.

1. Introduction

North Queensland Bulk Ports Corporation (NQBP) commissioned Port and Coastal Solutions Pty Ltd (PCS) to undertake work to support the 2020 maintenance dredging program at the Port of Weipa. This included the following:

1) to analyse the turbidity and metocean conditions over the duration of the dredge program, including 12 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 turbidity data; and
4) provide a technical report which presents and interprets both the in-situ benthic turbidity data and satellite-derived turbidity data collected over the entire pre-, during and post-dredging periods.

Following completion of the 2020 maintenance dredging program and the 12 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 2018/19 financial year, the Port of Weipa handled approximately 27 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 typically ranging from approximately 300,000 m^3 to 1,000,000 m^3 with an outlier event in 2019 of 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). Based on detailed bathymetric analysis by PCS (2018a) 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).

The 2018/19 wet season had multiple large wave events (three TCs and a prolonged tropical low) which all impacted the Weipa region and resulted in the largest sedimentation in the Port in history. Approximately 2.5 million m^3 of sediment was deposited in the South Channel over this period, which is more than three times larger than the previous highest annual sedimentation volume (PCS, 2020a). As a result, the 2019 maintenance dredging program was significantly larger than any previous years, with a total of just over 2.4 million m^3 removed in June and July 2019 (PCS, 2019a).

There were no TCs during the 2019/20 wet season and only one wave event which resulted in significant wave heights greater than 2 m. As a result, the sedimentation within the South Channel was significantly less than the previous year and more in line with typical sedimentation volumes. The very high sedimentation in 2018/19 was found to be a result of multiple large wave events occurring over the wet season, which included two tropical cyclones and a prolonged tropical low (PCS, 2019b). The 2020 maintenance dredging program commenced on the 4th May 2020 at 06:00 and was completed at 06:00 on 28th May 2020. During the program approximately 300,000 m^3 (excluding 13 dredge trips in the Inner Harbour) was relocated to the Albatross Bay DMPA by the TSHD Brisbane.

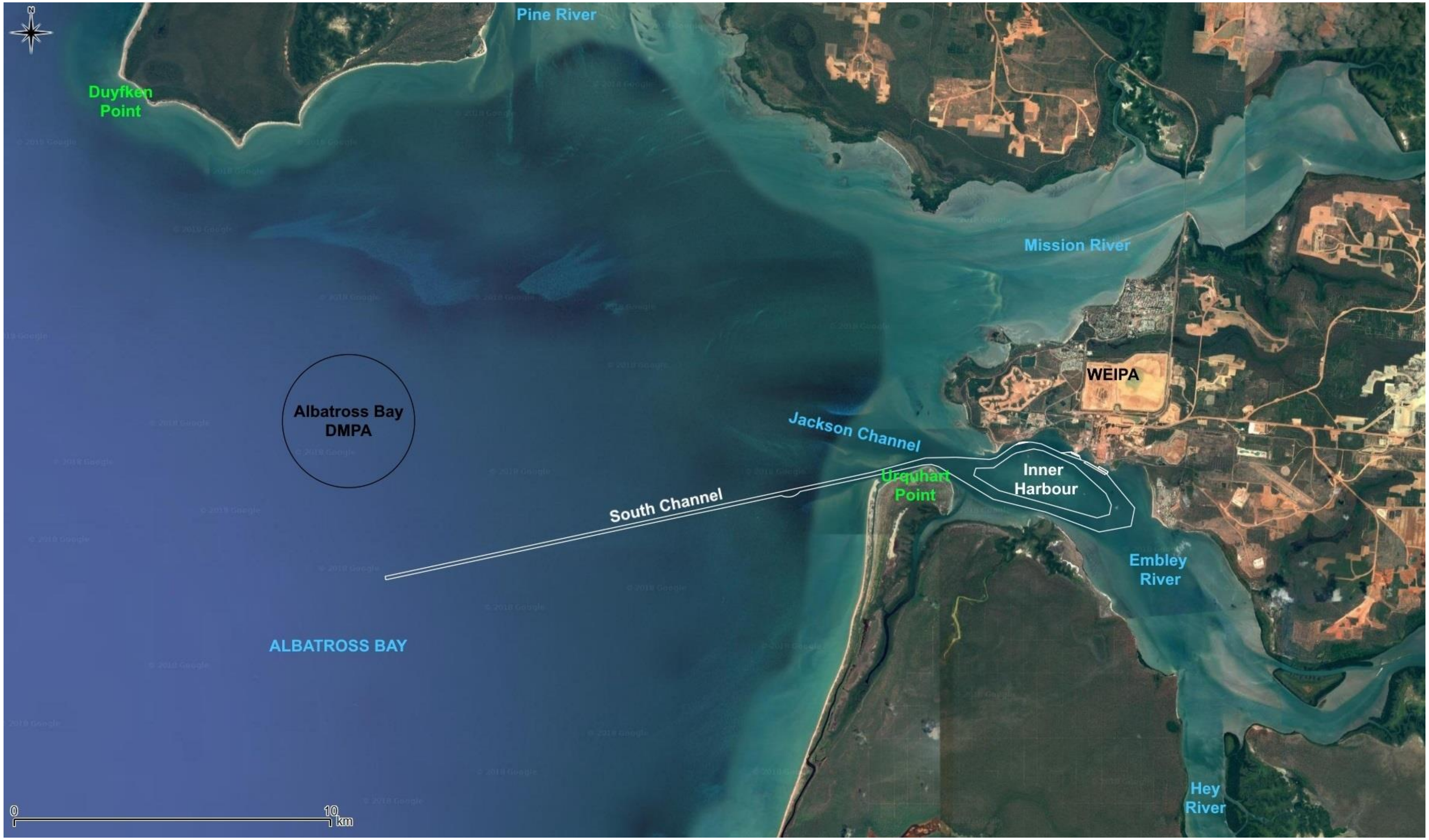

Figure 1. Layout of the Port of Weipa.

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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 in-situ turbidity monitoring undertaken are provided in **Section 3**;
- analysis of the in-situ and satellite-derived turbidity 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.

2. Dredge Program

The Port of Weipa 2020 maintenance dredging program commenced on the 4th May at 6:00 Australian Eastern Standard Time (AEST) and was completed on the 28th May at 06:00 AEST. Over this 24 day period a total of 220 dredge loads were relocated to the Albatross Bay DMPA, with an average of 9 loads per day. The following areas were dredged:

- South Channel, SC6 to SC10 (Figure 3): 48 loads of silt were dredged from this section of the South Channel with dredging in this area undertaken on the 7th, 10th – 12th, 14th, 16th, 18th – 22nd and 25th – 28th May 2020;
- South Channel, SC10 to SC14 (Figure 3): 134 loads of silt and two mixed loads of sand and silt were dredged from this section of the South Channel with dredging in this area undertaken every day between the 4th and 27th May 2020;
- South Channel, SC14 to Urquhart Point (Figure 3): five mixed loads of sand and silt in addition to two loads of silt were dredged between beacons SC14 and SC16 of the South Channel. Between beacons SC16 and SC22 five loads of sand and one mixed load of sand and silt was dredged, while from beacons SC21 to Urquhart Point 10 loads of sand were dredged. Dredging in these areas was undertaken on the 5th, 6th, 9th, 10th, 12th, 13th, 20th, 23rd and 26th May 2020; and
- Inner Harbour, CN3 to CN5, CS3 to CS5, East Cora Bank, Lorim Point Wharf and Weipa General (Figure 4) :10 loads of mixed sand and silt were dredged from the berths at Lorim Point Wharf, between beacons CS3 to CS5 and CN3 to CN5 and Weipa General (assumed to be loads made up of multiple Inner Harbour locations). A further two loads of silt were dredged from East Cora Bank and between beacons CN3 to CN5, in addition to one load of sand dredged from Weipa General. Dredging within the Inner Harbour areas was undertaken on the 8th, 11th, 14th – 16th, 18th and 21st May 2020.

Based on the above it is clear that the majority of the maintenance dredging undertaken as part of the 2020 program was focused in the South Channel, with close to 95% of the dredge loads from this area. It is important to note that the maintenance dredging requirement within the South Channel was not uniform, with approximately 65% of the sediment removed from between SC10 and SC14 which represents approximately 20% of the total length of the South Channel (3.75 km of the total 17.5 km length of the channel). An example plot showing the track of the TSHD Brisbane during one week of the 2020 maintenance dredging program further highlights how the maintenance dredging requirement in the South Channel varies spatially (Figure 5).

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, WQ4 & WQ5), DES waverider buoy (WRB) and South Channel (beacons SC2 – SC24).

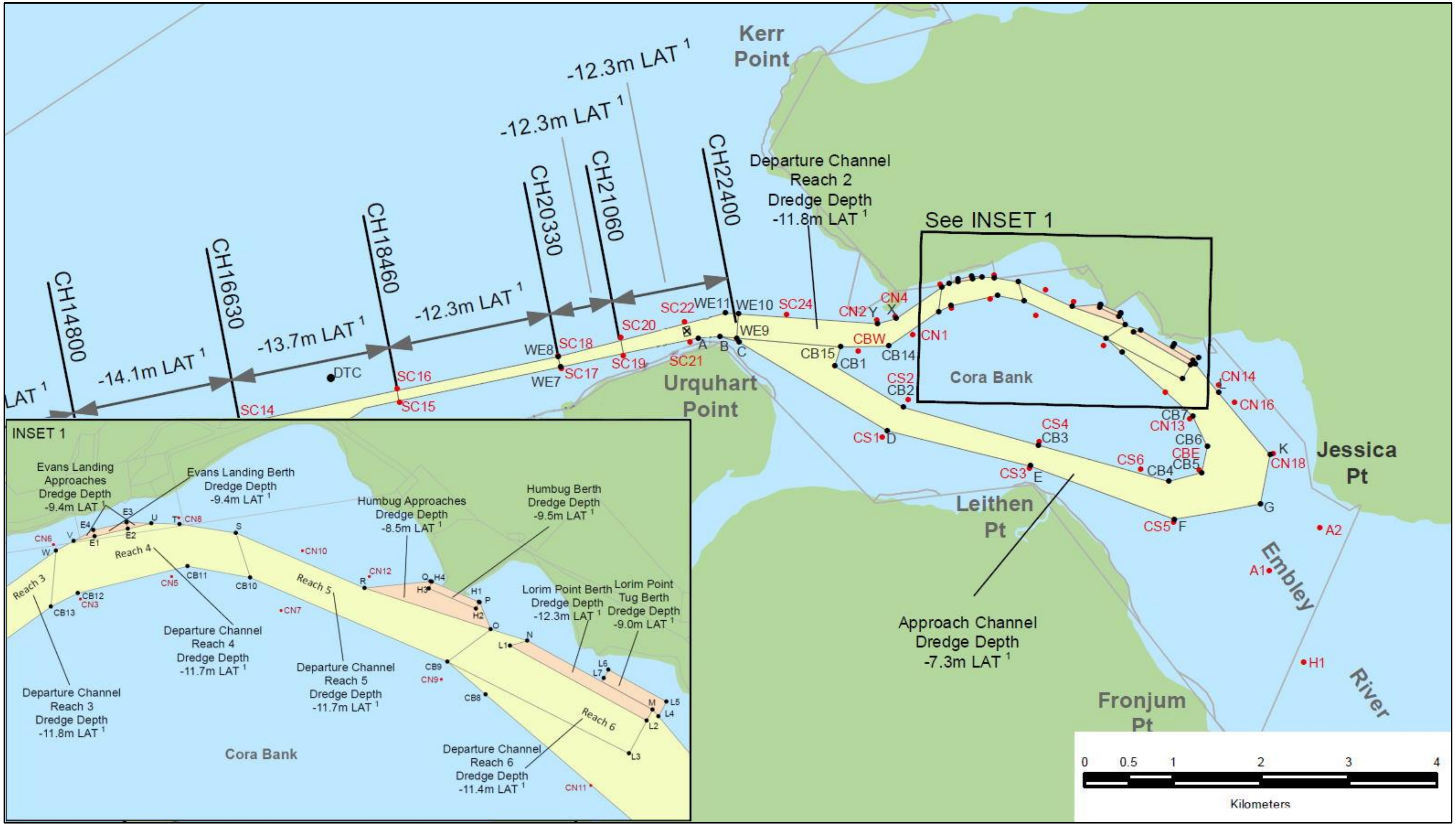


Figure 4. **Location of the Port of Weipa and beacons within the Inner Harbour (adapted from NQBP, 2019).**

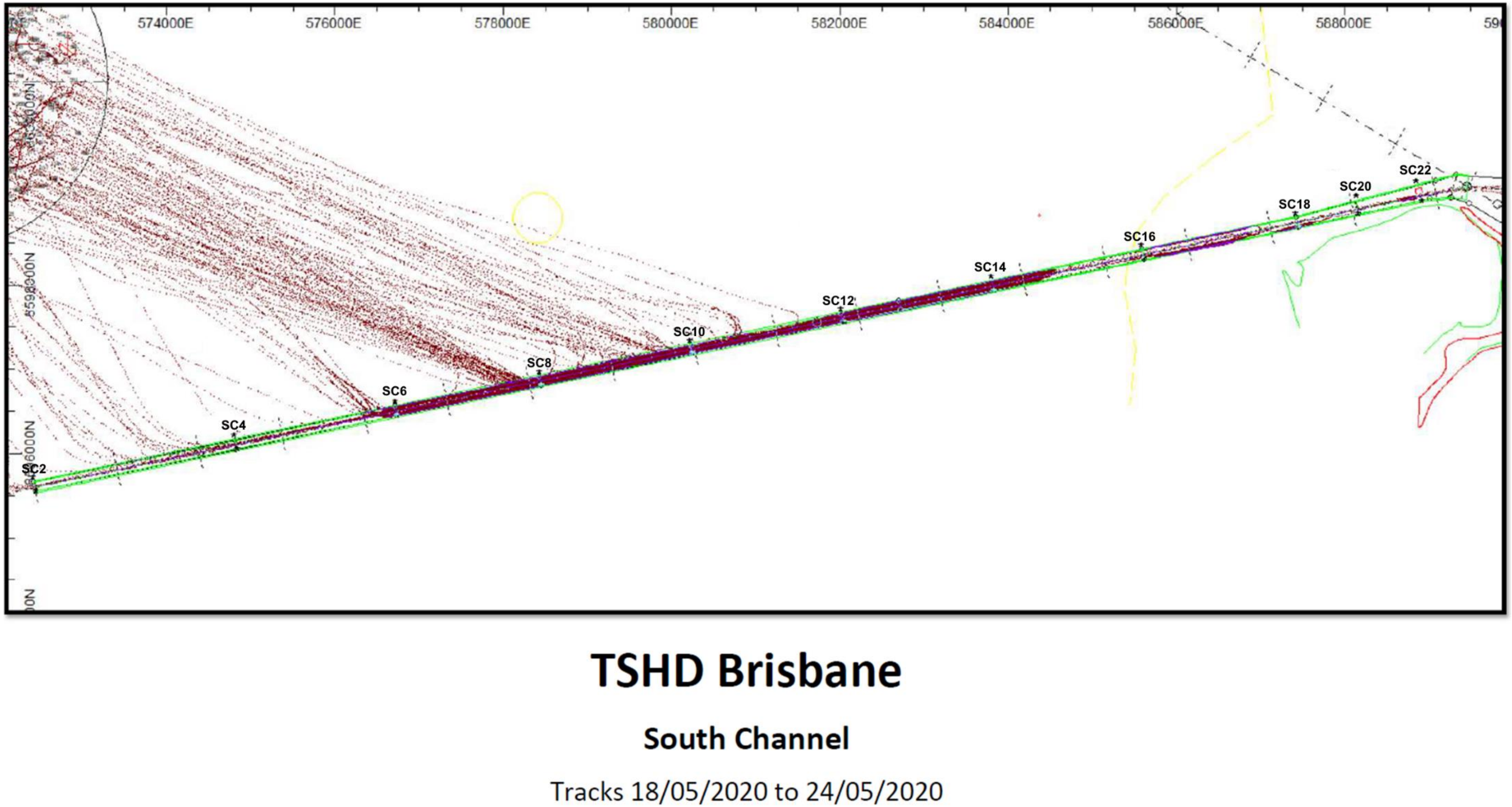


Figure 5. Tracks of the TSHD Brisbane during the Port of Weipa 2020 maintenance dredging program.

