Gladstone Sediment Budget: Model Refinement and Validation

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Synopsis: Refinement and validation of the TUFLOW FV and SWAN models for the Port of Gladstone to assist with development of a quantitative sediment budget.

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1 Introduction

1.1 Background

Gladstone Port Corporation (GPC) is undertaking a Sustainable Sediment Management Project (SSMP) under the Deed of Agreement enacted with the Commonwealth of Australia to support sustainable management of maintenance dredging sediment within the Port of Gladstone (PoG).

As part of the SSMP, a quantitative sediment budget is being established to improve understanding of the natural resuspension and sediment transport patterns in the PoG region and to put into context the release of sediment during maintenance dredging and material placement at the East Banks Sediment Disposal Site (EBSDS). Data collected during the 2017 and 2018 maintenance dredging campaigns is being used to inform the development of the sediment budget as described in the Sediment Movement Data Interpretation Report produced by Port and Coastal Solutions (PCS 2019).

GPC commissioned BMT to refine and validate the TUFLOW FV numerical hydrodynamic and sediment transport model to simulate the sediment dynamics within the PoG and the surrounding Great Barrier Reef World Heritage Area (GBRWHA) to augment the existing data set, which will ultimately be used to inform the PoG quantitative sediment budget.

1.2 Study Objectives and Scope

The objective of this study is to further refine and validate the TUFLOW FV numerical hydrodynamic and sediment transport model to demonstrate its suitability for use in developing a quantitative sediment budget for the PoG. As part of the study, the calibration of the existing PoG model (BMT, 2019b) was adjusted using data from the 2018-19 monitoring campaigns then several additional periods were simulated to provide model output for a range of different conditions. Model output was analysed to extract relevant data to be used as inputs to the quantitative sediment budget. The scope of this study is as follows:

- Calibration of existing TUFLOW FV model using data collected during the 2018-19 monitoring campaigns (01/09/2018 – 01/03/2019);
- Simulation of additional periods, 01/10/2012 – 01/06/2013 and 01/06/2014 – 01/07/2015, with subsequent validation of model performance;
- Assessment of metocean conditions at the EBSDS conducive to resuspension and transport of dredged sediment and extraction of net sediment mass fluxes for areas of interest, and across selected transects within the PoG.

2 Hydrodynamic Model Description

2.1 Numerical Modelling Software

The hydrodynamic modelling component of these assessments uses the TUFLOW FV software, which is developed and distributed by BMT (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 estuaries to 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, 2015a).

The TUFLOW FV model is configured as a 3D model with baroclinic coupling from both salinity and temperature variations. Atmospheric heat fluxes and water column heat dynamics are 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 is used for the hydrodynamic model. The vertical grid has 11 layers representing the top 10 m of the water column, 13 layers between depths of 10 m and 50 m, and five layers between depths of 50 m and 500 m.

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

2.2 Model Domain and Mesh

The domain of the TUFLOW FV hydrodynamic model used in this study is the same as that used in recent environmental impact assessment projects in the PoG (BMT, 2019b). The model domain encompasses 32,000 km^2, from Sandy Cape in the south to Cape Manifold in the north, which is large enough to accurately represent the full extent of any dredging-related suspended sediment plumes within the Great Barrier Reef Marine Park (GBRMP) and GBRWHA. The TUFLOW FV model mesh is presented in Figure 2-1 and Figure 2-2.

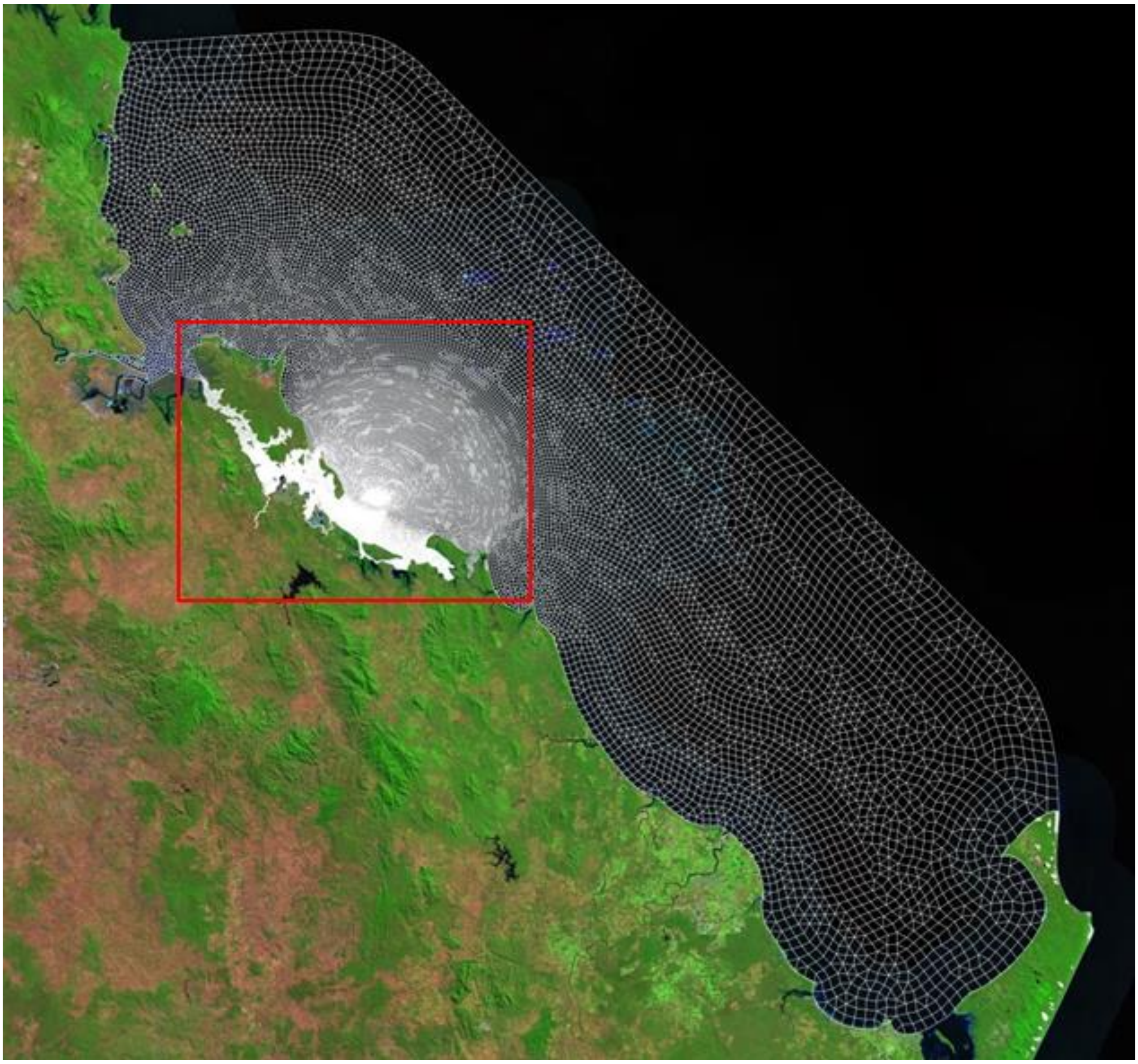


Figure 2-1 TUFLOW FV Model Mesh – Whole Model Domain

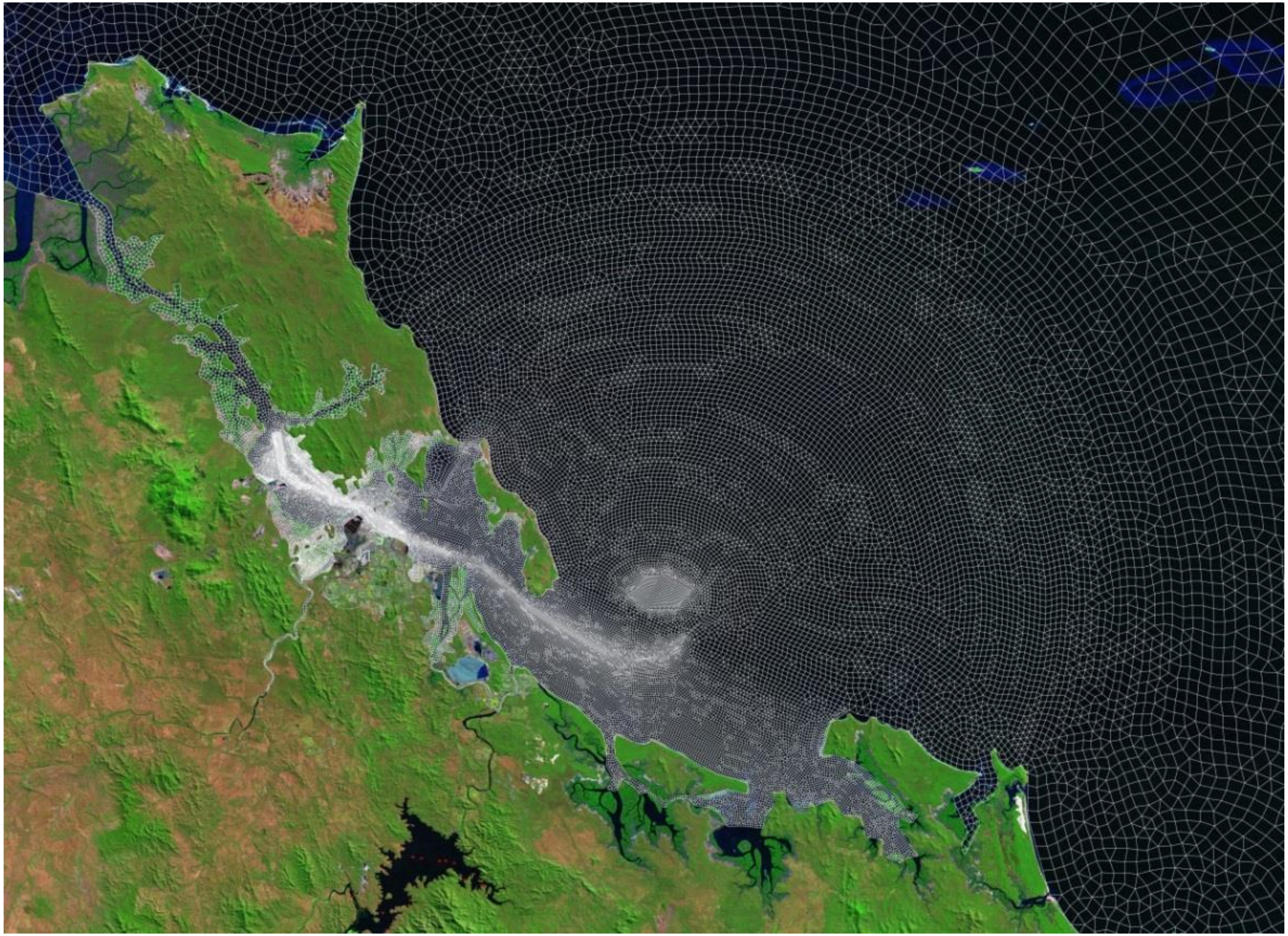


Figure 2-2 TUFLOW FV Model Mesh – Local Scale (Red Boxed Area in Figure 2-1)

2.3 Bathymetric Data

Bathymetric data in the vicinity of the PoG was sourced from existing Digital Elevation Models developed by BMT. The bathymetry is sourced from a large number of datasets acquired over many years.

- Detailed hydrographic survey data of the dredged channels, swing basins and berths as provided by Maritime Safety Queensland (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 (updated to November 2018);
- 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.

Bathymetric data offshore (30m horizontal resolution) was sourced from Project 3DGBR: a high-resolution depth model for the Great Barrier Reef and Coral Sea (Beaman 2018). Where this data interfaced with the local Digital Elevation Model, the two datasets was checked for consistency and smoothed where necessary (see Figure 2-3).

The bathymetry of the model was updated with recent survey data from GPC which included the dredging undertaken for the liquefied natural gas (LNG) projects on Curtis Island and the first stage of the Wiggins Island Coal Terminal (WICT) Project. The model bathymetry is therefore an accurate representation of the actual bathymetry of the Port during the model hindcast periods. The adopted model bathymetry is illustrated in Figure 2-4 and Figure 2-5.

