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Monitoring of Maintenance Dredging Plumes – Gladstone Harbour, November 2014

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Monitoring of Maintenance Dredging Plumes – Gladstone Harbour, November 2014

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Synopsis: **A report detailing the effects of maintenance dredging and sea disposal of dredged material by the trailing arm suction hopper dredge (TSHD) *Brisbane* on ambient water quality at Port Curtis in November 2014.**

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Executive Summary

Background and Approach

Gladstone Ports Corporation (GPC) is responsible for the maintenance dredging of the Port of Gladstone which is undertaken by the Trailer Suction Hopper Dredge (TSHD) *Brisbane*. The dredged material is disposed at sea at the East Banks Sea Disposal Site (EBSDS) in accordance with sea dumping permits issued by the Department of the Environment (DOE). Gladstone Harbour has been maintenance dredged since the mid 1970's.

Dredging, disposal of dredged sediments and the subsequent re-suspension of dredged sediments increases suspended sediment concentrations in the water column. Following a previous study undertaken in 2013, BMT WBM undertook modelling studies in 2014 investigating the potential effects of maintenance dredge plumes and sea disposal activities on estuarine ecosystems in Port Curtis. This assessment was based on dredge volume estimates provided by GPC and the model was calibrated using plume monitoring data collected by BMT WBM in February 2014. Simulations were performed representing various potential future maintenance dredging requirements.

Based on near-field validated modelling results, most sensitive receptors surrounding the channel were found to be likely not affected by loading plumes. Dredge plumes were typically short-lived and had relatively low suspended solid concentrations compared to natural background levels. The exception were seagrass meadows surrounding the Passage Islands which were predicted to experience moderate plume intensities and durations under two of the modelled simulations (400,000 m^3 and 320,000 m^3 of dredging). It is noted the 2014 November / December Gladstone Harbour maintenance dredging campaign removed only 307 000 m^3. It is estimated that the volume of future maintenance dredging programs will be further reduced.

Based on these findings a monitoring study was undertaken to determine the behaviour, extents and intensities of plumes at and adjacent to the loading sites and the EBSDS during neap tides and calm weather. The monitoring consisted of a baseline water quality assessment prior to the dredging and plume monitoring during the dredging and disposal operations (November 2014) at five locations within Gladstone Harbour - Wild Cattle Cutting, Golding Cutting, Gatcombe Channel, Jacobs Channel and the EBSDS. Sediment entrained in the water column during dredging operations has the potential to remain in suspension longer and advect further when the tidal currents are higher and/or the wave climate rougher. During these periods, however, the natural levels of suspended natural sediments are higher making it difficult to isolate the dredge related sediments from the natural sediments. For this reason monitoring of dredge plumes within Port Curtis was performed during neap tides and during calm seas for offshore monitoring. The timing of the sampling during different tidal stages (ebb and flood tides) took into account the plume direction most likely to affect nearby sensitive receptor sites.

The measurements were performed using a boat mounted, downward facing Acoustic Doppler Current Profiler (ADCP) which provided the TSS concentrations throughout the water column along transects of the dredge plumes. Numerous profiles of the turbidity and Photosynthetically Active Radiation (PAR) were also conducted together with water samples used to quantify numerous environmental parameters such as total and dissolved nutrients and total organic carbon.

The results of the plume monitoring are summarised as follows:

Gatcombe Channel (Ebb Tide Dredging)

Dredging by the *TSHD Brisbane* was undertaken on an ebbing tide on 16th November 2014 along the northern toeline of the Gatcombe Channel. The dredger targeted isolated shoals over a channel length no more than 200m. The turbid plume was quite variable in its initial size and suspended solids concentration depending upon whether the dredger was dredging (steaming ahead) or was being manoeuvred astern to reposition itself for another pass over the shoal area.

The turbid plume was advected by the ebbing tide in a south-easterly direction almost completely along the channel alignment. Subsequently the plume was advected for only 500 metres from the dredging location before reaching background turbidity levels after approximately two hours.

Turbid plumes created by dredging on the ebb tide did not extend to any nearby sensitive marine receptors during the monitoring.

Gatcombe Channel (Flood Tide Dredging)

Dredging by *TSHD Brisbane* was conducted during a flooding tide on 16th November 2014 along the northern toe line of the Gatcombe Channel. Similar to the dredging undertaken during the ebbing tide, the dredger targeted isolated shoals over a channel length no more than 200m and turbid plumes were variable in size and suspended solids concentrations depending on the dredger's movements over the shoals.

The turbid plume was advected by the flooding tide in a north-westerly direction mainly along the channel (towards Quoin Island) with some displacement over and beyond the northern edge of the channel into the South Trees ship anchorage area and towards Manning Reef. Whilst a plume was discernible above background levels over 3.2km away from the loading site and visible for approximately two hours, the suspended solid concentrations within the plume were so low (approximately 5 mg/L) that impacts to any sensitive receptors on Manning Reef are considered highly unlikely. The plume would not have reached the seagrass communities on North Banks.

Jacobs Channel (Ebb Tide Dredging)

Dredging by *TSHD Brisbane* was undertaken over slack water and into an ebbing tide on 17th November within the swing basin adjacent to the APLNG gas loading wharf in Jacobs Channel. The dredger undertook three passes of approximately 400m over the dredging area before departing to the EBSDS.

A series of plumes were generated with each pass of the dredger and advected southwards with the ebbing tide. The majority of the plume sediments remained within the deeper sections of Jacobs Channel spreading out across its width and remaining near the bed. A smaller proportion of the suspended sediments passed over the spur separating the APLNG swing basin from the QCLNG materials offloading facility (MOF). Despite the plumes extending to the western edge of the channel they did not breach its confines and hence impinge on any of the seagrass communities on the banks of the Passage Islands. The sediments which passed into the MOF continued to advect southwards in the prevailing currents along the Curtis Island shoreline where shallow water depth restricted direct measurement to determine whether these dredge related sediments passed over previously mapped meadows close to Curtis Island. It is noted that these meadows were not present in 2009 and 2013. The dredge plume was discernible above background levels two hours from the cessation of dredging works by which time it had advected over 3 km down Jacobs Channel. The longevity of the plume was reflective of the fine sediments being dredged in the Swing Basin.

Golding Cutting (Flood Tide Dredging)

Dredging by *TSHD Brisbane* was conducted during slack water and into a flooding tide along the southern toe line of the Golding Cutting on 18th November 2014. The dredger made a single inbound pass before turning and steaming loaded for the EBSDS. Hence a single long plume was generated. The plume advected within the gently flooding currents in a north-westerly direction along the channel (towards Boyne Island) and beyond the western edge of the main channel into the Golding Bypass channel. Plumes were still visible above background levels one hour after the cessation of dredging over a distance of about 800 m.

Turbid plumes created by dredging extended within the boundary of mapped deep water seagrass habitat located west of the Golding Cutting (mapped in 2002 but not present in 2009 and 2013) and the associated bypass channel, extending as much as several hundred metres into the seagrass community. By the time the plume had advected beyond the bypass channel the concentrations were below 10 mg/L and unlikely to impact on any existing seagrass communities.

Wild Cattle Cutting (Flood Tide Dredging)

Dredging was conducted on a flooding tide on 18th November 2014 along the northern toe line of Wild Cattle Cutting. A single outbound pass was performed with a single long plume generated parallel to the channel.

The dredge plume was advected by the flooding tide in a south-westerly direction mainly along the channel (towards the Boyne Cutting) but also with some displacement over and beyond the northern edge of the channel onto East Banks. The plume was advected along the channel over 1 km by the flooding tide over a period of almost two hours until near background turbidity conditions were achieved.

The plume component displaced onto East Banks fell short of the rocky reef area by approximately 6 km. The plume was not advected towards the rocky reef areas at Jenny Lind Bank and did not pass over the deep water seagrass meadow in any detectable quantities.

East Banks Sea Disposal Site (Flood Tide Disposal)

The *TSHD Brisbane* placed dredged material on 19th November 2014 towards the centre of the EBSDS. According to the dredger's daily reports the Brisbane's dredged load consisted of silts from the Golding Channel. The tide was recently flooding with the currents swinging from southerly through to westerly.

The turbid dredge plume generated by disposal activities at the EBSDS was advected by the flooding tide south towards a mapped seagrass meadow. The plume was localised and of low intensity. The plume was identifiable for approximately 1.5 hours above the background concentrations by which time it had travelled approximately 1 km. The plume fell short of the deep water seagrass meadow by over 1 km.

Water Quality Impacts

Water quality profiling measurements generally indicated elevated turbidity and diminished light (PAR) availability in the dredge plumes compared to baseline water quality conditions. Temperature, salinity, pH and dissolved oxygen (close to saturation) were relatively stable throughout the water column at all locations and similar between baseline and plume monitoring.

As expected, TSS and nutrient concentrations (mainly total N and P and dissolved nitrate/nitrite and reactive phosphorus) were generally higher in the dredge plume water samples compared to those collected during baseline conditions. Sediment bound nutrients would be expected to settle out of suspension with sediment particles, whereas the dissolved nutrients would be expected to disperse within the ebb and flood tides.

Dissolved nutrient concentrations in dredge plume samples were generally higher with occasional values up to 40 times higher than the guideline or baseline sample values. Plume dispersion due to tidal processes would quickly achieve dissolved nutrient levels below guideline values or close to baseline conditions. Chlorophyll *a* concentrations were generally higher in the baseline water samples and were below laboratory detection in the plume samples. Thus, extensive algal blooms were not evident and are not expected to occur as a result of the maintenance dredging.

Concentrations of total aluminium, iron, and to a lesser extent manganese and zinc were elevated in the dredge plumes compared to baseline conditions. Particle-associated metals dominated over the dissolved, bioavailable fraction. It is expected that these sediment-bound metals would quickly settle out of suspension with sediment particles.

The concentrations of the bioavailable, dissolved fraction of all measured metals and metalloids were either below the laboratory detection limits or below their guideline trigger limits in all plume and baseline samples. The dissolved metal/metalloid concentrations were similar during baseline and dredging conditions for all investigated metals. It can therefore be concluded that the maintenance dredging activities in Gladstone harbour did not lead to an increase in the bioavailable metals and metalloids in the water column with dissolved metal/metalloid concentrations measured at levels which would unlikely result in adverse impacts to marine organisms.

Conclusions

In summary, turbid plumes generated during the maintenance dredging campaign in November 2014 were generally transient and dissipated to background concentrations mostly within two hours after cessation of the dredging or placement activities. Dredge plume concentrations during neap tides remained below 100 mg/L and were therefore within the limits of concentrations typically observed within the inner Gladstone Harbour during spring tide conditions. A major proportion of the turbid plumes remained within the dredged channel alignments with a smaller proportion sometimes extending outside the channel alignment. For most locations, the turbid plumes did not impact on nearby sensitive receptor sites. A portion of the dredge plumes passed over previous mapped seagrass meadows at Jacobs Channel close to Curtis Island and west of the Golding Cutting. It is noted that these previously mapped seagrass habitats were not observed in 2009 and 2013 surveys. Whilst elevated concentrations of total nutrients and metals were detected in plumes, these are expected to rapidly settle out of suspension with sediment particles. Elevated dissolved nutrients would be dispersed and advected by tidal currents and are therefore expected to reach background levels within a few hours. Overall, these results are consistent with previous modelling predictions and field measurements.

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1 Introduction

1.1 Background

Gladstone Ports Corporation (GPC) is responsible for the maintenance dredging of the Port of Gladstone. Maintenance dredging is undertaken on an approximately annual basis by the *TSHD Brisbane*. The dredged material is placed at sea within the East Banks Sea Disposal Site (EBSDS) in accordance with sea dumping permits issued by the Department of the Environment (DOE).

The conservation goals relevant to the maintenance dredging project are as follows:

- Ensure that maintenance dredging activities do not impact on the Outstanding Universal Value (OUV) of the Great Barrier Reef World Heritage Area (GBRWHA). This will be achieved by minimising or avoiding impacts to marine ecological values (Species, communities and habitats) supported in the Gladstone Harbour which contribute to the OUV of the GBRWHA.
- Undertake appropriate marine ecological condition monitoring in order to inform adaptive management actions that aim to minimise or avoid impacts to marine ecological components, process and services. This monitoring should coordinate with other broader national, GBR-wide and regional programs, in particular Port Curtis Integrated Monitoring Program (PCIMP) and the Gladstone Healthy Harbour Partnership (GHHP).

BMT WBM (2013 and 2014a) investigated the potential effects of dredge plumes on estuarine ecosystems in Port Curtis. BMT WBM (2014a) included modelling of plumes from maintenance dredging and sea disposal activities in the Port of Gladstone based on revised dredge volumes. Plume monitoring data collected in February 2014 supported the modelling (BMT WBM 2014b). Simulations were performed representing various potential future maintenance dredging requirements.

Model results predicted that plumes generated from placement of dredged material at the EBSDS are of low concentration and limited duration and are not expected to affect sensitive receptors adjacent to the EBSDS. This was consistent with plume monitoring results obtained in February 2014 (BMT WBM 2014b) which indicated that plumes had dissipated in less than two hours.

The intensity and duration of dredge loading plumes are highly dependent on the type of material being dredged, the behaviour of the dredger, and the stage within the tidal cycle. Modelling results predict that during neap tides maintenance dredging plumes at the loading sites would remain in the immediate dredging area and return to ambient concentrations within hours. During spring tides, these plumes have been modelled to remain in suspension much longer and cover a much larger distance. It is noted that ambient suspended sediment concentrations are typically high in Gladstone Harbour during spring tides which makes it difficult to detect the plumes above background.

Based on near-field validated modelling results, most sensitive receptors surrounding the channel are not likely to be affected by loading plumes with typically short-lived turbid plumes at relatively low suspended solid concentrations compared to natural background levels. However, some indirect impacts were predicted to occur at seagrass meadows surrounding the Passage Islands under two of the modelled simulations (400,000 m^3 and 320,000 m^3 of dredging), as these meadows experience the greatest duration and intensity of dredge plumes. It should be noted the 2014 November /December Gladstone Harbour maintenance dredging campaign removed only 307 000 m^3. This campaign was unique in that a significant amount of accumulated material left behind by the Western Basin capital dredging needed to be removed. It is estimated that the volume of future maintenance dredging programs will be reduced.

On the basis of this assessment, it was recommended that a field sampling program be carried out to measure the behaviours of dredge and sea dumping generated turbid plumes, and to re-assess potential impacts of plumes to sensitive ecological receptor sites. The monitoring recommendations outlined in BMT WBM (2014a) were subsequently adopted in GPC's Long Term Monitoring and Management Plan for maintenance dredging sea dumping activities.

The present study was commissioned by GPC to address this requirement.

1.2 Study Objectives

The objectives of this study were to:

- Quantify the behaviour, extent and intensities of plumes of suspended dredged sediments at and adjacent to the loading sites and EBSDS;
- Analyse water samples collected from within the dredge plumes (loading and disposal sites) with respect to a number of physical and chemical parameters;
- Based on the measurements assess the potential exposure of known sensitive receptors to sediment plumes and elevated nutrient concentrations;
- Determine the potential impacts of turbid plumes on seagrass meadows surrounding the Passage Islands; and
- Determine the need or otherwise for further more detailed investigations (such as further model validation) and implementation of mitigation measures.

1.3 The Dredging Process

The trailing suction hopper dredge (TSHD) *Brisbane* (Figure 1-1) is a 85 m long ocean-going vessel which performs maintenance and capital dredging works within the Port of Brisbane for around three months of the year and contract maintenance dredging services for other ports, , including the Port of Gladstone for the remainder.

The TSHD *Brisbane* is equipped with two trailing arm suction heads, on the port and starboard sides of the vessel, which are typically lowered and dragged along the seafloor, simultaneously dredging the bed sediments either side of the vessel as it progresses forward. The drag heads are lifted clear of the seabed when moving astern. To efficiently fill the hopper (volume 2,900 m^3) with dredged material, the vessel is usually operated in an overflowing mode whereby the dredged sediments are concentrated within the hopper over time. A telescoping weir within the centre of the hopper can be elevated to maximise the retention of dredged material before discharge from the hopper occurs. Excess water and suspended sediments are ultimately discharged from the hopper via the weir to the underside of the keel, approximately five metres below the water line.

Depending upon the nature of sediments to be dredged, dredging to effectively fill the dredge hopper generally lasts between 1 and 1.5 hours, typically without any overflow from the hopper occurring in the first 15-20 minutes. Subsequently, a dredging overflow plume of turbid water is usually obvious as the overflow water and suspended sediments discharged from the underside of the keel are entrained to the water surface by the action of the vessel's propellers operating near the stern of the vessel as it moves ahead. This results in an obvious surface plume of dredged sediment astern of the TSHD Brisbane for the remainder of the dredging duration.

Typically, the turbid water plume produced by overflow dredging extends from the water surface through the full height of the water column as the overflow sediments settle astern of the dredger. The turbid plumes formed by dredging can be extremely variable both spatially and temporally depending upon such factors as the mode and track of the dredger, the prevailing current regime and the sediments being dredged.

Following cessation of dredging the TSHD *Brisbane* typically delivers its load of dredged material to a designated spoil ground, i.e. the EBSDS. On arrival at the EBSDS the dredger typically slows to a speed of a few knots and the dredged sediment loaded within the hopper is deposited over the required placement area by opening a series of five valves set within the bottom of the hopper, allowing for gravitational settlement of dredged material from the vessel through the water column to the seafloor.

Figure 1-1 TSHD *Brisbane* Dredging in APLNG Swing Basin

2 Methodology

2.1 Dredge Plume Monitoring

2.1.1 General Approach

The sampling program was designed to maximise the potential for detecting dredge plumes at sensitive receptor sites. In this regard:

- The present study monitored the behaviour of individual plumes at loading and disposal locations in close proximity to known sensitive ecological receptor sites identified by BMT WBM (2014a). Five general locations were monitored (Figure 2-1):
  - Wild Cattle Cutting;
  - Golding Cutting;
  - Gatcombe Channel;
  - Passage Island (or Jacobs) Channel; and
  - East Banks Sea Disposal Site.
- Plume monitoring occurred during periods when ambient background turbidity would be lowest, thereby increasing the ability to detect dredge-generated turbidity. Background turbidity and suspended sediment concentrations are often high during average or spring tide conditions in Gladstone Harbour. Whilst turbid plumes would typically travel farthest during spring tide conditions, the ability to distinguish these plumes against elevated background concentrations would be severely limited. Therefore, small range neap tide conditions were targeted for the plume measurements.

The plume monitoring was planned to occur on either a flooding or ebbing tide (or both) for each of the five study locations depending on the location of sensitive marine communities (such as seagrass or corals) that would be potentially affected. The baseline water quality sampling was targeted for a mid-range tide to establish background levels during 'average' conditions in Gladstone Harbour.

2.1.2 Baseline Measurements

The baseline water quality sampling was undertaken prior to the maintenance dredging operations on the 2nd November 2014 around a neap low tide covering both ebb and flood flows. Measurements were collected from the five study locations, refer Figure 2-1.

The following field measuring instrumentation and techniques were employed during the course of the baseline measurements:

- Water quality profiling using a YSI model 6600 water quality sonde of turbidity, water temperature, electrical conductivity, salinity, pH, dissolved oxygen concentration and Photosynthetically Active Radiation (PAR).
- Water sampling for laboratory analysis of TSS, total and dissolved nutrients (Total N and P, nitrate + nitrite, ammonia, reactive phosphorus) and total Organic Carbon (TOC) for comparison

with the Queensland Water Quality Guidelines 2009 (QWQG) values for enclosed coastal areas in the Central Coast Queensland region. All samples were also analysed for total and dissolved metals (Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Hg, Ni, Ag, Zn) for comparison against the respective ANZECC (2000) marine trigger limits. Samples were collected from both the surface and near-bed.

2.1.3 Dredge Plume Measurements

All field measurements were conducted from the BMT WBM crewed vessel *Rush* operating in the vicinity of the dredge operations. The dredge plume measurements were undertaken during neap tides between 16th and 19th November 2014. During the dredge plume monitoring BMT WBM communicated and co-ordinated measurement and sampling activities with GPC and the *TSHD Brisbane* via mobile telephone or VHF marine radio.

The following field measuring instrumentation and techniques were employed during the course of the dredge plume monitoring:

- Water sampling for laboratory analysis of Total Suspended Solids (TSS) concentrations and Particle Size Distributions (PSD) to be used in the calibration of the turbidity probe and in assessments of the dredge plumes;
- Turbidity profiling, using the OBS-3A turbidity probe, within and beyond the extents of the dredge plumes for use in the calibration of the Acoustic Doppler Current Profiler (ADCP) and in assessments of the dredge plumes;
- Conducting transects of the dredge plumes with a vessel mounted downward facing ADCP to record the acoustic backscatter, providing an insight into the otherwise hidden plume characteristics across the various transects;
- Additional water quality profiling using YSI model 6600 and RBR XRX-620 multi-parameter water quality sondes for measurements of turbidity, water temperature, electrical conductivity, salinity, pH, dissolved oxygen concentration and Photosynthetically Active Radiation (PAR); and
- Additional water sampling for laboratory analysis of TSS, total and dissolved nutrients (Total N and P, nitrate + nitrite, ammonia, reactive phosphorus) and total Organic Carbon (TOC) for comparison with the Queensland Water Quality Guidelines 2009 (QWQG) values for enclosed coastal areas in the Central Coast Queensland region. All samples were also analysed for total and dissolved metals (Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Hg, Ni, Ag, Zn) for comparison against the respective ANZECC (2000) marine trigger limits.

It is noted that the water quality profile measurements were undertaken at a pace appropriate for collecting valid data. Due to unavoidable heave and roll movements of the survey vessel it is therefore possible that some water quality profiles have multiple data points with slightly different values at given depths.

LEGEND

- Water Quality Measurement Locations
- East Banks Sea Disposal Site
- Channel Extent
- Composite Seagrass Distribution (2002-2012)
- Seagrass Distribution (2012)
- Reefs (BMT WBM)
- Reefs (GBRMPA 2014)

Title:
Water Quality Measurement Sites

Figure: 2-1

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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2.2 Data Processing

2.2.1 ADCP Data Processing

Processed ADCP measurements were used to remotely measure the suspended sediment in the water column with a sufficient resolution to provide pictorial views of the suspended sediment associated with dredging.

ADCP measurements can be used to estimate suspended sediment concentrations throughout the water column, however an ADCP instrument does not directly measure TSS. The principle of ADCP operation is that a pulse of sound is propagated through the water column and is reflected / backscattered off suspended particles - such as suspended sediments. The Doppler shift of the backscattered acoustic signal is used to directly determine the water currents throughout the water column. The intensity of the backscattered echo can be translated into TSS values through a series of steps as detailed below.

Laboratory analysis of the TSS in water samples spanning a wide range of sediment concentrations provides the means to calibrate the handheld OBS turbidity profiling instrument. By pairing the TSS values with the Nephelometric Turbidity Units (NTU), recorded in the field by the OBS, the site and date specific NTU-TSS relationship can be determined.

The turbidity profiles measured with the OBS, once converted to TSS, are then used to derive a relationship between the ADCP acoustic signal backscatter intensity and TSS. The software package VISEA includes a built-in calibration module for this purpose which is based on acoustic theory. The calibration process requires information on water temperature and salinity at the site and various scaling factors and offsets for each of the four transducers.

The estimates of TSS obtained from the ADCP backscatter signal are typically plotted as a function of depth and chainage along each transect. TSS estimates are capped at a maximum value due to the uncertainty surrounding the backscatter–TSS relationship above that value. It should also be noted that due to its mounting and a measurement "blanking-distance", the ADCP was only able to resolve TSS profiles below a depth of approximately 1.5 m. The ADCP was also unable to estimate the TSS within approximately 1 m from the bed.

ADCP backscatter measurements are prone to occasional spikes/elevated values that are un-related to TSS in the water column. These spikes may arise due to a number of sources of interference, including bubbles generated near the surface by the dredge, survey vessel , 3rd-party vessel or other objects 'ensonified' in the water-column such as plankton, fish or seaweed. The data presented in this report has not been "cleaned" other than the TSS cap mentioned above. A watermarked warning has been stamped over the figures where interference from air bubbles has compromised the ADCP's ability to measure the TSS. For further commentary regarding such interference refer to Section 2.4.2.

2.2.2 ADCP Data Calibration

2.2.2.1 Calibration, Turbidity (NTU) to TSS

A total of 24 water samples were analysed for TSS and used to derive the NTU-TSS relationship of the OBS, a procedure detailed in Section 2.2. Refer to Appendix C for the tabulated TSS values and Figure 2-2 for the derived relationship. The relationship was derived using linear regression. The high coefficient of determination (R^2) value confirms the applicability of a linear relationship with a zero intercept. The zero intercept was adopted as it was assumed that there was zero turbidity when there was zero TSS. It is possible that there were small contributions to the turbidity from sources other than suspended sediments such as algae, however as suggested from the data such contributions were insignificant with respect to the current study.

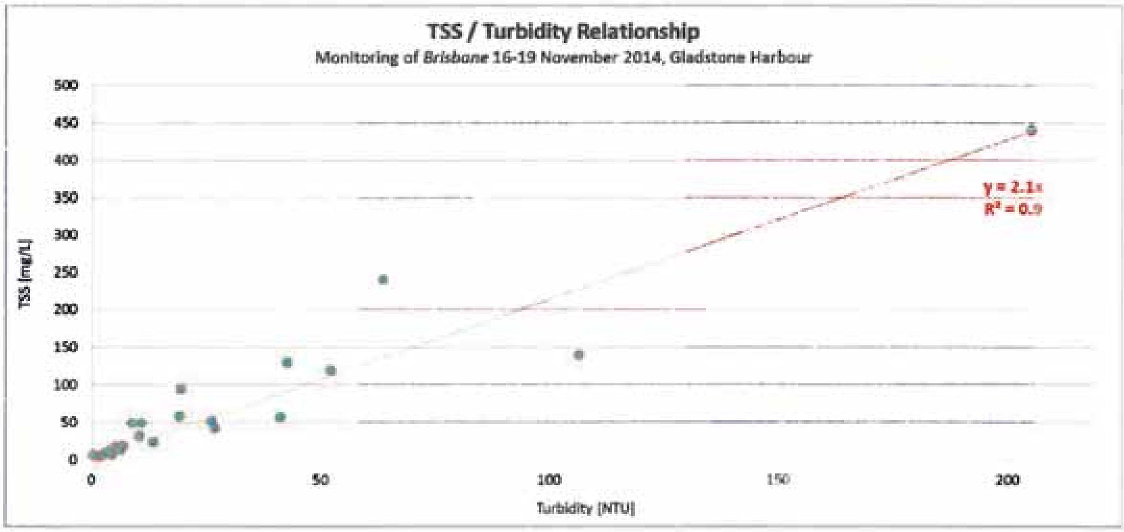

Figure 2-2 TSS / Turbidity Relationships

2.2.3 Calibration, Backscatter to TSS

The calibration was performed as outlined in Section 2.2 using the VISEA calibration module. Sufficient data were available to perform site specific calibrations for three of the four days of monitoring. Insufficient data were available to perform a site specific calibration for Gatcombe Channel. This data set was processed based on the calibration corresponding to measurements at Jacobs Channel on the following day.

The calibration parameters were consistent between the different data sets with no prevalent time, depth or concentration biases. Refer to Appendix K for the calibration plots. The calibration is deemed sufficient for the purposes of this study and observations made using the ADCP are consistent with those made using the OBS, the analysis of collected water samples and what was observed visually on each measurement day.

2.3 Water Sample Data Processing

Water samples were sent to the NATA accredited laboratories of Advanced Analytical Australia (primary laboratory) and Australian Laboratory Services (secondary laboratory) for analysis of nutrients and metals/metalloids. All laboratory LORs were either below or at their respective trigger limits where applicable.

The measured concentrations were assessed against the relevant QWQG (nutrients, TSS and chlorophyll a) and ANZECC (2000) (metals and metalloids) marine trigger limits. As stated in ANZECC (2000), 'the major toxic effect of metals comes from the dissolved fraction, so it is valid to filter samples and compare the filtered concentration against the trigger value'. Therefore, the bioavailable dissolved fraction of metals/metalloids was used for comparison against the ANZECC (2000) trigger limits.

2.3.1 QA/QC Samples

Sampling for nutrients and metals included collection of QA/QC samples:

- Intra-laboratory duplicates to test for primary laboratory variation - 20% of samples for both baseline and plume monitoring;
- Inter-laboratory duplicates to test for laboratory variation in analyses - 10% of samples for both baseline and plume monitoring;
- Field blanks on sampling equipment to test for potential sample contamination during sampling - One sample for each baseline and plume monitoring; and
- Trip blank in sample bottles to test for potential sample contamination during transport of samples - One sample for each baseline and plume monitoring.

An assessment of all QA/QC data was undertaken and the Relative Percent Difference between samples calculated for both intra- and inter- laboratory samples. The assessment criteria were as follows:

- Intra- and inter-laboratory duplicate samples should ideally agree within ±50%. It is, however, noted that this may not always the case, e.g. in case of concentrations measured close to the LOR. Small differences in concentrations close to the LOR can lead to relatively large changes in the RPD; and
- Field and trip blank sample concentrations should be at or near the detection limit of the method used.

2.4 Presentation of Results

2.4.1 ADCP Data

Figure 2-3 is an example plot demonstrating how the sediment plume measurement results have been presented in this report. The plots are comprised of two components, an upper and a lower component. The upper component is a profile-view of the ADCP transect which depicts the TSS concentrations along the transect and down through the water column. The lower component depicts the depth averaged plume concentrations in plan-view along the transect.

The coloured circles in the upper component of Figure 2-3 depict the two OBS profiles performed during the transect. The colour of the circles represents the TSS concentration returned by the OBS which align with those returned by the ADCP. The OBS profiles are plotted directly onto the elevation-chainage axes. As the OBS instrument is lowered down through the water column, a process which can take over a minute, the monitoring vessel often drifts with the wind/currents and hence the chainage along the transect increases with depth. Hence the OBS profiles do not appear vertical. OBS profiles were undertaken on selected transects with the aim to obtain measurements over a broad range of turbidity values to facilitate ADCP data calibration.

The black crosses in the upper component of Figure 2-3 indicate where the YSI water quality instrument was lowered. The YSI profiles in such figures can be linked to those presented in the turbidity and PAR profile plots using the time signature. For instance the YSI profile in Figure 2-3 corresponds to the green lines in Figure 3-13 and Figure 3-14. YSI profiles were taken on transects selected for water quality sampling.

The circular magenta marker in the upper component of Figure 2-3 indicates where the water quality sample for TSS measurements was collected. Water samples over a broad range of TSS concentrations (based on turbidity values) were collected to facilitate calibration of turbidity against TSS. The magenta labels adjacent to the markers are consistent with those which feature in the tables outlining the water quality results. For instance the water quality results corresponding to the magenta marker in Figure 2-3 are tabulated in Table 3-6.

The red 'x' plotted in the lower component of Figure 2-3 identifies the start of the ADCP transect which extends from left to right in the upper profile-view component of the plot. The timing of the measurement within the tidal cycle is depicted in the upper right hand corner of the plot (date shown on x-axis).

The operations of the TSHD *Brisbane* are represented by small coloured squares in the lower component of Figure 2-3. They depict the *Brisbane's* position at the time the transect was conducted and where and how the dredge had been operating for the past 45 minutes. Where the transect has been conducted more than 45 minutes after the TSHD *Brisbane* has departed then no coloured squares are plotted.

The extents of the nearest sensitive marine receptors are also plotted on the lower component of the plots. The patches of red diagonal stripes depict the composite seagrass distribution for 2002-2012 (Davies *et al.* 2013). The patches of dark green with black grass patterns depict the extents of seagrass meadows as of 2012 (Davies *et al.* 2013). The patches of light blue with black dot patterns depict the extents of known reefs (BMT WBM 2013). There are no mapped reef communities in Figure 2-3.

2.4.2 Potential Interferences

ADCP measurements of suspended sediment concentrations can occasionally be compromised by air bubbles generated by the dredger, other vessel traffic and waves. Plankton will also interfere with the ADCP measurements. Air bubbles and plankton reflect the acoustic signal emitted by the ADCP in the same manner as suspended sediments and hence can be erroneously interpreted as plumes of suspended sediments. To avoid any misinterpretation, plots depicting transects where air bubbles and/or plankton has interfered with the acoustic signal have been stamped with a warning. The OBS and YSI instruments are far less susceptible to such interference. There is no interference in Figure 2-3.

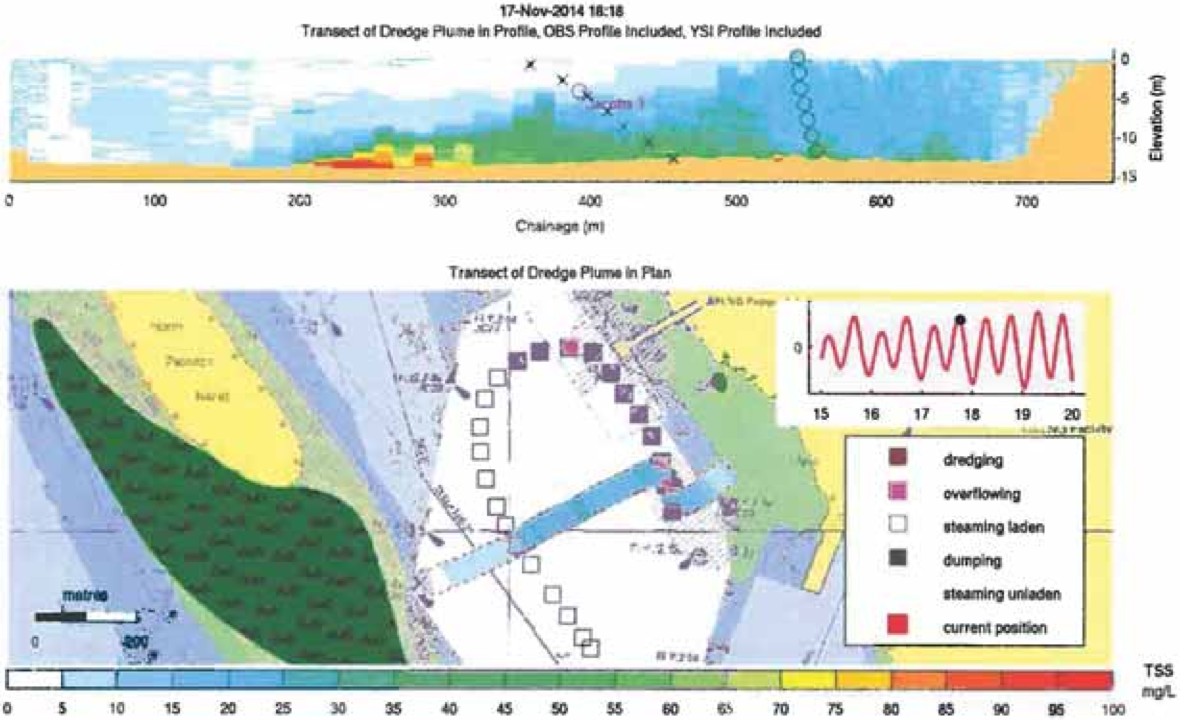

Figure 2-3 Example Figure One[1]

[1] Red hatched areas denote composite seagrass distribution for 2002-2012

3 Results

3.1 Dredging at Gatcombe Channel, Ebb Tide on 16th November 2014

3.1.1 Plume Monitoring

The ADCP measurements of the dredge plumes towards the end of the ebbing tide in the Gatcombe Channel are summarised in Figure 3-1 and Figure 3-2. A complete set of ADCP measurements which also depict the timing and locations of all relevant profiling (OBS and YSI) and water sampling is provided in Appendix E.

Dredging by the TSHD *Brisbane* was conducted on an ebbing tide along the northern toeline of the Gatcombe Channel. The ebb tidal range was approximately 1.4m. The nearest sensitive marine receptors that could potentially be affected on the ebbing tide, include the following:

- Rocky reef areas between Rocky Point and Gatcombe Head on Facing Island, located at varying distances (1.5km - 2.5km) from the east southeast to southeast sectors from the dredging area.
- An intertidal and sub-tidal seagrass community occupying an extensive area east of Boyne Island. The nearest seagrasses near Boyne Island are situated approximately 2.4km west southwest of the dredging area.

Dredging at this location involved the dredger targeting isolated shoals over a channel length no more than 200m. The turbid plume was variable in initial size and suspended solids concentration depending upon whether the dredger was dredging (steaming ahead) or was being manoeuvred astern to reposition itself for another pass over the shoal area. The dredger continued to operate through slack water and into the flooding tide (Section 3.2).

The turbid plume created by dredging and manoeuvring was advected by the ebbing tide in a south-easterly direction almost completely along the channel alignment (towards Buoy G1). Due to the stage of the tide (approaching slack water) the prevailing currents were slow. Subsequently the plume was advected for only 500 metres from the dredging location before reaching background turbidity levels after approximately two hours.

Turbid plumes created by dredging on the ebb tide did not extend to any nearby sensitive marine receptors during the monitoring.

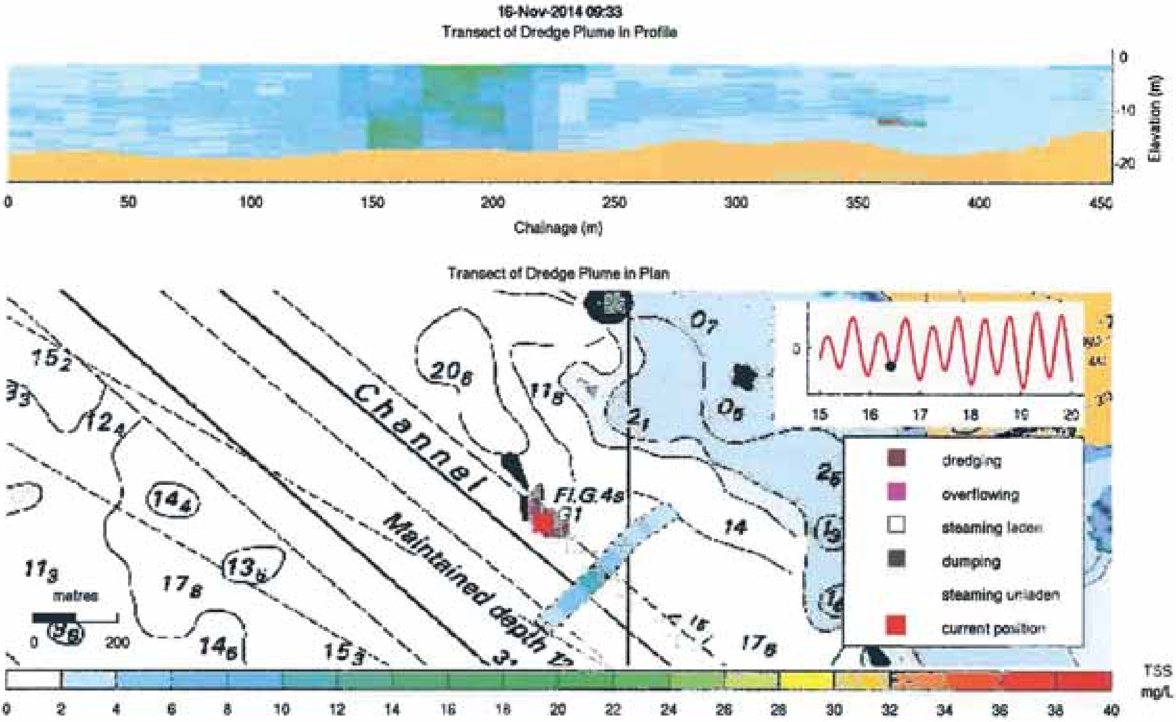

Figure 3-1 Dredging at Gatcombe Channel – Ebb Tide

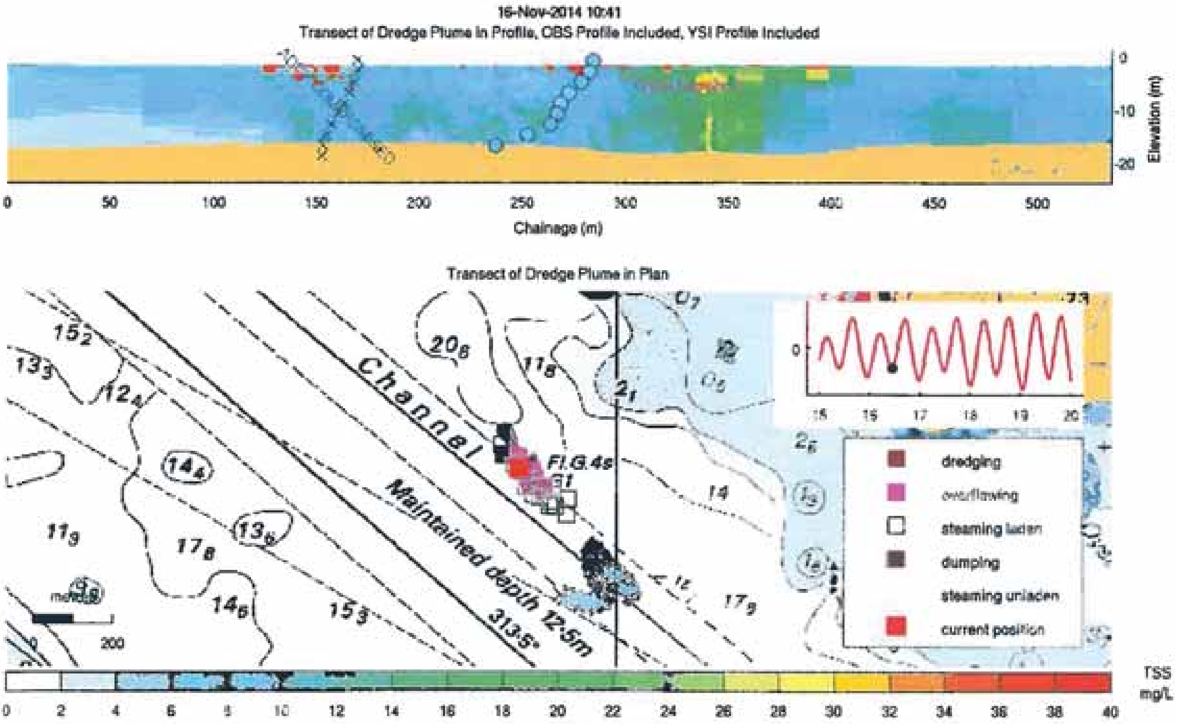

Figure 3-2 Dredging at Gatcombe Channel – Ebb Tide

3.1.2 Water Quality

3.1.2.1 Water Quality Profiles

The measurements for all environmental parameters including those from the baseline assessment are summarised in Table 3-1. Temperature, salinity, pH and dissolved oxygen were relatively constant throughout the water column. The pH sensor failed during the plume measurements at this location. Salinity was slightly higher during the baseline assessment compared to the plume measurements. Dissolved oxygen concentrations were close to saturation for both baseline and plume profiles.

The measured turbidity profiles including that from the baseline assessment are presented in Figure 3-3. The measured turbidity in the baseline profile increased steadily from around 1 NTU at the surface to approximately 5 NTU towards the bed with an average of 4 NTU through the water column. The turbidity was elevated within the dredge plumes compared to baseline with the average water column turbidity ranging between 17 and 29 NTU and a maximum turbidity of 49 NTU measured in the first dredge plume profile.

The measured PAR profiles including that from the baseline assessment are presented in Figure 3-4. Surface light availability was higher in two plume profiles compared to the baseline measurements mainly due to the cloudy conditions during the baseline assessment compared to the sunny conditions during the plume measurements at this location. Light availability was lowest through the water column for the first plume profile, consistent with the high turbidity values measured in this profile. Light availability declined rapidly down the water column with no light available below about 10m water depth for both baseline and plume measurements.