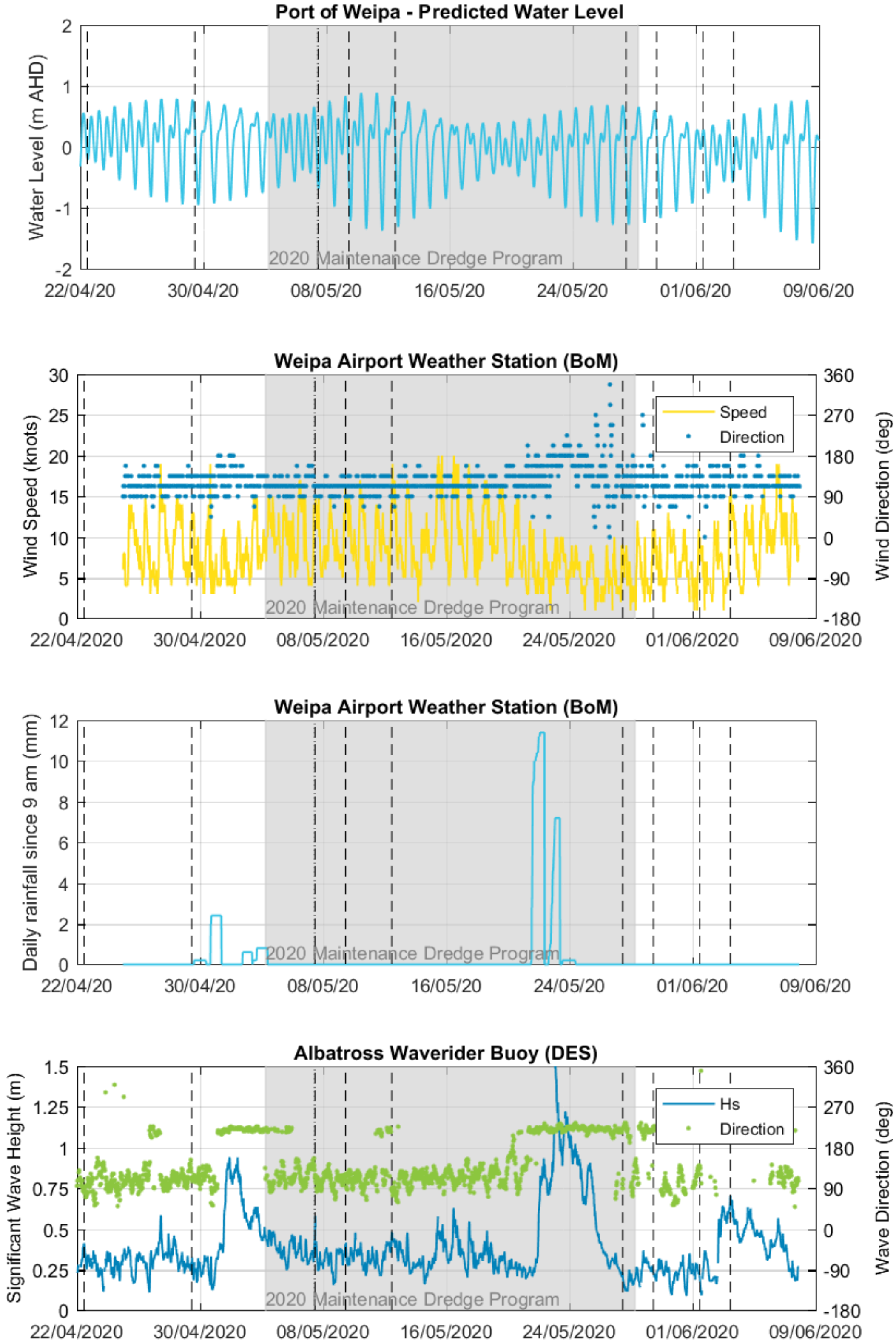
2.1. Metocean Conditions

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 6 along with when the maintenance dredging was undertaken and when satellite images are available. The figure shows the following:

- the meteorological conditions in the Weipa region over the monitoring period are fairly consistent and can be considered to generally be typical dry season conditions;
- there is very little rainfall during the majority of the dredge program, with the daily rainfall generally being less than 3 mm which is typical during the dry season. Between the 22nd and 24th May daily rainfall up to 11.5 mm was recorded, which coincides with the larger wave event. For reference, during the wet season months the daily rainfall will typically be above 3 mm for more than half the month, with daily peaks more than an order of magnitude higher occurring regularly;
- the winds are consistent for the first half on the monitoring period, with peak speeds during the day of 10 to 20 knots and lighter winds overnight. Between the 22nd and 28th May peak daytime wind speeds reduce to 5 to 10 knots, reducing further overnight. Wind directions are predominantly from the east to south-east (i.e. offshore at Weipa) throughout the monitoring period, with the exception of between the 22nd and 28th May when the wind direction changes to come from the south to south-west (i.e. cross shore to onshore at Weipa); and
- the wave conditions over the majority of the monitoring period are generated by the local offshore winds and result in small waves (significant wave height (H_s) of less than 0.5 m) which travel away from the Weipa shoreline. However, between the 1st and 4th May (just before the dredging program commenced) and 22nd to 26th May (during the last week of the dredging program) there were two south-westerly wave events with the H_s peaking at just under 1 m and 1.5 m, respectively. Over the monitoring period these wave events were the only time when waves in an onshore direction occurred. Waves from these directions would have had the potential to result in some resuspension of recently deposited fine-grained sediment on the seabed in shallow areas. In the context of typical dry season wave conditions, these wave events are quite extreme. This is discussed in more detail in Section 4.1.1.



Note: Dashed lines indicate times when satellite images were obtained and analysed, grey shaded area shows 2020 maintenance dredge program.

Figure 6. 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 a number of monitoring sites around the Port of Weipa. 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 instruments were serviced during the first week of the 2020 maintenance dredging program (8th May 2020) and the instruments were retrieved and data downloaded approximately three weeks after completion of the dredging program. The instruments provide near bed turbidity readings in Nephelometric Turbidity Unit equivalent (NTUe)[1]. Details of the benthic turbidity data available for this assessment are provided in Table 1. The table also notes the data return for each site over the 2020 maintenance dredging monitoring period, which includes 12 days pre-dredging, 24 days during dredging and 12 days post-dredging (48 days in total). The data return shows that there was no data loss at WQ1 and WQ2 while at WQ4 there were reliable data for 65% of the 2020 maintenance dredging monitoring period, with no data available between the 22nd April and the 9th May.

Table 1. Summary of ambient water quality monitoring data available for this assessment.

Location	Approx. Depth (m MSL)	Total Benthic Data Period	Data Return for 2020 Dredging Period
WQ1	5 m	19/01/18 to 16/06/20	100%
WQ2	4 m	16/03/18 to 16/06/20	100%
WQ4	4 m	19/01/18 to 16/06/20	65%

3.1. Previous Analysis

Benthic turbidity data from the ongoing ambient monitoring were analysed by PCS (2019c and 2020b) 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. Both of these turbidity intensity thresholds will be used to calculate the duration of time the thresholds were exceeded in Section 4.1.1 so that the assessment can be related to both previous studies. The 90th and 95th percentile turbidity intensity thresholds for the dry season period at the three ambient water quality monitoring sites which have been adopted for this assessment are shown in Table 2.

[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). However, previous comparison between concurrent data collected using 90 degree and 180 degree backscatter has shown comparable values (PCS, 2019d).

Table 2. Dry season benthic turbidity thresholds derived by PCS (2019c and 2020b).

Location	90th Percentile Turbidity Threshold (NTUe)	95th Percentile Turbidity Threshold (NTUe)
WQ1	17	21
WQ2	15	25
WQ4	18	28

4. Data Analysis

This section provides an analysis of the in-situ logger turbidity data and the satellite-derived turbidity data collected as part of the 2020 maintenance dredging program monitoring. The data have been used to help 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.

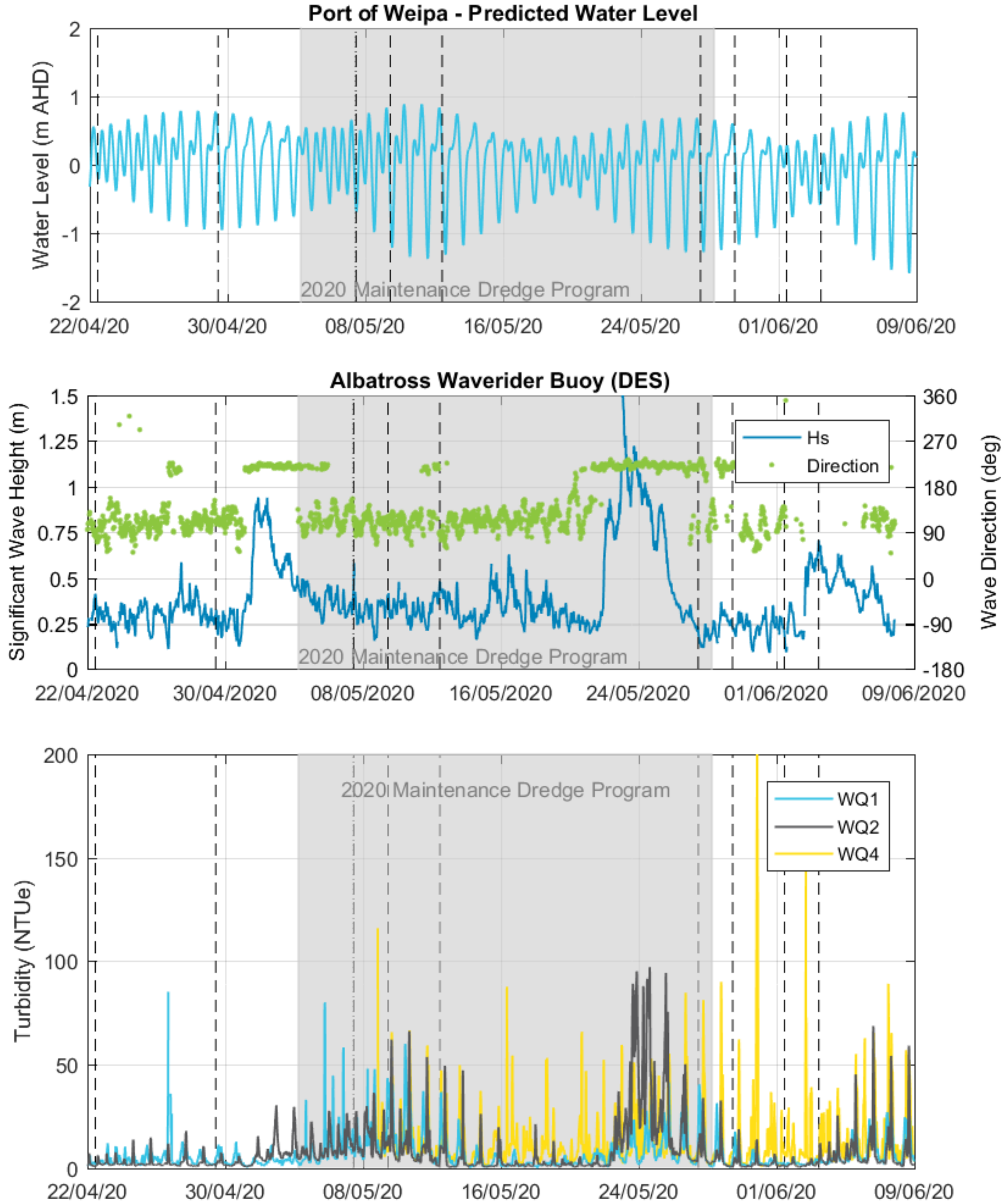
4.1. In-situ Turbidity Analysis

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 7, while individual plots for each monitoring site are shown in Figure 8. The figure shows that there is generally a tidal signal within the turbidity data at two of the three monitoring sites (WQ1 and WQ2), with increased turbidity correlating with the larger tidal range over the spring tides. The turbidity at WQ2 is also influenced by the wave conditions, with peaks in turbidity of approximately 30 NTUe occurring at the start of May due to a wave event where the significant wave height (H_s) exceeded 0.75 m [2] and peaks of close to 100 NTUe occurring around the 24th May due to a wave event where the H_s exceeded 1 m (peak of 1.53 m). The turbidity data at WQ4 has regular peaks in turbidity which exceed 50 NTUe, with the magnitude of the peaks not directly corresponding to the metocean conditions or the turbidity measurements at WQ1 (the other Inner Harbour site). A similar pattern was also observed at WQ4 during the 2019 maintenance dredging program, although during that period the peaks in turbidity at the site were significantly higher (reaching close to 3,000 NTUe) (PCS, 2019d). It was previously suggested that there was a localised process (e.g. seagrass blocking the turbidity sensor during certain stages of the tide resulting in artificially high turbidity values) which influenced the benthic turbidity measurements at WQ4 (PCS, 2019d). Based on the most recent measurements during the 2020 maintenance dredging program it appears that this localised process is continuing to result in elevated turbidity at WQ4.

Based on the benthic turbidity data at WQ1 and WQ2 it appears that the turbidity during the pre-, during and post-dredging periods of the 2020 maintenance dredging program was predominantly controlled by the metocean conditions. Although the peaks in turbidity of more than 50 NTUe at WQ2 between the 8th and the 16th May correlate with calm wave conditions and occur during the maintenance dredging program, the fact that similar magnitude peaks also occur post maintenance dredging between the 6th and 9th June 2020 indicates that the peaks are naturally driven, coinciding with the large spring tidal range which occurs over these periods. The benthic turbidity data at WQ4 also shows comparable timing and magnitude of peaks in turbidity during dredging and over the post-dredging period providing further evidence that the turbidity over both periods was predominantly controlled by the metocean conditions.

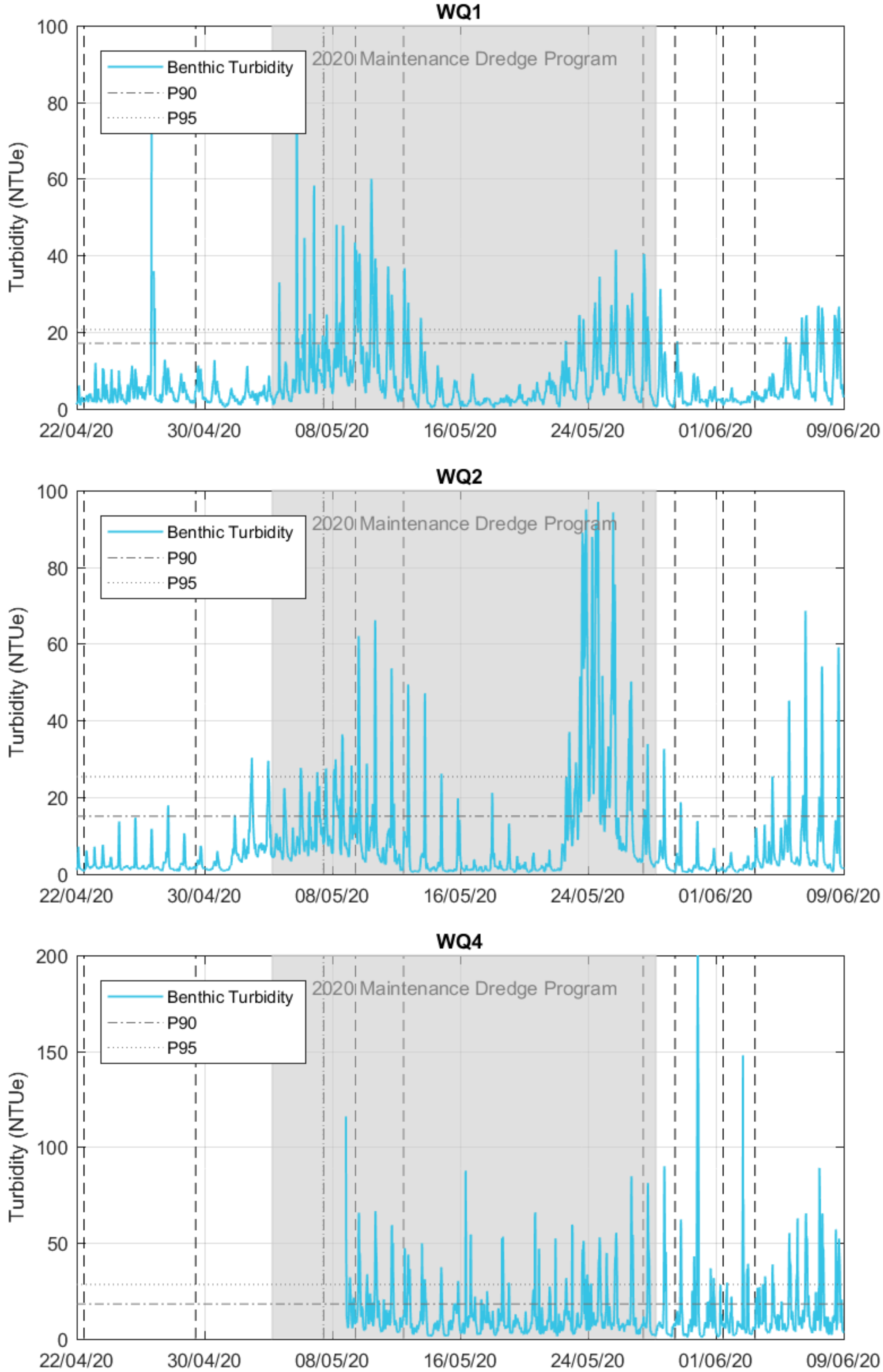
To further assess any potential increase in turbidity at the sites due to maintenance dredging the duration of time the benthic turbidity intensity thresholds were exceeded is analysed in the following section.

