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Port of Gladstone Maintenance Dredging Assessment of Potential Impacts

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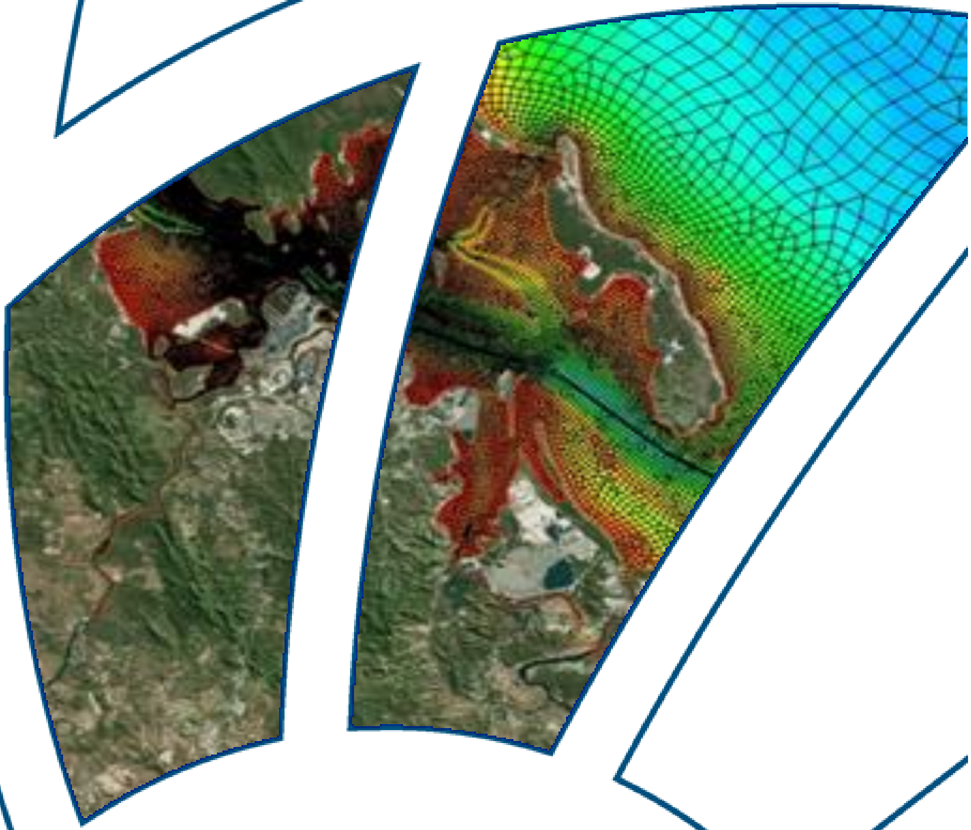

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Synopsis:	**An assessment of potential impacts of maintenance dredging and sea disposal at the Port of Gladstone. The report provides background material to support relevant dredging approvals.**

REVISION/CHECKING HISTORY

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Executive Summary

Gladstone Ports Corporation Limited (GPC) is responsible for maintenance dredging of the Port of Gladstone. The dredged material is disposed of at sea in at the East Banks Spoil Disposal Site (EBSDS) in accordance with Sea Dumping Permits issued by the Commonwealth Department of the Environment and Energy (DoEE).

This report provides the information required by the sea dumping permit application process (administered by DoEE) through a compilation of existing literature, data analysis, dredge plume monitoring, and hydrodynamic modelling. The general aims of this report are to describe the potential impacts of maintenance dredging activities and to assist the development of a monitoring framework that can be used to test impact hypotheses and predictions.

Port Curtis and surrounding areas support diverse estuarine and marine habitats, communities and species which together contribute to the maintenance of the Outstanding Universal Value of the Great Barrier Reef World Heritage Area (GBRWHA). It contains ecological receptors that are potentially sensitive to dredging-related changes to water quality (and sedimentation), most notably seagrass meadows and reef habitats and their communities.

Disturbance of soft sediment and rubble-reef communities will occur only where accretion levels impact channel design depths within the lawful channel area. Dredging is scheduled on an annual basis. Continued disturbance of macroinvertebrate communities at the EBSDS will occur, however localised direct loss is unlikely given the results of past monitoring (provided that the material continues to be “clean” and is spread in a similar fashion to past maintenance campaigns).

Plumes generated from spoil disposal at the EBSDS are of low concentration and limited duration and are not expected to affect sensitive receptors adjacent to the EBSDS. This is supported by the results of plume monitoring carried out during disposal of maintenance dredged material at the EBSDS which indicated that plumes were low in concentration and dissipated in less than two hours (BMT WBM 2014a). Turbidity from wave generated resuspension events on the EBSDS is insignificant in the context of ambient resuspended TSS. Modelling predictions and field monitoring suggest that plumes from the EBSDS do not affect surrounding seagrass and coral communities.

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. Areas around some berthing pockets have higher concentrations of fines than some outer sections of shipping channel where velocities are higher. Modelling shows that continuous dredging in the same location (particularly berth pockets and in the inner harbour) during spring tides tends to result in the largest plumes. Potential impacts from continuous dredging can be managed by alternating more frequently between inner and outer harbour dredging parcels during a campaign.

Maintenance dredging plumes monitored at loading sites over neap tides have remained in the immediate dredging area and returned 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 very difficult to field-validate loading plumes generated during spring tides because ambient turbidity is also high, making plumes harder to detect above background; therefore, modelling has been used to investigate plume behaviour during spring tides. During field investigations, nutrient concentrations within observed plumes were higher than ambient, but there was no evidence of harmful algal blooms or reduced dissolved oxygen observed (BMT WBM, 2014a). During spring tides, nutrient concentrations would be dispersed even more rapidly.

Based on near-field validated modelling results, most sensitive receptors surrounding the channel are not likely to be affected by loading plumes. However, some indirect impacts may occur at seagrass meadows surrounding the Passage Islands, as these meadows experience the greatest duration and intensity of dredge plumes. The extent and severity of this impact depends on a range of factors which cannot be simulated. In a worst-case scenario (low meadow resilience, recent disturbance history, continuous targeting of the LNG swing basins / berth parcels during the growing season) impacts would be expected to manifest as a reduction in cover rather than complete meadow loss, given the relatively short duration of plumes associated with the largest simulated campaign. These potential impacts are predicted to occur in the absence of any management or mitigation measures employed by GPC, which have not been considered in this report.

The TSHD Brisbane represents a low risk of species translocation because it works primarily within Queensland ports and the Port of Melbourne.. GPC conduct marine pest monitoring to update knowledge of marine pest status within Port Curtis.

GPC’s maintenance dredging monitoring program includes sediment sampling, plume monitoring, water quality sampling, seagrass, reef and benthic invertebrate monitoring as well as hydrographic surveys. The monitoring programs provide a basis for testing the following impact hypotheses:

- The deposited spoil does result in navigation hazards within and adjacent to the EBSDS.
- Disposal of dredged material will not result in contaminant related impacts to the marine environment.
- Sediments generated during dredging and disposal do not subsequently reach sensitive areas in amounts that would be harmful to the ecological value and amenity of the area.
- Pollutant concentrations within dredge plumes at the loading and disposal sites do not reach levels where toxic effects or algae blooms could occur.
- Maintenance dredging activities do not result in long-term changes to seagrass meadow extent and reef habitats.
- The deposited dredged material does not result in long term changes to benthic communities outside the EBSDS.
- Maintenance dredging does not result in the introduction of marine pests into new environments within the port area.

Aspects of this program have been, and will continue to be used to test impact hypotheses regarding the effects of maintenance dredging. The impact hypotheses developed in this report are supported by a large body of evidence that maintenance dredging will not result in:

- Contaminant-related impacts to marine communities.
- Navigational hazards.
- Reduced environmental value of surrounding sensitive areas.
- Toxic effects or algal blooms.
- Other water quality impacts causing environmental harm.

- Long-term changes to seagrass meadows, reef communities or benthic communities outside of the EBSDS.
- The introduction of marine pests to Port Curtis.

Monitoring should continue to test the validity of these impact hypotheses. Overall, it is expected that maintenance dredging does not lead to significant impacts to Matters of National Environmental Significance (MNES) or Matters of State Environmental Significance (MSES), especially with the application of appropriate mitigation strategies.

The modelled impact of dredging on the Total Suspended Solids (TSS) concentration presented in this report is less significant than that discussed in the previous maintenance dredging assessment (BMT WBM, 2014d). The reason for the difference in model results is mainly due to changes to the estimated plume source rates (based on additional data collection completed in September 2017), together with changes in model configuration and methodology (refer to Section 2.2.1 for more detail). These improvements in model validation and methodology yield a more accurate representation of the likely effects of dredging activity.

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1 Introduction

1.1 Background

Gladstone Ports Corporation Limited (GPC) is responsible for maintenance dredging of the Port of Gladstone (Figure 1-1). The dredged material is disposed of at sea at the East Banks Sea Disposal Site (EBSDS) in accordance with Sea Dumping Permits issued by the Commonwealth Department of the Environment and Energy DoEE (formerly the Department of Sustainability Environment Water Population and Communities DSEWPaC).

This report provides the information required by DoEE through a compilation of existing literature, data analysis, and hydrodynamic modelling. A number of different maintenance campaign volumes have been modelled representing the range of likely annual dredging requirements. This study updates the previous maintenance dredging assessment completed in 2014 (BMT WBM, 2014d) with improved modelling methodology and refined dredging plume source rates.

1.2 Study Objectives

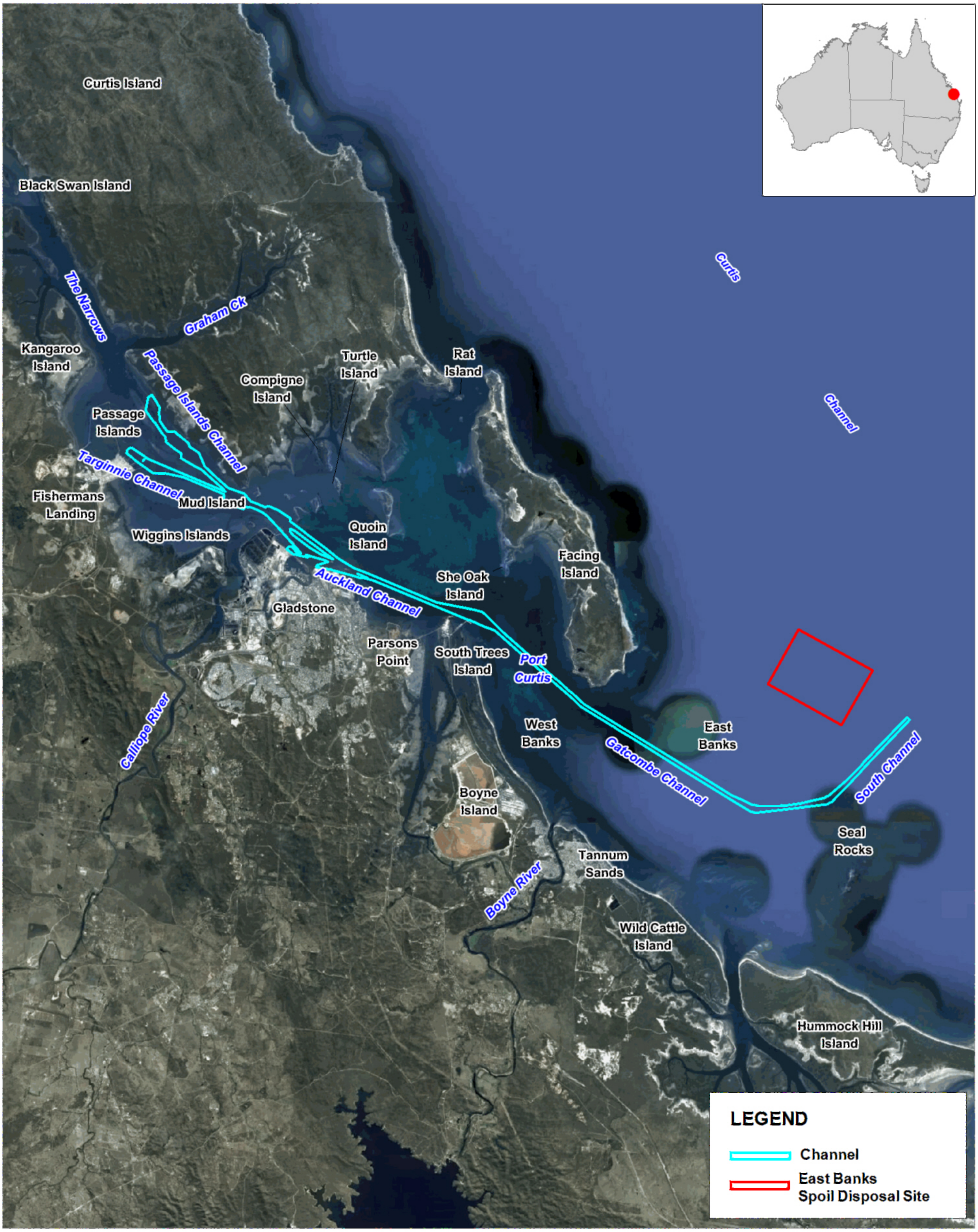
The specific objectives of the report are to:

- Identify relevant matters of national and state environmental significance, and the location of sensitive ecological receptors, within the footprint and in adjacent areas potentially affected by maintenance dredging;
- Assess potential changes to water quality and the marine environment associated with the proposed dredging; and
- Assess potential impacts to matters of national and state environmental significance as a result of dredging.

1.3 Key Terminology and Locations

The following key locations are referred to in this report and are shown in Figure 1-1:

- Study area – encompasses tidal waters within and adjacent to Port Curtis shown in Figure 1-1;
- East Banks Sea Disposal Site (EBSDS) – disposal location for maintenance dredged material, also known as the Dredged Material Placement Area (DMPA);
- Project area – refers to the lawful dredge footprint as shown in Figure 1-1;
- Zone of Impact – is defined as seabed areas within the Project area, and seabed areas containing seagrass and hard corals that are expected to be substantially modified (i.e. mortality) by dredge plumes, direct removal, and sediment deposition from dredged material (extents as defined in Section 5).
- Zone of Influence – is the area of seabed where plumes will be evident without necessarily causing mortality (extents as defined in Section 5).



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2 Methodology

2.1 Review of Existing Information

2.1.1 Identifying Features of Biodiversity Significance or Sensitivity

This report considers both matters of national and state environmental significance (MNES and MSES, respectively). MNES and MSES that were known or likely to occur within the Study Area were defined based on searches using the EPBC Protected Matters search tool (PMST), and the State Planning Policy (SPP) Interactive Mapping System. The searches identified: (i) legally defined areas listed under Commonwealth and State Government instruments (i.e. mapped conservation areas and other discrete environmental features; and (ii) in the case of PMST, species listed under the EPBC Act that are known or likely to occur within the study area.

Both the PMST and SPP Interactive Mapping System typically have limited locational precision with regard to defining habitats for listed species. Other information sources were therefore reviewed to determine the known or likely occurrence of species in the Project area and/or study area, including academic publications, consultancy reports, and wildlife on-line flora and fauna records. The determination of known or likely occurrences was based on: (i) confirmed records of the species; (ii) an assessment of habitat suitability, based primarily on the online Species Profile and Threats Database (Department of the Environment 2016).

2.1.2 Other Data Sources

Other data sources used to characterise environmental features and/or inform modelling assessments include:

- Navigation Chart 819 from the Australian Hydrographic Service showing known reefs.
- Bathymetry and typography – Digital Elevation Models (DEMs) with 10 m resolution for the surrounding area (BMT WBM).
- Latest bathymetry and channel extents within Port Curtis supplied by GPC.
- Reef habitat mapping outlined in BMT WBM (2015a).
- Seagrass mapping data supplied by GPC and contained with seagrass monitoring reports prepared by James Cook University TropWater (and predecessors Department of Primary Industries).
- Boundary condition data from global tidal, wind and atmospheric model outputs (NOAA, 2012).

2.2 Impact Assessment

2.2.1 Numerical Model

The numerical modelling software TUFLOW FV was used to simulate the three-dimensional hydrodynamics of the Port and the advection and dispersion of suspended sediment (both ambient sediment and plumes generated during dredging). TUFLOW FV carries out calculations on an unstructured mesh, which allows the mesh resolution to be enhanced in the areas of greatest interest.

The model configuration and boundary conditions have changed considerably since the previous assessment of maintenance dredging (BMT WBM, 2014d). The changes include:

- Modelling is now fully three-dimensional, and includes salinity and temperature influences on the vertical density structure (fully baroclinic), as well as atmospheric boundary conditions;
- Regional oceanic influences were incorporated in the offshore open ocean boundary conditions;
- Ambient (background) suspended sediment dynamics have been included in the modelling, to provide additional context for analysing dredging impacts, to allow calculation of light transmission impacts associated with dredging, and to improve the accuracy of modelling the resuspension of dredged sediment; and
- The dredging and placement plume source rates have been estimated more accurately, making use of available particle size distribution data, dredge operation mode statistics, and additional measurements of plume intensity carried out in September 2017 (refer to Appendix A for more details).

2.2.2 Model Extent

The model network extends over an area of some 2000 km^2, incorporating the Port of Gladstone and an ocean boundary extending up to 30km offshore. The tidal boundaries of the model include the eastern ocean boundary and also the northern end of the Narrows. Tidal estuaries incorporated into the model include the Calliope River, Auckland Inlet, South Trees Inlet and the Boyne River.

2.2.3 Model Bathymetry

The model bathymetry is based on a Digital Elevation Model (DEM) of the Port, which has been derived from the following survey components:

- Detailed hydrographic survey data of the dredged channels, swing basins and berths as provided by MSQ and GPC, together with the progressive inclusion of ongoing surveys to ensure that the model bed levels match the actual bathymetric configuration at the time of the simulation period; and
- Hydrographic survey data and outlines of the edges of the shoreline, mangroves and saltpans used in producing Boating Safety Charts of the area, as provided by MSQ.

Typical levels have been adopted for the edges of the mangroves and saltpan areas for interpolation in those upper inter-tidal zones where no specific survey level data is available. The various data components have been combined and prioritised with respect to date and detail where there is overlap in producing a base DEM. For modelling purposes, all data has been adjusted to a consistent AHD datum. The adopted model bathymetry and extent of the model coverage is illustrated in Figure 2-1.

2.2.4 Model Mesh

In developing the hydrodynamic model, consideration has been given to the underlying bathymetry in defining the mesh configuration. For example, model resolution was enhanced at locations of rapidly varying bathymetry or expected high flow regions based on channel definition, as well as to represent the dredged channels, swing basins and berth pockets.

To accurately represent the stratification of the water column due to vertical gradients in temperature and salinity, three sigma layers were used in conjunction with up to 14 additional vertical z layers. These multiple layers together with inclusion of baroclinic pressure gradient terms in the solution scheme allows for the development of a stratified water column in the model.

2.2.5 Boundary Conditions

Tidal flows that drive the hydrodynamics of the system were applied as boundary conditions to the model. The tidal inflows into the model were introduced by providing time-varying water level inputs at the two open boundaries derived from a global tidal model.

A SWAN spectral wave model was developed in order to include the influence of waves on the sediment dynamics (Delft University of Technology, 2006). Wave model outputs were input as a boundary condition for the TUFLOW FV model to enable the calculation of wave-related bed shear stresses.

Due to the large scale of the model, regional oceanic effects needed to be incorporated in the offshore open ocean boundary conditions. This was done using HYCOM global ocean circulation model hindcast outputs (www.hycom.org). This model provided 3D current, salinity and temperature data which was applied on the ocean boundary in combination with the tidal water level variation.

Further boundary conditions were also applied to the model to represent atmospheric influences. These boundary conditions were derived from the NOAA NCEP, Climate Forecast System Reanalysis (CFSR) (www.ncep.noaa.gov) and included wind, temperature, humidity, short and long wave radiation, which were applied on a spatially varying grid throughout the model domain with a temporal resolution of one hour.

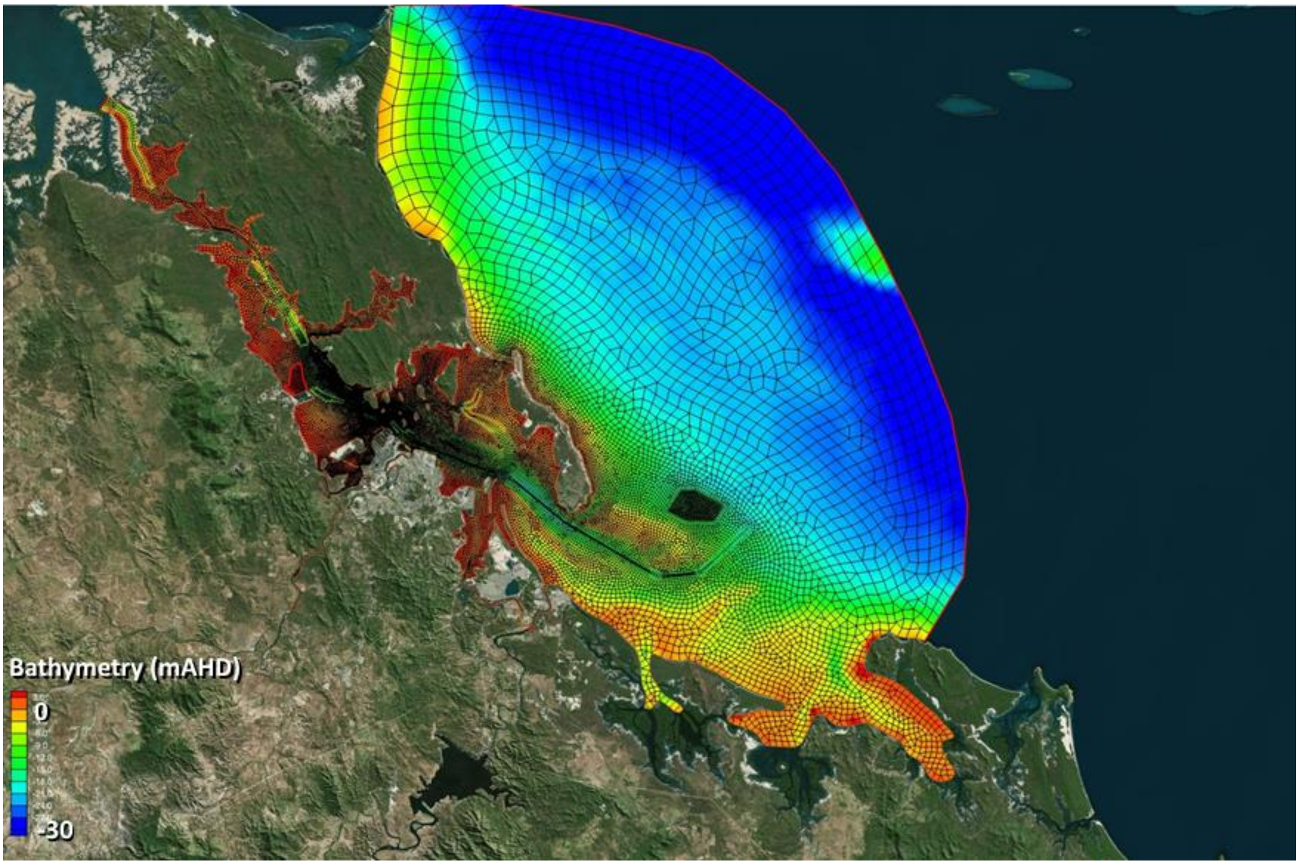


Figure 2-1 TUFLOW FV Mesh of the Gladstone Region

2.2.6 Model Validation

The TUFLOW FV numerical model used for the purposes of this study has been developed over a period of eight years, and has been progressively updated, refined and calibrated over that time using a large number of recorded water level and current velocity measurements (refer to BMT WBM 2011a, 2011b, 2012c and 2013 for details). The validation of the model included comparisons with water level measurements at Auckland Point and South Trees (over several two-month periods – Nov-Dec 2009, Feb-Mar 2011 and Oct-Dec 2011), comparisons with measured currents by bottom-mounted ADCP at two locations (one week at each in Nov-Dec 2009) and comparisons with recorded wave data at the Gladstone Waverider buoy (one year of data - 2011). The wave model has only been validated using data collected at several sites within and outside the estuary.

The full model calibration and validation results are presented in Appendix A.

2.2.7 Dredging Inputs

The full duration of each of the maintenance dredging campaigns was modelled during the period August – October 2017, which is consistent with the usual timing of maintenance dredging activities in Gladstone. This period included significant spring tides and is considered typical of hydrodynamic conditions within the Port of Gladstone.

The key assumptions for calculation of the suspended sediment released by the TSHD are:

- Cycle times, dredging times per cycle and overflow time per cycle were calculated for each dredge parcel based on analysis of historical dredging logs.
- Source Rates:
    - Drag head and propeller wash: 2% of the fines in the dredged materials;
    - Overflow: 80% of the fines in the materials go overboard through the overflow and 15% of this volume goes in to the passive plume; and
    - Disposal: 10% of the fines in the dredged material.

The full derivation of the source rates for each dredging parcel and validation of the source rates using ADCP transect measurements is presented in Appendix A. Note that the source rates used for the dredging plumes have been refined (mostly reduced in magnitude) since the previous assessment of maintenance dredging activities which was completed in 2014 (BMT WBM, 2014d), based on the additional validation results.

2.2.8 Impact Assessment Methodology

The effects of dredging were assessed based on modelled increases in suspended sediment concentration and sedimentation above natural or ambient levels. Both ambient and dredge related signals have been resolved in the predictive model, which allows for an understanding of how significant the dredge contribution is in relation to ambient conditions.

Depth-averaged Total Suspended Solids (TSS) values are presented here since they are most relevant to assessing ecological impacts due to the reduction in seabed Photosynthetically Active Radiation (PAR). Sedimentation impacts were derived from the daily rate of change in bed sediment mass. The adopted sedimentation rate units are mg/cm^2/day.

The anticipated effects of dredging have been assessed using two different presentation techniques:

- Time series at sensitive receptor sites; and
- Spatial plots based on percentile analysis.

2.2.9 Time Series Analysis

Time series provide a simple way to present TSS increases due to dredging at predetermined points of interest. Having simulated both dredging and ambient sediment, the time series show both these contributions to the total signal and in doing so provide important information on the relative magnitude of the dredging related signal. Time series of depth averaged ambient and dredging-related TSS are provided for several sites in Appendix B of this report for the simulated dredging campaign. The modelled total TSS at each location is the sum of the dredging-related and ambient TSS. Time series of the deposition rate for dredged and ambient sediment are provided in Appendix C, with time-series of PAR shown in Appendix D.

2.2.10 Percentile Analysis

Spatial representations of the dredging impacts were based on percentile exceedance analysis of the model results and were derived by applying a moving 30-day analysis window over a two month simulation period. The 30 day window period is somewhat arbitrary but in a physical hydrodynamic context represents the approximate duration of two (2) consecutive spring-neap tidal cycles, while in an ecological context it is a meaningful timescale for assessing ecological impacts, noting that physiological effects of moderate TSS levels to both corals and seagrass species typically occurs at time scales measured in days to weeks (see Erftemeijer *et al*., 2012; Chartrand *et al*., 2012). The moving window analysis was undertaken by moving the 30 day window by 10 day increments over the simulation period.

The percentile impact plots correspond to the predicted increase in TSS over ambient conditions that are attributable to the dredging. Impacts at each percentile level were calculated for every 30-day window during the simulation, and the maximum increase for any window at each location in the model domain is presented. Different locations within the model will have experienced their worst period at different times during the simulation and the different percentile statistics may also have occurred during different 30 day windows. It is important to note that the presented TSS percentile plots do not represent the plume extent at any one particular instant in time.

Percentile values considered in this report are 95th and 50th, which correspond to exceedance durations of 1.5 days (5%) and 15 days (50%) respectively for the 30 day window. The highest percentiles correspond to relatively acute and short-lived increases in TSS while the lower percentiles correspond to more chronic longer-term increases.

The spatial percentile exceedance dredging impact plots are presented in tandem with the equivalent modelled ambient percentile statistics, calculated as the average over all 30 day windows during the simulation period. This allows the increases in TSS due to dredging to be seen relative to the modelled ambient conditions.

Key features of the moving window percentile analysis include:

- Consideration of a range of impact durations from acute to chronic.
- Can be applied to a long-term programme and capture periods of high intensity versus low intensity impacts.
- A similar analysis applied to the baseline data can quantify the ambient conditions including natural variability across different periods. This can be used to derive meaningful thresholds for the impacts.

The results of the percentile analysis are presented in Section 5.2.1.

3 Dredging Project Description

3.1.1 Maintenance Dredging Volumes and Locations

Analysis of historical maintenance dredging campaign volumes indicates that there is significant variability in the year-to-year maintenance dredging requirements at the Port. For this reason, four synthetic campaigns were simulated in the numerical modelling system to represent the likely range of maintenance dredging volume requirements in a single (typically annual) campaign. The volume and assumed duration of each of the campaigns is shown in Table 3-1.

Table 3-1 Simulated Maintenance Dredging Campaigns

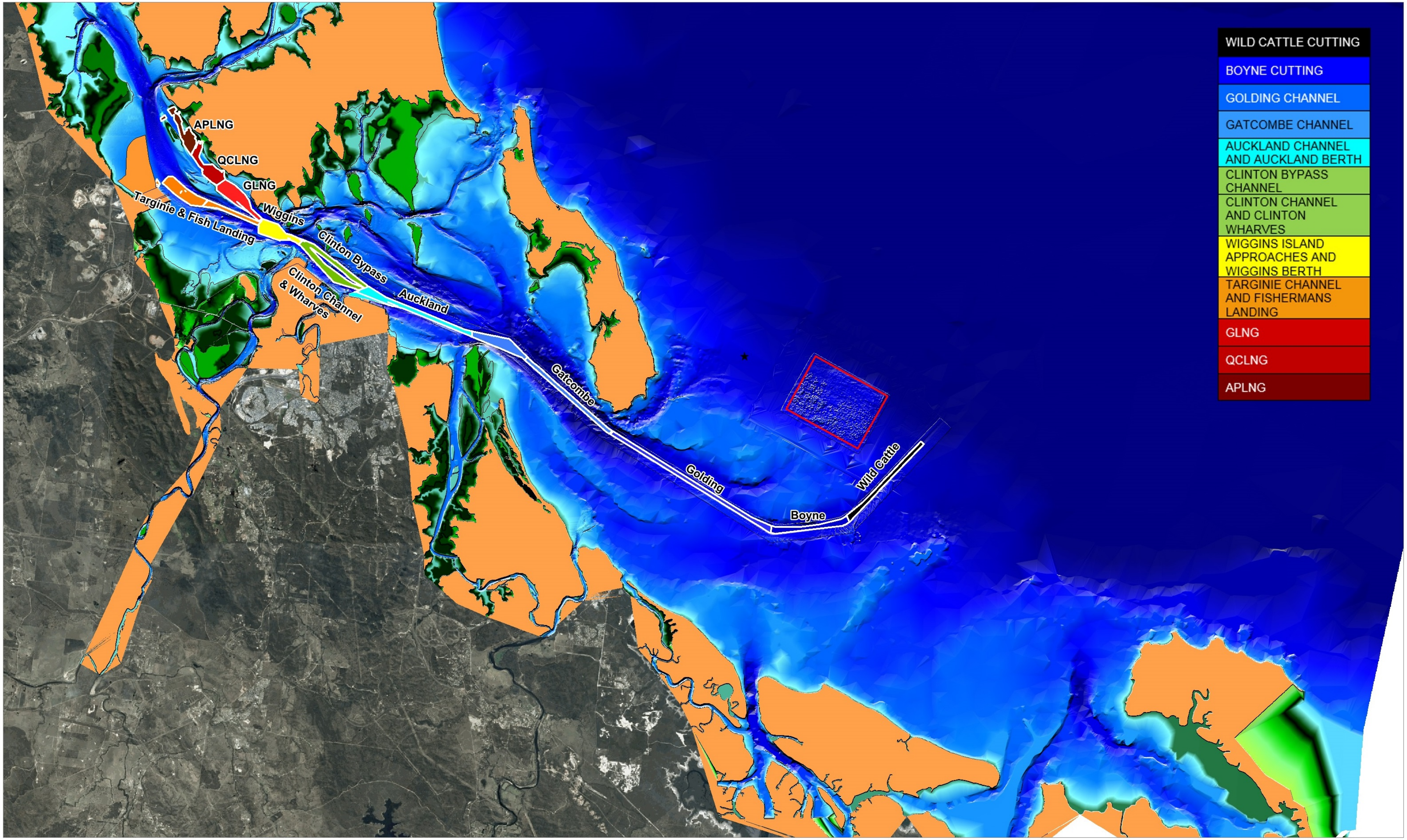
Simulation	Vol. Total	Duration
1	200,000 m^3	4 weeks
2	260,000 m^3	5.3 weeks
3	300,000 m^3	6 weeks
4	340,000 m^3	6.8 weeks

It has been assumed in the modelling methodology that the TSHD *Brisbane* will perform its future maintenance campaigns in a similar manner to its past campaigns. The daily reports describing the TSHD *Brisbane's* past maintenance dredging campaigns were analysed by BMT WBM (BMT WBM, 2014d). The analysis provided insights into the typical amount of time spent dredging and steaming, the order in which dredge parcels were targeted, the total number of dredge cycles in the campaign and the total length of the campaign in days.

Analysis of past campaigns provided an estimate of the percentage of the total maintenance dredging task for each of the twelve dredging parcels in Table 3-2. For each simulated dredging scenario, the volume allocated to each of the dredging parcels was derived according to the percentage allocations in Table 3-2. The locations of each dredge parcel are listed in Table 3-2 are shown in Figure 3-1. The colours of the various parcels in Table 3-2 match the colours of the polygons in Figure 3-1.

Table 3-2 Distribution of Simulated Maintenance Dredging Requirements

Parcel	***Percentage of Group's Maintenance Requirement [%]***
WILD CATTLE CUTTING	15
BOYNE CUTTING	3
GOLDING CHANNEL	20
GATCOMBE CHANNEL	3
AUCKLAND CHANNEL AND AUCKLAND BERTH	3
CLINTON BYPASS CHANNEL	2
CLINTON CHANNEL AND CLINTON WHARVES	2
WIGGINS ISLAND APPROACHES AND WIGGINS BERTH	13
TARGINIE CHANNEL AND FISHERMANS LANDING	5
GLNG	7
QCLNG	7
APLNG	20



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Locations of Maintenance Dredging Parcels

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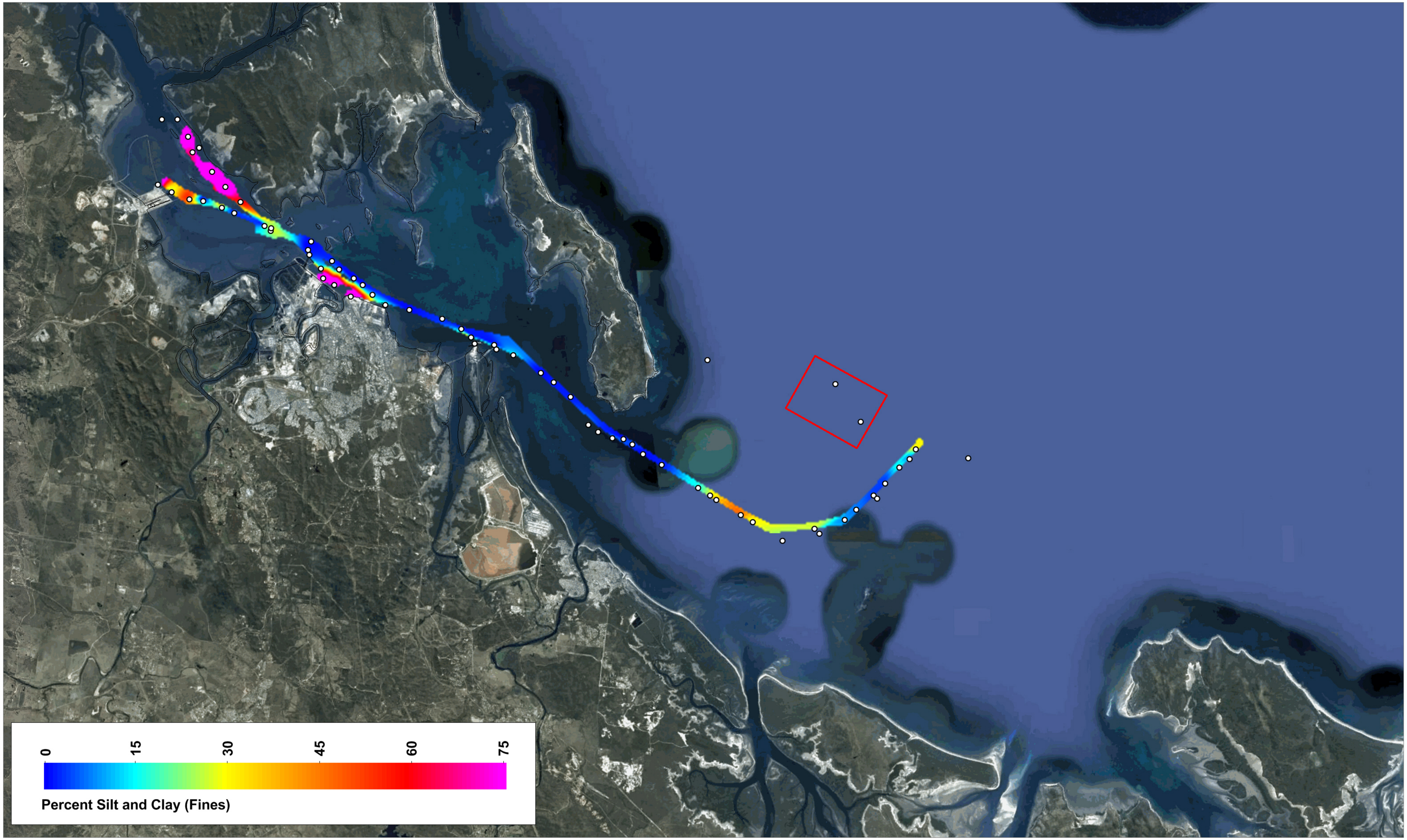
3.1.2 Dredged Material Characteristics

Figure 3-2 is a map of particle size distributions (PSD) of surface sediments in dredged areas, based on sediment data collected by BMT WBM (2012c; 2014b). In 2012, approximately 54% of sampling locations were dominated (i.e. >90% of sample) by gravel and sand material. Surface sediments in channels were typically comprised of coarse material, with coarse gravel comprising up to 80% of samples at some locations. Four of the six investigated wharf sites were also dominated by sands and gravel, although two wharfs sites were dominated by silts and clays. The WBDDP areas surveyed in 2014, had showed that there were variable amounts of fines in the Targinie Channel, while the Jacobs Channel (Passage Islands Channel) was dominated by fine materials. Thus, the blind endings of the berth pockets, and the Jacobs Channel tend to be filled with finer material, while coarser material tends to accumulate in the long open stretches of channel in the middle and outer harbour.



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Interpolated Particle Size Distribution of Surface Sediments in Channel Areas (BMT WBM 2012c; 2014b)

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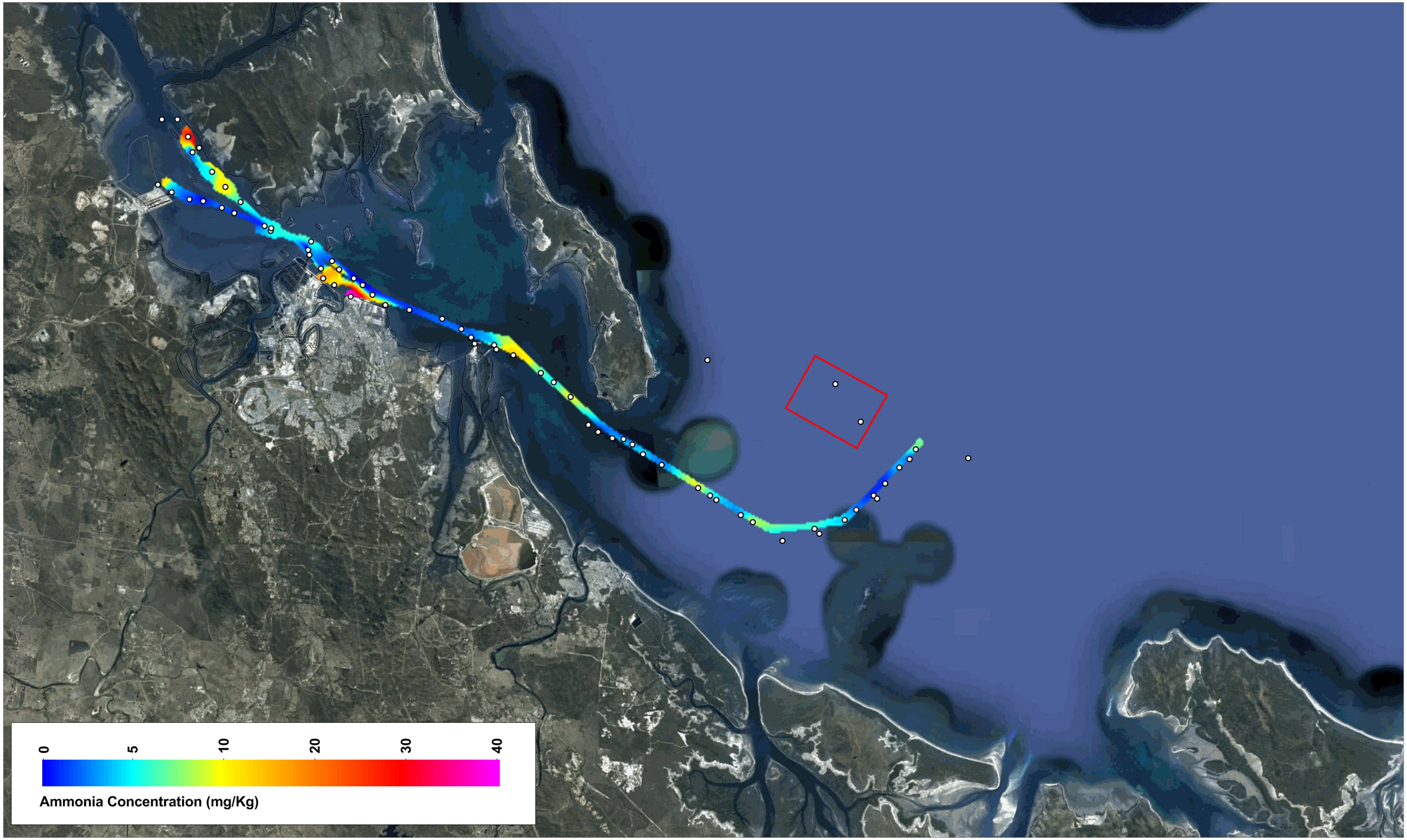
The chemical analysis of the sediments indicated that the channel and wharf sediments were clean with respect to all investigated contaminants, including trace metals/metalloids, Poly Aromatic Hydrocarbons (PAHs), BTEX, total petroleum hydrocarbons, pesticides, organotins and Polychlorinated Biphenyls (BMT WBM 2012c; 2014b). Except for metals/metalloids and PAHs, all other contaminants were found to be below the laboratory limits of reporting. The 95% upper confidence levels (UCLs) for the detected contaminants were all below screening levels set out in the NAGD.

In 2012 the 95% UCLs for ammonia and total organic carbon (TOC) were 6.9 mg/kg and 0.47% compared to background sites which varied between 1.1 and 2.8 mg/kg total ammonia and 0.06 to 0.31% TOC (BMT WBM 2012c). In 2014 the additional areas of the Western Basin had 95% UCLs for ammonia and total organic carbon (TOC) of 12.9 mg/kg and 1.1% (BMT WBM 2014b). Over most of the dredge footprint concentrations of ammonia in surface sediments were very low, with highest concentrations occurring in areas of fine sediment deposition such as Auckland Point Berths and Jacobs Channel (Figure 3-3). While 4 mg/kg is the screening level for ammonia in subsequent updates to the NAGD (Simpson *et al*., 2013), the Port Curtis Integrated Monitoring Program (PCIMP) has adopted a sediment ammonia concentration of 15 mg/kg (95th percentiles of reference data) as their recommended guideline for ecosystem protection. The 95% UCLs for ammonia within dredged sediments were below this guideline value, with four samples exceeding 15 mg/kg in the new Western Basin areas, specifically at Fisherman’s landing near the reclamation, behind the RG Tanna Wharf, and in the QCLNG section of the Jacobs Channel.

The differences in TOC and ammonia content between the background sites and the dredged areas reflect differences in the environmental characteristics of these areas. In this regard, the background sites were located at, and adjacent to, the EBSDS, which represents an active hydrodynamic environment dominated by sand and gravel sediments. The berth pockets by contrast represent quiescent depositional environments which were typically dominated by fine sediment fractions. While data for other nutrients are not available from the 2012 data, it is expected that total nitrogen and phosphorus concentrations would reflect trends observed in PSD and ammonia.

The results of the 2012 and 2014 sediment quality assessments were similar to past sediment quality campaigns which did not find any parameters that exceeded the ANZECC (2000) Interim Sediment Quality Guidelines (ISQG, used by the former National Ocean Disposal Guidelines for Dredged material [NODGDM 2002]) or the NAGD (2009) screening levels. While past studies have found occasional exceedances in arsenic and tributyltin during 2006 (GHD 2006), elutriate testing showed that these concentrations would not result in water column impacts. Exceedances in arsenic above ISQGs have been observed several times since 1992 and are thought to be naturally occurring (GHD 2006) as reference sites occasionally also have concentrations of arsenic above screening levels.



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○ Sample Location

□ EBSDA

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Interpolated Distribution of Ammonia in Surface Sediments in Channel Areas (BMT WBM 2012c; 2014b)

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4 Environmental Context and Biodiversity Values

4.1 General Environmental Features

4.1.1 Hydrodynamic Environment

Port Curtis is a macro tidal environment with spring tidal ranges exceeding 4.5 m, and neap tidal ranges of approximately 1 m. Due to the large tidal storage areas and the amplification effect on water levels, good tidal flushing and high tidal velocities generally exist within the main channels of Port Curtis. Typically observed spring tide velocities within dredged shipping channels are up to approximately 2.0 m/s (see Figure 4-1).

The energetic macro-tidal hydrodynamic conditions in Port Curtis play an important role in the context of natural bed remobilisation processes and associated patterns in total suspended solid concentrations. Within the Port, the bed shear stress associated with the tidal currents is generally the dominant driver of sediment resuspension and wave-related bed shear stress is of secondary importance. In the outer reaches of the Port, and in offshore areas, wave energy is higher and tidal velocities are lower, and therefore, the wave-related bed shear stress is a much more significant driver of resuspension processes. Both current-related and wave-related bed shear stresses are included in the modelling. Figure 4-2 shows an example of modelled sediment fluxes on an ebbing spring tide (top panel) and flooding spring tide (bottom panel).

Measured turbidity within the Port shows substantial variation in turbidity levels over each tidal cycle as well as significant variation between neap tidal and spring tidal periods. There is also substantial spatial variation in turbidity levels throughout the Port, particularly during spring tidal periods.

The surface sediments in the main channels of the Port where tidal velocities are high are typically dominated by coarser fractions with the finer particles having being swept away. The shallower intertidal areas are a mixture of sands and silts with fine soft silts dominating in the lower current/wave energy areas.

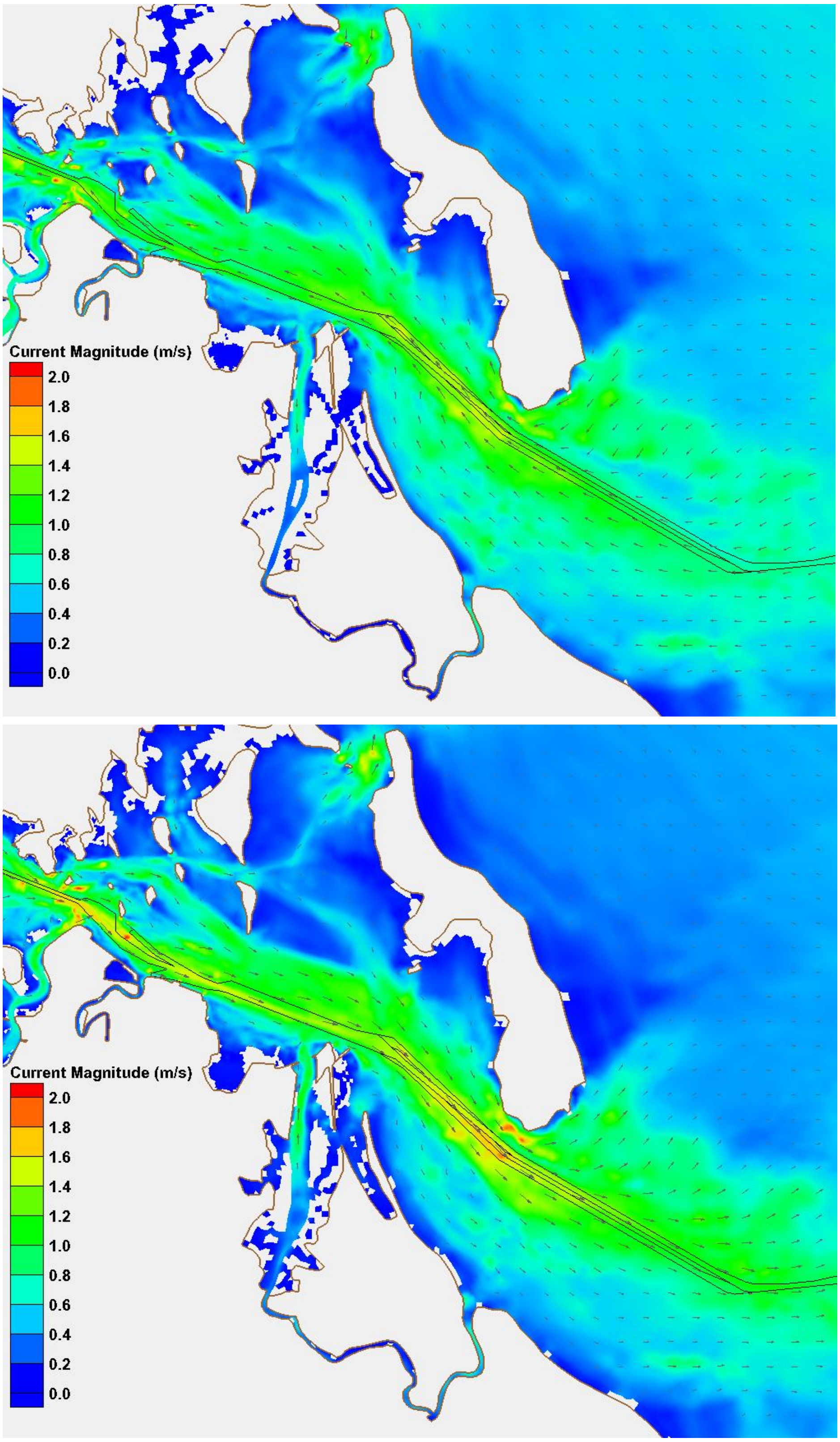

Figure 4-1 Example Spring Tidal Currents; Flood (Top), and Ebb (Bottom)

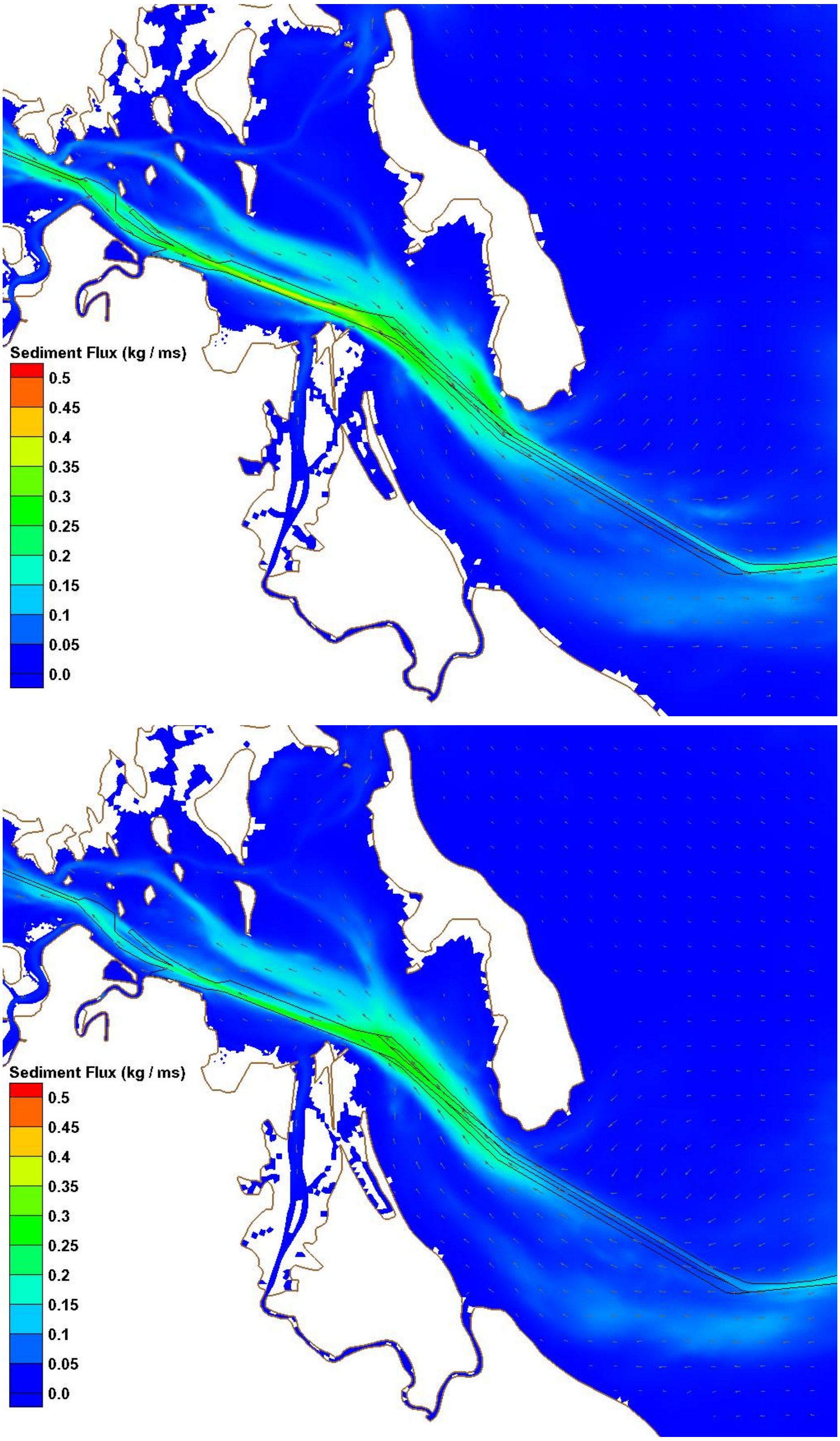

Figure 4-2 Example Sediment Fluxes (kg/s per metre) for Ebb Spring Tide (Top) and Flood Spring Tide (Bottom)

4.1.2 Water Quality

The Port Curtis Integrated Monitoring Program (PCIMP) is a long-term water quality and ecological monitoring program that began in 2005, and is a key data source used to produce the Gladstone Healthy Harbour Partnership (GHHP) Gladstone Harbour annual report card. Port Curtis is divided into 13 zones, as shown in Figure 4-3.

The Inner Harbour, Outer Harbour, Western Basin and Mid Harbour zones (all classified as *Moderately Disturbed* waters under *Environmental Protection Policy (Water) 2009*) have a marine character and water quality is generally good, although like other parts of Port Curtis, nutrients have occasionally exceeded relevant Queensland Water Quality Objectives (QWQOs). The QWQOs for the Gladstone Harbour area are based on national and state water quality guidelines and objectives (ANZECC/ARMCANZ 2000; DERM 2009; DEHP 2014b) and are used to provide context to the PCIMP data (Gladstone Healthy Harbour Partnership 2016). Low levels of dissolved metals have been recorded across all 13 zones with occasional peaks in concentrations that exceed the ANZECC/ARMCANZ (2000) guideline concentrations. Most recently, concentrations of lead, nickel and zinc have been low across all zones, while aluminium and manganese have been low in concentration in all zones except for Boat Creek (classified as *Moderately Disturbed* waters under *Environmental Protection Policy (Water) 2009*).

The long-term means and standard errors for PCIMP sites from the Inner Harbour are shown in Figure 4-4. The Inner Harbour sites have consistently had pH that met the QWQO, whereas arsenic, copper and nutrients have exceeded the relevant QWQO or ANZECC/ARMCANZ (2000) guideline. It should be noted that ammonia concentration data collected prior to July 2015 has been erroneously analysed by the laboratory and should be disregarded. Quarterly grab-based turbidity measurements also exceeded the QWQO median range (Figure 4-4) and logging instruments have consistently recorded peaks in TSS exceeding 80 mg/L in the Inner and Mid Harbour (see Appendix A).

The key processes affecting water quality in the central harbour are high concentrations of nutrients from point and diffuse sources, and strong pulsed turbidity events that occur when spring tides resuspend benthic sediment. Port Curtis is a highly dynamic system that is generally well mixed, with greatest areas of turbidity occurring between Wiggins Island and Graham Creek, in the upper reaches of the Narrows, and within South Trees Inlet. These processes have implications for the distribution of seagrasses and corals which are typically found away from the areas that experience the greatest tidally driven resuspension.

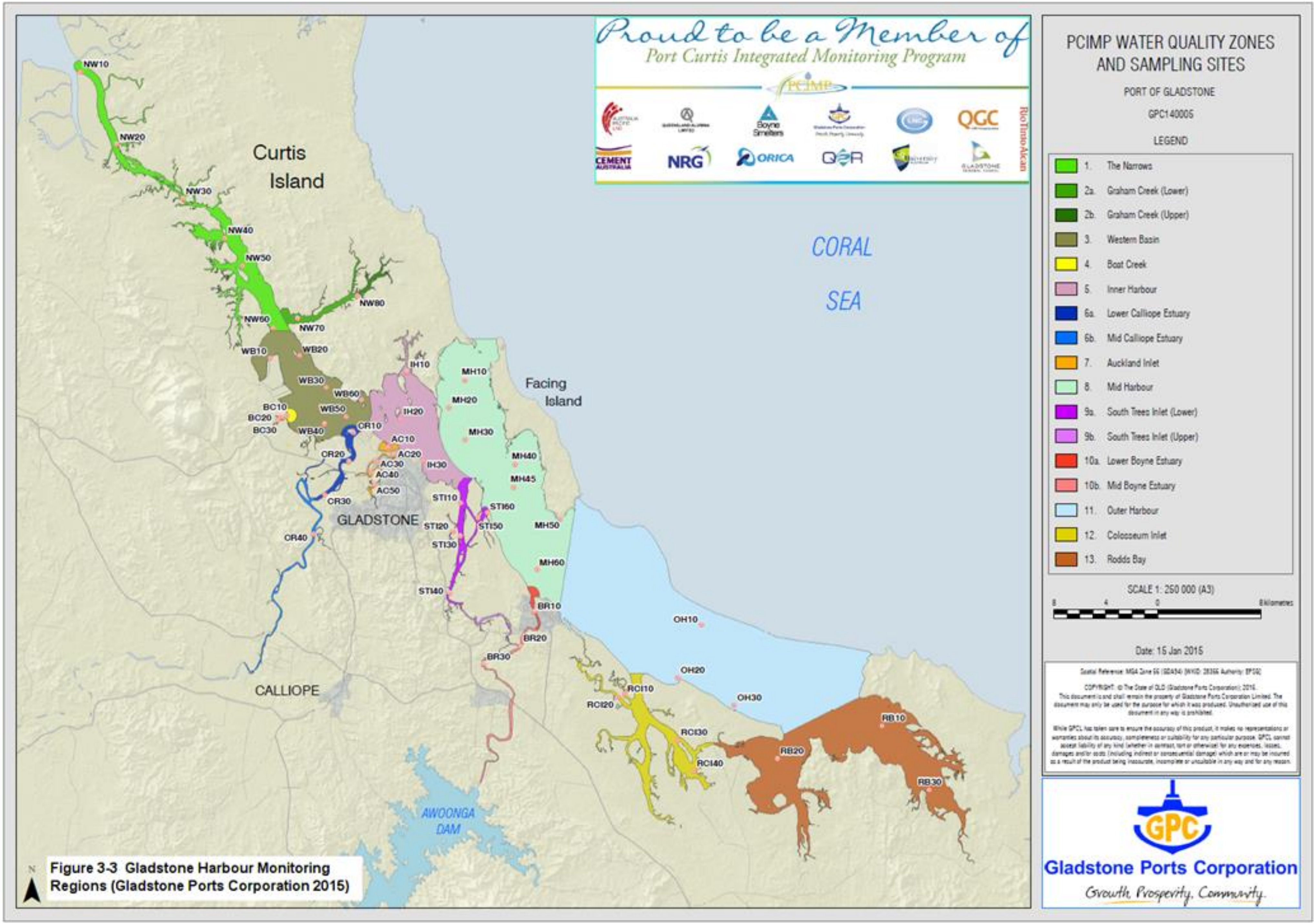

Figure 3-3 Gladstone Harbour Monitoring Regions (Gladstone Ports Corporation 2015)

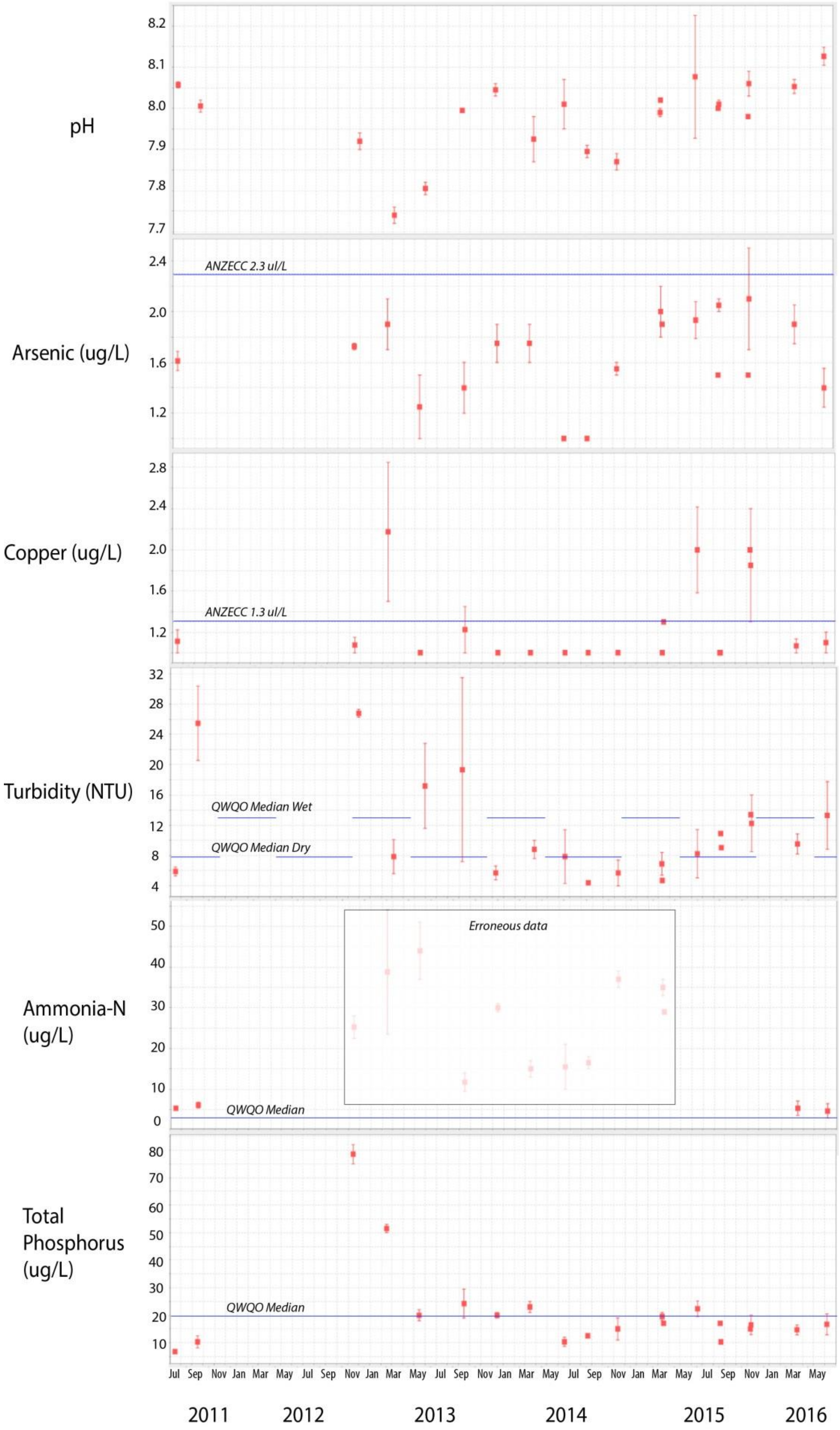

Figure 4-4 Mean (+/- SE) pH, arsenic (total), copper (total), turbidity, ammonia, and total phosphorus for the Inner Harbour (data compiled from PCIMP, 2016)

4.1.3 Sediment Quality

PCIMP data collected in 2015 indicated that sediment quality scores were uniformly very good across all zones of Gladstone Harbour due to low levels of metals (cadmium, copper, lead, nickel and zinc) and total PAHs. Arsenic and nickel were the only parameters that were somewhat elevated; in particular arsenic in the Outer Harbour and nickel in Auckland Inlet and The Narrows. Concentrations of these metals are frequently elevated in naturally occurring sediments within Port Curtis.

4.1.4 Marine Habitats

Port Curtis supports a range of intertidal and subtidal habitats that are important in maintaining a range of ecological values. Intertidal habitats (rocky shores, mangroves, saltmarsh, saltpan and mud flats) occur throughout the Port Curtis area, and seagrass meadows and reefs are well developed.

The following provides a summary of the marine habitats located within or adjacent to dredge areas, namely seagrass meadows, reefs and soft sediment habitats. Although extensive areas of intertidal habitat (mangroves, saltmarsh, saltpan and mud flats) occur throughout Port Cutis, these are outside of the zone of impact from dredging (see Section 5) and are not considered further.

4.1.4.1 Seagrass Meadows

Spatial and Temporal Patterns

Six species of seagrass have been identified in Port Curtis by James Cook University TropWater (formerly Department of Agriculture Forestry and Fisheries DAFF), namely: *Zostera muelleri*[1], *Halodule uninervis*, *Cymodocea serrulata, Halophila spinulosa*, *Halophila ovalis*, and *Halophila decipiens*.

In the last decade of monitoring, the greatest seagrass meadow extent was mapped in 2002, and this is shown as composite layer with additional mapping from 2009, 2012, 2014, and 2016 in Figure 4-5. Figure 4-5 shows two broad types of seagrass meadow:

- Permanent/ approaching permanent coastal meadows, which occur on tidal flats and dominated by *Zostera* and a range of other species; and
- Deepwater meadows (>5 m deep), which are typically sparser than coastal meadows and are typically dominated by *Halophila* species.

The results of monitoring studies indicate that the distribution, extent and density of seagrass meadows within Port Curtis and surrounds can show great variation over a range of temporal scales. At inter-annual time-scales, there was a major reduction in seagrass meadow extent in the period 2009-2013, and a period of recovery in subsequent years (Figure 4-6). Between 2009 and 2011, seagrass cover and biomass at Fisherman’s Landing, Wiggins Island, and Rodds Bay had almost disappeared with average percent cover less than 1% (Sankey and Rasheed 2011) and *H. ovalis* was no longer observed at the study area. The disappearance of seagrass from these areas was thought to be related to heavy rainfall associated with strong Southern Oscillation Index values for 2010 and 2011 (Sankey and Rasheed 2011).

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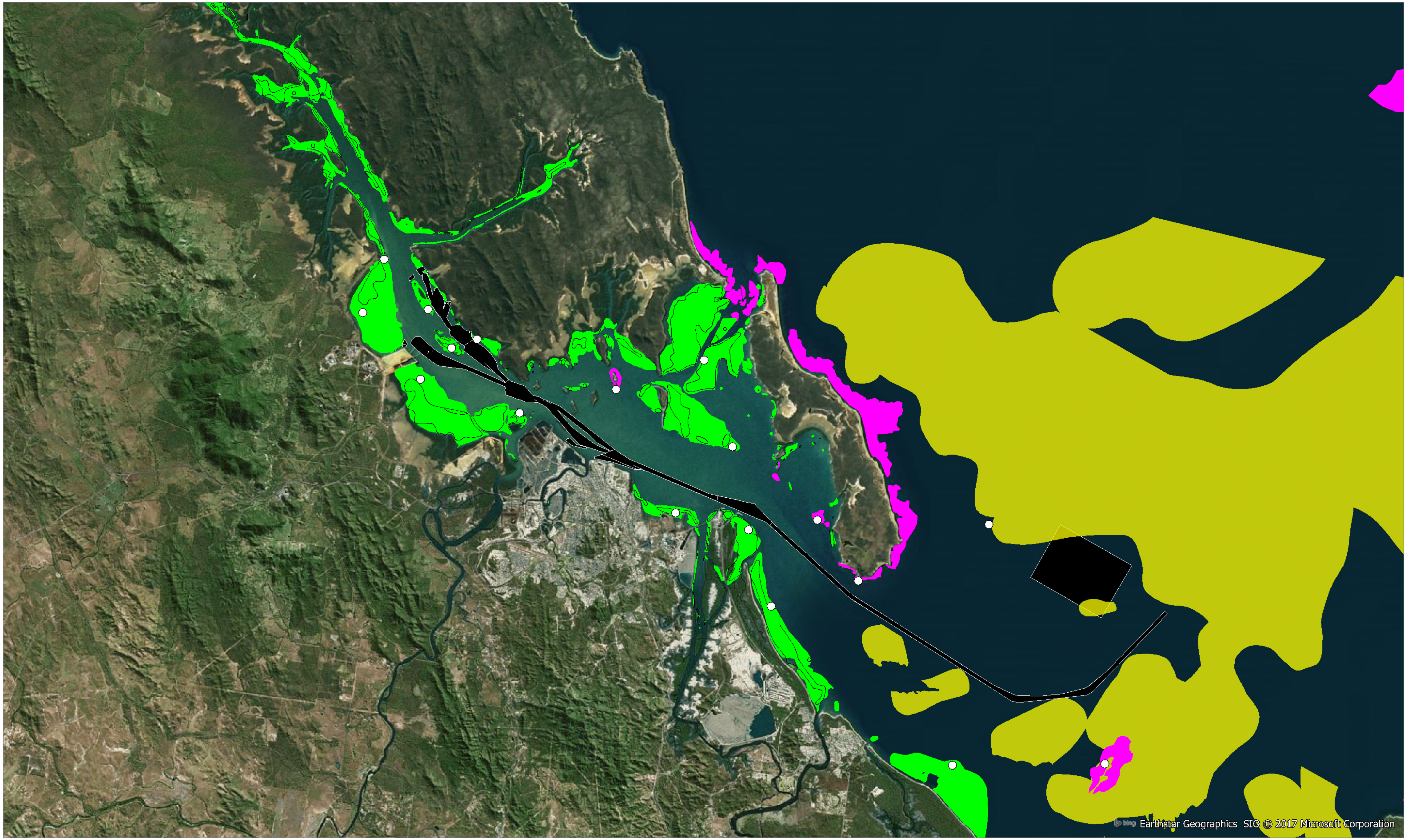
[1] *Zostera muelleri* subspecies *capricorni* (Ascherson) 1876 afterwards referred to as *Zostera muelleri*

Seagrass distribution measured in January 2012 was greater than it was in February 2011 (Sankey *et al.* 2012), but was still much reduced in extent compared to the distribution mapped in 2002 (Figure 4-6). Heavy rainfall associated with Cyclone Oswald resulted in further reductions in seagrass meadow extent between 2012 and March 2013 at Fisherman's Landing, Wiggins Island and Rodds Bay, (Amies *et al.* 2013). Since this time, there was a steady increase in meadow extent to 2015, with a further reduction in 2016 (Rasheed *et al.*, 2017). Meadow area is yet to reach pre-flood extent.



LEGEND

- ■ Dredge Footprint and EBSDS
- 🟨 Seagrass Deepwater Composite Distribution (2002-2016)
- 🟩 Seagrass Coastal Composite Distribution (2002-2016)
- ☐ Seagrass Coastal Distribution 2016 (JCU)
- 🟪 Coral Reefs (BMT WBM 2014)
- ○ Model Output Points

Title:

Location of Seagrasses and Corals in Port Curtis

Figure: 4-5

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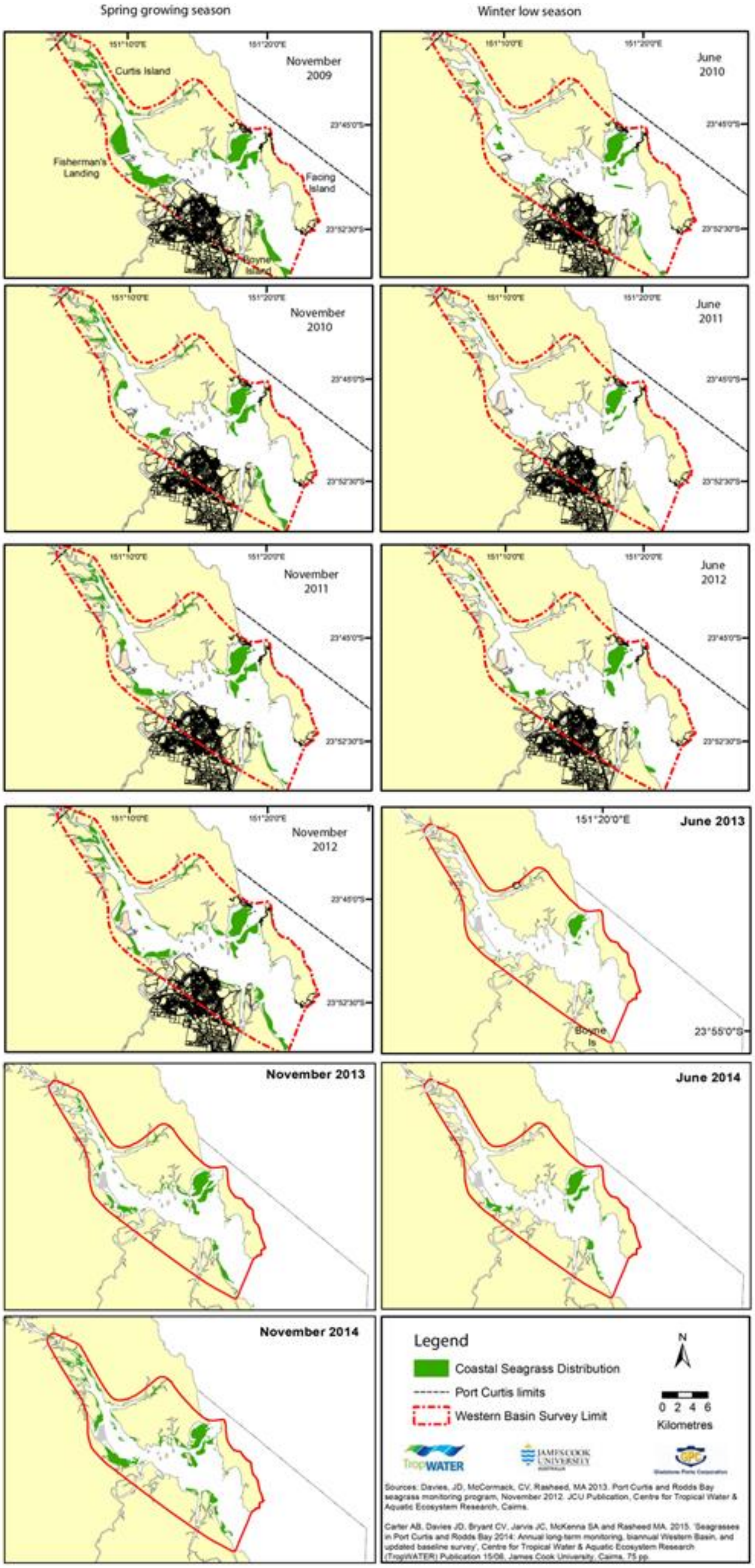


Sources: Davies, JD, McCormack, CV, Rasheed, MA 2013. Port Curtis and Rodds Bay seagrass monitoring program, November 2012. JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research, Cairns.

Carter AB, Davies JD, Bryant CV, Jarvis JC, McKenna SA and Rasheed MA. 2015. 'Seagrasses in Port Curtis and Rodds Bay 2014: Annual long-term monitoring, biannual Western Basin, and updated baseline survey', Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 15/08, James Cook University, Cairns, 75 pp.

Figure 4-6 Changes in Seagrass Meadow Extent between November 2009 and 2014 (Davies *et al.* 2013, Carter *et al.* 2015)

Existing Condition

Chartrand *et al*. (2012) developed a light-based threshold to protect seagrass meadows during the growing season in Port Curtis based on field-based experiments. This threshold has been adopted for the present study, and is as follows: *2-week rolling average of photosynthetically active radiation (PAR) > 6 mol photons/m*^{2}*/day during the growing season*. PAR conditions have mostly been maintained above the PAR threshold (i.e. were suitable for seagrass growth) since the 2011 and 2013 flood events (Figure 4-7).

The most recent seagrass condition monitoring was undertaken in 2016(Rasheed *et al.* 2017), and patterns in seagrass health have been monitored since 2009, and include sites in the Narrows, Fisherman's Landing, Wiggins Island, Pelican Banks, Facing Island and Rodds Bay. Key indicators within each of the monitoring meadows include:

- Biomass: changes in average above-ground biomass.
- Percent cover.
- Light availability.
- Species composition: relative abundance of species.

The time series of seagrass percent cover, light availability and temperature between 2009 and 2015 at Fisherman's Landing, Wiggins Island, and the Pelican Banks are shown Figure 4-7. All three time series show a reduction in percent cover after the 2010-11 floods, and that there has been limited recovery at Fisherman's Landing and Wiggins Island. Seagrass cover at Pelican Banks was less severely affected by the 2010-11 and 2013 floods, but as of 2016, has not yet returned to levels observed prior to these flood events, despite good light climate during this period.

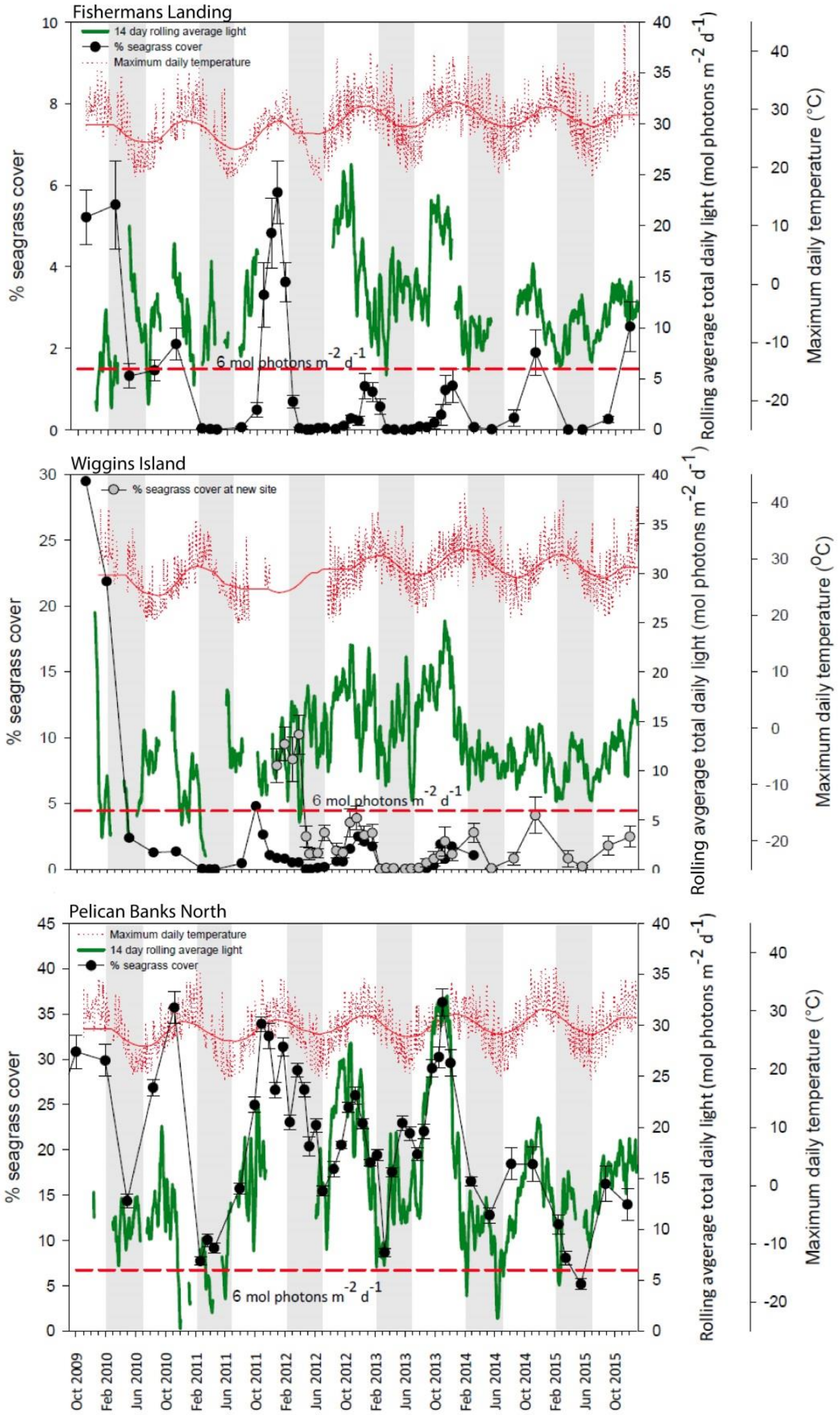


Figure 4-7 Time series of PAR (2 week rolling av.), temperature and biomass at Fisherman’s Landing (top), Wiggins Island (middle), and Pelican Banks (below) (Bryan *et al*. 2016)

4.1.4.2 Reefs and Hard Substrates

Hard substrate habitats in Port Curtis include natural reefs and intertidal rocky shores, and artificial hard structures (rock walls, pylons etc.). Several studies have mapped the extent of rocky shores and reefs within Port Curtis (Rasheed *et al*. 2003; Connolly *et al*. 2005; URS 2009, BMT WBM 2009).

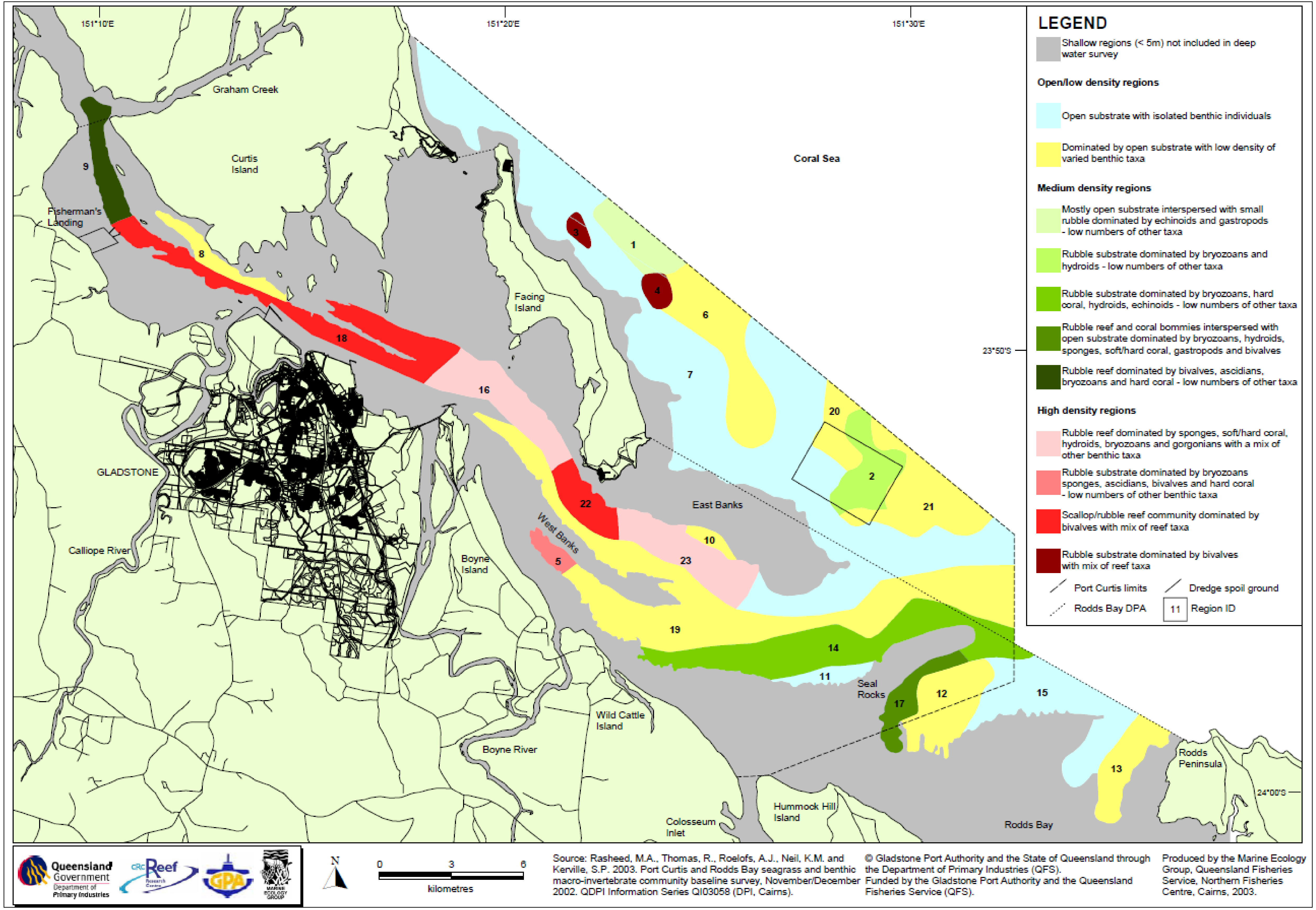
Rasheed *et al*. (2003) mapped deepwater benthic communities within Port Curtis (Figure 4-8). It should be noted that this was a snap-shot survey and had limited spatial replication. Rubble banks were recorded throughout the deeper sections of Port Curtis, and most of the deeper areas between East Banks to southern Curtis Island were comprised of 'high density' assemblages. These higher density assemblages were comprised of:

- Scallop/rubble reef assemblages dominated by bivalves and a range of other reef biota; and
- Rubble reef areas dominated by sponges, soft/hard coral, hydroids, bryozoans and gorgonians with a mix of other benthic taxa.

The natural rocky shores along the south-west coast of Curtis Island consisted of terrigenous fringing reefs (see BMT WBM mapping in Figure 4-11). The supra-littoral and upper intertidal zone of these rocky shores was typically comprised of unconsolidated soft sediment (mud, sand and gravel), and the mid to lower intertidal zone was comprised of either massive/bedrock platform reef, boulder fields or rubble fields (BMT WBM 2009). All rocky shores in this area were dominated by oysters in the intertidal zone (BMT WBM 2009), and sponges, soft coral, hydroids, gorgonians and algae in the subtidal zone (URS 2009).

BMT WBM (2009) recorded high hard coral cover at several shallow (<2 m deep) subtidal reefs in the study area including Bushy Island, Manning Reef and surrounding Facing Island. Follow-up surveys in 2014 indicate that reef communities within the study area experienced a major change in structure since the 2009 baseline surveys (BMT WBM, 2015a). In contrast to 2009 surveys, reefs at Port Curtis in 2014 had minimal living hard coral cover, and were dominated by bare substrate, turfing algae and macroalgae. Reef communities between Port Curtis and Rodds Bay also had low hard coral cover, however, limited baseline data make changes through time difficult to determine. Nearshore reefs along the eastern coastline of Facing Island, which are less affected by floods, had diverse and abundant hard coral cover in 2014, similar to 2010 survey results (BMT WBM, 2015a). Modelling and measurement data showed that reefs within Gladstone Harbour were strongly affected by flood events in 2010 and 2013, with reduced salinities and high turbidity likely to be a major driver of change in coral cover.

Coral monitoring undertaken in 2015 revisited a small selection of the previously surveyed sites within Gladstone Harbour (Thompson *et al.* 2015) , all of which were noted by BMT WBM (2015a) as having suffered coral loss. Thompson *et al.* (2015) found that the surveyed reefs had not recovered to pre-2010 levels of coral cover. No data are available to assess trends in the condition of other reefs in Gladstone Harbour and along the eastern shoreline of Facing Island. Recovery is likely to take many years given the slow rate observed so far and the relatively low density of recruiting corals.



Source: Rasheed, M.A., Thomas, R., Roelofs, A.J., Neil, K.M. and Kerville, S.P. 2003. Port Curtis and Rodds Bay seagrass and benthic macro-invertebrate community baseline survey, November/December 2002. QDPI Information Series QI03058 (DPI, Cairns).

© Gladstone Port Authority and the State of Queensland through the Department of Primary Industries (QFS). Funded by the Gladstone Port Authority and the Queensland Fisheries Service (QFS).

Produced by the Marine Ecology Group, Queensland Fisheries Service, Northern Fisheries Centre, Cairns, 2003.

Figure 4-8 Deepwater Benthic Macro-Invertebrate Regions in Port Curtis, November/December 2002 (Source: Rasheed *et al.* 2003)

4.1.4.3 Soft Sediment Habitats and Communities

Soft sediment invertebrate communities within Port Curtis were comprehensively described by Currie and Small (2005) and have been described in lesser detail by LNG proponents. Soft sediment communities within and adjacent to the EBSDS have also been described as a part of dredge monitoring conducted by BMT WBM (2006; 2007, 2012b) and Vision Environment (2017).

Currie and Small investigated changes in macroinvertebrates at 30 sites in Port Curtis, twice yearly, over 6 years between 1995 and 2001. Currie and Small (2005) found that the bivalve *Carditella torresi* and to a lesser extent the sea-squirt *Ascidia sydneiensis* were the most abundant taxa, particularly in subtidal waters. Great variability in community structure was observed. Gradients in abundance and species richness were principally driven by depth and sediment grain size, with extremely fine, or extremely coarse sediments having the lowest richness and abundance. Species richness and abundance were lowest on intertidal muddy substrates, and greatest in coarse, sandy-sediments predominantly occurring in the deeper channels of the estuary. Bivalve molluscs, ascidians, polychaetes and pistol shrimp (*Alpheus* sp.) were among the most important taxa defining the difference between intertidal and subtidal sediments.

Nearshore tropical and sub-tropical benthic fauna communities are dynamic, varying across multiple temporal scales (Stephenson 1980; Alongi 1989; Currie and Small 2005; BMT WBM 2012). Currie and Small (2005) found that benthic communities in Port Curtis did not show predictable seasonal trends, unlike in higher latitudes where seasonal changes in water temperature and other processes can lead to changes in community structure. Instead, Currie and Smith (2005) found that temporal changes in communities were more closely aligned with the Southern Oscillation Index (SOI), with the most significant El Nińo (drought) episode during the measurement period coincident with a halving of taxa richness and abundance. Correlation analysis found significant positive correlations between benthos abundance/richness and turbidity, on which Currie and Smith (2005) concluded that high turbidity provided favourable conditions for benthic communities.

It is possible that Cyclone Yasi and associated flooding in 2011 had resulted in changes to benthic communities since the Currie and Smith (2005) study. For example, BMT WBM (2012) examined temporal patterns in benthic communities at and near the EBSDS . No strong seasonality was observed, however benthic abundance and to a lesser extent richness was observed to significantly decline at most locations immediately before and one month after Cyclone Yasi. Other case studies demonstrate that river flows and associated nutrient inputs can promote benthic abundance in the longer term (e.g. review by Gillanders and Kingsford 2002). No significant changes in communities were observed over the EDSDS and surrounding environments between the 2016 and 2017 wet season and the 2017 dry season (Vision Environment 2017)

Table 4-1 Abundance (per 0.1 m^2) and richness measures measured by Currie and Small (2005)

Parameter	Currie and Small (2005)
Dominant taxa	*Carditella torresi* (14% of individuals), *Ascidia sydneiensis* (4% of individuals)
Proportion of uncommon taxa (accounting for <2% of individuals)	98% of species
Mean (± s.e.) no. individuals per 0.1 m^2	5.9 ± 0.40 to 24.4 ± 1.25
Mean (± s.e.) no. taxa	3.6 ± 0.20 to 11.6 ± 0.48 per 0.1 m^2
Mean (± s.e.) no. polychaetes per 0.1 m^2	1.0 ± 0.09 to 8.0 ± 0.59
Mean (± s.e.) no. molluscs per 0.1 m^2	4.0 ± 0.32 to 10.3 ± 0.71
Mean (± s.e.) no. crustaceans per 0.1 m^2	0.6 ± 0.09 to 2.7 ± 0.28

Vision Environment (2017) undertook an assessment of benthic macroinvertebrate abundance and richness assemblages within the maintenance dredge footprint and adjacent non-dredged areas. The results of this study are difficult to compare with those recorded in Currie and Small (2005) or BMT WBM (2012) due to the different authors reporting grab volume versus grab area. Notwithstanding this, Vision Environment (2017) found no significant difference in macroinvertebrate communities in areas that had been dredged and undredged areas (Vision Environment 2016). This suggests that benthic assemblages may have a high capacity to recover from disturbance due to maintenance dredging.

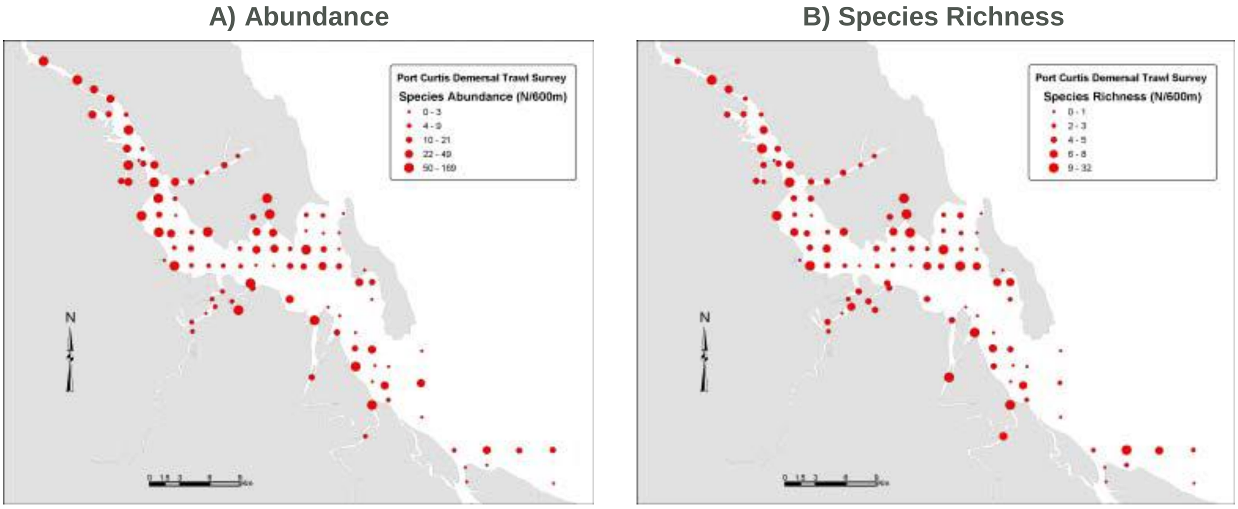
4.1.4.4 Fish Communities from Soft Sediments

Port Curtis contains a broad range of habitats for marine and estuarine fish. Connolly *et al.* (2006) undertook the most detailed fish surveys in Port Curtis, where 105 intertidal and shallow subtidal sites were surveyed using a 5 m wide beam trawl.

The survey recorded 88 fish species and 2294 individuals from 315 replicate trawl shots. Small schooling fish dominated the samples as is typical of similar environments elsewhere in Queensland (Blaber *et al.* 1989). Approximately 30 species of the fish species recorded were of direct or indirect economic importance.

Sites located on mud flats and seagrass meadows in the study area had the richest (i.e. highest number of species) and most abundant fish assemblages on a Port Curtis wide scale (Figure 4-10). Connolly *et al.* (2006) also found that seagrass meadows had a distinctive fish fauna that differed from assemblages on 'unvegetated' habitats, emphasizing the importance of seagrass in maintaining biodiversity values.

Connolly *et al.* (2006) also undertook studies using stable isotope analysis to trace energy pathways and nutrient cycling in Port Curtis. They found that seagrass was an important component at the base of food webs, including in areas beyond the seagrass meadows themselves. The analysis suggested that the food webs that sustain many economically important fisheries species caught over mudflats (e.g. whiting) and in mangrove-lined creeks (e.g. mud crabs) rely largely on organic matter produced in seagrass meadows.


A) Abundance

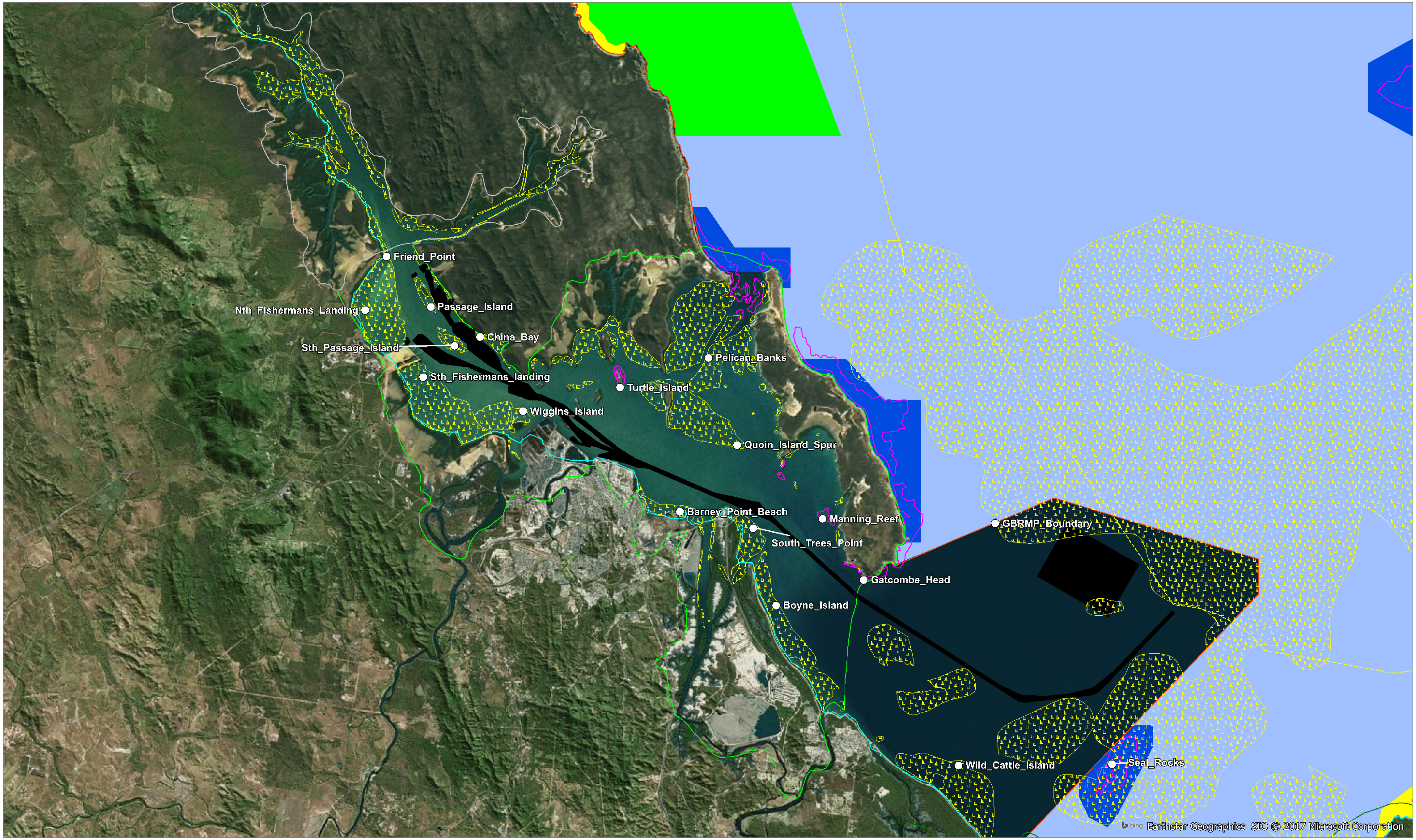
B) Species Richness

Figure 4-9 Map of Port Curtis showing a) Total Species Abundance and b) Total Species Richness of Demersal Fish Collected from 3 Replicate Beam Trawl Samples (200 m Length) at 105 Sampling Stations (Source: Connolly *et al.* 2006)

4.2 Matters of National Environmental Significance (MNES)

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), provides for the protection of MNES. Table 4-2 lists MNES and describes their potential relevance to this assessment. The locations of MNES of relevance to dredging activities in Port Curtis are shown in Figure 4-11. Figure 4-1 also includes the mapped extents of coral reef (BMT WBM 2014) and seagrass meadows (maximum recorded extent to 2015), as these are considered the major sensitive ecological receptors of relevance to maintenance dredging activities, and provide habitat for several species listed as MNES.

Relevant MNES to Port Curtis are the Great Barrier Reef World Heritage Area/National Heritage Place, and threatened species and migratory species. These are summarised below.



LEGEND

- ■ Dredge Footprint and EBSDS
- ▨ Seagrass composite distribution (2002-2016)
- ☐ Coral Reefs (BMT WBM 2014)
- — World Heritage Area Boundary
- — Port Curtis Wetland (DIW)
- — The Narrows Wetland (DIW)
- — Colosseum Inlet Rodds Bay (DIW)
- — Commonwealth Marine Area

Great Barrier Reef Marine Park Zoning

- — GBR Wetland Boundary
- ■ General Use Zone
- ■ Habitat Protection Zone
- ■ Marine National Park Zone
- ■ Conservation Park Zone

** Great Barrier Reef Marine Park Authority 2006*

Title:

Features Listed as Matters of National Environmental Significance and Model Output Points

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Table 4-2 Matters of National Environmental Significance and Relevance to Port Curtis

MNES*	Description
World Heritage Sites and National Heritage Places	Great Barrier Reef World Heritage Area (GBRWHA) extends throughout the Great Barrier Reef region and includes most of Port Curtis. The GBRWHA is listed as a National Heritage Place.
Great Barrier Reef Marine Park (GBRMP)[2]	The GBRMP is located offshore of Port Curtis and extends into the southern part of Rodds Bay. The dredge footprint is located outside the GBRMP.
Nationally threatened species and ecological communities (including marine turtles and whales)	Refer to Section 4.2.2
Migratory species (including dugong, whale shark and several threatened marine megafauna species)	Refer to Section 4.2.2
Commonwealth marine areas	The Commonwealth marine area is located approximately 18 km east of the dredge footprint.
Wetlands of international importance (Ramsar site)	There are no Ramsar sites within 90 km of Port Curtis.

(*) actions that are listed MNES which are not relevant to maintenance dredging are: (i) nuclear actions, and (ii) a water resource a water resource, in relation to coal seam gas development and large coal mining development

4.2.1 Great Barrier Reef World Heritage Area/National Heritage Place

The Great Barrier Reef World Heritage Area (GBRWHA) extends from the low water mark on the Queensland coast to past the edge of the continental shelf, and from the tip of Cape York Peninsula to just north of Fraser Island. It includes mangroves, rocky reefs, sandflats, open ocean and the deep sea floor. GBRWHA, like other Australian World Heritage Properties, is listed as a Matter of National Environmental Significance (MNES) under sections 12 and 15A of the EPBC Act. The Great Barrier Reef is also listed as a National Heritage Place (and shares the same boundaries as the GBRWHA), which is listed as a MNES under sections 15B and 15C of the EPBC Act.

GBRWHA was listed in 1981 in recognition of the range of natural and cultural heritage that contributes to the Outstanding Universal Value (OUV) of the property. The GBRWHA listing document identifies specific examples of values/attributes underpinning each criterion for OUV. Generally the examples of values/attributes identified in the GBRWHA listing document are not location specific, and therefore, do not specifically define marine ecological values/assets supported in Port Curtis. For this reason, it is not meaningful or practicable to identify specific features within the Port Curtis that meet each of the criteria.

Of the criteria for which the GBRWHA is listed, Port Curtis supports the following:

- Coral reefs;
- Lagoonal benthos;

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[2] *Great Barrier Reef Marine Park Act 1975* (GBRMP Act) is also relevant to the protection of marine ecological values within the boundaries of the marine park that may be affected by dredging

- Seagrass meadows and mangrove ecosystems;
- Habitats for threatened species;
- Coastal/continental islands (Facing Island, Curtis Island) of exceptional natural beauty; and
- Many species of coral, macroalgae, crustaceans, polychaetes, molluscs, phytoplankton, fish, seabirds, mammals and reptiles.

The existing integrity of marine habitats varies throughout Port Curtis; however nearshore areas around Gladstone, particularly those within the operational port areas, are generally in the most modified condition.

The Queensland Government is currently advancing master planning for the priority ports of Gladstone, Abbot Point, Townsville, and Hay Point/Mackay in accordance with the Sustainable Ports Development Act (Ports Act). Master planning for priority ports is one of the port-related actions of the Reef 2050 Long-Term Sustainability Plan, and is mandated under the Ports Act. Priority port master planning has a timeframe up to 2050 to align with the Reef 2050 Long-Term Sustainability Plan (DSD 2016).

Through port master planning, the Queensland Government is seeking to effectively manage the land and marine areas needed for the efficient development and operation of the priority ports, while ensuring that the Outstanding Universal Value of the Great Barrier Reef (GBR) World Heritage Area is an intrinsic consideration in port development, management and governance (DSD 2016).

4.2.2 Threatened and Migratory Species

The EPBC Act Protected Matters Search Tool was used to identify EPBC listed threatened marine fauna species and ecological communities that occur or could occur within the study area. The subtropical and temperate coastal saltmarsh community, listed as Vulnerable, was returned as a threatened marine ecological community within 5 km of the assessment site.

Table 4-3 provides a list of threatened, migratory and listed species identified using the EPBC Act Protected Matters Search Tool, together with an assessment of known or likely occurrence in the study area. Species known or likely to occur near dredge areas include marine turtles, dolphins and dugongs.

Table 4-3 EPBC Protected Matters Database Search Results for Threatened and EPBC Act Listed Migratory Marine Species (29 November 2017)

Species	Status (EPBC/ NCA)	Habitat^{A} and Distribution	Outer Harbour/ nearshore channel
Marine Mammals			
Megaptera novaeangliae Humpback Whale	EPBC: V, M, C NCA: V	Pelagic Oceanic waters from Antarctica to northern Qld. Feeds in Antarctica waters on plankton.	Likely – transient visitor to site.
Balaenoptera edeni Bryde's whale	EPBC: M, C NCA: Not Listed	Pelagic Coastal waters of Australia and southern Africa where it	Unlikely

Species	Status (EPBC/ NCA)	Habitat^A and Distribution	Outer Harbour/ nearshore channel
		searches for baitfish (Van Dyck and Strahan 2008).	
Balaenoptera musculus Blue whale	EPBC: E, M, C NCA: Not Listed	Pelagic Widespread in oceanic waters surrounding the Australian continent at various times of the year. Feeds on plankton.	Unlikely
Orcinus orca Killer whale, Orca	EPBC: M, C NCA: Not Listed	Pelagic Occurs throughout the world's oceans. Marine mammals are key prey (Van Dyck and Strahan 2008).	Unlikely
Orcaella heinsohni, Australian snubfin dolphin	EPBC: M, C (as O. brevirostris) NCA: V	Bentho-pelagic, feeds on benthos and pelagic biota Recorded across northern Australia (Qld, NT, WA) where it inhabits riverine, estuarine and coastal waters.	Present
Sousa sahulensis Australian humpback dolphin	EPBC: M, C NCA: V	Bentho-pelagic, feeds on benthos and pelagic biota Occurs in coastal and estuarine areas, including rocky reefs (Van Dyck and Strahan 2008).	Likely - This species has a wide home-range and undertakes regular movements within and out of Port Curtis (Cagnazzi et al. 2011). Surveys by GHD (2009) indicate that this was the most abundant dolphin species in Port Curtis. Within Port Curtis, this species has been observed within channels and in close association with sand/mud banks near creek mouths (GHD 2009). It was recorded around Fisherman's Landing in moderate numbers. Calves were observed among groups for many of these sightings, suggesting that Port Curtis is in an important calving area GHD (2009).
Dugong dugon Dugong	EPBC: M, LM NCA: V	Marine habitats with shallow nutrient rich water with silt allowing intact sea grass meadows to grow. Distributed from coastal Shark Bay (WA) to Moreton Bay in Queensland (Van Dyck and Strahan 2008).	Present
Marine Reptiles			
Caretta caretta Loggerhead Turtle	EPBC: E, M, LM NCA: E	Pelagic and benthic species. Forages on marine invertebrates (Wilson and Swan 2004). Port Curtis is not known to represent a nesting site.	Likely - Most sightings of this species in the region have been in close proximity to channels where they are thought to feed (Pers. Comm. C. Limpus,15-11-13).
Chelonia mydas Green Turtle	EPBC: V, M, LM NCA: V	Bentho-pelagic Marine waters and near the seabed. Port Curtis is recognised as an important foraging area, where it feeds mainly on seagrass and benthic invertebrates (Wilson and Swan	Likely - The Project area has soft substrates which do not represent foraging habitat for this species. Likely to transit through the Project area. Important foraging areas include seagrass meadows in Rodds Bay, Shoal Bay, Pelican Banks and the Narrows (GHD 2009, 2011), coral and rocky reefs throughout the

Species	Status (EPBC/ NCA)	Habitat^A and Distribution	Outer Harbour/ nearshore channel
		2004). Low density nesting occurs around Port Curtis.	region and along the mangrove fringes (DEHP 2013, Pers. Comm. C. Limpus,15-11-13).
Dermochelys coriacea Leathery Turtle, Leatherback Turtle	EPBC: E, M, LM NCA: E	Pelagic Oceanic species which feeds on jellyfish and other soft bodied invertebrates (DEWHA 2007, Wilson 2005). Rarely nests on the Australian coastline (mostly Territory and Cape York Peninsula).	Unlikely – oceanic species
Eretmochelys imbricata Hawksbill Turtle	EPBC: V, M, LM NCA: V	Bentho-pelagic No critical nesting areas known in the region. Not thought to be common in Port Curtis.	Possible - GHD (2009) reported this species in low abundance around North Passage. Incidental sightings of hawksbill turtles in Port Alma and Port Curtis are predominantly associated with foraging habitats, including seagrass meadows, reefs and soft-bottomed subtidal areas (Pers. Comm. C. Limpus,15-11-13).
Lepidochelys olivacea Olive Ridley Turtle, Pacific Ridley Turtle	EPBC: E, M, LM NCA: E	Bentho-pelagic Deep waters. May be a transient visitor to Port Curtis, but not common.	Unlikely – oceanic species
Natator depressus Flatback Turtle	EPBC: V, M, LM NCA: V	Bentho-pelagic Marine species found around reef areas. Facing and Curtis Islands represent important nesting areas.	Likely- Flatback turtles are carnivorous and forage predominantly on soft-bottomed inter-tidal and sub-tidal habitats, typically at depths ranging from 6 to 35 meters (DEHP 2013), as occurs throughout Port Curtis including the Project area. Nesting flatback turtles return to nesting beaches approximately every 15 days throughout the season and are dispersed throughout the region during the inter-nesting period (Limpus 1971, DEHP 2013, Pers. Comm. C. Limpus,15-11-13).
Crocodylus porosus estuarine crocodile, salt-water crocodile	EPBC: M, LM NCA: V	Bentho-pelagic Coastal rivers, swamps, inland rivers, open sea (Wilson and Swan 2004). Rare in Port Curtis.	Unlikely – preference for tidal creeks rather than open waters
Sharks and Rays			
Pristis zijsron Green Sawfish, Dindagubba, Narrowsnout Sawfish	EPBC: V M NCA: Not listed	Benthic Thought to occur north of Cairns in estuaries and river mouths, embankments and beaches. Benthic feeder, found in depths from 1 m to 70 m.	Unlikely – while suitable habitat is present in the Project area, the Project area appear to be outside known geographic range.
Rhincodon typus Whale Shark	EPBC: V M NCA: Not listed	Pelagic Wide ranging tropical species. Critical habitat in Australia includes Ningaloo Reef in WA, the Coral Sea and Christmas Island. Port Curtis not known to	Unlikely – Low abundance regionally and lack of deep waters limit habitat value of the Project area.

Species	Status (EPBC/ NCA)	Habitat[A] and Distribution	Outer Harbour/ nearshore channel
		represent an important habitat for this species.	
Carcharodon carcharias Great White Shark	EPBC: V M NCA: Not listed	Pelagic Wide ranging species recorded from Central Qld through temperate seas to WA. Typically aggregates near seal colonies and believed to migrate through Queensland waters during winter months.	Unlikely – oceanic species occasionally reported from Capricorn Bunker
Lamna nasus Porbeagle, Mackerel Shark	EPBC: M	Pelagic Occurs in waters from southern Qld to south-west Australia, in oceanic waters off the continental shelf, occasionally coastal.	Unlikely – oceanic species
Manta alfredi Reef Manta Ray	EPBC: M	Pelagic Inhabits tropical and sub-tropical coastal waters in NSW, Qld and WA, often near coral reefs or seamounts. Only recently distinguished from Manta birostris	Unlikely – oceanic species
Manta birostris Giant Manta Ray	EPBC: M	Pelagic Inhabits tropical and sub-tropical coastal waters in NSW, Qld and WA, often near coral reefs or seamounts	Unlikely – oceanic species

A = unless cited otherwise, information was derived from the SPRAT database (DoEE 2017)

E = Endangered; V = Vulnerable; M = Migratory Marine; C = Cetacean; LM = Listed Marine

The EPBC Protected Matters database search results also identified that numerous species of sea snake, pipefish, and sea horses occur or could occur in Port Curtis. These species are listed marine species and are protected under the EPBC Act, but are not considered to be threatened under EPBC or state legislation. These species could occur across a wide range of habitats found within Port Curtis.

The current survey is focused on the direct dredge impact area. Due to water depths and modelling outputs of the likely plume extent the dredging is not expected to impact intertidal marine habitat areas. For this reason, listed threatened and migratory marine birds have not been included in the above table. Assessment of Western Basin Reclamation Area (WBRA) has been completed separately to the present survey and subsequently this area has not been considered here. However, ongoing surveys have also indicated the presence of red necked stints (*Calidris ruficollis*; near threatened) and eastern curlew (*Numenius madagascariensis*; critically endangered) in the WBRA (Wildlife Unlimited 2016).

4.3 Matters of State Environmental Significance

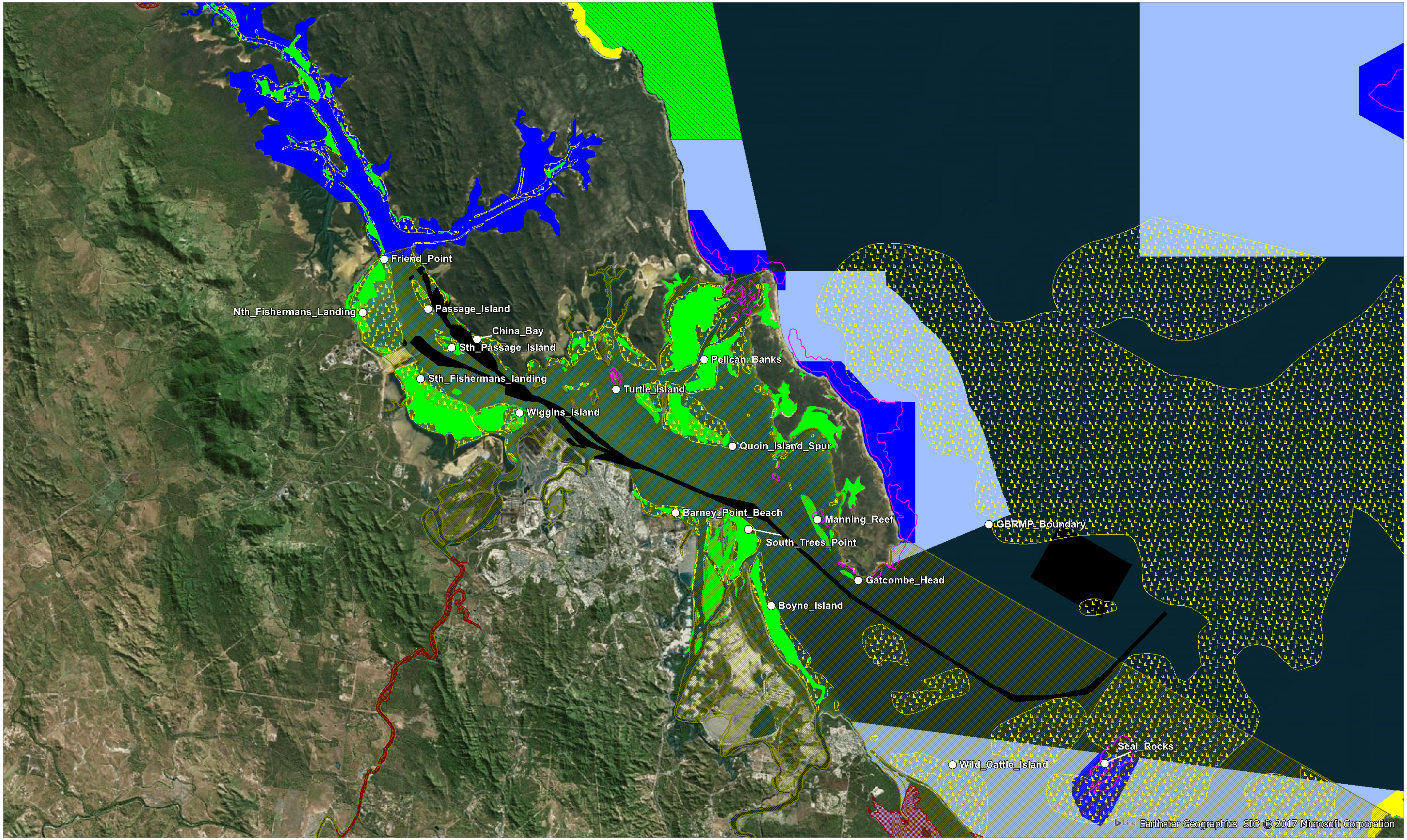
Matters of state environmental significance (MSES), referenced under the State Planning Policy (SPP) 2013, are environmental values that are protected under Queensland legislation including the *Nature Conservation Act* 1992 (NC Act), *Marine Parks Act* 2004 (MP Act), the *Fisheries Act* 1994, *Environmental Protection Act* 1992, the *Regional Planning Interests Act* 2014, and the *Vegetation Management Act* 1999. MSES have been defined by the Queensland Government as the following natural values and areas:

- Protected areas under the NC Act.
- Marine parks and land within a ‘marine national park’, ‘conservation park’, scientific research’, ‘preservation’ or ‘buffer’ zone under the MP Act.
- Areas within declared fish habitat areas (FHAs).
- Endangered, vulnerable and near threatened (EVNT) and special least concern species.
- Regulated vegetation, including:
  - Category B, C and R areas.
  - Areas of essential habitat for wildlife prescribed as endangered or vulnerable under the NC Act.
  - Regional ecosystems (REs) that intersect with watercourses/wetlands.
- Wetland/watercourse features that are:
  - Wetlands in a wetland protection area.
  - Wetlands of high ecological significance (HES).
  - Wetlands/watercourses in high ecological value (HEV) waters.
- Designate precincts in a Strategic Environmental Area.
- Legally secured offset areas.

With the exception of ENVT and special least concern species, all of these features are spatially defined based on mapping and regulations. For species, the Queensland Government *Method for mapping: Matters of State environmental significance for use in land use planning and development assessment* (v1.4, DEHP, 2014a) uses a number of mapping layers as a ‘surrogate’ for species occurrence. This includes essential habitat mapping, peer-reviewed modelled habitat distributions, mapped distributions based on known habitat factors, and point records within remnant or regrowth REs. In addition, this mapping methodology adopts dugong protection areas (relevant to Project), southeast Queensland koala habitat value areas (not relevant), and Ramsar sites (not relevant) as specific surrogates for the occurrence of dugongs, koalas and migratory shorebirds (respectively).

Table 4-4 Matters of State Environmental Significance and Relevance to Port Curtis

MNES*	Description
Protected areas under the NC Act	There are no marine areas within Port Curtis that are classed as a protected area for the purpose of the NC Act. Garden Island Regional Park is located in Port Curtis outside the dredge footprint.
Marine parks and land within a 'marine national park', 'conservation park', scientific research', 'preservation' or 'buffer' zone under the Marine Parks Act 2004 (MP Act)	The Great Barrier Reef Coast Marine Park (GBRCMP) is located offshore of Port Curtis and extends into the southern part of Rodds Bay, and the Narrows. The dredge footprint is located outside the GBRCMP. The closest GBRCMP feature to the study area listed as a MSES is the marine national park zone located on the eastern shoreline of Curtis Island, outside the study area.
Areas within declared fish habitat areas (FHAs)	The Colosseum Inlet Fish Habitat Area is located approximately 30 km south-east of the dredge footprint. The recently declared Calliope River FHA level B is located 4 km south-west of the dredging footprint
EVNT and special least concern species	All marine waters in Port Curtis considered to provide habitat for threatened wildlife and/or iconic species listed under NC Act Dredge footprint is within the Port Curtis - Rodds Bay Dugong Protection Area
(HES wetlands protected under EP Act	Many of the seagrass meadows present in Port Curtis are considered HES wetlands
Wetlands and watercourses in HEV waters	No HEV areas present
Regulated vegetation	None in marine waters potentially affected by maintenance dredging
Strategic Environmental Area	None present in Port Curtis
Legally secured offset areas	None present in Port Curtis



LEGEND

- ■ Dredge Footprint and EBSDS
- ▨ Seagrass composite distribution (2002-2014)
- □ Coral Reefs (BMT WBM 2014)
- ▨ Rodds Bay Dugong Protection Zone
- 🟩 High Ecological Significance Wetlands
- 🟥 Calliope River and Colosseum Inlet Fish Habitat Areas

Great Barrier Reef Coastal Marine Park Zoning

- 🟦 General Use Zone
- 🟦 Habitat Protection Zone
- ▨ Marine National Park Zone
- 🟨 Conservation Park Zone

** Great Barrier Reef Marine Park Authority 2006*

Title:

Features Listed as Matters of State Environmental Significance and Model Output Points

Figure:
4-11

Rev:
A

N

0 3 6km
Approx.Scale

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Overall, the most relevant MSES to maintenance dredging are:

- HES wetland communities – most of which are based on mapping of seagrass meadows.
- Habitat for EVNT and special least concern species – which is based mostly on seagrass, mangrove and saltmarsh community mapping, and in the case of dugongs, the boundaries of Rodds Bay Dugong Protection Area. Key species is this regard are dugongs, sea turtles, shorebirds and nearshore dolphin species. Note that many of the threatened species and species groups (e.g. shorebirds) listed under NC Act are also listed as MNES, and therefore Table 4-3 applies in this regard.

4.4 Ecological Values and Objectives

4.4.1 Ecological Values

The most significant receptors that are sensitive to the effects of dredging are seagrasses and hard corals. Their significance relates to the fact that they support biodiversity, fisheries resources, and threatened species, and are vulnerable to reductions in light, sedimentation, and eutrophication.

Seagrasses

Seagrasses are benthic primary producer habitats that provide a range of functions in the maintenance of coastal/estuarine ecosystem. Based on the community characteristics of these meadows and case studies elsewhere, the following values are known or likely to be supported:

- Promotion of biodiversity values. As discussed in Section 4.1.4.3, seagrass meadows support unique fish assemblages unlike those found in other habitats within Port Curtis. Therefore, seagrass meadows provide an important role in promoting local biodiversity of Port Curtis (Connolly *et al*. 2006).
- Provision of food resources for dugongs and green turtles. The preferred seagrass species of dugong (Halophila species) is dominant/sub-dominant throughout the area.
- Provision of habitat for adult and juvenile stages of many fish and invertebrate species of fisheries significance.
- Maintaining foodwebs that support important fisheries. Stable isotope analysis demonstrated that seagrass formed the basis of food-webs supporting important fisheries species in Port Curtis (Connolly *et al*. 2006; see Section 4.1.4.3).
- Seagrasses are generally thought to play a role in the stabilization of sediments and sediment nutrient cycling (Larkum *et al*. 1989).

Seagrass and other marine plants are protected under the *Fisheries Act 1994* and a permit is required for their disturbance and/or removal.

Hard Substrates and Reefs

Natural and artificial hard substrates represent a dominant habitat type within the study area, and also perhaps the most structurally complex and taxonomically rich. The deep-water rubble reefs of channel areas have been found to have high densities of benthic epifauna (non-photosynthetic) compared to other subtidal habitats within the Port Curtis (Rasheed *et al.* 2003).

Reefs, particularly those dominated by coral such as those surrounding Facing Island and Seal Rocks, or with similar structural diversity support adult and juvenile life history stages of a range of commercially important fish species. These areas also provide foraging habitat for a range of marine turtle species including hawksbill and loggerhead turtles.

It is also likely that reef communities on rock walls and rubble reefs, particularly filter-feeders, provide an important role in maintaining water quality and converting energy through the food-chain.

4.4.2 Environmental Quality Objectives

Broadly speaking, the objectives of this investigation and any subsequent monitoring programs associated with maintenance dredging will be to maintain the value of the environment as described above. Specifically, this involves ensuring that:

- Dredging activities do not adversely affect the Outstanding Universal Value of the Great Barrier Reef World Heritage Area (GBRWHA).
- There are no significant long-term changes in the health of (and no net loss of) high ecological value sensitive receptors such as coral reefs and seagrass meadows.
- No long term changes to water quality conditions occurs as a result of GPC activities.
- Appropriate marine ecological condition monitoring is undertaken to inform adaptive management actions that aim to minimise or avoid impacts to marine ecological components, process and services.
- Direct impacts are confined to the dredge loading site (dredged footprint), and that any impacts outside of the lawful footprint are short-term and reversible.

4.5 Other Environmental Values

In Queensland, Environmental Values (EVs) and WQOs are established under the Environmental Protection (Water) Policy 2009 (EPP (Water)), which is subordinate legislation under the Environmental Protection Act 1994. EVs and WQOs are provided by the Queensland Department of Environment and Heritage Protection (DEHP). An EV is the value placed on a waterbody by the community, as outlined in the *Environmental Protection (Water) Policy 2009* (EPP Water). EVs are essentially the goals that the community wants to achieve for their waterways. WQOs are based on local historic data, the condition of the waterway, and are developed in close consultation with the local community in order to protect the relevant EVs. The water quality objectives have been refined from national and state water quality guidelines (ANZECC/ARMCANZ 2000; DERM 2009).

Environmental values for waters of the Gladstone Harbour, (Moderately Disturbed condition) are provided in DEHP (2014b) and EVs relating to the maintenance dredging area are summarised in Table 4-5. WQOs to support the EVs identified below are listed in Table 4-6. Model output points shown in Figure 4-5 and Figure 5-7 are listed in Table 4-5 and Table 4-6.

Table 4-5 Relevant EVs for Gladstone Harbour (DEHP 2014b)

Gladstone Harbour (model output points)	Aquatic ecosystems	Irrigation	Farm Supply/use	Stock water	Aquaculture	Human consumer	Primary recreation [#]	Secondary recreation [#]	Visual recreation	Drinking water [^]	Industrial use	Cultural and spiritual values
Western Basin inc. Boat Ck and Lower Calliope– MD2421 (1, 2, 3, 4, 10)	✓					✓		✓	✓		✓	✓
Inner Harbour inc. Auckland Inlet – MD2422 (5, 6, 7)	✓					✓	✓	✓	✓	✓	✓	✓
Mid Harbour inc. Lower Boyne– MD2423 (8, 9)	✓					✓	✓	✓	✓	✓	✓	✓
Outer Harbour inc. DMPA – MD2424	✓					✓	✓	✓	✓	✓	✓	✓

MD = mildly disturbed waters as per EPP Water, number is location designation

[#] The selection of recreational EVs for waters does not mean that these waters are free of dangerous aquatic organisms, for example venomous organisms (e.g. marine stingers including box jellyfish, irukandji jellyfish), crocodiles, and sharks. Direct contact with dangerous aquatic organisms should be avoided. Refer to EHP CrocWatch, council, www.health.qld.gov.au, www.beachsafe.org.au, www.marinestingers.com.au and other information sources for further details on swimming safety and information on specific waters.[^] Waters in which desalination for drinking water may apply.

Table 4-6 Base-flow Water Quality Objectives for Gladstone Harbour (20th, 50th and 80th percentiles and pH ranges) (DEHP 2014b)

Gladstone Harbour (model output points)	Ammonia (µg/L)	Oxidised Nitrogen (µg/L)	Total Nitrogen (µg/L)	Filterable reactive P (µg/L)	Total Phosphorus (µg/L)	Chl-a (µg/L)	Dissolved Oxygen (% sat)	Dry Season Turbidity (NTU)	Derived Dry Season TSS (x 1.6 NTU)	Wet Season Turbidity (NTU)	Derived Wet Season TSS (x 1.6 NTU)	pH (<40mS/cm)	pH (>40mS/cm)
Western Basin (1, 2, 3, 4, 10)	3 3 8	1 4 16	145 170 210	1 3 7	14 18 29	0.5 1.0 2.0	91 96 100	4 8 17	6.4 12.8 27.2	7 13 29	11.2 20.8 46.4	7.2-8.2	7.4-8.3
Inner Harbour (5, 6, 7)	3 3 10	2 5 12	130 160 220	1 3 6	15 21 33	0.5 1.0 2.0	93 96 98	4 8 17	6.4 12.8 27.2	7 13 29	11.2 20.8 46.4	7.2-8.2	7.4-8.3
Mid Harbour (8, 9)	3 3 12	1 3 9	110 135 200	1 2 3	9 14 23	0.5 1.0 2.0	94 97 101	2 4 7	3.2 6.4 11.2	4 9 16	6.4 14.4 25.6	7.2-8.2	7.4-8.3
Outer Harbour	3 4 5	1 3 6	115 130 170	1 1 3	9 13 21	0.5 1.0 2.0	94 97 101	1 3 6	1.6 2.6 9.6	2 7 13	3.2 11.2 20.8	8.0 8.1 8.4	8.0 8.1 8.4
Open coastal spoil ground	<3	<1	<20 (ann. mean)	No WQO	<8	≤0.45	95-105	<1	<1.6	<2	<3.2	8.1-8.4	8.1-8.4

5 Assessment of Potential Impacts

Table 5-1 is a summary of potential impacts associated with maintenance dredging. A summary of likely effects to marine ecological resources is provided in the following sections.

Table 5-1 Potential Impacts Relevant to Dredging Activities for maintenance dredging

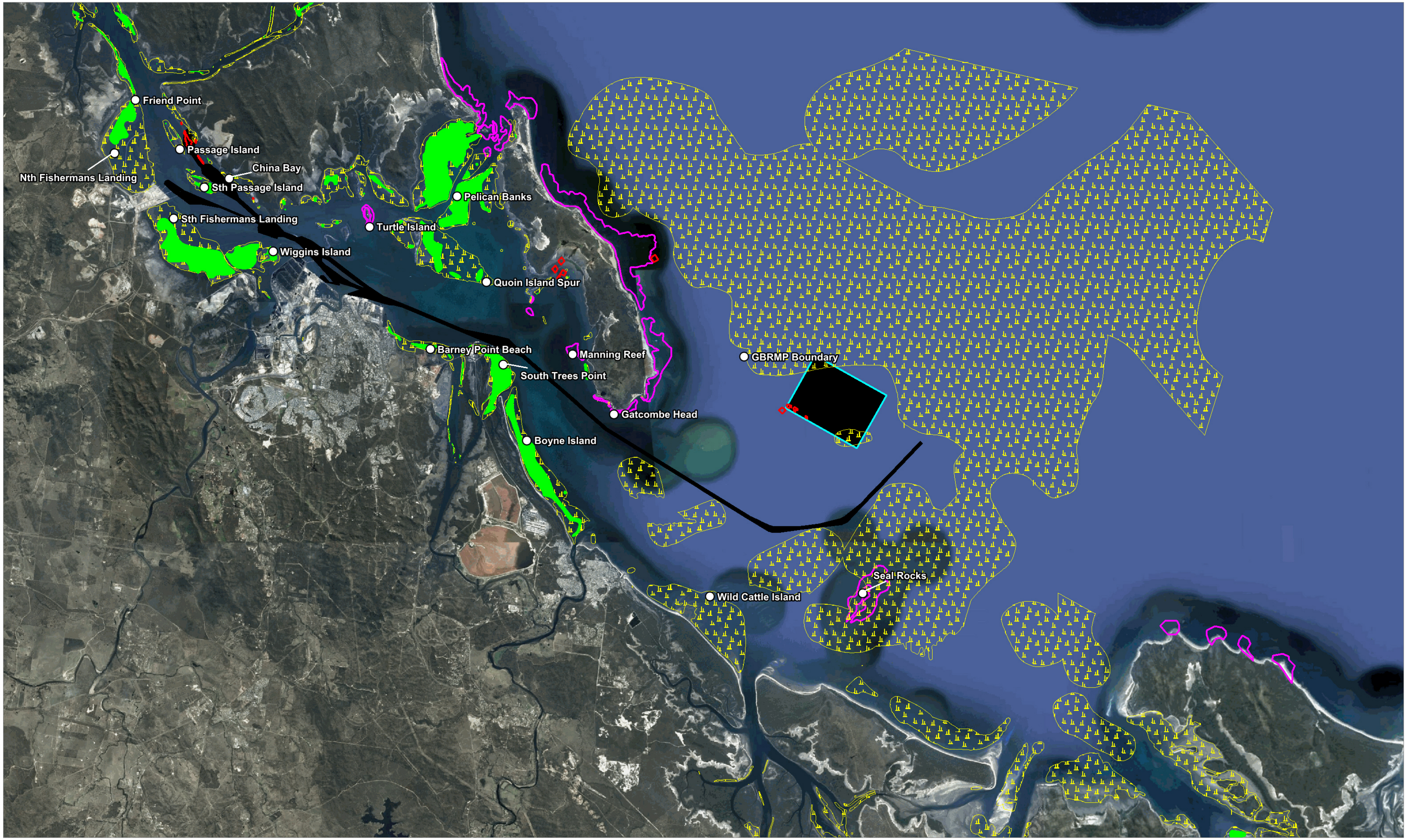
Impact Type	Potential Primary Impact	Potential Secondary Effects	Section
Direct	Temporary loss and mobilisation of benthic fauna at loading site and offshore EBSDS	Change in prey availability for marine fauna	5.1, 5.2,
Direct	Long-term change in benthic habitat conditions and benthic fauna at the loading site and offshore EBSDS	Change in prey availability for marine fauna	5.1, 5.2, 5.3
Indirect	Increased concentrations of sediments and other pollutants due to dredging and dredged material disposal	Loss or degradation of seagrass and corals	5.3.2.2, 5.3.2.1
Direct	Noise and vessel strike	Injury or mortality of marine megafauna	5.4
Direct	Increased potential for marine pest introductions	Out-competition of native species and loss of biodiversity values	5.5
Indirect	Impacts to other users such as recreational and commercial fishers from dredge plant, turbidity, sedimentation and other pollutants.	Loss of Income, negative stakeholder interaction	5.6

5.1 Direct Modifications to Benthic Habitats and Communities Associated with Dredging

Ship access to the existing harbour is along the South, Gatcombe, Auckland, Clinton, Targinie and Jacob’s Channels, which are presently maintained to achieve a declared depth of -10.6 to -18.6 m LAT, and have an approximate length of 44 km. The existing dredged area covers approximately 14.75 km^2. It should be noted that the entire channel area is not dredged during each campaign, with maintenance dredging expected to occur over <1.0 km^2 in parts of the gazetted channels, in select channel towlines, berths and some isolated locations.

These habitats are disturbed by maintenance dredging on an annual basis. It is therefore expected that benthic communities are in a constant state of flux, with cyclic disturbance and recovery patterns. However as discussed in Section 4.1.4.3, Vision Environment (2016) found that benthic invertebrate assemblages had similar abundance and richness in the proposed dredge footprint compared to non-dredged areas, suggesting that assemblages are resilient to disturbance. For the purposes of this assessment, all maintained channels (Figure 1-1) are classified as being in the impact zone (see Section 1.3).

The footprint of the direct dredging impact zone is shown in Figure 5-1.