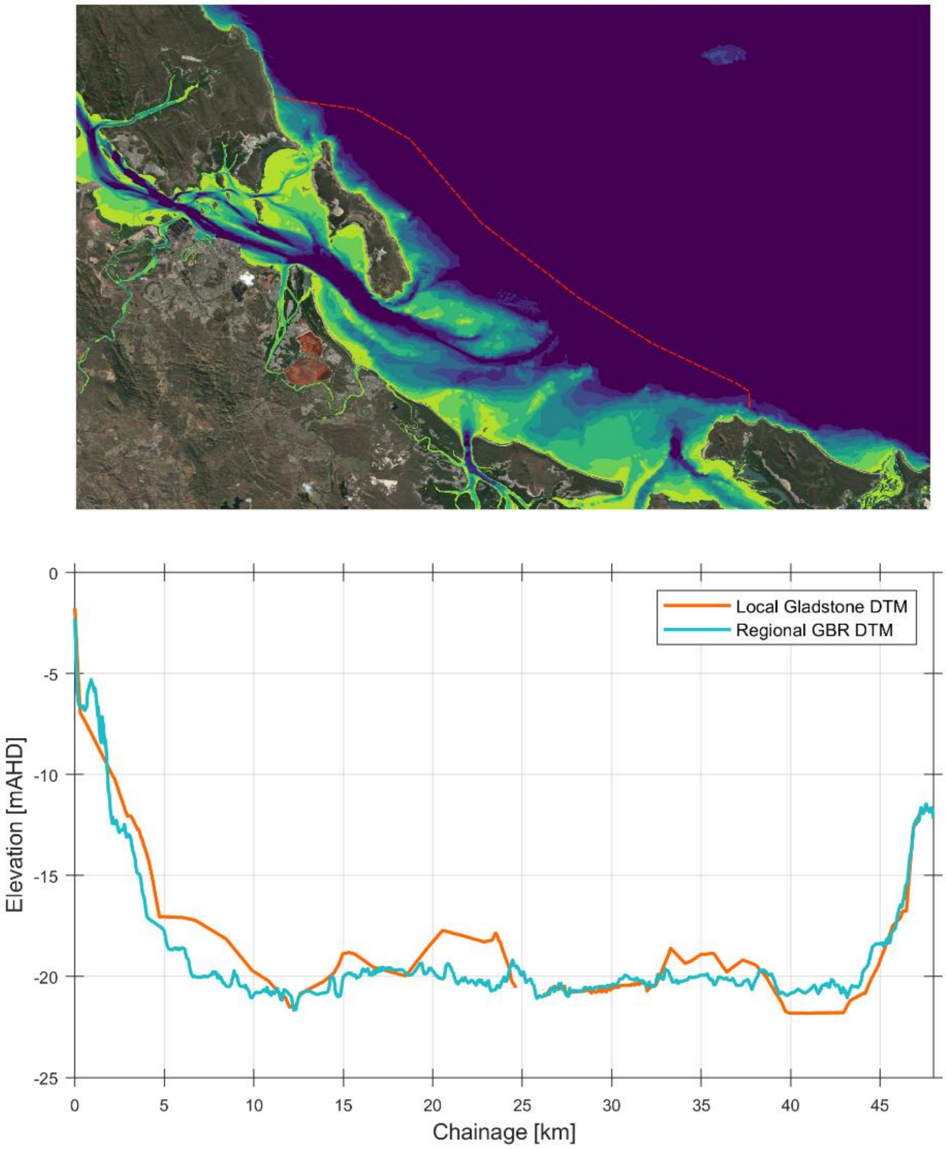


Figure 2-3 Comparison at Interface of Regional and Local Bathymetric Datasets

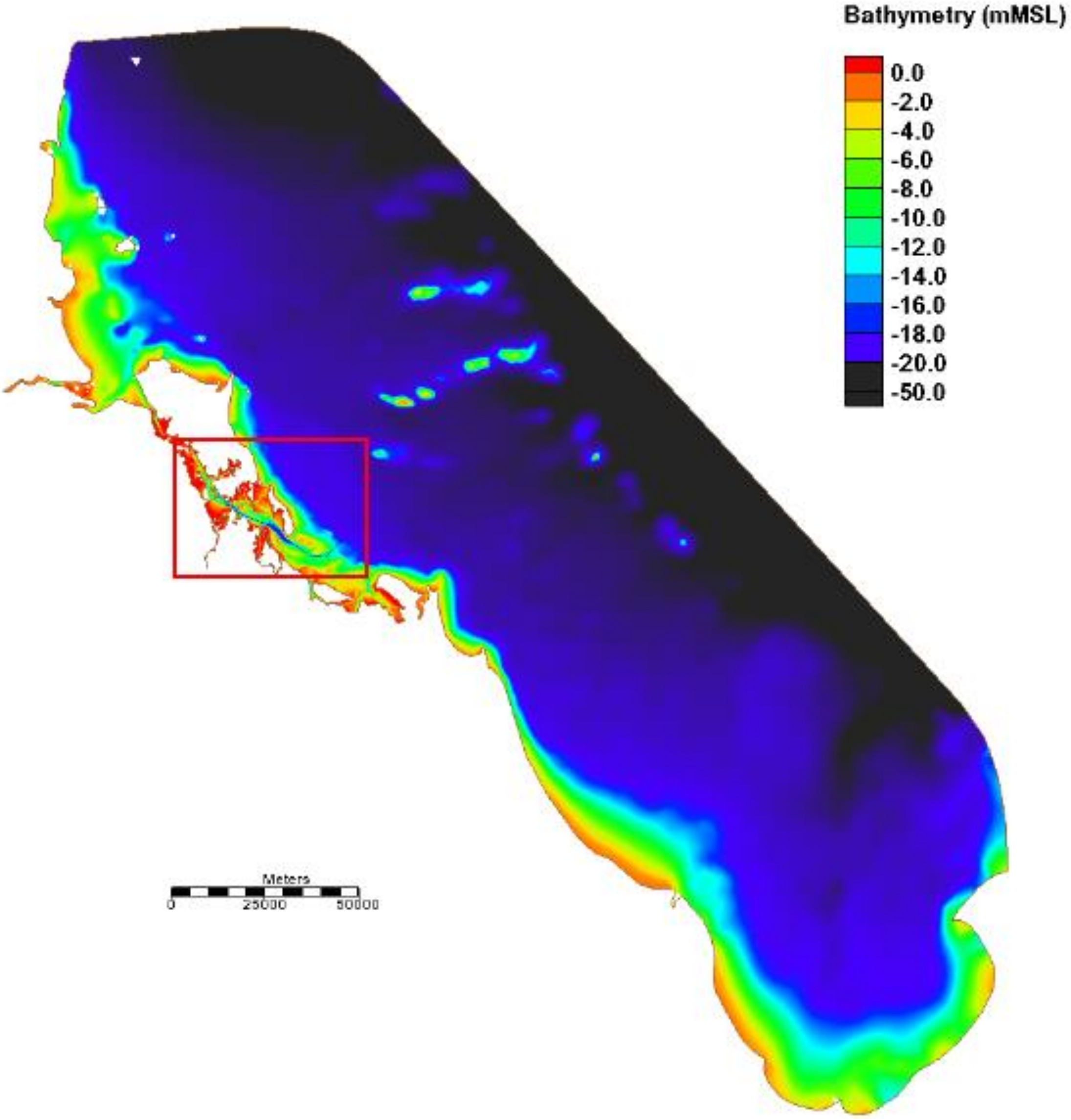


Figure 2-4 Model Bathymetry – Whole Model Domain

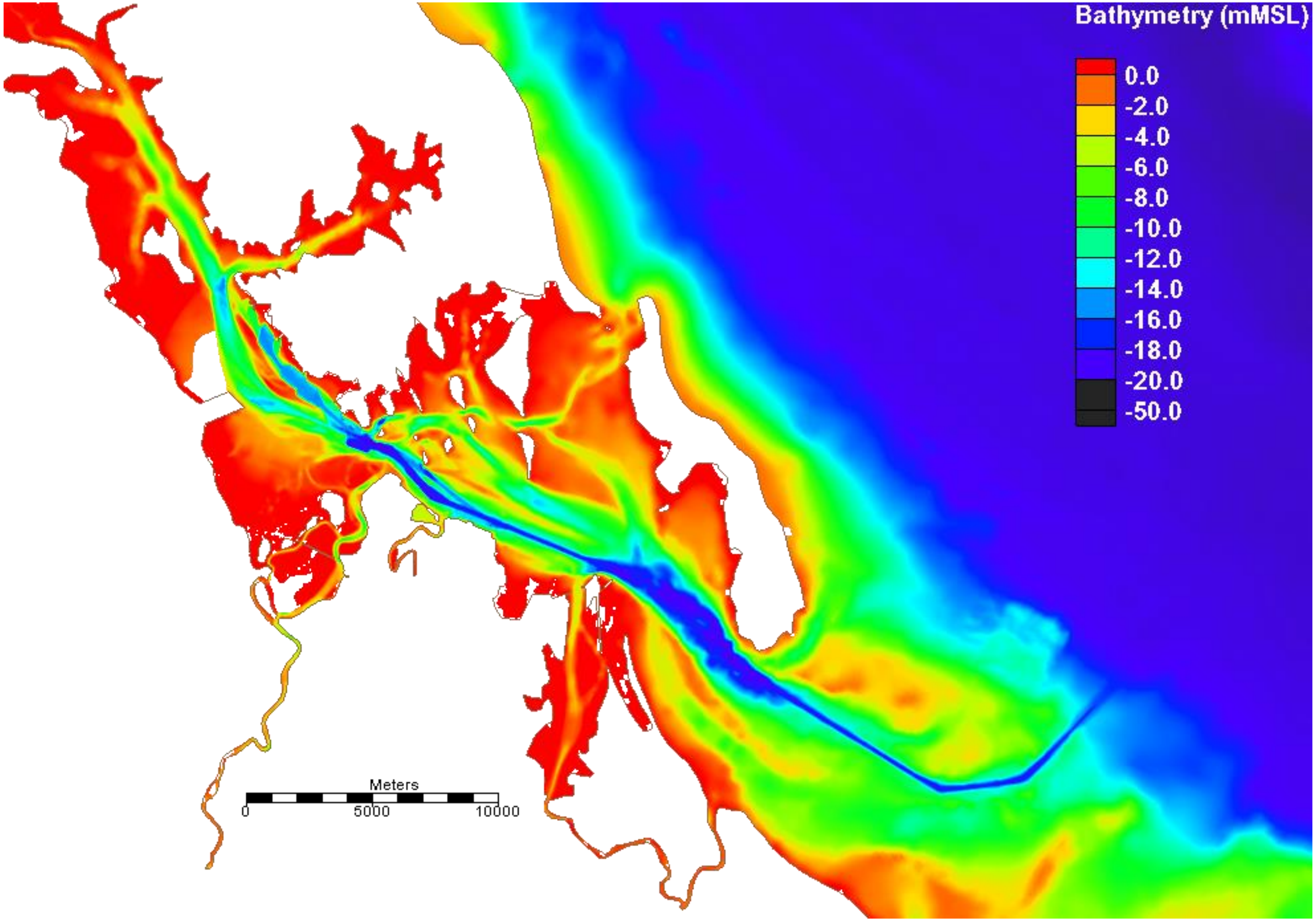


Figure 2-5 Model Bathymetry – Local Scale (Red Boxed Area in Figure 2-4)

3 Wave Model Description

A wave model that was developed as part of recent environmental assessment work (BMT, 2019b) was used 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 white-capping, 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 includes a coarse regional-scale grid (~1,000 m resolution), a nested medium-scale grid (~250 m resolution) and a nested local-scale grid (~50 m resolution). The domains of the SWAN grids are shown in Figure 3-1. The bathymetry used for the wave model grids was the same as that discussed in Section 2.3.

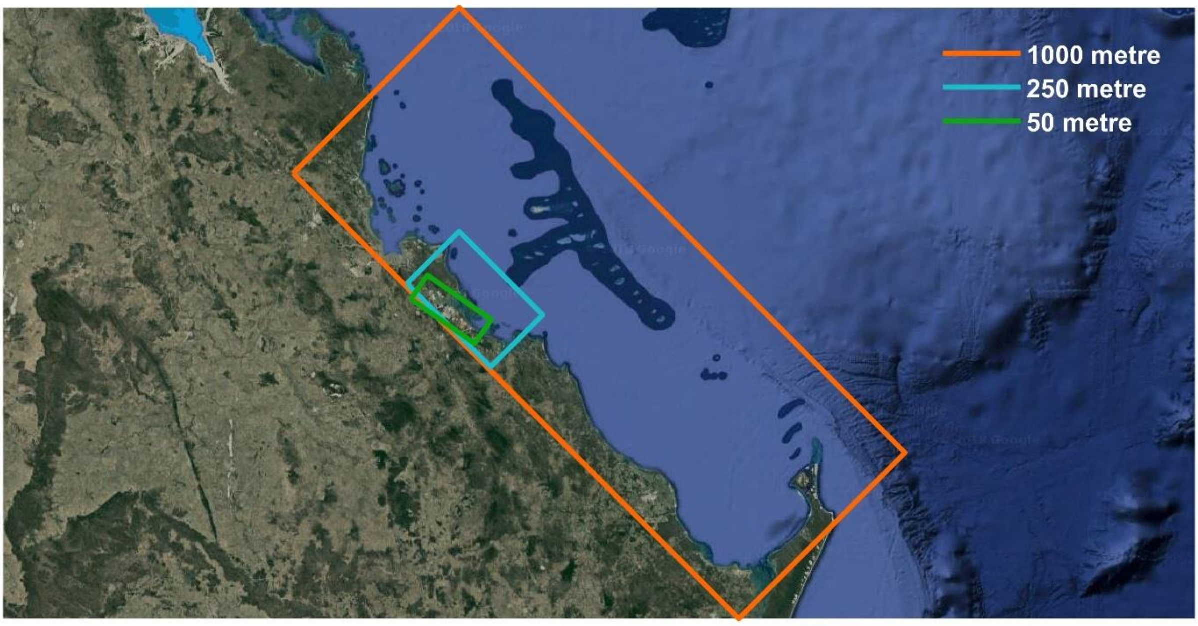


Figure 3-1 SWAN Model Domains

4 Model Boundary Conditions

The boundary conditions applied to the model were the same as those used in recent modelling projects in the PoG (BMT, 2019b).

4.1.1 Tide

Tidal boundary conditions along the open ocean boundary of the model were sourced from a larger 2D TUFLOW FV hydrodynamic model of the Coral Sea, also developed by BMT. The Coral Sea tide model boundary conditions were generated using tidal constituents supplied by the Bureau of Meteorology (BoM), National Tide Centre (NTC), derived from the Australian Regional Tide Model (5-minute spatial resolution).

4.1.2 Oceanic Currents

Regional current forcing (residual water level, current magnitude and direction), and profiles of temperature and salinity were also applied on the open model boundaries of the model. These were derived from the ocean general circulation model, HYCOM (HYCOM, 2019) and varied both in space (longitude, latitude and elevation) and time. The HYCOM model has a spatial resolution of approximately 8 km and a temporal resolution of 24 hours. The water level specified on the model boundary was a linear superposition of the HYCOM water level and the tidal water level. 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 conditions).

4.1.3 Atmospheric Forcing

Boundary condition data, including air temperature, long and short wave radiation, precipitation and relative humidity were also obtained from the global National Centers for Environmental Prediction Climate Forecast System Reanalysis model (NCEP CFSR) (National Oceanic and Atmospheric Administration, 2012). These model outputs had the same spatial and temporal resolution as the wind outputs and were applied to the hydrodynamic model only.

4.1.4 Wind

Wind velocity boundary conditions for the calibration period were obtained from global NCEP CFSR model reanalyses (National Oceanic and Atmospheric Administration, 2012). 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.

A comparison of the BoM ‘Gladstone Radar’ data and the NCEP CFSR model output is provided in Figure 4-1. The model output is in close agreement with the measured wind speed and direction at that location. The CSFR model output does slightly underestimate the diurnal variation in magnitude and direction, which may be due to local sea breeze effects. Note that the BoM wind speeds are 10-minute averages, while the CFSR model output has a temporal resolution of 1 hour, with no averaging.

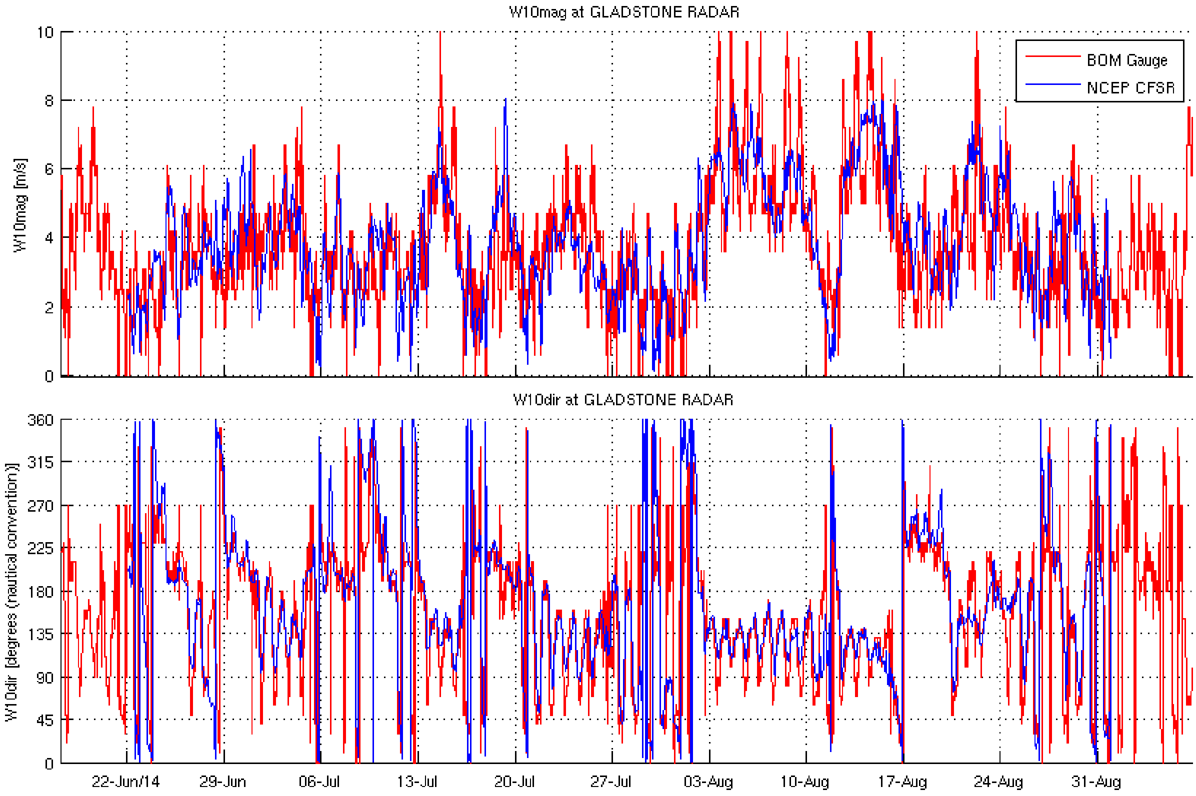


Figure 4-1 **Comparison of 10m Wind Speed (Top) and Wind Direction (Bottom) for the NCEP CFSR Model Output (Blue Line) and the Bureau of Meteorology Gauge (Red) at Gladstone Radar. Mean Squared Error (MSE) for W10mag = 1.715**

4.1.5 Swell

The regional-scale wave model was supplied with swell boundary conditions from the global Wave Watch III model (NOAA, 2012).

4.1.6 Freshwater Inflows

There are a number of tidal tributaries incorporated in the model, including the Calliope and Boyne Rivers. The normal day to day fluvial component of flow within these river systems is generally insignificant in relation to the tidal fluxes through Port Curtis, except during major flood events. Freshwater inputs for the model calibration and validation periods were obtained from DNRM data (Department of Natural Resources and Mines, 2019), as well as a hydrologic catchment model developed by BMT for the Port Curtis region. Additional data for Awoonga Dam spillway flows was sourced from the Gladstone Area Water Board. The sediment fluxes associated with these freshwater flows were also included in the ambient sediment dynamics modelling (and calibration process).

5 Model Calibration

The BMT TUFLOW FV model of the PoG has undergone extensive calibration and validation processes as part of previous projects, in particular as part of the Gatcombe and Golding Cutting Channel Duplication Project Environmental Impact Statement (BMT, 2019b). The model hydrodynamics were validated using a number of long-term Acoustic Doppler Current Prolifer (ADCP) time series measurements, as well as water level time series and measured velocities across key transects over a full tidal cycle. The SWAN wave model was also calibrated and validated using ADCP and wave buoy data. The ambient sediment dynamics model was calibrated and validated using more than 12 months of collected turbidity data.

The Gladstone TUFLOW FV sediment transport model focusses on reproducing the suspended sediment dynamics, since it models the advection and dispersion of sediment particles suspended in the water column (silt, clay and fine sand particles). Bedload transport of coarse sand and gravel is not explicitly modelled (although future extension of the model may allow this). Suspended sediment transport processes are of primary interest in the development of the sediment budget, since it is suspended sediment that is most relevant for considering light attenuation effects on seagrasses and coral. Bedload transport of coarser sediment is more significant in offshore areas and does contribute to sedimentation in the outer parts of the Port of Gladstone shipping channels. Estimates of the source rates of plume generation during dredging activity have been developed over a period of time, based on input from expert dredging consultants and measurements carried out during monitoring of dredging activity by boat-mounted ADCP. The most recent derivation and validation of plume generation source rates is presented in the report Port of Gladstone Maintenance Dredging Assessment of Potential Impacts (BMT, 2017).

Additional targeted model calibration was carried out for this project, with the objective of improving the prediction of the ambient sediment dynamics in the Port of Gladstone. Two separate data collection campaigns were conducted in 2018-19. The first (07/09/2018 to 27/09/2018) involved deployment of fixed loggers and ADCP transect measurements at the three entrances to Port Curtis to measure ambient sediment fluxes. The ADCP transect data collection process and the measurement results are described in Appendix A (BMT, 2019a). The second campaign (23/10/2018 to 12/02/2019) involved deployment of fixed loggers at various locations local to the EBSDS for monitoring turbidity and hydrodynamics before, during and after the spoil placement activity associated with the 2018 maintenance dredging campaign.

An initial simulation from 01/09/2018 to 01/03/2019 was used to establish the baseline performance of the existing PoG model (BMT 2019b) compared to the measured data from both of the 2018-2019 measurement campaigns. Initial assessment of the results indicated that agreement with measured turbidity data near the EBSDS was generally good, while the modelled predictions for the ambient sediment flux at the measured transects from the September 2018 period were acceptable at the Narrows and the South Entrance but needed improvement at The North Entrance. For that reason, the focus of improvement of the model during the calibration process was to improve the predictions of ambient sediment flux at the North Entrance, without reducing the accuracy of the model in reproducing the sediment dynamics offshore. For further details on the turbidity measurement campaign and data quality control, refer to the Sediment Movement Data Interpretation Report (PCS, 2019). A summary of the data used for model calibration is provided in Table 5-1. Refer to Figure 5-1 for data collection locations.

Table 5-1 Summary of Data Used for Model Calibration

Location	Calibration Data	Period of Measurements
Narrows	Water and sediment mass flux (Boat mounted ADCP & OBS)	08/09/2018 & 12/09/2018
North Entrance	Water and sediment mass flux (Boat mounted ADCP & OBS)	10/09/2018 & 13/09/2018
South Entrance	Water and sediment mass flux (Boat mounted ADCP & OBS)	07/09/2018 & 15/09/2018
MH01	Benthic Turbidity (WetLab NTU), Wave Spectrum (AWAC) & Current profile (ADCP)	07/09/2018 to 27/09/2018
MH51	Surface Turbidity (WetLab NTU) & Current profile (ADCP)	07/09/2018 to 27/09/2018
EBW	Benthic Turbidity (WetLab NTU), Wave Spectrum (AWAC) & Current profile (ADCP)	23/10/2018 to 12/02/2019
EBE	Benthic Turbidity (WetLab NTU), Wave Spectrum (AWAC) & Current profile (ADCP)	23/10/2018 to 12/02/2019
OH02	Benthic Turbidity (WetLab NTU)	23/10/2018 to 12/02/2019
OH04	Benthic Turbidity (WetLab NTU)	23/10/2018 to 12/02/2019
OH06	Benthic Turbidity (WetLab NTU)	23/10/2018 to 12/02/2019

The model calibration process involved minor localised changes to the existing sediment transport model configuration and adjustment of processing procedure for the transect flux measurements to improve the model predictions of sediment mass flux at the entrances to the PoG. No global changes to sediment transport parameters were made (such as critical shear stress thresholds for erosion and deposition, or erosion rate) to avoid degrading the model accuracy in areas that were already well calibrated.

The three main changes adopted for the final model simulations included:

- Limiting the wave bed shear stress application to depths greater than 1m, to reduce excessive erosion of fines on mudflats;
- Reduction of fines fraction in initial bed mass in some shallow areas around the islands in the mid harbour section of the PoG; and
- Extrapolation of the measured sediment concentration in the top bin of the ADCP transect measurements to account for the portion of the water column not measured directly by the ADCP (the ADCP head was 0.5 m below the water surface, and the blanking distance to the top of the first measurement bin was 0.44 m).

Time series comparisons of modelled turbidity to turbidity observed during the 2018-19 measurement campaigns are provided in Figure 5-2 to Figure 5-10. The criteria used to assess model performance included the ability to reproduce the observed semidiurnal and spring-neap variation in turbidity magnitude, and (for offshore sites) the ability to reproduce the observed turbidity spikes associated with wave events. A modelled turbidity that is generally within a factor two of the measured turbidity is considered acceptable due to the complexity of the modelling task. The model achieved an acceptable level of predictive skill for turbidity across all locations and conditions.

For the first measurement campaign (07/09/2018 to 27/09/2018), a period when no dredging activity was being undertaken, the model accurately predicted turbidity at both North Entrance (Figure 5-2) and South Entrance (Figure 5-3). The ambient turbidity signal at both locations appeared to be predominantly tidally driven, with some small wave events that generated spikes in turbidity at the North Entrance.