[2] this was identified by PCS (2019d) as an approximate threshold which when exceeded resulted in noticeable increases in turbidity at WQ2.



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

Figure 7. Metocean and turbidity conditions at Weipa over the monitoring period, with water level (upper), waves (middle) and turbidity at the three monitoring sites (lower).



Note: Vertical dashed lines indicate periods when satellite images were obtained and analysed, grey shaded area shows dredge period.

Figure 8. Measured turbidity data 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 percentiles benthic turbidity intensity thresholds were exceeded at the three monitoring sites was calculated over 12 days pre-dredging, the 24 days during dredging and 12 days post-dredging for the 2020 maintenance dredging program (Table 3). The results show similar patterns in the benthic duration exceedances at WQ1 and WQ2, with the lowest duration exceedances over the pre-dredging period and the highest exceedances during the dredging period. At WQ4 the duration exceedance during the dredging period is similar to WQ1, but the duration exceedances over the post-dredging period are between two and three times higher.

The benthic turbidity thresholds were defined using the 90th and 95th percentile of the measured turbidity data during the dry season. As a result, the thresholds would typically be expected to be exceeded for 10% and 5% of time, which over the 24 day dredge program would equal 58 hours and 29 hours respectively (and half of this for the 12 day pre- and post-dredging periods). Based on this, the duration exceedance values for WQ1 and WQ2 presented in Table 3 show that the duration exceedances were well below average over the pre-dredging period, slightly below average over the post-dredging period and well above average over the dredging period. Statistical analysis of the measured wave conditions in Table 4 shows that the waves were much more energetic during the dredging period compared to the pre- and post-dredging periods. Over the dredging period the H_s was above the 0.75 m threshold (when turbidity noticeably increases as WQ2) for almost three days in total compared to a day over the pre-dredging period and no time over the post-dredging period. The peak H_s over the dredging period was 1.53 m, which is the third largest dry season wave event measured at the Albatross Bay WRB since measurements began in 2009. The H_s in Albatross Bay rarely exceeds 1 m during the dry season (typically up to two events per dry season, but some years have none). In addition to increasing turbidity in the South Channel, the magnitude and duration of the wave event that occurred during the maintenance dredge program would also be expected to increase the turbidity within the Inner Harbour area as water from Albatross Bay is imported during the flooding tide. This can be seen at WQ1 in Figure 8, which shows larger peaks in turbidity between the 23rd and 28th May than between the 6th and 9th June despite the tidal range being smaller over the May period. The elevated turbidity at WQ1 in the Inner Harbour between the 5th and 13th May is thought to be a result of sediment suspended by the wave event at the start of May gradually being transported from Albatross Bay into the Inner Harbour combined with the occurrence of large spring tides. This is further considered using the satellite-derived turbidity data in Section 4.2.2.1.

Table 3. Duration of exceedance of the previously derived benthic turbidity intensity thresholds over the Port of Weipa 2020 maintenance dredging program.

Location	12 days Pre-Dredging (hrs)		24 days During Dredging (hrs)		12 days Post-Dredging (hrs)	
	90th %ile	95th %ile	90th %ile	95th %ile	90th %ile	95th %ile
WQ1	2.2	1.5	82.5	63.2	22.2	14.8
WQ2	9.7	2.5	126.0	65.2	18.7	8.8
WQ4	-[1]	-[1]	88.5	50.5	60.2	34.2

[1] no reliable benthic turbidity data were available at WQ4 during the pre-dredging period.

Table 4. Measured significant wave height at the Albatross Bay WRB statistics over the Port of Weipa 2020 maintenance dredging program.

Statistic	Pre-Dredging	During Dredging	Post-Dredging	Entire Period
Median H_s (m)	0.32	0.34	0.29	0.33
90th percentile H_s (m)	0.64	0.81	0.55	0.65
95th percentile H_s (m)	0.84	0.97	0.60	0.86
Maximum H_s (m)	0.94	1.53	0.71	1.53
Hours H_s > 0.75 m	23.5	69.5	0	93

To further assess whether the turbidity over the 2020 maintenance dredging program monitoring period remained within the natural range, the duration exceedance of the 90th percentile turbidity has been compared to the duration thresholds (scaled to the 24 day dredge duration) suggested by PCS (2020b). These thresholds were suggested as possible adaptive management thresholds which could be adopted sequentially to minimise the risk of any impacts to sensitive receptors. The average duration of 58 hours was exceeded at all three of the sites, but the 90th percentile duration[3] was not exceeded at any of the sites which would have been the threshold when some adaptive management measures would be required. This shows that even though the turbidity appears high during the dredging period compared to the pre- and post-dredging periods, it is still well within the range of natural variability and is predominantly driven by the metocean conditions(rather than a result of maintenance dredging). This will be further considered based on the spatial extent of any plumes shown by the satellite-derived turbidity data in the following section.

4.2. Satellite-Derived Data

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 the placement of dredged sediment at the Albatross Bay DMPA), satellite imagery was sourced. High-resolution imagery from the Sentinel-2 (10 m) and Landsat-8 (30 m) sensors was sourced over the 2020 maintenance dredging program at the Port of Weipa. The imagery was subsequently 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). It is important to note that the data have not been calibrated to local measured TSM in the Weipa region. However, a validation exercise has been undertaken as part of this assessment to determine the the accuracy of the satellite-derived TSM against the in-situ near bed turbidity data, this is provided in section 4.2.1. Irrespective of local calibration, the spatial variability shown by the images provides a reliable indication of how the turbidity varies in the region and allow areas with higher turbidity to be identified.

Satellite-derived turbidity data is 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. 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 Weipa region the repeat satellite coverage is relatively high for the Sentinel-2 sensor (every 2 to 3 days). This is because the area is partially covered by two separate satellite tracks, so that alternate images cover the outer area (offshore from Urquhart Point) and the inner area (but still extending offshore of the DMPA). While the entire region is not covered for each image, the overlap between the two tracks means that most of the South Channel area is covered in all images.

[3] This was 116 hours, 176 hours and 115 hours for a 20 day dredge at WQ, WQ2 and WQ4, respectively.

Over the entire 48 day pre-, during and post-dredging monitoring periods a total of 18 high resolution satellite images were captured. However, high cloud cover over some of the pre-dredging passes (24/04/20 to 27/04/20 and 02/05/20 to 04/05/20) and during dredging (14/05/20 to 24/05/20) meant that only ten usable images were available. Details of the final satellite images analysed as part of this assessment are provided in Table 5 for the pre-dredging monitoring period, Table 6 during dredging and Table 7 for the post-dredging monitoring period.

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

Date and Time	Satellite Name	Details
22/04/2020 11:00 AEST	Sentinel-2	No cloud.
29/04/2020 10:50 AEST	Sentinel-2	Some patches of cloud, mainly over the Inner Harbour region.

Table 6. Available satellite images during dredging.

Date and Time	Satellite Name	Details
07/05/2020 10:39 AEST	Landsat-8	No cloud. At this time the TSHD Brisbane had just started dredging between SC14 and SC16 in the South Channel (dredging commenced at 10:34 AEST) and placement of the previous load at the Albatross Bay DMPA was completed at 09:44 AEST.
07/05/2020 11:00 AEST	Sentinel-2	Some cloud. At this time the TSHD Brisbane was dredging between SC14 and SC16 in the South Channel (dredging commenced at 10:34 AEST) and placement of the previous load at the Albatross Bay DMPA was completed at 09:44 AEST.
09/05/2020 10:50 AEST	Sentinel-2	Large amount of cloud but dredger still visible. At this time the TSHD Brisbane had recently started dredging at Urquhart Point (dredging commenced at 10:38 AEST) and placement of the previous load at the Albatross Bay DMPA was completed at 09:28 AEST.
12/05/2020 11:00 AEST	Sentinel-2	Large amount of cloud but dredger still visible. At this time the TSHD Brisbane had recently started dredging at Urquhart Point (dredging commenced at 10:44 AEST) and placement of the previous load at the Albatross Bay DMPA was completed at 09:42 AEST.
27/05/2020 11:00 AEST	Sentinel-2	No cloud. At this time the TSHD Brisbane had recently started dredging between SC12 and SC14 in the South Channel (dredging commenced at 10:51 AEST) and placement of the previous load at the Albatross Bay DMPA was completed at 10:07 AEST.

Table 7. Available satellite images for the post-dredging monitoring period.

Date and Time	Satellite Name	Details
29/05/2020 10:50 AEST	Sentinel-2	No cloud. The final load of the TSHD Brisbane was from SC8 to SC10 of the South Channel and the dredging was completed 03:02 AEST on 28/05/20 and placement completed at 03:47 on 28/05/20.
01/06/2020 11:00 AEST	Sentinel-2	No cloud. Bulk carrier visible departing through the South Channel close to SC18.
03/06/2020 10:50 AEST	Sentinel-2	No cloud.

4.2.1. Data Validation

To provide an understanding of the accuracy of the values from the satellite-derived TSM data, a validation process has been undertaken with the data being compared to the available in-situ logger data at WQ1, WQ2 and WQ4. Over the 48 day monitoring period associated with the 2020 maintenance dredging program satellite-derived TSM data (in mg/l) have been compared with the in-situ benthic suspended sediment concentration (SSC) data (in mg/l) measured by the JCU loggers. The in-situ SSC data was calculated by JCU by applying site specific turbidity to SSC correlations which were developed based on previous measurements and processed water samples. Data were only compared when measurements from both methods were available at the site at the same time. This meant that the number of comparative data points available for the correlation varied between the sites, with the most data at WQ2 as all satellite images covered this area, while only every other image covered the Inner Harbour area. The correlation between the satellite-derived TSM data and the in-situ benthic logger SSC data over the 2020 maintenance dredging monitoring period is shown in Figure 9. The correlation shows the following:

- the satellite-derived TSM data can be used to provide a reliable representation of the benthic in-situ measured SSC data at the three sites (the R-squared for the correlation is 0.94);
- the satellite-derived TSM data overpredicts the concentrations during periods of low SSC (measured SSC of around 5 mg/l and below), with the minimum value recorded by the satellite-derived TSM being 4.4 mg/l , while the lowest measured in-situ SSC was 0.8 mg/l. This is not considered a significant shortcoming of the satellite-derived TSM data, rather something that needs to be taken into consideration if the absolute TSM values are being analysed during periods with low concentrations; and
- the fact that it is possible to develop a strong correlation, which is close to a 1:1 fit, between the satellite-derived TSM and the in-situ SSC data suggests that the concentrations close to the bed can be considered to be representative of the depth-averaged concentrations through the water column (which is what the satellite measures). This is not surprising given the relatively shallow depth at the three measurement sites (between 4 and 5 m below MSL).

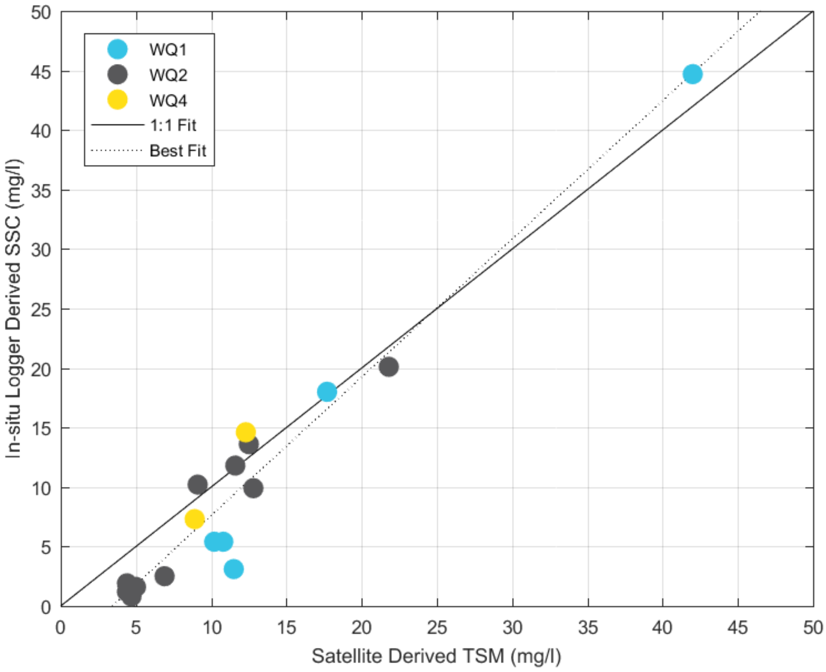


Figure 9. Correlation between satellite-derived TSM and in-situ logger derived SSC over the 2020 maintenance dredge monitoring period.

4.2.2. 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 2020 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).

4.2.2.1. Regional Scale

To provide an understanding of how the turbidity in Albatross Bay varied over the 2020 Maintenance Dredging Program, plots of the satellite-derived turbidity in the Albatross Bay region for eight of the ten satellite image times are shown in Figure 10 to Figure 18 (the remaining two have too much cloud cover for regional plots and so only zoomed in plots are shown for these times). The plots show the following:

- Pre-Dredging: the pre-dredging images show that TSM throughout the majority of Albatross Bay was relatively low (less than 10 mg/l), which corresponds to the calm metocean conditions over this period. However, the images do show that areas with elevated TSM of 10 to over 25 mg/l can naturally occur throughout Albatross Bay and in the adjacent estuaries, with the potential for localised areas of elevated TSM in the region of the South Channel and Albatross Bay DMPA;
- During Dredging: there were two south-westerly wave events which influence TSM values within Albatross Bay during dredging. Wave event 1 occurred between the 1st and 4th May (pre-dredging) with a peak H_s of just under 1 m. Prior to wave event 1 the metocean conditions were calm with wave heights of under 0.5 m for approximately seven weeks. Wave event 2 occurred between the 22nd and 26th May (during dredging) with a peak H_s of just over 1.5 m. Between wave events 1 and 2 there is approximately two and a half weeks of calm conditions. Further details of the two wave events are provided below:

- Wave event 1: the images from both sensors on the 7th May 2020 (Figure 12 and Figure 13) show higher TSM throughout Albatross Bay compared to the images during the pre-dredging period, with large areas with the TSM above 15 mg/l. The metocean conditions during the wave event are likely to have resulted in resuspension of natural fine-grained sediment which was deposited on the seabed in shallow areas of Albatross Bay between 15th March (when the previous wave event occurred) and the 1st May. Although the image on the 9th May has a large amount of cloud cover, it still shows enough of Albatross Bay to indicate that the TSM has reduced since the 7th May, showing that some of the suspended sediment has been deposited on the bed. It is therefore expected that the higher TSM shown on the 7th May is predominantly natural suspended sediment which is still present following wave event 1, as opposed to turbidity resulting from the maintenance dredging; and
- Wave event 2: the image on the 27th May (Figure 15) captures increased TSM associated with the second south-westerly wave event. TSM values associated with this event are lower throughout much of Albatross Bay compared to those associated with wave event 1. It is likely that the lower TSM values associated with wave event 2 can be attributed to less fine grained sediment being available for resuspension in the shallow water areas compared to wave event 1. The fine-grained sediment will have been deposited over the period since the previous resuspension event, which for wave event 2 was two and a half weeks while for wave event 1 it was approximately seven weeks.

- Post-Dredging: the post-dredging image on the 29th May 2020 shows generally low TSM throughout much of Albatross Bay with some localised plumes present in the Albatross Bay DMPA and around the South Channel which could be related to the dredging. These localised plumes are no longer present on the images on the 1st and 3rd June 2020, with the former image showing low TSM throughout and the latter showing elevated TSM which is likely to be due to increased wave energy, with an H_s of 0.75 m and waves from a south-westerly direction.