Table 3-1 Water quality profile summary- Gatcombe Channel (ebb)

Gatcombe Channel (ebb)	Parameter	Temp (°C)	Salinity (ppt)	pH	Dissolved Oxygen (%)	Turbidity (NTU)	Light - PAR (µmol m^{-2} s^{-1})
Baseline 2/11/14, 12:57	Min	25.93	38.30	8.05	95.30	1.10	0.10
	Max	26.17	38.57	8.11	99.20	5.70	89.40
	Average	26.09	38.51	8.06	96.95	4.00	11.93
Plume 16/11/14, 9:53	Min	26.37	36.81	-	97.46	0.99	0.00
	Max	26.43	36.98	-	101.68	49.09	159.02
	Average	26.39	36.83	-	98.14	29.32	7.67
Plume 16/11/14, 10:28	Min	26.37	36.82	-	97.62	8.05	0.00
	Max	26.47	36.90	-	100.85	23.48	168.10
	Average	26.39	36.84	-	97.93	17.02	28.39
Plume 16/11/14, 10:42	Min	26.39	36.81	-	97.54	3.52	0.00
	Max	26.43	36.90	-	101.60	63.57	183.03
	Average	26.40	36.84	-	98.10	24.44	27.78

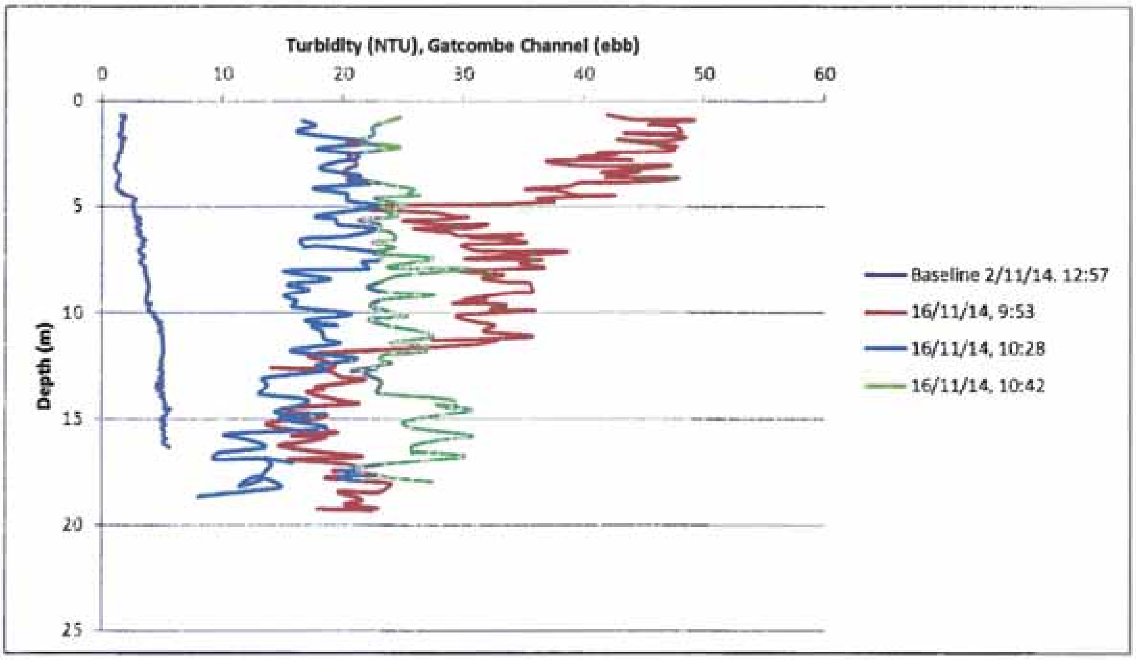

Figure 3-3 Turbidity profiles- Gatcombe Channel (ebb)

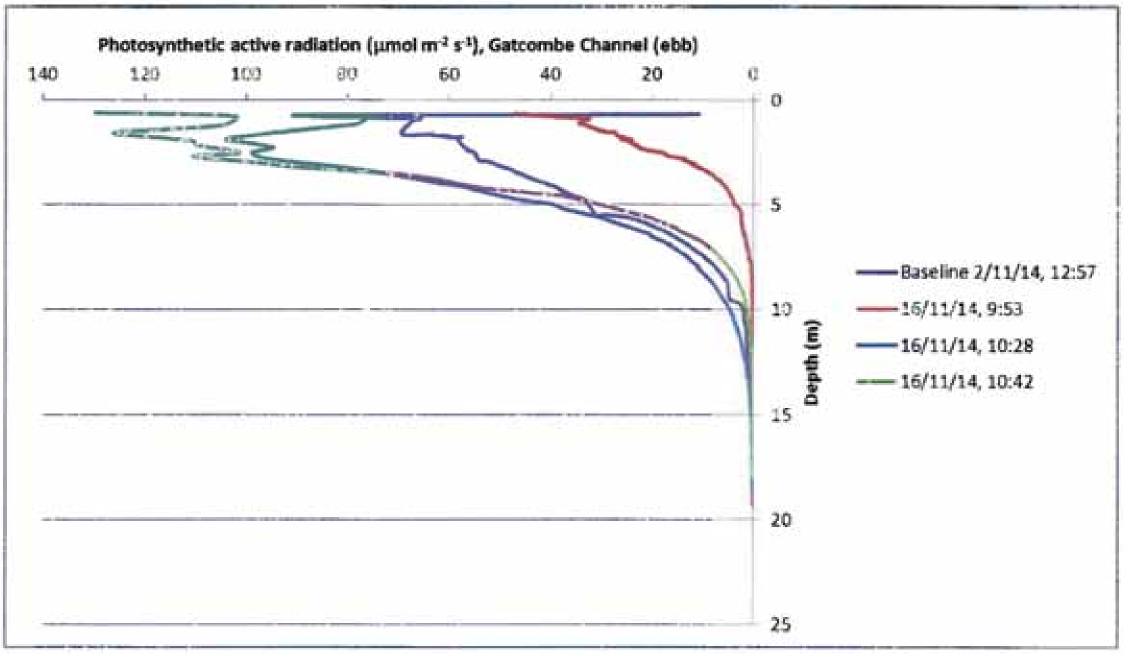

Figure 3-4 PAR profiles- Gatcombe Channel (ebb)

3.1.2.2 Water Quality Grab Samples

Results of the water quality grab sampling for both the baseline and plume monitoring at the Gatcombe Channel during ebb tide are presented in Table 3-2.

As expected, TSS and nutrient concentrations were generally elevated in the plume samples compared to the baseline samples. The reactive phosphorus concentrations exceeded the QWQG limit about four times. Total phosphorus concentrations in the plume samples were up to 2.6 times higher than the QWQG trigger value. It is noted, however, that baseline total phosphorus concentrations also exceeded the QWQG trigger value by a factor of 1.6. Nitrite/nitrate concentrations exceeded or met the QWQG trigger limit in all three plume samples by up to 2 times.

With the exception of one plume sample, TSS concentrations remained below the QWQG trigger value. The chlorophyll *a* concentration exceeded the QWQG value in the bottom baseline sample. Chlorophyll *a* concentrations were below the LOR in all dredge plume samples.

Dissolved metal/metalloid concentrations were either below the LOR or below their respective ANZECC (2000) trigger limits in all samples. Total aluminium, iron and zinc concentrations were elevated in the plume samples compared to the baseline assessment. However, the dissolved fraction of these metals was either below the LOR or similar between baseline and plume measurements.

It is noted that the total chromium concentration in the baseline bottom sample was relatively high (16 µg/L). Similarly, the total zinc concentration in plume sample 1 was 27 µg/L. However, the bioavailable dissolved concentrations of these samples were well below the respective ANZECC trigger limits.

Table 3-2 Water quality results- Gatcombe Channel (ebb)[2]

Gatcombe Channel Parameter	Unit	LOR	ANZECC /QWQG Trigger	Baseline		Dredge Plume Sampling		
				Top	Bottom	1	2	3
Nutrients, TSS, Chlorophyll								
Total Phosphorus	µg/L	10	20	33	33	53	42	47
Ortho-Phosphorus	µg/L	5	6	<LOR	<LOR	23	21	23
Ammonia-Nitrogen	µg/L	5	8	<LOR	<LOR	<LOR	<LOR	<LOR
Nitrite + Nitrate (as N)	µg/L	2	3	<LOR	<LOR	6	5	3
Total Nitrogen	µg/L	50	200	50	<LOR	70	<LOR	<LOR
Solids (Suspended)	mg/L	2	15	2.1	8.8	10	24	13
Chlorophyll a	µg/L	2	2	1	8.5	<LOR	<LOR	<LOR
Total Organic Carbon	mg/L	0.1	-	2.7	1.8	2.7	2.4	2.9
Metals and Metalloids								
Aluminium (Total)	µg/L	5	-	15	17	140	71	68
Aluminium (Dissolved)	µg/L	5	-	<LOR	12	<LOR	<LOR	<LOR
Arsenic (Total)	µg/L	0.5	-	2.2	2	1.6	1.6	1.5
Arsenic (Dissolved)	µg/L	0.5	-	1.9	2	1.4	1.4	1.5
Cadmium (Total)	µg/L	0.1	-	<LOR	<LOR	<LOR	<LOR	<LOR
Cadmium (Dissolved)	µg/L	0.1	0.7	<LOR	<LOR	<LOR	<LOR	<LOR
Chromium (Total)	µg/L	0.5	-	1.8	16	0.8	0.74	0.85
Chromium (Dissolved)	µg/L	0.5	4.4	1.2	0.82	<LOR	<LOR	<LOR
Copper (Total)	µg/L	0.5	-	1.1	0.8	<LOR	<LOR	<LOR
Copper (Dissolved)	µg/L	0.5	1.3	0.99	0.8	<LOR	<LOR	<LOR
Iron (Total)	µg/L	5	-	20	18	230	120	130
Iron (Dissolved)	µg/L	5	-	<LOR	<LOR	<LOR	<LOR	<LOR
Lead (Total)	µg/L	0.1	-	<LOR	<LOR	0.12	0.15	0.11
Lead (Dissolved)	µg/L	0.1	4.4	<LOR	<LOR	<LOR	<LOR	<LOR
Manganese (Total)	µg/L	0.5	-	4.7	5.2	9.9	7.4	11
Manganese (Dissolved)	µg/L	0.5	-	2.1	2.6	1.4	1.3	1.4
Mercury (Total)	µg/L	0.1	-	<LOR	<LOR	<LOR	<LOR	<LOR
Mercury (Dissolved)	µg/L	0.1	0.1	<LOR	<LOR	<LOR	<LOR	<LOR
Nickel (Total)	µg/L	0.1	-	<LOR	<LOR	0.35	0.27	0.25
Nickel (Dissolved)	µg/L	0.1	7	<LOR	<LOR	0.2	0.13	0.24
Silver (Total)	µg/L	0.1	-	<LOR	<LOR	<LOR	<LOR	<LOR
Silver (Dissolved)	µg/L	0.1	1.4	<LOR	<LOR	<LOR	<LOR	<LOR
Zinc (Total)	µg/L	0.5	-	1.5	0.52	27	3.2	2
Zinc (Dissolved)	µg/L	0.5	15	1.5	<LOR	1.1	1.3	1.9

[2] Orange shading = guideline limit met or exceeded; green shading = concentration below the laboratory limit of reporting (LOR)

3.2 Dredging at Gatcombe Channel, Flood Tide on 16th November 2014

3.2.1 Plume Monitoring

The ADCP measurements of the dredge plumes during a flooding tide in the Gatcombe Channel are summarised in Figure 3-5 and Figure 3-6. A complete set of ADCP measurements which also depict the timing and locations of all relevant profiling (OBS and YSI) and water sampling is provided in Appendix B.

Dredging by TSHD *Brisbane* was conducted during flooding tides along the northern toe line of the Gatcombe Channel. The flood tidal range was of approximately 1.7m range. The nearest sensitive marine communities which could be potentially affected on the flood tide consisted of the following:

- Bushy Islet, She Oak Island, Manning Reef and Observation Point on Facing Island, located at varying distances from the northeast to northwest sectors from the dredging area. Manning Reef, with an assemblage of hard corals and macro algae (BMT WBM, 2009) was the closest sensitive receptor site, located approximately 1.3km northeast of the dredging area.
- An intertidal and sub-tidal seagrass community occupying an extensive area on North Bank, adjoining Quoin Island. The nearest seagrasses at North Banks are situated approximately 5.4km northwest of the dredging area.

Dredging at this location involved the dredger targeting isolated shoals over a channel length no more than 200m. The dredger therefore manoeuvred forward and astern many times over the same area, which resulted in a turbid plume which was quite variable in its initial suspended solids concentration. The plume turbidity and initial size was dependent upon whether the dredger was dredging (steaming ahead) or was being manoeuvred astern to reposition itself for another pass over the shoal area.

The turbid plume created by dredging and manoeuvring was advected by the flooding tide in a north-westerly direction mainly along the channel (towards Quoin Island) with some displacement over and beyond the northern edge of the channel into the South Trees ship anchorage area and towards Manning Reef. Figure 3-6 depicts a plume discernible above background levels over 3.2km from the dredging site. Despite being discernible above background levels the concentrations within the plume were so low (approximately 5 mg/L) that impacts to any sensitive receptors on Manning Reef are considered highly unlikely. The plume would not have reached the seagrass communities on North Banks.

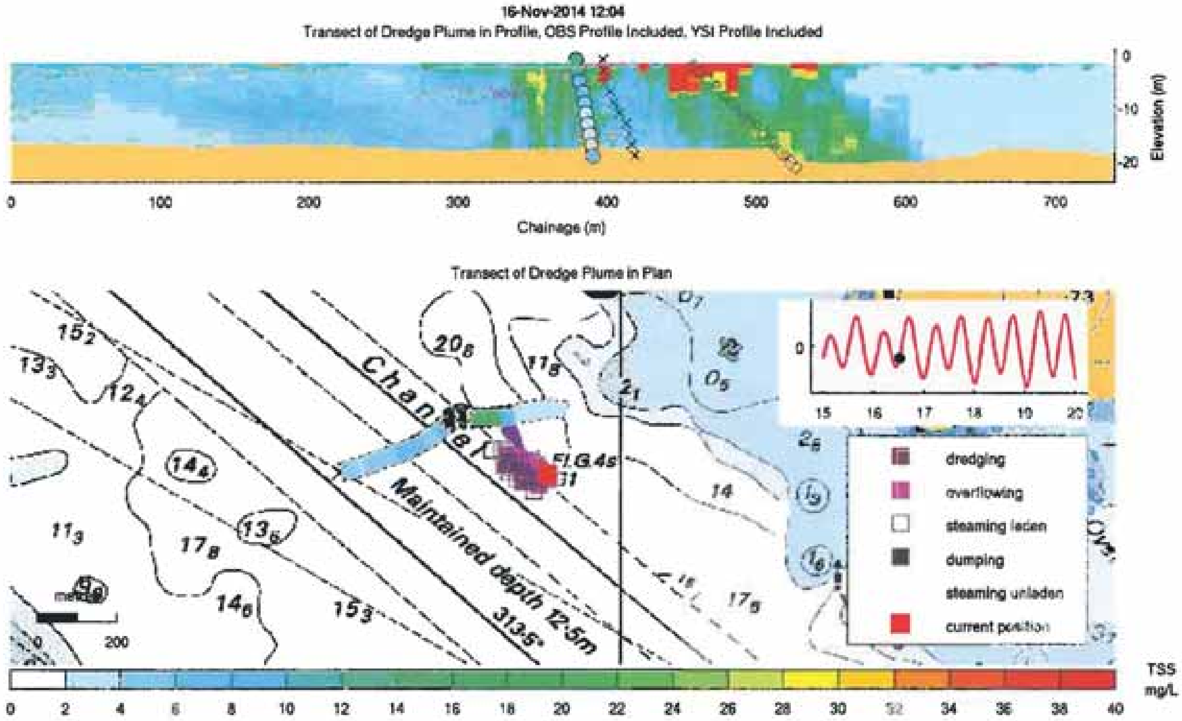

Figure 3-5 Dredging at Gatcombe Channel – flood tide

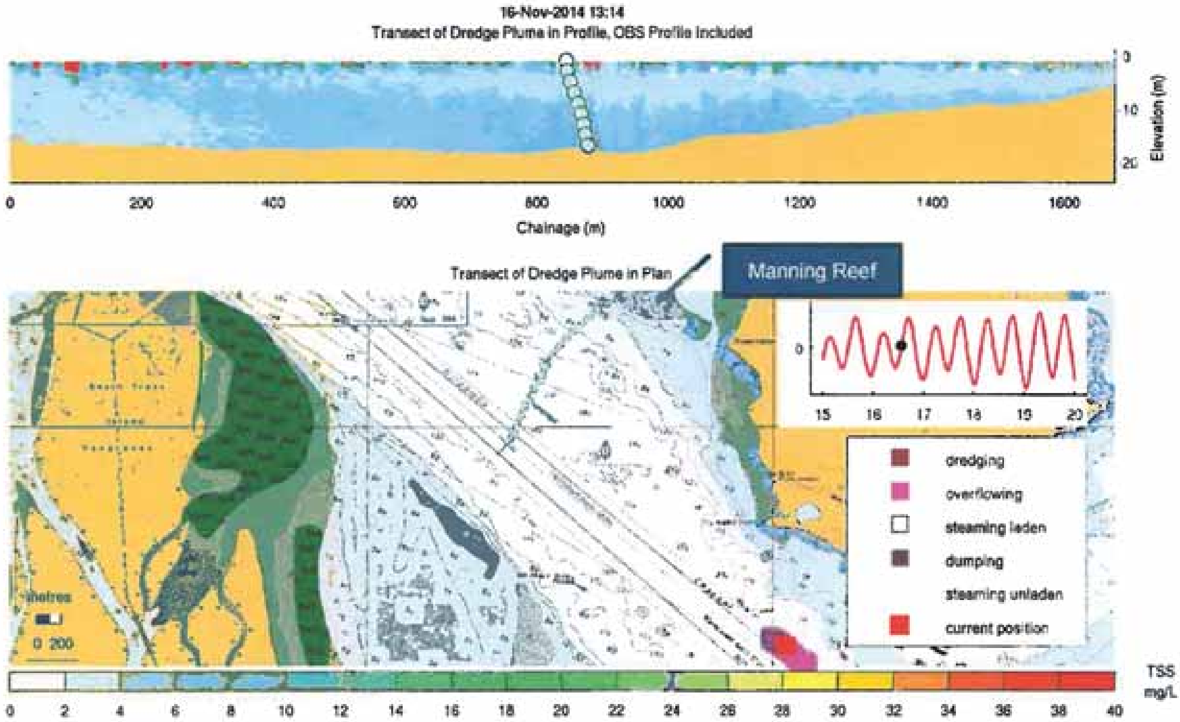

Figure 3-6 Dredging at Gatcombe Channel – flood tide

3.2.2 Water Quality

3.2.2.1 Water Quality Profiles

The water quality profile data for the flood tide Gatcombe Channel measurements are summarised in Table 3-3.

Temperature, salinity, pH and dissolved oxygen were relatively constant through the water column. The pH sensor failed during the plume measurements at this location. Salinity was slightly higher during the baseline assessment compared to the plume measurements. Dissolved oxygen concentrations were close to saturation for both baseline and plume profiles.

The measured turbidity profiles are presented in Figure 3-7. Turbidity was elevated within the dredge plumes compared to baseline with the average water column turbidity ranging between 15 and 25 NTU. Maximum turbidity values were about 40-50 NTU in surface waters for the last two plume profiles. Baseline average and maximum turbidity was 4.0 NTU and 5.7 NTU, respectively.

The measured PAR profiles including that from the baseline assessment are presented in Figure 3-8. Surface light availability was higher in all plume profiles compared to the baseline measurements due to the cloudy conditions during the baseline assessment. Light availability diminished rapidly with depth with no light available at about 5 to 8m water depth during the plume assessment. This was comparable to baseline light availability under cloudy conditions. The measurements of light availability were consistent with the turbidity measurements for the respective plume profiles.

Table 3-3 Water quality profile summary- Gatcombe Channel (flood)

Gatcombe Channel (flood)	Parameter	Temp (°C)	Salinity (ppt)	pH	Dissolved Oxygen (%)	Turbidity (NTU)	Light - PAR (µmol m⁻² s⁻¹)
Baseline 2/11/14, 12:57	Min	25.93	38.30	8.05	95.30	1.10	0.10
	Max	26.17	38.57	8.11	99.20	5.70	89.40
	Average	26.09	38.51	8.06	96.95	4.00	11.93
Plume 16/11/14, 11:49	Min	26.42	36.82	-	98.07	1.92	0.00
	Max	26.60	36.94	-	99.17	20.87	893.69
	Average	26.48	36.88	-	97.17	15.53	51.07
Plume 16/11/14, 12:02	Min	26.39	36.83	-	97.47	12.52	0.00
	Max	26.58	36.86	-	100.01	49.53	545.28
	Average	26.48	36.84	-	98.86	25.12	20.71
Plume 16/11/14,	Min	26.43	36.78	-	98.05	9.09	0.00
	Max	26.49	36.84	-	100.02	45.87	463.46
	Average	26.46	36.80	-	99.16	23.96	15.31

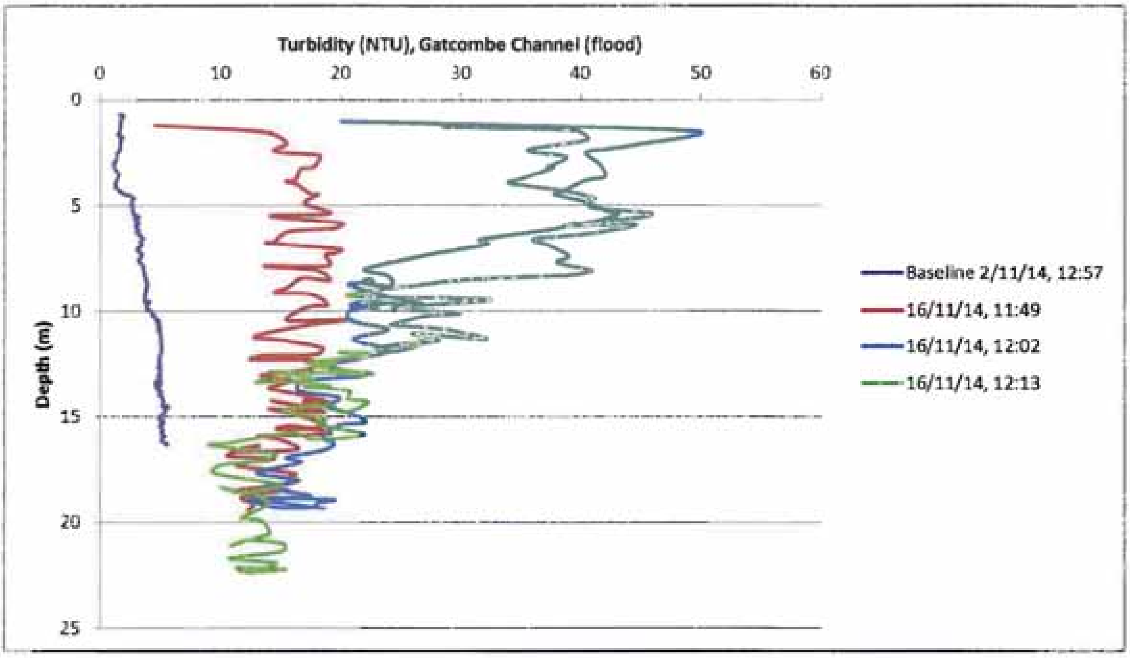

Figure 3-7 Turbidity profiles- Gatcombe Channel (flood)

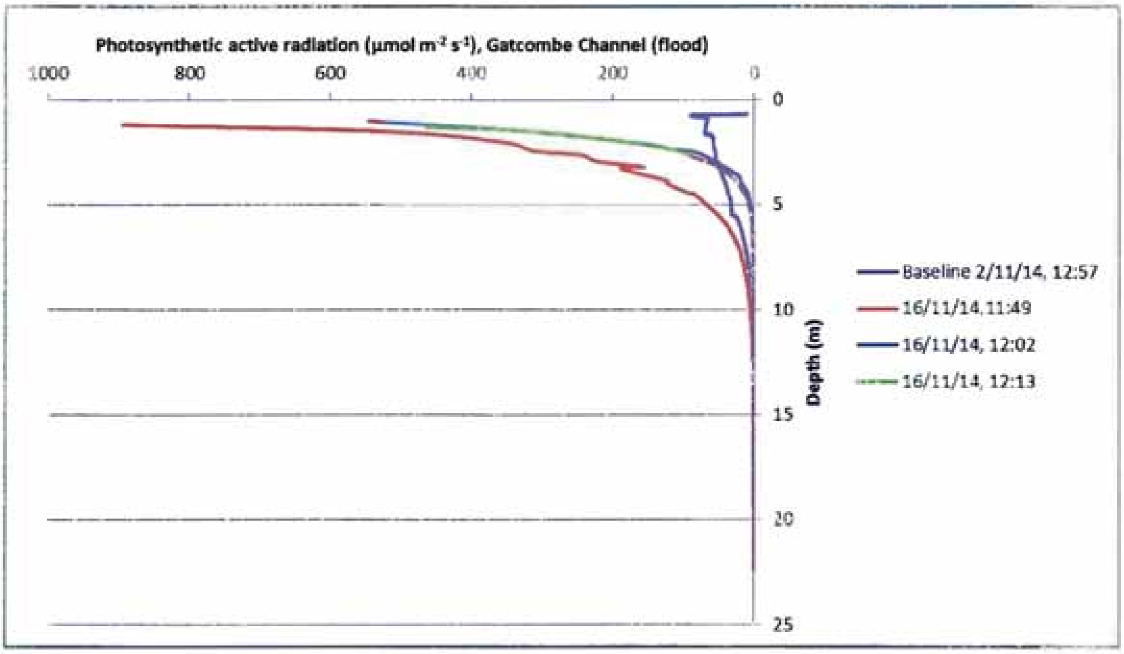

Figure 3-8 PAR profiles- Gatcombe Channel (flood)

3.2.2.2 Water Quality Grab Samples

Results of the water quality grab sampling for both the baseline and plume monitoring at the Gatcombe Channel during a flooding tide are presented in Table 3-4.

As expected, TSS and nutrient concentrations were generally elevated in the plume samples compared to the baseline samples. The reactive phosphorus concentrations exceeded the QWQG limit up to 4.5 times. Total phosphorus concentrations exceeded the QWQG trigger limit 1.6 times in the baseline samples and up to 2.8 times in the plume samples. The concentration of nitrite/nitrate exceeded the QWQG trigger limit between 3 and 46 times in the first two plume samples but was below the LOR in the third plume sample.

TSS concentrations exceeded the QWQG trigger value in two plume samples. The chlorophyll *a* concentration exceeded the QWQG value in the bottom baseline sample. Chlorophyll *a* concentrations were below the LOR in all dredge plume samples.

Total concentrations of aluminium, iron and to a lesser extent manganese and zinc were elevated in the plume samples compared to the baseline assessment. However, the dissolved fraction of these metals was either below the LOR or similar between baseline and plume measurements. Dissolved metal/metalloid concentrations were either below the LOR or below their respective ANZECC (2000) trigger limits in all baseline and plume samples.

Table 3-4 Water quality results- Gatcombe Channel (flood)[3]

Parameter	Unit	LOR	ANZECC /QWQG Trigger	Baseline		Dredge Plume Sampling		
				Top	Bottom	1	2	3
Nutrients, TSS, Chlorophyll								
Total Phosphorus	µg/L	10	20	33	33	37	43	56
Ortho-Phosphorus	µg/L	5	6	<LOR	<LOR	18	20	27
Ammonia-Nitrogen	µg/L	5	8	<LOR	<LOR	<LOR	<LOR	<LOR
Nitrite + Nitrate (as N)	µg/L	2	3	<LOR	<LOR	140	9	<LOR
Total Nitrogen	µg/L	50	200	50	<LOR	160	<LOR	84
Solids (Suspended)	mg/L	2	15	2.1	8.8	19	25	13
Chlorophyll a	µg/L	2	2	1	8.5	<LOR	<LOR	<LOR
Total Organic Carbon	mg/L	0.1	-	2.7	1.8	3.3	3.2	3.3
Metals and Metalloids								
Aluminium (Total)	µg/L	5	-	15	17	56	95	200
Aluminium (Dissolved)	µg/L	5	-	<LOR	12	<LOR	<LOR	<LOR
Arsenic (Total)	µg/L	0.5	-	2.2	2	1.6	1.5	1.7
Arsenic (Dissolved)	µg/L	0.5	-	1.9	2	1.1	1.5	1.3
Cadmium (Total)	µg/L	0.1	-	<LOR	<LOR	<LOR	<LOR	<LOR
Cadmium (Dissolved)	µg/L	0.1	0.7	<LOR	<LOR	<LOR	<LOR	<LOR
Chromium (Total)	µg/L	0.5	-	1.8	16	0.71	0.88	0.88
Chromium (Dissolved)	µg/L	0.5	4.4	1.2	0.82	<LOR	<LOR	<LOR
Copper (Total)	µg/L	0.5	-	1.1	0.8	<LOR	<LOR	<LOR
Copper (Dissolved)	µg/L	0.5	1.3	0.99	0.8	<LOR	<LOR	<LOR
Iron (Total)	µg/L	5	-	20	18	93	81	190
Iron (Dissolved)	µg/L	5	-	<LOR	<LOR	<LOR	<LOR	<LOR
Lead (Total)	µg/L	0.1	-	<LOR	<LOR	<LOR	0.1	<LOR
Lead (Dissolved)	µg/L	0.1	4.4	<LOR	<LOR	<LOR	<LOR	<LOR
Manganese (Total)	µg/L	0.5	-	4.7	5.2	6.7	5.6	5.9
Manganese (Dissolved)	µg/L	0.5	-	2.1	2.6	0.84	1.2	1.5
Mercury (Total)	µg/L	0.1	-	<LOR	<LOR	<LOR	<LOR	<LOR
Mercury (Dissolved)	µg/L	0.1	0.1	<LOR	<LOR	<LOR	<LOR	<LOR
Nickel (Total)	µg/L	0.1	-	<LOR	<LOR	0.79	0.46	0.46
Nickel (Dissolved)	µg/L	0.1	7	<LOR	<LOR	0.28	0.32	0.34
Silver (Total)	µg/L	0.1	-	<LOR	<LOR	<LOR	<LOR	<LOR
Silver (Dissolved)	µg/L	0.1	1.4	<LOR	<LOR	<LOR	<LOR	<LOR
Zinc (Total)	µg/L	0.5	-	1.5	0.52	2.9	2	2.2
Zinc (Dissolved)	µg/L	0.5	15	1.5	<LOR	1.5	1.2	0.54

[3] Orange shading = guideline limit met or exceeded; green shading = concentration below the laboratory limit of reporting (LOR)

3.3 Dredging at Jacobs Channel, Ebb Tide on 17th November 2014

3.3.1 Plume Monitoring

The ADCP measurements of the dredge plumes in Jacobs Channel are summarised in Figure 3-9 to Figure 3-12. A complete set of ADCP measurements which also depict the timing and locations of all relevant profiling (OBS and YSI) and water sampling is provided in Appendix G.

Dredging by TSHD *Brisbane* was conducted over slack water and into an ebbing tide within the swing basin adjacent to the APLNG gas loading wharf in Jacobs Channel. The ebb tidal range was approximately 2.4m.

The nearest sensitive marine communities that could potentially be affected on the ebbing tide, were intertidal and sub-tidal seagrass communities on the banks of both North and South Passage Islands and the banks along the western coast of Curtis Island. The seagrass meadows mapped within the APLNG dredged facilities (Figure 3-9) no longer exist due to capital development of the area.

The *Brisbane* entered the Swing Basin from the South with lowered drag heads, making a first pass of the berth area. The dredger made two more equivalent passes of approximately 400m before departing for the EBSDS.

A series of plumes were generated with each pass of the dredger and advected southwards with the ebbing tide. The majority of the plume sediments remained within the deeper sections of Jacobs Channel spreading out across its width and remaining near the bed. A smaller proportion of the suspended sediments passed over the spur separating the APLNG swing basin from the QCLNG materials offloading facility (MOF). Despite the plumes extending to the Western edge of the channel they did not breach its confines and hence impinge on any of the seagrass communities on the banks of the Passage Islands. The sediments which passed into the MOF continued to advect southwards in the prevailing currents along the Curtis Island shoreline where shallow water depth restricted direct measurement to determine whether these dredge related sediments passed over previously mapped meadows close to Curtis Island. It is noted that Bryant et al. (2014) have not detected seagrass in this area in 2013.

The dredge plume was still discernible above background levels two hours from the cessation of dredging works by which time it had advected over 3 km down Jacobs Channel. The longevity of the plume is reflective of the fine sediments that were being dredged in the swing basin during this campaign.

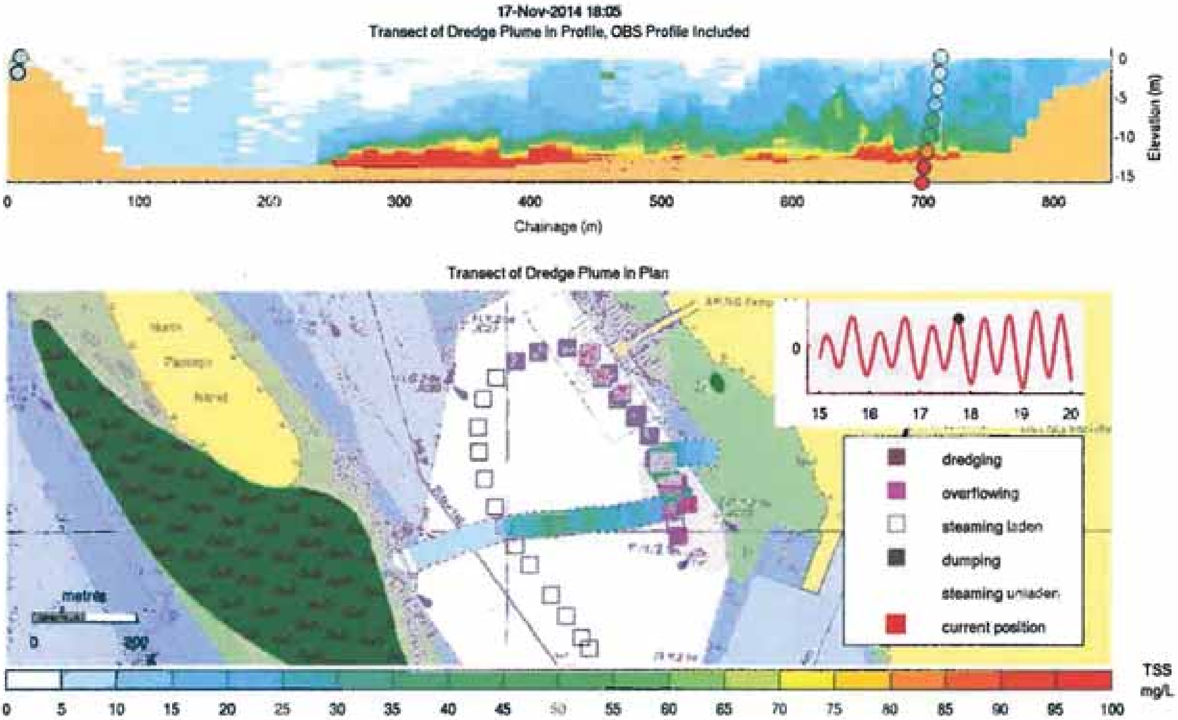

Figure 3-9 Dredging at Jacobs Channel – ebb tide

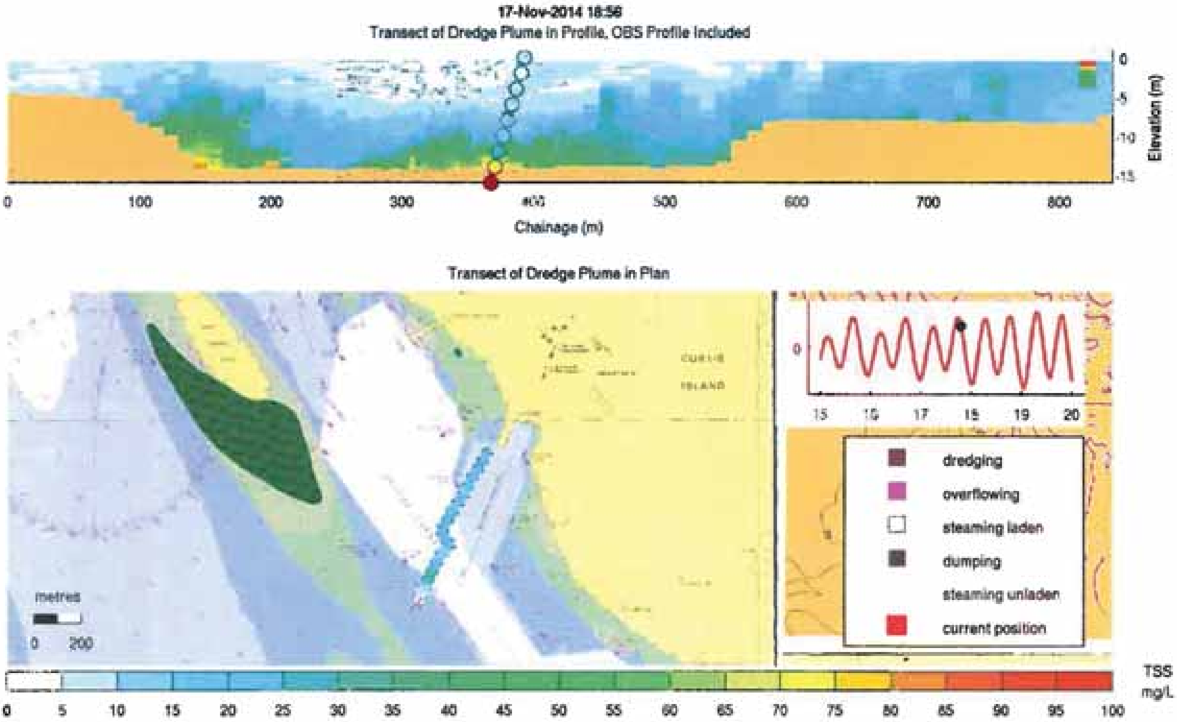

Figure 3-10 Dredging at Jacobs Channel – ebb tide

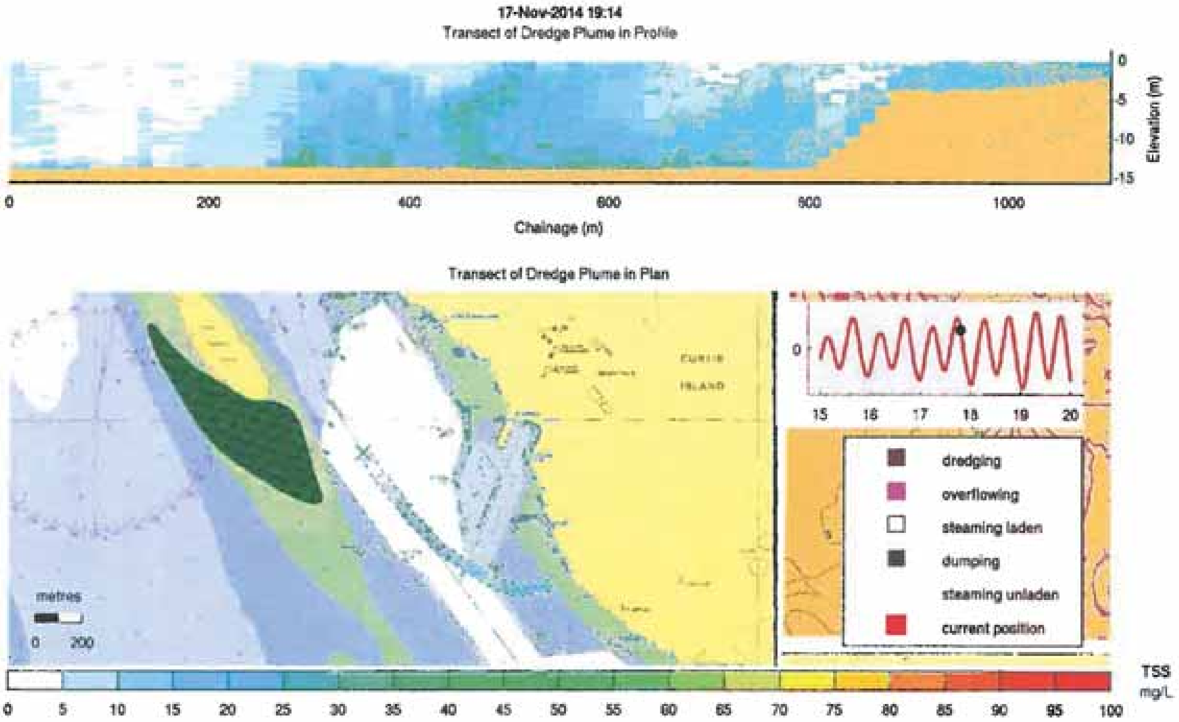

Figure 3-11 Dredging at Jacobs Channel – ebb tide

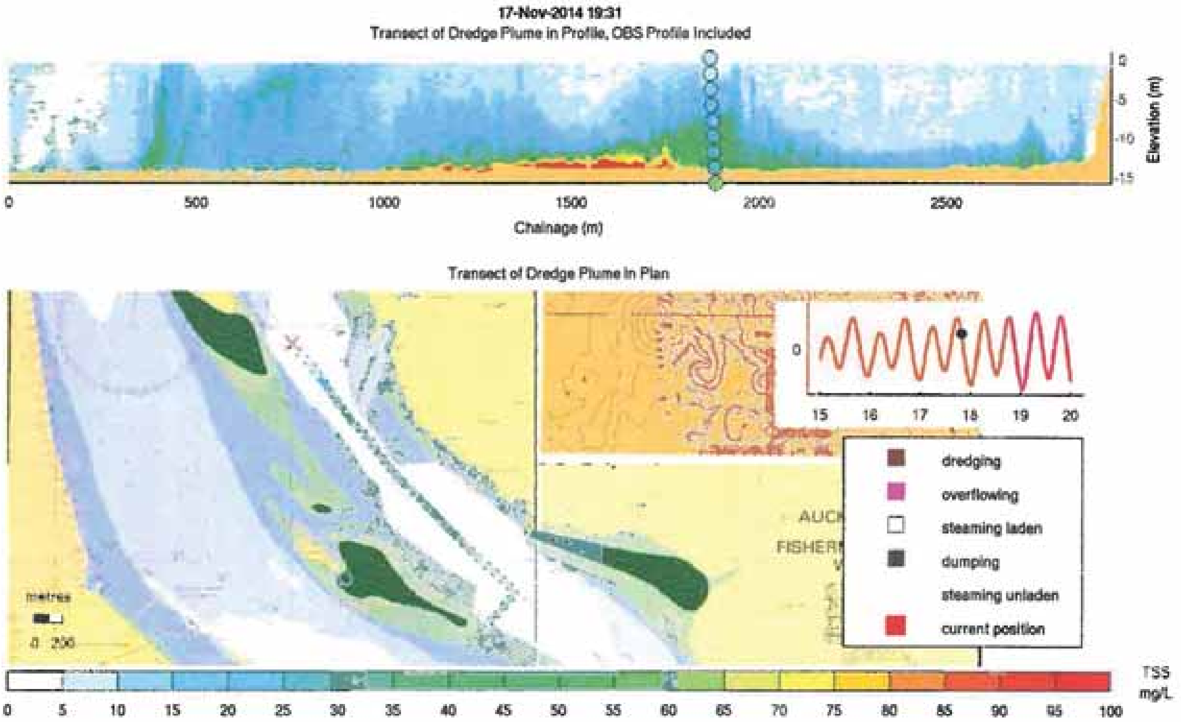

Figure 3-12 Dredging at Jacobs Channel – ebb tide

3.3.2 Water Quality

3.3.2.1 Water Quality Profiles

Table 3-5 shows the ebb tide Jacobs Channel profile data. Temperature, salinity, pH and dissolved oxygen were relatively constant through the water column. Dissolved oxygen concentrations were close to saturation (90%-95%) for both baseline and plume profiles.