During the second measurement campaign (23/10/2018 to 12/02/2019), a period characterised by elevated turbidity resulting from maintenance dredging activity and energetic wave conditions, the model also had acceptable predictive skill. At locations local to the EBSDS (Figure 5-4 to Figure 5-8) the model typically over-estimated turbidity to some degree, but did match the overall temporal variation due to ambient sediment suspended during energetic wave conditions. At locations within the inner harbour (Figure 5-9 and Figure 5-10) the model underestimated the turbidity level, but did replicate the observed temporal variation in turbidity with reasonable accuracy.

The calibrated model performance simulating the total flow rate and sediment mass flux for the measured transects (BMT, 2019a) is shown in Figure 5-11 to Figure 5-16. Time series comparisons indicate the model has an acceptable level of performance in predicting volume fluxes of water across the transects. Comparisons between measured and modelled sediment mass flux indicate that the model performance is adequate, but better in some locations and at certain times than others. Time series comparison of modelled and observed sediment mass flux across the main entrances to the PoG indicates consistent underprediction of fluxes at The Narrows and overprediction at the North Entrance. At South Entrance (the dominant sediment import/export location) the model performs relatively well in reproducing the measured fluxes.

Assessment of net sediment mass flux, shown in Table 5-2, indicates potentially large overpredictions in sediment mass outflux at the North and South entrance during spring tides. Observed net flux values are however subject to large errors due to the limited resolution and discrete nature of transect measurements. Indeed, any net flux estimate (observed or measured) is difficult to obtain because it is the difference between two large numbers (flow in and flow out), each of which are subject to large uncertainties due to the difficulty of obtaining accurate measurements and the challenges of accurately reproducing the ambient sediment dynamics in the numerical model.

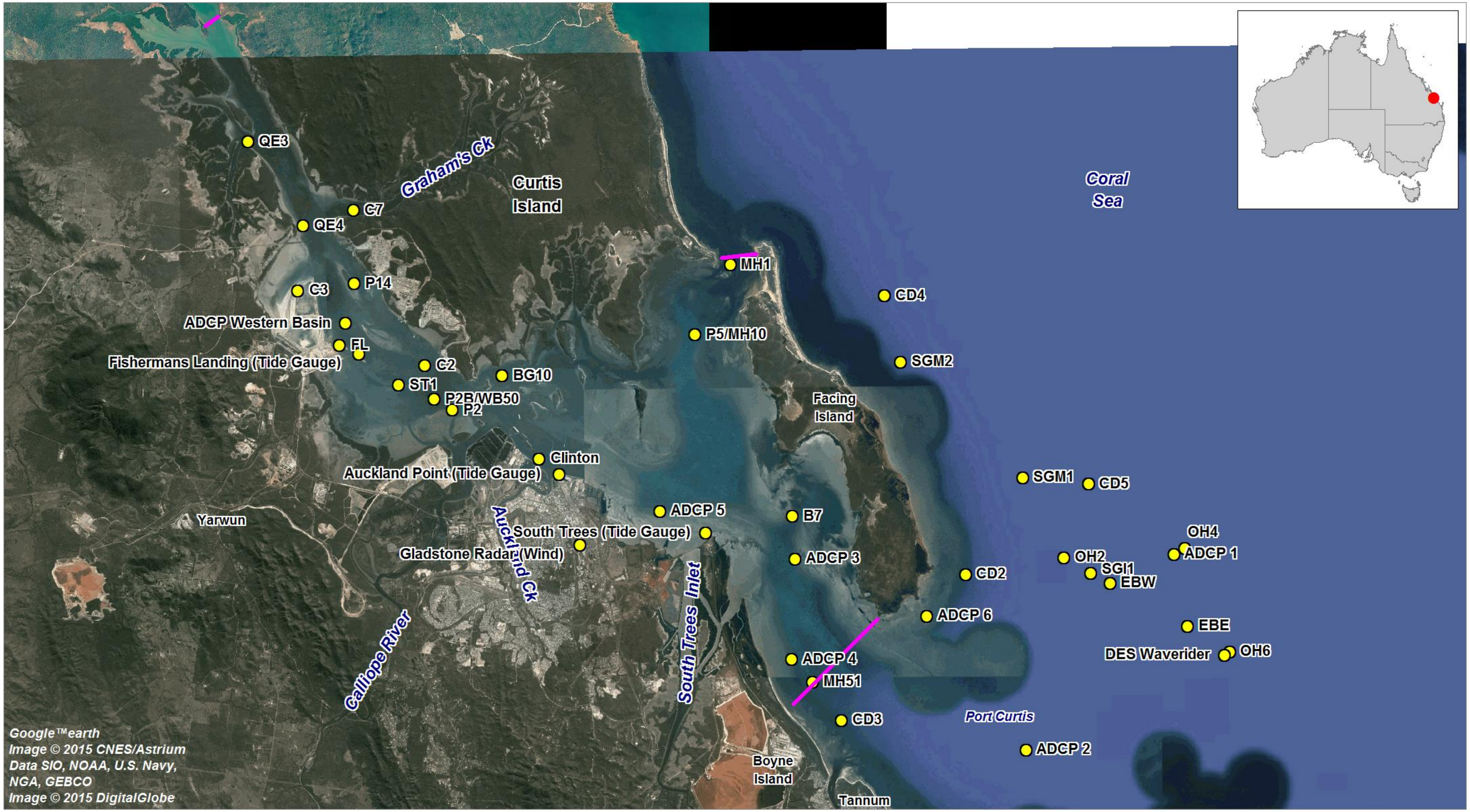
Table 5-2 Comparison of Transect Net Sediment Mass Flux (Positive = Into the Port)

Transect	Observed Net Sediment Mass Flux (Tonnes)	Modelled Net Sediment Mass Flux (Tonnes)	Difference (%)
Narrows Normal	38	9.3	76
Narrows Spring	114	65	43
North Entrance Normal	-21	-52	148
North Entrance Spring	-11	-132	1071
South Entrance Normal	1191	786	34
South Entrance Spring	-436	-1459	234

Overall, the model tends to overestimate the gross sediment flux both into the Port on flood tides and out of the Port on ebb tides. However, the model tends to overestimate the outgoing flux by a larger margin, so the model results overall suggest a larger net flux out of the Port, or smaller net flux into the Port (depending on the transect and the conditions), than is indicated by the measured data.

In order to assess the accuracy of the spatial representation of the ambient turbidity represented in the model, comparisons were made with satellite-derived turbidity estimates (PCS, 2019). The modelled depth-averaged turbidity is presented together with the satellite-derived estimates in Figure 5-17 to Figure 5-22. The modelled spatial distribution of the turbidity is similar to the satellite-derived data in most cases, noting that there are limitations to the accuracy of the measurements (as well as the model) and that the colour scales for the respective plots are not an exact match.

Additional hydrodynamic model calibration plots are provided in Appendix B.



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● Instrument Location

— ADCP Transect

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Measurement Locations

Figure:

5-1

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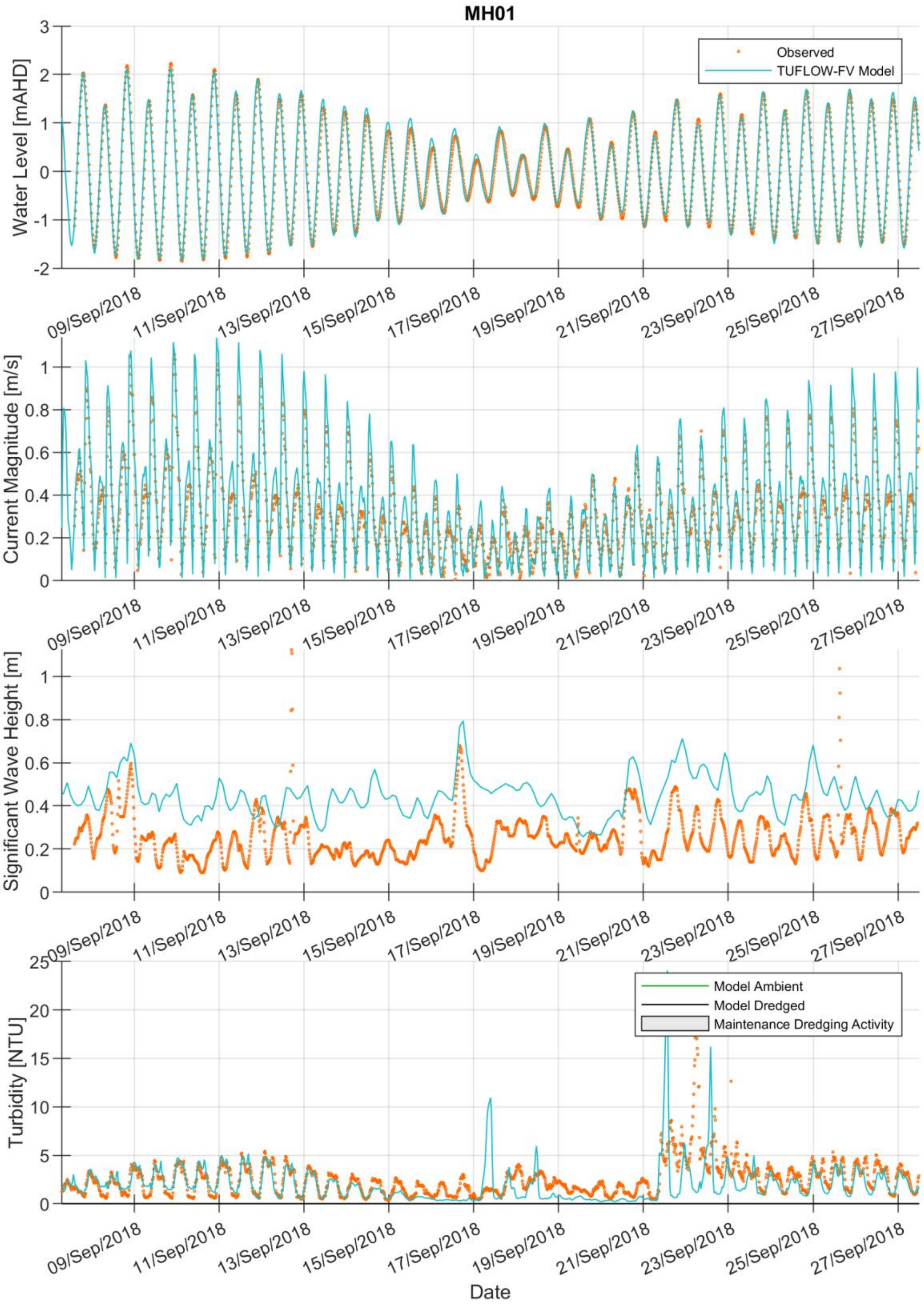


Figure 5-2 Timeseries comparison of modelled and observed Water Level (Top), Current Magnitude (Centre Top), Sig. Wave Height (Centre Bottom) and Turbidity (Bottom) at MH01

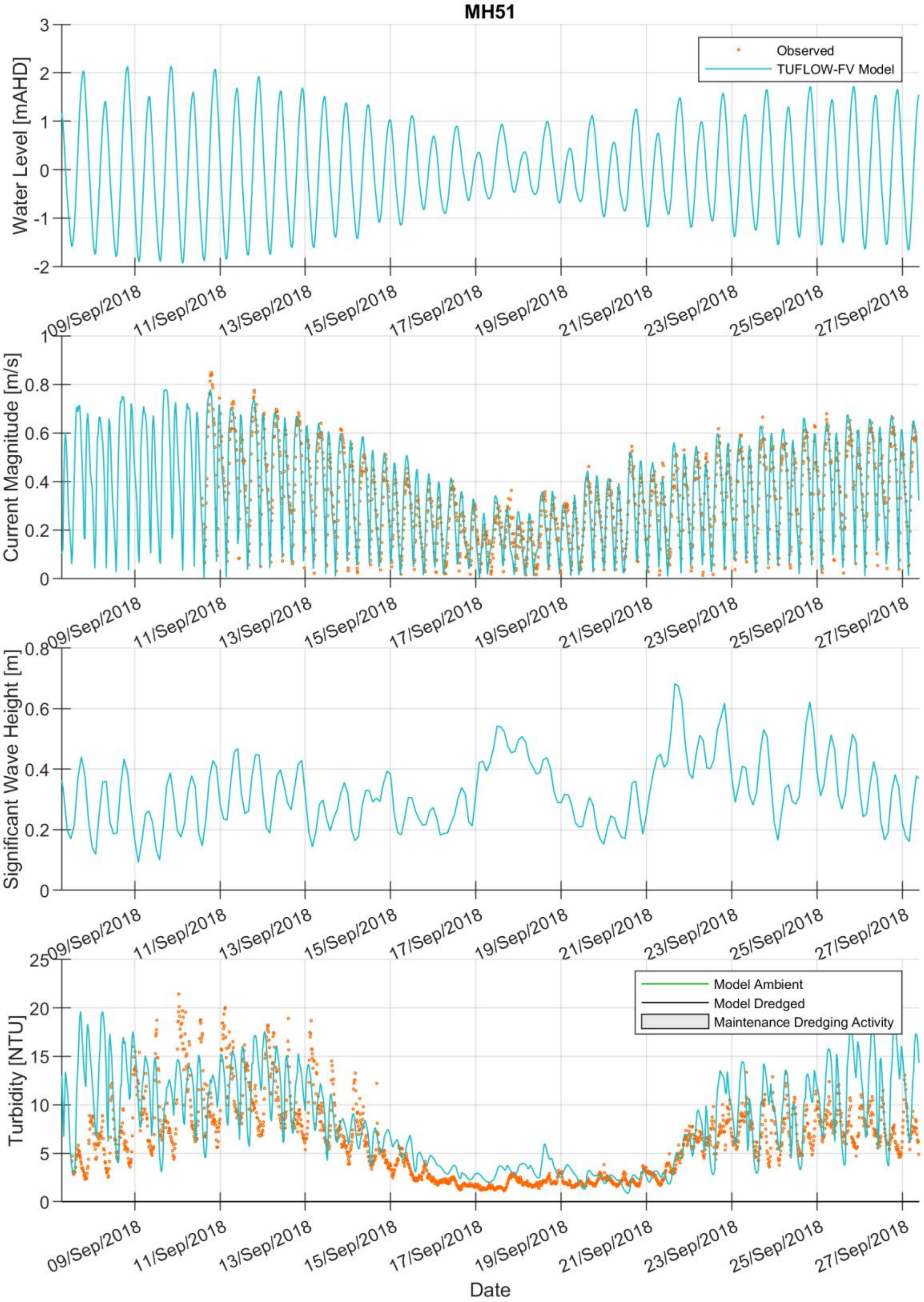


Figure 5-3 Time series Comparison of Modelled and Observed Water Level (Top), Current Magnitude (Centre Top), Sig. Wave Height (Centre Bottom) and Turbidity (Bottom) at MH51

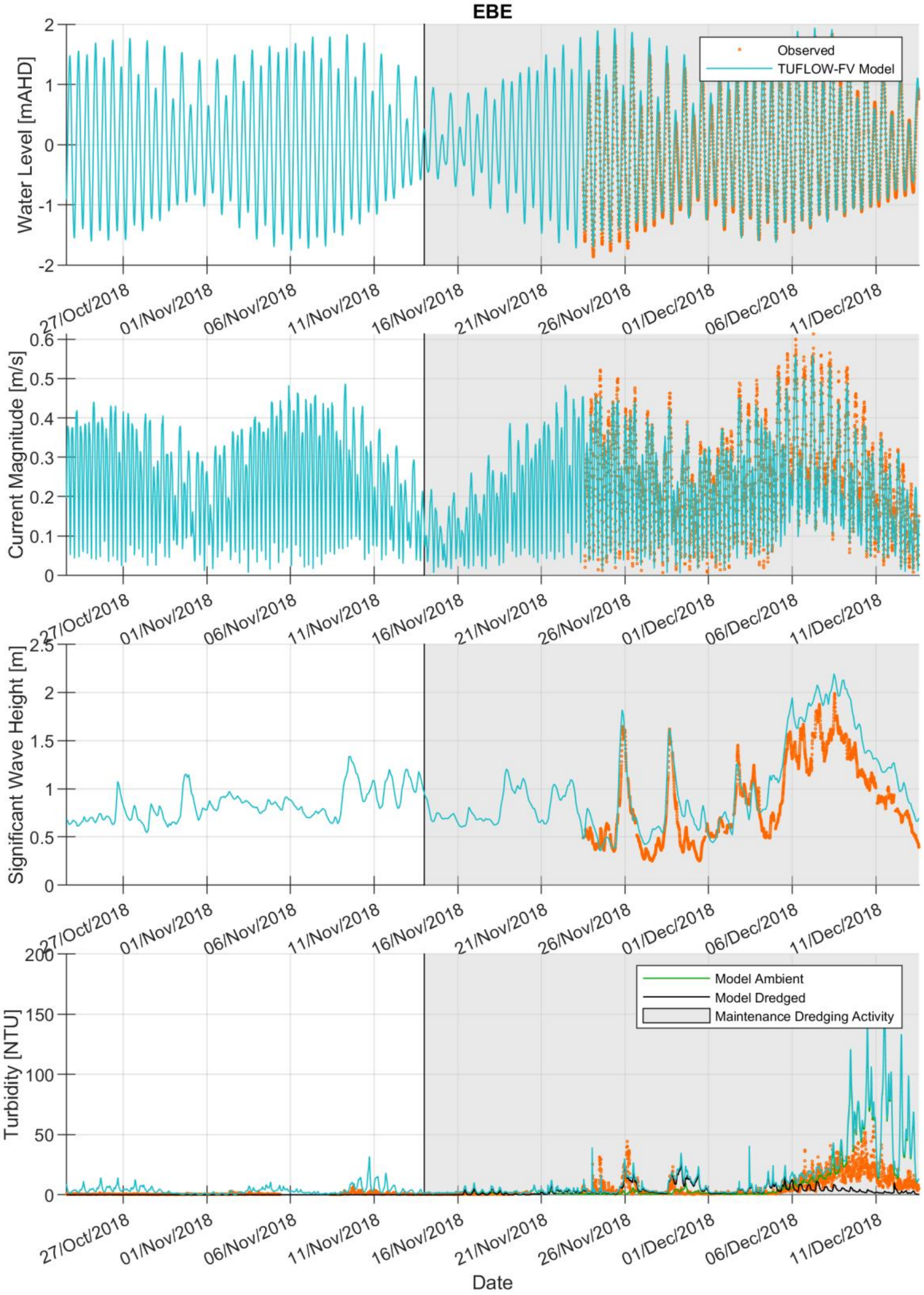


Figure 5-4 Time series Comparison of Modelled and Observed Water Level (Top), Current Magnitude (Centre Top), Sig. Wave Height (Centre Bottom) and Turbidity (Bottom) at EBE