LEGEND

▢ EBSDS

▢ Coral Reefs (BMT WBM 2014)

▨ Seagrass composite distribution (2002-2016)

🟩 Coastal Seagrass (JCU 2016)

○ Receptors

Dredging Zone of Influence (>10mg/L change to 95th percentile TSS)

■ Direct Impact

Title:

Direct Impacts and Plume Zone of Influence over Sensitive Receptors (Simulation 4: 340,000 cubic m)

Figure:
5-1

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A

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0 3 6km
Approx.Scale

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In the longer term, communities that do not experience regular sedimentation; hence, do not require regular maintenance dredging, will support high-density epibenthic communities, similar to those described elsewhere in the deep, high-velocity natural channels of Port Curtis.

5.2 Direct Dredged Material Placement Impacts to Benthos

5.2.1 Habitat Changes (Long-term Impacts)

This investigation has studied the effects of up to 340,000 m^3 of predominantly silts, sands and gravel being placed within the existing offshore EBSDS within a 12 month period. It should be noted that 340,000 m^3 is a conservative maximum estimate.. The dredger aims to evenly spread the load over the EBSDS, such that water depths are maintained at a minimum depth of approximately -8 m LAT

The long history of dredging in Port Curtis has resulted in substrate changes, with the offshore EBSDS becoming more heterogeneous than reference areas (more habitat diversity) and more fine material becoming deposited adjacent to the EBSDS (BMT WBM 2012b). The EBSDS is subject to low to moderate levels of bed sheer-stress, which winnows out the finer material, leaving the coarser material behind on the EBSDS. Silts then preferentially settle out in the deeper waters immediately adjacent to the EBSDS, and gradually decrease in concentration along a depth contour with distance away from the EBSDS.

These changes have also resulted in long-term community changes, with more fauna and flora requiring hard substrates found on the EBSDS, and taxa that inhabit depositional environments becoming more abundant directly adjacent to the EBSDS. The results of the offshore macroinvertebrate monitoring program showed that these communities and their respective benthic substrates differed between the EBSDS and directly adjacent sites prior to the material placement campaign which was being monitored, suggesting a longer-term change in community had already occurred.

Subsequent remobilisation of fine material to adjacent areas did not have any observed detrimental effects on macroinvertebrate communities. This was observed in 2011 when 126,000 m^3 of maintenance material was placed, and when 600,000 m^3 of capital material was placed (BMT WBM 2012b). It was suggested that communities in these areas had adapted to regular sediment deposition, and that the remobilisation of material from these two campaigns acted as a source of food for filter and deposit feeding organisms. Indeed, near-field impact locations often had the highest abundance and richness of all locations investigated and total abundance appeared to increase slightly in response to maintenance and capital material placement.

5.2.2 Smothering Impacts (Short-term Impacts)

In the short term, dredged material placement is expected to result in the smothering of most sessile flora (i.e. seagrass and algae) and fauna (e.g. soft corals, sea pens, gorgonians, sponges etc.) within the EBSDS. The amount of smothering depends on the depth of placed sediment; it is possible that some more mobile burrowing fauna will be able to migrate through the placed sediments when material volumes are relatively small. The effects of different placement volumes were described in the offshore macroinvertebrate monitoring program (BMT WBM 2012b).

Part of the 2011 maintenance dredging campaign occurred over 19 days in February 2011 where 126,000 m^3 of maintenance material was placed on the offshore EBSDS. The effects of this campaign on benthic invertebrates within, and adjacent to the EBSDS were investigated using a spatially and temporally replicated before-after/ control/impact monitoring design over 15 months from July 2010 to September 2011 (Figure 5-2, BMT WBM 2012b). The monitoring period included the effects of Cyclone Yasi and associated rainfall, which had a larger effect on communities than maintenance or capital dredging effects.

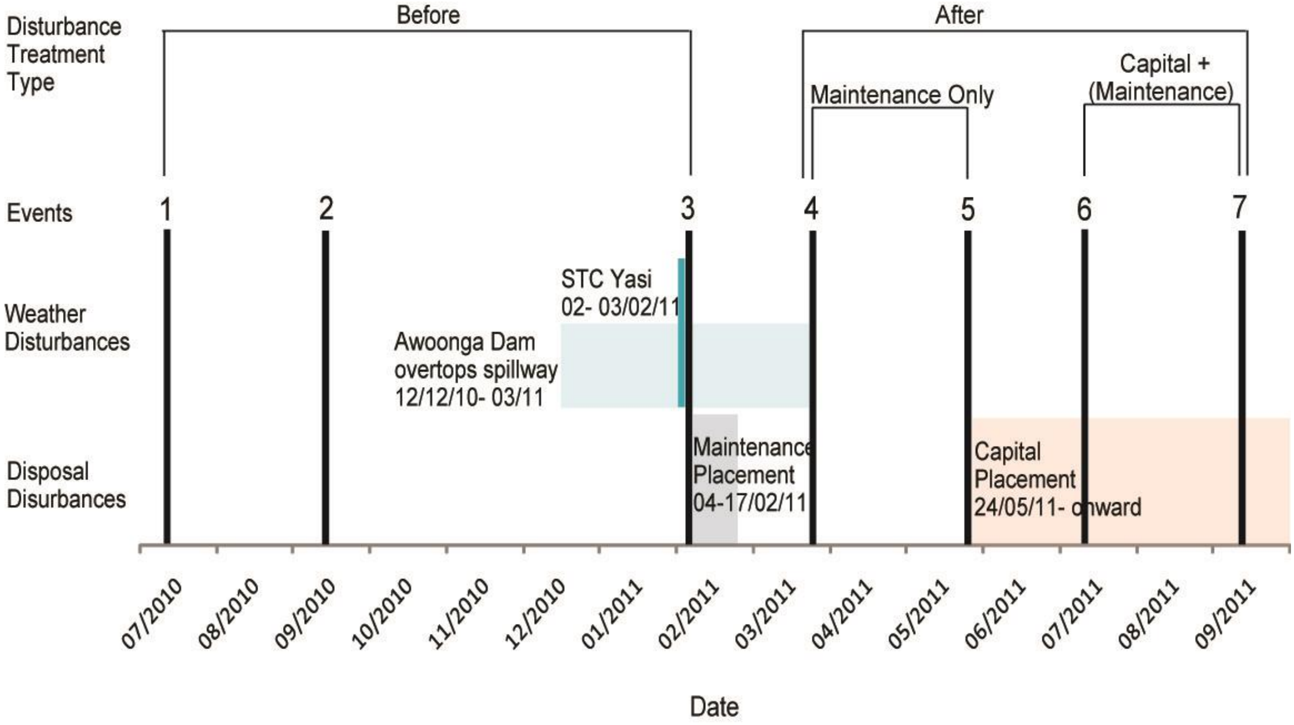


Figure 5-2 Timeline Showing Weather and Dredged Material Placement Disturbances with respect to Macroinvertebrate Monitoring (BMT WBM 2012b)

Importantly, the study showed that the effects of maintenance dredging could not be resolved above environmental variation on the EBSDS, or at locations directly adjacent to it (where some fine material is remobilised and deposited). In other words, broad-scale environmental changes were stronger than changes due to maintenance dredging. The direct effects of capital dredging on the EBSDS (reductions in abundance and richness) became apparent in the 7th and final monitoring event, after approximately 600,000 m^3 of capital material had been placed on the EBSDS, but no detrimental effects were observed adjacent to the EBSDS.

Other earlier studies on the effects of maintenance material placement macroinvertebrates within and adjacent to the EBSDS have had similar findings to the offshore macroinvertebrate monitoring program (BMT WBM 2012b). GHD (2006) found that abundance and richness on the EBSDS equalled or exceeded pre-disturbance levels within one year of material placement. Similarly, BMT WBM (2006) concluded that there was little evidence that dredged material disposal affected benthic communities in areas other than the dredged material disposal site. While the design of some of these older studies did not account for near-field plume effects, these were factored into the design of the offshore macroinvertebrate monitoring program (BMT WBM 2012b).

These studies show that there are well established cycles in macroinvertebrate abundance and richness exhibited as winter peaks and summer troughs. The primary impacts of disposal have been a reduction in richness and abundance within the EBSDS, directly related to burial. These have only been observable when large quantities of dredged material have been place over the EBSDS. While contaminated sediment disposal elsewhere in the world has resulted in community changes (a loss of sensitive species), this has not been observed on the Port Curtis EBSDS, and is probably related to a lack of contamination in disposed sediments. The biggest changes in communities appear to be the result of substrate changes, with the EBSDS becoming more heterogeneous than reference areas (more habitat diversity) and fine material increasing in areas directly adjacent to the EBSDS.

Due to the small quantity of dredged material placed during maintenance dredging relative to the total area of the EBSDS, each campaign does not result in complete coverage of the EBSDS with dredged material. Consequently, different parts of the EBSDS will be affected at different times, creating a mosaic of patches with different disturbance histories (BMT WBM 2012b). During and after the dredge campaign, benthic organisms will colonise the EBSDS through the following mechanisms:

- Survival of dredging and re-invasion by biota entrained in dredged material (plumes): this involves passive settlement to seafloor and/or active re-invasion of sediment by re-suspended organisms).
- Larval settlement from water column: (active and passive depending larval habitat choice and biology). Recolonisation may also occur via larvae settling, which may be dependent on sediment conditions and is typically slower than adult migration (Skilleter 1998).
- Post-colonisation invasion by adults and juveniles: (active from non-disturbed patches, possible in response to new resources). Adult and sub-adult macrobenthic fauna can also actively recruit to the EBSDS. This means recolonisation may depend on the mobility of the animals present in adjacent areas i.e. tube dwellers versus mobile burrowers.

While opportunistic species and primary colonisers will commence settlement shortly after disturbance, other less mobile species will take longer to re-colonise the EBSDS. Some more mobile surface dwelling fauna such as prawns and shrimps, amphipods, isopods and some worms may move from adjacent undisturbed habitats into the EBSDS. Most benthic fauna species have a planktonic stage, and would eventually colonise the EBSDS through larval settlement.

The recovery timescales will depend on the species or assemblage under consideration. In terms of benthic infauna, most studies done in dynamic coastal environments such as the Port Curtis EBSDS have found relatively rapid recolonisation following dredged material placement (measured in time scales of weeks to months) (see BMT WBM 2012b). This is consistent with trends at sea disposal sites in the GBRWHA (e.g. Cruz-Motta and Collins 2004; Hydrobiology Pty Ltd 2003, Chartrand *et al.* 2009).

5.3 Indirect Dredged Material Placement Impacts to Benthos

5.3.1 Modelling Results

5.3.1.1 Sediment Mobilisation during Loading and Disposal

In the following section, the modelling results for the 340,000m^3 dredging campaign are analysed and discussed. The modelling results for the other campaign volumes indicate similar patterns but with lower magnitude of effects. The model outputs for all scenarios are presented in Appendix E.

The modelled increase in the TSS percentiles due to dredging activity and placement at the EBSDS is shown in Figure 5-3. The top panel of Figure 5-3 shows the increase in the 50th percentile of the depth-averaged TSS over a 30 day period, which is an indication of the chronic impact of the dredging activity (the 50th percentile TSS is exceeded for approximately 15 days over a 30 day period). The bottom panel of Figure 5-3 shows the increase in the 95th percentile of the depth-averaged TSS over a 30 day period, which is an indication of the acute impact of the dredging activity (the 95th percentile TSS is exceeded for approximately 36 hours over a 30 day period).

The 50th percentile impact plot for the 340,000 m^3 scenario shows that the chronic influence of the dredging activity is confined mostly to the Jacob's Channel area. The highest areas of increased TSS levels are in the vicinity of the dredge footprint, with a maximum increase of 5 mg/L; no areas experienced an increase of more than 10 mg/L in the 50th percentile TSS increase. Therefore, the Zone of Impact is limited to the direct impact footprint only (Figure 5-1).

The 95th percentile impact plot for the 340,000 m^3 scenario indicates that the 95th percentile TSS increased by more than 15 mg/L above ambient in the Passage Islands Channel area; however, most areas within the estuary experienced an increase of less than 5 mg/L. The increase in the 95th percentile TSS in the vicinity of the EBSDS was up to 10mg/L due to resuspension of dredged sediment (see Section 5.3.1.3). The areas where the 95th percentile TSS increased by more than 10 mg/L are shown as the Zone of Influence (Figure 5-1). The Zone of Influence for other modelled dredging campaign volumes is non-existent (i.e., the modelled increase in the 95th percentile TSS was below 10mg/L throughout the study area).

All of the time series plots of TSS at the sensitive receptor points are shown in Appendix B, while a subset of TSS time series are shown for the Passage Islands, Wiggins Island, Quoin Island Spur, Manning Reef, Gatcombe Head, the GBRMP Boundary, and Seal Rocks Reef as examples of TSS dynamics across the modelled extent in Figure 5-4. The influence of the dredging on TSS levels is temporary and minor compared to the ambient TSS signal except at the Passage Islands. The level of suspended sediment in the water column following the conclusion of the dredging programme decreases after the conclusion of the dredging campaign. Spring tide cycles can be seen elevating TSS from ambient sources as well as the dredged component. At the GBRMP boundary, the relative contribution of dredged sediments to overall TSS is higher, due to the proximity to the EBSDS; however the dredging-related TSS is only elevated during a resuspension event, which coincides with elevated ambient TSS. The dredging-related component of the total TSS remains relatively low.

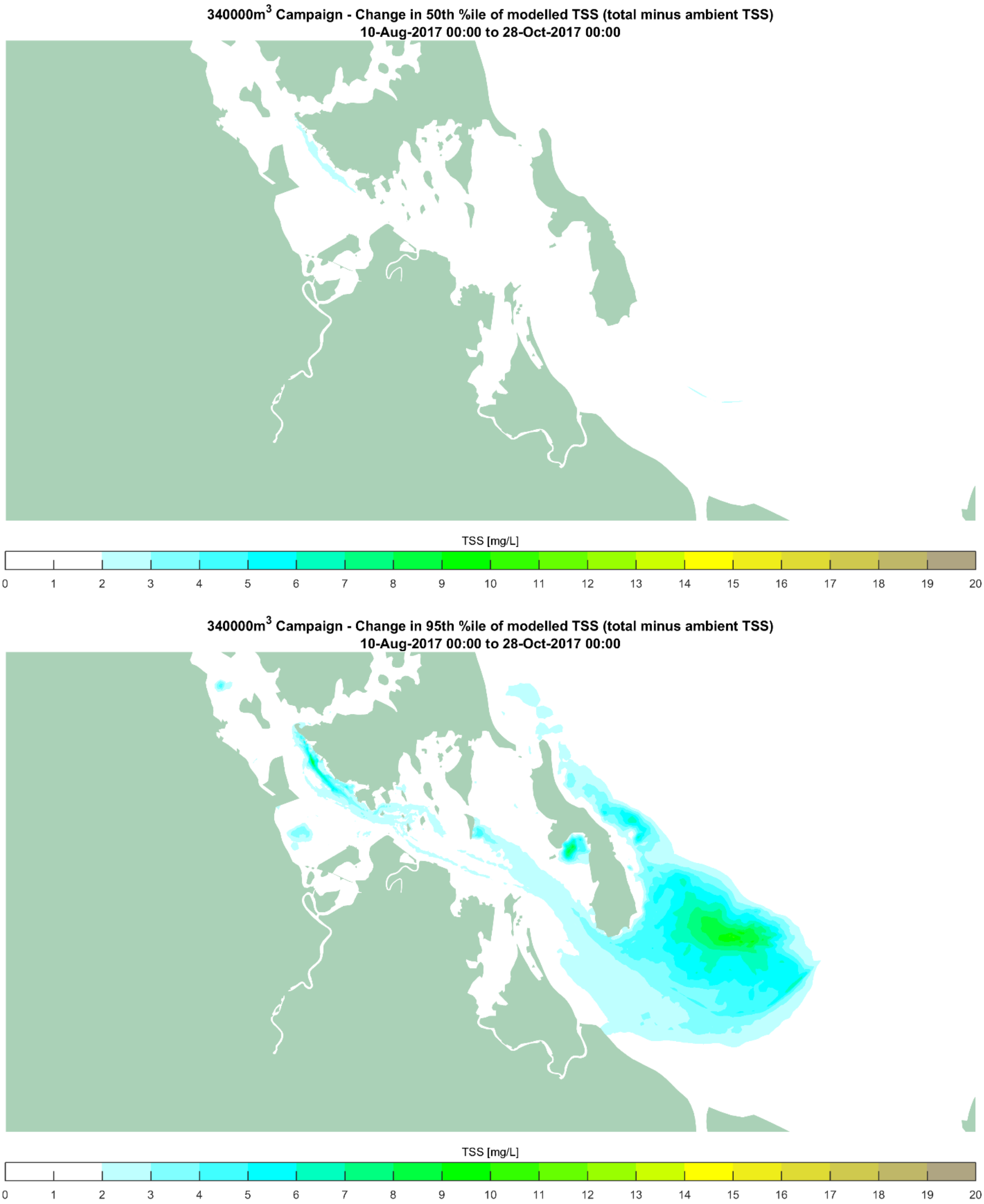


Figure 5-3 Modelled Increase in the 50th Percentile TSS (above) and 95th Percentile TSS (below) for the 340,000 m^3 scenario.

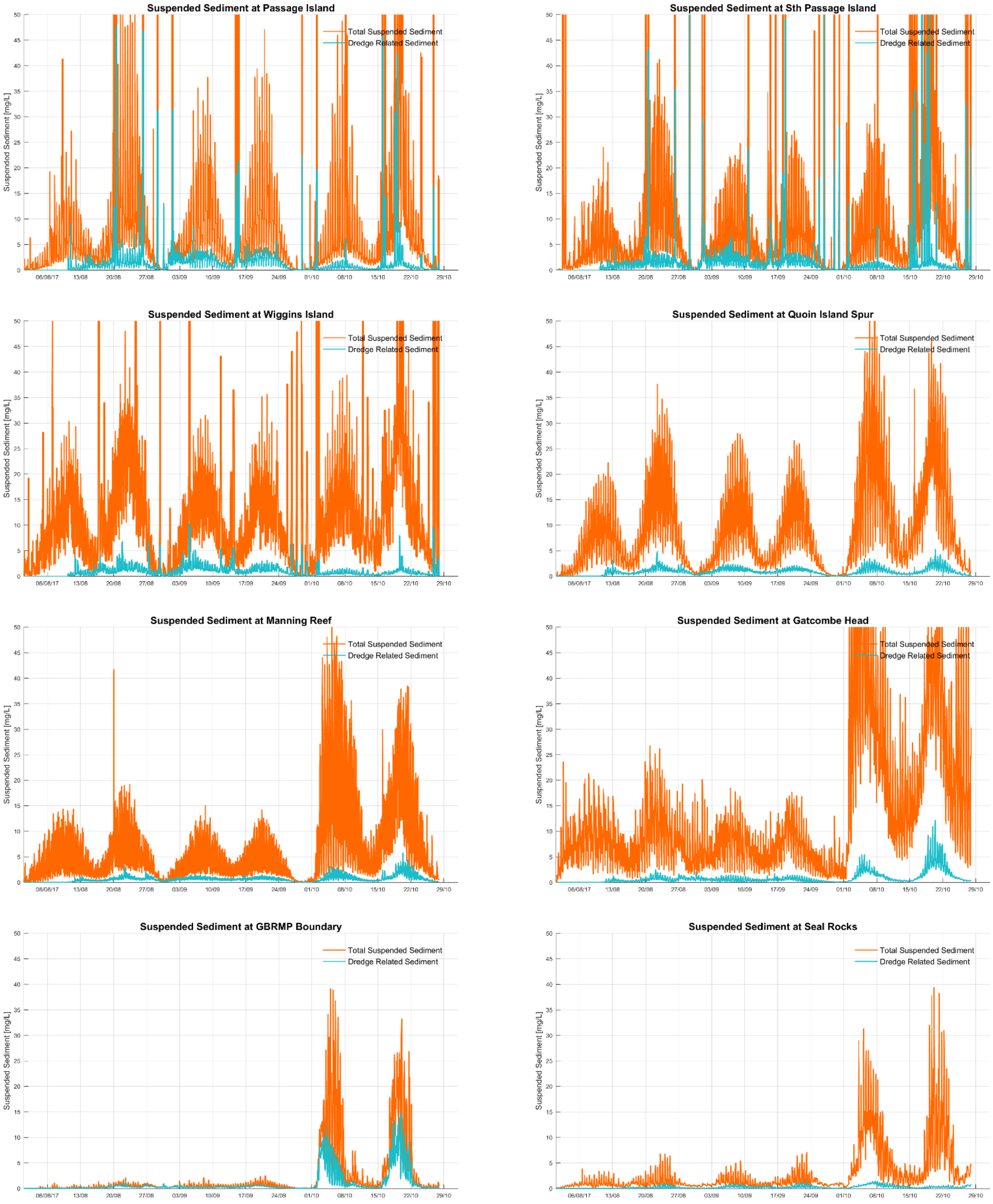


Figure 5-4 Time series of Modelled TSS at Passage Islands (North and South), Wiggins Island, Quoin Island Spur, Manning Reef, Gatcombe Head, the GBRMP Boundary, and Seal Rocks Reef for the 340,000 m^3 scenario

5.3.1.2 Sediment Deposition

The effect of dredging on rates of sediment deposition was relatively minor across most of the study area. The modelled increase in the median rates of sediment deposition in the 340,000 m^3 simulation (Figure 5-5) shows that almost all of the study area would expect increases in the median deposition rate of less than 10 mg/cm^2/day (equivalent to 10 kg/m^2 /day). Small areas exceeding 10 mg/cm^2/day of sedimentation are predicted to occur in the Wild Cattle Cutting and Passage Islands sections of the main channel.

The relative contribution of ambient and dredged sediment to deposition rate is shown for the south Passage Island site, Wiggins Island, and Manning Reef in Figure 5-6. Dredged sediment made up a small percentage of the total rate of deposition of sediment in all cases. Time series for deposition rates of ambient and dredged sediment are shown in Appendix B.

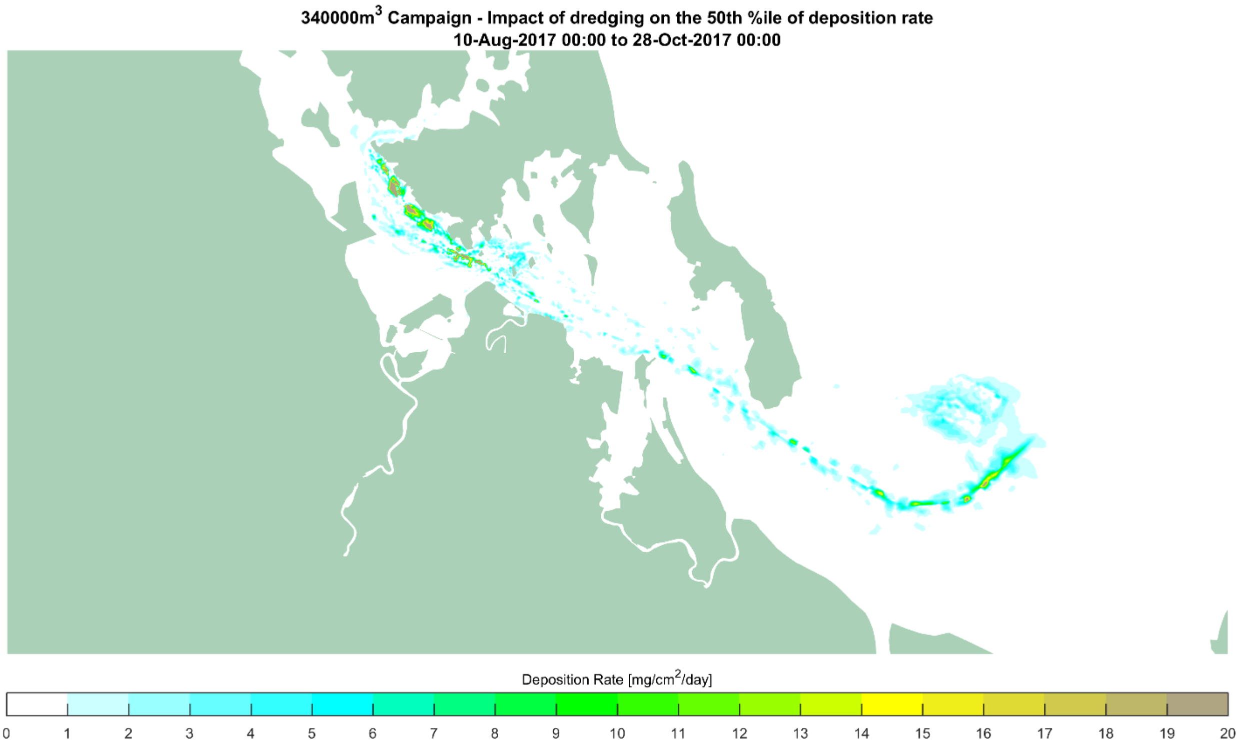
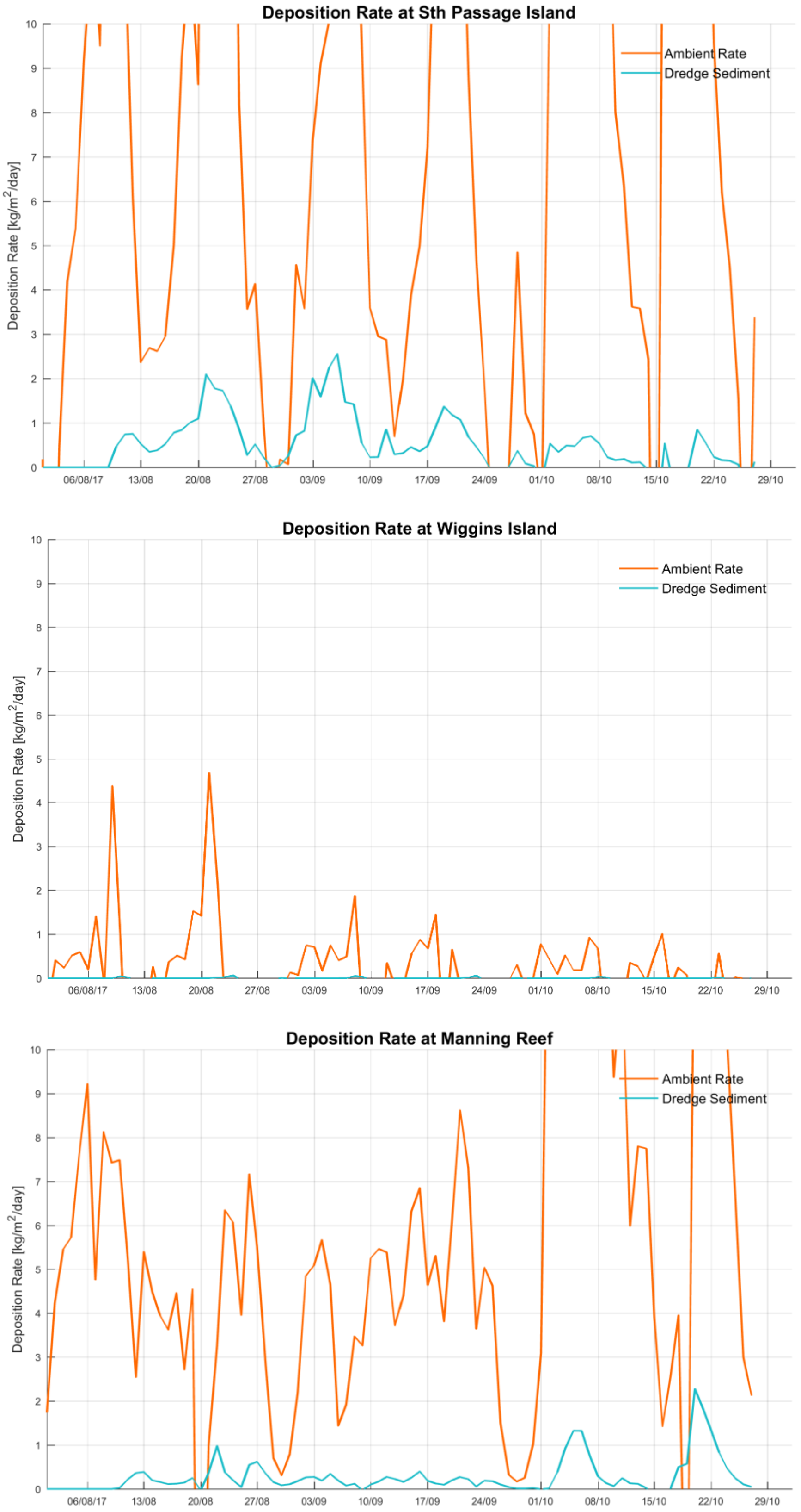


Figure 5-5 Modelled Increase in the 50th Percentile of the Sediment Deposition Rate



Deposition Rate at Sth Passage Island

Deposition Rate at Wiggins Island

Deposition Rate at Manning Reef

Figure 5-6 Time series of Modelled Sediment Deposition at South Passage Island, Wiggins Island, and Manning Reef

5.3.1.3 Sediment Re-suspension from the EBSDS

The model was run for an additional 30 days following the completion of each dredging campaign in order to assess the potential for resuspension of dredged sediment following placement at the EBSDS. The additional 30 day period included two large wave events, as see in the time series of significant wave height at the Gladstone Waverider Buoy presented in Figure 5-7. The peak significant wave height of 2.05m is only exceeded for a total of approximately 1.5 days per year at that location based on analysis of the long term wave height data.

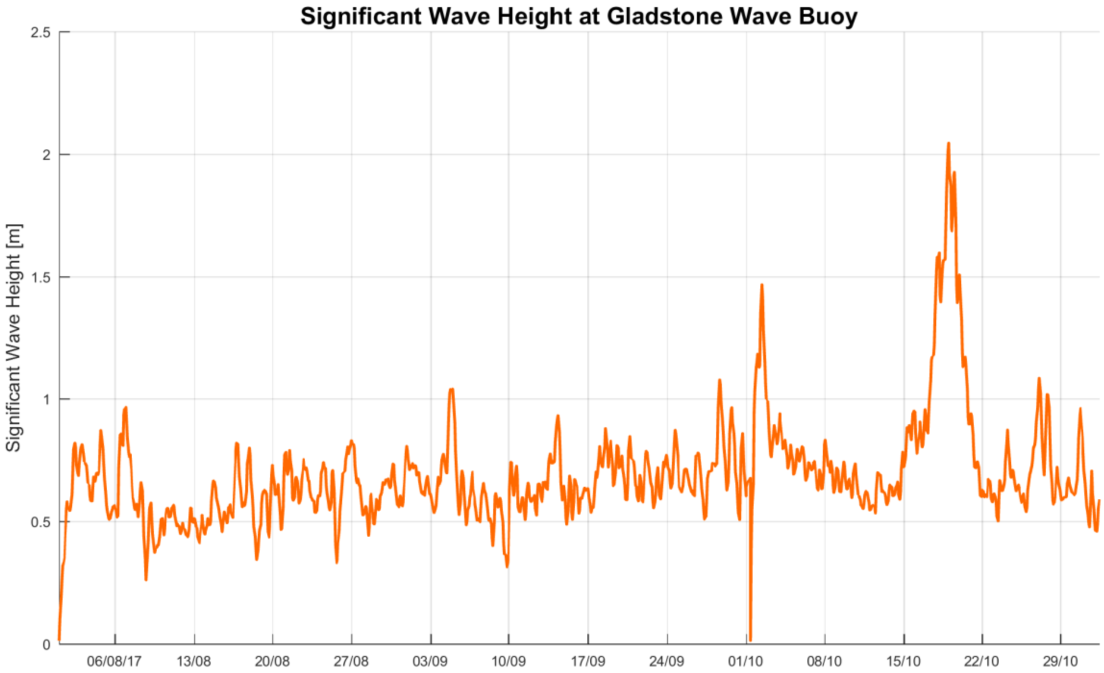


Figure 5-7 Time Series of Significant Wave Height at the Gladstone Waverider Buoy during the Modelling Period

The modelled wave event did generate some resuspension of dredged material at the EBSDS, which can be seen in the increase in the 95th percentile TSS due to dredged sediment in the vicinity of the EBSDS in Figure 5-3, of up to 10mg/L. This does not represent a significant 'Zone of Influence', since the area where the 95th percentile was increased by over 10mg/L was very small.

The contributions of ambient and dredging-related sediment to the total TSS and deposition rate at the GBRMP border, just north of the EBSDS, are shown in Figure 5-8 for the 340,000m^3 campaign.

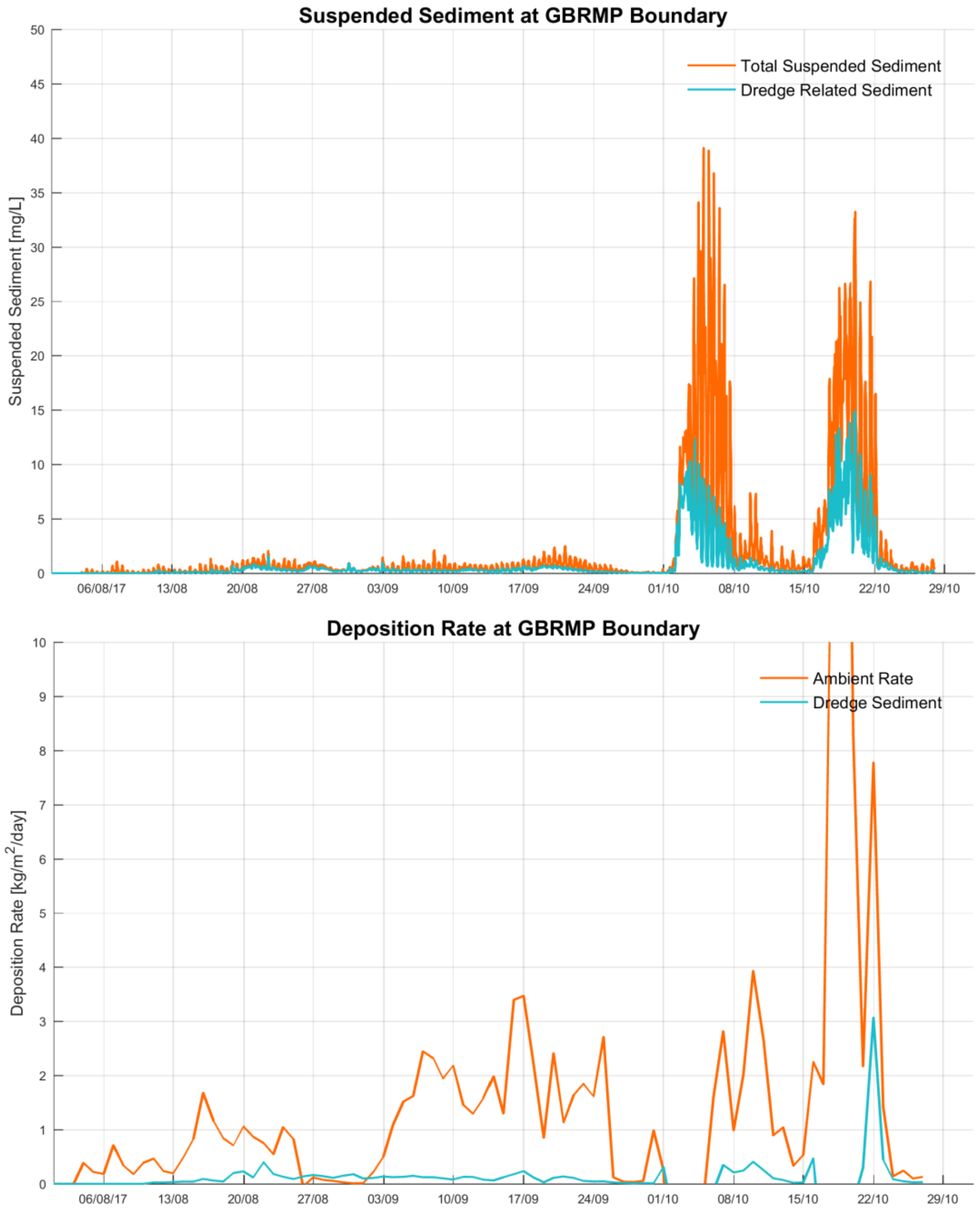


Figure 5-8 Time series of TSS and Sediment Deposition at the GBRMP Boundary Near the EBSDS

5.3.2 Potential Ecological Effects

Dredging and dredge material disposal will generate turbid plumes that are predicted to occur over some areas containing seagrasses, hard corals and their habitat. Modelled maintenance dredge loading has the largest potential to adversely affect these habitats. Modelled material disposal plumes and re-suspension plots are insignificant compared to ambient suspended sediment concentrations, or do not coincide with sensitive receptors. The following describes the indirect impacts of turbid plumes and sedimentation on marine habitats, and flora and fauna. Note that secondary (flow-on) impacts of habitat and food resource loss/modification to marine fauna species are considered in Section 5.3.2.6.

5.3.2.1 Reef Communities

Suspended Sediments

Hard corals can be sensitive to high rates of sedimentation and suspended solid concentrations. Sediments generated by dredging may affect corals by smothering (deposition of sediments), and by reducing light availability through high turbidity levels. High sedimentation and turbidity can lead to coral stress, which may lead to disease, reduced calcification and growth rates, and if persistent, coral bleaching and eventually mortality. While coral communities in Port Curtis have adaptations to cope with periodic high sedimentation and turbidity (e.g. mucous secretions), levels outside the range of natural variability generally cannot be tolerated in the medium to long term.

Turbidity and sedimentation tolerance limits differ among species. Erftemeijer and Reigl (2008) reviewed 53 studies examine the sensitivities of corals to turbidity and/or sedimentation, and found that some species in naturally turbid nearshore environments could tolerate suspended sediment concentrations up to 165 mg/L. In the context of a dredge campaign of 28-66 days, the minimum experimental TSS where total coral colony mortality was recorded was 30 mg/L for a period of 84 days, 100 mg/L for a period of 28 days, and 476 mg/L for a period of 2.7 days (*n* = 8 case studies). Partial coral colony mortality has been observed at as low as 49 mg/L over 10 days (*n* = 27 case studies)[3].

It is recognised that there are many factors that ultimately control the response of corals and seagrass to elevated suspended sediments, and that experimental data should be considered cautiously. Furthermore, turbidity is naturally high within Port Curtis, and would consistently exceed many of the experimentally-derived ‘stress’ thresholds (particularly for those derived for clear water species not found in the Port Curtis) most of the time. Natural peaks in tidally resuspended turbidity in Port Curtis suggest that periods of low turbidity during neap tides are important “breaks” in the turbidity cycle that allow light dependent communities access to more light. It is therefore important to consider the duration of turbidity events, perhaps more so than the intensity of these events, given the natural frequency of high intensity tidal resuspension.

Notwithstanding these limitations, a modelled increase in the 50th percentile TSS of more than 10mg/L has been adopted as a nominal threshold for assessment purposes. Based on observed natural turbidity values up to 75 mg/L TSS in central Port Curtis, and experimental impact TSS concentrations, an increase in the 50th percentile TSS of 10 mg/L was considered highly conservative.

Plume modelling results show that most reef sites (Seal Rocks, Gatcombe Head, Manning Reef) had dredging-related TSS levels of <5 mg/L (Figure 5-4, and Appendix B). Turtle Island Reef was the closest reef location to maintenance dredging operations but was predicted to have dredging-related TSS levels of less than 5 mg/L for the entire 340,000 m^3 dredging simulation. Based on field observations (BMT WBM 2009), this reef has low (<1%) hard coral cover, reflecting high ambient

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[3] This excludes a case study done on clear water species not found in Port Curtis

turbidity at this location. Therefore, major impacts to hard corals due to TSS are not expected on the basis of these results.

Sedimentation

Erftemeijer and Reigl's (2008) review of sensitivities of corals to sedimentation found that some species tolerated sedimentation rates >300 mg/cm^2/day (over a 14 day period), but varied markedly among species. Thresholds for daily rates of sedimentation are summarised by Erftemeijer *et al.* (2012) and are presented as mg/cm^2. Model outputs from dredged sediments are presented as kg/m^2 of sediment, which is equivalent to mg/cm^2.

The highest rate of sedimentation predicted for a coral reef site was at Manning Reef (Figure 5-9, Appendix C). Peaks in total sedimentation at Manning Reef were less than daily thresholds for the most sensitive corals (<10 mg/cm^2/day) from Erftemeijer *et al.* (2012). Predicted rates of sedimentation from maintenance re-suspension plots are well below 10 mg/cm/day in areas predicted to receive the highest sedimentation. Based on this, indirect sedimentation impacts to corals are not expected.

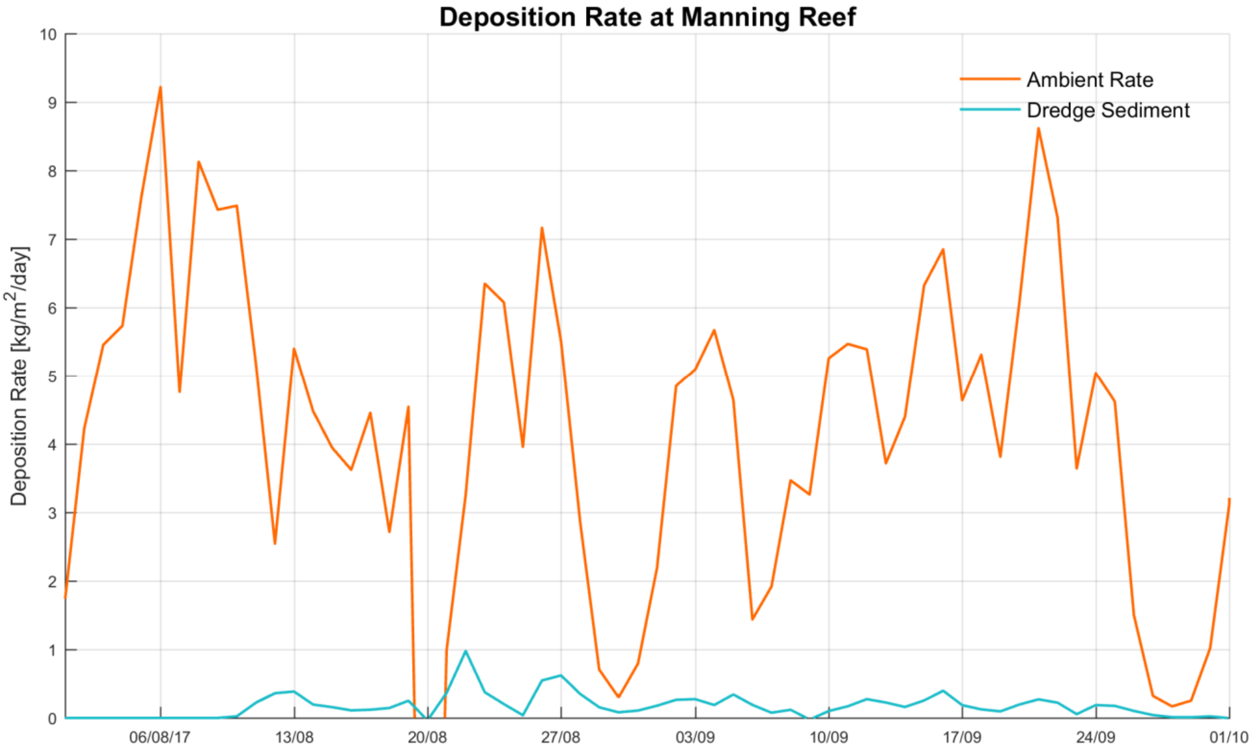


Figure 5-9 Deposition Time Series at Manning Reef

5.3.2.2 *Seagrass*

TSS/Light

The seagrass species that occur in Port Curtis have relatively high light requirements, typically requiring between 10 and 30% of surface irradiance for survival (Erftemeijer *et al.* 2006). Specific tolerances to light reductions vary among seagrass species, as follows:

- *Halophila ovalis* is the most common deepwater species in Port Curtis is known to be among the most sensitive species to increased turbidity and associated light attenuation (Longstaff *et al*. 1999). This species can show signs of stress after several days of complete light attenuation and mortality within 30 days of prolonged darkness (Longstaff *et al*. 1999).
- Species of *Halodule* appear to be more tolerant to light deprivation that *H. ovalis*, with congener *Halodule pinifolia* surviving up to 3-4 months following complete light attenuation (Longstaff *et al*. 1999). Halodule uninervis appears to be more tolerant to light deprivation than *Z. muelleri*; meadows (Collier *et al*. 2012); meadows experiencing periods of irradiance below 3 mol/m^2/day for 16-18% of the time over 3 months had more than a 50% loss in cover.
- *Zostera muelleri* is present in the nearshore areas of Port Curtis and can survive up to a month at low light levels (5% surface irradiance) (Grice *et al*. 1996). Shading studies within Port Curtis (Chartrand *et al*. 2012) have shown that *Z. muelleri* is most vulnerable to shading during the growth season, between July and January. Based on a combination of field experiments and observations, a light-based trigger value of 6 mol/m^2/day within a rolling two-week average is required to sustain or increase *Z. muelleri* meadows in the growing season (July to January). *Z. muelleri* tolerates reductions in light occurring up to two weeks in duration during the growth season.

Monitoring near North Passage Island from May to October 2011 shows that the relationship between turbidity and PAR at 1 m below the water surface follows an exponential decay relationship (Vision Environment 2011). The light-based trigger value of 6 mol/m^2/day (Chartrand *et al.* 2012) corresponds with approximately 50 NTU, based on the relationship below, which is equivalent of approximately 80 mg/L TSS based on the relationship in BMT WBM (2012a); TSS= 1.6 NTU. Seagrasses growing deeper than this, or those with low resilience (e.g. less energy reserves, affected by other stressors) may be affected by lower TSS concentrations.

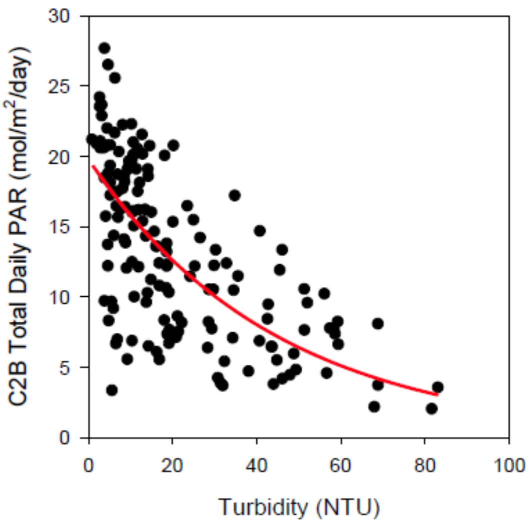


Figure 5-10 Relationship between Subsurface PAR and Turbidity (NTU) at Passage Island Site C2B (Vision Environment 2011)

As indicated in Chartrand *et al*. (2012) seagrass light requirements are best explained by a two-week rolling average, which considers the natural turbidity cycles within Port Curtis that occur every fortnight. Seagrass meadows regularly experience reductions in light associated with spring tide turbidity, making the light available during neap tides particularly important for seagrass.

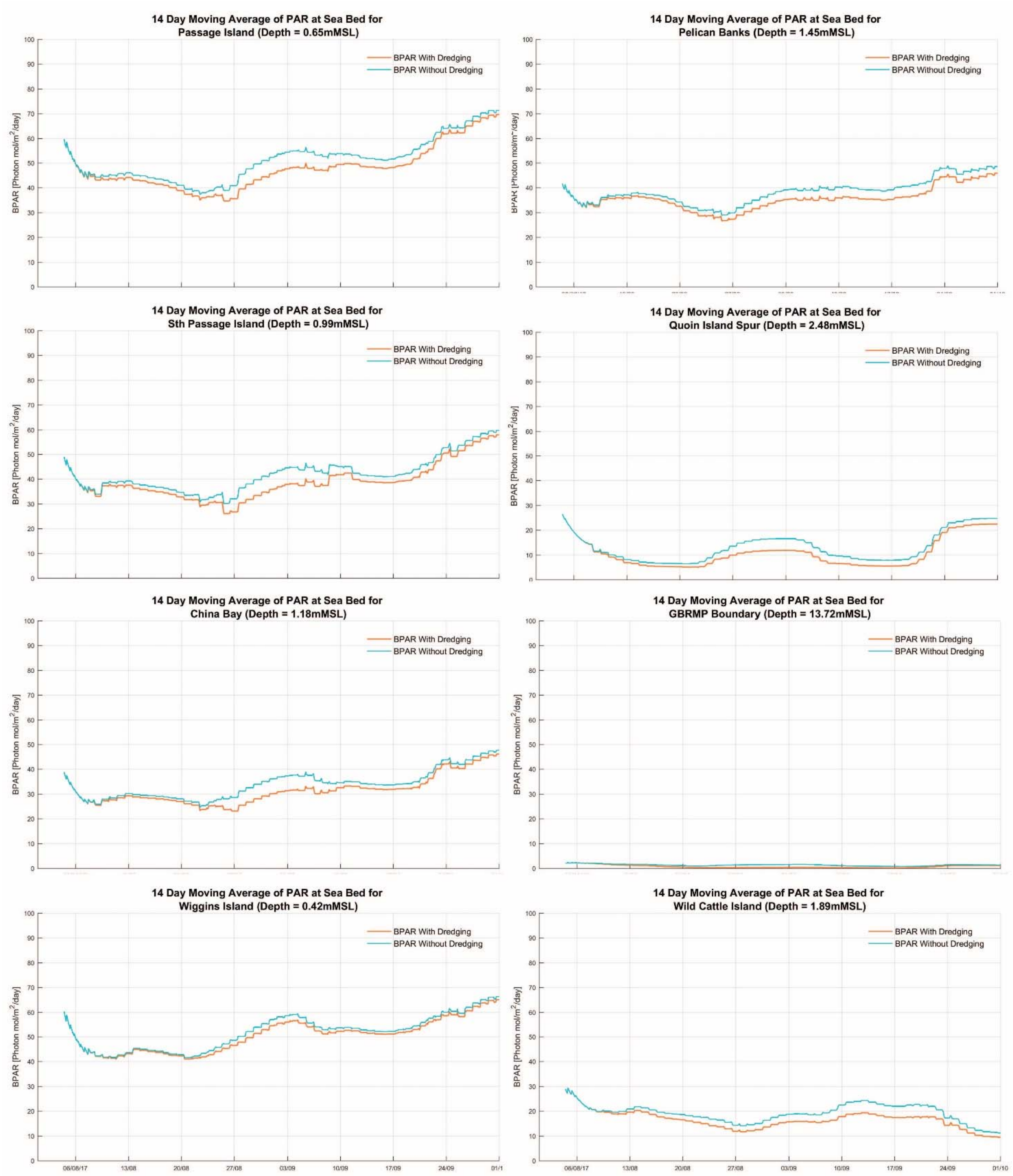
Potential light reduction impacts were assessed using modelled PAR and dredging-related TSS. A 10 mg/L dredging-related TSS over half of the modelling simulation (50% exceedance) was used as conservative threshold for assessing potential effects to seagrass. Because ambient TSS can reach concentrations of 75 mg/L during spring tides, 10 mg/L dredging-related TSS (in addition to ambient) could result in the two-week rolling average PAR requirement falling below 6 mol/m^2/day at meadows 1 m below the water surface (noting that PAR impacts are specifically assessed using 6 mol/m^2/day threshold below).

Zones of Influence (above 10 mg/L increase in the 95th percentile TSS) and Zones of Impact (above 10 mg/L increase in the 50th percentile TSS [not observed] plus the direct dredging footprint) are shown for the worst-case simulation (340,000 m^3) in Figure 5-1. Modelled impacts to the 95th and 50th percentiles of TSS and deposition rate are shown for all simulations in Appendix E, which are less significant than the worst case 340,000 m^3 scenario.

Figure 5-1 and Figure 5-3 show that turbid plumes infrequently extend over areas containing deepwater seagrass and coastal seagrass meadows. Figure 5-4 presents time series for sensitive receptor locations potentially affected by dredge plumes. Seagrass meadows near Passage Islands are predicted to be most affected by dredge plumes, with 10 mg/L dredging-related TSS predicted to occur on multiple occasions. The periods with over 10 mg/L dredging-related TSS at Passage Islands were short-term spikes, with durations measured in hours rather than days. These short-term spikes were coincident with periods of high background TSS.

Seagrasses are tolerant of short-term TSS spikes (and associated light reductions), but are intolerant of periods where light falls below critical thresholds for periods measured in weeks (Chartrand *et al*. 2012). On this basis, benthic PAR was calculated as a function depth and modelled TSS, and the two-week rolling average was calculated. Time-series of derived the two-week moving average for benthic PAR values is presented in Figure 5-11 for each of the sensitive receptor locations. Modelling predicts that dredging would not result in benthic PAR falling below the 6 mol/m^2/day threshold at seagrass receptor locations, including the Passage Islands meadows. The 6 mol/m^2/day threshold was not met at the GBRMP boundary, which is too deep to meet the threshold with or without dredging. Seagrasses located in deepwaters at the GBRMPA boundary consist of sparse *Halophila* meadows, which have a different light requirement than the *Zostera* meadows on which the 6 mol/m^2/day threshold was developed (Collier *et al.* 2016). Overall, modelling presented herein suggest that while plumes can extend to sensitive receptor sites, they are short-term features, consistent with monitoring observations. The extent and severity of impacts depends on a range of factors which cannot be simulated. In a worst-case scenario (low meadow resilience, recent disturbance history, continuous targeting of swing basin / berth parcels during the growing season) impacts would be expected to manifest as stress and possibly a reduction in cover rather than complete meadow loss, given the relatively short duration of plumes associated with the largest simulated campaign (up to several weeks). These potential impacts are predicted to occur in the absence of any management or mitigation measures employed by GPC, which have not been considered in this report. Monitoring is required to validate modelling predictions and to inform the need for additional mitigation measures.

Modelling results for the scenarios less than 340,000m^3 indicate an increase in the 95th percentile TSS of less than 10mg/L in the vicinity of Passage Islands, so no Zone of Influence exists according to the definition.



14 Day Moving Average of PAR at Sea Bed for Passage Island (Depth = 0.65mMSL)

14 Day Moving Average of PAR at Sea Bed for Pelican Banks (Depth = 1.45mMSL)

14 Day Moving Average of PAR at Sea Bed for Sth Passage Island (Depth = 0.99mMSL)

14 Day Moving Average of PAR at Sea Bed for Quoin Island Spur (Depth = 2.48mMSL)

14 Day Moving Average of PAR at Sea Bed for China Bay (Depth = 1.18mMSL)

14 Day Moving Average of PAR at Sea Bed for GBRMP Boundary (Depth = 13.72mMSL)

14 Day Moving Average of PAR at Sea Bed for Wiggins Island (Depth = 0.42mMSL)

14 Day Moving Average of PAR at Sea Bed for Wild Cattle Island (Depth = 1.89mMSL)

Figure 5-11 Benthic PAR Time Series Showing the Reduction Associated with Dredging at Passage Islands (North and South), China Bay, Wiggins Island, Pelican Banks, Quoin Island, the GBRMP Boundary, and Wild Cattle Island.

Sedimentation

Seagrasses are also sensitive to sedimentation impacts. A review of case studies by Erftemeijer and Lewis (2006) found that the impacts of sedimentation depend on several critical factors such as depth of burial and life history of the species involved. Based on a case-study in the Philippines, *Halophila ovalis* was reported to tolerate sedimentation levels of 20 mm/annum (Vermaat *et al.* in Erftemeijer and Lewis 2006). However, burial experiments by Duarte *et al.* (1997) demonstrated that *H. ovalis* showed higher growth in experimental plots that received 40-80 mm of sediment than control plots that did not receive any sediment. It was suggested that under conditions of high light availability, sedimentation may in the long term enhance growth by increasing the availability of nutrients.

Predicted rates of sedimentation at seagrass meadows sites in Port Curtis are well below threshold levels outlined in Erftemeijer and Lewis (2006). On this basis, it is not expected that seagrass meadows would be substantially modified as a result sedimentation.

5.3.2.3 *Mangroves*

Mangroves are not sensitive to reduced light as a result of increased turbidity. Excess levels of sedimentation can cause stress to mangroves as a result of smothering and burial of root systems. This can lead to reduced vigour to death, depending on the amount and type of sedimentation, and the species under consideration. The case studies considered by Ellison (1998) recorded mangrove stress or death with sediment deposition depths of 50 to 700 mm. Natural sedimentation rates within mangrove forests vary spatially and temporally, but have been reported to be generally less than 5 mm/annum, reaching up to 10 mm/annum (Ellison 1998).

Modelling results do not predict any significant sedimentation from maintenance dredging in mangrove areas and no impacts are expected.

5.3.2.4 *Soft Sediment Communities*

Disposal

Monitoring of benthic communities within and adjacent to the EBSDS by BMT WBM indicate benthic macroinvertebrate communities are resilient to changes associated with maintenance material placement, and the long history of dredged material placement activities has created a change in community structure within and adjacent to the EBSDS. Within the EBSDS sediments are coarser and support more attached sessile forms, while adjacent communities are dominated by deposit feeders over softer sediments.

Previous investigations demonstrate that dredged material placed at the existing offshore EBSDS rapidly settles and tends to have little short-term effect on areas outside the EBSDS (BMT WBM 2012b). As discussed in Section 5.2 the effect of placement within the EBSDS is heavily dependent on the volume of material relocated. The 2011 macrobenthic monitoring campaign was demonstrated that while placement effects were benign after disposal of 126,000 m^3 of maintenance material, the effects 600,000 m^3 of capital material placement resulted in markedly decreased abundance and richness (BMT WBM 2012b).

Therefore, future campaigns in the order of 150-200,000 m^3 are likely to result in similar effects on the EBSDS and surrounding soft sediment to what has been observed previously (assuming “clean” material continues to be placed, and that these effects are largely related to physical burial).

However, it is also recognised that ‘baseline’ conditions at the EBSDS and immediate surrounds have been substantially modified by the recent placement of capital material from the WBDDP, and that communities will likely be in a state of flux and recovery.

Loading Site

Benthic communities adjacent to the loading site may be indirectly affected by dredging by:

- Increasing food resources availability in the form of suspended sediments and benthic fauna;
- Increasing sediment deposition levels, resulting in burial of sessile fauna; and
- Increasing suspended sediment concentrations causing the interference or blocking of respiratory and feeding structures.

There is a lack of information on critical levels of sedimentation or suspended sediment concentrations that would result in smothering, clogging of the filtering apparatus or other deleterious effects to benthic macroinvertebrates. The benthic macroinvertebrate communities regularly experience TSS concentrations greater than 70 mg/L, and it is therefore unlikely that species that are highly sensitive to sediment loading would occur here.

5.3.2.5 Fish and Nektobenthic Invertebrates of Commercial Significance

Fish and invertebrates that inhabit Port Curtis regularly experience periods of tidally driven turbidity. Fish have a lateral line system that it used to detect prey, which allow many fish species to feed in highly turbid waters. However, physiological effects to fish can occur at very high suspended sediment concentrations. For example, Jenkins and McKinnon (2006) suggested that TSS concentrations 4000 mg/L could block gills, eventuating in fish mortality. There are very few documented cases of fish kills resulting solely from turbid plumes, and predicted TSS levels are not predicted to approach these levels.

Prawns and portunid (mud and sand) crabs represent key species of commercial significance, and utilise both nearshore and offshore waters (including parts of the study area) as part of their life-cycle. These species primarily inhabit turbid water environments, and are tolerant of a wide range of turbidity conditions. These species are also highly mobile and actively burrow into soft sediments, and are therefore tolerant of high rates of sediment burial. Therefore, indirect impacts to prawns and crabs as a result of high suspended sediment concentrations and sedimentation from maintenance dredging are not expected.

5.3.2.6 Flow-on Plume Effects to Turtles and Dugong

Record stranding rates for turtles and dugongs have been recorded in 2011 and 2012 across the entire Queensland coast, as a result of habitat loss (seagrass) associated with flooding, high turbidity and low visibility. These conditions make fauna more susceptible to starvation and boat strike.

Maintenance dredging plumes are not expected to significantly impact on seagrass meadows (noting the limitations outlined in section 5.3.2.2) or corals, nor are major changes to benthic macroinvertebrate communities expected. It is therefore highly unlikely that dredging would result in a loss of food resource availability to the extent where flow-on effects to turtles and dugong would occur.

The sediment plumes created by dredging will temporarily reduce visibility. The dolphins species found in the study area are capable of successfully foraging in turbid waters. Dolphins often stir up bed sediments when foraging for benthic prey, resulting in limited to no visibility for prey detection. It is thought that dolphins detect prey using echolocation rather than visual cues (Mustoe 2006, 2008). Dugongs have poorly developed eyesight and rely on bristles on their upper lip, rather than visual cues, to detect seagrass food resources. Therefore, high suspended solid concentrations generated by dredging and dredged material placement are not expected to adversely affect foraging success for cetaceans or dugongs. Sea turtles generally have good eyesight and rely on visual and olfactory cues to detect prey and other food resources (e.g. Swimmer *et al*. 2005). Flatback turtles are known to feed in turbid shallow waters (Robins 1995) and may not be directly affected by turbid plumes generated by dredging. Other species such as green and hawksbill turtle, which feed on seagrass and/or in reef environments, may avoid areas affected by turbid plumes. It is noted however that the key feeding areas for these species are not predicted to be exposed to highly turbid dredge plumes.

5.3.3 Other Water Quality Effects

Dredging has the potential to mobilise nutrients and toxicants into the water column from disturbance of marine sediments.

As discussed in Section 4.1.3, sediment quality analyses of maintenance dredged material found that material was “clean” in accordance with NAGD (BMT WBM 2012c). In this regard, the upper 95% confidence limits of the mean for all trace metals/metalloids and other toxicants were below NAGD screening levels. This indicates that dredging is unlikely to cause significantly elevated concentrations of these toxicants in the water column.

5.3.3.1 Past Monitoring

There are some sections of the dredged channel which contain a high proportion of fine sediments, and these areas were found to have higher proportion of total organic carbon (TOC) and nutrients than other sections of the channel (and reference sites elsewhere). Monitoring was carried out in 2014 to measure nutrient concentrations within plumes generated by dredging and dredged material disposal (BMT WBM 2014b; 2014c). In summary, the studies showed:

- Under ambient (pre-dredging) conditions, TSS, chlorophyll a, nitrate (+ nitrite), total phosphorus and nitrogen often exceeded Water Quality Guideline values (ANZECC/ARMCANZ 2000; DERM 2009). Water samples collected near the sea floor generally had higher nutrient and sediment concentrations than those near the surface.
- Water quality profiling measurements 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 stable throughout the water column at all locations and similar between baseline and plume monitoring events. Chlorophyll-*a*

concentrations (an indicator of algae biomass) were consistently low during both baseline and dredge monitoring events.

- TSS and nutrient concentrations (mainly total nitrogen and ammonia) were higher in the dredge plume water samples compared to the baseline event, and generally exceeded Water Quality Guideline values (ANZECC ARMCANZ 2000; DERM 2009), including the toxicity trigger value for ammonia.
- Tidal processes would disperse and dilute nutrients in the water column, and given expected dilution rates, are predicted to achieve background levels at timescales measured in hours rather than 10s of hours or days.
- The high dissolved oxygen concentrations of waters within and offshore of Port Curtis would rapidly oxidise ammonia to nitrate and then (non-toxic) nitrite, minimising the risk of toxic effects.
- Metals and metalloids measured in dredge plumes at Jacobs Channel in July 2014 were below ANZECC/ARMCANZ (2000) toxicity trigger levels.

While not considered to represent a key risk issue, water quality will be measured at the loading site during dredging through a water quality monitoring program. The monitoring program will provide a basis for (i) assessing short-term water quality impacts of dredging on receiving environments, and (ii) the need or otherwise for further investigations and management actions.

5.3.3.2 2017 Nutrient Monitoring

Field and Laboratory Methods

Field measurements were conducted from the small research vessel *Harry John* operating in the vicinity of the dredge operations in September 2017.

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 to be used in the calibration of the turbidity probe and in assessments of the dredge plumes. Selected samples were also analysed for Particle Size Distribution (PSD) and nutrient concentrations.
- Turbidity profiling, using a Campbell Scientific 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 1200kHz Teledyne RDI ADCP to record the acoustic backscatter, providing an insight into the otherwise hidden plume characteristics across the various transects; and
- Deployment of a drogue into the plume to assist with the ADCP transects and turbidity profiling, thus ensuring that measurements were collected from where the concentrations of suspended sediments were highest.

Table 5-2 Sampling site details - nutrients

Location	Sample timing	Date/Time	Tide stage
EBSDS	Background	27/09/2017 11:15	Flood
	Plume during disposal	27/09/2017 12:31	High
	Plume after hour following disposal	27/09/2017 13:18	High
WICT	Background	28/09/2017 08:45	Flood
	Plume at start of over-flow	28/09/2017 10:02	High
	Plume at end of over-flow	28/09/2017 10:42	High
GLNG*	Plume at start of over-flow	28/09/2017 11:28	High
	Plume at end of over-flow	28/09/2017 13:20	Ebb
	Plume 1 hr post dredging	28/09/2017 14:18	Ebb
	Plume 1.5 hr post dredging	28/09/2017 14:46	Ebb

*note no background measurement collected

Water samples were analysed by ALS Pty Ltd for the parameters shown in Table 5-3.

Table 5-3 Laboratory analytes and limits of reporting

Analyte grouping/Analyte	Unit	Limit of reporting
EA025: Total Suspended Solids dried at 104 ± 2°C	mg/L	5
EK255A: Ammonia as N	mg/L	0.005
EK257A: Nitrite as N	mg/L	0.002
EK258A: Nitrate as N	mg/L	0.002
EK259A: Nitrite and Nitrate (NOx) as N	mg/L	0.002
EK260A: Organic Nitrogen as N	mg/L	0.01
EK261A: Total Kjeldahl Nitrogen as N	mg/L	0.01
EK262A: Total Nitrogen as N	mg/L	0.01
EK267A: Total Phosphorus (Persulfate Digestion) as P	mg/L	0.005
EK271A: Reactive Phosphorus as P	mg/L	0.001
EP008: Chlorophyll a	mg/m^3	1

Results

Figure 5-12 and Figure 5-13 show the concentration of various nitrogen and phosphorus species, respectively, at the EBSDS and two dredge sites. Organic nitrogen was the dominant nitrogen species in all water samples, followed by ammonia and nitrate. Nitrite concentrations were below laboratory detection limits. In terms of phosphorus, filterable reactive phosphorus was typically below detection limit of 0.001 mg/L, and represented a low proportion of total phosphorus.

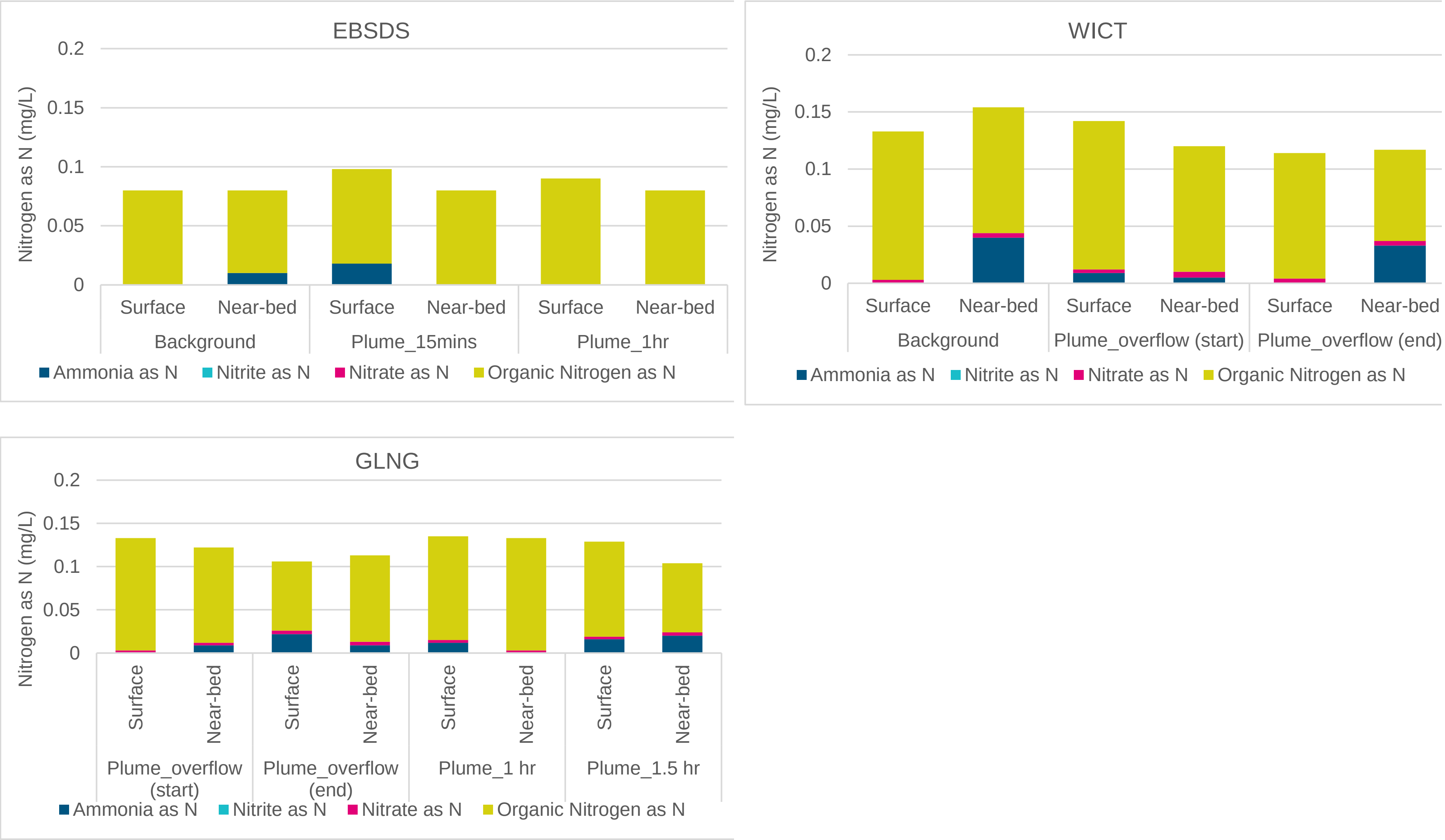


Figure 5-12 Nitrogen concentrations (mg/L) at the EBSDS and the WICT and GLNG dredge sites near the seabed bed and at the surface

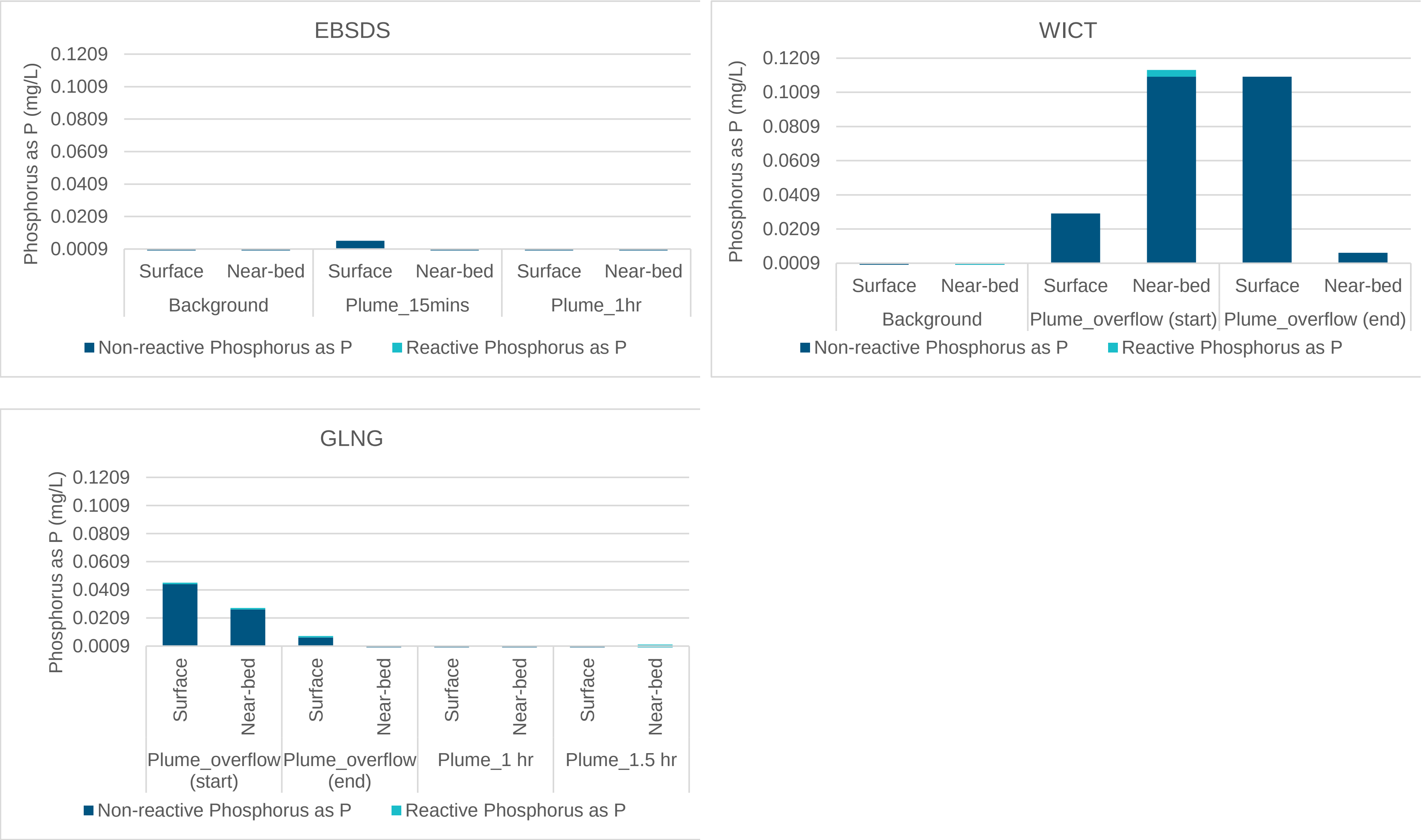


Figure 5-13 Phosphorus concentrations (mg/L) at the EBSDS and the WICT and GLNG dredge sites near the seabed bed and at the surface

EBSDS

- Ammonia was detected in the near-bed background sample (0.010 mg/L) and in the surface plume during disposal (0.018 mg/L). Ammonia was not detected (i.e. <0.005 mg/L) in the visible dredge plume one hour post disposal. Ammonia was well below the toxicity trigger value of 0.9 mg/L for 95% species protection, but exceeded the WQO of 0.003 mg/L in the two samples in which it was detected.
- Organic nitrogen concentrations were consistent over time, and did not increase in dredge plumes.
- Nitrate and nitrite were not detected (<0.002 mg/L) in any samples.
- The WQO for total nitrogen (TN) (0.1 mg/L) was met in all samples.
- Total phosphorus concentrations were less than the detection limit of 0.005 mg/L in all but one sample (surface plume = 0.006 mg/L). The WQO for total phosphorus (TP) (0.008 mg/L) was met in all samples.
- Filterable reactive phosphorus was not detected in any samples (<0.001 mg/L), and therefore met the WQO of 0.001 mg/L.

These results suggest that nutrient concentrations in plumes generated by dredge material disposal resulted in very small (<0.008 mg/L), short-term (less than 1 hour) increases in ammonia concentrations within the EBSDS. All other nutrients were below detection limits or were not higher in plumes than background.

Dredge Sites

- Ammonia in the near-bed background sample at Wiggins Island Coal Terminal (WICT) was 0.04 mg/L, which was an order of magnitude below the toxicity trigger value of 0.9 mg/L but slightly greater than the WQO of 0.03 mg/L (median for Western Basin area). Ammonia concentrations in dredge plume samples were ≤0.033 mg/L, with only one sample not meeting the WQO. There were no consistent trends in ammonia concentrations between near-bed and surface water samples.
- Organic nitrogen concentrations were consistent over time, and had similar concentrations between dredge plume samples and background.
- Nitrite was not detected (<0.002 mg/L) in any samples.
- Nitrate was 0.003 to 0.004 mg/L in background samples, and 0.003 to 0.005 mg/L in plume samples (average = 0.003 mg/L). Near bed concentrations were typically greater than surface in both background and plume samples, most likely due to sediment nutrient flux to the water column.
- The WQO for TN (0.17 mg/L) was met in all samples (0.01 to 0.15 mg/L).
- Total phosphorus concentrations were less than the detection limit of 0.005 mg/L in background samples. Total phosphorus temporarily increased in the dredge plume when the dredge hopper

was over-flowing, ranging from <0.005 to 0.046 mg/L (average 0.018 mg/L). However, total phosphorus was below detection limits (i.e. background) in plume samples ≥1 hour after dredging. The WQO for TP (0.018 mg/L) was exceeded in three plume samples.

- Filterable reactive phosphorus was typically either not detected (<0.001 mg/L) or 0.001 mg/L in most samples. All but one sample met the WQO of 0.003 mg/L; the near-bed plume sample at WICT during overflow (0.004 mg/L).

These results suggest that dredging resulted in short-term (<1 hour) low intensity increases in total phosphorus and filterable reactive phosphorous, and possibly nitrate. Ammonia concentrations in plume samples were less than background.

Discussion

In the present study, increases (above background) in nutrient species were recorded in plumes generated by dredging and disposal. These results are consistent with monitoring undertaken in Gladstone Harbour and the EBSDS in 2014 (BMT WBM 2014). Increases in nutrient concentrations occur as a result of the following processes:

- Resuspension of particulate-bound nutrients by the dredge head at the dredge site.
- Release of dissolved nutrients contained in pore waters as a result of disturbance of the seafloor by the dredge head.
- Release of particulate-bound and dissolved nutrients in dredged sediments and waters from the dredge hopper into the disposal site.

The results indicate that most nitrogen and phosphorus in dredge plumes was particulate-bound forms contained in organic matter. Particulate forms are the lease bioavailable, but eventually break down over time to more readily bioavailable forms (e.g. ammonia). Organic matter degradation processes are not fundamentally altered by dredging and disposal. The degradation rates of organic matter to bioavailable nutrients in pore water depends on the form of the organic matter. Phytoplankton has high reactivity and is therefore broken down at timescales <1 year. Most organic matter in nearshore sediments (including dredged sediments) is terrestrial matter with low reactivity, with degradation half-life measured in years to millennia (Batley *et al.* 2015).

In a review of monitoring studies in Queensland and worldwide, Batley *et al.* (2015) suggested that increased concentrations of soluble ammonia associated with pore water release and desorption from particles was typically of most concern, whereas release of dissolved nitrite, nitrate and phosphate were generally minor and of least concern. The results of the present study confirm that ammonia was the dominant form of bioavailable nitrogen in dredge and disposal plumes.

Ammonia (and other nutrient) concentrations exceeded the local WQO but did not approach the toxicity guideline value for ammonia. Furthermore, ammonia and other bioavailable forms are highly unlikely to result in persistent water quality impacts. While the present study represents a snap-shot and was replicated in time and space, the data shows that nutrients in plumes generated by dredging and disposal did not persist for more than one hour. This is consistent with monitoring results for highly nutrient enriched dredged sediments (from Toondah Harbour) disposed at Mud Island DMPA (BMT WBM 2009) found that ammonia concentrations in the water column were close or slightly above background concentrations within 10 minutes of dredged material placement, and had returned to background concentrations (often below laboratory detection limit of ~0.002 mg/L) within one hour of disposal. These results indicate that through dilution and biological uptake of nutrients in dredged sediments in the water column, nutrient concentrations were well below levels of potential concern.

5.4 Effects to Megafauna Due to Vessel Strike and Noise

5.4.1 Vessel Strike

Marine animals that swim near the water surface, such as whales, dolphins, dugongs and turtles, could interact with the dredger. A dredger is slow-moving, which would provide marine fauna time to evade the approaching vessel. Turtles are also highly mobile and will tend to avoid the dredger. When active, sea turtles must swim to the ocean surface to breathe every few minutes, however, they can remain underwater for as long as two hours without breathing when they are resting. There are recorded incidences of turtles being killed or injured by trailer suction hopper dredgers. Cutter-suction and back-hoe dredgers pose a low risk to turtles as they do not have trailing suction dragheads (Dickerson *et al*. 2004).

GHD (2005), citing personal communication from Dr Limpus, suggest that the numbers of turtles captured during dredging across all Queensland Ports is decreasing, with an average of 1.7 loggerhead turtles per year being captured across all ports. The TSHD *Brisbane* undertaking maintenance dredging in Gladstone has reported capturing five turtles in the 10 year period between 2005 and 2015 (Mocke *et al.* 2016). Given the relatively low numbers of turtles captured by dredgers compared to other activities, and the use of effective management and operational practices to reduce the potential for turtle capture, it is not considered that the proposed dredging will have a significant impact on turtle populations in the study area. Direct effects of loading (dredger interaction) will be mitigated using existing practices aboard the *Brisbane* as a part of their environmental management plan and in accordance with GPC’s permit conditions and adaptive monitoring and management framework.

5.4.2 Noise

Underwater noise assessments carried out in association with the Western Basin dredging suggest suggested that cetaceans and dugongs may start to show a behavioural response within 2 km from the dredger or associated booster pumps, while turtles would be affected within 50 m (BPM 2013). This assumes no attenuation or amplification in sound due to the physical environment. Dolphins, dugong or turtles remaining within 1 m of a dredge or booster pump for more than 10 minutes would suffer immediate physical impact (BPM 2013). However, even at relatively close distances it would take time for injuries to occur. At 100 m away, impacts would not occur for any animal until at least 1 hour of exposure to dredge noise or 3 hours of exposure to booster pump noise. Given the close distances and durations required, it was considered that marine megafauna in the Gladstone region were unlikely to suffer physical impacts from dredging noise. The dredger will represent an intermittent noise source that has the potential to temporarily interfere with marine megafauna communications during the dredge campaign.

5.5 Introduced Marine Pests

5.5.1 Existing Status

More than 250 non-indigenous marine species have been recorded in Australian waters to date (NIMPCG 2013). There are several potential vectors by which non-indigenous species may enter domestic waters; however, it is thought that most species are unintentionally introduced through shipping and vessel movements, either in ballast waters or from biofouling on the hull of vessels (Hewitt and Campbell 2010). Other vectors include intentional transfer of aquaculture and mariculture organisms, transfer of food products for the aquarium trade and use of biological material for packing (Hewitt and Campbell 2010). Asian green mussels (*Perna viridis*), considered to be a potential threat in tropical waters, were found on a vessel's hull in Cairns harbour 2001 and Caribbean tubeworm (*Hydroides sanctaecrucis*) has also been introduced there (Souter 2009).

A baseline marine pest survey was carried in Port Curtis in 2000 (Lewis *et al.* 2001). This aim of this baseline survey was to describe existing non-indigenous species, including target pest species listed by the Australian Ballast Water Management Committee, Hewitt and Martin (1996) and Furlani (1996). Although no pest species were detected, 10 introduced species were found, including the ascidians *Styela plicata* and *Botrylloides leachi*; the bryozoans, *Amathia distans*, *Bugula neritina*, *Cryptosula pallasiana*, *Watersipora subtorquata*, and *Zoobotryon verticillatum*; the hydrozoan *Obelia dichotoma*; the isopod, *Paracerceis sculpta*, and the dinoflagellate *Alexandrium sp*. Each of these species are found in ports across Australia and internationally, and were not thought to represent a threat to native species in Port Curtis, apart from some spatial competition from some of the bryozoans species (Lewis *et al.* 2001).

The most recent marine pest survey in Port Curtis was undertaken by Vision Environment (2015). The survey discovered four species registered on National Introduced Marine Pest Information System (NIMPIS), including the Caribbean tubeworm (*Hydroides sanctaecrucis*), sea lettuce (*Ulva fasciata*), sponge isopod (*Paracerceis sculpta*), and the encrusting bryozoan (*Cryptosula pallasiana*) (Vision Environment 2015). These species appear to be relatively widespread throughout the port and are not considered high-risk species, although the Caribbean tubeworm is considered medium impact pest by CSIRO. Based on their ubiquity in other Australian ports, throughout Port Curtis, and their present pest status, their presence did not warrant a pest emergency response (Vision Environment 2015).

It should be noted that field studies of introduced marine species should not be considered exhaustive, given the difficulties associated with surveying large ports and the fundamental lack of taxonomic information for many marine species (Sliwa *et al.* 2009). Given that many marine taxa are difficult to identify to species, these could represent native species or non-native introductions. Lewis *et al.* (2001) specifically targeted known or potential pest species so it is likely that marine pest prevalence estimates are more reliable than those of total introduced species estimates.

5.5.2 Potential Impacts

There are two key vectors for introduced marine pests entering a port: biofouling of the vessel hull, or the release of pests into the marine environment via ballast waters (Hewitt and Campbell 2010). Vessels (including dredgers, cargo vessels, high speed craft etc.) can subsequently translocate pests within and outside the port area. In areas containing marine pests, there is a risk that pests could be transferred by the dredger from the dredge site to the EBSDS. As discussed in Section 5.5.1, despite the presence of introduced species in Port Curtis, none of these are considered marine pest species. Based on this, it is considered that the risk of translocating pest species within the port (i.e. from the loading site to the EBSDS) is considered to be low.

Any TSHD dredger contracted to undertake dredging works will be required to comply with best practices, including AQIS and Biosecurity Queensland requirements in relation to ballast water and marine pest management, including the National System for the Prevention and Management of Marine Pest Incursions, in particular the National Biofouling Management Guidance for Non-Trading Vessels.

The TSHD *Brisbane* represents a low risk of species translocation because it works primarily within Queensland ports and the Port of Melbourne.

5.6 Impacts on Other Users

Maintenance dredging operations and associated plumes and sedimentation have the potential to impact other users of the area, including commercial and recreational fishers, recreational boating enthusiasts, and vessel traffic to the LNG projects on Curtis Island.

Potential impacting processes include:

- interference with other vessels. Maintenance dredging operations are unlikely to significantly interfere with small craft movements. Dredger movements comprise a small proportion of total ship movements in the port. Maritime Safety Queensland (MSQ) also advises small craft to keep clear of ship navigation areas, including shipping channels, berths, swing basins etc. subject to maintenance dredging. Dredging operations are co-ordinated around the movements and berthing schedules of larger ships.
- direct effects to fishing operations. Commercial fishing activities in Port Curtis includes setting of crab pots, nets and trawling. Netting and trawling are not permitted in navigational areas subject to maintenance dredging, therefore direct effects to commercial fishing operators are not expected.
- indirect effects due to dredge plume. Modelling predicts that sediment plumes and sedimentation rates created by dredging will be within the range of natural tidally generated turbidity during spring tides. As described in Section 5.2, plumes are not expected to significantly impact on high value fisheries habitats such as seagrass, high-density epibenthos or mangroves, and on this basis significant impacts to fisheries resource values are not expected.

6 Summary of Impacts to Protected Matters

6.1 Matters of National Environmental Significance

Section 4.2 provides an overview on MNES relevant to the proposal, and potential impacts were considered based on the study findings in Section 5.

6.1.1 GBRWHA

Dredging activities will be carried out in the GBRWHA, which will result in temporary impacts to water quality near the dredge loading site during dredging, and effects to benthic communities within the dredge loading site (which based on Section 4.1.4.3, suggest impacts are of a temporary nature). Significant impacts to biodiversity values are not expected as:

- Dredging will be carried out within existing channels, which represents a previously disturbed environment rather than a green-field site.
- Dredging areas are not known or likely to support habitats of critical importance to threatened or otherwise conservation dependent species or communities.
- Habitat within the disturbance footprint is not known or likely to provide unique or critical functions to the maintenance of aquatic ecosystems within Port Curtis.
- Indirect impacts to habitats and communities of high biodiversity value (seagrass, and surrounding reefs) are not expected.
- Direct or flow-on impacts to threatened or migratory species are not expected.

In the context of EPBC Act Significant Impact Guidelines 1.1 (DEWHA 2009; see Table 6-1), it is expected that the proposed dredging will:

- Not result in loss of one or more World Heritage values;
- Not result in one or more World Heritage values to be degraded or damaged; and
- Not result in one or more World Heritage values to be notably altered, modified, obscured or diminished.

Table 6-1 Criteria listed by the EPBC Act 1999 for a 'significant impact' and the 'likelihood' of impact to World Heritage Values, Commonwealth Marine Waters or Great Barrier Reef

Significance criteria	Assessment
Reduce the diversity or modify the composition of plant and animal species in all or part of a World Heritage property.	Maintenance dredging will lead to short-term modifications to benthic fauna assemblage structure as a result of dredging in the channel and disposal at the EBSDS. These impacts are expected to be highly localised (i.e. within the lawful dredging and disposal footprint), and are not expected to result in broader scale impacts to the biodiversity values of Port Curtis.
Fragment, isolate or substantially damage habitat important for the conservation of biological diversity in a World Heritage property.	Maintenance dredging will remove sediments from <1km^2 of existing channel extent. Such habitats are well represented elsewhere within other parts of the non-dredged channel. None of the area to be disturbed is habitat that is known to be unique to Port Curtis. Maintenance dredging will not isolate marine habitats. Maintenance dredging and disposal at the EBSDS will not form a barrier to fauna movements within, or in and out of, Port Curtis.
Cause a long-term reduction in rare, endemic or unique plant or animal populations or species in a World Heritage property. Fragment, isolate or substantially damage habitat for rare, endemic or unique animal populations or species in the World Heritage property.	In the absence of mitigation, modelling suggests that maintenance dredging could lead to short-term water quality impacts at some meadows at Passage Islands. Any detectable secondary effects to seagrass meadows are expected to be minor in magnitude (possible stress but unlikely to cause major loss of biomass), highly localised and of a temporary nature. Long term declines in the population status of any species are not expected to occur as a result of maintenance dredging. Endemic coral species are known from northern Port Curtis, but these are remote from the potential impacts of dredging.

6.1.1.1 *Impacts to OUV*

The outstanding universal value (OUV) of the Great Barrier Reef is composed of cultural and natural heritage elements. The four natural heritage criteria that the GBRWHA satisfy are its geological phenomena, ecological and biological processes, its aesthetics and natural beauty, and its biological diversity including the threatened species it supports. The integrity of the GBRWHA and the value of these attributes are supported by the sheer size of the property and its potential for effective conservation management.

As described above, proposed maintenance dredging is not expected to impact flora, fauna, or have flow-on effects to threatened species. The proposed dredging is also not expected to affect the property's geological phenomena, or significantly impact the ecological or biological processes. The dredging works will not permanently alter the natural beauty of the property beyond the dredge campaign; they will not result in greater vessel occupancy or additional permanent infrastructure. Therefore, impacts to the OUV are not expected from the maintenance dredging activity.

6.1.2 Threatened and Migratory Species

Section 5.1 considers potential impacts to marine fauna. The proposed dredging activities are not expected to lead to significant direct or indirect effects to listed threatened or migratory species in accordance with the EPBC Act Significant Impact Guidelines 1.1 (DEWHA 2009). In this regard, the proposed dredging is predicted:

- Not to result in significant indirect impacts to important habitats;
- Not to result in significant risk of invasive species entering the port and affecting threatened species; and
- Not to result in significant increased risk of direct impacts due to vessel strike or noise impacts (see Section 5.4).

Therefore, in the context of EPBC Act Significant Impact Guidelines 1.1 (DEWHA 2009):

- A long-term decrease in the size of an important population of a species is not expected;
- A reduction in the area of occupancy of an important population is not expected;
- Fragmentation of an existing important population into two or more populations is not expected;
- Adverse effects to habitat critical to the survival of a species is not expected;
- Disruption of the breeding cycle of an important population is not expected;
- Modify, destroy, remove or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline is not expected;
- Result in invasive species that are harmful to a vulnerable species becoming established in the vulnerable species' habitat is not expected;
- Introduce disease that may cause the species to decline is not expected;
- Interfere substantially with the recovery of the species is not expected;
- Substantially modify, destroy or isolate an area of important habitat for a migratory species is not expected;
- Result in an invasive species that is harmful to the migratory species becoming established in an area of important habitat for the migratory species is not expected; and
- Seriously disrupt the lifecycle (breeding, feeding, migration or resting behaviour) of an ecologically significant proportion of the population of a migratory species is not expected.

6.1.3 Other MNES

Predicted loading and tailwater plumes do not extend into the Commonwealth Marine Area (including the GBR marine park) and resuspension plumes are minor compared to ambient turbidity. Plumes are remote (several hundred kilometres south of the nearest Ramsar site located at Shoalwater and Corio Bays. No impacts to these MNES are expected.

6.2 Matters of State Environmental Significance

Section 4.3 provides an overview on MSES relevant to the proposed maintenance dredging, and potential impacts were considered based on the study findings in Section 5.

6.2.1 Wetlands and Watercourses

Dredging activities will be carried out with the potential for turbid plume impacts to result in temporary reductions in water quality affecting seagrass meadows near the dredge loading site. Seagrass meadows are listed as wetlands of high ecological significance and offsets may be required if dredging is deemed to have significant residual impact. Significant residual impacts to seagrass meadows are not expected because:

- Major direct or indirect impacts to seagrass meadows are not expected.
- Seagrass meadows with potential to be affected by dredge plumes could be protected by mitigation measures that may include the relocation of the dredger or the establishment of an adaptive monitoring program.
- The potential for dredging to introduce invasive species into the wetland (seagrass meadows) is very low considering:
  - There are no high-risk marine pests in Port Curtis.
  - Current pest species are largely found on pylons.

6.2.2 Protected Wildlife Habitat

Section 5.1 considers potential impacts to marine fauna. The proposed dredging activities are not expected to lead to significant direct or indirect effects to protected wildlife. In accordance with the significant residual impact criteria, the proposed dredging is predicted:

- Not to lead to a long-term decrease in the size of a local population.
- Not to reduce the extent of occurrence of the species or fragment and existing population.
- Not to result in genetically distinct populations resulting from habitat isolation.
- Not to result in invasive species establishing that are detrimental to endangered or vulnerable species.
- Not to introduce diseases that may cause the population to decline.
- Not to interfere with the recovery of a species.
- Not to disrupt ecologically significant locations used for breeding, feeding, nesting, migration or resting.

6.2.3 Fish Habitat Areas and Highly Protected Zone of State Marine Parks

As per Section 4.3, the dredging activities will take place adjacent to the Great Barrier Reef Coastal Marine Park which covers similar areas to the GBR marine park. Based on significant residual impact criteria for protected areas, the proposed dredging will **not:**

- Result in exclusion or reduction in the public use or enjoyment of the part or all of the nearby protected areas.
- Reduce the natural or cultural values of all or part of the Coastal Marine Park.

State significant residual impact criteria for highly protected zones of State Marine Parks refer specifically to works to be conducted within these zones. As the proposed dredging falls outside of these area boundaries, these criteria are not relevant.

7 Impact Hypotheses

7.1 Adaptive Management Framework

The environmental management objectives relevant to maintenance dredging are as follows:

- Ensure that maintenance dredging activities do not impact the Outstanding Universal Value 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 Port Curtis which contribute to the 'outstanding universal value' of the GBRWHA.
- There are no significant long-term changes in the health of (and no net loss of) high ecological value sensitive receptors such as coral reefs and seagrass meadows.
- Appropriate marine ecological condition monitoring is undertaken to inform adaptive management actions that aim to minimise or avoid impacts to marine ecological components, process and services.
- Direct impacts are confined to the dredge loading site (dredged footprint) and within the offshore EBSDS, and that impacts outside of the lawful footprint are short-term and reversible.

As information relating to the status of marine ecosystems may change over time, a mechanism will be developed that allows for the review of these objectives to ensure that the monitoring program specifically addresses issues of concern to port management and stakeholders. This will be discussed with the Technical Advisory and Consultative Committee (TACC), as required.

In the context of these objectives and the adaptive approach outlined above, GPC proposes to undertake monitoring of the marine environment where:

- Sensitive or particularly high environmental value habitats may be adversely affected through the dredging or disposal activities; or
- There are gaps in knowledge or some uncertainty regarding the extent of potential impact and confirmation of assumptions or previous monitoring is considered warranted.

Where relevant, information from the monitoring programs will be used to inform any required changes to the maintenance dredging program to ensure that the objectives are achieved.

The following describes the proposed monitoring that will be used to assess any impacts of maintenance dredging, and is subject to review and revision.

7.2 Impact Hypotheses

7.2.1 Sediment Quality Assessments of Dredged Material

With regard to sediment contaminants of potential concern (CoPC), the impact hypothesis to be tested in future monitoring is as follows:

‘Disposal of dredged material will not result in contaminant related impacts to the marine environment’

A sediment quality sampling program will be carried out to:

- Quantify concentrations of trace metals/metalloids, hydrocarbons and other potential pollutants in maintenance dredged material;
- Assess the contaminant status of dredged sediments with reference to the process outlined in the NAGD; and
- Based on the above, determine whether maintenance dredged material is suitable for unconfined sea disposal, or whether further testing is required.

The NAGD provides the framework for assessment of potential contaminants and suitability of dredged material for ocean disposal. NAGD requires data to be ‘current’, meaning data that are a maximum of five years old, and where there is no reason to believe that the contamination status has changed significantly. The NAGD states that new data will be required where contamination of the site is likely to have increased or new pollution sources are present (such as a new industry or accidental spills). In this context, no major changes in pollution risk are expected in the foreseeable future, so a maximum five years between surveys is considered appropriate.

7.2.2 Hydrographic Survey at the EBSDS

Hydrographic survey data provides a basis for assessing dredged material deposition patterns within the zone of placement impact, the identification of potential navigation hazards, and the capacity of the EBSDS for future disposal events. With regard to seabed water depths, the impact hypothesis to be tested in future monitoring is as follows:

‘The deposited spoil does result in navigation hazards within and adjacent to the EBSDS.’

7.2.3 Water Quality at the Loading Site and EBSDS

Dredging, dredged material disposal and the subsequent re-suspension of dredged sediments will increase sediment concentrations in the water column, as described in the preceding report sections. Modelling predicts that suspended sediment concentrations at most key receptor sites will be relatively small (<10 mg/L) and of a short duration. While TSS and other water quality parameters (e.g. dissolved oxygen, nutrients, metals etc.) are not expected to result in impacts to estuarine biota (Section 5.3.3), further monitoring is recommended to test this hypothesis.

The impact hypotheses to be tested in future monitoring are as follows:

‘Sediments generated during dredging and disposal do not subsequently reach sensitive areas in amounts that would be harmful to the ecological value and amenity of the area’.

‘Pollutant concentrations within dredge plumes at the loading and disposal sites do not reach levels where toxic effects or algae blooms could occur.’

7.2.4 Seagrass and Reef Habitats

Seagrass and reef habitats occur adjacent to the dredged area and are predicted to receive turbid plumes from maintenance dredging. Turbid plumes in these areas are predicted to mostly be short-lived and have low TSS values compared to natural background levels. Seagrass and reef habitats are considered are unlikely to be impacted however validation monitoring is required.

The impact hypothesis to be tested in future monitoring is as follows:

‘Maintenance dredging activities do not result in long-term changes to seagrass meadow extent and reef habitats.’

7.2.5 Benthic Fauna Communities at the EBSDS

Benthic fauna communities within the EBSDS are the main ecological receptors to be affected by dredged material disposal (i.e. smothering, water quality changes and changes in sediment type). Previous monitoring programs undertaken by GPC quantified changes to benthic fauna communities associated with the maintenance dredging activities, as well as the effects of initial disposal of capital dredged sediments from the Western Basin project.

The impact hypothesis to be tested in future monitoring is as follows:

‘The deposited dredged material does not result in long term changes to benthic communities outside the EBSDS.’

7.2.6 Introduced Marine Pests

Under the National System for the Prevention and Management of Marine Pest Incursions the Australian Marine Pest Monitoring Manual and accompanying Australian Marine Pest Monitoring Guidelines have been developed. These were released in early February 2010.

The impact hypothesis to be tested in future assessments is as follows:

‘Maintenance dredging does not result in the introduction of marine pests into new environments within the port area.’

Table 7-1 Impact Hypothesis Summary

Component	Impact Hypothesis
Sediment quality	Disposal of dredged material will not result in contaminant related impacts to the marine environment
Water quality	Sediments generated during dredging and disposal do not subsequently reach sensitive areas in amounts that would be harmful to the ecological value and amenity of the area
	Pollutant concentrations within dredge plumes at the loading and disposal sites do not reach levels where toxic effects or algae blooms could occur
Benthic habitats and communities	Maintenance dredging activities do not result in long-term changes to seagrass meadow extent and reef communities
Benthic habitats and communities	The deposited spoil does not result in long term changes to benthic communities outside the EBSDS
Hydrographic survey	The deposited spoil does result in navigation hazards within and adjacent to the EBSDS
Marine pests	Maintenance dredging does not result in the introduction of marine pests into new environments within the port area

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Appendix A Model Validation Report

Port of Gladstone Maintenance Dredging Impact Assessment - Model Validation Report

From:	Dr Paul Guard, Steven Ettema	To:	Anthea Bennett
Date:	26 October 2017	CC:	
Subject:	Model Validation Report		

1 Background

BMT WBM undertook an assessment of the potential environmental impacts associated with ongoing maintenance dredging activities at the Port of Gladstone (BMT WBM, 2017). This technical memorandum has been prepared to provide detailed information on the model configuration, calibration and validation.

2 Model Configuration

2.1 Numerical Modelling Software

The hydrodynamic modelling component of this assessment was undertaken using the TUFLOW FV software, which is developed and distributed by BMT WBM (www.tuflow.com). TUFLOW FV is a numerical hydrodynamic model for the three-dimensional (3D) Non-Linear Shallow Water Equations (NLSWE). The model is suitable for solving a wide range of hydrodynamic systems ranging in scale from open channels and floodplains through to estuaries, coasts and oceans.

The Finite-Volume (FV) numerical scheme employed by TUFLOW FV is capable of solving the NLSWE on both structured rectilinear grids and unstructured meshes comprised of triangular and quadrilateral elements. The flexible mesh allows for seamless boundary fitting along complex coastlines or open channels as well as accurately and efficiently representing complex bathymetries with a minimum number of computational elements. The flexible mesh capability is particularly efficient at resolving a range of scales in a single model without requiring multiple domain nesting. Further details regarding the numerical scheme employed by TUFLOW FV are provided in the TUFLOW FV Science Manual (BMT WBM 2013).

The TUFLOW FV model was configured as a 3D model with baroclinic coupling from both salinity and temperature variations. Atmospheric heat fluxes and water column heat dynamics were simulated internally within TUFLOW FV. The inclusion of baroclinic pressure gradient terms in the solution scheme allows for the development of a stratified water column, although in Port Curtis and the outer harbour this is rarely observed due to the mixing associated with the high energy tidal environment.

A hybrid z-coordinate vertical grid configuration with three surface “sigma” layers was adopted for the hydrodynamic model. The vertical grid had 14 z-layers representing the top 50 m of the water column.

The General Ocean Turbulence Model (www.gotm.net) was linked with TUFLOW FV to control vertical mixing of both momentum and sediment, employing a 2-equation k-omega turbulence scheme. A Smagorinsky model was used for the estimation of the horizontal eddy viscosity and diffusivity coefficients.

A wave model was developed in order to simulate the wave-related stresses (particularly bed shear stresses) that have an influence on hydrodynamics, sediment re-suspension and sediment transport. The SWAN (Delft University of Technology 2006) numerical model was used for this purpose. SWAN is a third-generation spectral wave model, which is capable of simulating the generation of waves by wind, dissipation by whitecapping depth-induced wave breaking, bottom friction and wave-wave interactions in both deep and shallow water. SWAN simulates wave/swell propagation in two-dimensions, including shoaling and refraction due to spatial variations in bathymetry and currents. The SWAN wave model was provided with water level and current boundary conditions from the hydrodynamic model. The calculated wave parameters (including near-bottom orbital velocity and near-bottom wave period) were then provided to the hydrodynamic model for calculation of the combined wave-current bed shear stress.

Suspended sediment transport is modelled by calculating the time-varying concentration of constituent sediment fractions (fine sand, silt, clay particles) as a function of time and 3D space. The scalar conservation equations are solved for the advection and diffusion of each constituent, and exchange of sediment with the numerical bed is modelled according to the calculated pickup and deposition rates (see Section 6.1 for further details).

2.2 Model Extent

The model network extends over an area of some 2000 km^2, incorporating the Port of Gladstone and an ocean boundary extending up to 30km offshore. The tidal boundaries of the model include the eastern ocean boundary and also the northern end of the Narrows. Tidal estuaries incorporated into the model include the Calliope River, Auckland Inlet, South Trees Inlet and the Boyne River. The extent of the hydrodynamic model coverage is illustrated in Figure 2-1.

The SWAN wave model included a coarse GBR-scale grid (~500 m resolution), a nested regional-scale grid (~120 m resolution) and a nested local-scale grid (~50 m resolution). The domains of the three SWAN grids are shown in Figure 2-2.

2.3 Model Bathymetry

The model bathymetry is based on a Digital Elevation Model (DEM) of the Port, which has been derived from the following survey components:

- Detailed hydrographic survey data of the dredged channels, swing basins and berths as provided by MSQ and GPC, together with the progressive inclusion of ongoing surveys to ensure that the model bed levels match the actual bathymetric configuration at the time of the simulation period;
- Detailed hydrographic survey data of broad areas of the Port, from MSQ and GPC; and
- Hydrographic survey data and outlines of the edges of the shoreline, mangroves and saltpans used in producing Boating Safety Charts of the area, as provided by MSQ.

Typical levels have been adopted for the edges of the mangroves and saltpan areas for interpolation in those upper inter-tidal zones where no specific survey level data is available. The various data components have been combined and prioritised with respect to date and detail where there is overlap in producing a base DEM. For modelling purposes, all data has been adjusted to a consistent AHD datum. The best available representation of the final post-LNG dredging bathymetry adjacent to Curtis Island was used in the model, and clearance survey data was used to incorporate the WICET dredging. The adopted model bathymetry is illustrated in Figure 2-1.

In developing the hydrodynamic model, consideration has been given to the underlying bathymetry in defining the mesh configuration. For example, model resolution was enhanced at locations of rapidly varying bathymetry or expected high flow regions based on channel definition, as well as to represent the dredged channels, swing basins and berth pockets.

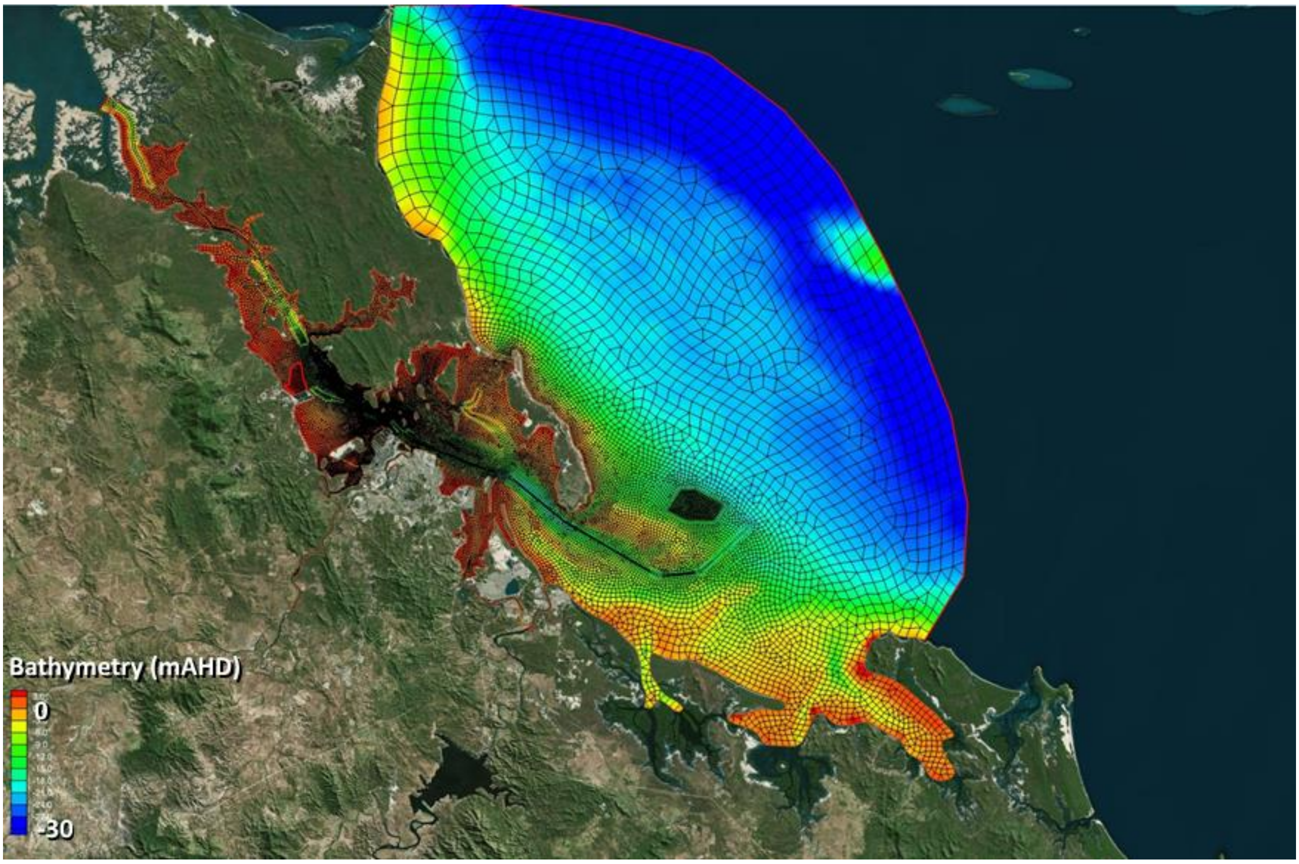


Figure 2-1 TUFLOW FV Mesh of the Gladstone Region

Figure 2-2 SWAN Wave Model Domains (GBR domain – Top, Regional Domain – Middle, Local Domain – Bottom)

3 Model Boundary Conditions

3.1 Tide

Tidal flows that drive the hydrodynamics of the system were applied as boundary conditions to the model. The tidal inflows into the model were introduced by providing time-varying water level inputs at the two open boundaries derived from a regional scale Great Barrier Reef model. This model is forced with tidal predictions provided by the National Tide Centre (NTC).

3.2 Oceanic Currents

Due to the large scale of the model, regional oceanic effects were incorporated in the offshore open ocean boundary conditions. This was done using HYCOM global ocean circulation model hindcast outputs (www.hycom.org). This model provided 3D current, salinity and temperature data which was applied on the ocean boundary in combination with the tidal water level variation. At each time step the velocity profiles at the open ocean boundary were specified as a superposition of the HYCOM velocity profile and the depth-averaged tidal current and then relaxed barotropically using an active Flather (1976) condition. This minimises the reflection of outward propagating barotropic waves at the model open boundaries (allows for the over-specification of the boundary condition).

Note that due to the highly energetic tidal conditions within Gladstone Harbour, the hydrodynamics within the estuary are not very sensitive to variations in the oceanic current boundary conditions.

3.3 Wind

Wind velocity boundary conditions for the calibration period were obtained from global NCEP Climate Forecast System Reanalysis (CFSR) model reanalyses (https://rda.ucar.edu/#!pub/cfsr.html). The CFSR model has a spatial resolution of 0.2 degrees in the study area which is high enough to minimise errors arising from interpolation in the vicinity of the shoreline. The temporal resolution of the CFSR outputs is one hour. This wind field was applied to both the hydrodynamic and wave models.

3.4 Atmospheric

Other atmospheric boundary condition data, including air temperature, long and short wave radiation and relative humidity were also obtained from global NCEP CFSR model reanalyses (https://rda.ucar.edu/#!pub/cfsr.html). These model outputs had the same spatial and temporal resolution as the wind outputs and were applied to the hydrodynamic model only.

4 Assessment Period Characteristics

4.1 Tide, Wind and Wave Conditions

The impact assessment model simulations were carried out over the period September-November 2017, a period which included large spring tides. The recorded water level at Auckland Point during this period is provided in Figure 4-1. Times series plots of modelled wave conditions at Gladstone Wave Buoy are presented in Figure 4-2. The wind and wave roses for the assessment period are shown in Figure 4-3. For comparison purposes, the long term wind and wave roses are provided in Figure 4-4. Note that the hydrodynamic and wave conditions within Gladstone Harbour are not very sensitive to the wind boundary conditions due to the energetic tidal conditions and the relatively sheltered wave environment.

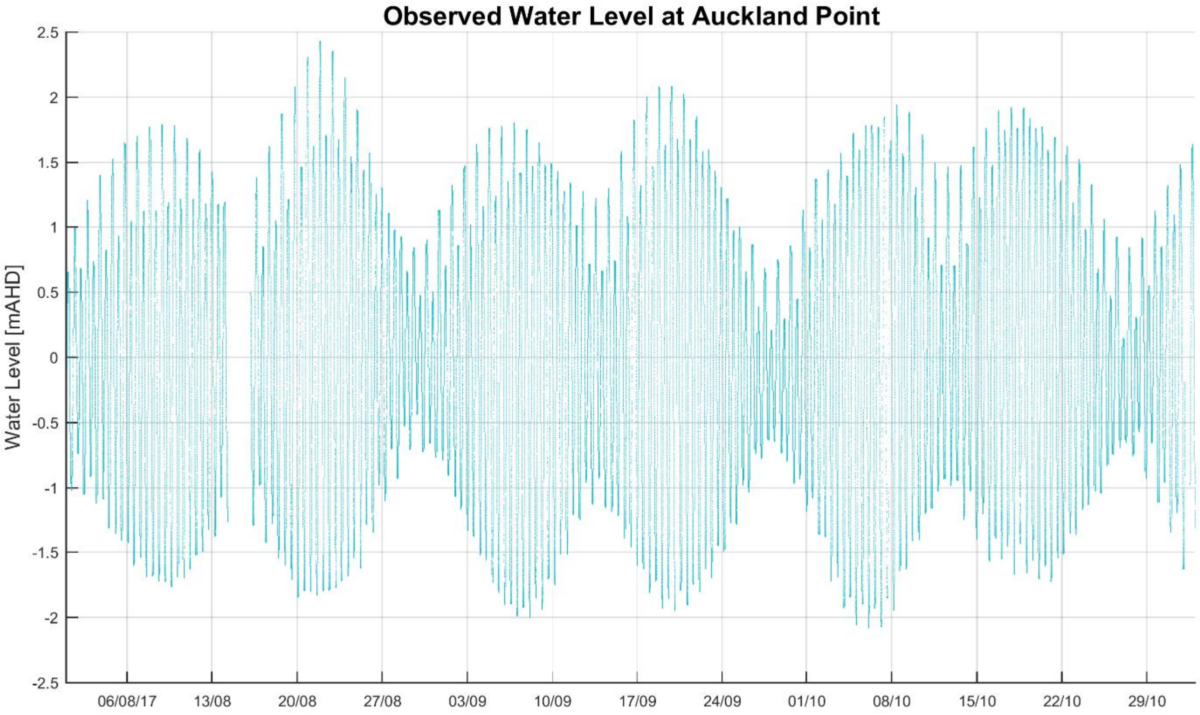


Figure 4-1 Recorded Water Level During the Assessment Period (m AHD)

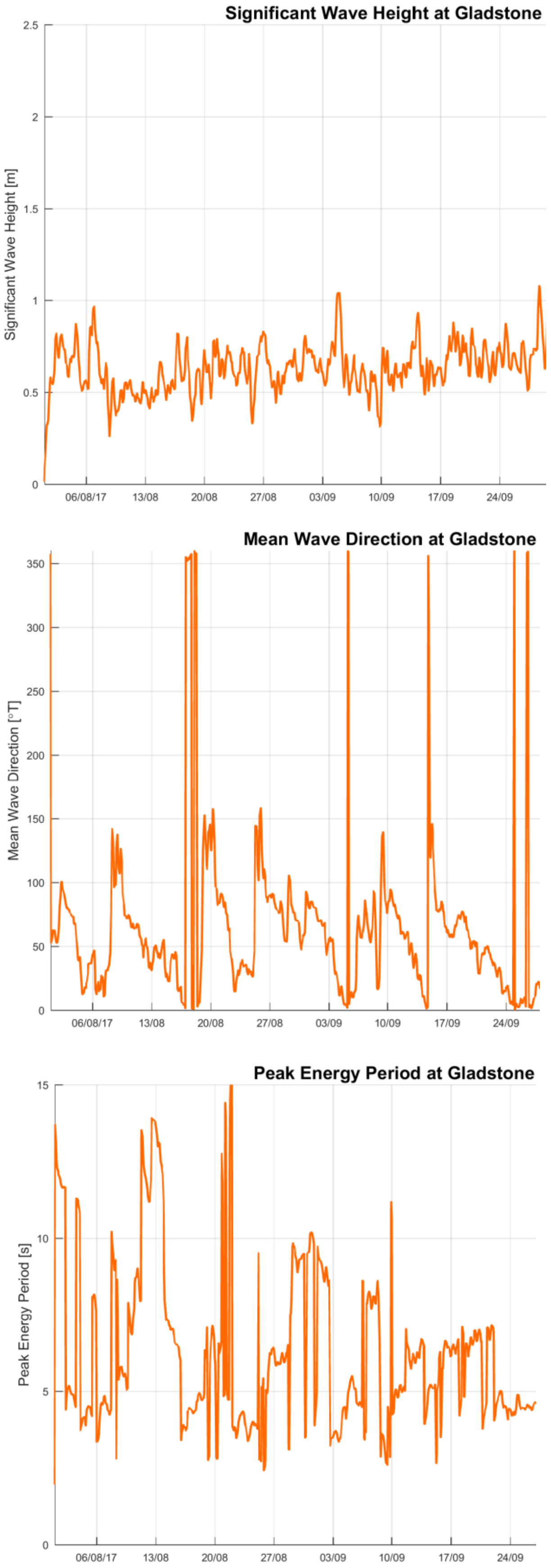
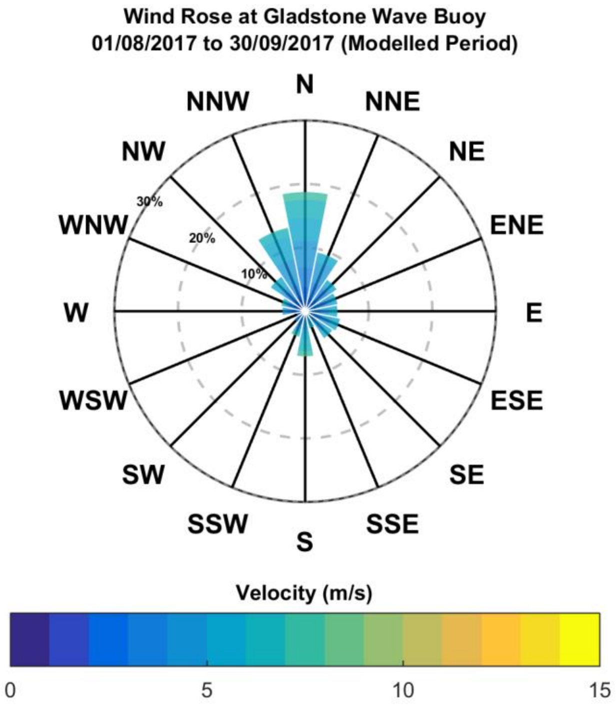


Figure 4-2 Modelled Wave Conditions at Gladstone Wave Buoy During the Assessment Period



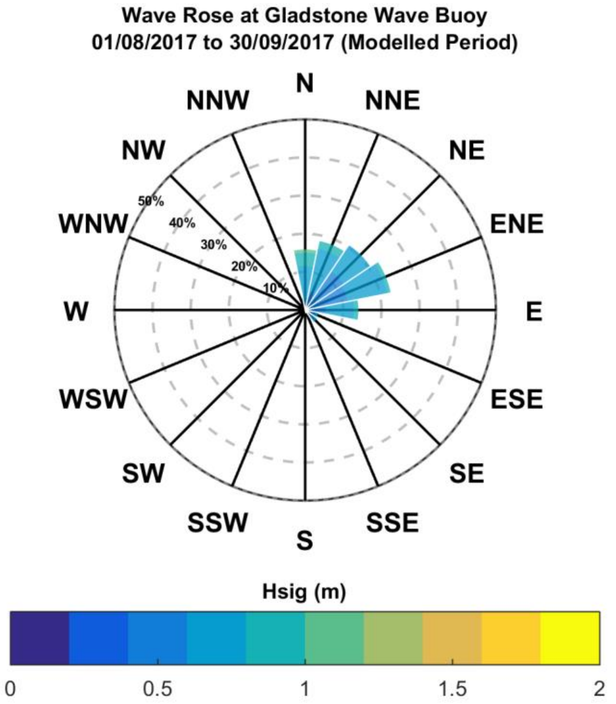


Figure 4-3 Assessment Period (Aug-Nov 2017) Wind Rose (Top) and Wave Rose (Bottom)
Wind Data: NCEP CFSRv2 Wave Source: SWAN Model

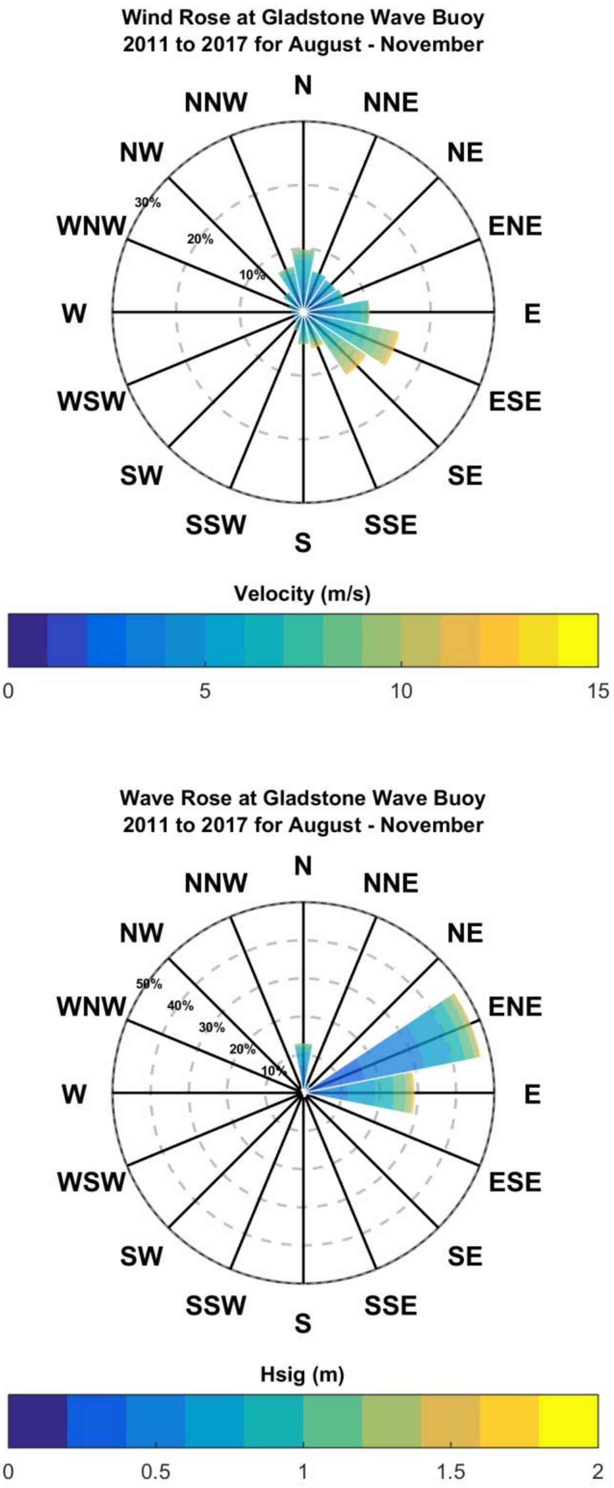


Figure 4-4 Long Term (2011-2017) Wind Rose (Top) and Wave Rose (Bottom)
Wind Data: NCEP CFSRv2 Wave Data: Gladstone Waverider Source: Qld Government

5 Hydrodynamic and Wave Model Validation

5.1 Water Levels

The TUFLOW FV model was run in 3D mode for the period 15 August 2014 to 1 November 2014 using a bathymetric configuration that matched the harbour geometry at that time. The harbour geometry and bathymetry has not changed significantly since that period and the model is therefore representative of existing conditions. The modelled and recorded water levels for part of the modelling period at the MSQ tide gauges at Auckland Point and South Trees are shown in Figure 5-2 and Figure 5-3 (for gauge locations, refer to Figure 5-1). Agreement between the modelled and measured water levels is generally very good. Where discrepancies exist they are likely due to the limitations of using global model hindcasts for the model boundary conditions rather than locally recorded data.

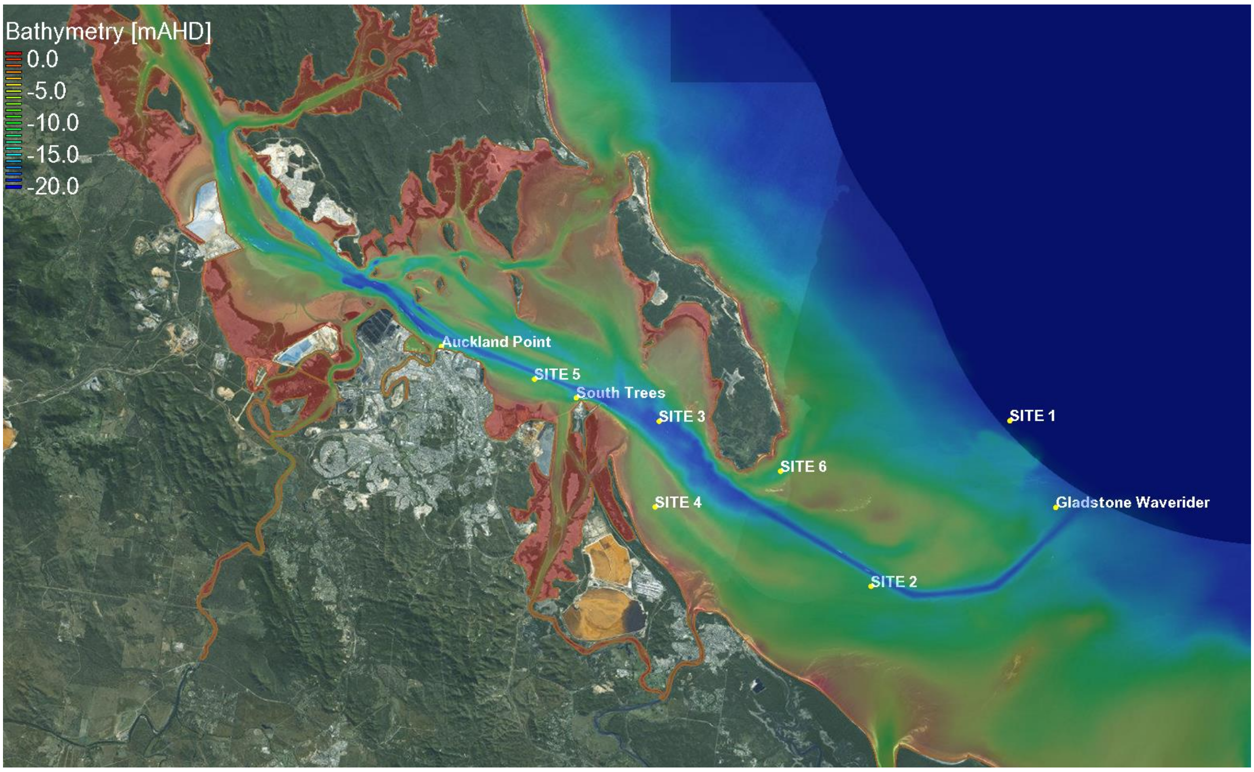


Figure 5-1 Water Level, Current and Wave Measurement Sites

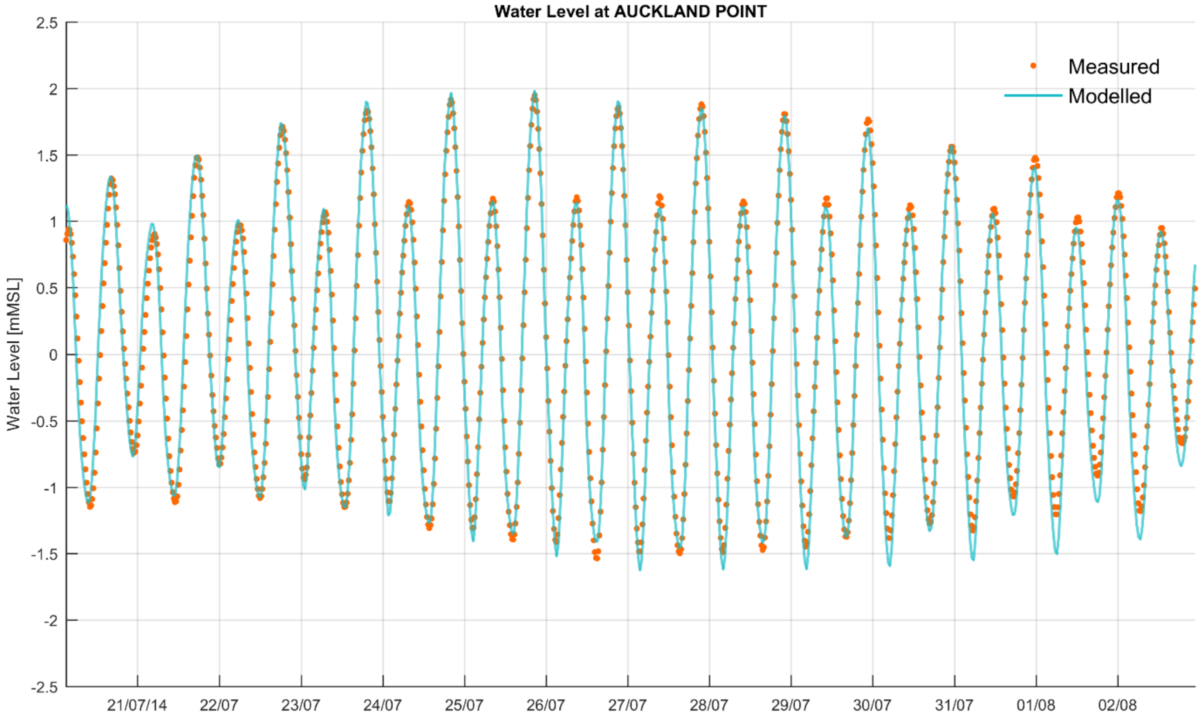


Figure 5-2 Modelled (Solid Line) and Measured (Dots) Water Levels at Auckland Point

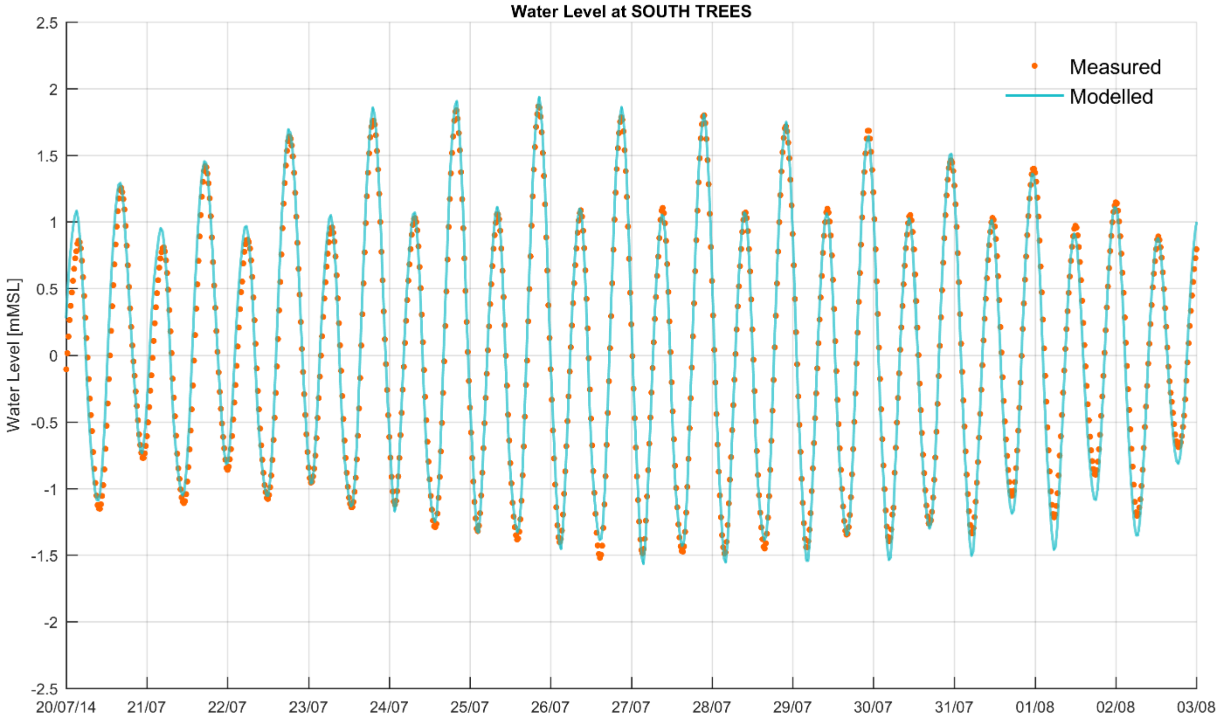


Figure 5-3 Modelled (Solid Line) and Measured (Dots) Water Levels at South Trees

5.2 Currents

Current data was collected using bottom-mounted Acoustic Doppler Velocity Profilers (ADCPs) at six locations within Gladstone Harbour (refer to Figure 5-1). The modelled depth-averaged current velocity during the calibration period is compared to the measured current data in Figure 5-4, Figure 5-5, Figure 5-6, Figure 5-7, Figure 5-8 and Figure 5-9. Overall, the current velocity is accurately reproduced by the TUFLOW FV hydrodynamic model. Where discrepancies exist, the errors may be due to inaccuracies in the applied boundary conditions, complex local bathymetric effects and/or large spatial gradients in the local water velocity.