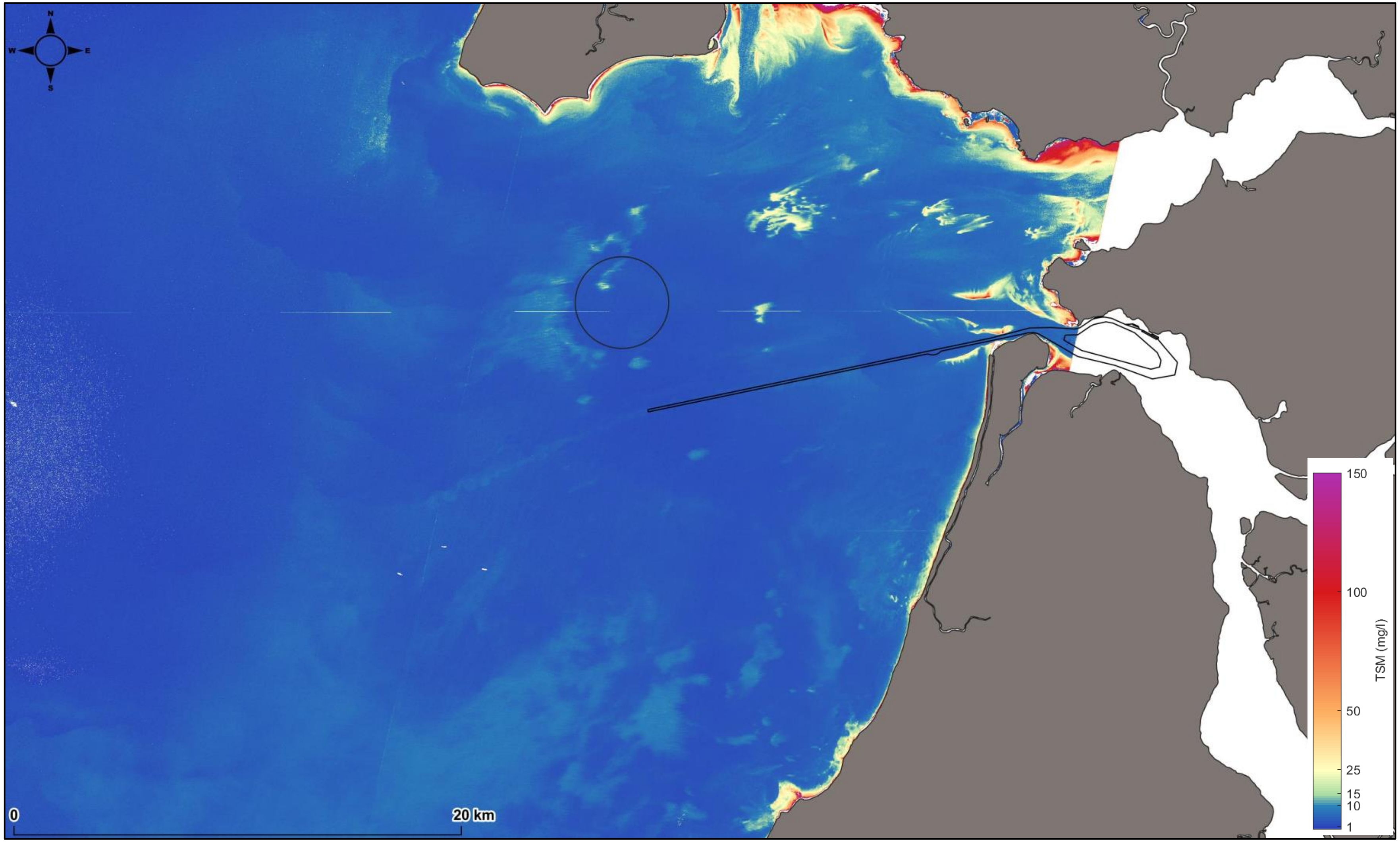
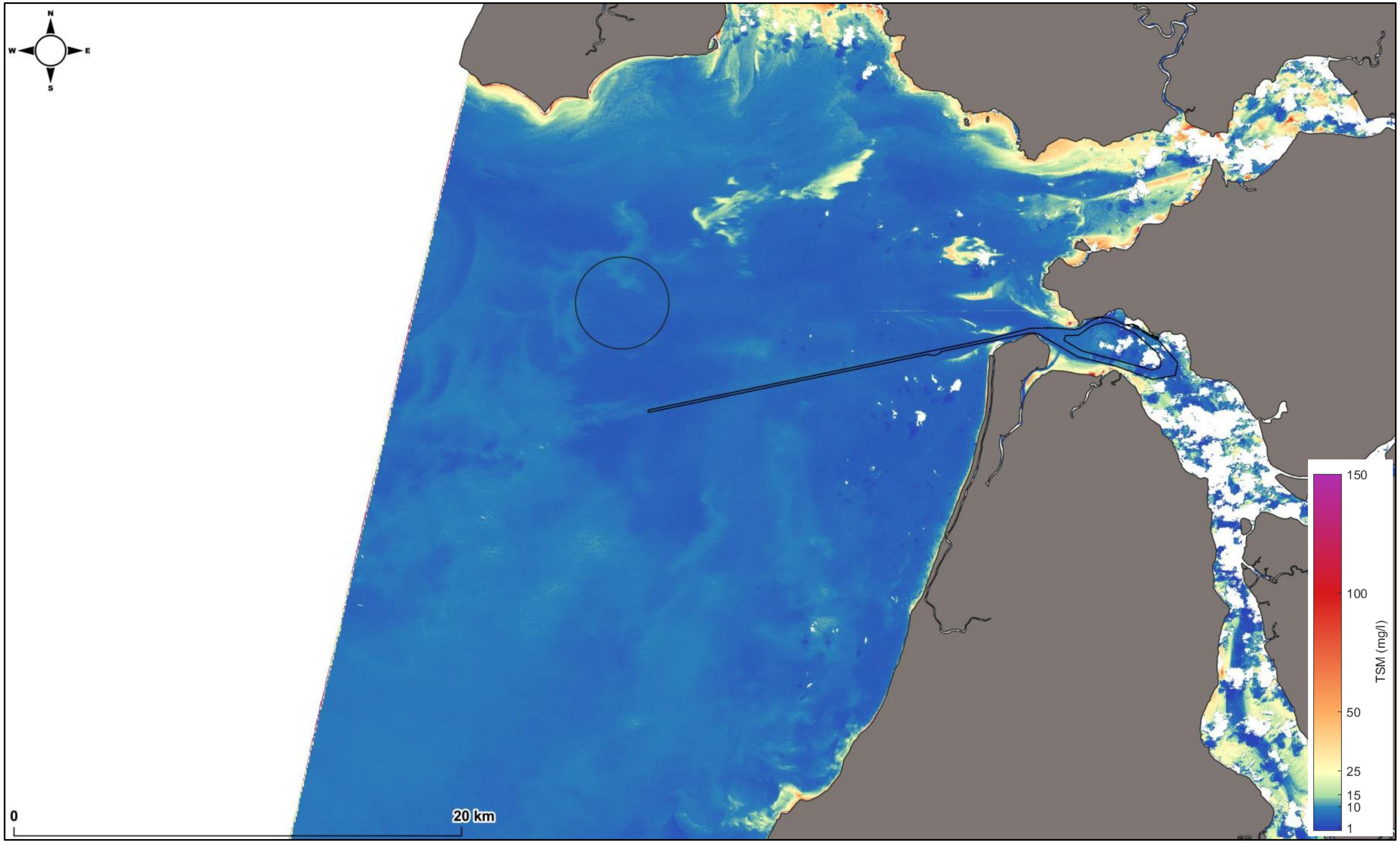


Figure 10. Satellite-derived turbidity from the Sentinel-2 sensor for Albatross Bay on 22/04/2020 at 10:50 AEST (pre-dredging).



Note: the white areas represent cloud cover.

Figure 11. Satellite-derived turbidity from the Sentinel-2 sensor for Albatross Bay on 29/04/2020 at 11:00 AEST (pre-dredging).

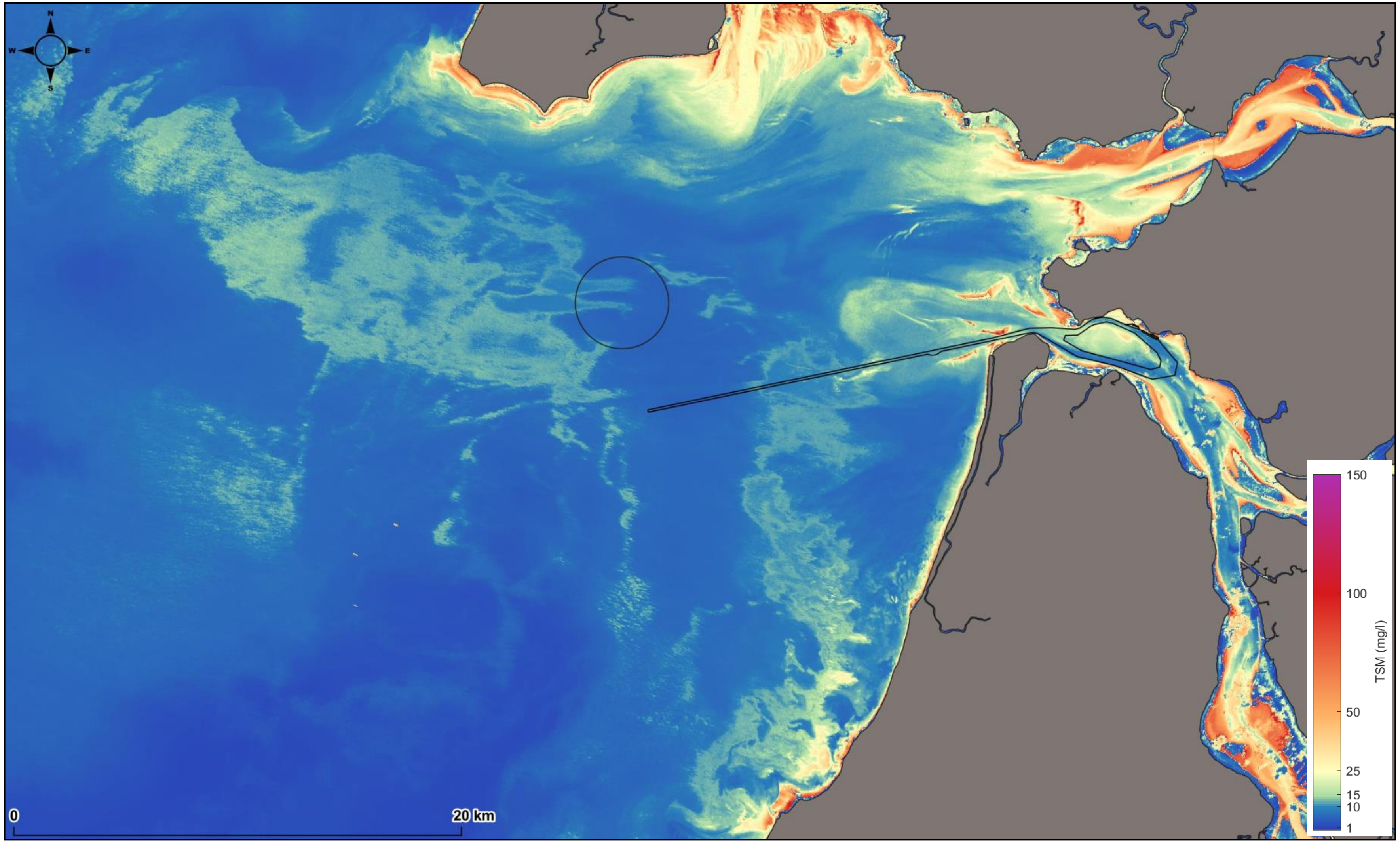


Figure 12. Satellite-derived turbidity from the Landsat-8 sensor for Albatross Bay on 07/05/2020 at 10:39 AEST (during dredging).

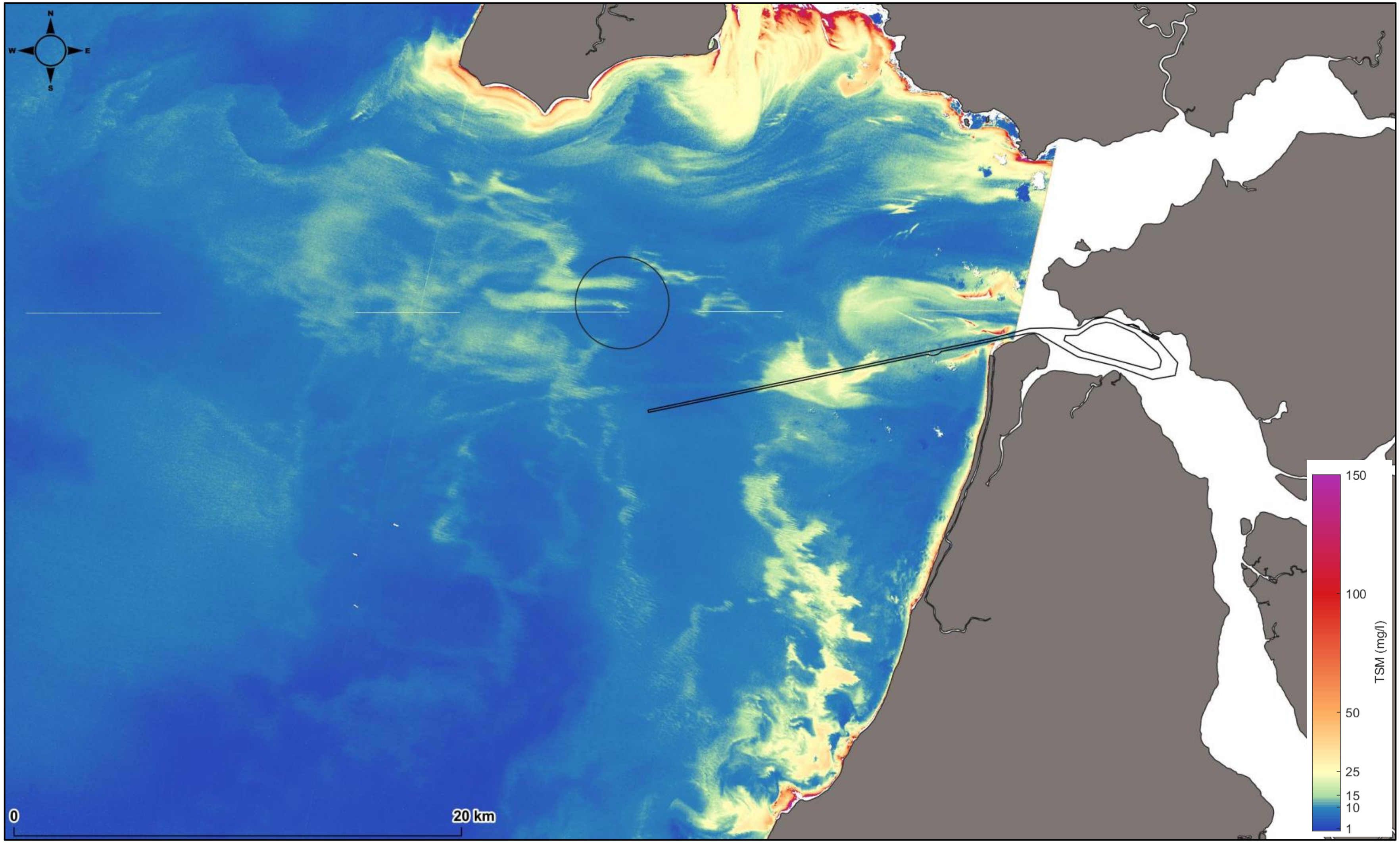
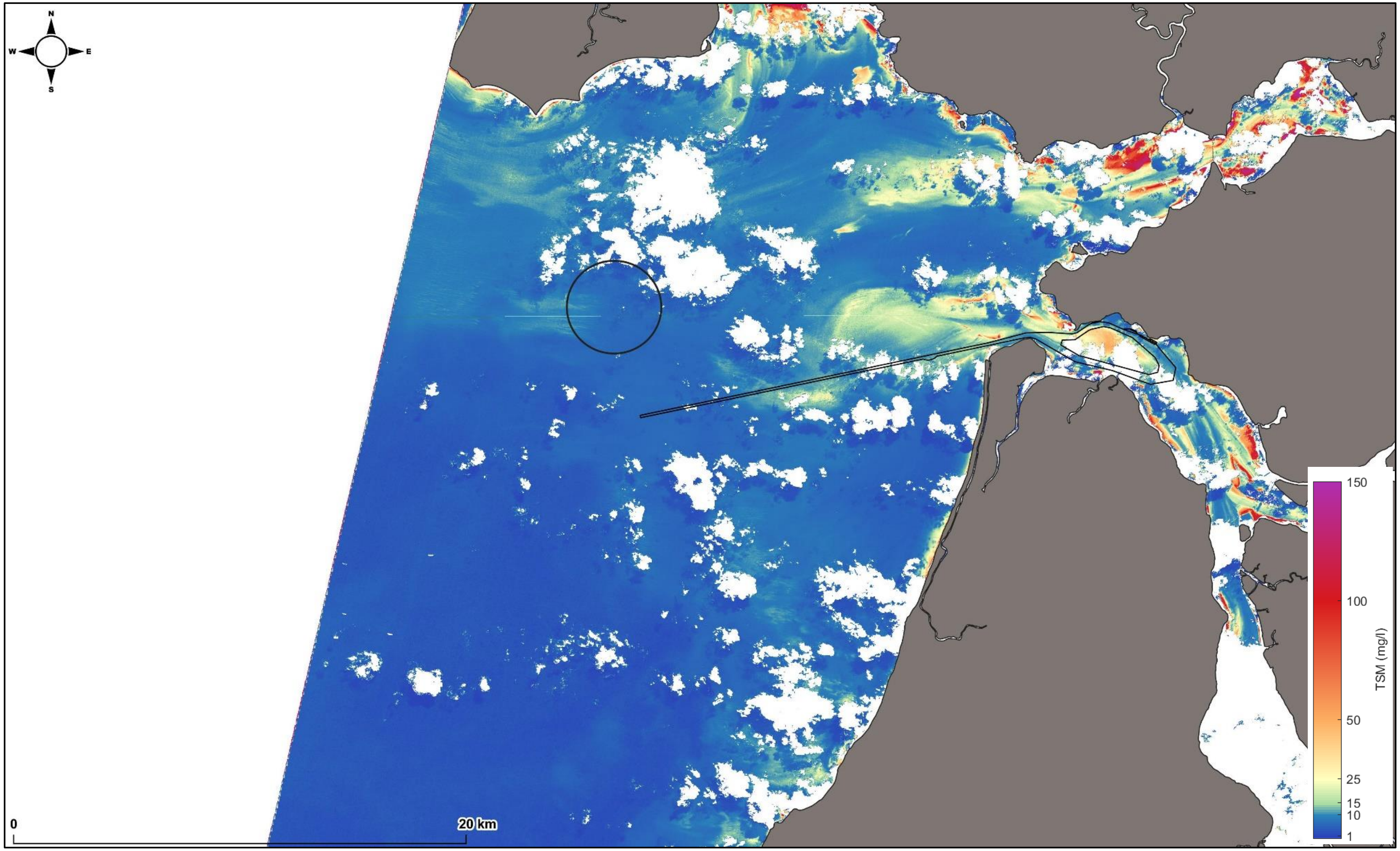