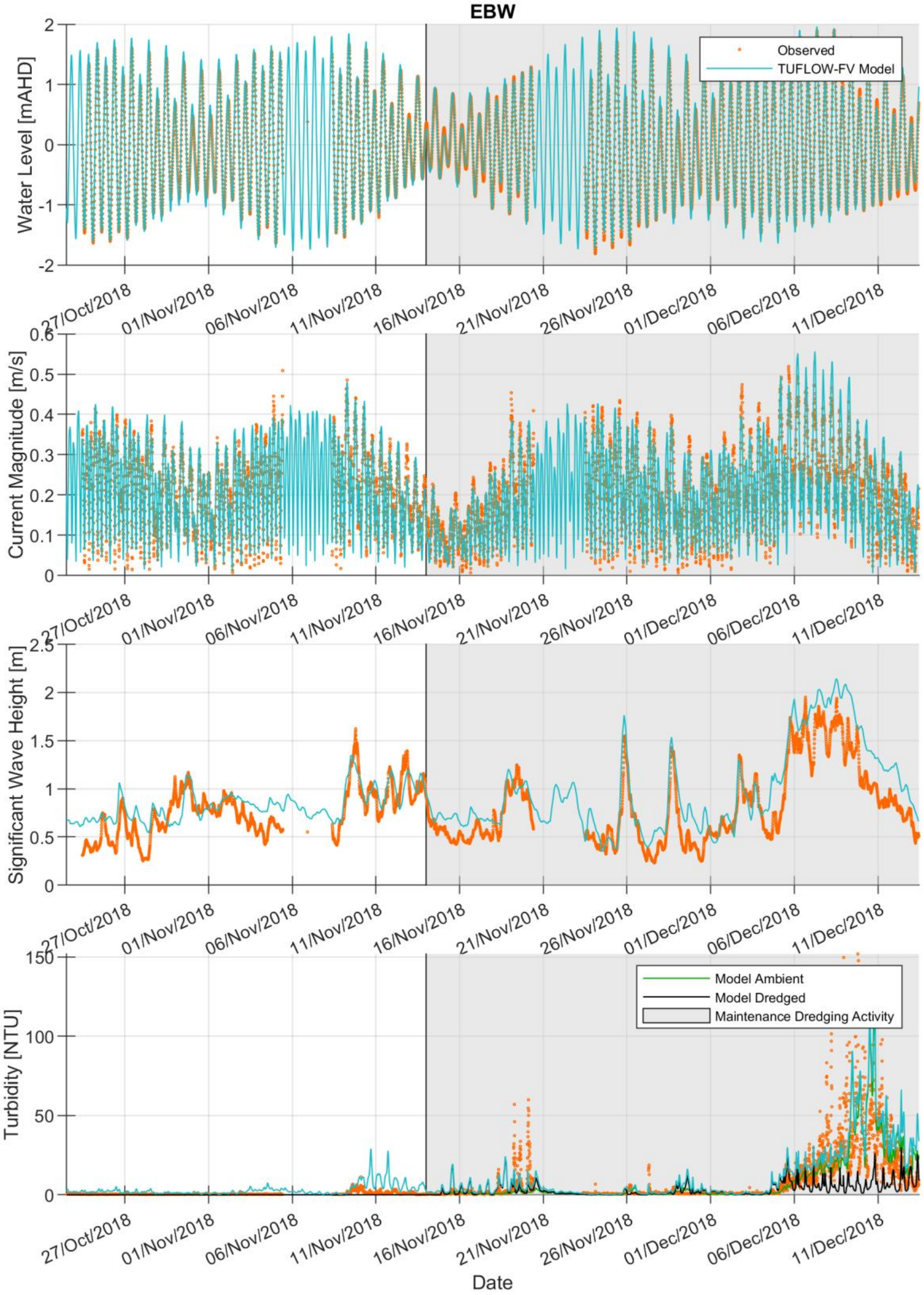


Figure 5-5 Time series Comparison of Modelled and Observed Water Level (Top), Current Magnitude (Centre Top), Sig. Wave Height (Centre Bottom) and Turbidity (Bottom) at EBW

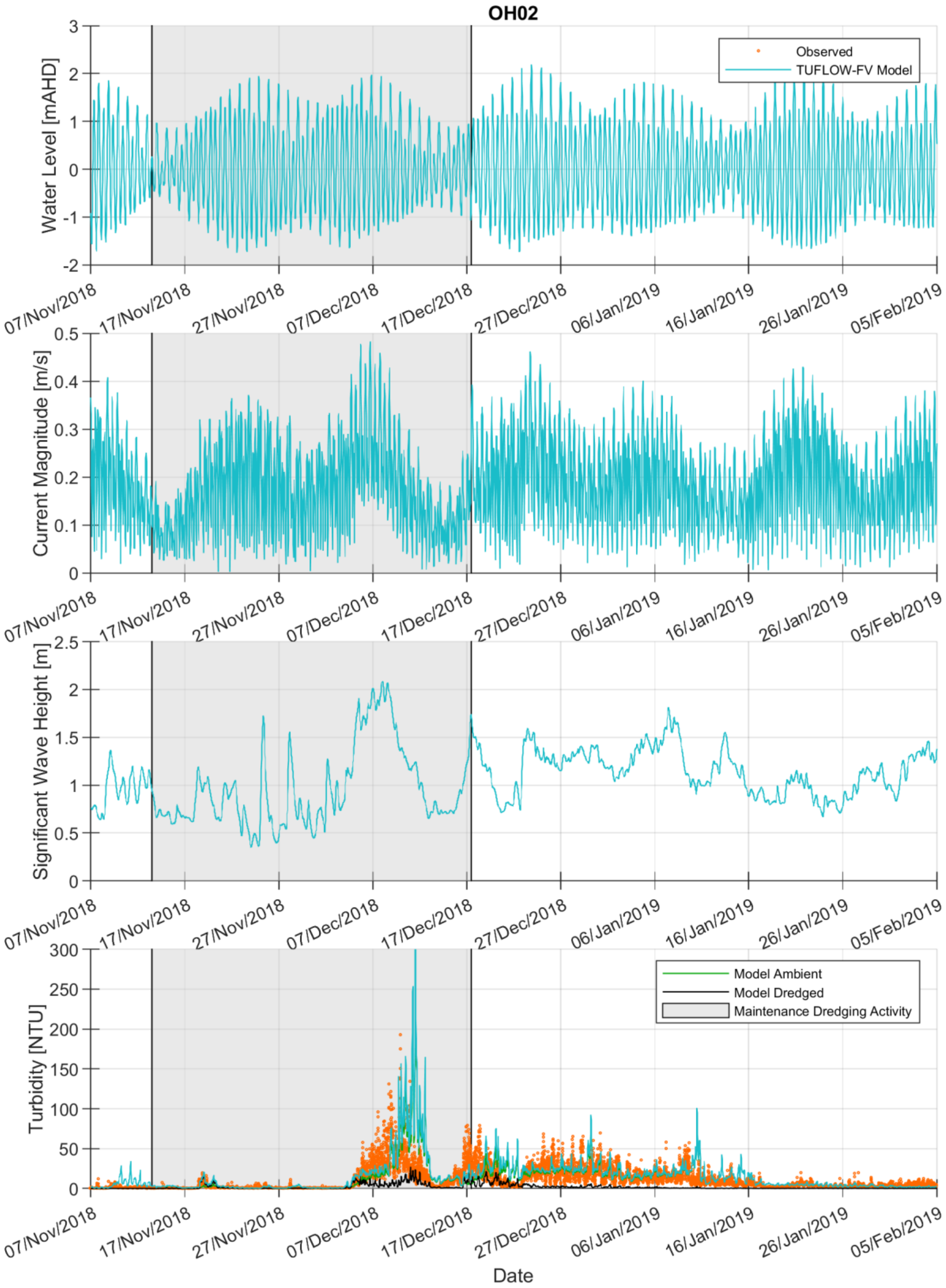


Figure 5-6 Time series Comparison of Modelled and Observed Water Level (Top), Current Magnitude (Centre Top), Sig. Wave Height (Centre Bottom) and Turbidity (Bottom) at OH02

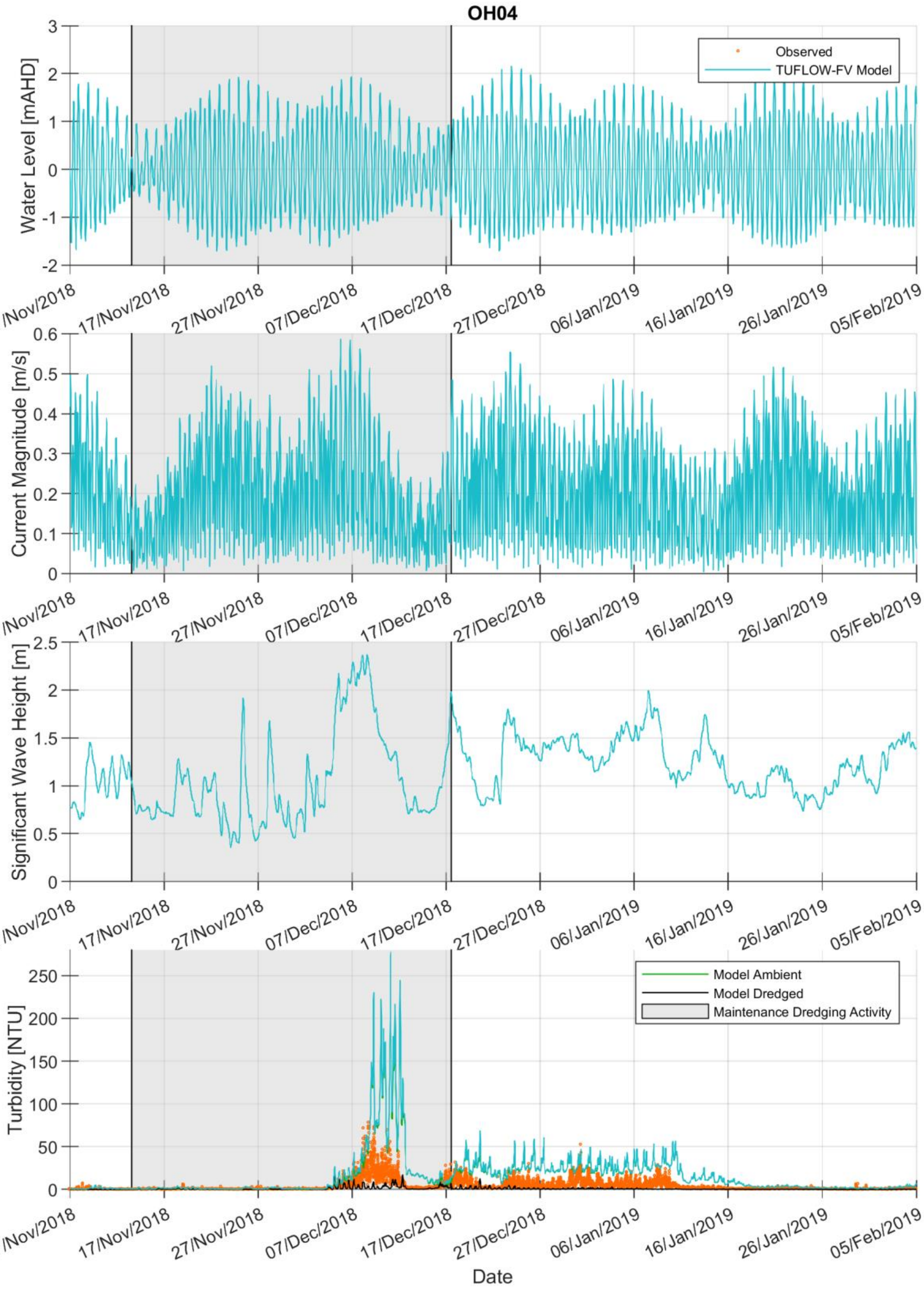


Figure 5-7 Time series Comparison of Modelled and Observed Water Level (Top), Current Magnitude (Centre Top), Sig. Wave Height (Centre Bottom) and Turbidity (Bottom) at OH04

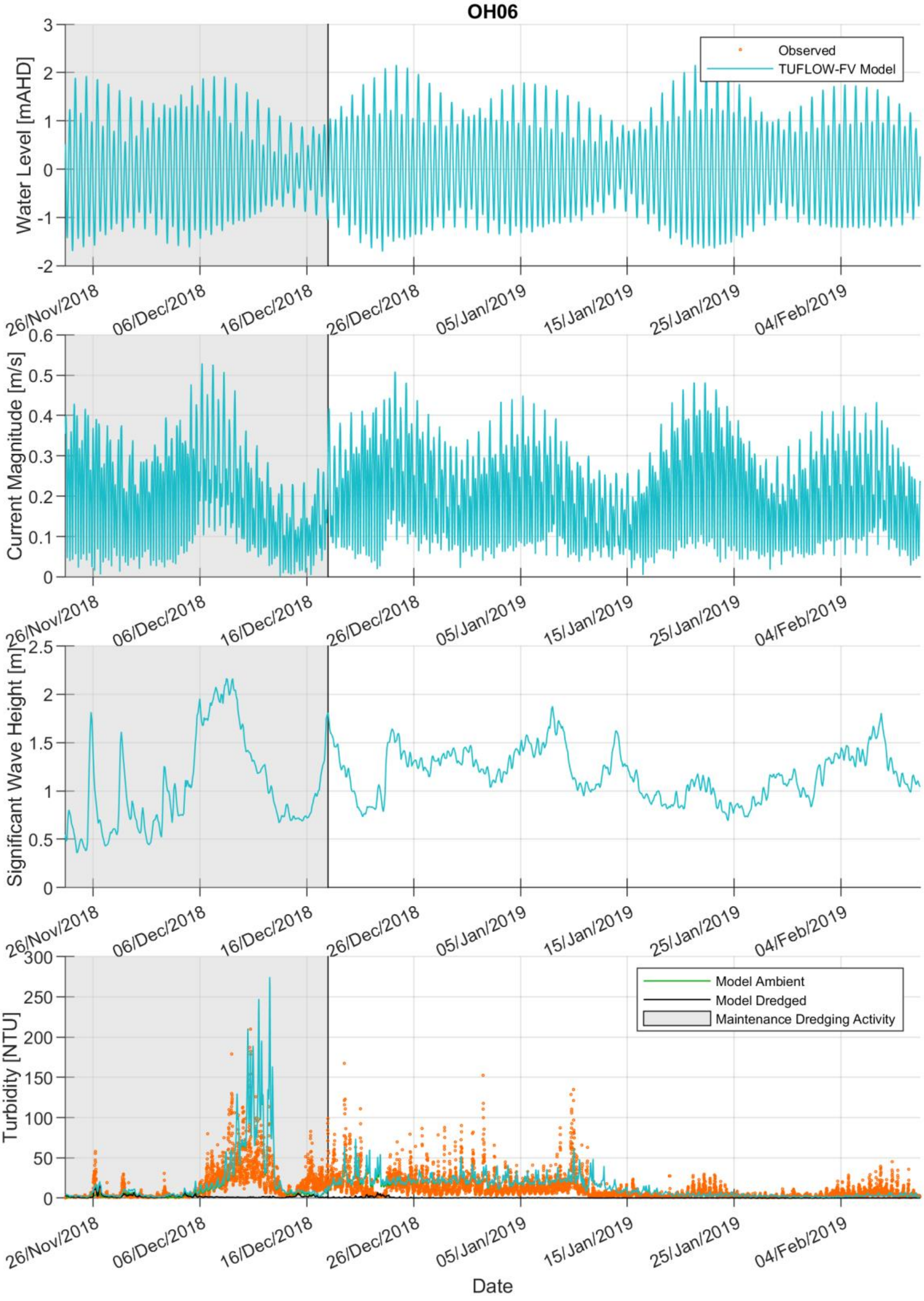


Figure 5-8 Time series Comparison of Modelled and Observed Water Level (Top), Current Magnitude (Centre Top), Sig. Wave Height (Centre Bottom) and Turbidity (Bottom) at OH06

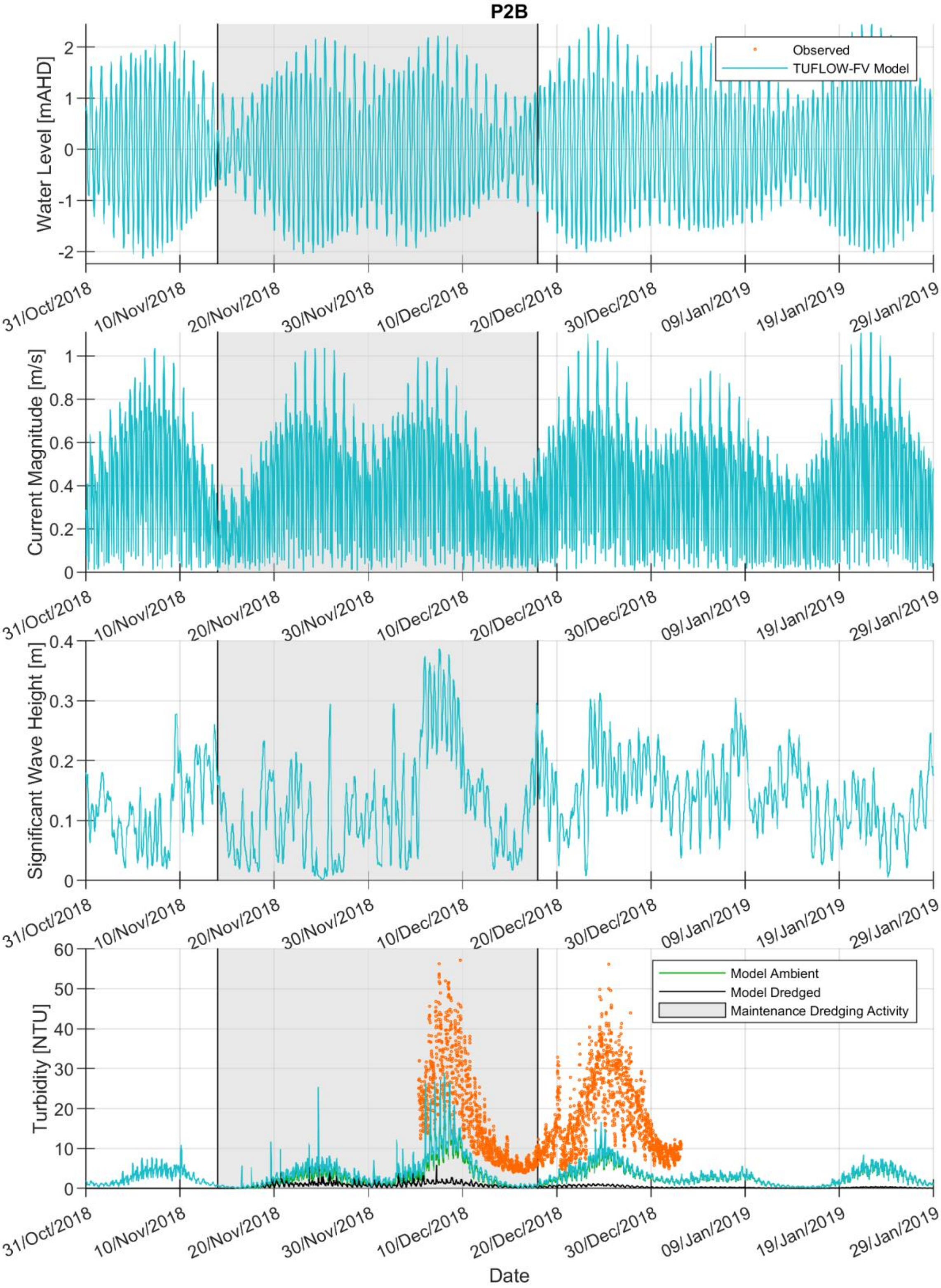


Figure 5-9 Time series Comparison of Modelled and Observed Water Level (Top), Current Magnitude (Centre Top), Sig. Wave Height (Centre Bottom) and Turbidity (Bottom) at WB50