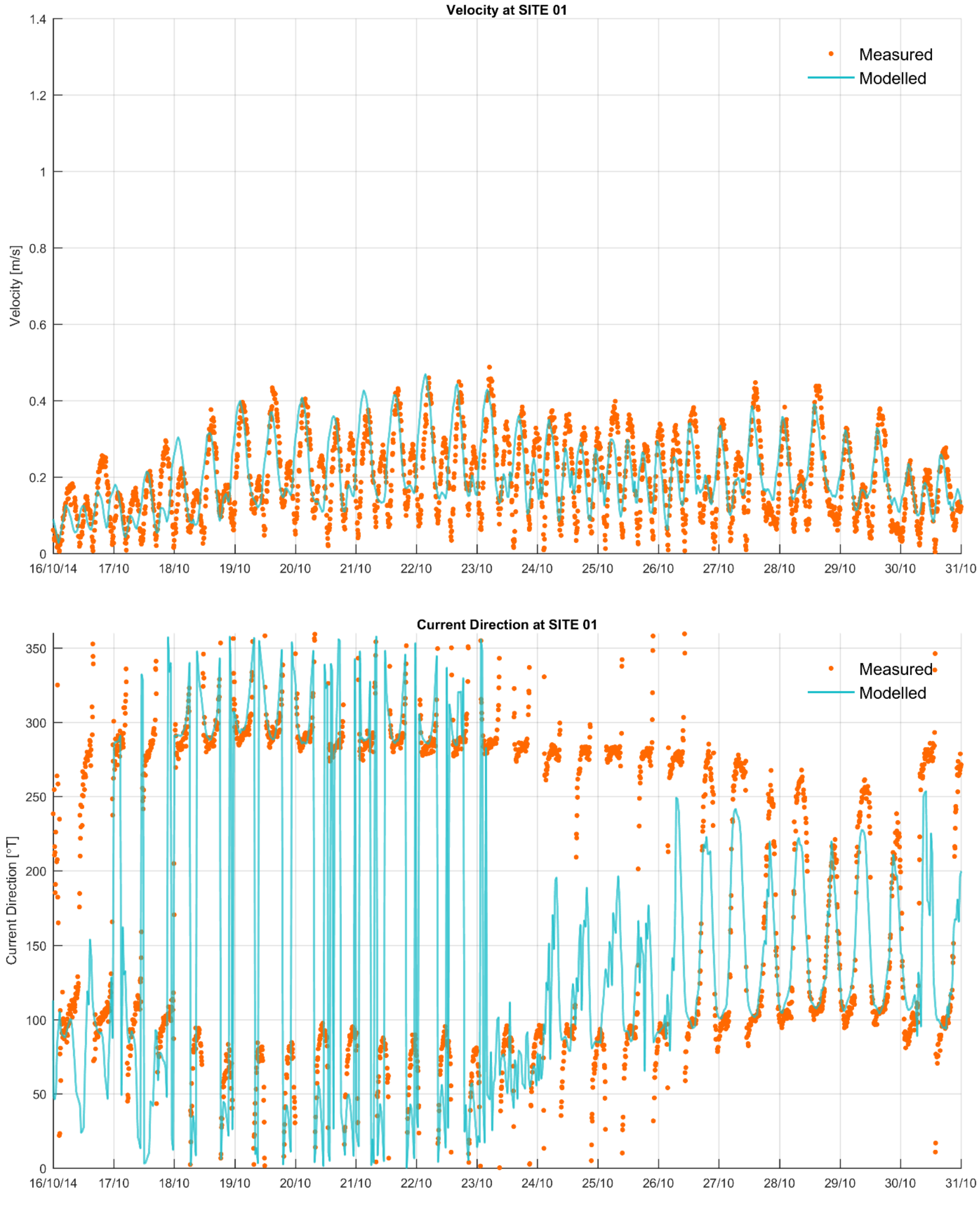


Figure 5-4 Modelled (Solid Line) and Measured (Dots) Depth-Averaged Current Velocity at Site 1

Figure 5-5 Modelled (Solid Line) and Measured (Dots) Depth-Averaged Current Velocity at Site 2

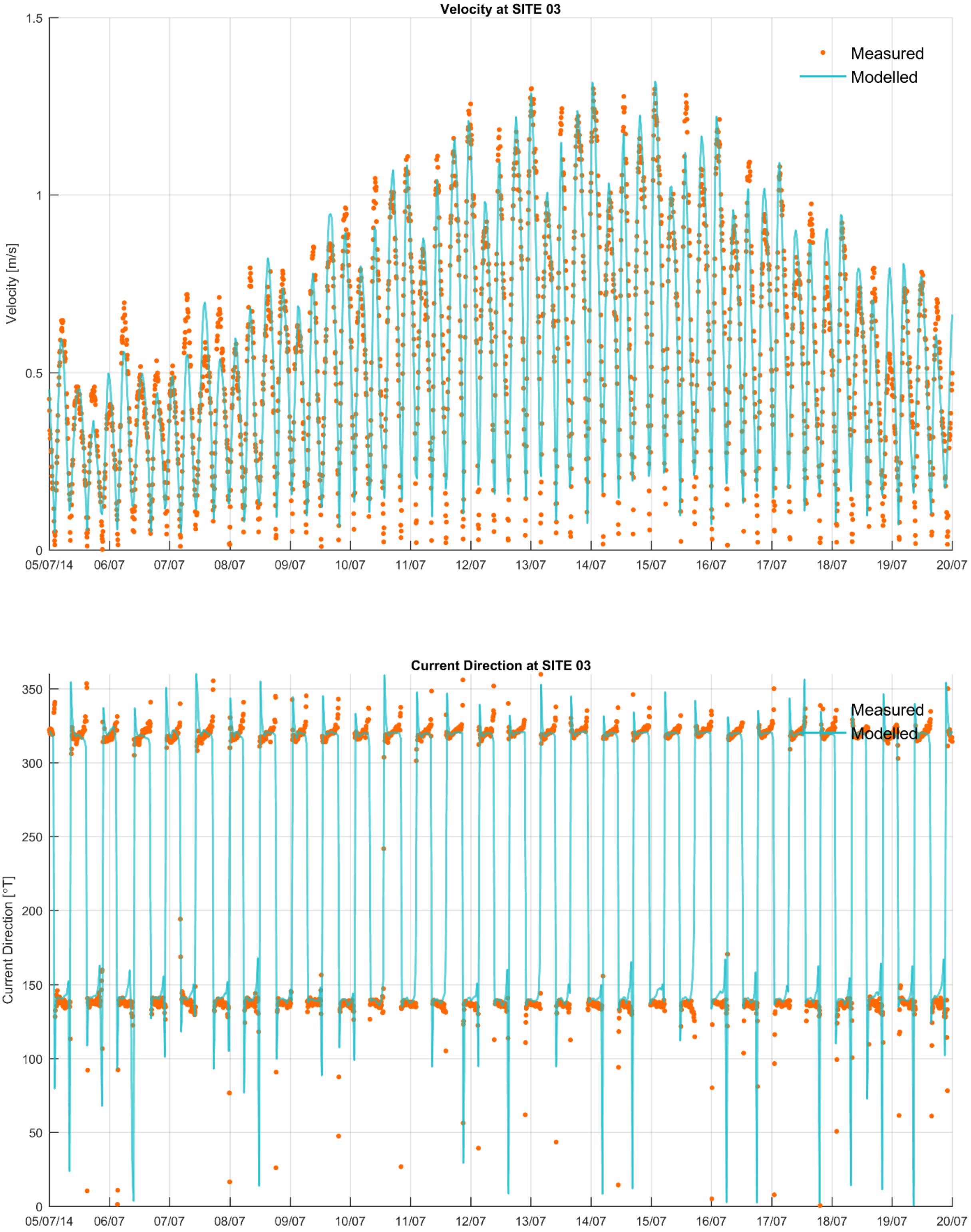


Figure 5-6 Modelled (Solid Line) and Measured (Dots) Depth-Averaged Current Velocity at Site 3

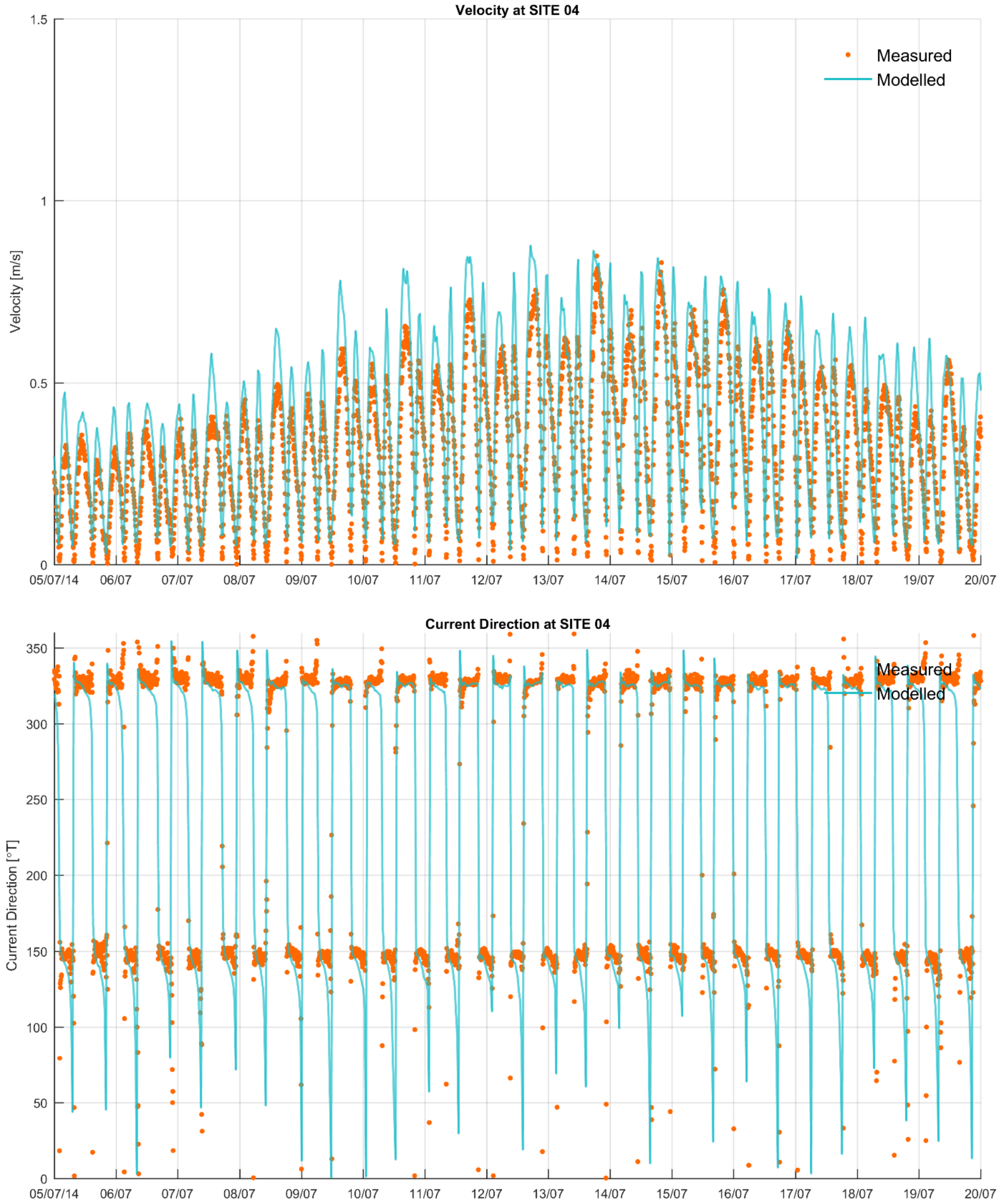


Figure 5-7 Modelled (Solid Line) and Measured (Dots) Depth-Averaged Current Velocity at Site 4

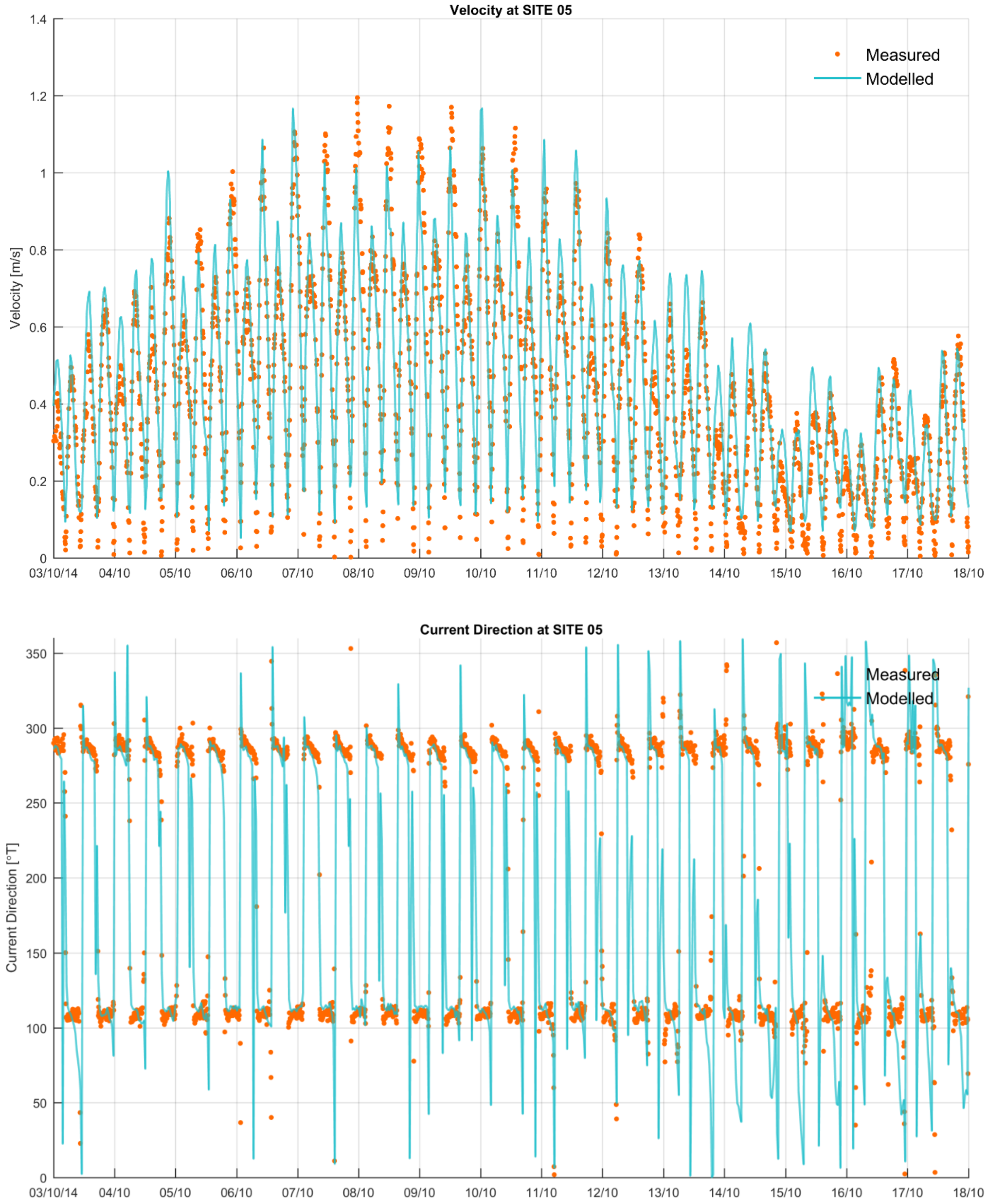


Figure 5-8 Modelled (Solid Line) and Measured (Dots) Depth-Averaged Current Velocity at Site 5

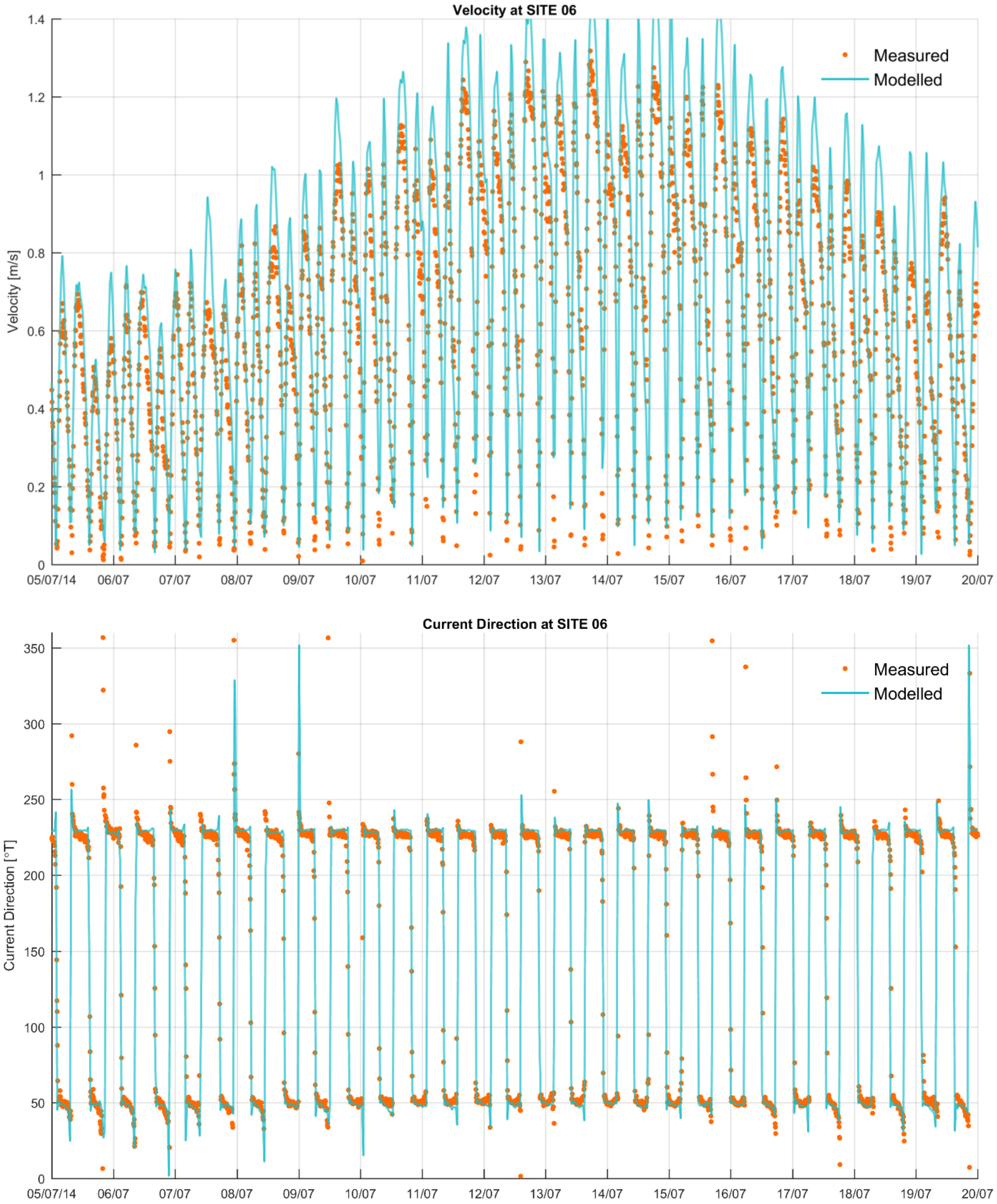


Figure 5-9 Modelled (Solid Line) and Measured (Dots) Depth-Averaged Current Velocity at Site 6

5.3 Waves

Wave data was collected at four locations within Gladstone Harbour using bottom mounted ADCPs (refer to Figure 5-1 for locations). The modelled wave conditions during the calibration period are compared to wave data in Figure 5-10, Figure 5-11, Figure 5-12 and Figure 5-13. Overall, the wave parameters are accurately reproduced by the SWAN wave model.

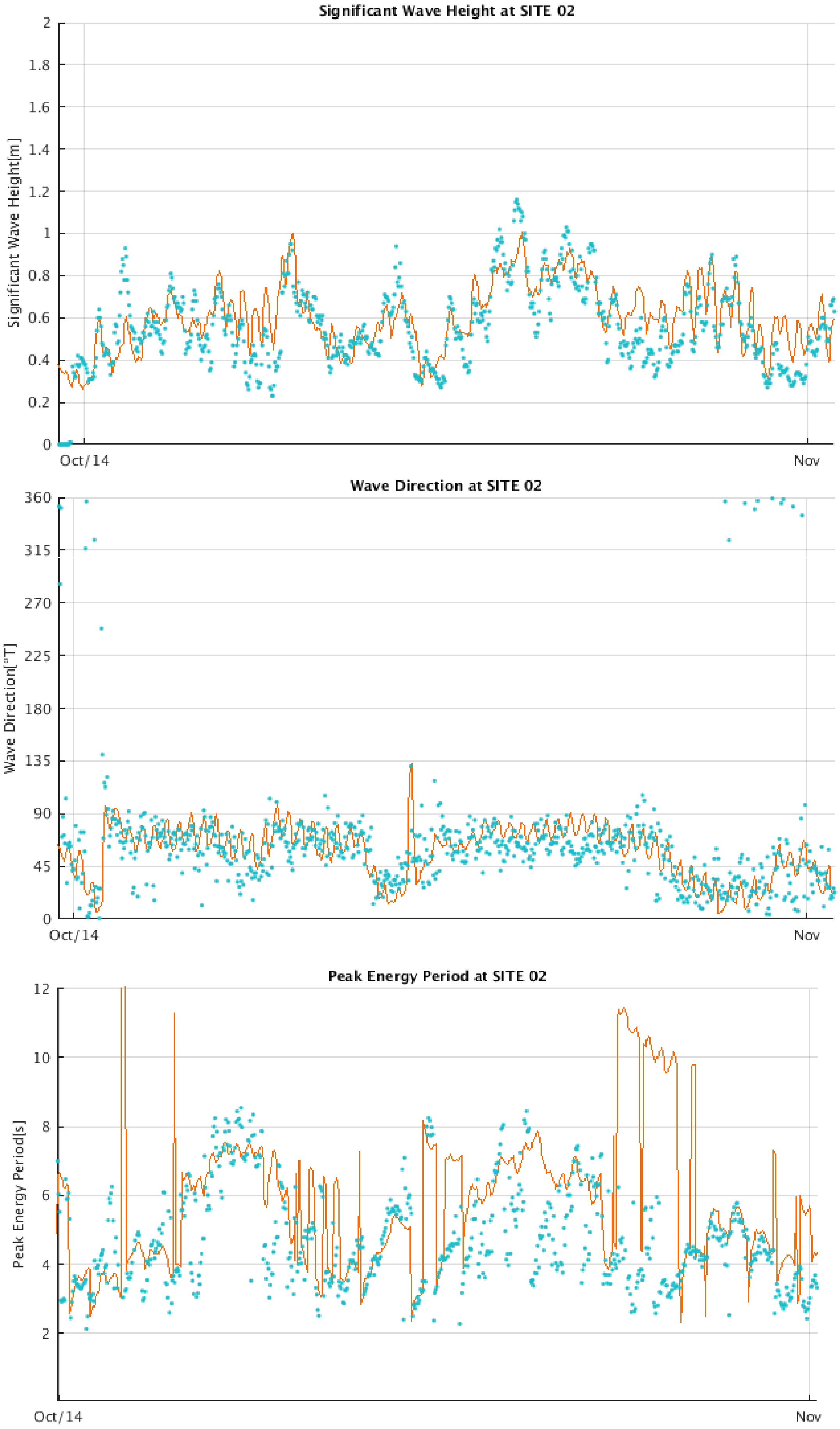


Figure 5-10 Modelled (Solid Line) and Measured (Dots) Wave Parameters at Site 2

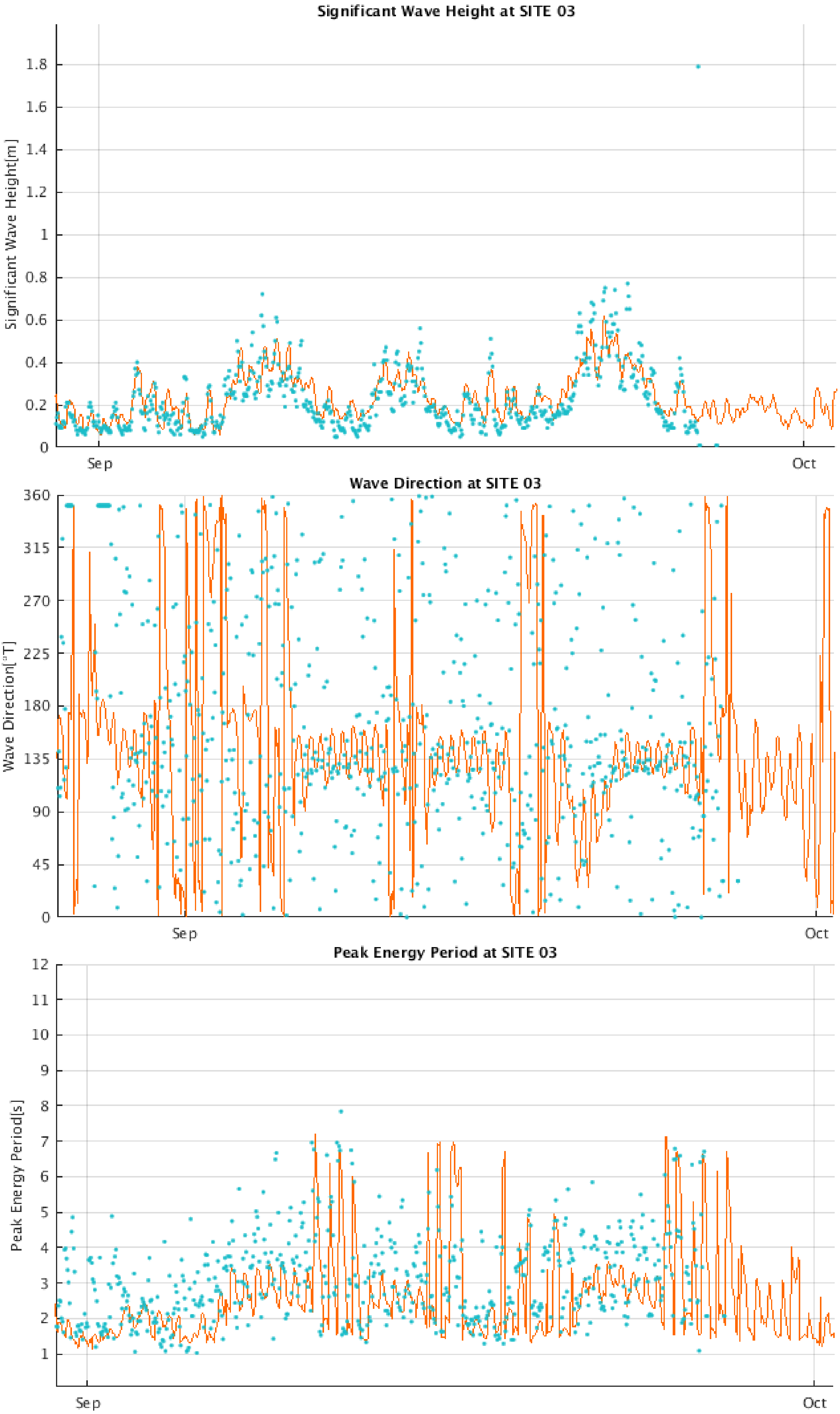


Figure 5-11 Modelled (Solid Line) and Measured (Dots) Wave Parameters at Site 3

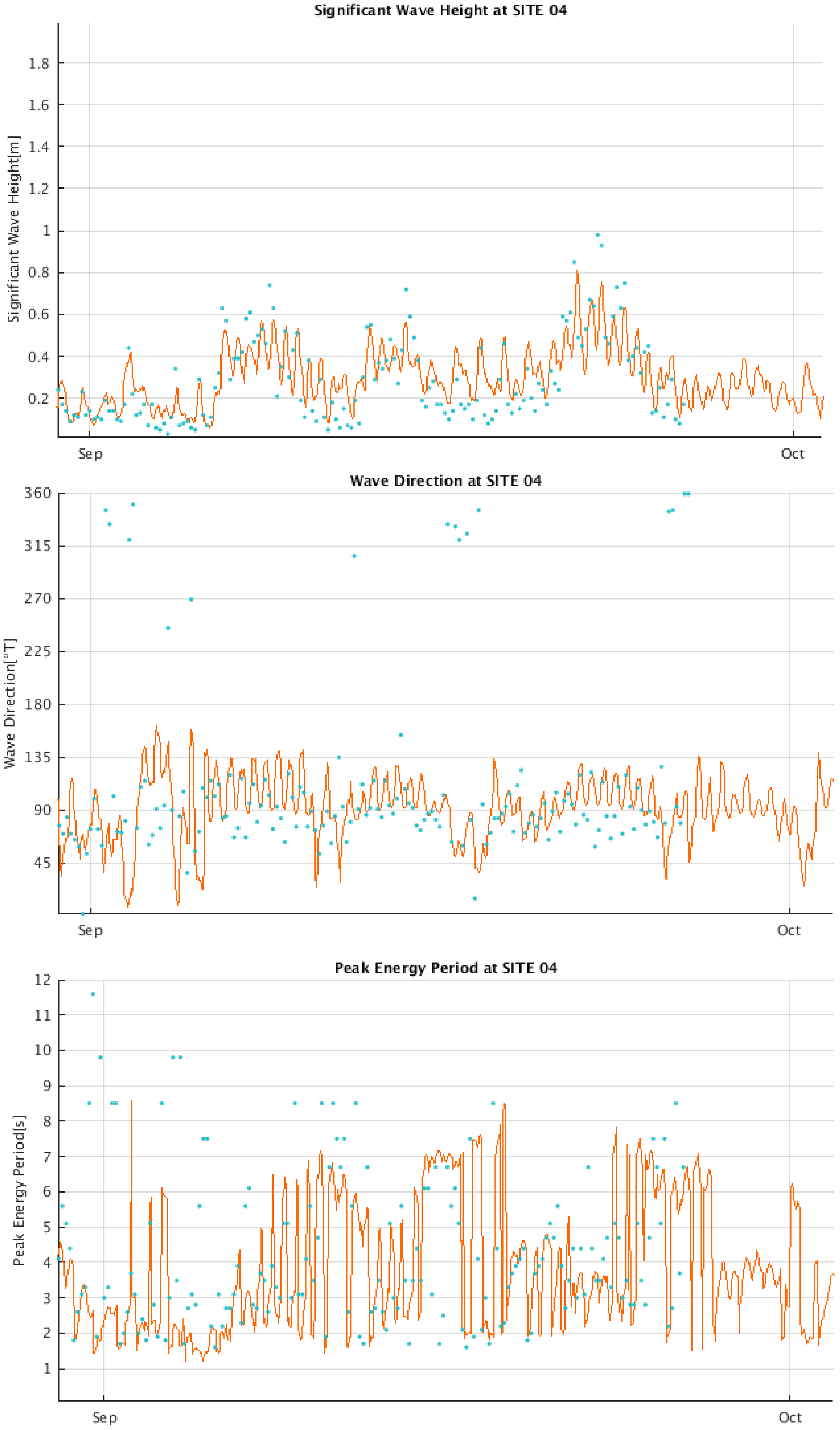


Figure 5-12 Modelled (Solid Line) and Measured (Dots) Wave Parameters at Site 4

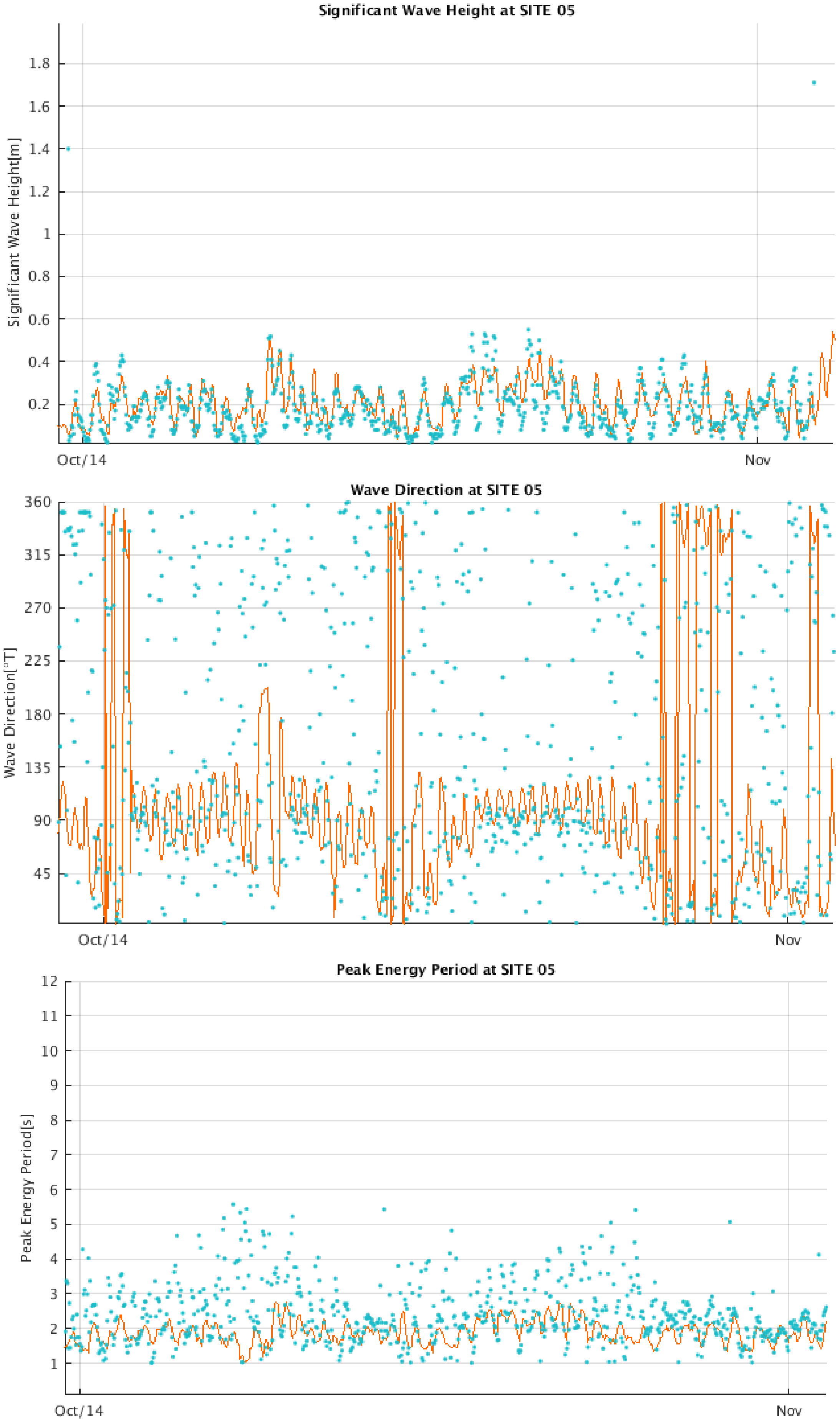


Figure 5-13 Modelled (Solid Line) and Measured (Dots) Wave Parameters at Site 5

6 Sediment Model Validation

6.1 Modelling Methodology

In order to accurately assess the potential impacts of dredging-related suspended sediment plumes it is important to include natural (ambient) sediments in the simulation. This allows for the mixing of dredged sediments and natural sediments within the model, and also allows an assessment of the relative significance of the dredging-related turbidity compared to the ambient turbidity.

The TUFLOW FV model was run for the period 1 June 2014 to 1 August 2014 in order to simulate the ambient sediment dynamics within Port Curtis and allow comparisons with measured turbidity data.

The sediment module of TUFLOW FV simulates the exchange of sediments between the bed and the water column. The clear water sediment settling velocity, w_s, is directly specified and is assumed to have no dependence on either suspended sediment concentration (e.g. flocculation or hindered settling). The modelled rate of sediment deposition is a function of the total suspended sediment concentration (TSS), the still-water fall velocity (w_s) and the combined wave-current bed shear stress (τ_b), according to the relationship:

$$Q_d = w_s . TSS . \max\left(0,\ 1 - \frac{\tau_b}{\tau_{cd}}\right) \quad \text{[g/s per m}^2\text{]}$$

where τ_{cd} is a model parameter defining the critical shear stress for deposition. As such, sediment settling is reduced below its still water value by the action of bed shear stress and associated vertical mixing in the water column. The rate of erosion is calculated according to:

$$Q_e = E . \max\left(0,\ \frac{\tau_b}{\tau_{ce}} - 1\right) \quad \text{[g/s per m}^2\text{]}$$

where Q_e is the erosion rate, E is an erosion rate constant and τ_{ce} is the critical bed shear stress for erosion. Three sediment types were modelled, with settling velocities shown in Table 6-1. Note that the adopted settling velocity for each type is essentially an arbitrary choice in this case, only roughly corresponding to the broad sediment classes of ‘fine sand’, ‘silt’ and ‘clay’.

Table 6-1 Settling Velocities for Each Sediment Type

Sediment Type	Settling Velocity (m/s)
Fine Sand	1 x 10^{-2}
Silt	1 x 10^{-3}
Clay	1 x 10^{-4}

Since the available data on the seabed sediment composition is very limited, the existing seabed distribution of fine sediment within Port Curtis was approximated in the model by running a “warmup” simulation. This simulation was run with an initial condition of a uniform thickness of sediment throughout the model (30% non-erodible sediments, 40% fine sand, 20% silt and 10% clay), allowing redistribution of the sediment to occur such that energetic parts of the model (e.g. the main channels) had sediment removed from the bed while sediment accumulated in other parts of the model (e.g. mud flats). Use of a model that was not “warmed up” would result in re-suspension predictions that are incorrectly dominated by erosion from zones that are unlikely to harbour mobile fine sediments. Bed morphology changes were not included in the “warmup” simulations (i.e. bed levels remained fixed in the model).

Comparison of the measured and modelled turbidity from a series of calibration runs (varying the erosion rate and the critical shear stress thresholds) led to the choice of the following parameters:

τ_{ce} = 0.2 N/m^2 τ_{cd} = 0.18 N/m^2 E = 1 g/m^2/s

The adopted parameter sets are well within the accepted literature ranges. A turbidity to TSS relationship of 1 Nephelometric Turbidity Unit (NTU) = 1.6 mg/L has been used based on analysis of data collected during the Western Basin Dredging and Disposal Project (refer Figure 6-1).

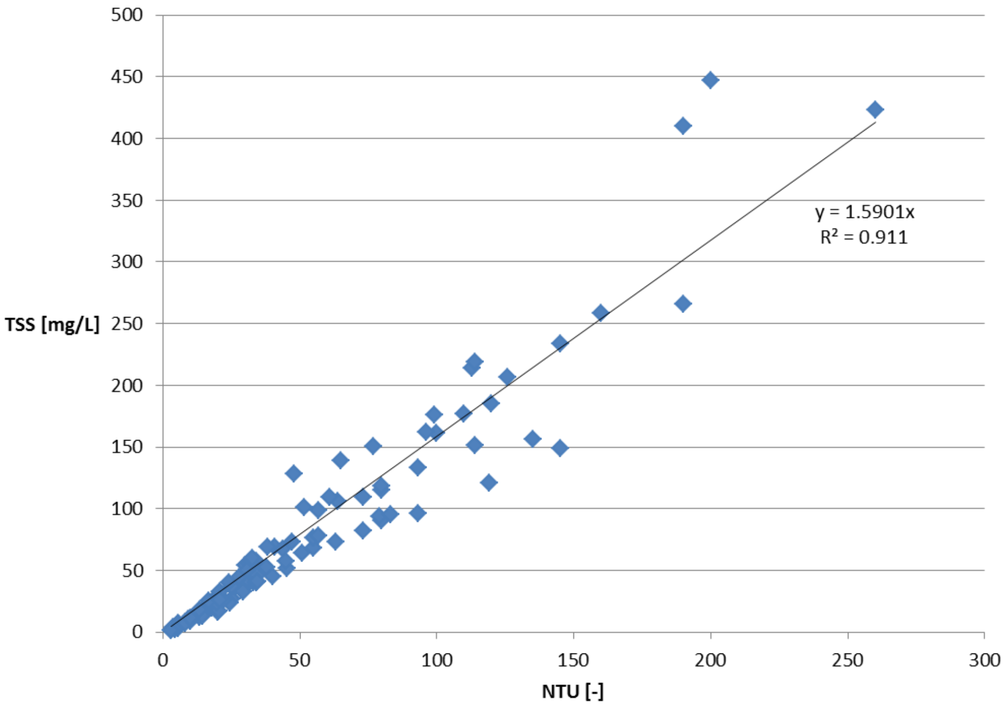


Figure 6-1 TSS–NTU Relationship from the Western Basin Dredging and Disposal Project Samples n = 139

6.2 Ambient Suspended Sediment Model Validation

Figure 6-3 to Figure 6-10 show comparisons between the measured and modelled Turbidity at the locations shown in Figure 6-2. The model reproduces the natural suspended sediment dynamics reasonably well within the Port, capturing both the diurnal variation and the spring-neap tidal cycle variation. Note that although the model does tend to overestimate the turbidity level at some locations at certain times and underestimate the turbidity level at other locations and times, the ambient sediment dynamics are only included in the modelling to provide some context for the reporting of the dredging plume impacts and to improve the accuracy of resuspension modelling. The ambient turbidity model outputs are not relied upon for the setting of impact thresholds or for the calculation of impact/influence zones.

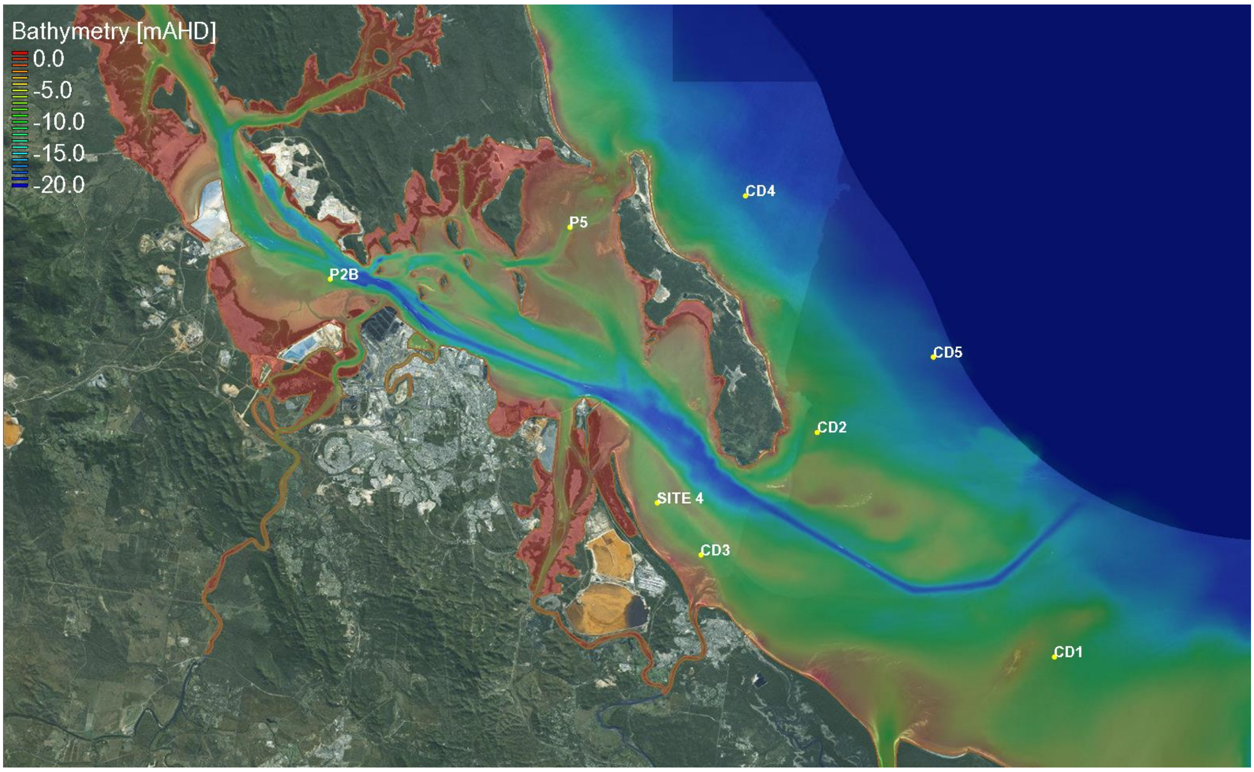


Figure 6-2 Location of Recorded Ambient Turbidity Data

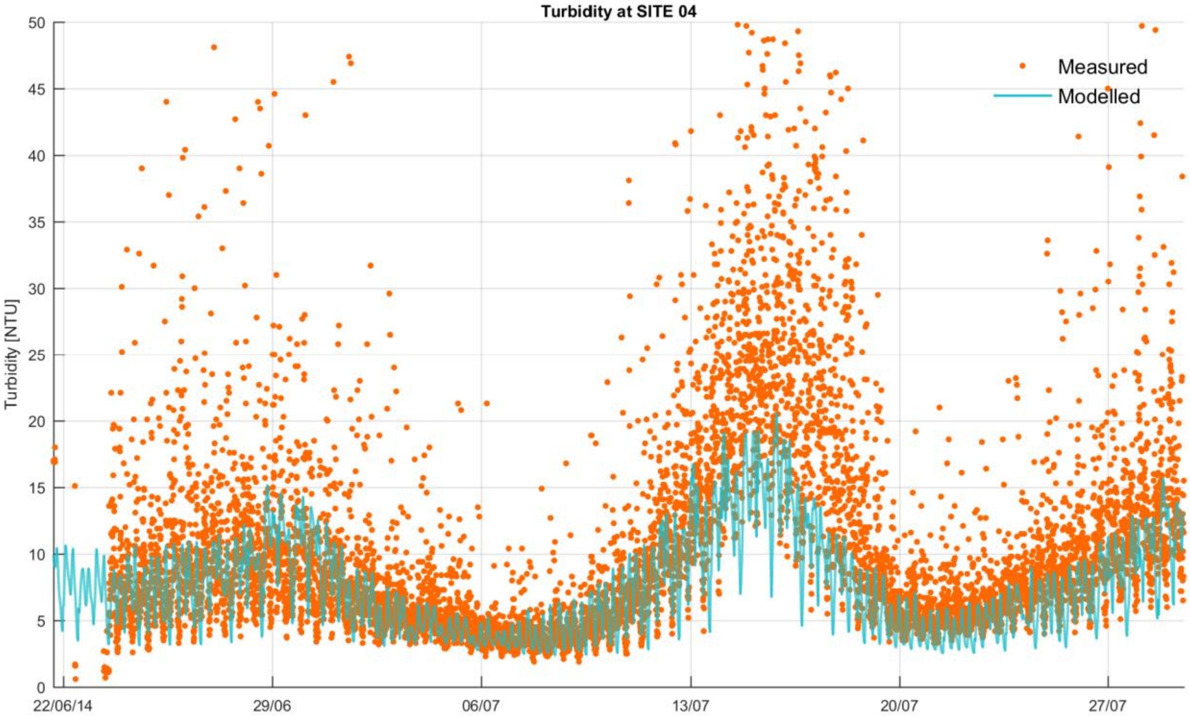
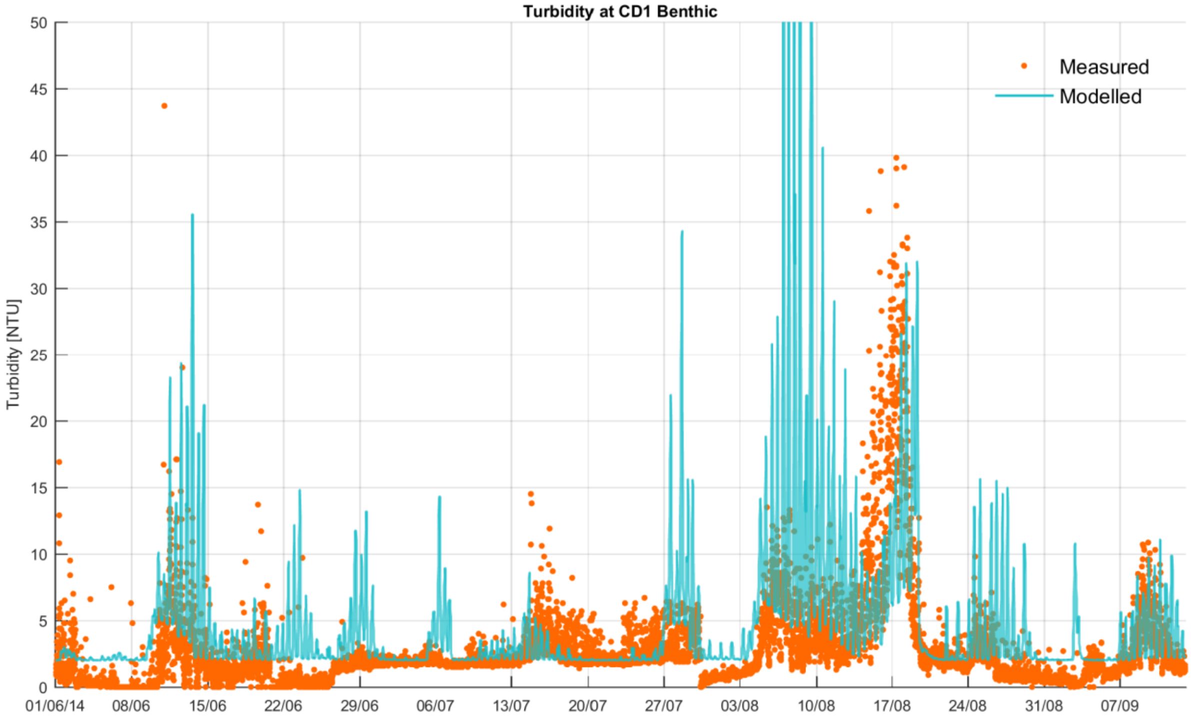


Figure 6-3 Measured Turbidity (Dots) and Modelled Turbidity (Solid Lines) at the bed for Site 04



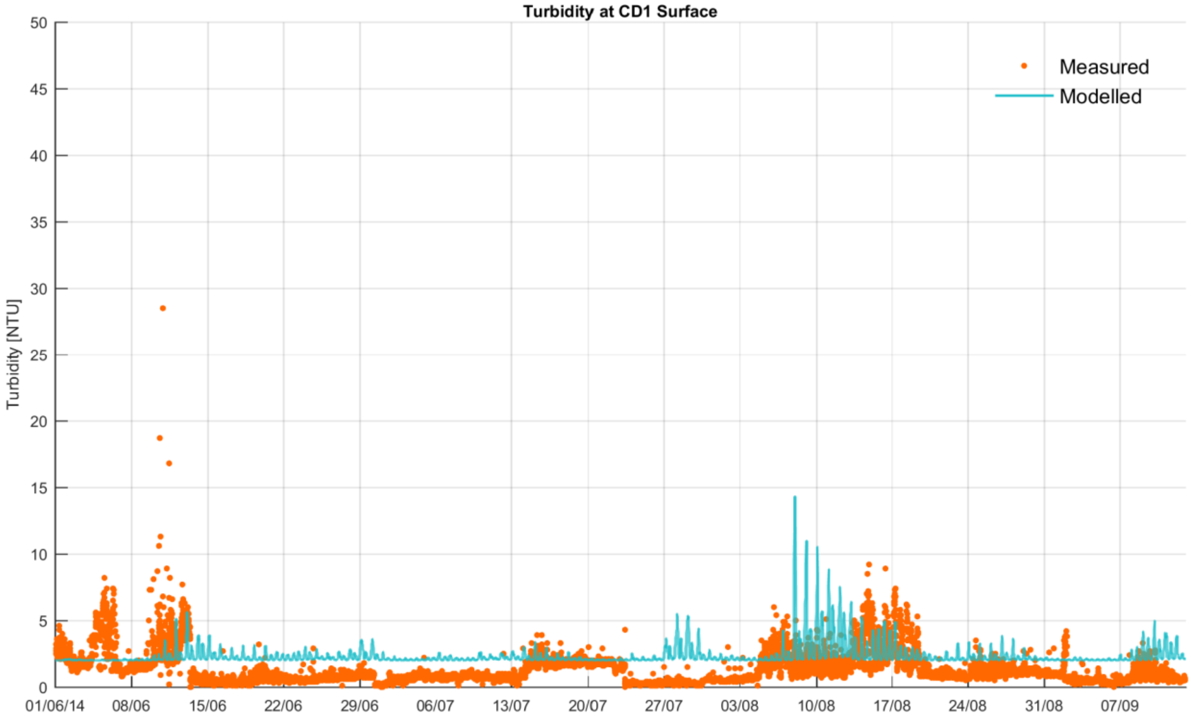


Figure 6-4 Measured Turbidity (Dots) and Modelled Turbidity (Solid Lines) at the bed (top) and surface (bottom) for site CD1

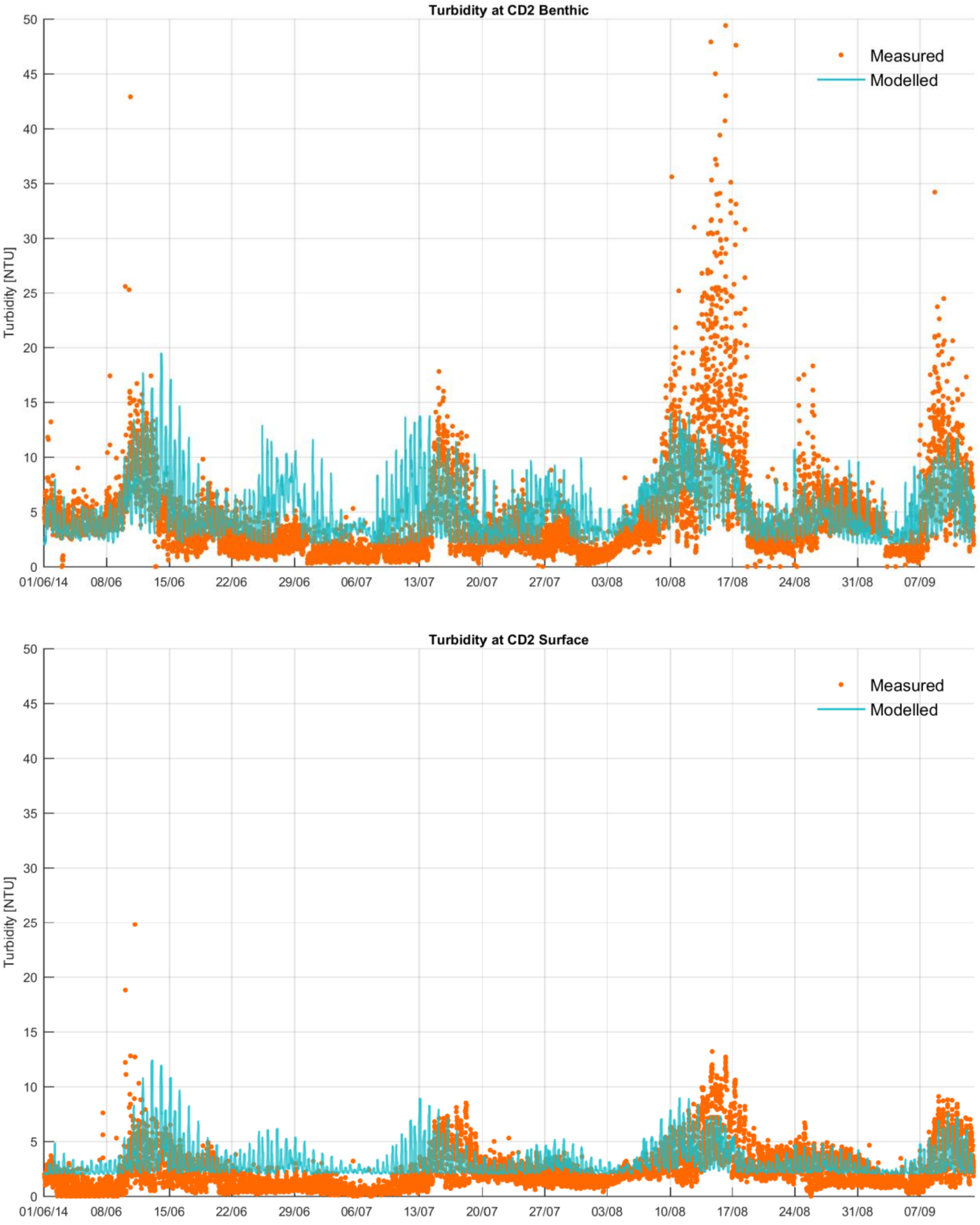


Figure 6-5 Measured Turbidity (Dots) and Modelled Turbidity (Solid Lines) at the bed (top) and surface (bottom) for site CD2

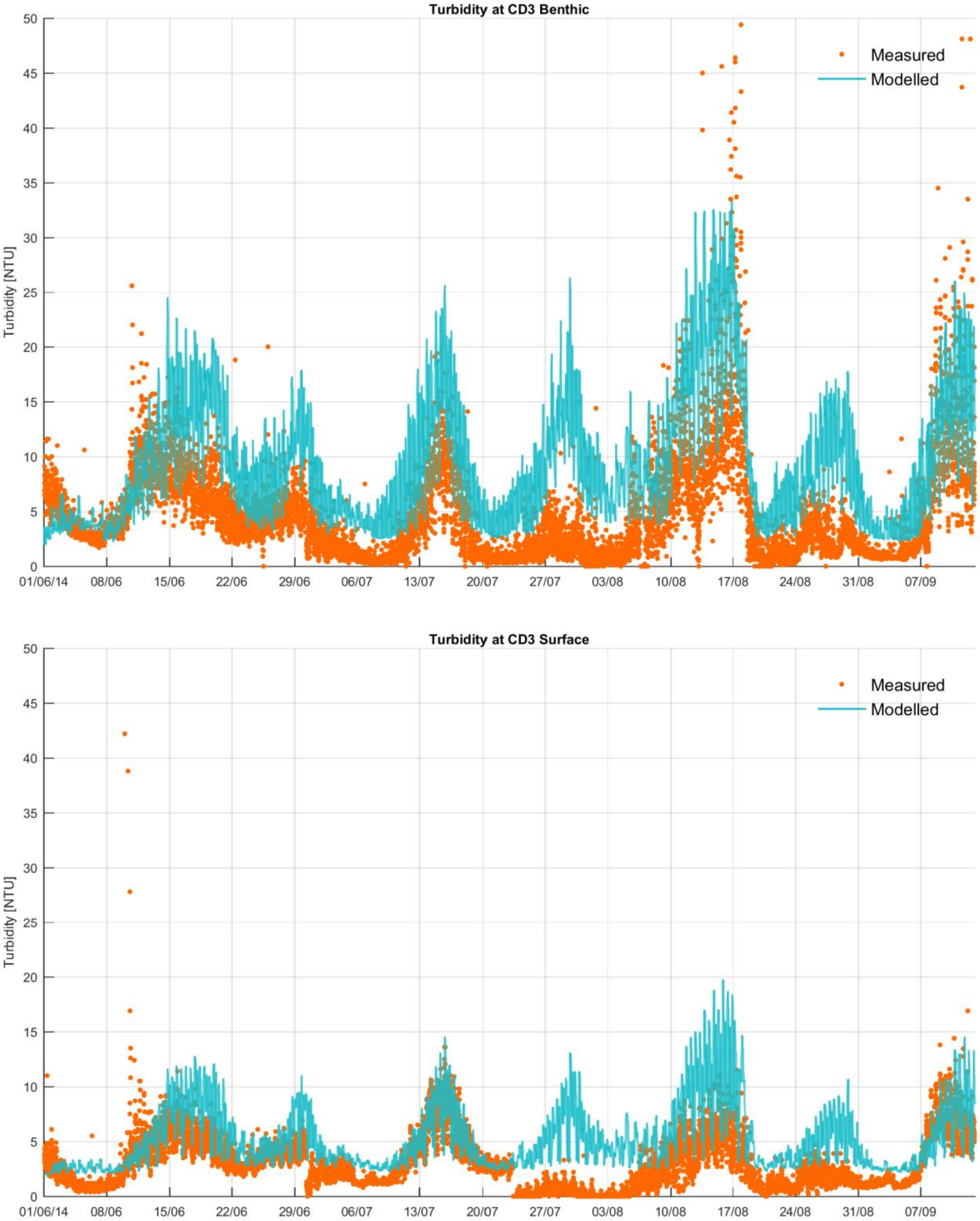


Figure 6-6 Measured Turbidity (Dots) and Modelled Turbidity (Solid Lines) at the bed (top) and surface (bottom) for site CD3

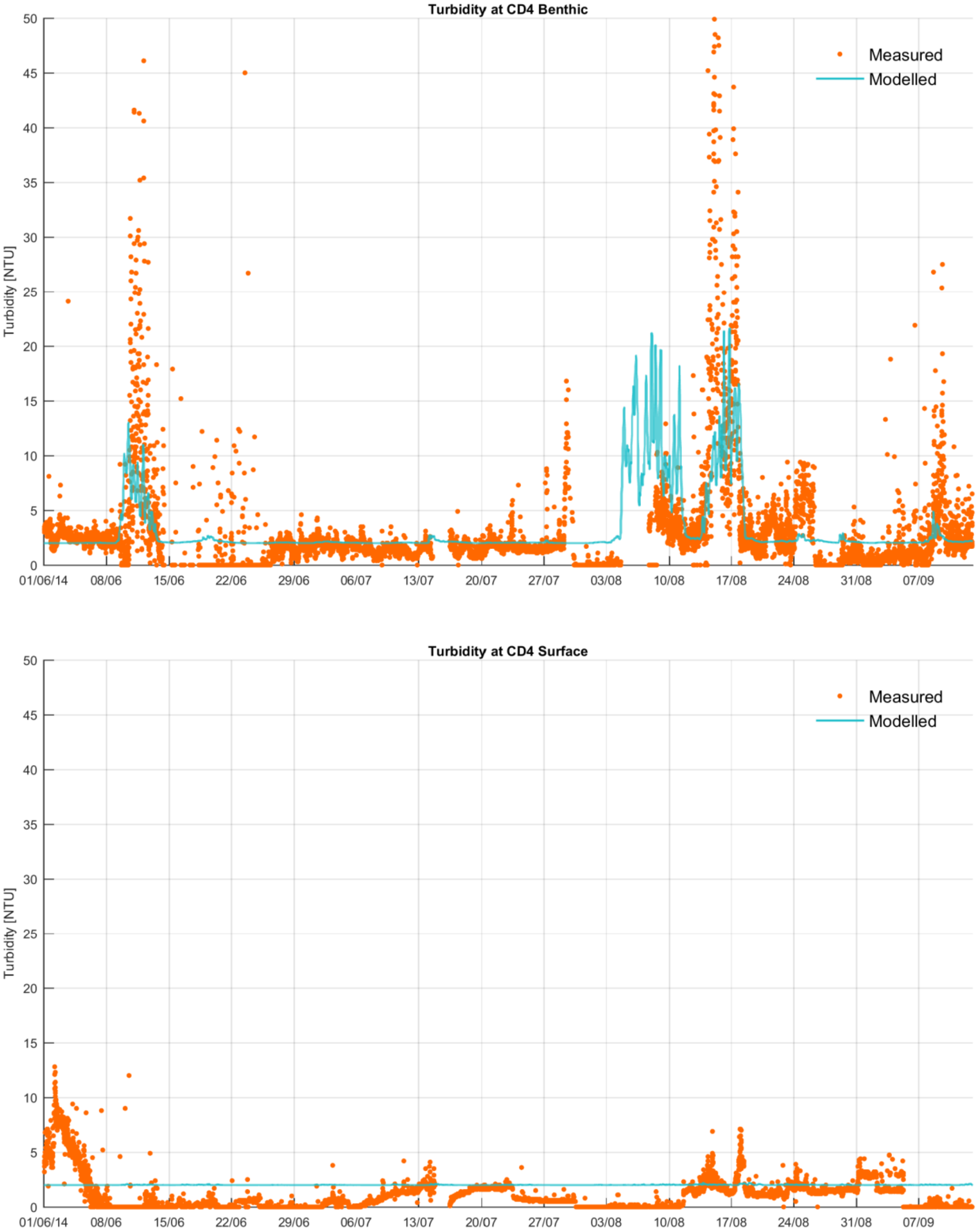


Figure 6-7 Measured Turbidity (Dots) and Modelled Turbidity (Solid Lines) at the bed (top) and surface (bottom) for site CD4

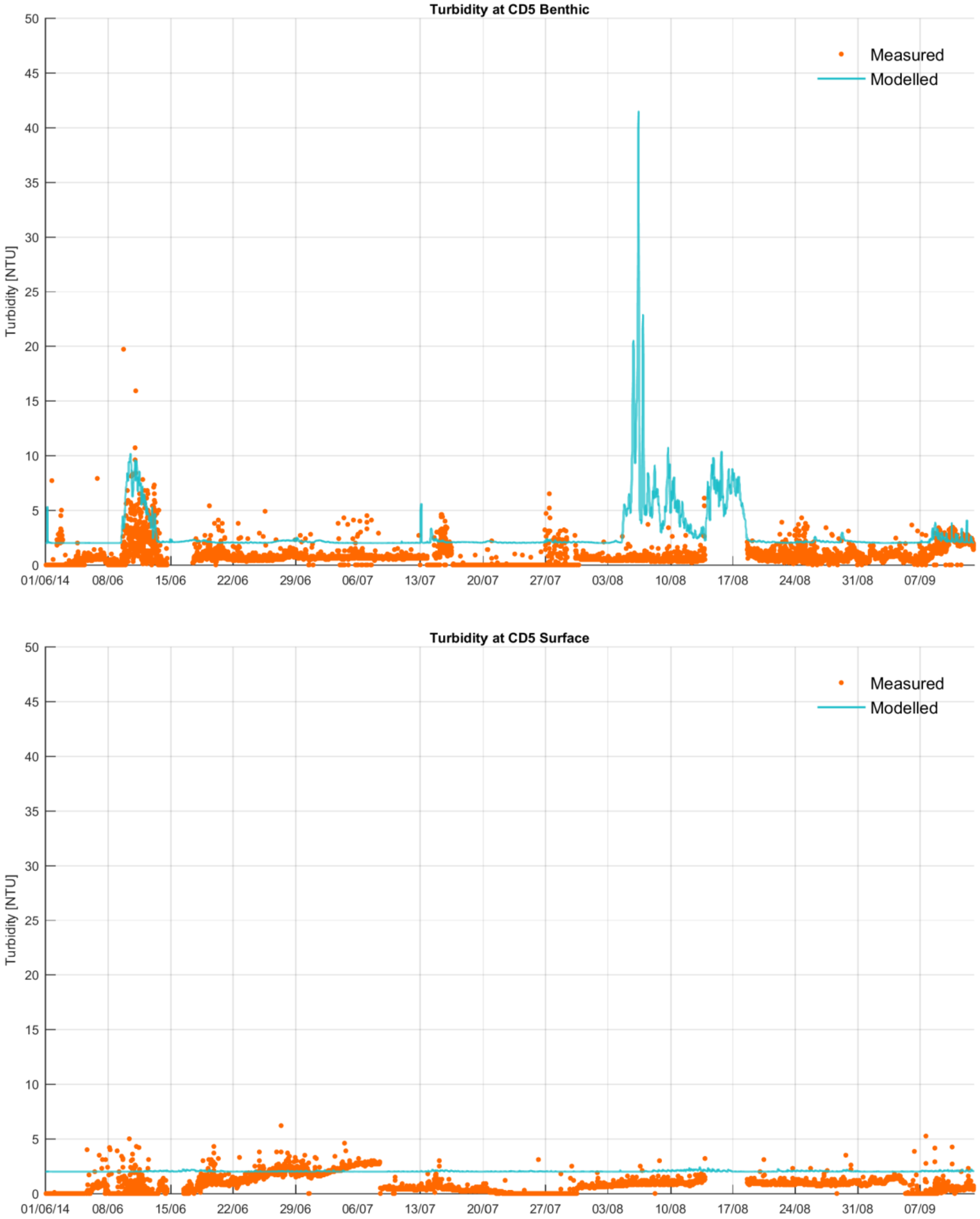


Figure 6-8 Measured Turbidity (Dots) and Modelled Turbidity (Solid Lines) at the bed (top) and surface (bottom) for site CD5

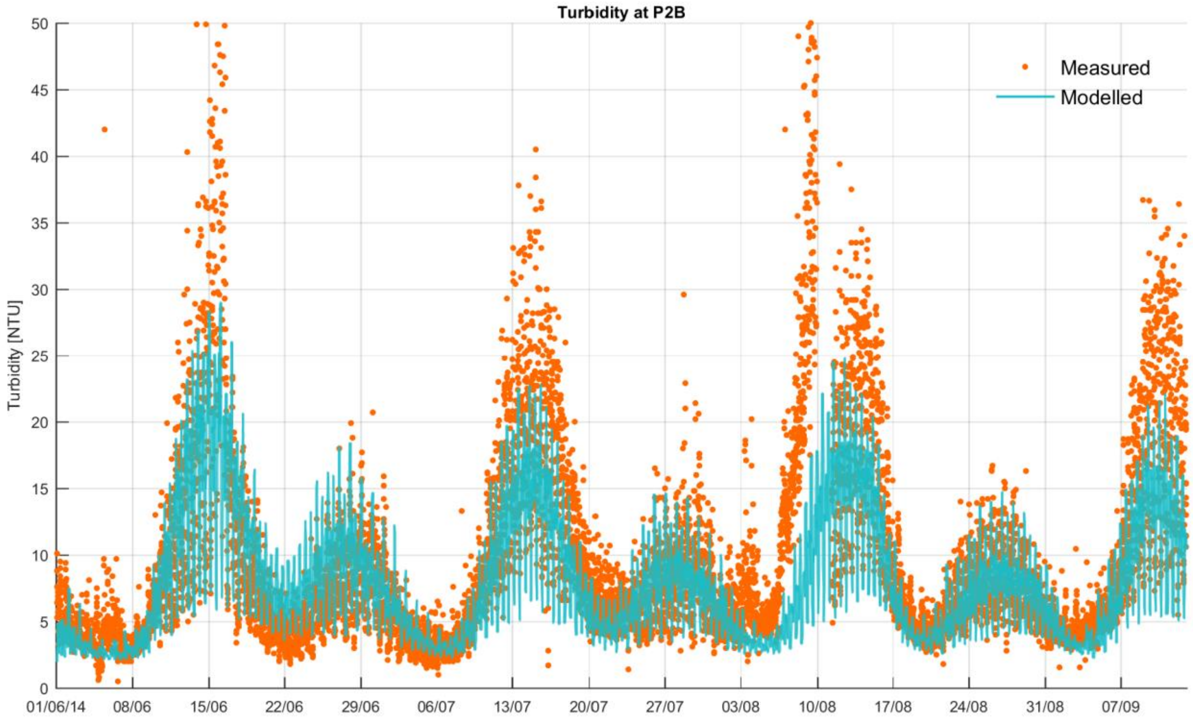


Figure 6-9 Measured Turbidity (Dots) and Modelled Turbidity (Solid Lines) at the bed for site P2B

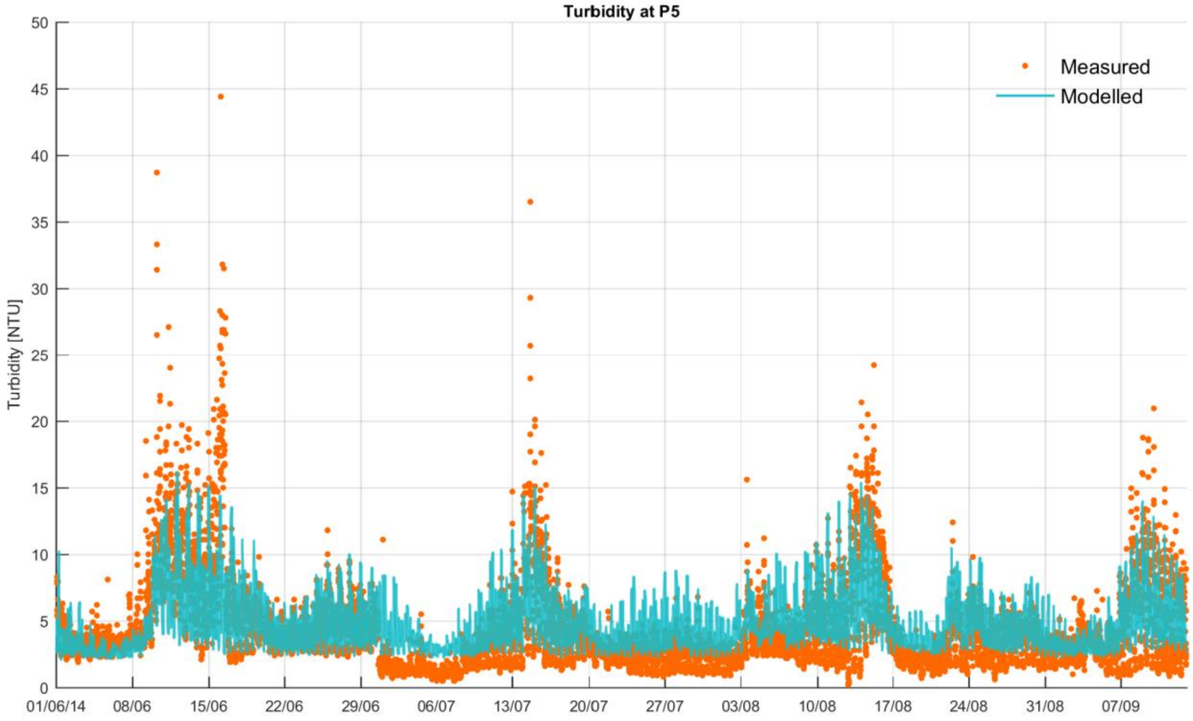


Figure 6-10 Measured Turbidity (Dots) and Modelled Turbidity (Solid Lines) at the bed for site P5

7 Dredging Plume Source Validation

BMT WBM carried out extensive measurements of dredging plume intensity during the 2017 maintenance dredging campaign at the Port of Gladstone to further refine and validate the assumed plume source rates that are used in the maintenance dredging impacts assessment process.

7.1 Dredge Plume Measurements

7.1.1 Field and Laboratory Methods

Field measurements of plume TSS concentrations were conducted from the small research vessel *Harry John* operating in the vicinity of the dredge operations. During the dredge plume monitoring, BMT WBM communicated and co-ordinated measurement and sampling activities with the dredging plant *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 to be used in the calibration of the turbidity probe and in assessments of the dredge plumes. Selected samples were also analysed for Particle Size Distribution (PSD) and nutrient concentrations (Table 7-1).
- Turbidity profiling, using a Campbell Scientific 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 1200kHz Teledyne RDI ADCP to record the acoustic backscatter, providing an insight into the otherwise hidden plume characteristics across the various transects; and

Deployment of a drogue into the plume to assist with the ADCP transects and turbidity profiling, thus ensuring that measurements were collected from where the concentrations of suspended sediments were highest.

Table 7-1 Sampling site details - nutrients

Location	Sample timing	Date/Time	Tide stage
DMPA	Background	27/09/2017 11:15	Rising
	Plume during disposal	27/09/2017 12:31	Rising
	Plume after hour following disposal	27/09/2017 13:18	High Tide
WICT	Background	28/09/2017 08:45	Low Tide
	Plume at start of over-flow	28/09/2017 10:02	Rising
	Plume at end of over-flow	28/09/2017 10:42	Rising
GLNG*	Plume at start of over-flow	28/09/2017 11:28	Rising
	Plume at end of over-flow	28/09/2017 13:20	Rising
	Plume 1 hr post dredging	28/09/2017 14:18	Rising
	Plume 1.5 hr post dredging	28/09/2017 14:46	Rising

*note no background measurement collected

Water samples were analysed by ALS Pty Ltd for the parameters shown in Table 7-2.

Table 7-2 Laboratory analytes and limits of reporting

Analyte grouping/Analyte	Unit	Limit of reporting
EA025: Total Suspended Solids dried at 104 ± 2°C	mg/L	5
EK255A: Ammonia as N	mg/L	0.005
EK257A: Nitrite as N	mg/L	0.002
EK258A: Nitrate as N	mg/L	0.002
EK259A: Nitrite and Nitrate (NOx) as N	mg/L	0.002
EK260A: Organic Nitrogen as N	mg/L	0.01
EK261A: Total Kjeldahl Nitrogen as N	mg/L	0.01
EK262A: Total Nitrogen as N	mg/L	0.01
EK267A: Total Phosphorus (Persulfate Digestion) as P	mg/L	0.005
EK271A: Reactive Phosphorus as P	mg/L	0.001
EP008: Chlorophyll *a*	mg/m^3	1

7.1.2 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.

Water samples were sent to the laboratories of Advanced Analytical Australia for analysis of the TSS and PSD.

7.1.3 Calibration

A relationship between turbidity and TSS was empirically derived using linear regression in Microsoft Excel. The calibration of backscatter to TSS was performed using the VISEA calibration module. Sufficient data were available to perform both site and day specific calibrations. The calibration parameters were consistent between the various monitoring efforts with no prevalent time, depth or concentration biases. The calibrations are 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.

7.2 Presentation of Results

7.2.1 ADCP Data

Figure 7-1 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 lower component is a profile-view of the ADCP transect which depicts the TSS concentrations along the transect and through the water column. The upper component depicts the depth averaged plume concentrations in plan-view along the transect.

The coloured circles in the lower component of Figure 7-1 depict the OBS profile performed on 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. Transects which were performed in an East to West direction have been reversed so the lower plan view plot links more intuitively with the upper profile view plot. In these transects the OBS profiles, plotted depth against chainage, will slope in the opposite direction to those conducted during transects extending from West to East. OBS profiles were not performed for every transect.

The red ‘x’ plotted in the upper component of Figure 7-1 identifies the start of the ADCP transect which extends from left to right in the lower profile-view component of the plot. The timing of the measurement within the tidal cycle is depicted in the upper left hand corner of the plot.

The operations of the TSHD *Brisbane* are represented by small coloured squares in the upper component of Figure 7-1. 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 60 minutes. In Figure 7-1, whilst the ADCP transect was conducted, the *Brisbane* was dredging with overflow (magenta squares). Since transects were often performed more than 60 minutes past the time at which the dredger created the plume, not all plots have the coloured squares.

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 concentrations below a depth of approximately 1.5 m. The ADCP was also unable to estimate the TSS within approximately 1 m from the bed.

Background concentrations have not been removed from the data. Several of the data sets include a transect conducted before the dredge commenced operations and hence depict the background concentrations at that time. Where possible, the transects extend beyond the extents of the dredge plume and hence can be used to quantify the background concentrations at the time of the transect.

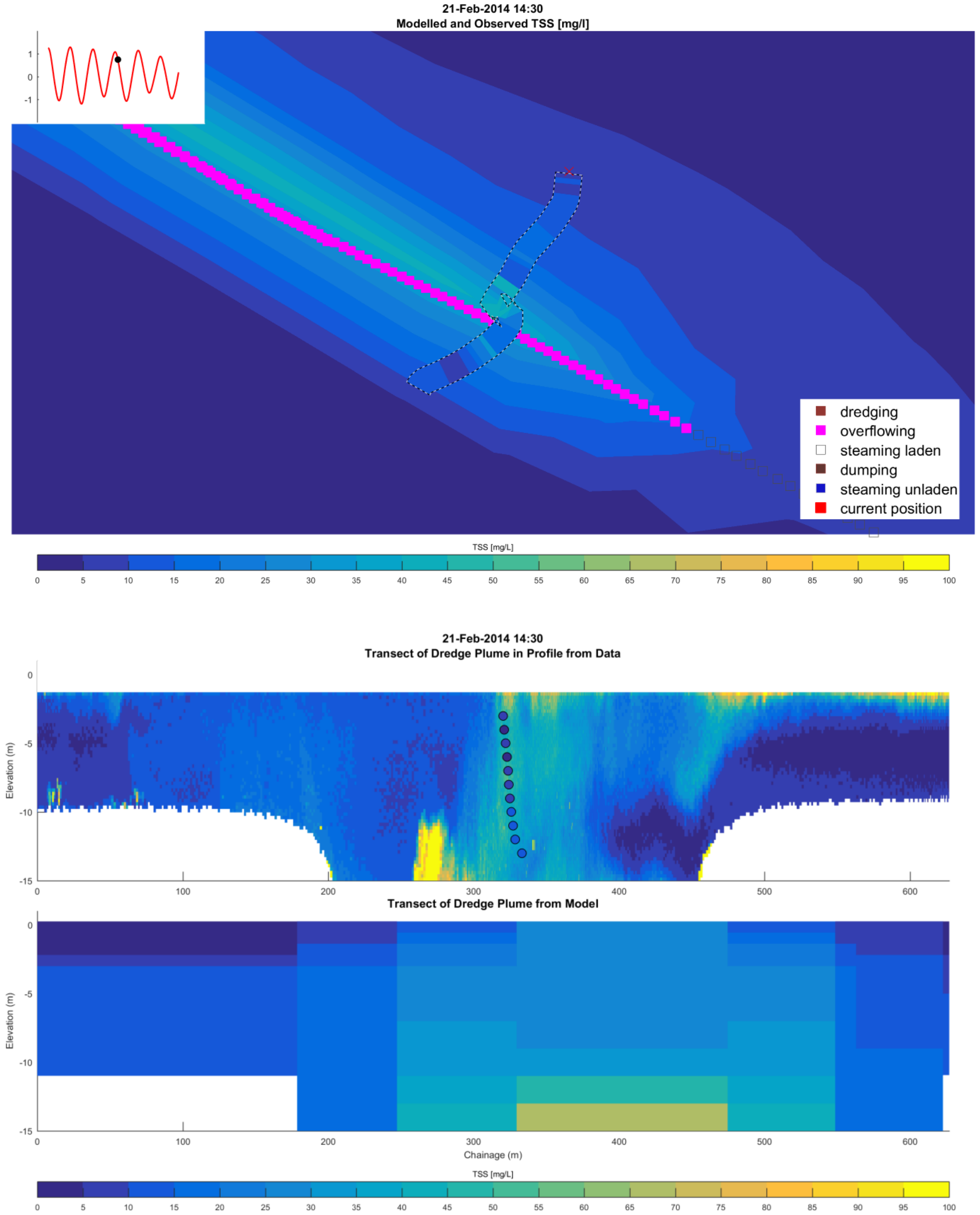


Figure 7-1 Example Figure

7.2.2 Potential Interferences

ADCP measurements of suspended sediment concentrations can occasionally be compromised by air bubbles generated by the dredger, other vessel traffic and waves. Fish and plankton will also interfere with the ADCP measurements. Air bubbles and fish 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. The OBS instrument is far less susceptible to such interference.

7.3 Dredging Parcel Characteristics and Plume Source Rate Assumptions

The modelled dredging plume source rates were estimated based on the likely particle size distribution of sediment in each dredging parcel as indicated by sampling results presented in the 2014 maintenance dredging assessment (BMT WBM, 2014). In addition, historical dredge logs were analysed to determine a realistic dredging operation patterns in each parcel (including the cycle time and the amount of time spent overflowing). The estimated plume source rates were then validated by comparing the modelled plume concentrations with the measured plume concentrations from the ADCP transect data. The objective of this process was to more accurately characterise the likely plume source rates for maintenance dredging in different parts of Gladstone Harbour.

7.3.1 Sediment Parameters

A representative particle size distribution for each dredging parcel was determined based on the sampling results presented in the 2014 maintenance dredging assessment (BMT WBM, 2014). Limits were applied for the fine-grain material concentration used in the model. A lower limit of 40% fines was used to provide conservative estimates of the sediment composition in the sandier regions such as Gatcombe and Wild Cutting Channel. An upper limit of 60% fines was also applied, in order to avoid overestimation of plume intensity in areas with a higher fines content. This value was determined by a calibration process using the measurements of plume characteristics in the Jacobs Channel area. Sediment parameters (both measured and modelled) are summarised in Table 3.

Table 3 Sediment Distribution by Channel Sub-Areas

Location	Sediment Composition			Modelled Composition		
	Sand	Silt	Clay	Sand	Silt	Clay
WILD CATTLE CUTTING	88%	8%	4%	60%	27%	13%
BOYNE CUTTING	76%	16%	8%	60%	27%	13%
GOLDING CHANNEL	81%	13%	6%	60%	27%	13%
GATCOMBE CHANNEL	97%	2%	1%	60%	27%	13%
SOUTH TREES BERTH	94%	4%	2%	60%	27%	13%
AUCKLAND CHANNEL	91%	6%	3%	60%	27%	13%
AUCKLAND POINT BERTH	46%	36%	18%	46%	36%	18%
CLINTON CHANNEL	80%	13%	7%	60%	27%	13%
CLINTON WHARVES	73%	18%	9%	60%	27%	13%
TARGINIE CHANNEL	89%	8%	4%	60%	27%	13%
FISHERMANS LANDING	57%	28%	14%	57%	28%	14%
WIGGINS ISLAND	80%	14%	7%	60%	27%	13%
GLNG	33%	45%	22%	40%	40%	20%
QCLNG	6%	63%	31%	40%	40%	20%
APLNG	3%	65%	32%	40%	40%	20%

7.3.2 Dredge Phasing

Dredge logs supplied from historical campaigns of the *TSHD Brisbane* were used to analyse the operational mode of the dredge based on location. These modes were dredging (without overflow), overflow dredging, steaming laden, dumping and steaming unladen. Further analysis of the dredge logs was used to determine the typical time to overflow, and time overflowing in each dredging parcel. This allowed an effective productivity to be determined for the individual sections of the channel. These parameters are summarised in Table 4.

Table 4 Dredge Production Rates by Channel Sub-Areas

Location	Average Time to Overflow [minutes]	Average Time Overflowing [minutes]	Pre-overflow Effective Production Rate [m3/hr]	Overflow Effective Production Rate [m3/hr]
WILD CATTLE CUTTING	20	65	2204	1168
BOYNE CUTTING	27	40	2490	1320
GOLDING CHANNEL	14	43	3262	1729
GATCOMBE CHANNEL	20	90	1773	939
SOUTH TREES BERTH	20	78	1956	1037
AUCKLAND CHANNEL	20	95	1706	904
AUCKLAND POINT BERTH	20	92	1941	882
CLINTON CHANNEL	15	67	2376	1259
CLINTON WHARVES	15	67	2376	1259
TARGINIE CHANNEL	15	50	2892	1533
FISHERMANS LANDING	15	79	2154	1110
WIGGINS ISLAND	15	56	2686	1423
GLNG	15	40	3774	1585
QCLNG	13	50	3529	1482
APLNG	15	88	2309	970

7.3.3 Dredge Loads

Average dredge loads were determined based on the above two sections (which are derived from data) and the following assumptions, based on advice from GPC's dredging consultant.

- The *TSHD Brisbane* removes 2000m^3 of in-situ material per dredge cycle;
- 2% of the pumped fines are released into a plume by the drag head;
- 80% of the fine-grained material is lost during overflow;
- 25% of the sand is lost during overflow; this is to account for fine grained sand which may be lost in overflow;
- 15% of the overflowed material enters the passive plume, the remainder goes to the seabed;
- 10% of the fines remaining in the dredge enters the plume during placement at the DMPA;
- 2% of the sand remaining in the dredge enters the plume during placement at the DMPA; this is to account for any remaining fine-grained sand;
- Placement of material happens over a 10-minute window.

The derived dredge loads, based on these assumptions, are summarised in Table 5.

Table 5 Dredge Loads by Channel Sub-Areas

Location	Pre-Overflow Dredge Load [kg/s]			Overflow Dredge Load [kg/s]			Placement into Water Column [kg/s]			Placement onto Seabed [kg/s]		
	Sand	Sand	Clay	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay
WILD CATTLE CUTTING	0	7	3	28	39	20	102	109	54	4986	977	488
BOYNE CUTTING	0	7	4	31	45	22	95	129	65	4670	1165	583
GOLDING CHANNEL	0	10	5	41	58	29	101	109	55	4965	983	491
GATCOMBE CHANNEL	0	5	3	22	32	16	104	100	50	5104	896	448
SOUTH TREES BERTH	0	6	3	25	35	18	103	103	52	5054	927	464
AUCKLAND CHANNEL	0	5	3	21	31	15	105	98	49	5122	885	442
AUCKLAND POINT BERTH	0	5	3	12	30	15	58	95	48	2829	859	430
CLINTON CHANNEL	0	7	4	30	43	21	104	100	50	5102	898	449
CLINTON WHARVES	0	7	4	30	43	21	104	100	50	5102	898	449
TARGINIE CHANNEL	0	9	4	36	52	26	102	107	54	4996	963	482
FISHERMANS LANDING	0	4	2	17	27	13	66	67	34	3245	607	304
WIGGINS ISLAND	0	8	4	34	48	24	103	104	52	5038	937	469
GLNG	0	11	5	20	65	33	49	124	62	2404	1120	560
QCLNG	0	10	5	19	61	31	51	116	58	2523	1046	523
APLNG	0	7	3	13	40	20	54	108	54	2648	968	484

7.4 Model Validation Results

Model results were compared with measurement from the 2014 and 2017 monitoring campaigns across dredging operations in various channel sub-areas and at the DMPA. This section presents a selection of plots for each sub-area where measurements were taken. Overall the simulated dredge plume suspended sediment concentration agreed well with the measurements. The modelled plume intensity was generally slightly higher than measured, providing conservative estimates for the potential maintenance dredging impacts.

7.4.1 GLNG Dredging

Dredging in the channel adjacent to the GLNG facility, monitored in the September 2017 campaign, was a non-typical dredge cycle for the area. The monitored dredge cycle involved multiple passes over an individual pocket of material taking 2.5 hours to complete the cycle in this area. As a result, the modelled plume concentrations are marginally higher than the measured concentrations. This can be observed in the dredge transect presented in Figure 7-2. This figure illustrates the model accurately matching the spatial features of the plume, although overestimating its intensity.

7.4.2 APLNG Dredging

Dredge plumes monitored adjacent to APLNG as part of the September 2017 campaign were replicated well by the numerical model. Figure 7-3 shows a good reproduction of the observed depth averaged concentration across the plume. There is some disparity in the concentration profile in the water column between modelled and observed with the modelled plume being distributed more towards the bed.

7.4.3 WICT Dredging

A small parcel of dredging was observed adjacent to WICT as part of the September 2017 monitoring campaign. The *TSHD Brisbane* was monitored for a period of 1 hour during overflow dredging at this location prior to moving to GLNG to complete the dredge cycle. Despite the limited data for this location, modelling a plume at this location had satisfactory results, replicating the approximate spatial extent well.

7.4.4 DMPA Placement

Plumes arising from placement at the DMPA were monitored on three separate occasions, twice in September 2017 and once in February 2014. Representative plots of dredge plume transect are presented in Figure 7-4 for the 2017 campaign and Figure 7-5 for the 2014 campaign. It is worth noting that the observed TSS concentrations at the DMPA in 2014 were significantly lower than those in 2017. Comparisons between the model and the data from 2017 and 2014 indicate that overall the placement loads are higher than those observed (only marginally for 2017 and significantly for 2014). It is considered that variability of the placement plume source characteristics justifies some conservatism in the modelling assumptions here.

7.4.5 Gatcombe Channel Dredging

One dredging operation the in Gatcombe Channel was monitored in February 2014. Figure 7-6 illustrates that the model accurately replicates the extent and concentration of this dredge plume in this predominantly sandy location.

7.4.6 Golding Channel Dredging

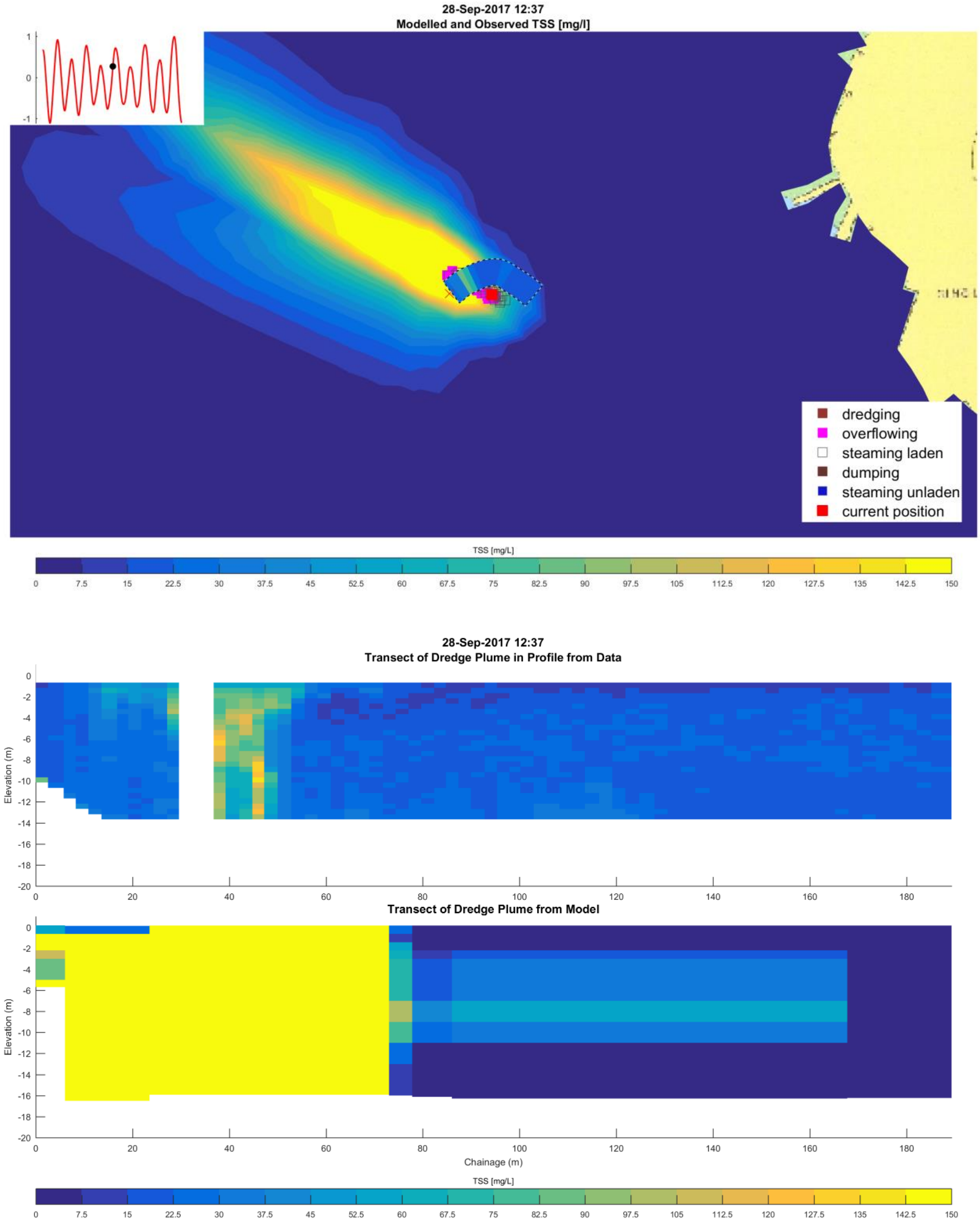
Transects through dredging plumes monitored at the Golding Channel during the February 2014 campaign are presented alongside modelling results in Figure 7-7. This plot shows good agreement of both the depth averaged sediment concentration and the spatial extent of the overflow plume generated during the dredging activity.

7.4.7 Wild Cattle Channel

Figure 7-8 illustrates a measured transect and model output for a dredging plume in the Wild Cattle Channel from the 2014 campaign. The approximate spatial extent and concentration is replicated well by the model, capturing the dispersion of the plume to the north outside the main channel.

7.4.8 QCLNG Dredging

A modelled and measured transect through an overflow dredge plume near QCLNG from 2014 is presented in Figure 7-9. The model accurately represents the plume concentration and dispersion characteristics.



28-Sep-2017 12:37
Modelled and Observed TSS [mg/l]

28-Sep-2017 12:37
Transect of Dredge Plume in Profile from Data

Transect of Dredge Plume from Model

Figure 7-2 Transect Through Overflowing Dredge Plume at GLNG

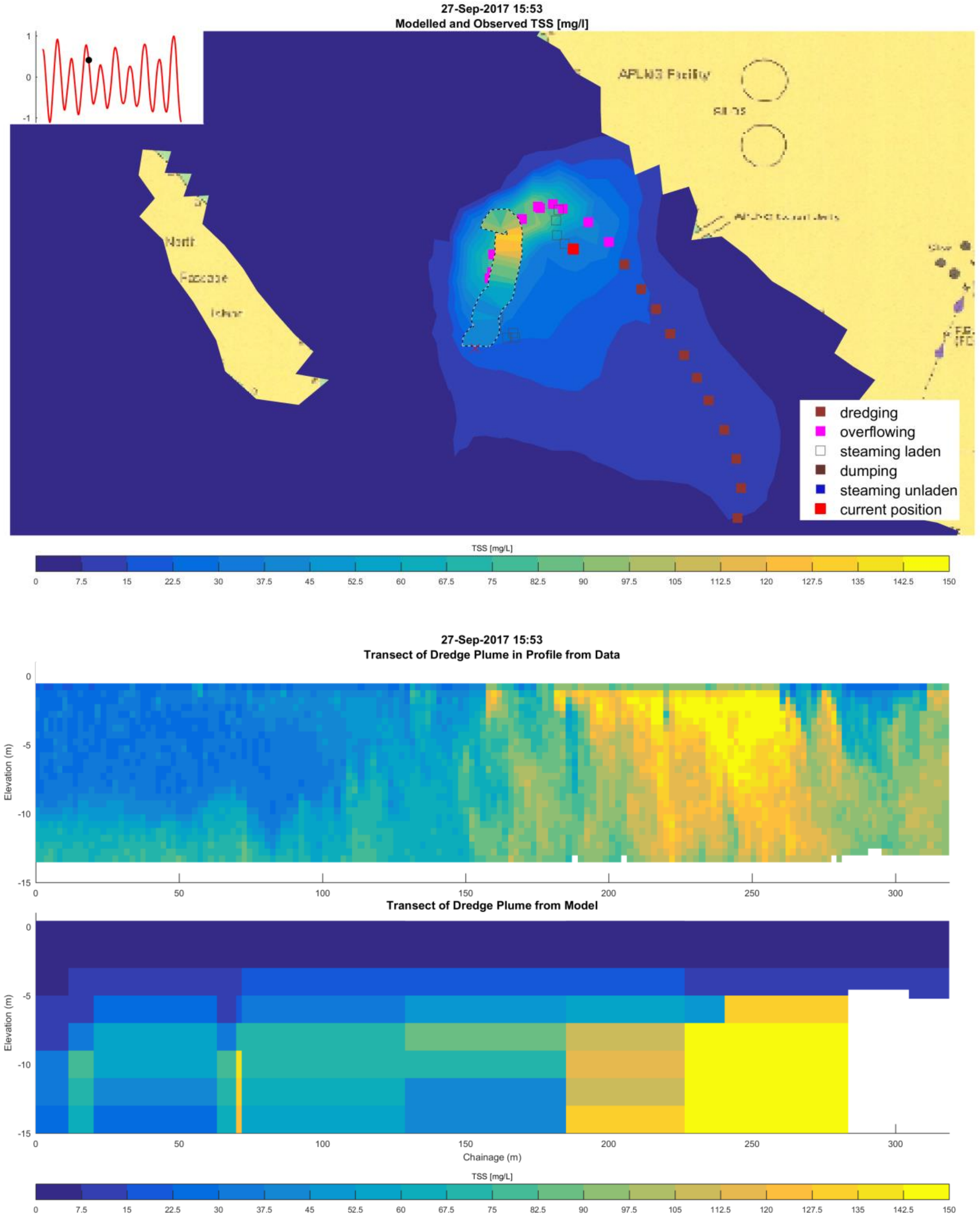


Figure 7-3 Transect Through Overflowing Dredge Plume at APLNG

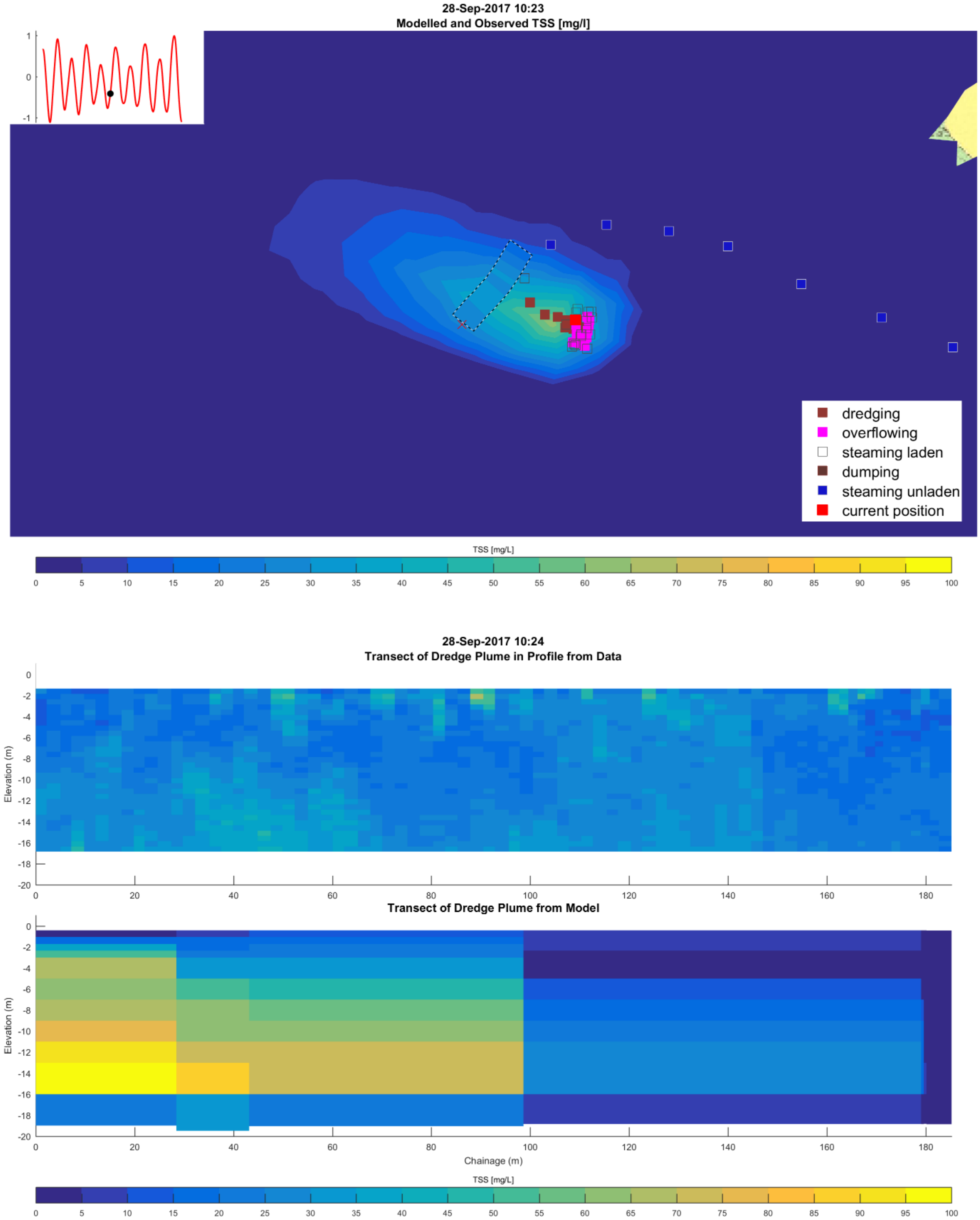


Figure 7-3 Transect Through Overflowing Dredge Plume at WICT

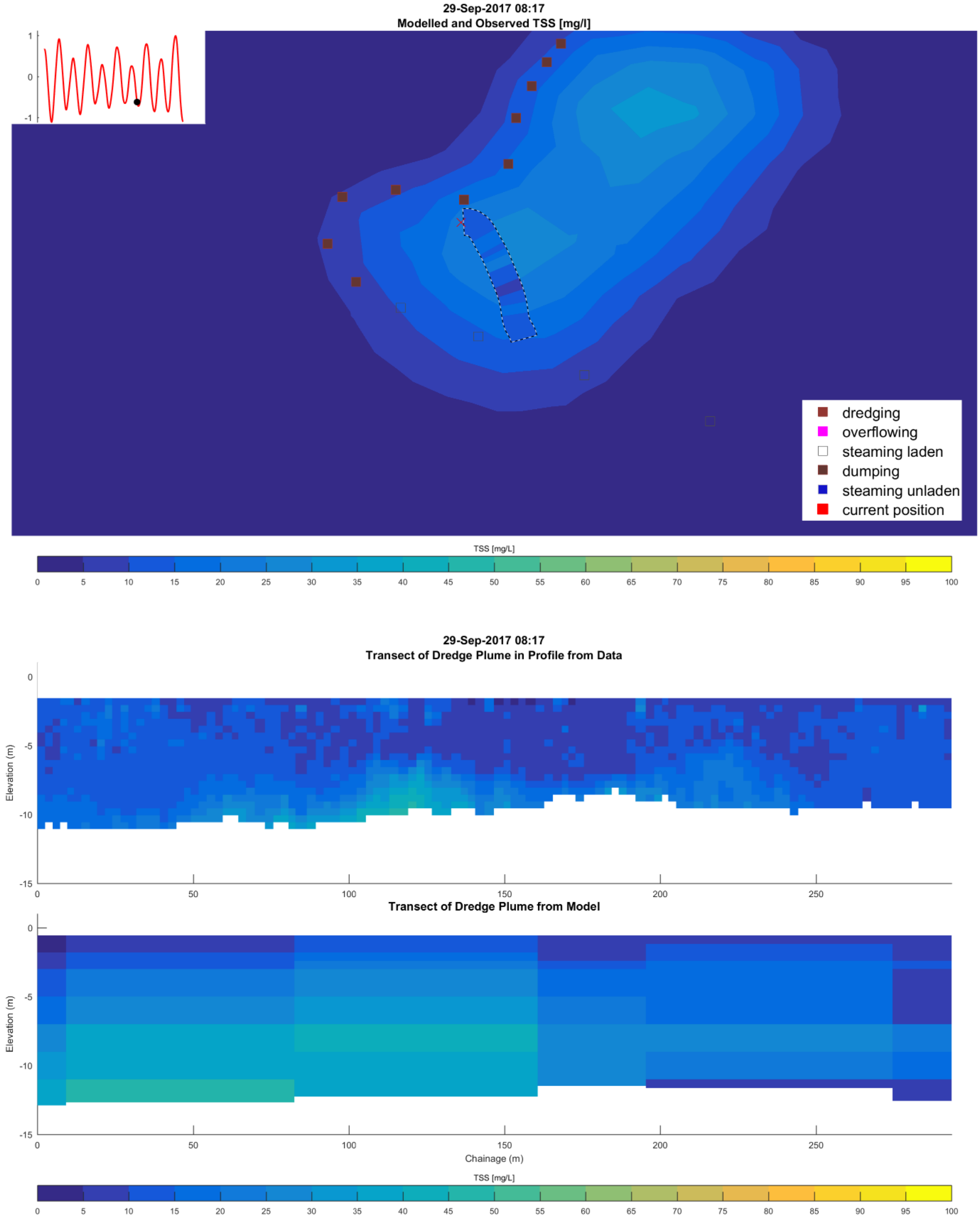


Figure 7-4 Transect Through Plume at the DMPA September 2017

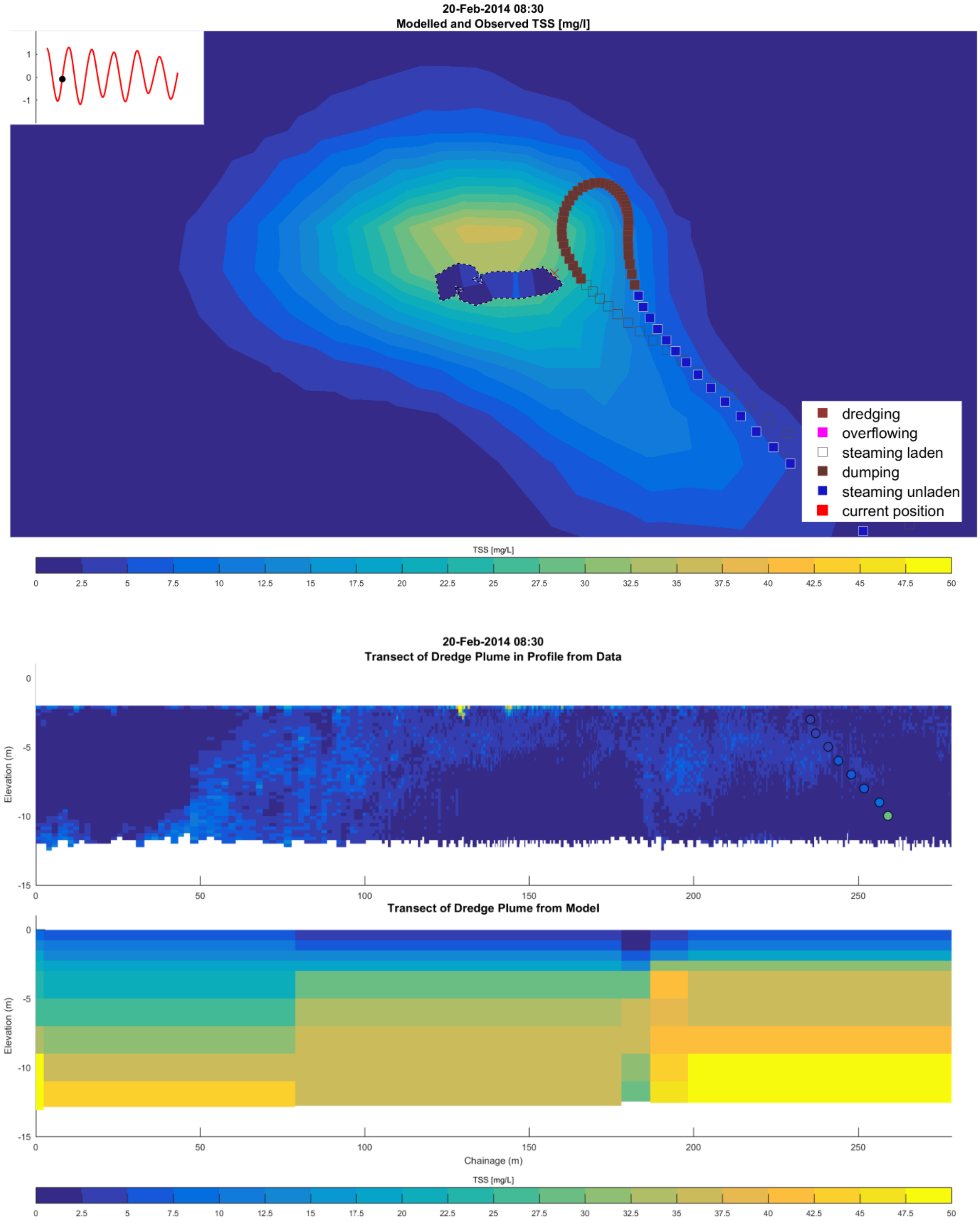


Figure 7-5 Transect Through Plume at the DMPA February 2014

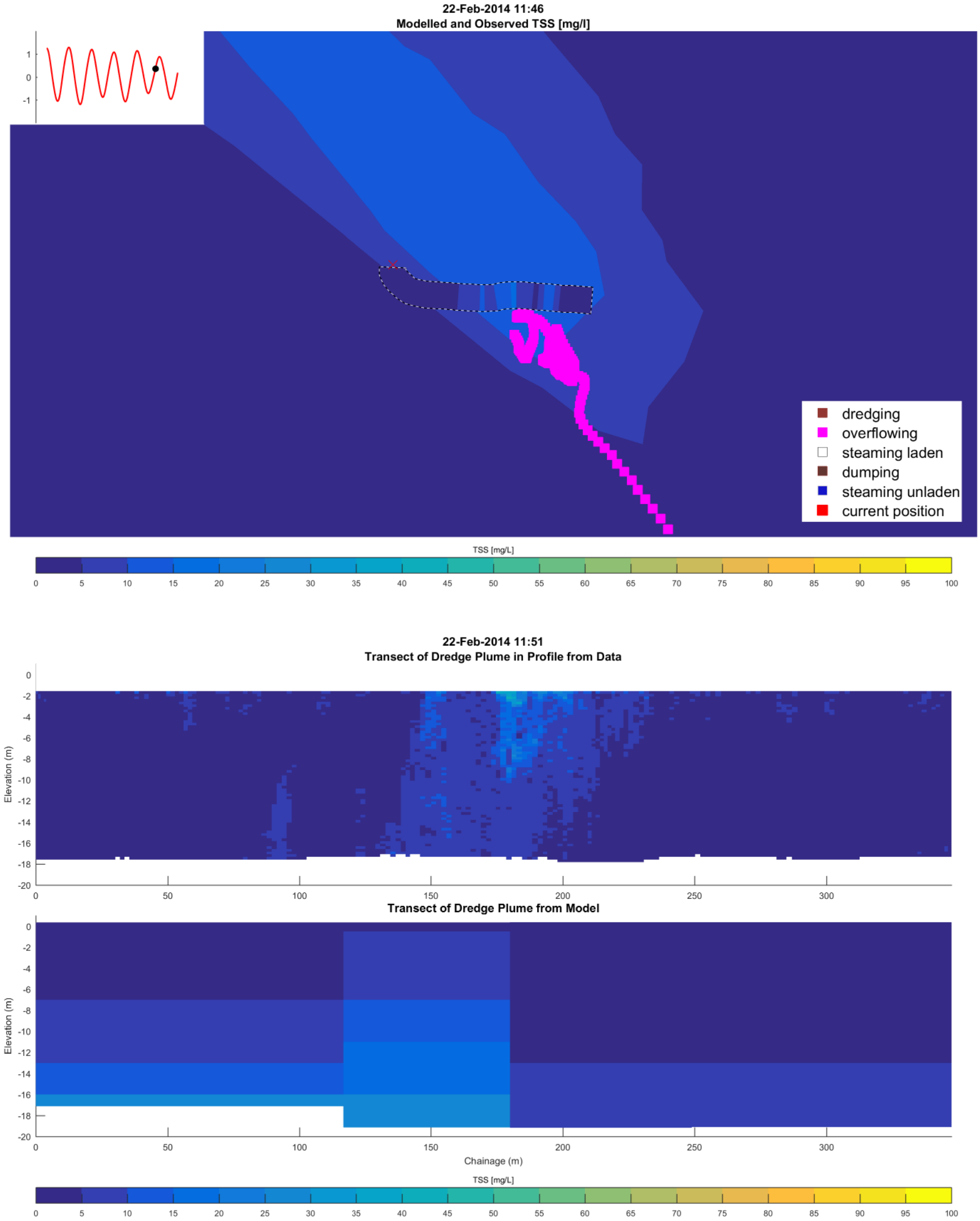


Figure 7-6 Transect Through Dredge Plume in Gatcombe Channel

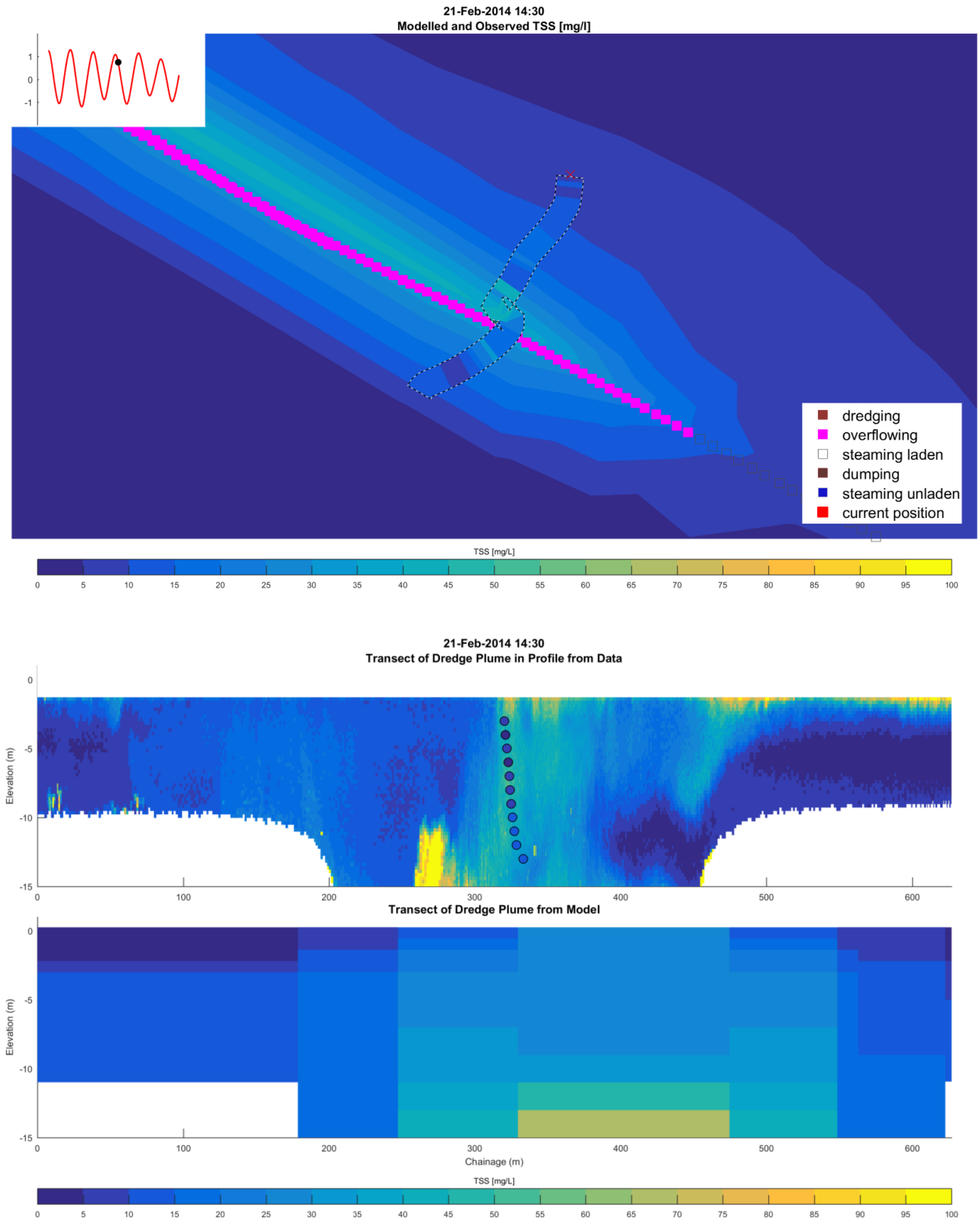


Figure 7-7 Transect Through Dredge Plume in Golding Channel

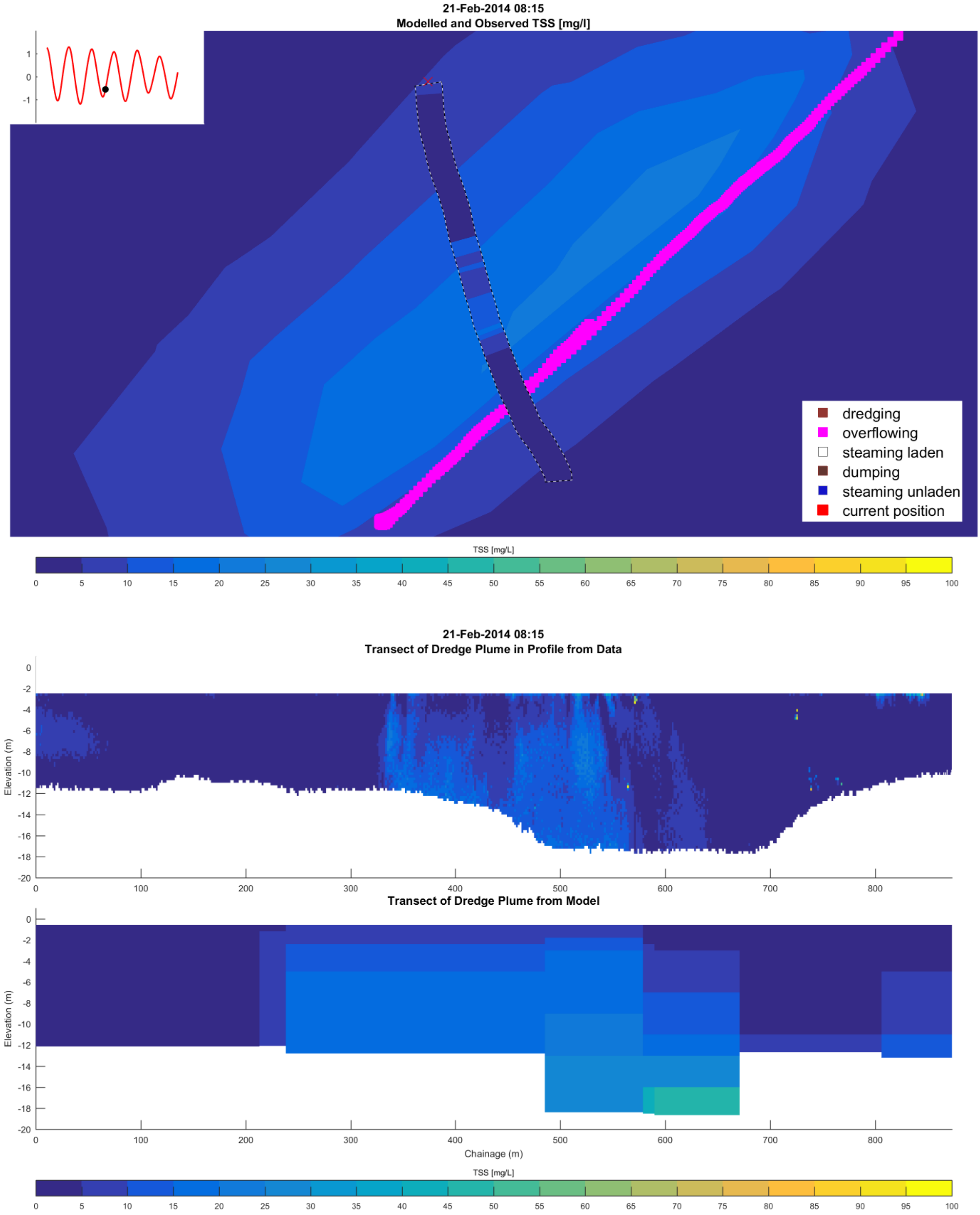


Figure 7-8 Transect Through Dredge Plume in Wild Cattle Channel

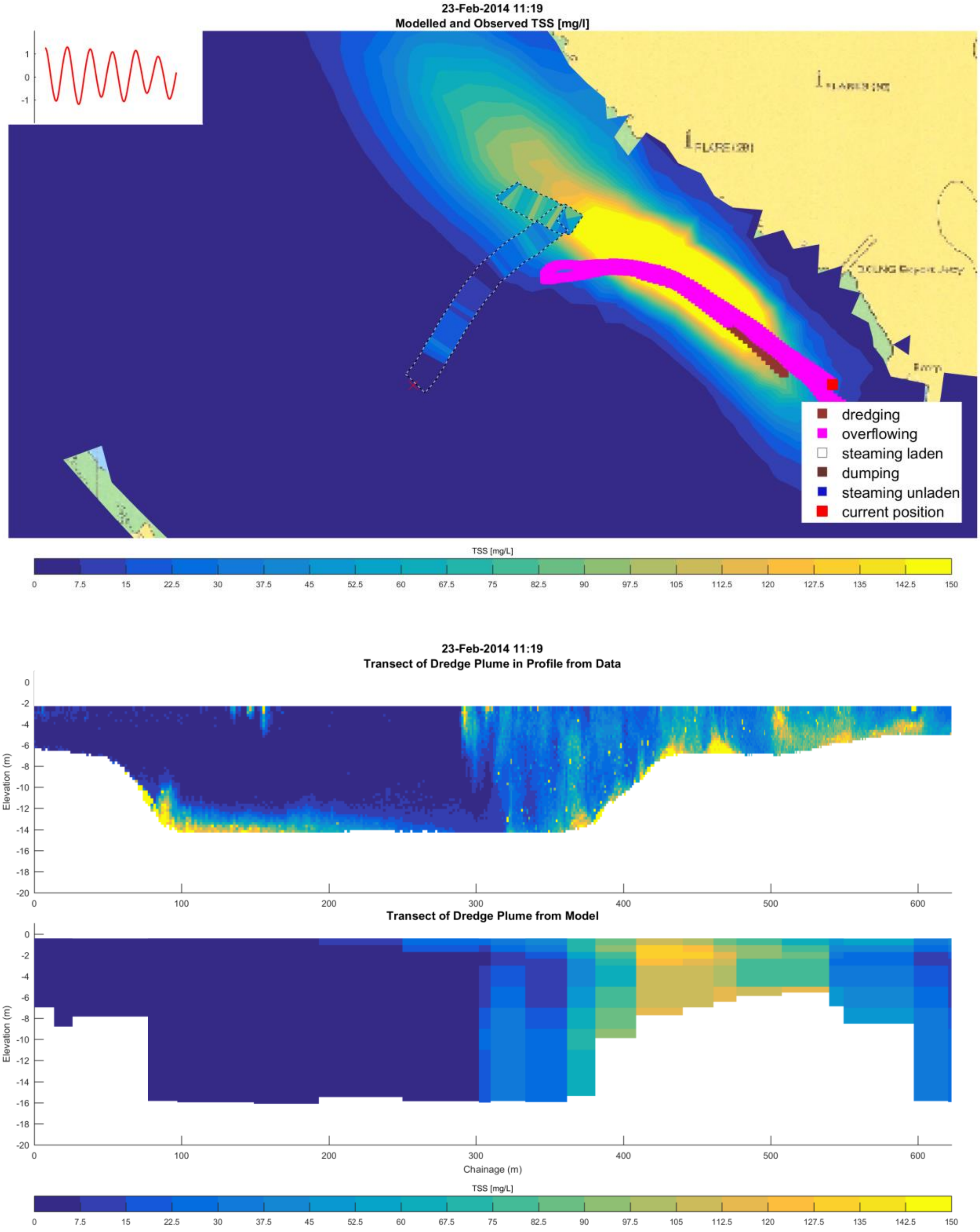


Figure 7-9 Transect Through Dredge Plume near APLNG

8 Conclusion

This report documents the model configuration, boundary conditions and validation results for the numerical modelling system used in the Port of Gladstone maintenance dredging impact assessment report (BMT WBM, 2017).

The numerical modelling system is fit-for-purpose, and has been validated using a variety of measurements of water levels, currents, wave parameters and ambient turbidity. The model is sufficiently accurate to characterise the existing marine environment in Gladstone Harbour, and it is an appropriate tool for the assessment of the likely impacts of dredging on turbidity levels within the Harbour.

9 References

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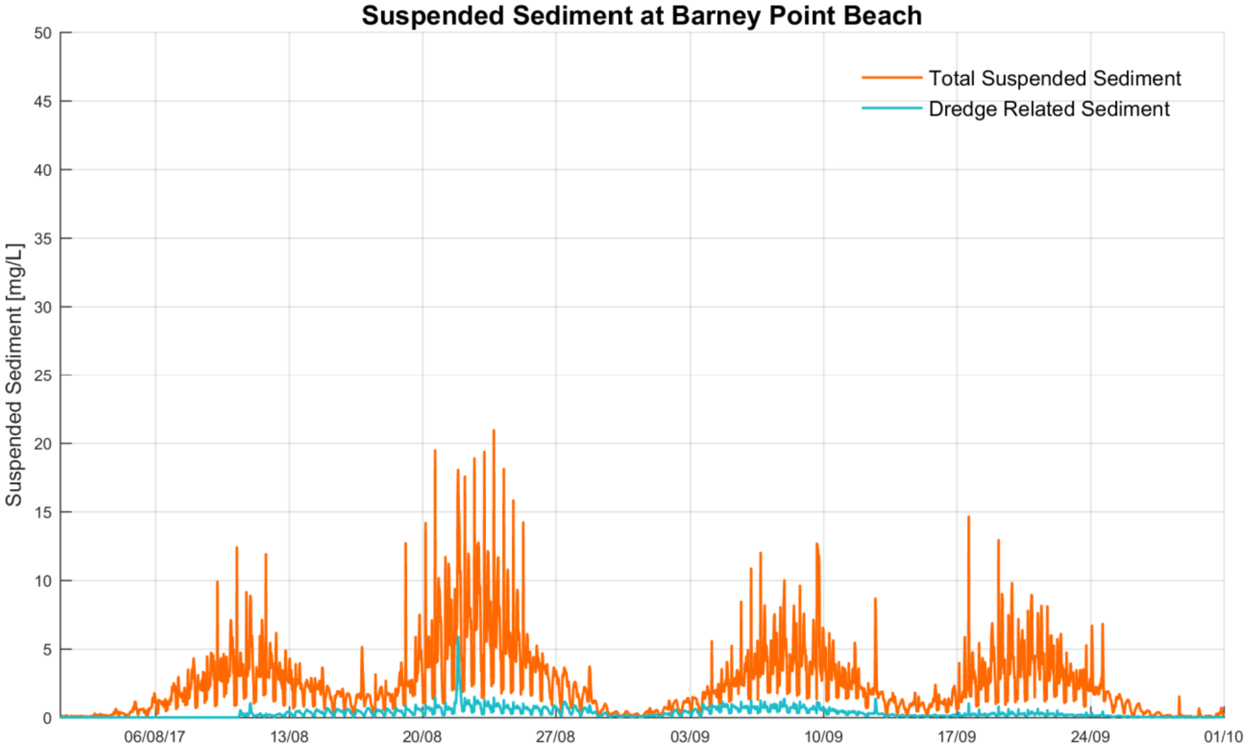
BMT WBM, 2017. Port of Gladstone Maintenance Dredging - Assessment of Potential Impacts. R.B22900.001.00.Maintenance_Dredging_Assessment.pdf

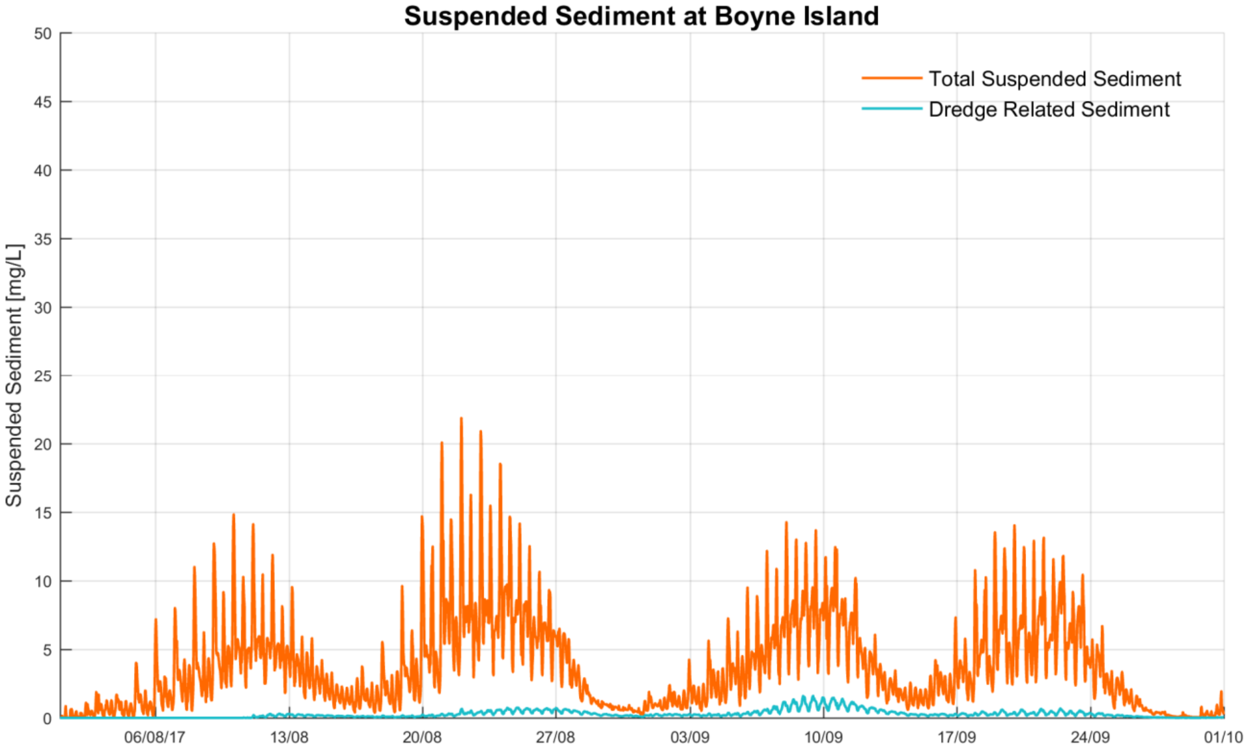
Delft University of Technology, 2006. SWAN - Scientific and Technical documentation. Available from http://www.swan.tudelft.nl (Version 40.91AB, April 2013).

Flather, R.A., 1976. A tidal model of the northwest European continental shelf. Mem. Soc. R. Sci. Liege 10(6): 141–164.