The measured turbidity profiles are presented in Figure 3-13. Turbidity was elevated within the dredge plumes compared to baseline with the average water column turbidity ranging between 13 and 39 NTU compared to an average of 6 NTU for the baseline assessment. Maximum turbidity values up to 75 NTU were typically recorded close to the seafloor in the plume profiles shortly after dredging.

The measured PAR profiles including that from the baseline assessment are presented in Figure 3-14. Surface light availability was lower in all plume profiles compared to the baseline measurements. While it was sunny during both baseline and plume measurements, it is noted that the plume light profiles were taken in the late afternoon hours compared to early afternoon for the baseline measurements. Light availability diminished rapidly with depth with maximum light penetration down to 2 m water depth during the plume assessment. Light penetrated down to about 9m water depth during the baseline assessment.

Table 3-5 Water quality profile summary-Jacobs Channel

Jacobs Channel	Parameter	Temp (°C)	Salinity (ppt)	pH	Dissolved Oxygen (%)	Turbidity (NTU)	Light - PAR (μmol m^{-2} s^{-1})
Baseline 2/11/14, 14:22	Min	26.91	38.94	7.96	91.90	3.90	0.00
	Max	27.34	38.99	7.98	96.90	15.40	288.10
	Average	27.09	38.96	7.97	94.32	6.06	43.75
Plume 17/11/14, 17:37	Min	27.66	38.39	8.01	87.90	5.00	0.00
	Max	27.84	38.55	8.12	95.50	75.60	211.03
	Average	27.77	38.44	8.03	90.94	39.25	6.80
Plume 17/11/14, 17:53	Min	27.32	38.38	7.99	88.00	14.50	0.01
	Max	27.82	38.78	8.03	94.40	65.30	31.20
	Average	27.77	38.41	8.02	91.13	21.27	1.76
Plume 17/11/14, 18:15	Min	27.09	38.31	8.01	89.20	5.00	0.00
	Max	27.84	38.90	8.10	95.60	33.00	6.97
	Average	27.80	38.36	8.04	92.56	13.77	0.51

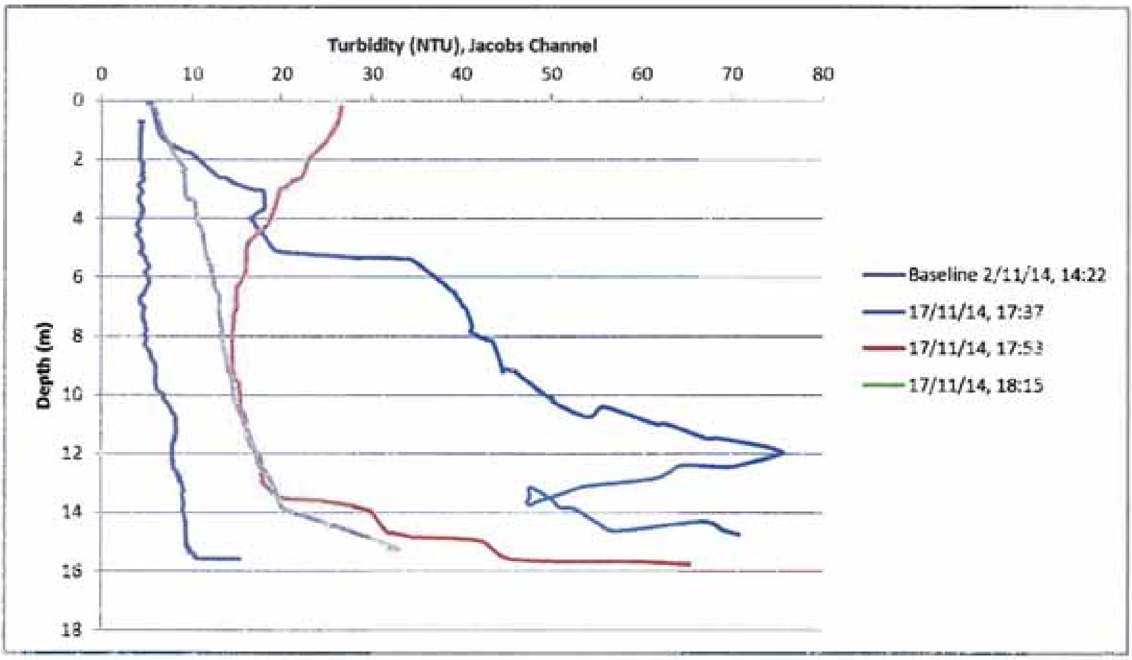

Figure 3-13 Turbidity profiles- Jacobs Channel

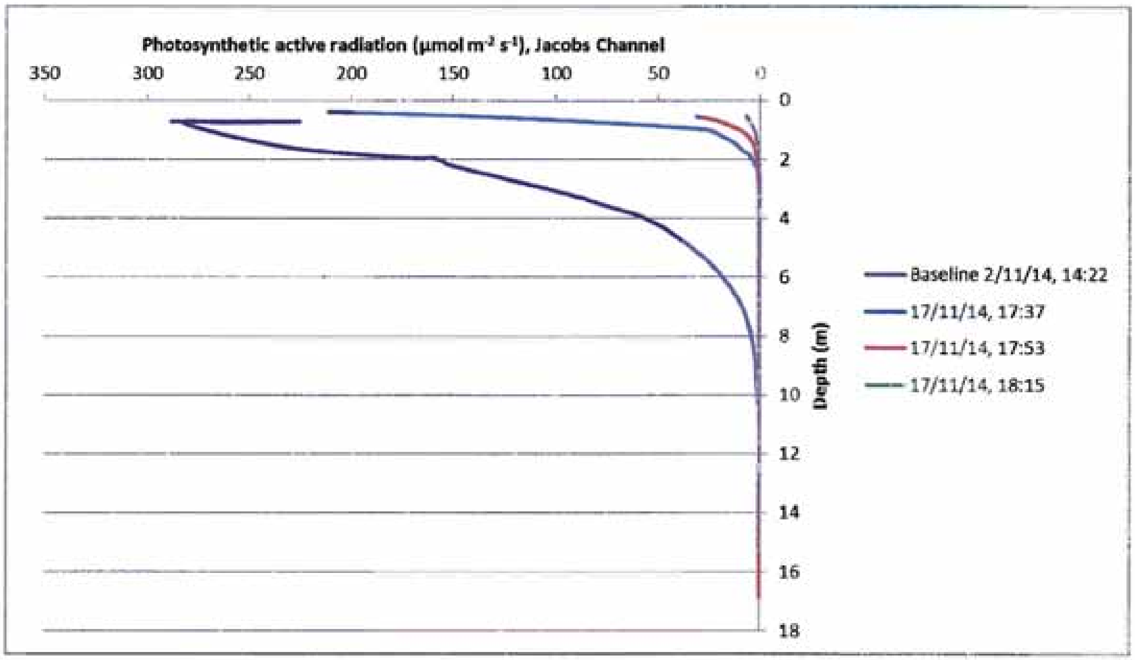

Figure 3-14 PAR profiles- Jacobs Channel

3.3.2.2 Water Quality Grab Samples

The water quality grab sampling results for the ebb tide Jacobs Channel measurements are presented in Table 3-6.

Nutrient and TSS concentrations were generally elevated in the plume samples compared to the baseline measurements. Total and reactive phosphorus concentrations exceeded the QWQG limit in both plume and baseline samples. Nitrite + nitrate concentrations exceeded the QWQG limit 7 to 40 times in the plume samples whilst concentrations were below the LOR in the baseline samples. The QWQG limit of 200 µg/L for total nitrogen was met in the first plume sample. Furthermore, TSS concentrations exceeded the QWQG limit in the first two plume samples. Whilst chlorophyll *a* concentrations were below the LOR in all three plume samples, the QWQG limit for chlorophyll *a* was exceeded up to 5.5 times in the two baseline samples.

Dissolved metal/metalloid concentrations were either below the LOR or below their respective ANZECC (2000) trigger limits in all baseline and plume samples. Total concentrations of aluminium, iron and to a lesser extent manganese and zinc were elevated in the plume samples compared to the baseline assessment. However, the dissolved fraction of these metals was either below the LOR or similar between baseline and plume measurements.

Table 3-6 Water quality results-Jacobs Channel[4]

Parameter	Unit	LOR	ANZECC /QWQG Trigger	Baseline		Dredge Plume Sampling		
				Top	Bottom	1	2	3
Nutrients, TSS, Chlorophyll								
Total Phosphorus	µg/L	10	20	36	37	54	50	55
Ortho-Phosphorus	µg/L	5	6	8	9	31	42	27
Ammonia-Nitrogen	µg/L	5	8	<LOR	<LOR	<LOR	<LOR	<LOR
Nitrite + Nitrate (as N)	µg/L	2	3	<LOR	<LOR	120	20	30
Total Nitrogen	µg/L	50	200	<LOR	<LOR	200	56	170
Solids (Suspended)	mg/L	2	15	<LOR	<LOR	26	47	9
Chlorophyll a	µg/L	2	2	8.5	11	<LOR	<LOR	<LOR
Total Organic Carbon	mg/L	0.1	-	2.5	3.2	3.6	2.5	3.4
Metals and Metalloids								
Aluminium (Total)	µg/L	5	-	33	41	29	520	150
Aluminium (Dissolved)	µg/L	5	-	5.2	7.6	7.6	<LOR	<LOR
Arsenic (Total)	µg/L	0.5	-	1.8	1.9	1.4	1.7	1.4
Arsenic (Dissolved)	µg/L	0.5	-	1.7	1.6	1.2	1.1	1.1
Cadmium (Total)	µg/L	0.1	-	<LOR	<LOR	<LOR	<LOR	<LOR
Cadmium (Dissolved)	µg/L	0.1	0.7	<LOR	<LOR	<LOR	<LOR	<LOR
Chromium (Total)	µg/L	0.5	-	1.9	1.2	0.52	1.2	1.1
Chromium (Dissolved)	µg/L	0.5	4.4	0.98	0.82	<LOR	<LOR	<LOR
Copper (Total)	µg/L	0.5	-	1.2	1.2	0.76	1.1	0.89
Copper (Dissolved)	µg/L	0.5	1.3	1.1	1	0.57	<LOR	<LOR
Iron (Total)	µg/L	5	-	48	56	<LOR	470	140
Iron (Dissolved)	µg/L	5	-	<LOR	<LOR	<LOR	<LOR	<LOR
Lead (Total)	µg/L	0.1	-	0.13	0.17	<LOR	0.19	<LOR
Lead (Dissolved)	µg/L	0.1	4.4	<LOR	<LOR	<LOR	<LOR	<LOR
Manganese (Total)	µg/L	0.5	-	8.8	11	4.9	18	9
Manganese (Dissolved)	µg/L	0.5	-	3.3	2.9	4.2	3.9	2.4
Mercury (Total)	µg/L	0.1	-	0.1	<LOR	<LOR	<LOR	<LOR
Mercury (Dissolved)	µg/L	0.1	0.1	<LOR	<LOR	<LOR	<LOR	<LOR
Nickel (Total)	µg/L	0.1	-	0.33	0.36	0.66	1	0.65
Nickel (Dissolved)	µg/L	0.1	7	<LOR	0.26	0.61	0.4	0.32
Silver (Total)	µg/L	0.1	-	<LOR	<LOR	<LOR	<LOR	<LOR
Silver (Dissolved)	µg/L	0.1	1.4	<LOR	<LOR	<LOR	<LOR	<LOR
Zinc (Total)	µg/L	0.5	-	<LOR	3.6	2.4	2.5	9.5
Zinc (Dissolved)	µg/L	0.5	15	<LOR	1.4	1.7	1.3	2.6

[4] Orange shading = guideline limit met or exceeded; green shading = concentration below the laboratory limit of reporting (LOR)

3.4 Dredging at Golding Cutting, Flood Tide on 18th November 2014

3.4.1 Plume Monitoring

The ADCP measurements of the dredge plumes during a flood tide in the Golding Cutting are summarised in Figure 3-15 to Figure 3-18. A complete set of ADCP measurements which also depict the timing and locations of all relevant profiling (OBS and YSI) and water sampling is provided in Appendix H.

Dredging by TSHD *Brisbane* was conducted during slack water and into a flooding tide along the southern toe line of the Golding Cutting. The flood tidal range was approximately 2.3m. The nearest sensitive marine receptors potentially affected on the flooding tide consisted of the following:

- A deep water seagrass meadow (mapped in 2002 but not present in 2009 and 2013 [Thomas *et al.* 2010, Bryant *et al.* 2014]) which adjoins the Golding Cutting and dredging area.[5] Whilst no seagrass has been detected in this area in recent years, past studies have shown that this site can support seagrass. It is therefore considered a potential sensitive receptor site.

The TSHD *Brisbane* made a single inbound pass before turning and steaming loaded for the EBSDS. Hence a single long plume was generated. The plume advected within the gently flooding currents in a north-westerly direction along the channel (towards Boyne Island) and beyond the western edge of the main channel into the Golding Bypass channel. Plumes were still visible above background levels one hour after the cessation of dredging over a distance of about 800 m.

Turbid plumes created by dredging did extend within the boundary of a potential sensitive marine receptor. The plume component displaced west of the main Golding Channel was advected within the deep water seagrass habitat located west of the Golding Cutting and the associated bypass channel, extending as much as several hundred metres into the seagrass community. By the time the plume had advected beyond the bypass channel the concentrations were below 10 mg/L and unlikely to impact on any existing seagrass communities.

[5] A small rocky reef community was mapped on East Banks (GBRMPA 2014), approximately 3.7km northwest of the dredging area. Surveys in 2014 that this reef does not support coral or high density benthic assemblages and on this basis is not considered to represent a sensitive ecological receptor site (BMT WBM 2014a)

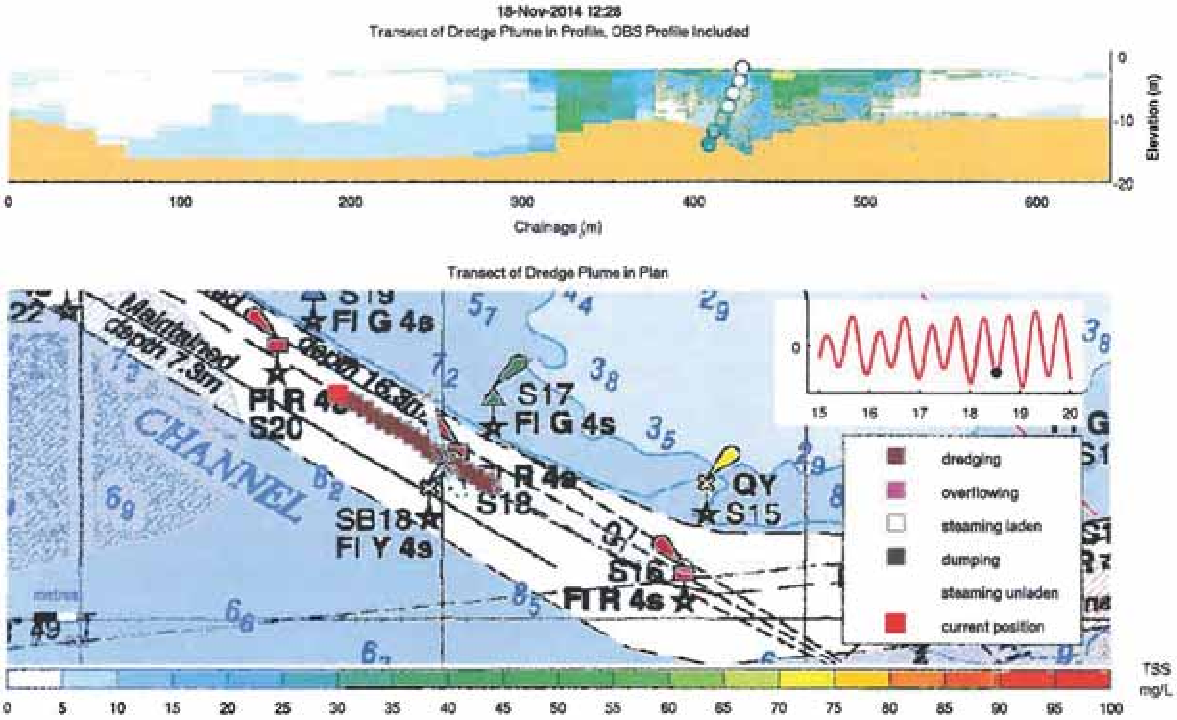

Figure 3-15 Dredging at Golding Cutting – flood tide

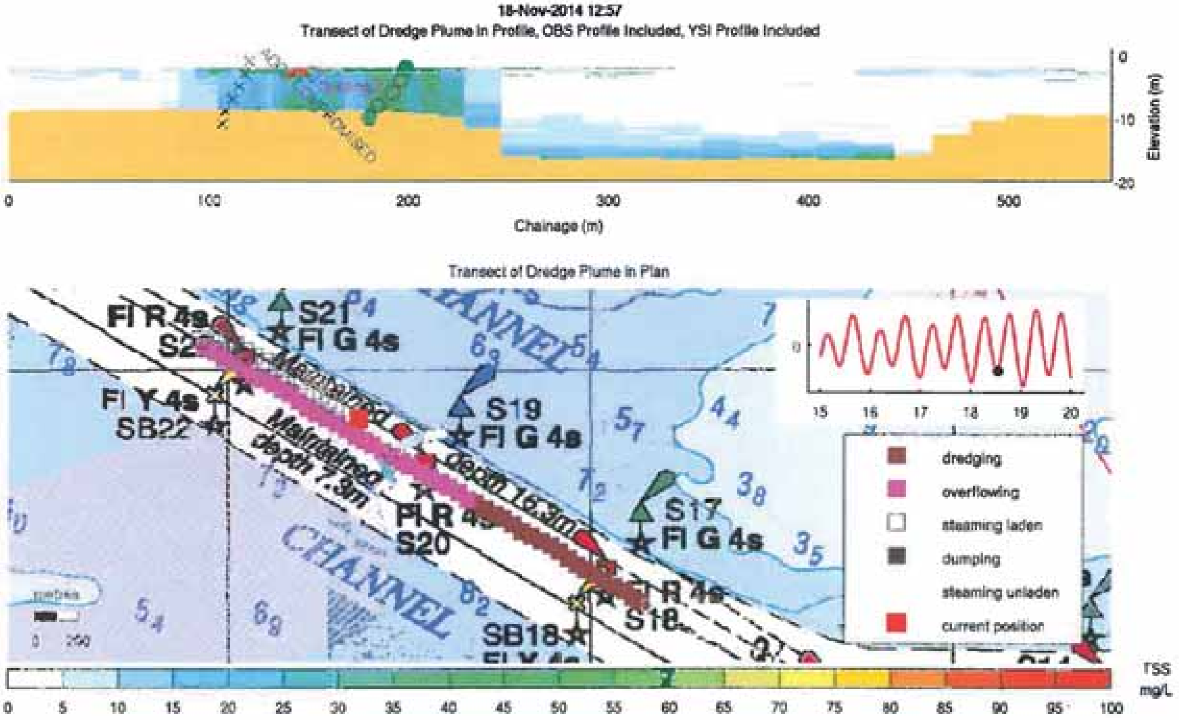

Figure 3-16 Dredging at Golding Cutting – flood tide

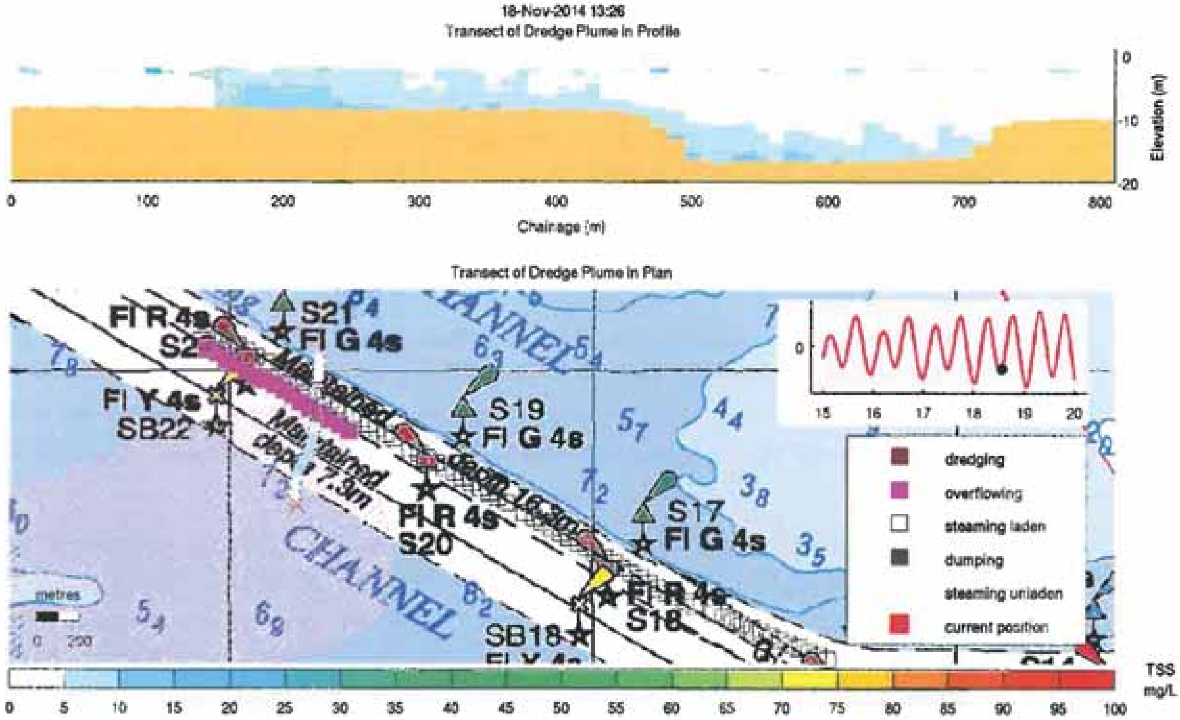

Figure 3-17 Dredging at Golding Cutting – flood tide

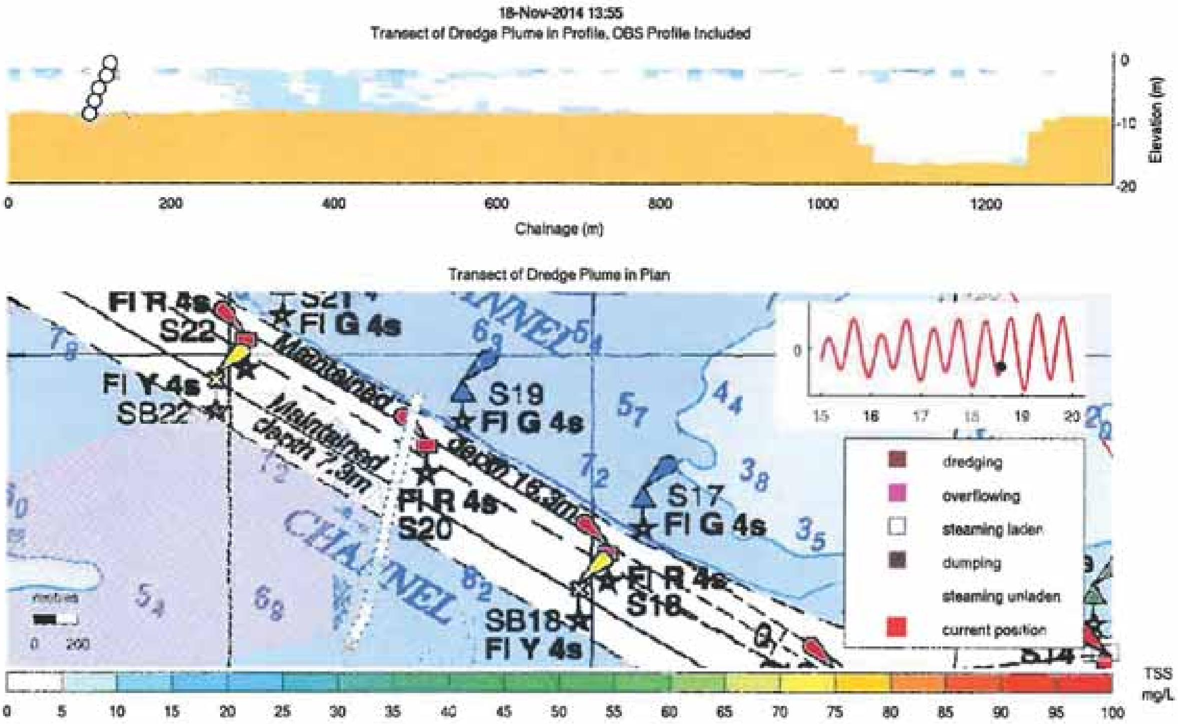

Figure 3-18 Dredging at Golding Cutting – flood tide

3.4.2 Water Quality

3.4.2.1 Water Quality Profiles

A summary of the profile data for the Golding Cutting flood tide dredging is provided in Table 3-7. Temperature, salinity, pH and dissolved oxygen were relatively constant through the water column for both baseline and plume profiles. Dissolved oxygen concentrations were close to saturation (94%-99%) for both baseline and plume profiles.

Figure 3-19 shows the measured turbidity profiles. As expected, turbidity was elevated within the dredge plumes compared to the baseline measurements. The average turbidity in the dredge plumes ranged between 10 and 26 NTU compared to an average of 1.7 NTU for the baseline profile. Turbidity typically increased with depth with the maximum turbidity of 35 NTU measured close to the seafloor. Turbidity was relatively uniform through the water column in the baseline profile.

The measured PAR profiles for the baseline and plume measurements are shown in Figure 3-20. The availability of light diminished rapidly with depth in the dredge plume profiles with no light available between 2 and 4.5m of water depth. In contrast, light was available down to about 14 m of water depth during baseline conditions. Ambient light conditions were similar between baseline and plume measurements. The PAR results agree with the observed turbidity values measured during baseline and dredging.

Table 3-7 Water quality profile summary-Golding Cutting

Golding Cutting	Parameter	Temp (°C)	Salinity (ppt)	pH	Dissolved Oxygen (%)	Turbidity (NTU)	Light - PAR (μmol $m^{-2}s^{-1}$)
Baseline 2/11/14; 12:01	Min	25.44	38.02	8.10	97.50	1.00	6.70
	Max	25.53	38.08	8.14	99.20	2.80	543.50
	Average	25.47	38.04	8.13	98.59	1.71	96.78
Plume 18/11/14, 12:36	Min	26.90	37.42	8.20	93.90	11.70	0.00
	Max	26.94	37.57	8.27	94.90	35.10	490.10
	Average	26.92	37.53	8.21	94.41	21.70	26.73
Plume 18/11/14, 12:55	Min	25.96	37.53	8.20	93.80	22.80	0.00
	Max	26.95	38.41	8.25	95.80	28.10	537.60
	Average	26.85	37.65	8.21	94.29	25.77	29.46
Plume 18/11/14, 13:10	Min	25.64	37.53	8.20	94.10	3.70	0.00
	Max	27.01	38.71	8.26	95.70	14.60	1369.06
	Average	26.92	37.59	8.21	94.53	10.25	114.17

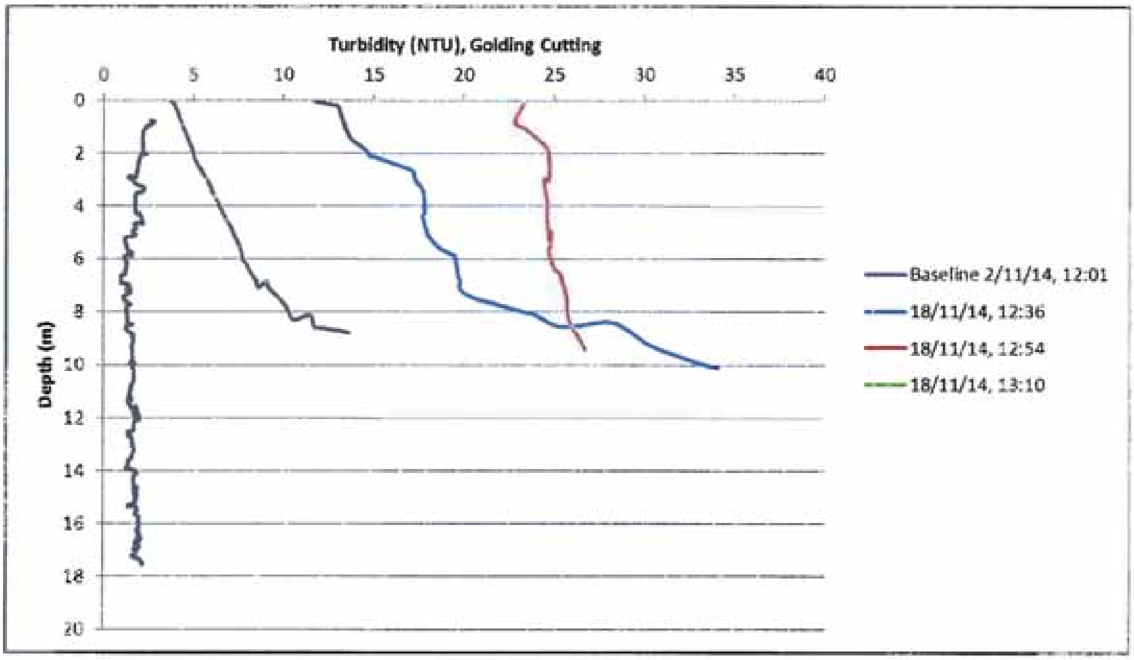

Figure 3-19 Turbidity profiles- Golding Cutting

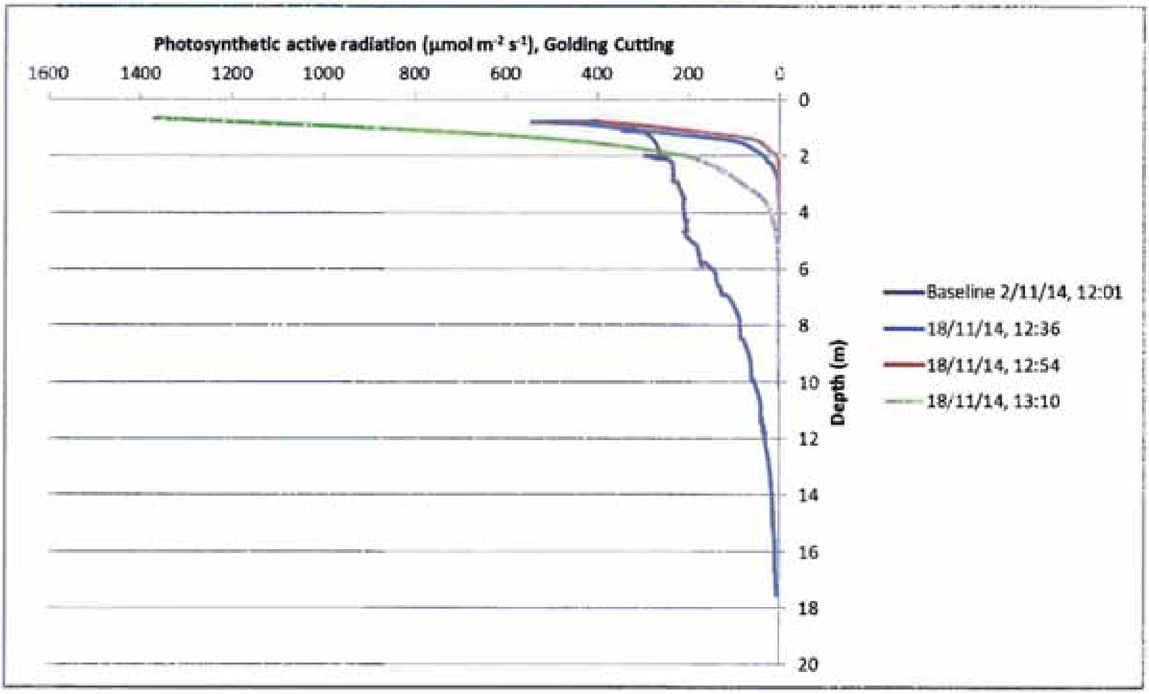

Figure 3-20 PAR profiles- Golding Cutting

3.4.2.2 Water Quality Grab Samples

Table 3-8 presents the baseline and plume water quality grab sample results for the Golding Cutting. TSS and nutrient concentrations were generally elevated in the plume samples compared to the baseline samples. Total phosphorus concentrations exceeded the QWQG limit in both baseline and plume samples, with approximately two times higher total phosphorus concentrations in the plume samples, exceeding the QWQG limit approximately 2.5 to 3-fold. The reactive phosphorus concentration was below the LOR in the baseline samples and exceeded the QWQG limit up to six times in the plume samples. TSS concentrations exceeded the QWQG limit up to 1.5-fold in the plume samples but were below the LOR in the baseline samples. Chlorophyll *a* concentrations exceeded the QWQG limit in the two baseline samples with a particularly high concentration measured in the surface sample (33 µg/L, over 16 times the QWQG limit). Chlorophyll *a* concentrations were below the LOR in all plume samples.

Total concentrations of aluminium, iron and to a lesser extent manganese and zinc were elevated in the plume samples compared to the baseline assessment. However, the dissolved fraction of these metals was either below the LOR or similar between baseline and plume measurements. Dissolved metal/metalloid concentrations were either below the LOR or below their respective ANZECC (2000) trigger limits in all baseline and plume samples.

Table 3-8 Water quality results- Golding Cutting[6]

Golding Cutting-Parameter	Unit	ANZECC /QWQG Trigger	Baseline		Dredge Plume Sampling		
			Top	Bottom	1	2	3
Nutrients, TSS, Chlorophyll							
Total Phosphorus	µg/L	20	32	34	64	56	50
Ortho-Phosphorus	µg/L	6	<LOR	<LOR	33	25	35
Ammonia-Nitrogen	µg/L	8	<LOR	<LOR	<LOR	<LOR	<LOR
Nitrite + Nitrate (as N)	µg/L	3	<LOR	<LOR	<LOR	<LOR	<LOR
Total Nitrogen	µg/L	200	<LOR	<LOR	58	53	51
Solids (Suspended)	mg/L	15	<LOR	<LOR	21	22	23
Chlorophyll a	µg/L	2	33	9.6	<LOR	<LOR	<LOR
Total Organic Carbon	mg/L	-	2.6	2.7	3	3.6	3
Metals and Metalloids							
Aluminium (Total)	µg/L	-	16	14	520	270	230
Aluminium (Dissolved)	µg/L	-	<LOR	<LOR	<LOR	<LOR	<LOR
Arsenic (Total)	µg/L	-	2.7	2.2	2	1.9	1.8
Arsenic (Dissolved)	µg/L	-	1.9	2	1.5	1.6	1.6
Cadmium (Total)	µg/L	0.7	<LOR	<LOR	<LOR	<LOR	<LOR
Cadmium (Dissolved)	µg/L	0.7	<LOR	<LOR	<LOR	<LOR	<LOR
Chromium (Total)	µg/L	4.4	1.7	1.5	1.4	1.1	0.89
Chromium (Dissolved)	µg/L	4.4	1.3	1.1	<LOR	<LOR	<LOR
Copper (Total)	µg/L	1.3	1.1	1	0.66	<LOR	<LOR
Copper (Dissolved)	µg/L	1.3	0.7	0.98	<LOR	<LOR	<LOR
Iron (Total)	µg/L	-	13	15	510	260	210
Iron (Dissolved)	µg/L	-	<LOR	<LOR	<LOR	<LOR	<LOR
Lead (Total)	µg/L	4.4	<LOR	<LOR	0.24	0.13	<LOR
Lead (Dissolved)	µg/L	4.4	<LOR	<LOR	<LOR	<LOR	<LOR
Manganese (Total)	µg/L	-	3.2	3	11	7.1	5.4
Manganese (Dissolved)	µg/L	-	1	0.85	1.9	1.1	1.3
Mercury (Total)	mg/L	0.1	<LOR	<LOR	<LOR	<LOR	<LOR
Mercury (Dissolved)	mg/L	0.1	<LOR	<LOR	<LOR	<LOR	<LOR
Nickel (Total)	µg/L	7	0.19	0.26	0.53	0.22	0.65
Nickel (Dissolved)	µg/L	7	<LOR	<LOR	0.19	0.19	0.17
Silver (Total)	µg/L	1.4	<LOR	<LOR	<LOR	<LOR	<LOR
Silver (Dissolved)	µg/L	1.4	<LOR	<LOR	<LOR	<LOR	<LOR
Zinc (Total)	µg/L	15	1.2	0.62	3.5	2	1.6
Zinc (Dissolved)	µg/L	15	<LOR	0.52	1.1	<LOR	<LOR

[6] Orange shading = guideline limit met or exceeded; green shading = concentration below the laboratory limit of reporting (LOR)

3.5 Dredging at Wild Cattle Cutting, Flood Tide on 18th November 2014

3.5.1 Plume Monitoring

The ADCP measurements of the dredge plumes at Wild Cattle Cutting are summarised in Figure 3-21 to Figure 3-23. A complete set of ADCP measurements which also depict the timing and locations of all relevant profiling (OBS and YSI) and water sampling is provided in Appendix I.

Dredging was conducted on a flooding tide along the northern toe line of Wild Cattle Cutting. A single outbound pass was performed. The flood tidal range was approximately 2.3m. The nearest sensitive receptors potentially affected on the flooding tide consisted of the following:

- Rocky reef areas at Jenny Lind Bank, with the nearest reef outcrops being approximately 3.3km south of the dredging area
- A deep water seagrass meadow mapped in 2009 (Thomas *et al.* 2010) located south of the cutting.

A single long plume was generated parallel to the channel. The dredge plume was advected by the flooding tide in a south-westerly direction mainly along the channel (towards the Boyne Cutting) but also with some displacement over and beyond the northern edge of the channel onto East Banks. The plume was advected along the channel over 1 km by the flooding tide over a period of almost 2 hours until near background turbidity conditions were achieved. The plume component displaced onto East Banks fell short of the rocky reef area by approximately 6 km. The plume was not advected towards the rocky reef areas at Jenny Lind Bank and did not pass over the deep water seagrass meadow in any detectable quantities.

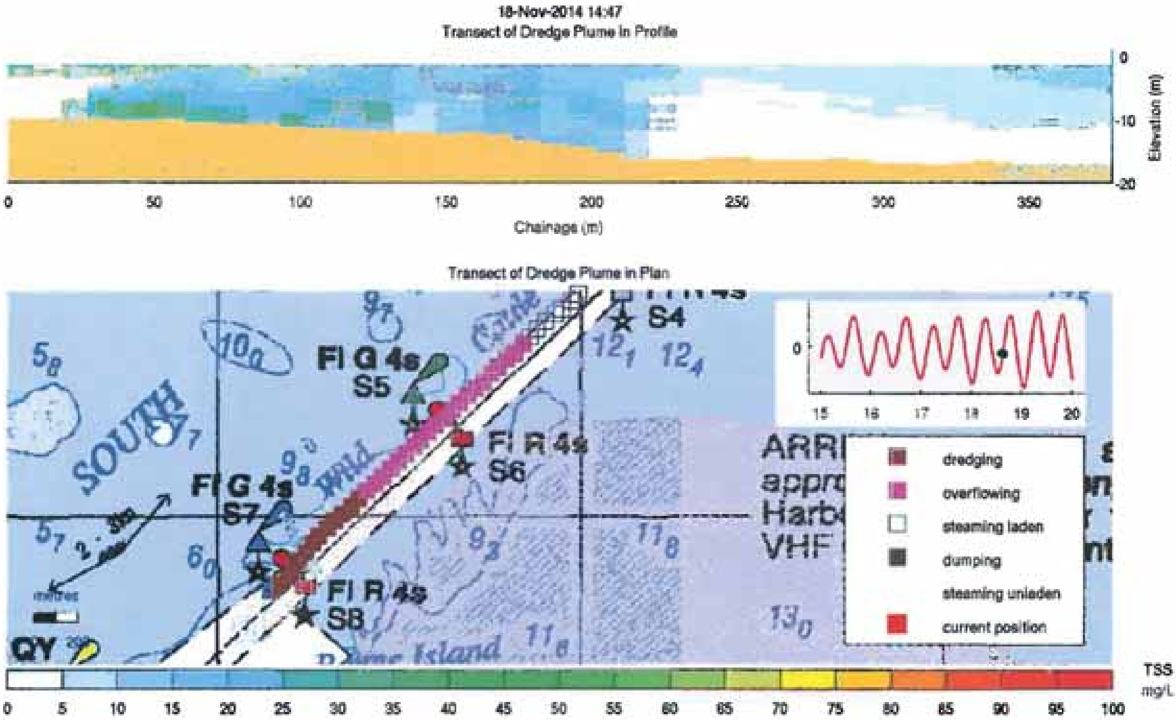

Figure 3-21 Dredging at Wild Cattle Cutting – flood tide

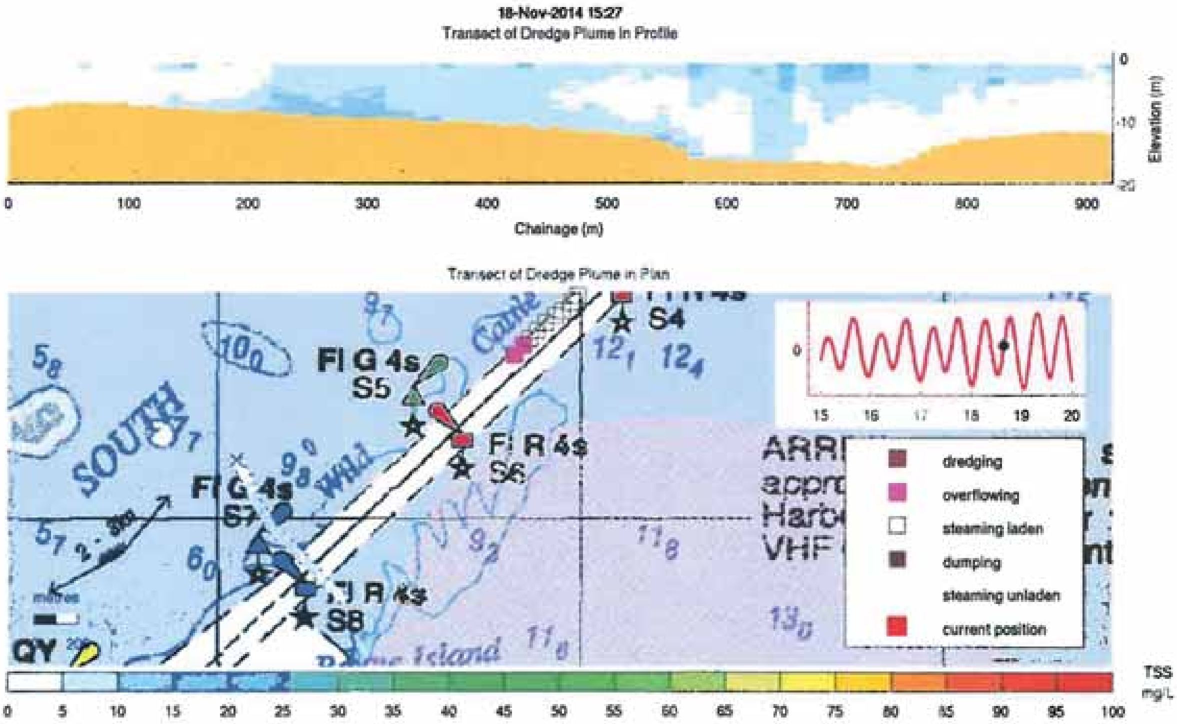

Figure 3-22 Dredging at Wild Cattle Cutting – flood tide

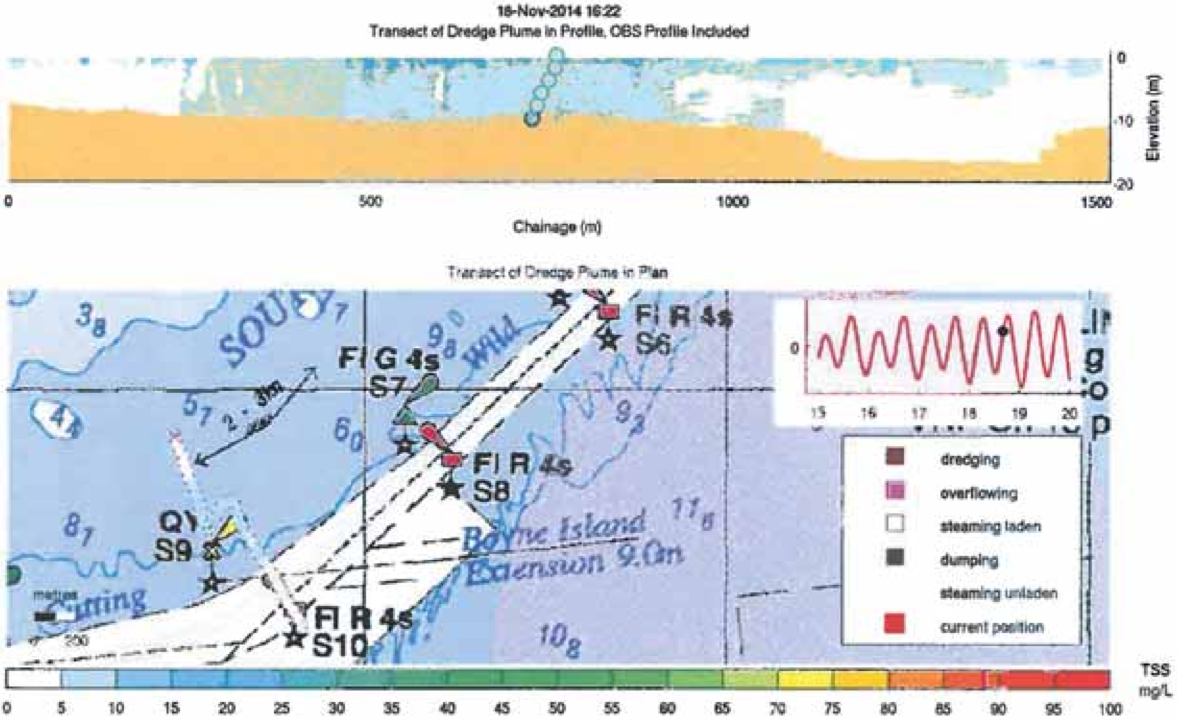

Figure 3-23 Dredging at Wild Cattle Cutting – flood tide

3.5.2 Water Quality

The water quality measurement profiles for the Wild Cattle Cutting are provided in Table 3-9 for both baseline and plume profiles. Temperature, salinity, pH and dissolved oxygen were relatively constant through the water column. Dissolved oxygen concentrations were close to saturation (95%-102%) for both baseline and plume profiles.