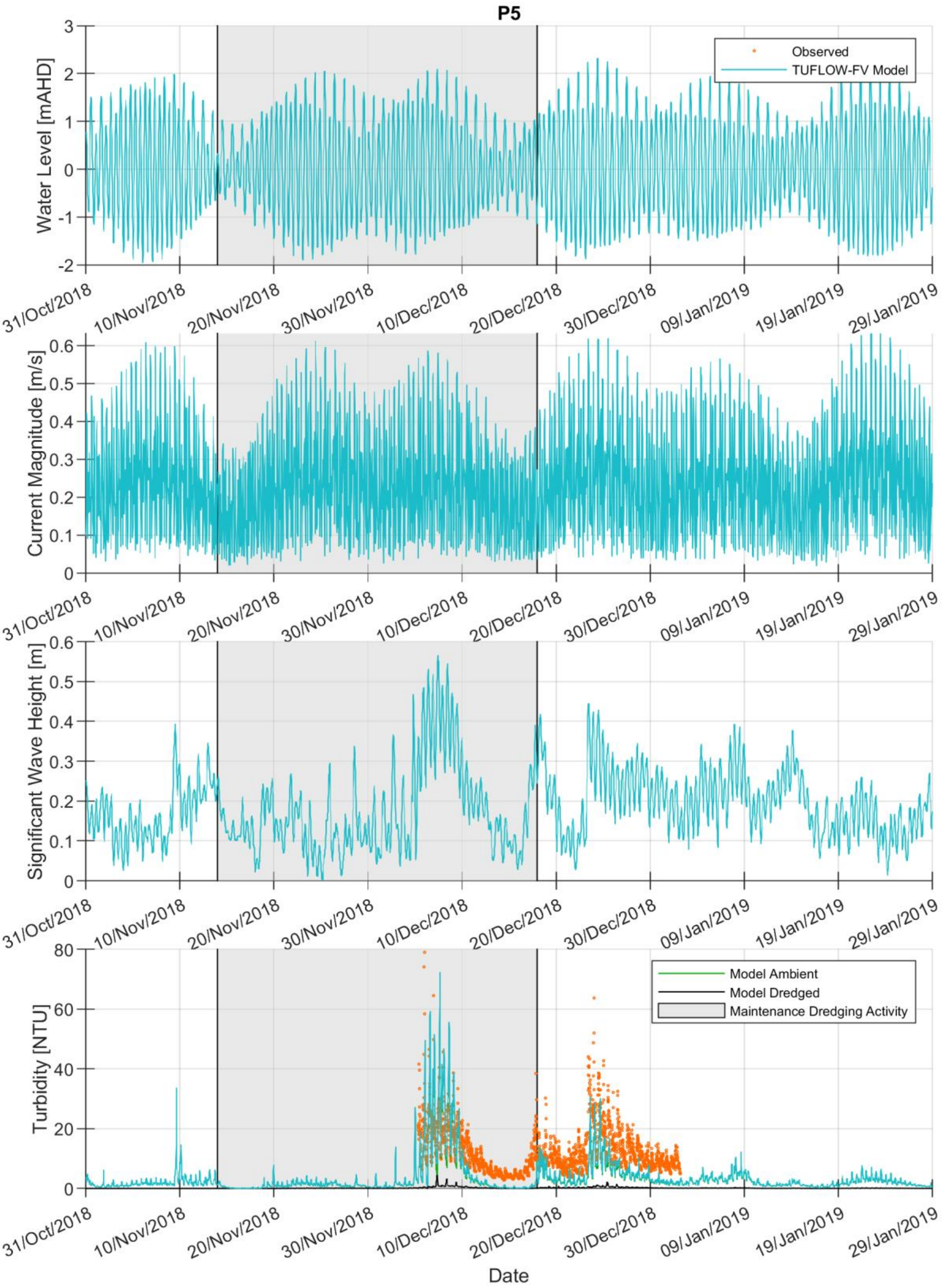


Figure 5-10 Time series Comparison of Modelled and Observed Water Level (Top), Current Magnitude (Centre Top), Sig. Wave Height (Centre Bottom) and Turbidity (Bottom) at MH10

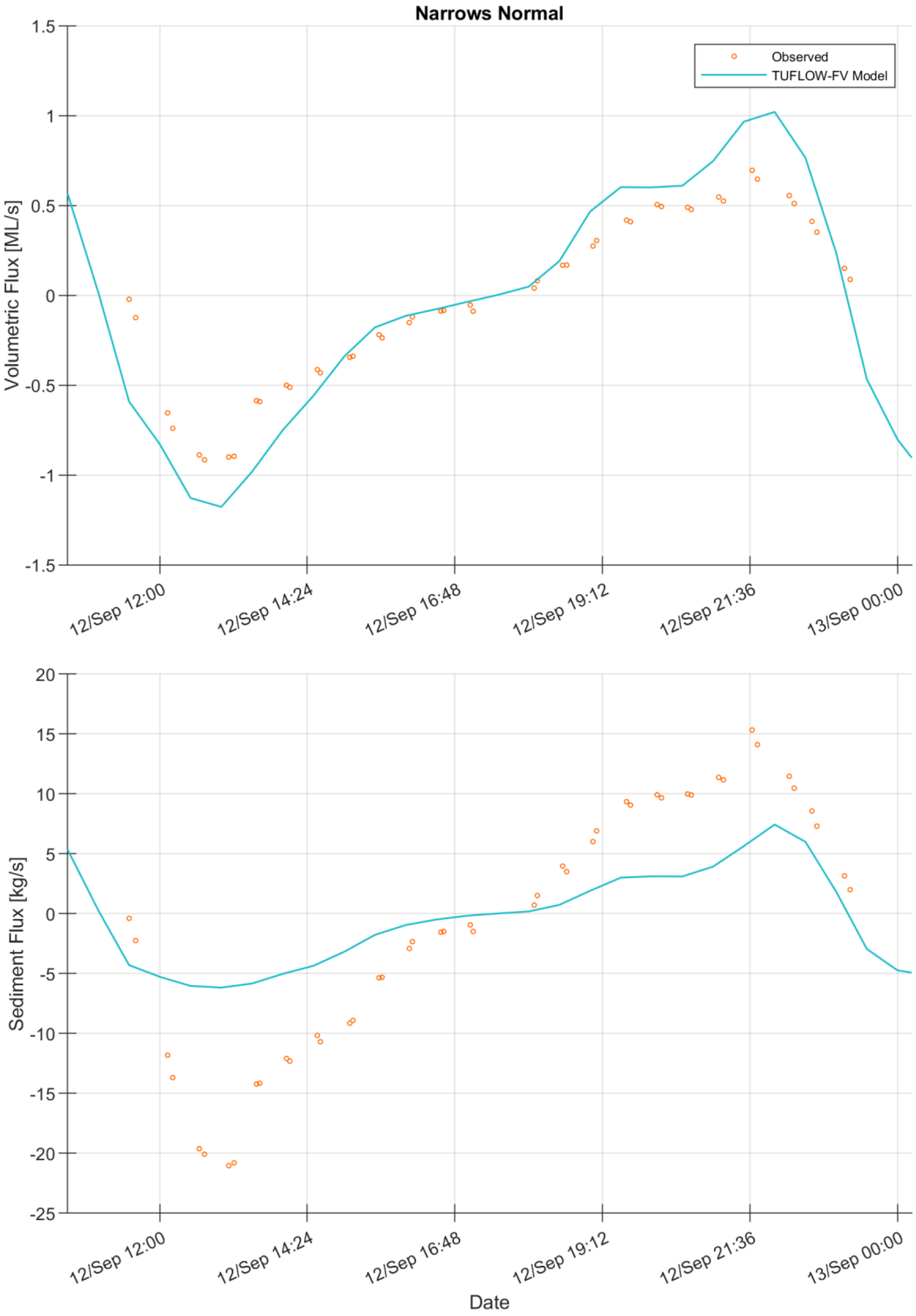


Figure 5-11 Time Series Comparison of Modelled and Observed Transect Flow Rate (Top) and Sediment Mass Flux (Bottom) at Narrows During Normal Tide Conditions

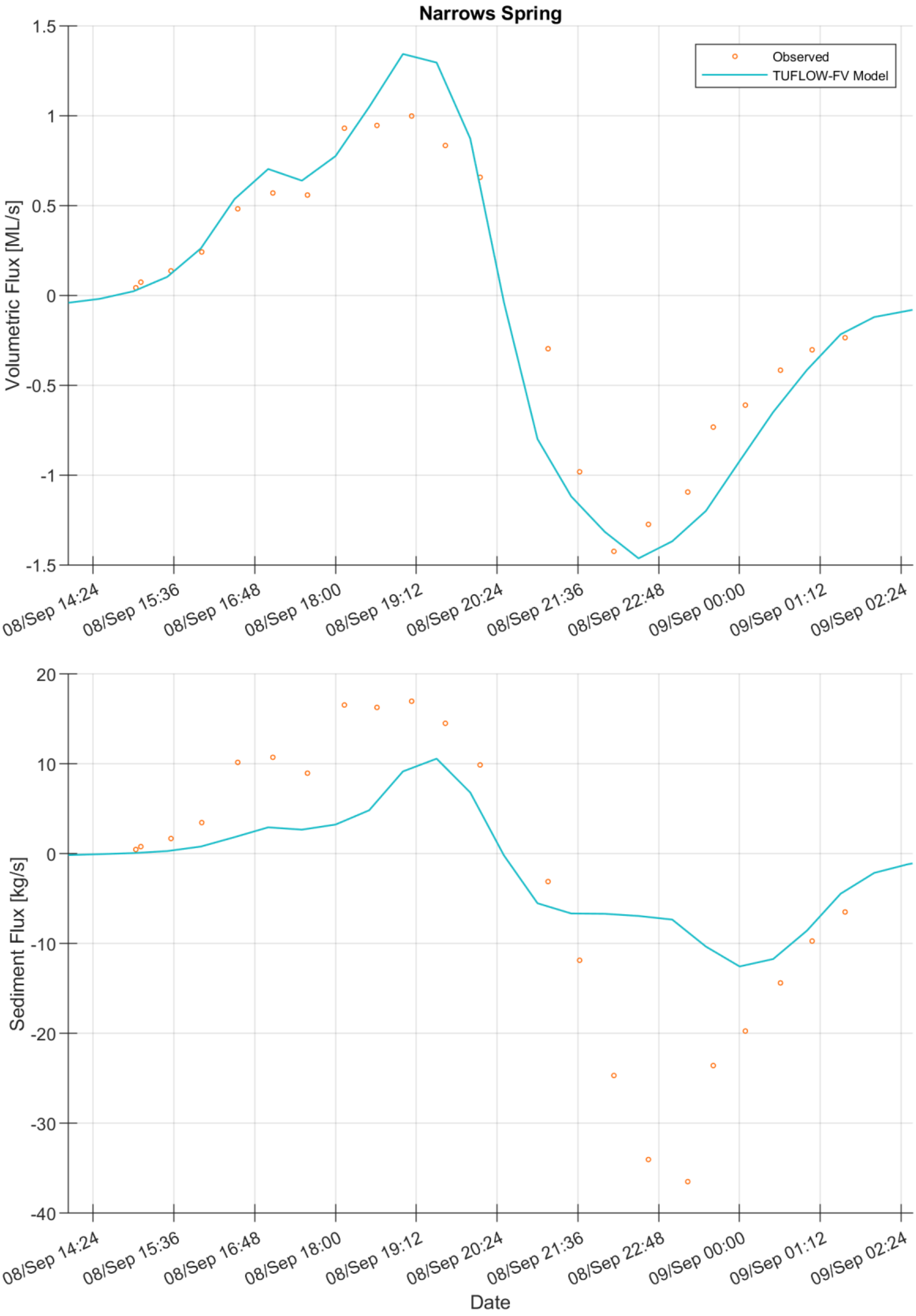


Figure 5-12 Time Series Comparison of Modelled and Observed Transect Flow Rate (Top) and Sediment Mass Flux (Bottom) at Narrows During Spring Tide Conditions

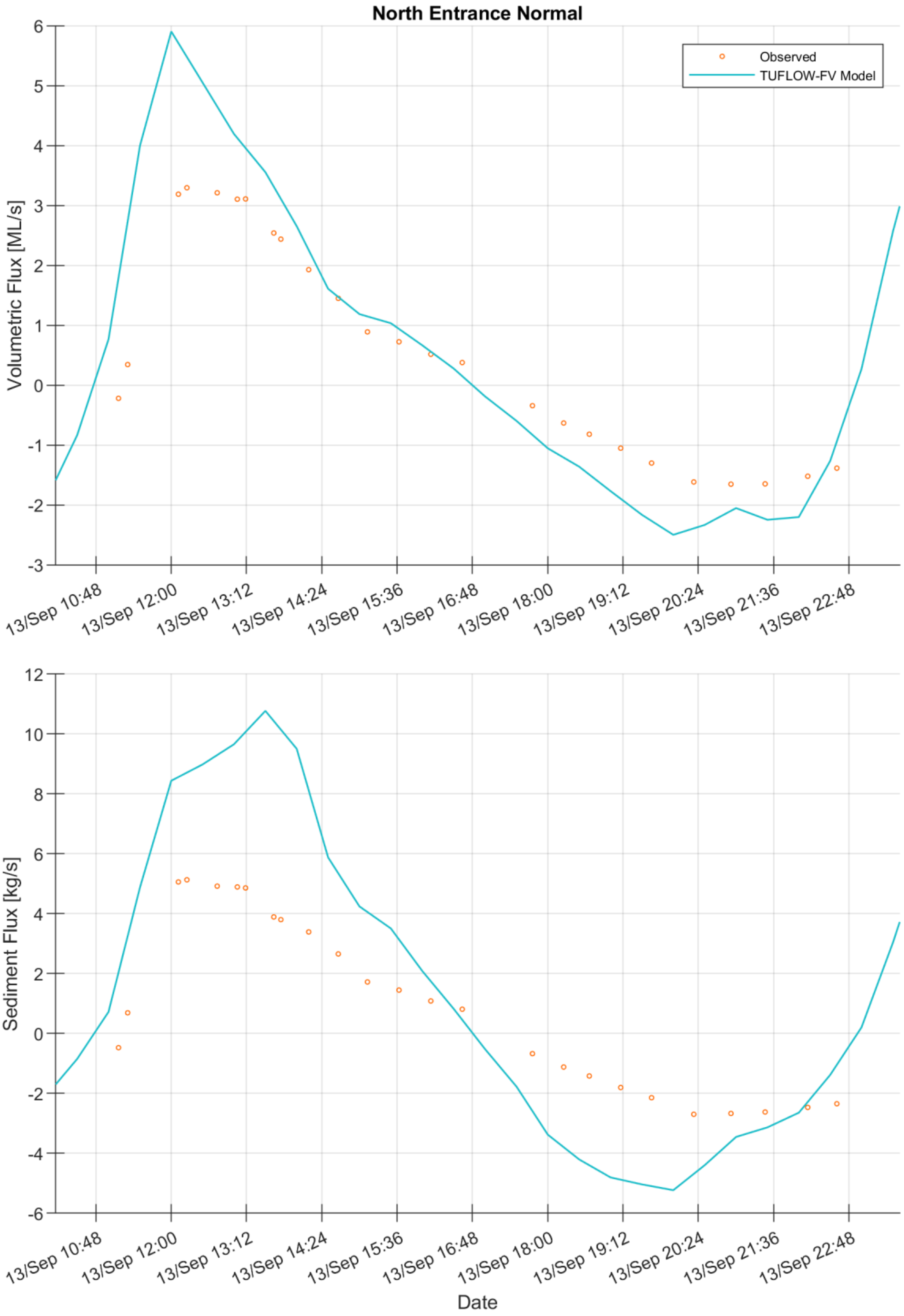


Figure 5-13 Time Series Comparison of Modelled and Observed Transect Flow Rate (Top) and Sediment Mass Flux (Bottom) at North Entrance During Normal Tide Conditions

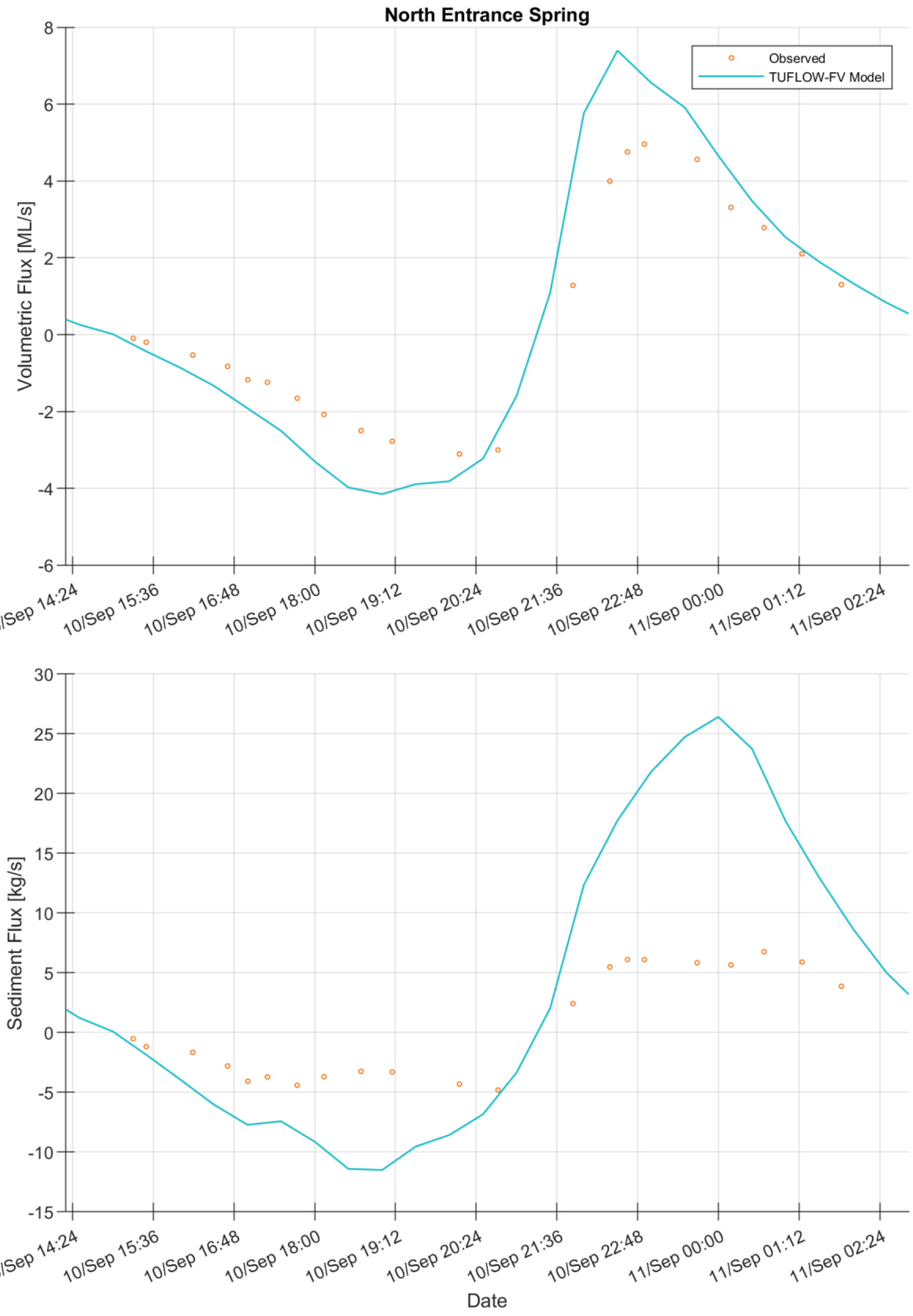


Figure 5-14 Time Series Comparison of Modelled and Observed Transect Flow Rate (Top) and Sediment Mass Flux (Bottom) at North Entrance During Spring Tide Conditions