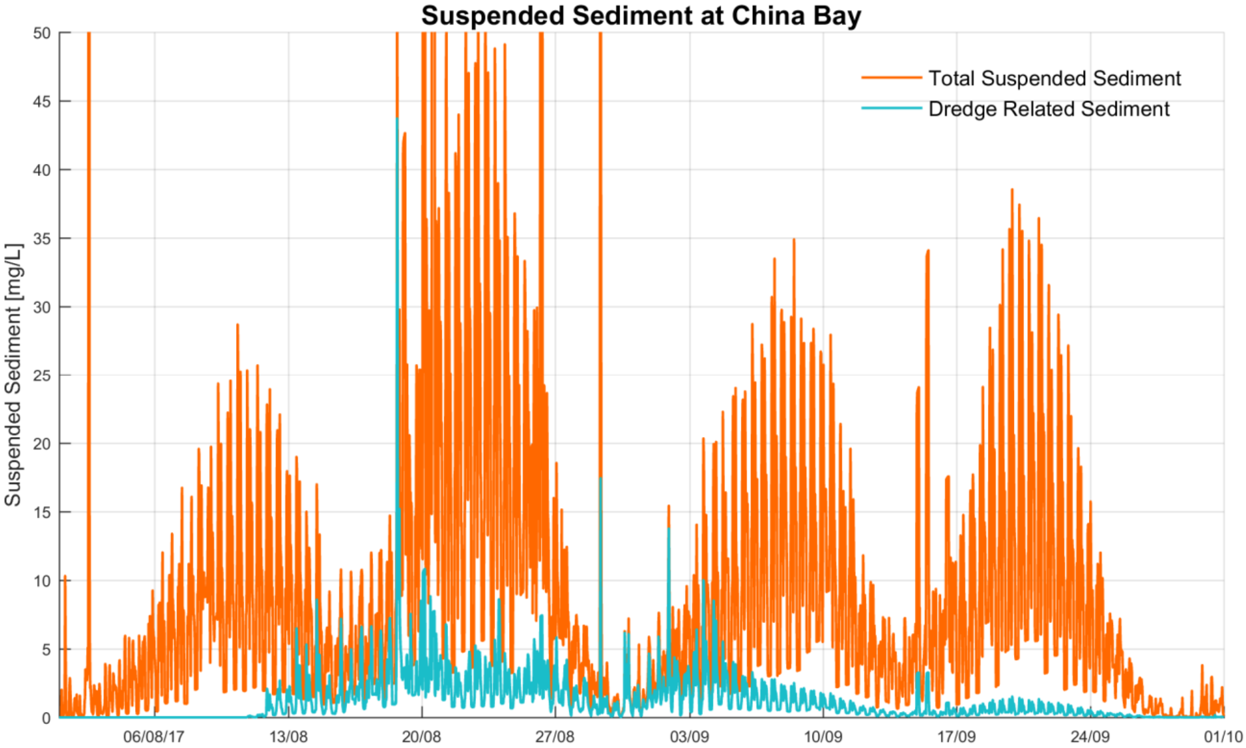
Appendix B Time Series of TSS for Dredged and Ambient Sediment

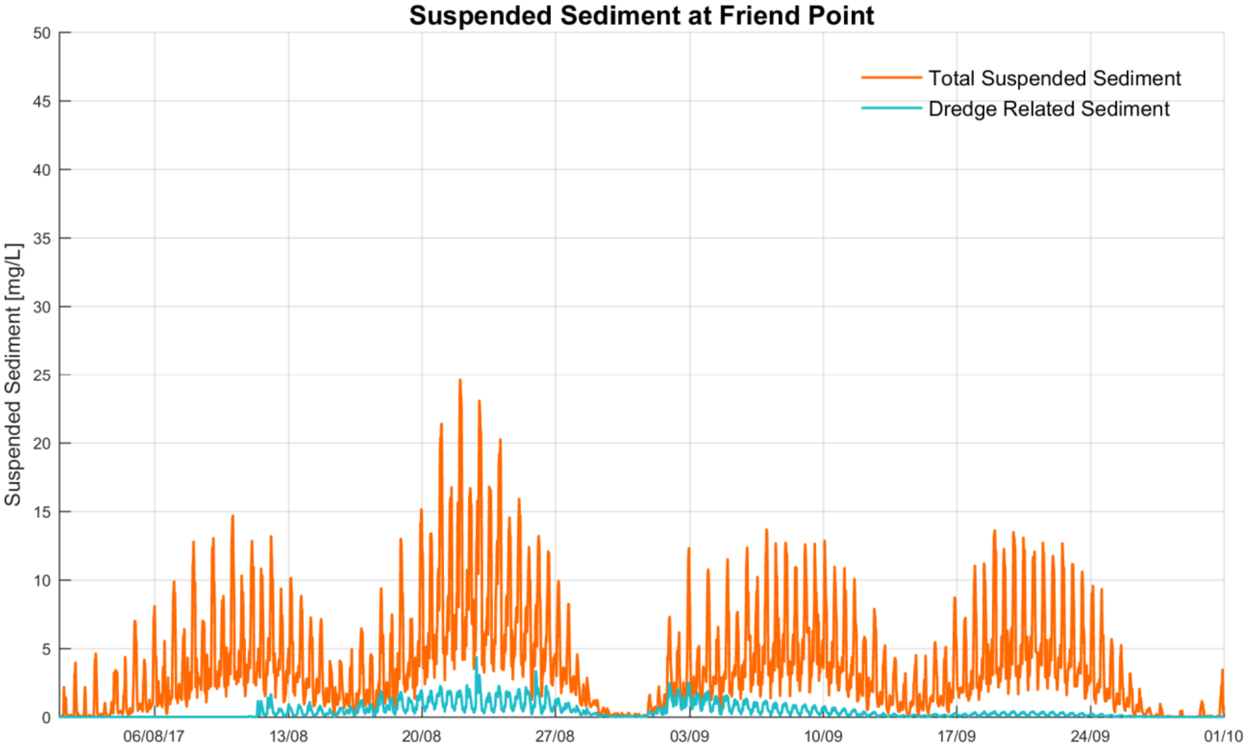
220,000m^3 Campaign



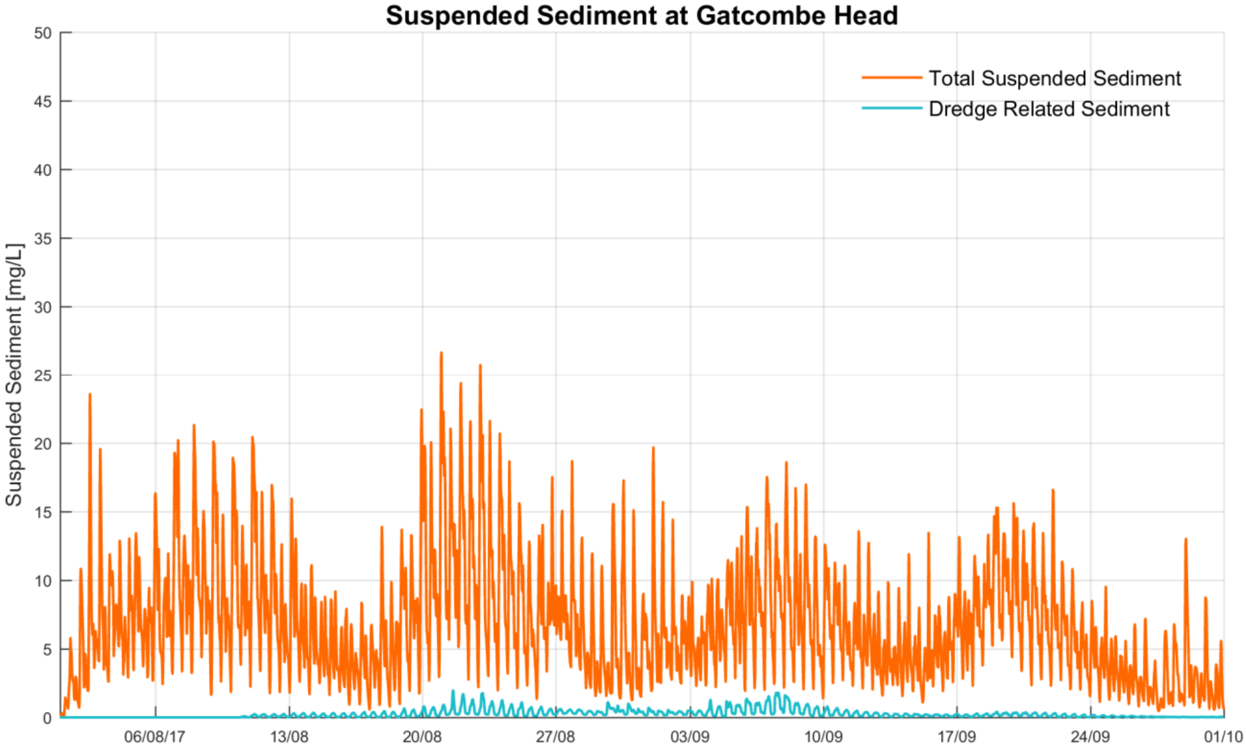


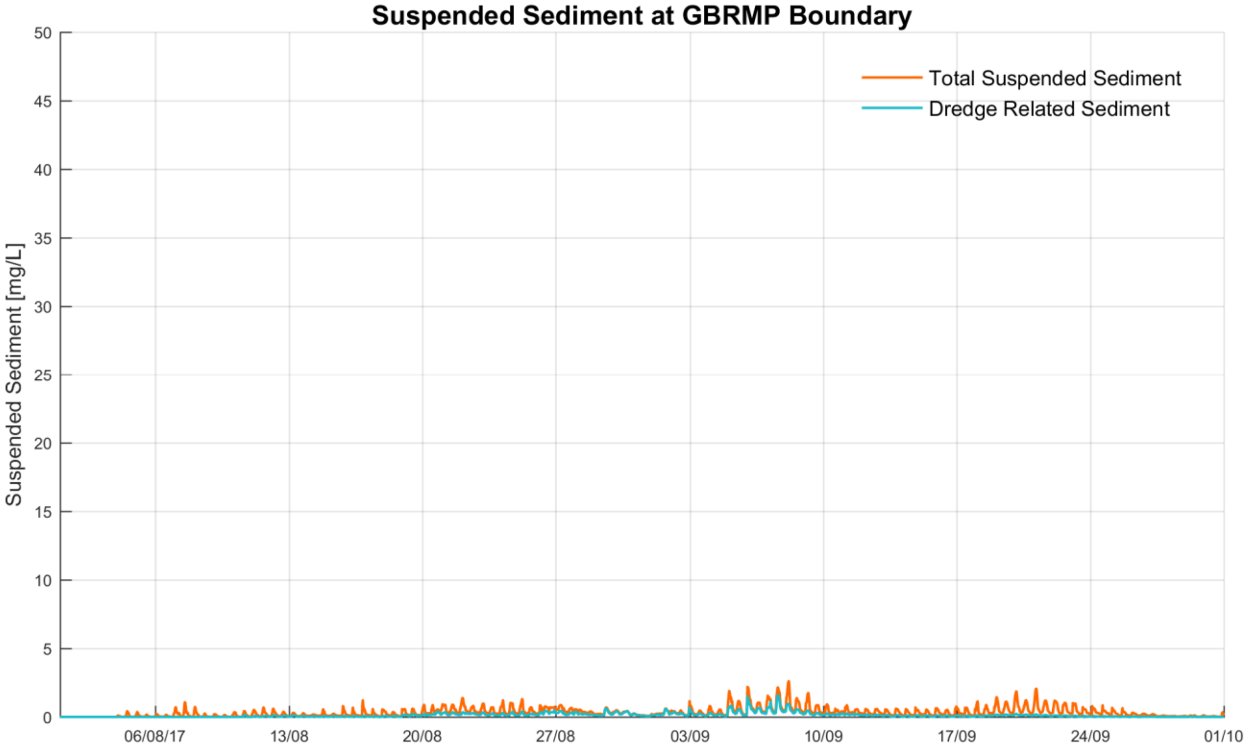
Time Series of TSS for Dredged and Ambient Sediment



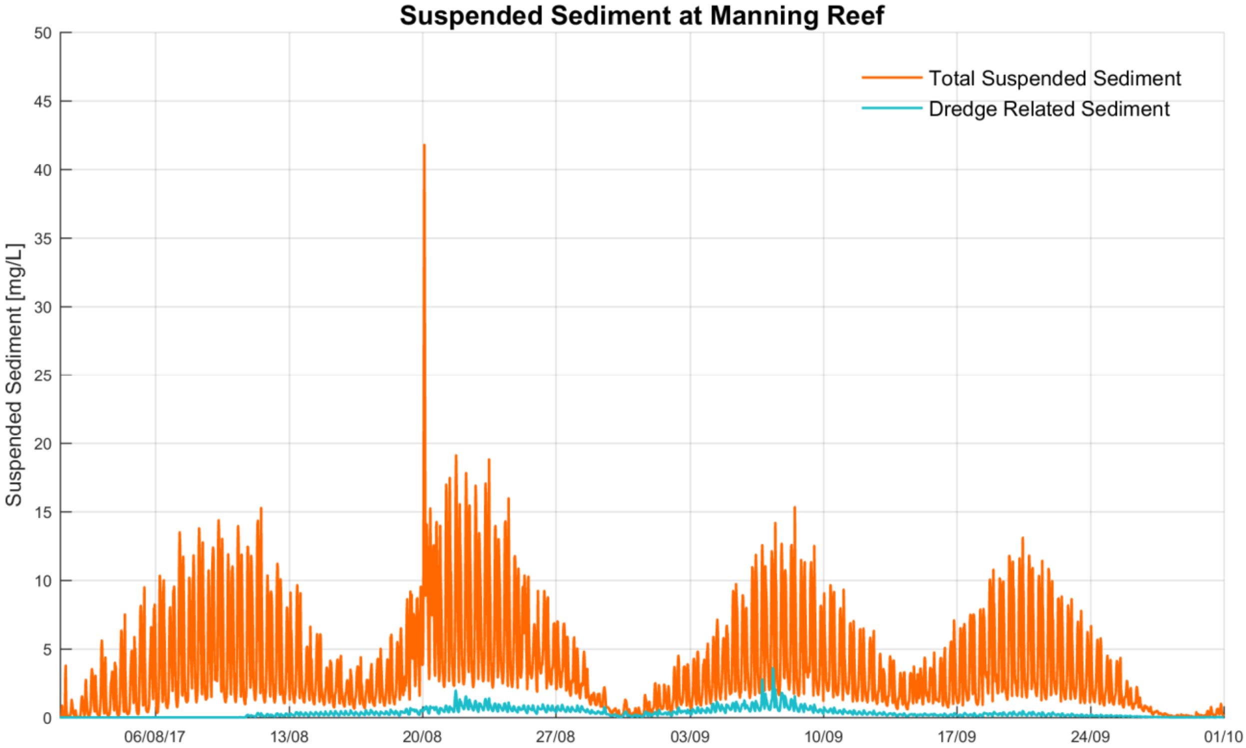


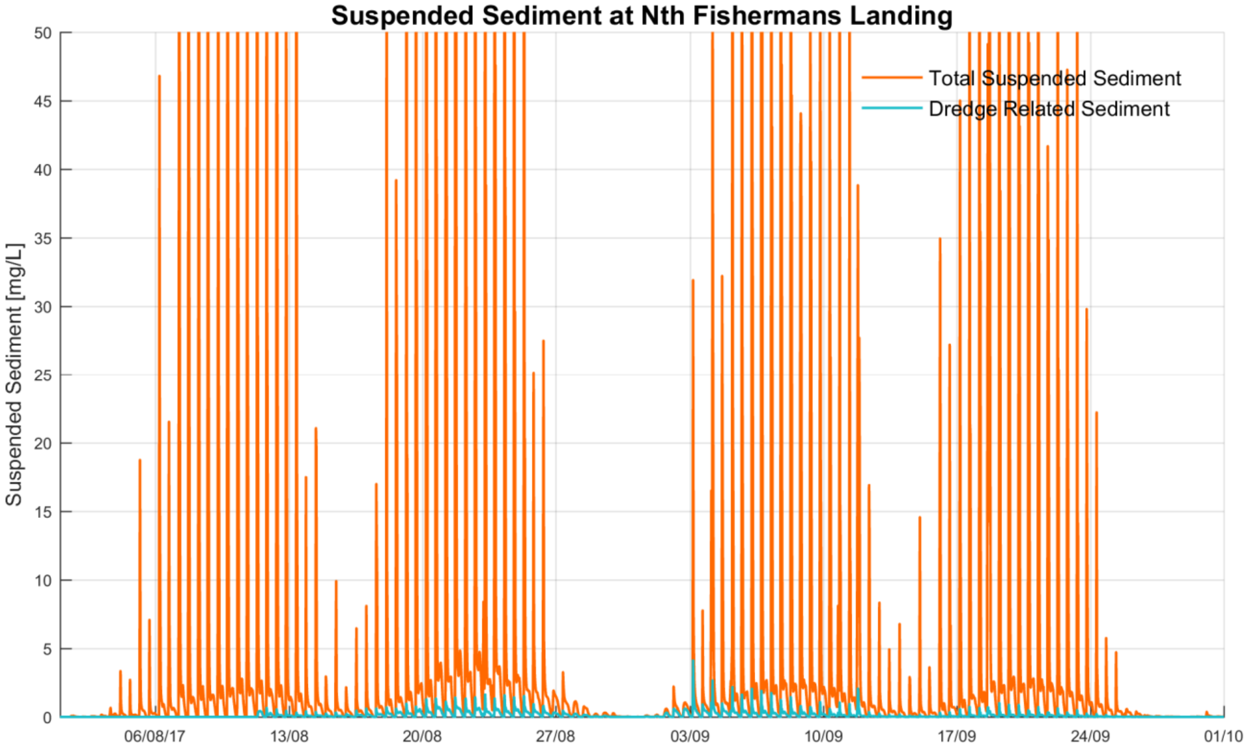
Time Series of TSS for Dredged and Ambient Sediment





Time Series of TSS for Dredged and Ambient Sediment





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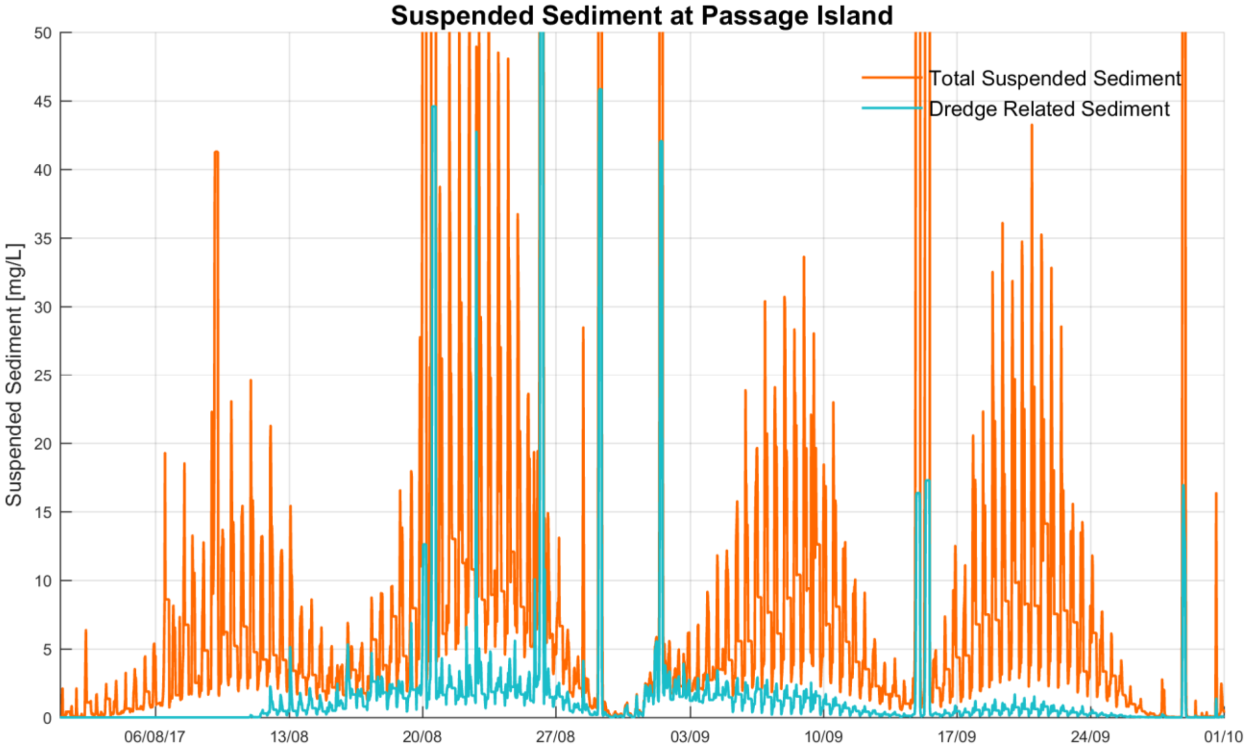
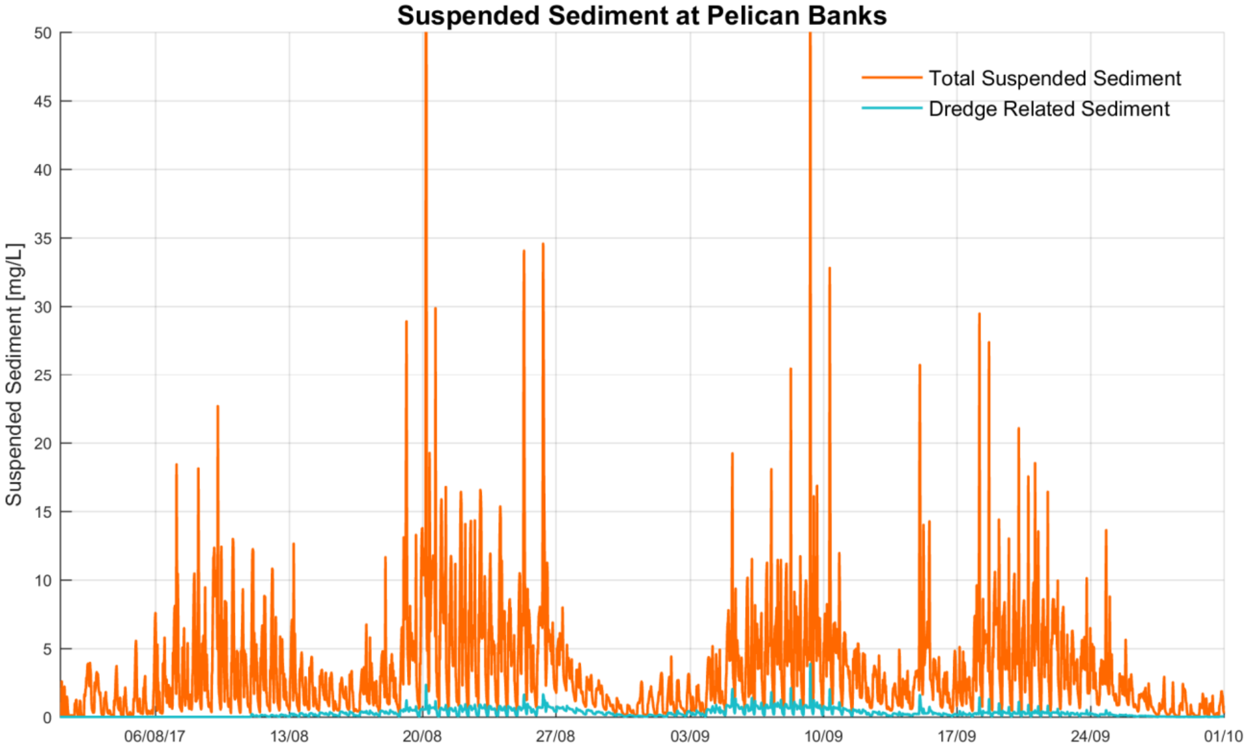
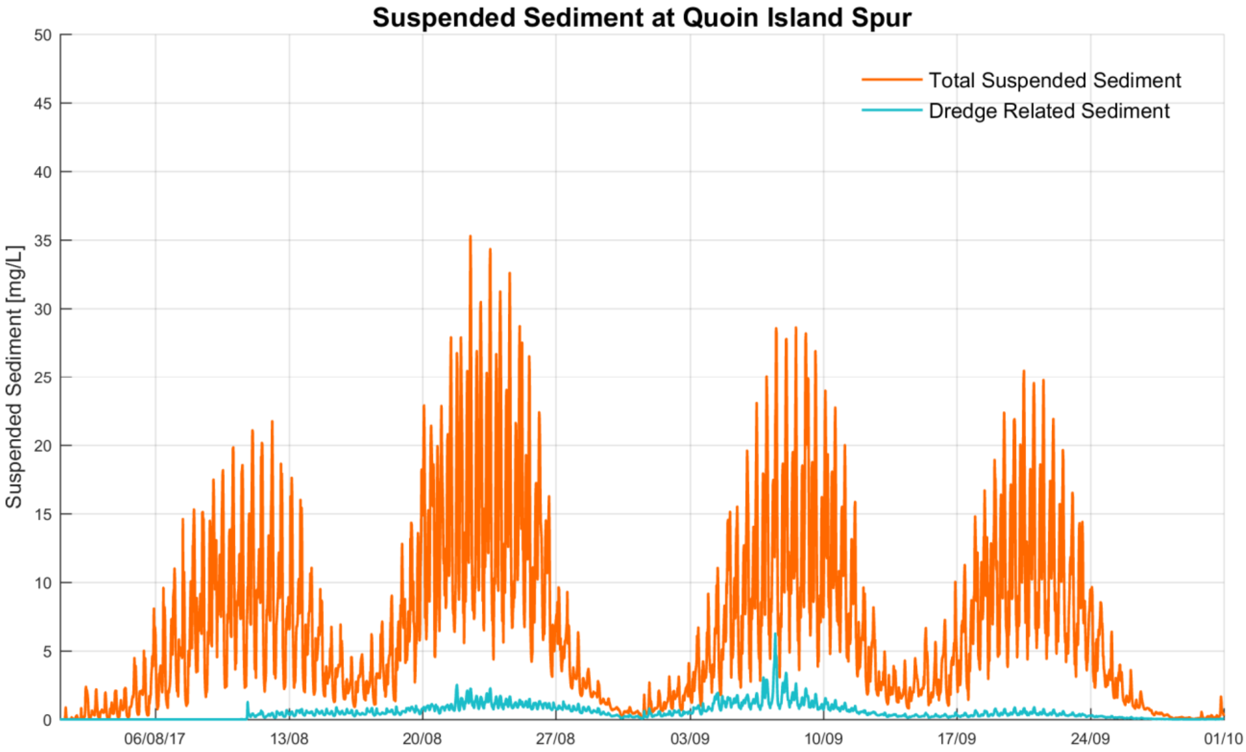
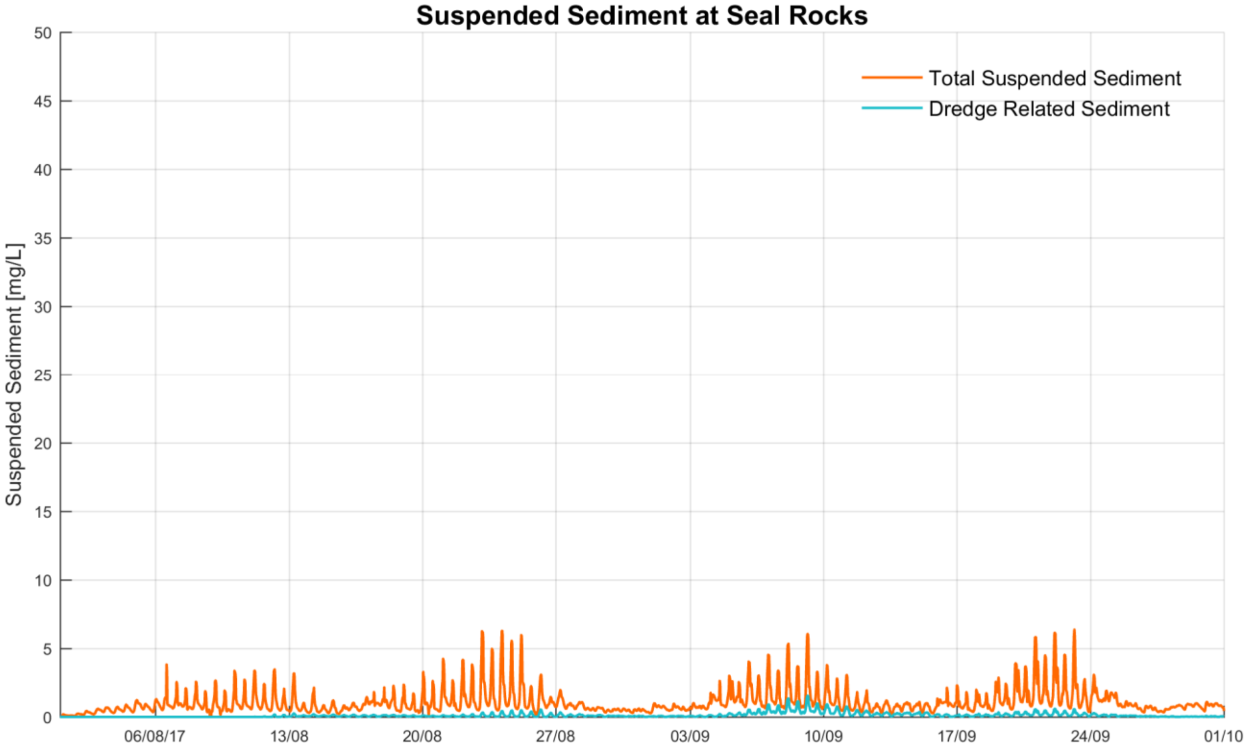




Time Series of TSS for Dredged and Ambient Sediment





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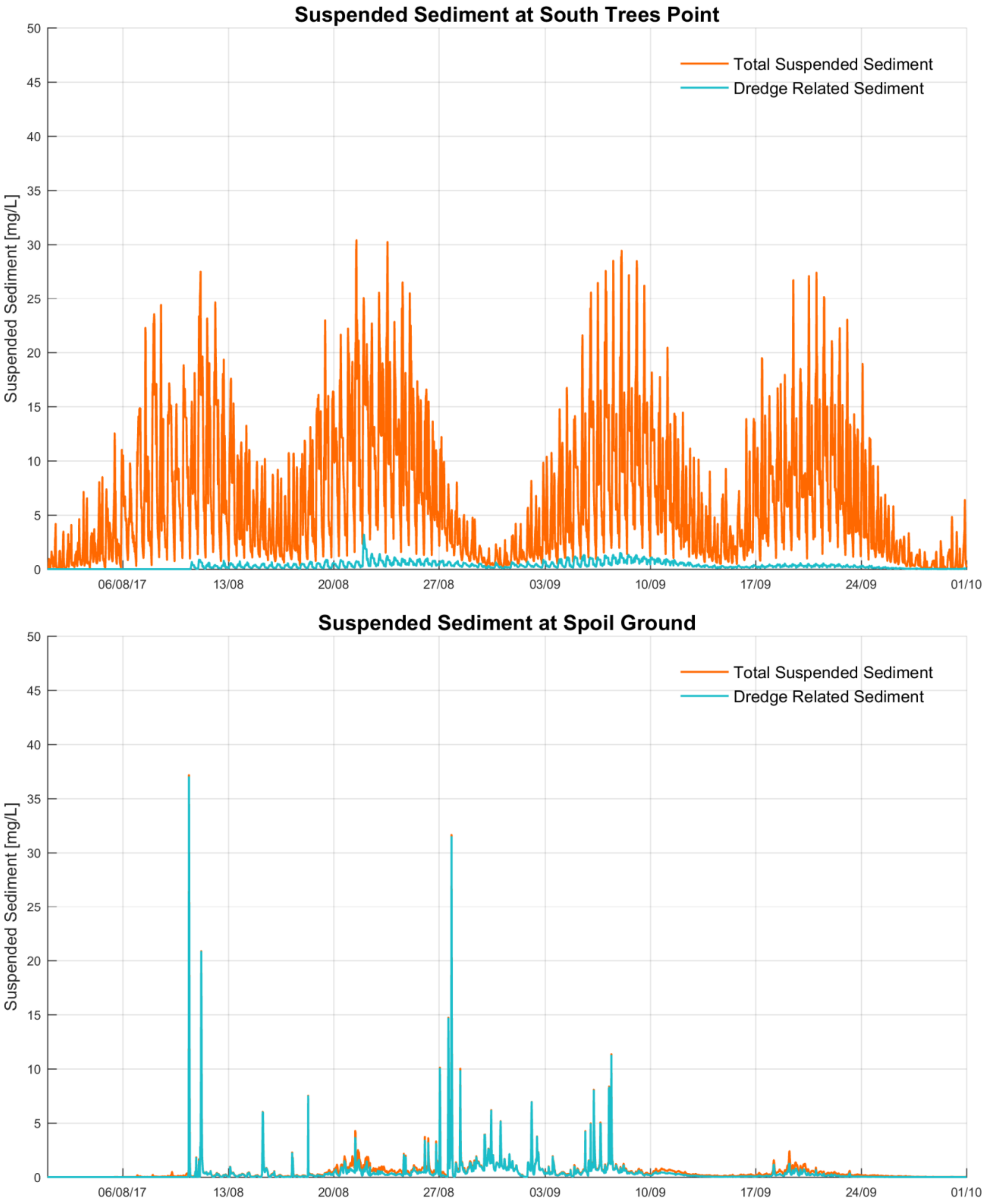

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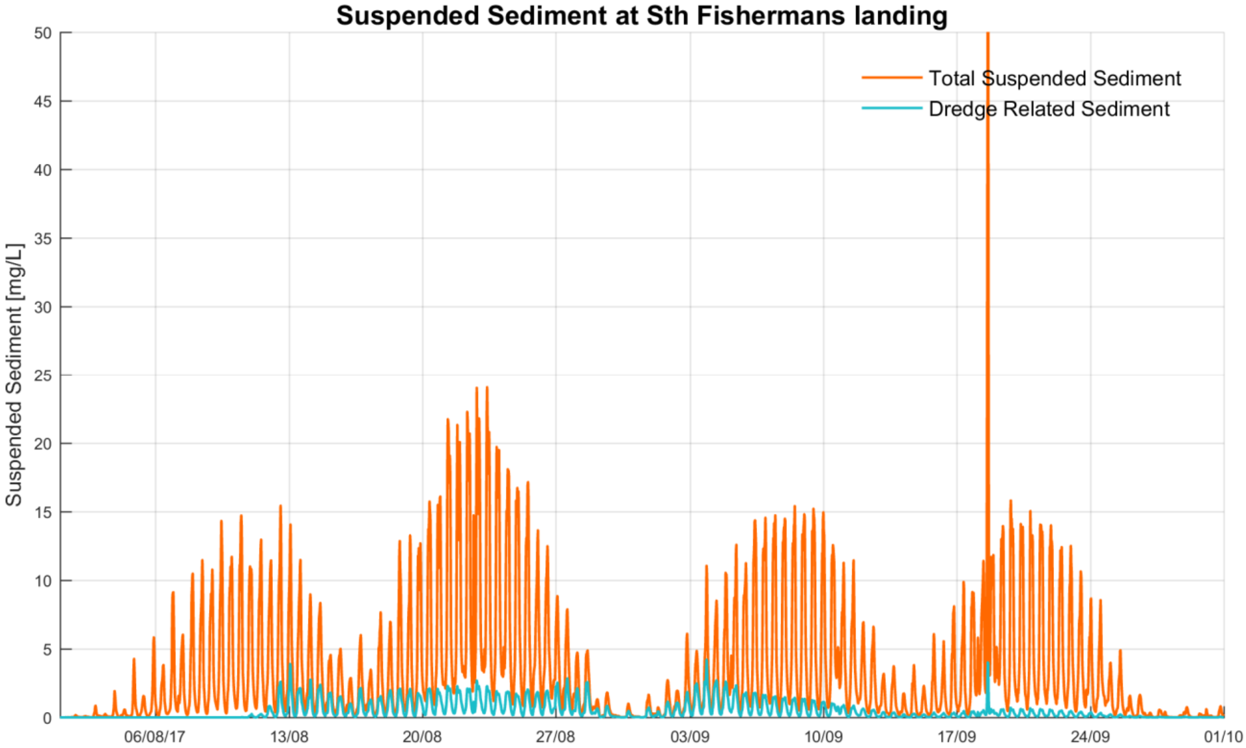

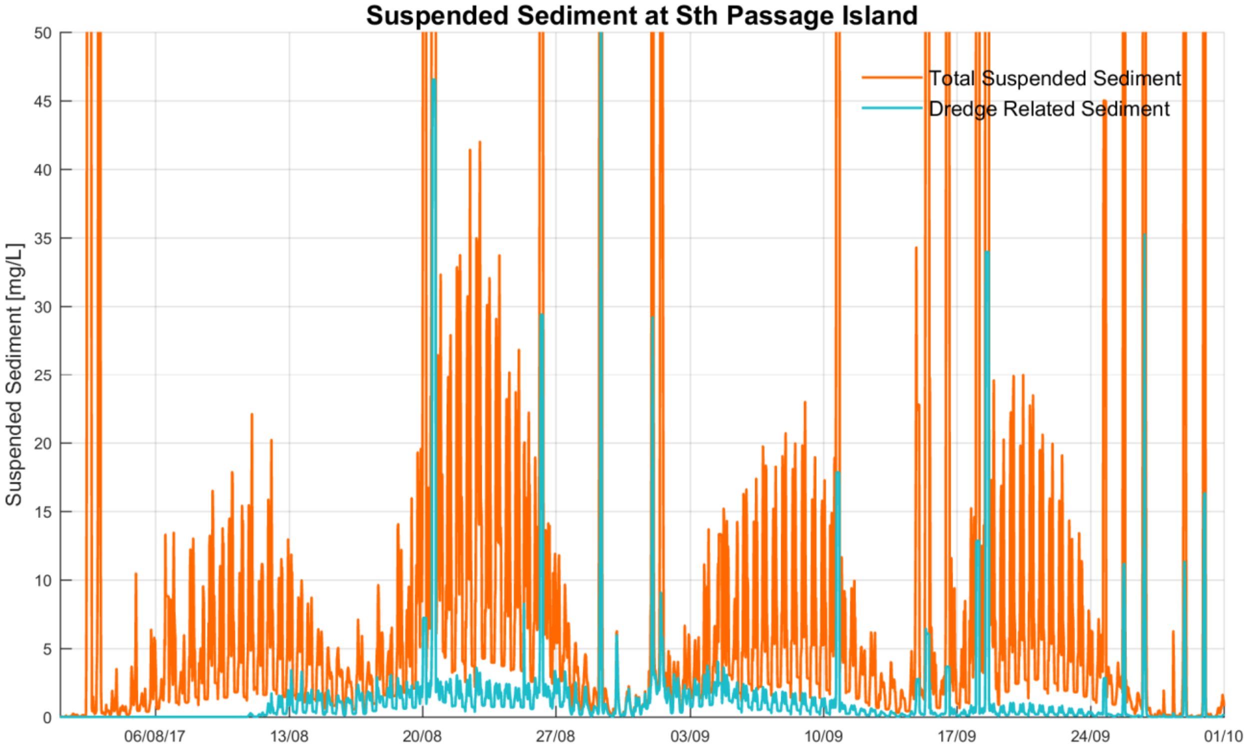

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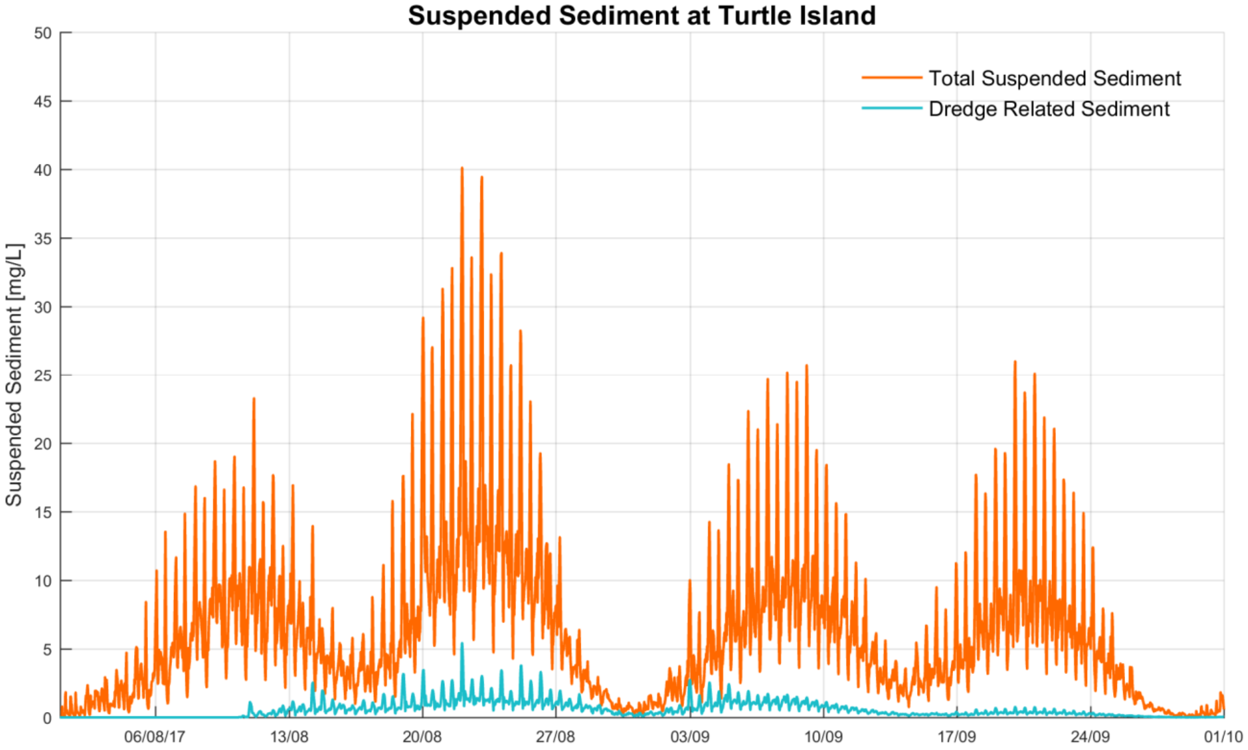
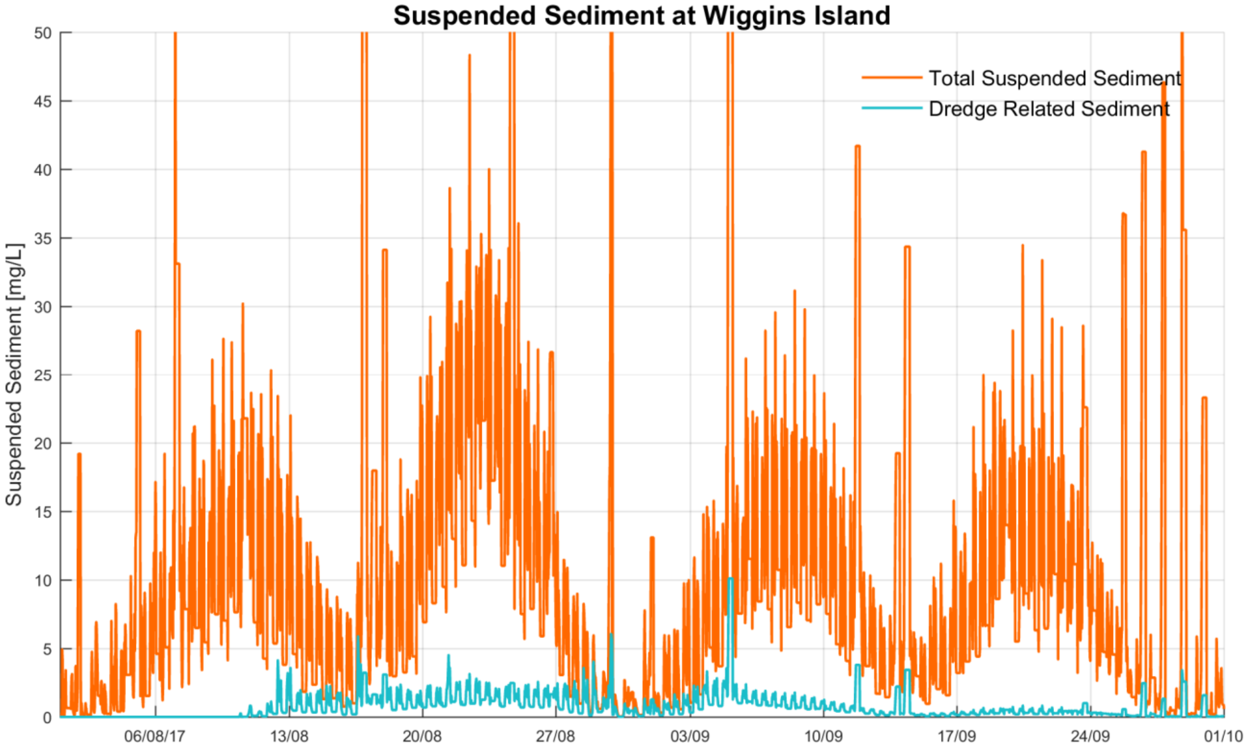
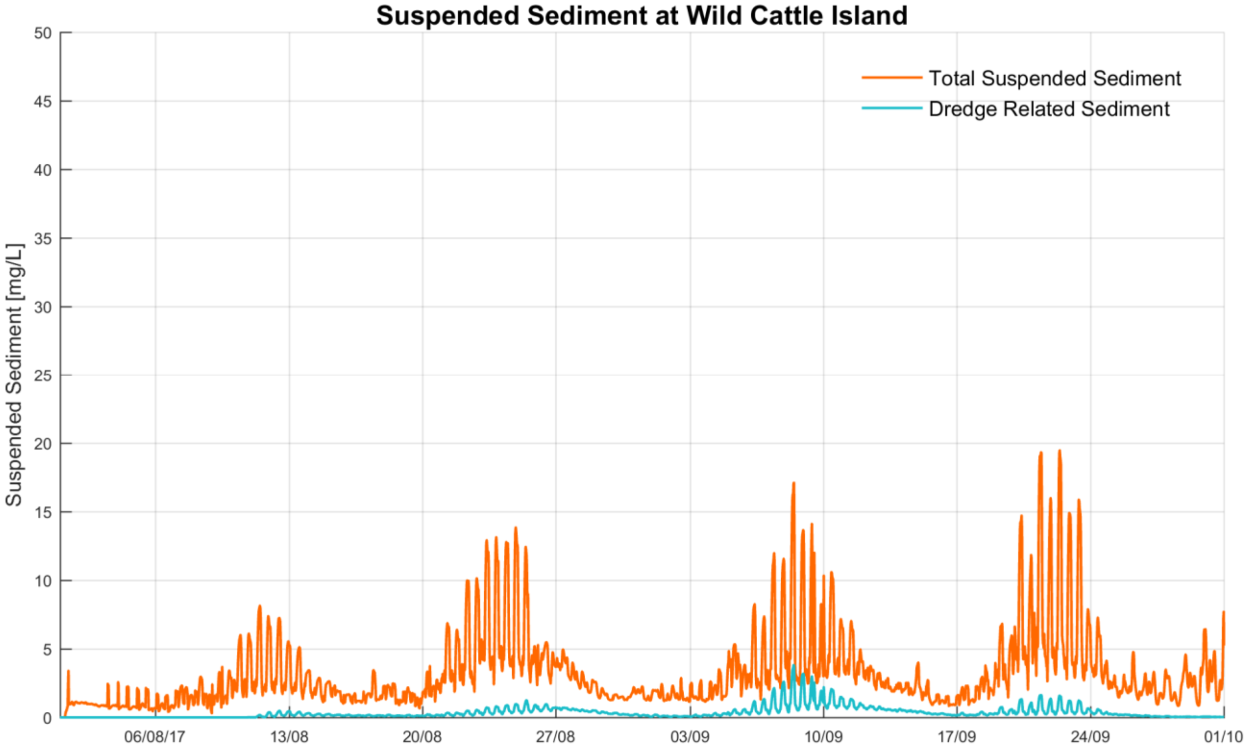
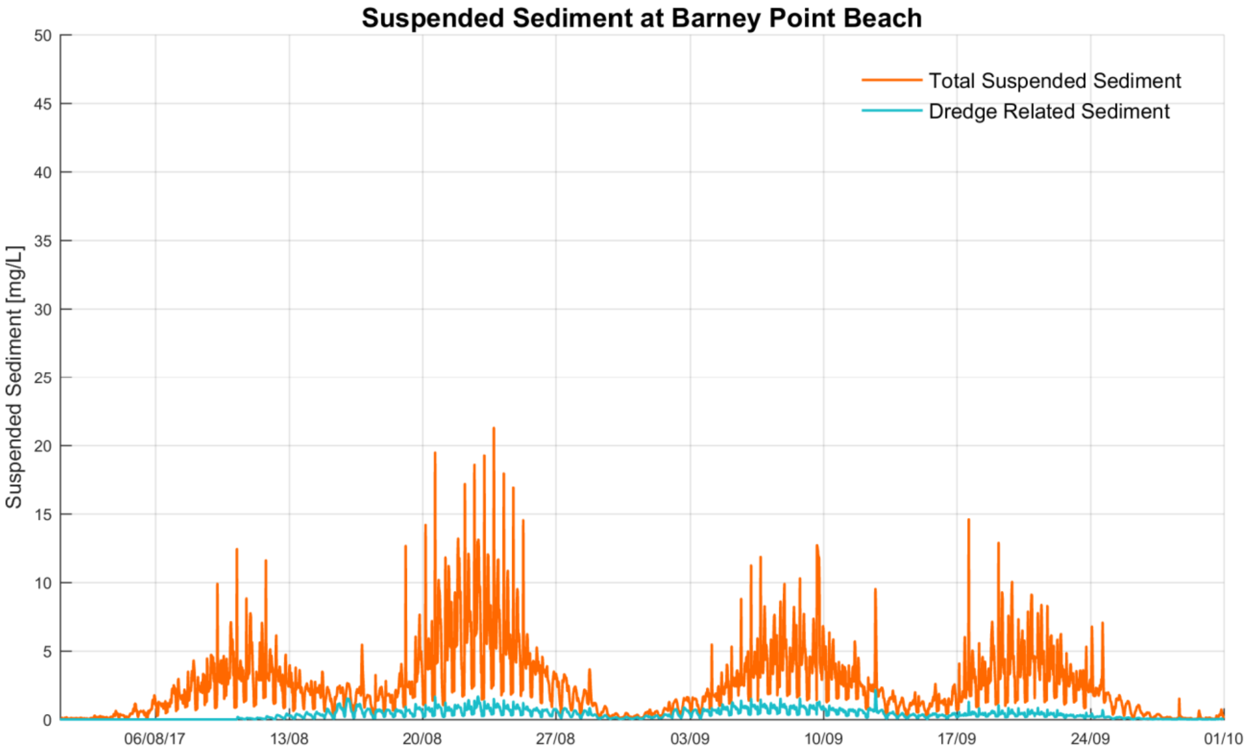


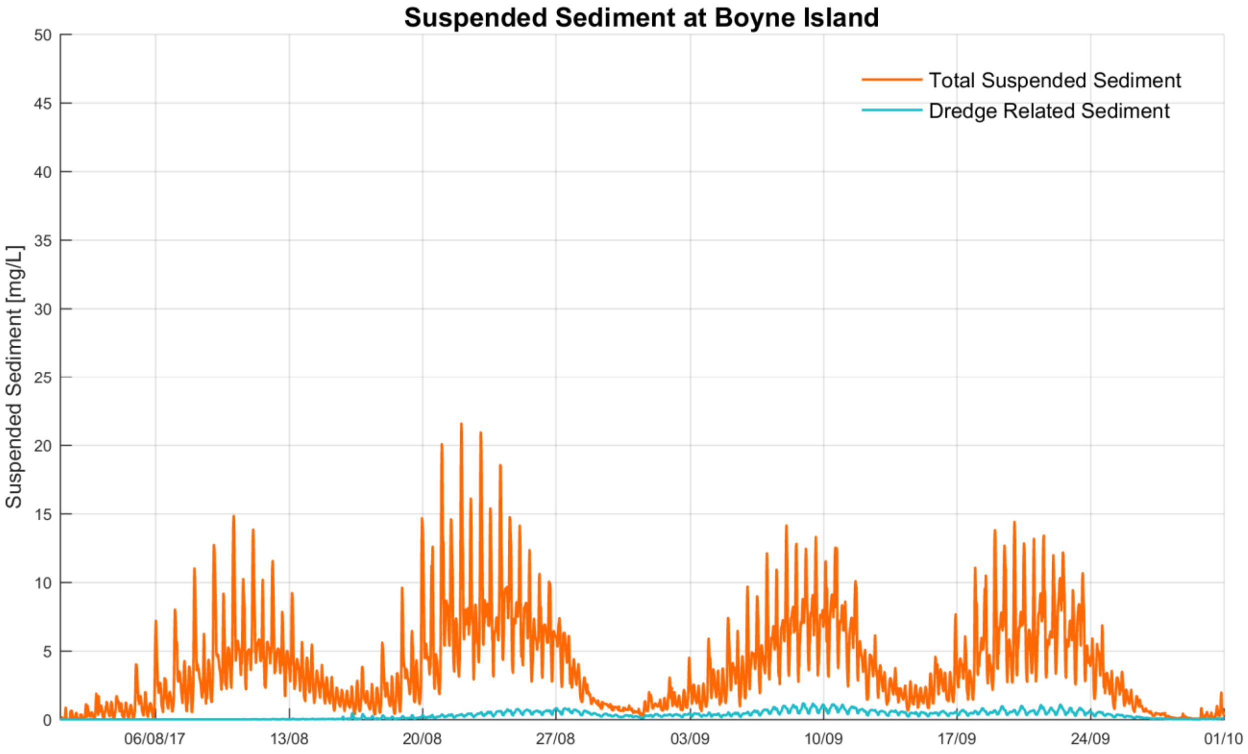


Time Series of TSS for Dredged and Ambient Sediment

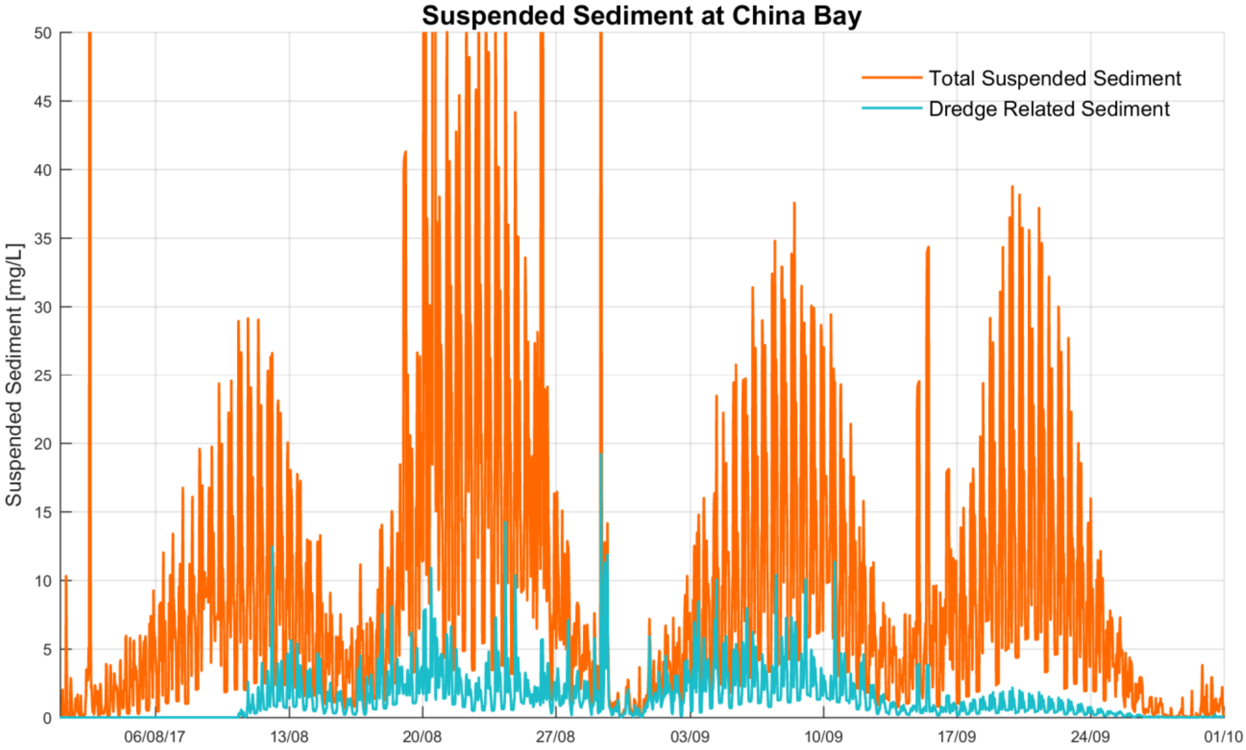


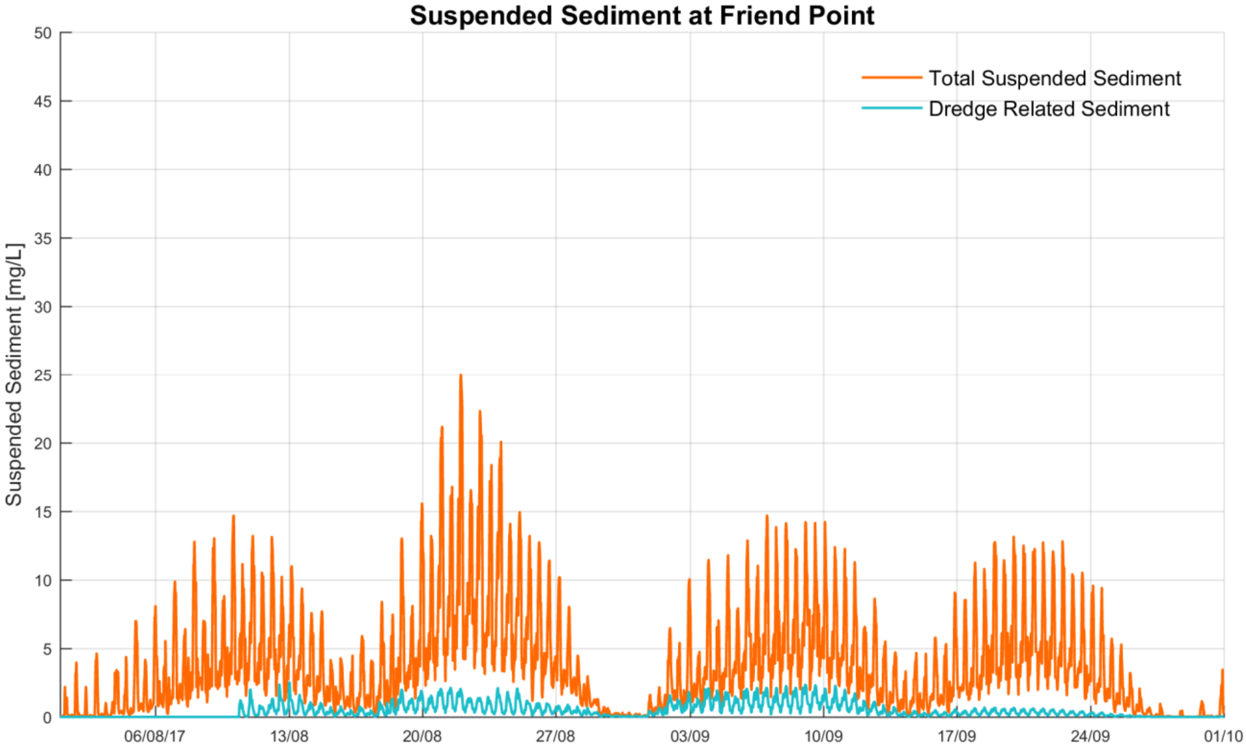
260,000m^3 Campaign





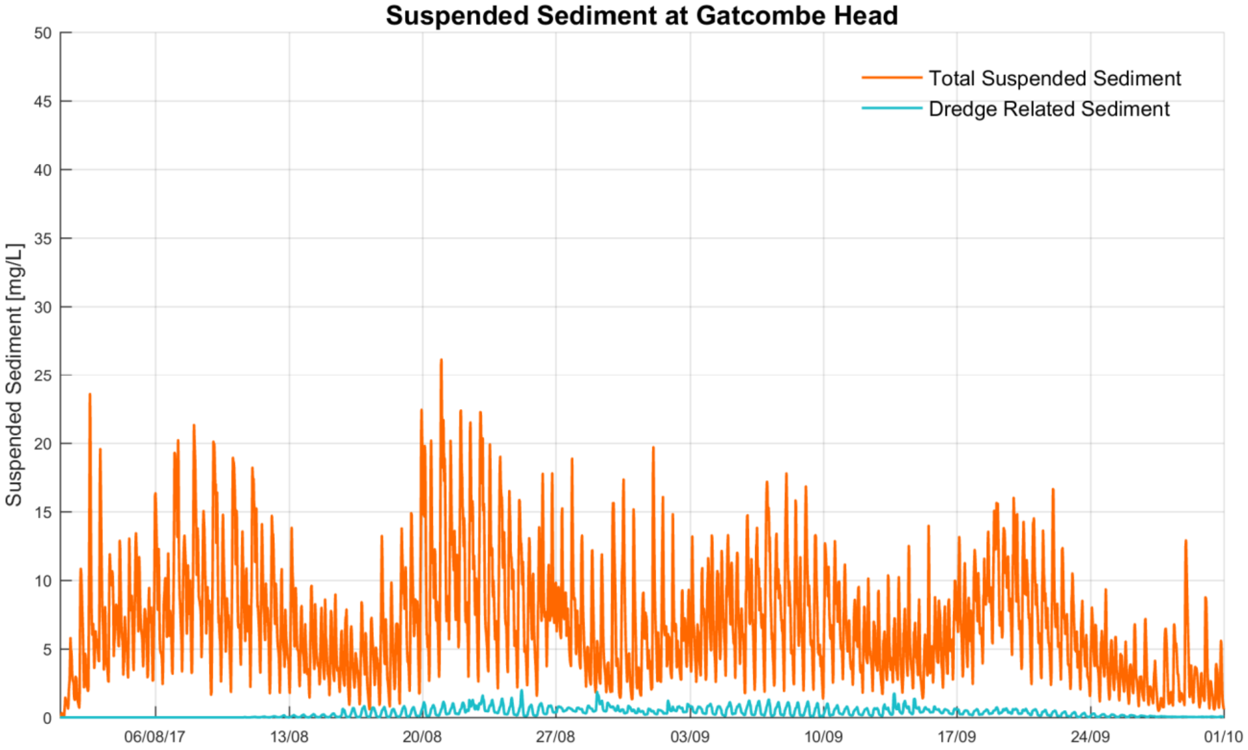
Time Series of TSS for Dredged and Ambient Sediment



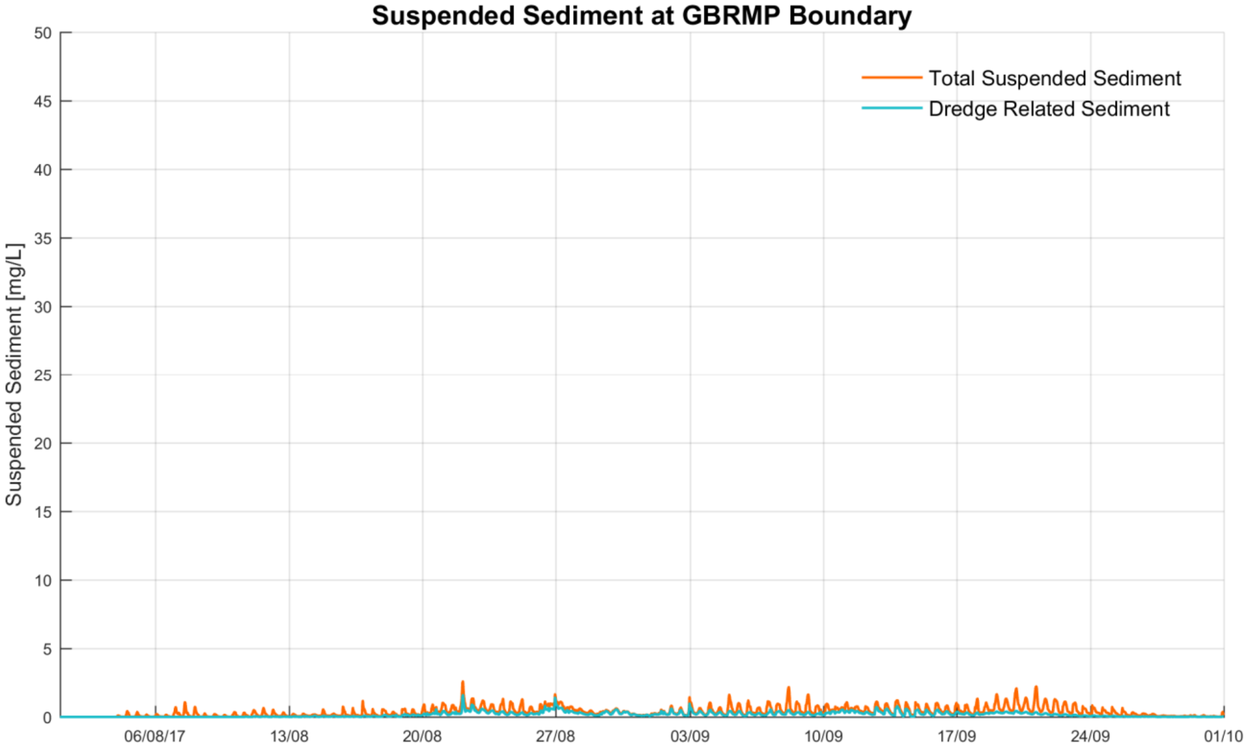


Time Series of TSS for Dredged and Ambient Sediment

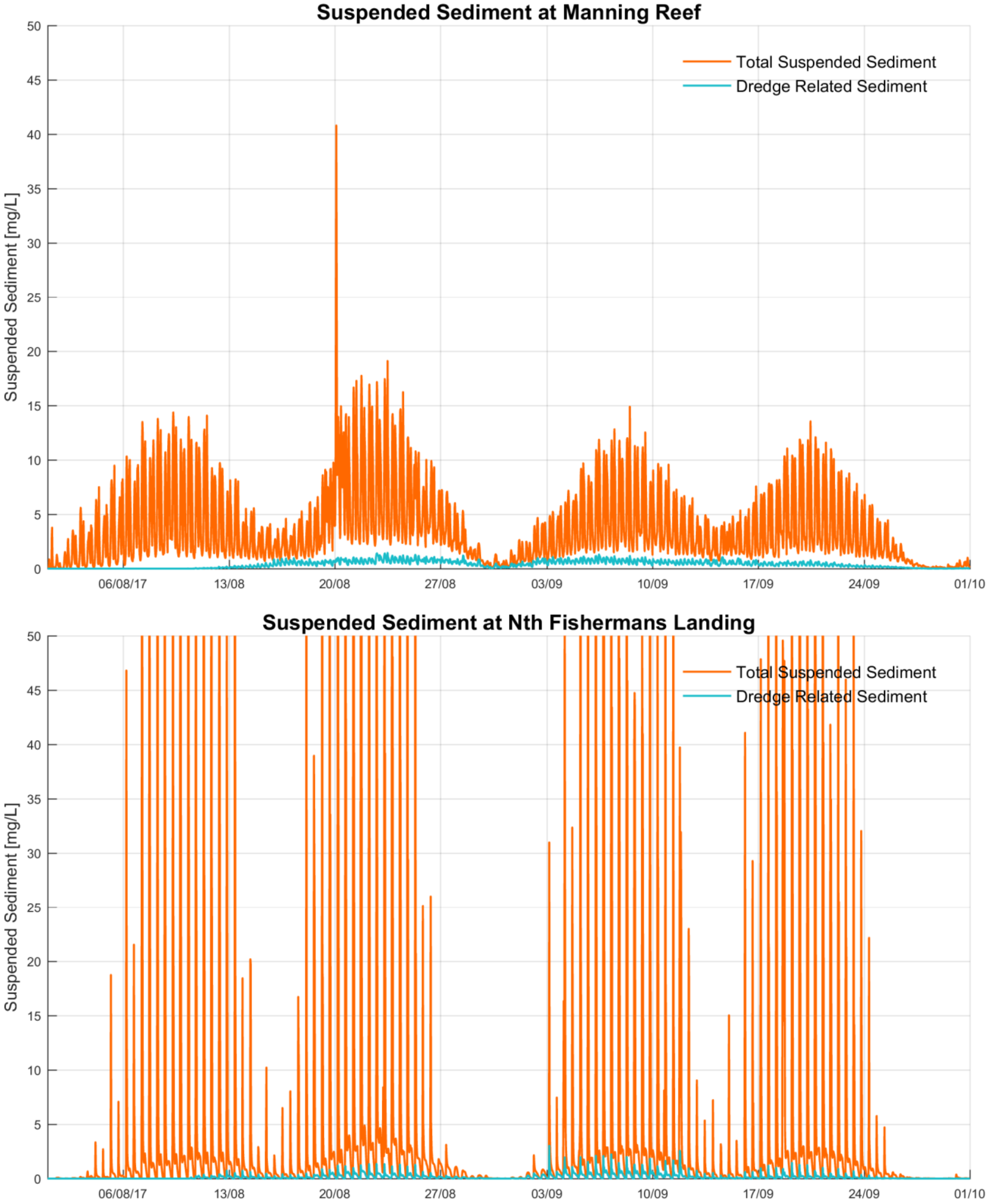
Suspended Sediment at Gatcombe Head



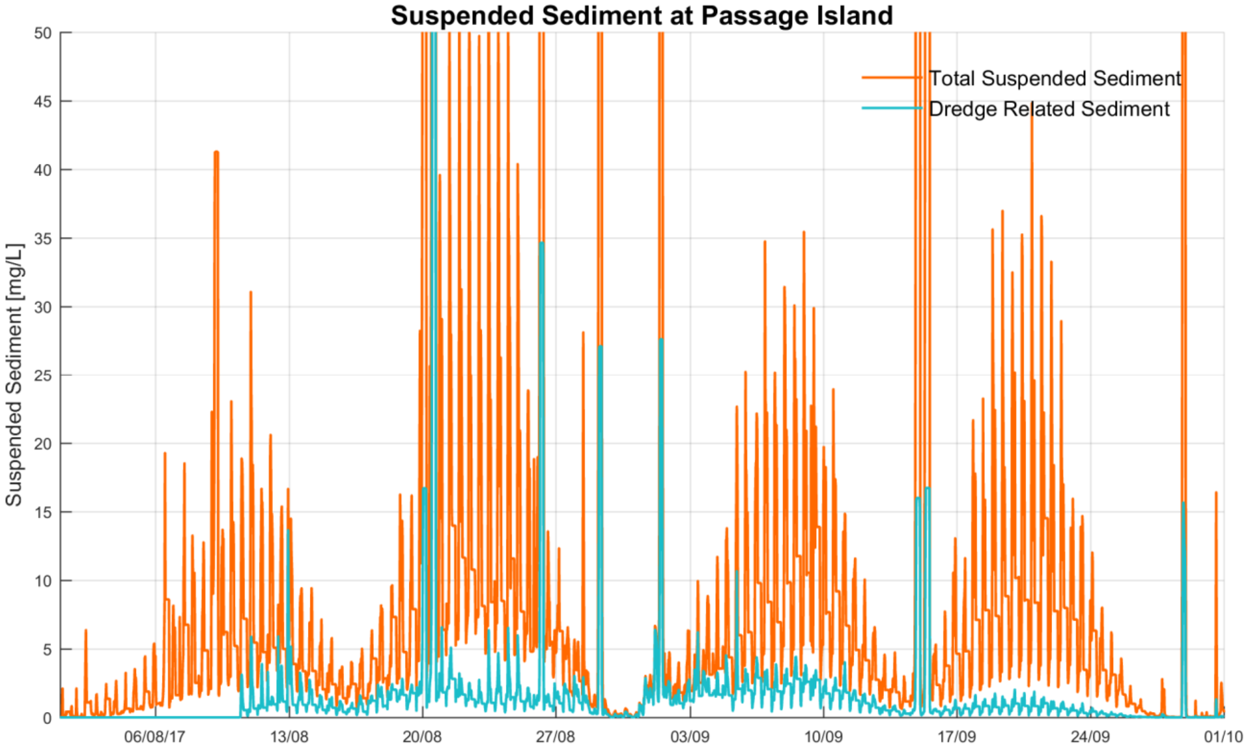
Suspended Sediment at GBRMP Boundary

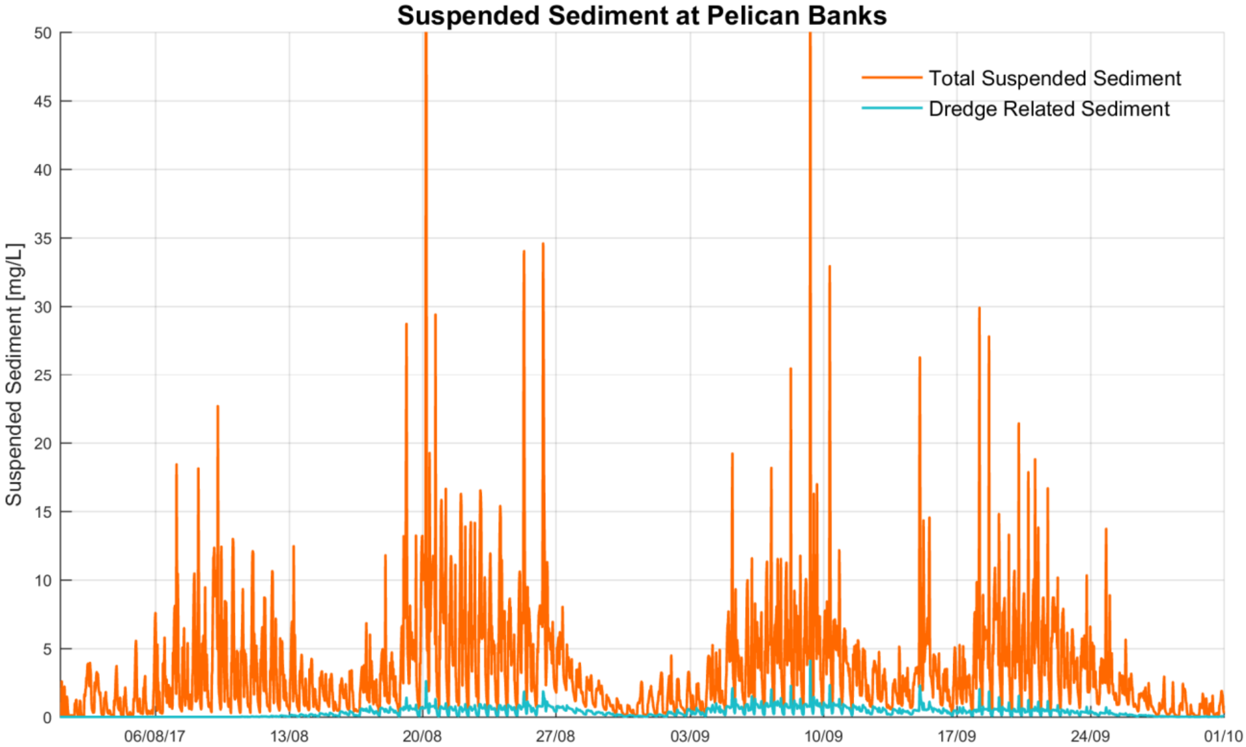


Time Series of TSS for Dredged and Ambient Sediment

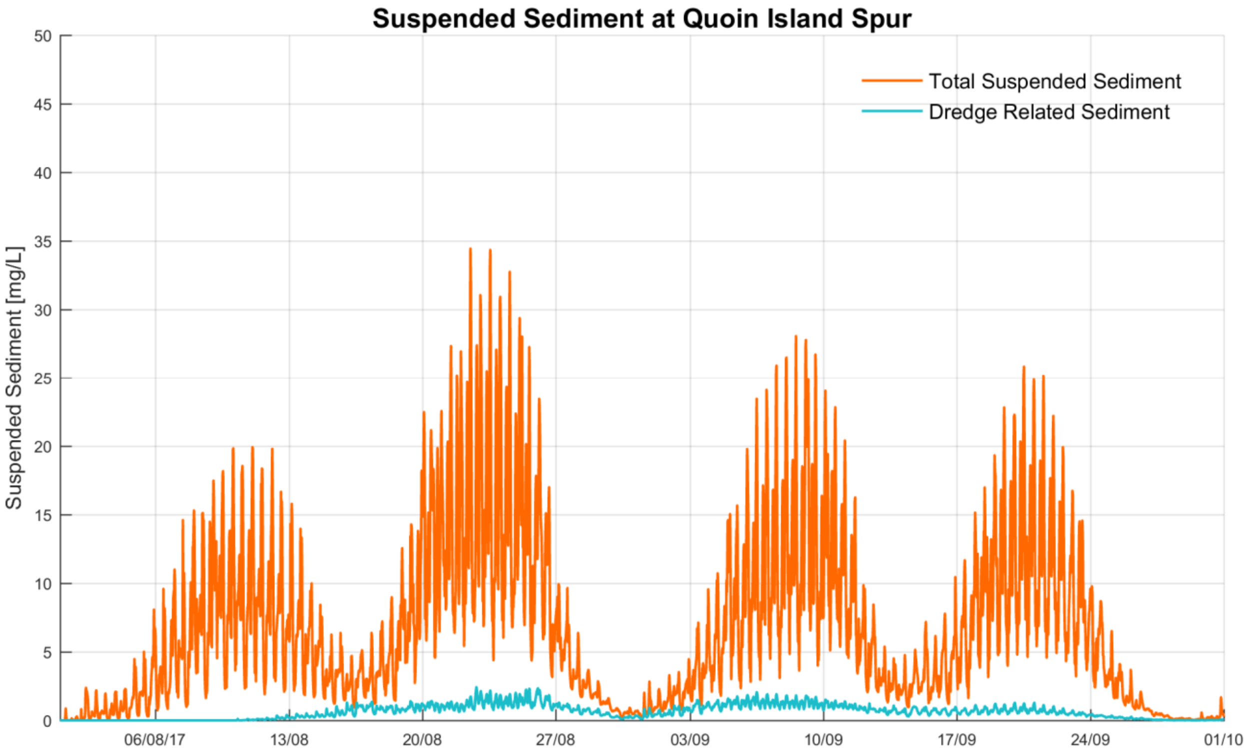


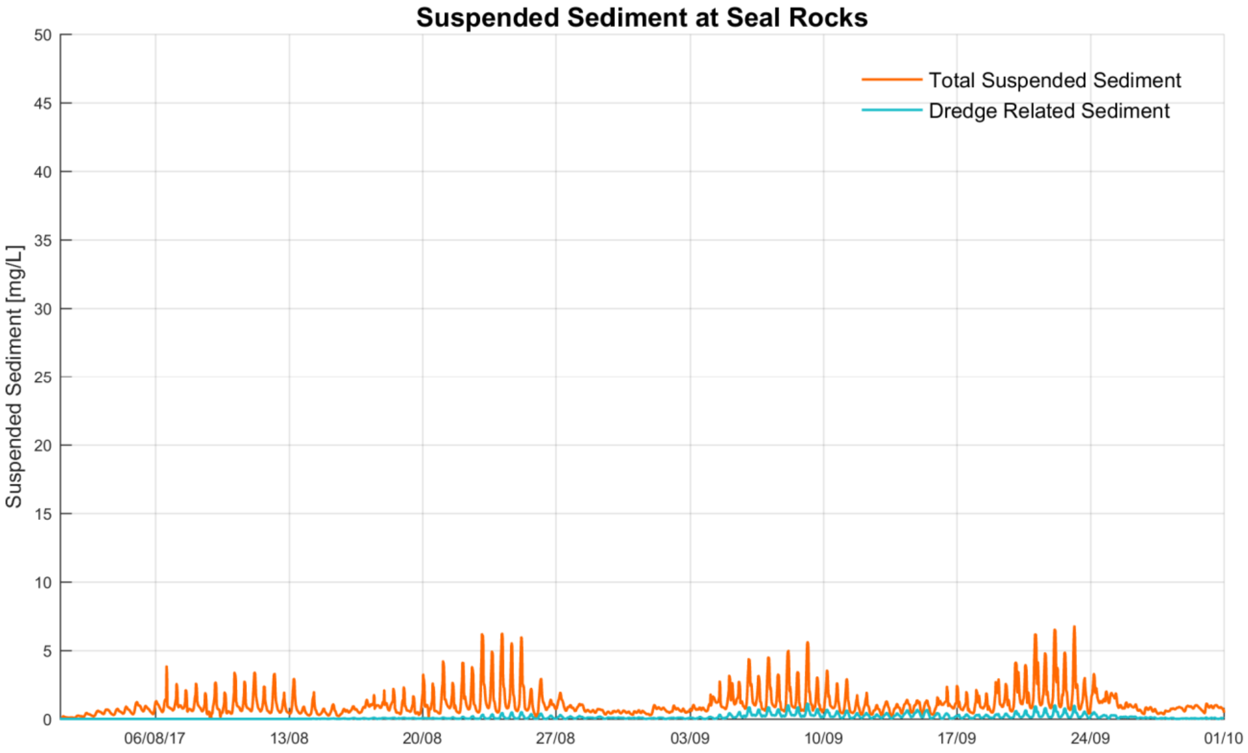
Time Series of TSS for Dredged and Ambient Sediment



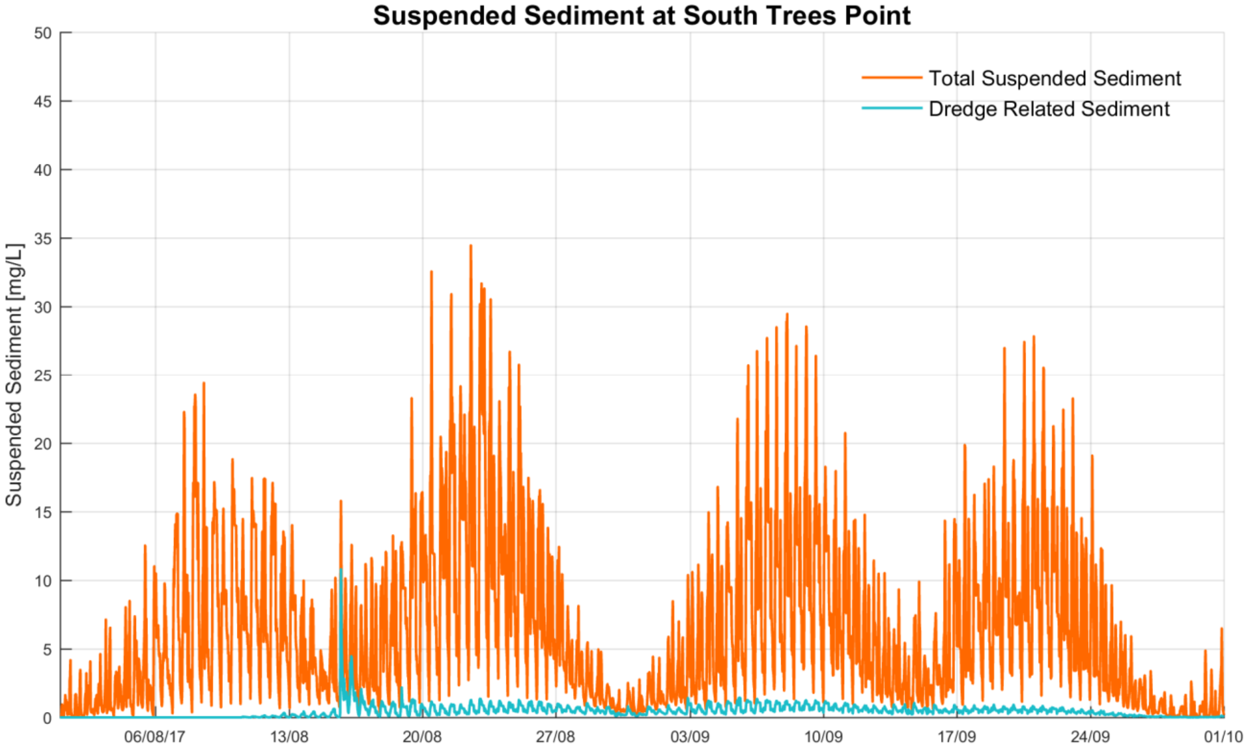


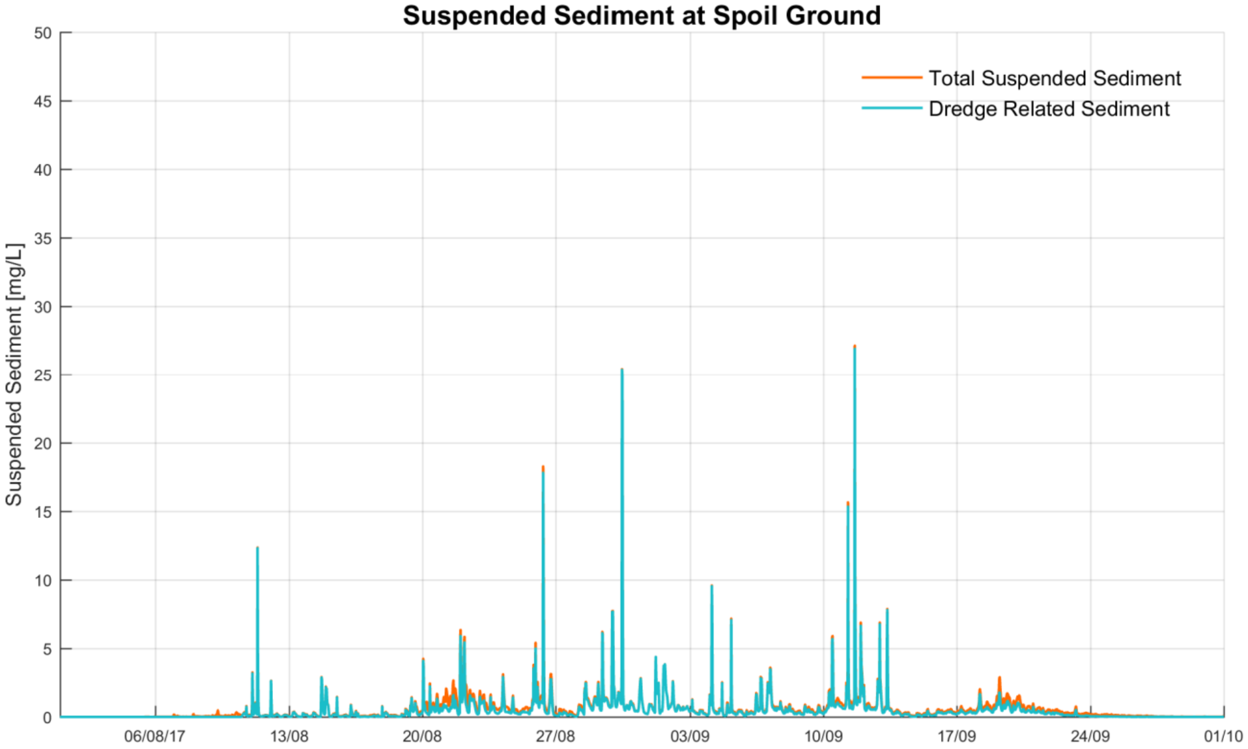
Time Series of TSS for Dredged and Ambient Sediment


Suspended Sediment at Quoin Island Spur

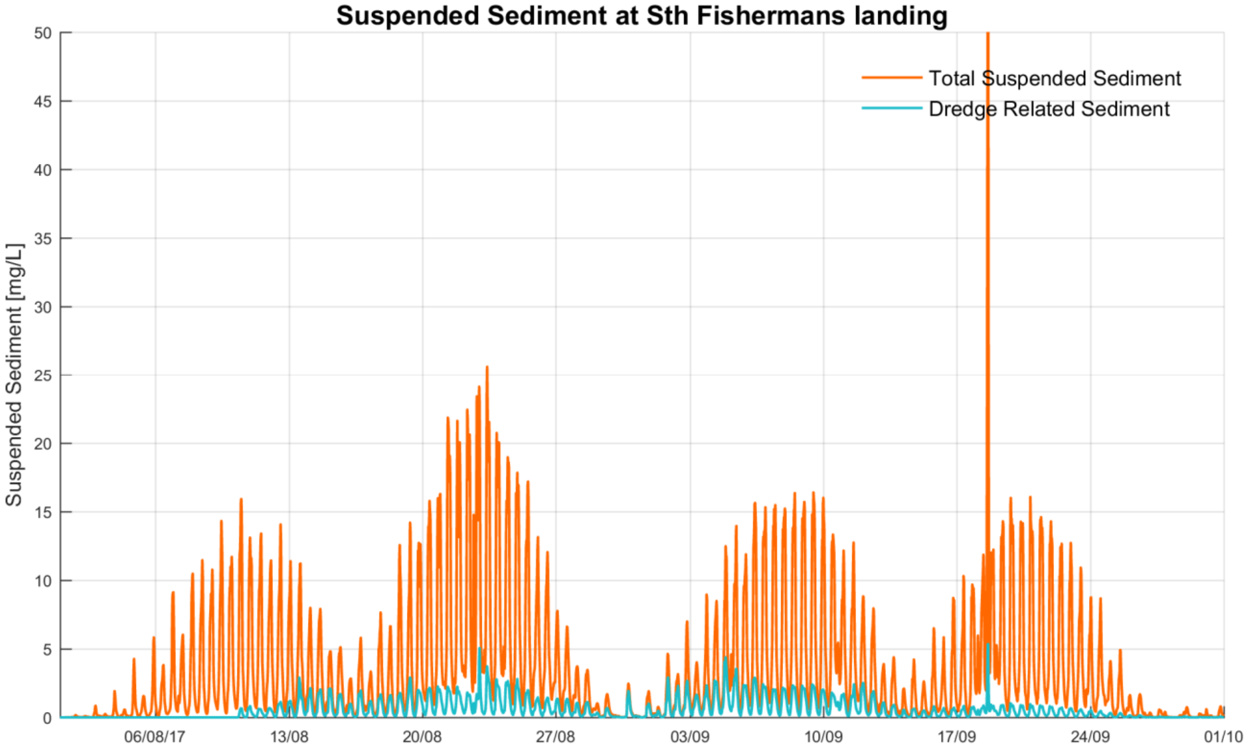

Suspended Sediment at Seal Rocks

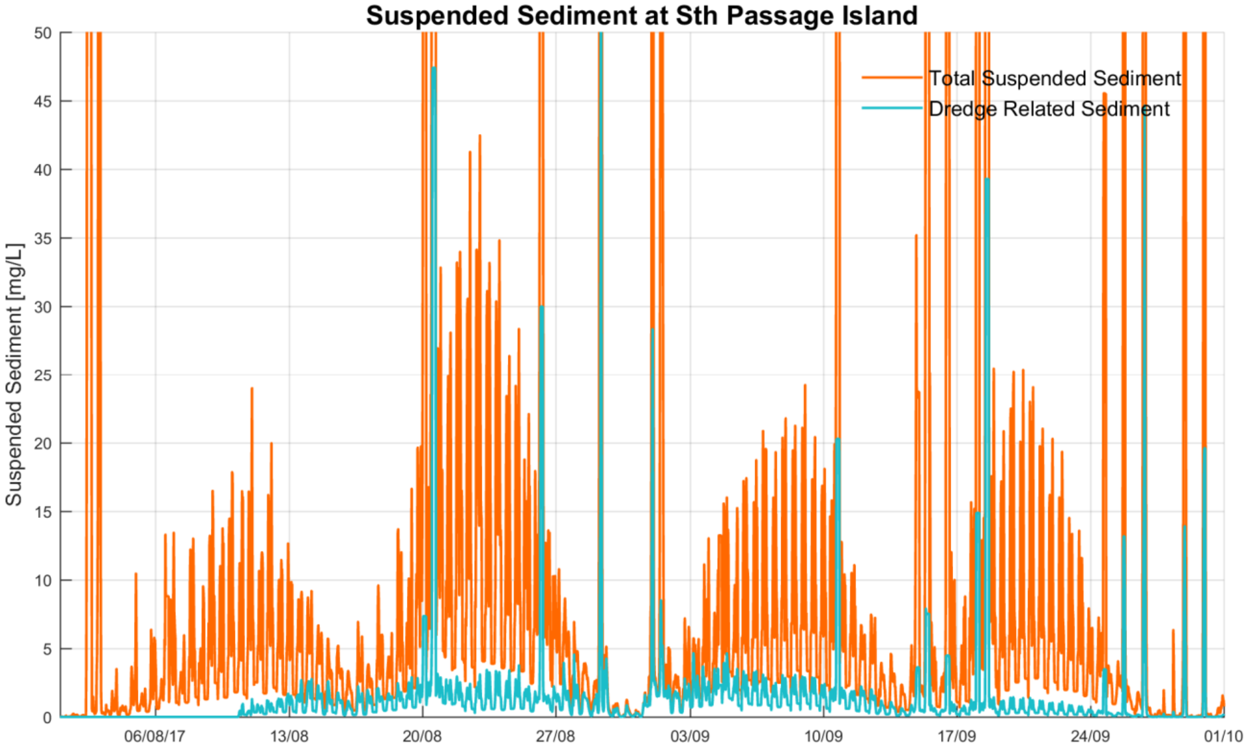
Time Series of TSS for Dredged and Ambient Sediment



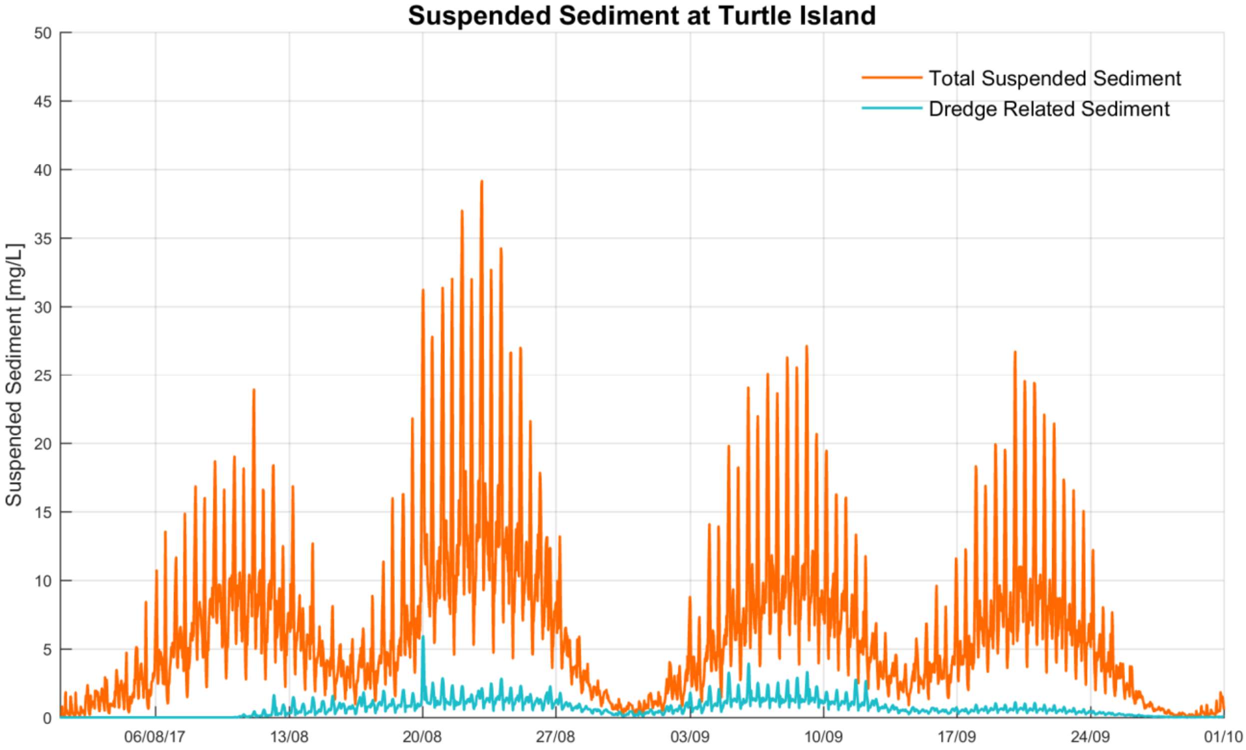


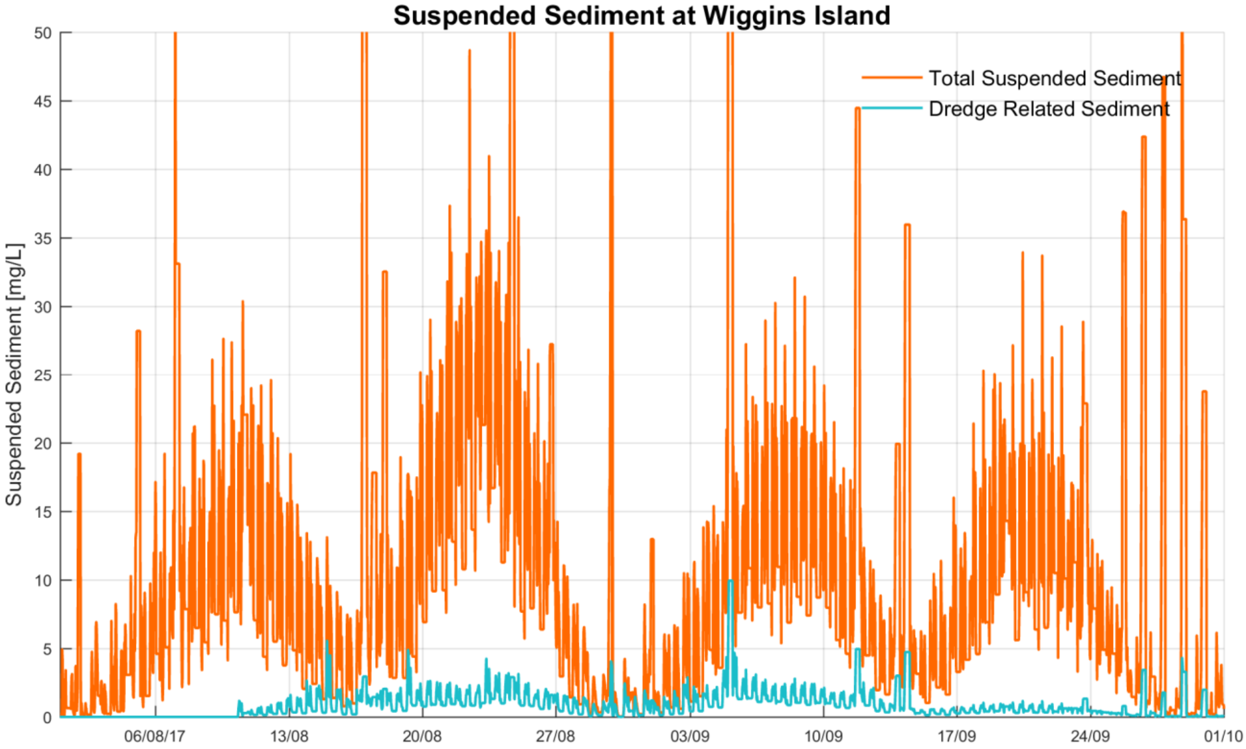
Time Series of TSS for Dredged and Ambient Sediment

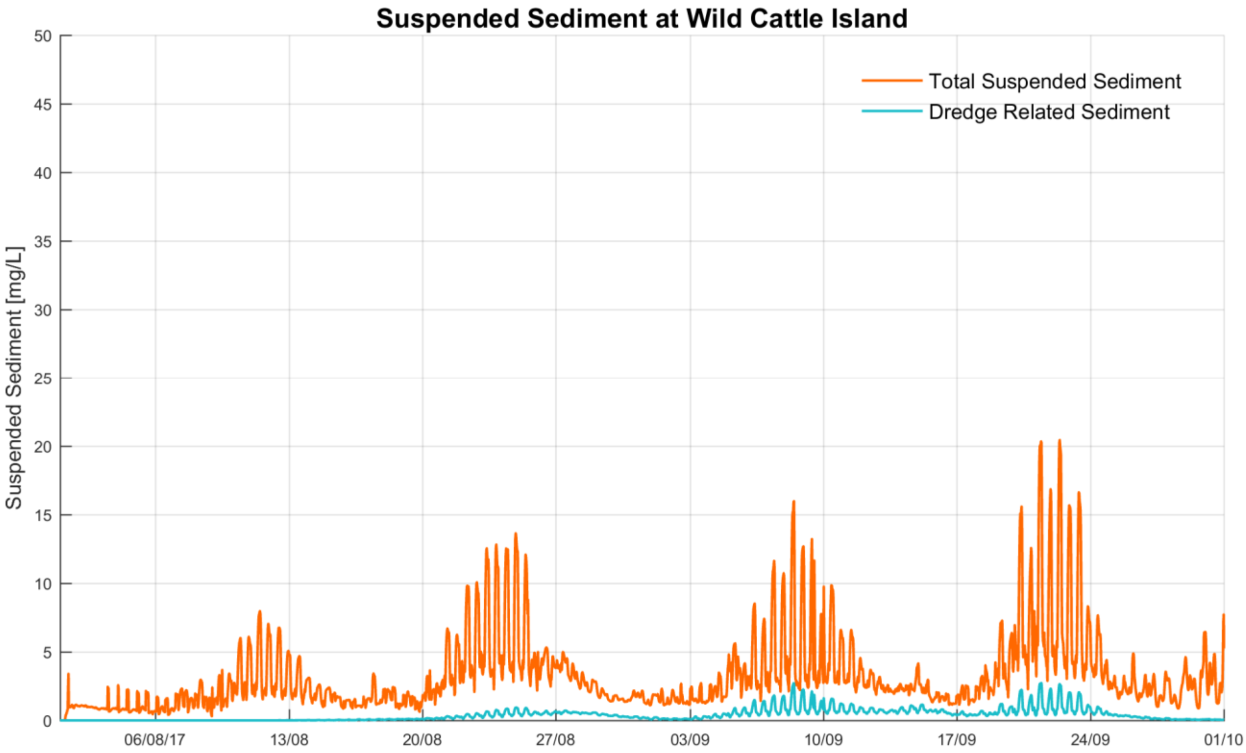




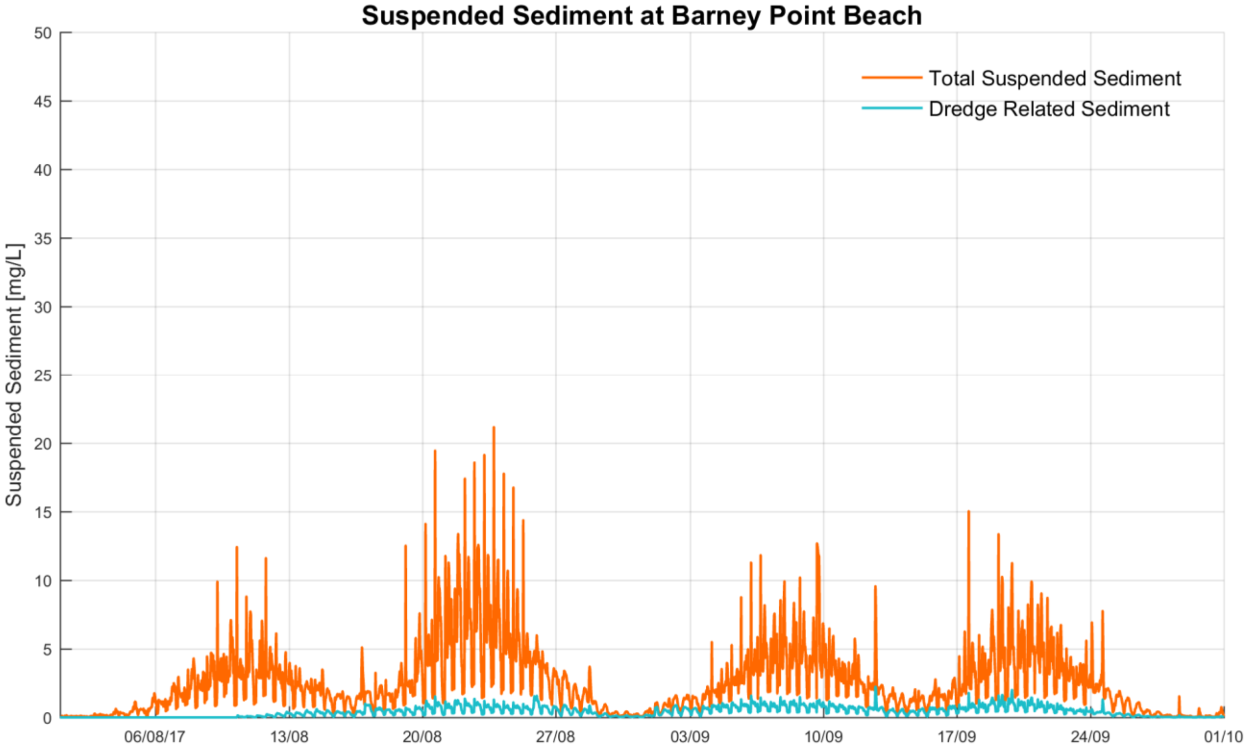
Time Series of TSS for Dredged and Ambient Sediment

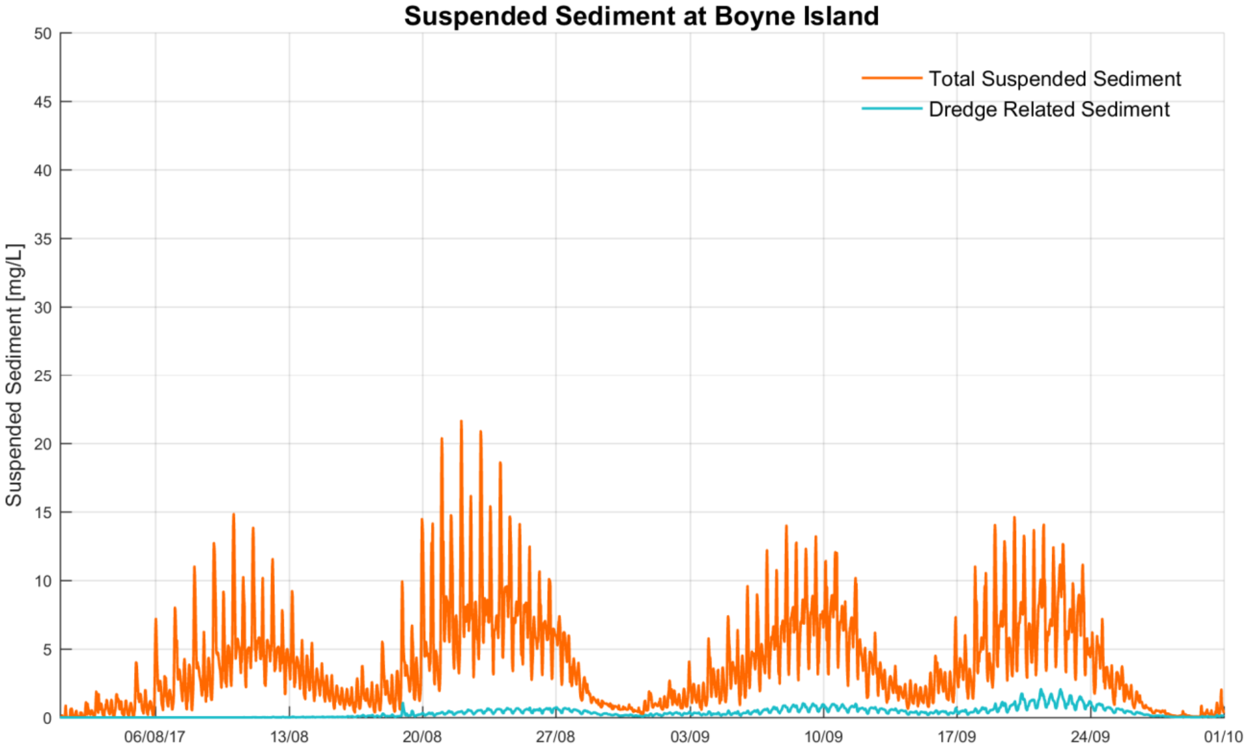




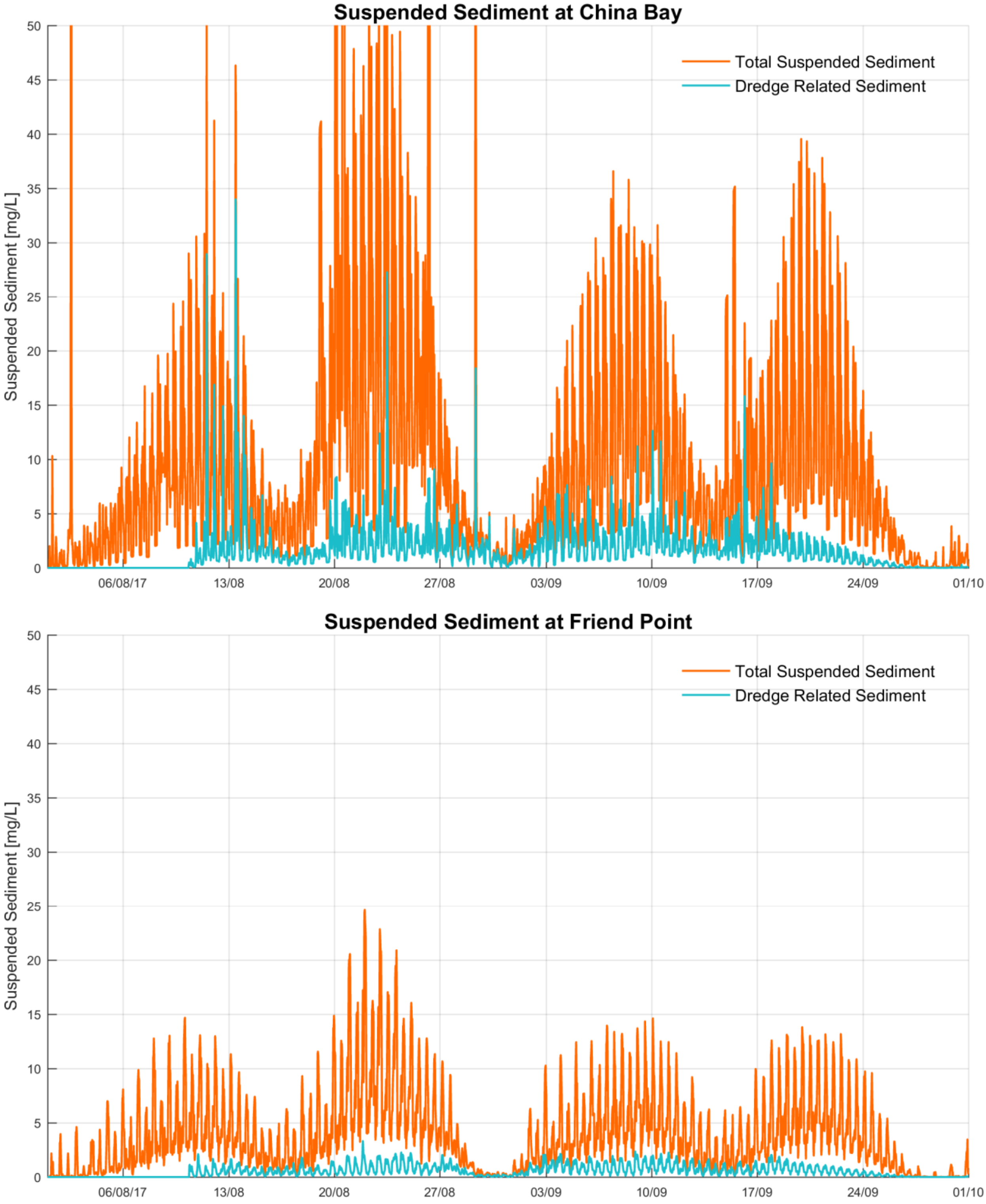

Suspended Sediment at Wild Cattle Island
Suspended Sediment [mg/L]
0
5
10
15
20
25
30
35
40
45
50
06/08/17
13/08
20/08
27/08
03/09
10/09
17/09
24/09
01/10
Total Suspended Sediment
Dredge Related Sediment

300,000m^3 Campaign

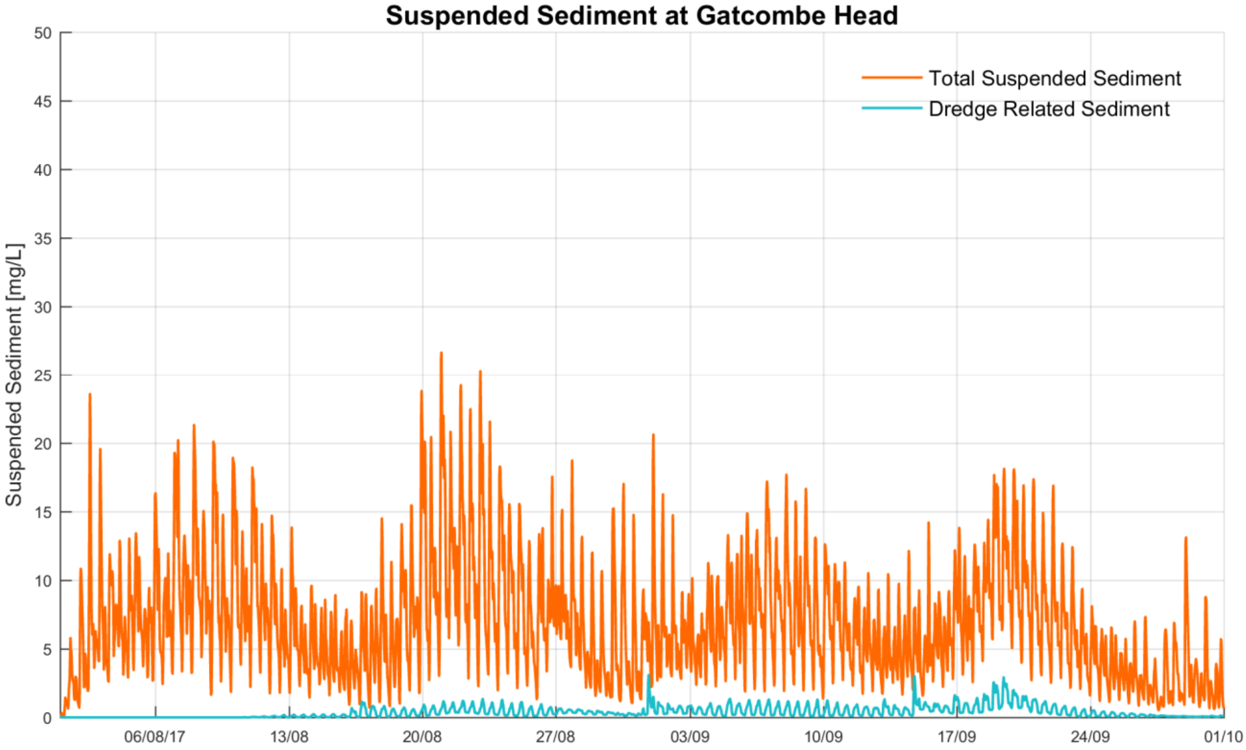


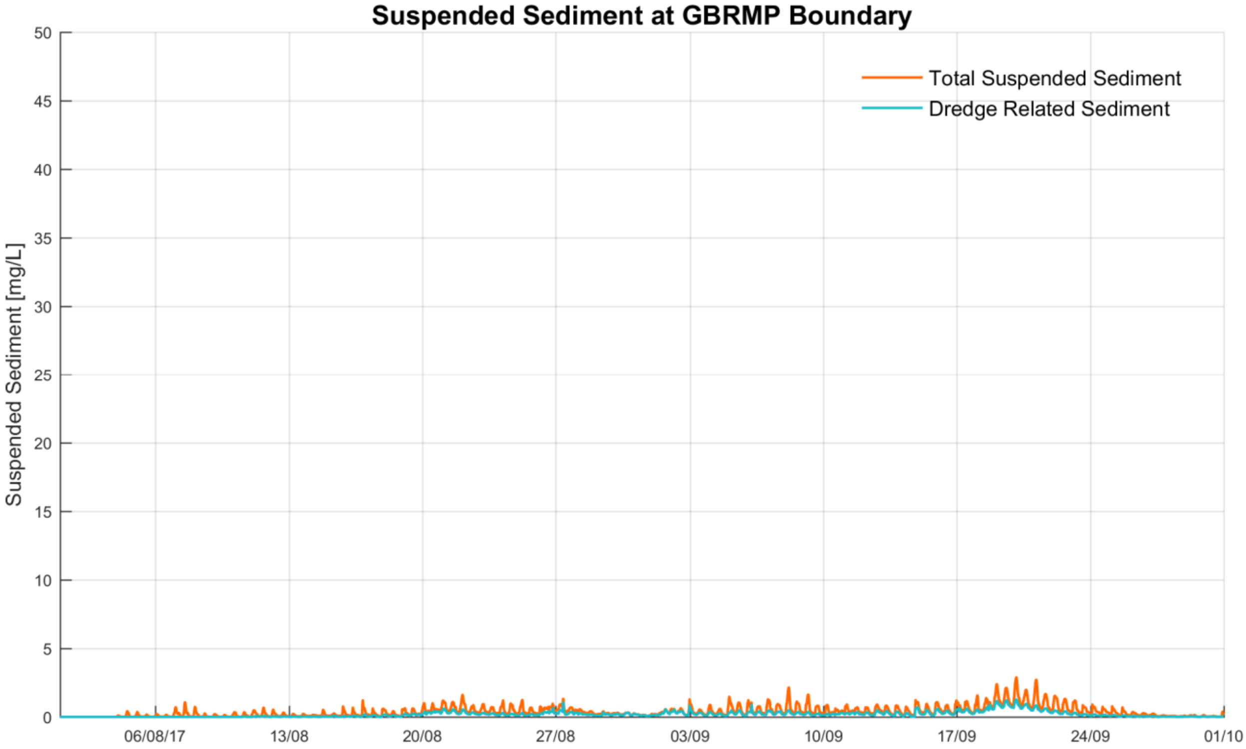


Time Series of TSS for Dredged and Ambient Sediment

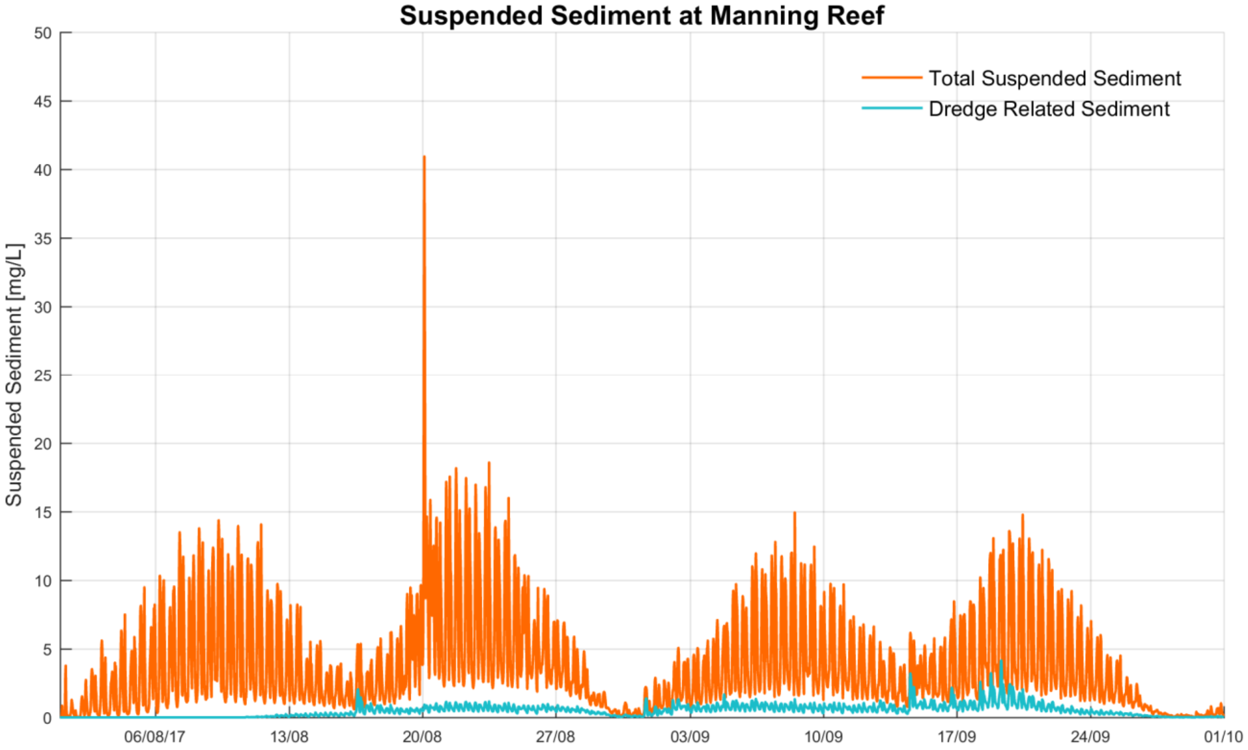


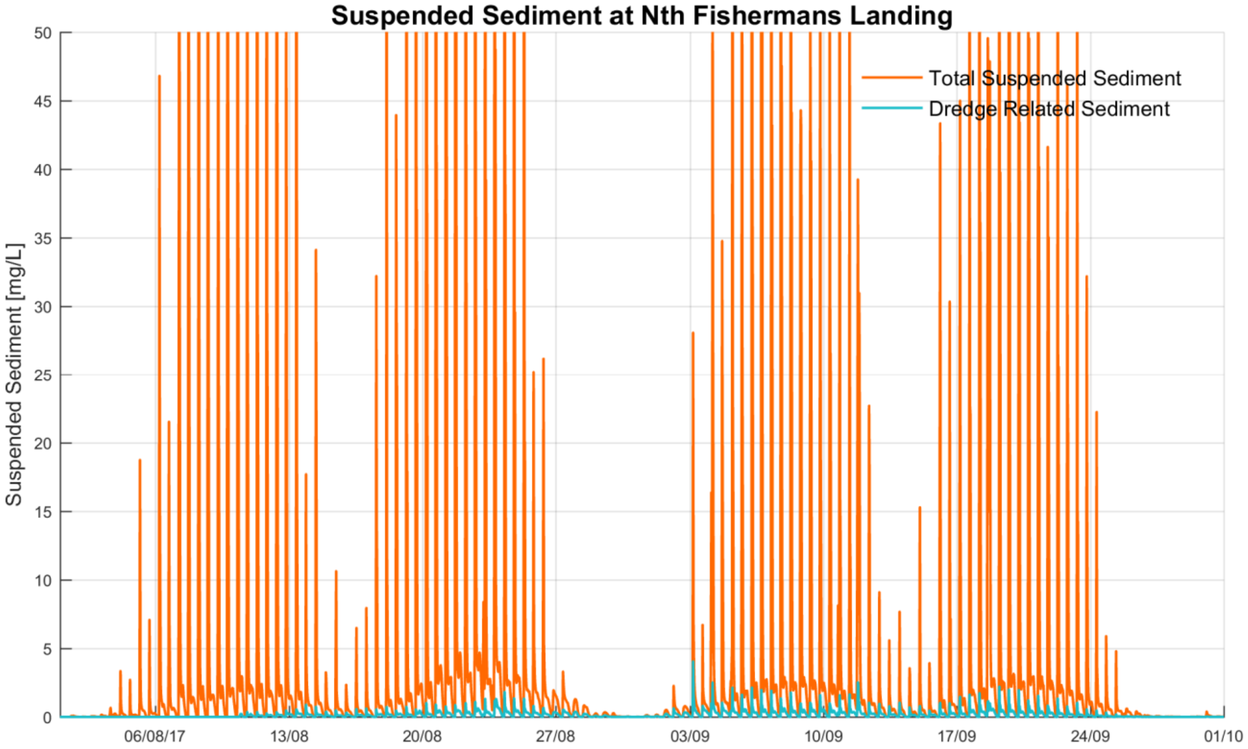
Time Series of TSS for Dredged and Ambient Sediment



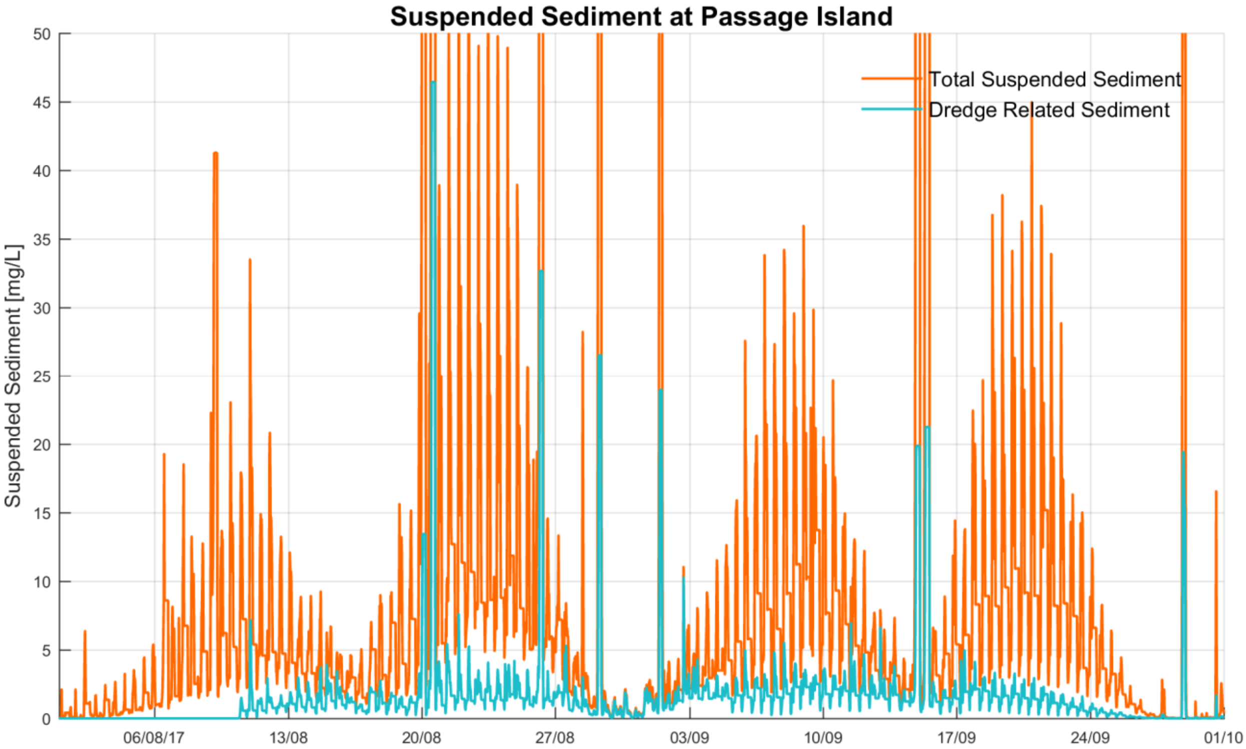


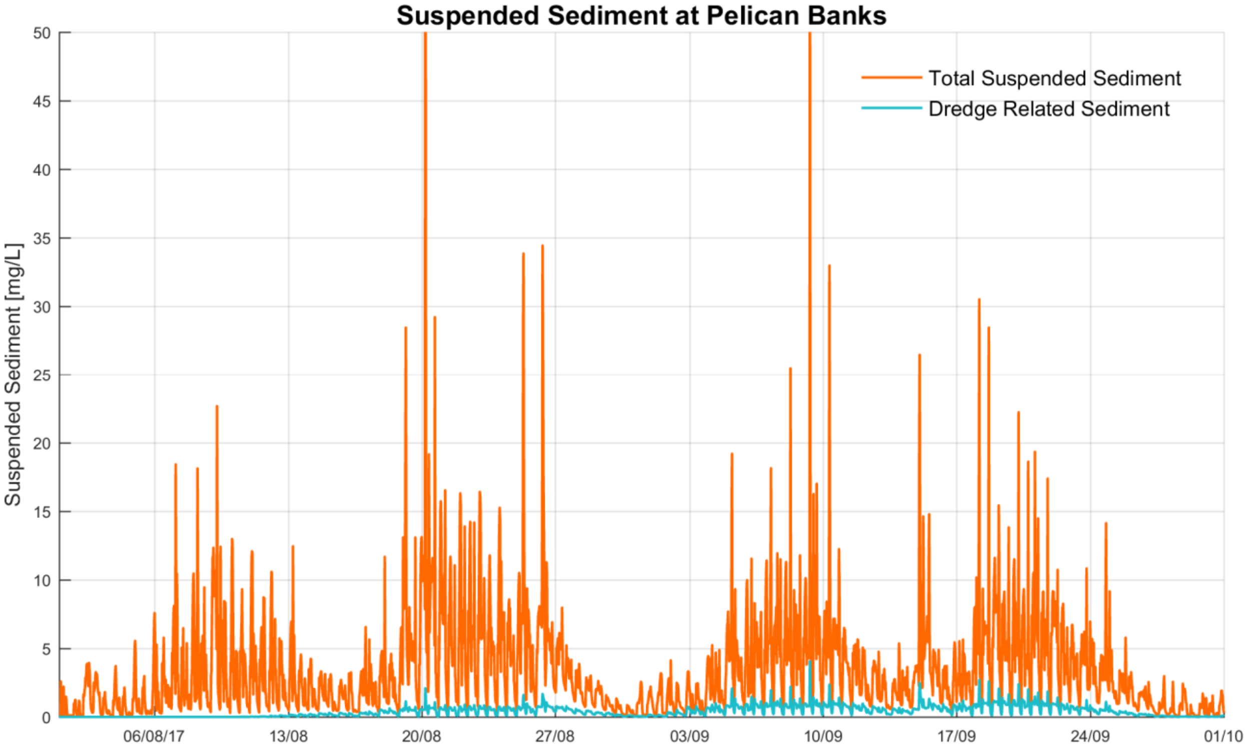
Time Series of TSS for Dredged and Ambient Sediment



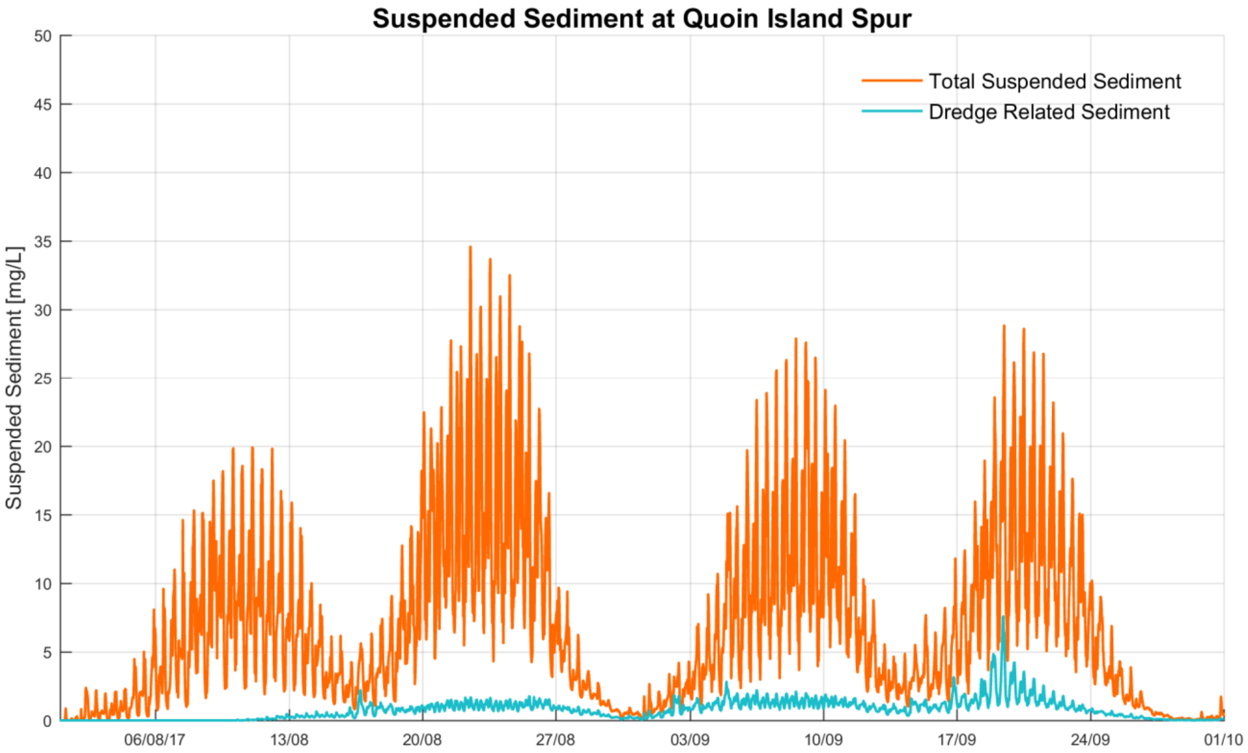


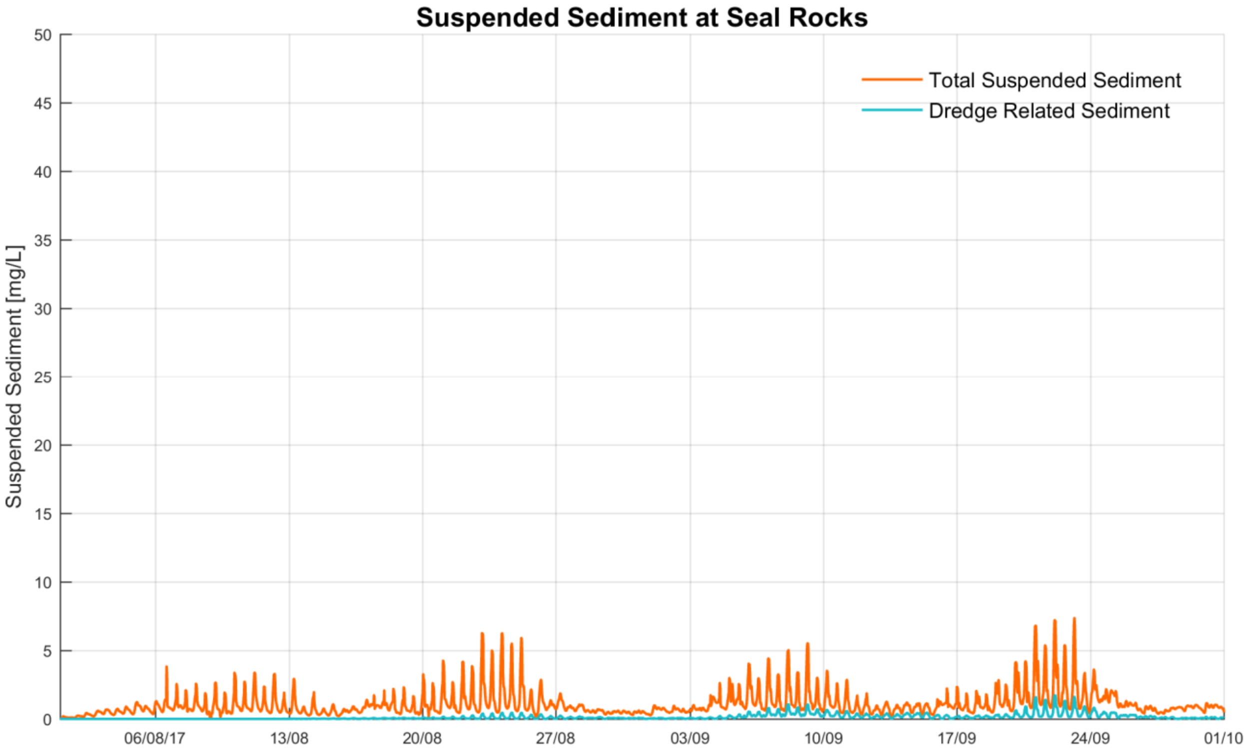
Time Series of TSS for Dredged and Ambient Sediment



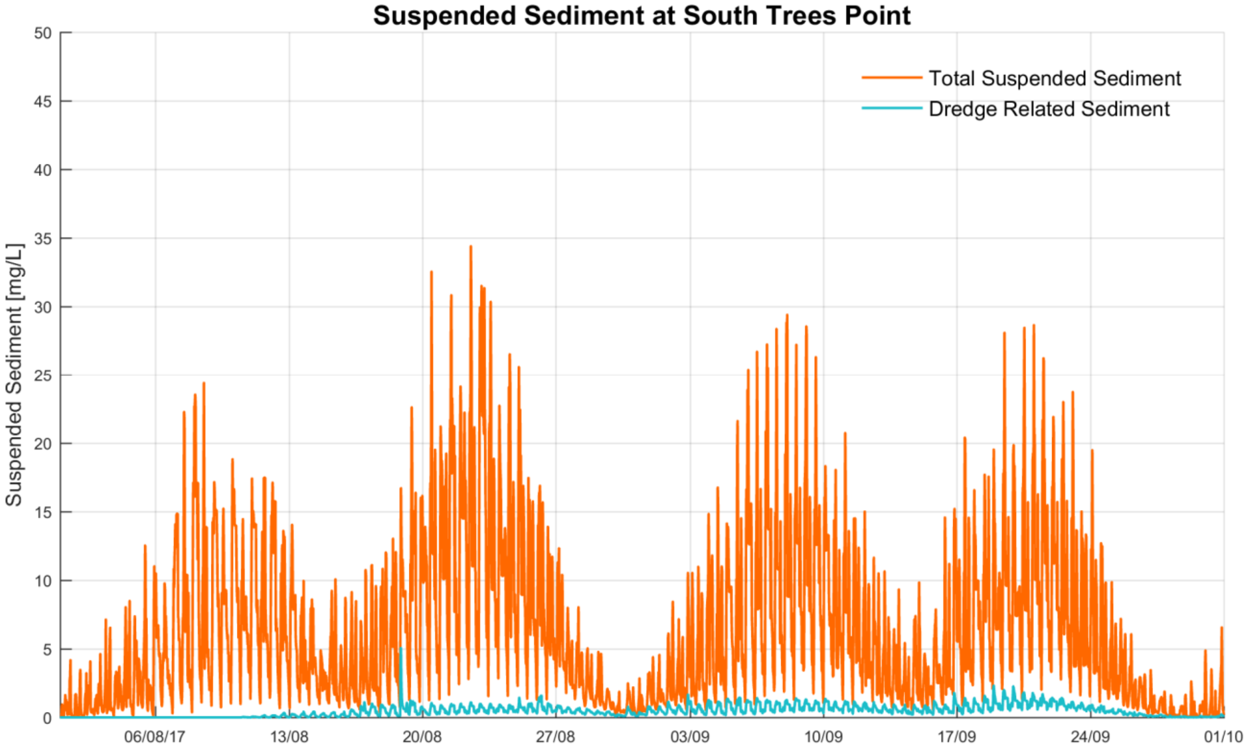


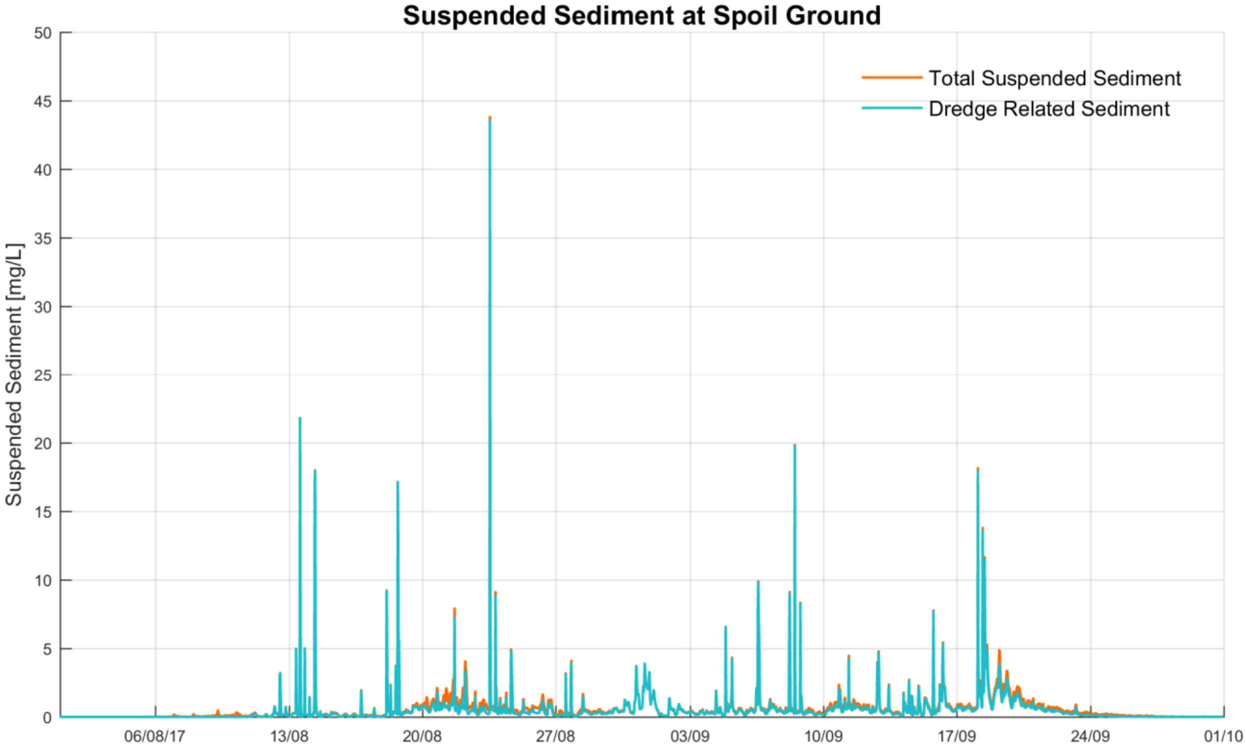
Time Series of TSS for Dredged and Ambient Sediment