The measured turbidity profiles are shown in Figure 3-24. As expected, turbidity was elevated within the dredge plumes compared to the baseline measurements. The average turbidity in the dredge plumes ranged between 9 and 14 NTU compared to an average of about 1 NTU for the baseline profile. Turbidity typically increased with depth with the maximum turbidity of 23 NTU measured close to the seafloor in the first plume profile. Turbidity was relatively uniform through the water column in the baseline profile with slightly higher turbidity measured close to the water surface.

The measured PAR profiles for the baseline and plume measurements are shown in Figure 3-25. The availability of light diminished rapidly with depth in the dredge plume profiles with no light available at about four m of water depth. In contrast, light was available down to the seafloor at about 14 m of water depth during baseline conditions. The PAR results agree well with the observed turbidity values measured during baseline and dredging. Ambient light conditions were similar for both baseline and plume measurements.

3.5.2.1 Water Quality Profiles

Table 3-9 Water quality profile summary-Wild Cattle Cutting

Wild Cattle Cutting	Parameter	Temp (°C)	Salinity (ppt)	pH	Dissolved Oxygen (%)	Turbidity (NTU)	Light - PAR (µmol m^{-2} s^{-1})
Baseline 2/11/14, 10:58	Min	25.20	37.81	8.16	100.20	0.00	134.60
	Max	25.42	37.83	8.17	101.90	3.40	1574.00
	Average	25.29	37.82	8.17	100.95	1.10	546.38
Plume 18/11/14, 14:33	Min	26.69	36.33	8.25	93.30	6.80	0.00
	Max	27.71	37.25	8.30	95.90	23.00	948.71
	Average	26.77	37.18	8.26	95.34	14.03	74.84
Plume 18/11/14, 14:49	Min	26.45	37.10	8.07	94.30	7.70	0.00
	Max	26.70	37.27	8.24	95.80	11.30	862.58
	Average	26.68	37.13	8.23	95.28	9.71	83.46
Plume 18/11/14, 14:59	Min	25.72	37.08	8.06	94.50	4.60	0.00
	Max	26.68	37.89	8.25	95.90	13.50	1191.28
	Average	26.61	37.15	8.24	95.55	9.36	71.36

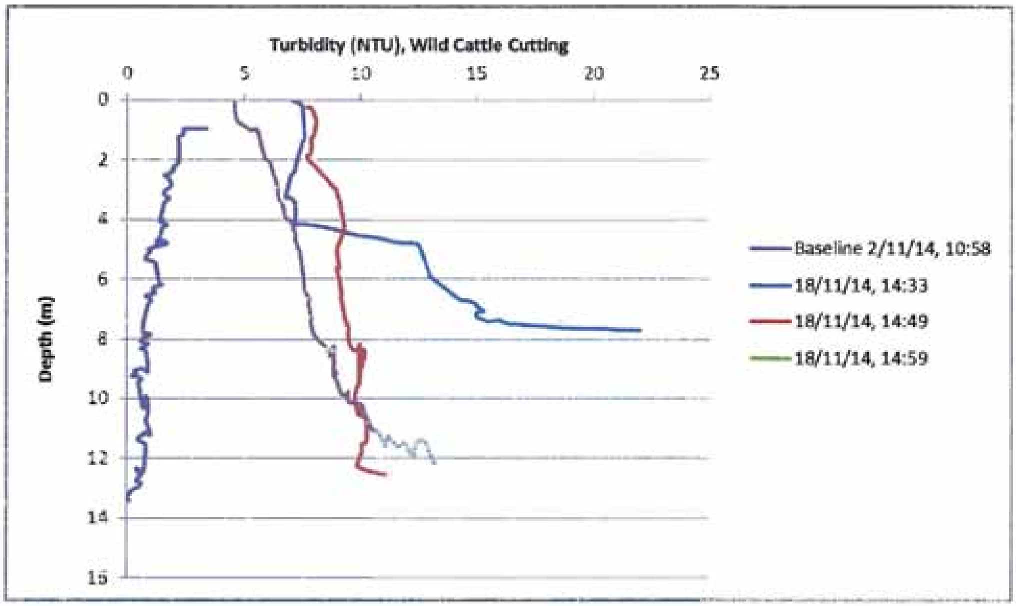

Figure 3-24 Turbidity profiles- Wild Cattle Cutting

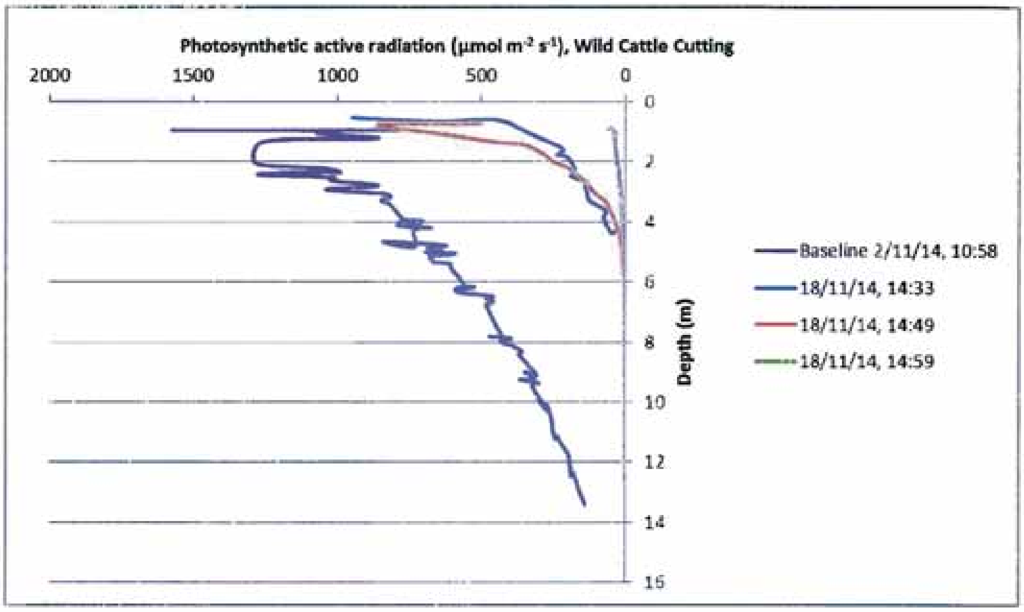

Figure 3-25 PAR profiles- Wild Cattle Cutting

3.5.2.2 Water Quality Grab Samples

Table 3-10 presents the water quality analysis results for the Wild Cattle Cutting baseline and plume samples. The concentrations of TSS and total phosphorus were elevated in the plume samples compared to baseline conditions. The total phosphorus concentrations exceeded the QWQG limit in the baseline and plume samples with up to twice the total phosphorus measured in the plume samples. The concentration of nitrate + nitrite met the QWQG limit in one of the plume samples. An elevated nitrate + nitrite concentration was measured in the baseline surface sample (20 µg/L). TSS concentration exceeded the QWQG limit in two plume samples whereas the TSS concentration was below the LOR in the two baseline samples. The concentration of chlorophyll *a* exceeded the QWQG limit in the two baseline samples but was below the LOR in the plume samples.

Total concentrations of aluminium, iron and to a lesser extent manganese and nickel were elevated in the plume samples compared to the baseline assessment. However, the dissolved fraction of these metals was either below the LOR or similar between baseline and plume measurements. Dissolved metal/metalloid concentrations were either below the LOR or below their respective ANZECC (2000) trigger limits in all baseline and plume samples.

Table 3-10 Water quality results- Wild Cattle Cutting[7]

Parameter	Unit	LOR	ANZECC /QWQG Trigger	Baseline		Dredge Plume Sampling		
				Top	Bottom	1	2	3
Nutrients, TSS, Chlorophyll								
Total Phosphorus	µg/L	10	20	31	32	64	49	40
Ortho-Phosphorus	µg/L	5	6	<LOR	<LOR	<LOR	<LOR	<LOR
Ammonia-Nitrogen	µg/L	5	8	<LOR	<LOR	<LOR	<LOR	<LOR
Nitrite + Nitrate (as N)	µg/L	2	3	20	3	<LOR	3	2
Total Nitrogen	µg/L	50	200	76	<LOR	<LOR	<LOR	<LOR
Solids (Suspended)	mg/L	2	15	<LOR	<LOR	28	12	24
Chlorophyll a	µg/L	2	2	12	11	<LOR	<LOR	<LOR
Total Organic Carbon	mg/L	0.1	-	3.2	2.9	3	3.3	2.9
Metals and Metalloids								
Aluminium (Total)	µg/L	5	-	<LOR	<LOR	380	74	93
Aluminium (Dissolved)	µg/L	5	-	<LOR	<LOR	<LOR	<LOR	<LOR
Arsenic (Total)	µg/L	0.5	-	4.1	2.2	1.9	1.7	1.7
Arsenic (Dissolved)	µg/L	0.5	-	2.3	2.1	1.7	1.6	1.6
Cadmium (Total)	µg/L	0.1	-	<LOR	<LOR	<LOR	<LOR	<LOR
Cadmium (Dissolved)	µg/L	0.1	0.7	<LOR	<LOR	<LOR	<LOR	<LOR
Chromium (Total)	µg/L	0.5	-	1.3	1.1	1.2	1.1	0.94
Chromium (Dissolved)	µg/L	0.5	4.4	1.2	0.98	<LOR	<LOR	<LOR
Copper (Total)	µg/L	0.5	-	0.9	0.69	0.58	<LOR	<LOR
Copper (Dissolved)	µg/L	0.5	1.3	<LOR	<LOR	<LOR	<LOR	<LOR
Iron (Total)	µg/L	5	-	<LOR	<LOR	300	48	64
Iron (Dissolved)	µg/L	5	-	<LOR	<LOR	<LOR	<LOR	<LOR
Lead (Total)	µg/L	0.1	-	0.11	<LOR	0.16	<LOR	<LOR
Lead (Dissolved)	µg/L	0.1	4.4	<LOR	<LOR	<LOR	<LOR	<LOR
Manganese (Total)	µg/L	0.5	-	1.9	1.6	7.1	3	4.1
Manganese (Dissolved)	µg/L	0.5	-	1.4	1.6	1.6	1	1.1
Mercury (Total)	µg/L	0.1	-	<LOR	<LOR	<LOR	<LOR	<LOR
Mercury (Dissolved)	µg/L	0.1	0.1	<LOR	<LOR	<LOR	<LOR	<LOR
Nickel (Total)	µg/L	0.1	-	<LOR	<LOR	0.63	0.23	0.56
Nickel (Dissolved)	µg/L	0.1	7	<LOR	<LOR	0.26	0.2	0.2
Silver (Total)	µg/L	0.1	-	<LOR	<LOR	<LOR	<LOR	<LOR
Silver (Dissolved)	µg/L	0.1	1.4	<LOR	<LOR	<LOR	<LOR	<LOR
Zinc (Total)	µg/L	0.5	-	1.2	1.8	1.4	1.3	1.7
Zinc (Dissolved)	µg/L	0.5	15	1	<LOR	1.3	1.3	<LOR

[7] Orange shading = guideline limit met or exceeded; green shading = concentration below the laboratory limit of reporting (LOR)

3.6 Placement at EBSDS, Flood Tide on 19th November 2014

3.6.1 Plume Monitoring

The ADCP measurements of the dredge plumes at the EBSDS are summarised in Figure 3-26 to Figure 3-28. A complete set of ADCP measurements which also depict the timing and locations of all relevant profiling (OBS and YSI) and water sampling is provided in Appendix J.

The *TSHD Brisbane* placed dredged material at approximately 1315 on the 19th November 2014 towards the centre of the EBSDS. The dredged load consisted of 960 tonnes of silts from the Golding Channel. The tide was recently flooding with the currents swinging from southerly through to westerly.

The nearest sensitive marine receptors potentially affected on the newly flooding tide consisted of the following:

- A deep water seagrass meadow 100m south of the southern boundary of the EBSDS (Davies *et al.* 2013).
- Gatcombe Head has several rocky reefs containing branching and solitary reef building corals interspersed amongst a macroalgae (*Sargassum sp.*) over-storey (BMT WBM, 2009).

The turbid dredge plume generated by disposal activities at the EBSDS was advected by the recently flooding tide south towards the deep water seagrass meadow. The plume was localised and of low intensity. The plume was identifiable for approximately 1.5 hours above the background concentrations by which time it had travelled approximately 1 km. The plume fell short of the deep water seagrass meadow by over 1 km.

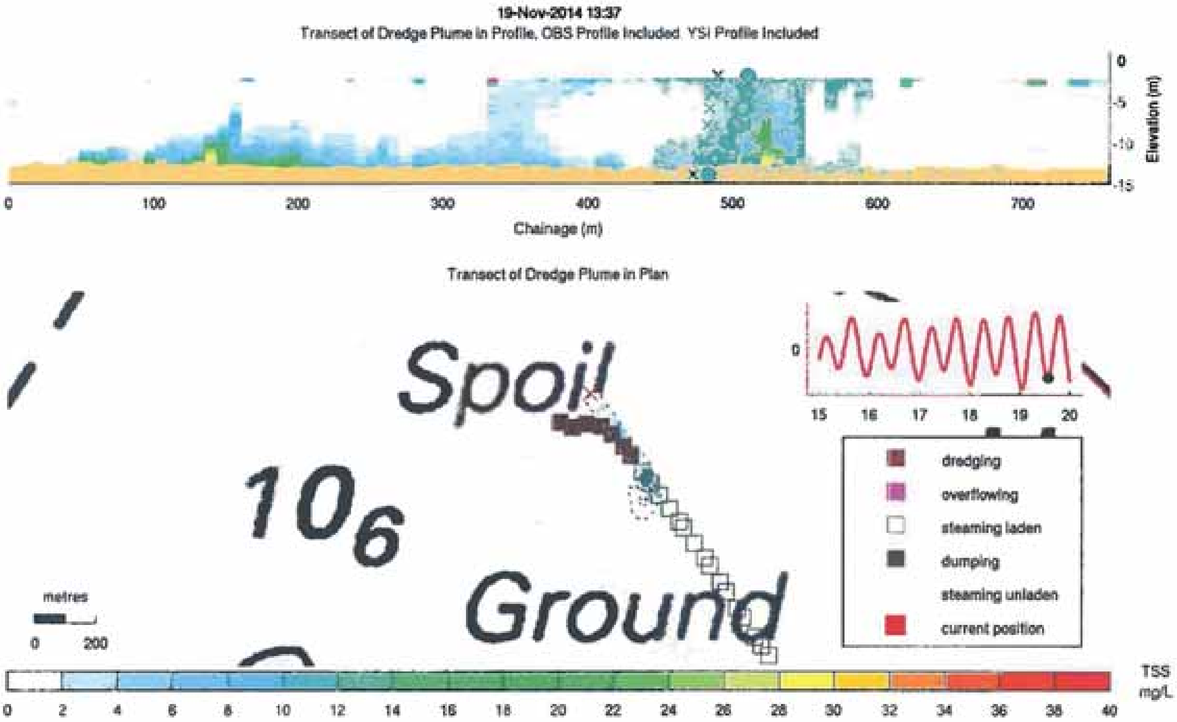

Figure 3-26 Disposal at EBSDS

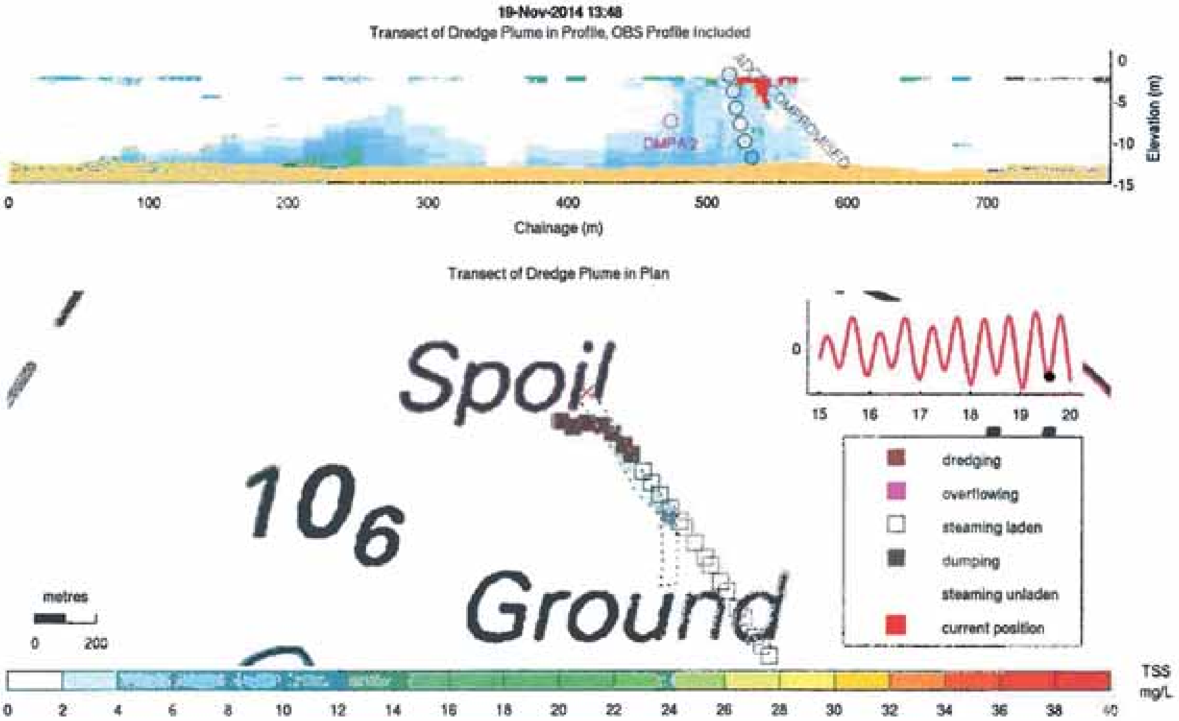

Figure 3-27 Disposal at EBSDS

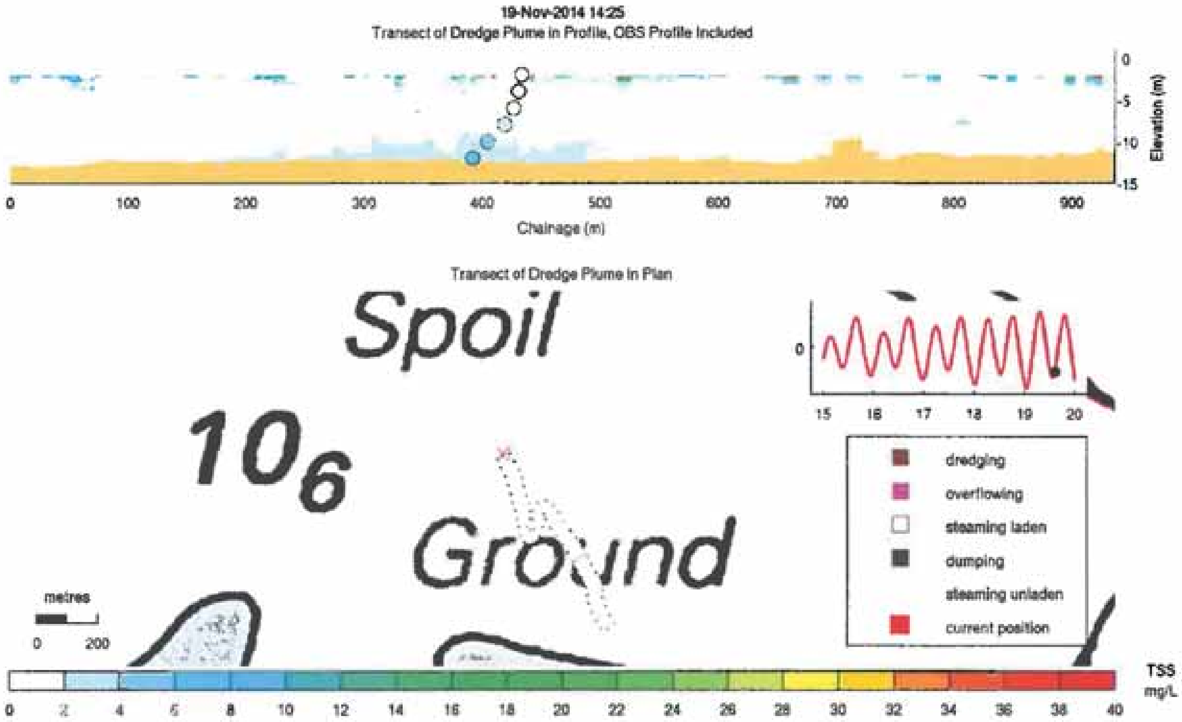

Figure 3-28 Disposal at EBSDS

3.6.2 Water Quality

3.6.2.1 Water Quality Profiles

A summary of the water quality profiles collected at the EBSDS during baseline conditions and dredging is shown in Table 3-11. Temperature, salinity, pH and dissolved oxygen were relatively constant through the water column for both baseline and plume measurements. Dissolved oxygen concentrations were close to saturation (94%-103%) for both baseline and plume profiles.

The measured turbidity profiles are shown in Figure 3-29. Turbidity was elevated within all three dredge plume profiles compared to the baseline measurements. The average turbidity in the dredge plumes ranged between 7.5 and 15.4 NTU compared to an average of about 0.5 NTU for the baseline profile. Turbidity typically increased with depth with the maximum turbidity of 23 NTU measured close to the seafloor in the first plume profile. Turbidity was relatively uniform through the water column in the baseline profile.

The measured PAR profiles for the baseline and plume measurements are shown in Figure 3-30. The availability of light diminished rapidly with depth in the dredge plume profiles with no light available in about 4 to 5 m of water depth. In contrast, light was available down to at least 13 m of water depth during baseline conditions. Ambient light conditions were similar for both baseline and plume measurements. The PAR results agree well with the observed turbidity values measured during baseline and dredging.

Table 3-11 Water quality profile summary- EBSDS

EBSBS	Parameter	Temp (°C)	Salinity (ppt)	pH	Dissolved Oxygen (%)	Turbidity (NTU)	Light - PAR (µmol m⁻² s⁻¹)
Baseline 2/11/14, 09:38	Min	24.89	37.71	8.12	101.00	0.00	29.90
	Max	25.30	37.77	8.15	102.90	2.30	1480.60
	Average	24.97	37.74	8.15	101.87	0.47	467.04
Plume 19/11/14, 13:23	Min	26.01	36.84	8.24	94.40	6.70	0.00
	Max	26.33	37.19	8.29	95.50	23.20	715.78
	Average	26.29	36.90	8.25	95.02	15.37	45.28
Plume 19/11/14, 13:33	Min	25.36	36.80	8.08	93.70	6.90	0.00
	Max	26.36	37.67	8.23	95.60	15.40	915.10
	Average	26.25	36.89	8.22	94.89	9.68	79.82
Plume 19/11/14, 13:36	Min	25.36	36.79	8.23	93.40	3.80	0.00
	Max	26.35	37.66	8.27	96.00	12.90	483.88
	Average	26.31	36.85	8.23	94.72	7.54	55.72

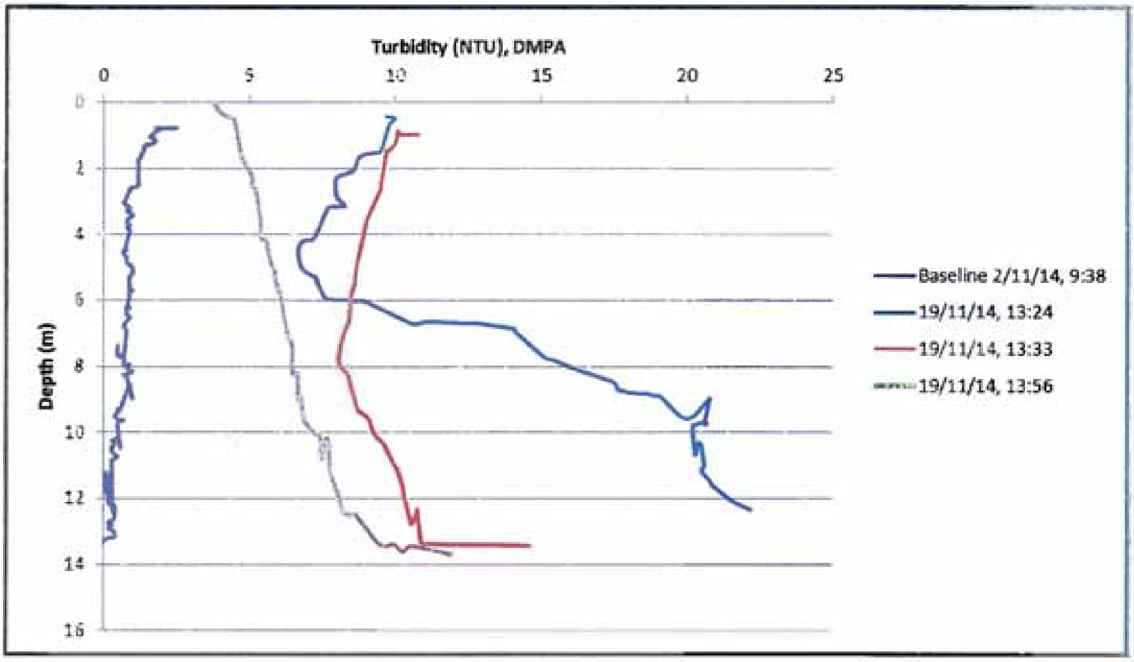

Figure 3-29 Turbidity profiles- EBSDS

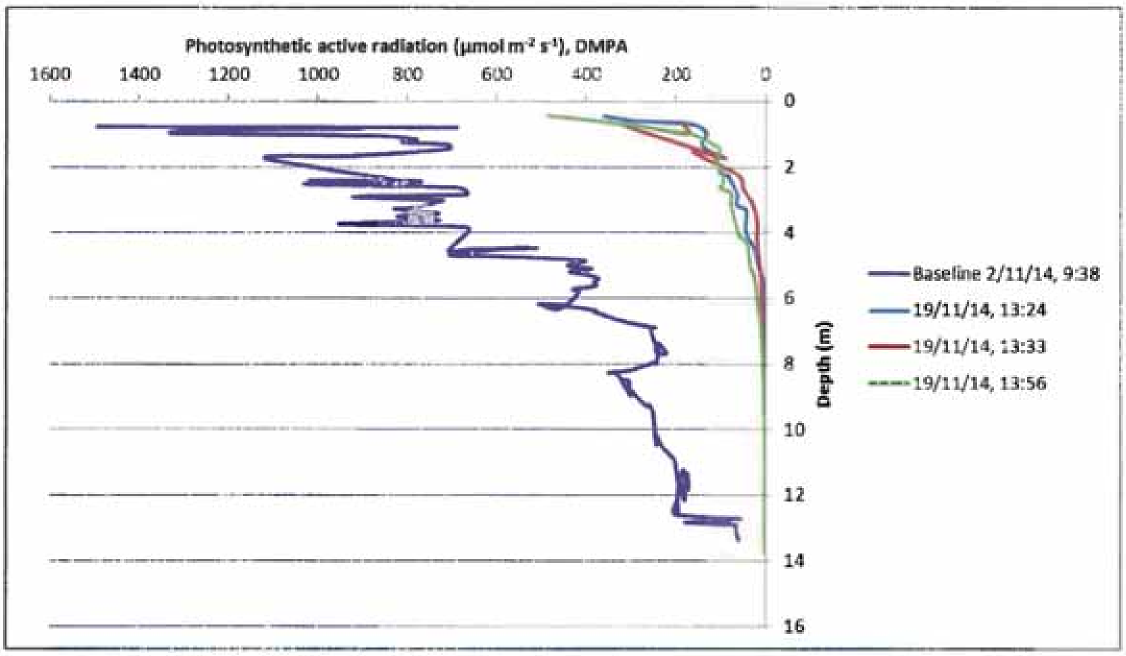

Figure 3-30 PAR profiles- EBSDS

3.6.2.2 *Water Quality Grab Samples*

The water quality analysis results for the EBSDS baseline and plume samples are presented in Table 3-12.

Nutrient and TSS concentrations were generally elevated in the plume samples compared to baseline conditions. Total phosphorus concentrations exceeded the QWQG limit in the baseline and plume samples. Reactive phosphorus concentrations exceeded the QWQG limit in two plume samples. The concentration of nitrate + nitrite met the QWQG limit in one of the plume samples. TSS concentration marginally exceeded the QWQG limit in two plume samples whereas the TSS concentration was relatively low in the two baseline samples. The concentration of chlorophyll *a* exceeded the QWQG limit in surface baseline sample but was below the LOR in the plume samples and the bottom baseline sample.

Total concentrations of aluminium, iron and to a lesser extent manganese were elevated in the plume samples compared to the baseline assessment. However, the dissolved fraction of these metals was either below the LOR or similar between baseline and plume measurements. Dissolved metal/metalloid concentrations were either below the LOR or below their respective ANZECC (2000) trigger limits in all baseline and plume samples.

Table 3-12 Water quality results- EBSDS[8]

EBSDS - Parameter	Unit	LOR	ANZECC /QWQG Trigger	Baseline		Dredge Plume Sampling		
				Top	Bottom	1	2	3
Nutrients, TSS, Chlorophyll								
Total Phosphorus	µg/L	10	20	30	32	53	42	44
Ortho-Phosphorus	µg/L	5	6	<LOR	<LOR	26	20	<LOR
Ammonia-Nitrogen	µg/L	5	8	<LOR	<LOR	<LOR	<LOR	<LOR
Nitrite + Nitrate (as N)	µg/L	2	3	<LOR	2	<LOR	2	3
Total Nitrogen	µg/L	50	200	160	<LOR	<LOR	<LOR	<LOR
Solids (Suspended)	mg/L	2	15	2.7	2.3	16	11	16
Chlorophyll a	µg/L	2	2	12	<LOR	<LOR	<LOR	<LOR
Total Organic Carbon	mg/L	0.1	-	3.2	<LOR	2.9	2.9	2.7
Metals and Metalloids								
Aluminium (Total)	µg/L	5	-	7.9	7.8	110	43	59
Aluminium (Dissolved)	µg/L	5	-	<LOR	<LOR	<LOR	<LOR	15
Arsenic (Total)	µg/L	0.5	-	3.7	2.6	1.3	1.4	1.4
Arsenic (Dissolved)	µg/L	0.5	-	3.6	2.3	1.2	1.3	1.4
Cadmium (Total)	µg/L	0.1	-	0.15	<LOR	<LOR	<LOR	<LOR
Cadmium (Dissolved)	µg/L	0.1	0.7	0.15	<LOR	<LOR	<LOR	<LOR
Chromium (Total)	µg/L	0.5	-	1	1.1	0.8	0.68	0.77
Chromium (Dissolved)	µg/L	0.5	4.4	0.69	0.72	<LOR	<LOR	<LOR
Copper (Total)	µg/L	0.5	-	<LOR	0.77	<LOR	<LOR	<LOR
Copper (Dissolved)	µg/L	0.5	1.3	<LOR	0.72	<LOR	<LOR	<LOR
Iron (Total)	µg/L	5	-	<LOR	<LOR	90	23	37
Iron (Dissolved)	µg/L	5	-	<LOR	<LOR	<LOR	<LOR	<LOR
Lead (Total)	µg/L	0.1	-	<LOR	<LOR	0.12	<LOR	<LOR
Lead (Dissolved)	µg/L	0.1	4.4	<LOR	<LOR	<LOR	<LOR	<LOR
Manganese (Total)	µg/L	0.5	-	2.6	2.1	5.1	2	3.5
Manganese (Dissolved)	µg/L	0.5	-	2	2	1.2	0.76	3.4
Mercury (Total)	µg/L	0.1	-	<LOR	<LOR	<LOR	<LOR	<LOR
Mercury (Dissolved)	µg/L	0.1	0.1	<LOR	<LOR	<LOR	<LOR	<LOR
Nickel (Total)	µg/L	0.1	-	2.6	<LOR	0.27	0.2	0.2
Nickel (Dissolved)	µg/L	0.1	7	<LOR	<LOR	0.13	0.19	0.18
Silver (Total)	µg/L	0.1	-	<LOR	<LOR	<LOR	<LOR	<LOR
Silver (Dissolved)	µg/L	0.1	1.4	<LOR	<LOR	<LOR	<LOR	<LOR
Zinc (Total)	µg/L	0.5	-	2.1	1.4	0.65	<LOR	<LOR
Zinc (Dissolved)	µg/L	0.5	15	<LOR	0.68	<LOR	<LOR	<LOR

[8] Orange shading = guideline limit met or exceeded; green shading = concentration below the laboratory limit of reporting (LOR)

3.7 Water Sample QA/QC Assessment

The results of the QA/QC sample assessment (refer to Section 2.3.1 for details) are shown in Table 3-13 and Table 3-14 for the baseline and plume sampling campaigns, respectively.

3.7.1 Field Blanks

The field blank test have been undertaken to detect any potential contamination from the sampling equipment used for obtaining the water samples.

The field blank assessment was satisfactory for both baseline and plume sampling campaigns indicating that the sampling equipment and procedures did not lead to contamination of the samples. Concentrations of all nutrients and most metals/metalloids were below the laboratory LOR in the baseline and plume field blank samples. The only exception was a detection of total zinc in the baseline field blank sample. However, the detection was very low (0.6 µg/L) and close to the LOR (0.5 µg/L) and is therefore not considered problematic.

3.7.2 Trip Blanks

The trip blank test was undertaken to test for any potential contamination due to the sample bottles used or during transport of the samples.

The trip blank assessment was satisfactory for both baseline and plume sampling indicating that no sample contamination occurred during transport or as a result of the sample bottles. Concentrations of all nutrients and most metals/metalloids were below the laboratory LOR in the baseline and plume field blank samples. The only exception was a detection of total manganese in the baseline trip blank sample. However, the detection was very low (0.8 µg/L) and close to the LOR (0.5 µg/L) and is therefore not considered problematic, especially considering the typically much higher total manganese concentrations detected in the actual samples.

3.7.3 Intra-lab and Inter-lab Duplicates

The intra-lab duplicate assessment was undertaken to test for potential variation in the analyses undertaken by the primary laboratory. The purpose of the inter-lab assessment was to test for variation between the primary and secondary laboratories.

The intra-lab and inter-lab duplicate assessments were generally satisfactory with the Relative Percent Difference (RPD) for most parameters within the ±50% criterion for both baseline and plume campaigns.

However, several exceedances of the RPD were detected, primarily associated with total nutrients and total metal concentrations. With regards to total metal concentrations, most exceedances were noted for aluminium, iron, manganese, nickel and zinc. These metals were also typically found at higher total concentrations in the plume samples and therefore appear to be related to suspended sediment particles. Variability in the number and nature of suspended particles in the subsamples and associated particle-bound nutrients and metals was likely the cause of the relatively high RPD between duplicates. This would be particularly the case for the plume samples with relatively high suspended solid concentrations.

Exceedances of the ±50% RPD criterion were also noted for a few dissolved metal species, e.g. arsenic, manganese, nickel and zinc. The exceedances were related to typically low concentrations close to the LOR for these metals/metalloids. Small differences in concentrations close to the LOR can lead to relatively large changes in the RPD value. It is noted that none of the dissolved metal/metalloid concentrations in the duplicate samples exceeded the respective ANZECC trigger limits.

Whilst the QA/QC sample analysis indicated variability in some of the measured parameters, these results likely affect natural variability in water with relatively high suspended sediment concentrations. This variability does not change the overall observed patterns in water quality and the conclusions drawn from the primary water quality samples. For example, whilst a certain degree of variability in the dissolved (bioavailable) metal/metalloid fraction was measured, none of the dissolved metal/metalloid concentrations in the duplicate samples exceeded the respective ANZECC trigger limits, similar to the analysis results of the primary samples.

Table 3-13 QA/QC Results – Baseline Sampling

Parameter	Unit	Field blank	Trip blank	GC Top	GC Top Intra-lab	RPD(%)	JC Top	JC Intra-lab	RPD(%)	JC Inter-lab	RPD(%)
Ortho-Phosphorus	µg/L	<LOR	<LOR	<LOR	6.0	N/A	8.0	8.0	0.0	<LOR	N/A
Total Phosphorus	µg/L	<LOR	<LOR	33.0	33.0	0.0	36.0	38.0	5.4	8.0	127.3
Ammonia-Nitrogen	µg/L	<LOR	<LOR	<LOR	<LOR	N/A	<LOR	3.0	N/A	<LOR	N/A
Nitrite + Nitrate (as N)	µg/L	<LOR	<LOR	<LOR	<LOR	N/A	<LOR	<LOR	N/A	2.0	N/A
Total Nitrogen	µg/L	<LOR	<LOR	50.0	<LOR	N/A	<LOR	<LOR	N/A	170.0	N/A
Solids (Suspended)	mg/L	<LOR	-	2.1	<LOR	N/A	<LOR	<LOR	N/A	<LOR	N/A
Chlorophyll a	µg/L	-	-	1.0	-	N/A	8.5	-	N/A	-	N/A
Total Organic Carbon	mg/L	<LOR	-	2.7	2.0	29.8	2.5	2.6	3.9	2.0	22.2
Aluminium (Dissolved)	µg/L	-	-	<LOR	<LOR	N/A	5.2	<LOR	N/A	7.0	29.5
Arsenic (Dissolved)	µg/L	-	-	1.9	2.2	14.6	1.7	1.5	12.5	1.4	19.4
Cadmium (Dissolved)	µg/L	-	-	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	N/A
Chromium (Dissolved)	µg/L	-	-	1.2	1.1	8.7	1.0	1.1	11.5	<LOR	N/A
Copper (Dissolved)	µg/L	-	-	1.0	0.9	14.1	1.1	0.9	23.4	<LOR	N/A
Iron (Dissolved)	µg/L	-	-	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	N/A
Lead (Dissolved)	µg/L	-	-	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	N/A
Manganese (Dissolved)	µg/L	-	-	2.1	4.0	62.3	3.3	2.6	23.7	2.8	16.4
Mercury (Dissolved)	µg/L	-	-	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	N/A
Nickel (Dissolved)	µg/L	-	-	<LOR	<LOR	N/A	<LOR	<LOR	N/A	0.8	N/A
Silver (Dissolved)	µg/L	-	-	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	N/A
Zinc (Dissolved)	µg/L	-	-	1.5	0.7	72.7	<LOR	<LOR	N/A	<LOR	N/A
Aluminium (Total)	µg/L	<LOR	<LOR	15.0	20.0	28.6	33.0	18.0	58.8	280.0	157.8
Arsenic (Total)	µg/L	<LOR	<LOR	2.2	2.4	8.7	1.8	1.5	18.2	1.6	11.8
Cadmium (Total)	µg/L	<LOR	<LOR	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	N/A
Chromium (Total)	µg/L	<LOR	<LOR	1.8	1.1	48.3	1.9	1.1	53.3	<LOR	N/A
Copper (Total)	µg/L	<LOR	<LOR	1.1	1.4	24.0	1.2	0.9	31.9	<LOR	N/A
Iron (Total)	µg/L	<LOR	<LOR	20.0	19.0	5.1	48.0	43.0	11.0	310.0	146.4
Lead (Total)	µg/L	<LOR	<LOR	<LOR	<LOR	N/A	0.1	<LOR	N/A	<LOR	N/A
Manganese (Total)	µg/L	<LOR	0.8	4.7	7.2	42.0	8.8	9.9	11.8	11.1	23.1
Mercury (Total)	µg/L	<LOR	<LOR	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	N/A
Nickel (Total)	µg/L	<LOR	<LOR	<LOR	<LOR	N/A	0.3	<LOR	N/A	1.0	100.8
Silver (Total)	µg/L	<LOR	<LOR	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	N/A
Zinc (Total)	µg/L	0.6	<LOR	1.5	0.7	72.7	<LOR	<LOR	N/A	<LOR	N/A

Table 3-14 QA/QC Results – Dredge Plume Sampling

Parameter	Unit	Field blank	Trip blank	JC1	JC1 intra-lab	RPD(%)	JC2	JC2 intra-lab	RPD(%)	JC3	JC3 intra-lab	RPD(%)	WC2	WC2 intra-lab	RPD(%)	WC1	WC1 intra-lab	RPD(%)	SG3	SG3 inter lab	RPD(%)	GOLD 2	GOLD 2 inter-lab	RPD(%)	GOLD 3	GOLD 3 inter-lab	RPD(%)
Ortho-Phosphorus	µg/L	<LOR	<LOR	31	14	[illegible]	-	-	-	27	28	3.6	<LOR	<LOR	N/A	<LOR	68	N/A	<LOR	2	N/A	-	-	-	35	<LOR	N/A
Total Phosphorus	µg/L	<LOR	<LOR	54	31	54.7	-	-	-	55	60	8.7	49	40	20.2	40	44	9.5	44	<LOR	N/A	-	-	-	<LOR	<LOR	N/A
Ammonia-Nitrogen	µg/L	<LOR	<LOR	<LOR	<LOR	N/A	-	-	-	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	-	-	-	<LOR	<LOR	N/A
Nitrite + Nitrate (as N)	µg/L	<LOR	<LOR	120	6	181.0	-	-	-	30	60	66.7	3	<LOR	N/A	<LOR	70	N/A	<LOR	7	N/A	-	-	-	<LOR	<LOR	N/A
Total Nitrogen	µg/L	<LOR	<LOR	0.2	<LOR	N/A	-	-	-	170	140	19.4	25	<LOR	N/A	<LOR	97	N/A	<LOR	140	N/A	-	-	-	51	160	[illegible]
Solids (Suspended)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chlorophyll a	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Organic Carbon	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aluminium (Dissolved)	µg/L	<LOR	-	-	-	-	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	15	11	30.8	<LOR	7	N/A	-	-	-
Arsenic (Dissolved)	µg/L	<LOR	-	-	-	-	1.1	1.1	0.0	1.1	1	9.5	1.6	1.6	0.0	1.6	1.6	0.0	1.4	2.4	[illegible]	1.6	2.7	[illegible]	-	-	-
Cadmium (Dissolved)	µg/L	<LOR	-	-	-	-	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	-	-	-
Chromium (Dissolved)	µg/L	<LOR	-	-	-	-	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	-	-	-
Copper (Dissolved)	µg/L	<LOR	-	-	-	-	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	-	-	-
Iron (Dissolved)	µg/L	<LOR	-	-	-	-	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	9	N/A	<LOR	6	N/A	-	-	-
Lead (Dissolved)	µg/L	<LOR	-	-	-	-	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	-	-	-
Manganese (Dissolved)	µg/L	<LOR	-	-	-	-	3.9	4.6	20.7	2.4	2.3	4.3	1	1.2	18.2	1.1	1.1	0.0	3.4	2	[illegible]	1.1	2.1	62.5	-	-	-
Mercury (Dissolved)	µg/L	<LOR	-	-	-	-	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	-	-	-
Nickel (Dissolved)	µg/L	<LOR	-	-	-	-	0.4	<LOR	N/A	0.3	0.6	66.7	0.2	0.24	18.2	0.2	0.21	4.9	0.18	0.7	[illegible]	0.19	0.8	[illegible]	-	-	-
Silver (Dissolved)	µg/L	<LOR	-	-	-	-	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	-	-	-
Zinc (Dissolved)	µg/L	<LOR	-	-	-	-	1.3	3.1	[illegible]	2.6	2.4	8.0	1.3	<LOR	N/A	<LOR	0.6	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	-	-	-
Aluminium (Total)	µg/L	<LOR	<LOR	-	-	-	520	44	[illegible]	150	140	6.9	74	79	6.5	93	86	7.8	59	98	49.7	270	380	33.8	-	-	-
Arsenic (Total)	µg/L	<LOR	<LOR	-	-	-	1.7	1.3	26.7	1.4	1.2	15.4	1.7	1.9	11.1	1.7	1.7	0.0	1.4	2.6	[illegible]	1.9	3	44.9	-	-	-
Cadmium (Total)	µg/L	<LOR	<LOR	-	-	-	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	-	-	-
Chromium (Total)	µg/L	<LOR	<LOR	-	-	-	1.2	1	18.2	1.1	1.1	0.0	1.1	0.84	26.8	0.94	0.89	5.5	0.8	<LOR	N/A	1.1	<LOR	N/A	-	-	-
Copper (Total)	µg/L	<LOR	<LOR	-	-	-	1.1	0.7	44.4	0.9	0.9	0.0	<LOR	10	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	-	-	-
Iron (Total)	µg/L	<LOR	<LOR	-	-	-	470	140	[illegible]	140	120	15.4	48	47	2.1	64	44	37.0	37	92	[illegible]	260	493	[illegible]	-	-	-
Lead (Total)	µg/L	<LOR	<LOR	-	-	-	0.2	0.2	0.0	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	0.13	0.3	79.1	-	-	-
Manganese (Total)	µg/L	<LOR	<LOR	-	-	-	18	12	40.0	9	7.3	20.9	3	3	0.0	4.1	3	31.0	3.5	4.4	22.8	7.1	11.9	[illegible]	-	-	-
Mercury (Total)	µg/L	<LOR	<LOR	-	-	-	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	-	-	-
Nickel (Total)	µg/L	<LOR	<LOR	-	-	-	1	0.7	35.3	0.85	0.87	28.9	0.2	0.43	[illegible]	0.56	0.41	30.9	0.2	<LOR	N/A	0.22	0.8	[illegible]	-	-	-
Silver (Total)	µg/L	<LOR	<LOR	-	-	-	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	<LOR	<LOR	N/A	-	-	-
Zinc (Total)	µg/L	<LOR	<LOR	-	-	-	<LOR	3.6	N/A	9.5	3.6	[illegible]	1.3	0.78	[illegible]	1.7	1.2	34.5	<LOR	<LOR	N/A	2	<LOR	N/A	-	-	-

4 Discussion

The measured behaviour of sediment plumes generated by maintenance dredging and dredged material disposal by the *TSHD Brisbane* during the November 2014 campaign was consistent with past data collection campaigns and modelling-based predictions carried out by BMT WBM (2014a & 2014b). The key findings of these studies are as follows.