Figure 13. Satellite-derived turbidity from the Sentinel-2 sensor for Albatross Bay on 07/05/2020 at 11:00 AEST (during dredging).



Note: the white areas represent cloud cover.

Figure 14. Satellite-derived turbidity from the Sentinel-2 sensor for Albatross Bay on 09/05/2020 at 10:50 AEST (during dredging).

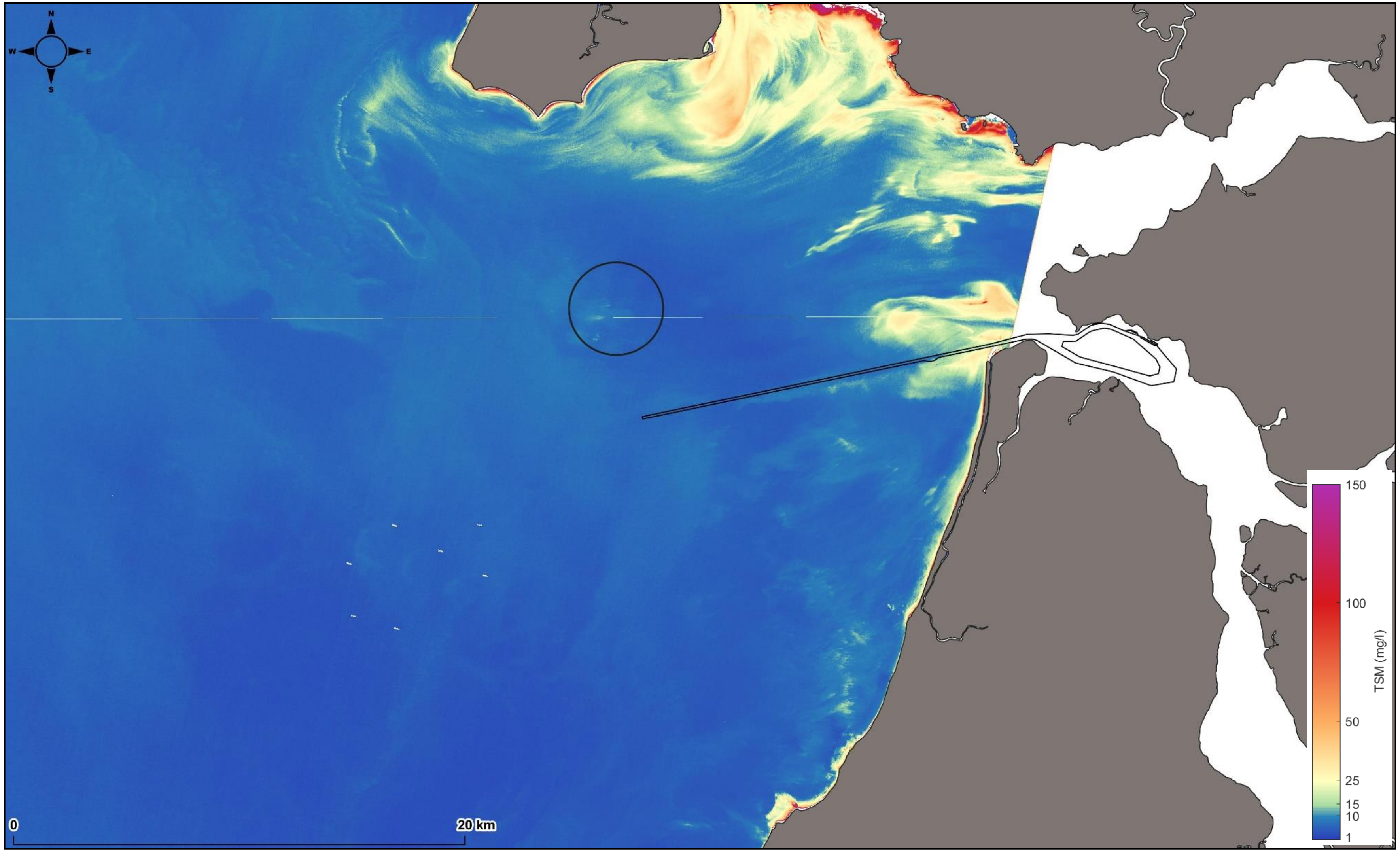


Figure 15. Satellite-derived turbidity from the Sentinel-2 sensor for Albatross Bay on 27/05/2020 at 11:00 AEST (during dredging).

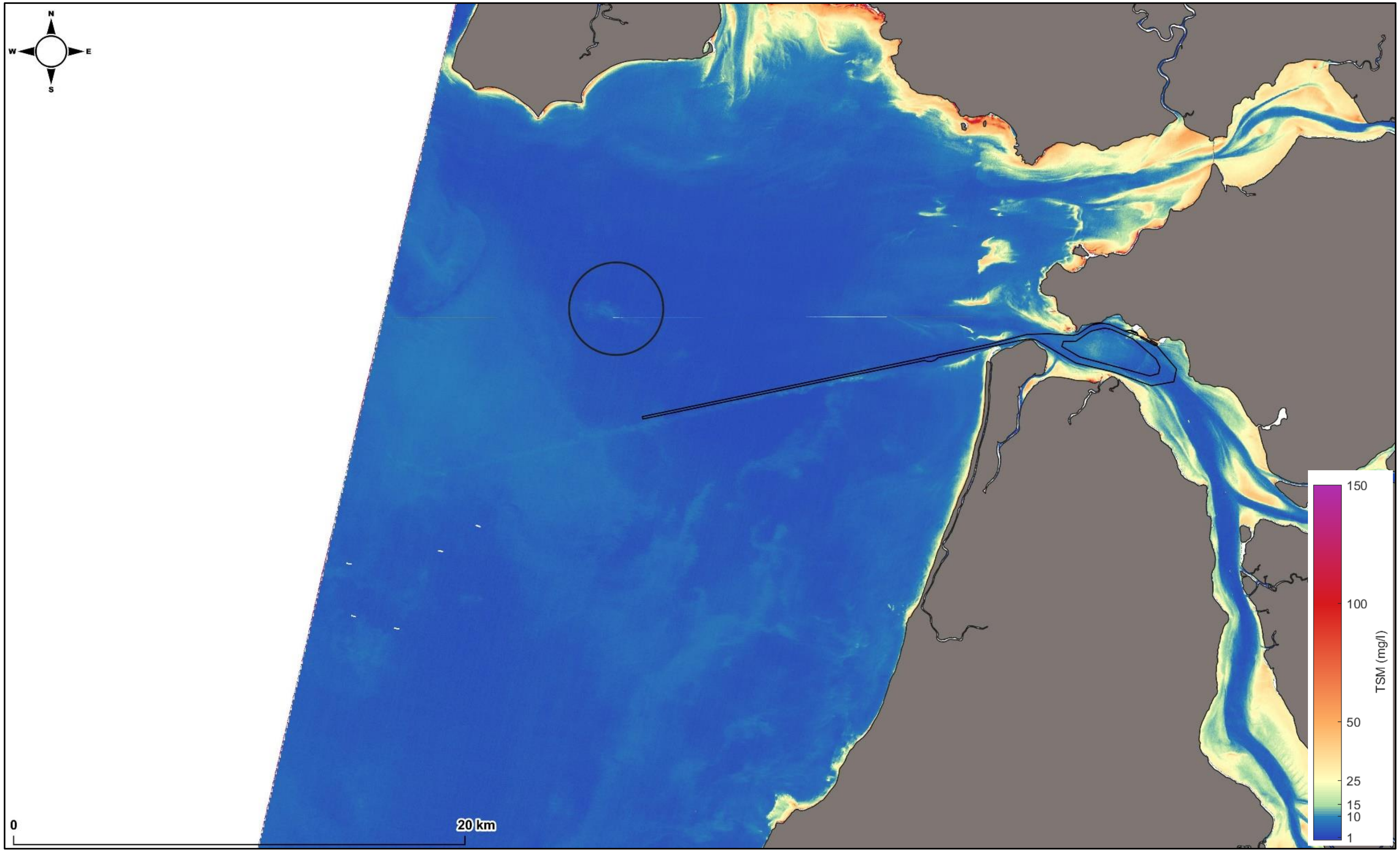


Figure 16. Satellite-derived turbidity from the Sentinel-2 sensor for Albatross Bay on 29/05/2020 at 10:50 AEST (post-dredging).

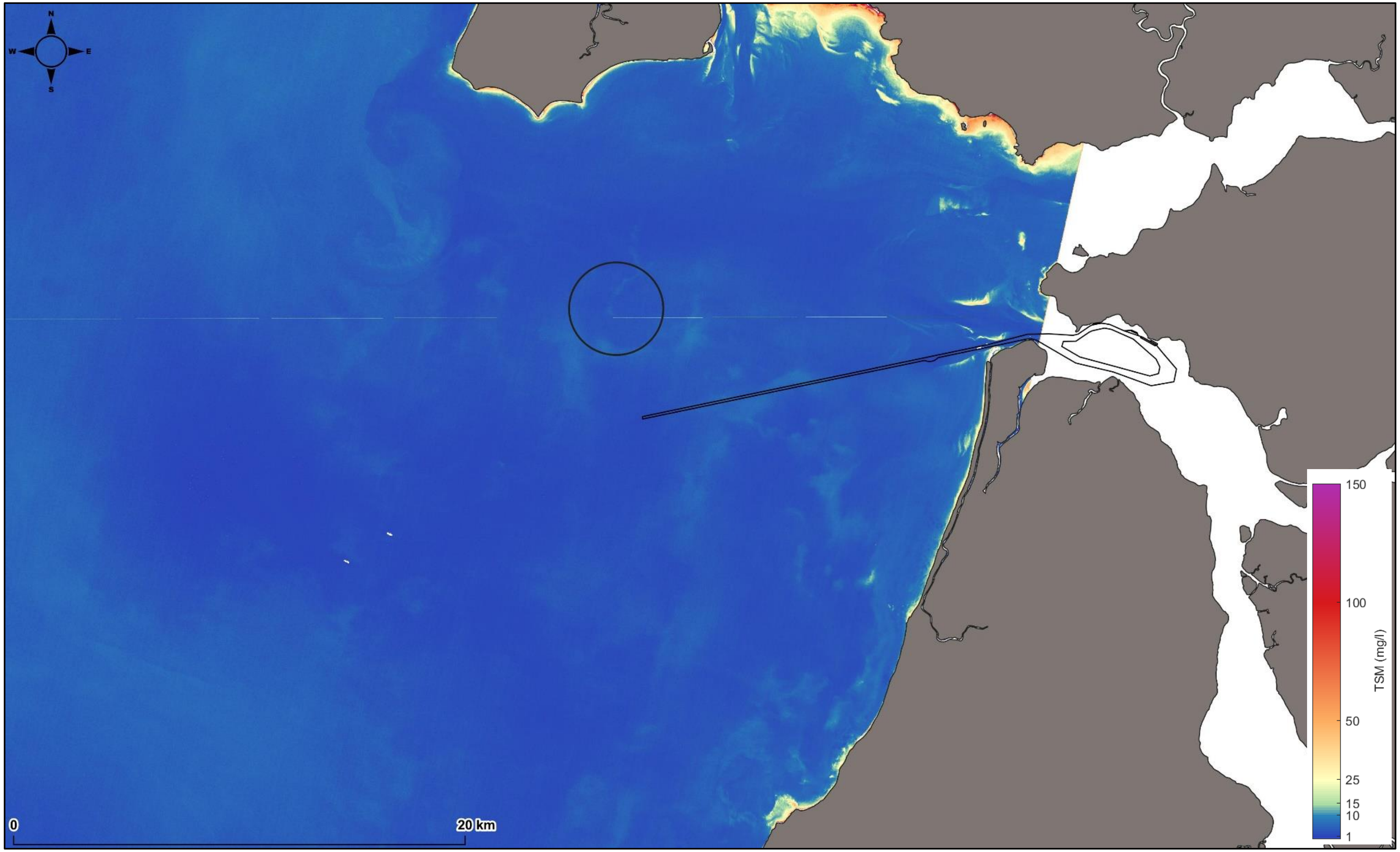


Figure 17. Satellite-derived turbidity from the Sentinel-2 sensor for Albatross Bay on 01/06/2020 at 11:00 AEST (post-dredging).

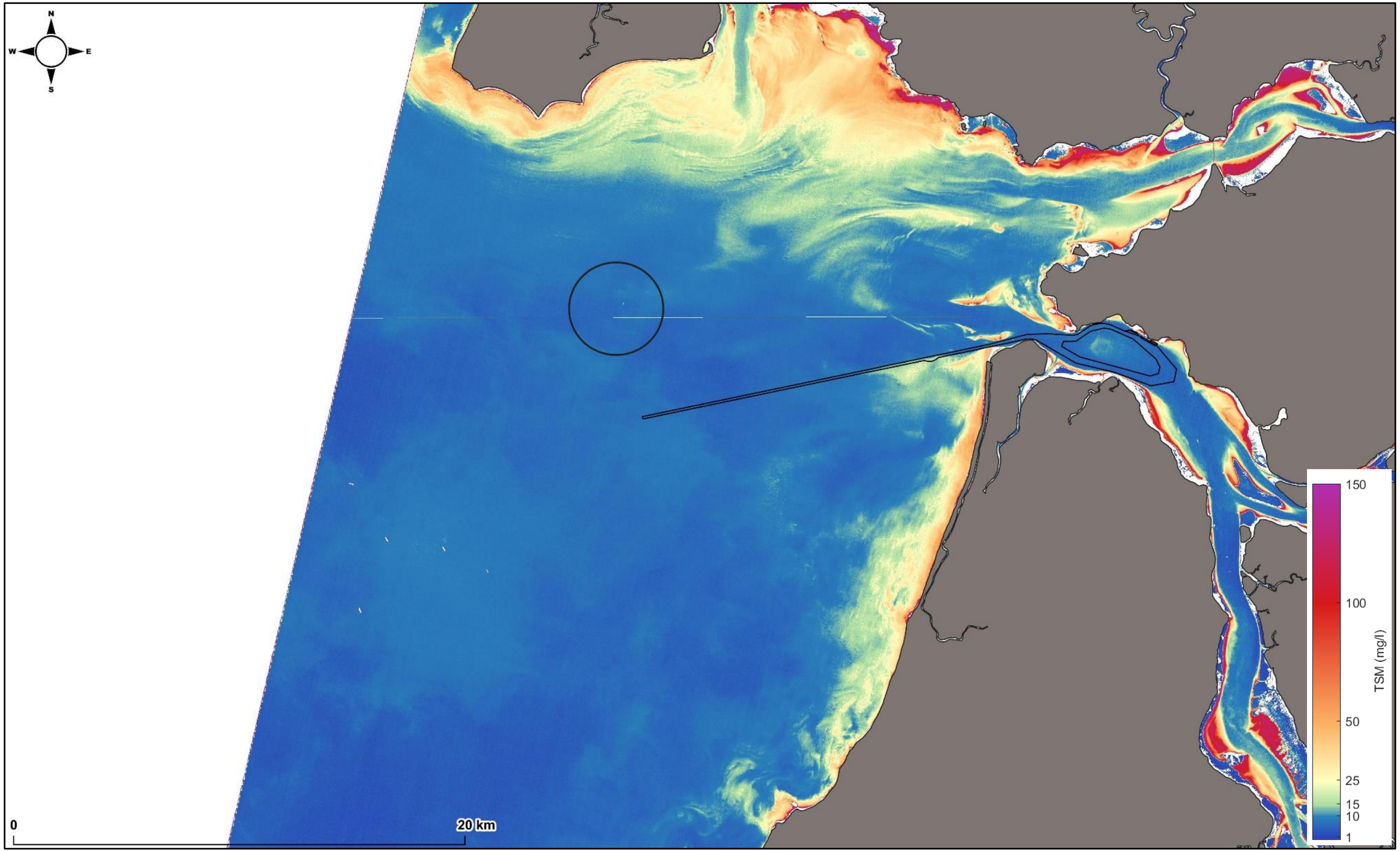


Figure 18. Satellite-derived turbidity from the Sentinel-2 sensor for Albatross Bay on 03/06/2020 at 10:50 AEST (post-dredging).