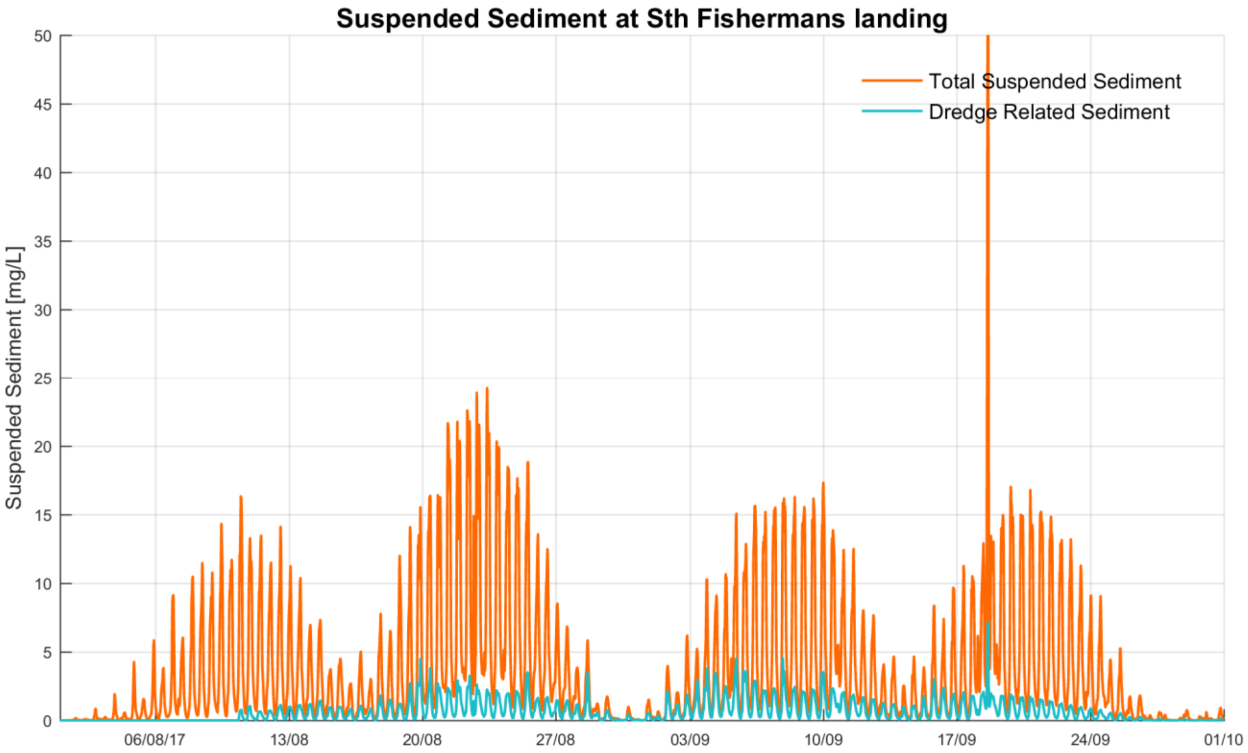


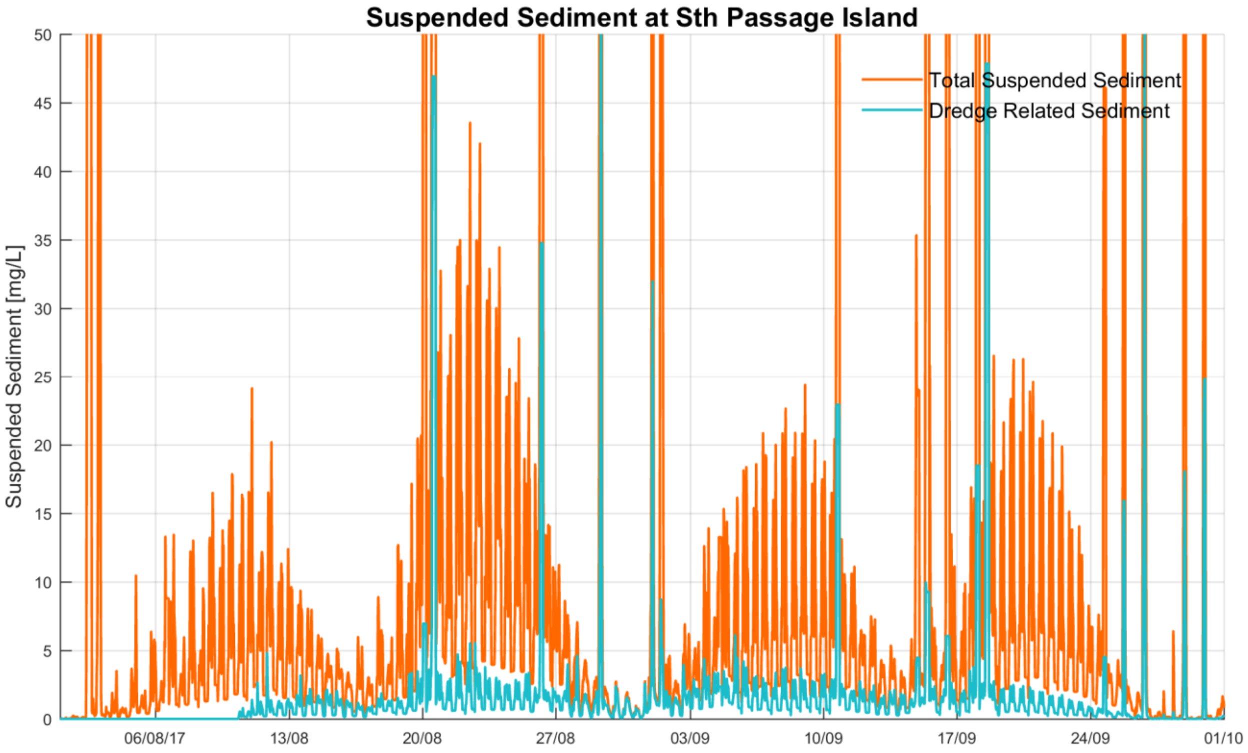
Time Series of TSS for Dredged and Ambient Sediment



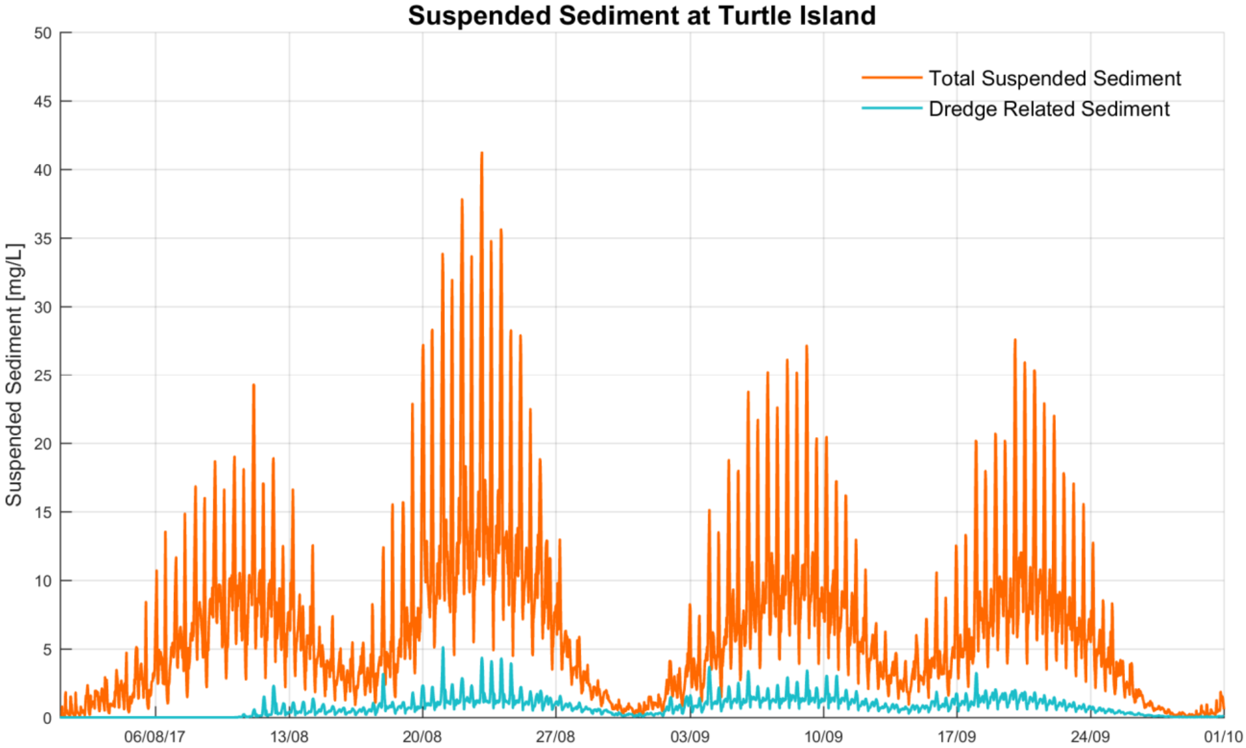


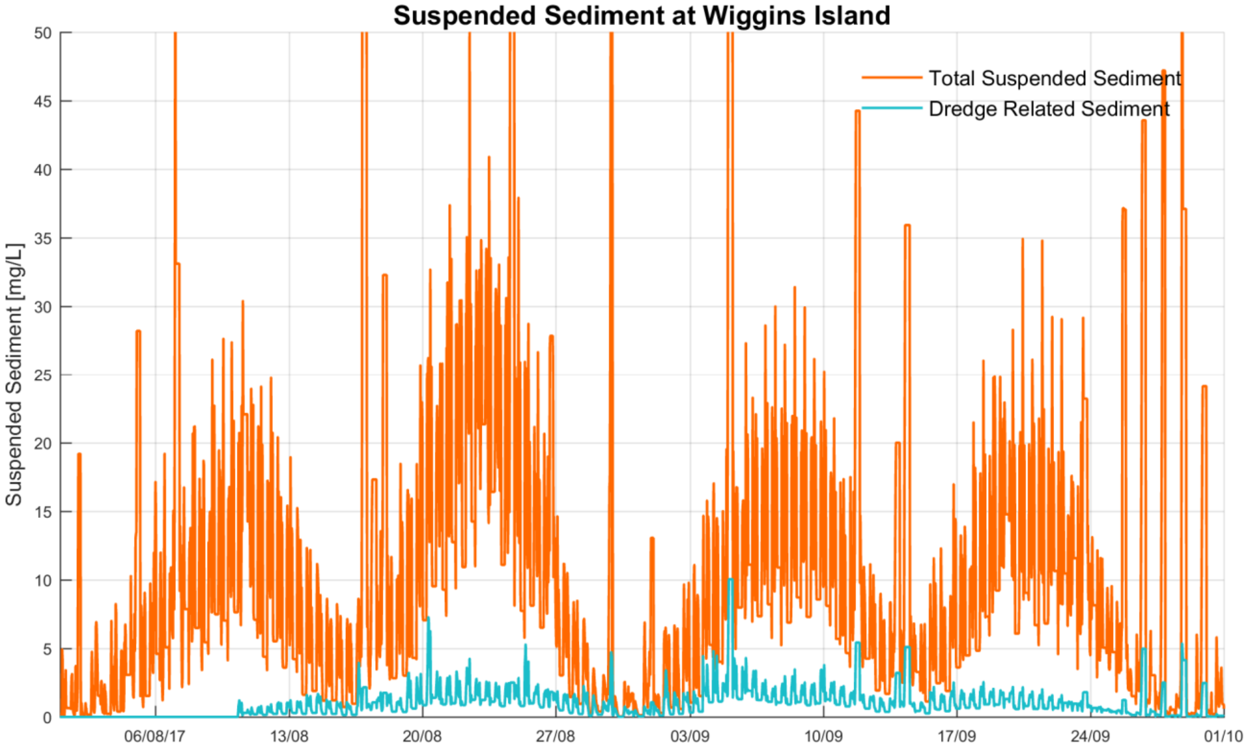
Time Series of TSS for Dredged and Ambient Sediment



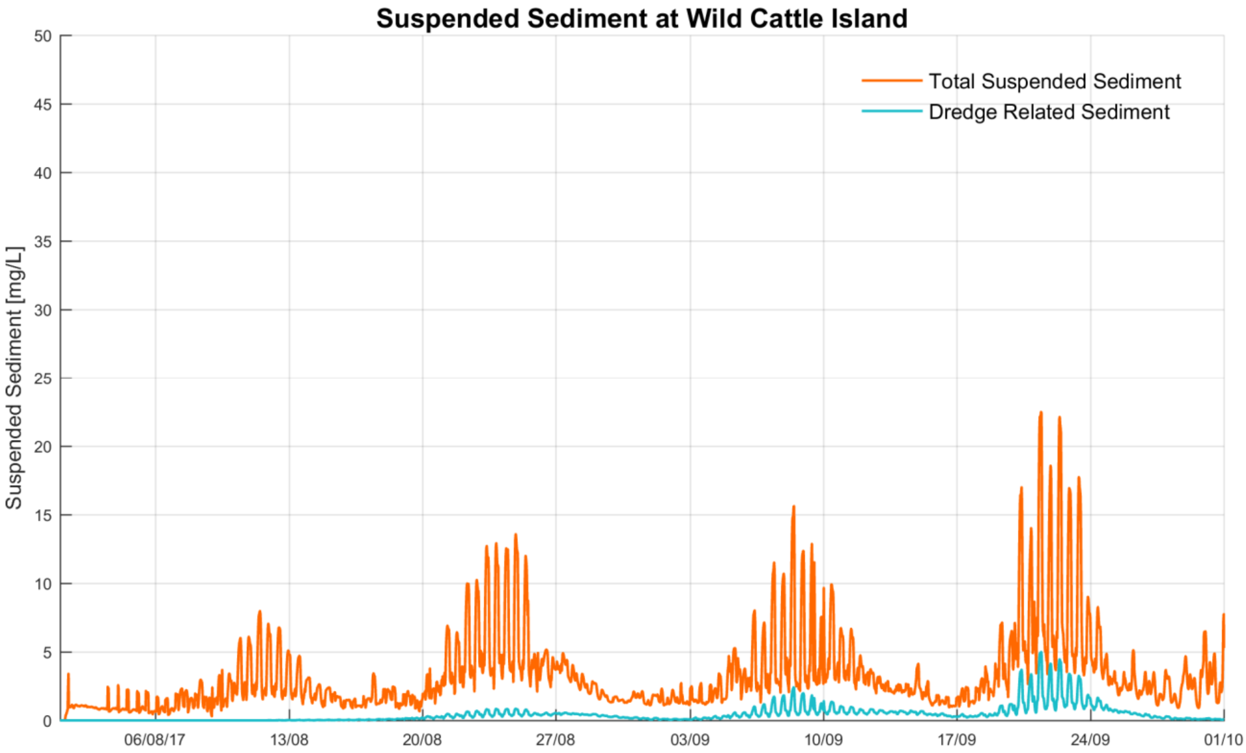


Time Series of TSS for Dredged and Ambient Sediment

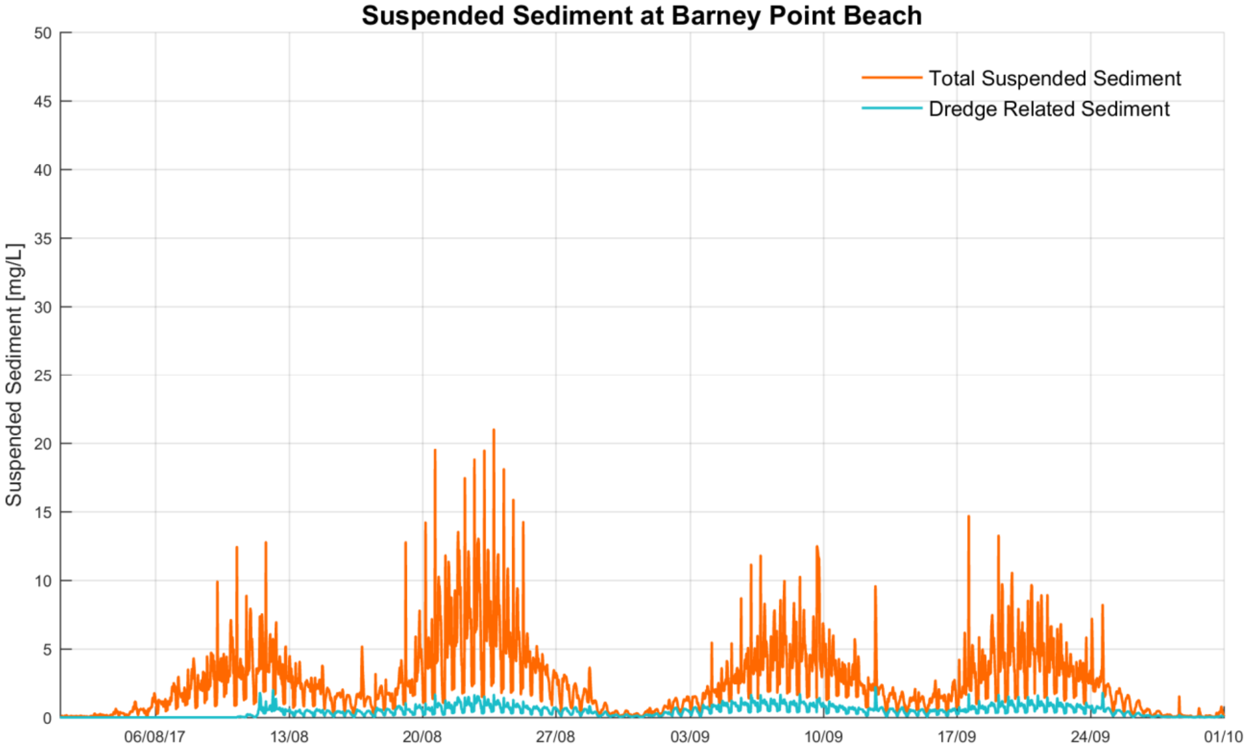


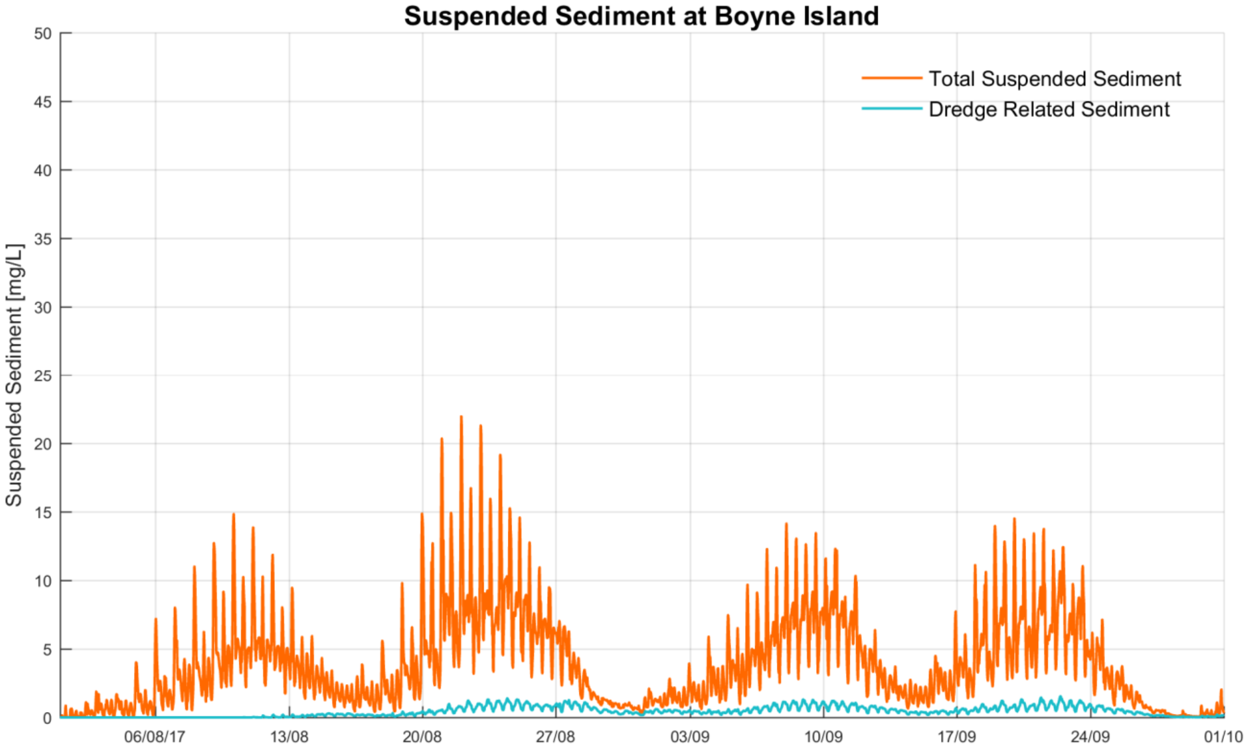


Time Series of TSS for Dredged and Ambient Sediment

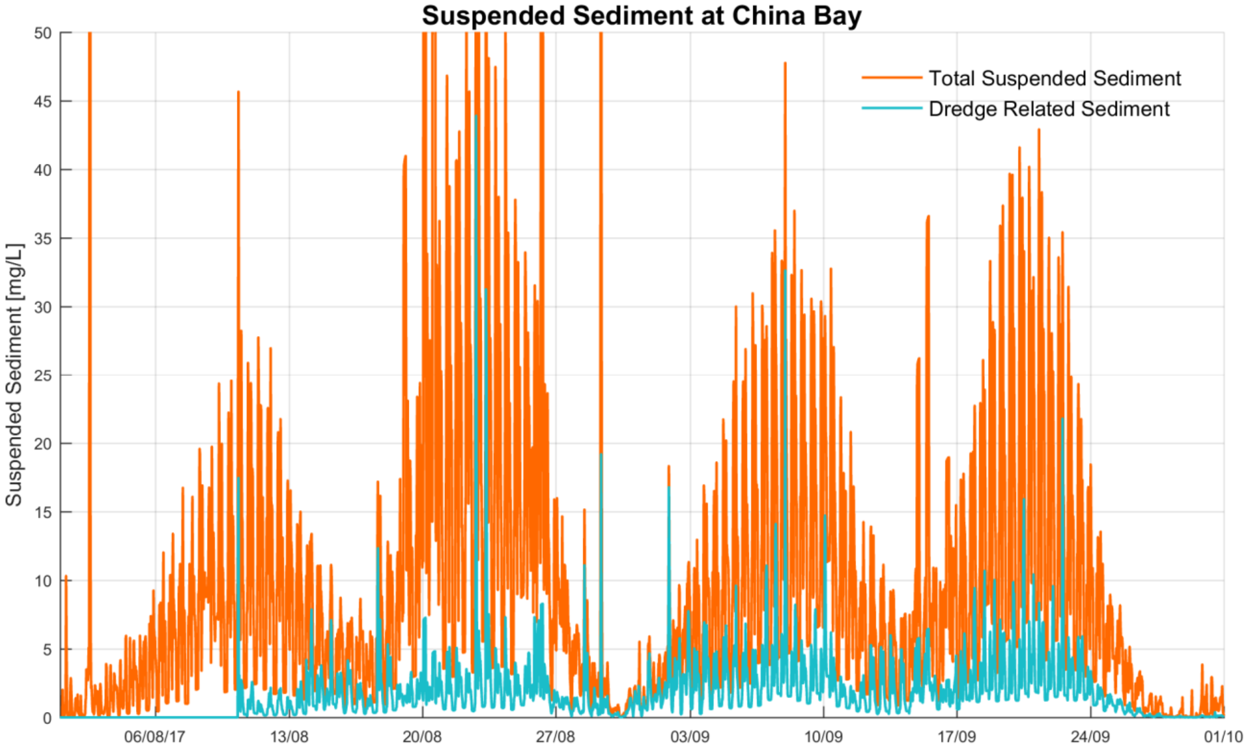


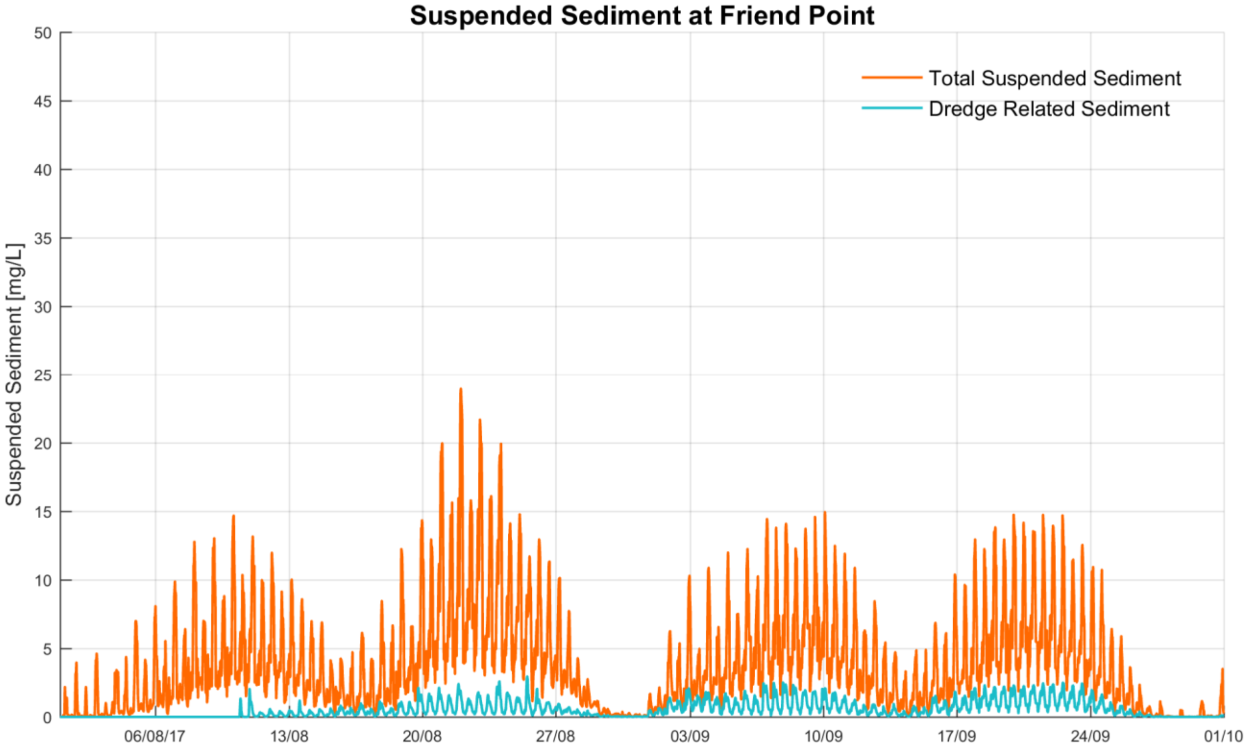
340,000m^3 Campaign



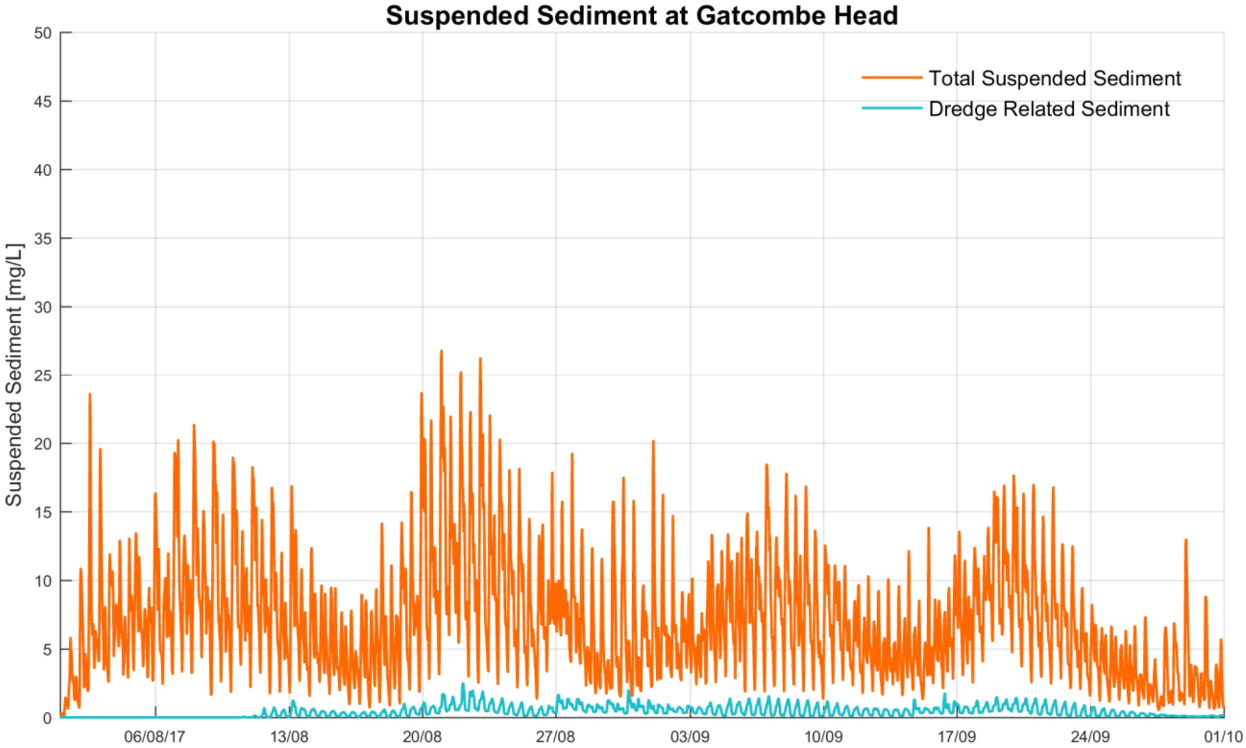


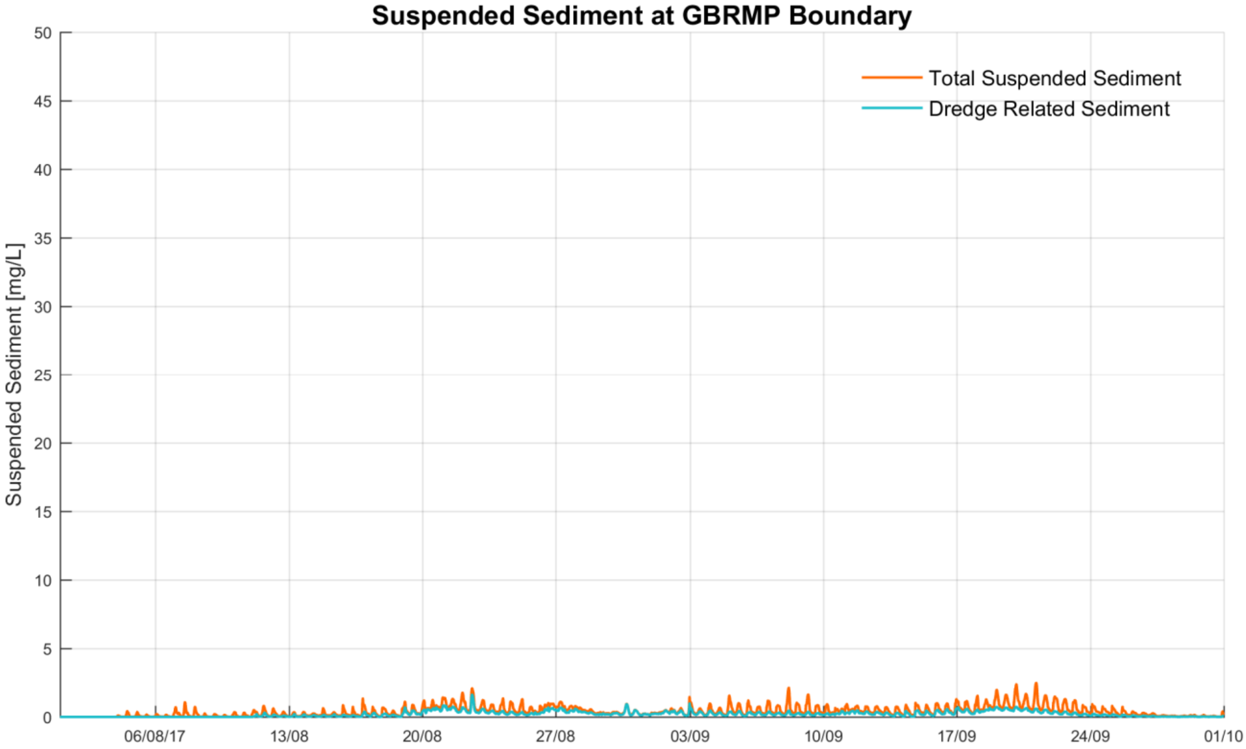
Time Series of TSS for Dredged and Ambient Sediment



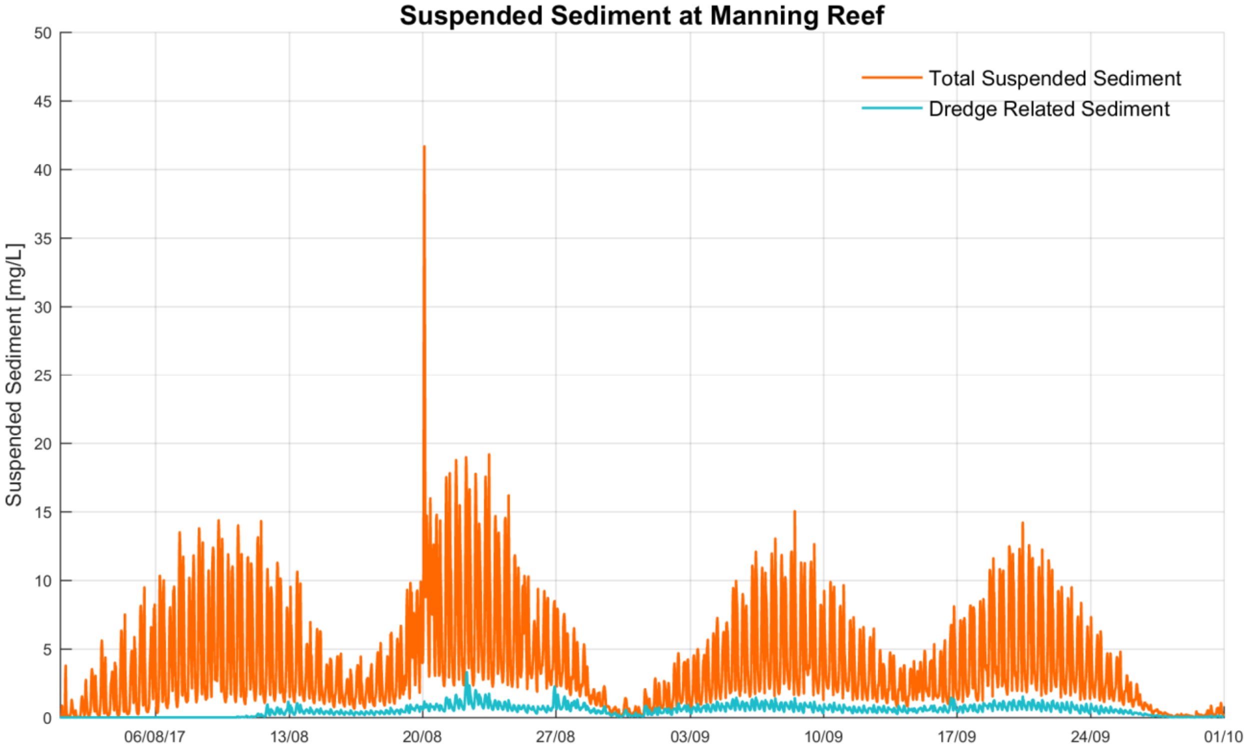


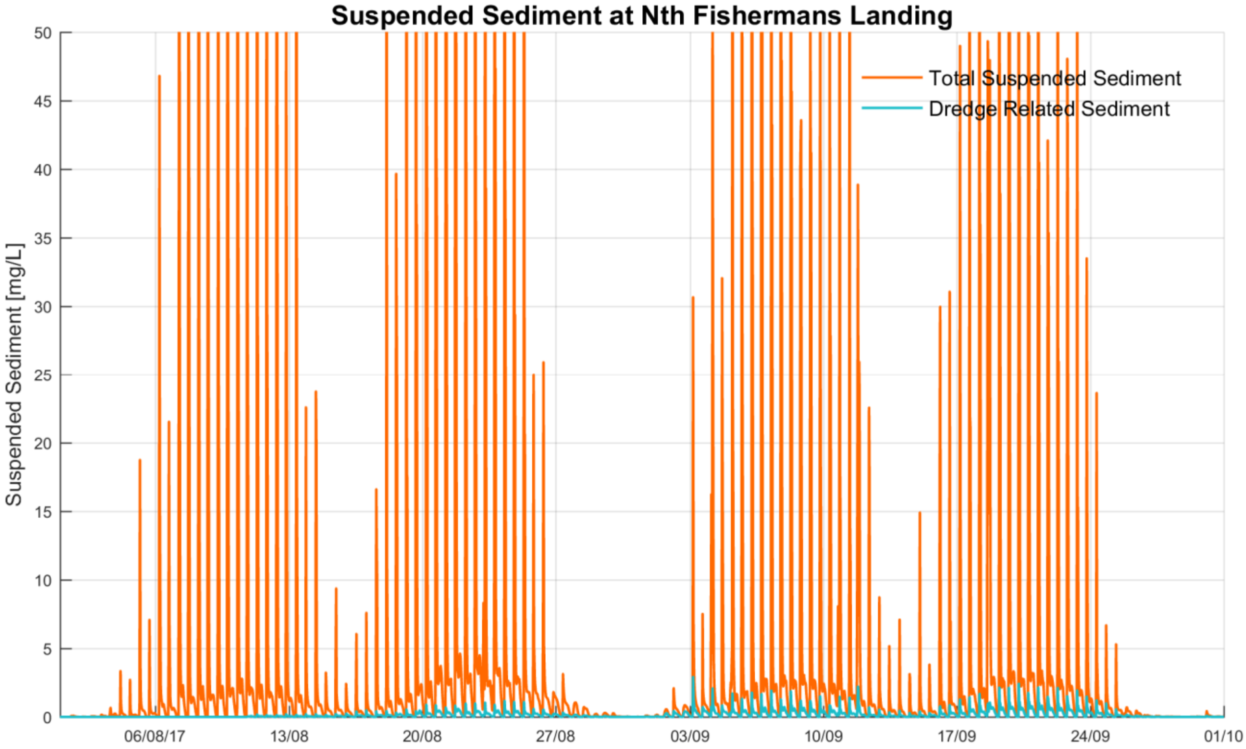
Time Series of TSS for Dredged and Ambient Sediment



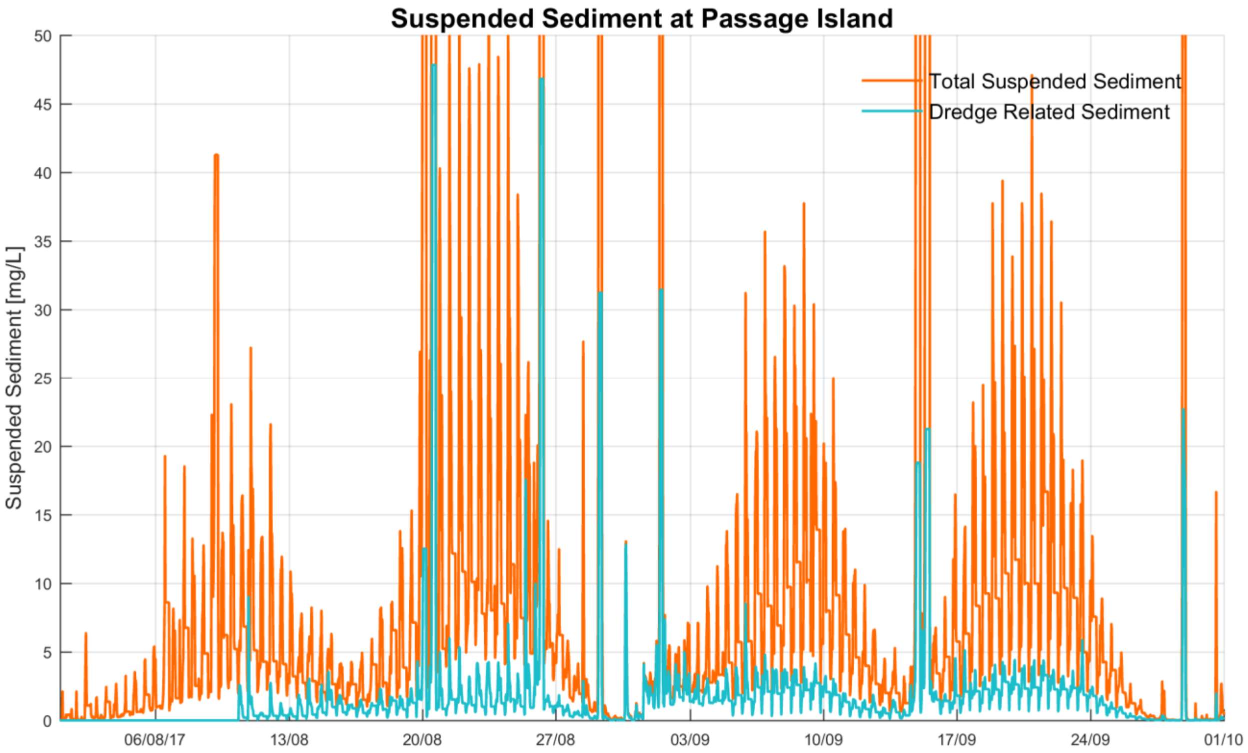


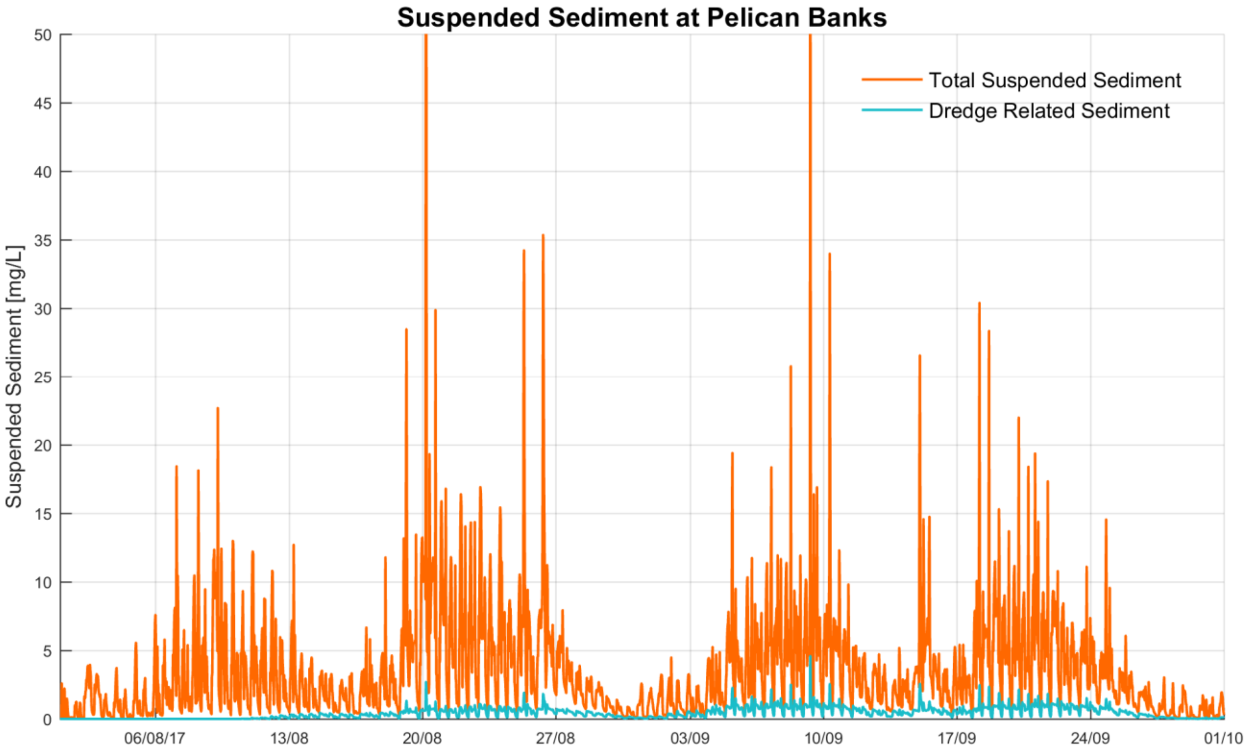
Time Series of TSS for Dredged and Ambient Sediment



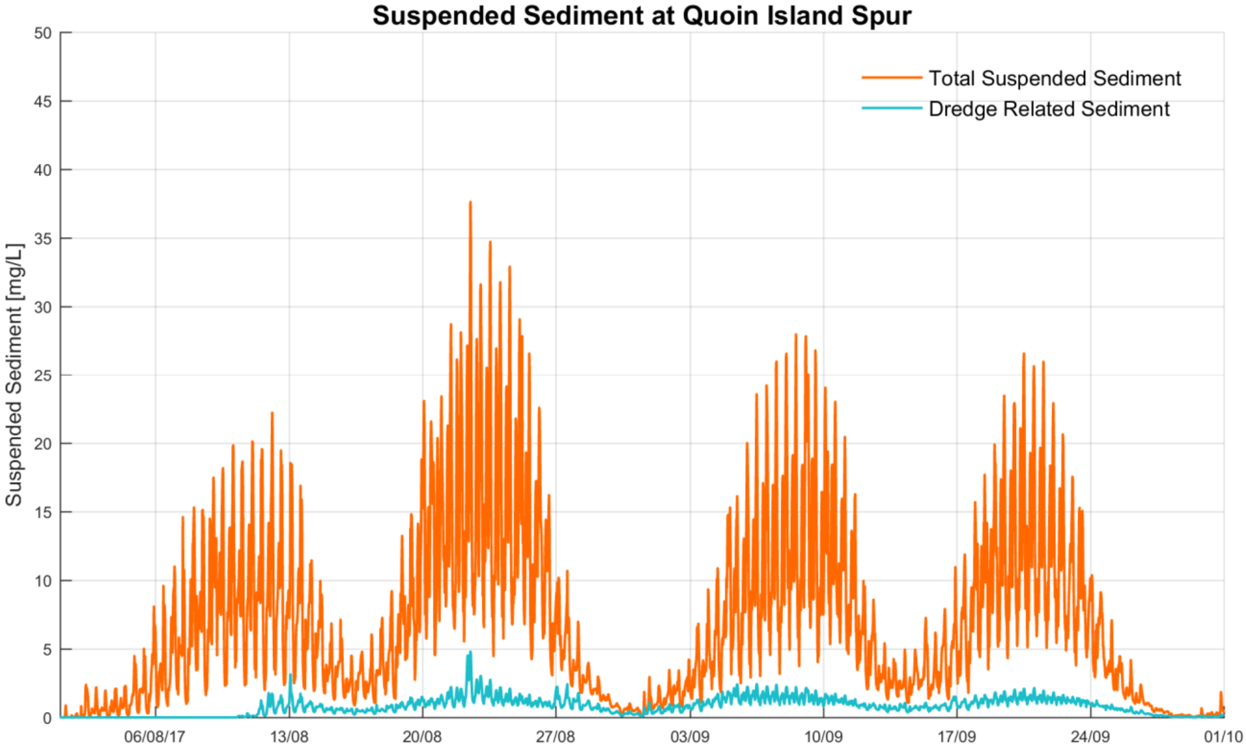


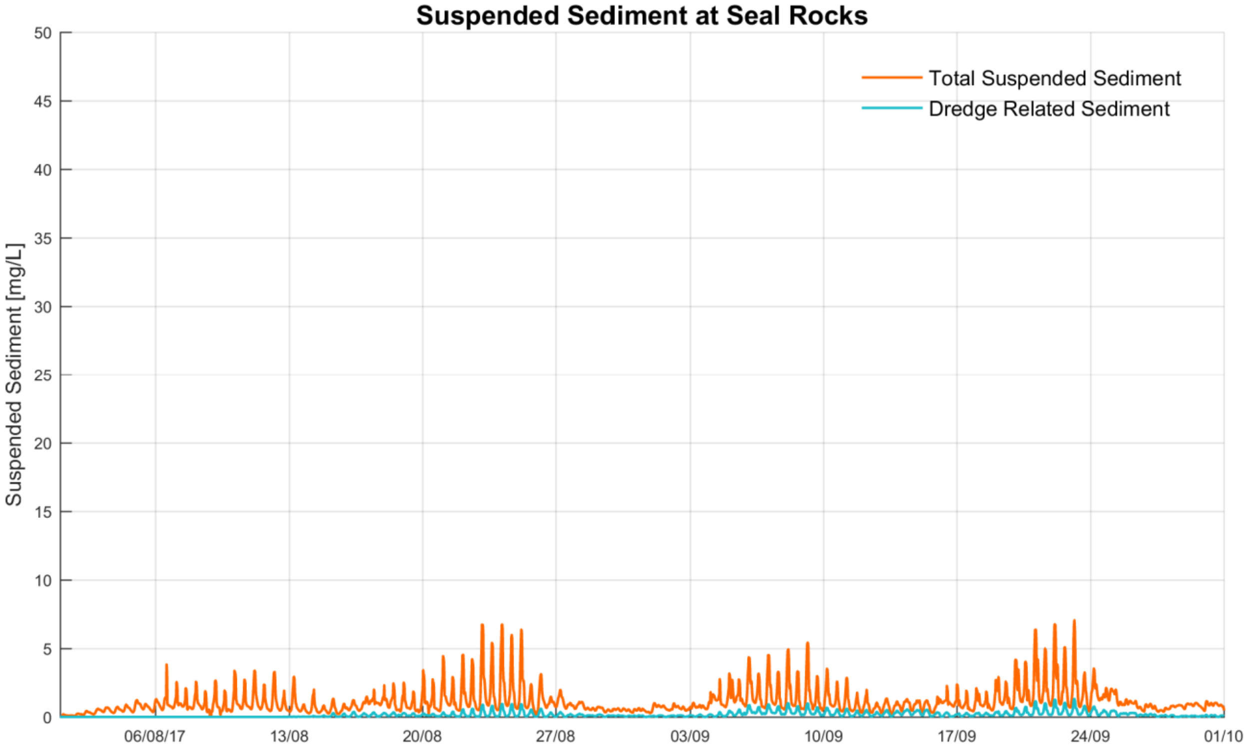
Time Series of TSS for Dredged and Ambient Sediment


Suspended Sediment at Passage Island

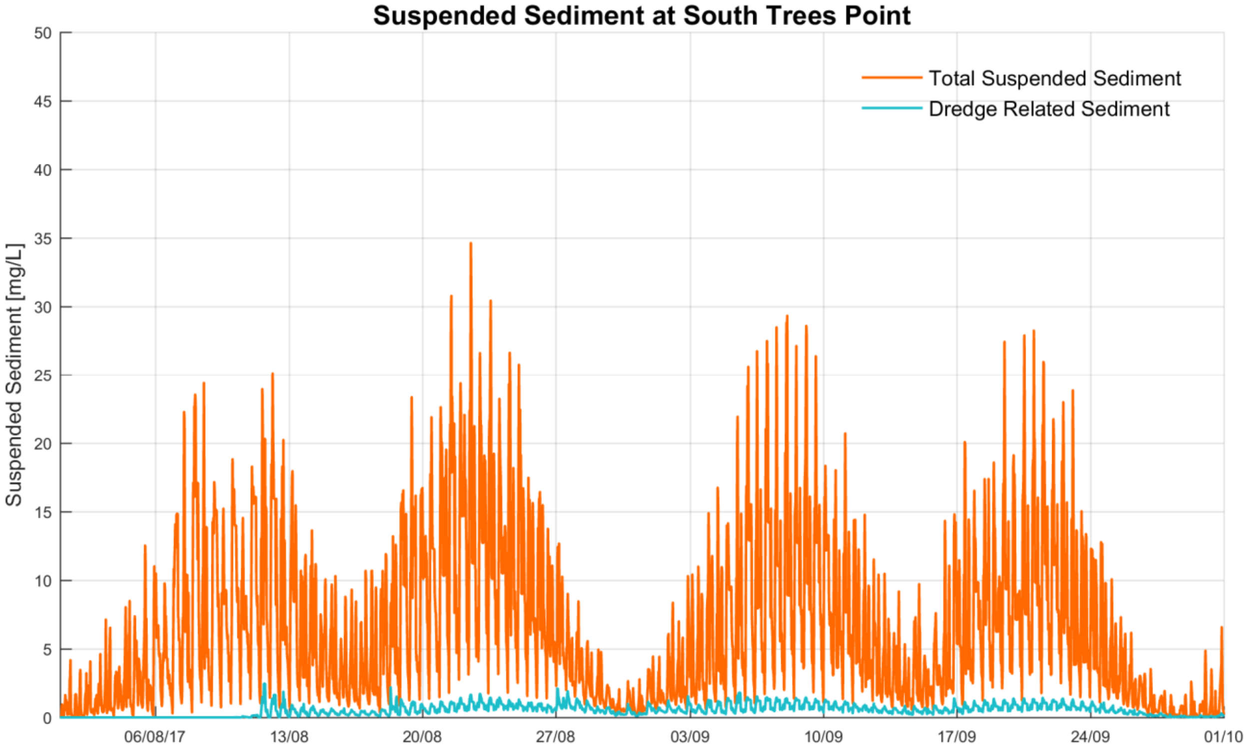

Suspended Sediment at Pelican Banks

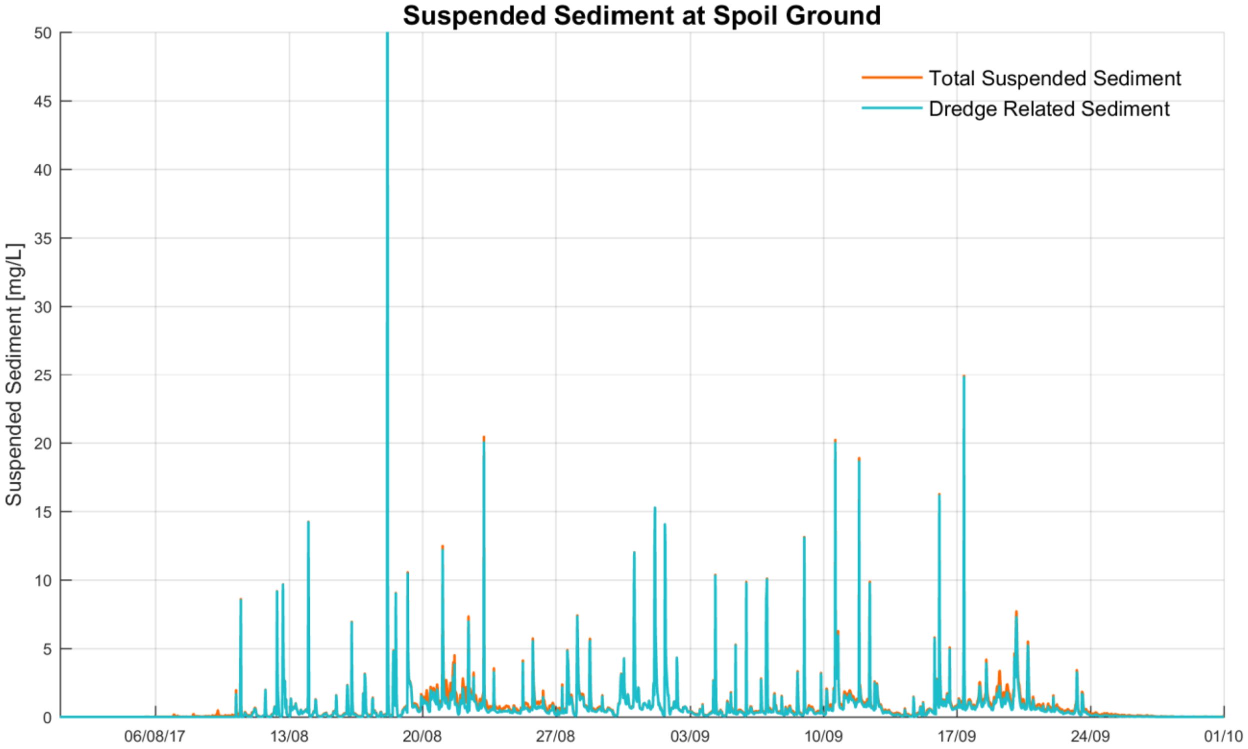
Time Series of TSS for Dredged and Ambient Sediment



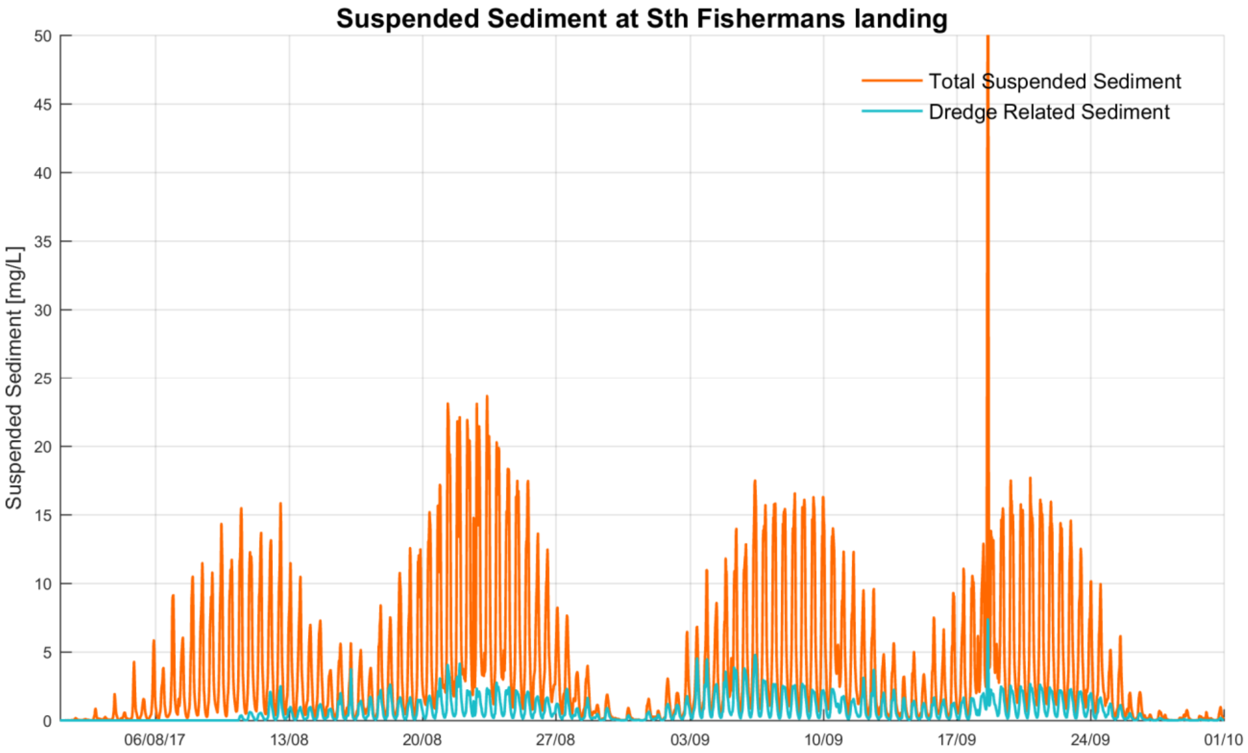


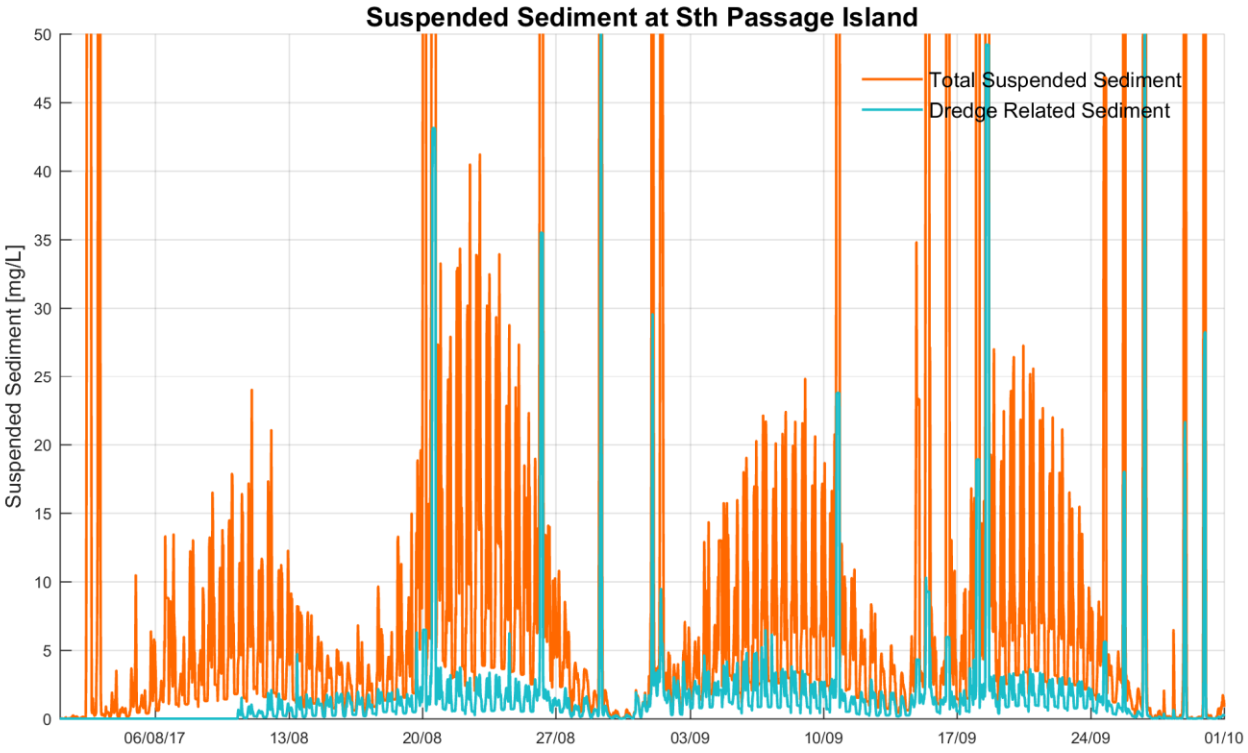
Time Series of TSS for Dredged and Ambient Sediment



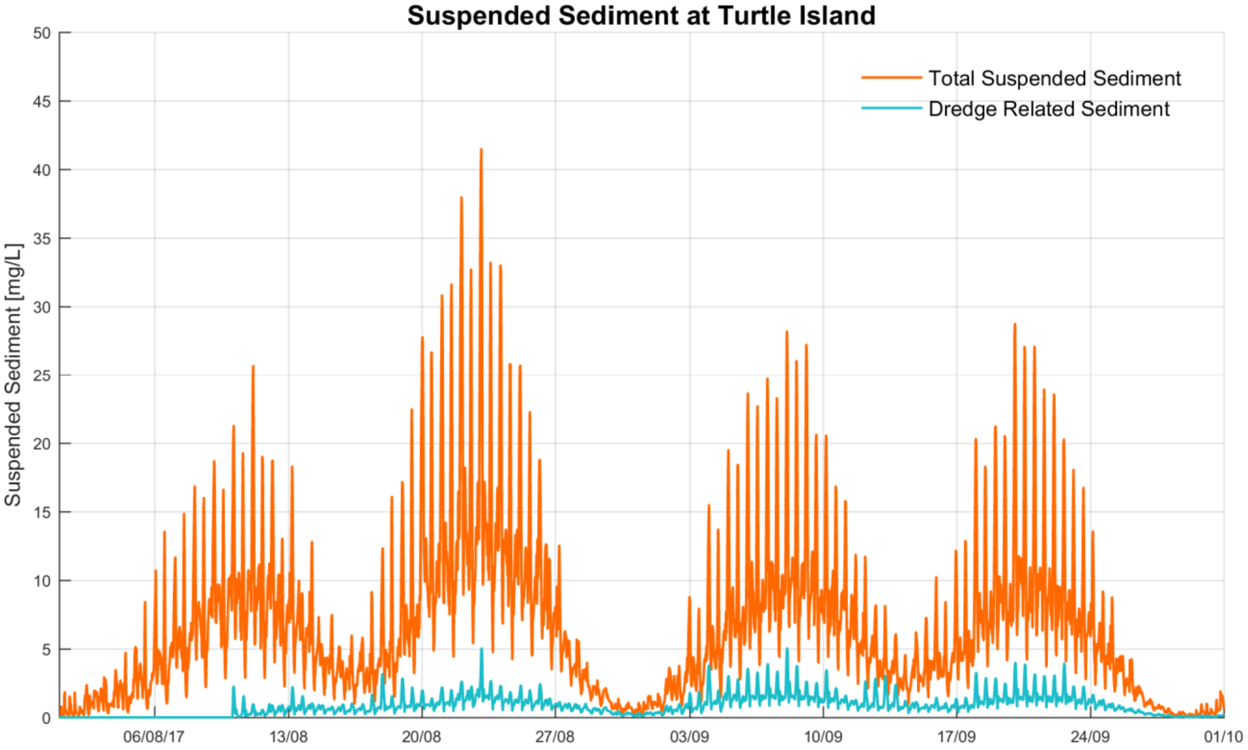


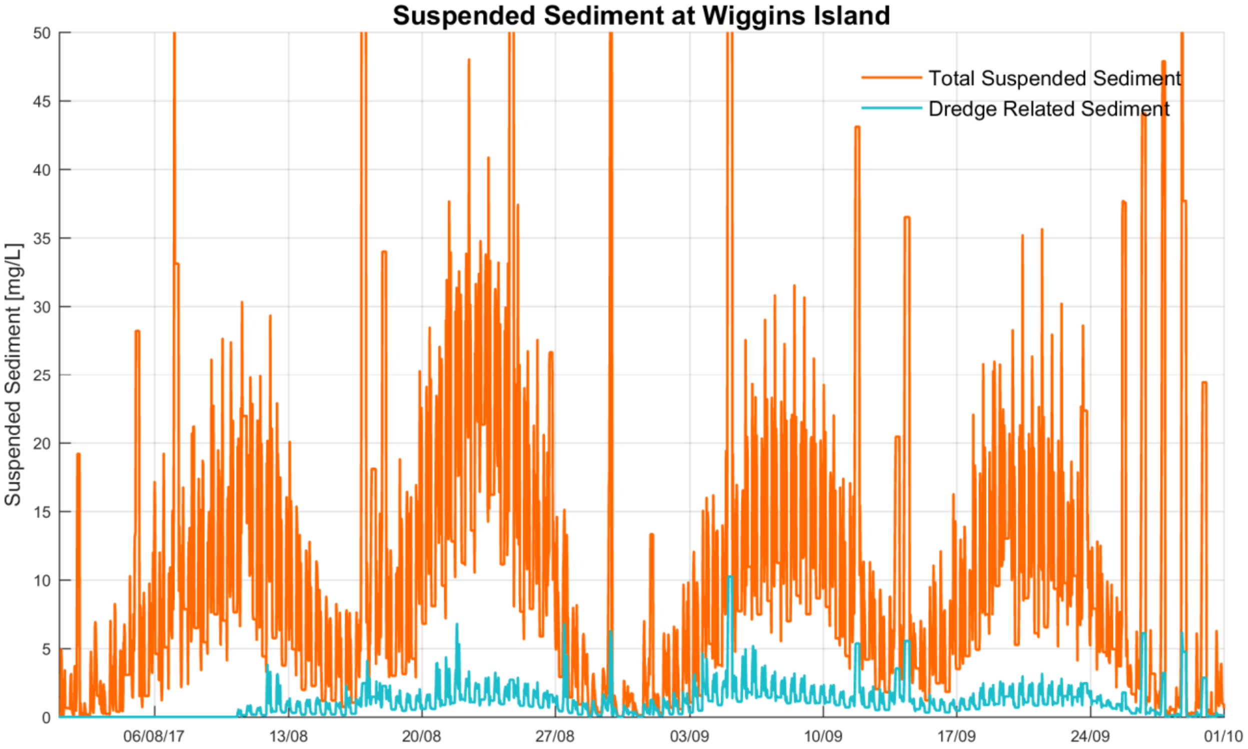
Time Series of TSS for Dredged and Ambient Sediment



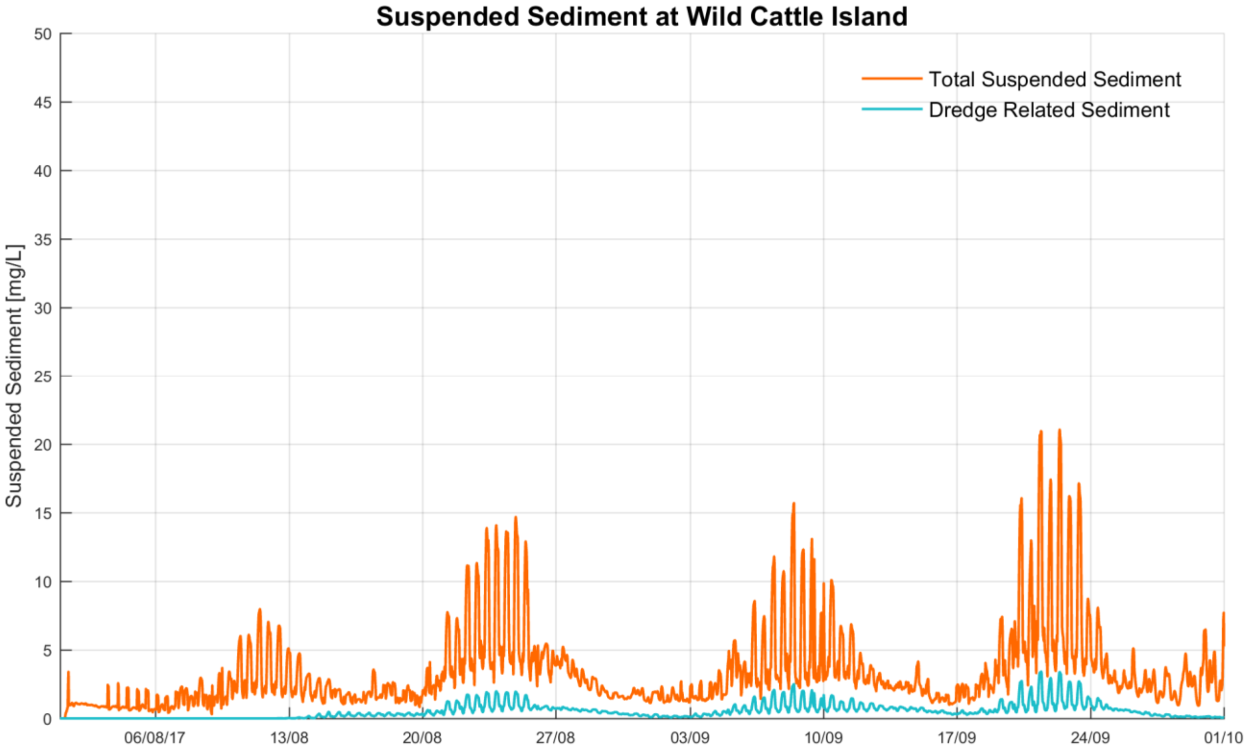


Time Series of TSS for Dredged and Ambient Sediment



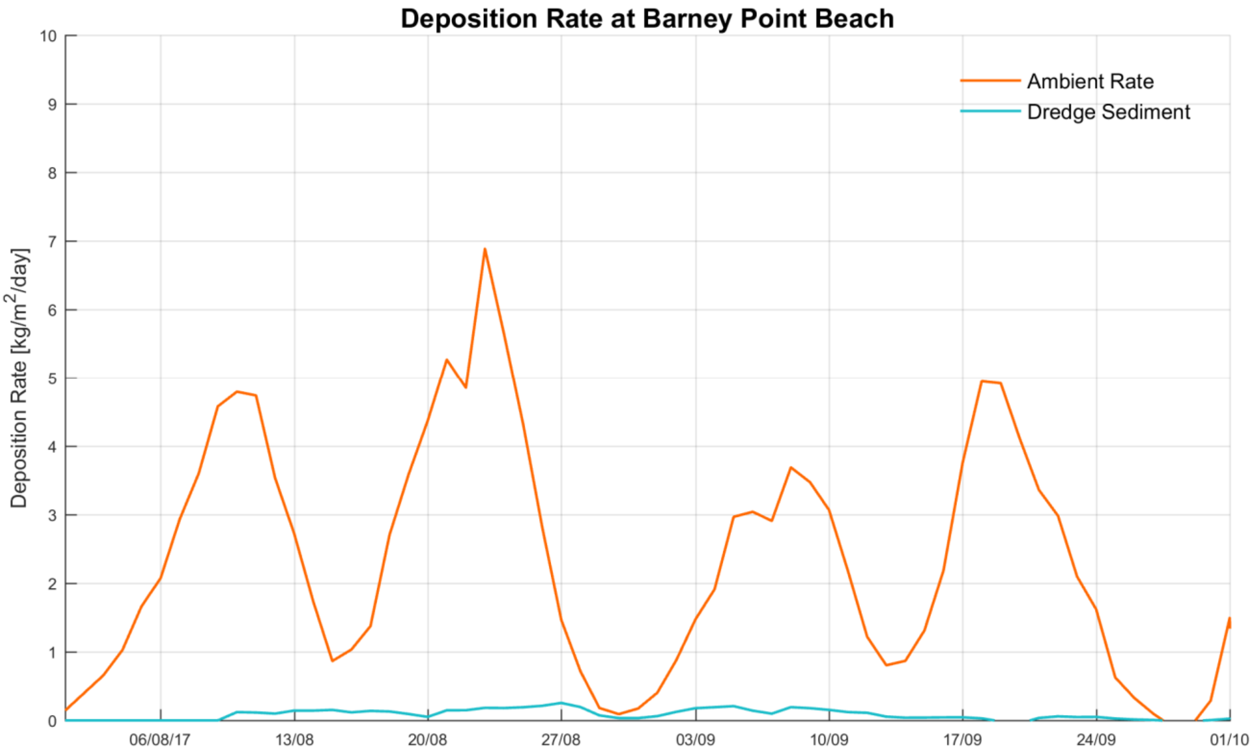


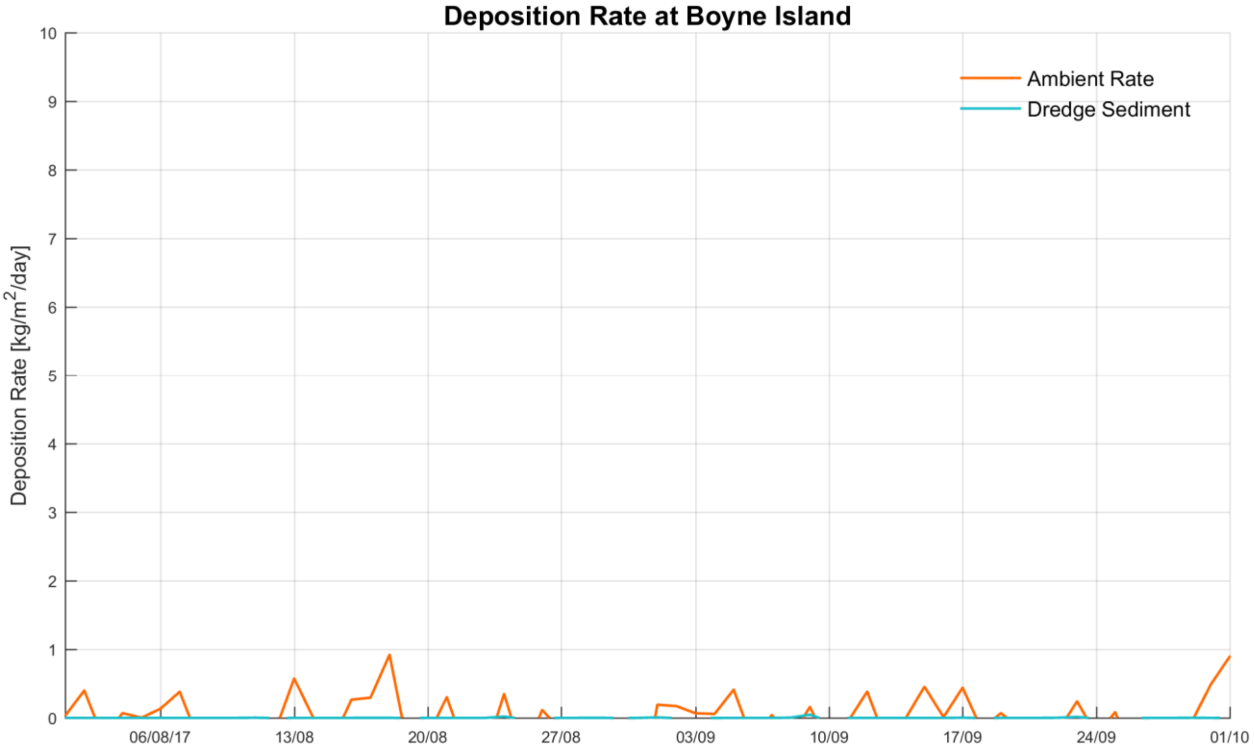
Time Series of TSS for Dredged and Ambient Sediment



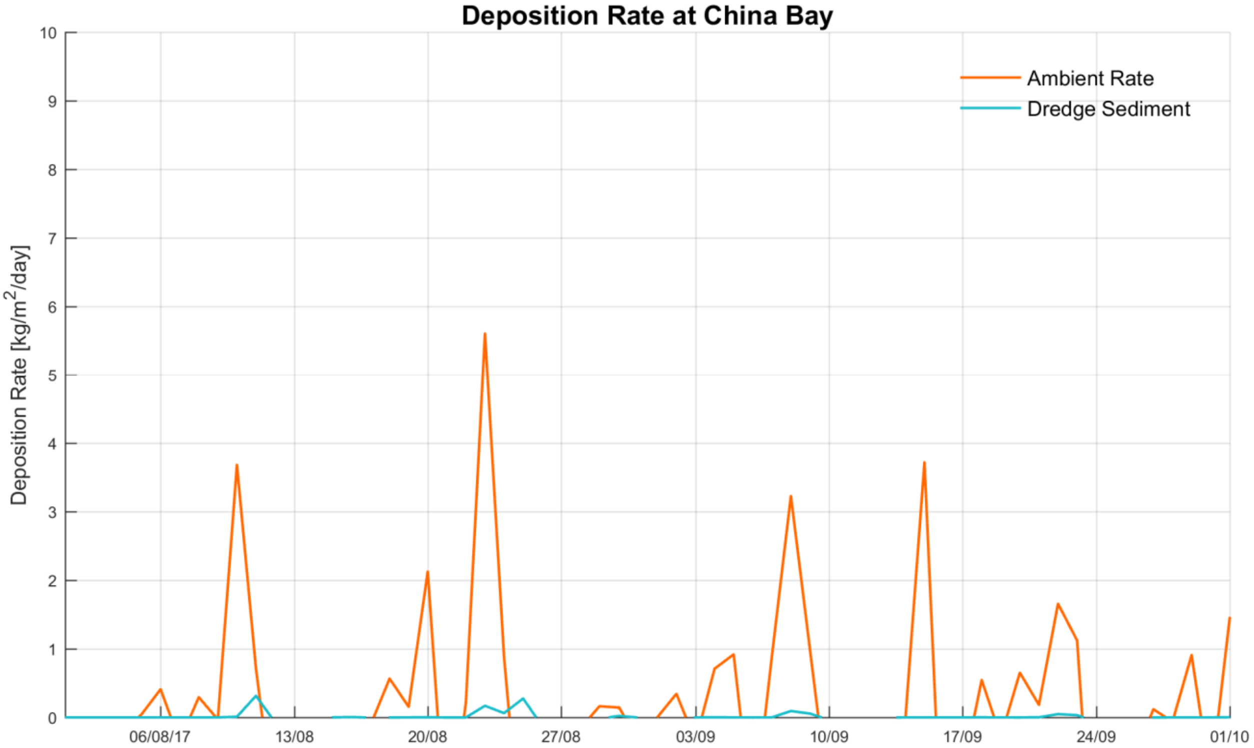
Appendix C Time Series of Deposition Rate for Dredged and Ambient Sediment

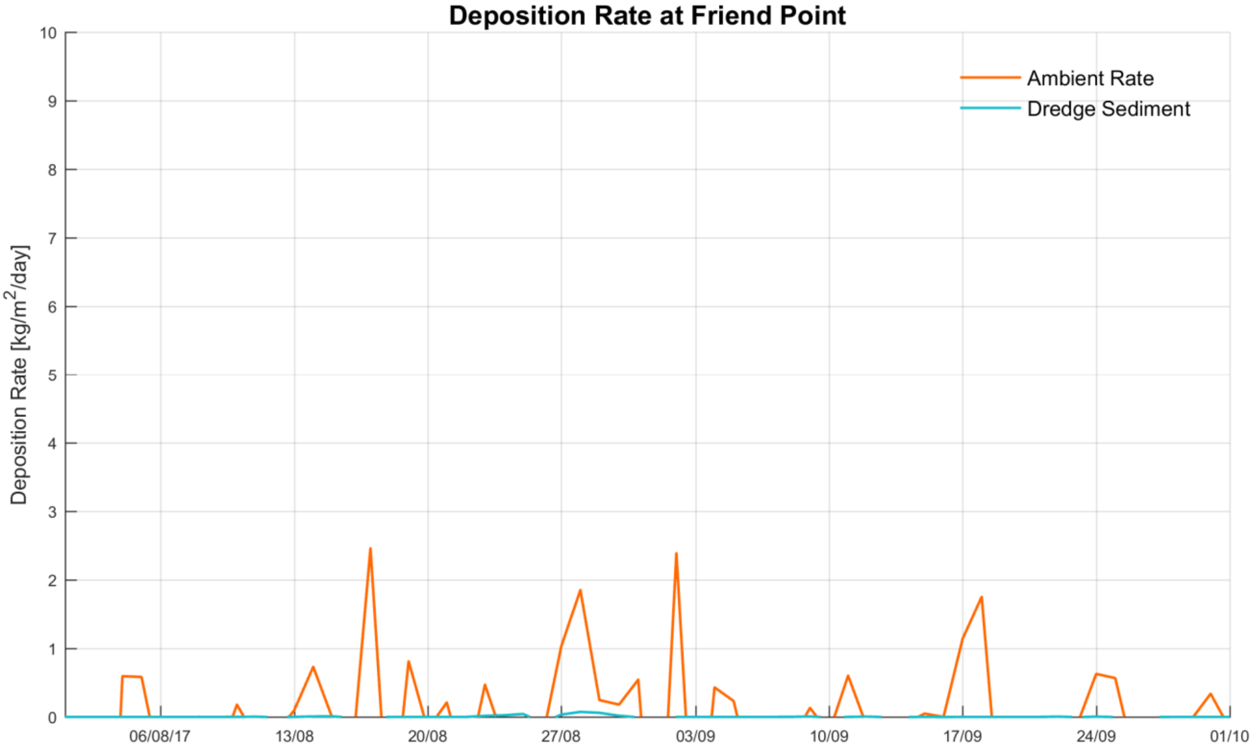
220,000m^3 Campaign



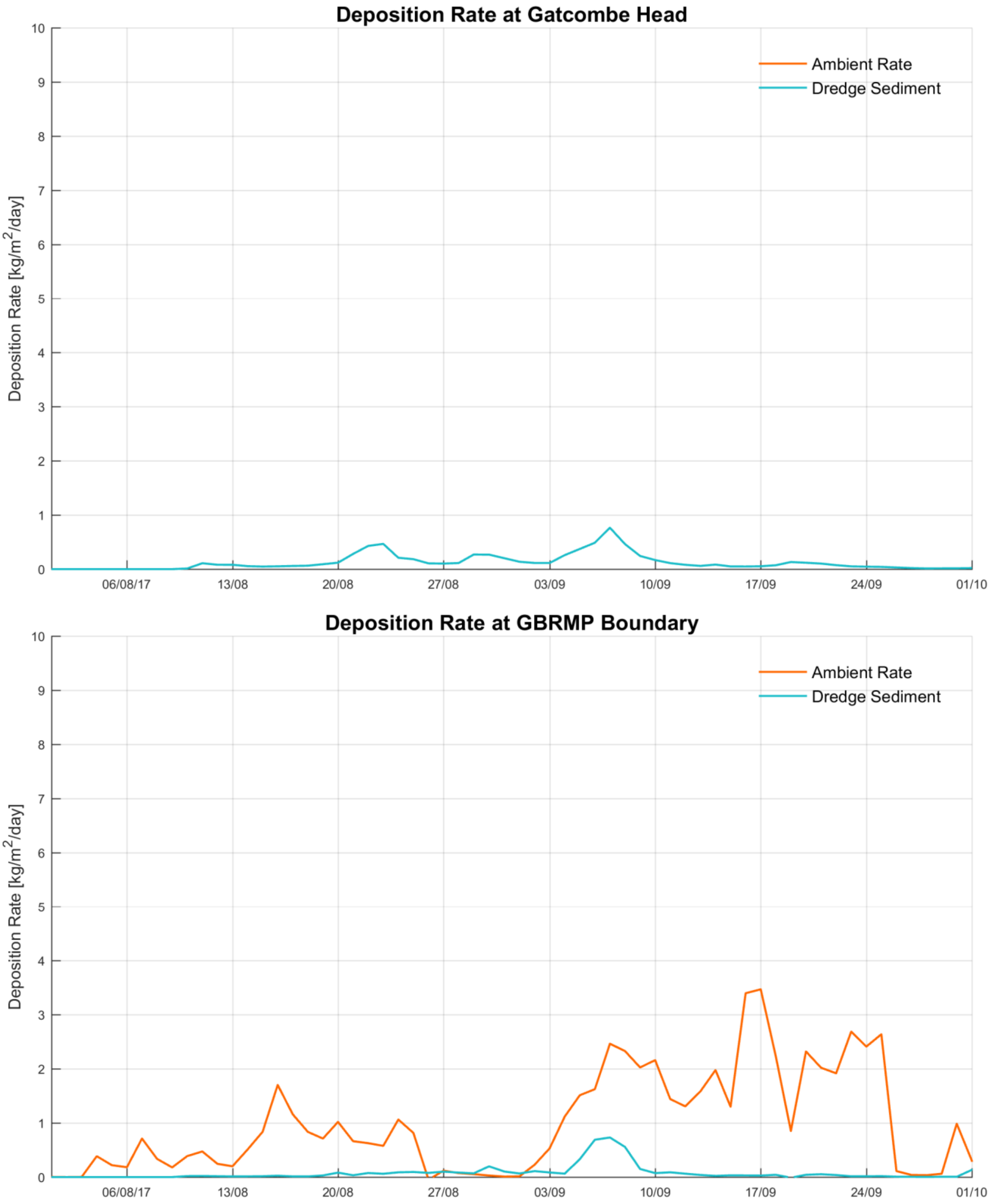


Time Series of Deposition Rate for Dredged and Ambient Sediment

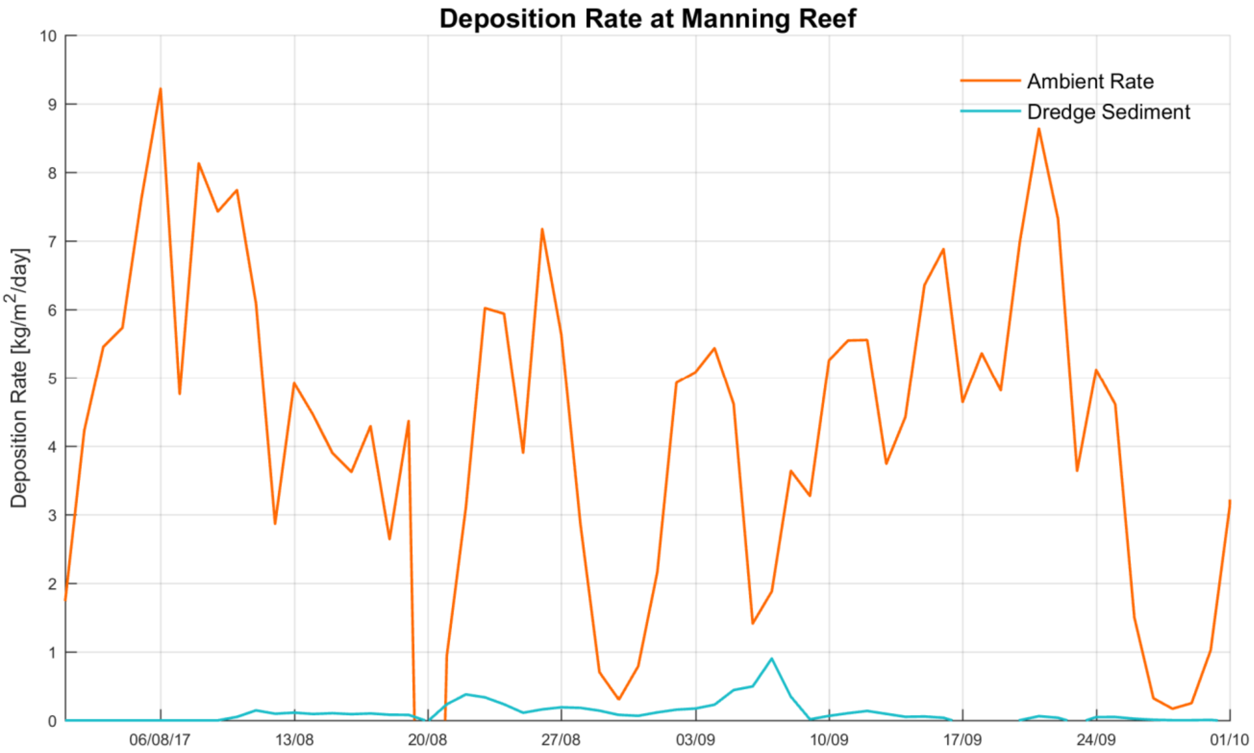


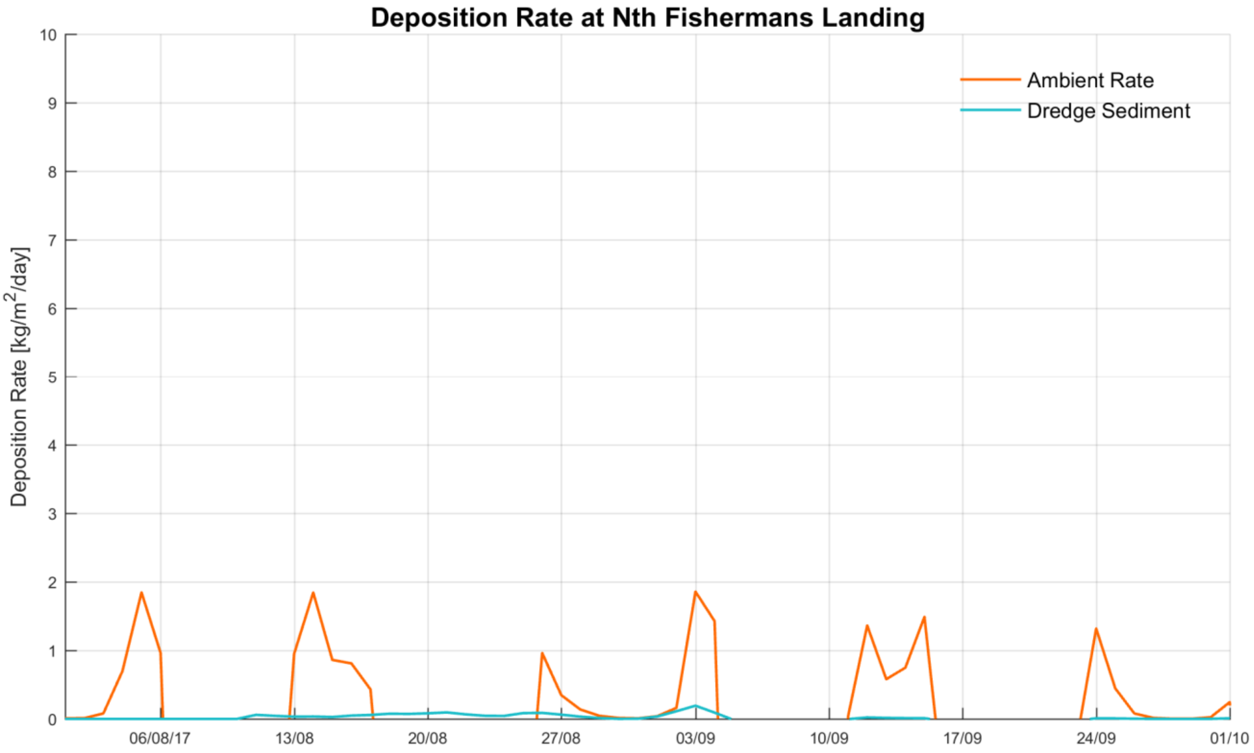


Time Series of Deposition Rate for Dredged and Ambient Sediment

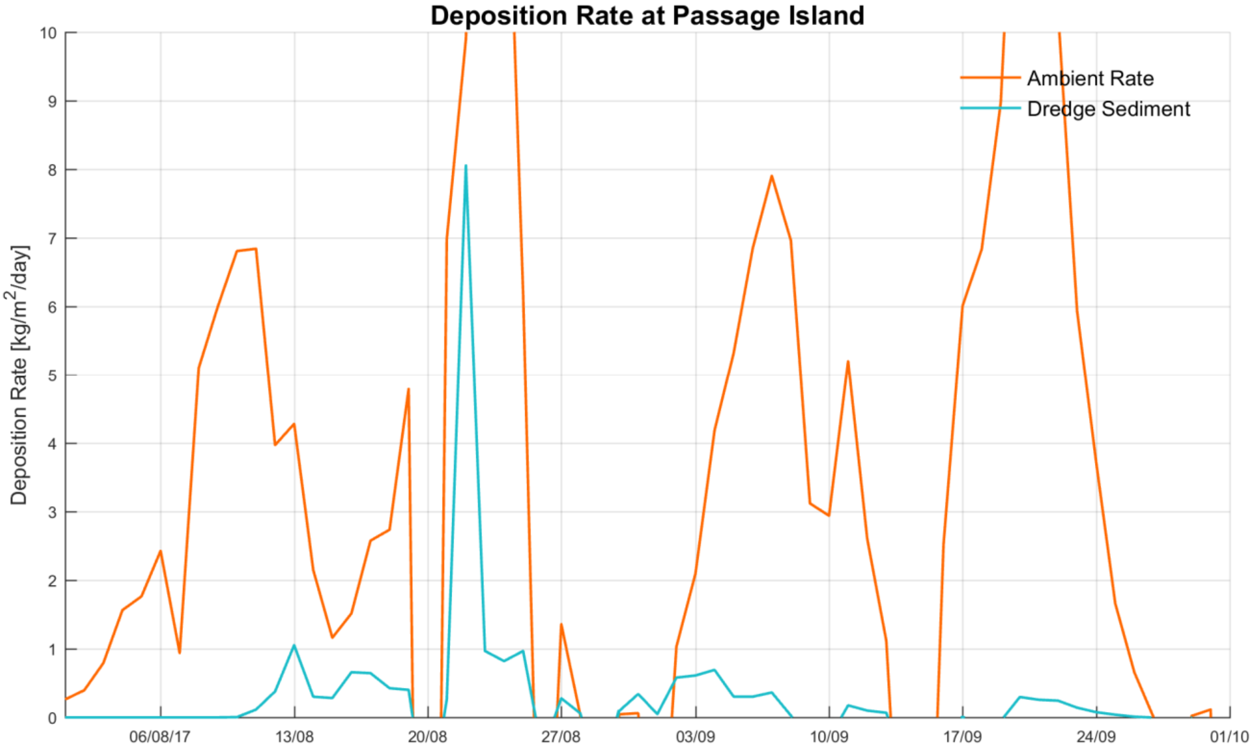


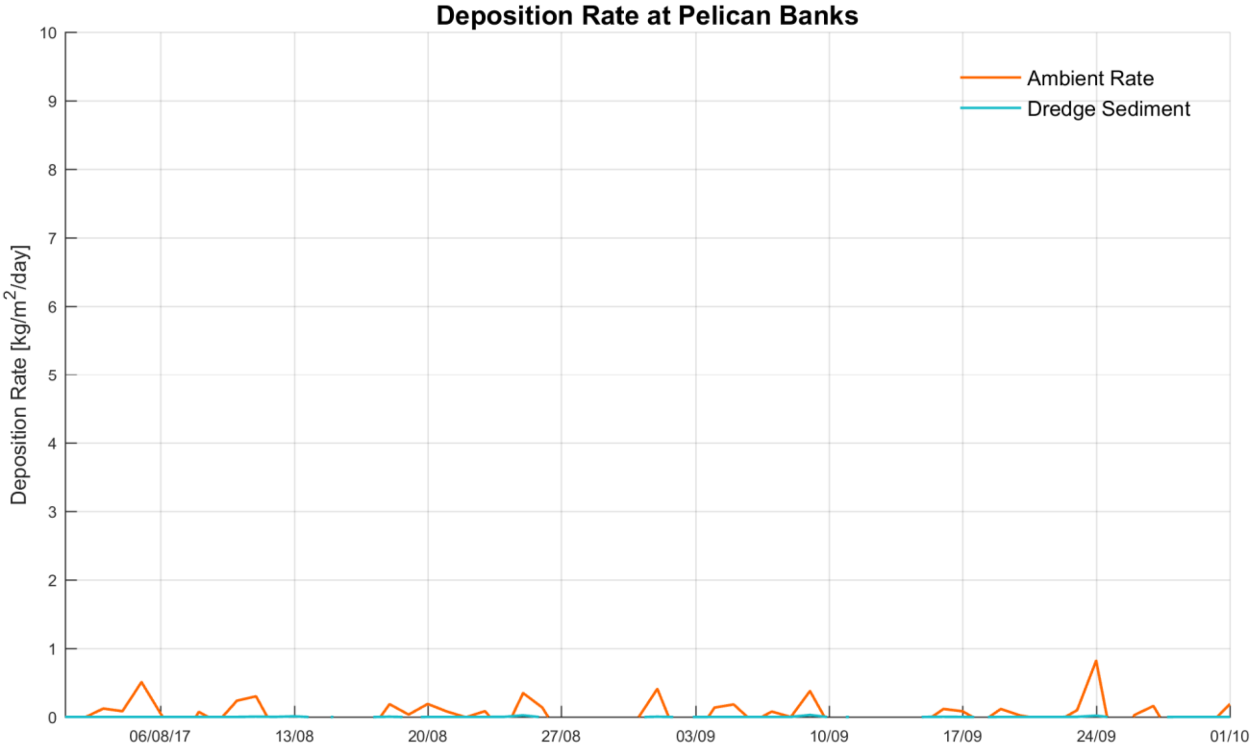
Time Series of Deposition Rate for Dredged and Ambient Sediment



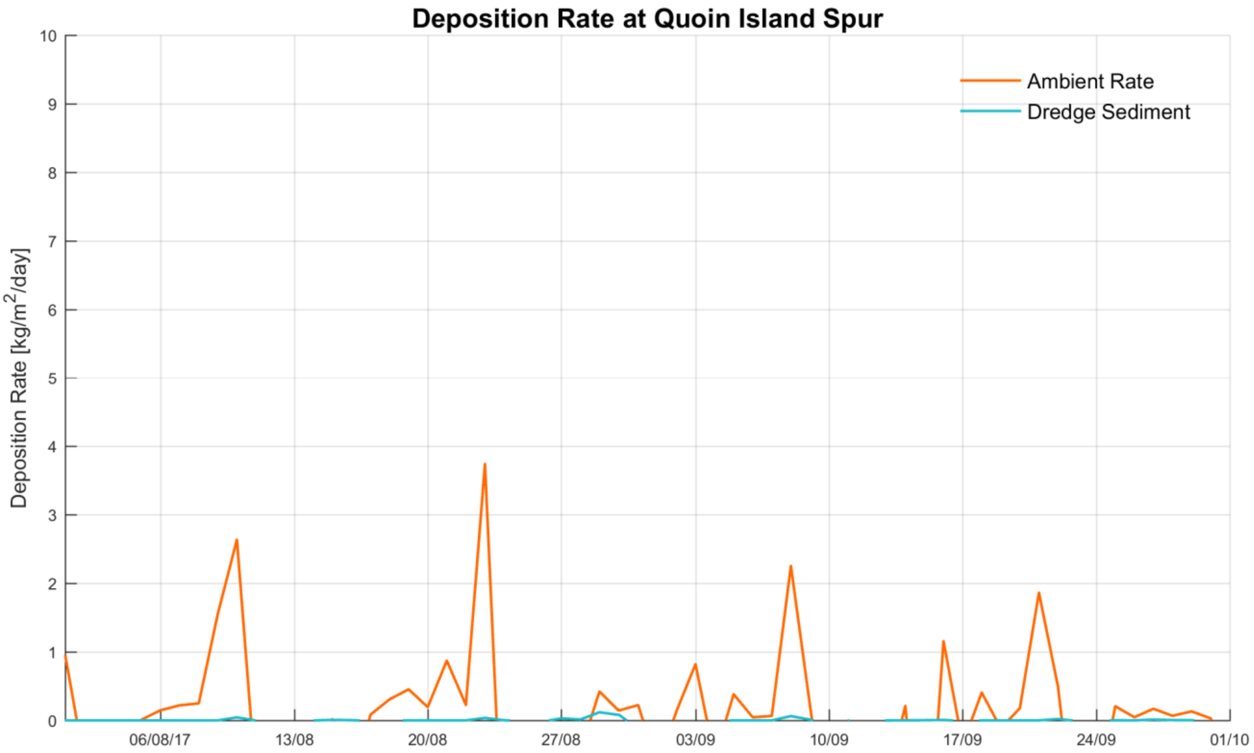


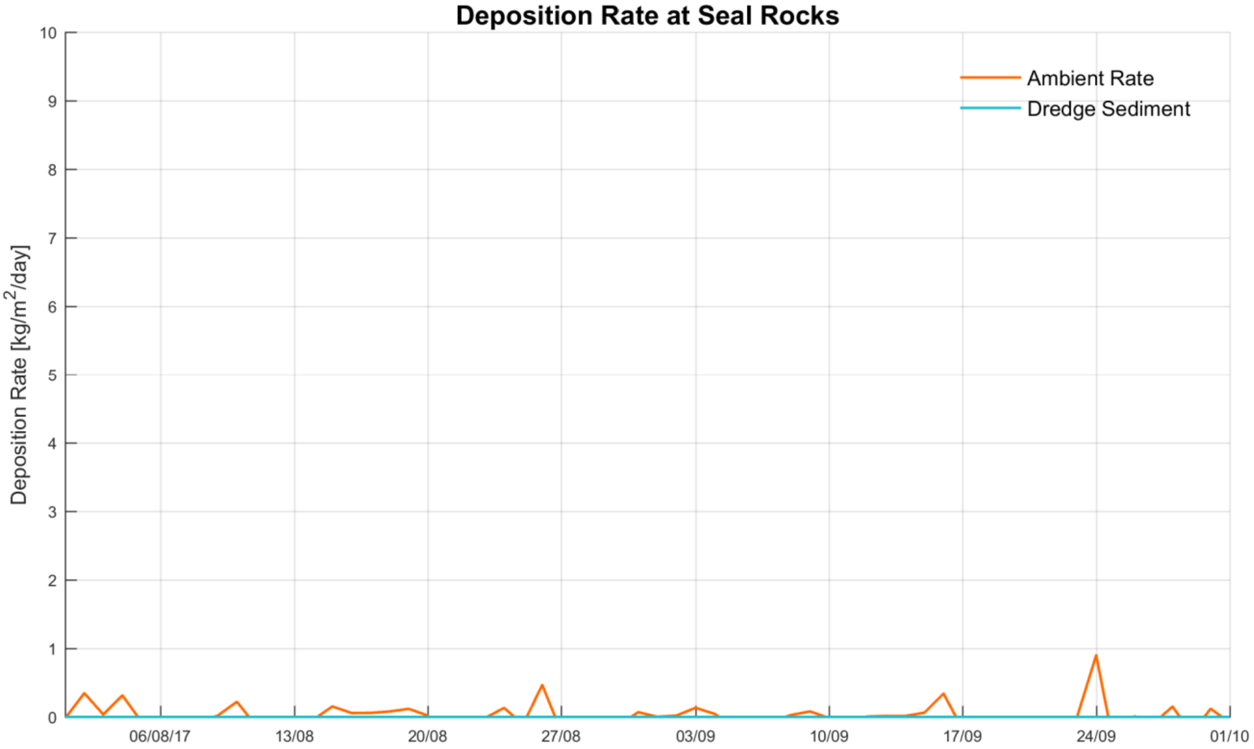
Time Series of Deposition Rate for Dredged and Ambient Sediment



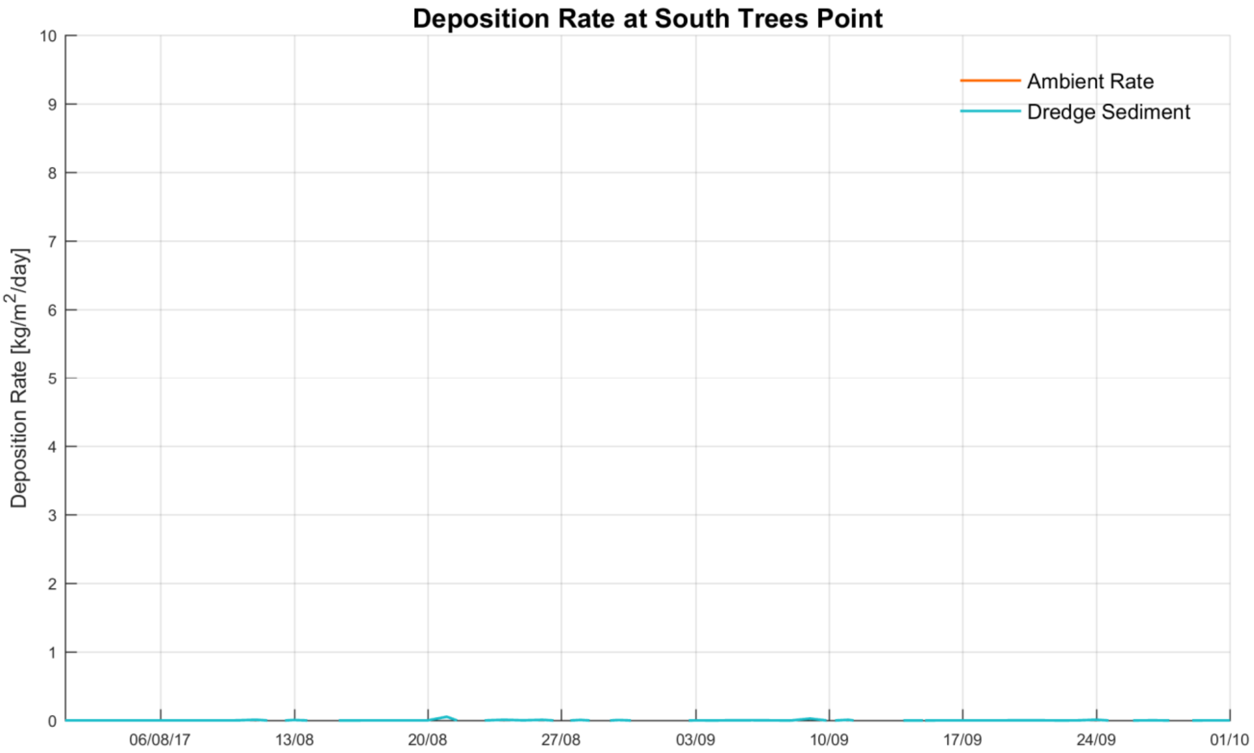


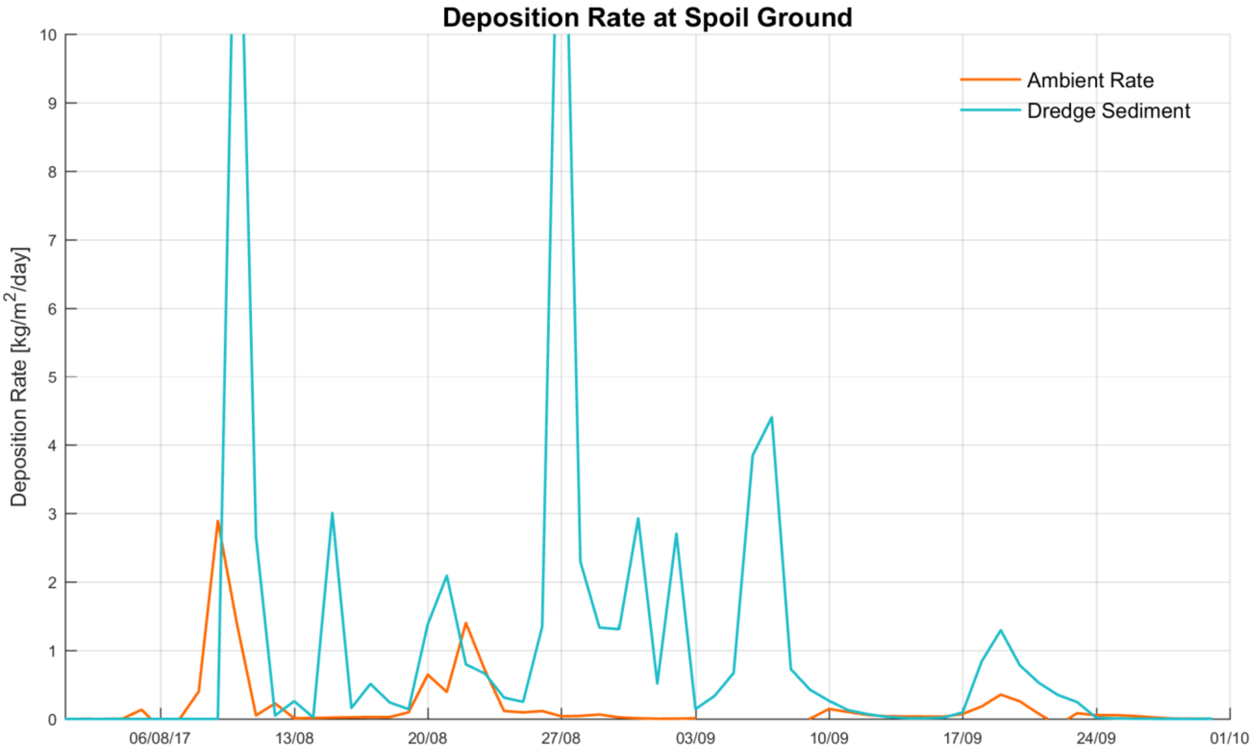
Time Series of Deposition Rate for Dredged and Ambient Sediment



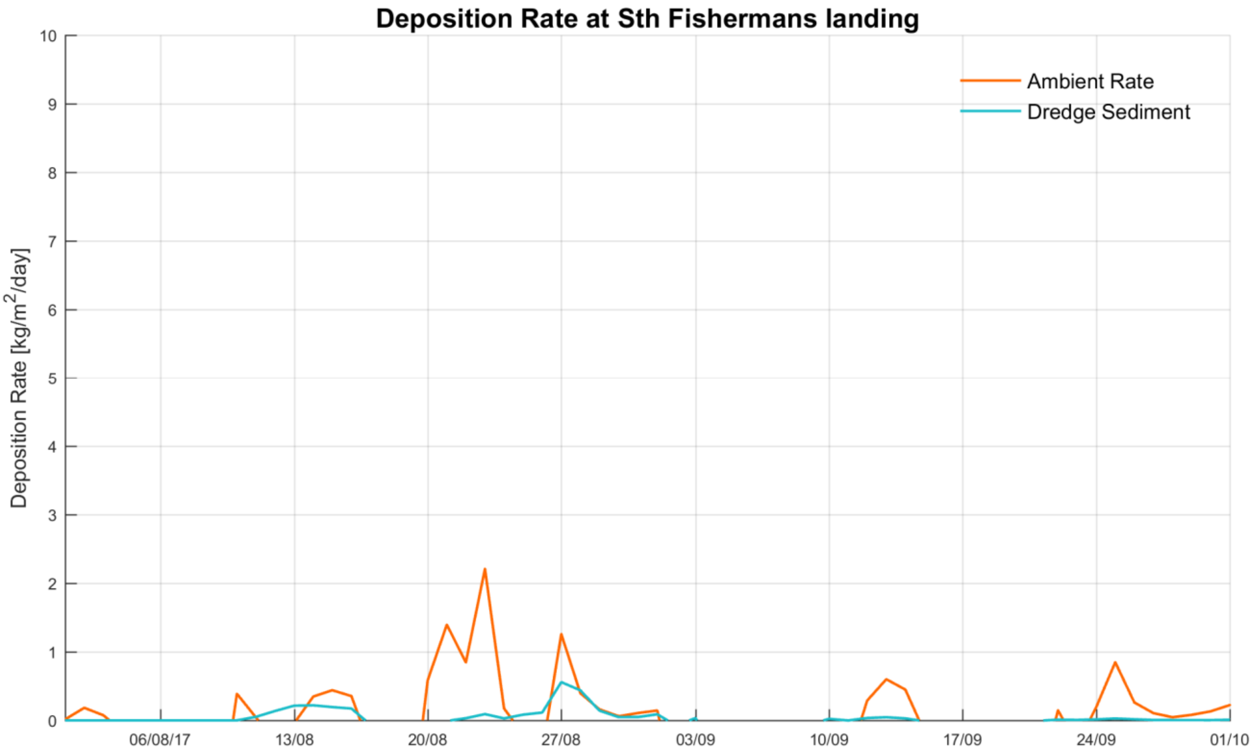


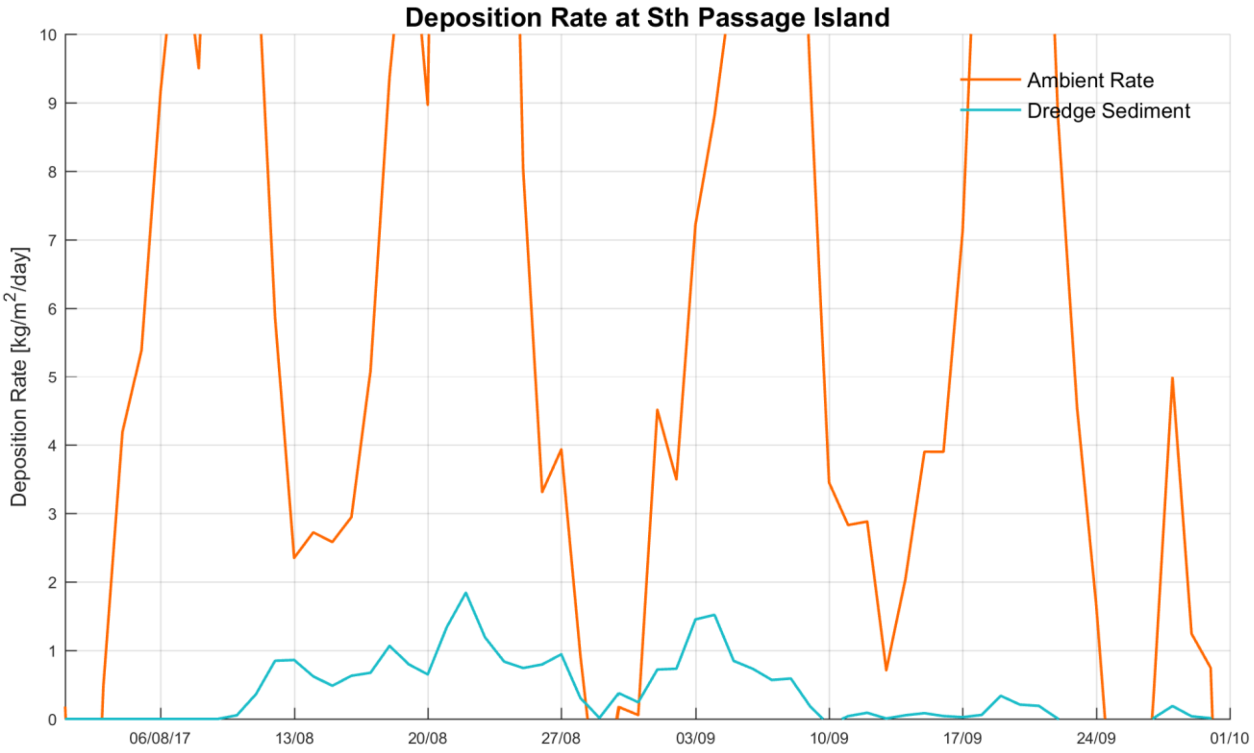
Time Series of Deposition Rate for Dredged and Ambient Sediment



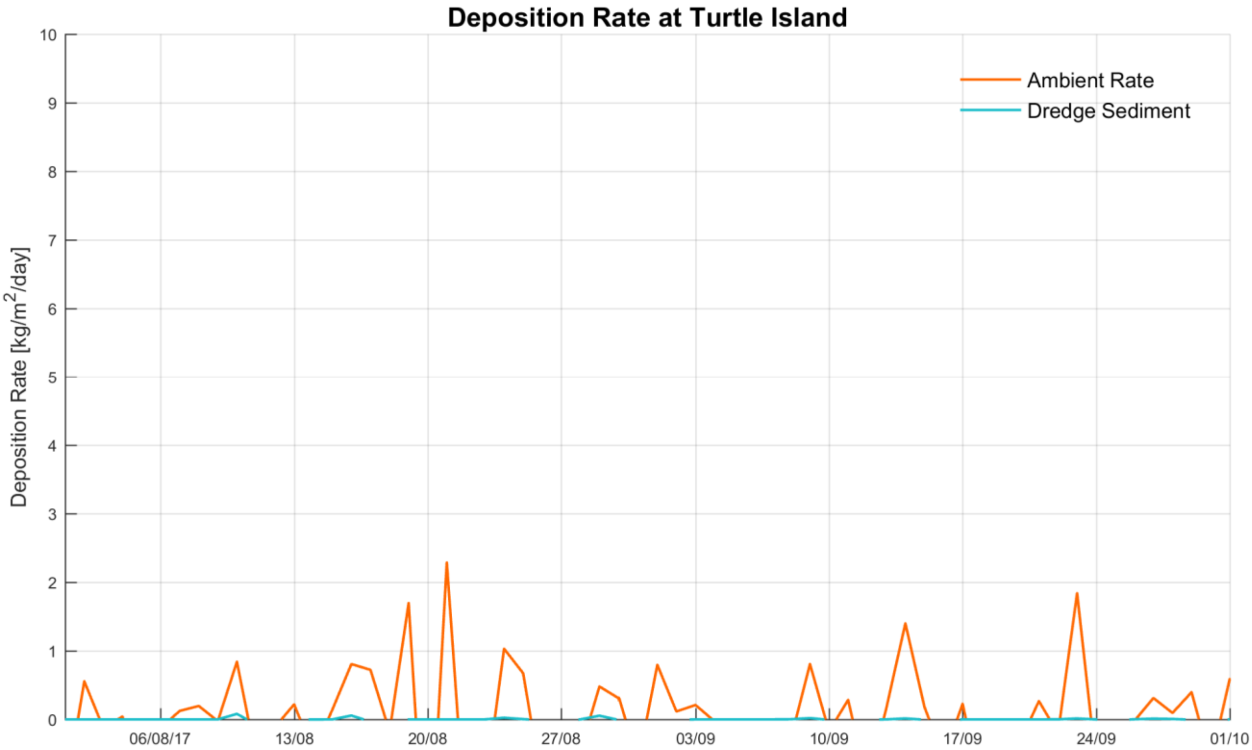


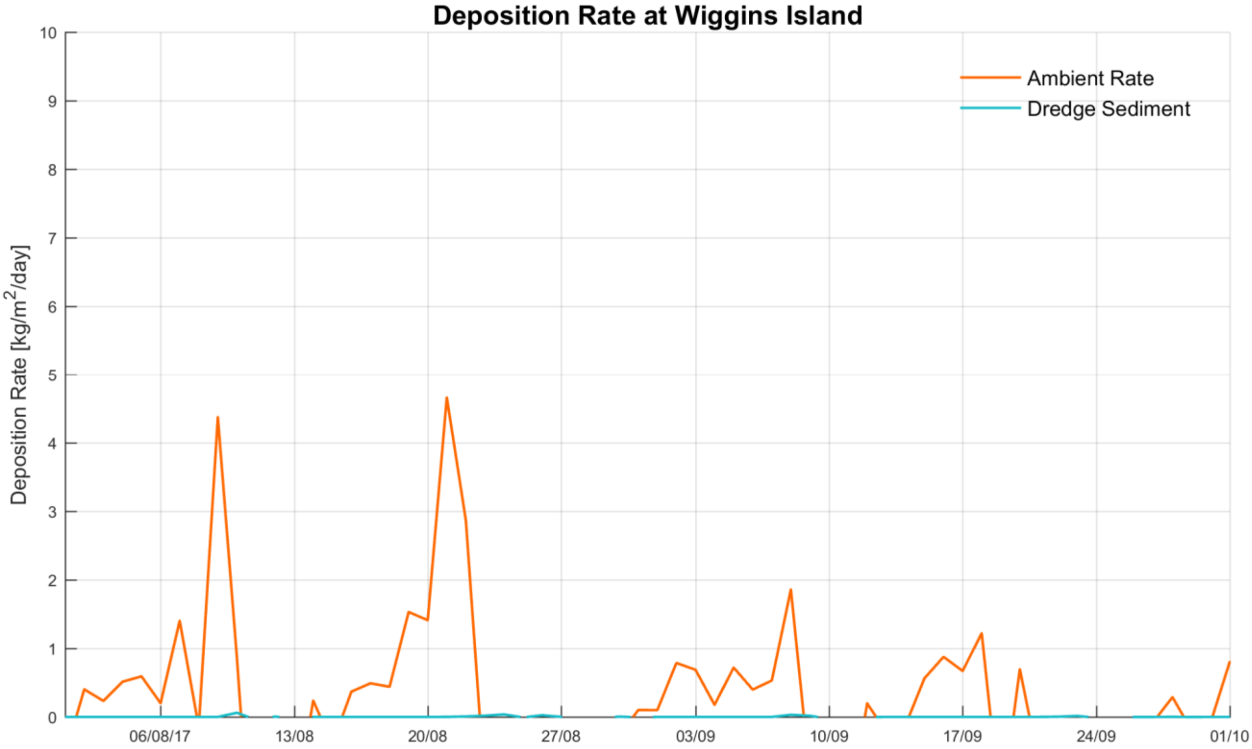
Time Series of Deposition Rate for Dredged and Ambient Sediment



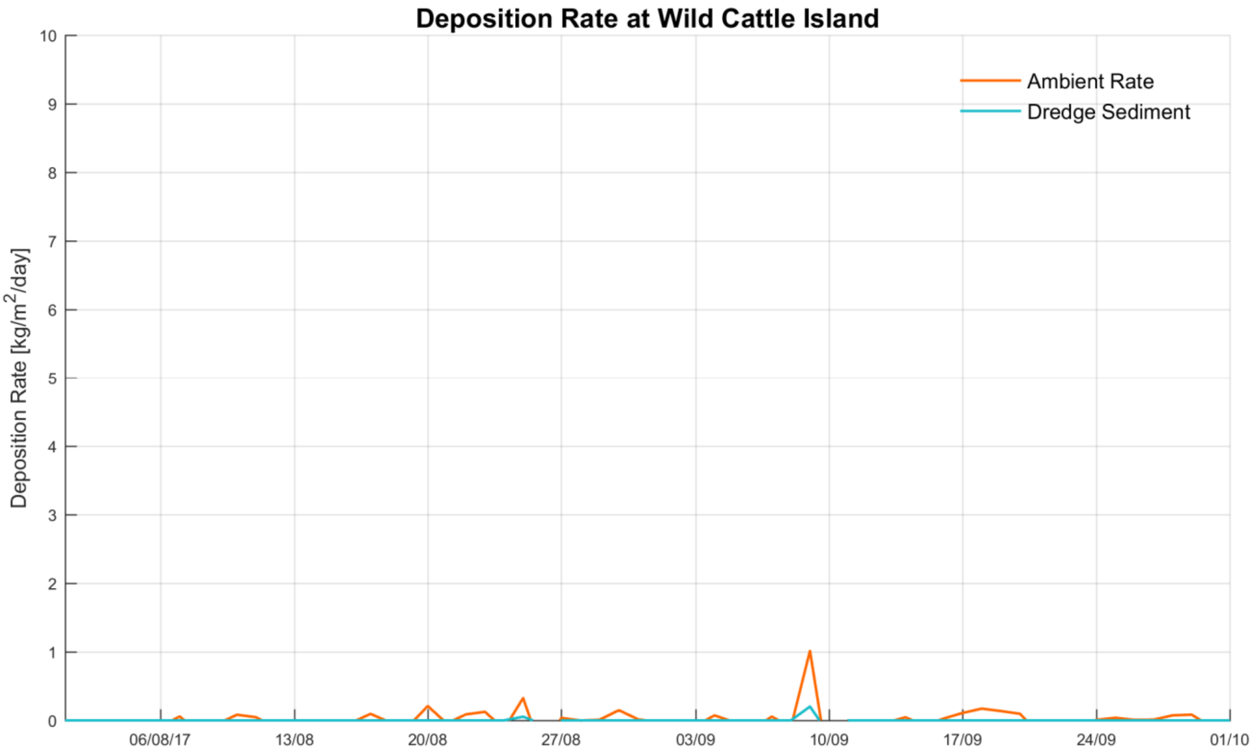


Time Series of Deposition Rate for Dredged and Ambient Sediment



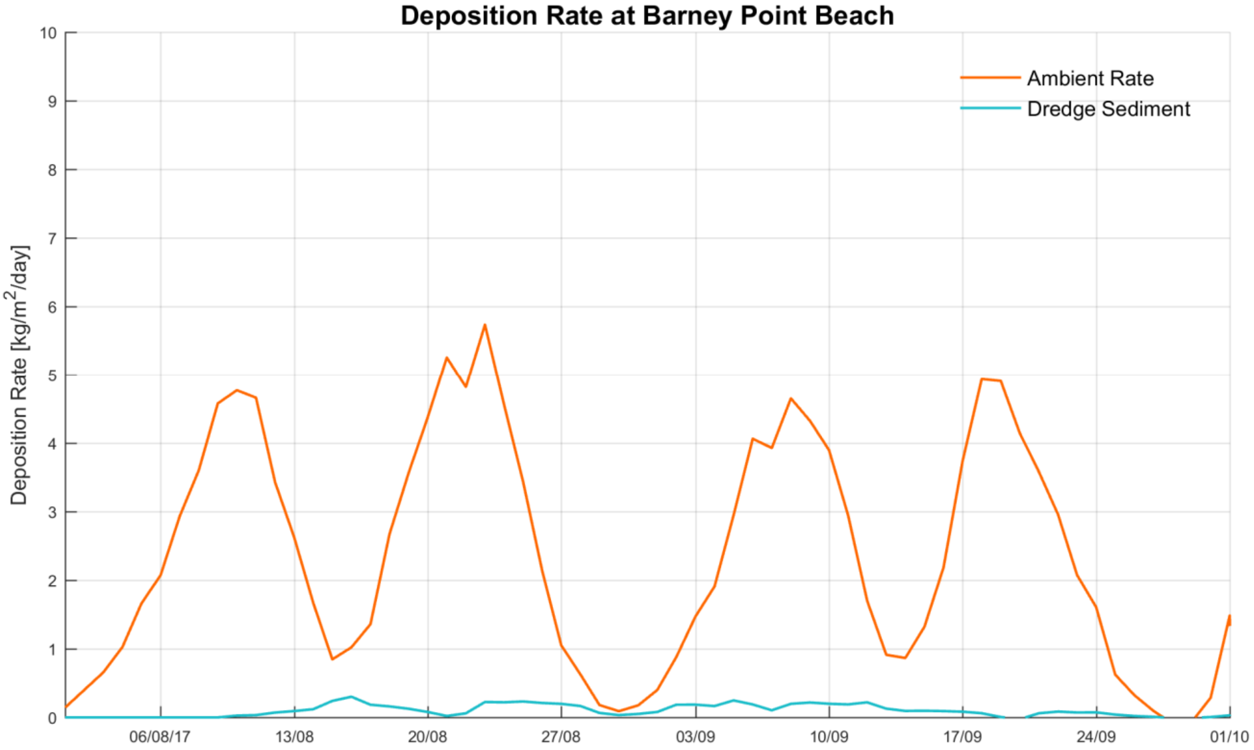


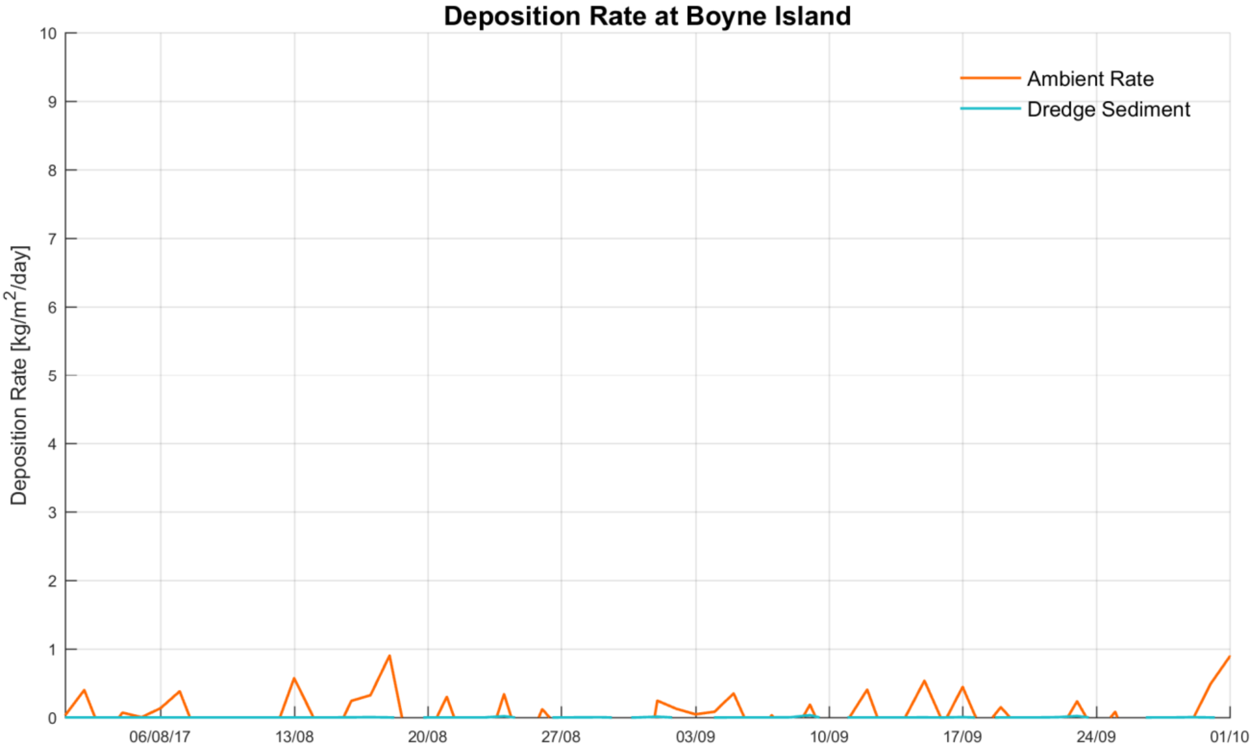
Time Series of Deposition Rate for Dredged and Ambient Sediment



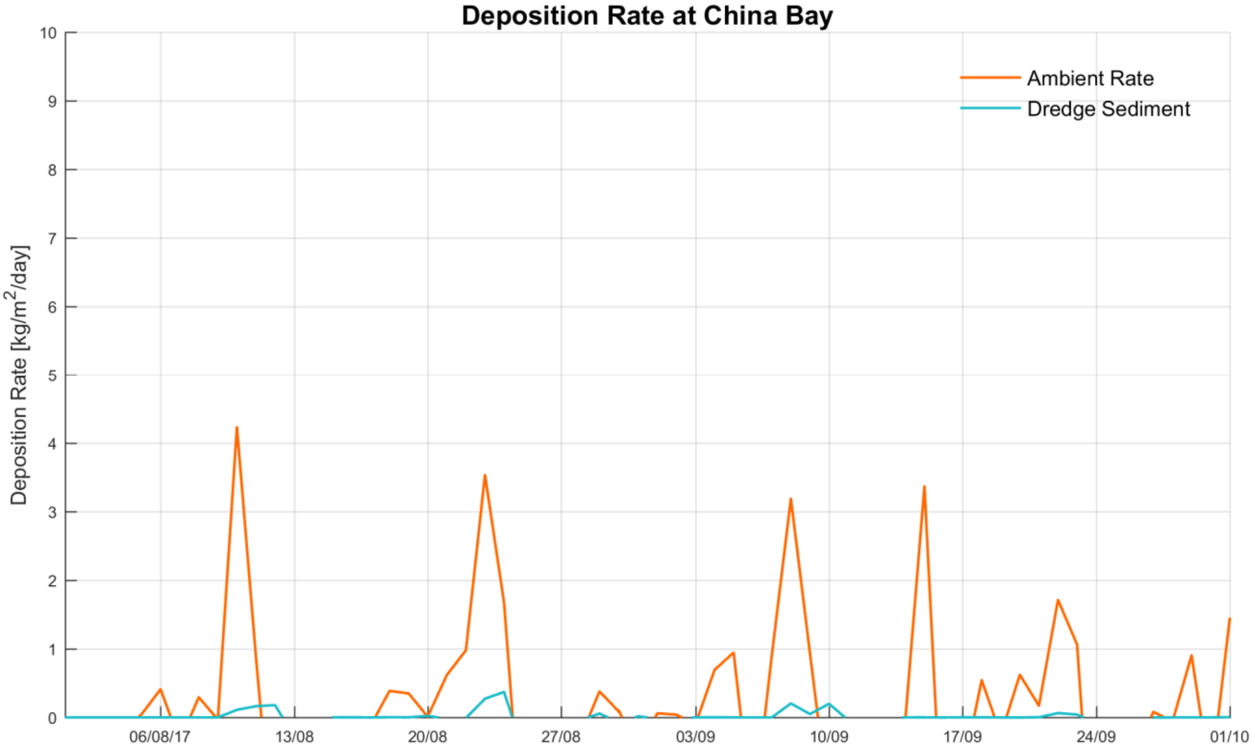
Time Series of Deposition Rate for Dredged and Ambient Sediment