4.1 Turbid Plumes at Sensitive Ecological Receptor Sites

4.1.1 Neap Tides

BMT WBM (2014a) identified and mapped the distribution of key sensitive ecological receptors within and adjacent to Port Curtis. The two key sensitive ecological receptors in the context of dredge plumes were:

- Reefs – particularly corals and algae, which require light for energy production and are therefore sensitive to sediment loading
- Seagrass – which also require light for energy production and therefore may be affected by high sediment concentrations.

Whilst such sensitive ecological receptors do not inhabit dredged facilities they often grow where dredge plumes can potentially pass over in the prevailing tidal currents. Dredge plumes may reduce the ability for sunlight to reach these reef and seagrass communities which can adversely impact on their health. Furthermore the suspended sediments within the plumes have the potential to settle onto such communities again adversely impacting on their health.

Monitoring of the plumes generated by the *TSHD Brisbane's* during both loading and disposal operations revealed that during neap tides dredge plumes likely passed over previously identified ecological receptors at some locations. The sediment plumes generated whilst dredging within the APLNG swing basin and berth pocket on the ebbing tide extended up onto the shallow banks of the LNG precinct of Curtis Island before advecting south towards previously mapped seagrass meadows. The shallow water prevented the monitoring vessel from accessing these mapped areas. These meadows were not identified in 2012 and 2013 surveys (Davies *et al.* 2013, Bryant *et al.* 2014). The plume generated whilst dredging the Golding Channel on the flooding tide extended over an area where deep water seagrass had previously been mapped. This seagrass was not observed in 2009 (Thomas *et al.* 2010) and was not surveyed in 2012 and 2013 (Davies *et al.* 2013, Bryant *et al.* 2014).

Consistent with modelling predictions, field measurements carried out in the present study confirmed that turbid plumes created by dredging and disposal operations during neap tides were transient features measurable for less than a few hours. At Golding Channel, for example, depth-averaged TSS concentrations at the deep water seagrass site were up to 20 mg/L, but subsided to background levels within 1.5 hrs. Given the short duration of this plume, it is unlikely that any deep water seagrass meadows would be harmed by the maintenance dredging operations over the measured neap tides. By the time the plume had advected beyond the bypass channel the concentrations were below 10 mg/L and unlikely to impact on any existing seagrass communities.

4.1.2 Spring Tides

The monitoring works presented in this study were conducted during neap tides and light winds when the ambient concentrations of suspended sediments were minimal. This made it possible to quantify the dredge plumes. During spring tides, when the tidal currents are significantly stronger, the potential for dredge plumes to reach sensitive ecological receptors is greater. This is because the relatively stronger currents have the potential to maintain the sediments in suspension longer and advect them further from the dredge material loading sites. However, dredge plumes are difficult to detect above the high background turbidity during spring tides in Gladstone harbour.

On this basis, the plume measurements conducted in this study cannot be directly used to assess the potential impacts to sensitive receptors during spring tide conditions. Modelling studies such as BMT WBM (2014b) which are calibrated using field monitoring data should be used for such assessments.

4.2 Other Water Quality Parameters

4.2.1 Physical Parameters

The measurements of physical parameters were consistent with the maintenance dredge plume monitoring undertaken in February 2014 (BMT WBM 2014b).

No major differences between the temperature, salinity, pH or dissolved oxygen were detected between the water quality profiles conducted in the absence of dredging (baseline conditions) and those targeting dredge plumes. These parameters remained relatively constant throughout the water column. As expected, the average and peak turbidities within the plume profiles were higher than the baseline values at all locations.

As expected, there was an inverse correlation between the PAR levels and the turbidity at given water depths, where relatively high turbidities were recorded, relatively low PAR levels were recorded. The plume profiles, with the exception of those for the EBSDS, were conducted whilst the *TSHD Brisbane* was loading and thus entraining sediments. Hence, the profiles during a dredge run do not depict a plume settling and dispersing with time and it can be expected that turbidities in plume profiles can vary, i.e. later plume profiles may have higher turbidity compared to earlier profiles.

It is noted that the baseline light availability close to the water surface at the Gatcombe Channel was lower than measured in some of the plume profiles. This can be explained by the cloudy conditions at this location during the baseline measurements compared to the sunny conditions during the ebb and flood dredge plume measurements. The baseline light availability at Gatcombe Channel through the water column profile during cloudy conditions was comparable to light availability affected by turbid dredge plumes during sunny conditions at this location.

As expected, TSS concentrations were typically higher in the dredge plume samples than during baseline conditions and concentrations in the plume samples often exceeded the QWQG trigger limit of 15 mg/L. It is noted that the QWQG limit for TSS of 15 mg/L is frequently exceeded significantly during the spring tides throughout Port Curtis and during wave events offshore by concentrations of naturally resuspended sediments. Sediments suspended by a dredger will add to the natural TSS concentrations however referring to such a static limit when considering the Gladstone Harbour is of limited use.

4.2.2 Nutrients

As expected, nutrient concentrations (mainly total nitrogen, NOx [nitrate + nitrite], total phosphorus and reactive phosphorus) were generally higher in the dredge plume water samples compared to those collected during baseline conditions. Ammonia concentrations were below the laboratory limit of detection at all locations during both baseline and dredging conditions.

Total nutrient concentrations in the plumes were typically two to six times higher than during baseline conditions. Sediment bound nutrients would be expected to settle out of suspension with sediment particles, whereas the dissolved nutrients would be expected to disperse within the ebb and flood tides.

Dissolved reactive phosphorus concentrations were typically four to six times higher than the QWQG trigger limit. Exceedances of more than 40 times the water quality trigger limit for dissolved NOx were measured in two plume samples in the Gatcombe and Jacobs Channels, however these were exceptions. It is noted that the baseline NOx concentration was also elevated more than 6 times above the guideline trigger limit in the surface baseline sample in the Wild Cattle Cutting. Plume dispersion due to tidal processes would relatively quickly result in dissolved nutrient levels below guideline values or close to baseline conditions.

Chlorophyll *a* concentrations were generally higher in the baseline water samples and typically exceeded the guideline trigger limit. In contrast, chlorophyll levels were below laboratory detection in all plume samples. Thus, extensive algal blooms were not evident and are not expected to occur as a result of the maintenance dredging.

The measurement of nutrient levels in dredge plumes was generally consistent with those undertaken in February 2014 (BMT WBM 2014b). However, measurement of dredge plumes in February 2014 showed elevated ammonia concentrations compared to baseline and only slightly elevated reactive phosphorus concentrations. In the present study, ammonia concentrations were below the laboratory detection limits in all samples and reactive phosphorus concentrations were elevated. These differences may be due to seasonal changes and differing dredge materials. The overall observed pattern of increased total and dissolved nutrient concentrations in dredge plumes compared to baseline was the same in both studies.

4.2.3 Metals and Metalloids

As expected, the dredging activities led to suspension of sediments in the water column. As a result, total concentrations of aluminium, iron, and to a lesser extent manganese and zinc were elevated in the dredge plumes. The measured data for these metals suggests that particle-associated metals dominated over the dissolved, bioavailable fraction. It is expected that these sediment-bound metals will quickly settle out of suspension to be deposited on the seafloor.

It is noted that the concentrations of the bioavailable dissolved fraction all measured metals and metalloids were either below the laboratory detection limits or below their respective ANZECC

(2000) trigger limits in all plume and baseline samples. The dissolved metal/metalloid concentrations were similar during baseline and dredging conditions for all investigated metals.

It can therefore be concluded that the maintenance dredging activities in Gladstone harbour did not lead to an increase in the bioavailable metals and metalloids in the water column with dissolved metal/metalloid concentrations measured at levels which would unlikely result in adverse impacts to marine organisms. These findings are very similar to those reported for a minor dredging campaign by the dredger Brisbane in July 2014 (BMT WBM 2014c).

5 Conclusion

The monitoring of the plumes generated by the TSHD *Brisbane* during November 2014 as it performed both loading and disposal operations within Gladstone Harbour during the neap tides allowed for:

- The quantification of the behaviour of the dredge plumes during these conditions;
- Assessment of the potential exposure of sensitive ecological receptors to dredge plumes during these conditions; and
- Providing a data set to complement past numerical modelling works.

The behaviour of the dredge plumes during the November 2014 maintenance dredging campaign can be summarised as follows:

- **Gatcombe Channel (ebb tide dredging):** the dredge plume in a south-easterly direction along the channel alignment reaching background turbidity levels about 500m away from the loading site. The plume did not extend to any nearby sensitive marine receptors.
- **Gatcombe Channel (flood tide dredging):** the plume was advected in a north-westerly direction towards Manning Reef along the channel alignment with the plume discernible up to 3.2 km away from the loading site. However, suspended solid within the plume were very low (approximately 5 mg/L) that impacts to sensitive marine receptors on Manning Reef are considered highly unlikely.
- **Jacobs Channel (ebb tide dredging):** a series of plumes were generated advecting southwards with the ebbing tide with the majority of the plume remaining within the deeper sections of the channel. A smaller proportion of the plume passed into the QCLNG materials offloading facility and likely passed over previously mapped seagrass meadows close to Curtis Island (seagrass was not observed in 2013 survey). Actual measurement of the plume in this area was restricted by shallow water depth. The plume was discernible over background concentrations for two hours after dredging and extended over 3 km down Jacobs Channel, reflective of the fine sediments dredged. The plumes did not affect the seagrass communities on the banks of the Passage Islands.
- **Golding Cutting (flood tide dredging):** the plume was discernible above background for about one hour after dredging and advected in a north-westerly direction along the channel and beyond the western edge of the main channel into the Golding Bypass channel. The plume extended over previously mapped deep water seagrass but was not present in 2009 and 2013 [Thomas et al 2010 and Bryant et al. 2014]) west of the Golding Cutting but it is not known if this seagrass community is still present; By the time the plume had advected beyond the bypass channel the concentrations were below 10 mg/L and unlikely to impact on any existing seagrass communities.
- **Wild Cattle Cutting (flood tide dredging):** the dredge plume was advected over a distance of 1 km in a south-westerly direction mainly along the channel for almost two hours until background concentrations were reached. The plume did not impact on any nearby sensitive receptors.

- **East Banks Sea Disposal Site (flood tide disposal):** the plume generated by placement of dredged material at the EBSDS was generally localised and of low intensity. The plume was advected south with the flooding tide for about 1 km and was detectable over background for approximately 1.5 hours after placement. The plume did not impact on any nearby sensitive receptors.

The behaviour of maintenance dredge plumes and associated water quality parameters are further summarised below.

Concentrations of over 100 mg/L were measured towards the bed in close proximity to the TSHD *Brisbane* when operating in the APLNG swing basin at Jacobs Channel. Concentrations at mid-depth were generally less than 50 mg/L. The near surface sediments released during overflow and those disturbed by the drag heads and propeller wash progressively settled towards the bed as the plume advected with the prevailing tide. The near-bed plume was still detectable two hours following the completion of dredging and 3 km downstream but remained within Jacobs Channel. The longevity of the plume and hence its potential to travel such a distance is reflective of the fine sediments being dredged. The quantities of fine sediments to be dredged from Jacobs Channel are anticipated to reduce in future campaigns. For all other monitoring locations including the EBSDS the plumes were less intense with concentrations generally under 50 mg/L and not extending as far from the dredging operations.

Although not directly measured due to the shallow water it could be inferred that plumes, generated by the TSHD *Brisbane* whilst it dredged the APLNG swing basin, would pass over some of the mapped seagrass meadows along the banks of Curtis Island. The concentrations of the plume sediments were approximately 20mg/L above ambient concentrations (< 5mg/L). It should be noted that these meadows were not mapped in the 2012 and 2013 surveys (Davies *et al.* 2013 and Bryant *et al.* 2014) and hence may no longer exist.

The plumes generated whilst the TSHD *Brisbane* dredged the Golding Cutting on the flooding tide advected over the previously mapped deep-water seagrass meadows adjacent to the Southern edge of the cutting. These meadows were not present in recent surveys. By the time the plume had advected beyond the bypass channel the concentrations were below 10 mg/L and unlikely to impact on any potentially existing seagrass communities. Dredge plumes did not impinge on any other known ecological receptors during the monitoring campaign.

BMT WBM's most recent modelling study (BMT WBM 2014a) should provide the reference when assessing the possible impacts to ecological receptors from maintenance dredging campaigns within Gladstone Harbour. The modelling included multiple possible maintenance campaigns, thus encompassing the inherent variability between campaigns. The modelling also spanned numerous spring-neap cycles and hence encompassed the inherent variability between the spring and neap tides. The modelling was based on field measurements collected in February 2014 (BMT WBM 4014b) with results consistent with measurements collected for the current study. The modelling works demonstrated that the plumes advected further from the dredging areas and over sensitive receptors more frequently and at higher concentrations during the spring tides. It should be noted that during spring tides the ambient levels of suspended sediments are also considerably higher, complicating the assessment of the potential impacts due to dredging.

Nutrient concentrations (mainly total N, NOx [nitrate + nitrite], total P and reactive phosphorus) were generally higher in the dredge plume water samples compared to those collected during baseline conditions. Total nutrient concentrations in the plumes were typically two to six times higher than during baseline conditions. Sediment bound nutrients would be expected to settle out of suspension with sediment particles and be deposited back onto the seafloor.

Dissolved nutrient concentrations exceeded guideline values up to 40 times in the dredge plumes. It is however noted, that plume dispersion due to tidal processes would relatively quickly result in dissolved nutrient levels below guideline values or close to baseline conditions. Whilst elevated nutrient concentrations can lead to growth of algae, it is noted that chlorophyll *a* concentrations were relatively high during baseline conditions (i.e. before the start of the dredging) and often exceeded guideline limits. In contrast, chlorophyll *a* was not detected in any of the plume samples. Therefore, extensive algae blooms are not expected to occur as a direct result of the dredging.

As a result of the dredging activities, total concentrations of aluminium, iron, and to a lesser extent manganese and zinc were elevated in the dredge plumes and were mainly present in particle-bound form. It is expected that these sediment-bound metals will quickly settle out of suspension to be deposited back onto the seafloor. Concentrations of the bioavailable, dissolved fraction of all investigated metals and metalloids were either below laboratory detection limits or below their respective guideline limits in dredge plumes and similar to baseline conditions. It can therefore be concluded that the maintenance dredging activities in Gladstone Harbour did not lead to an increase in the bioavailable metals and metalloids in the water column with dissolved metal/metalloid concentrations measured at levels which would unlikely result in adverse impacts to marine organisms.

6 References

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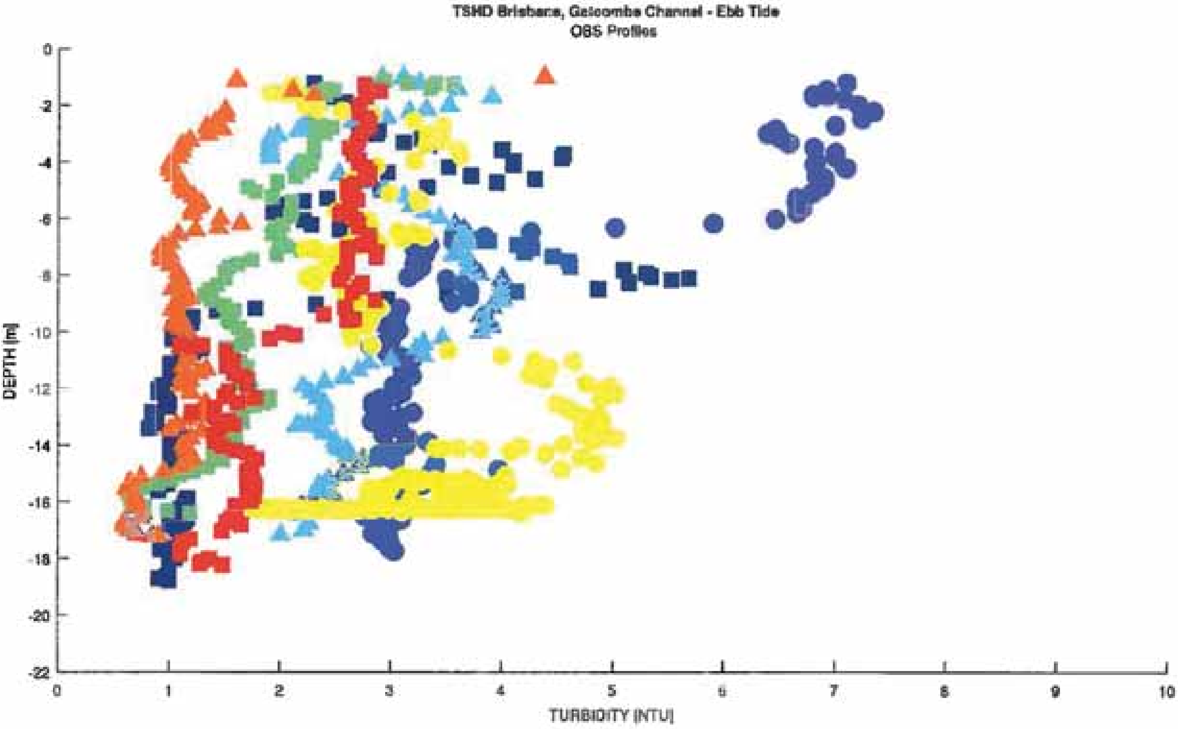
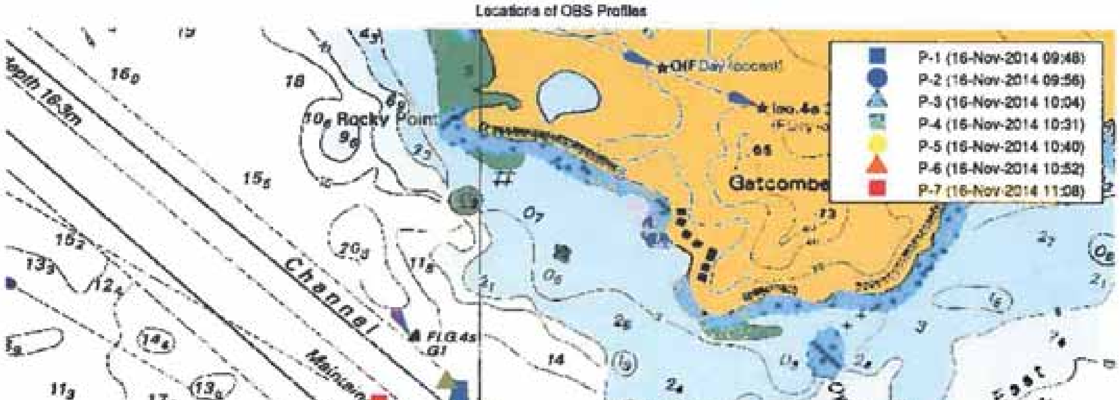
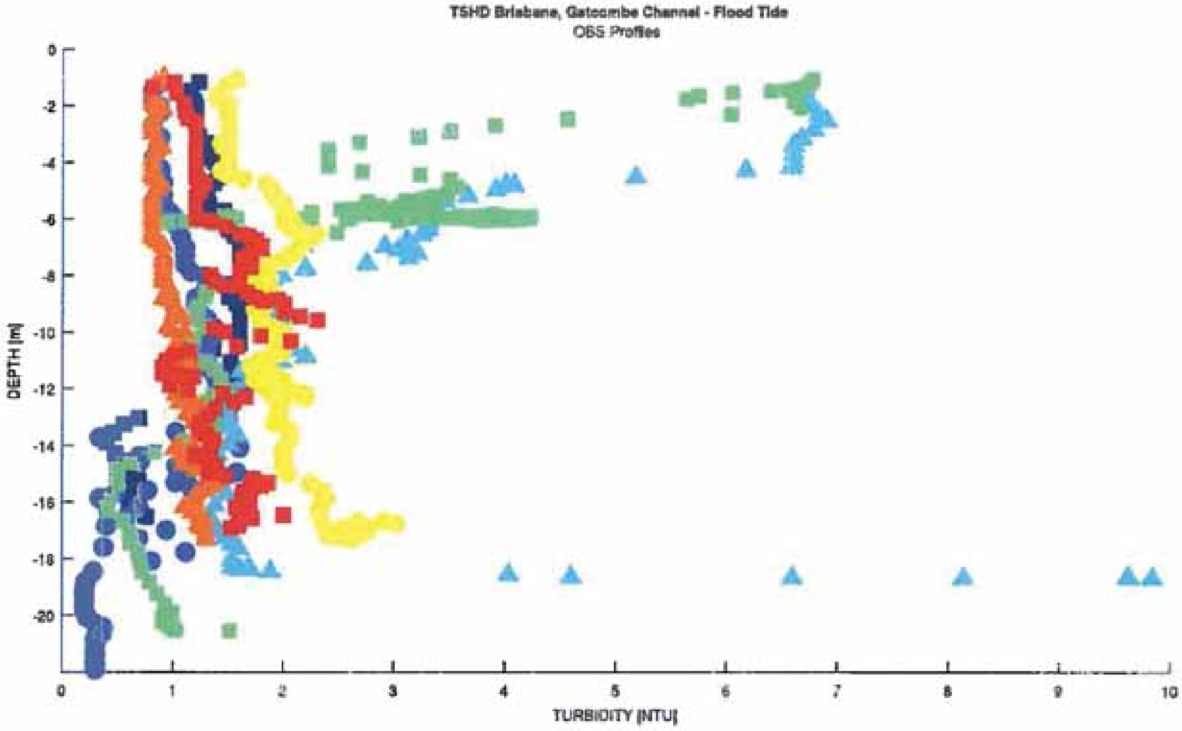
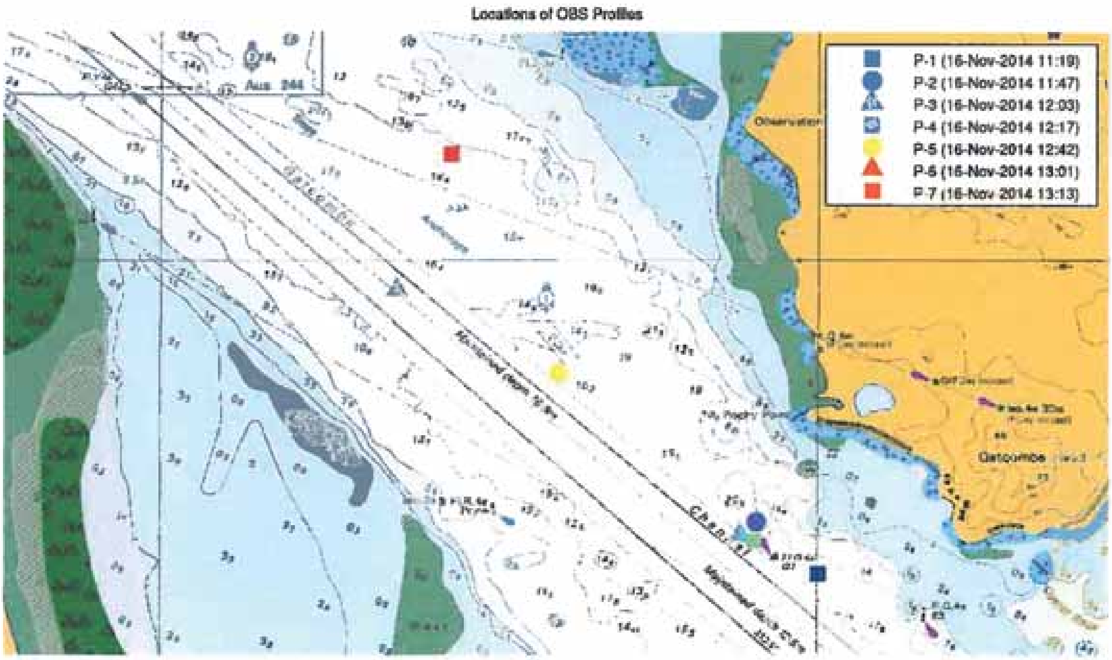
Appendix A Supplementary Turbidity Profiles, Gatcombe Channel, Ebb Tide





Appendix B Supplementary Turbidity Profiles, Gatcombe Channel, Flood Tide

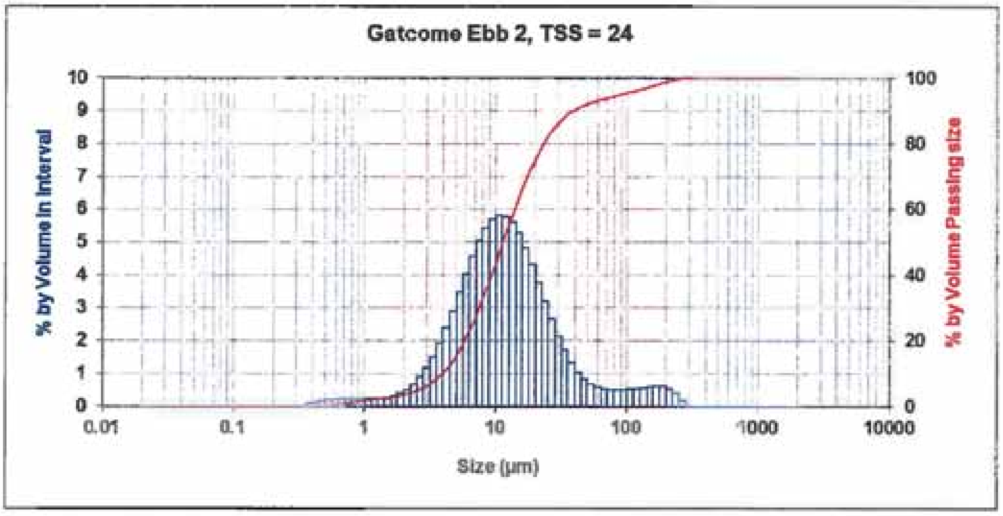


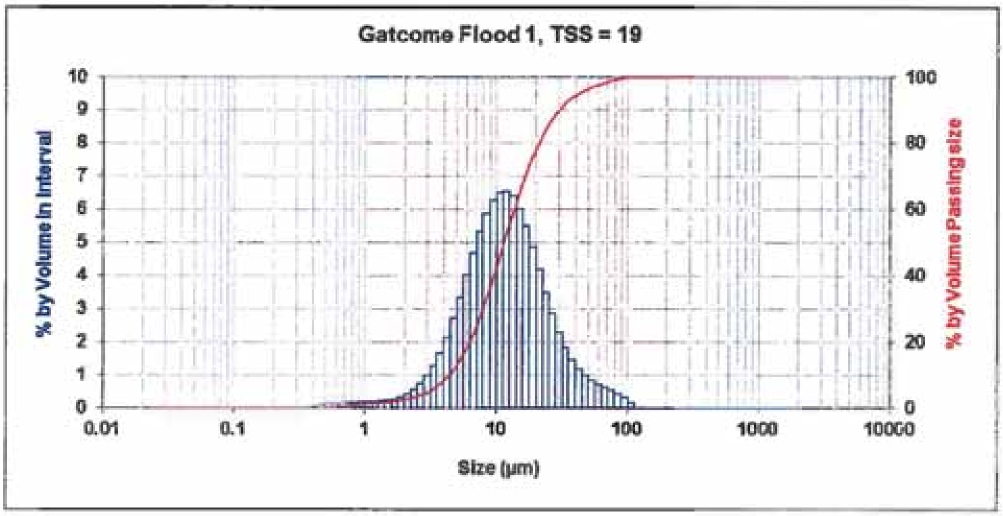


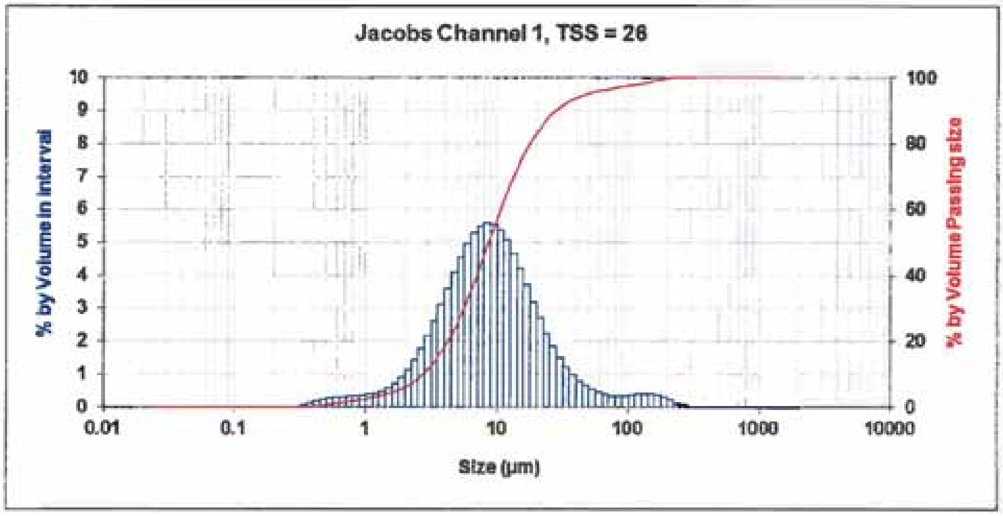
Appendix C Water Samples, TSS Analysis

TIME	DEPTH (m)	TSS (mg/L)
16/11/2014 12:20:00	0.5	5
16/11/2014 12:26:00	0.5	5
17/11/2014 17:29:50	12.9	440
17/11/2014 17:40:29	12.8	240
17/11/2014 17:48:59	12.6	140
17/11/2014 17:55:29	12.8	130
17/11/2014 18:03:27	13.6	120
17/11/2014 18:28:10	14.4	23
17/11/2014 18:41:44	15.7	42
17/11/2014 18:57:29	14.7	51
18/11/2014 12:42:22	7.1	58
18/11/2014 12:47:36	6.6	32
18/11/2014 12:58:05	7.0	94
18/11/2014 13:13:33	5.6	49
18/11/2014 14:54:05	10.1	19
18/11/2014 15:03:19	8.7	17
18/11/2014 15:35:19	2.7	6
18/11/2014 15:45:13	8.2	13
18/11/2014 15:48:34	1.4	9
18/11/2014 16:20:28	7.4	7
19/11/2014 13:24:12	0.3	32
19/11/2014 14:26:39	10.5	12
19/11/2014 16:16:59	12.4	57
19/11/2014 16:22:37	11.3	49