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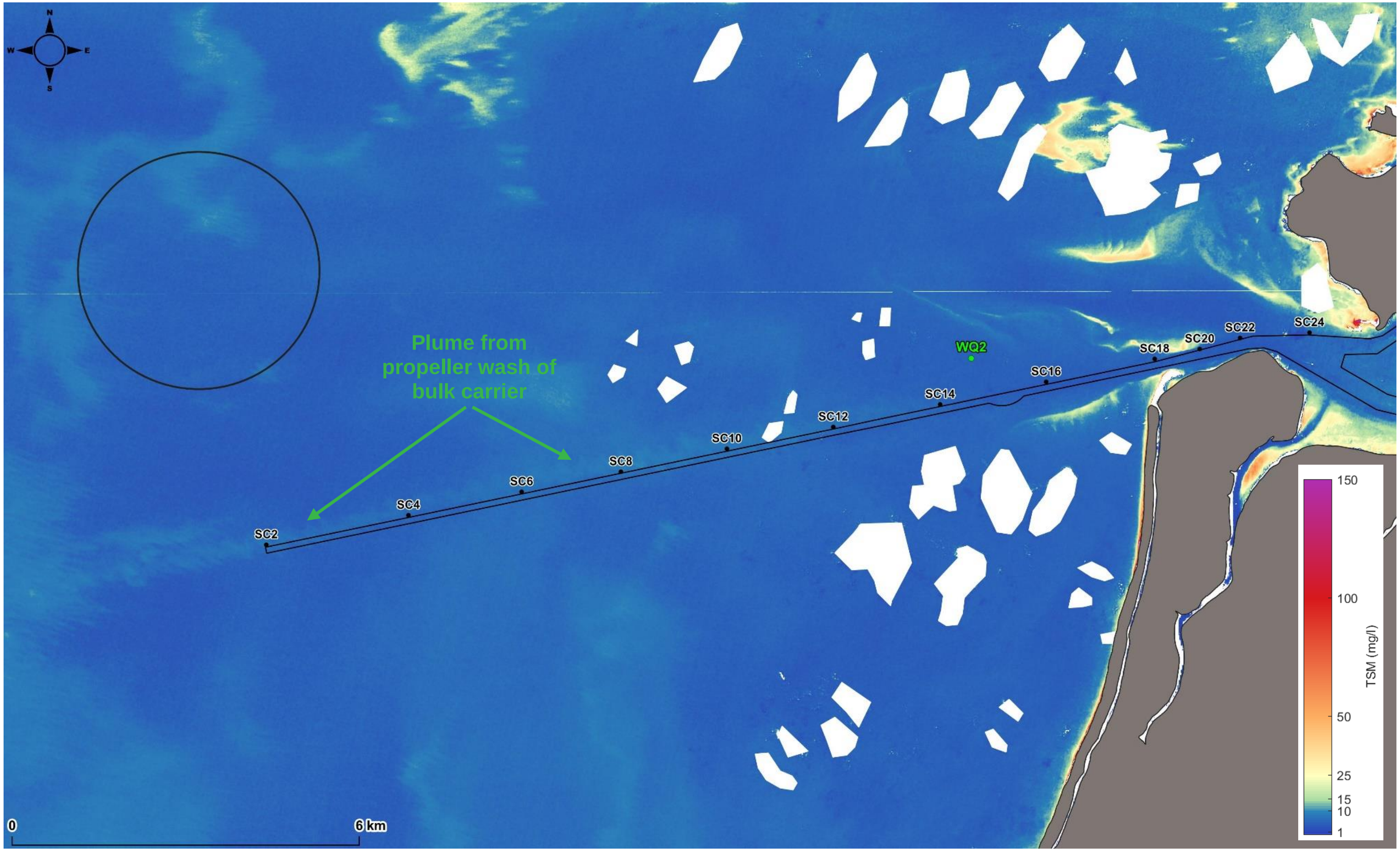
4.2.2.2. Local Scale

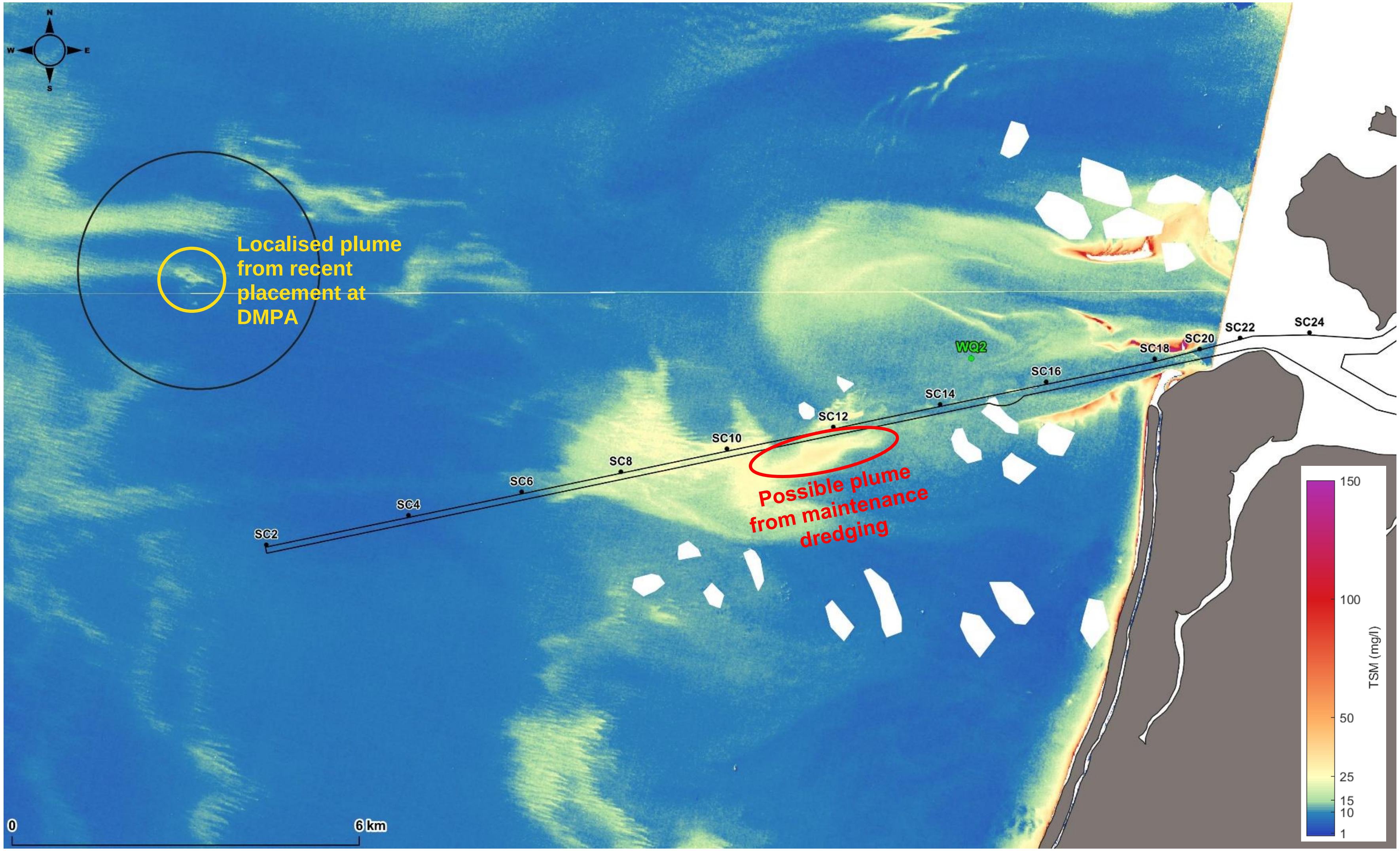
To show how the local turbidity around the Port of Weipa varied over the 2020 Maintenance Dredging program, plots of the satellite-derived TSM covering the South Channel and Albatross Bay DMPA are shown for the pre-, during and post-dredging periods in Figure 19 to Figure 24. The plots show the following:

- Pre-Dredging: Figure 19 shows a low concentration plume (10 to 15 mg/l) visible directly to the north along the majority of the South Channel and extending further offshore. This plume is likely to be due to resuspension caused by the propeller wash from a fully laden bulk carrier departing the Port. There are also natural low concentration (approximately 10 mg/l) plumes present within the Albatross Bay DMPA;
- During Dredging: the available images during the maintenance dredging program show localised plumes with concentrations of around 25 mg/l within the Albatross Bay DMPA due to recent placement of sediment within the DMPA. The plumes can be up to 1 km in length and are all within the Albatross Bay DMPA, showing that there is very limited transport of the plumes. In addition, there are also localised plumes adjacent to the South Channel, these could be residual plumes related to the maintenance dredging especially in the area between beacons SC6 and SC12. To further investigate the area of increased turbidity on the 7th May 2020 between beacons SC10 and SC14 (shown by the red ellipse in Figure 20), the true colour imagery is also presented which shows that the plume in the red ellipse (between beacons SC10 and SC14) is slightly more brown in colour compared to the plume to the west of beacon SC10 (Figure 24). In addition, the plume to the west of beacon SC10 is made up of striations of elevated turbidity, whereas the browner plume between beacons SC10 and SC14 is a relatively uniform concentration throughout. The two previous dredge loads prior to the image being captured were dredged from between beacons SC12 and SC14. Therefore, based on all the available information it is considered likely that the plume shown in the red ellipse in Figure 20 could either be due to or increased by recent maintenance dredging, while the larger plume to the west is likely to be predominantly natural. For reference, the plume in the red ellipse is approximately 2 km in length and 300 m in width with a concentration in the order of 25 mg/l. The plumes generated by the dredging activity do not reach the in-situ water quality monitoring station WQ2, which ties in with the findings in Section 4.1, which identified that the elevated turbidity levels over the maintenance dredging period, relative to the pre- and post-dredging periods, were due to natural processes; and
- Post-Dredging: the post-dredging image from the 29th May 2020 is approximately 30 hours after the last dredge load was placed at the Albatross Bay DMPA. The image shows a residual localised low concentration (approximately 10 mg/l) plume is still present in the Albatross Bay DMPA, this is likely to be from the final placements at the DMPA. This shows that the plume resulting from the placement can remain in suspension for more than 1 day following placement and that there is little to no residual transport of the plume as it is still present within the DMPA. There is also a plume present along the southern side of the South Channel, although this is thought to be predominantly from the propeller wash of a bulk carrier departing the Port, it is possible that it is also partially the residual plume from the final dredge loads which were from beacons SC8 to SC12. The TSM on the image from the 1st June 2020 appears to have completely returned to the natural conditions, showing that four days after completion of the dredging no visible plumes from the dredging activity remain.



Note: the white areas represent cloud cover.

Figure 19. Satellite-derived turbidity from the Sentinel-2 sensor for the Port of Weipa region on 29/04/2020 at 10:50 AEST (pre-dredging).



Note: the white areas represent cloud cover.

Figure 20. Satellite-derived turbidity from the Sentinel-2 sensor for the Port of Weipa region on 07/05/2020 at 11:00 AEST (during dredging).

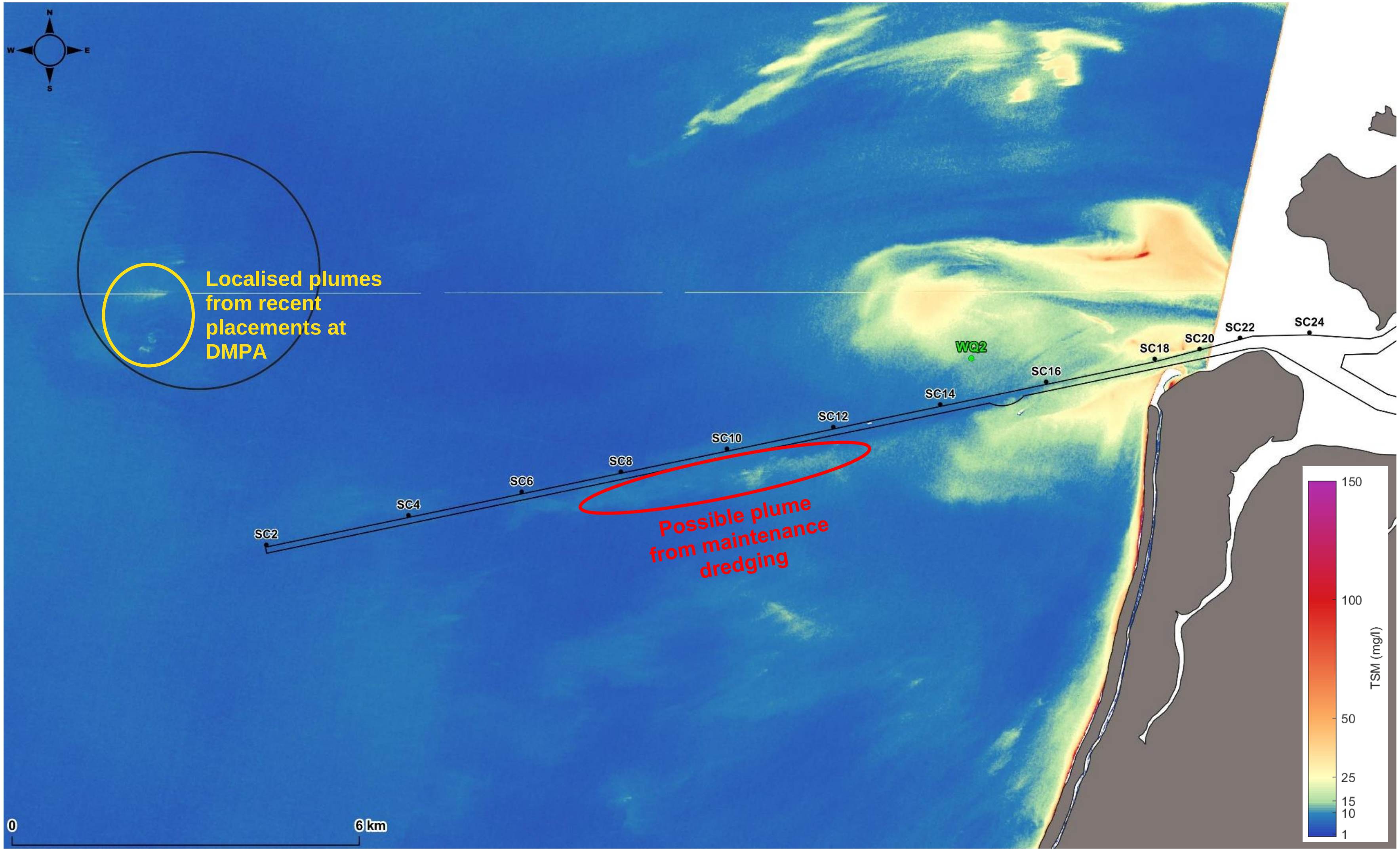


Figure 21. Satellite-derived turbidity from the Sentinel-2 sensor for the Port of Weipa region on 27/05/2020 at 11:00 AEST (during dredging).