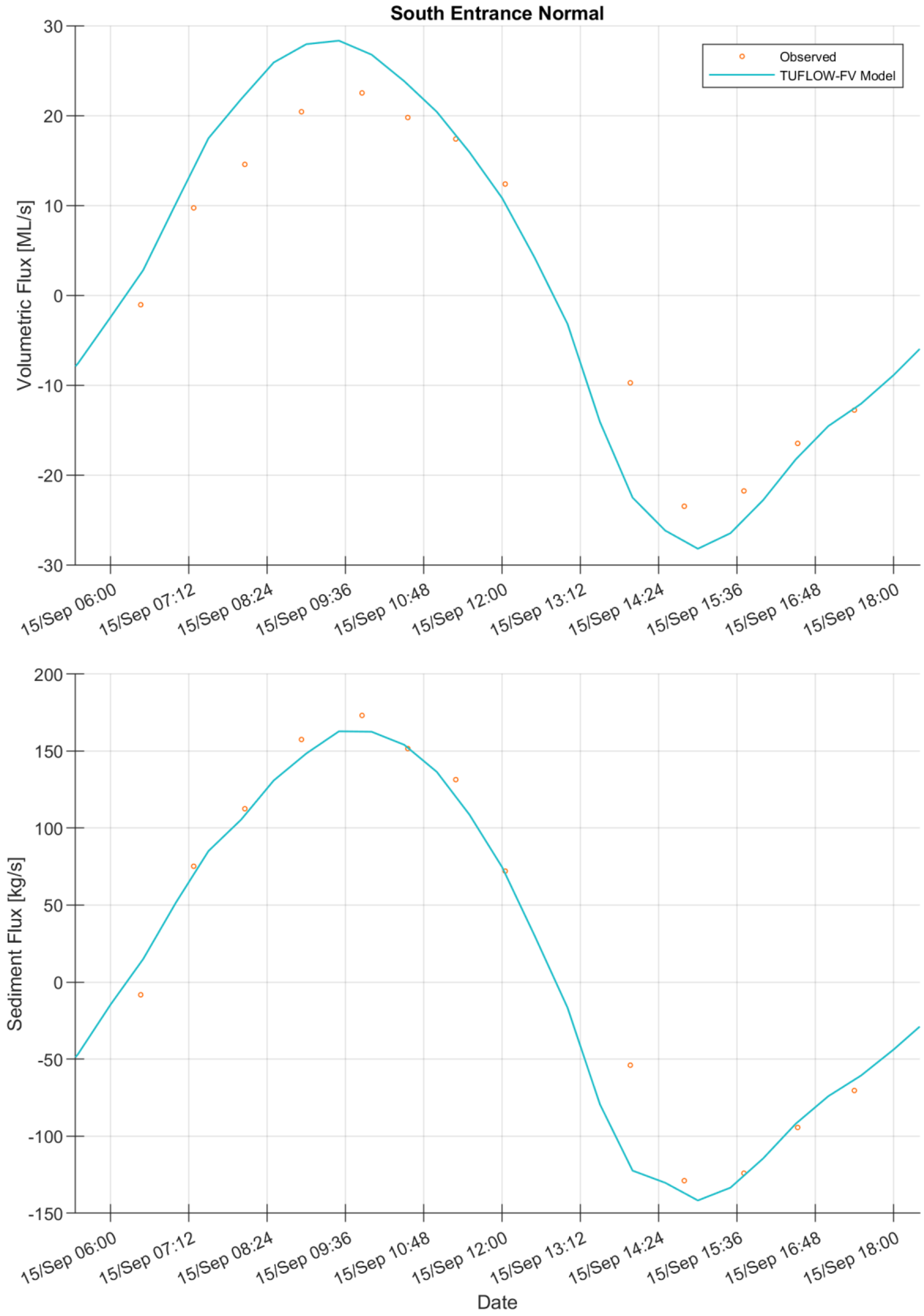


Figure 5-15 Time Series Comparison of Modelled and Observed Transect Flow Rate (Top) and Sediment Mass Flux (Bottom) at South Entrance During Normal Tide Conditions

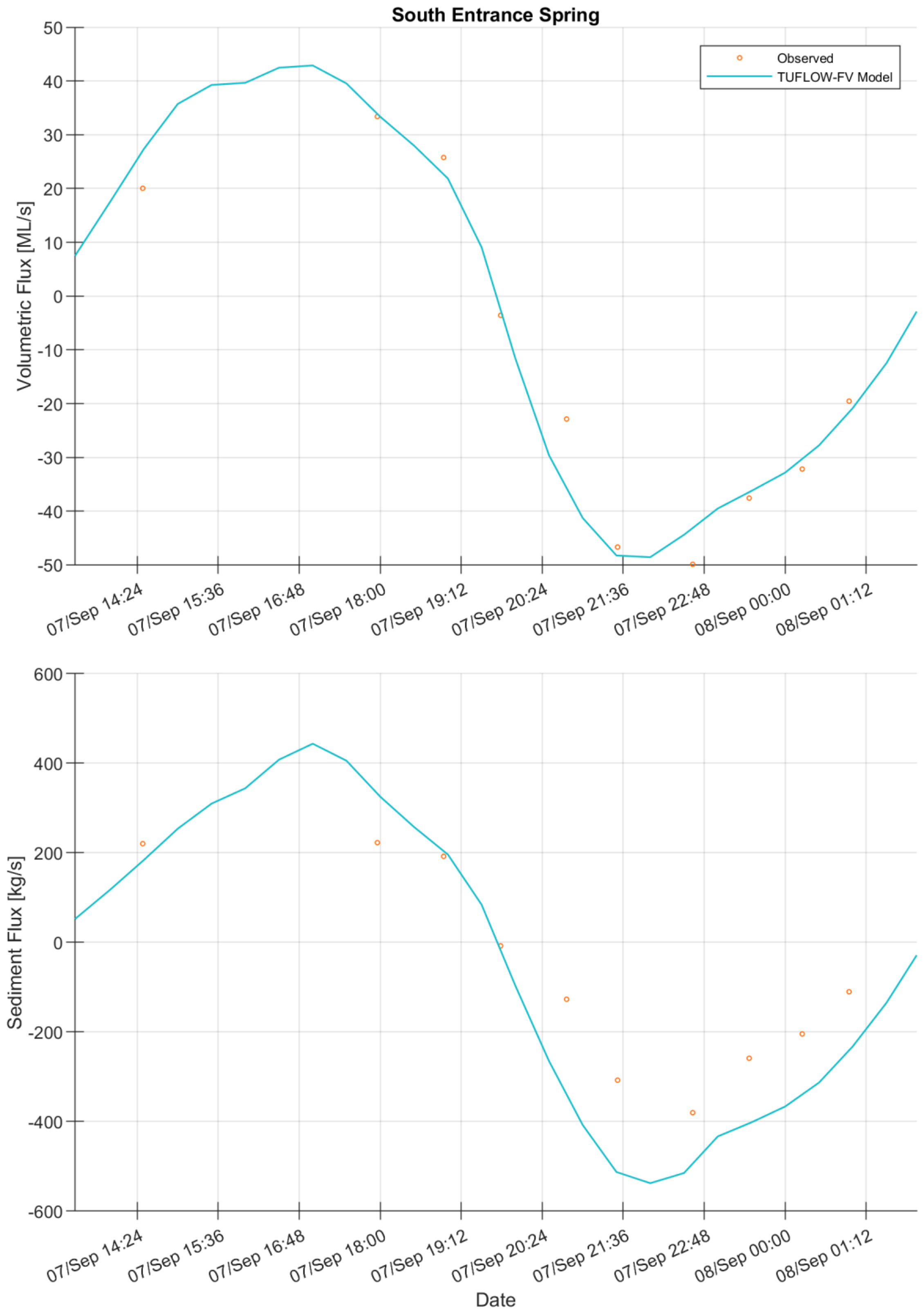


Figure 5-16 Time Series Comparison of Modelled and Observed Transect Flow Rate (Top) and Sediment Mass Flux (Bottom) at South Entrance During Normal Tide Conditions

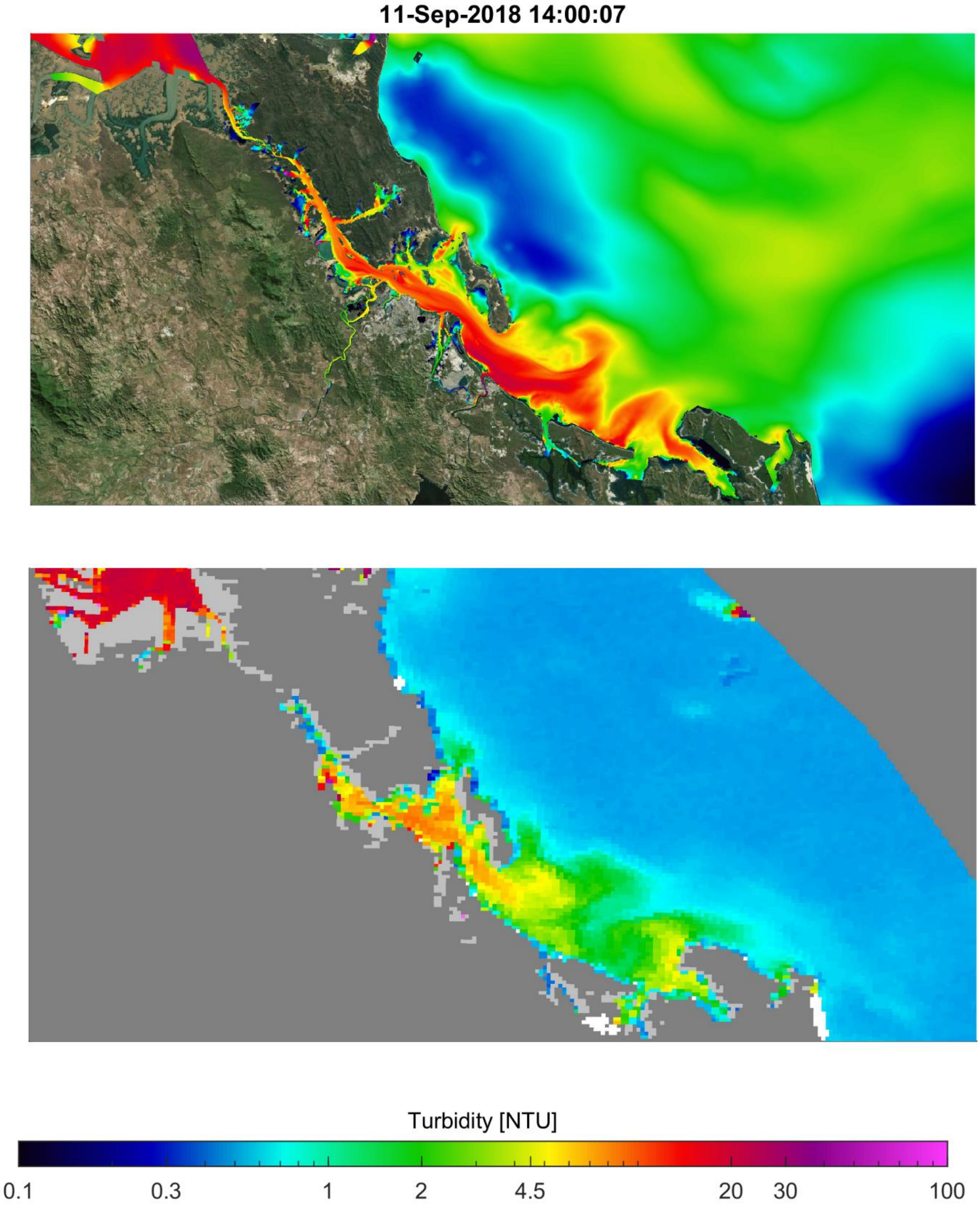


Figure 5-17 Modelled Turbidity (Top) Compared to Satellite-Derived Turbidity (Bottom) 11 Sep 2018

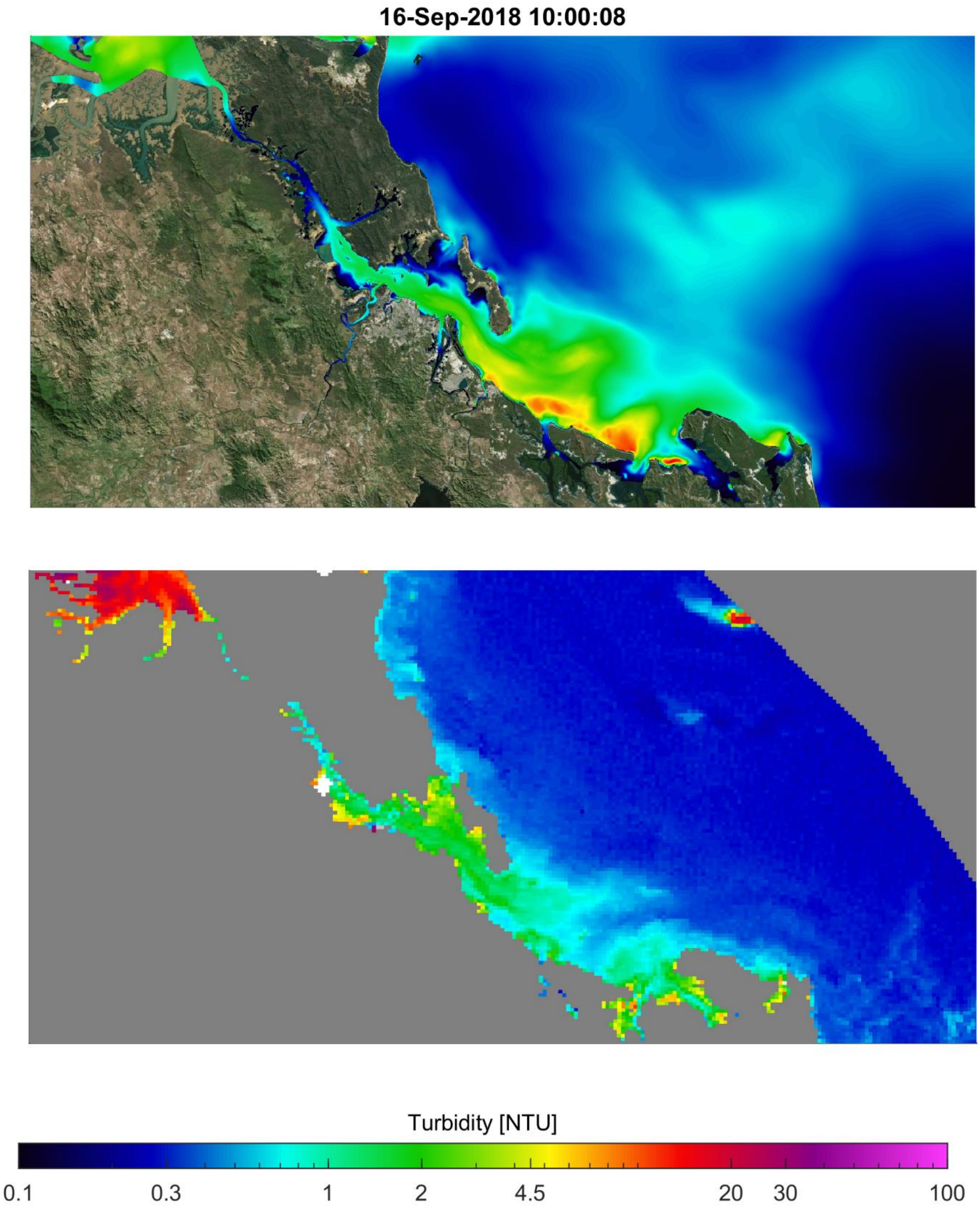


Figure 5-18 Modelled Turbidity (Top) Compared to Satellite-Derived Turbidity (Bottom) 16 Sep 2018

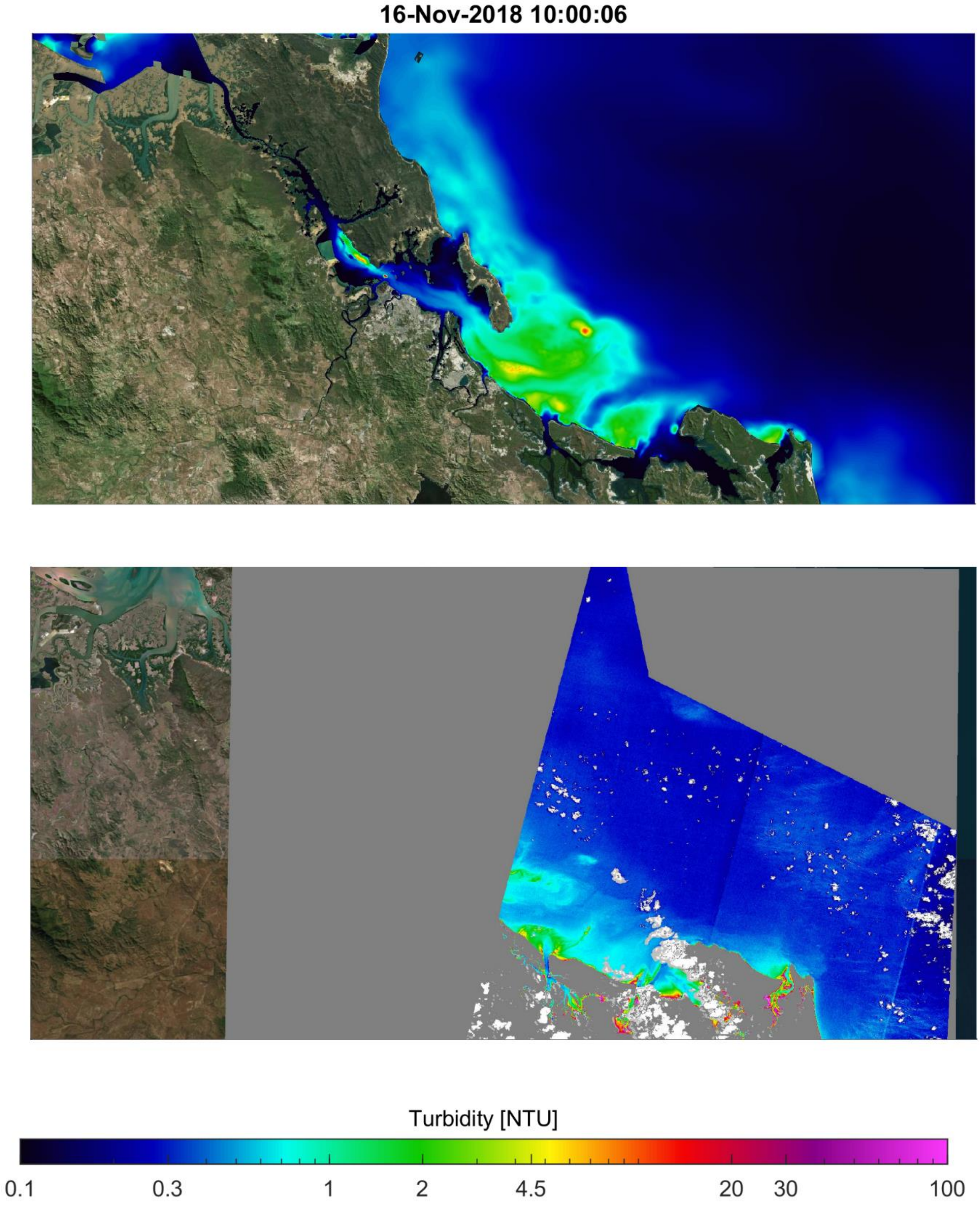


Figure 5-19 Modelled Turbidity (Top) Compared to Satellite-Derived Turbidity (Bottom) 16 Nov 2018