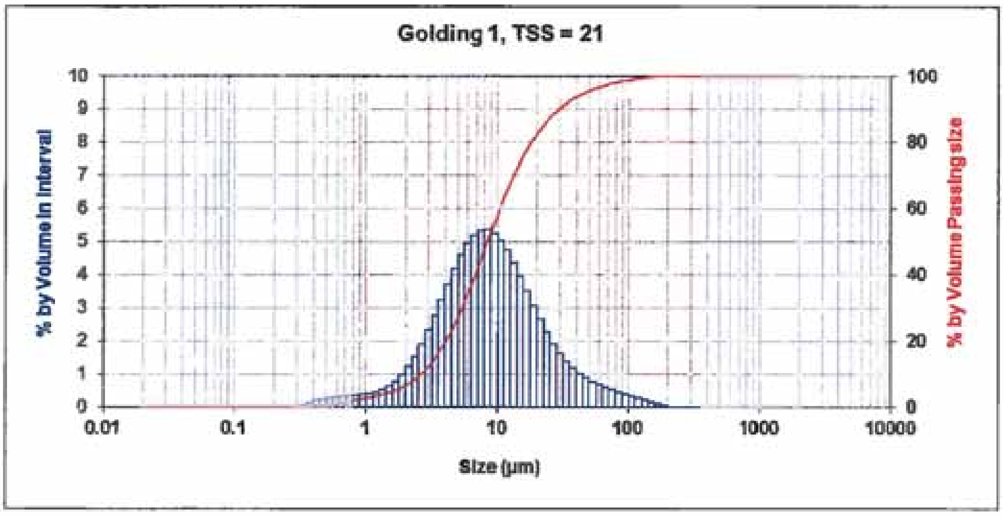
Appendix D Water Samples, PSD Analysis

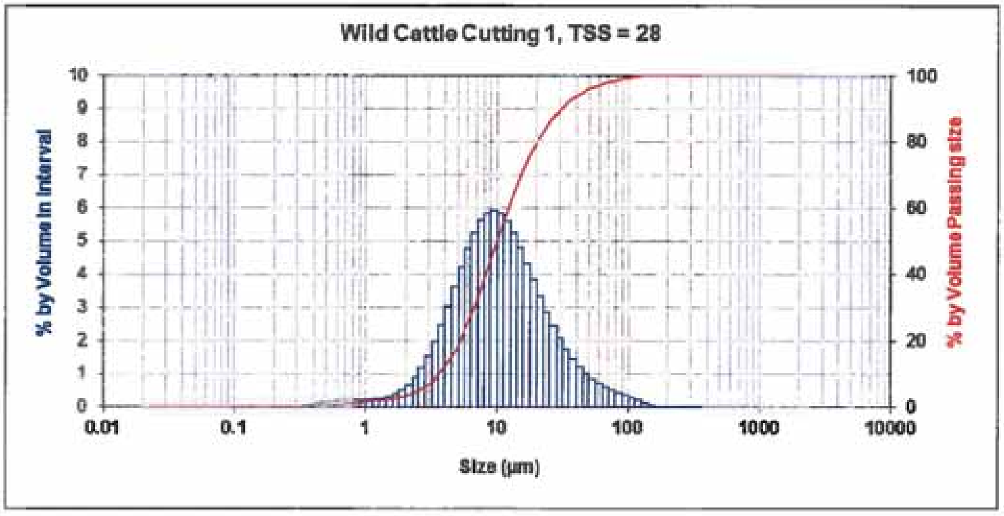


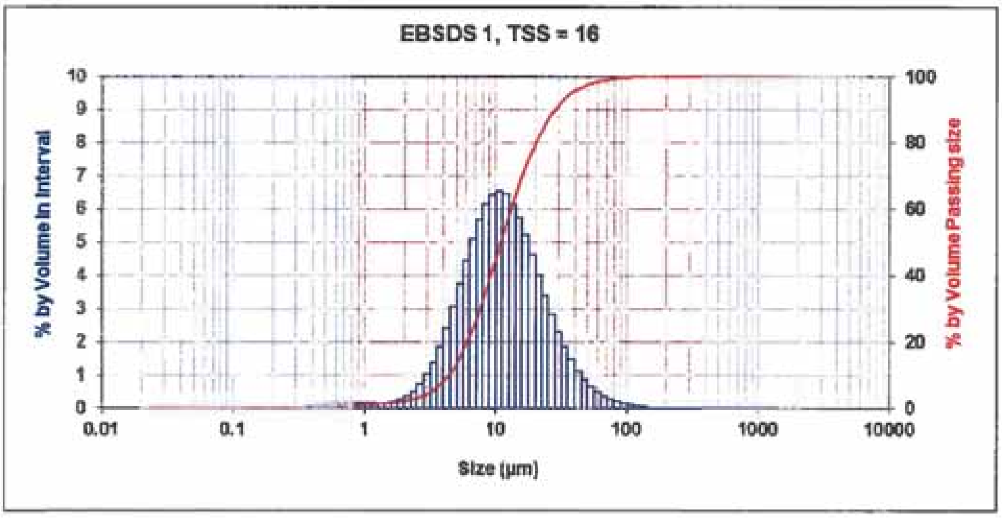




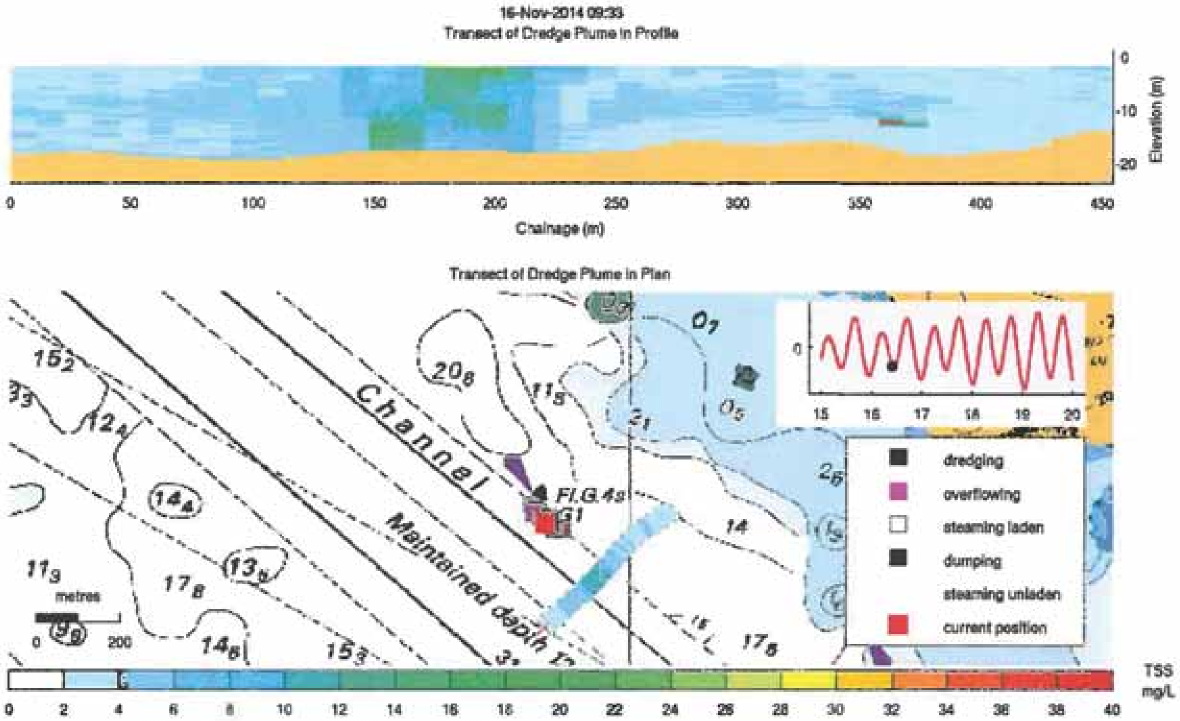
Water Samples, PSD Analysis

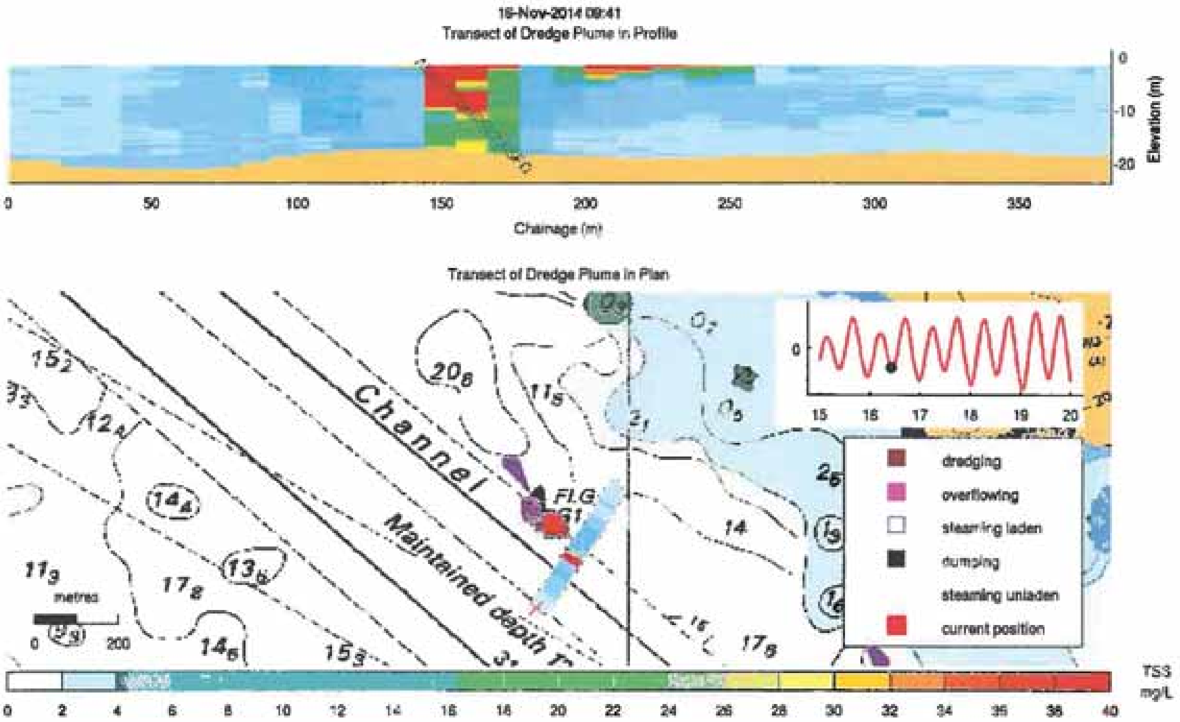




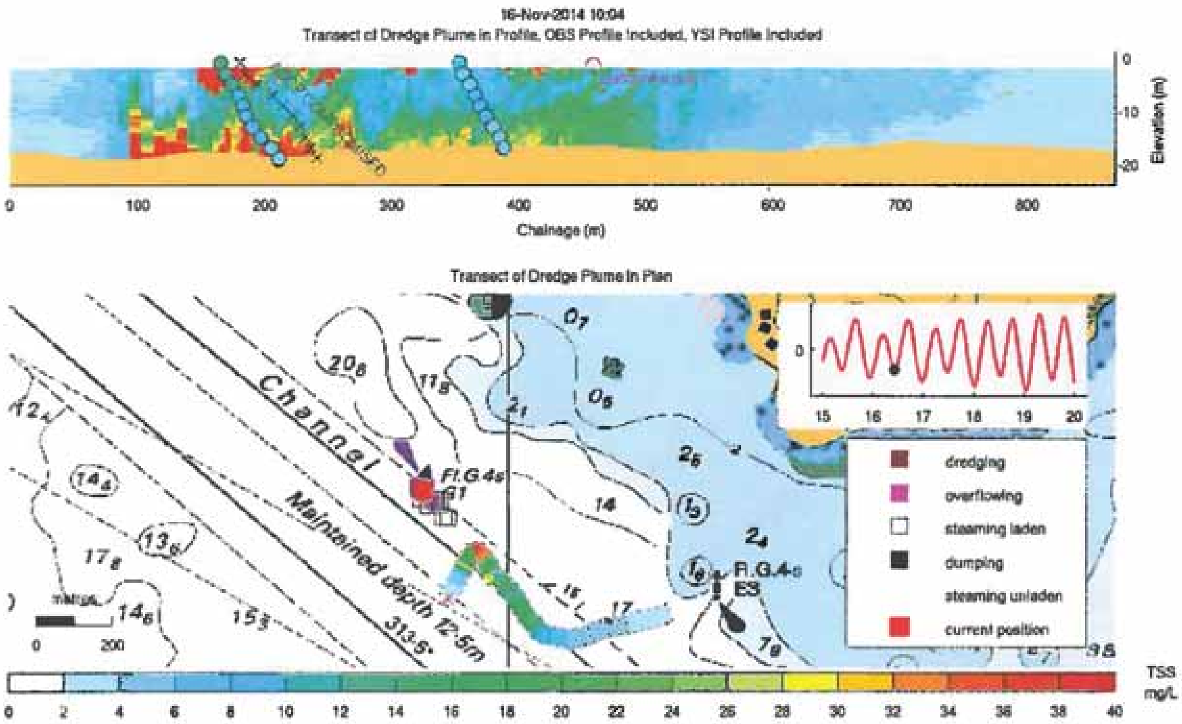


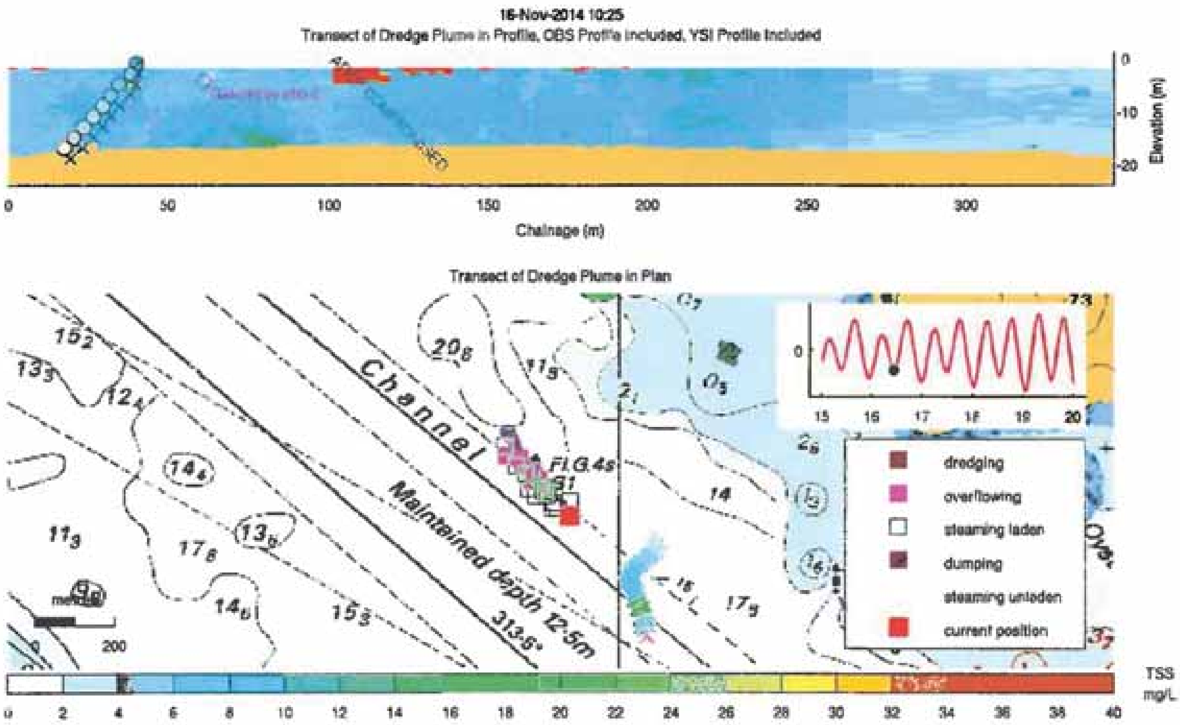
Appendix E Dredging at Gatcombe Channel, Ebb Tide



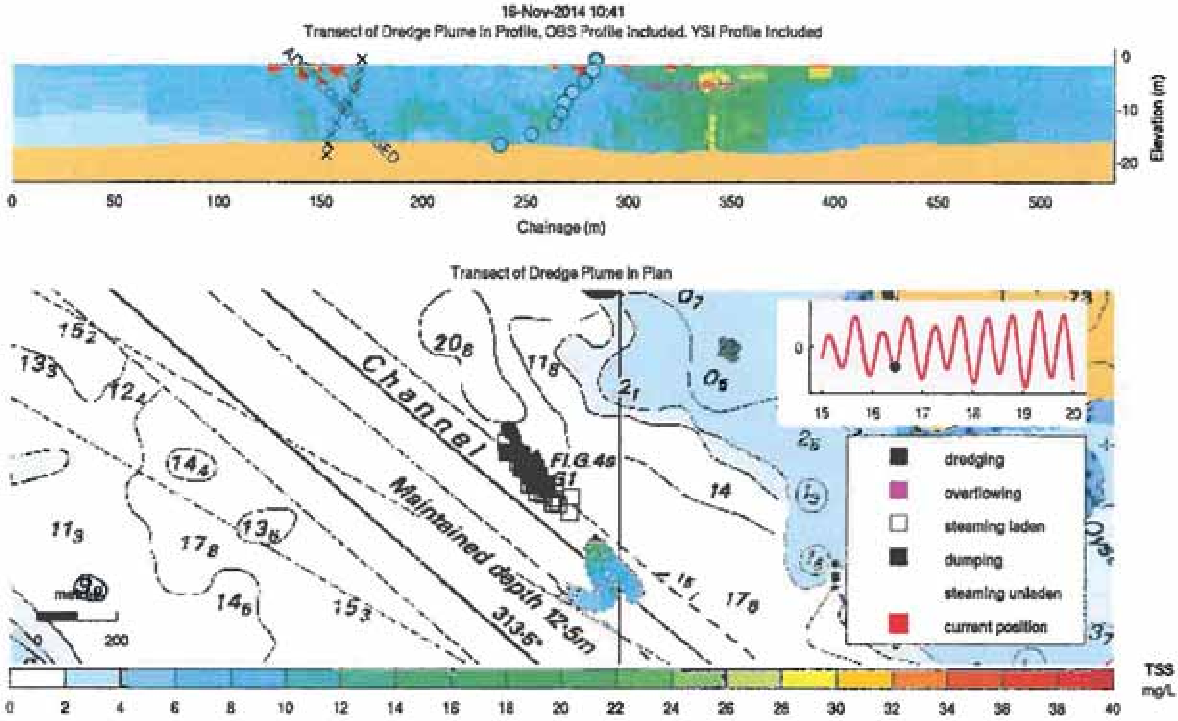


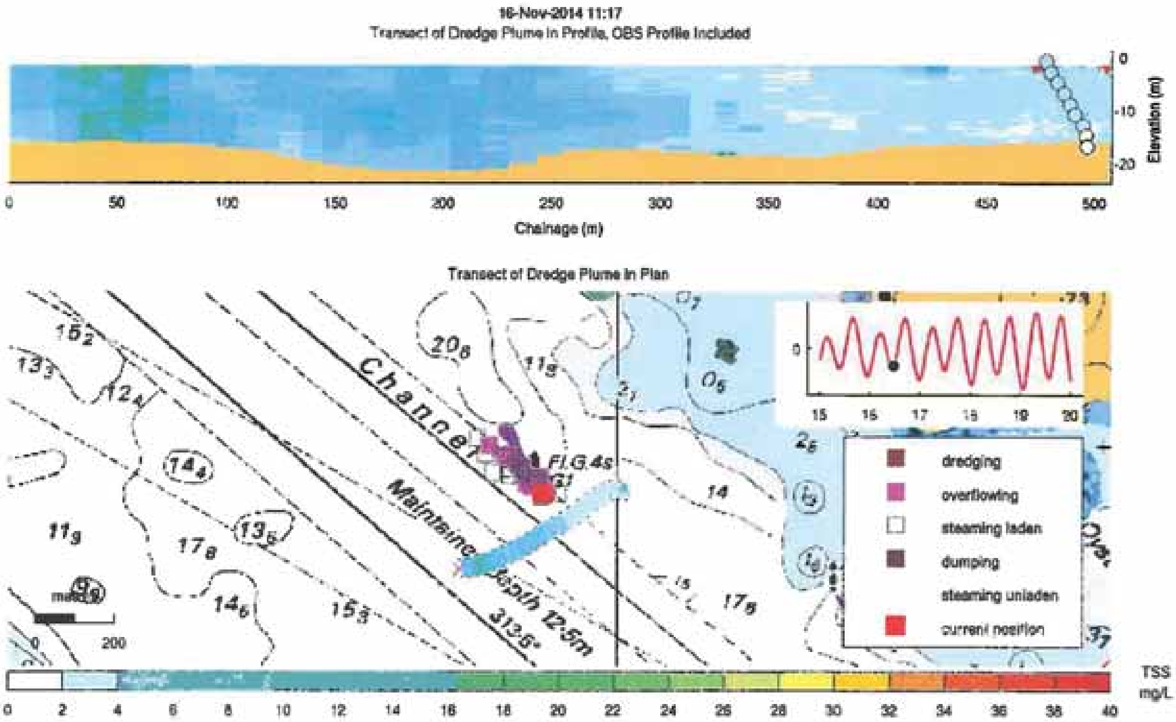
Dredging at Gatcombe Channel, Ebb Tide



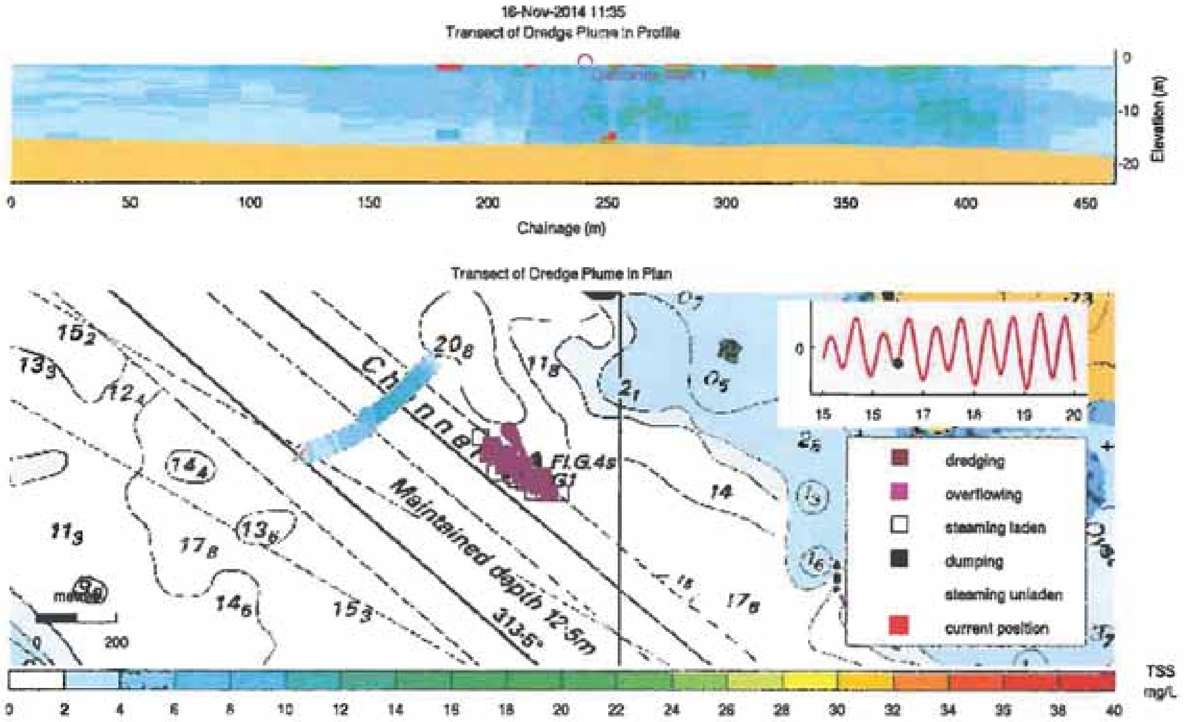


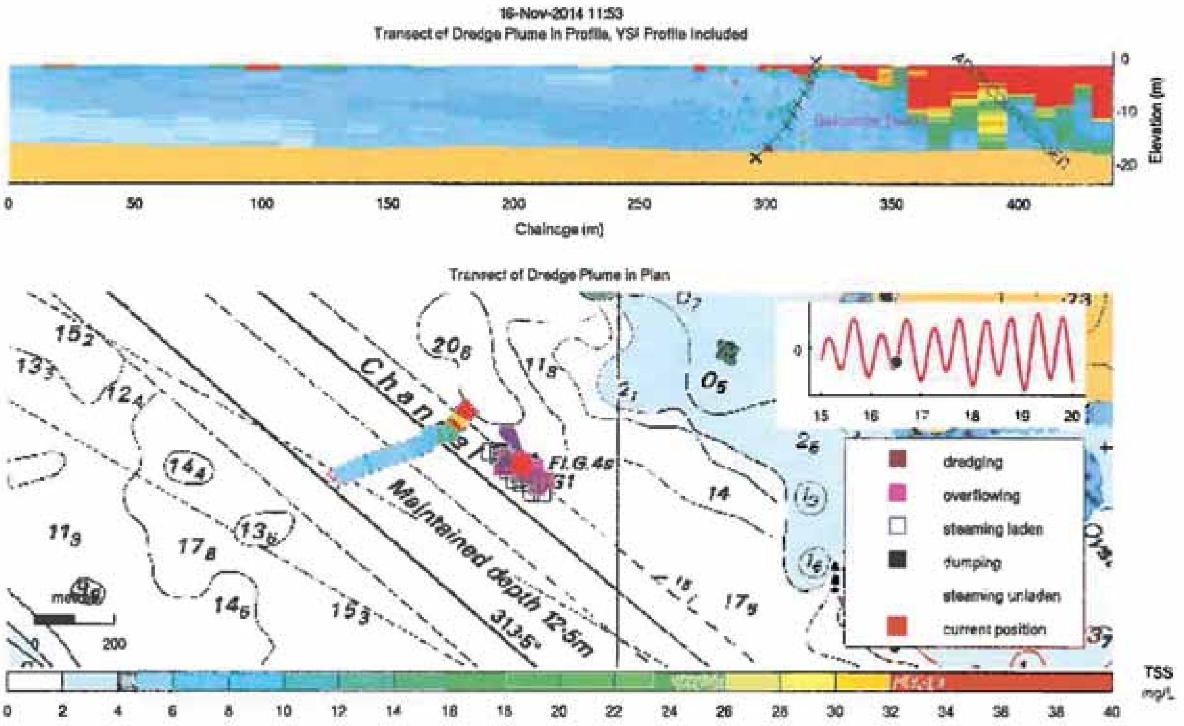
Dredging at Gatcombe Channel, Ebb Tide



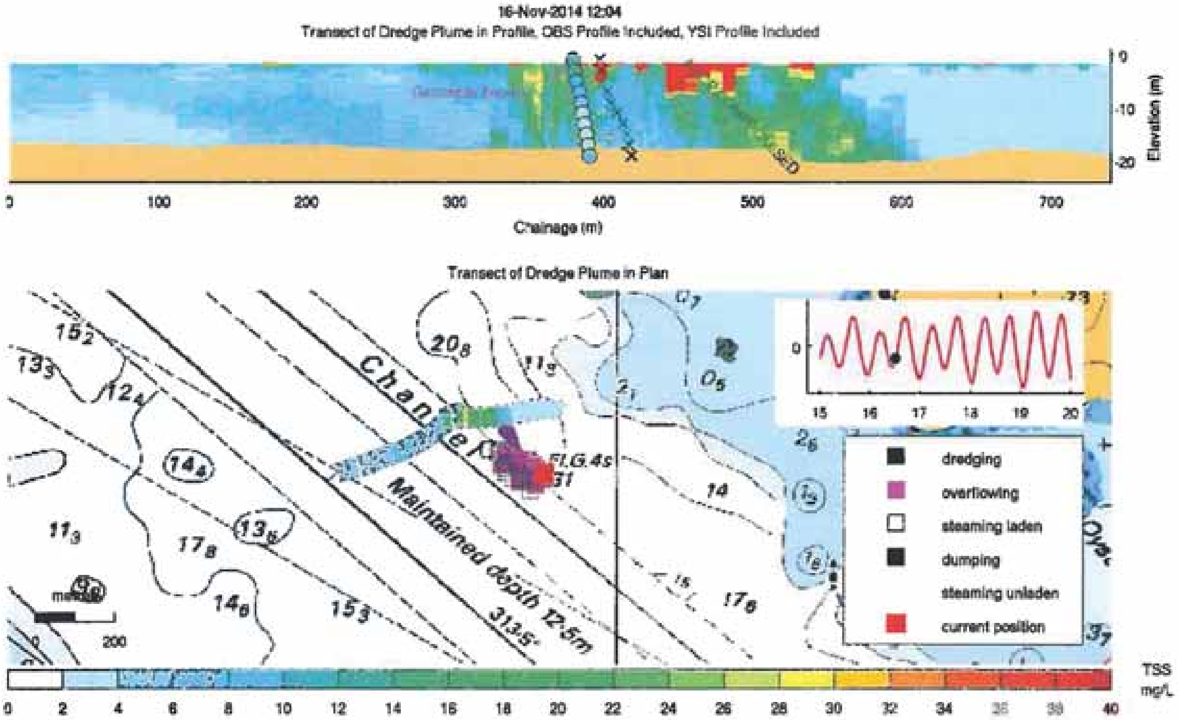


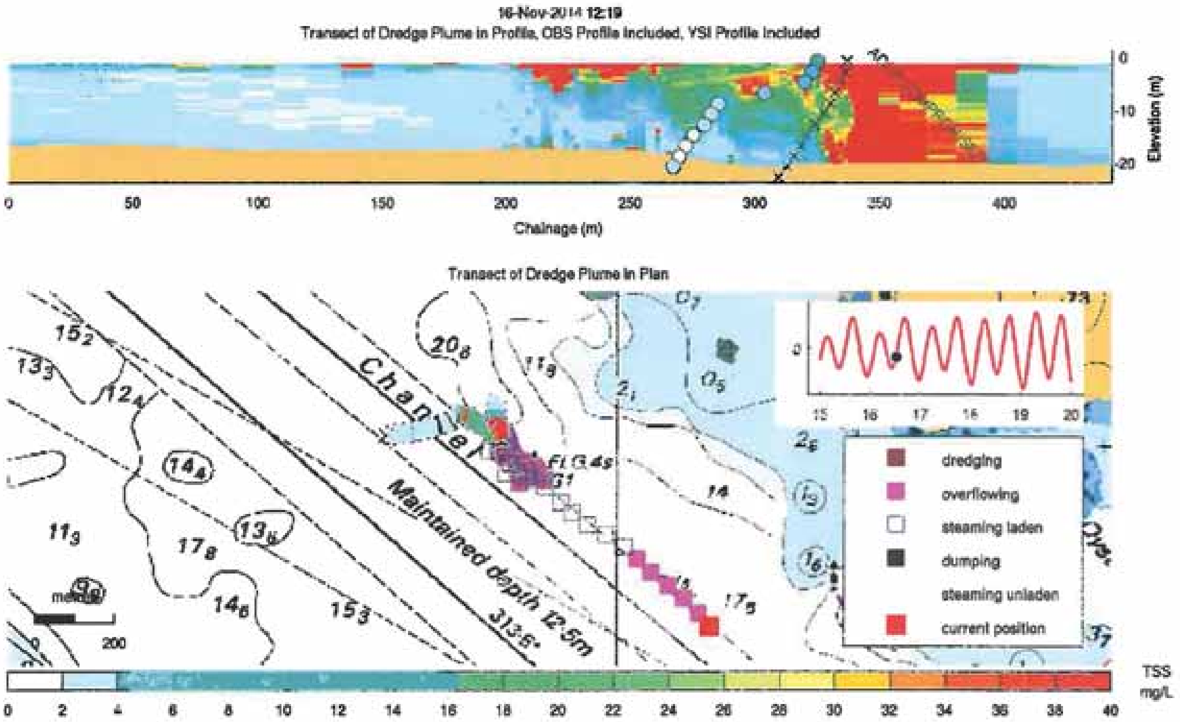
Appendix F Dredging at Gatcombe Channel, Flood Tide



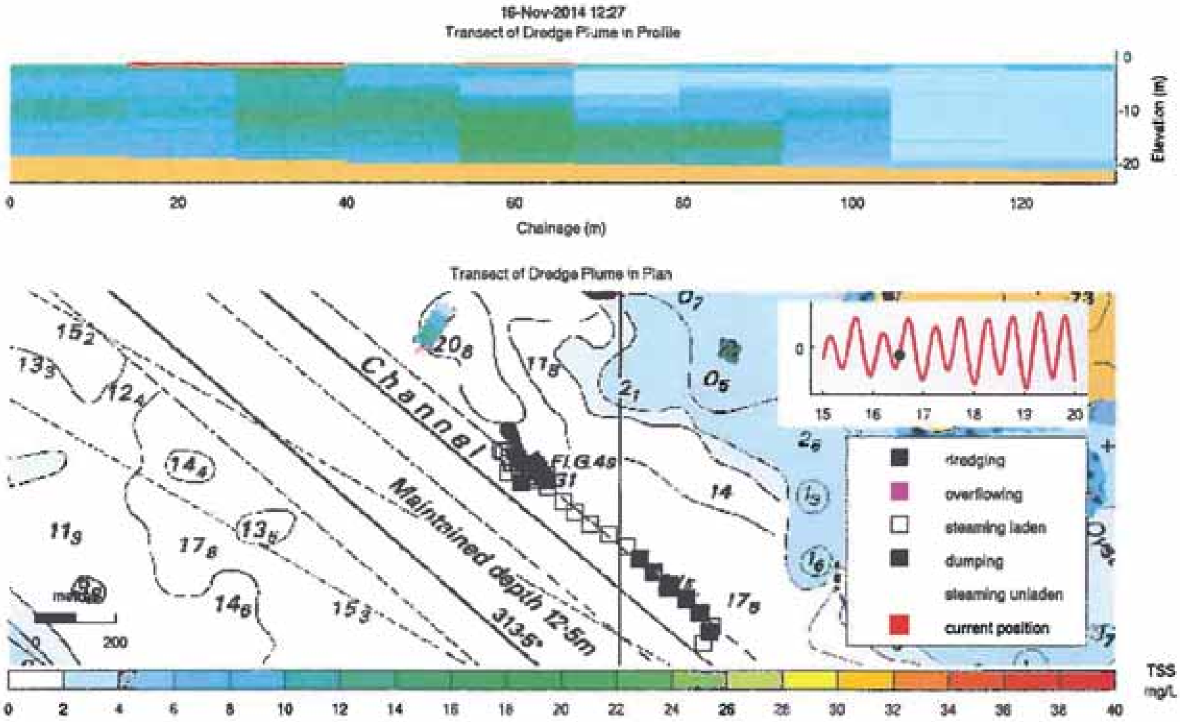


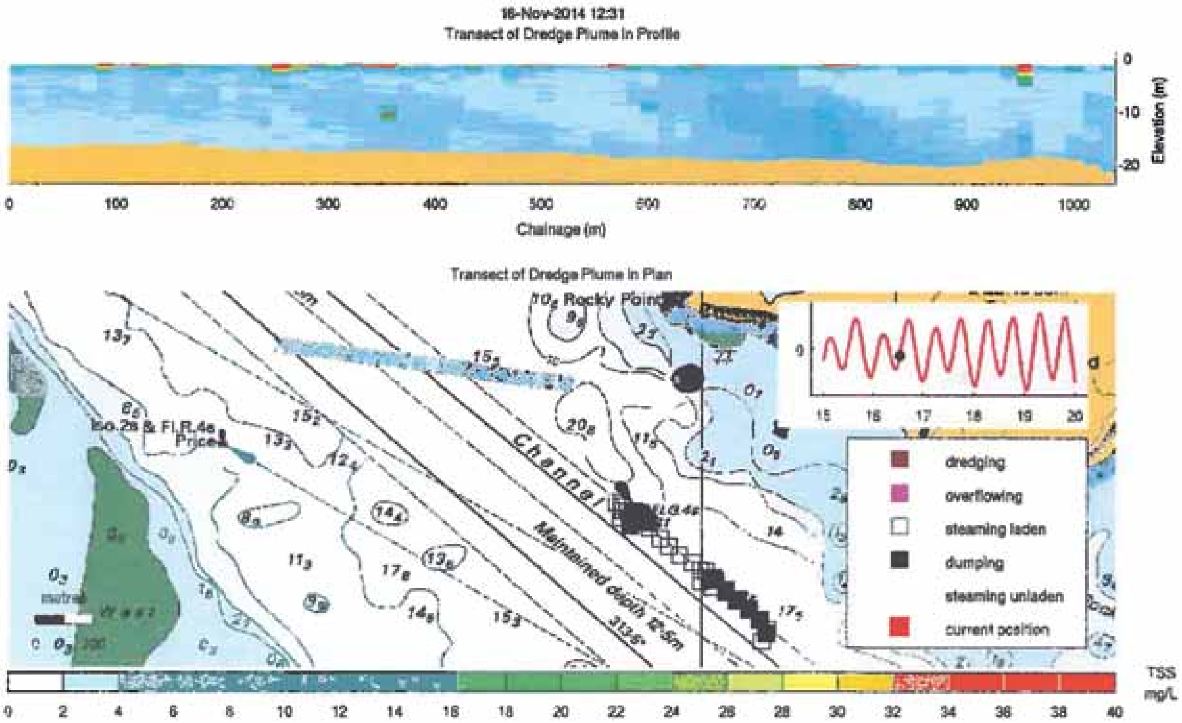
Dredging at Gatcombe Channel, Flood Tide



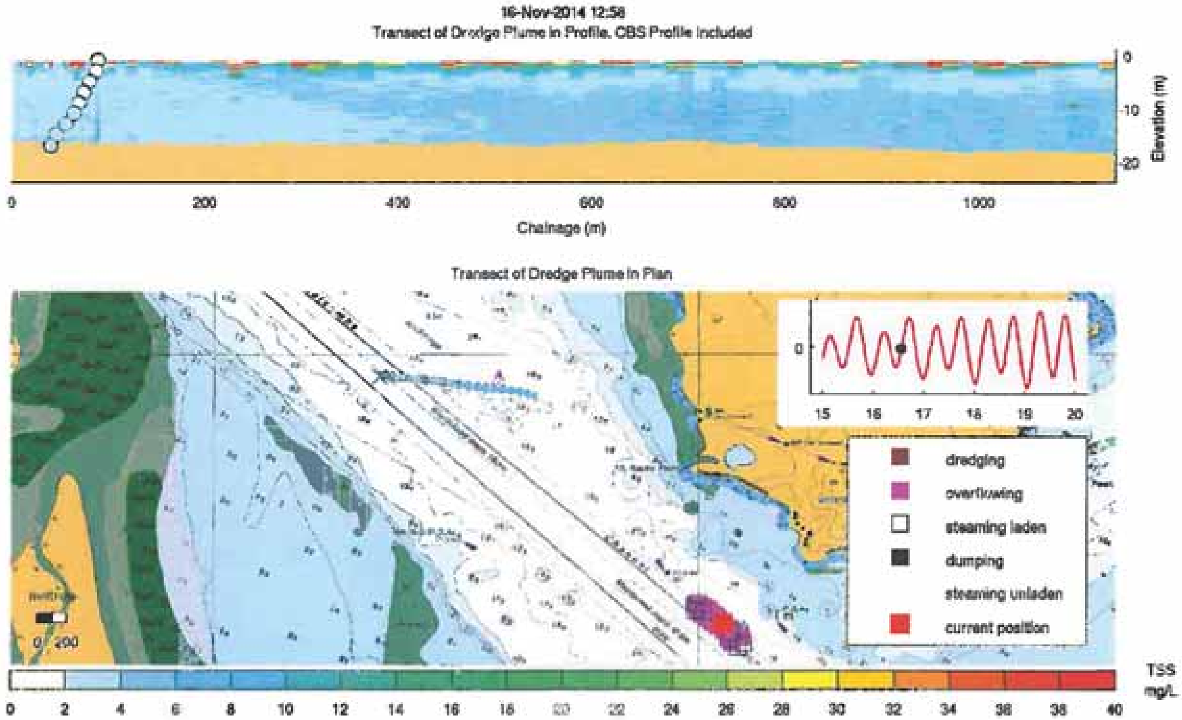


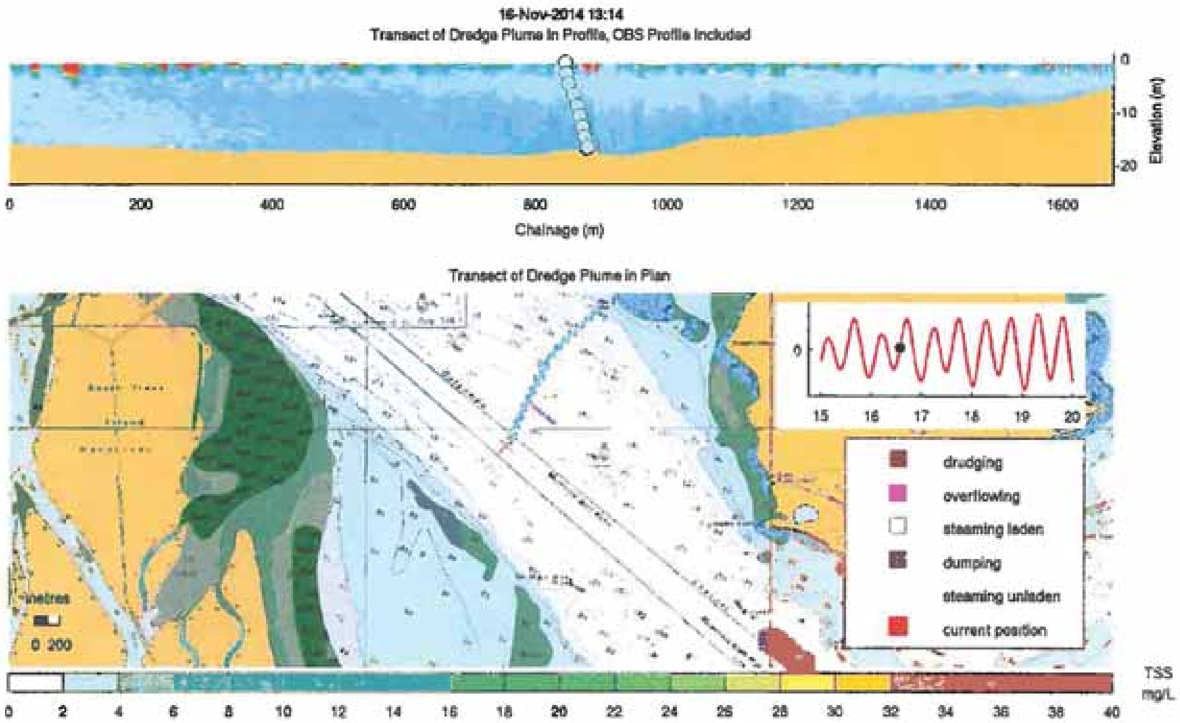
Dredging at Gatcombe Channel, Flood Tide



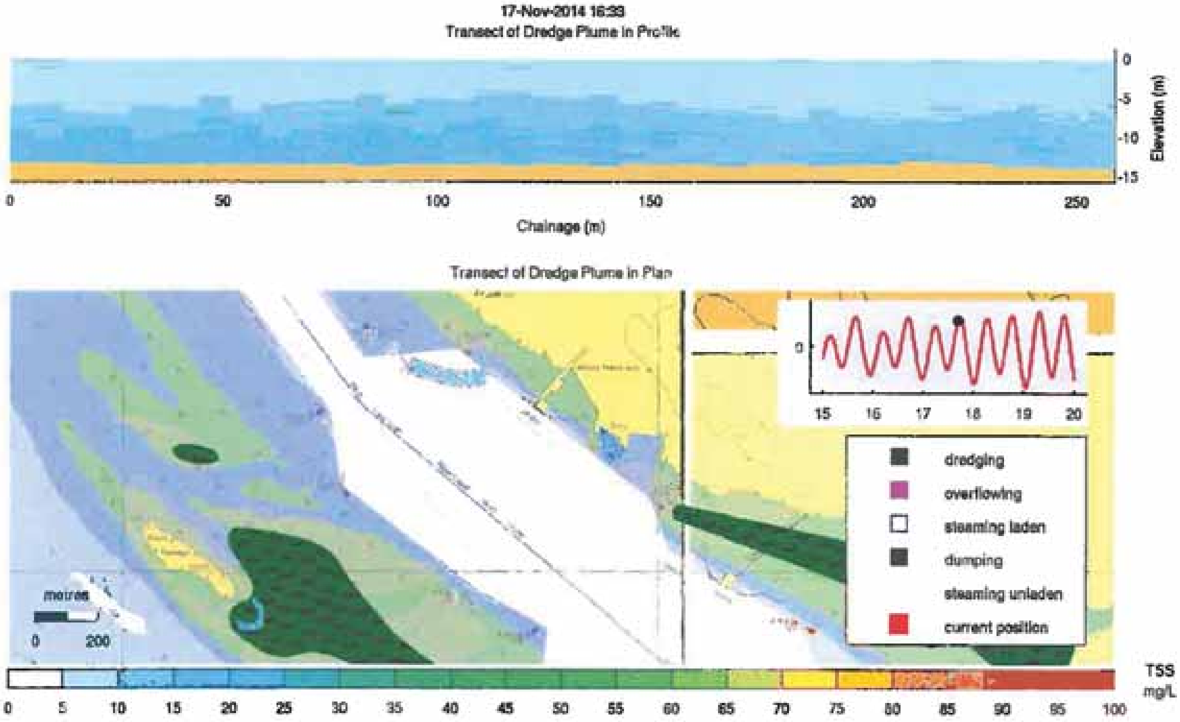


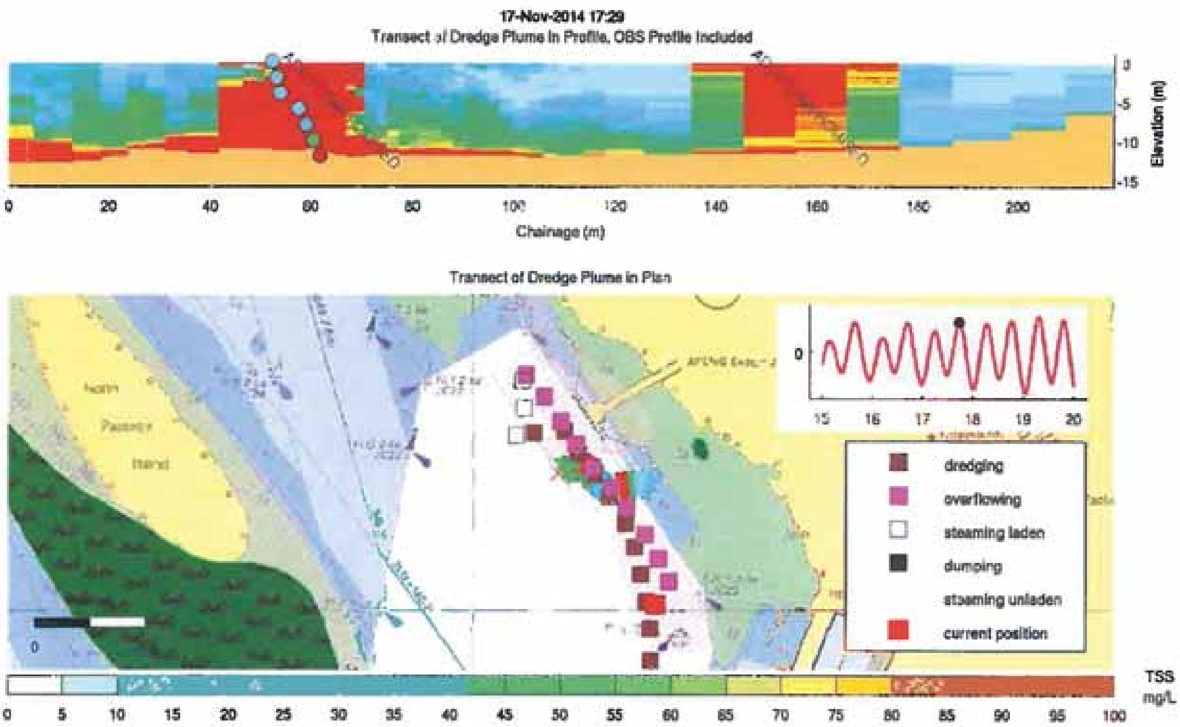
Dredging at Gatcombe Channel, Flood Tide