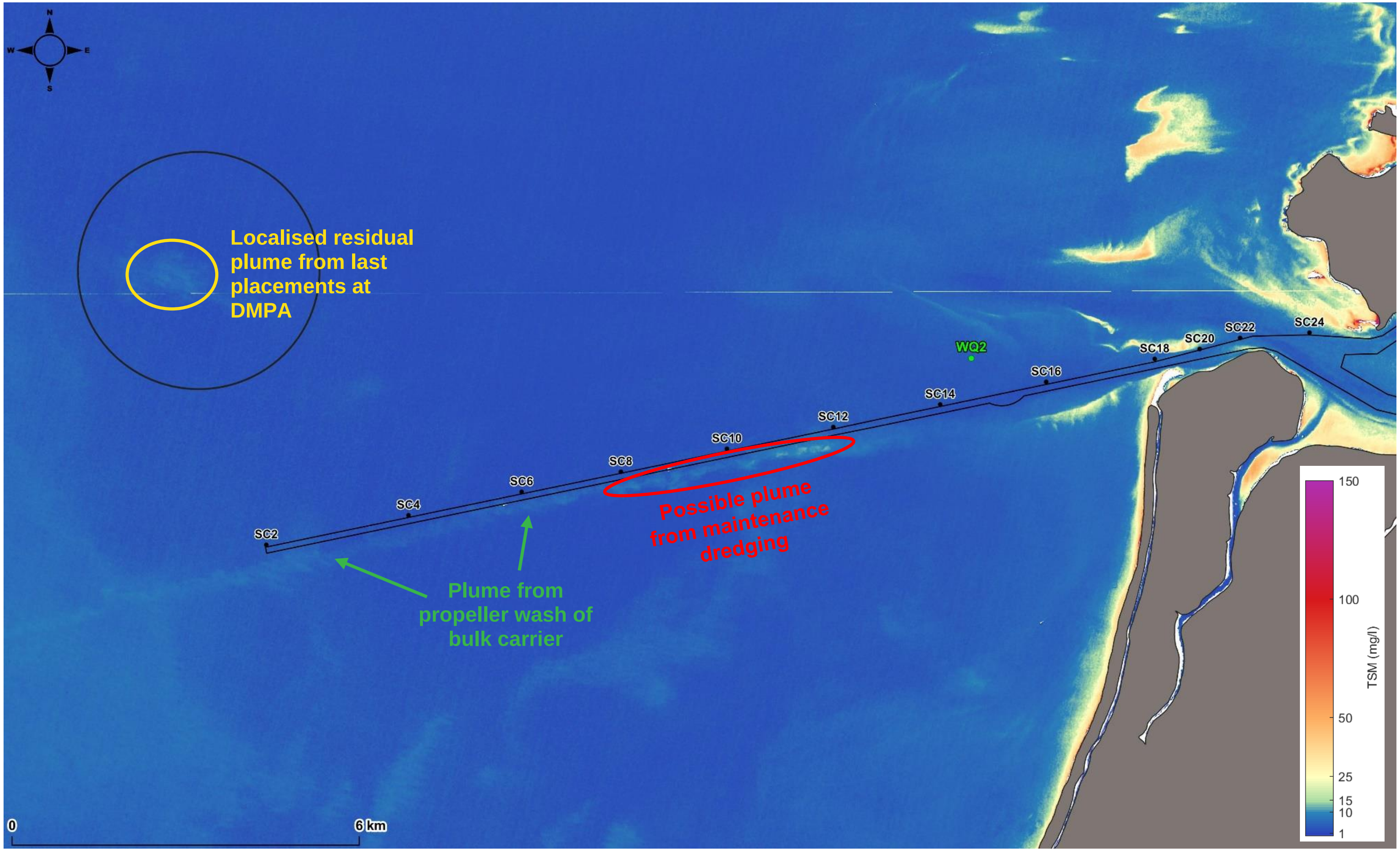


Figure 22. Satellite-derived turbidity from the Sentinel-2 sensor for the Port of Weipa region on 29/05/2020 at 10:50 AEST (post-dredging).

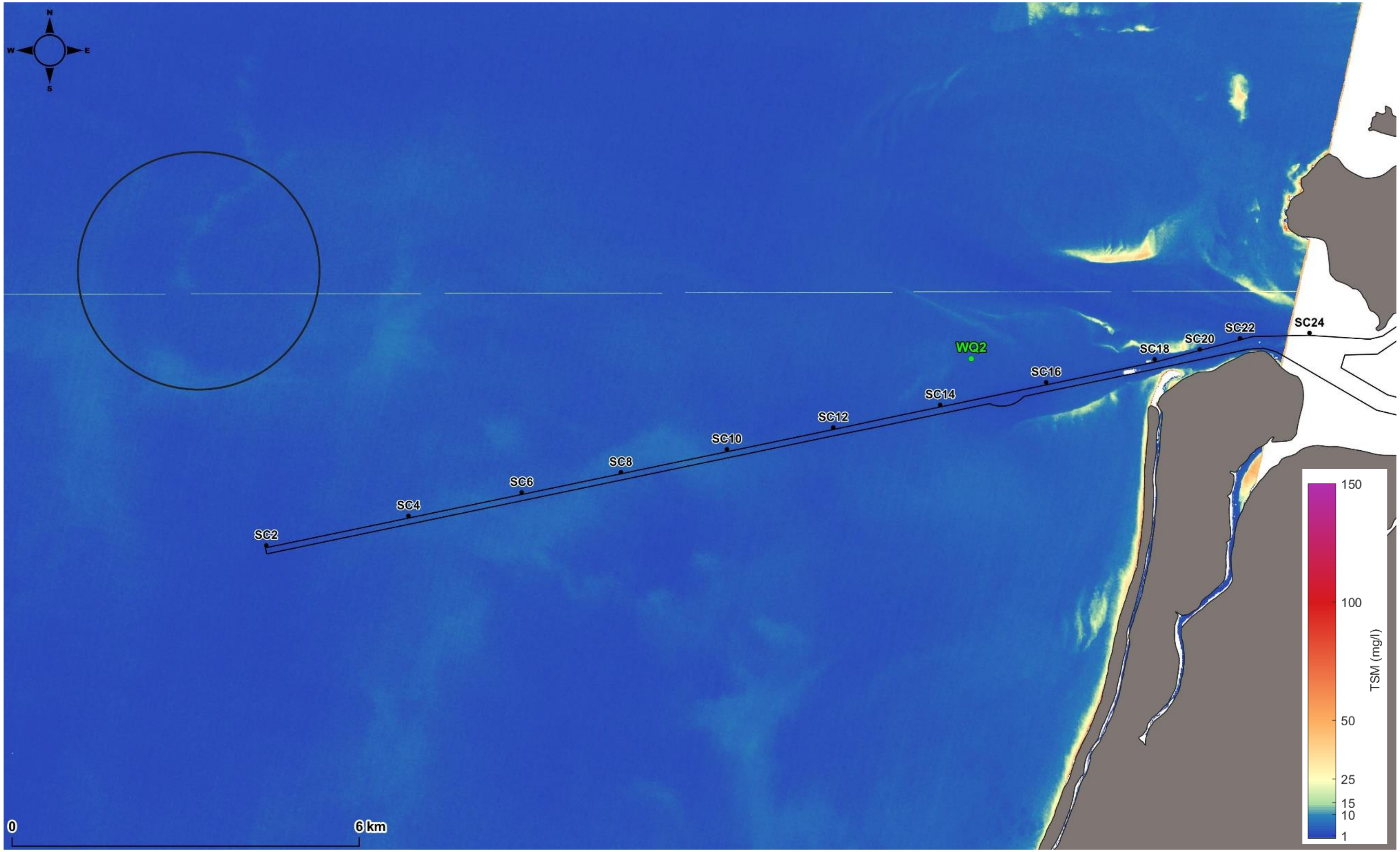


Figure 23. **Satellite-derived turbidity from the Sentinel-2 sensor for the Port of Weipa region on 01/06/2020 at 11:00 AEST (post-dredging).**

Note: the white polygons represent cloud cover.

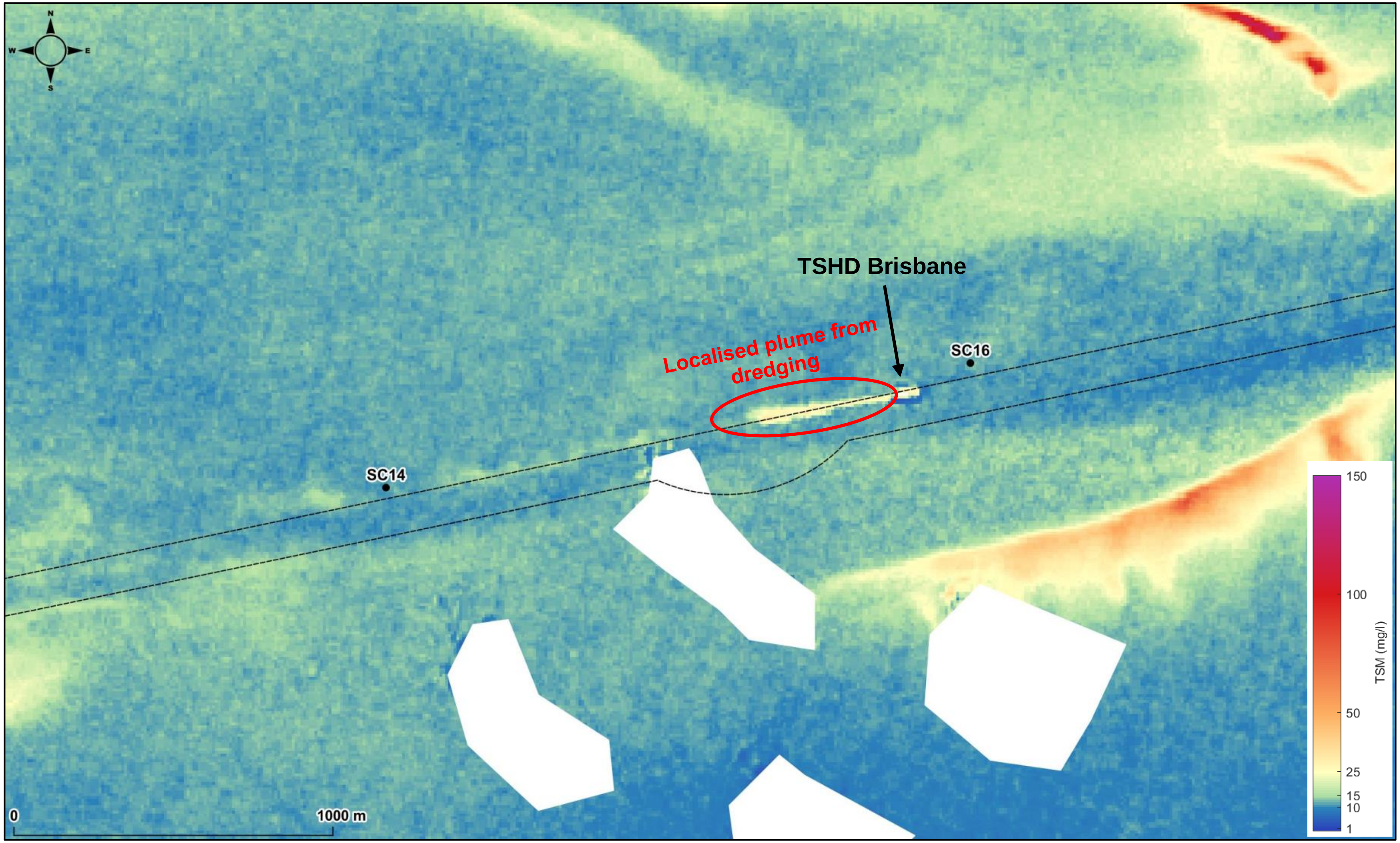
Figure 24. True colour satellite image from the Sentinel-2 sensor for the South Channel on 07/05/2020 at 11:00 AEST (during dredging).

4.2.2.3. Dredge Vessel Scale

To analyse the satellite-derived turbidity images for potential increases in turbidity due to the maintenance dredging activity, zoomed in plots of the TSHD Brisbane when dredging are shown in Figure 25 to Figure 28. The plots all show that a localised plume occurs behind the TSHD Brisbane, further details are provided below:

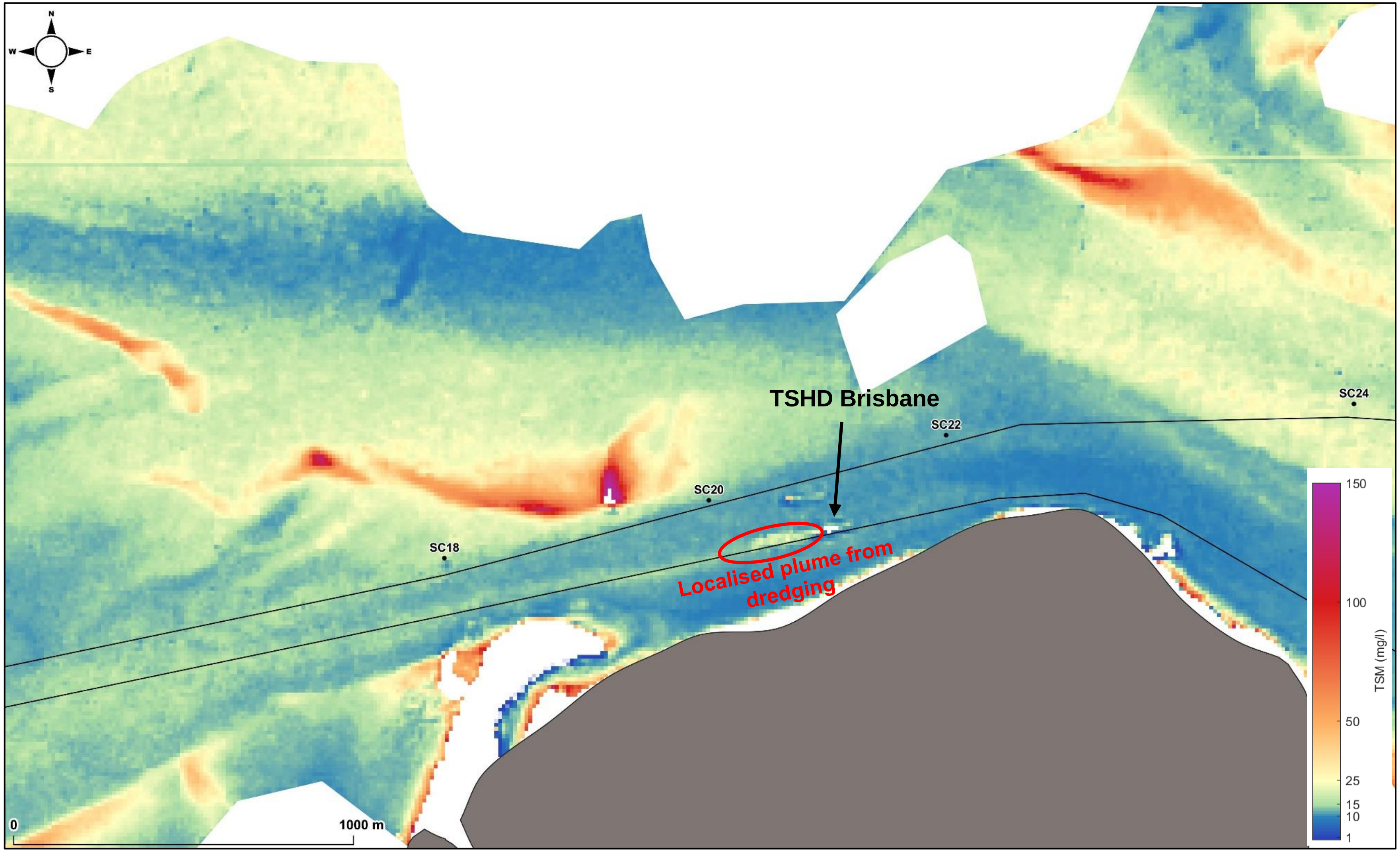
- the image from the 7th May 2020 shows a localised plume with a TSM concentration of around 25 mg/l extending approximately 500 m behind the dredger (the dredger is travelling in an easterly direction as it is returning from the DMPA). This image was taken 26 minutes after dredging commenced and so overflow from the hopper would likely have commenced approximately 10 minutes previously and it is the overflow from the hopper that would result in the majority of the localised visible plume. It is worth noting that in the earlier Landsat image from the 7th May 2020 (see Figure 12 for the zoomed out figure) there is no visible plume from the current cycle of maintenance dredging activity (i.e. at the location of the dredger), this is because the image was taken five minutes after dredging commenced in the South Channel and so no overflow from the hopper would have occurred (it typically takes between 10 and 20 minutes of dredging before the hopper is full and overflow starts);
- the plumes resulting from the maintenance dredging around the Urquhart Point section of the South Channel on the 9th and 12th May 2020 are shown in Figure 26 and Figure 27. The plots both show a small localised plume of between 25 and 50 mg/l directly behind the TSHD Brisbane, with the length of the plume varying from 300 to 500 m. The larger and higher concentration plume is present for the image which was taken 16 minutes after dredging commenced (i.e. when overflow could have been occurring for a few minutes), while dredging only commenced 12 minutes before the image with the smaller and lower concentration plume (i.e. when overflow might not be occurring or could have just started). During the 2020 maintenance dredging program the dredger typically took between 30 and 40 minutes to fill the hopper, meaning that overflow would have occurred for between 10 and 30 minutes per load. It is worth noting that the sediment being dredged around SC16 shown in Figure 25 is expected to be predominantly fine-grained silt and clay, while the sediment being dredged around Urquhart Point shown in Figure 26 and Figure 27 is expected to be predominantly sand which would generally be expected to result in a smaller and shorter duration plume; and
- the image from the 27th May 2020 shows only a very small, low concentration (10 mg/l) plume behind the TSHD Brisbane. The dredger started dredging between beacons SC10 and SC14 nine minutes before the image was captured, meaning that no overflow from the hopper would be occurring at this time. Therefore, the small visible plume is likely to be mainly due to the propeller wash from the vessel resuspending loosely consolidated fine-grained sediment from the channel as well as the dredge draghead causing some localised resuspension.