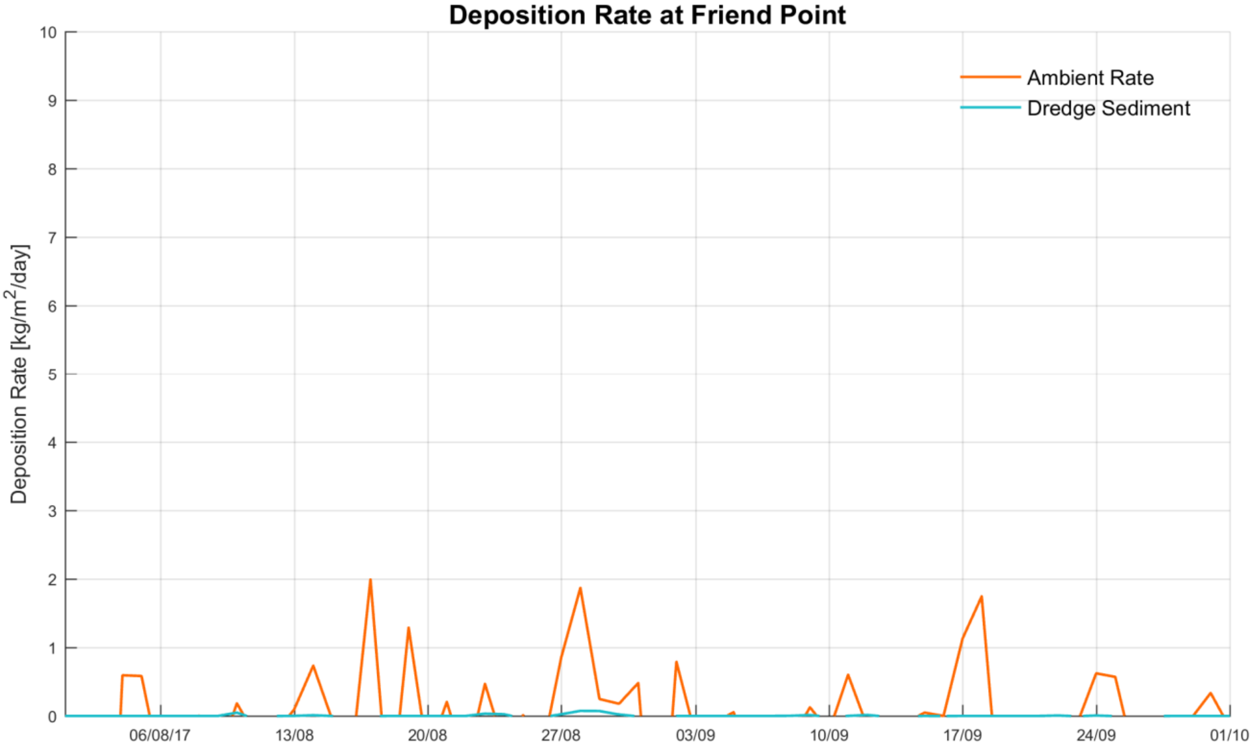
260,000m^3 Campaign



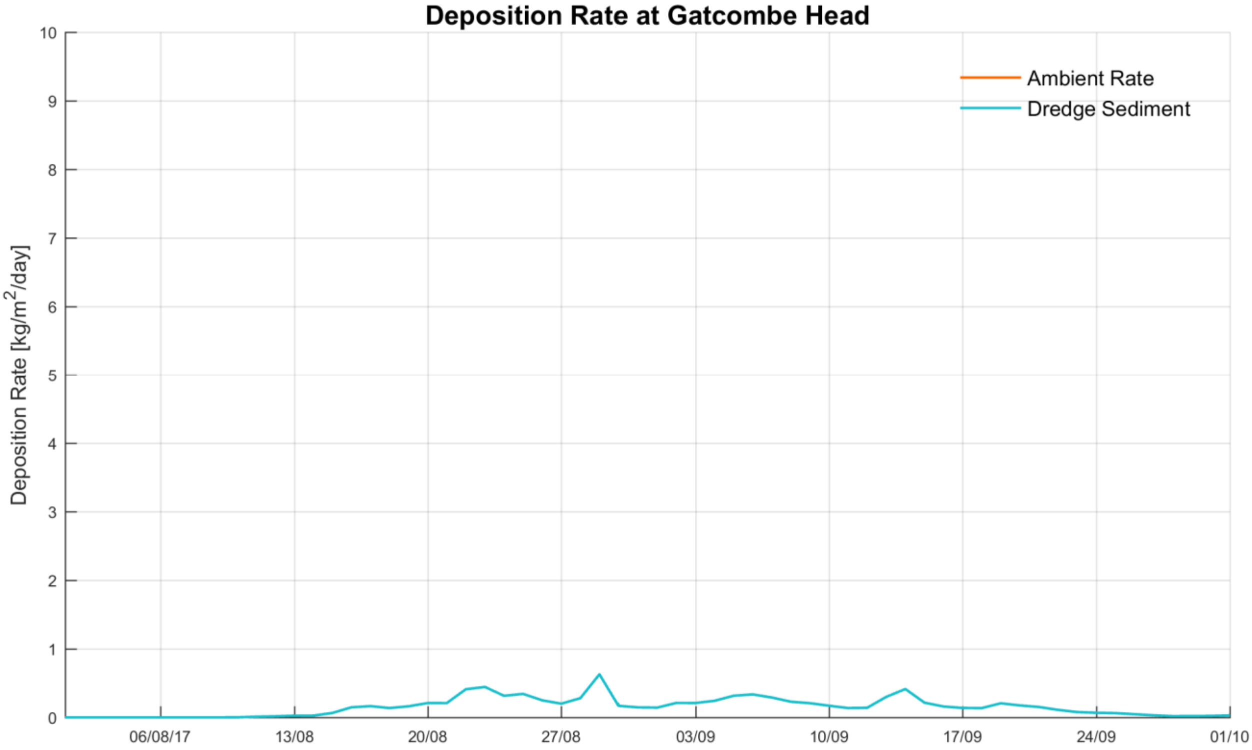


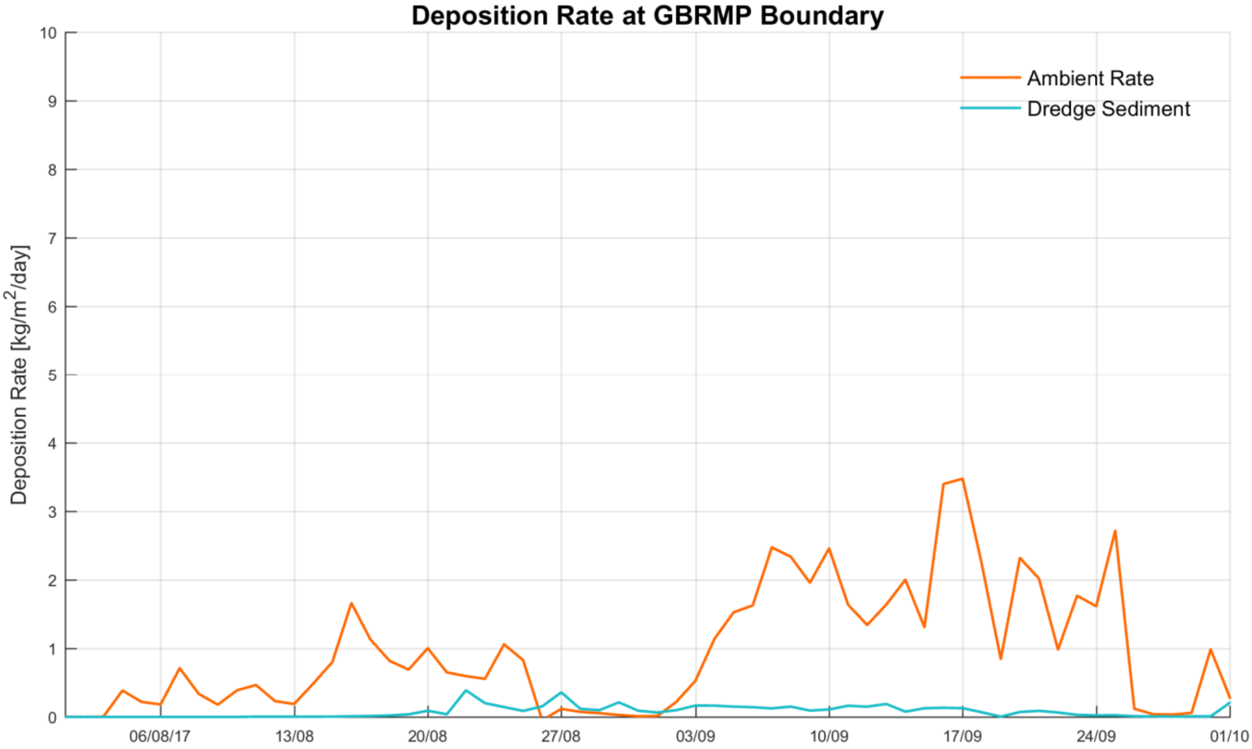
Time Series of Deposition Rate for Dredged and Ambient Sediment



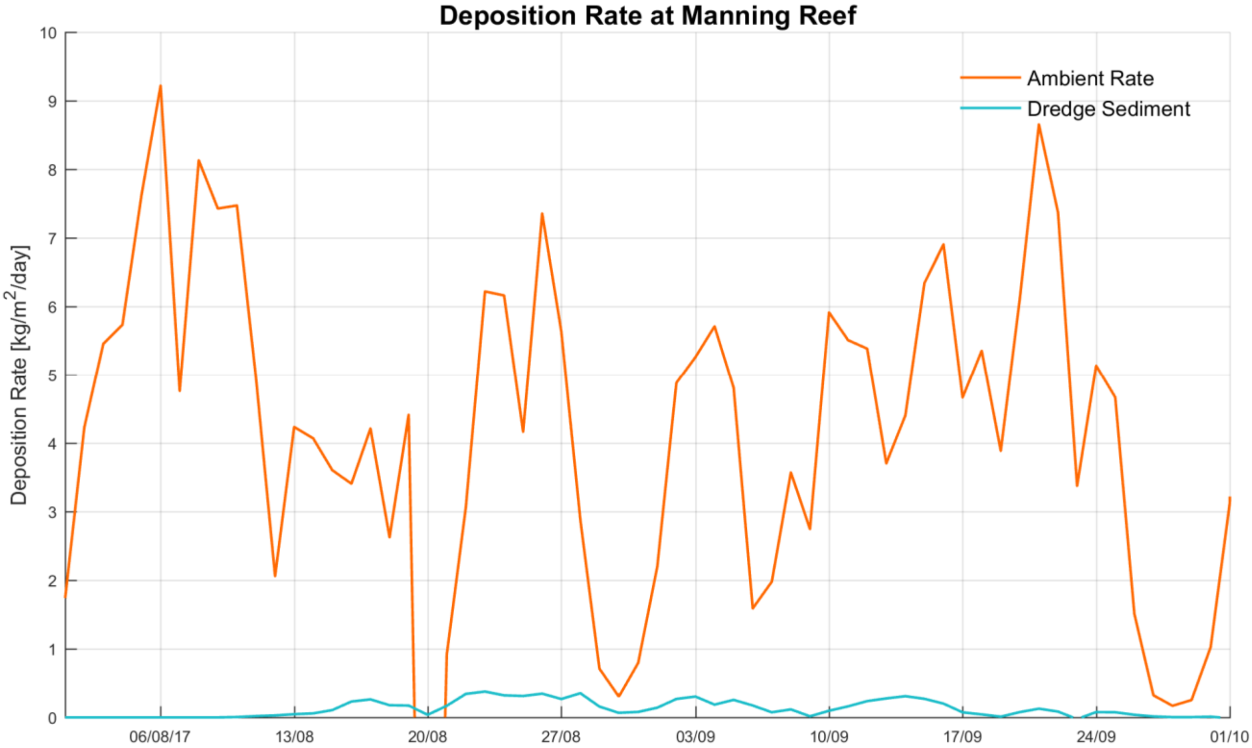


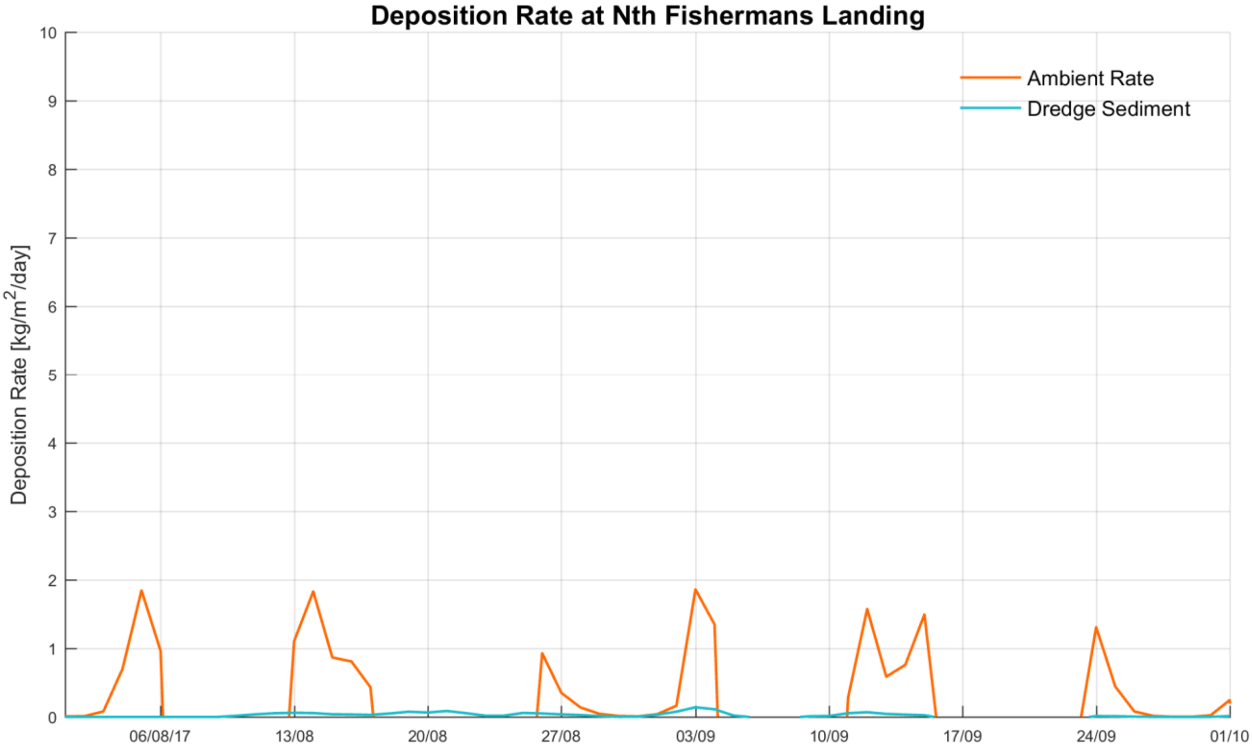
Time Series of Deposition Rate for Dredged and Ambient Sediment



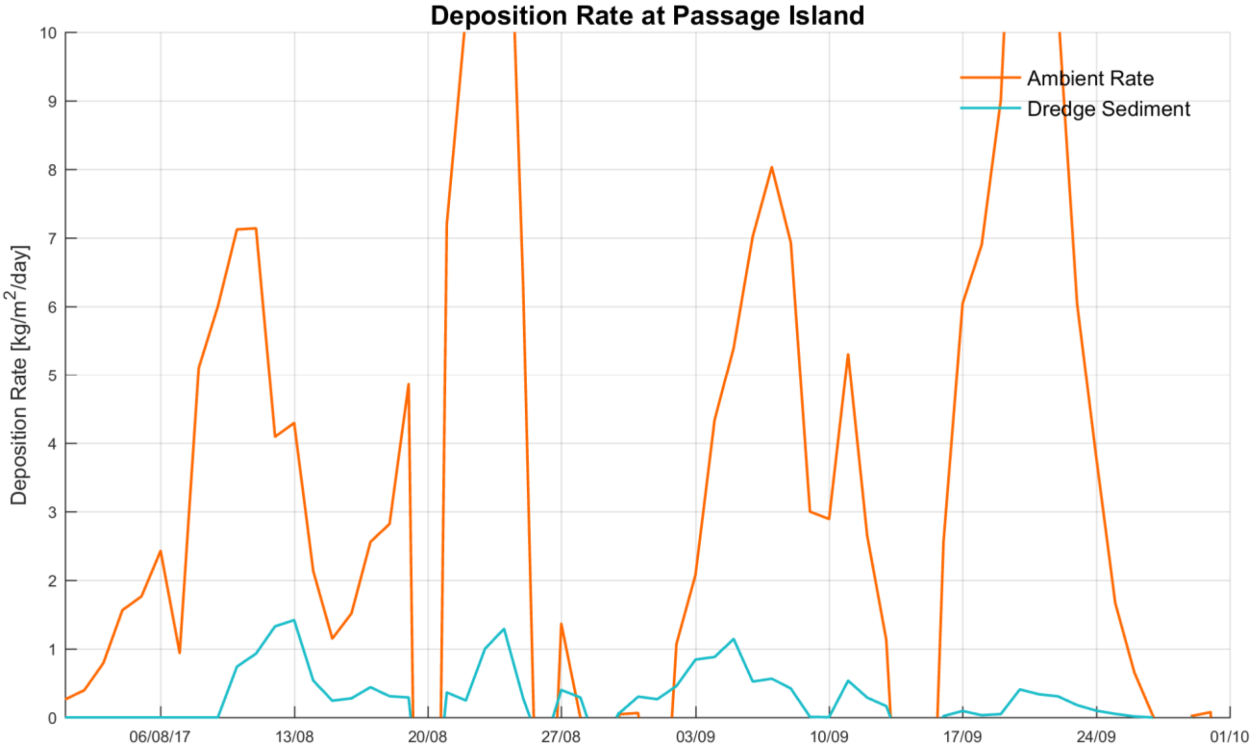


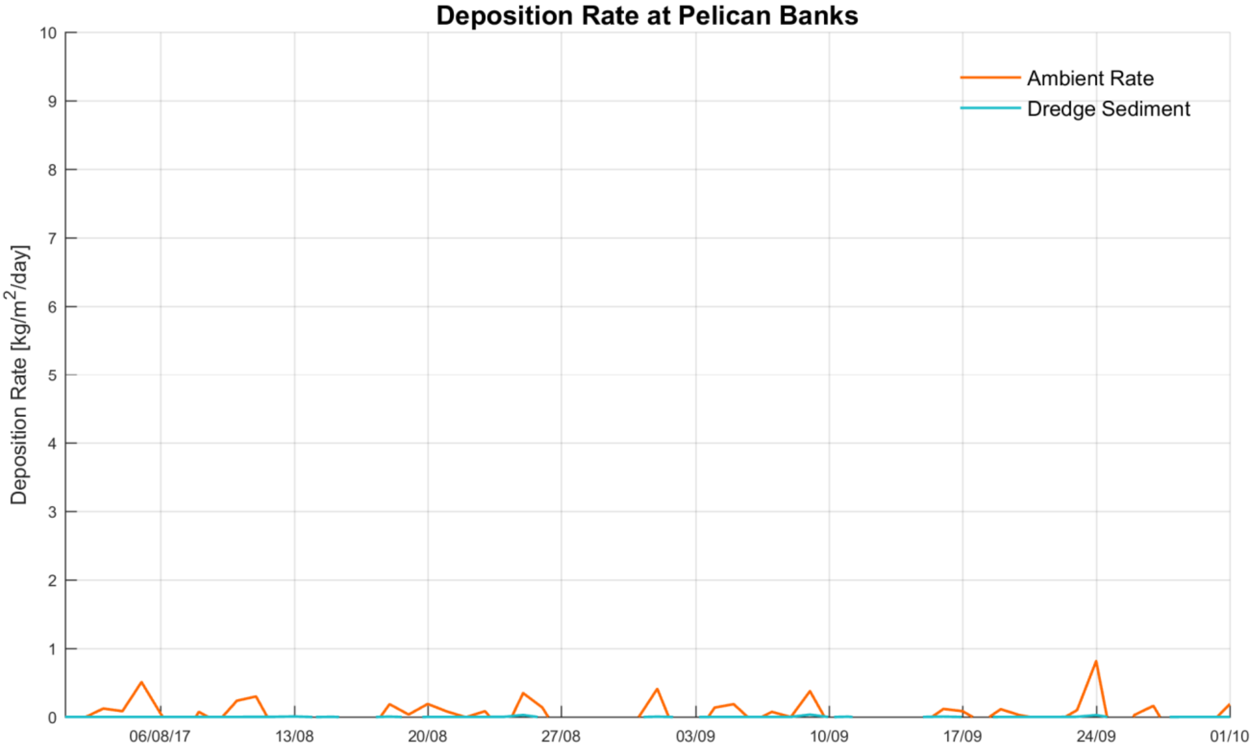
Time Series of Deposition Rate for Dredged and Ambient Sediment



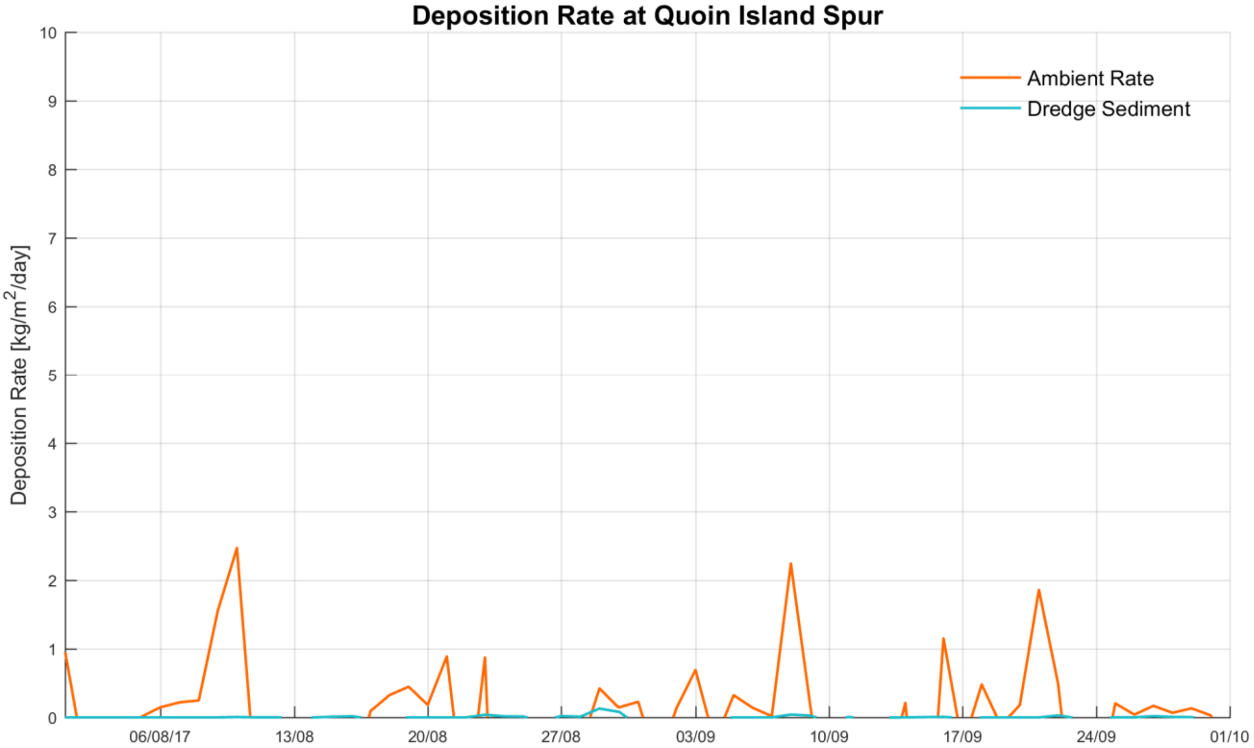


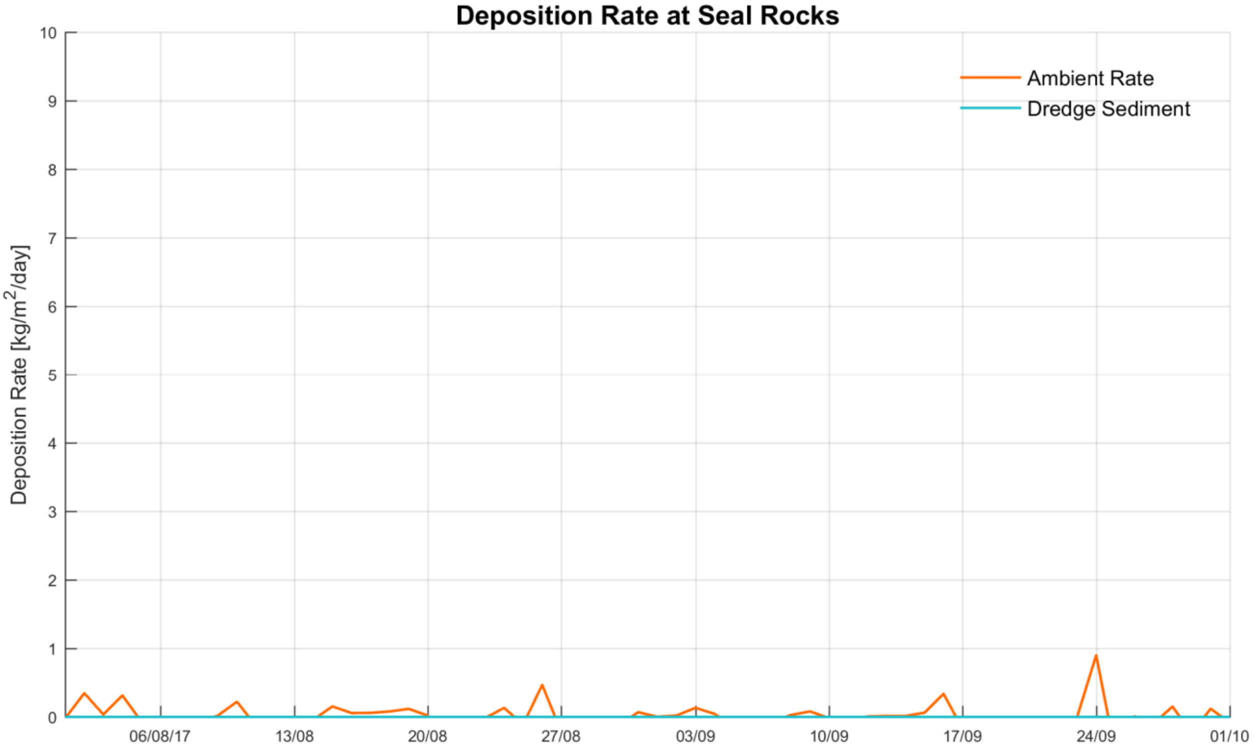
Time Series of Deposition Rate for Dredged and Ambient Sediment



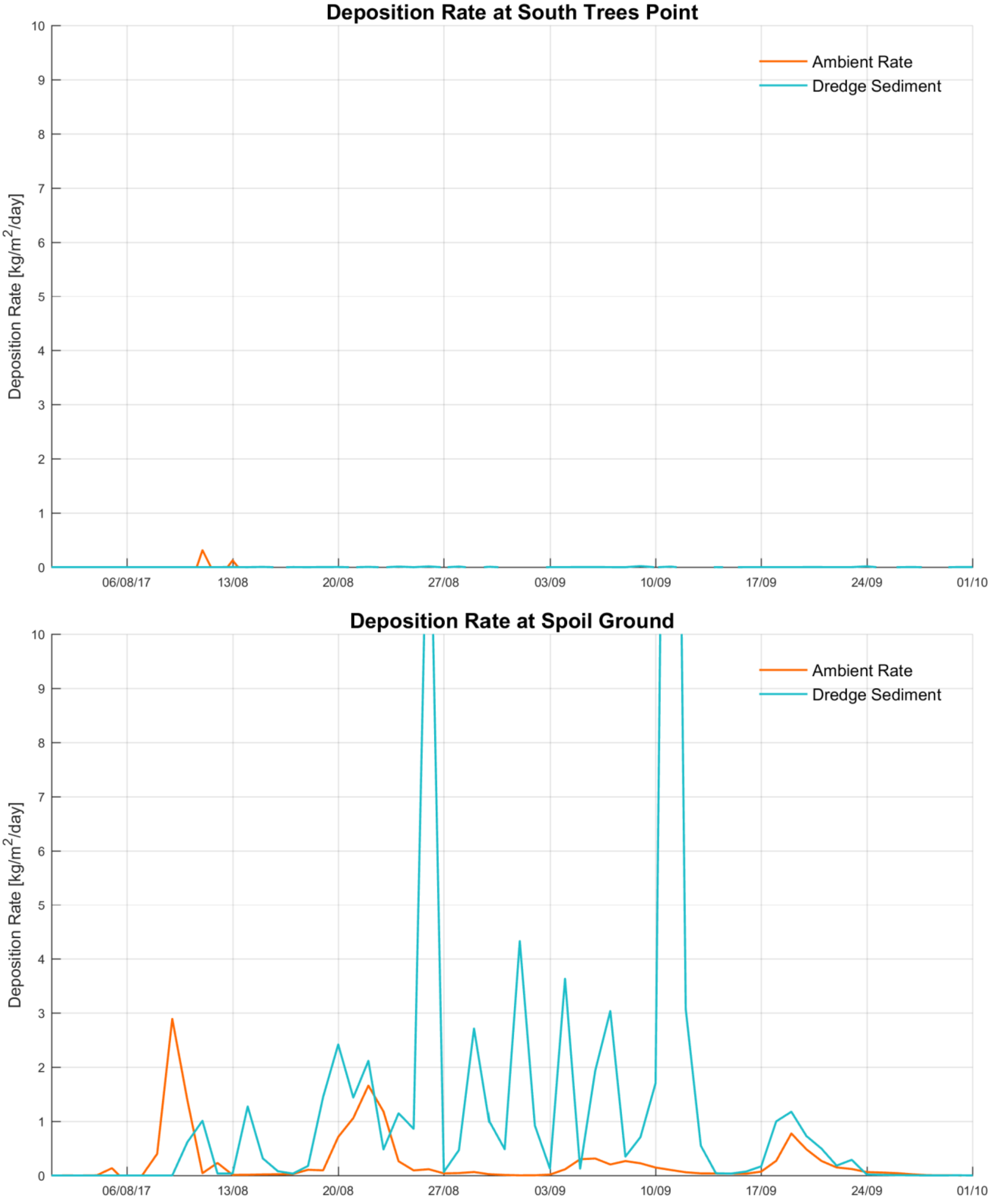


Time Series of Deposition Rate for Dredged and Ambient Sediment

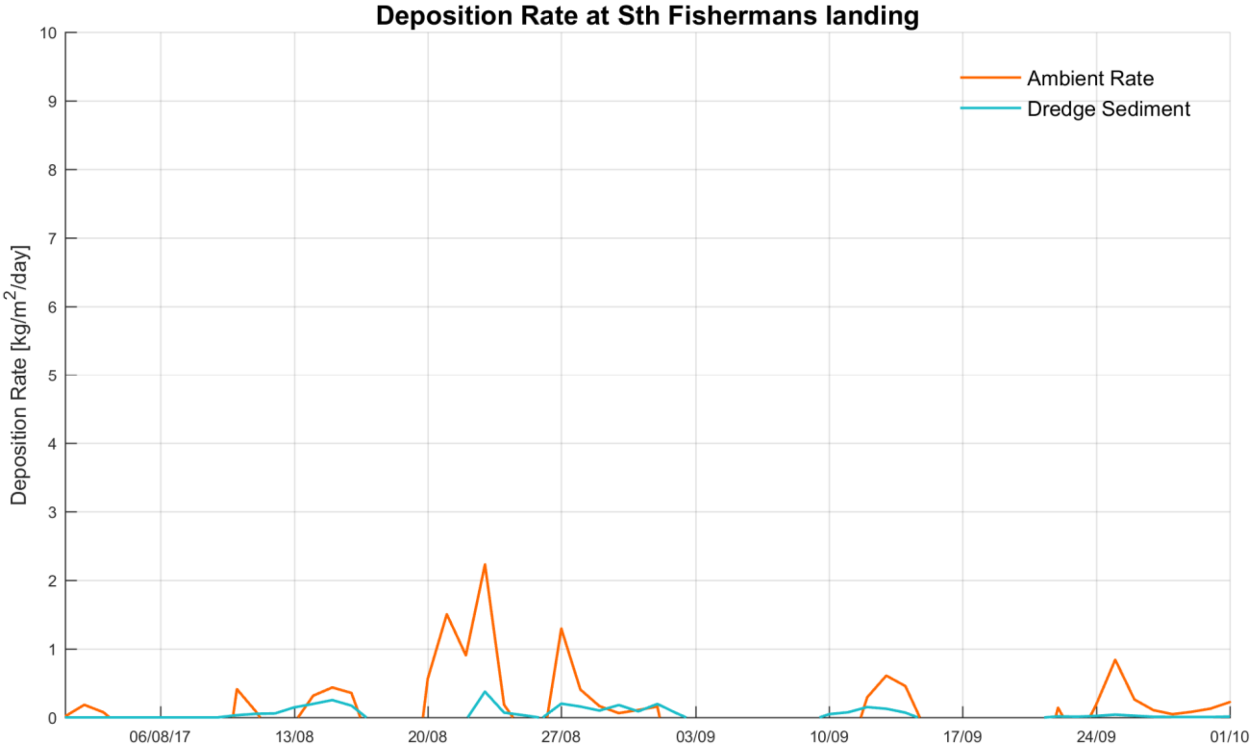


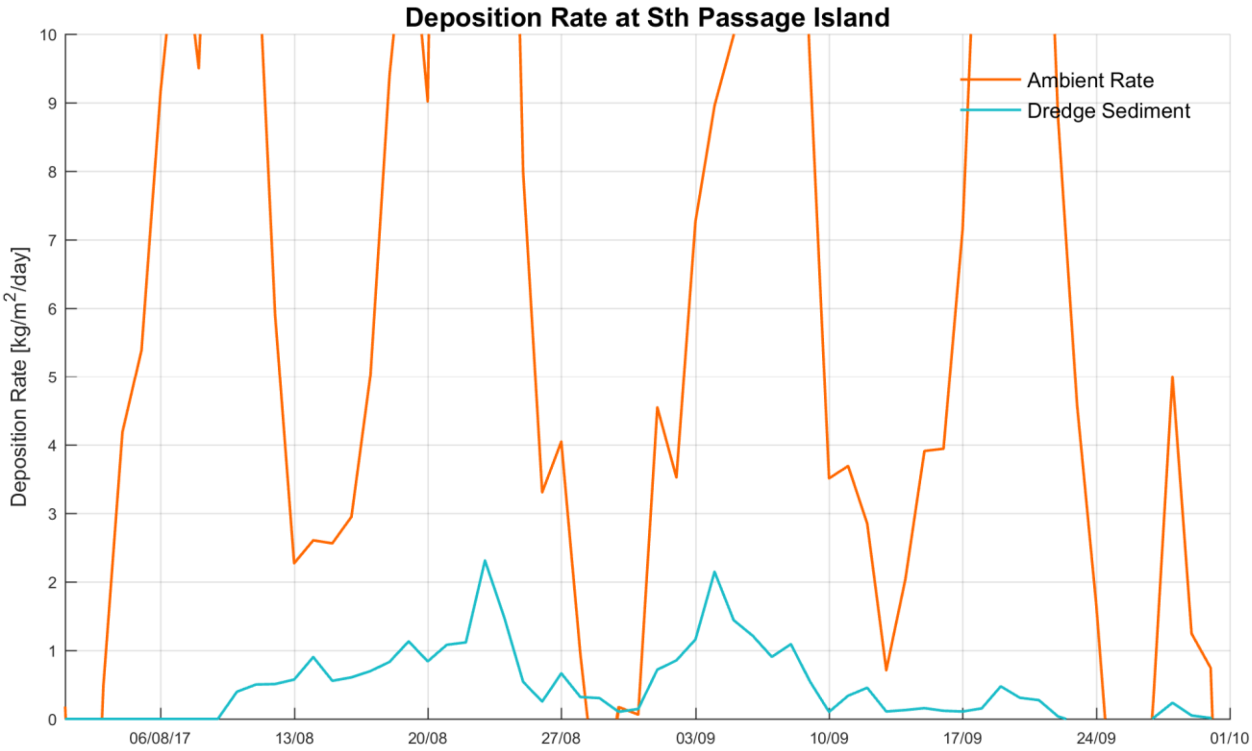


Time Series of Deposition Rate for Dredged and Ambient Sediment

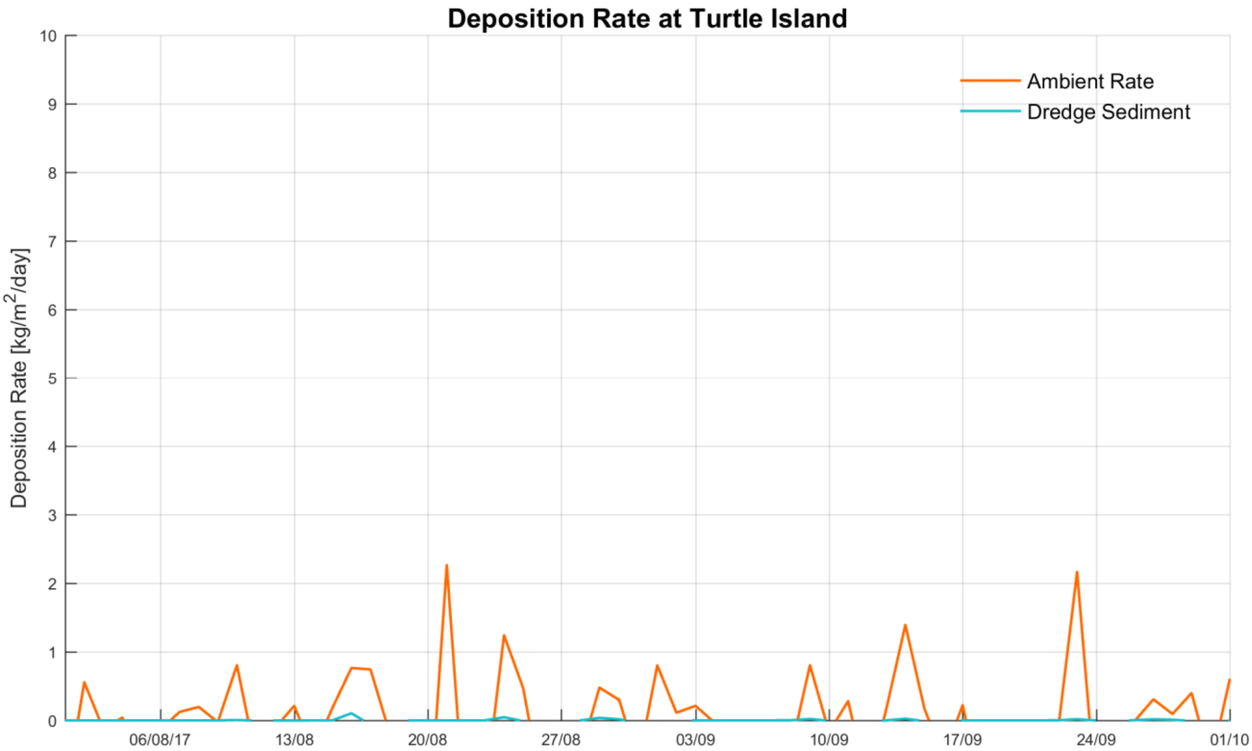


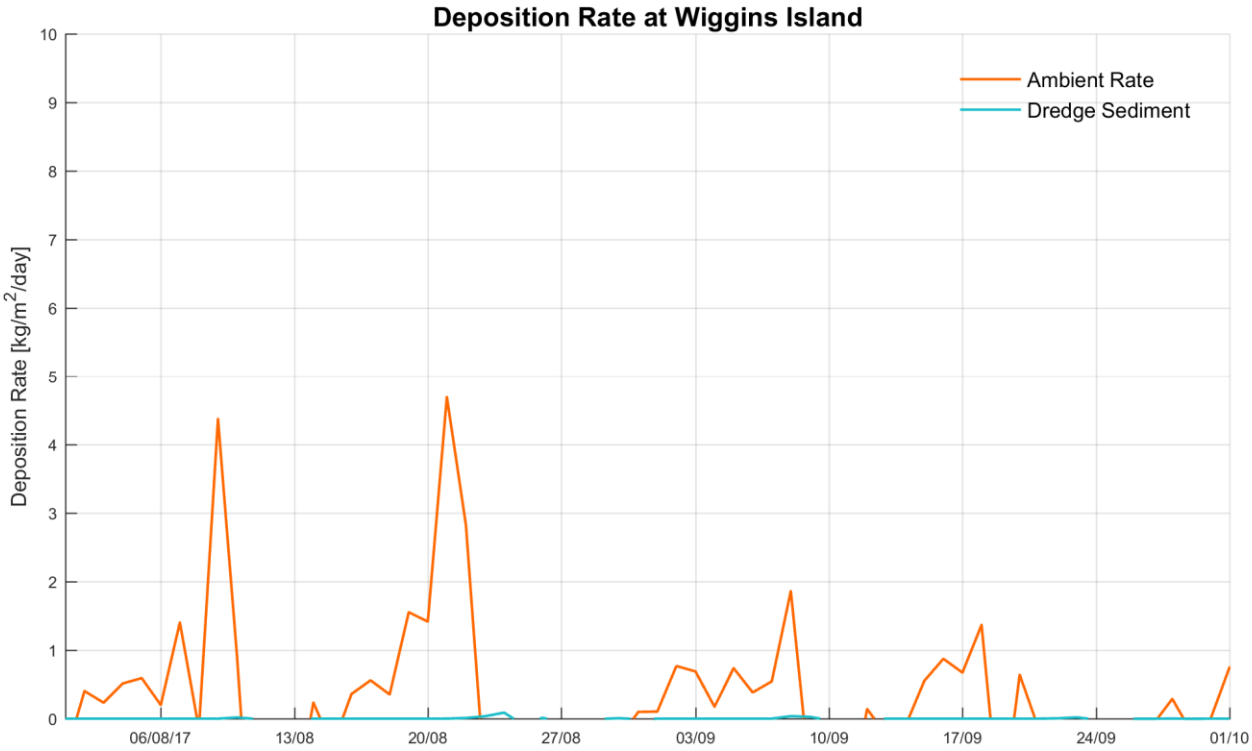
Time Series of Deposition Rate for Dredged and Ambient Sediment



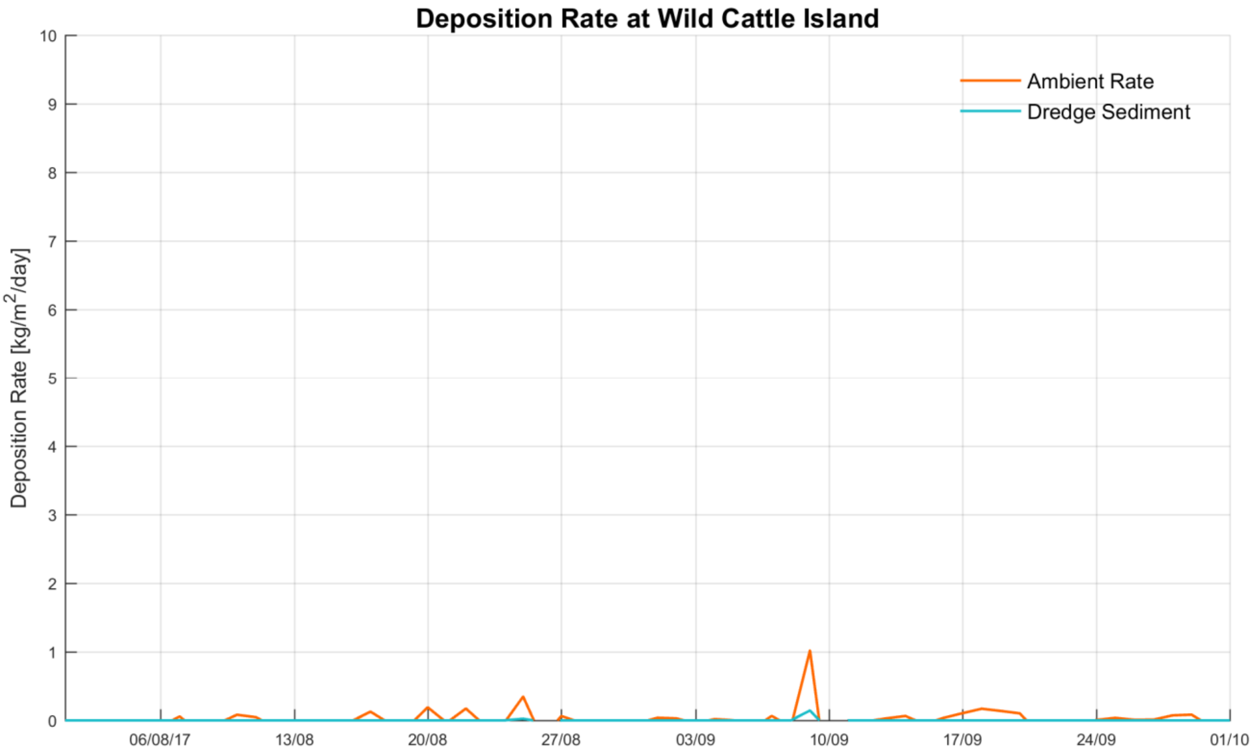


Time Series of Deposition Rate for Dredged and Ambient Sediment

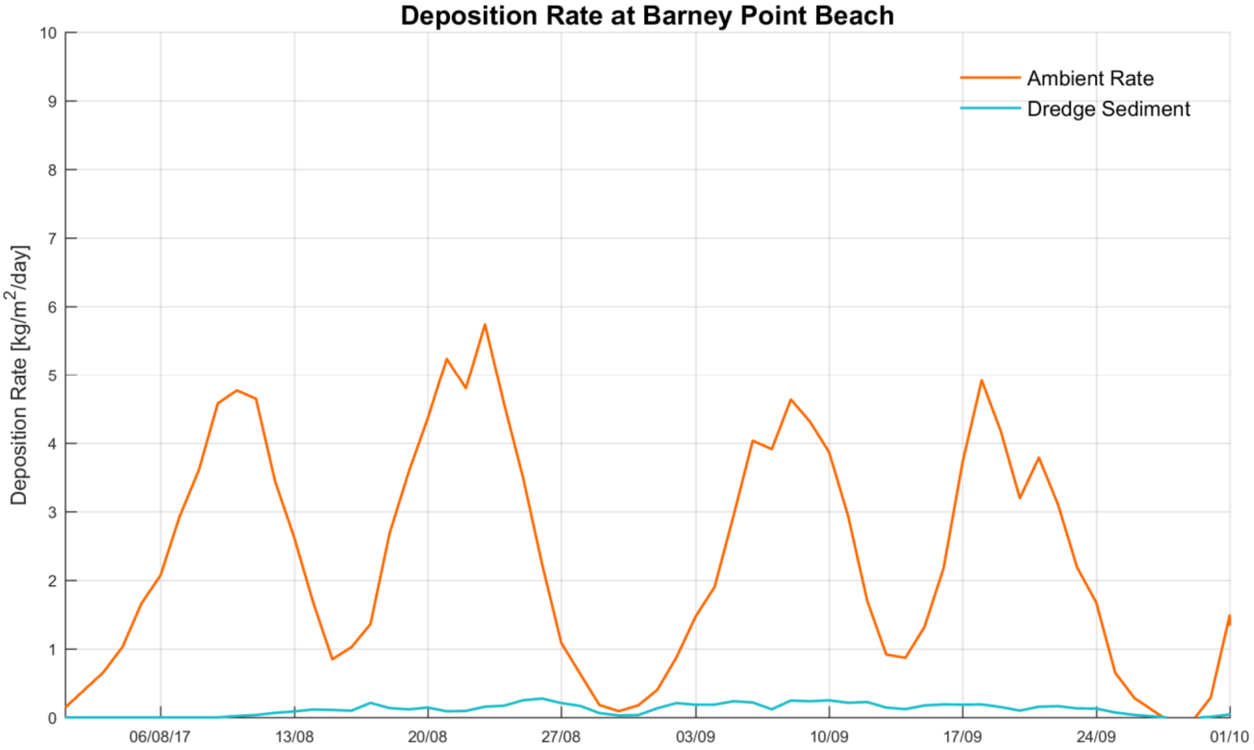


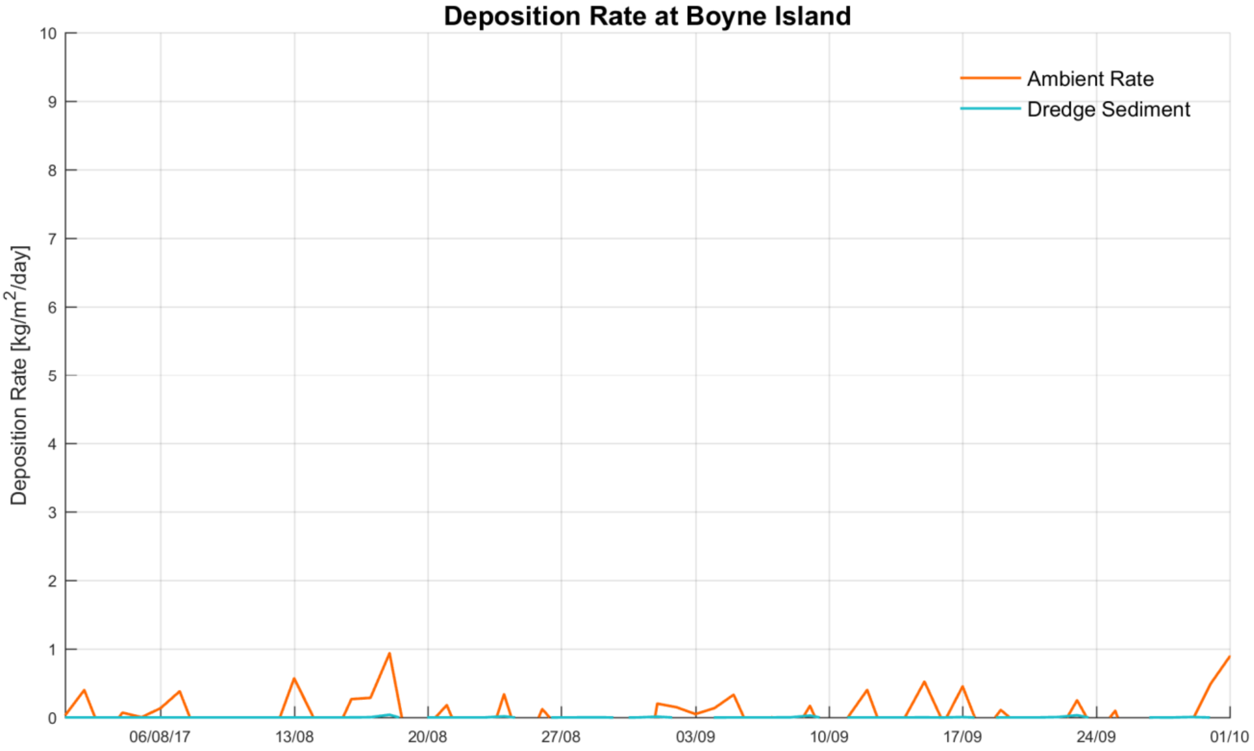


Time Series of Deposition Rate for Dredged and Ambient Sediment

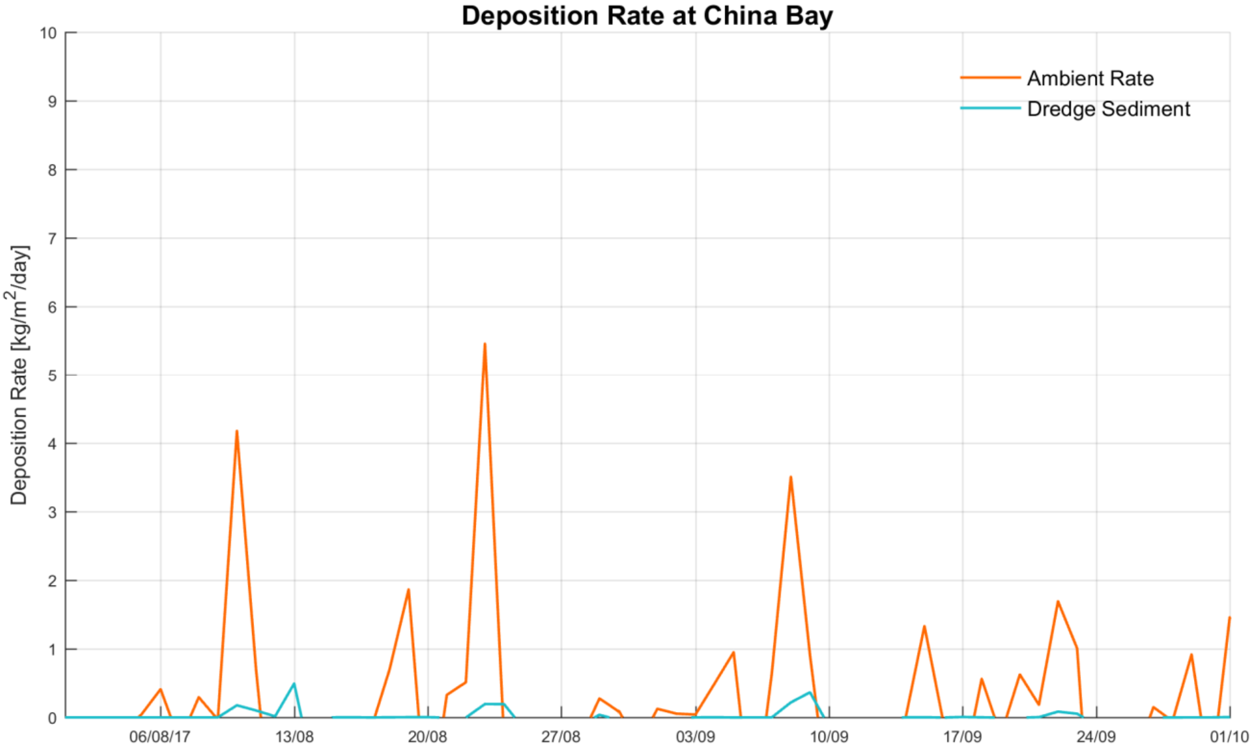


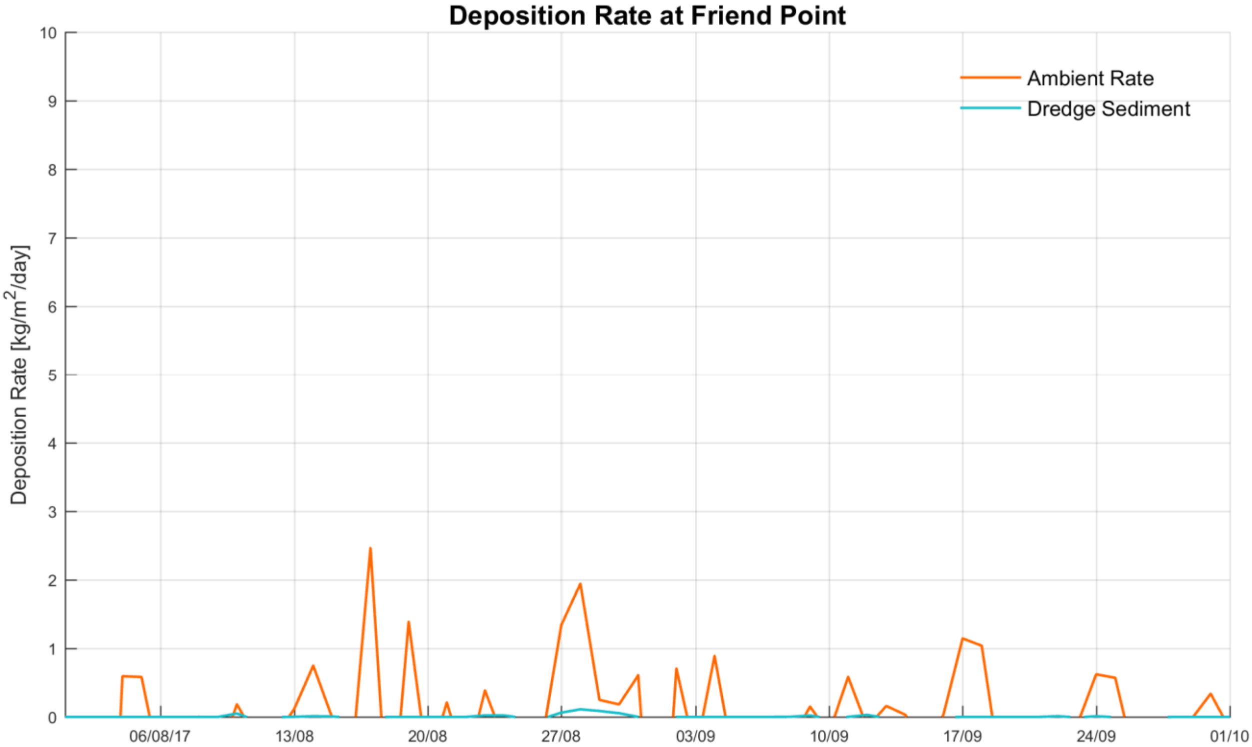
300,000m^3 Campaign



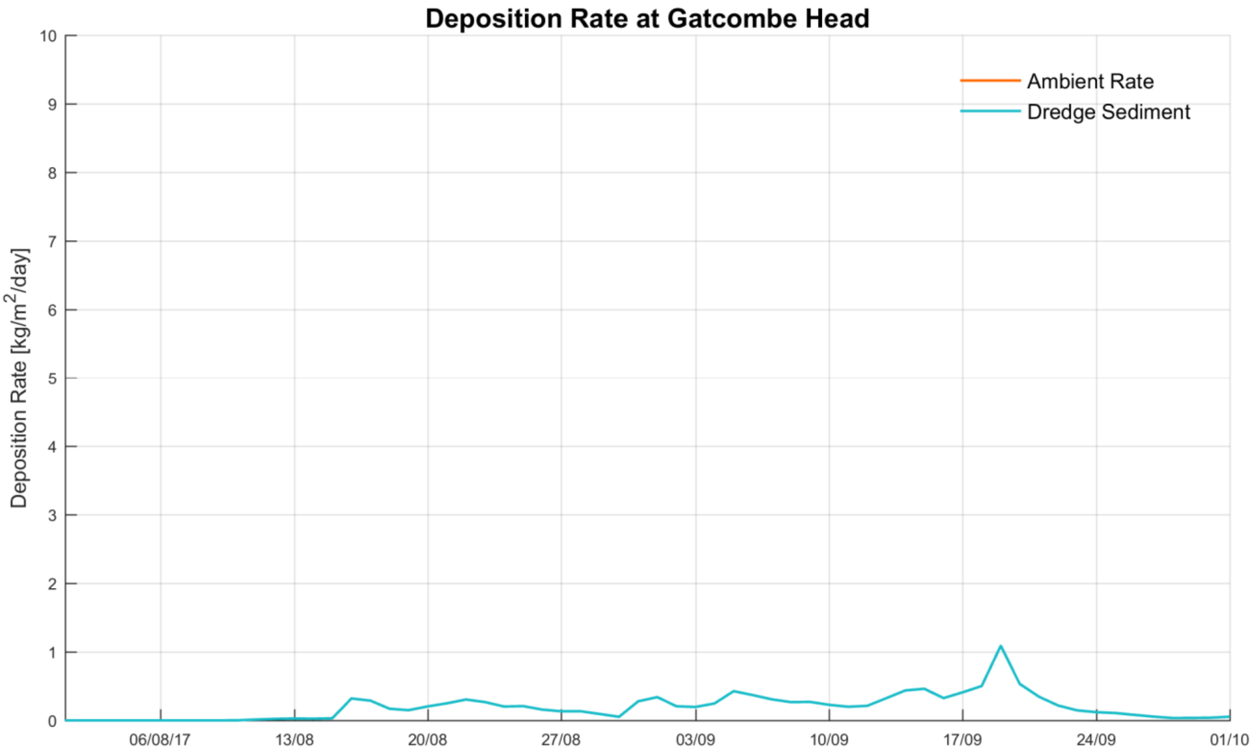


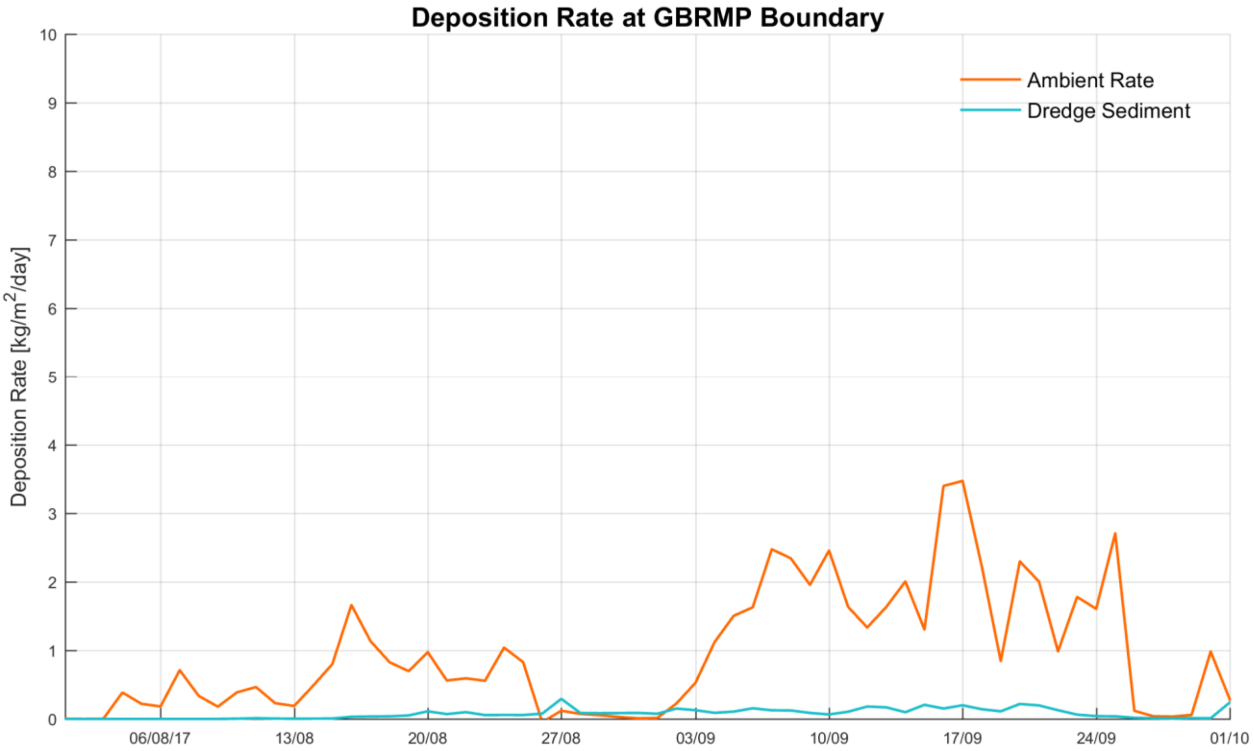
Time Series of Deposition Rate for Dredged and Ambient Sediment



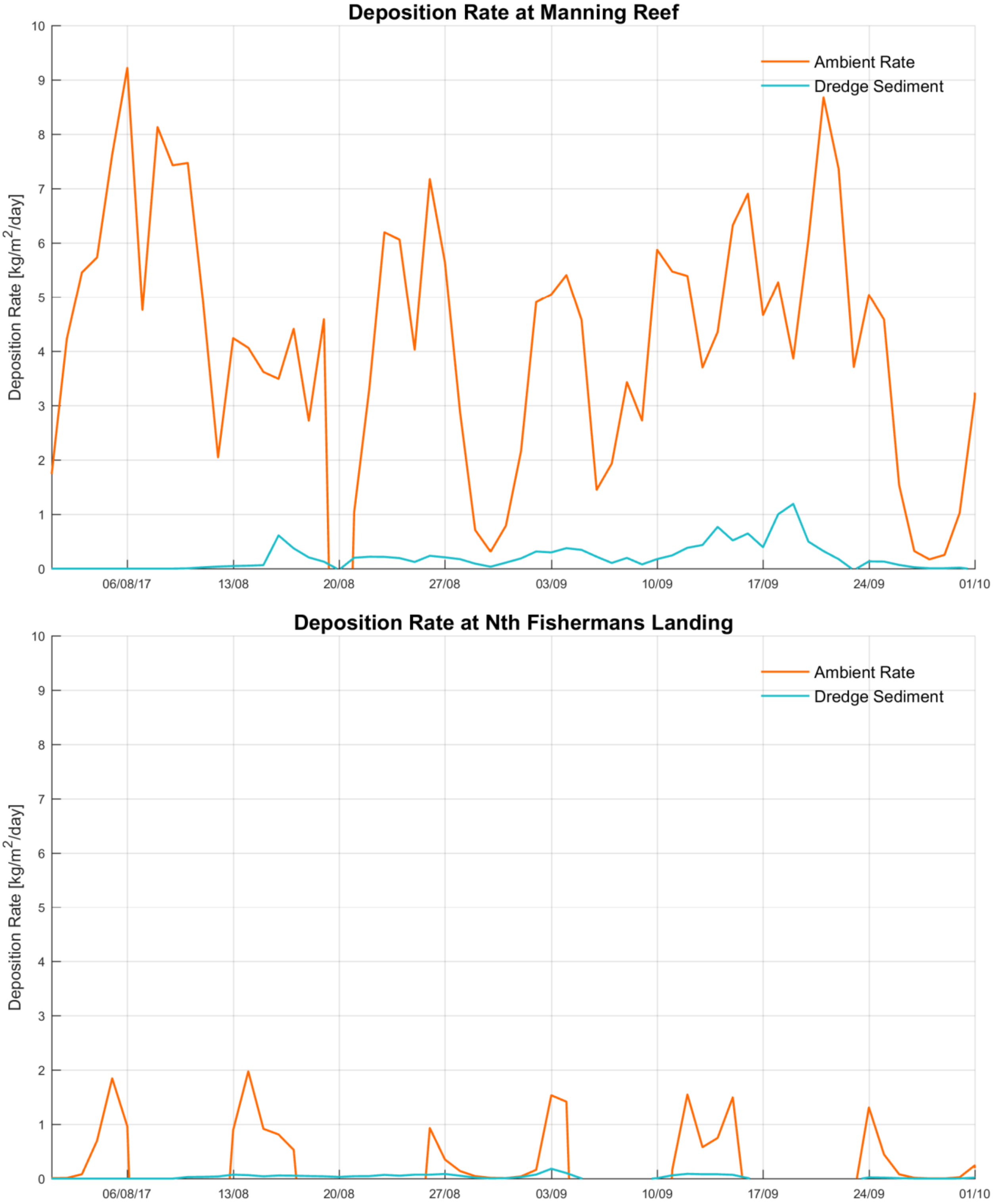


Time Series of Deposition Rate for Dredged and Ambient Sediment

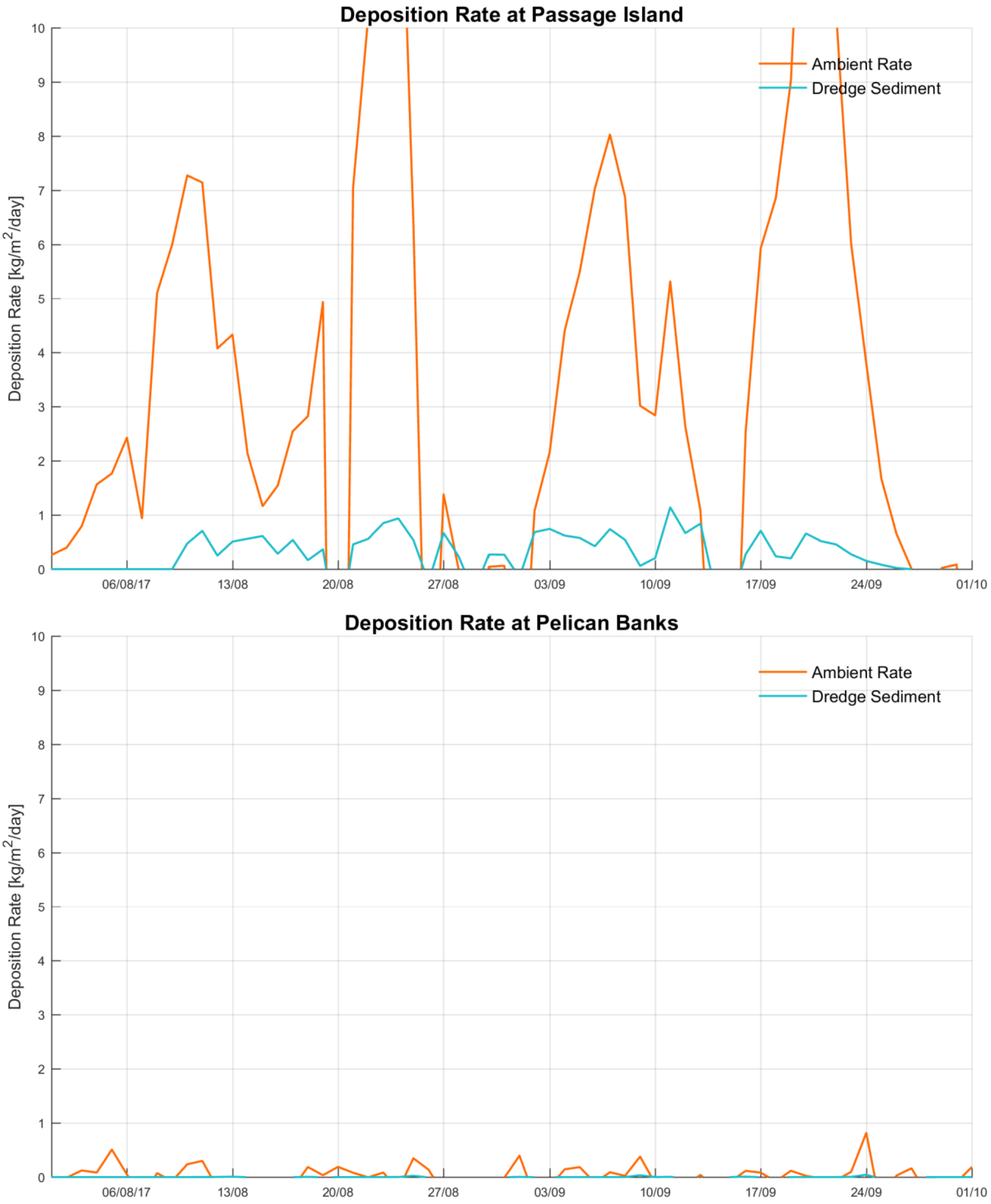




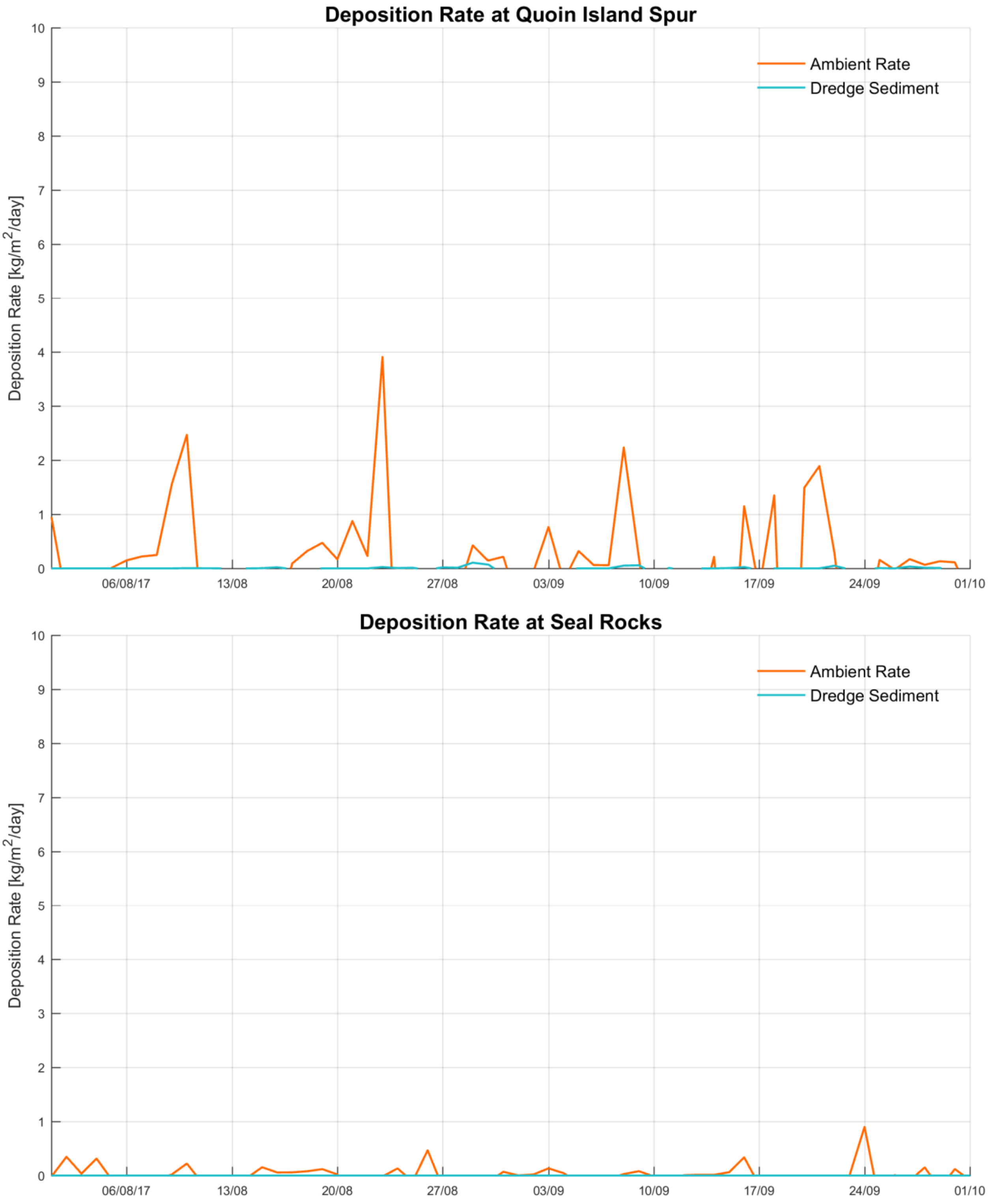
Time Series of Deposition Rate for Dredged and Ambient Sediment



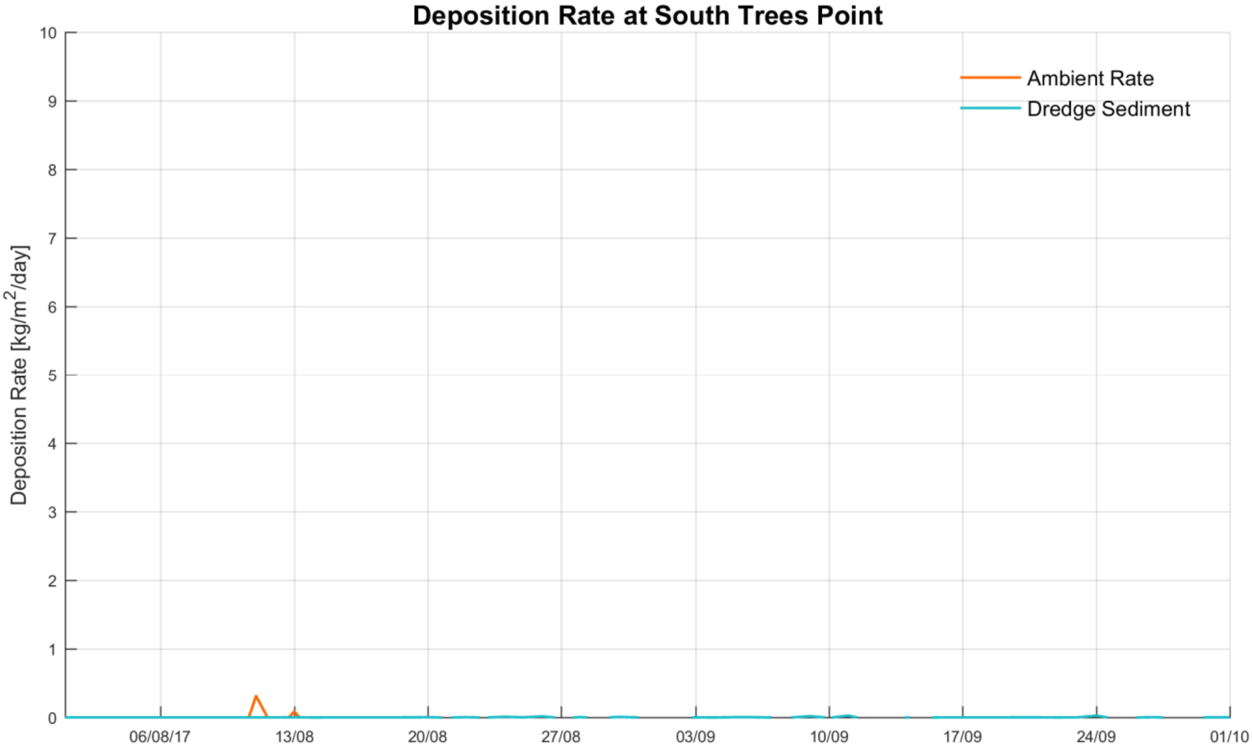
Time Series of Deposition Rate for Dredged and Ambient Sediment

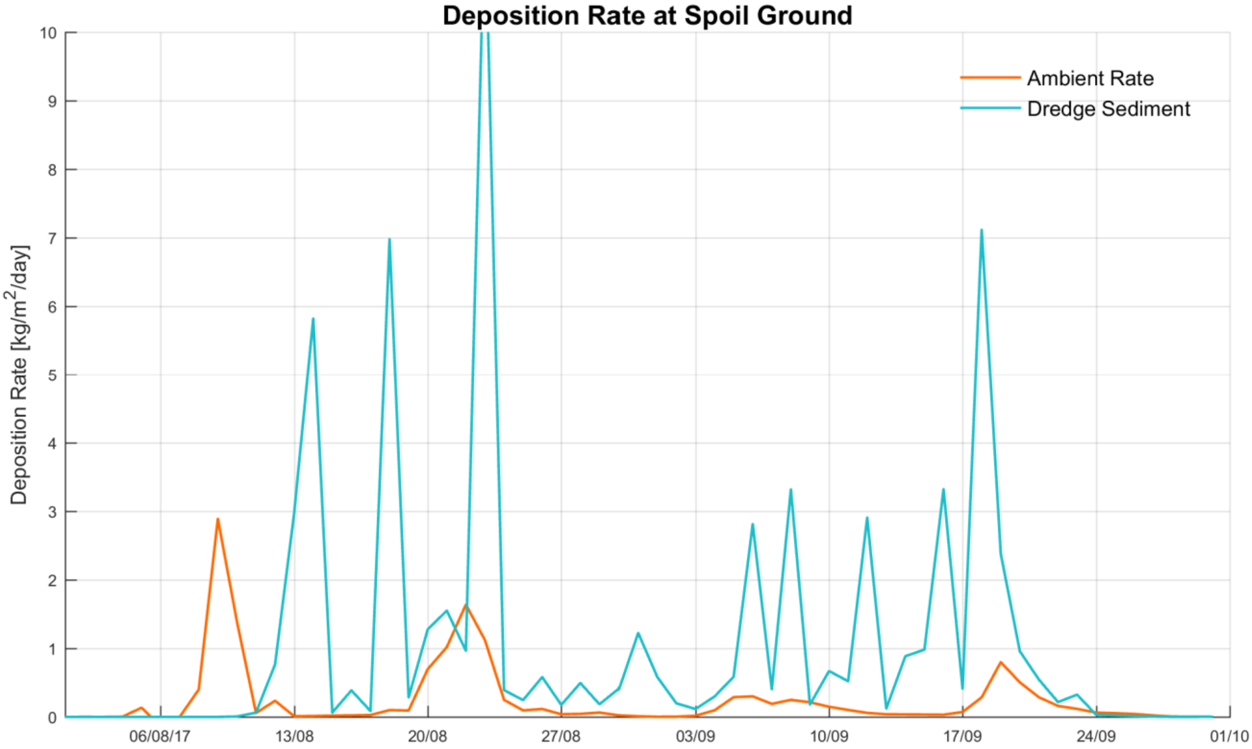


Time Series of Deposition Rate for Dredged and Ambient Sediment

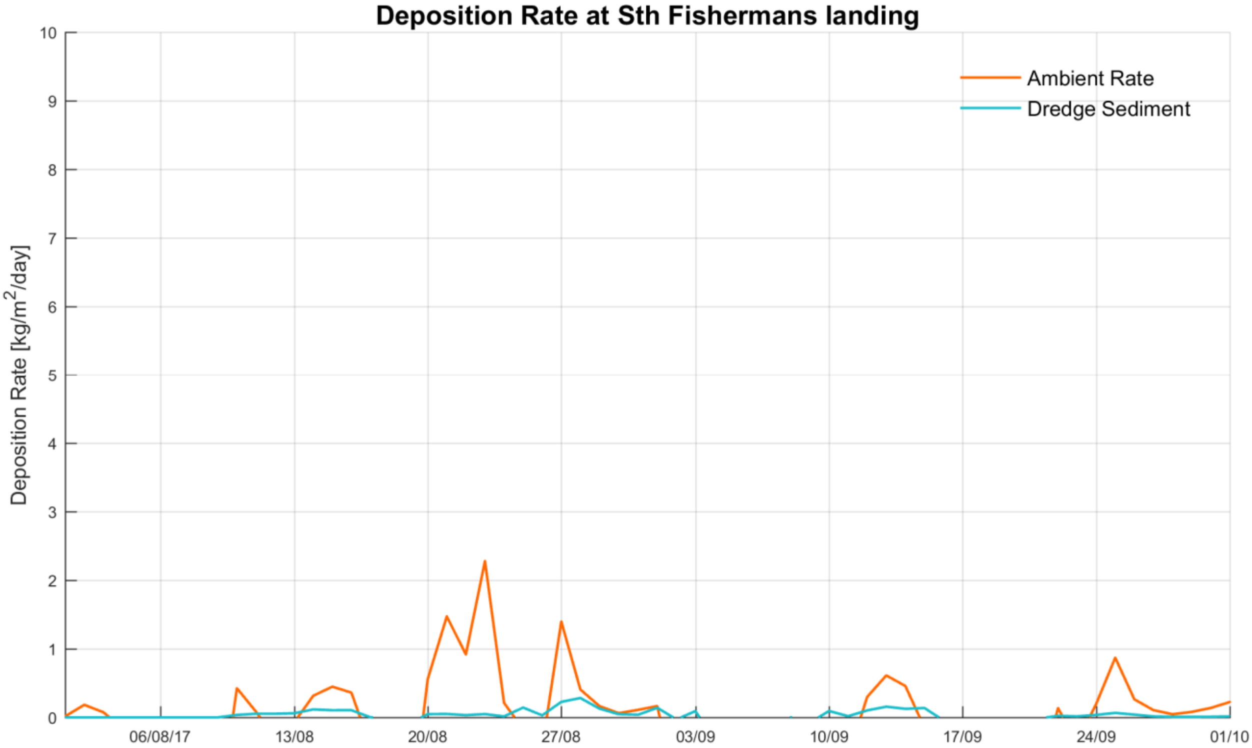


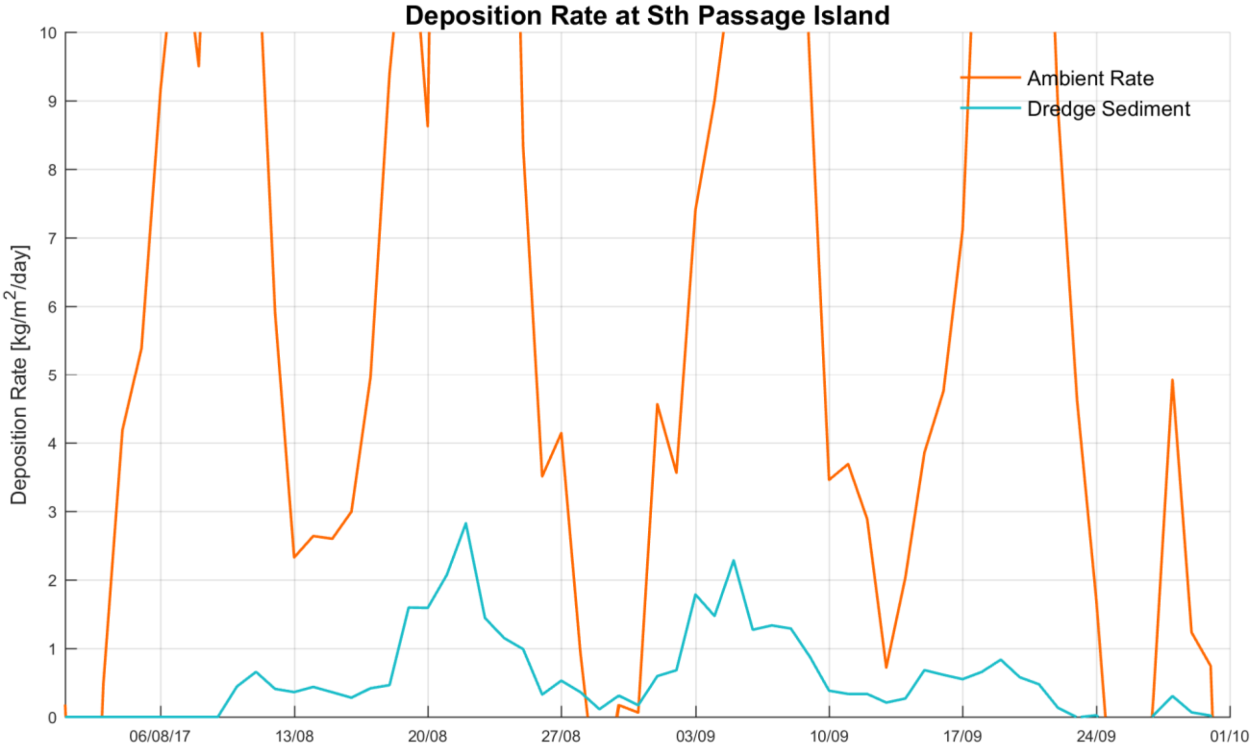
Time Series of Deposition Rate for Dredged and Ambient Sediment



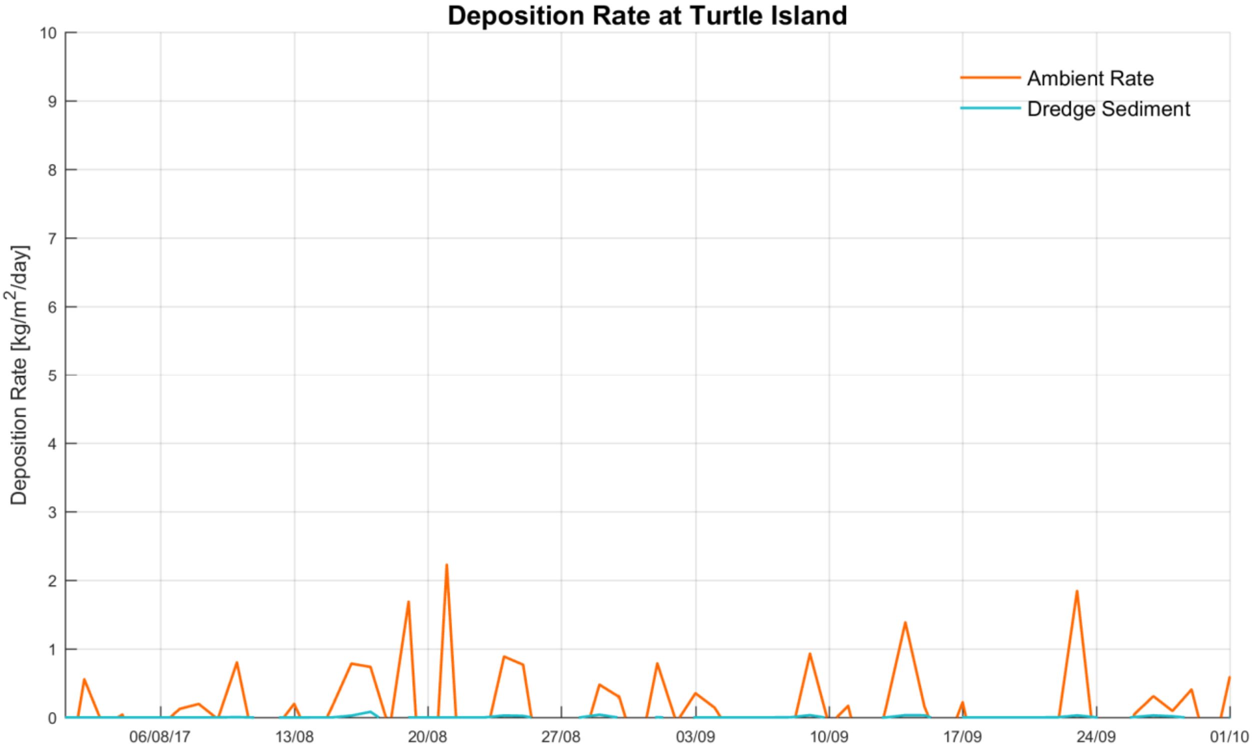


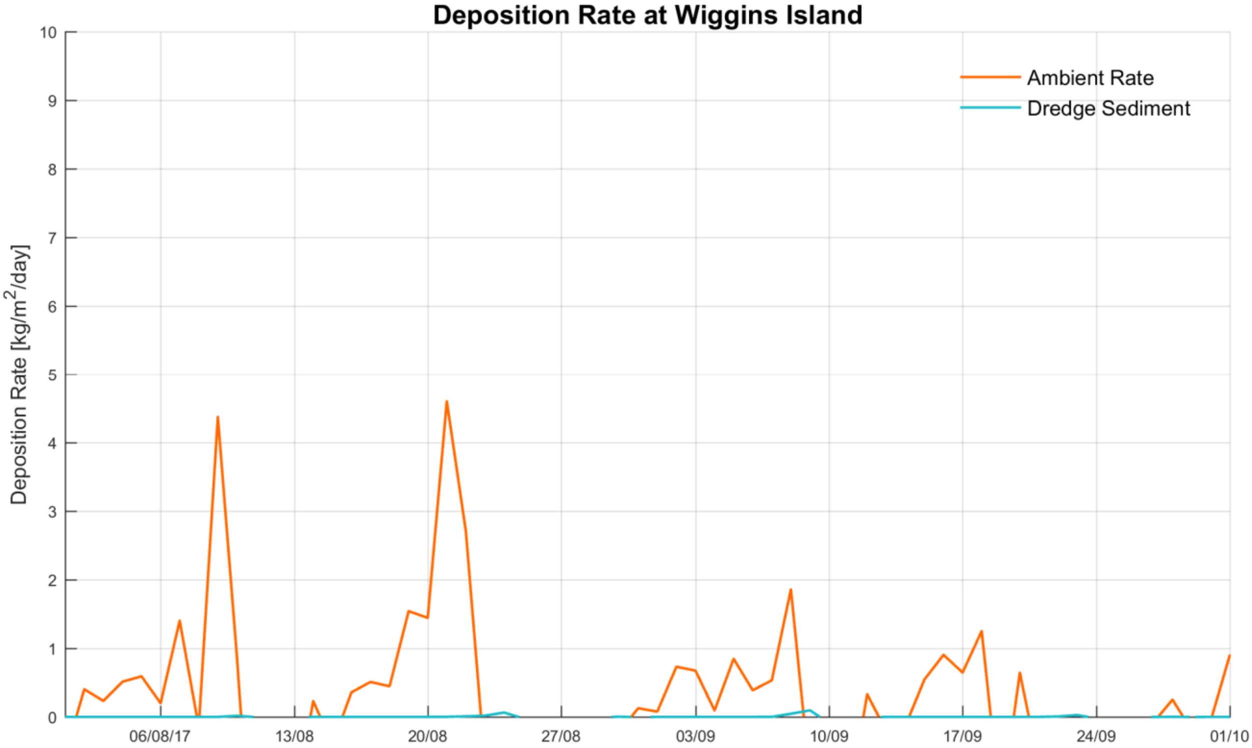
Time Series of Deposition Rate for Dredged and Ambient Sediment



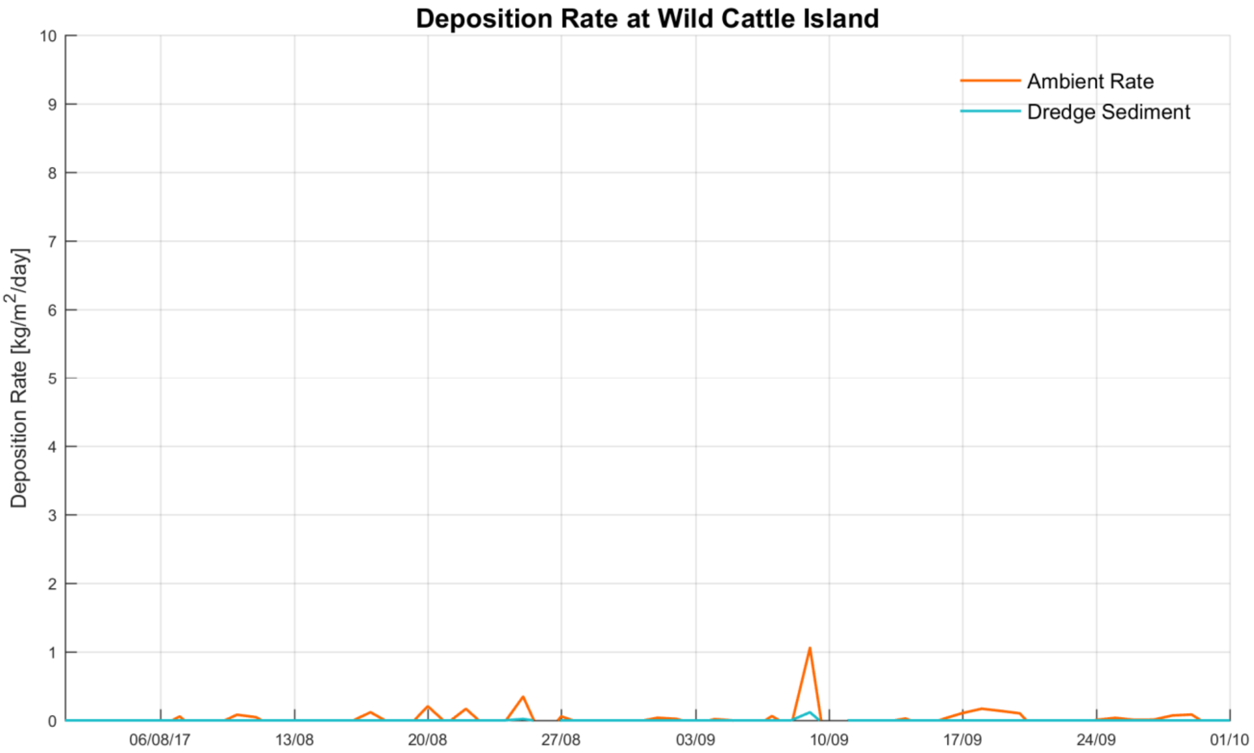


Time Series of Deposition Rate for Dredged and Ambient Sediment

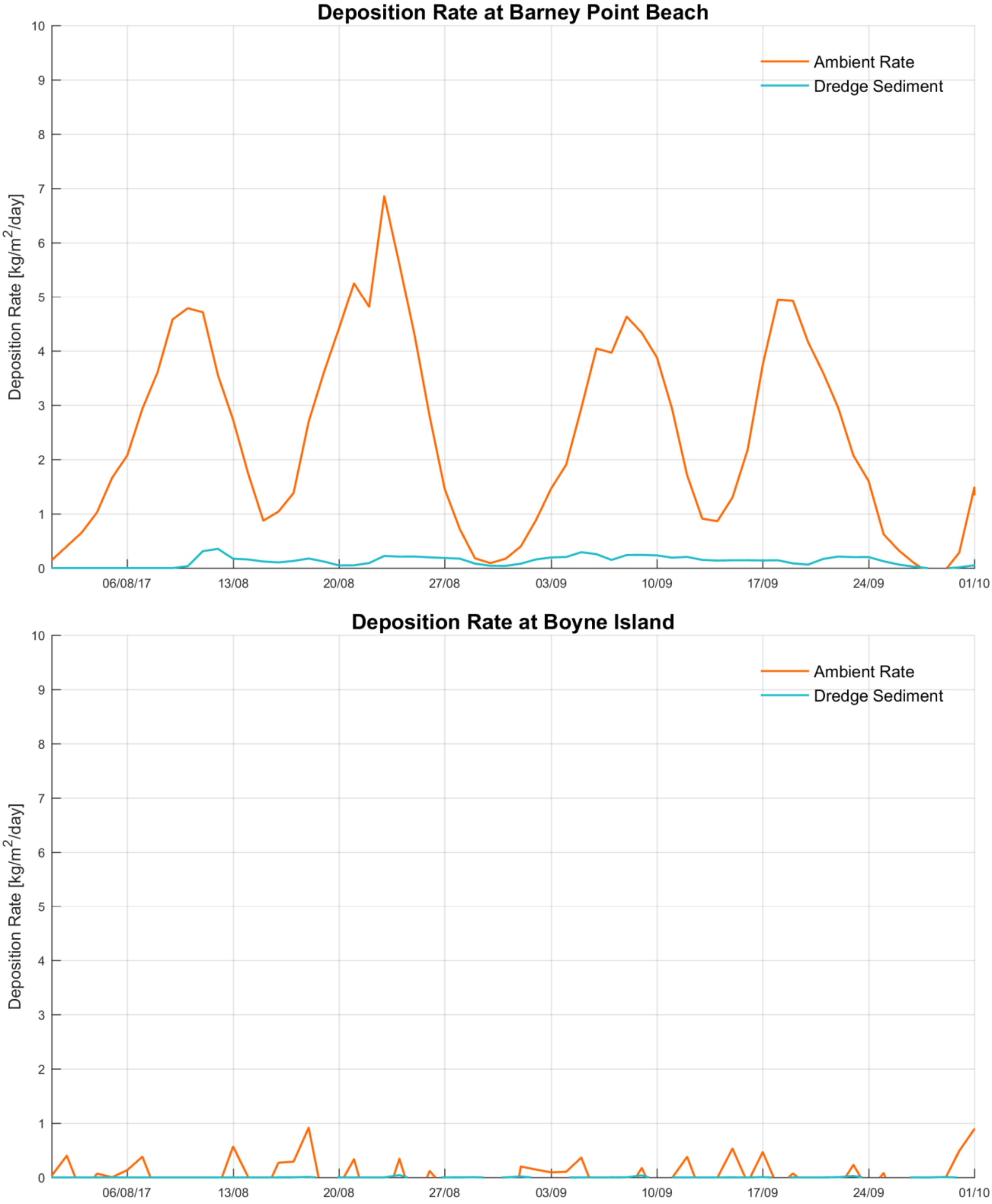




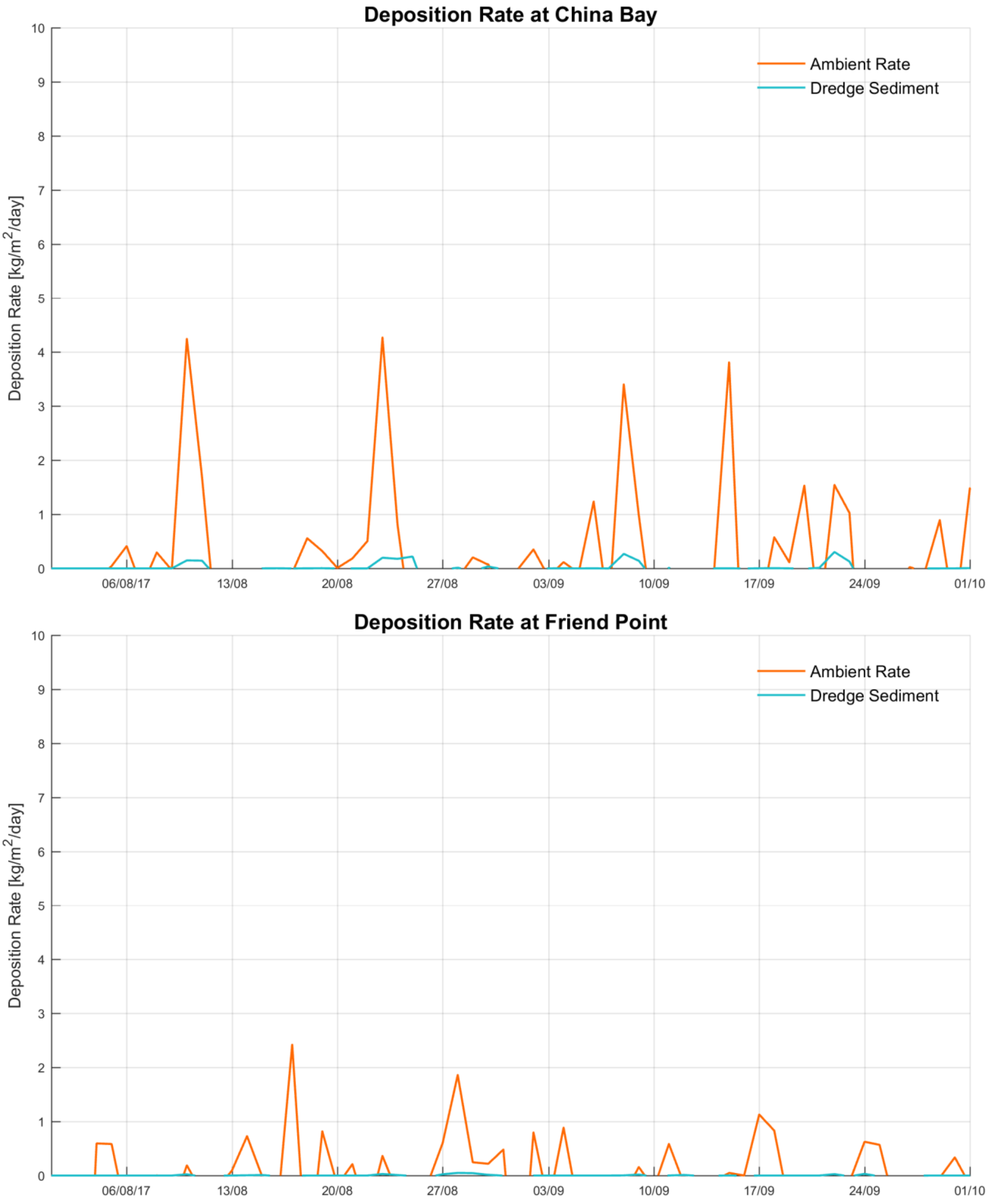
Time Series of Deposition Rate for Dredged and Ambient Sediment



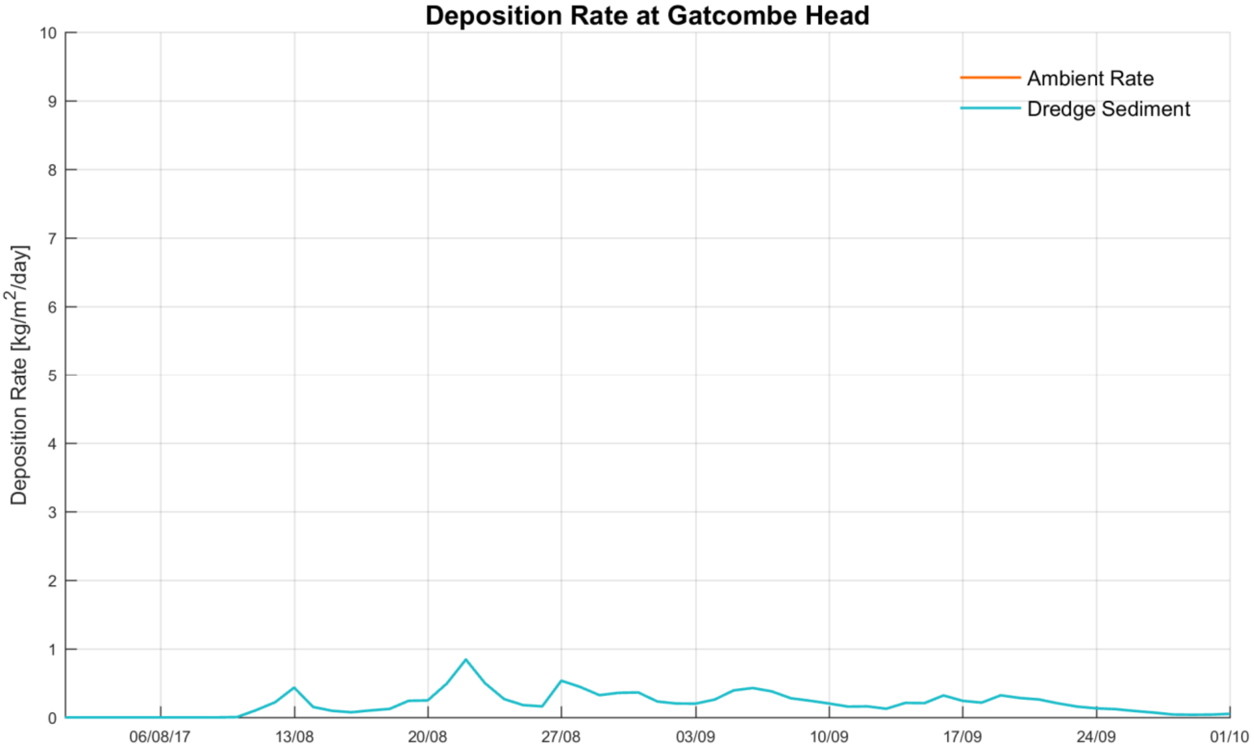
340,000m^3 Campaign

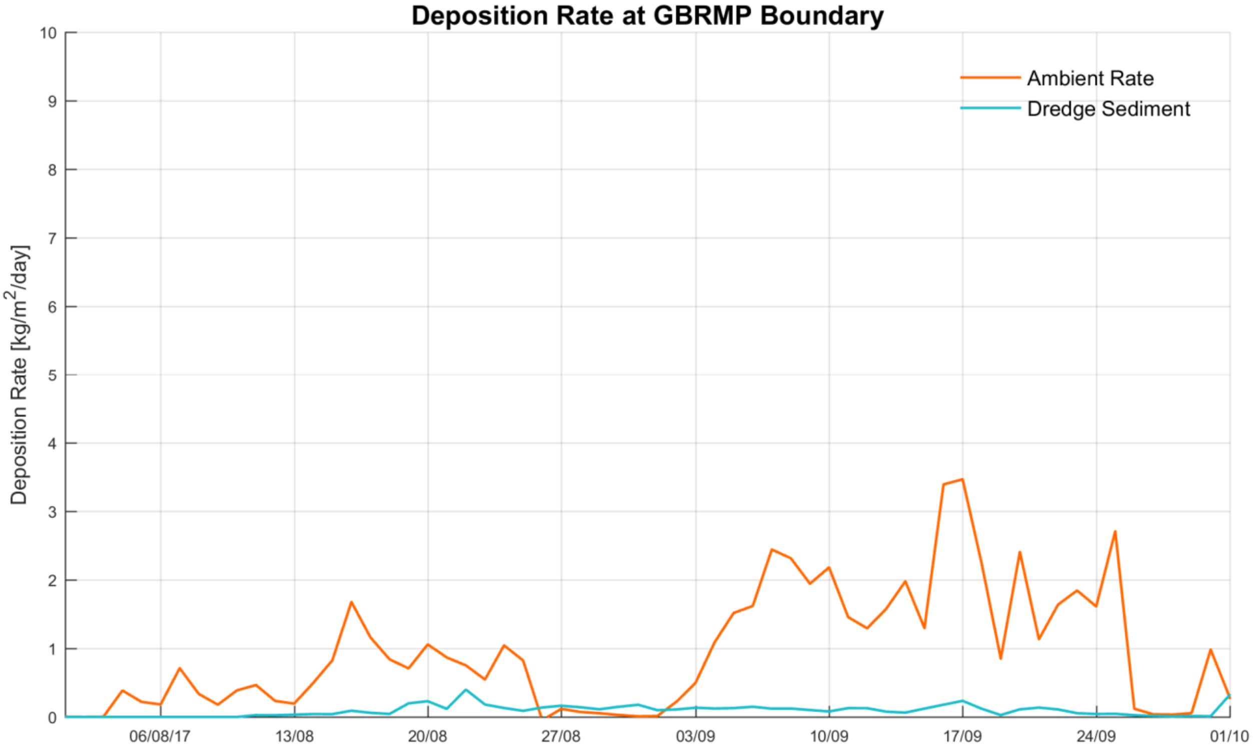


Time Series of Deposition Rate for Dredged and Ambient Sediment

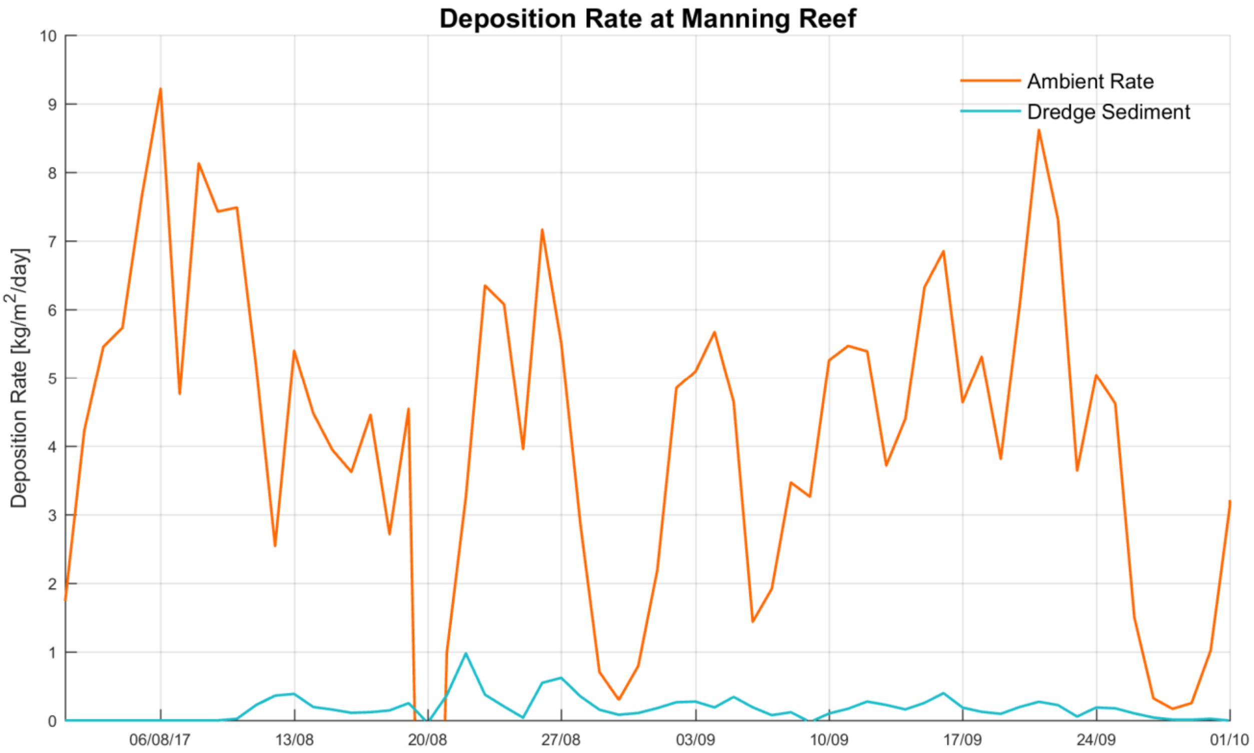


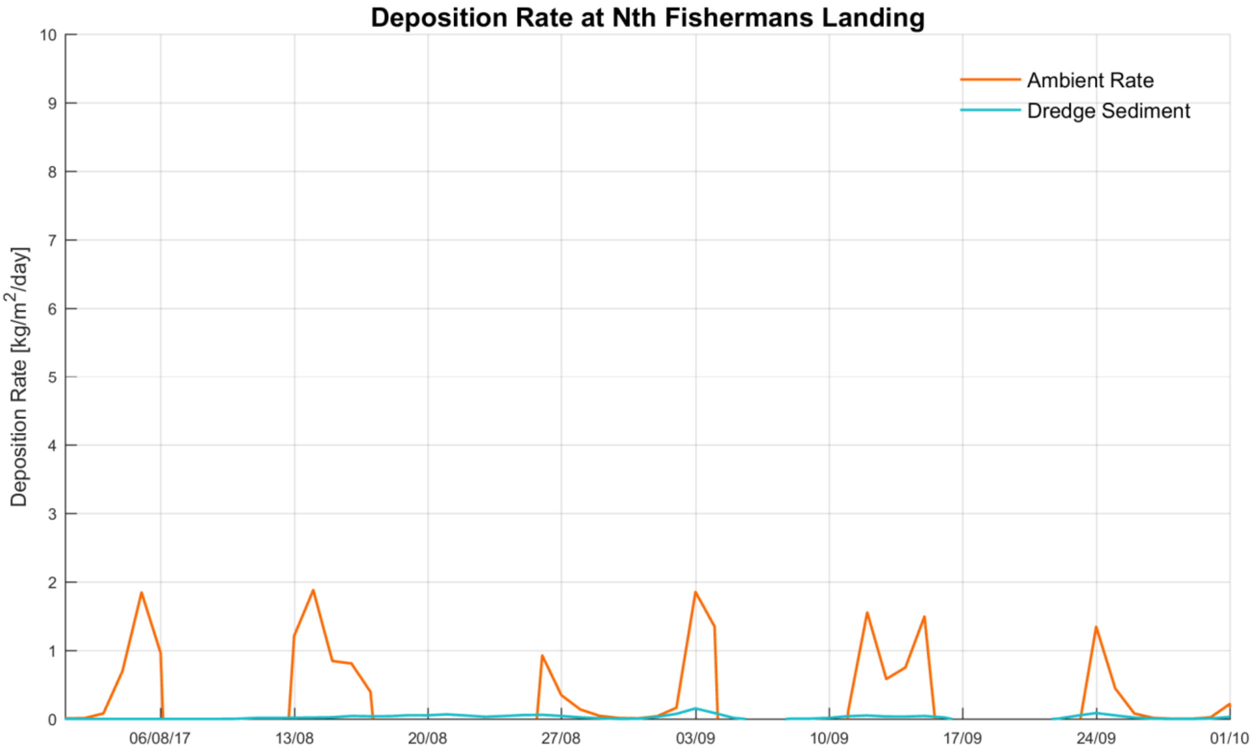
Time Series of Deposition Rate for Dredged and Ambient Sediment



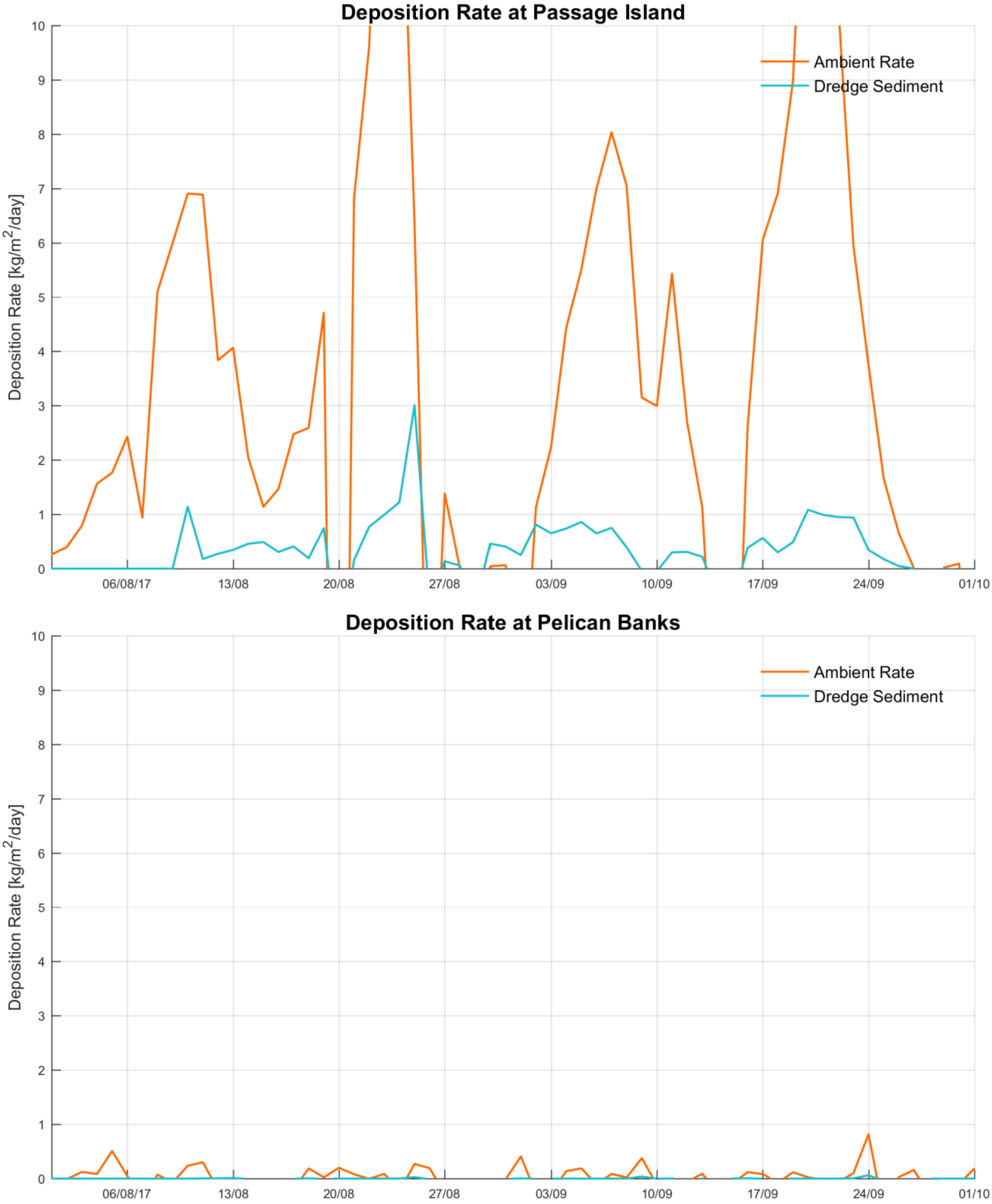


Time Series of Deposition Rate for Dredged and Ambient Sediment

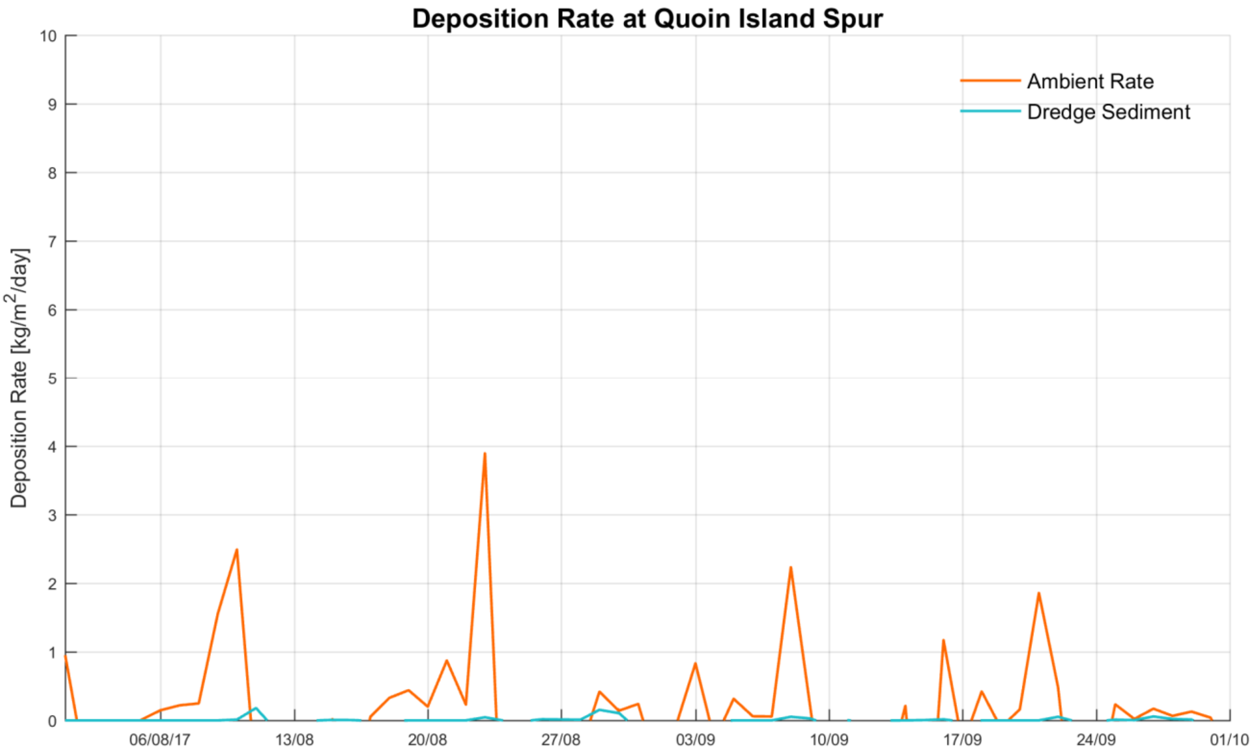


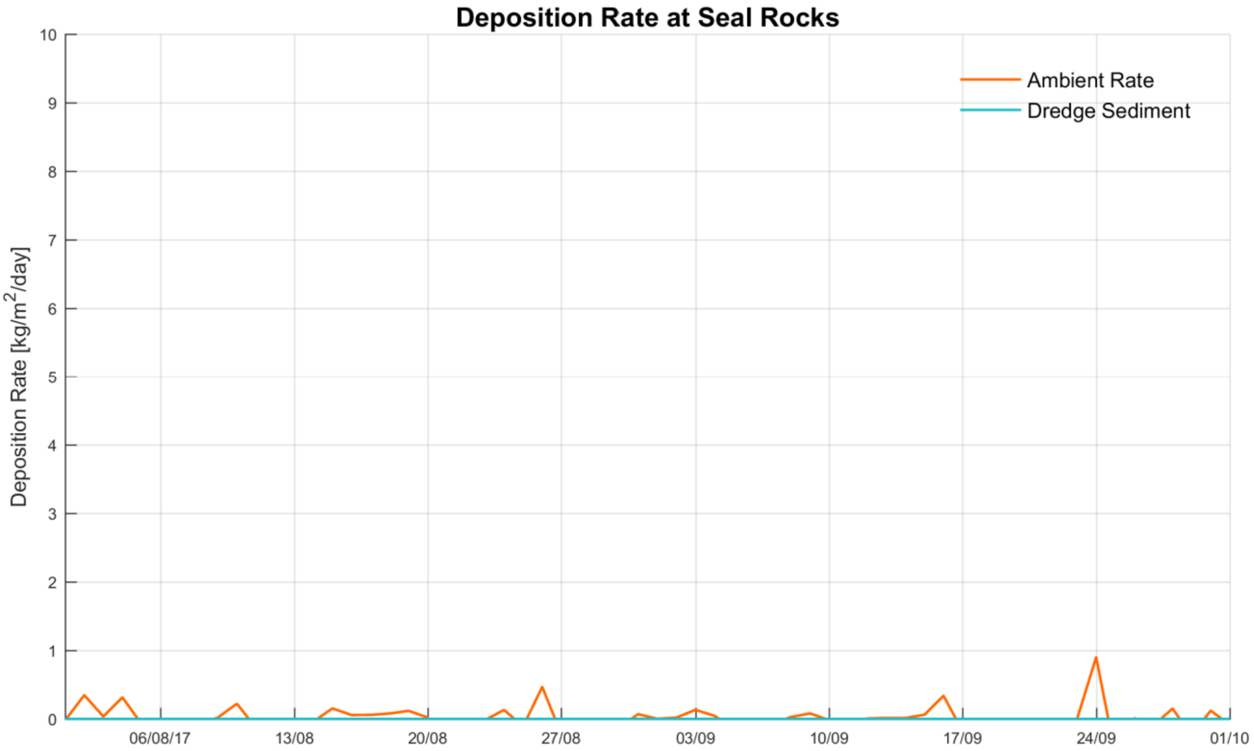


Time Series of Deposition Rate for Dredged and Ambient Sediment

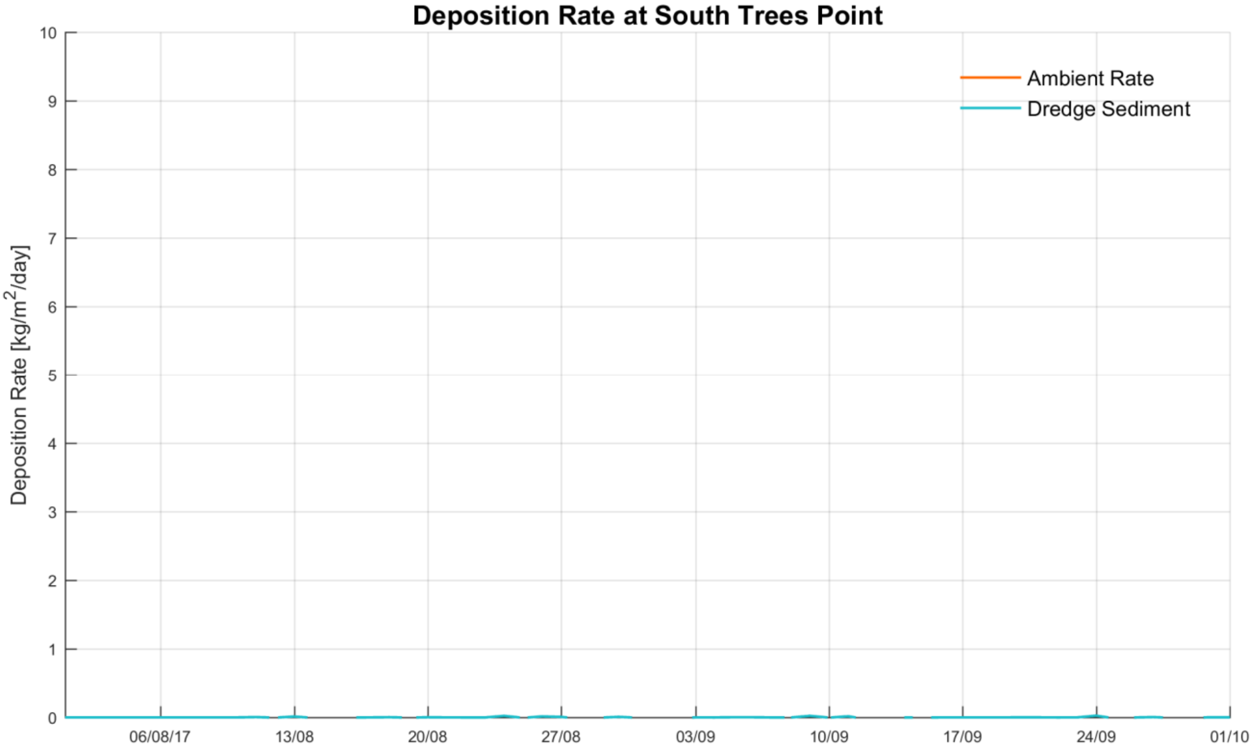


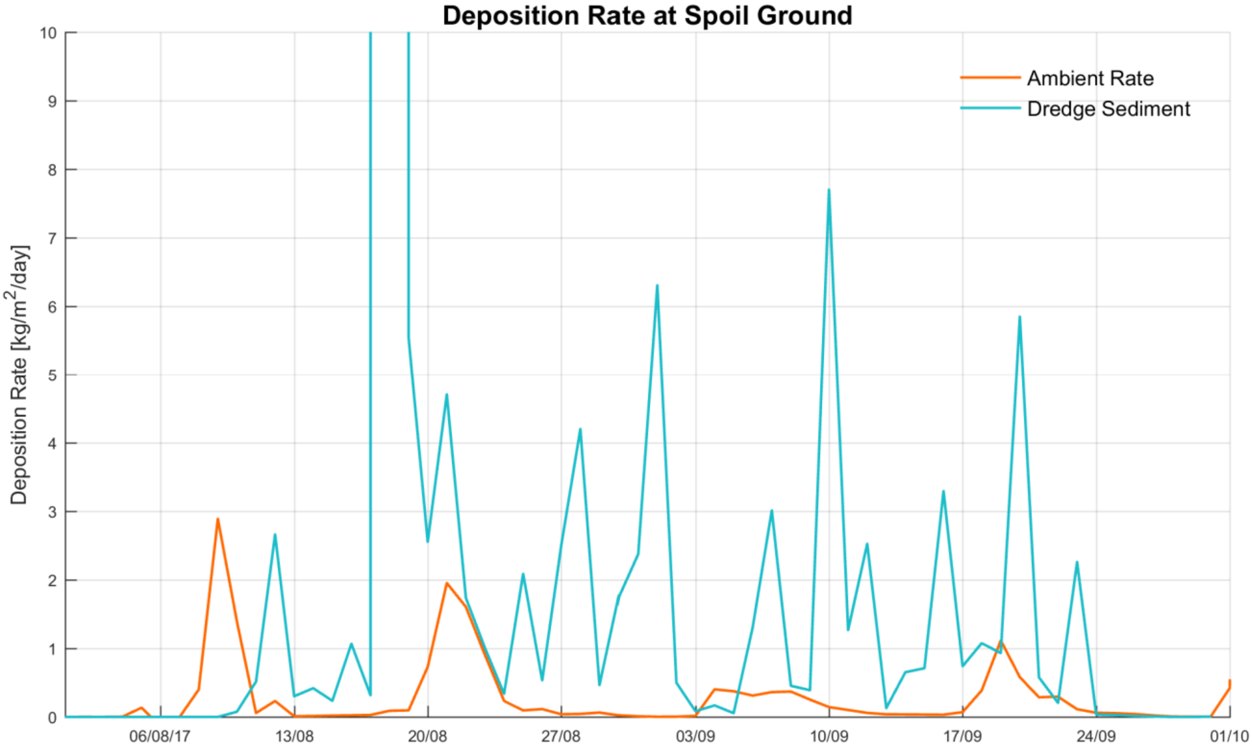
Time Series of Deposition Rate for Dredged and Ambient Sediment



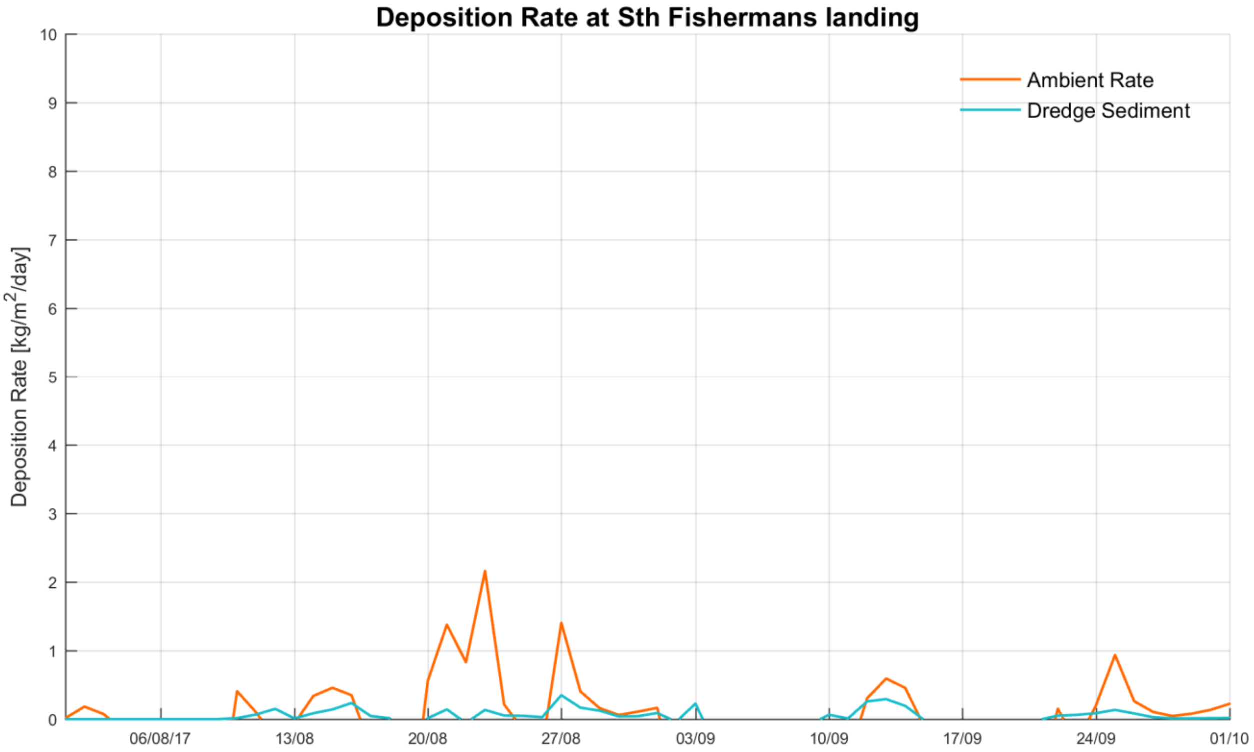


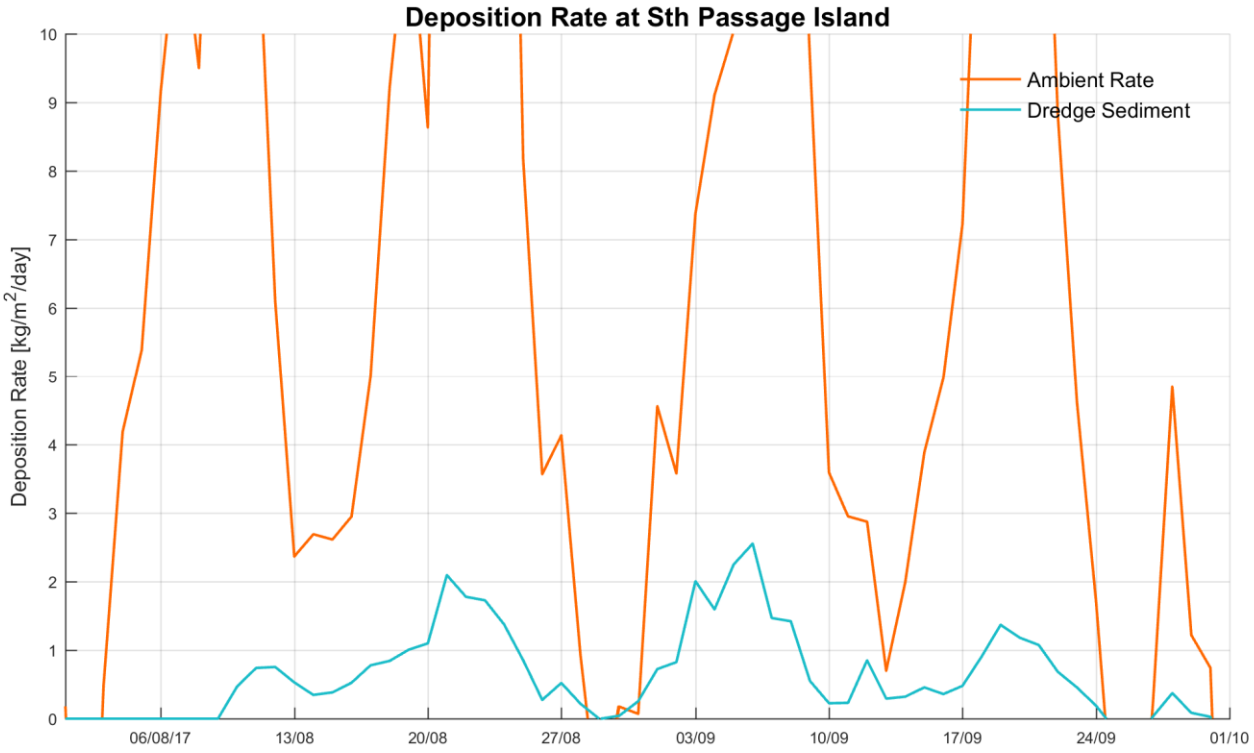
Time Series of Deposition Rate for Dredged and Ambient Sediment



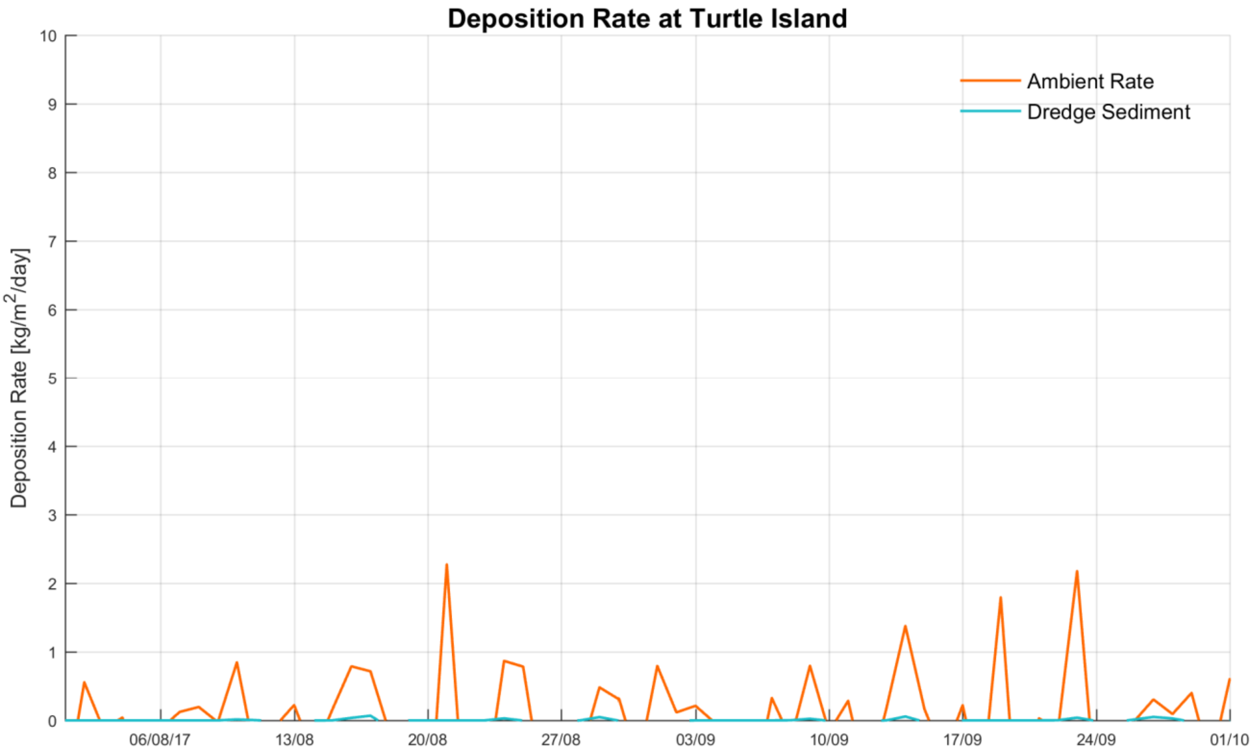


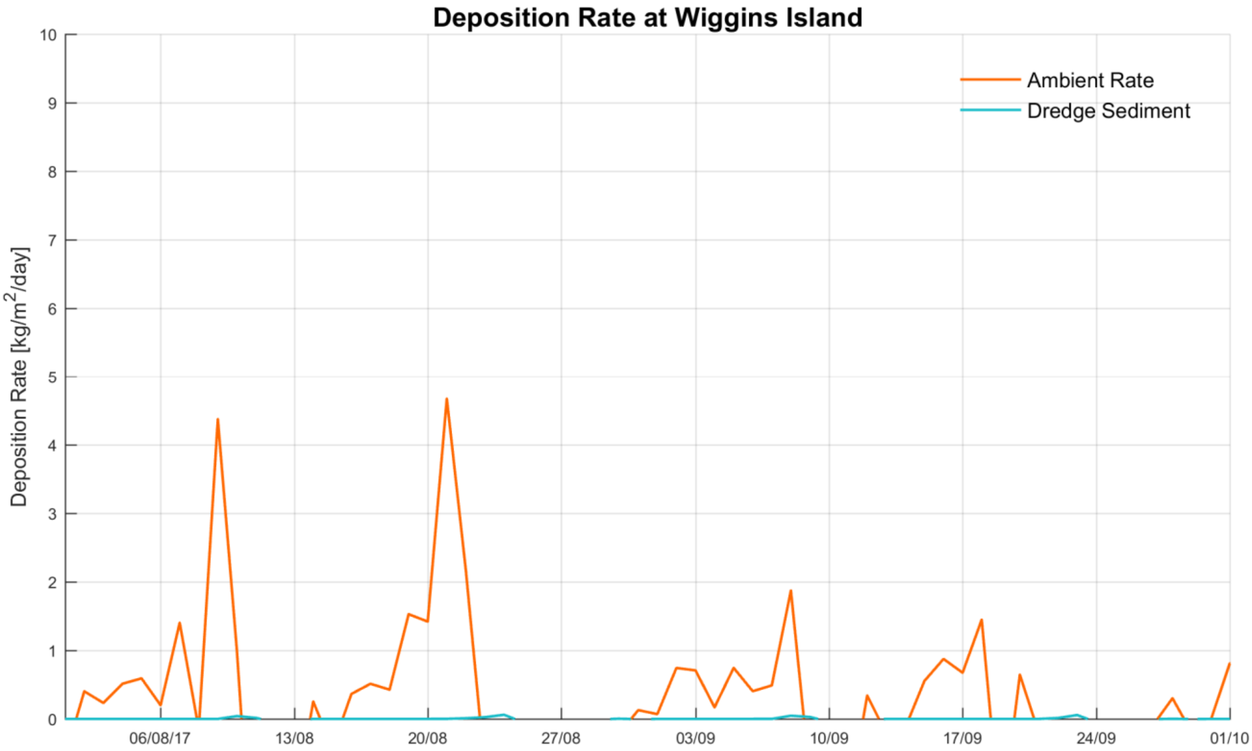
Time Series of Deposition Rate for Dredged and Ambient Sediment