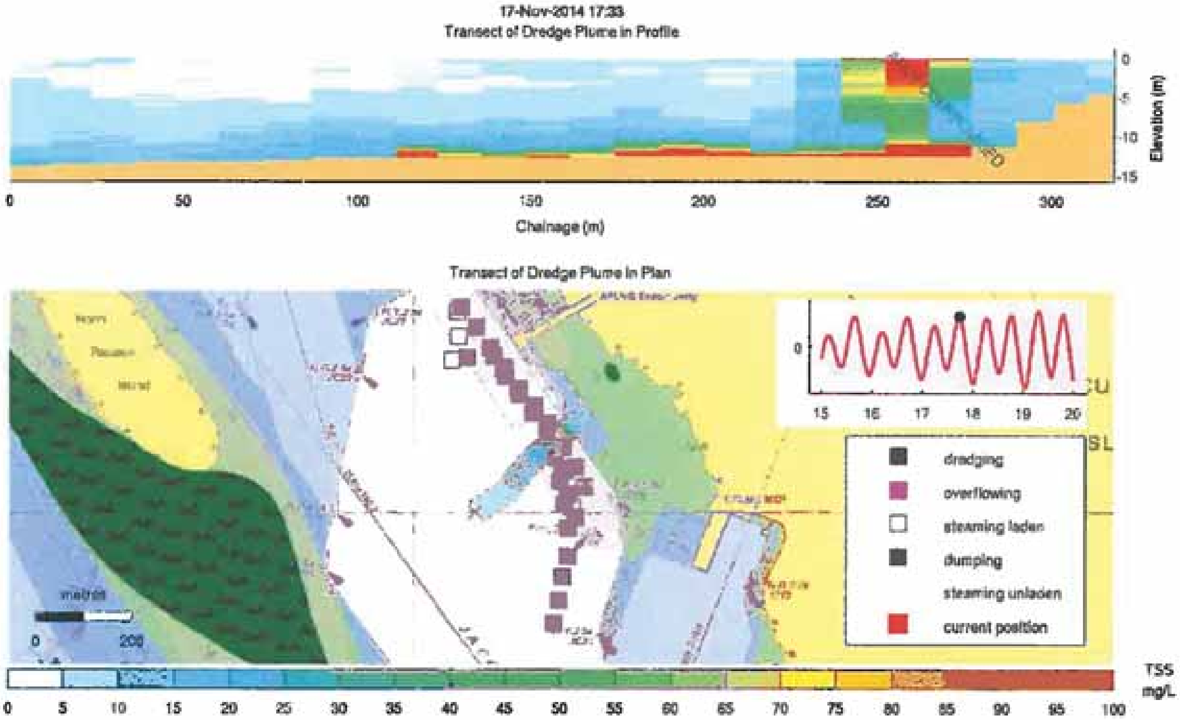


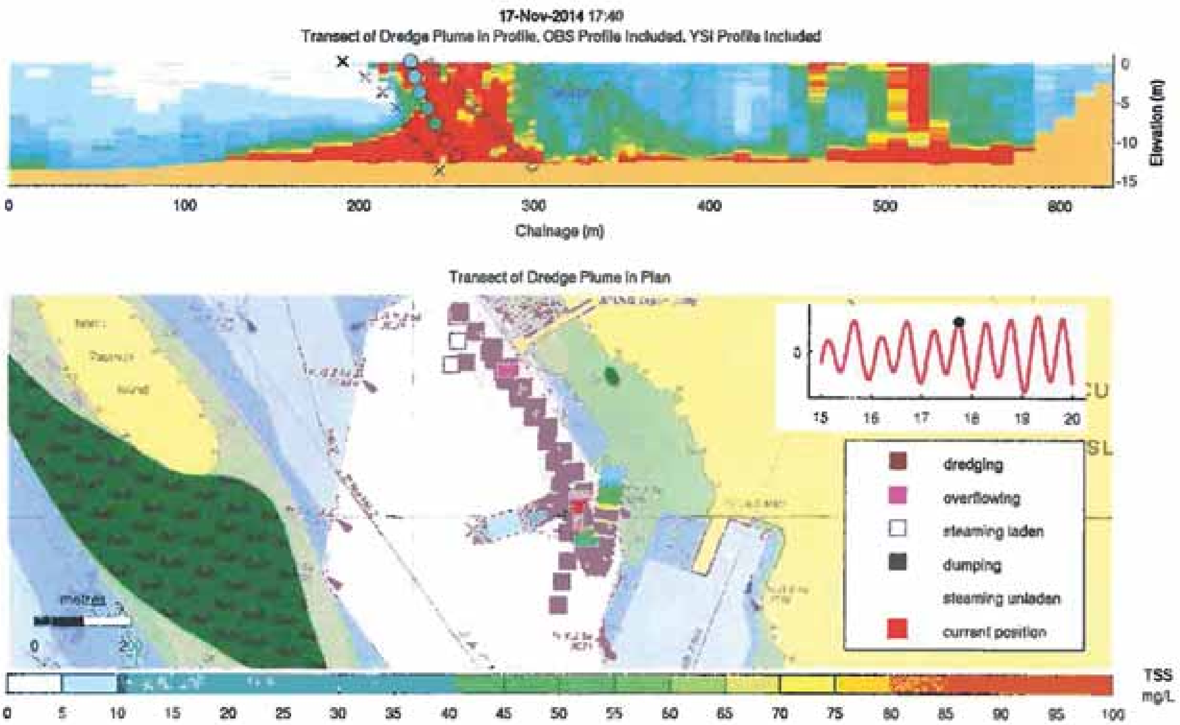
Appendix G Dredging at Jacobs Channel



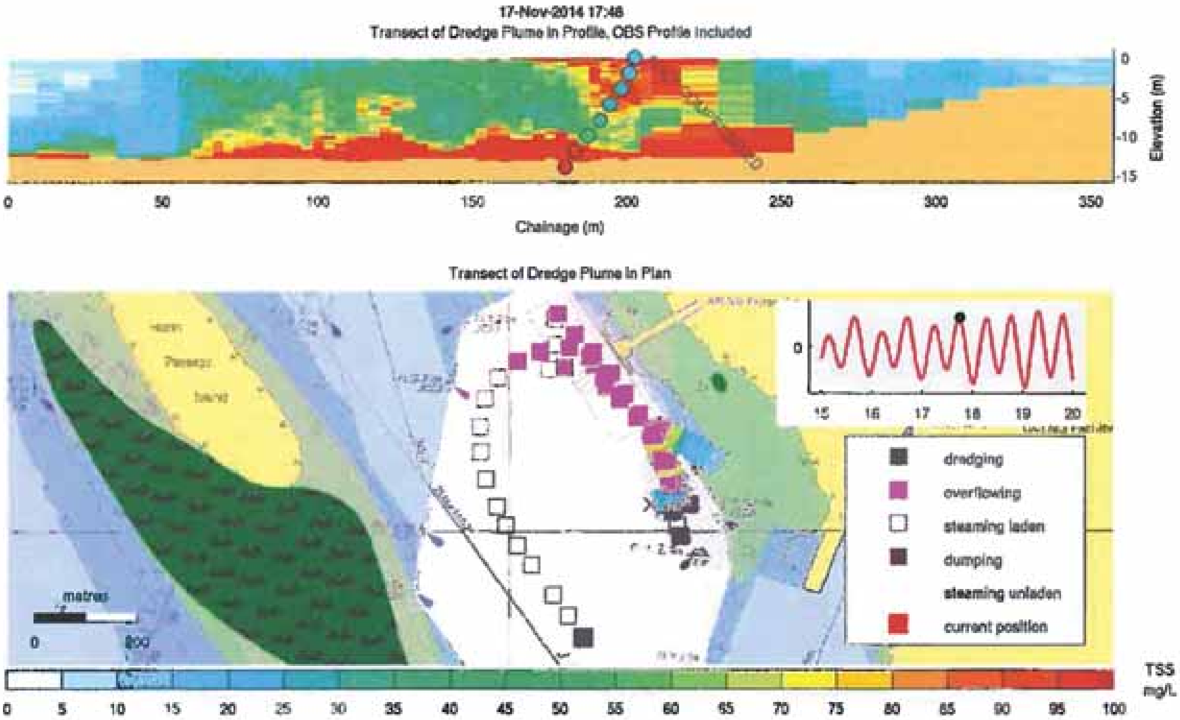


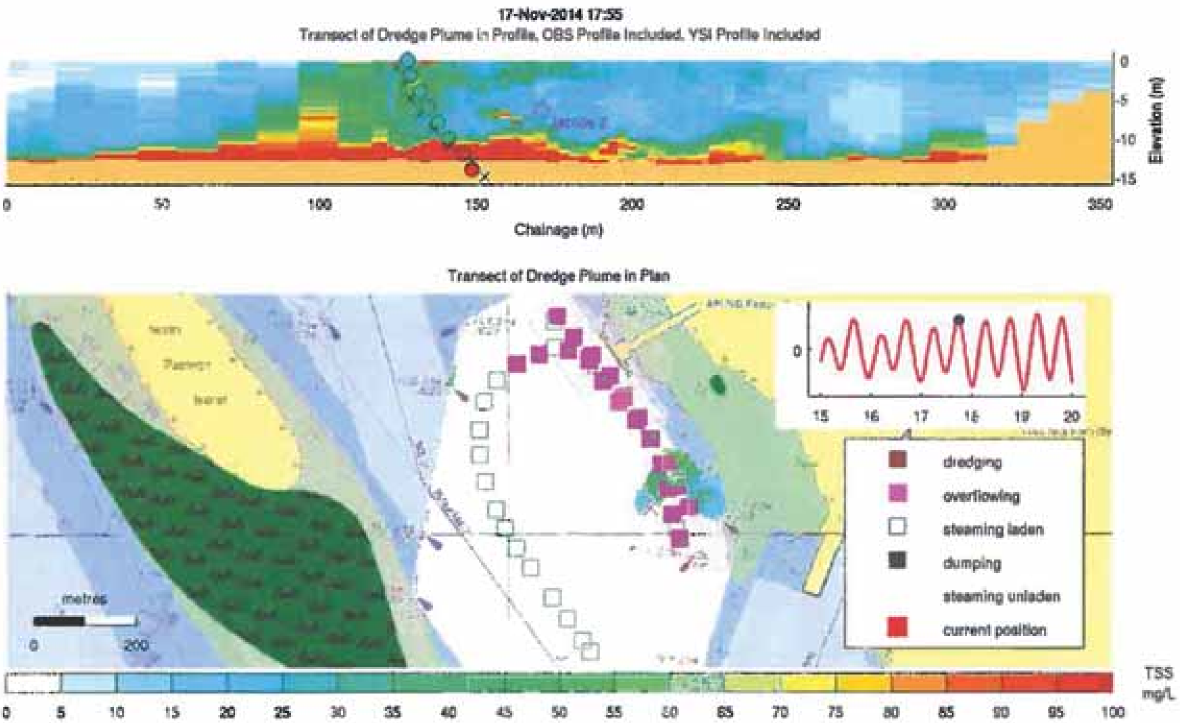
Dredging at Jacobs Channel



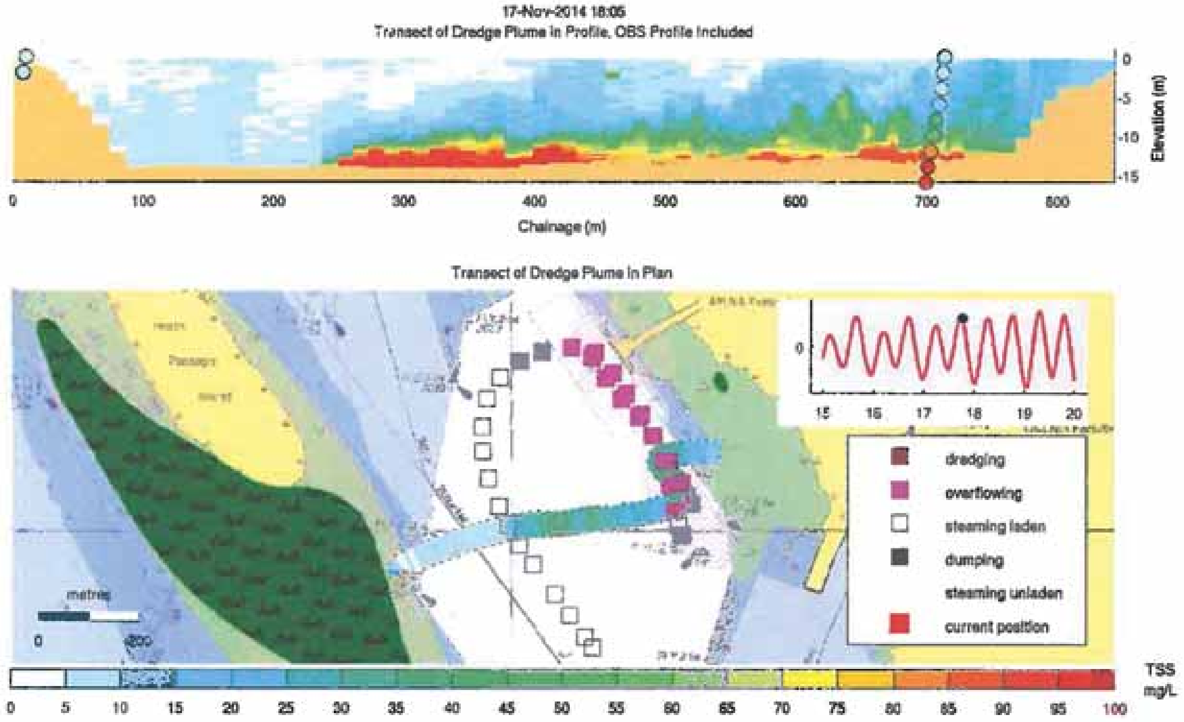


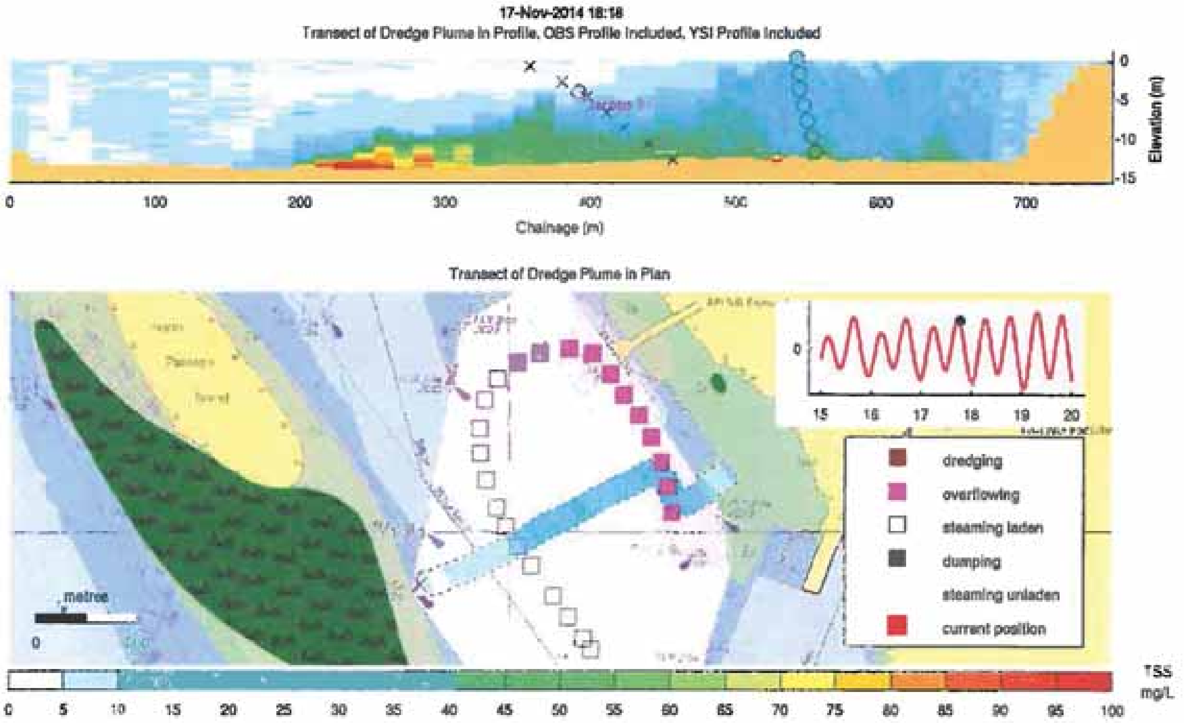
Dredging at Jacobs Channel



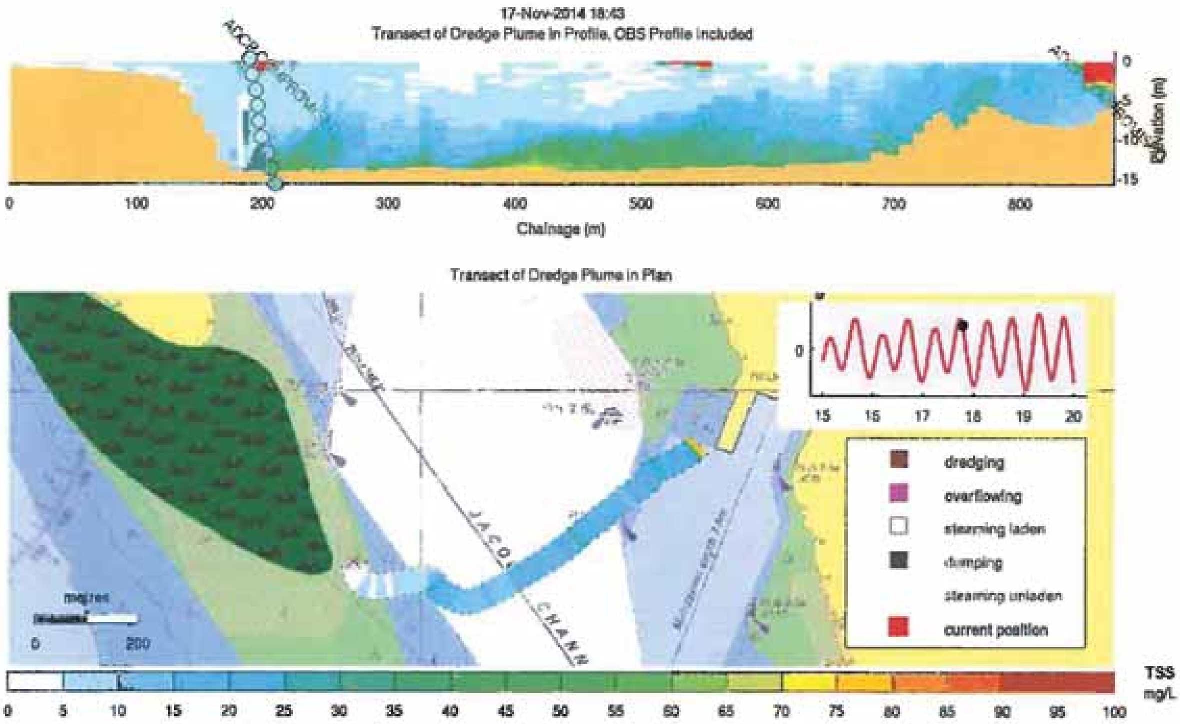


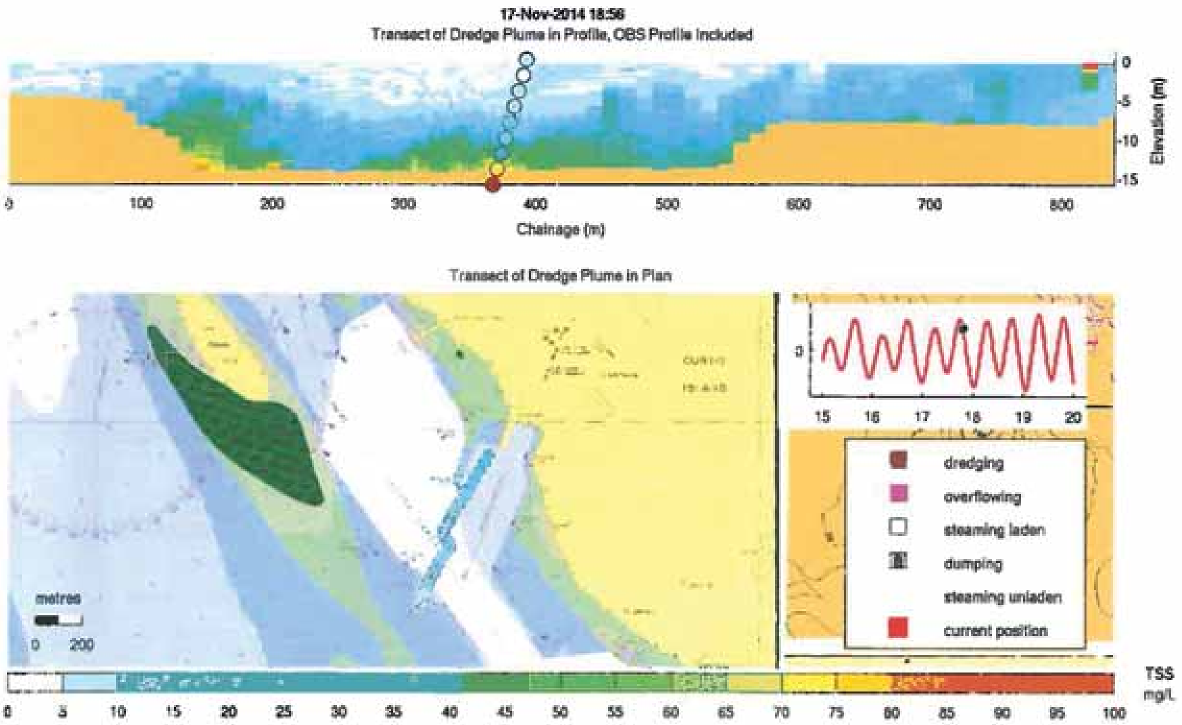
Dredging at Jacobs Channel





Dredging at Jacobs Channel

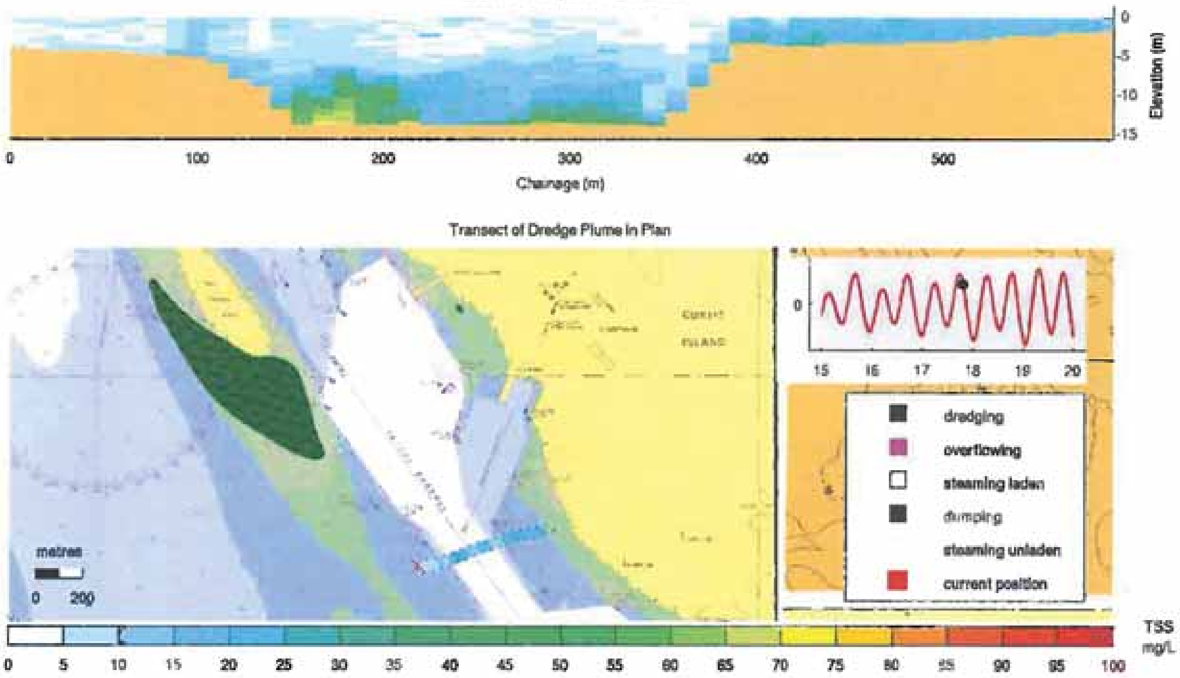




Dredging at Jacobs Channel

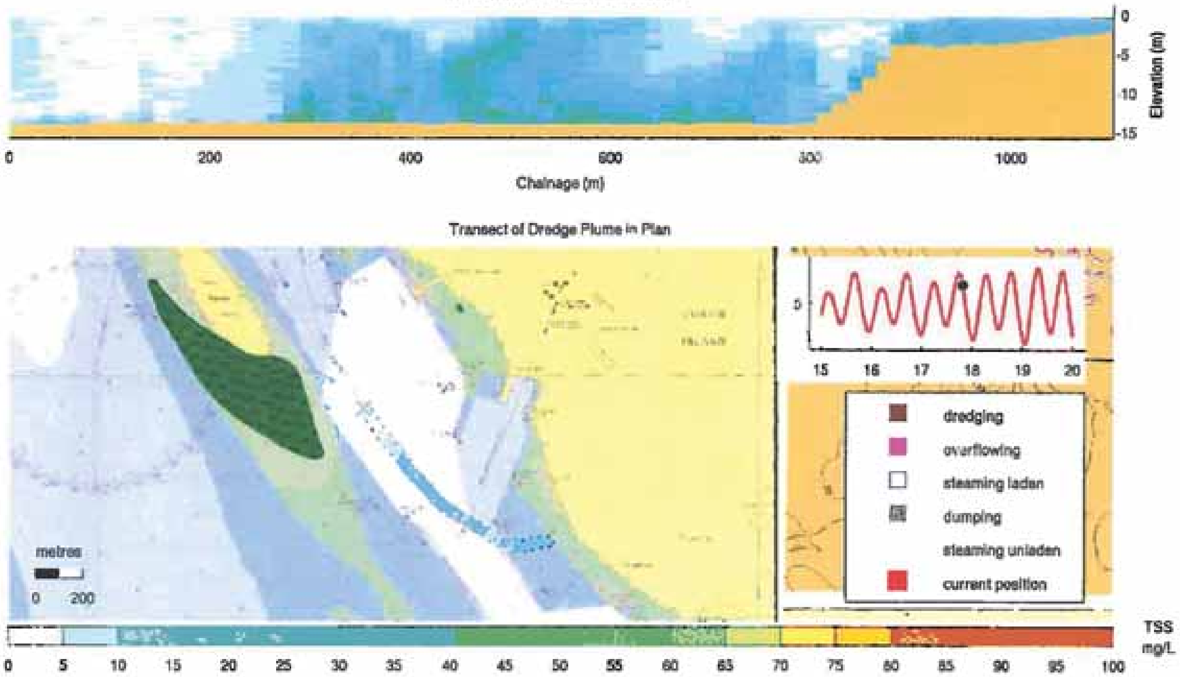
17-Nov-2014 19:06

Transect of Dredge Plume in Profile

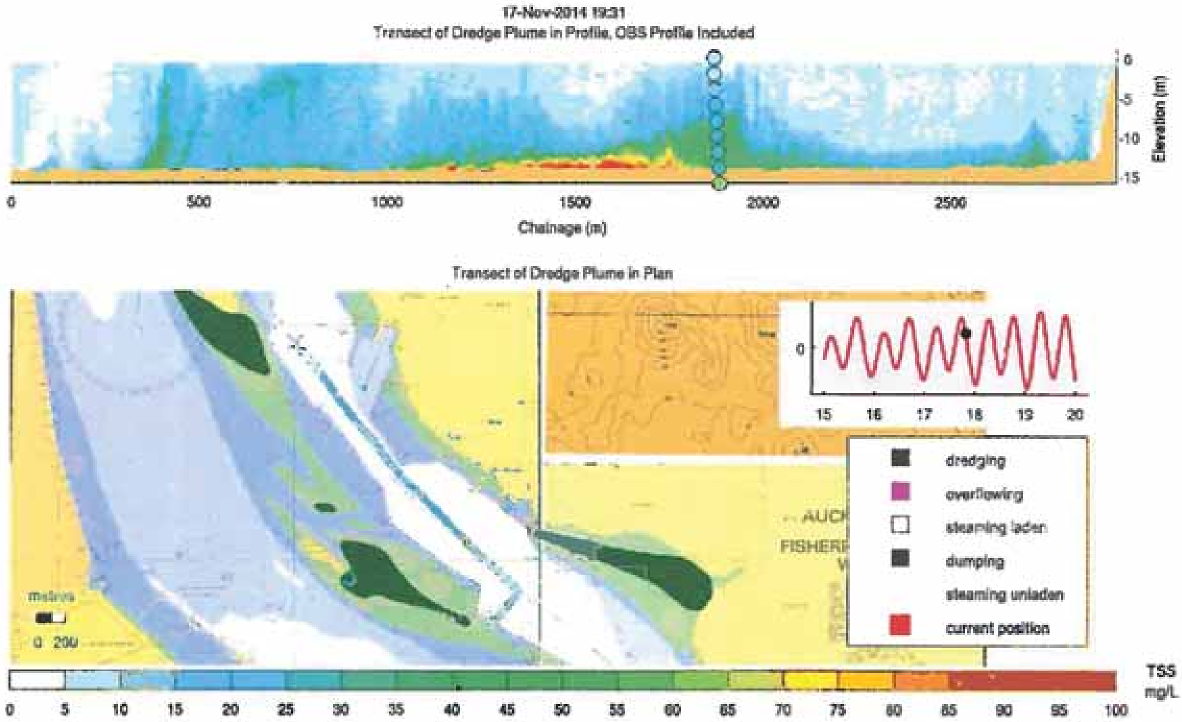


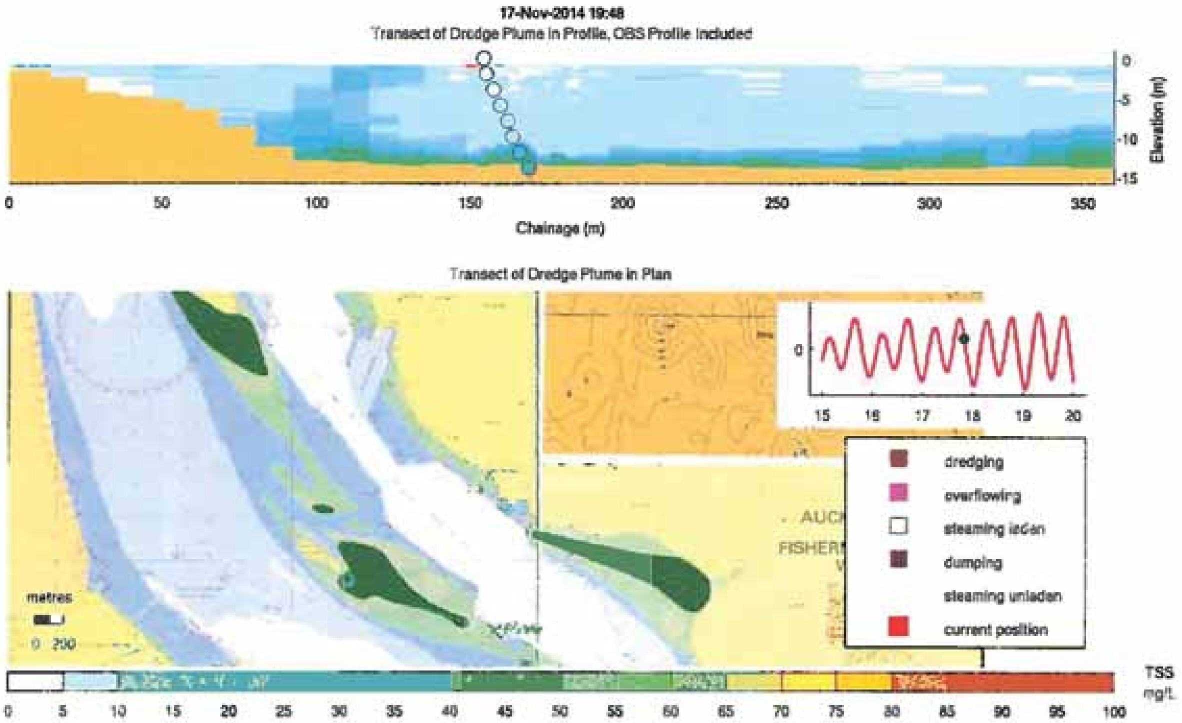
17-Nov-2014 19:14

Transect of Dredge Plume in Profile

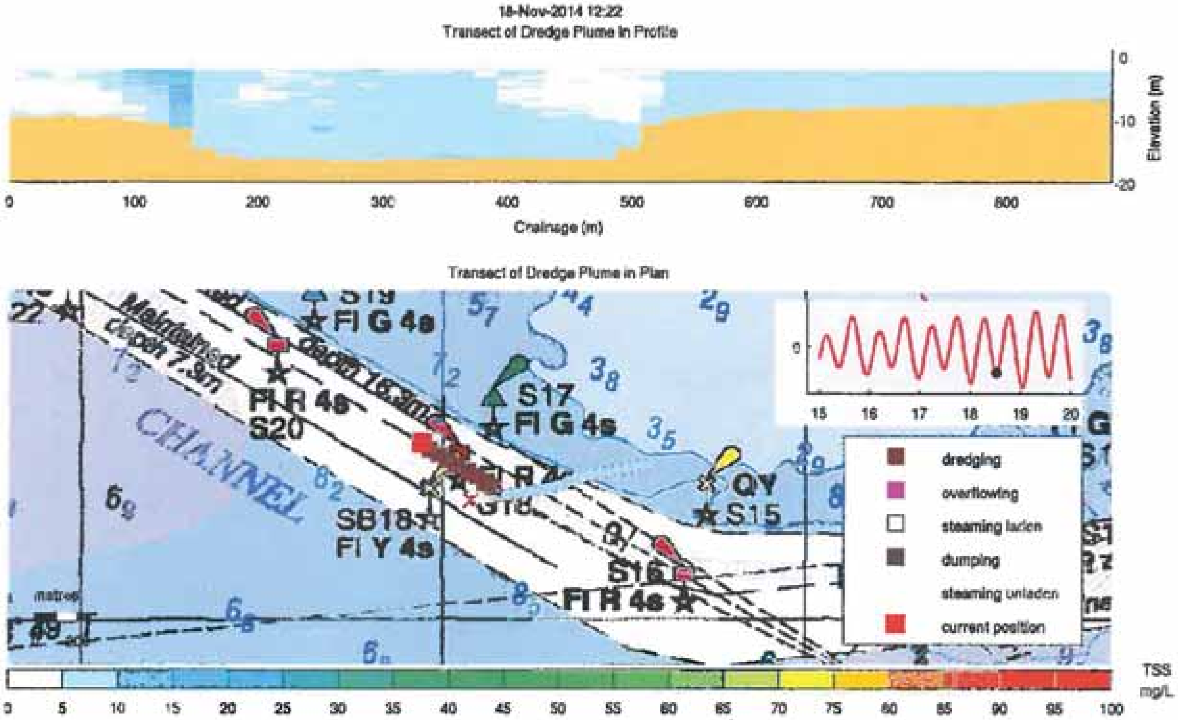


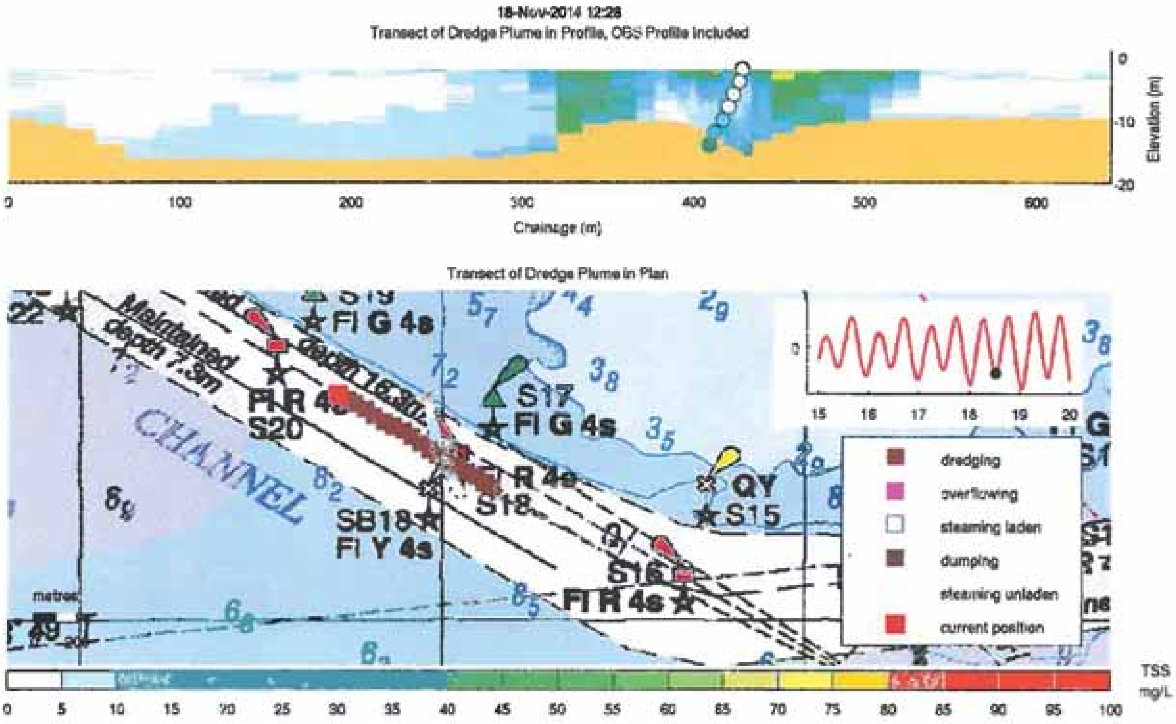
Dredging at Jacobs Channel



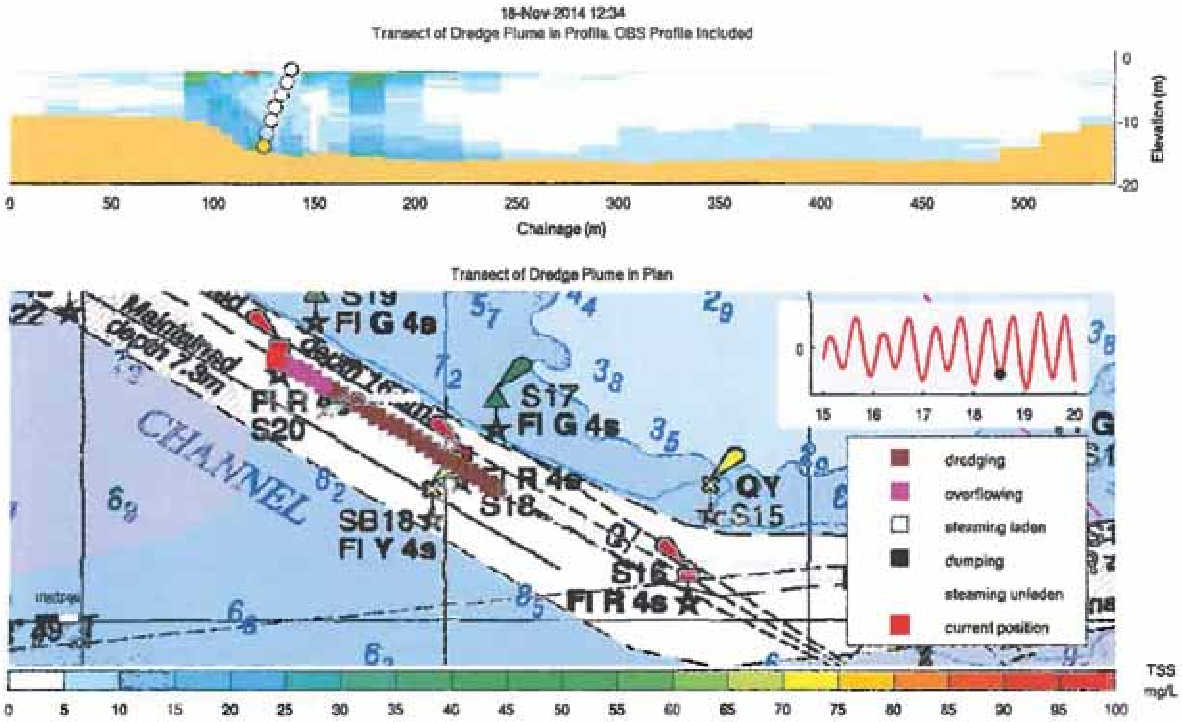


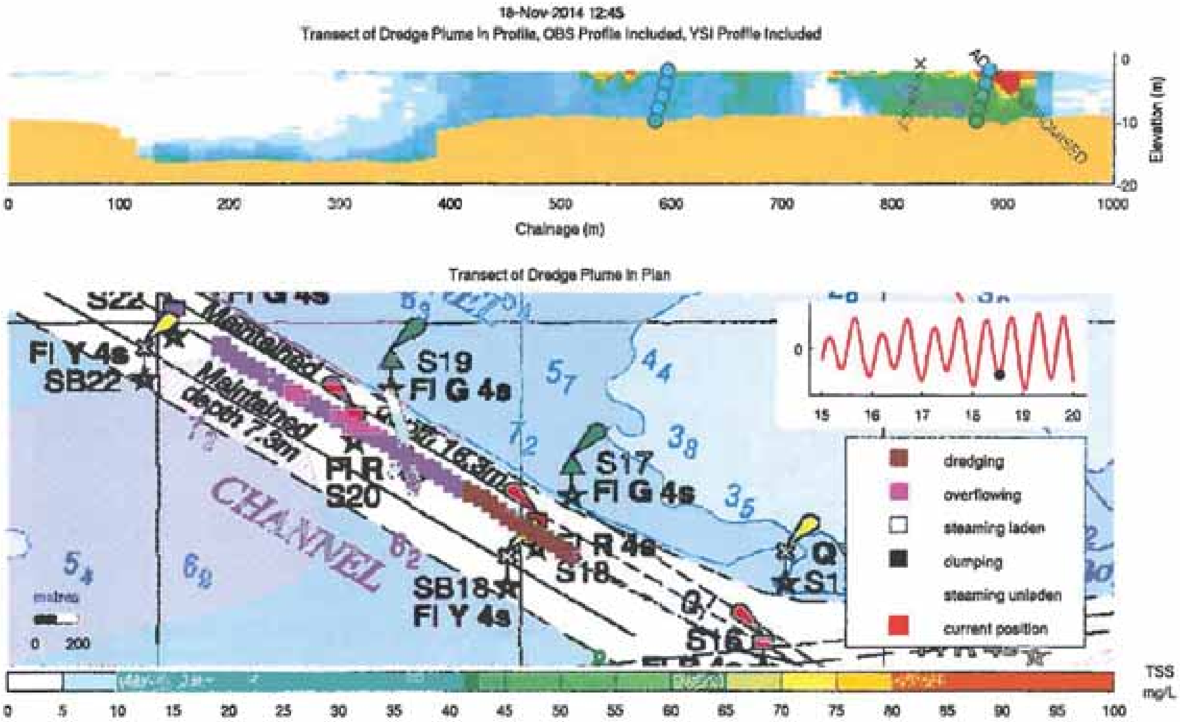
Appendix H Dredging at Golding Cutting

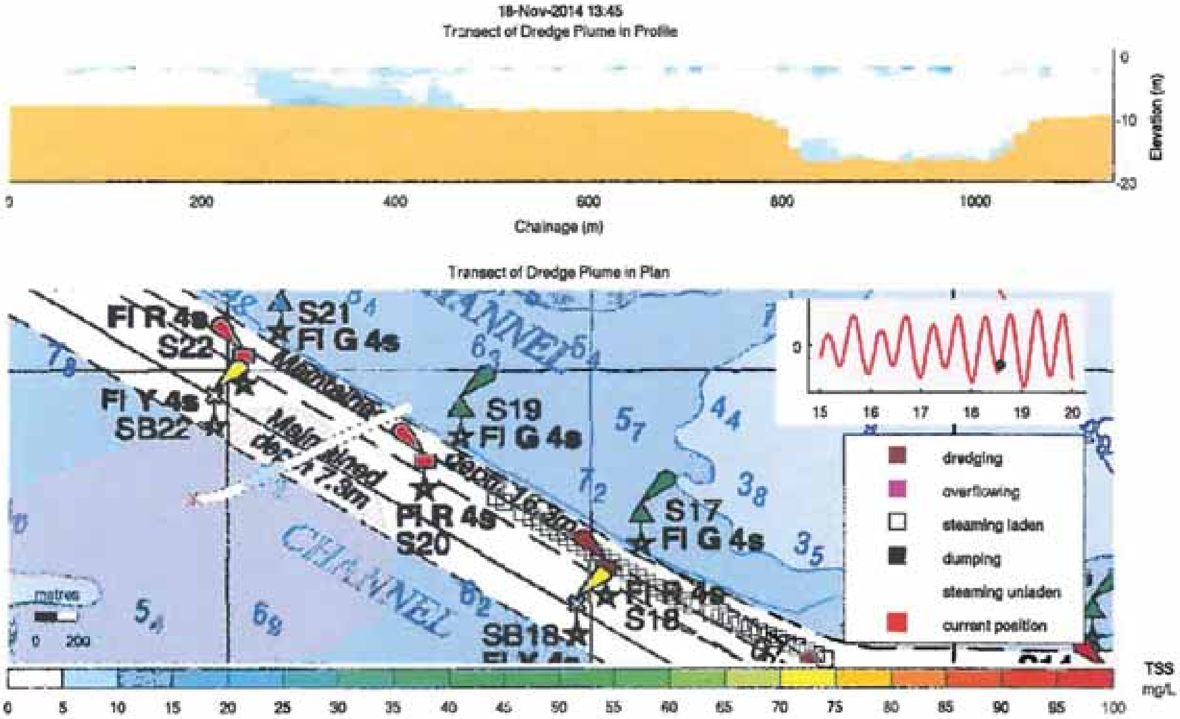


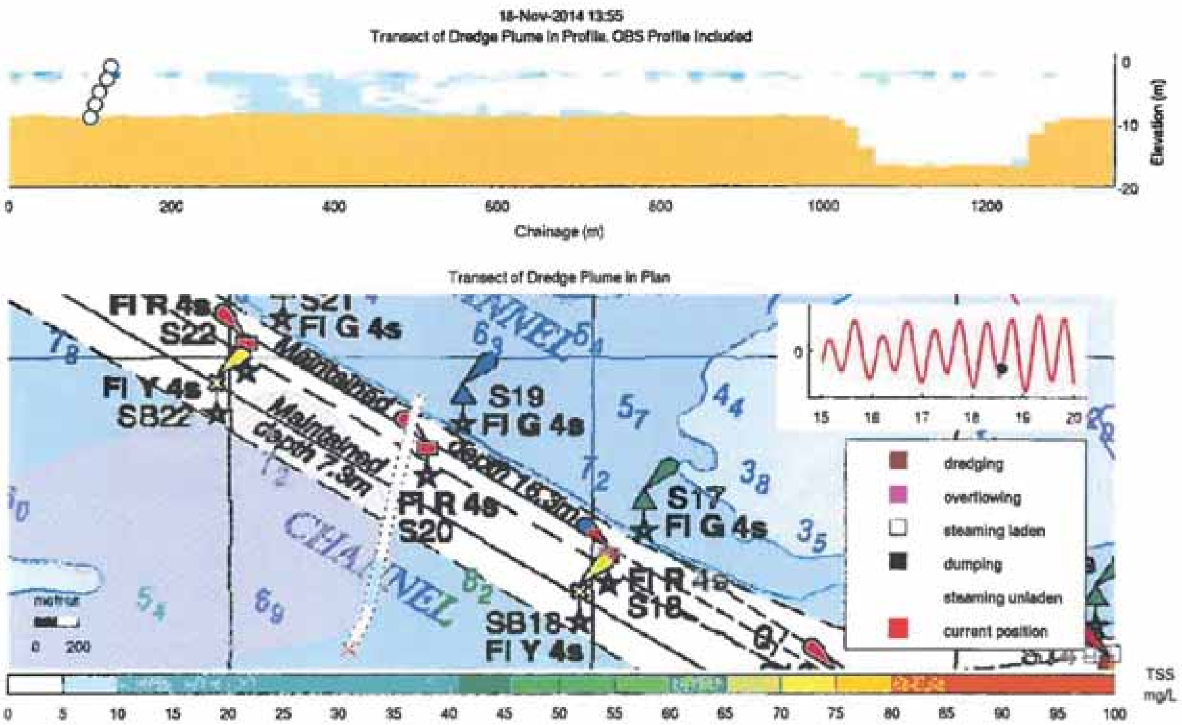


Dredging at Golding Cutting

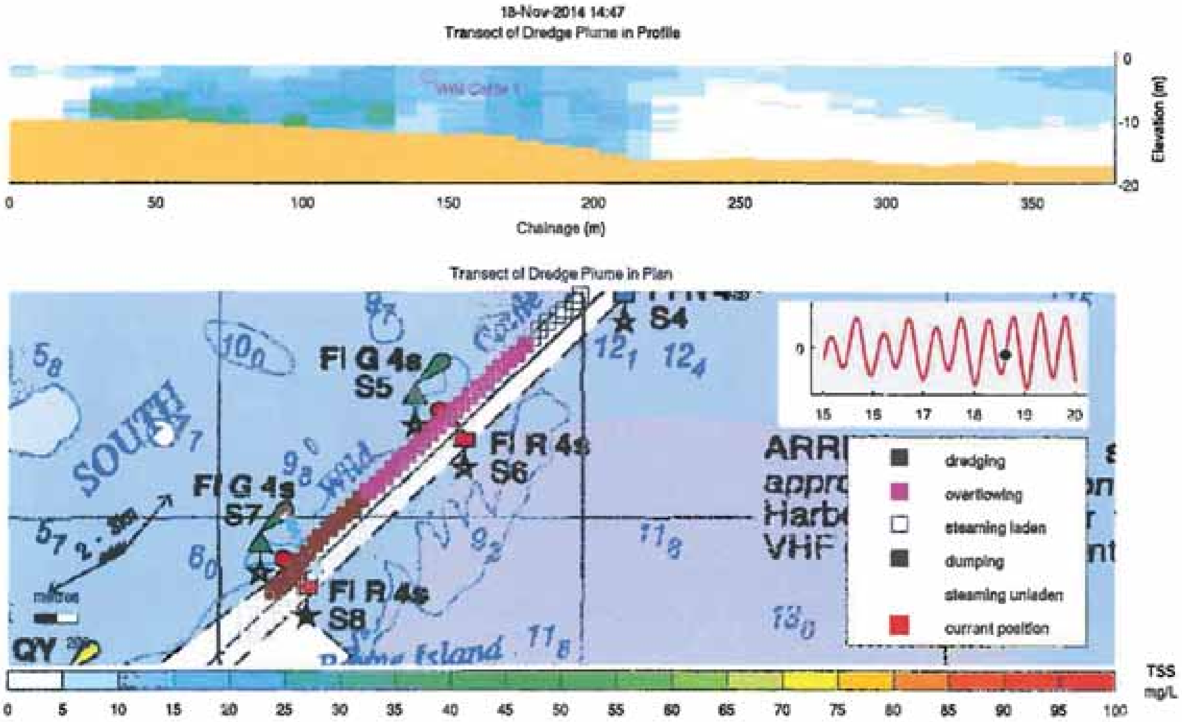


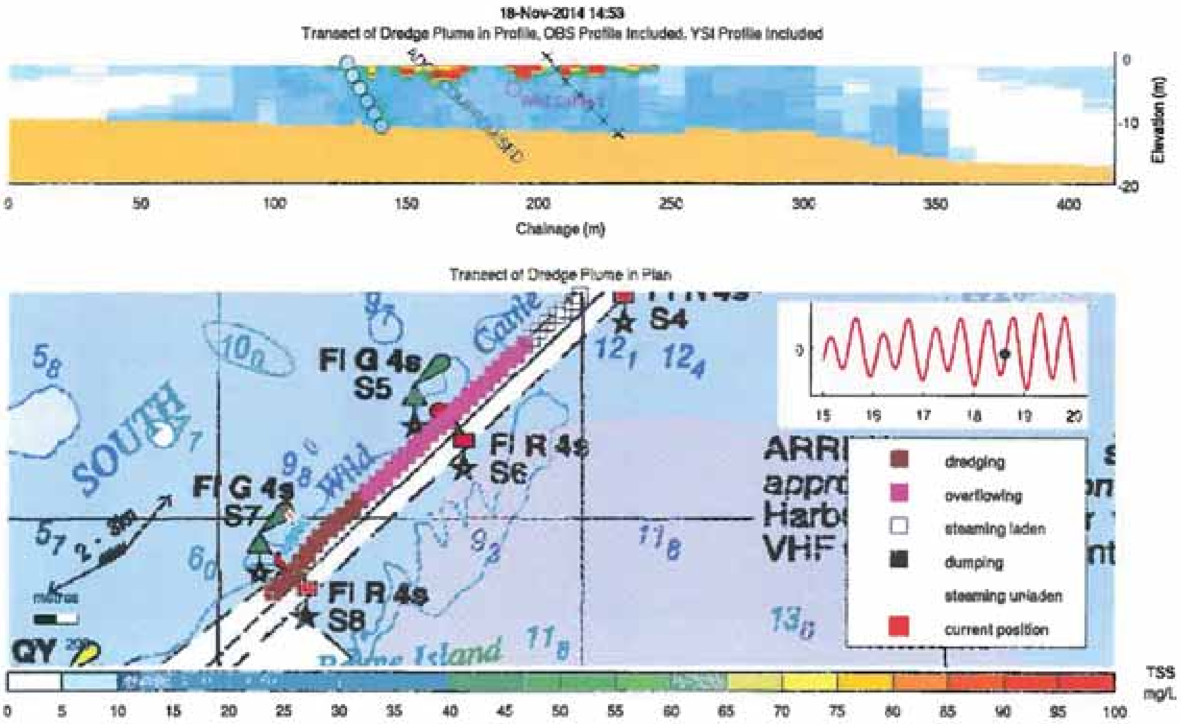


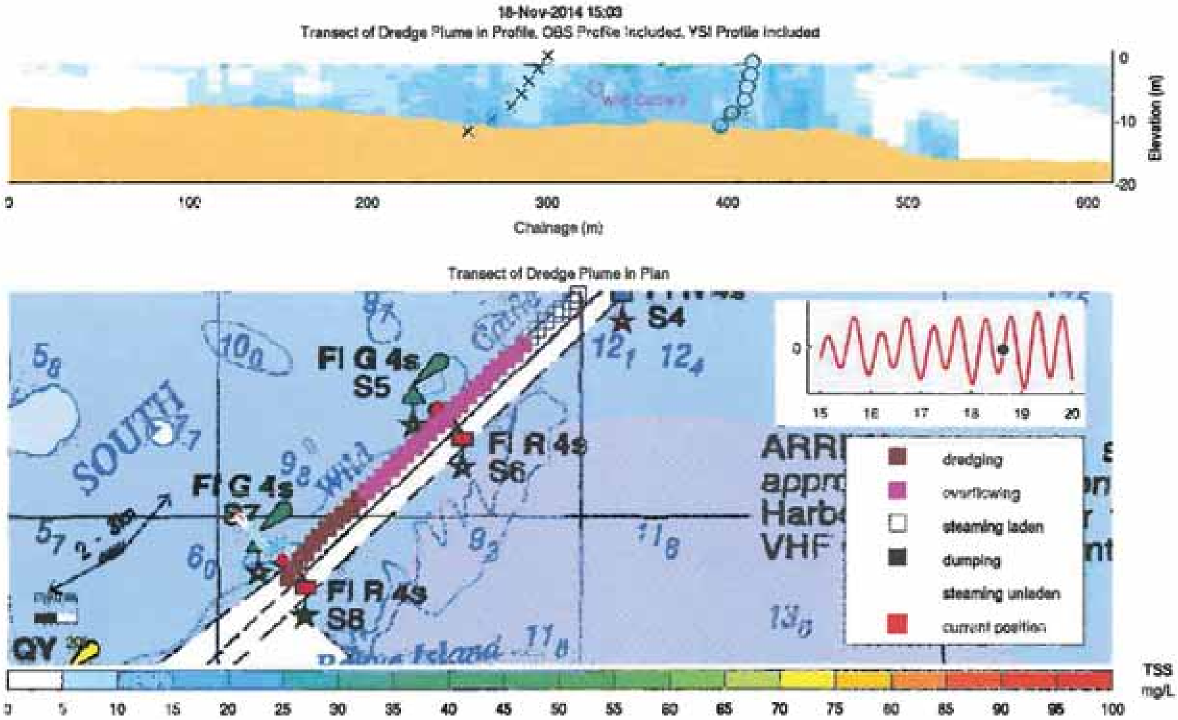

18-Nov-2014 13:45
Transect of Dredge Plume in Profile
Elevation (m)
Chainage (m)
Transect of Dredge Plume in Plan
dredging
overflowing
steaming laden
dumping
steaming unladen
current position
TSS
mg/L

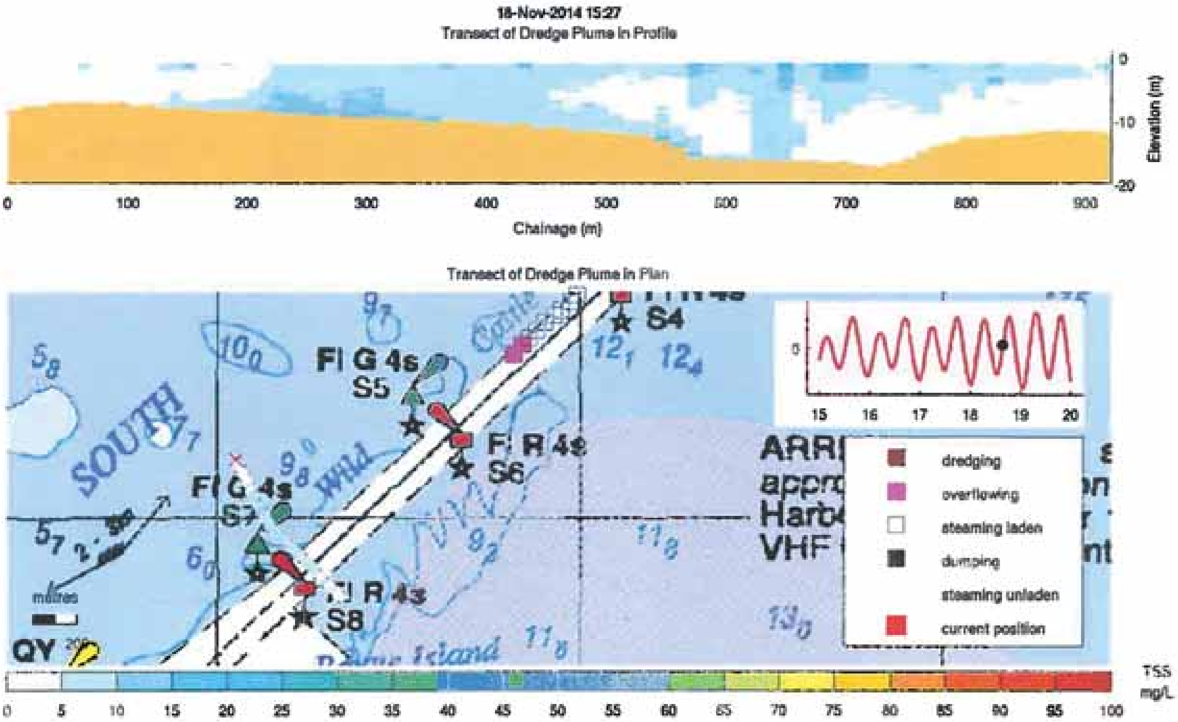

18-Nov-2014 13:55
Transect of Dredge Plume in Profile, OBS Profile Included
Elevation (m)
Chainage (m)
Transect of Dredge Plume in Plan
dredging
overflowing
steaming laden
dumping
steaming unladen
current position
TSS
mg/L

Appendix I Dredging at Wild Cattle Cutting

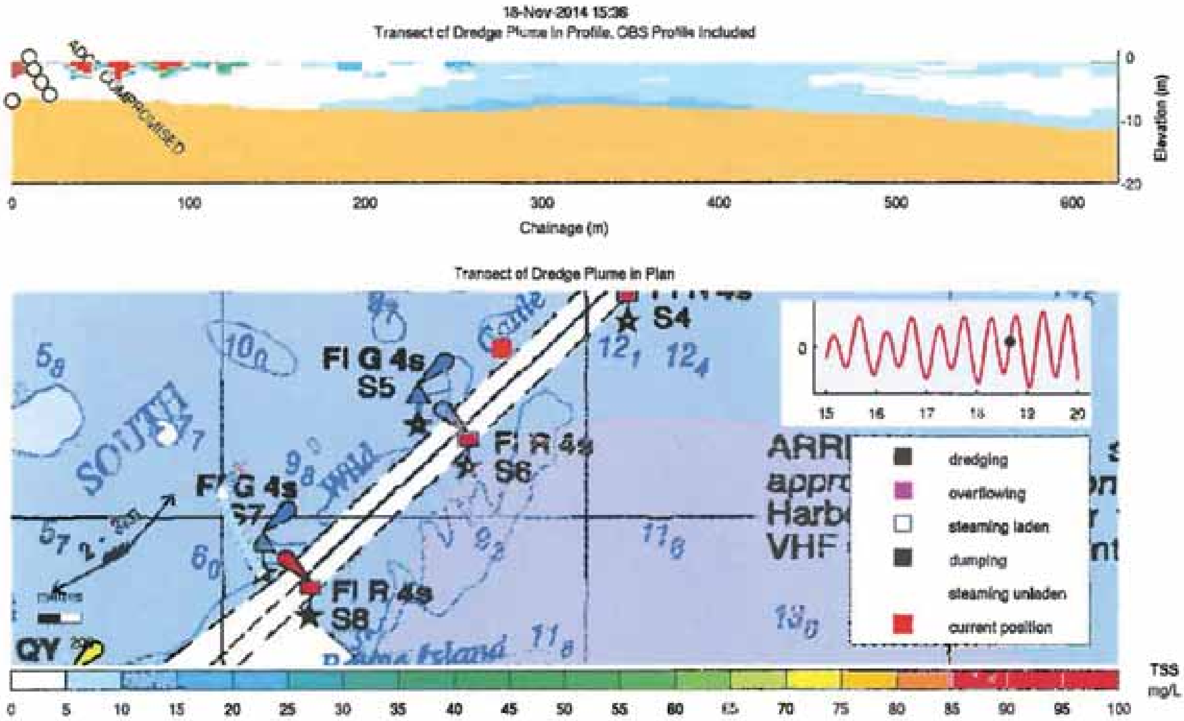


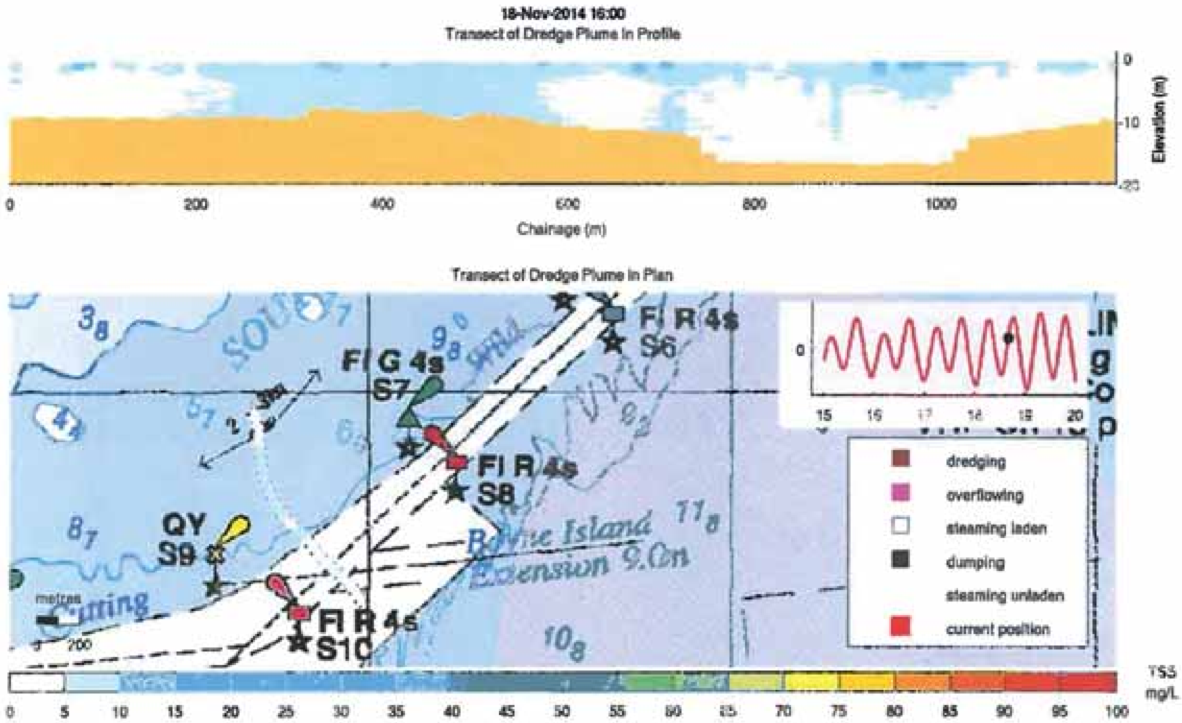


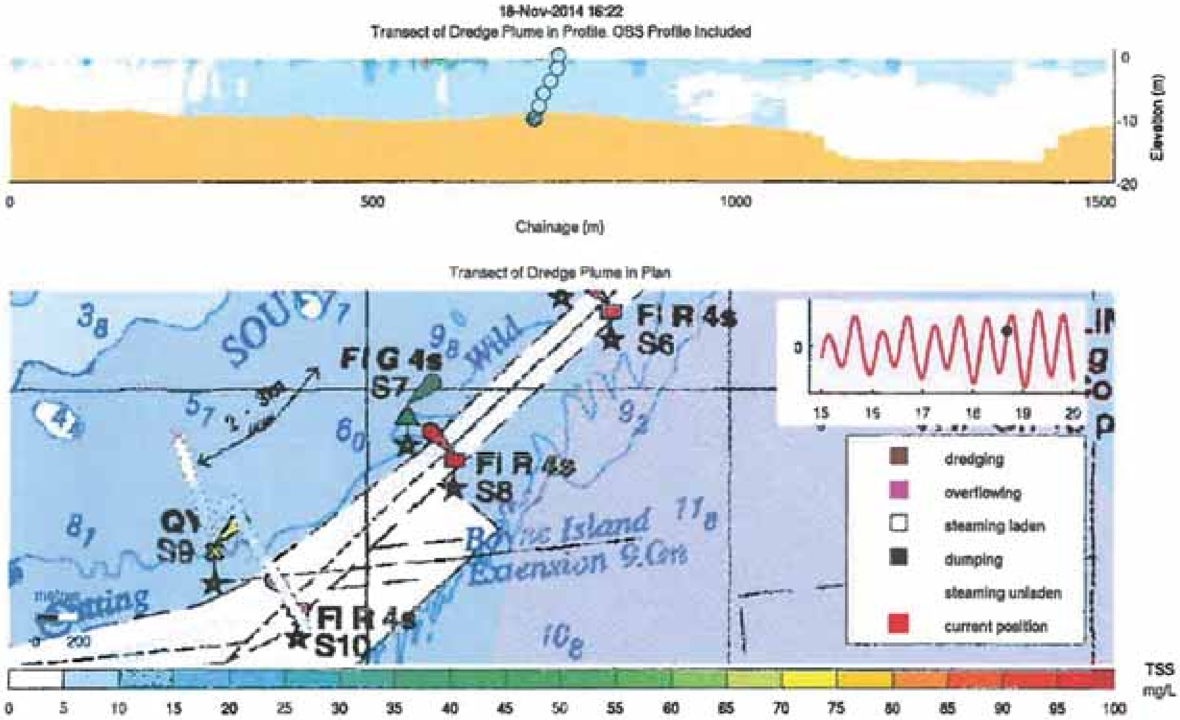

18-Nov-2014 15:03
Transect of Dredge Plume in Profile, OBS Profile Included, YSI Profile Included