The post-dredging image captured on the 29th May 2020 shows high turbidity in the Inner Harbour around the Lorim Point wharf due to a bulk carrier being assisted by two tugs to either berth or depart from the wharf (Figure 29). This activity resulted in TSM concentrations of between 25 and 50 mg/l occurring over a 1,000 m by 200 m area. These kind of vessel movements will occur regularly and appear to have the potential to result in higher concentration plumes in the Inner Harbour than the plumes from maintenance dredging.



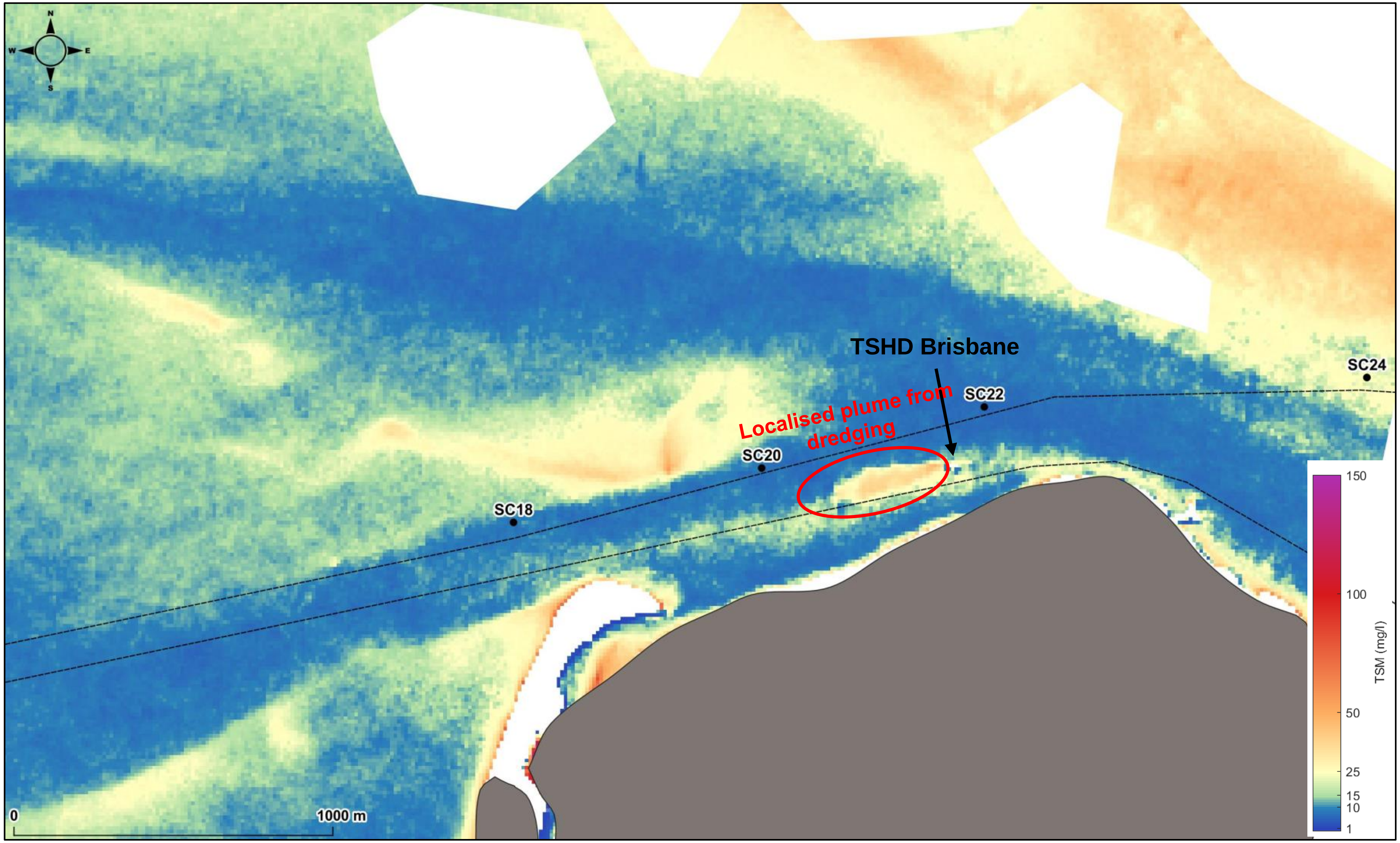
Note: the white polygons represent cloud cover

Figure 25. Satellite-derived turbidity from the Sentinel-2 sensor showing the TSHD Brisbane on 07/05/2020 at 11:00 AEST (during dredging).



Note: the white polygons represent cloud cover

Figure 26. Satellite-derived turbidity from the Sentinel-2 sensor showing the TSHD Brisbane on 09/05/2020 at 10:50 AEST (during dredging).



Note: the white polygons represent cloud cover

Figure 27. Satellite-derived turbidity from the Sentinel-2 sensor showing the TSHD Brisbane on 12/05/2020 at 11:00 AEST (during dredging).

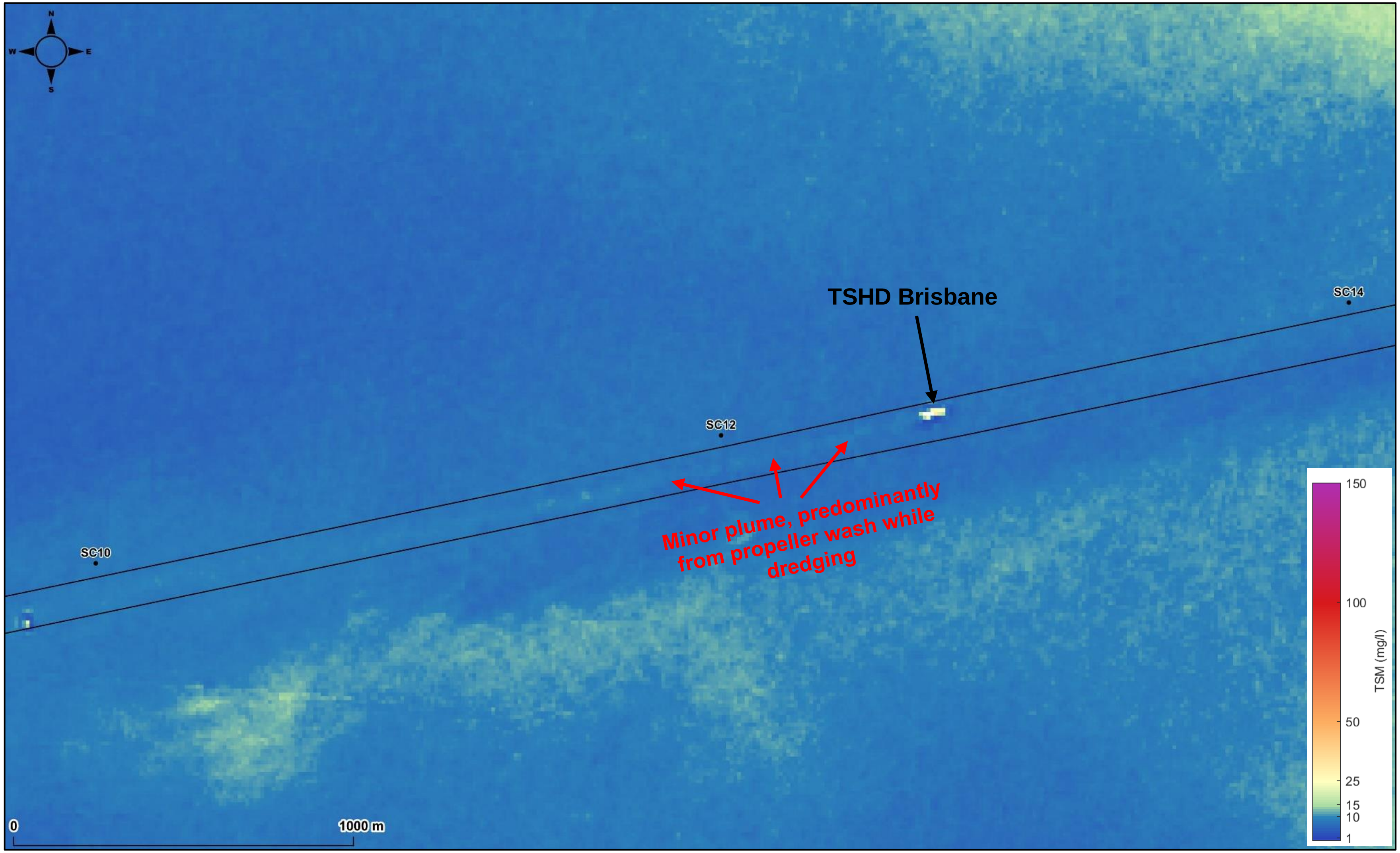


Figure 28. Satellite-derived turbidity from the Sentinel-2 sensor showing the TSHD Brisbane on 12/05/2020 at 11:00 AEST (during dredging).

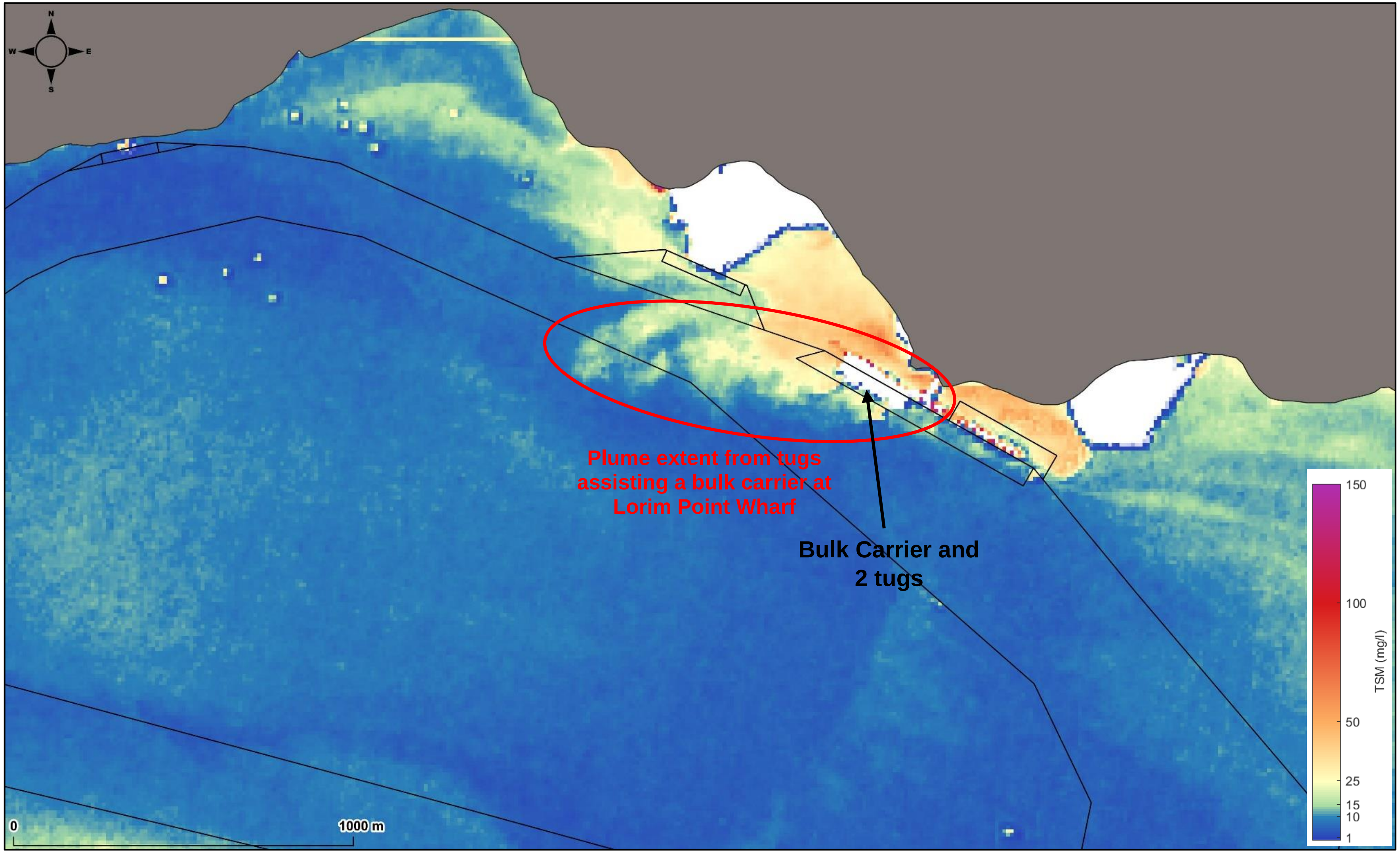


Figure 29. Satellite-derived turbidity from the Sentinel-2 sensor for Lorim Point Wharf on 29/05/2020 at 10:50 AEST (post-dredging).

5. Summary

This report has analysed and interpreted turbidity data collected pre-, during and post the Port of Weipa 2020 maintenance dredging program. The 2020 maintenance dredging program was undertaken by the TSHD Brisbane and involved the relocation of approximately 300,000 m^3 (excluding 13 dredge trips in the Inner Harbour) 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 wave conditions), with higher turbidity occurring during periods with larger waves. The key findings from the turbidity data analysis are as follows:

- based on the measured in-situ benthic turbidity data the turbidity during the pre-, during and post-dredging periods of the 2020 maintenance dredging program appears to have been predominantly controlled by the metocean conditions;
- the exceedance analysis of the in-situ measured benthic turbidity data shows increased duration exceedances over the dredging period of the 2020 maintenance dredging program. However, based on the available information this is expected to mainly be related to the metocean conditions as opposed to increased turbidity from maintenance dredging;
- the dredging and placement activities associated with the Port of Weipa 2020 maintenance dredging program have been found to result in visible plumes. Plumes were observed close to the dredger when dredging, adjacent to the South Channel and within the Albatross Bay DMPA. The size and concentration of the plumes varied, the largest plume was up to 2 km in length, 300 m in width with a concentration of approximately 25 mg/l, occurring adjacent to the South Channel due to ongoing dredging in the area;
- all of the plumes resulting from maintenance dredging (including those from both dredging and placement) were found to remain close to where they were created. This shows that little net residual transport occurs in the region, this was also noted during the 2019 maintenance dredging program and as part of the Port of Weipa Sustainable Sediment Management assessment (PCS, 2018b and 2019c). Based on this, it can be assumed that the majority of the sediment suspended by the maintenance dredging is subsequently redeposited close to where it was either dredged or placed;
- the Port of Weipa 2020 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 wave conditions over the monitoring period were significantly larger than the variations in turbidity due to the maintenance dredging; and
- the satellite imagery showed that following completion of the 2020 maintenance dredging program, the turbidity quickly (between one and four days) returned to natural conditions with no remaining areas with elevated turbidity due to the maintenance dredging and placement activities.

6. References

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