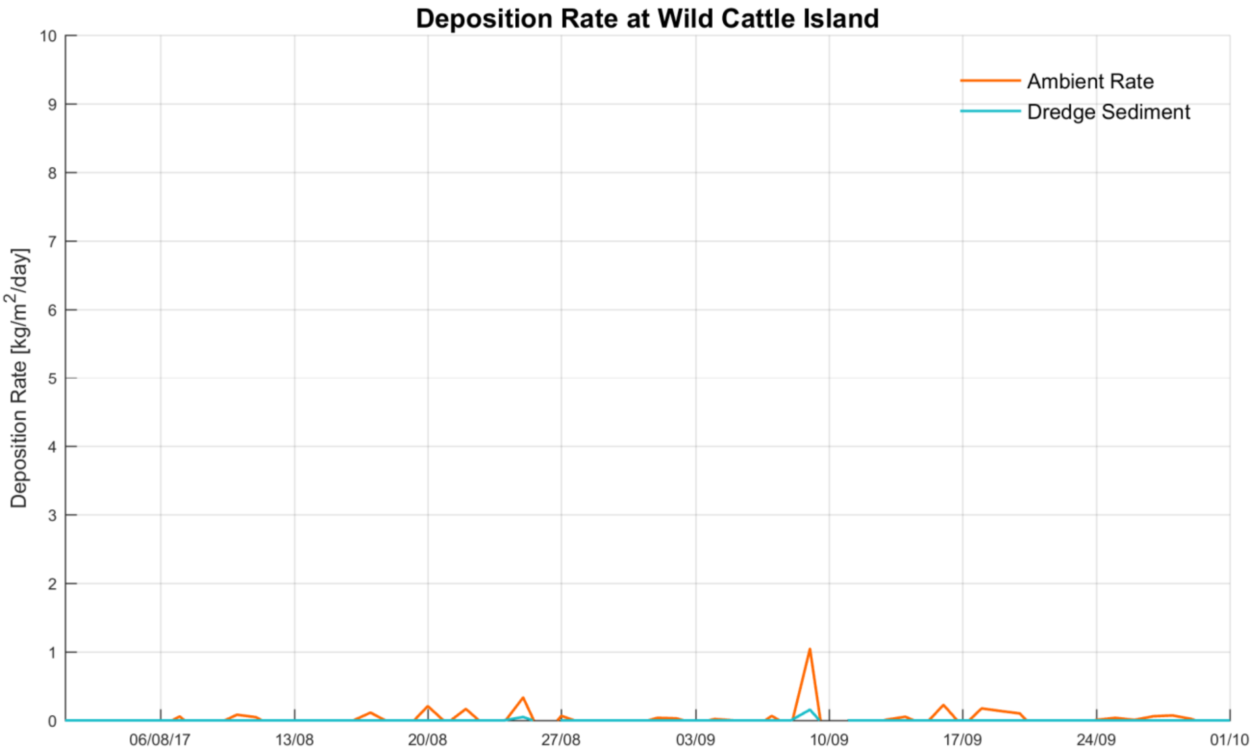


Time Series of Deposition Rate for Dredged and Ambient Sediment



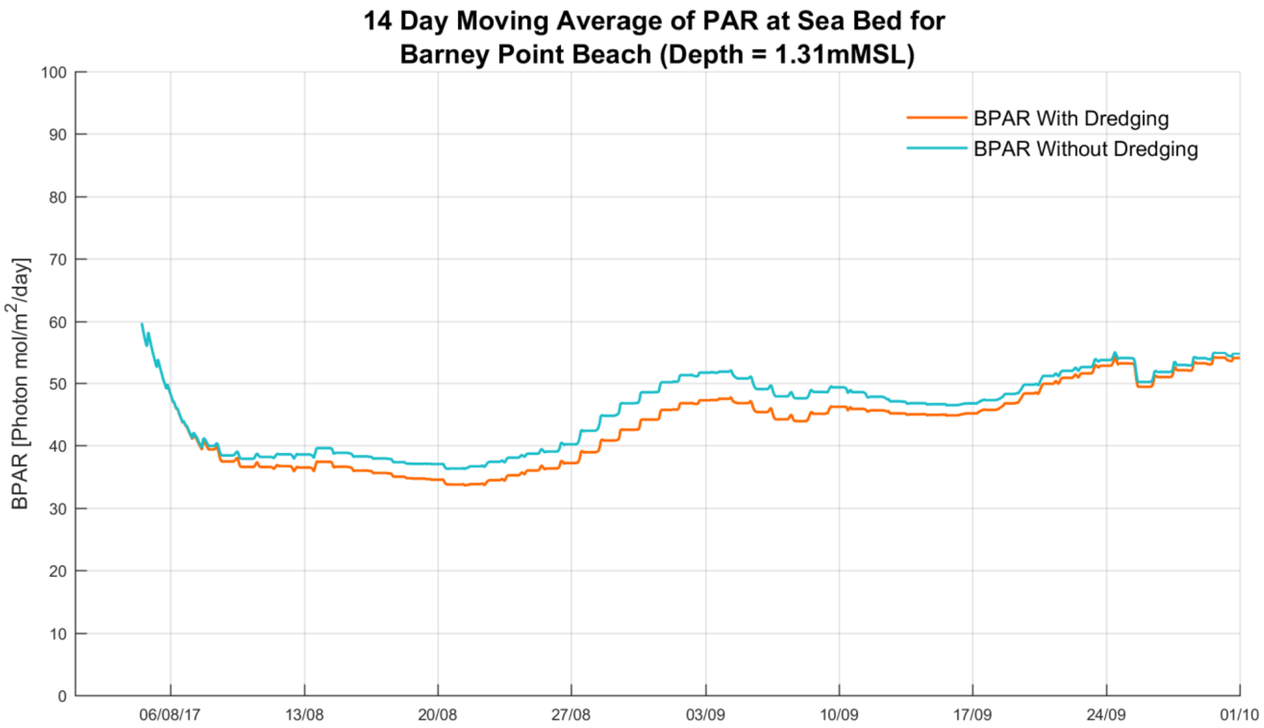


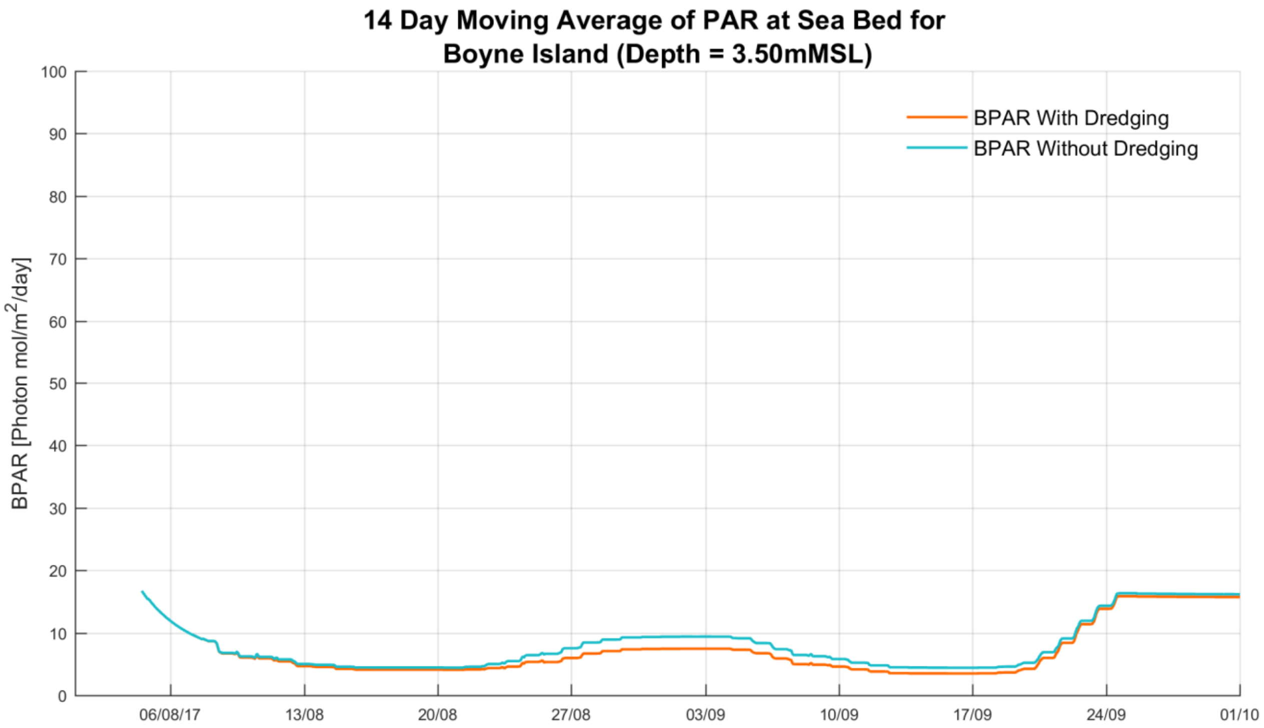
Time Series of Deposition Rate for Dredged and Ambient Sediment



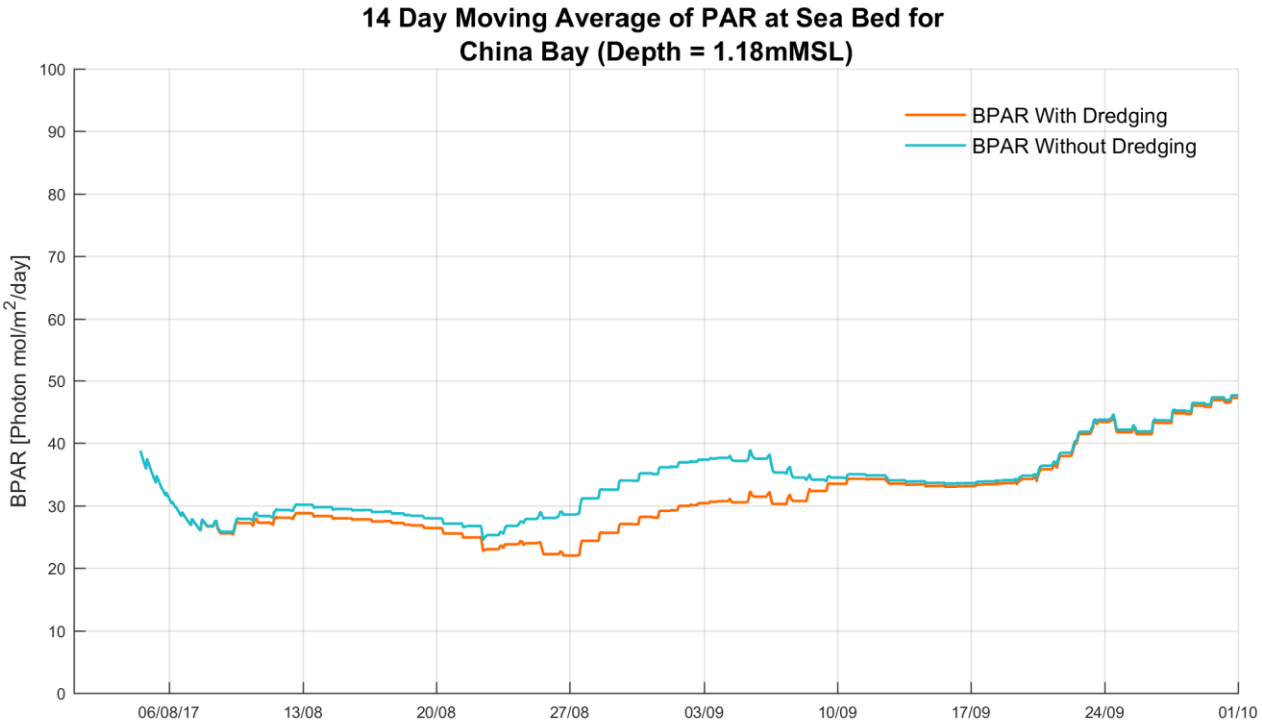
Appendix D Time Series of Benthic PAR

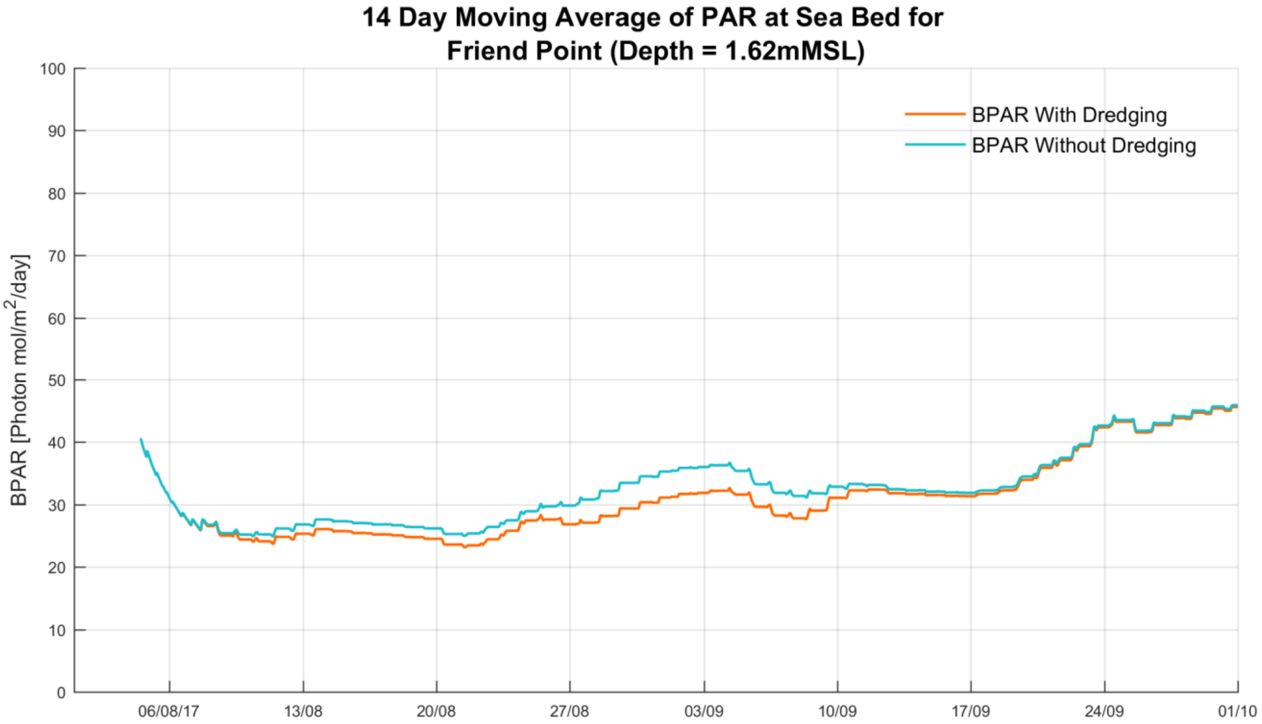
220,000m^3 Campaign



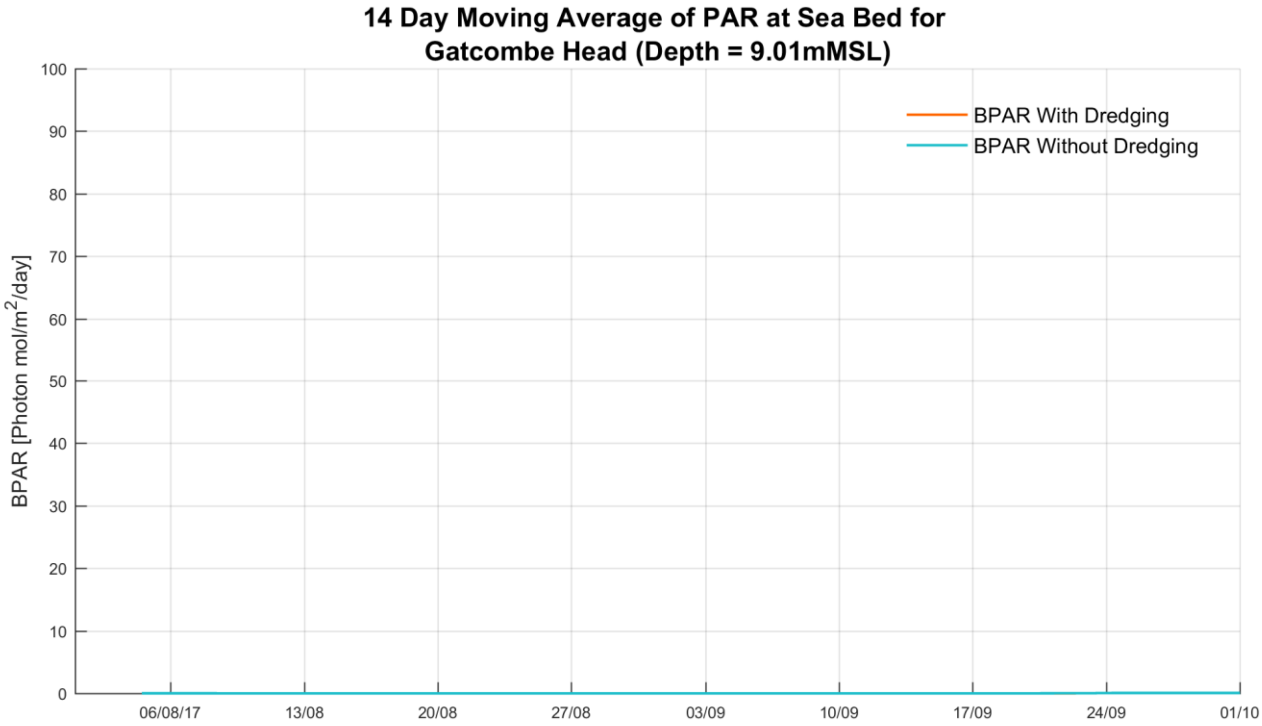


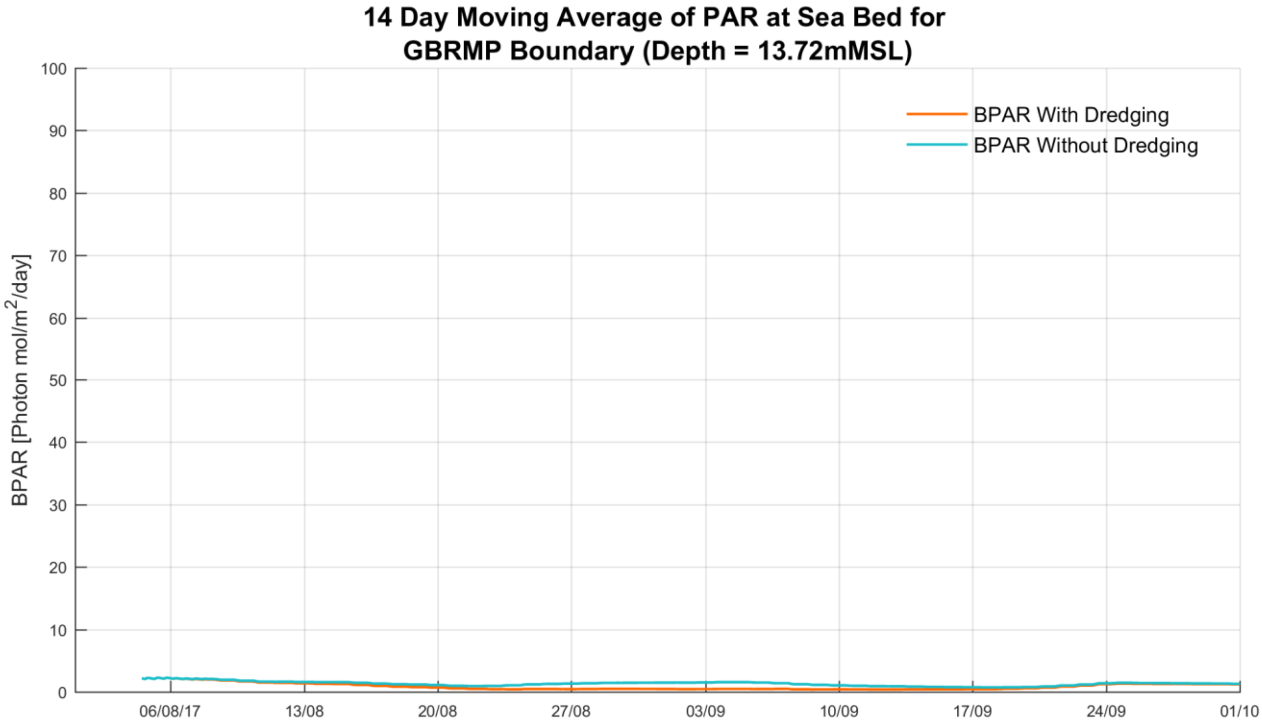
Time Series of Benthic PAR



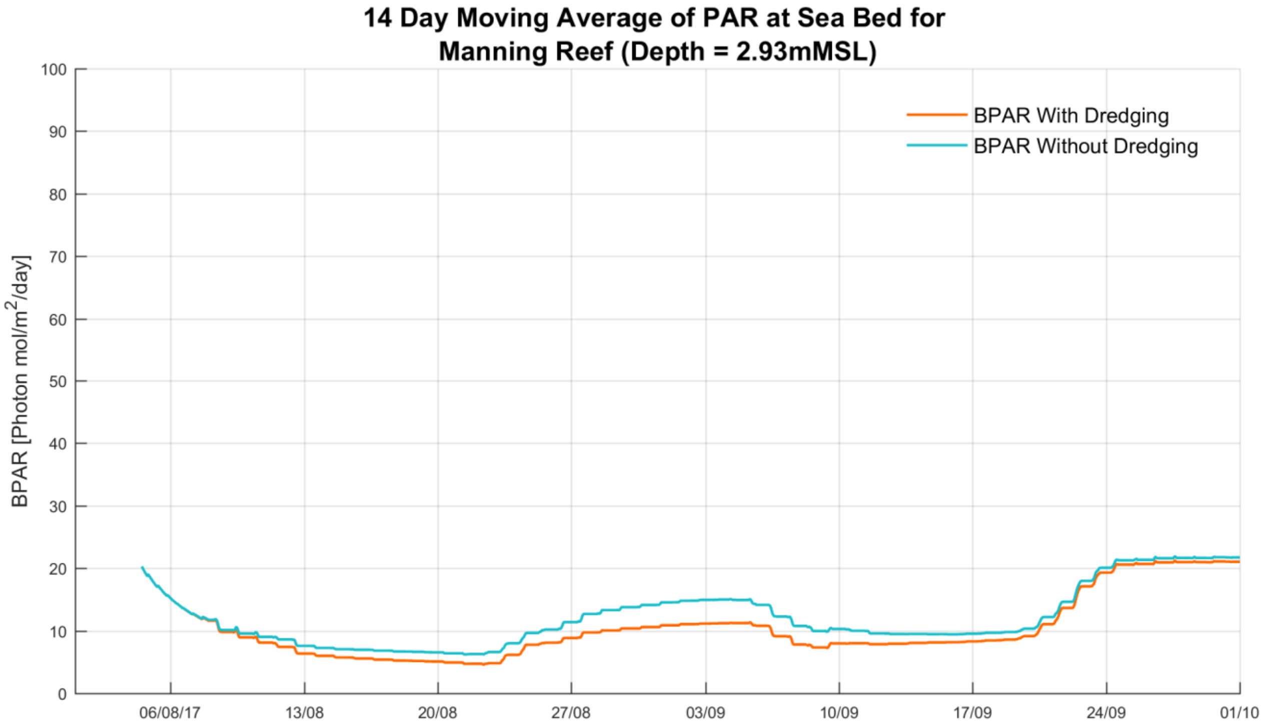


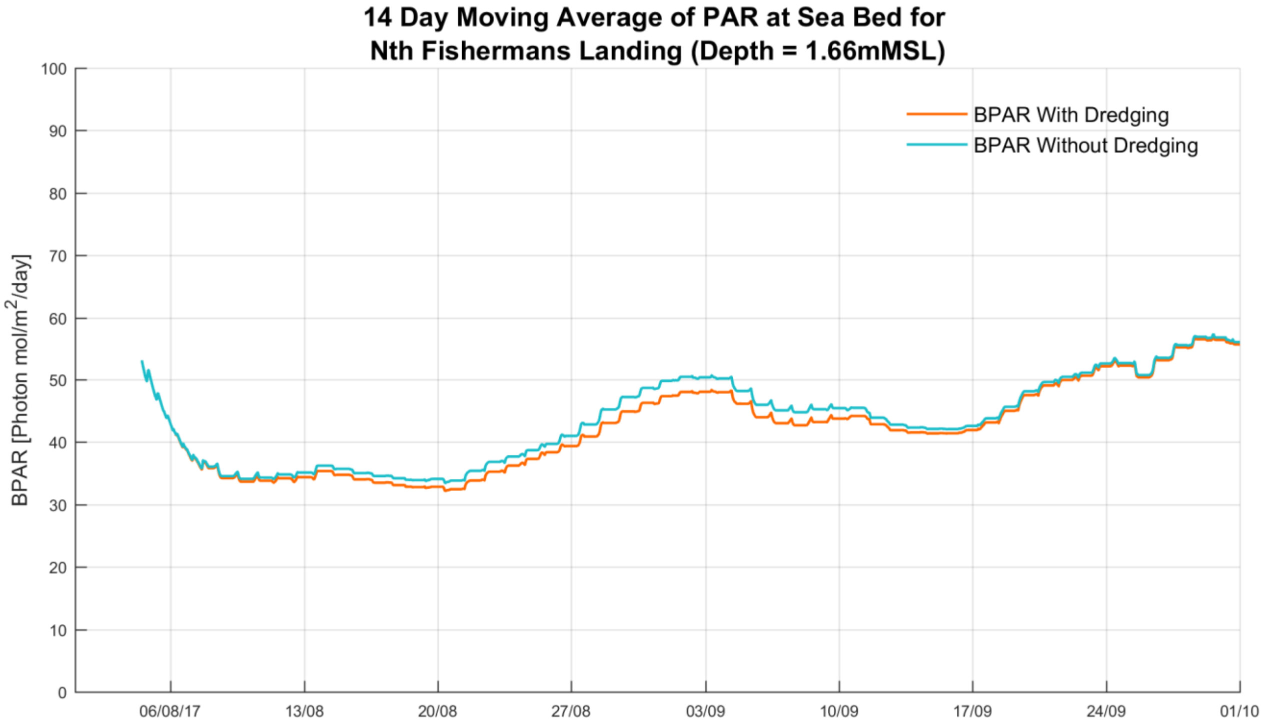
Time Series of Benthic PAR



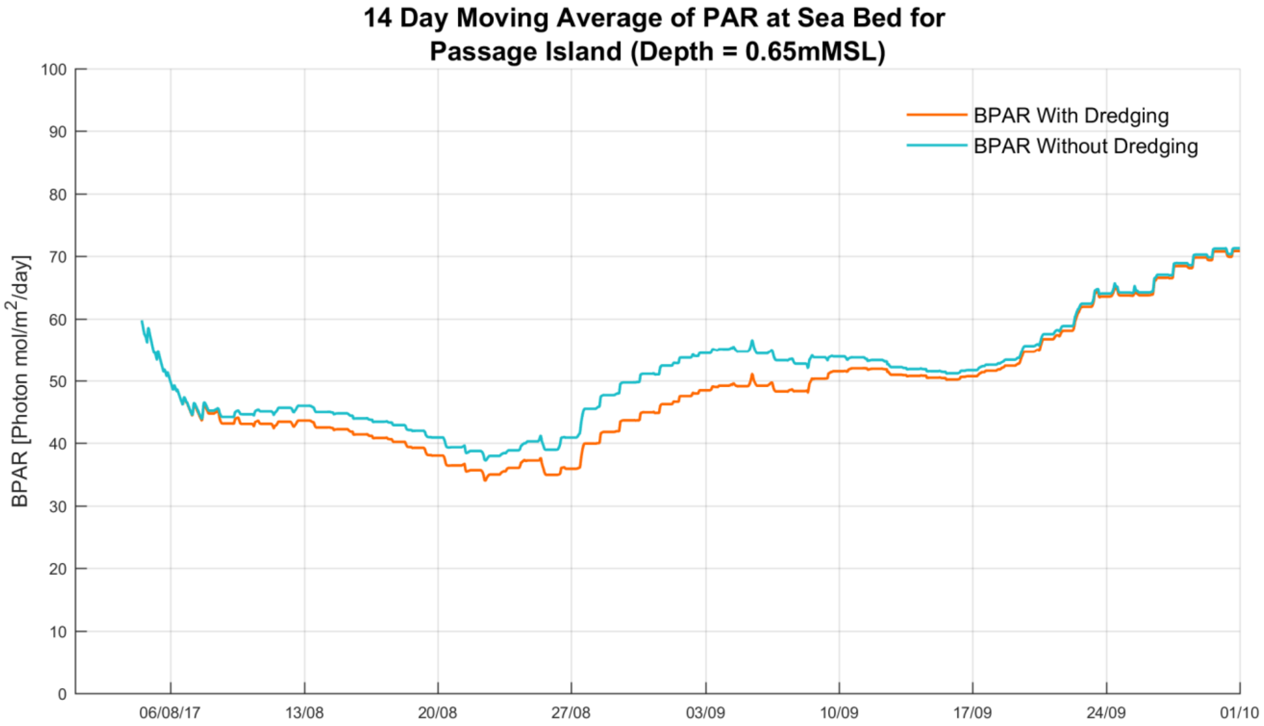


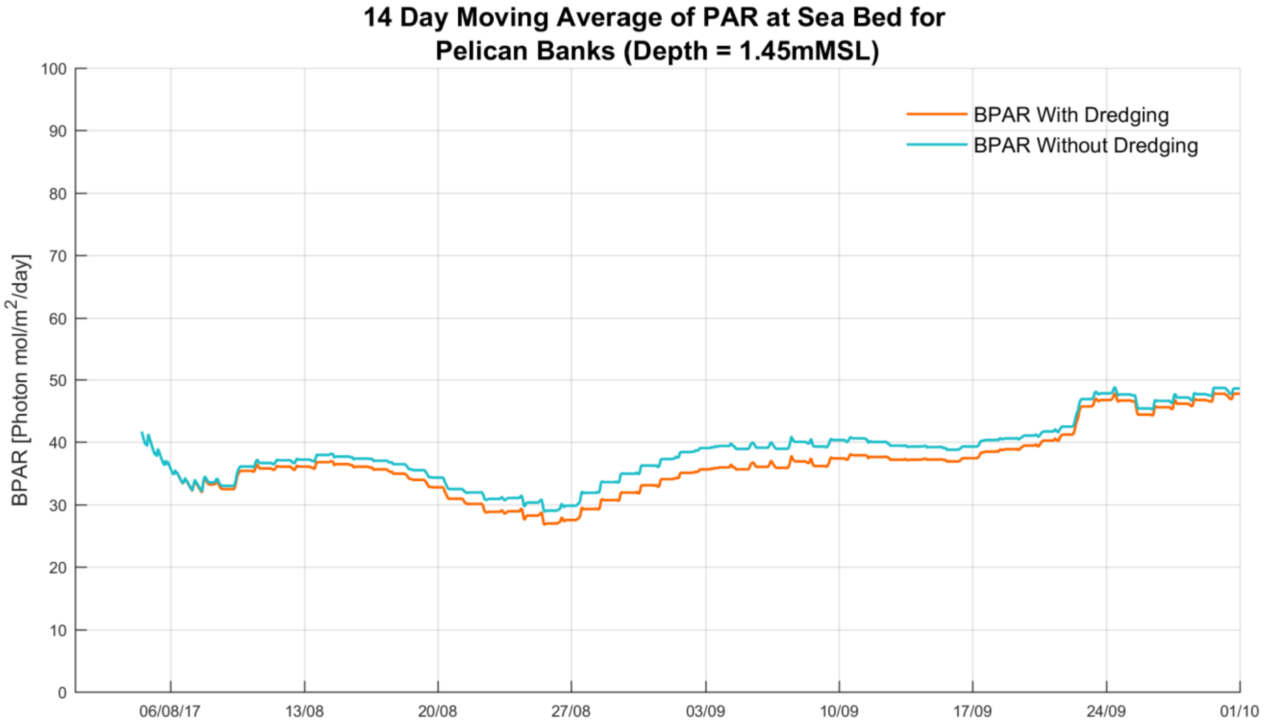
Time Series of Benthic PAR



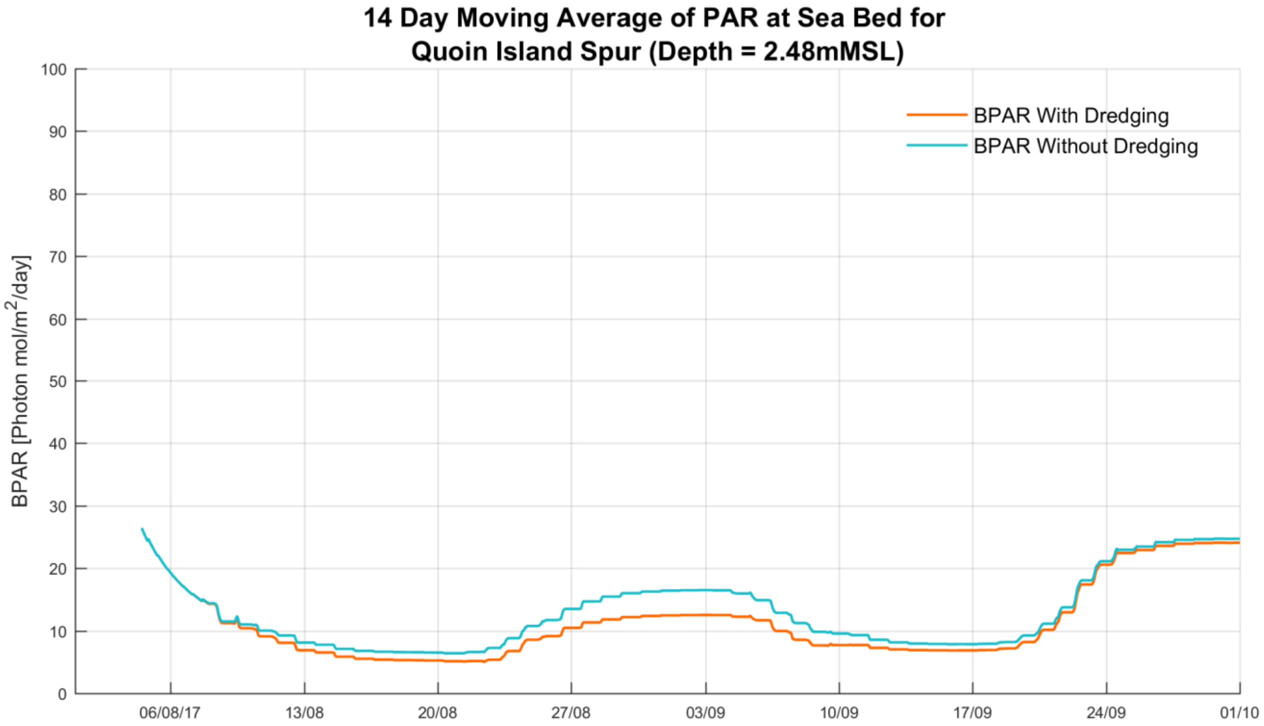


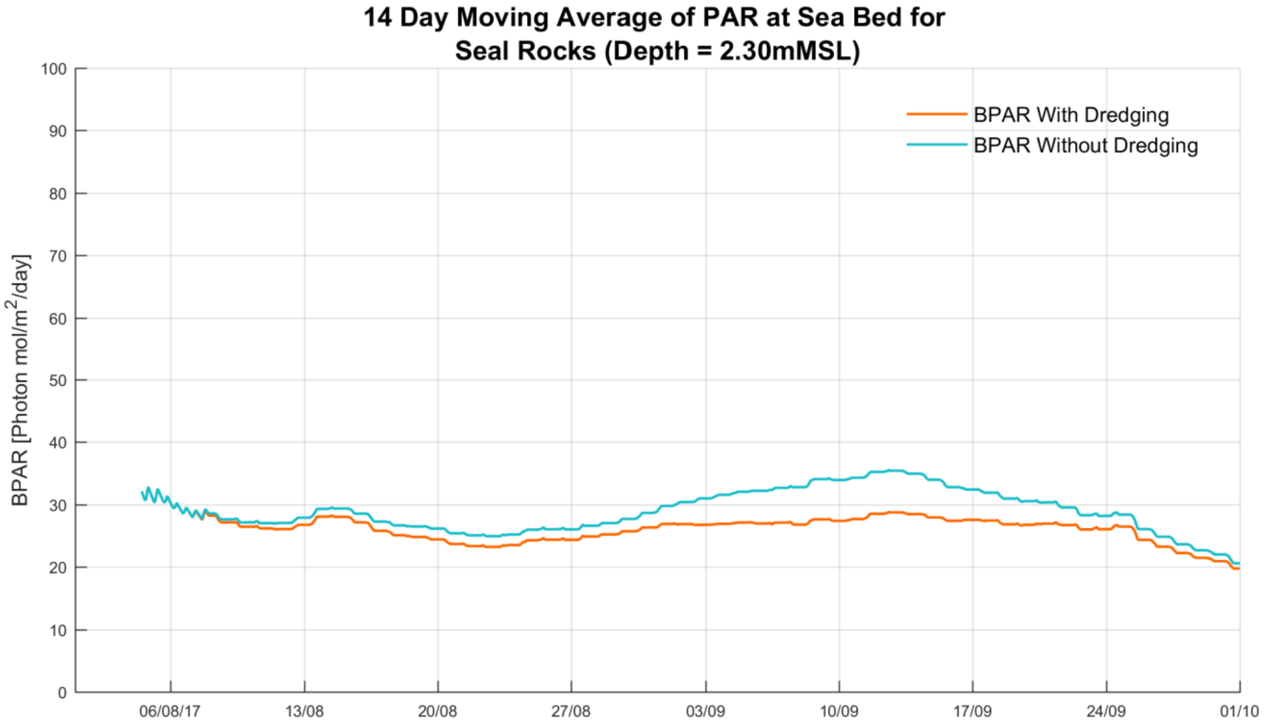
Time Series of Benthic PAR



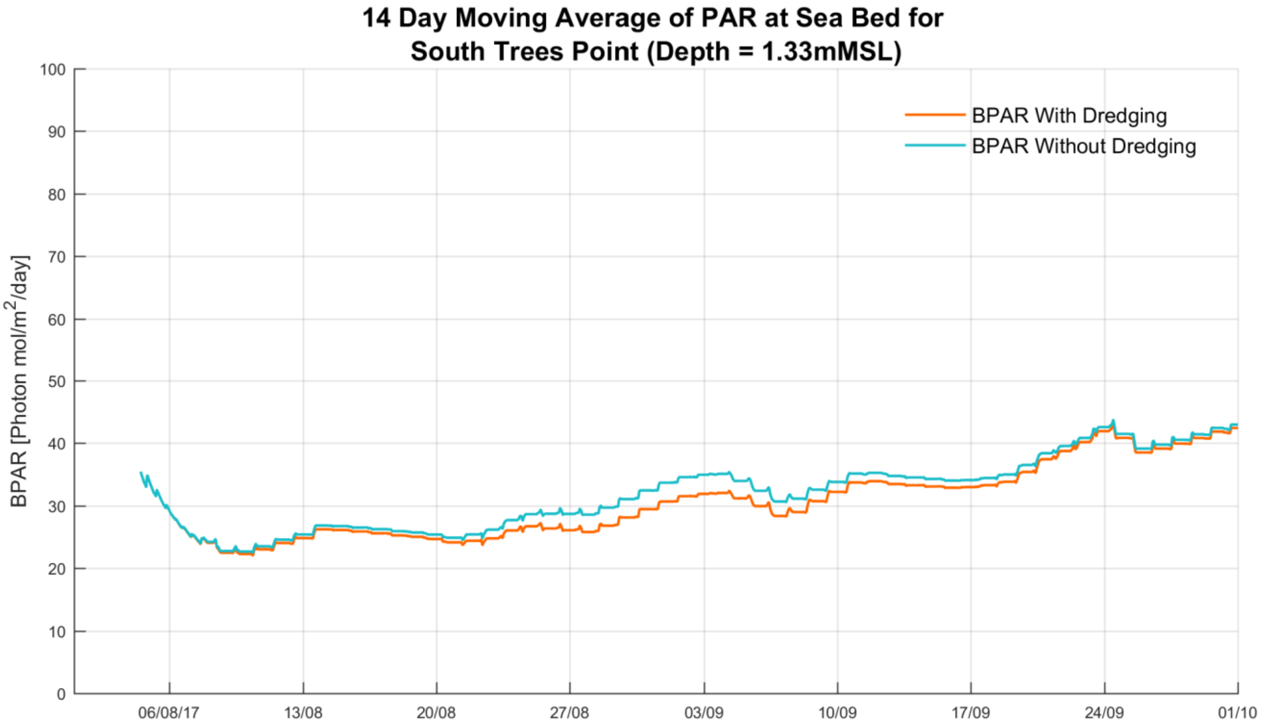


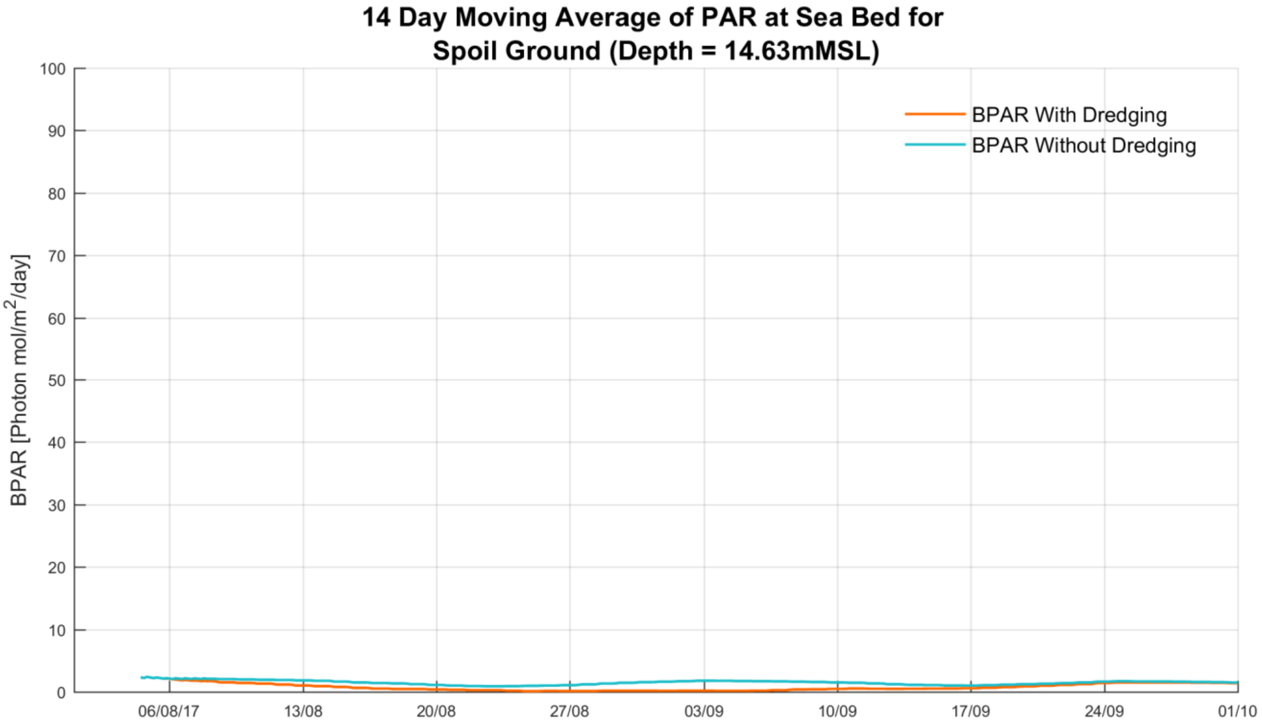
Time Series of Benthic PAR



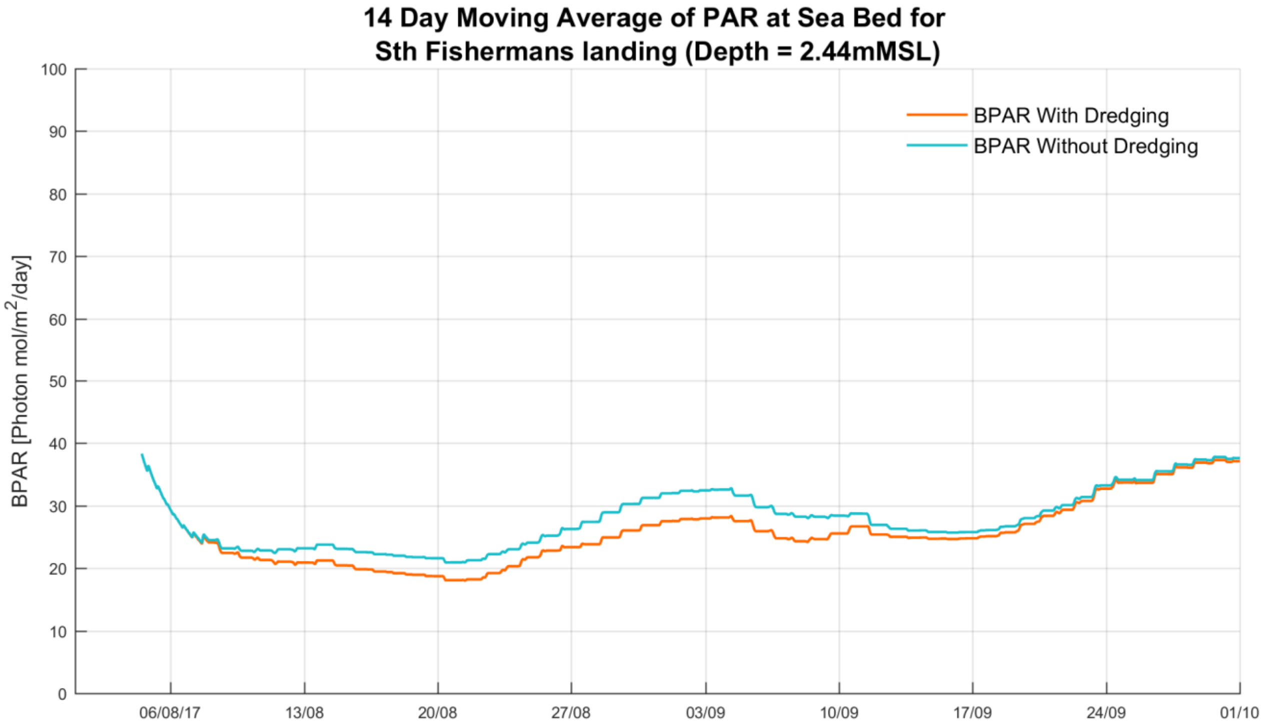


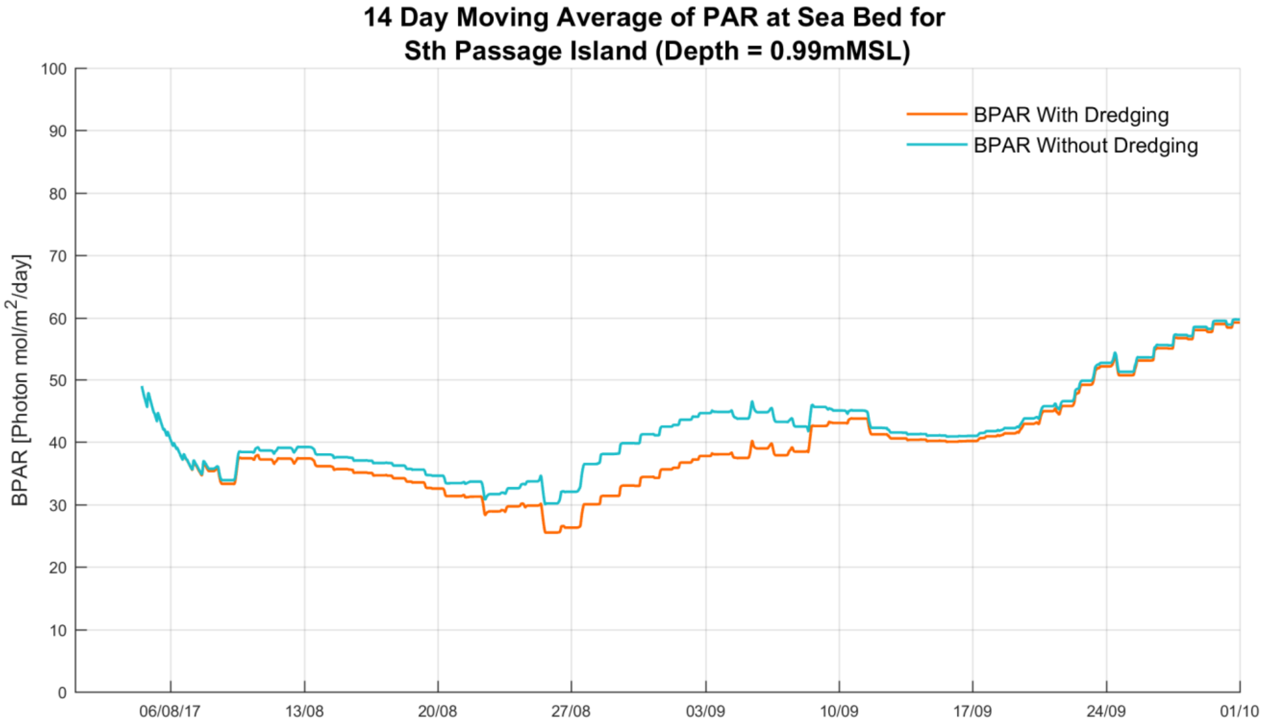
Time Series of Benthic PAR



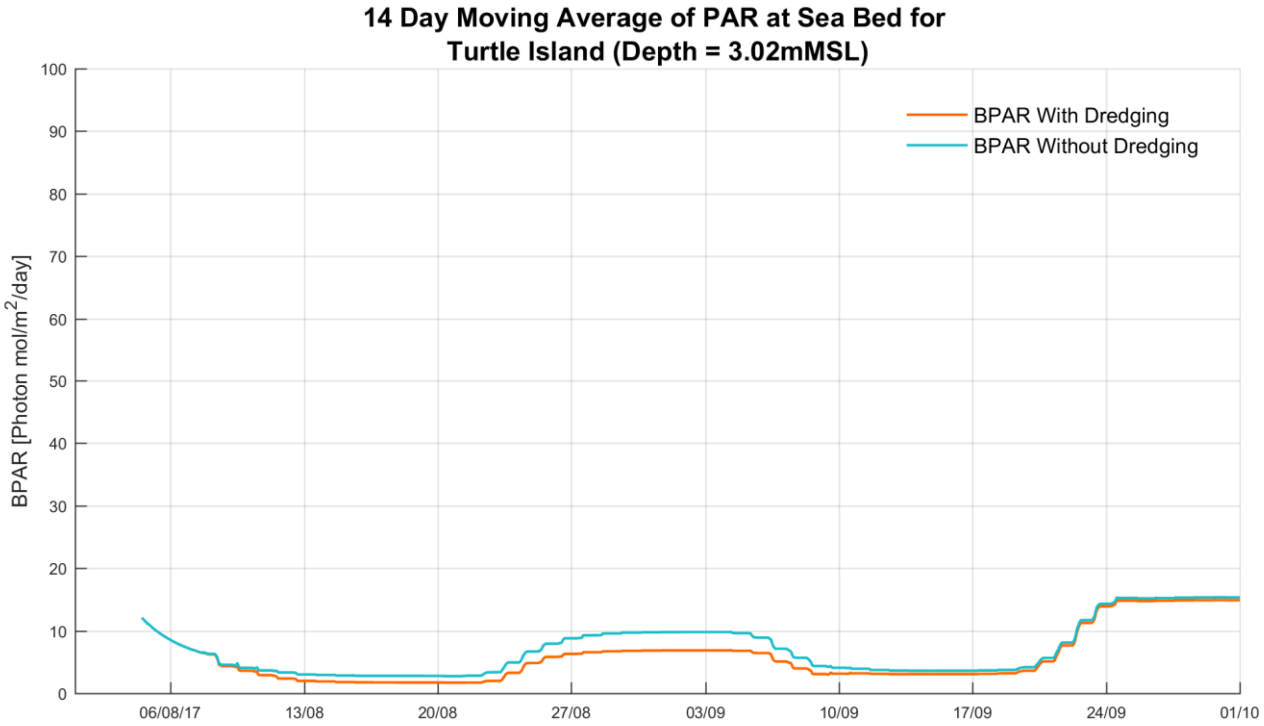


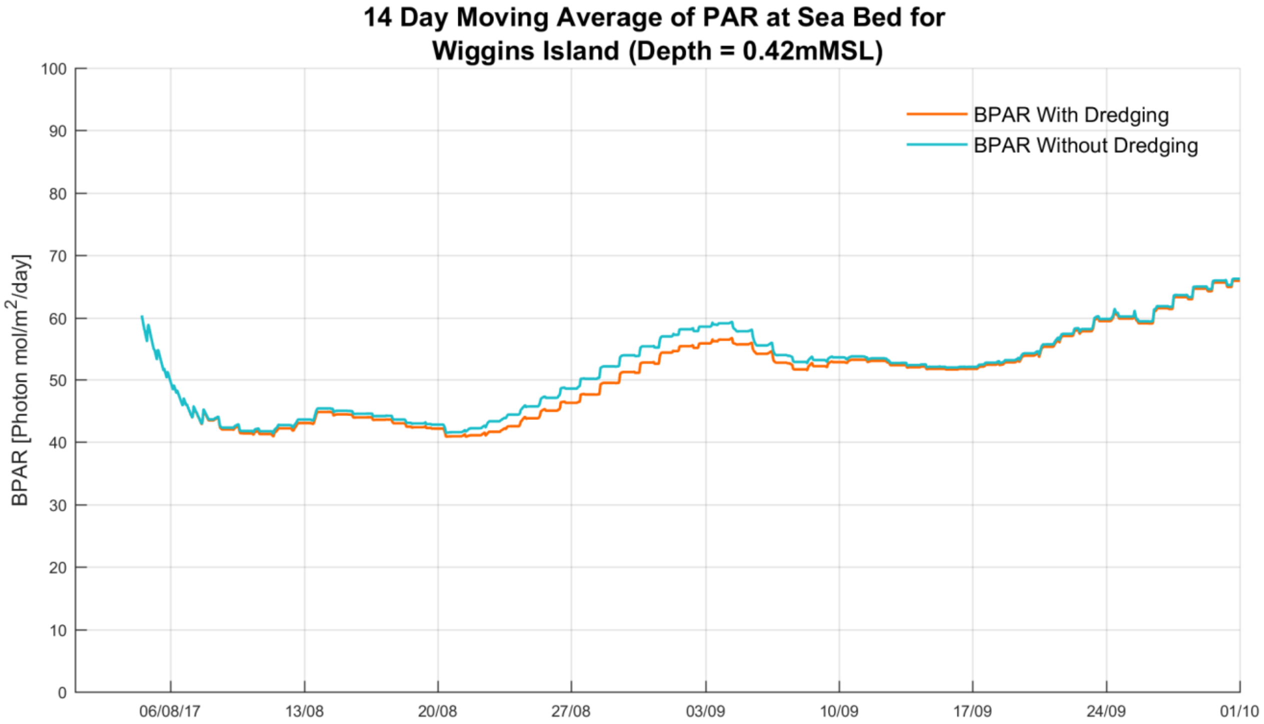
Time Series of Benthic PAR



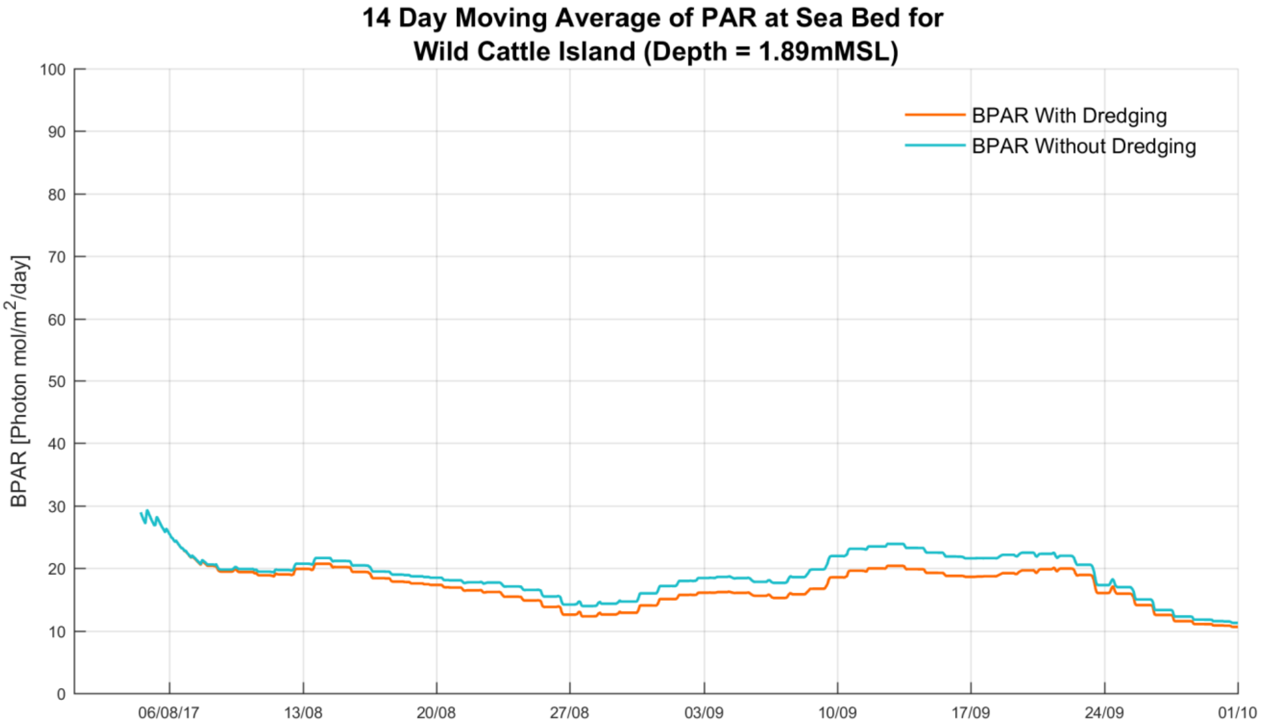


Time Series of Benthic PAR

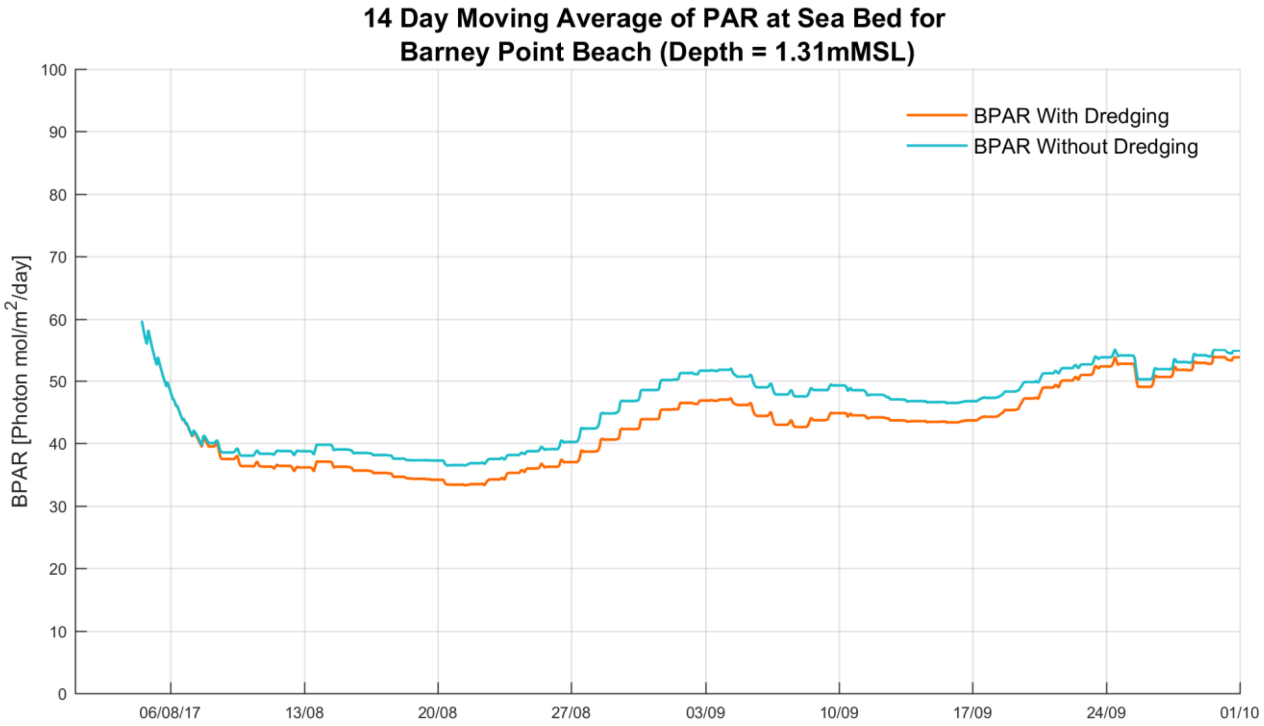


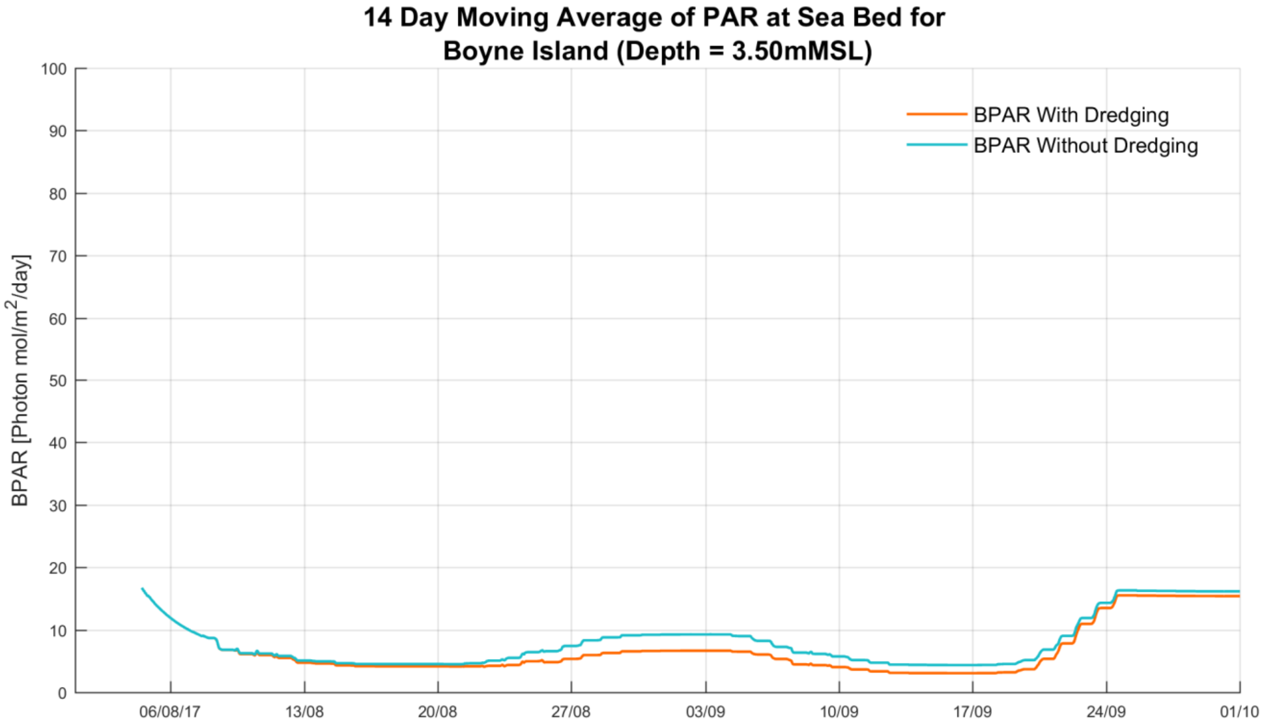


Time Series of Benthic PAR

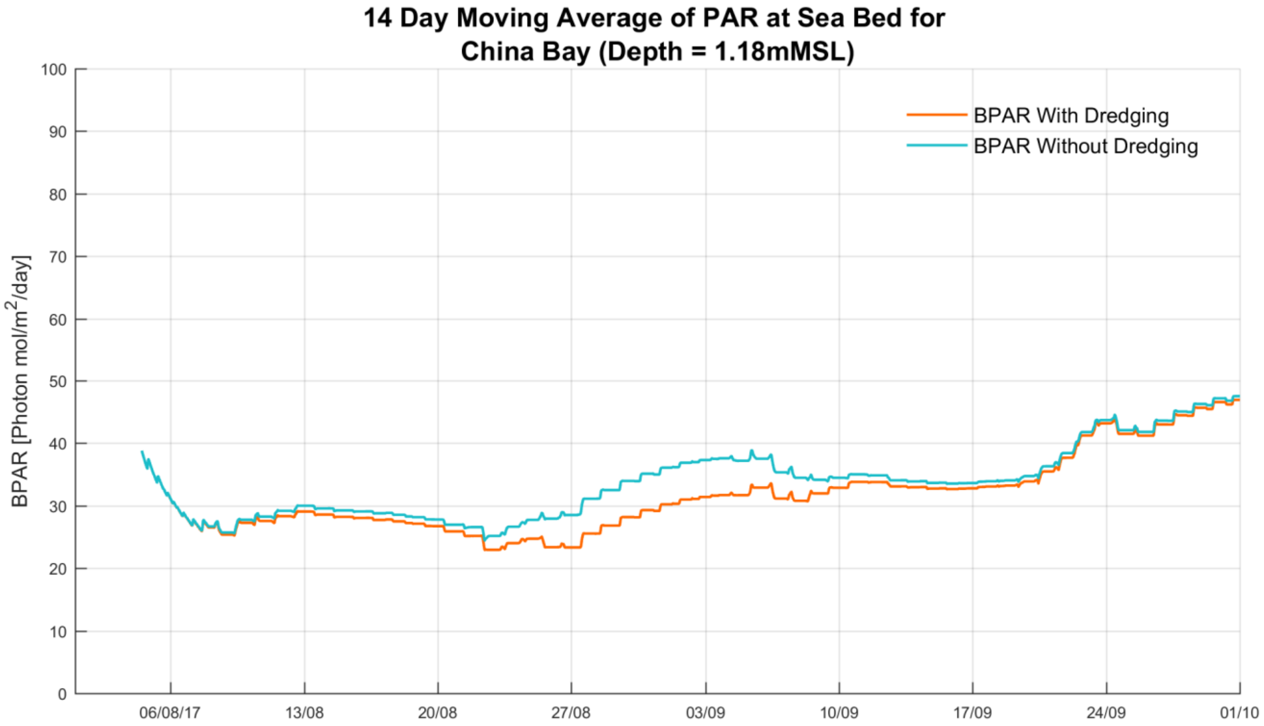


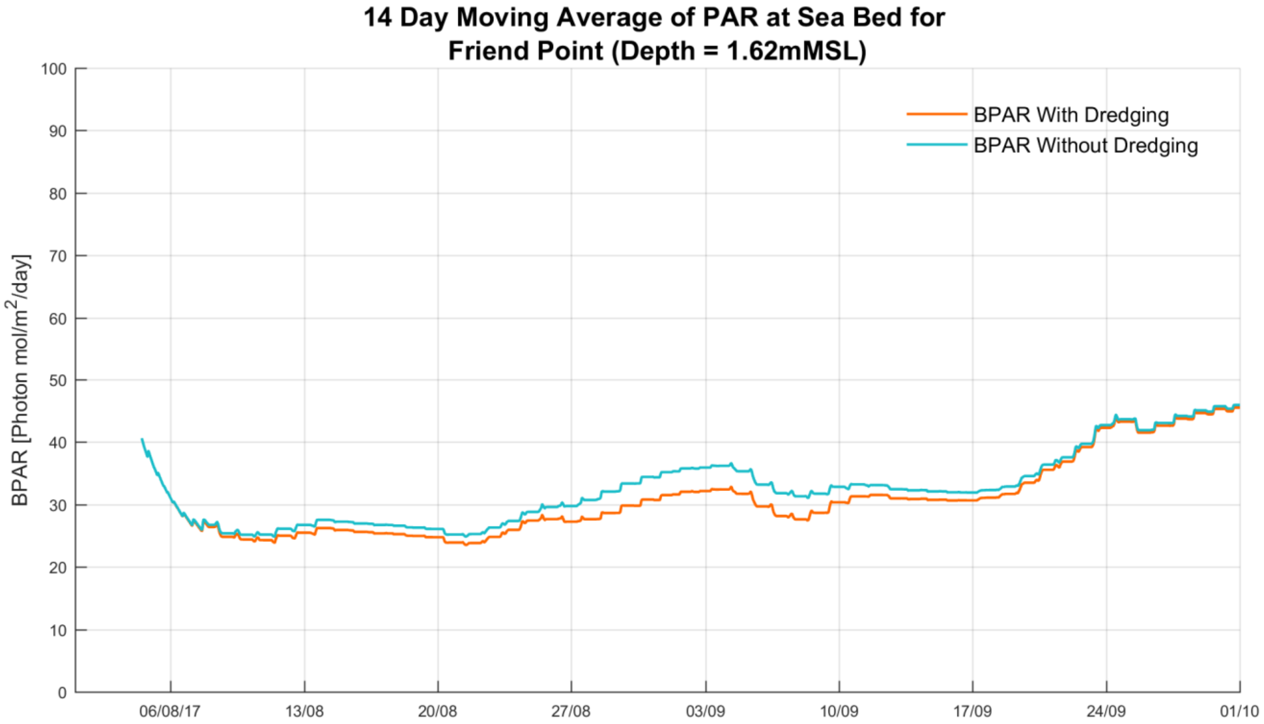
260,000m³ Campaign



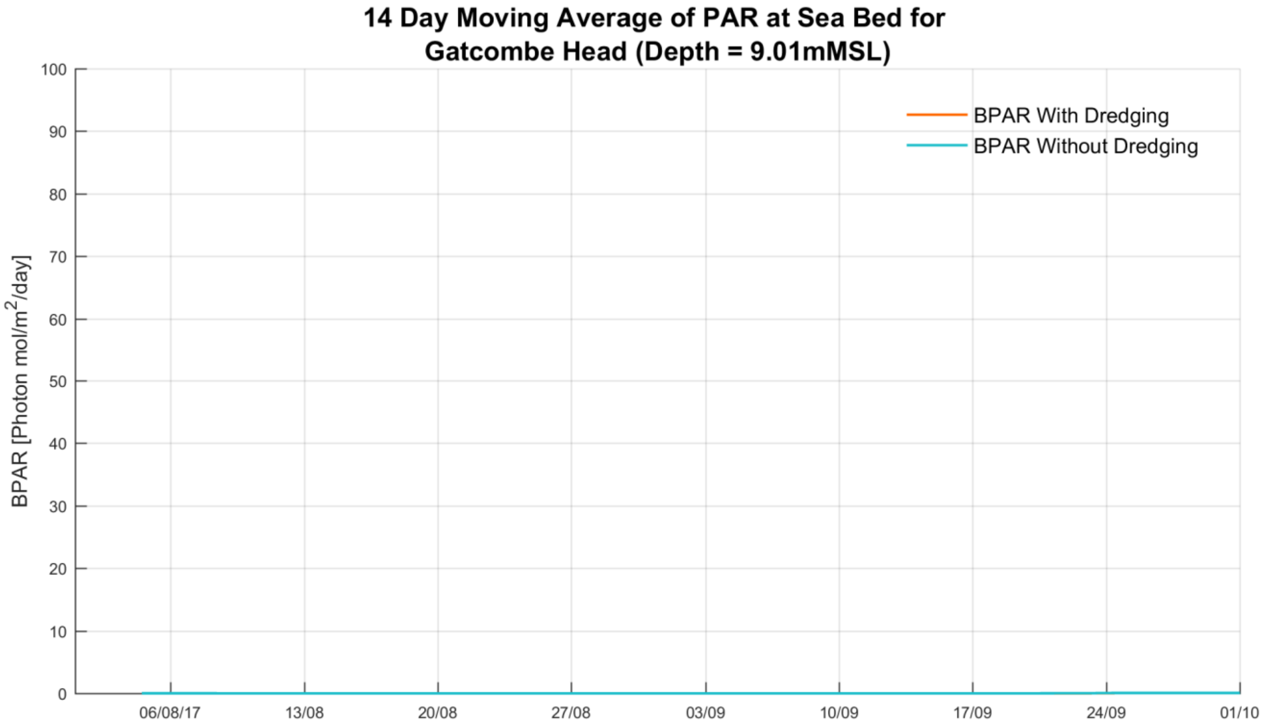


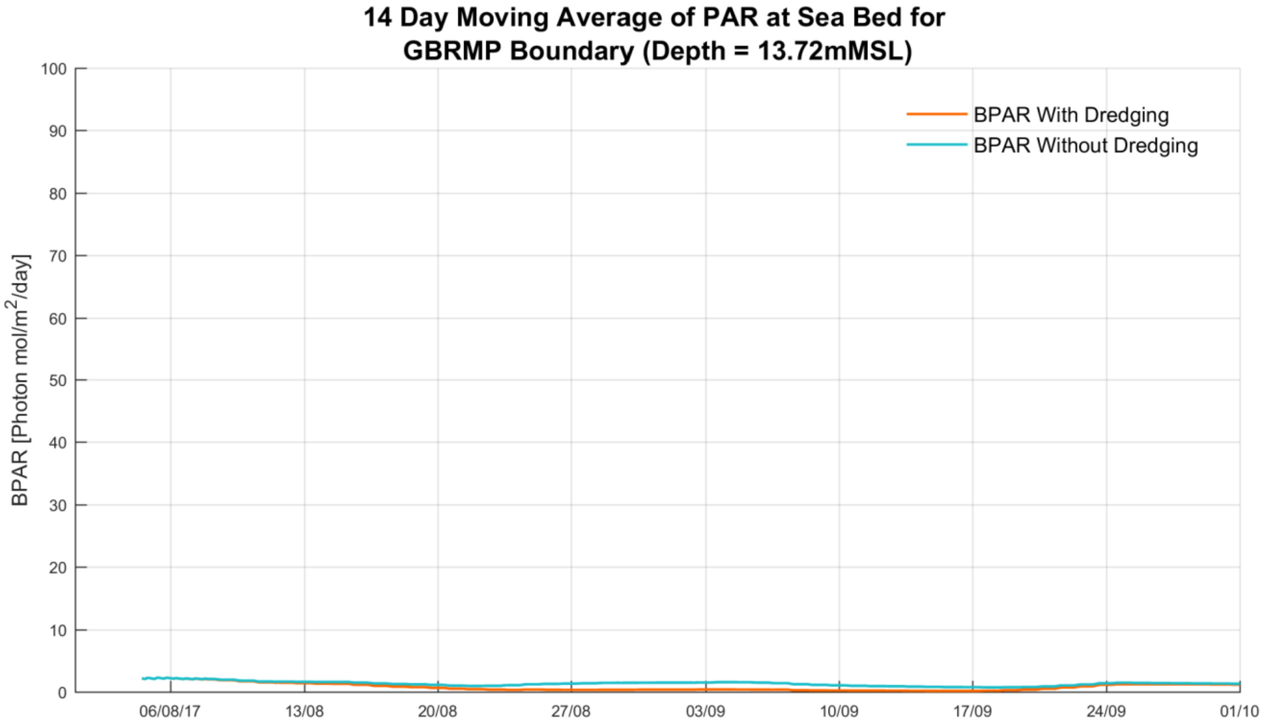
Time Series of Benthic PAR



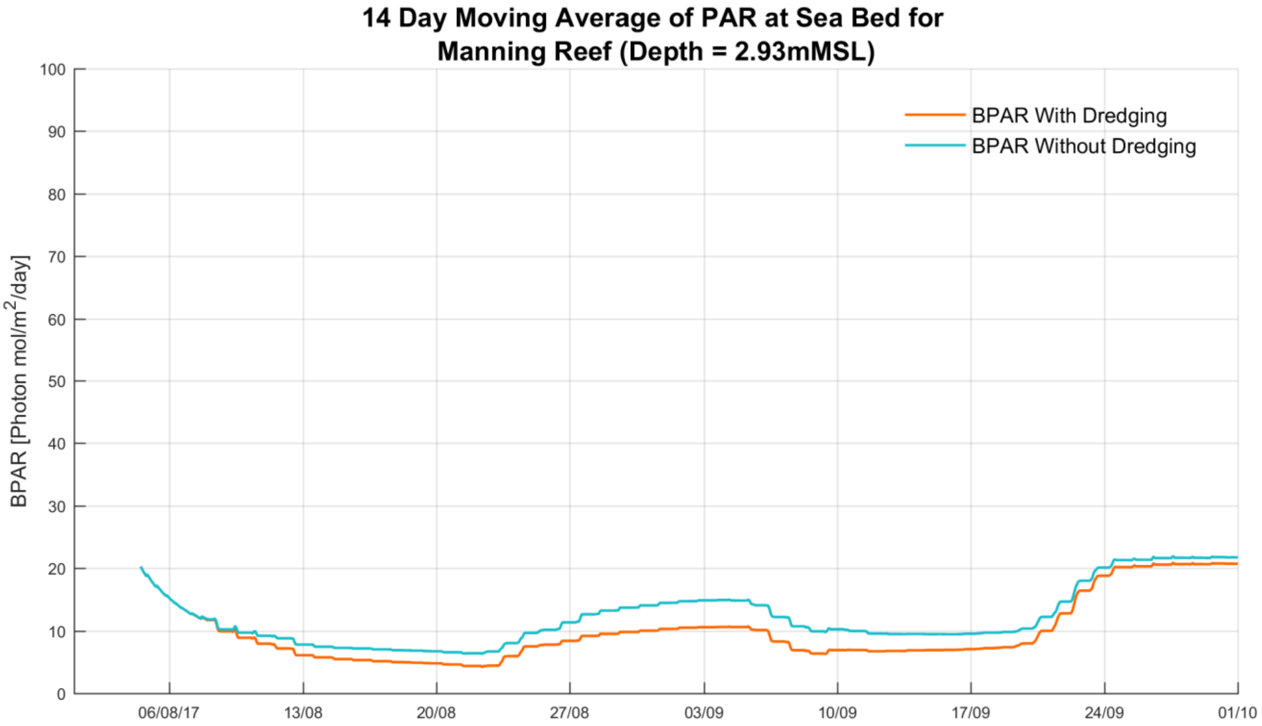


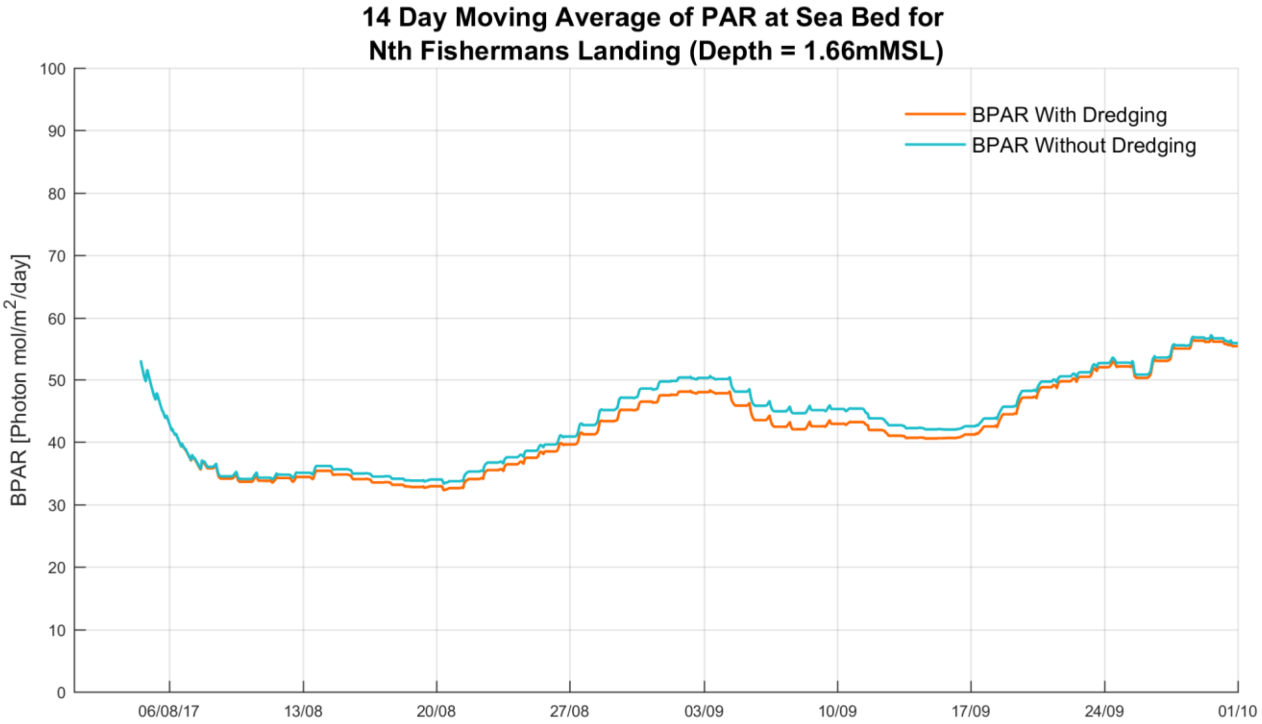
Time Series of Benthic PAR



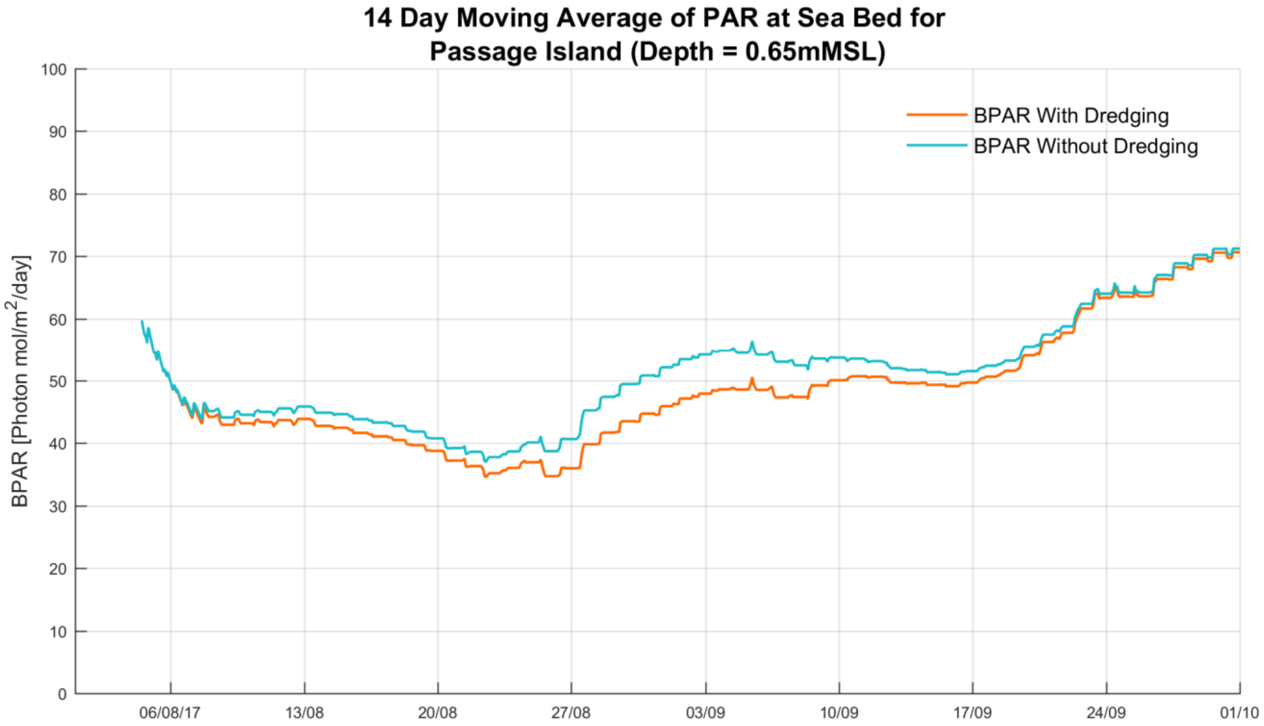


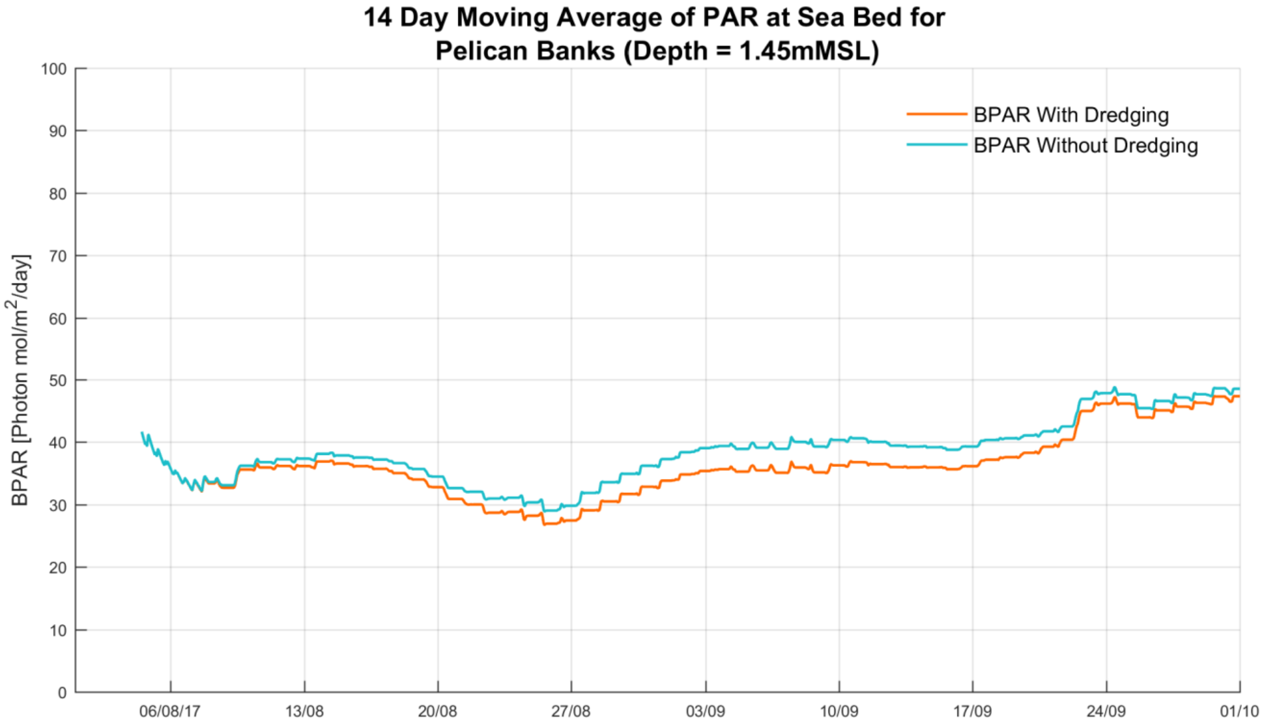
Time Series of Benthic PAR



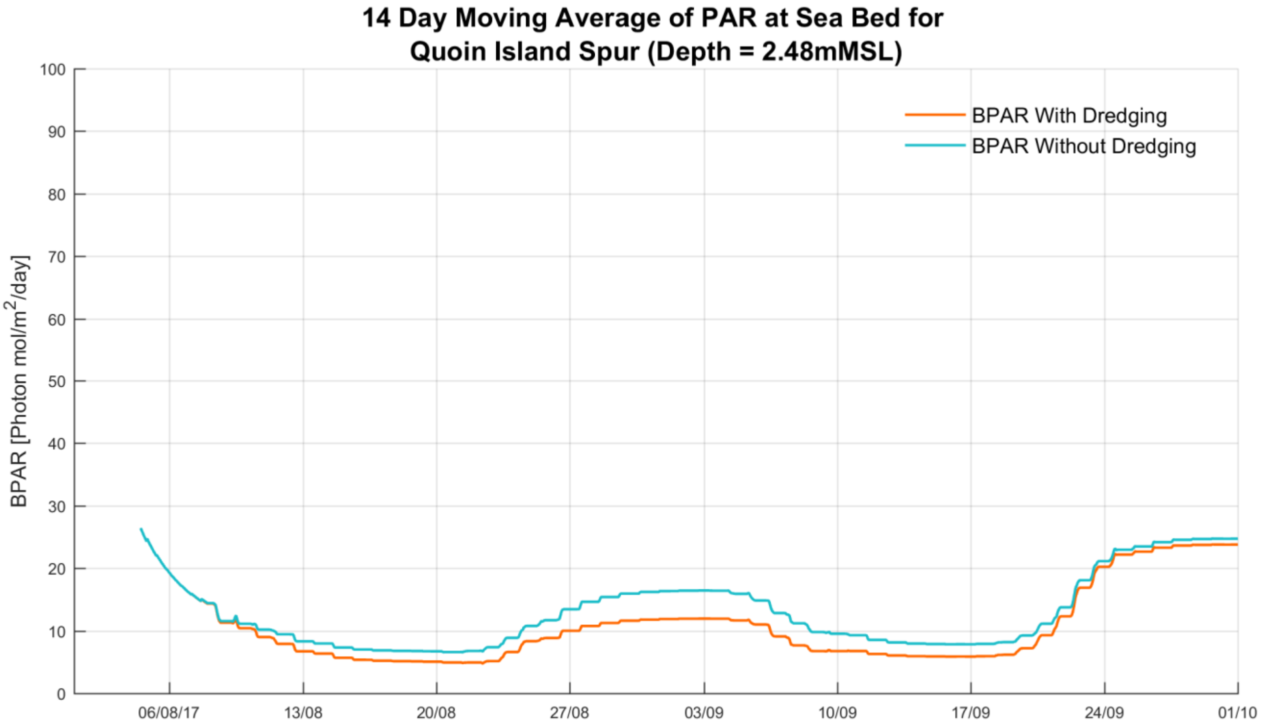


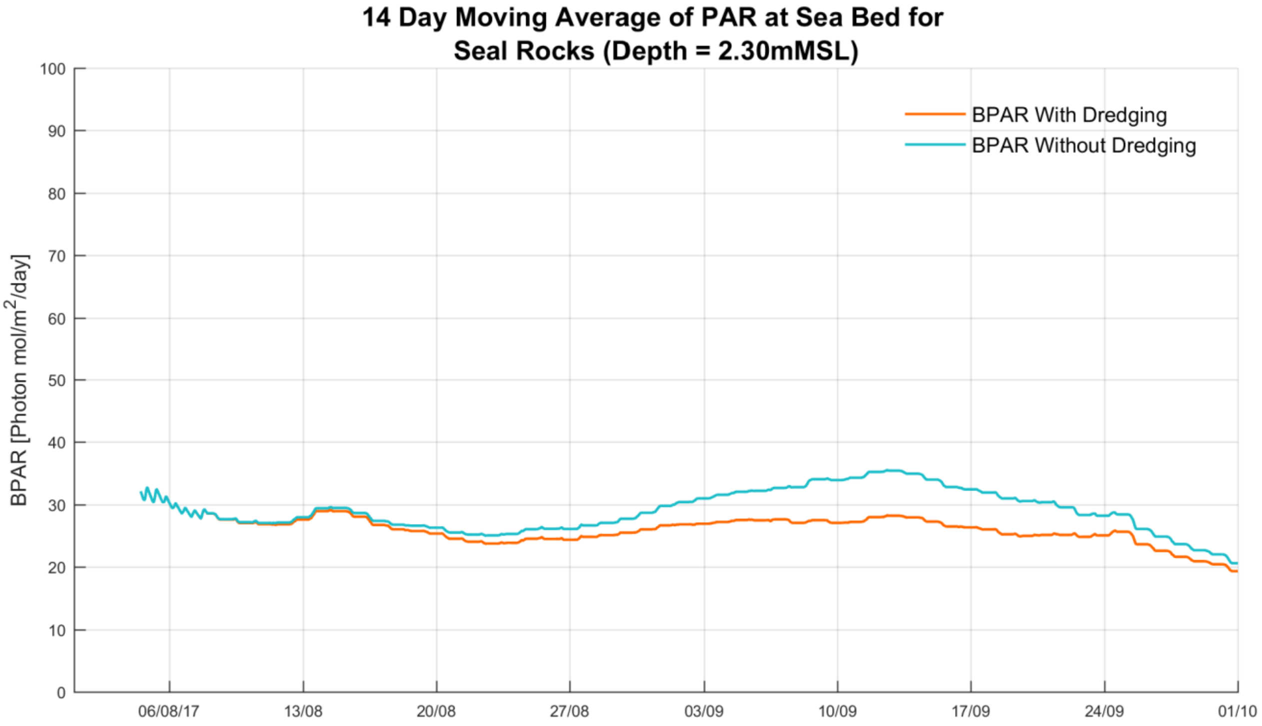
Time Series of Benthic PAR



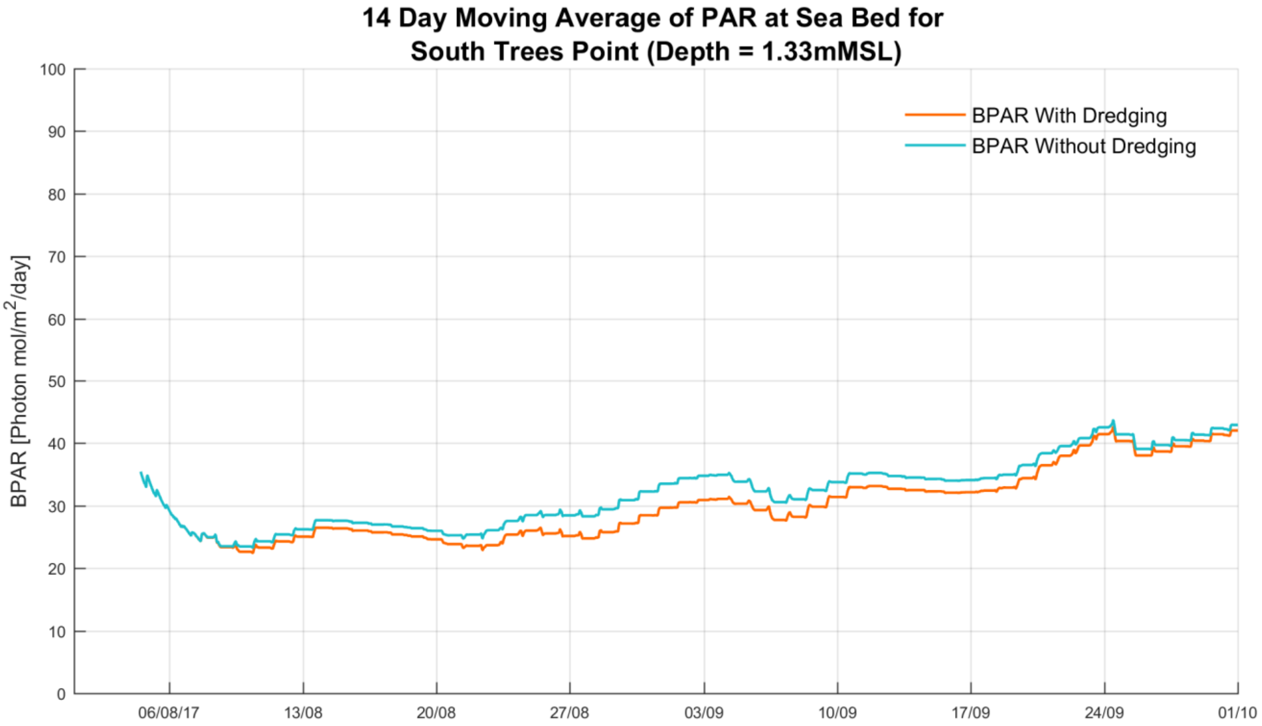


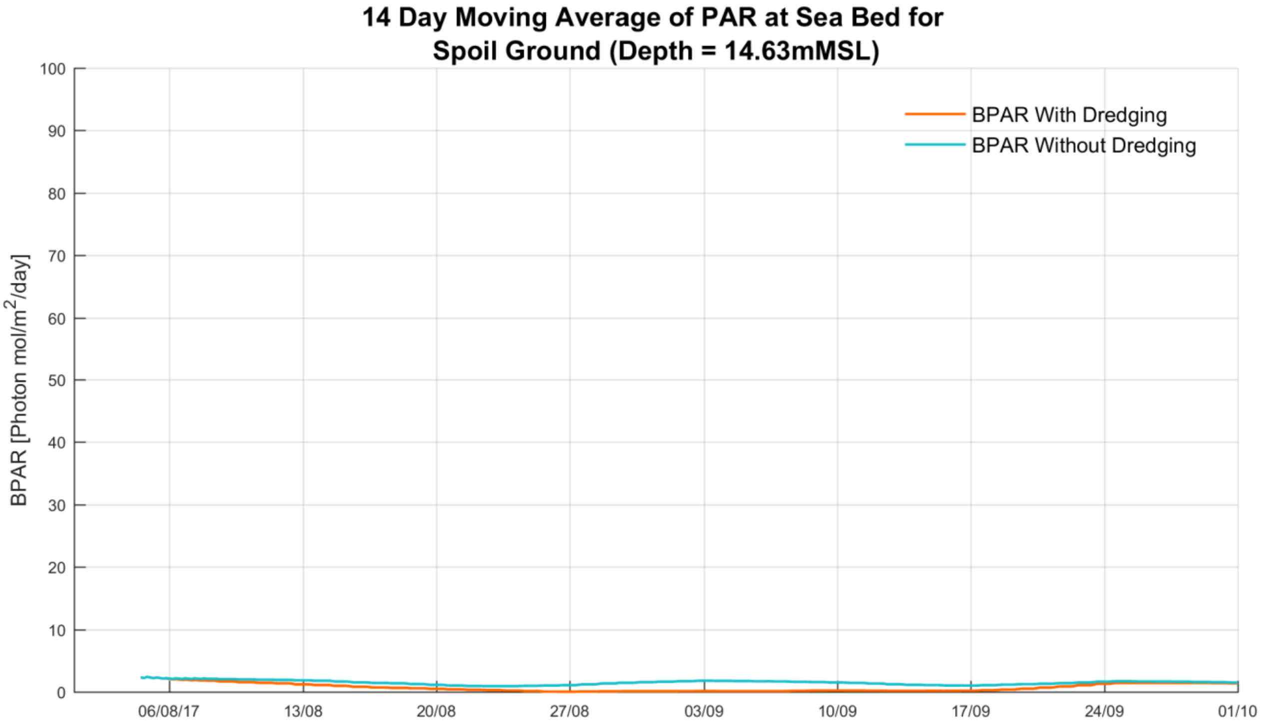
Time Series of Benthic PAR



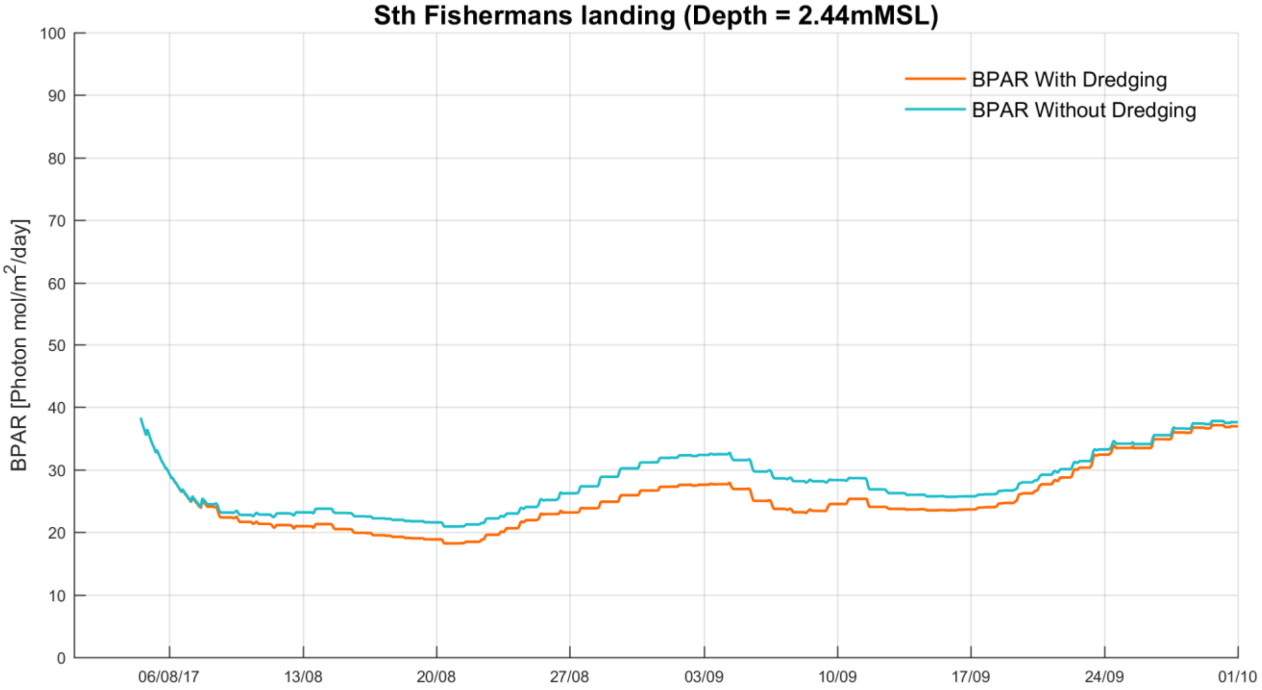


Time Series of Benthic PAR

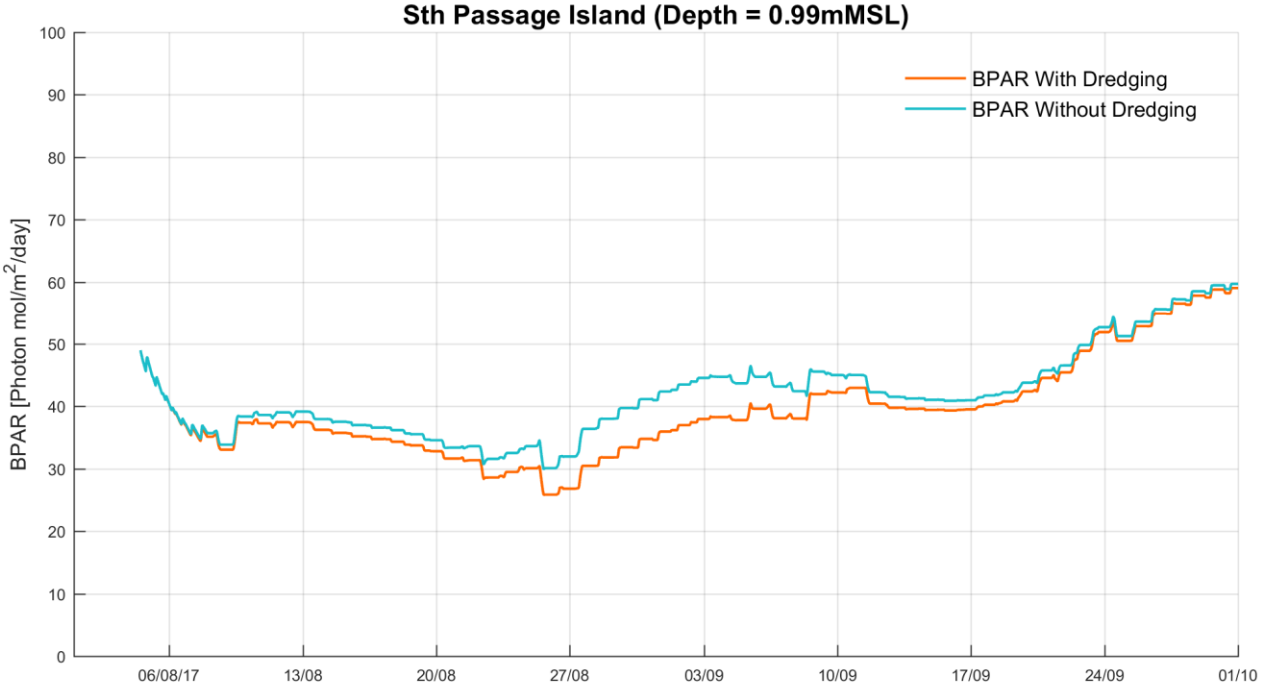




Time Series of Benthic PAR

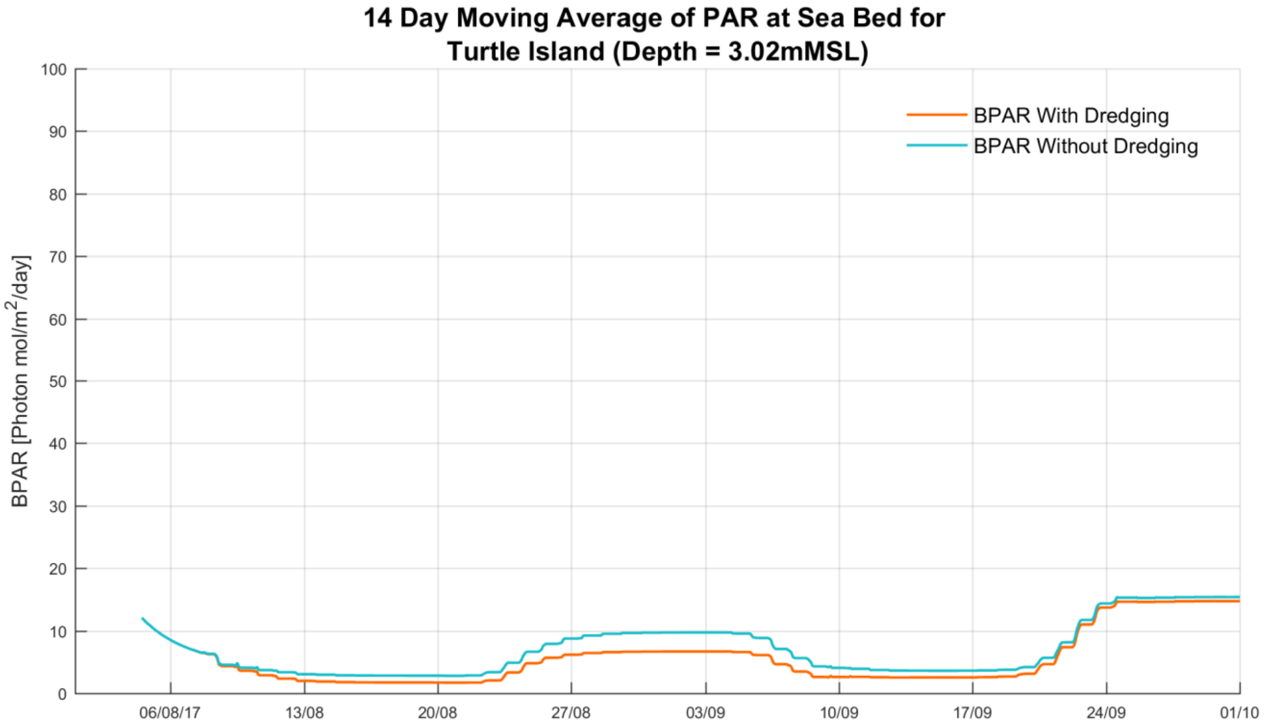


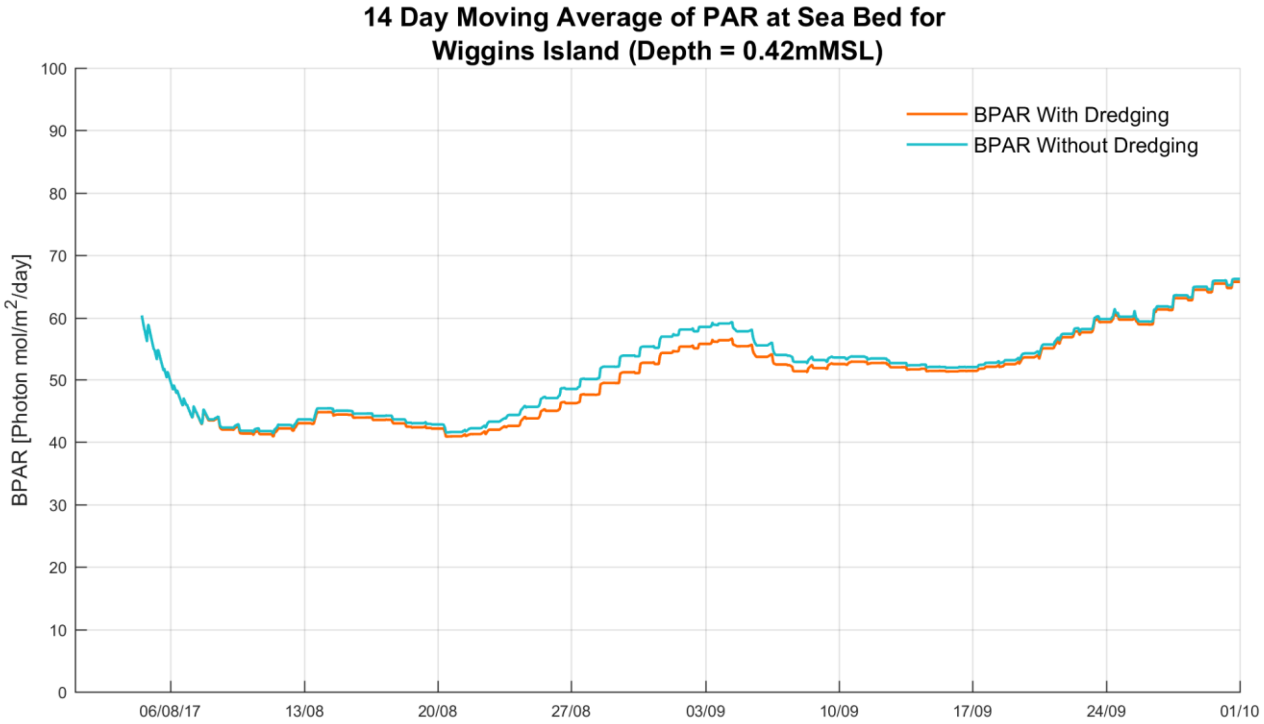
14 Day Moving Average of PAR at Sea Bed for Sth Fishermans landing (Depth = 2.44mMSL)



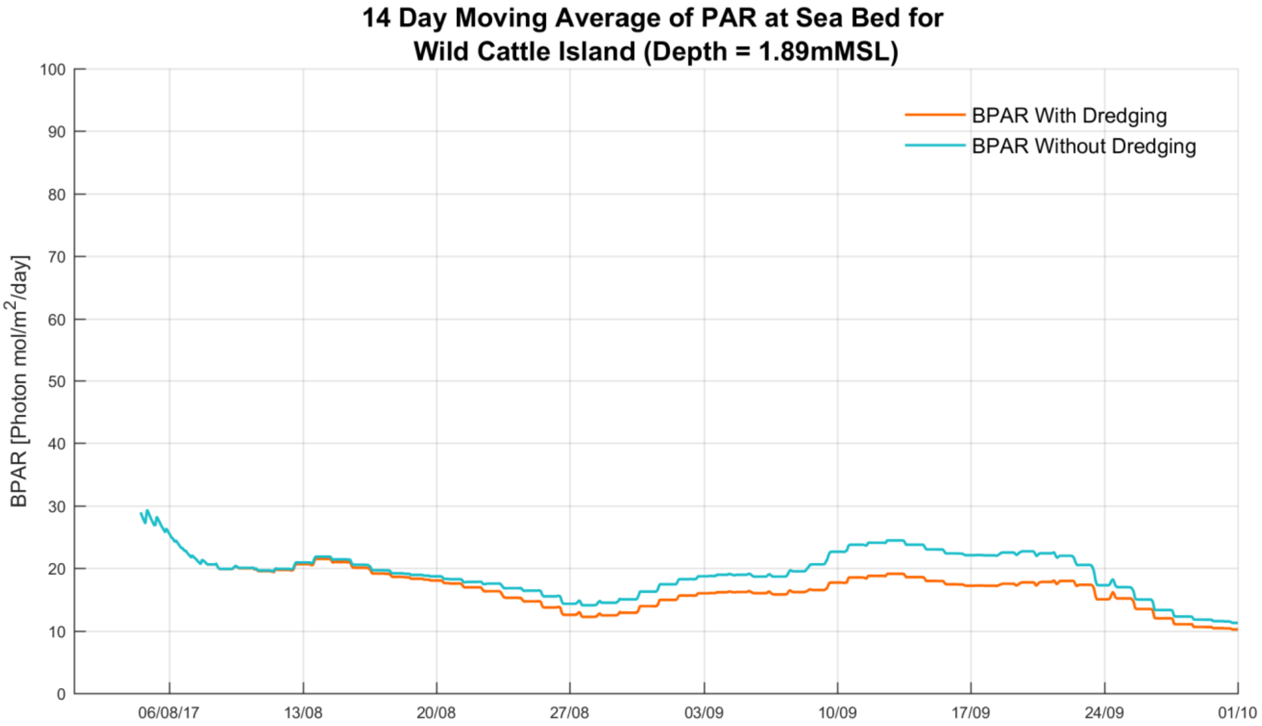
14 Day Moving Average of PAR at Sea Bed for Sth Passage Island (Depth = 0.99mMSL)

Time Series of Benthic PAR

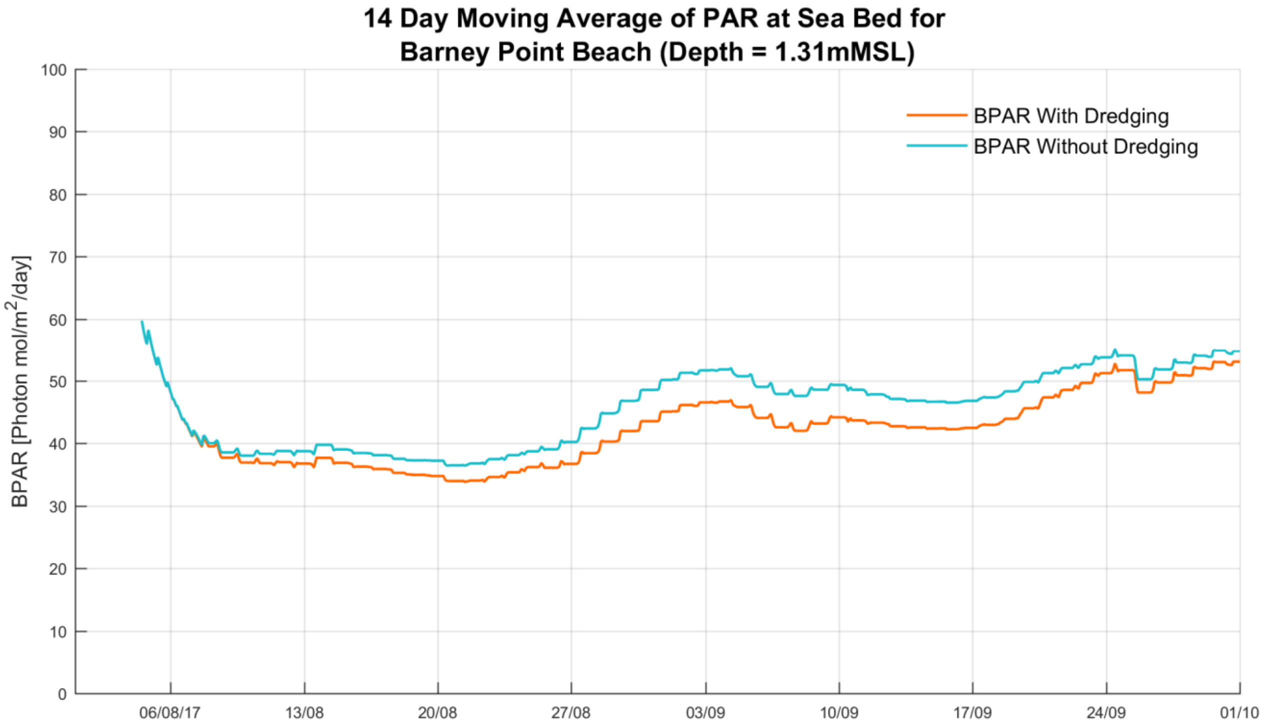


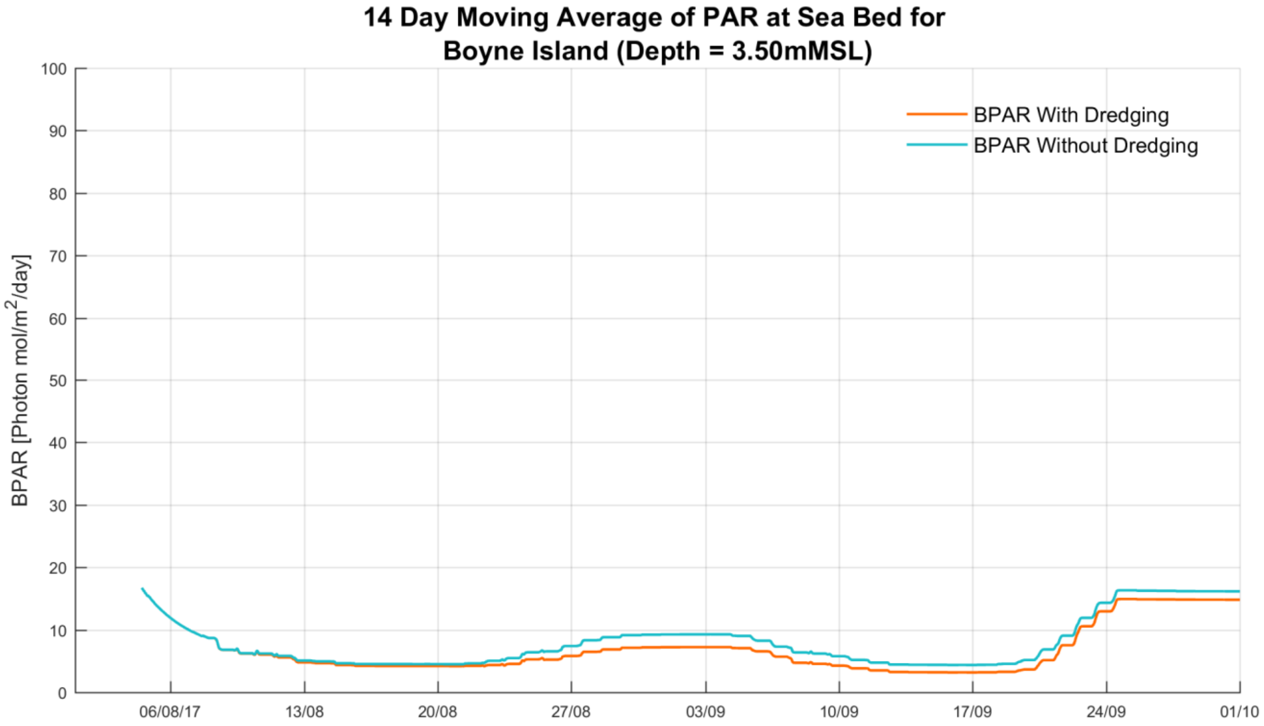


Time Series of Benthic PAR

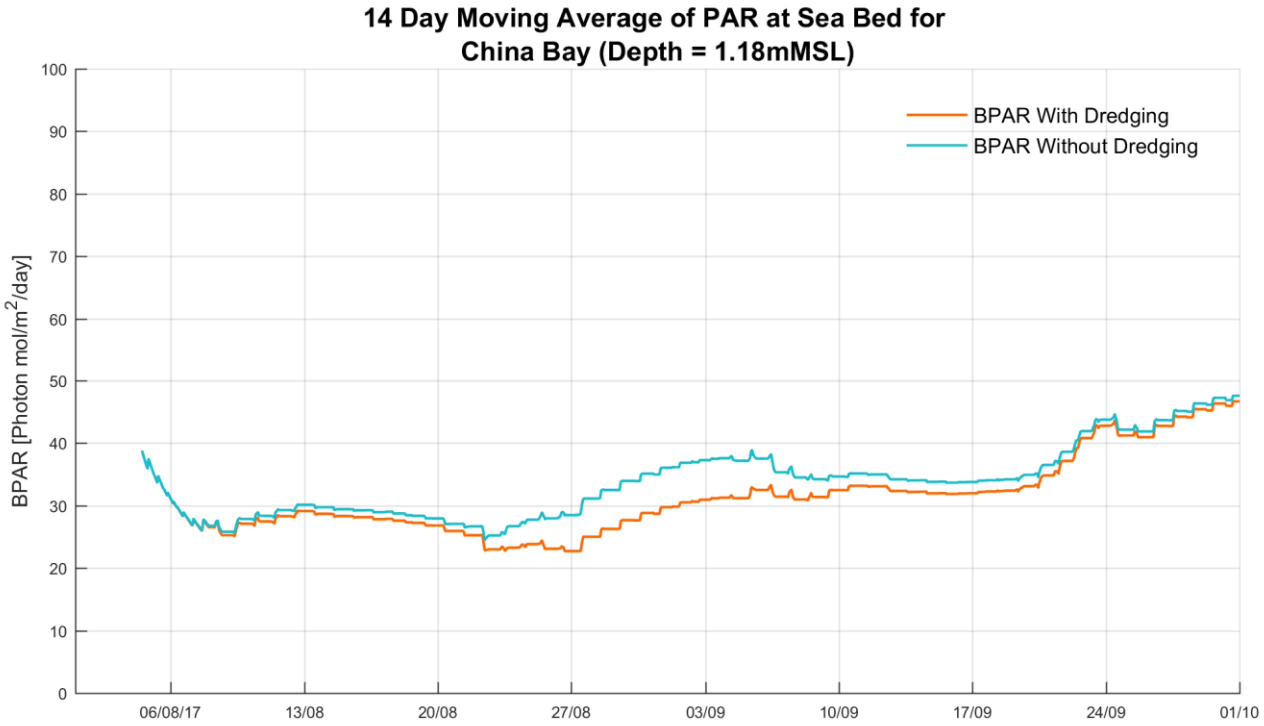


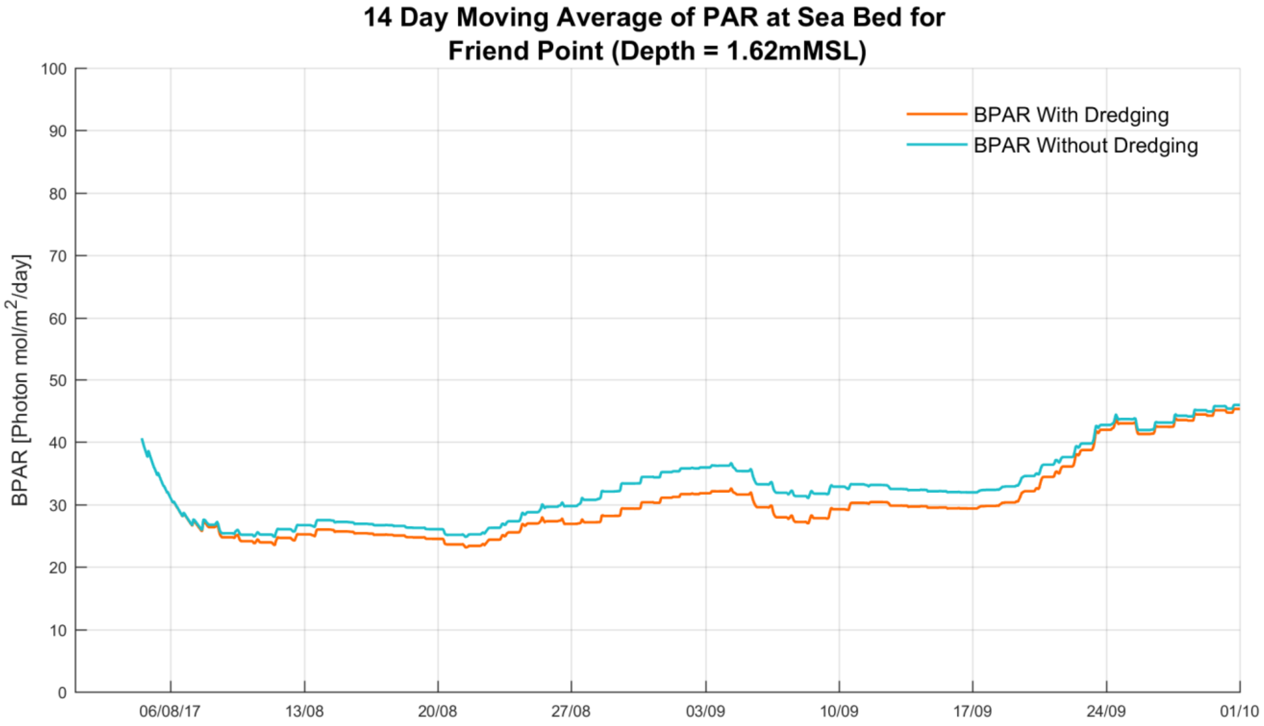
300,000m³ Campaign

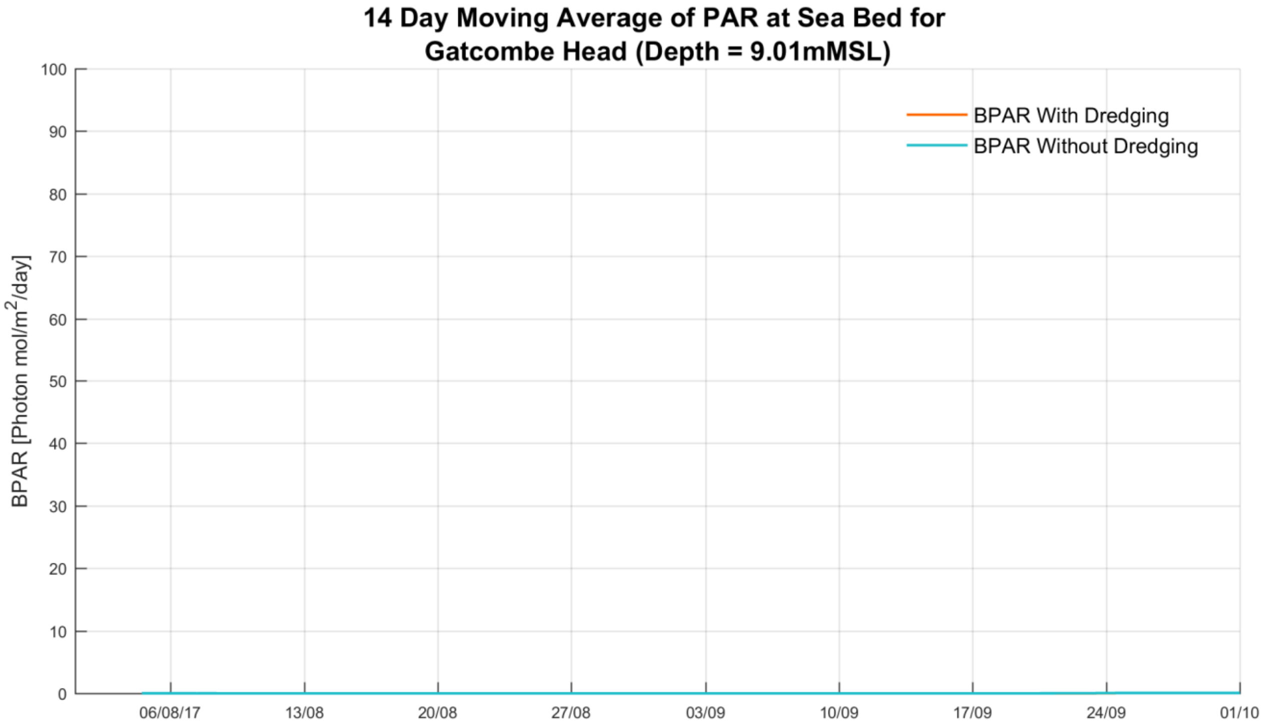


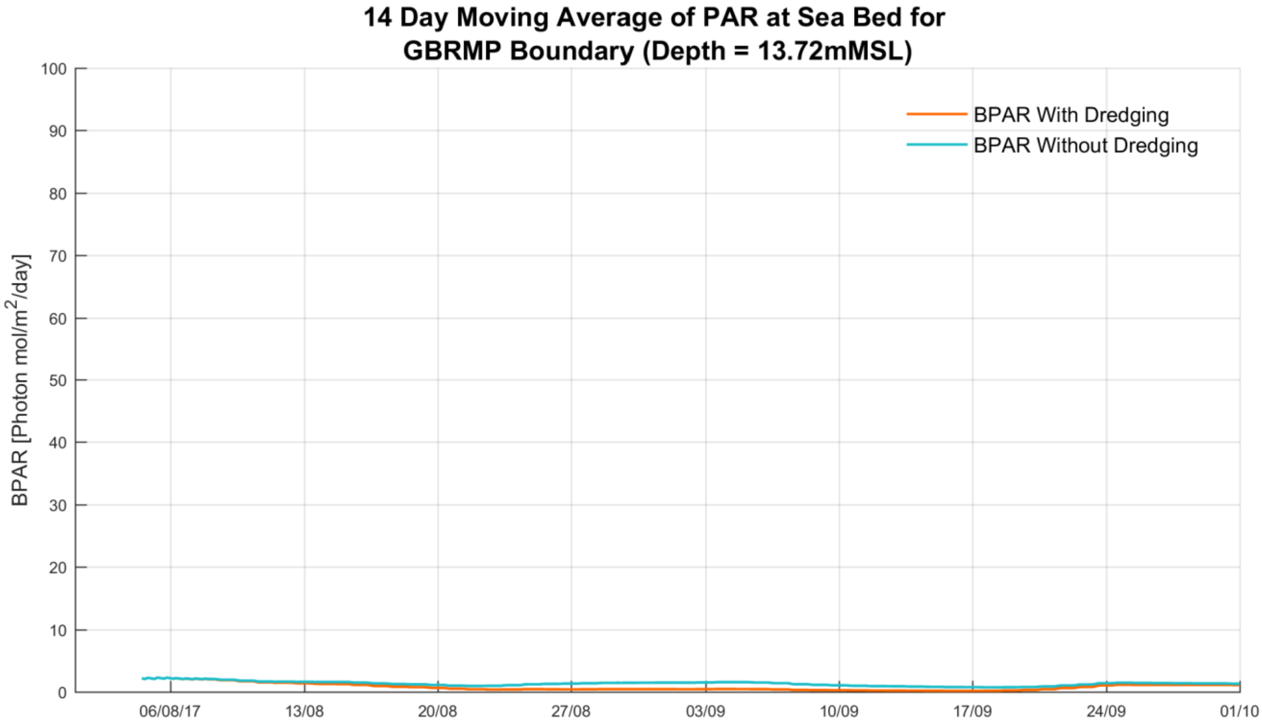


Time Series of Benthic PAR

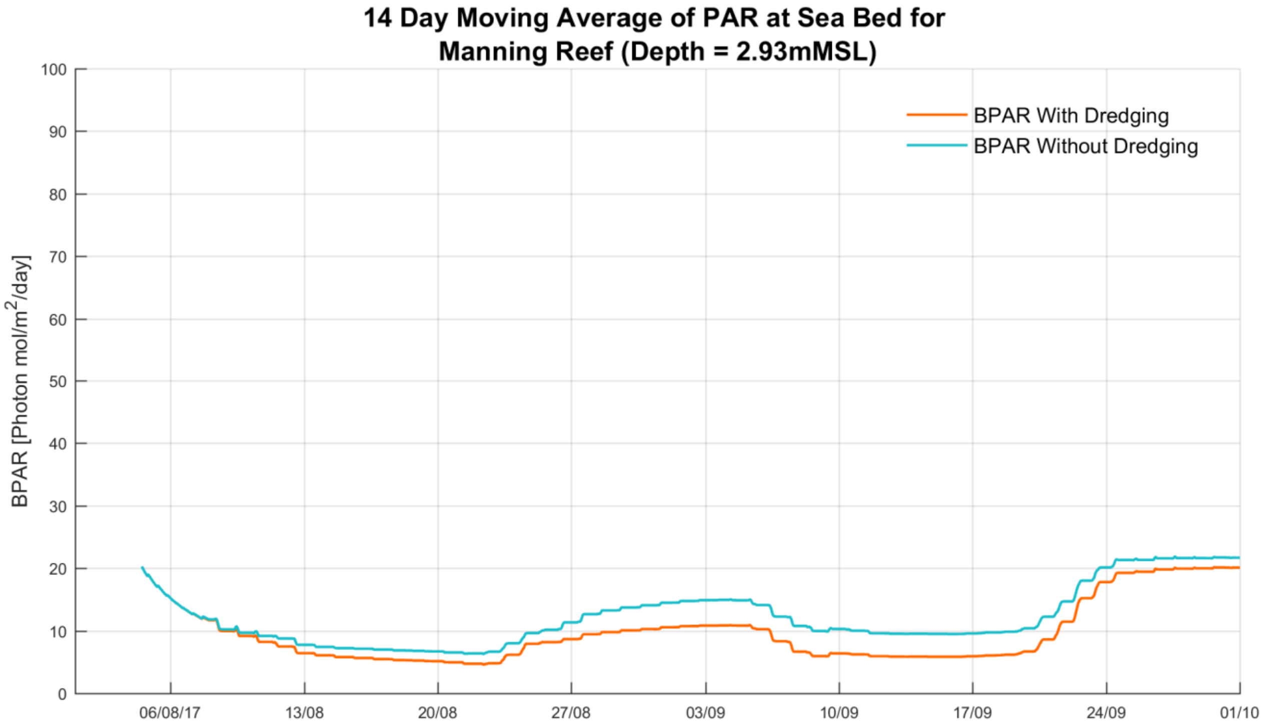


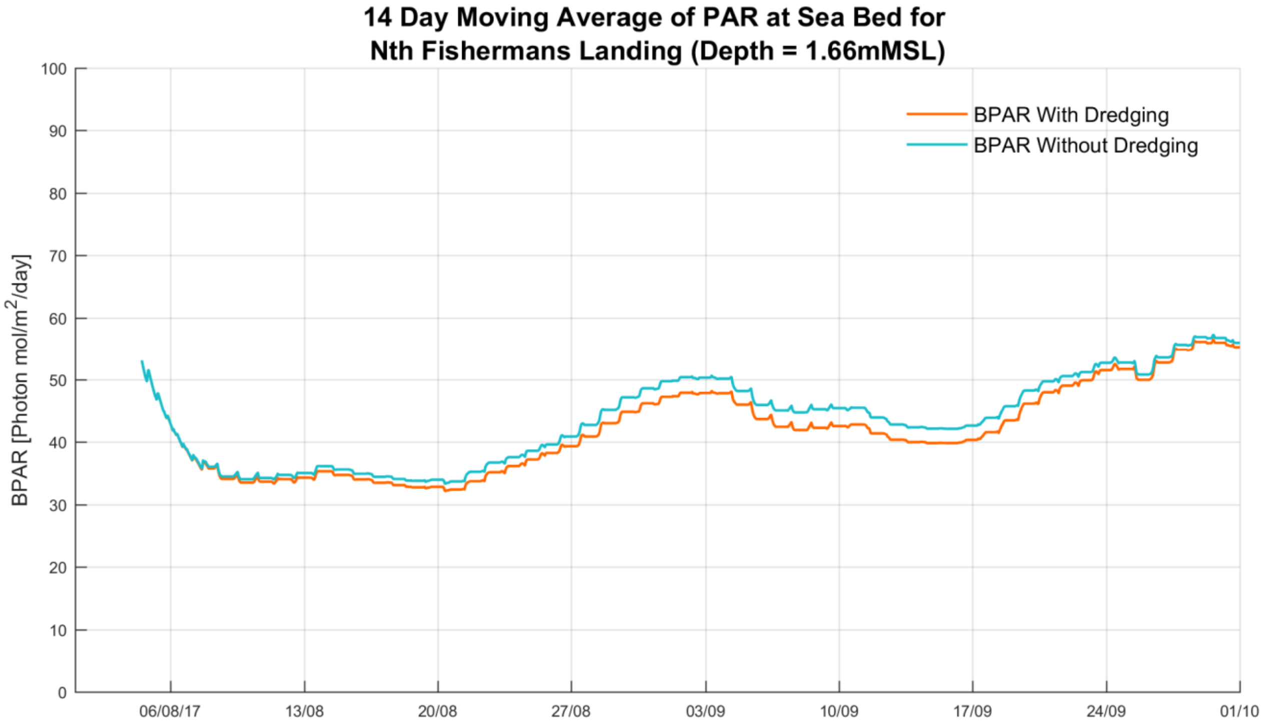



14 Day Moving Average of PAR at Sea Bed for
Gatcombe Head (Depth = 9.01mMSL)
BPAR [Photon mol/m^2/day]
0
10
20
30
40
50
60
70
80
90
100
06/08/17
13/08
20/08
27/08
03/09
10/09
17/09
24/09
01/10
BPAR With Dredging
BPAR Without Dredging