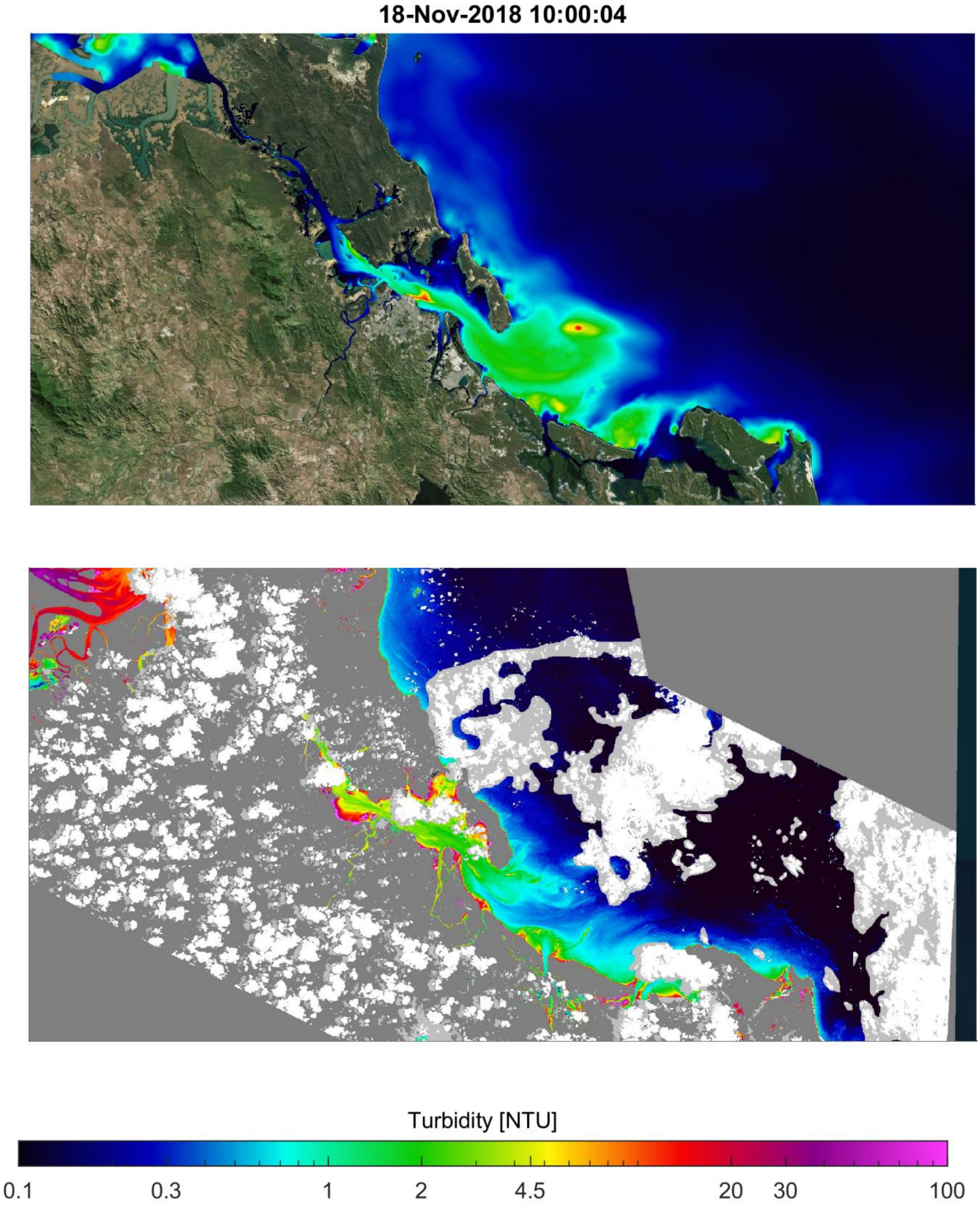


Figure 5-20 Modelled Turbidity (Top) Compared to Satellite-Derived Turbidity (Bottom) 18 Nov 2018

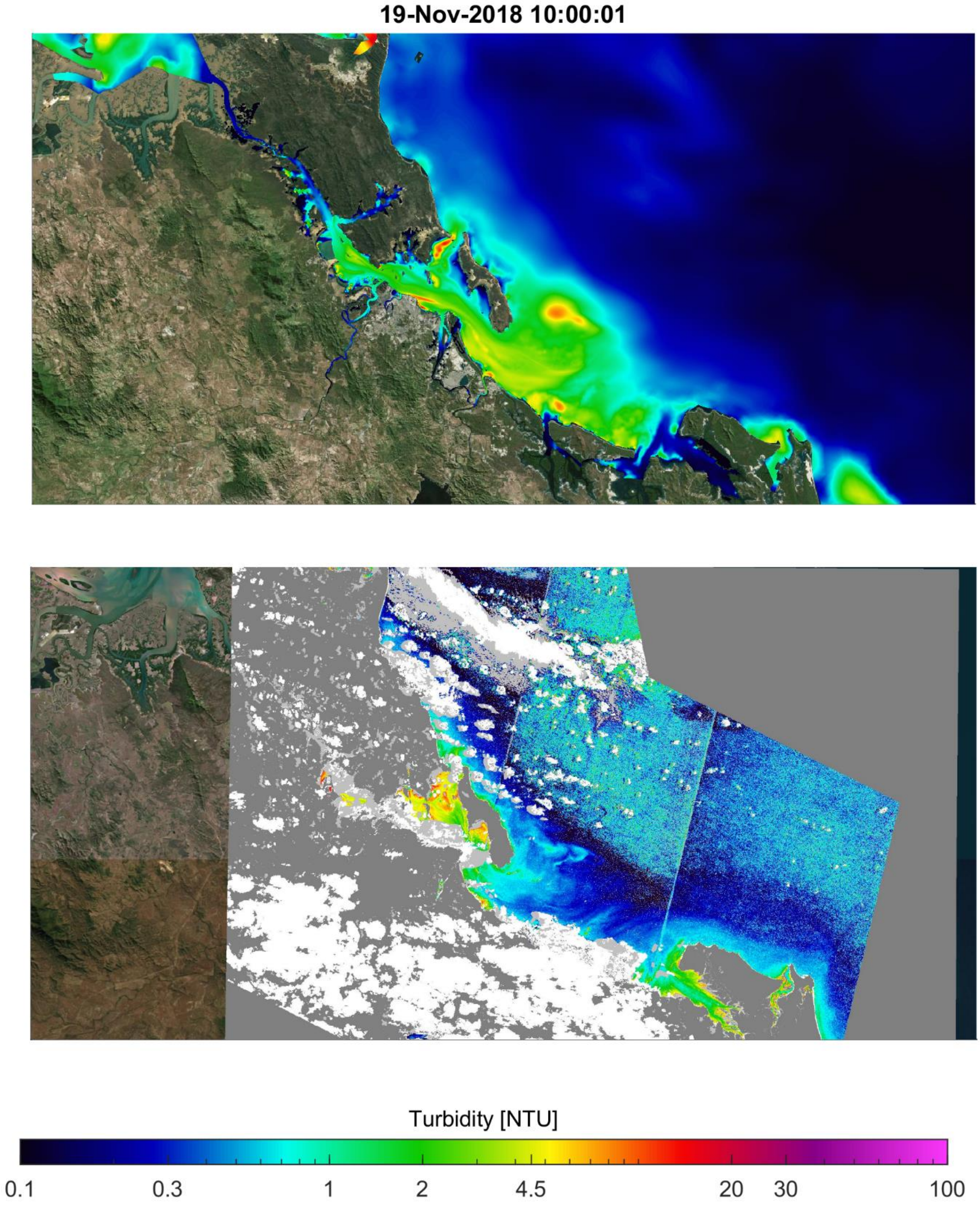


Figure 5-21 Modelled Turbidity (Top) Compared to Satellite-Derived Turbidity (Bottom) 19 Nov 2018

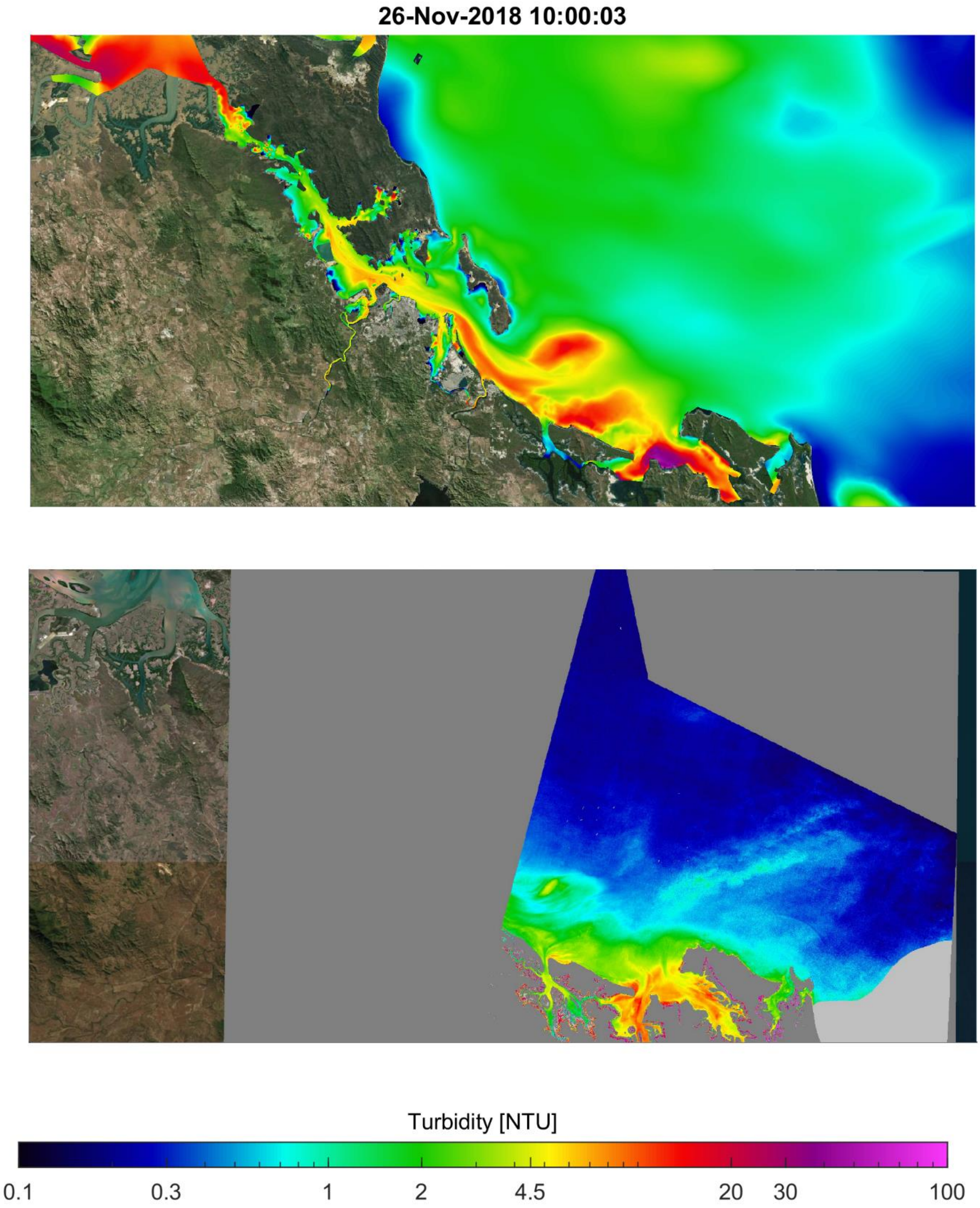


Figure 5-22 Modelled Turbidity (Top) Compared to Satellite-Derived Turbidity (Bottom) 26 Nov 2018

6 Model Hindcasts and Validation

Two additional hindcast simulations for the PoG were undertaken using the calibrated model to provide input data to the quantitative sediment budget and to assess the resuspension and transport of ambient and dredging-related sediment for a wider range of metocean conditions.

6.1 2012 – 2013 Hindcast

The 2012-2013 hindcast period (01/10/2012 – 01/06/2013) was characterised by extreme rainfall events in the Gladstone region which resulted in significant discharge of turbid water from river systems into Port of Gladstone and surrounding coastal waterbodies. A hydrograph from the Calliope river from the simulation period is shown in Figure 6-1. Flows for the Fitzroy, Calliope, Boyne and minor catchments were provided as inputs to the numerical model together with the best available estimates of the associated TSS.

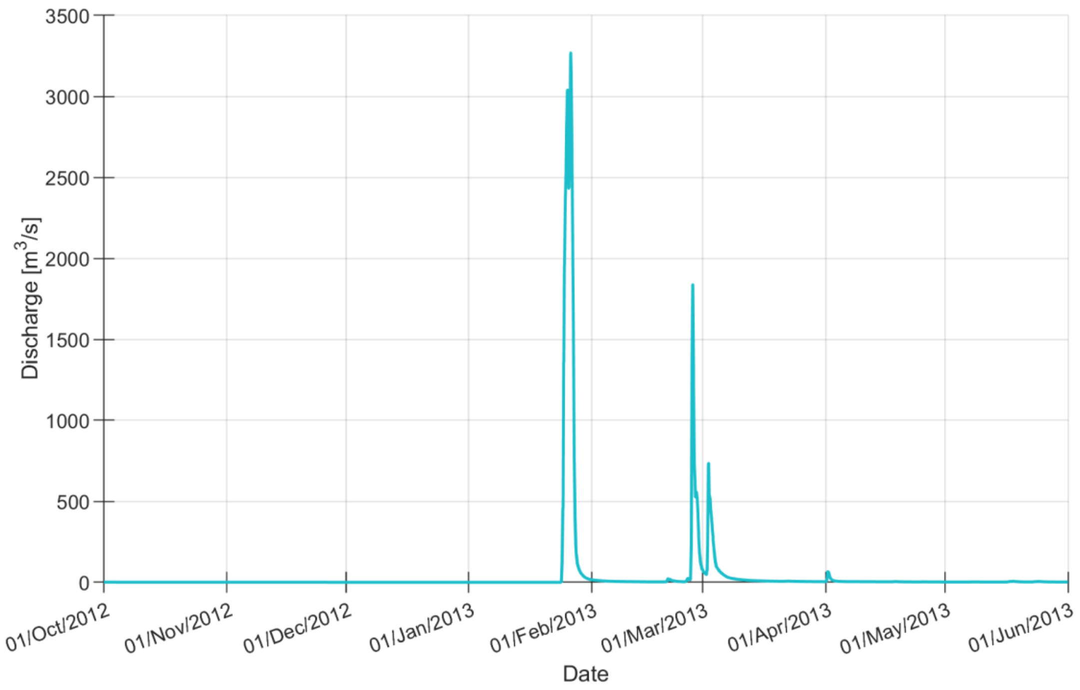
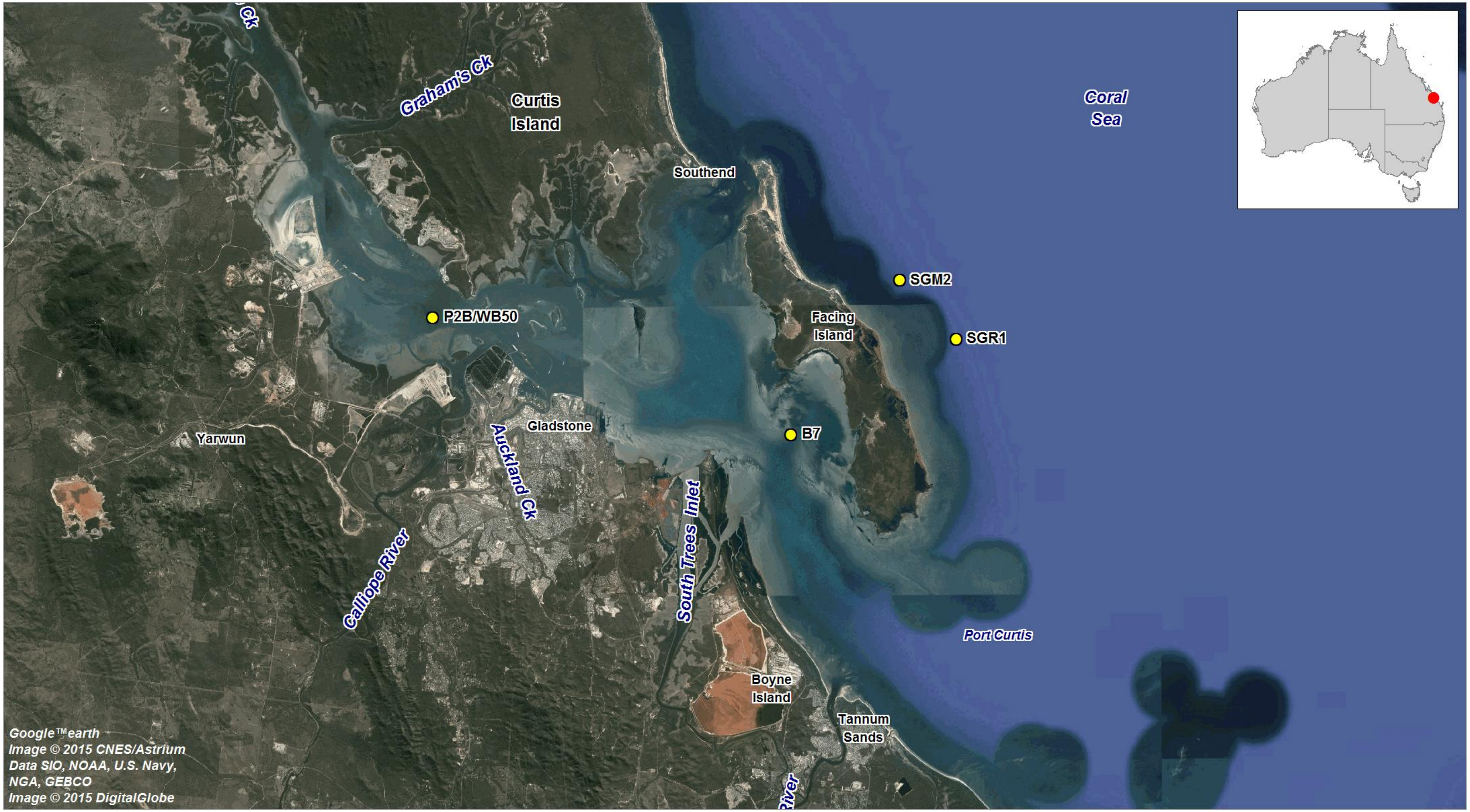


Figure 6-1 Calliope Hydrograph from the Castlehope Gauge (Department of Natural Resources and Mines, 2019)

The model was validated with turbidity data that was collected as part of a previous PoG project "Prioritisation of Reef Restoration and Enhancement Sites – Phase 2 and 3" (BMT, 2015b). As was done in the previous modelling work, to account for the different composition and bio-turbidity levels of sea and fresh water, conversion factors to derive turbidity from TSS were linearly scaled from 0.63 for seawater to 1.6 for fresh water. Locations where turbidity data was collected as part of the previous study are shown in Figure 6-2. Time series comparisons of modelled and observed turbidity at several inner and outer harbour locations are provided in Figure 6-3 to Figure 6-6.