Elevation (m)
Chainage (m)
Transect of Dredge Plume in Plan
Fl G 4s
S5
Fl R 4s
S6
S7
Fl R 4s
S8
S4
dredging
overflowing
steaming laden
dumping
steaming unladen
current position
TSS mg/L

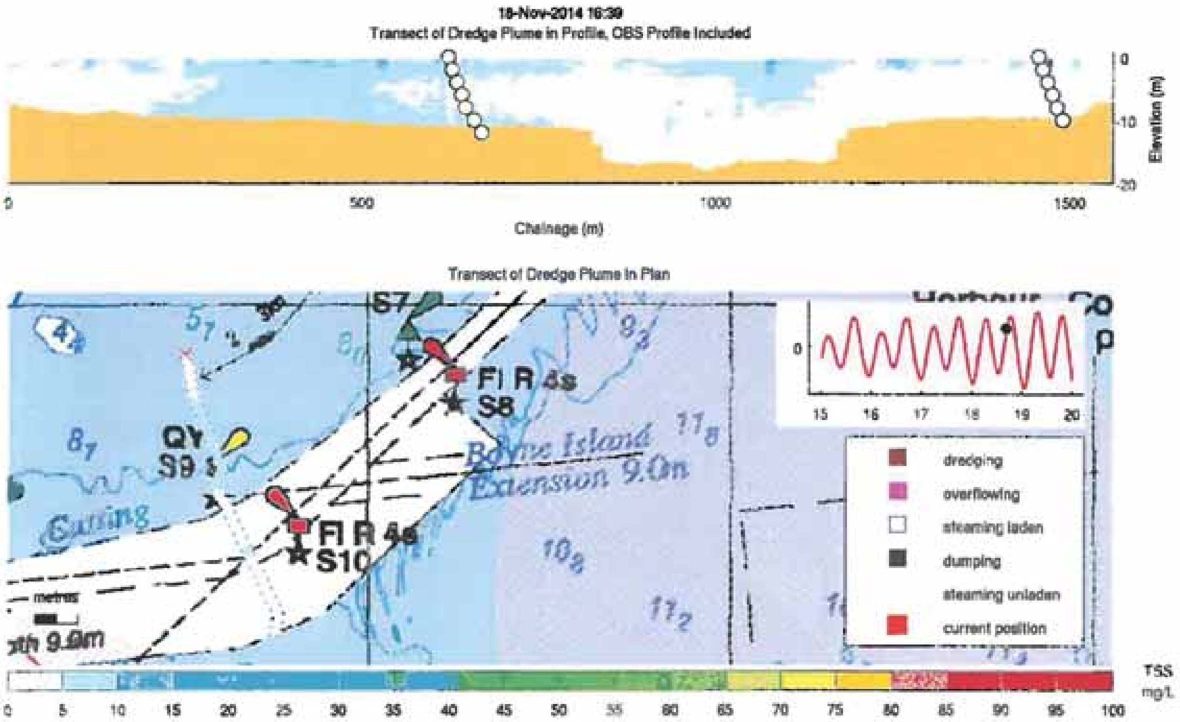

18-Nov-2014 15:27
Transect of Dredge Plume in Profile
Elevation (m)
Chainage (m)
Transect of Dredge Plume in Plan
Fl G 4s
S5
Fl R 4s
S6
S7
S8
S4
dredging
overflowing
steaming laden
dumping
steaming unladen
current position
TSS mg/L

Dredging at Wild Cattle Cutting

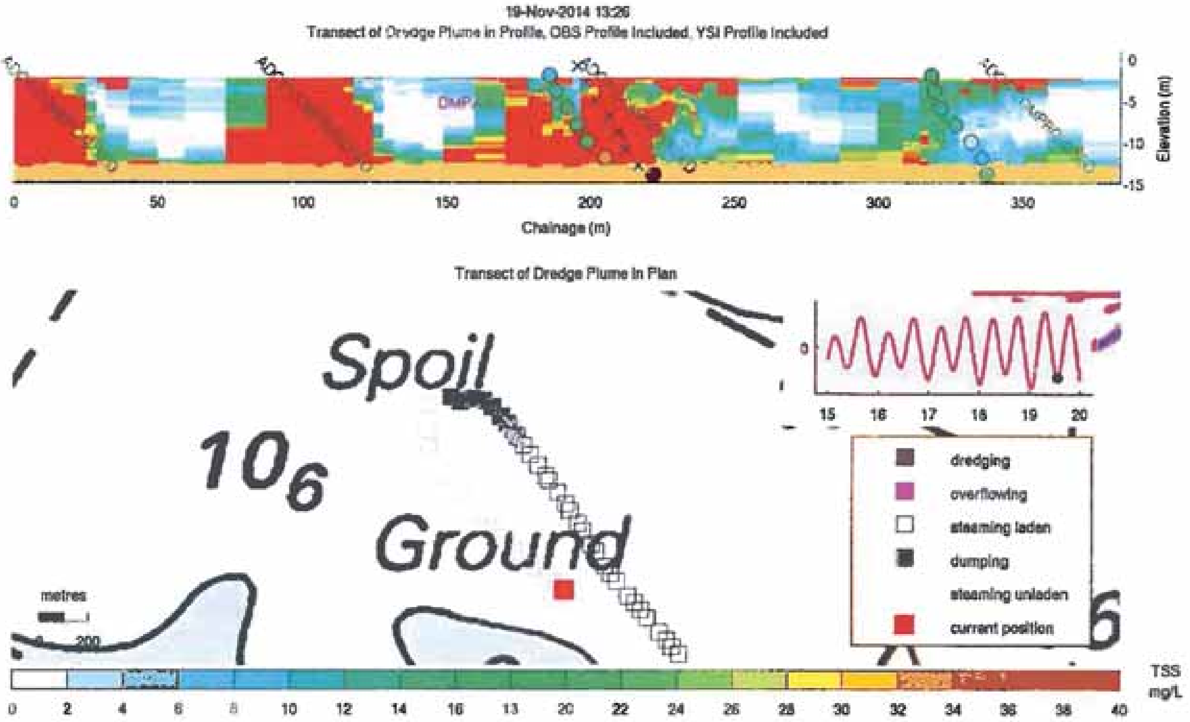


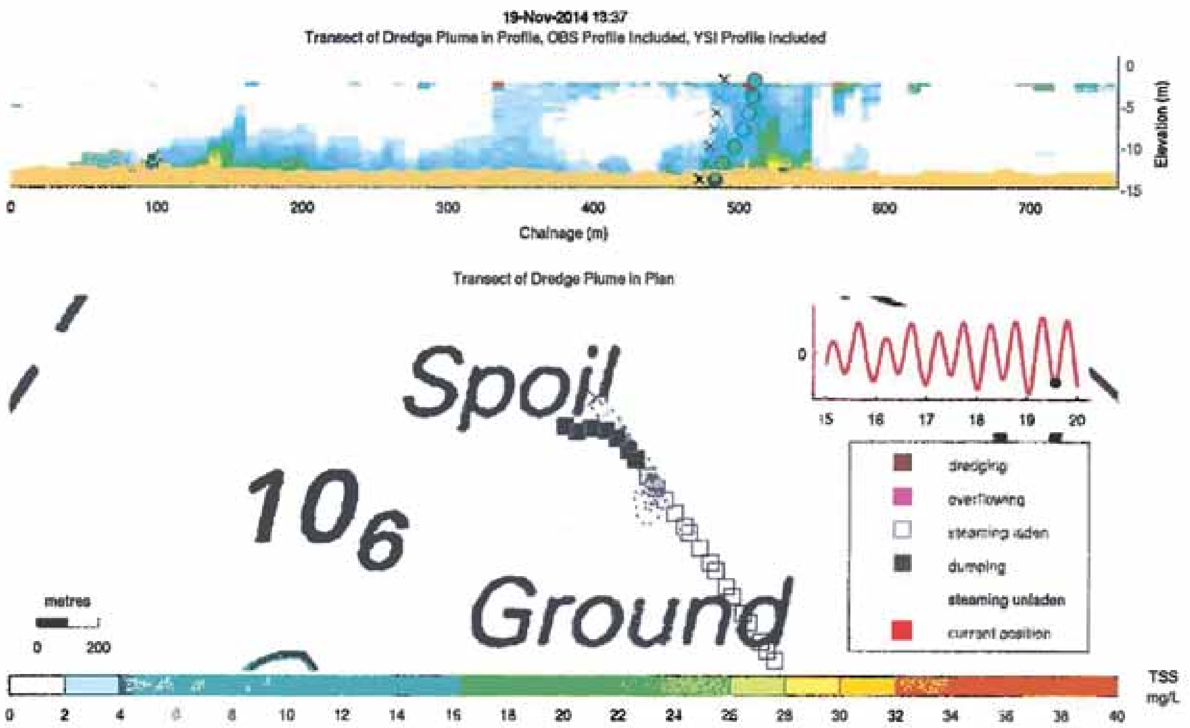


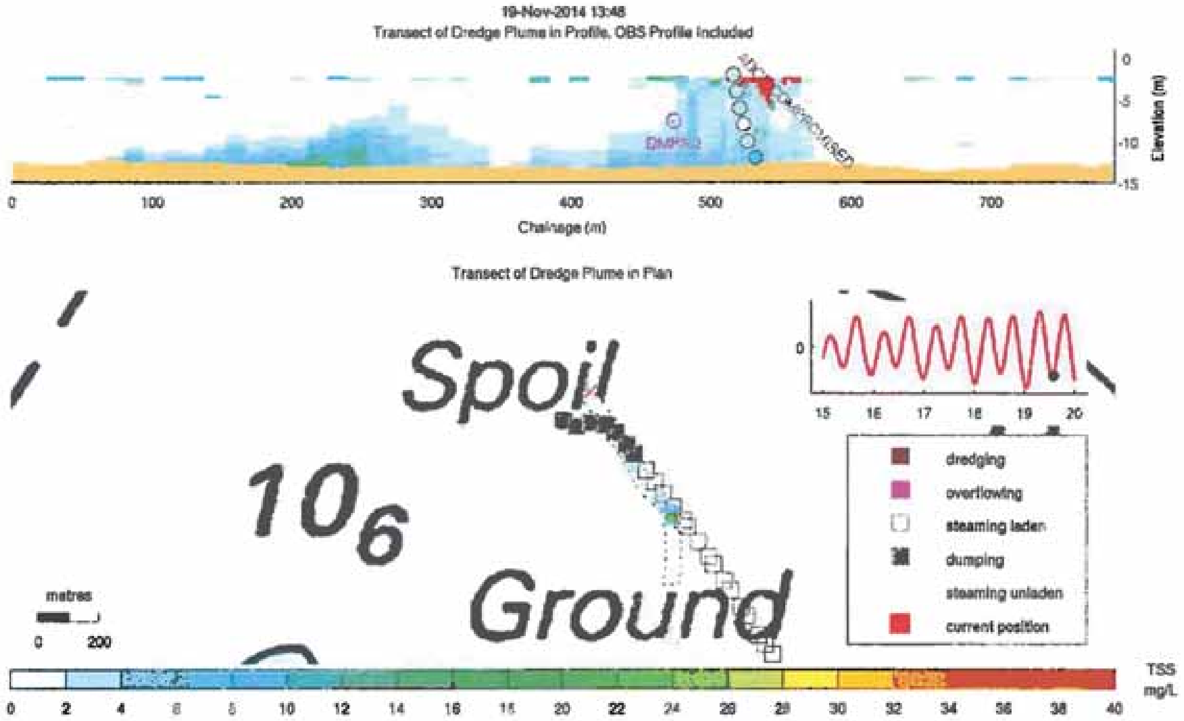

18-Nov-2014 16:22
Transect of Dredge Plume in Profile. OBS Profile Included
Chainage (m)
Elevation (m)
Transect of Dredge Plume in Plan
Fl R 4s
S6
Fl G 4s
S7
Fl R 4s
S8
Q
S9
Fl R 4s
S10
Boyne Island
Extension 9.0m
dredging
overflowing
steaming laden
dumping
steaming unladen
current position
TSS
mg/L

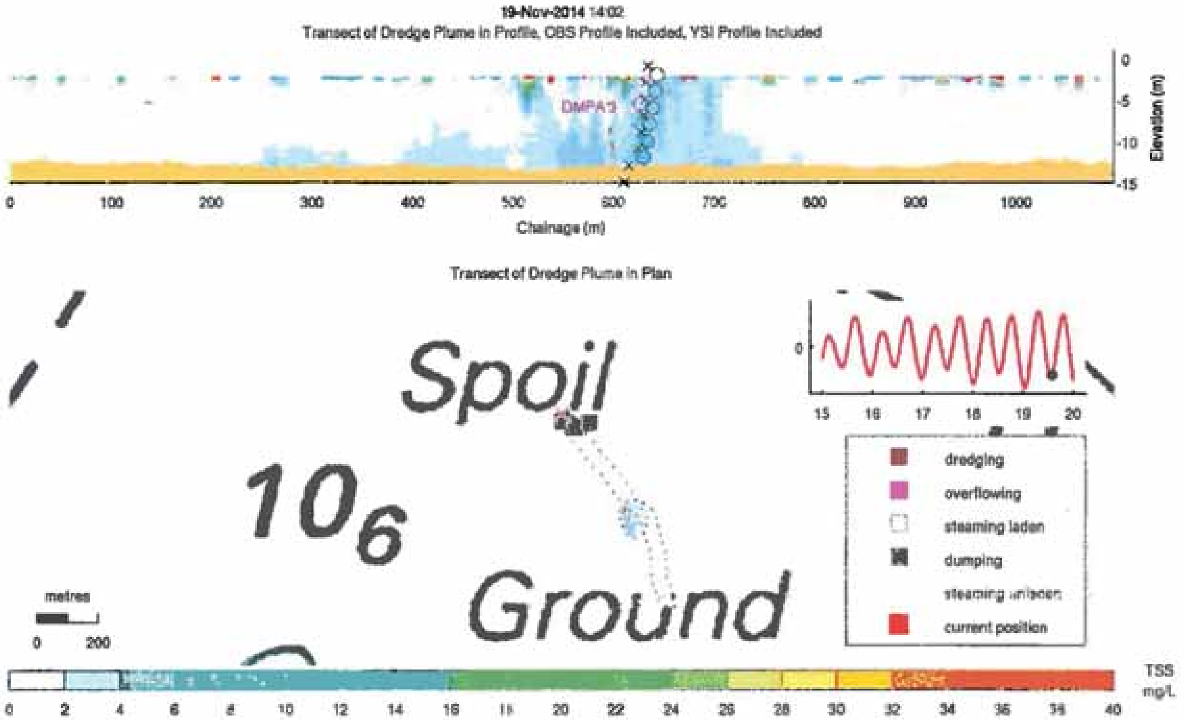

18-Nov-2014 16:39
Transect of Dredge Plume in Profile, OBS Profile Included
Chainage (m)
Elevation (m)
Transect of Dredge Plume in Plan
S7
Fl R 4s
S8
Q
S9
Fl R 4s
S10
Boyne Island
Extension 9.0m
dredging
overflowing
steaming laden
dumping
steaming unladen
current position
TSS
mg/L

Appendix J Dumping at EBSD

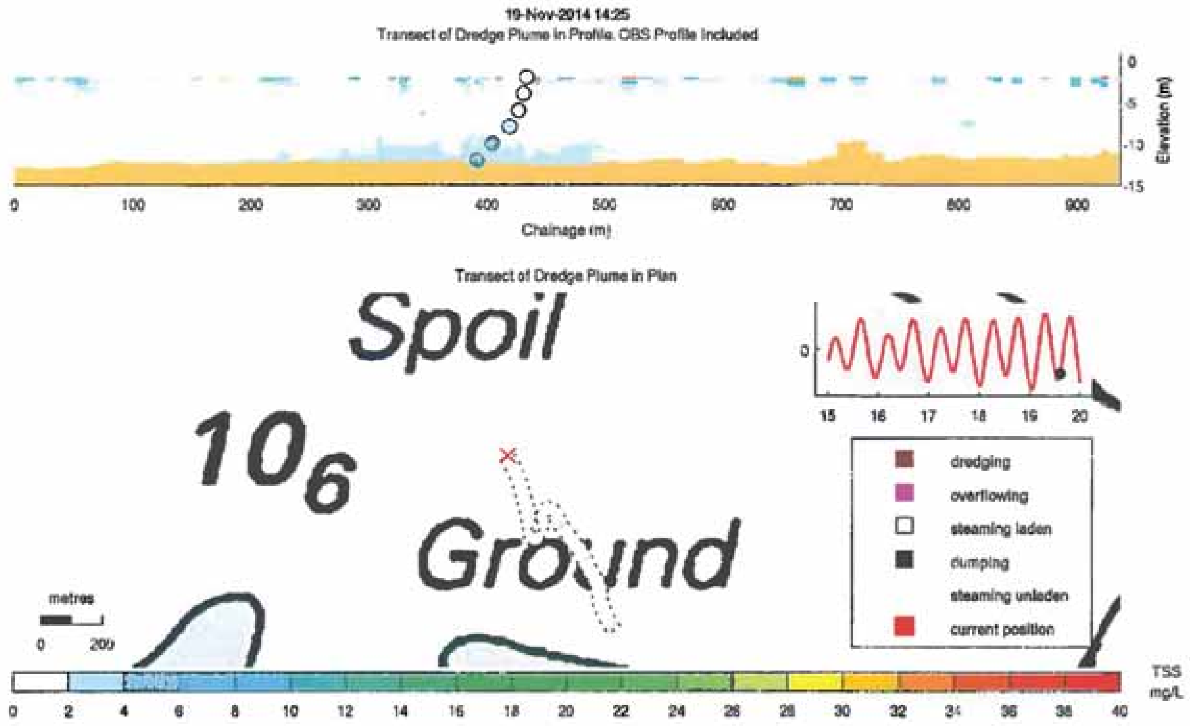


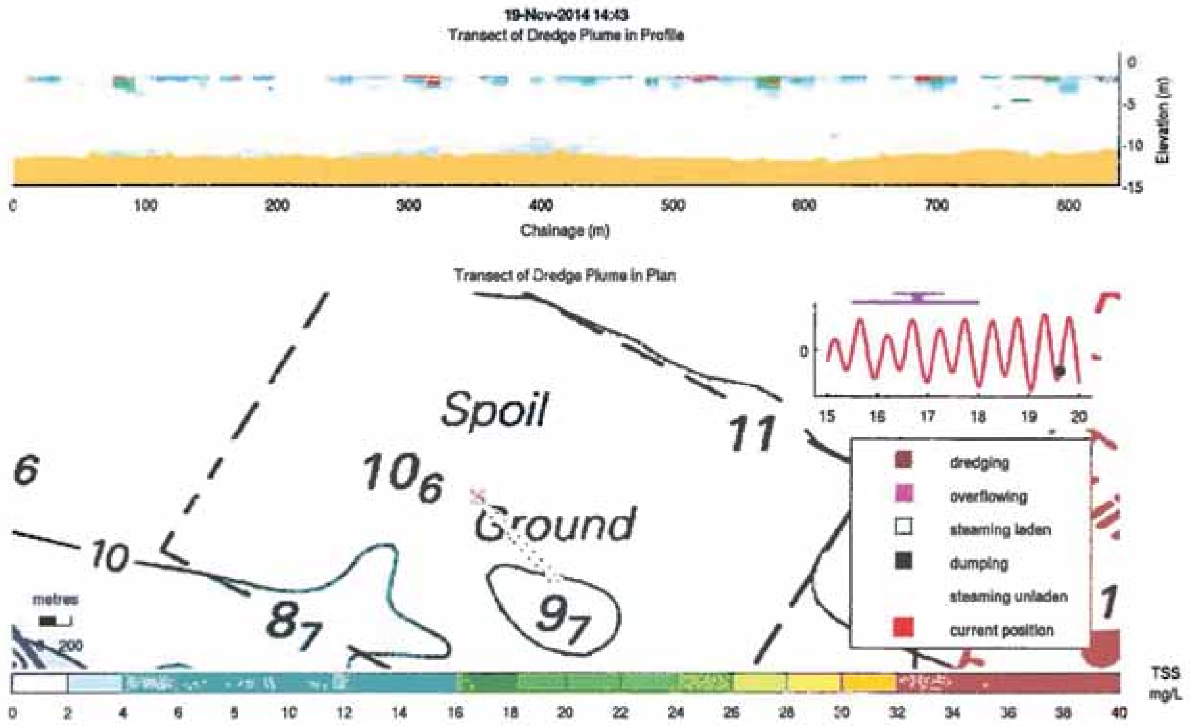



19-Nov-2014 13:48
Transect of Dredge Plume in Profile, OBS Profile Included
Elevation (m)
Chainage (m)
Transect of Dredge Plume in Plan
Spoil
10₆
Ground
metres
0 200
dredging
overflowing
steaming laden
dumping
steaming unladen
current position
TSS
mg/L

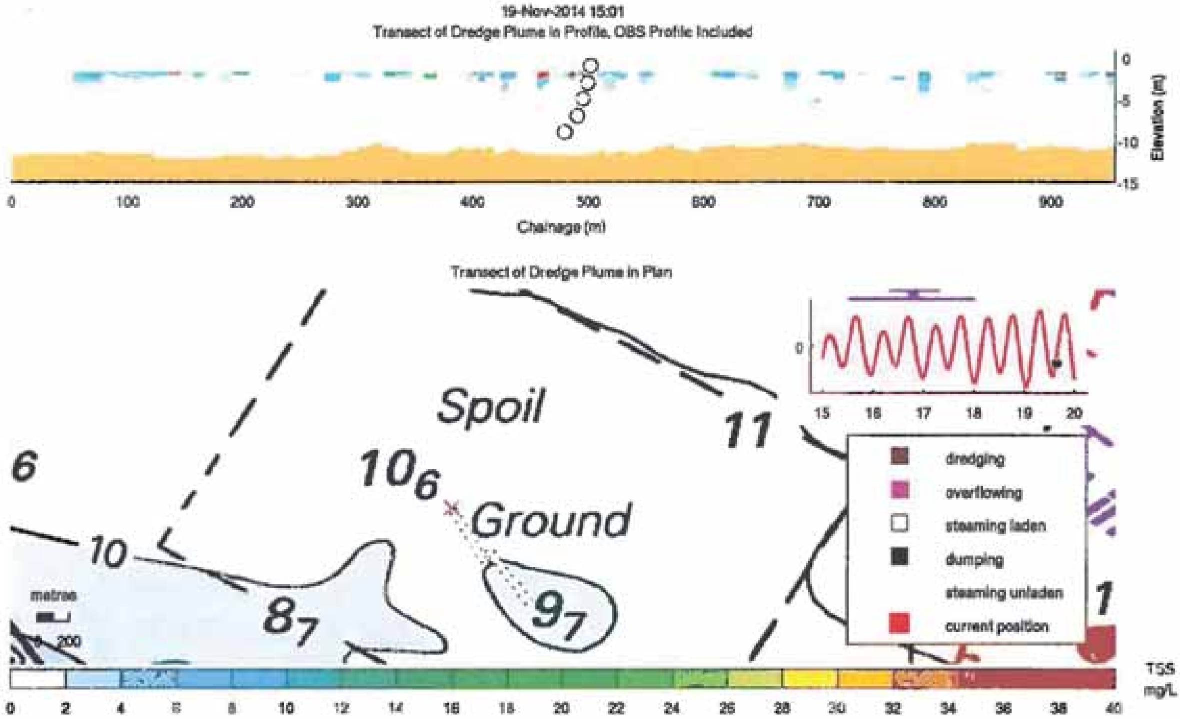

19-Nov-2014 14:02
Transect of Dredge Plume in Profile, OBS Profile Included, YSI Profile Included
Elevation (m)
Chainage (m)
Transect of Dredge Plume in Plan
Spoil
10₆
Ground
metres
0 200
dredging
overflowing
steaming laden
dumping
current position
TSS
mg/L

Dumping at EBSD





Dumping at EBSD



Appendix K Backscatter – TSS Calibration