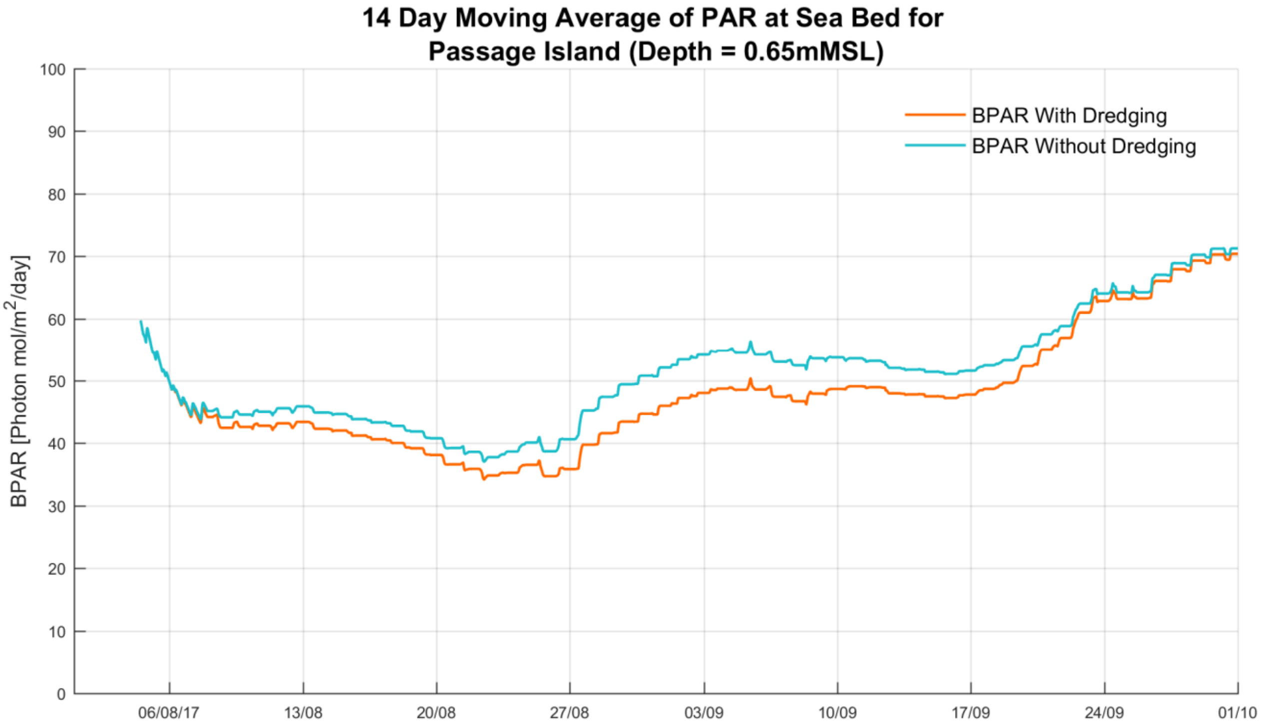

14 Day Moving Average of PAR at Sea Bed for
GBRMP Boundary (Depth = 13.72mMSL)
BPAR [Photon mol/m^2/day]
0
10
20
30
40
50
60
70
80
90
100
06/08/17
13/08
20/08
27/08
03/09
10/09
17/09
24/09
01/10
BPAR With Dredging
BPAR Without Dredging

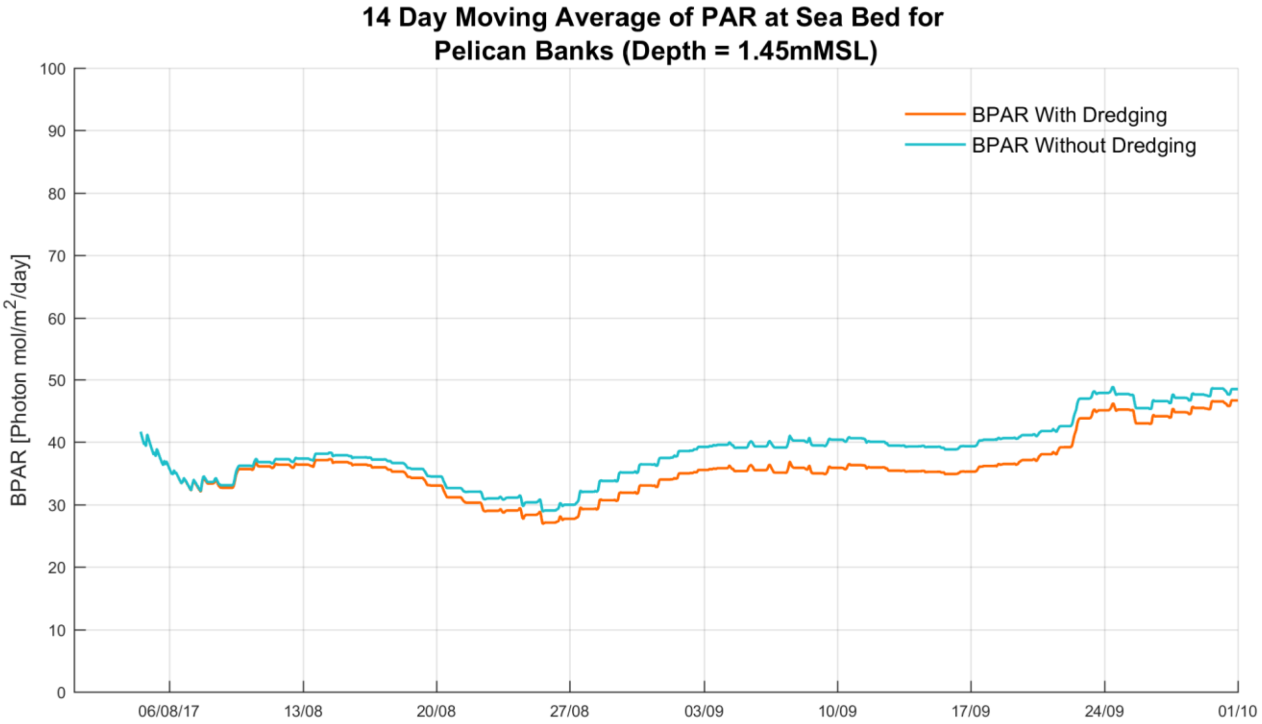
Time Series of Benthic PAR



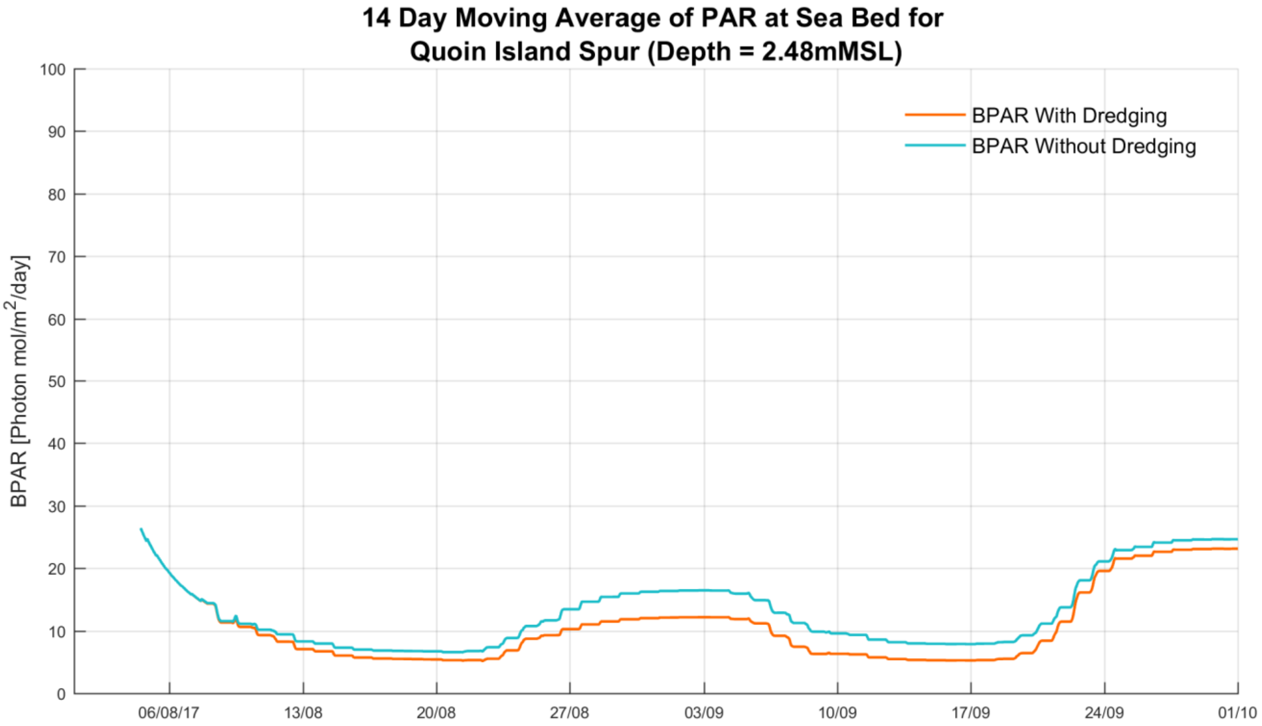


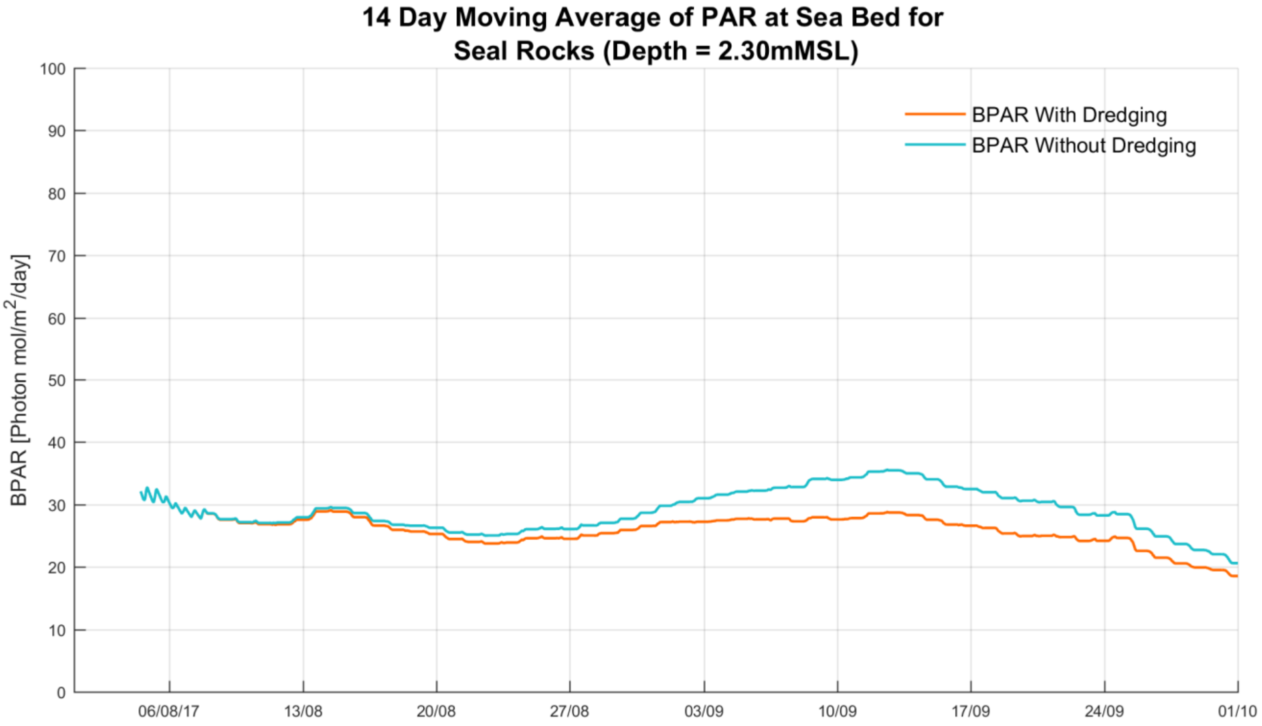
Time Series of Benthic PAR



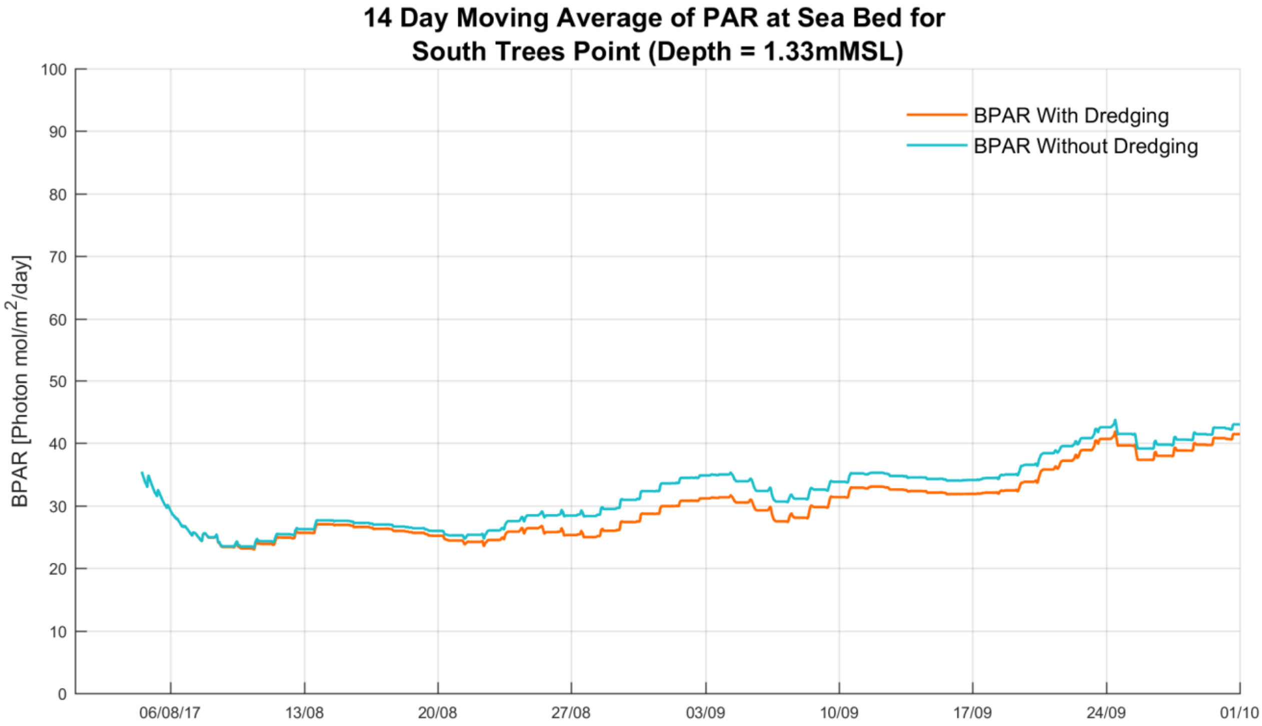


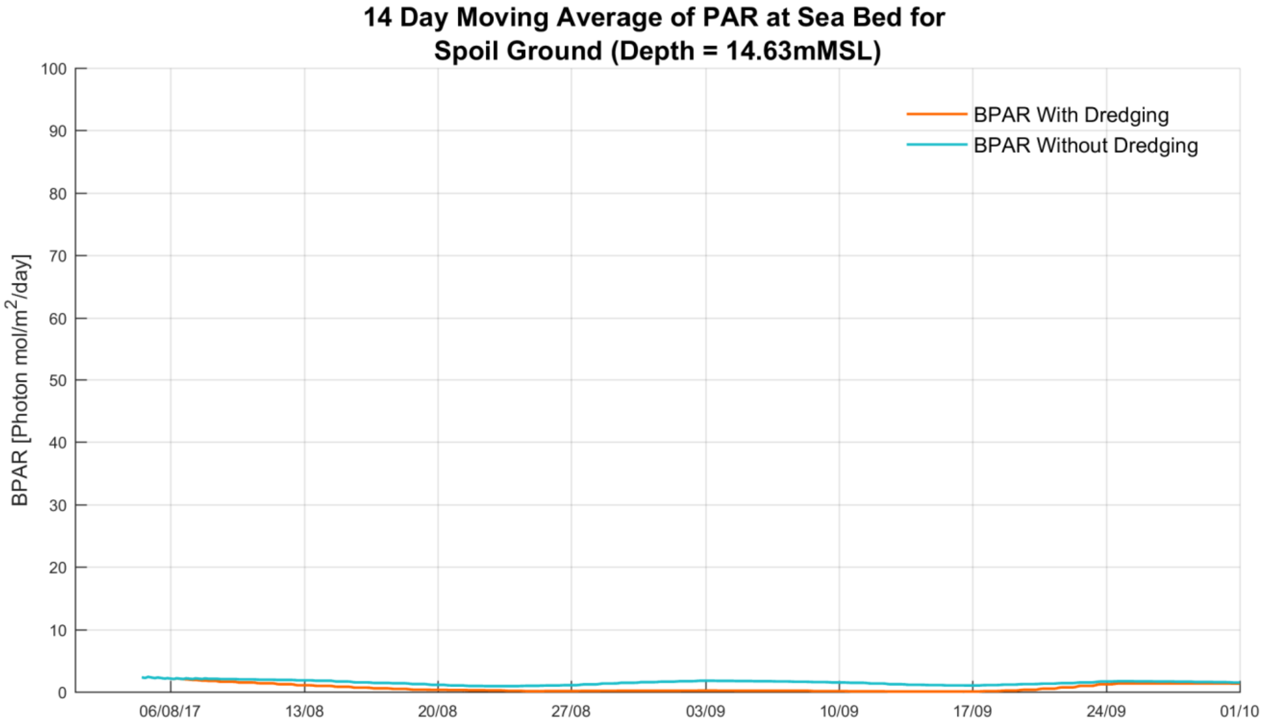
Time Series of Benthic PAR



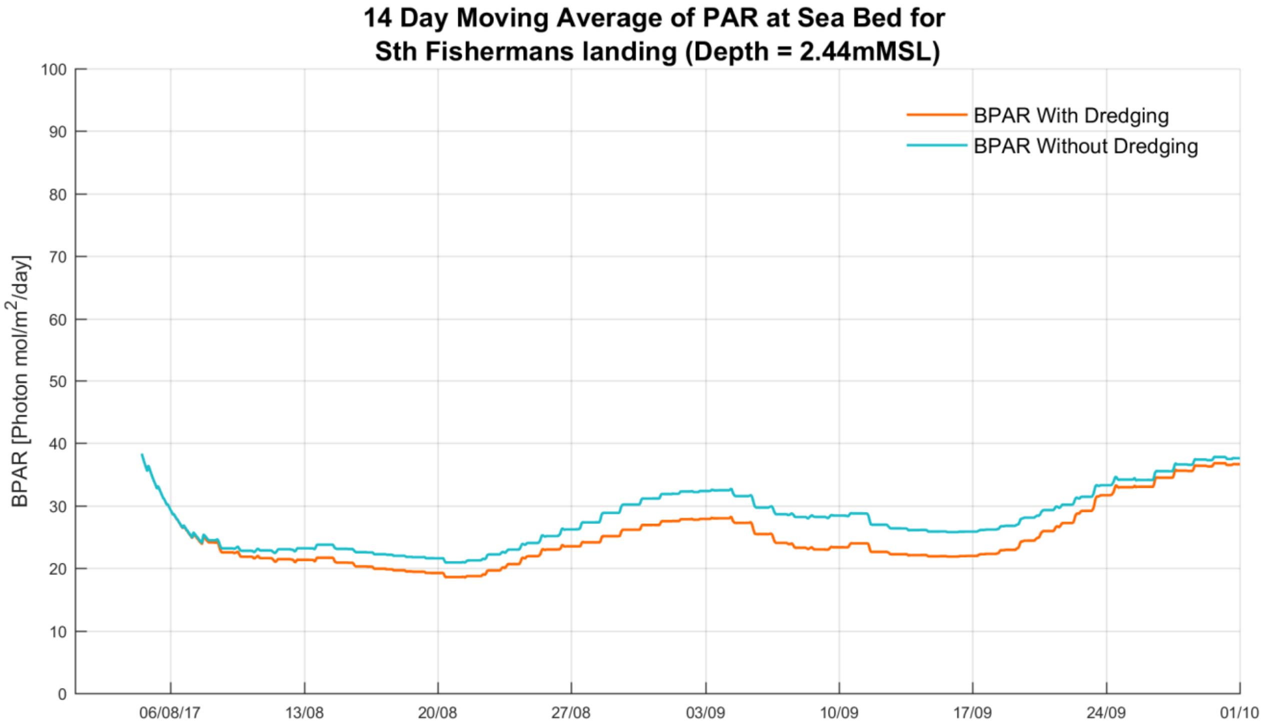


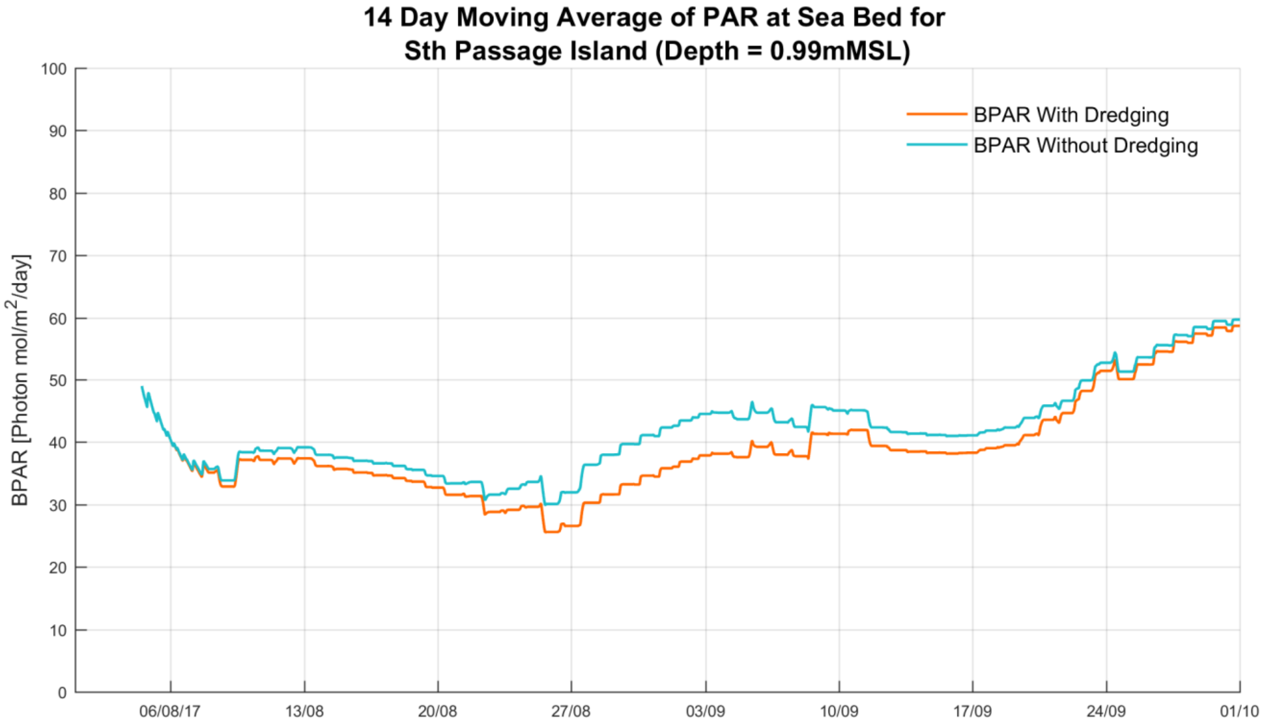
Time Series of Benthic PAR



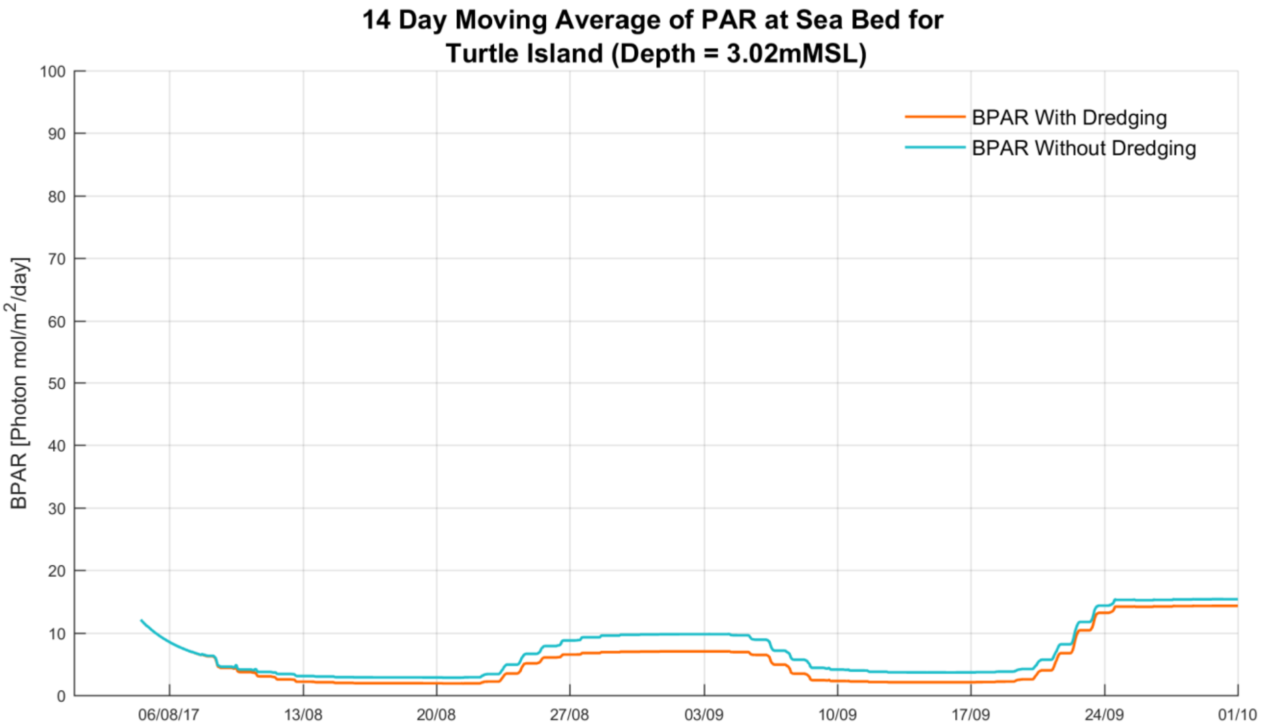


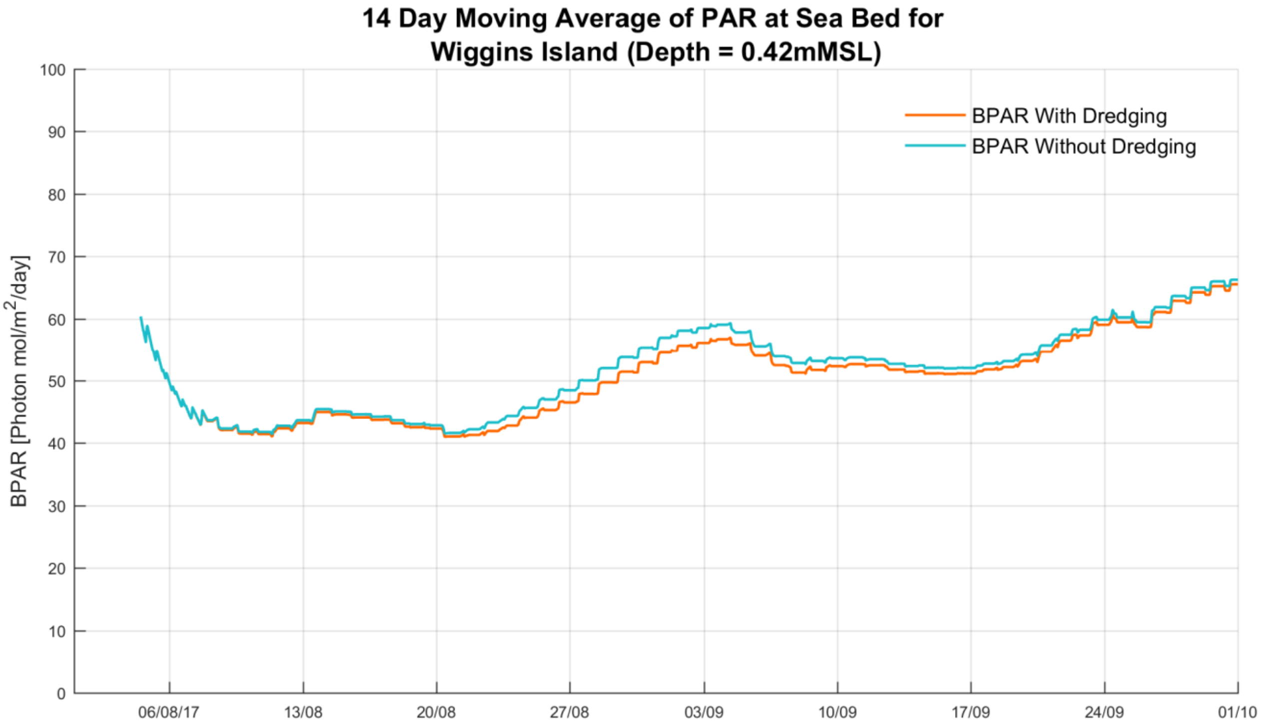
Time Series of Benthic PAR



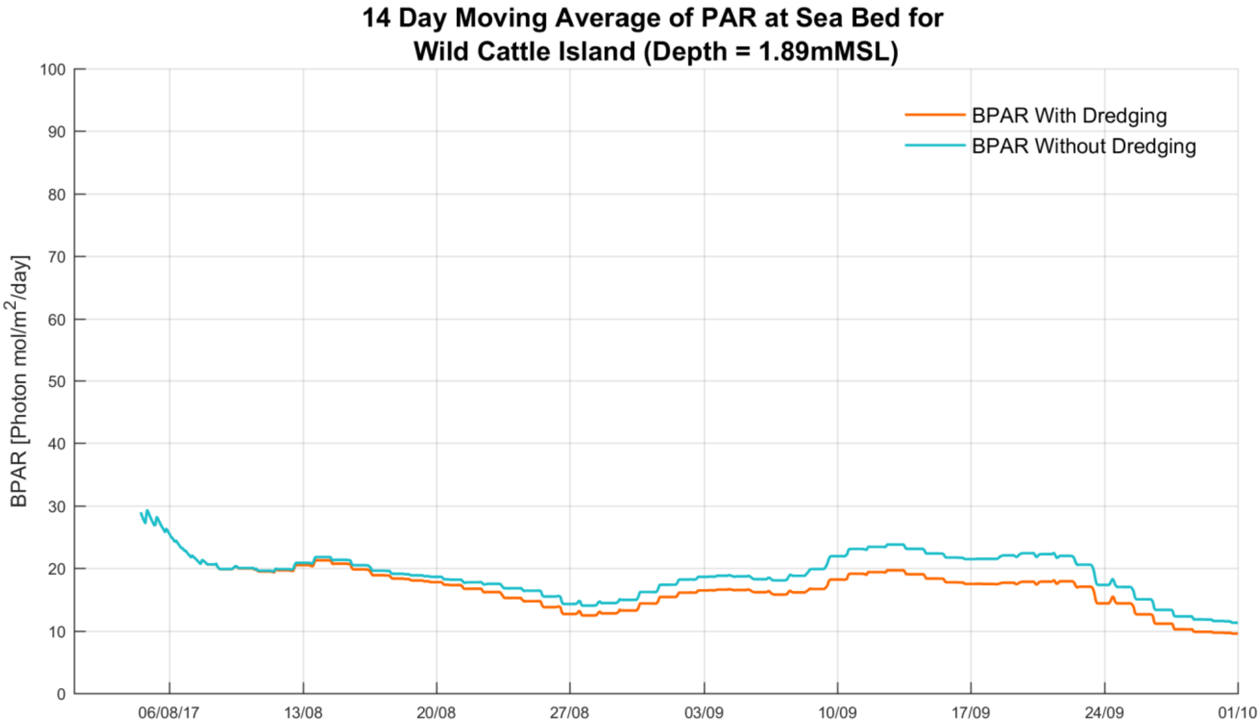


Time Series of Benthic PAR

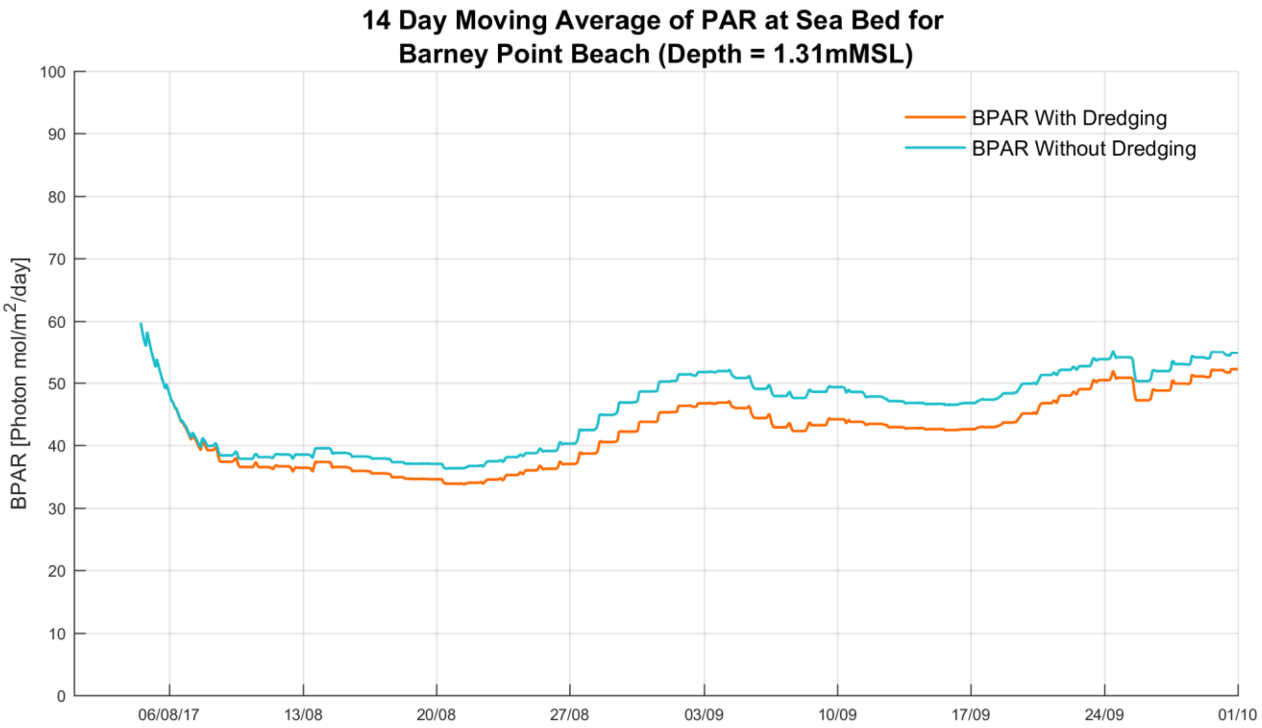


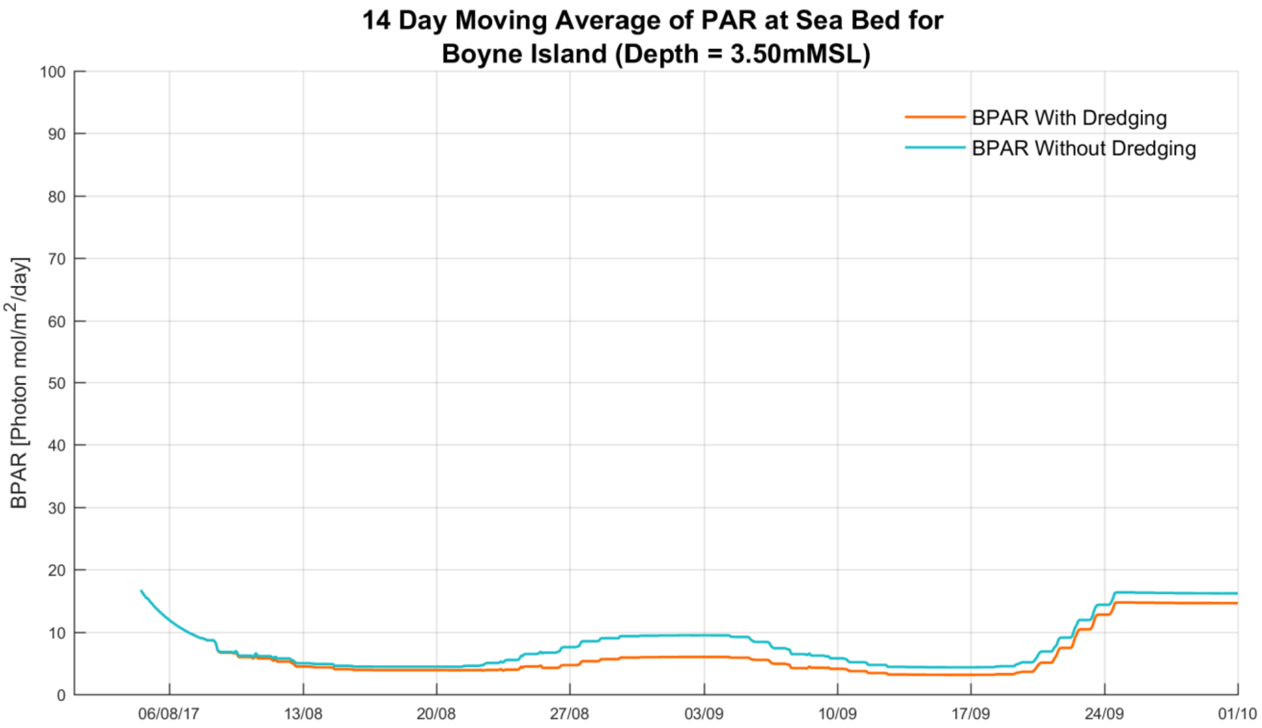


Time Series of Benthic PAR

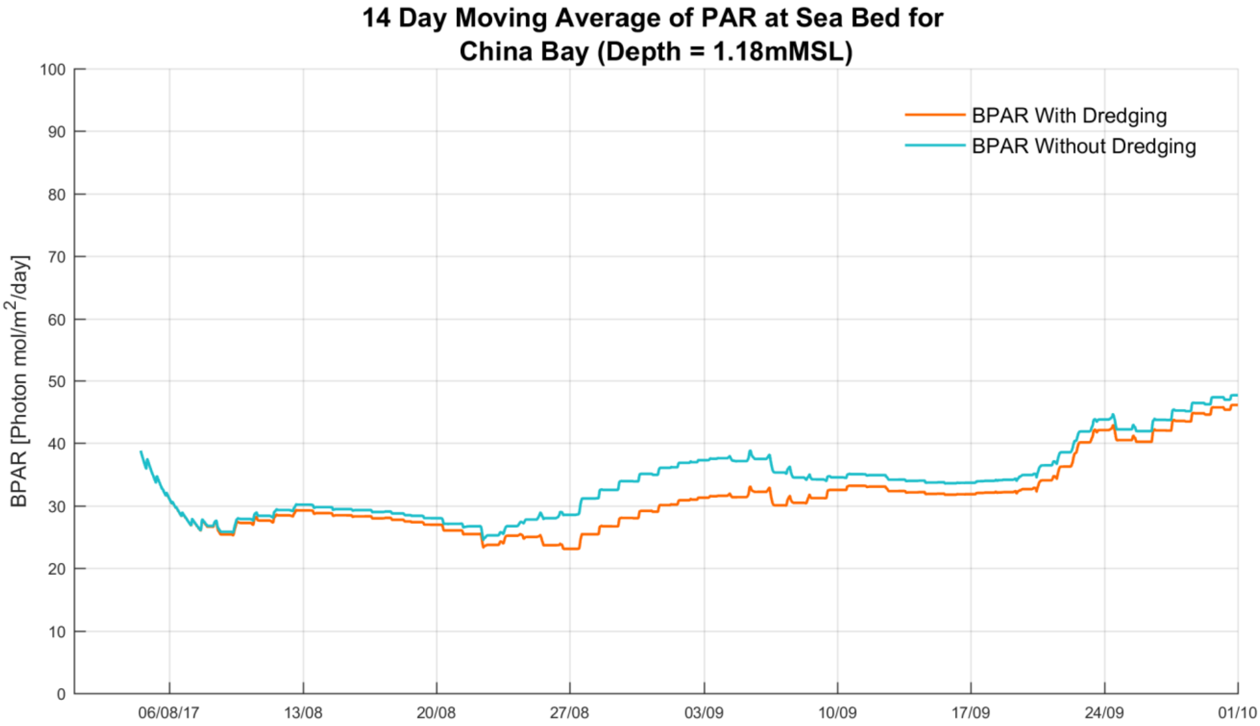


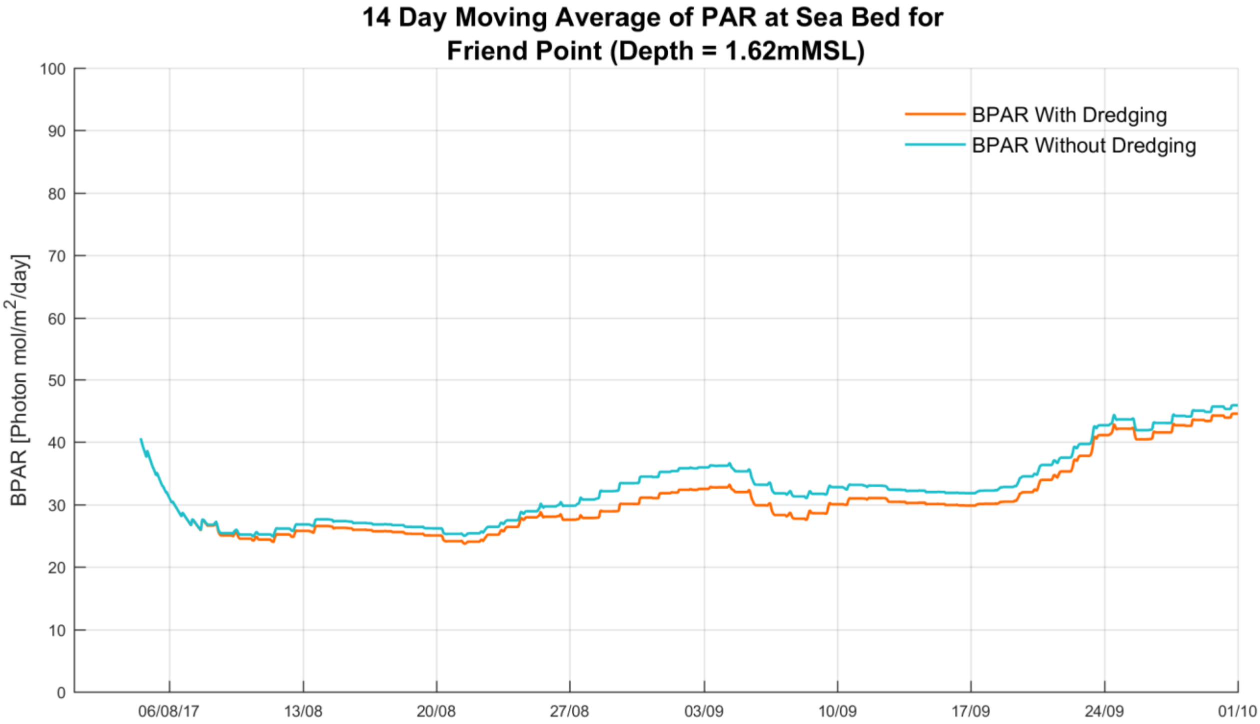
340,000m^3 Campaign

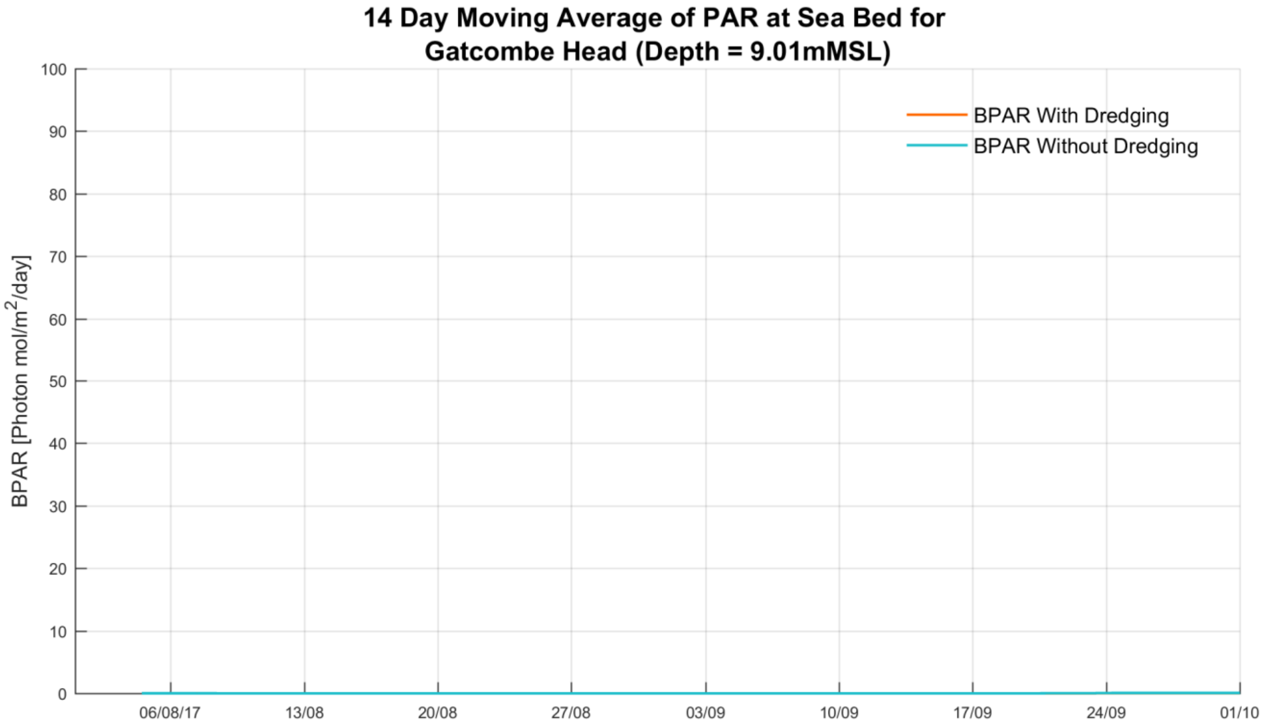


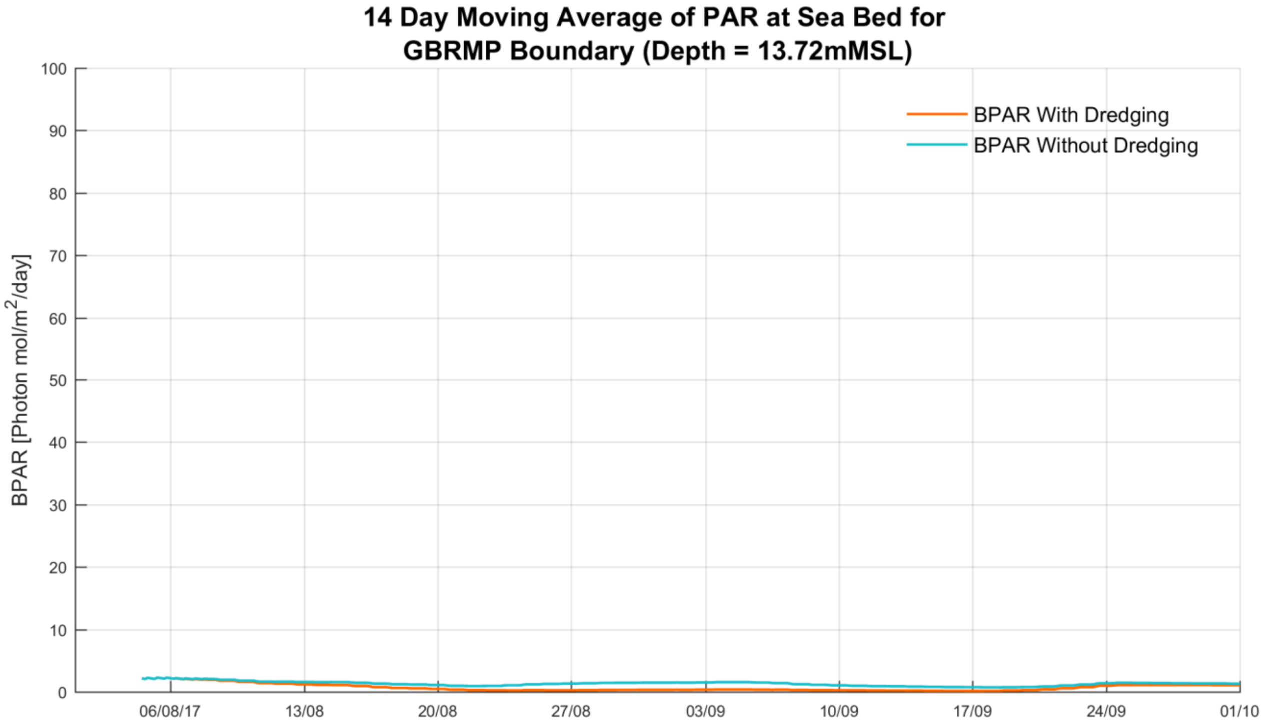


Time Series of Benthic PAR

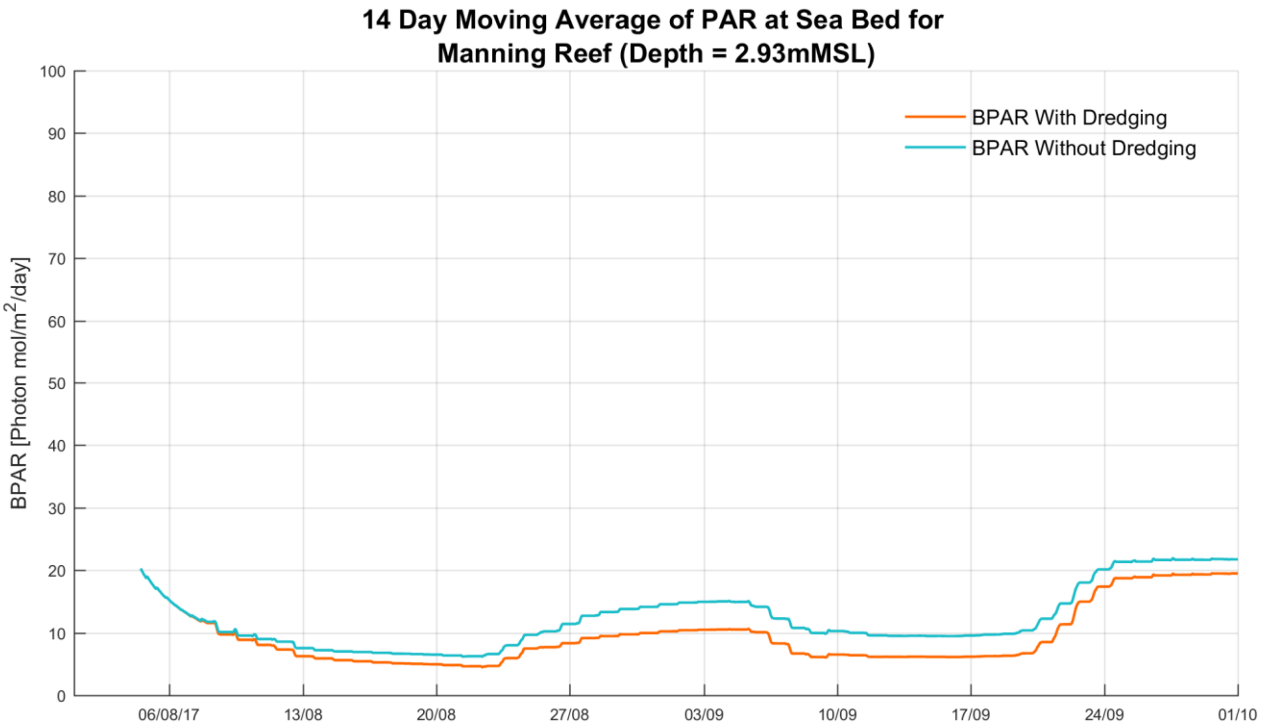


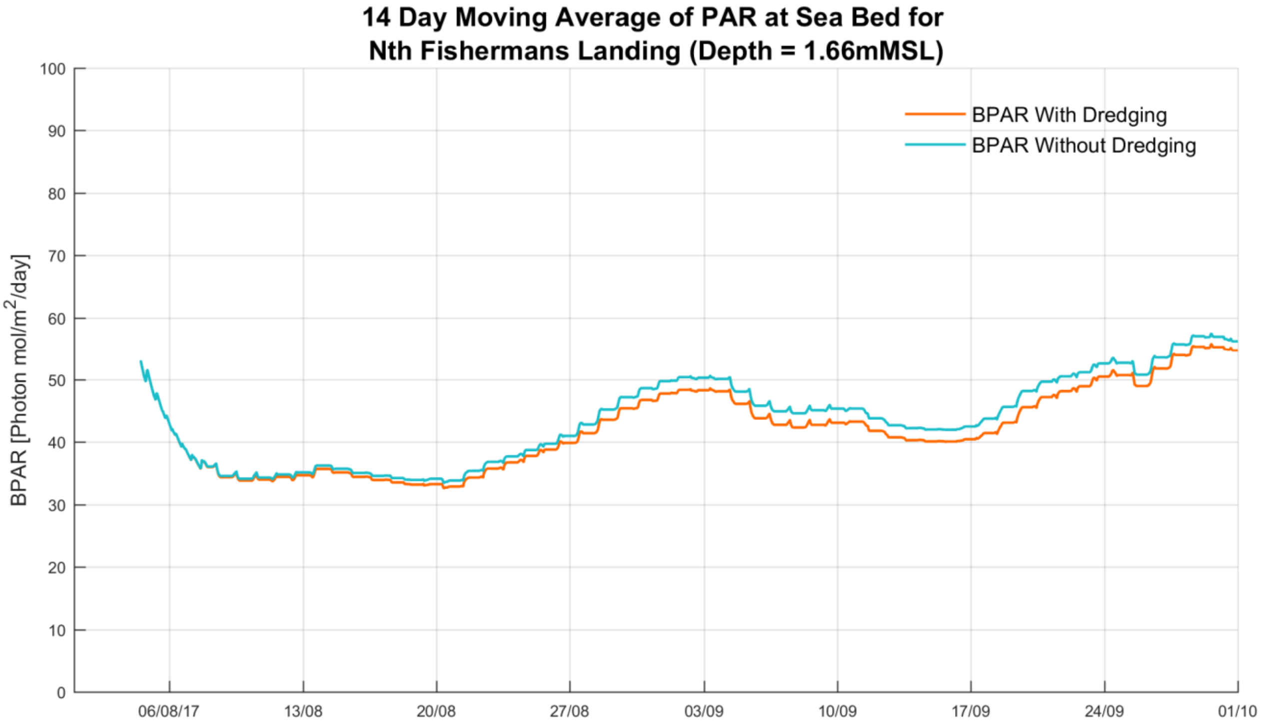



14 Day Moving Average of PAR at Sea Bed for
Gatcombe Head (Depth = 9.01mMSL)
BPAR [Photon mol/m2/day]
100
90
80
70
60
50
40
30
20
10
0
06/08/17
13/08
20/08
27/08
03/09
10/09
17/09
24/09
01/10
BPAR With Dredging
BPAR Without Dredging

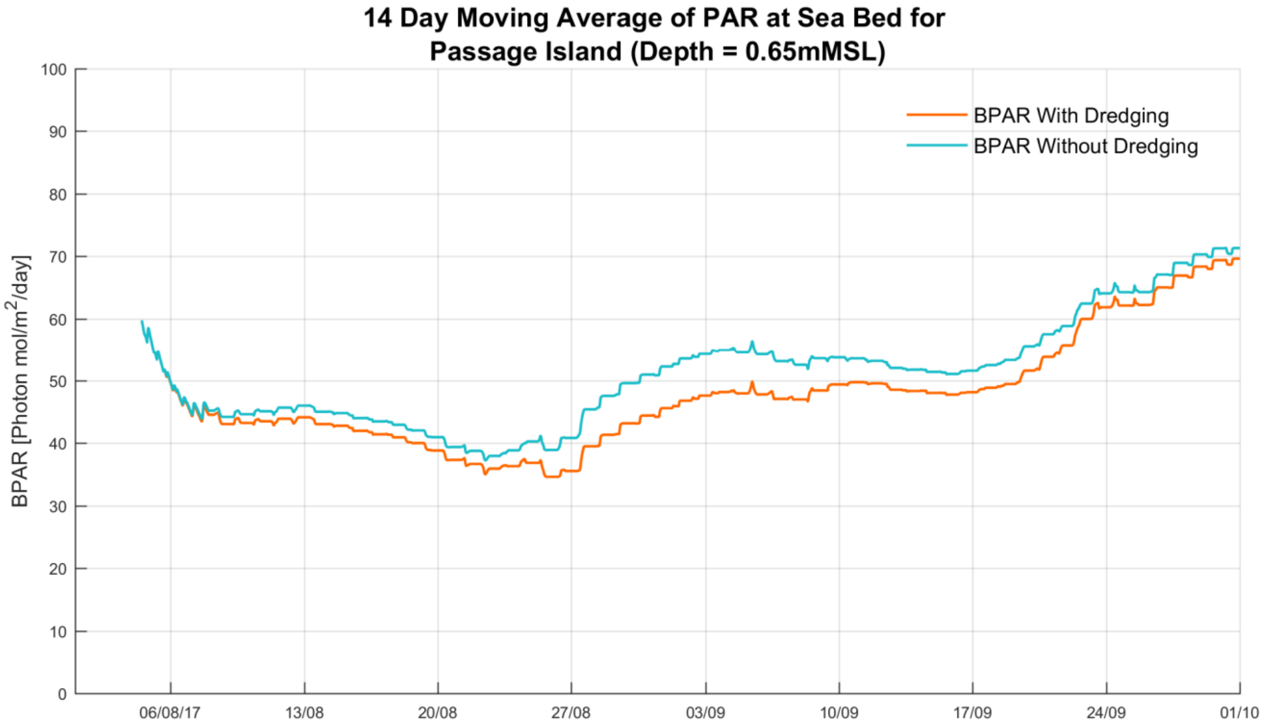

14 Day Moving Average of PAR at Sea Bed for
GBRMP Boundary (Depth = 13.72mMSL)
BPAR [Photon mol/m2/day]
100
90
80
70
60
50
40
30
20
10
0
06/08/17
13/08
20/08
27/08
03/09
10/09
17/09
24/09
01/10
BPAR With Dredging
BPAR Without Dredging

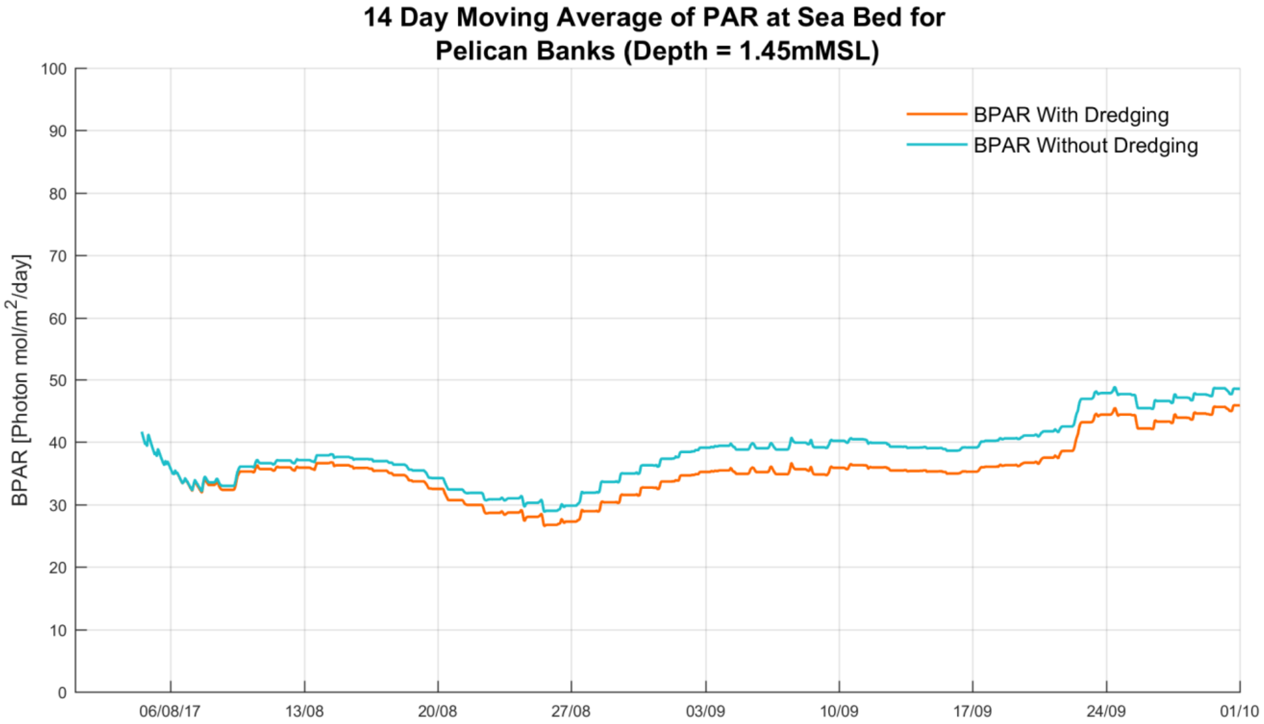
Time Series of Benthic PAR



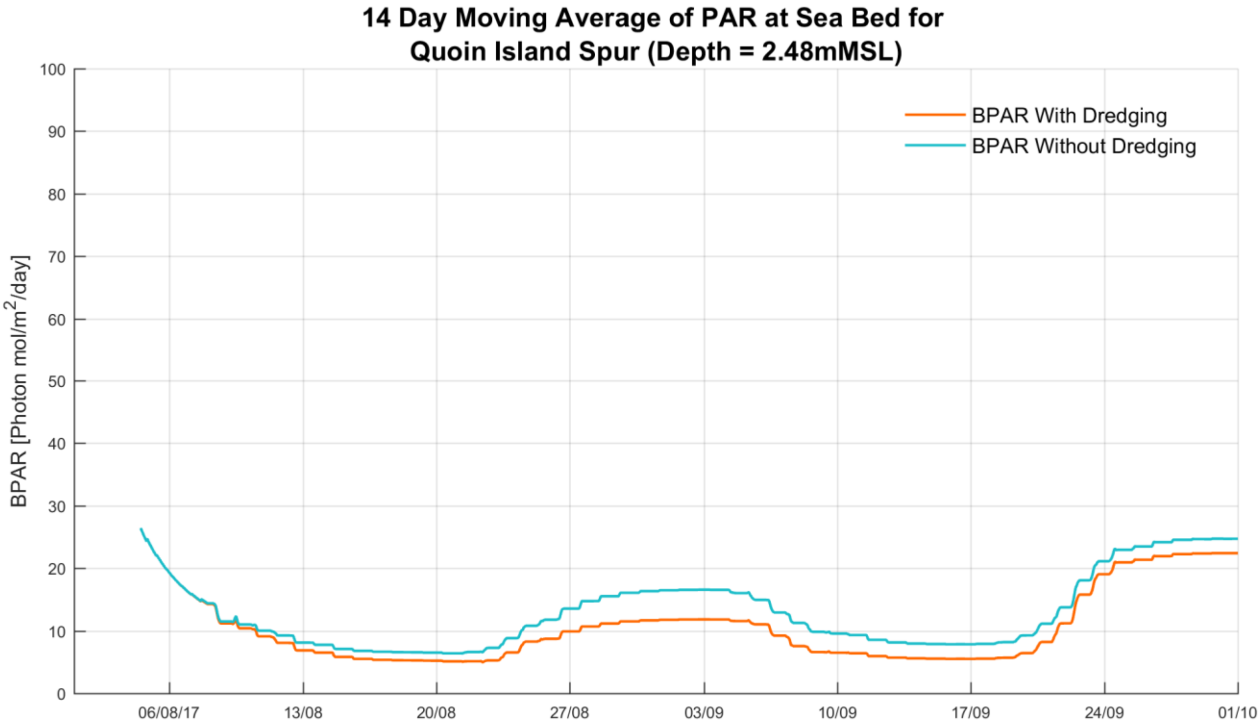


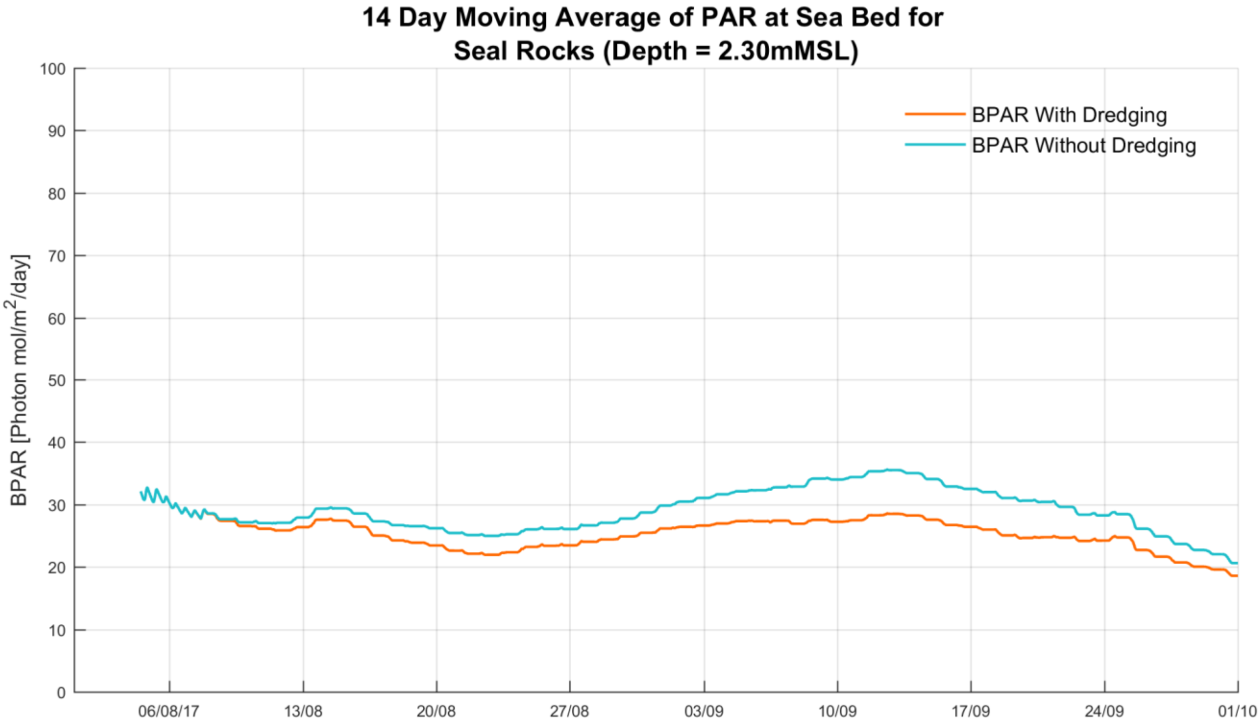
Time Series of Benthic PAR



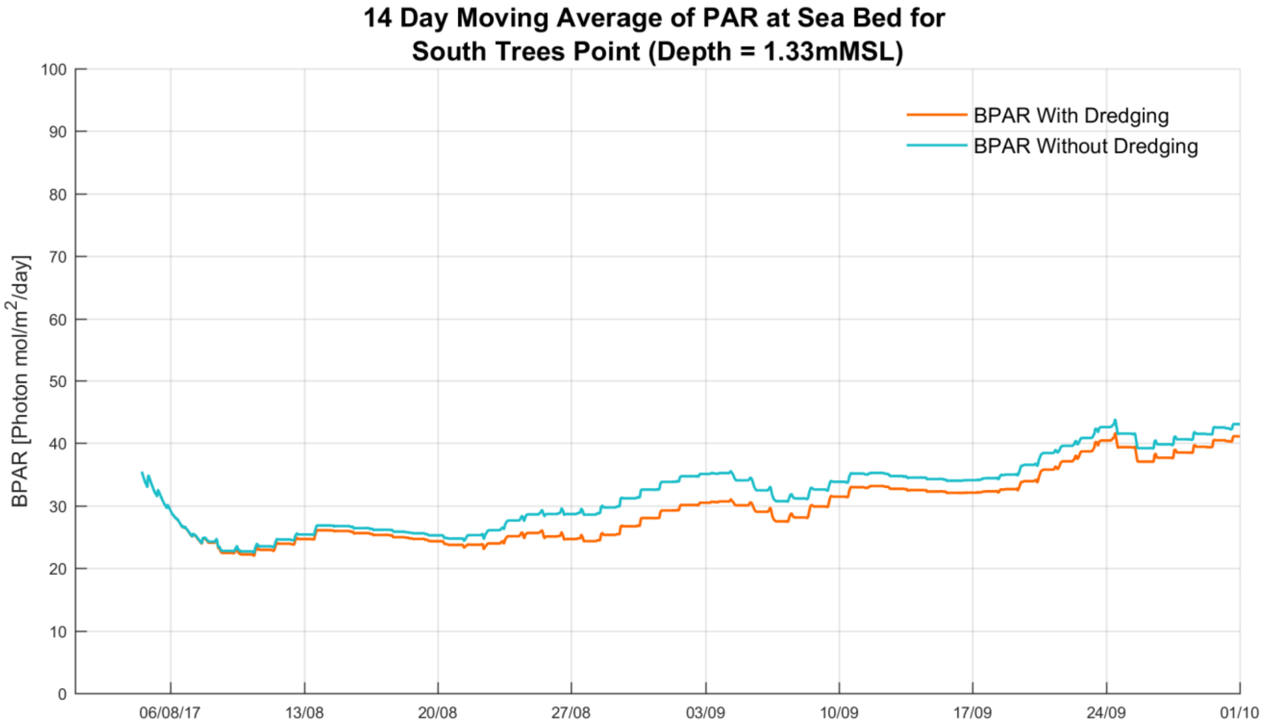


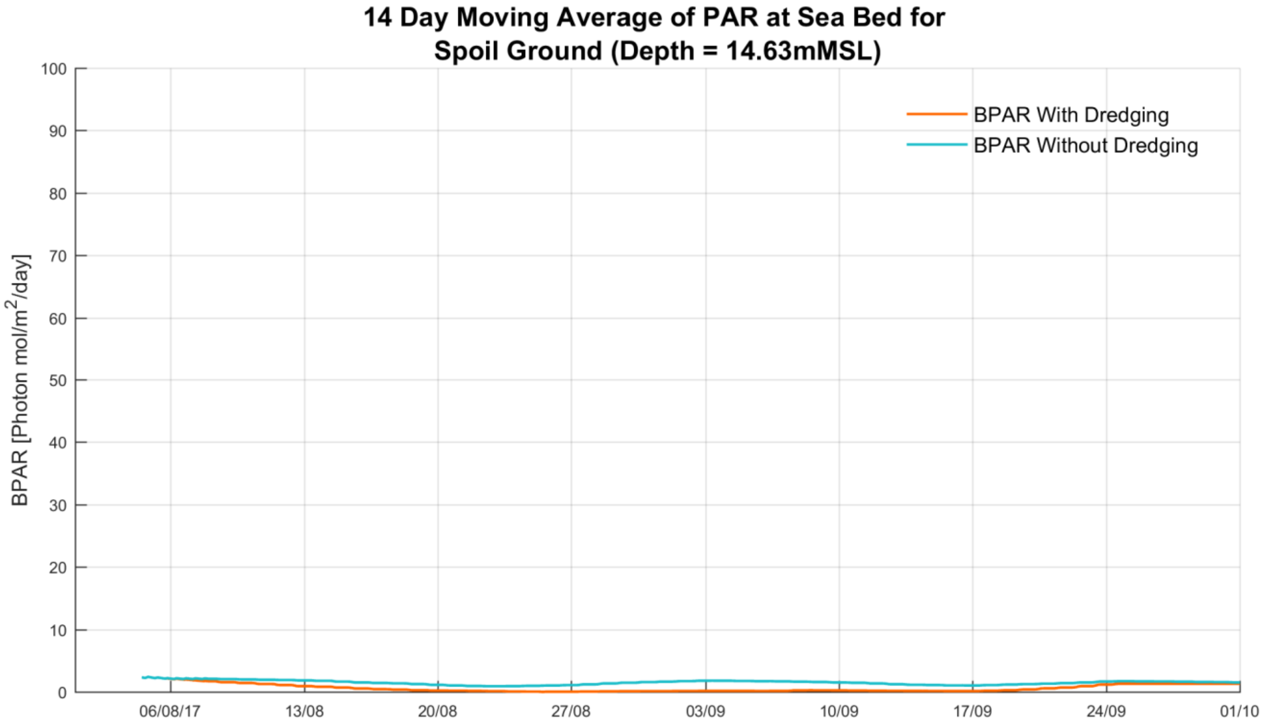
Time Series of Benthic PAR



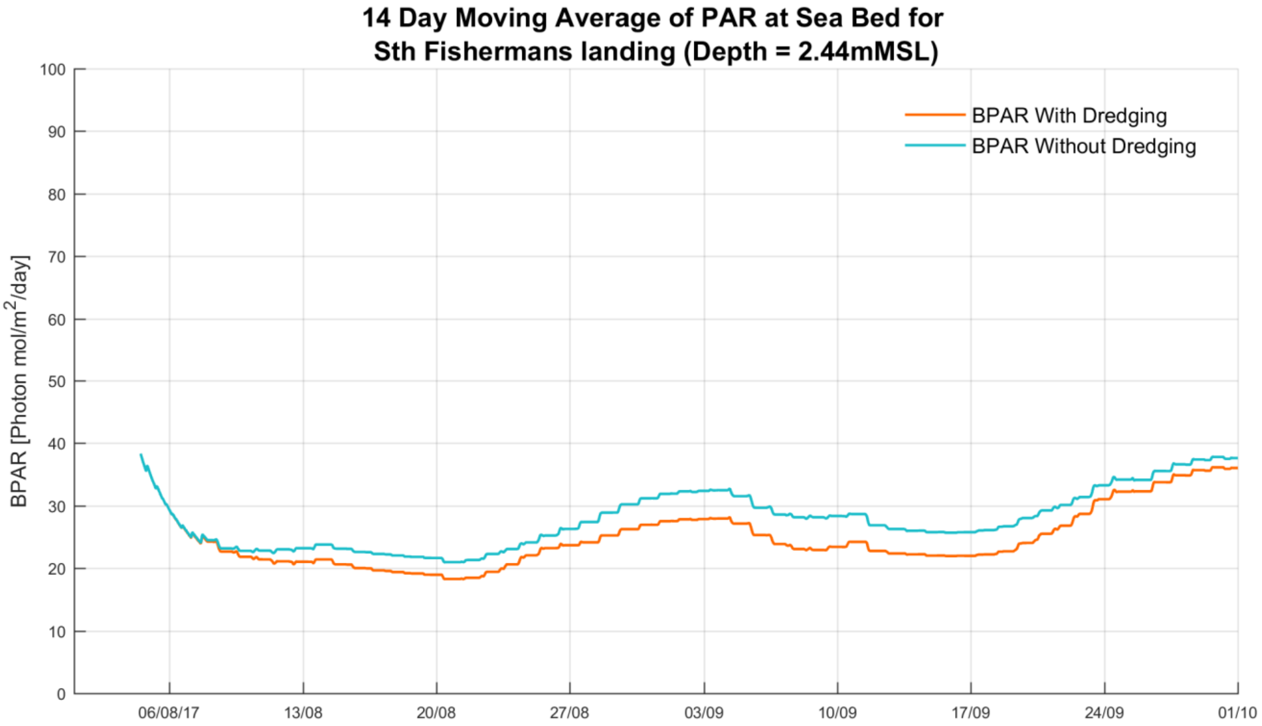


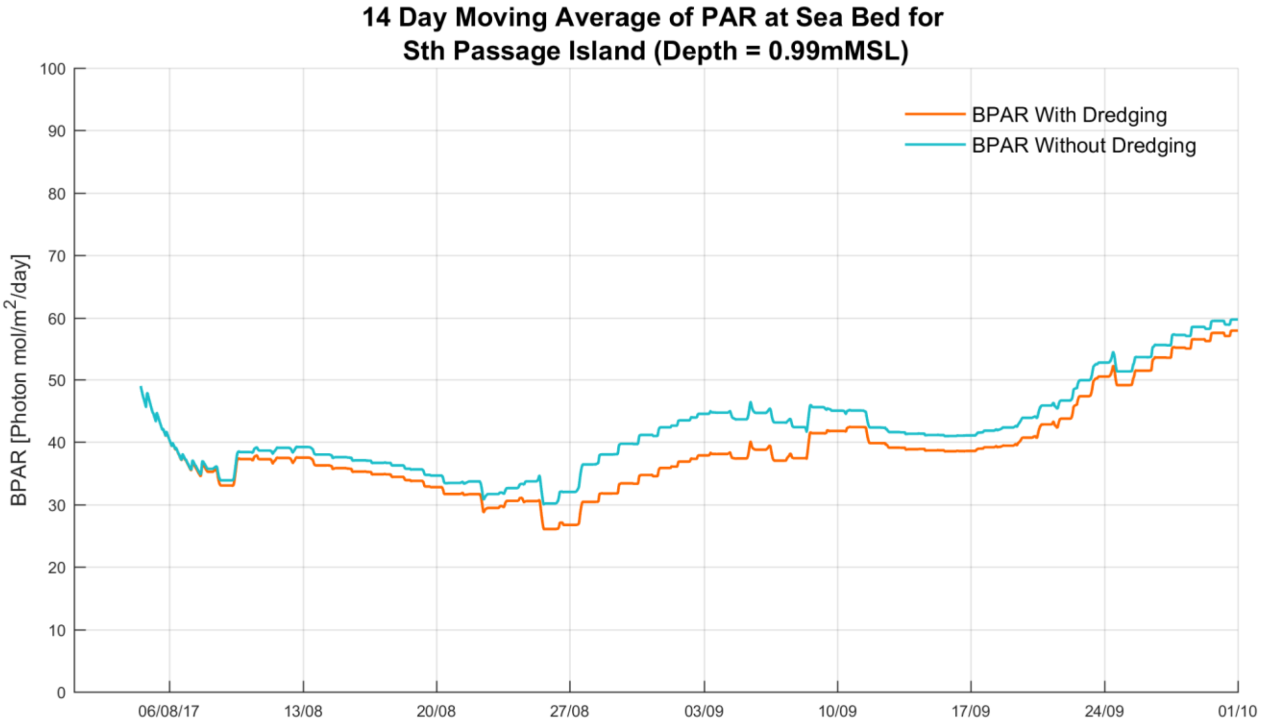
Time Series of Benthic PAR



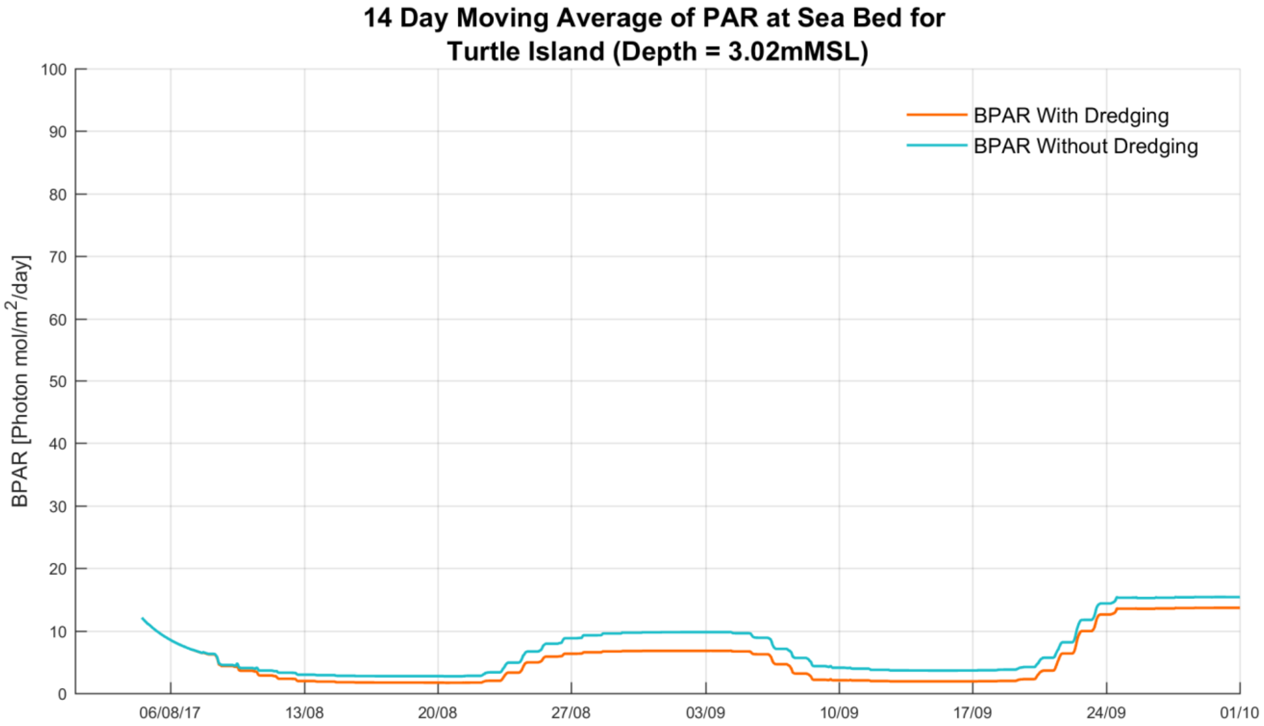


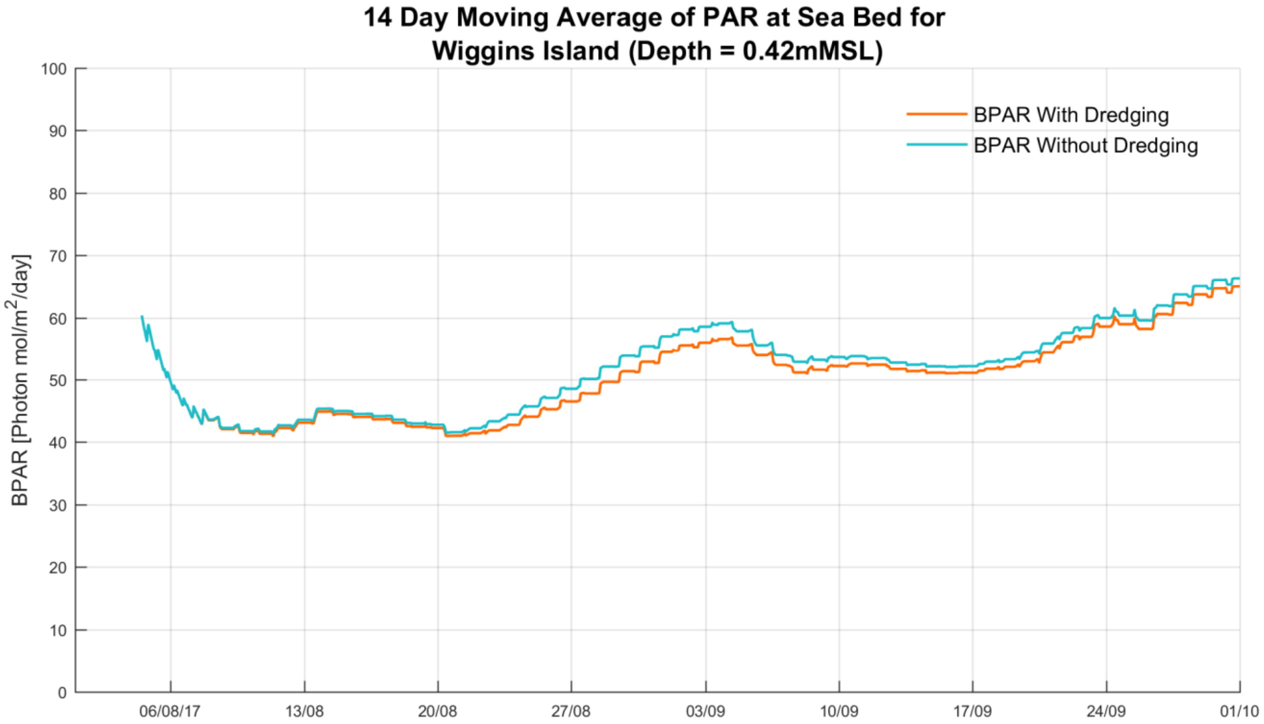
Time Series of Benthic PAR



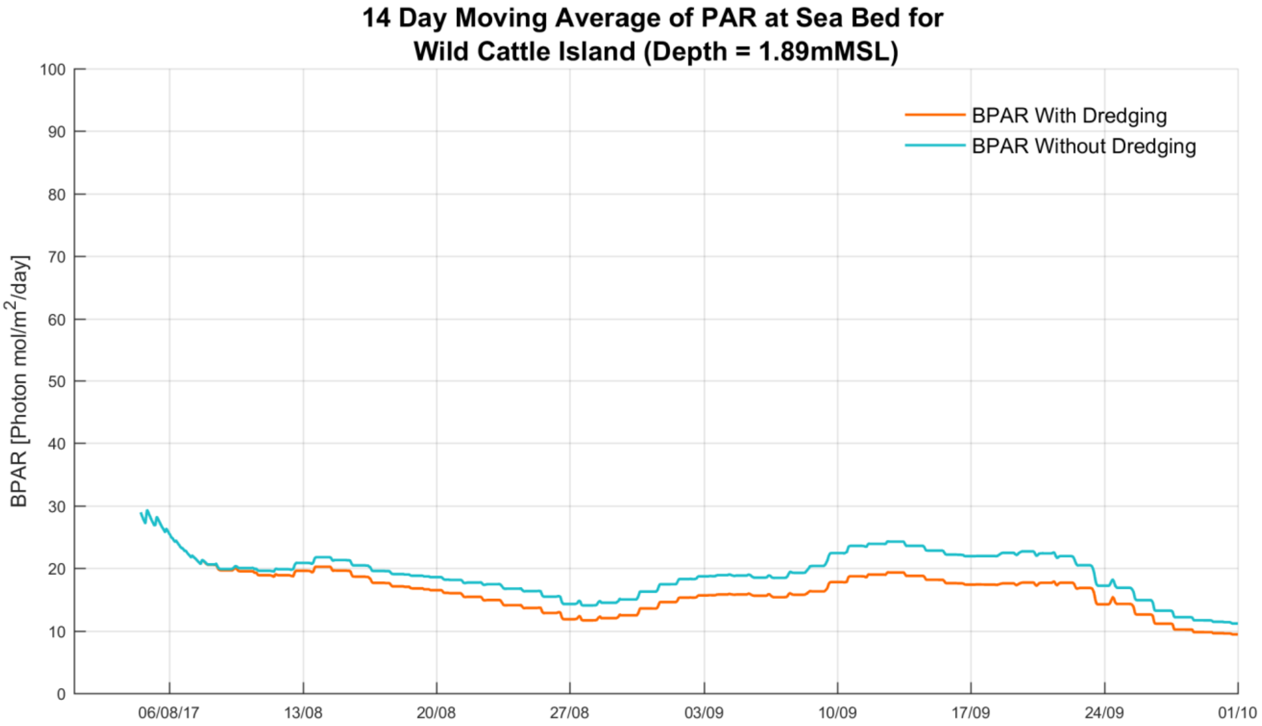


Time Series of Benthic PAR



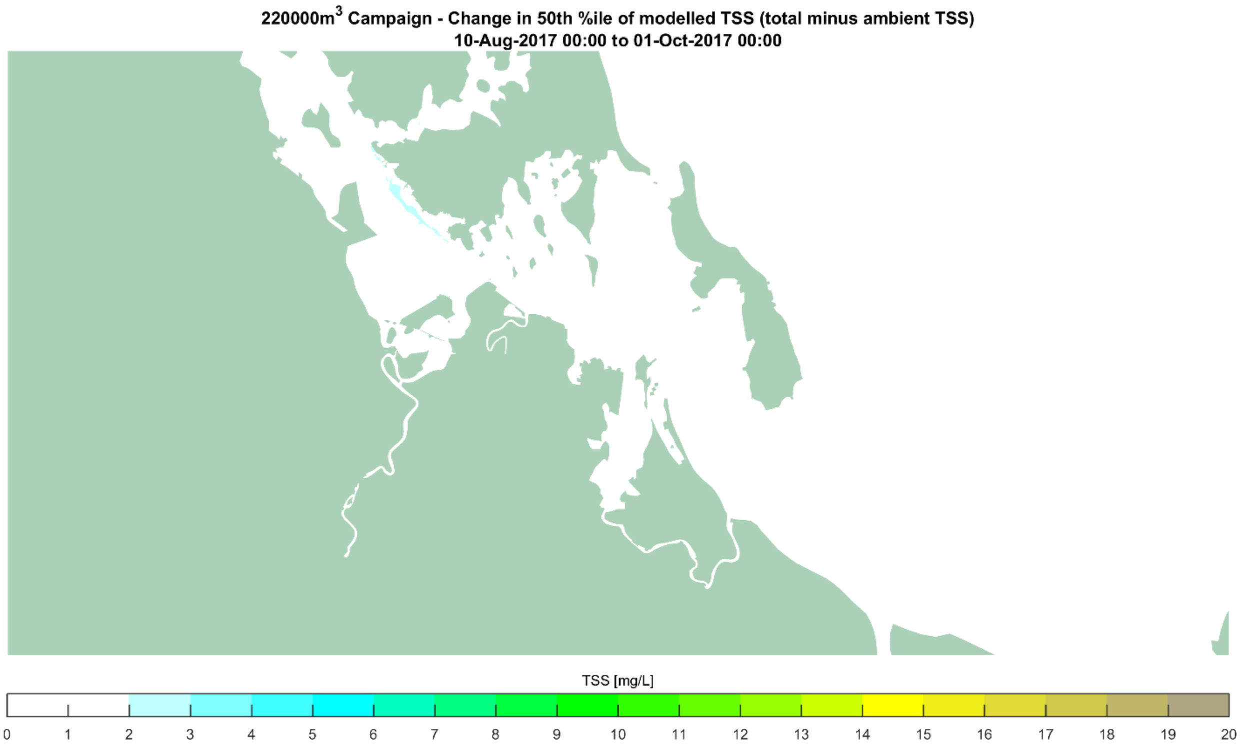


Time Series of Benthic PAR

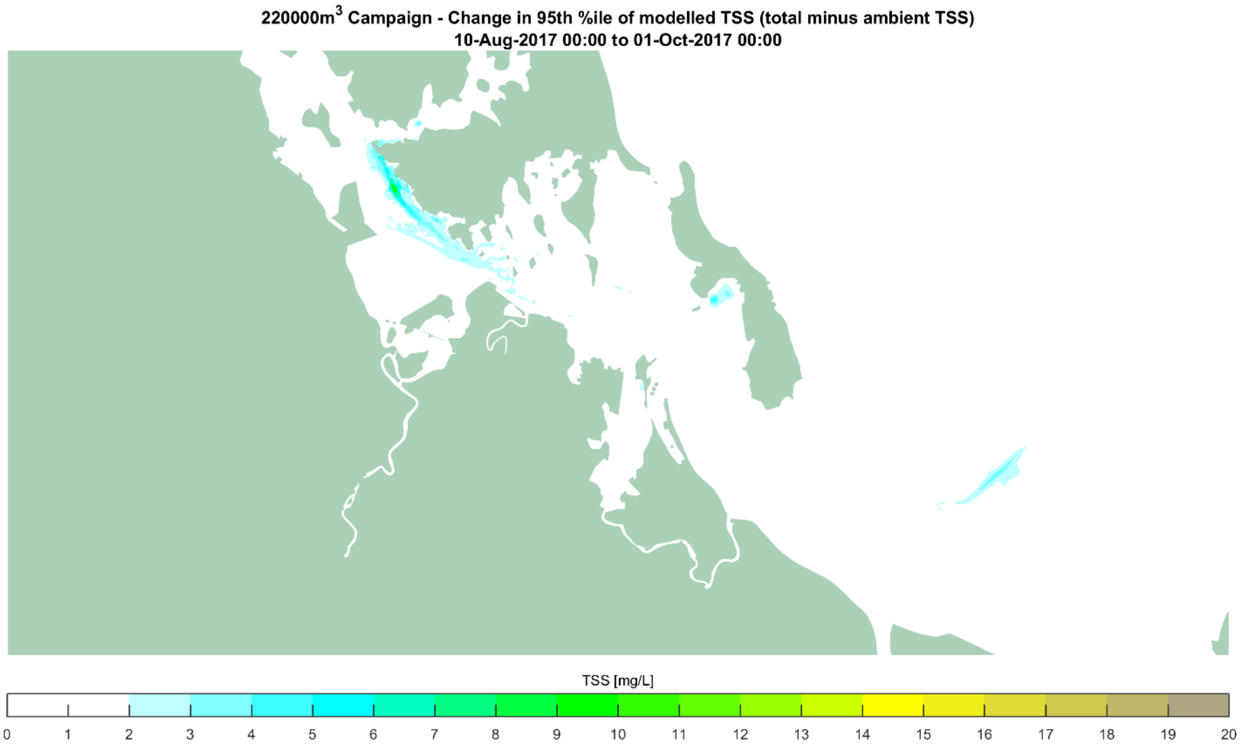


Appendix E Change in TSS Percentiles and Deposition Rate Percentiles due to Dredging for All Scenarios

Change in TSS Percentiles and Deposition Rate Percentiles due to Dredging for All Scenarios

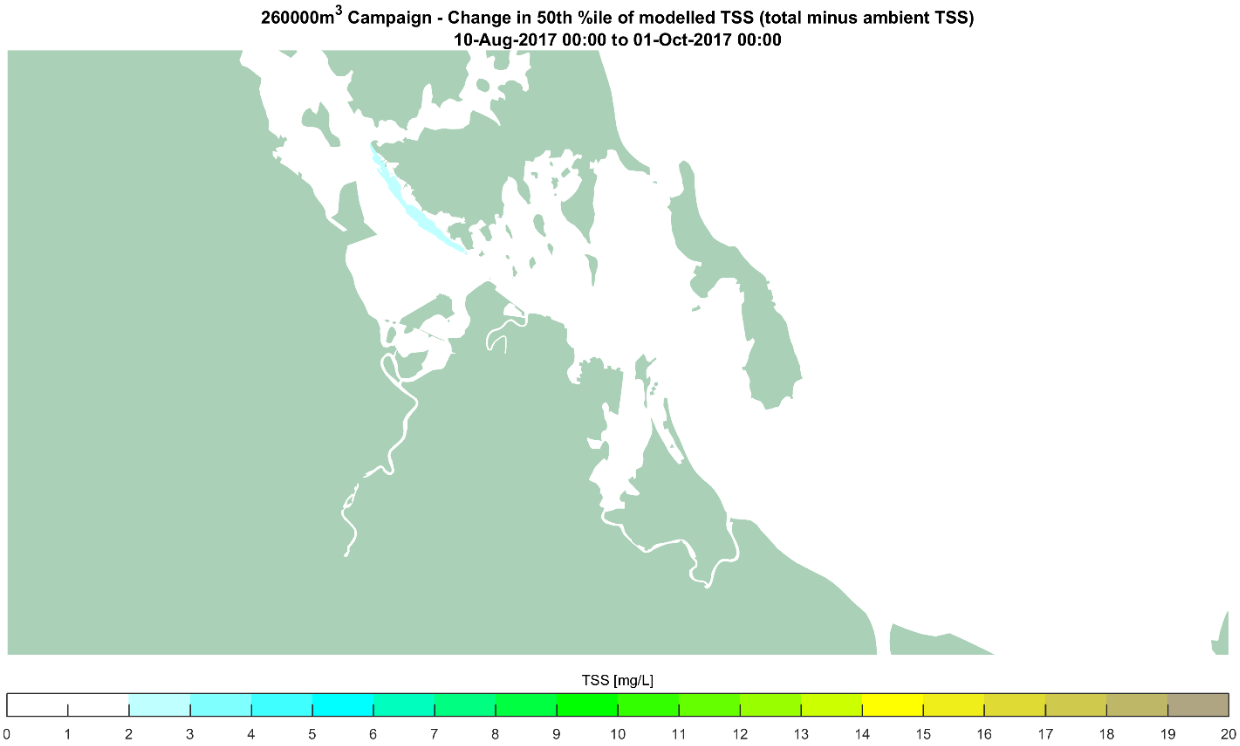


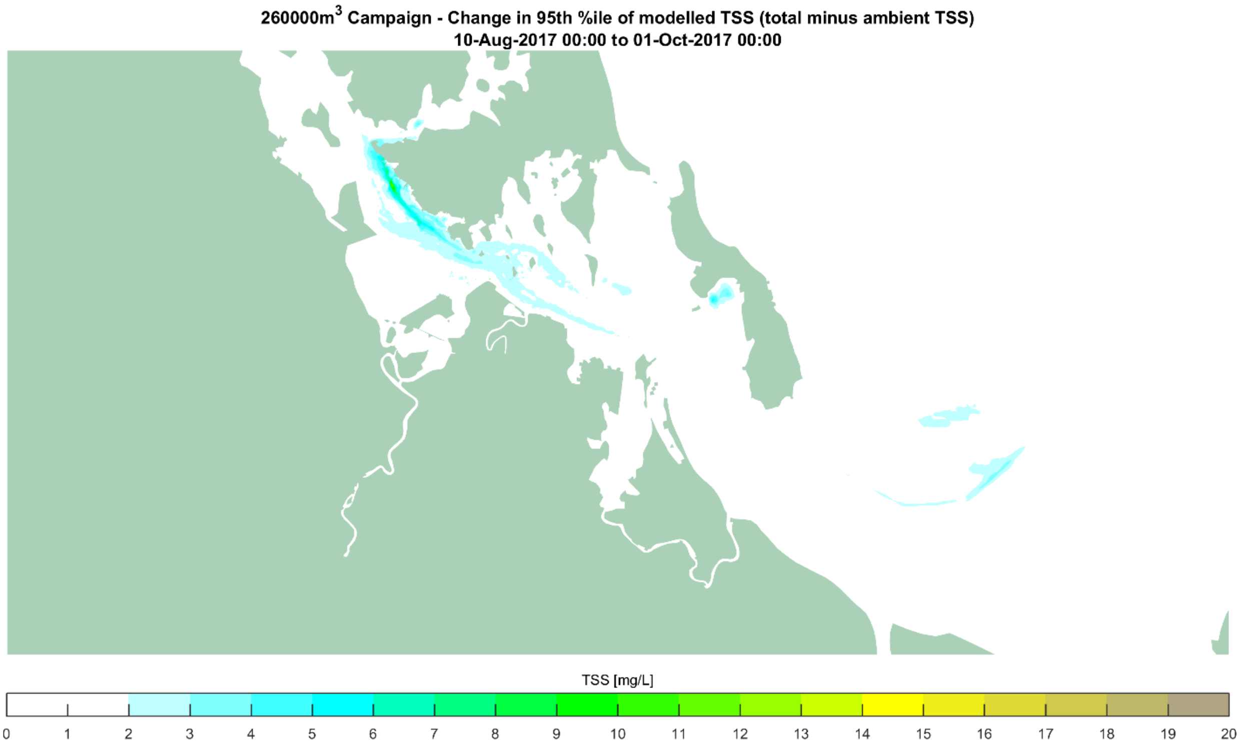
220000m^3 Campaign - Change in 50th %ile of modelled TSS (total minus ambient TSS)
10-Aug-2017 00:00 to 01-Oct-2017 00:00



220000m^3 Campaign - Change in 95th %ile of modelled TSS (total minus ambient TSS)
10-Aug-2017 00:00 to 01-Oct-2017 00:00

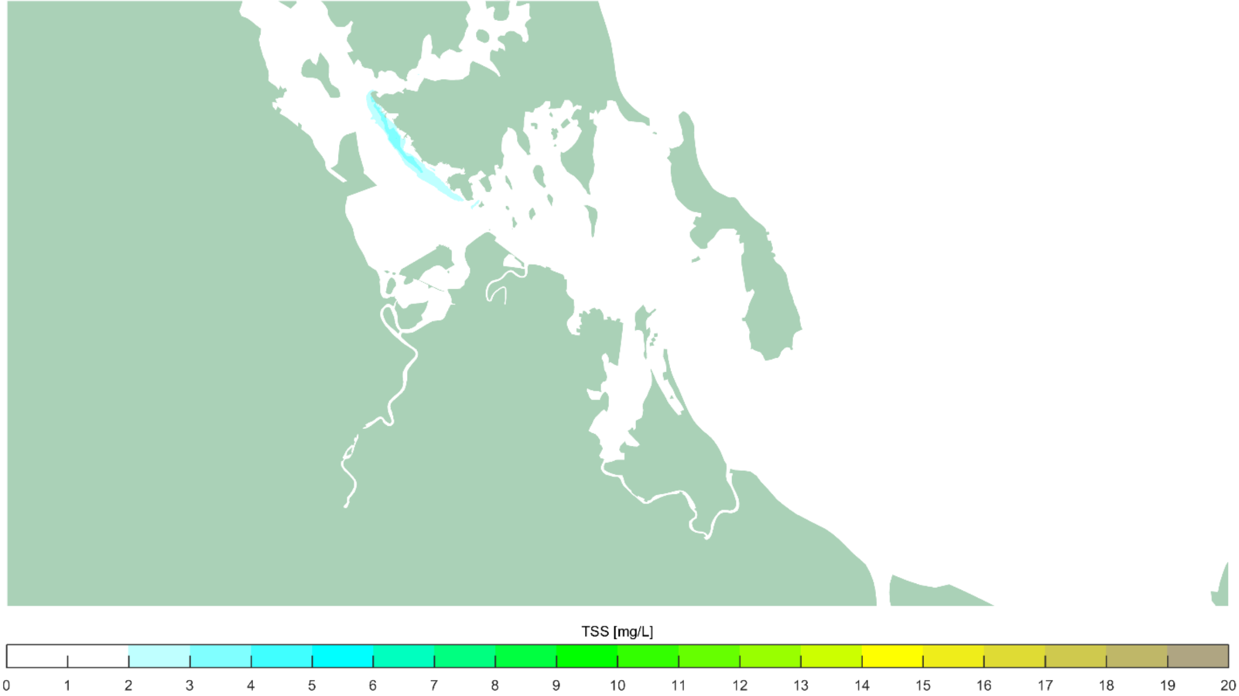
Change in TSS Percentiles and Deposition Rate Percentiles due to Dredging for All Scenarios



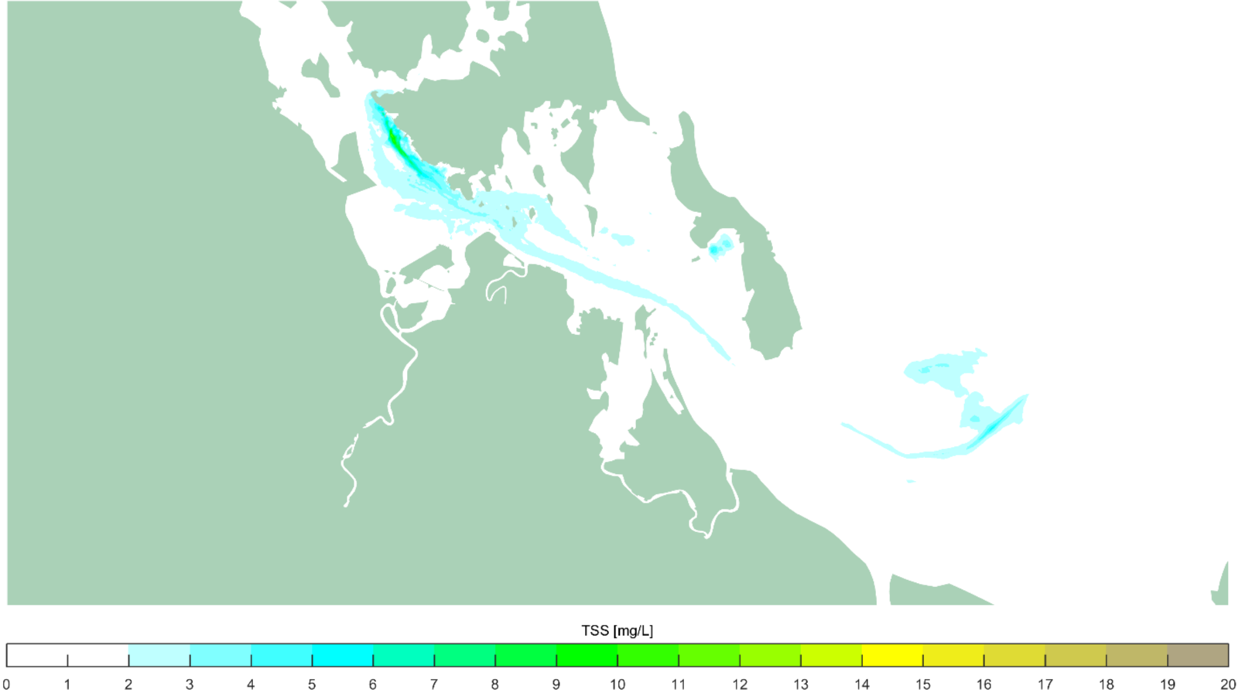


Change in TSS Percentiles and Deposition Rate Percentiles due to Dredging for All Scenarios

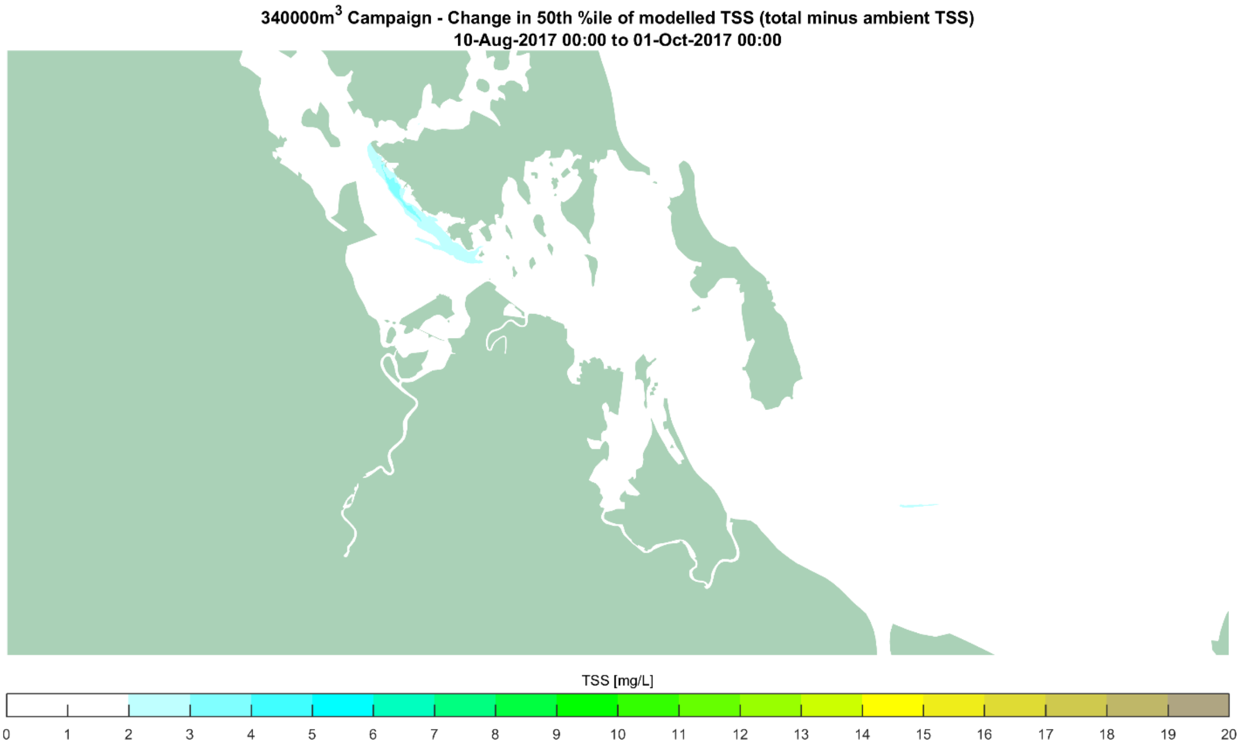
300000m^3 Campaign - Change in 50th %ile of modelled TSS (total minus ambient TSS)
10-Aug-2017 00:00 to 01-Oct-2017 00:00

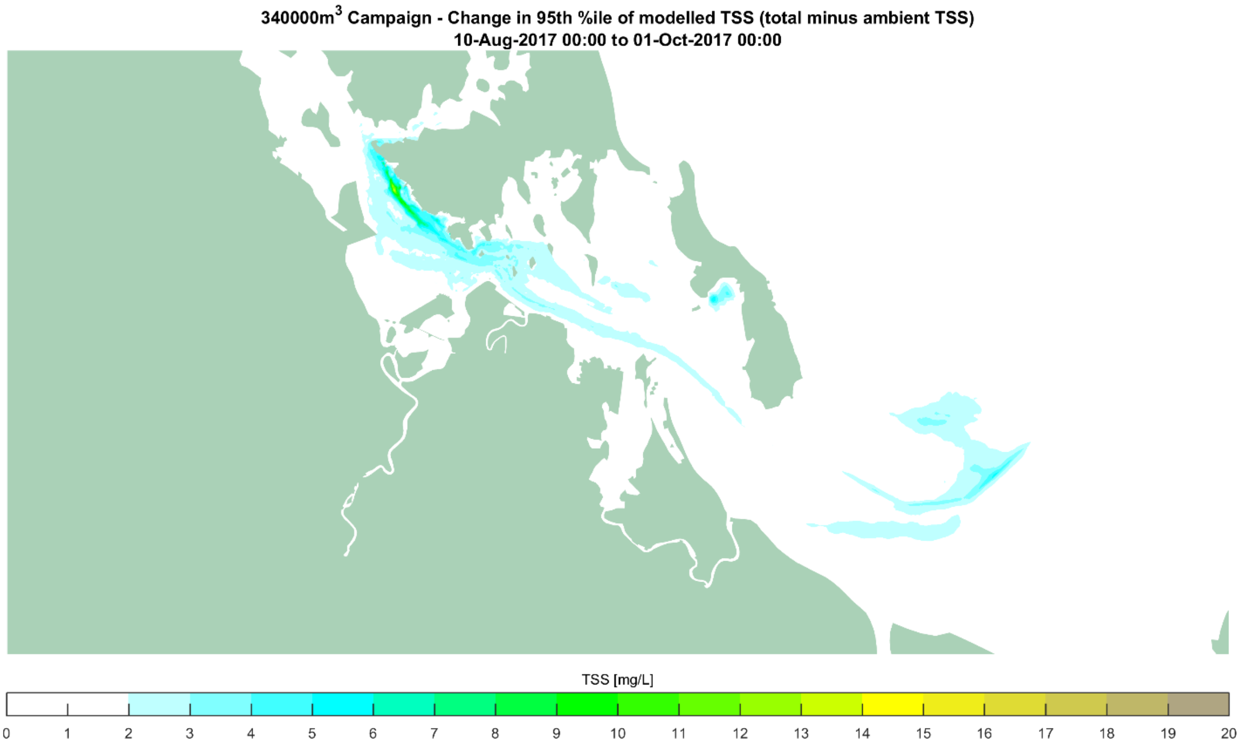


300000m^3 Campaign - Change in 95th %ile of modelled TSS (total minus ambient TSS)
10-Aug-2017 00:00 to 01-Oct-2017 00:00

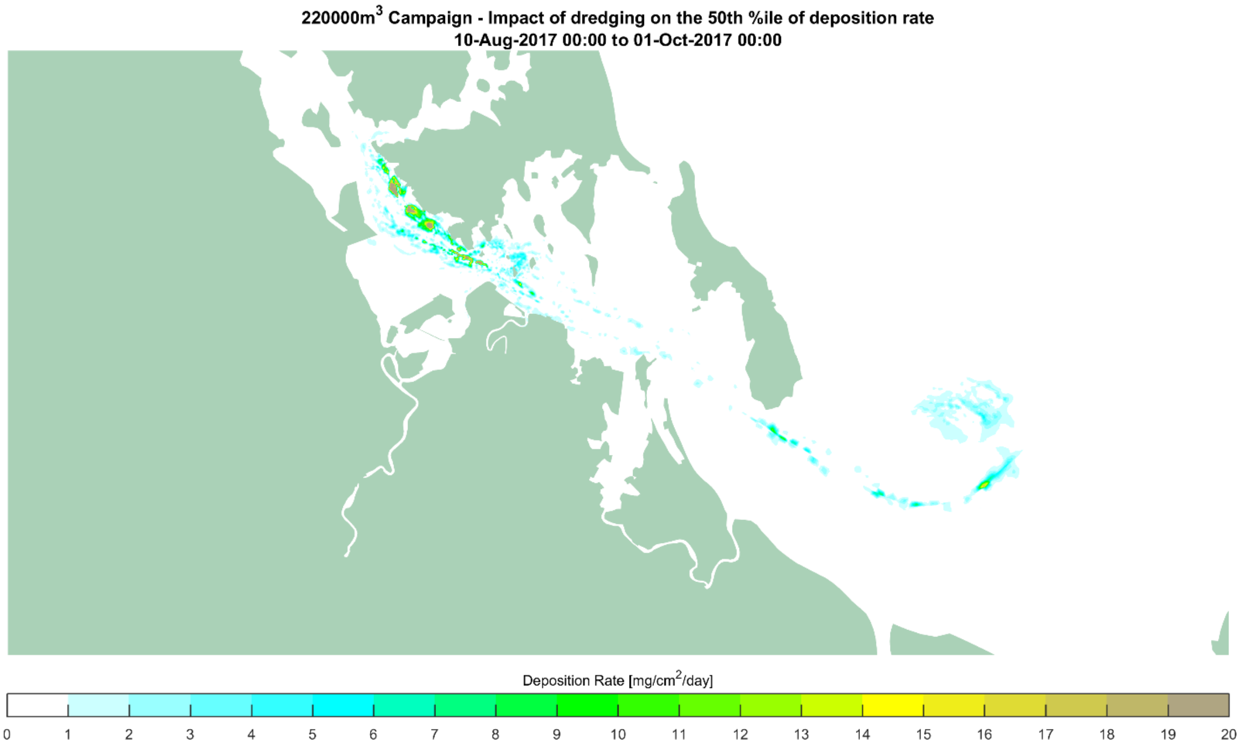


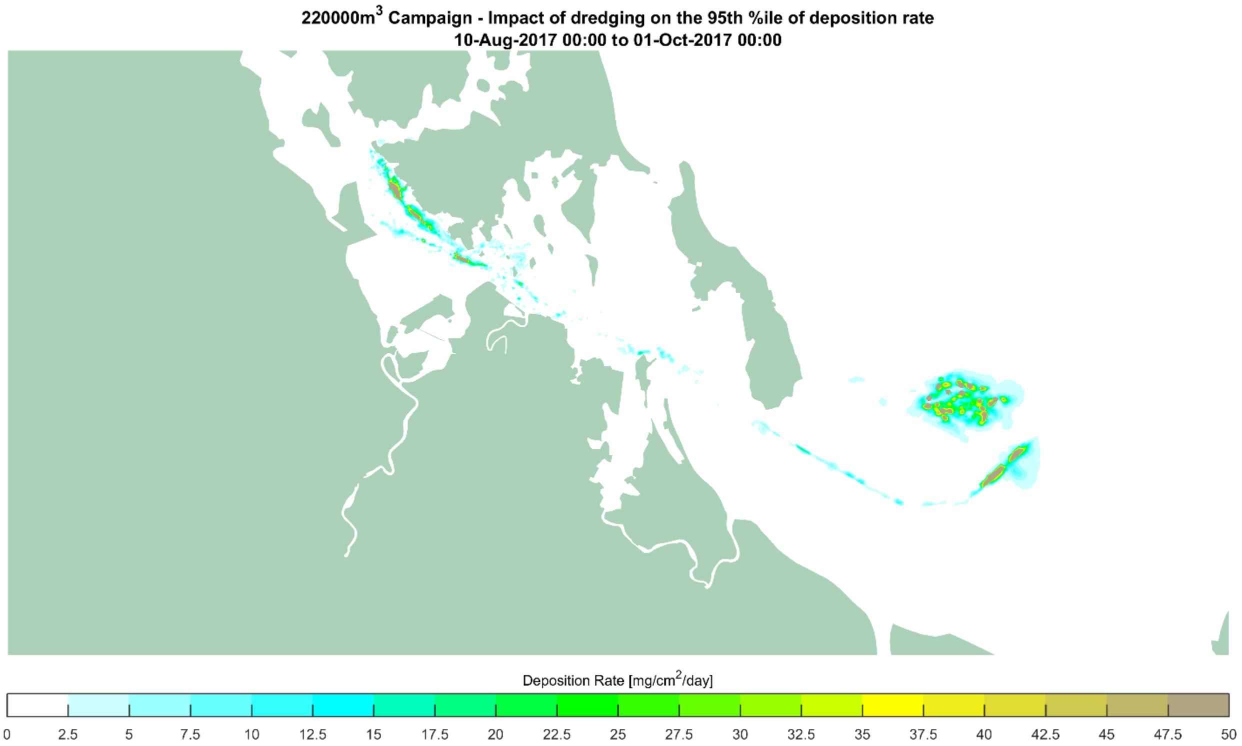
Change in TSS Percentiles and Deposition Rate Percentiles due to Dredging for All Scenarios



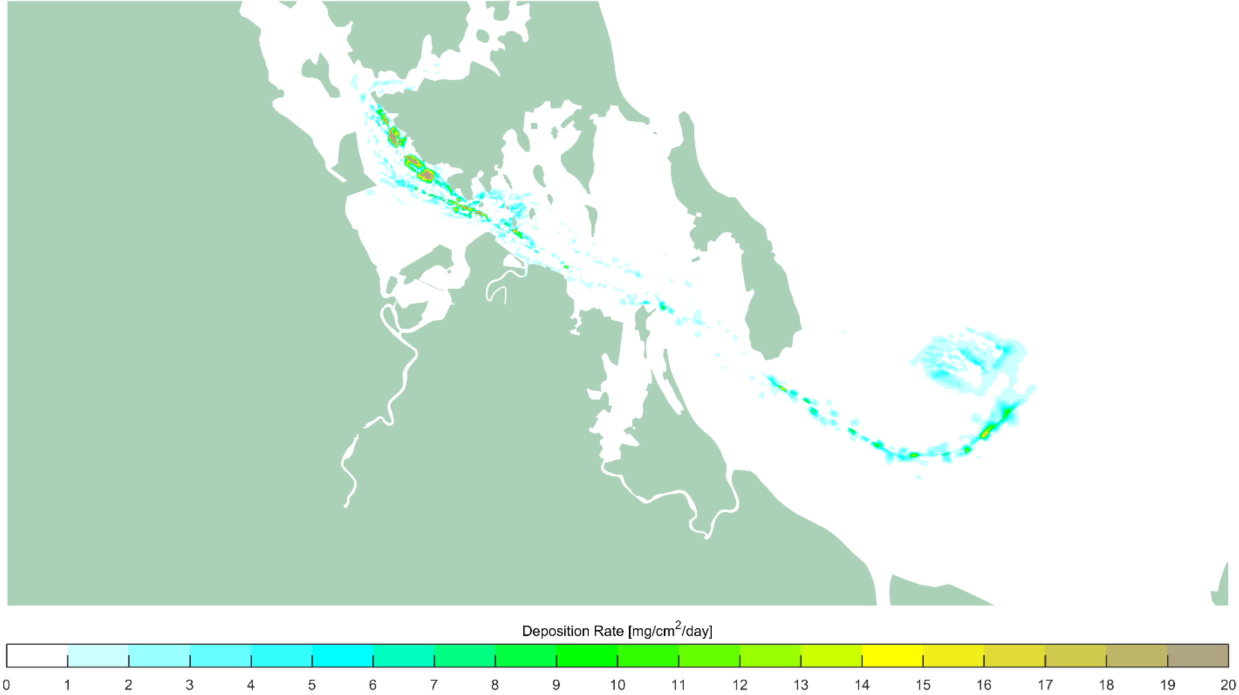


Change in TSS Percentiles and Deposition Rate Percentiles due to Dredging for All Scenarios

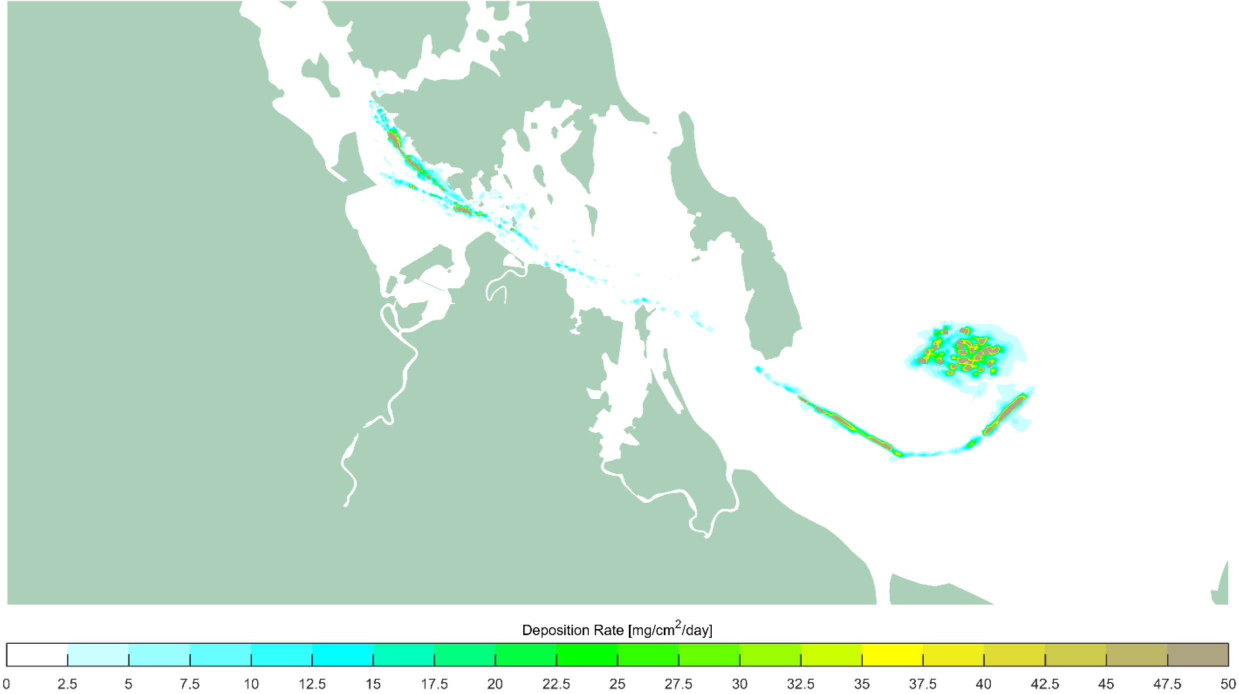




Change in TSS Percentiles and Deposition Rate Percentiles due to Dredging for All Scenarios

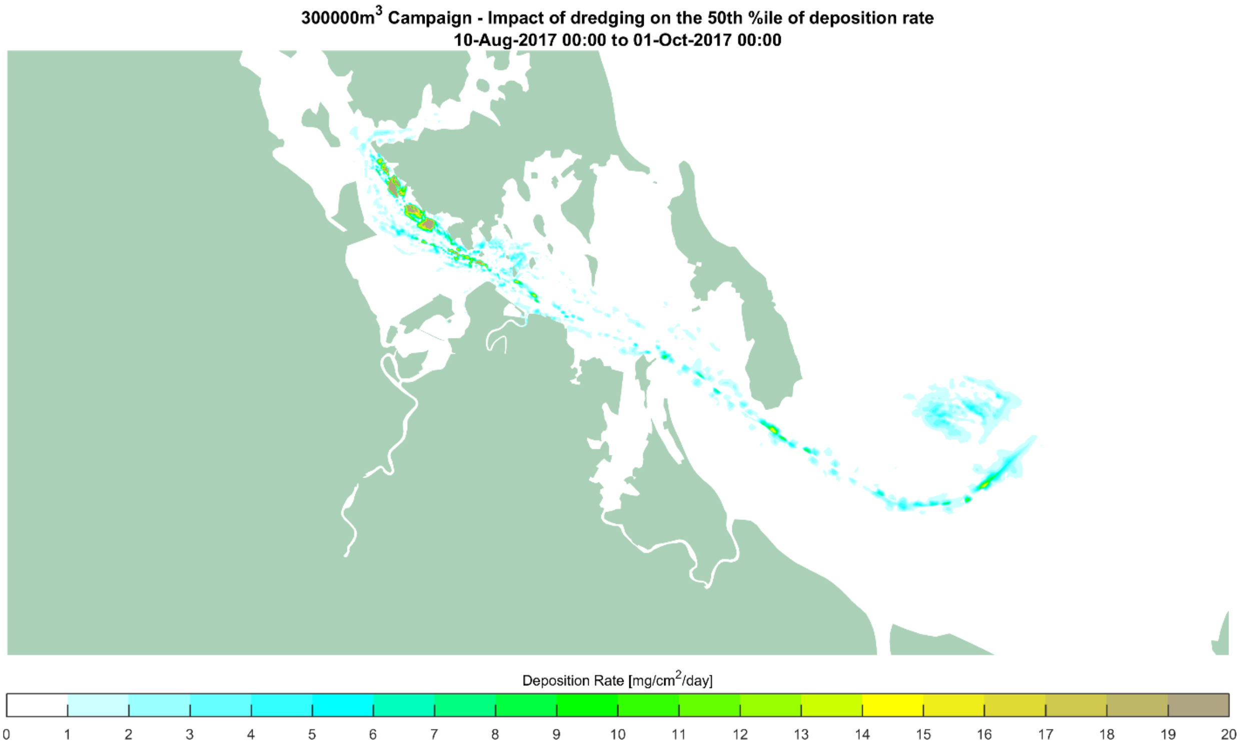


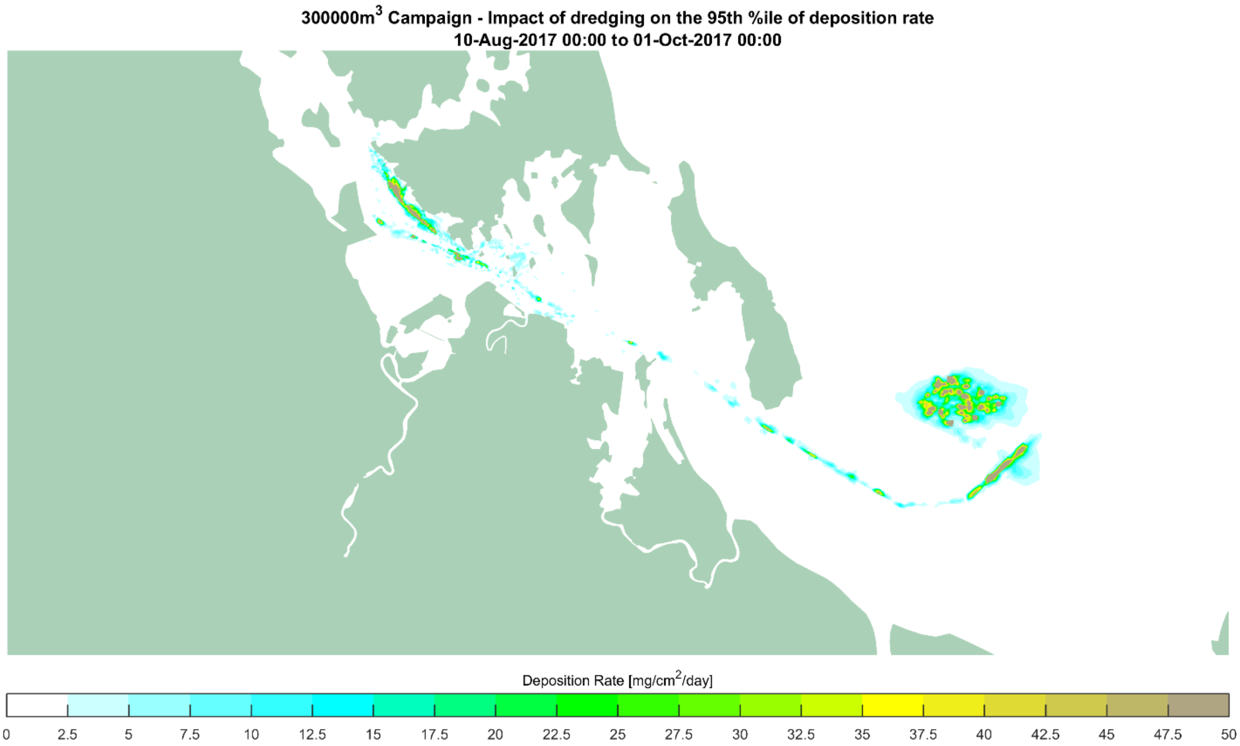
260000m^3 Campaign - Impact of dredging on the 50th %ile of deposition rate
10-Aug-2017 00:00 to 01-Oct-2017 00:00



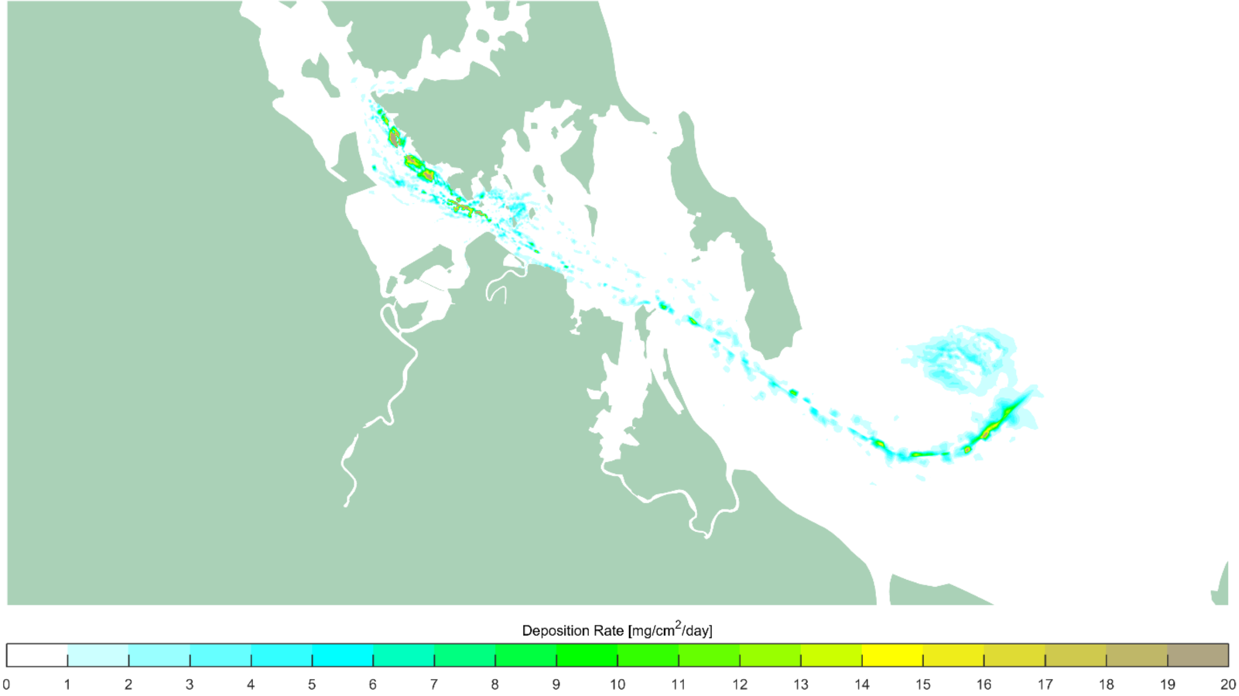
260000m^3 Campaign - Impact of dredging on the 95th %ile of deposition rate
10-Aug-2017 00:00 to 01-Oct-2017 00:00

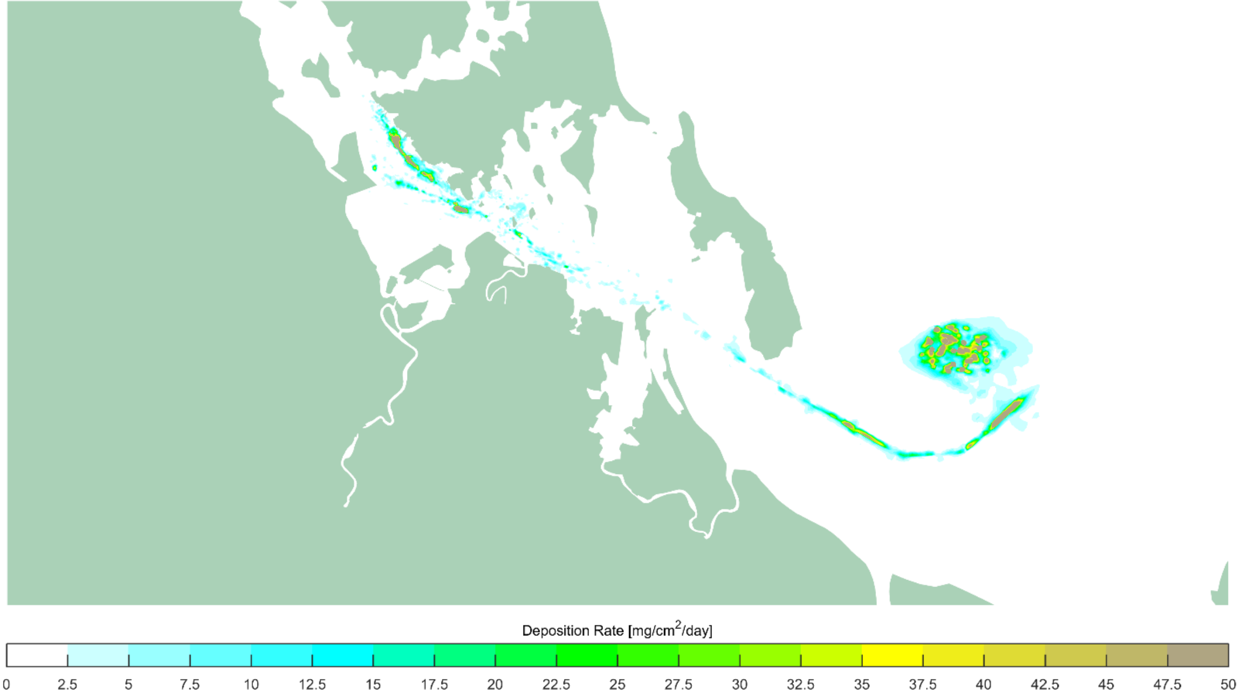
Change in TSS Percentiles and Deposition Rate Percentiles due to Dredging for All Scenarios





Change in TSS Percentiles and Deposition Rate Percentiles due to Dredging for All Scenarios


340000m^3 Campaign - Impact of dredging on the 50th %ile of deposition rate
10-Aug-2017 00:00 to 01-Oct-2017 00:00


340000m^3 Campaign - Impact of dredging on the 95th %ile of deposition rate
10-Aug-2017 00:00 to 01-Oct-2017 00:00

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