LEGEND

● Instrument Location

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Measurement Locations 2012-2013

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6-2

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0km 5 10

Approx. Scale

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As shown in Figure 6-1, two large runoff events occurred during the simulation period. The turbidity signal associated with these two events is reasonably resolved by the model, specifically at location WB50 (Figure 6-4). It should be noted that there was also a period of energetic wave conditions associated with the same storm event and as such elevated turbidity at offshore locations is likely due to wave driven suspension of ambient sediment, at SGM2 for example (Figure 6-5).

In general terms, the model tends to under-estimate the turbidity at some of the in-harbour sites (WB50, B7), and over-estimate the turbidity on some occasions at the offshore sites (SGM2, SGR1). Some level of disagreement is to be expected due to the complexity of the modelling task.

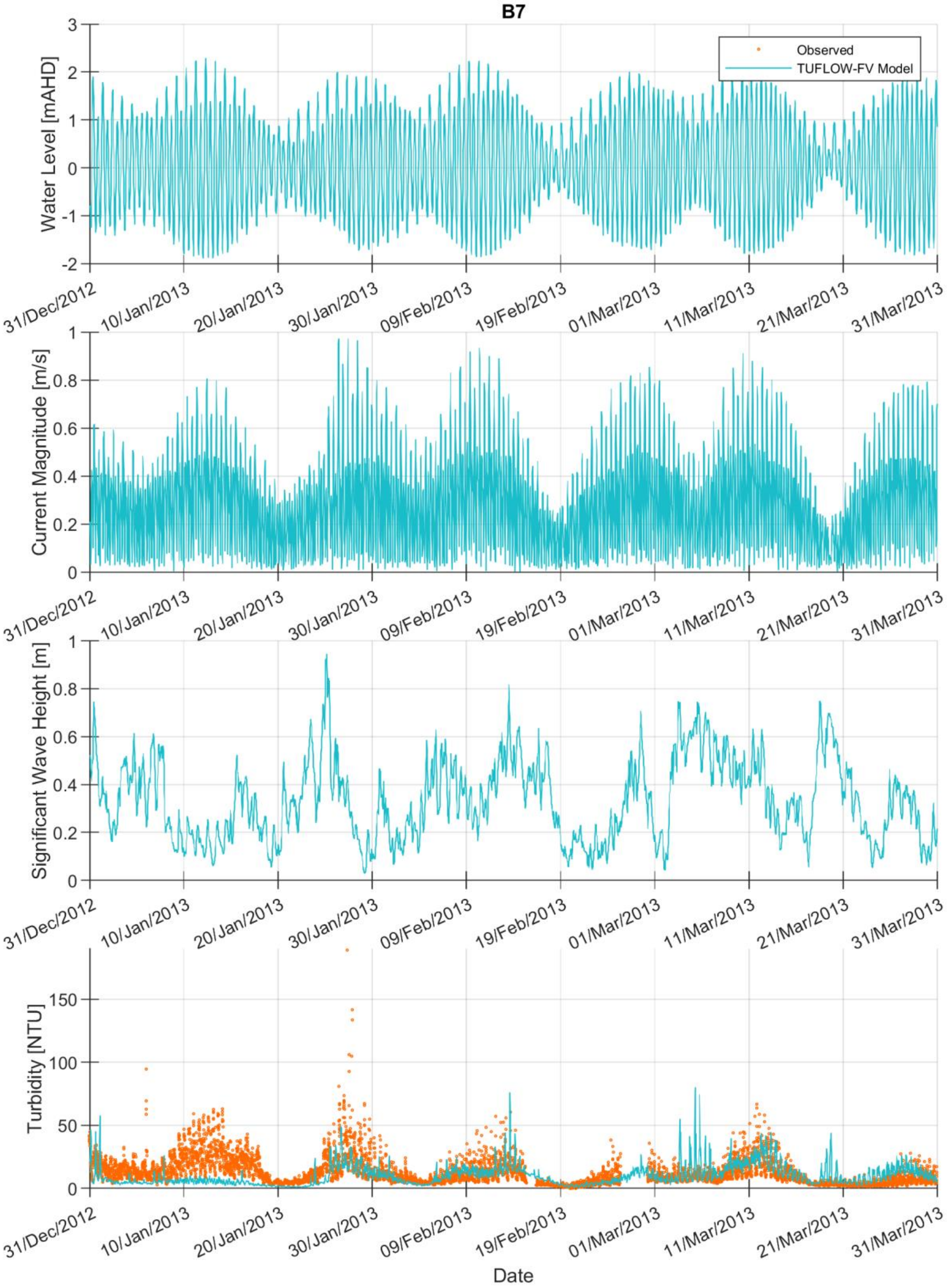

Figure 6-3 Time series Comparison of Modelled and Observed Water Level (Top), Current Magnitude (Centre Top), Sig. Wave Height (Centre Bottom) and Turbidity (Bottom) at B7

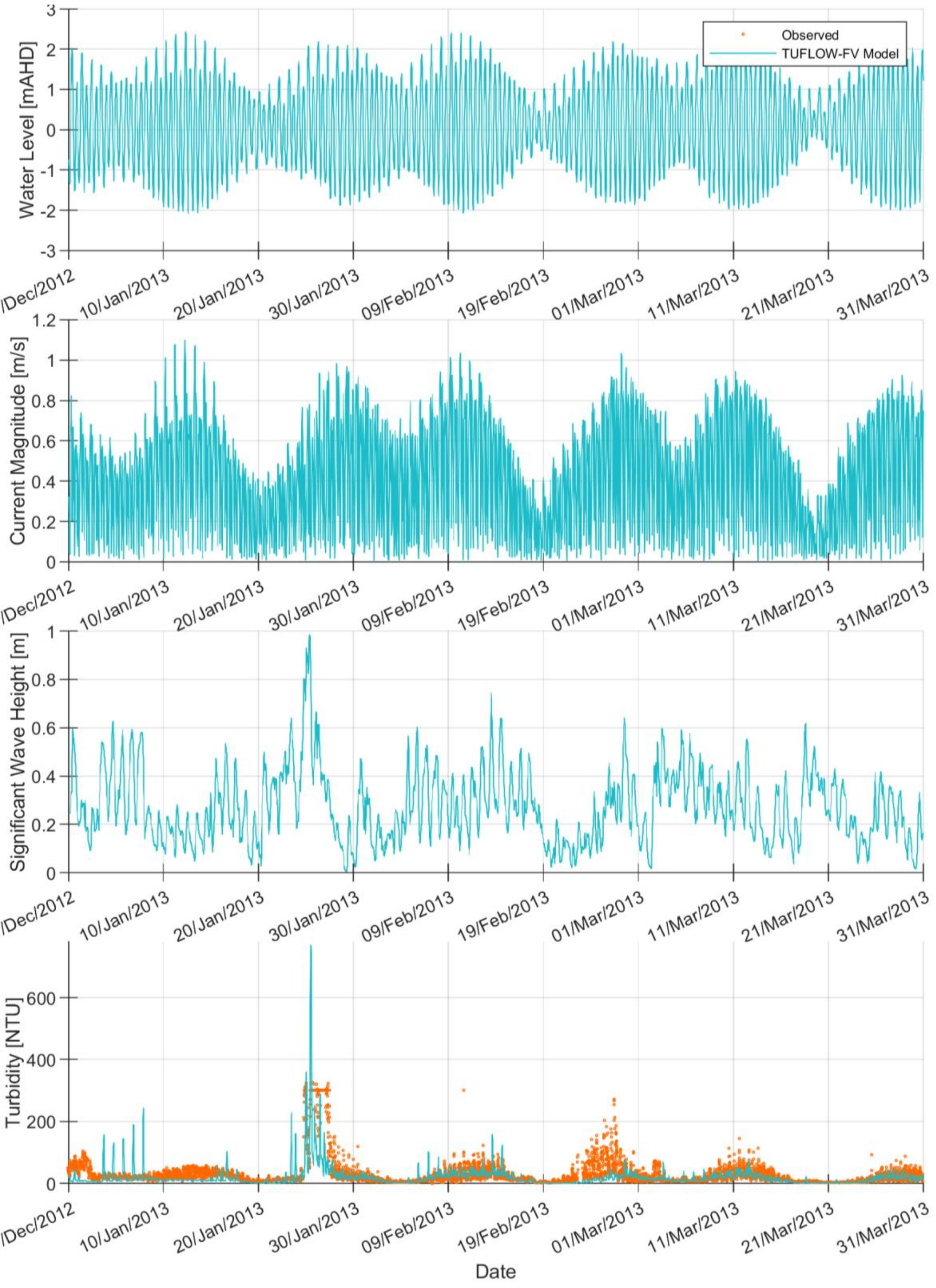

Figure 6-4 Time series Comparison of Modelled and Observed Water Level (Top), Current Magnitude (Centre Top), Sig. Wave Height (Centre Bottom) and Turbidity (Bottom) at WB50

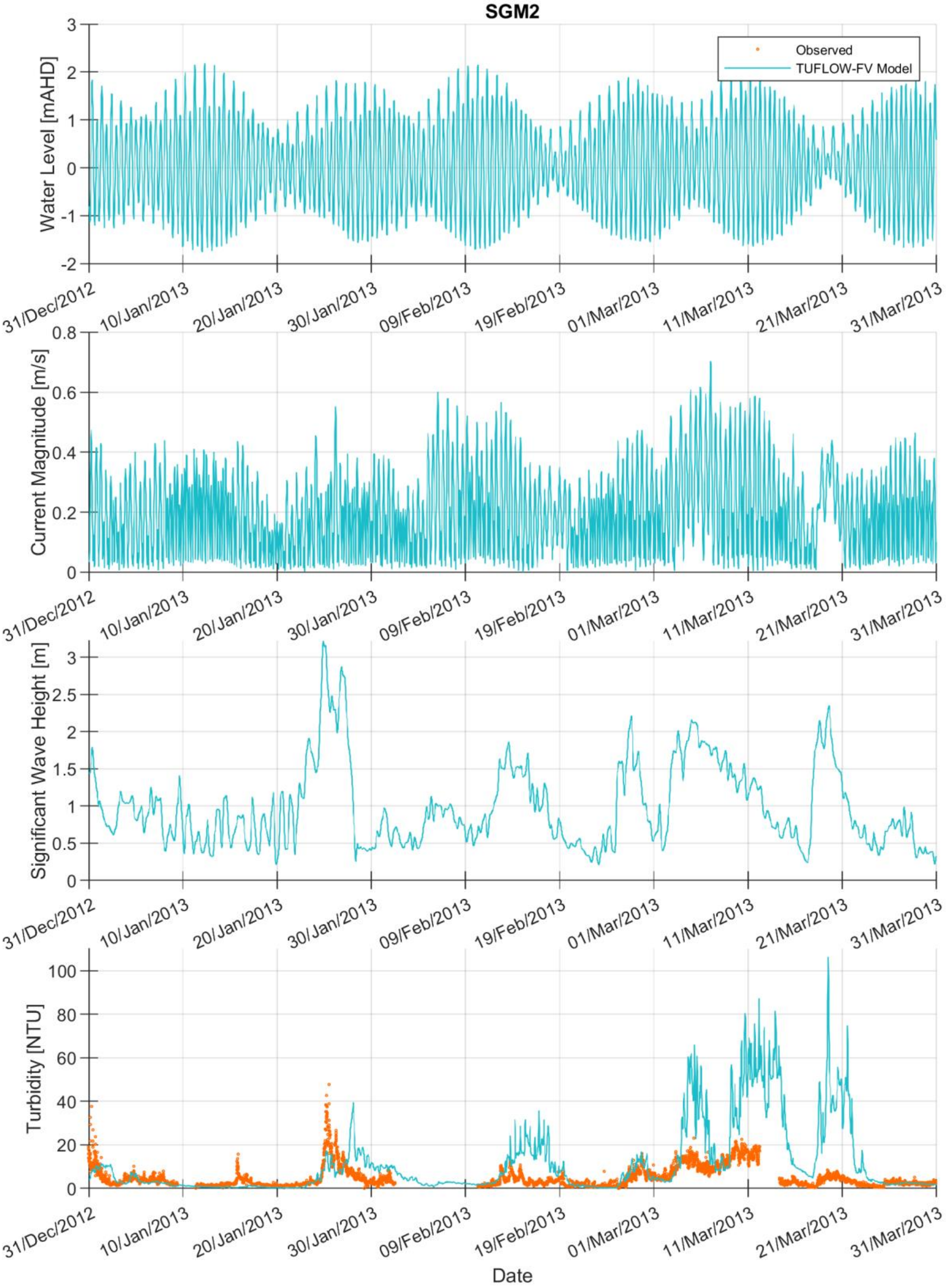

Figure 6-5 Time series Comparison of Modelled and Observed Water Level (Top), Current Magnitude (Centre Top), Sig. Wave Height (Centre Bottom) and Turbidity (Bottom) at SGM2

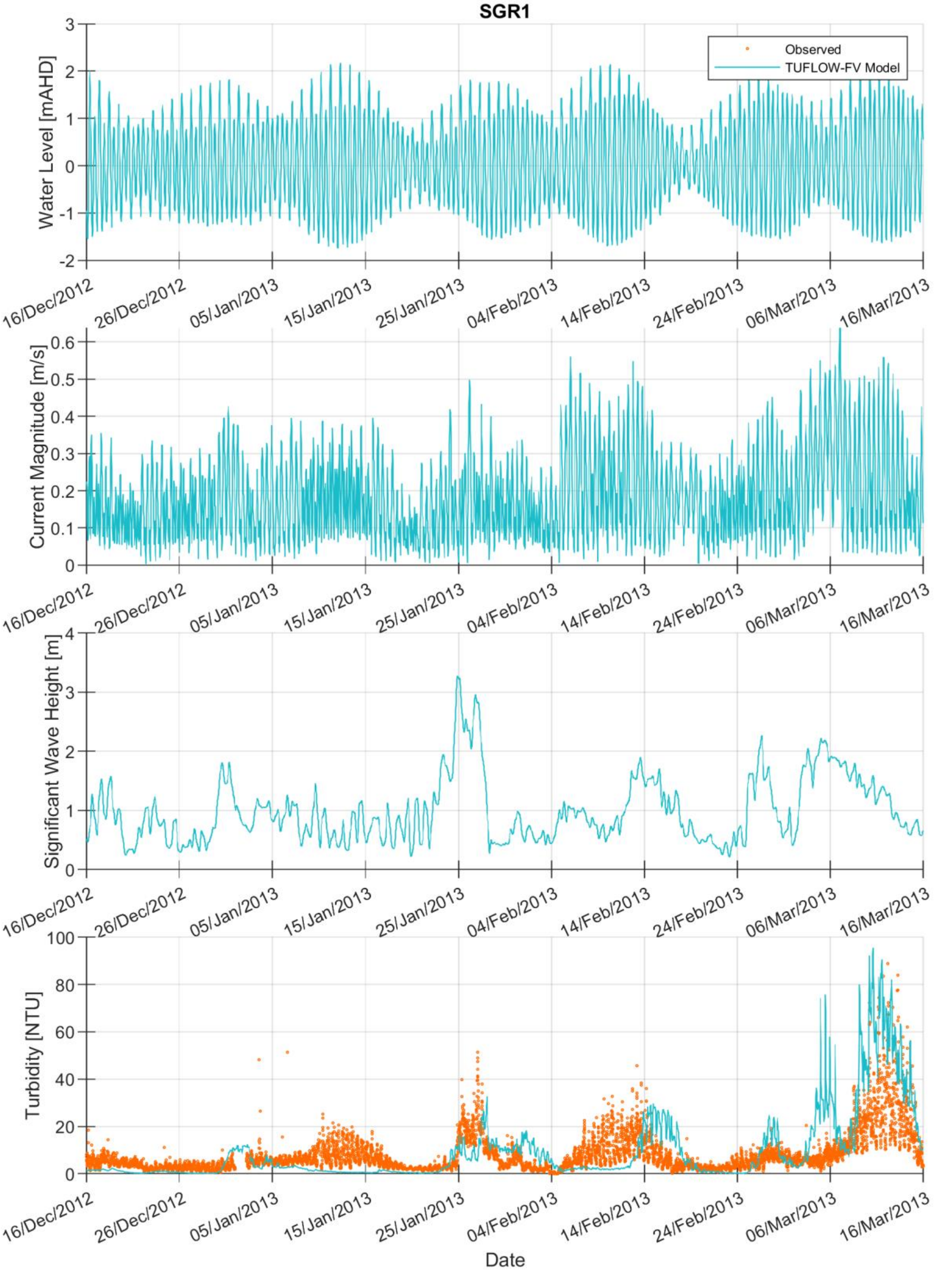

Figure 6-6 Time series Comparison of Modelled and Observed Water Level (Top), Current Magnitude (Centre Top), Sig. Wave Height (Centre Bottom) and Turbidity (Bottom) at SGR1

6.2 2014 – 2015 Hindcast

The 2014-2015 hindcast period (01/06/2014 – 01/07/2015) is characterised as a typical year for meteorological conditions at the PoG and has previously been used as a baseline data collection and calibration period for the Gatcombe and Golding Cutting Channel Duplication Project EIS (BMT, 2019b). Turbidity data for the hindcast period was collected as part of the EIS development process. Locations where turbidity data is available are shown in Figure 6-7.

A maintenance dredging campaign was included as part of the simulation, using the same parameterisation as that adopted for the maintenance dredging cumulative case assessment in the EIS (BMT, 2019b). This was a synthetic campaign representing a ‘typical’ volume of 260,000m^3 (approximately 286,000 tonnes dry mass) of sediment removed from the shipping channels and placed at the EBSDS.

Time series comparisons of modelled and observed turbidity at several inner and outer harbour locations shown in Figure 6-8 to Figure 6-11. A similar level of performance in predicting observed turbidity is achieved in the 2014-2015 hindcast as the 2012-2013 hindcast. Model predictions of observed turbidity are generally acceptable, with the model tending to under-estimate ambient turbidity at within-harbour locations and over-estimate turbidity during some events at offshore locations. This is consistent with the outcomes of the model calibration and the 2012-2013 hindcast, and some level of inaccuracy is expected due to the complexity of the modelling task.

Google™earth
Image © 2015 CNES/Astrium
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2015 DigitalGlobe

LEGEND

○ **Instrument Location**

— **ADCP Transect**

Title:

Measurement Locations Turbidity 2014-2015

Figure: **6-7**

Rev: **A**

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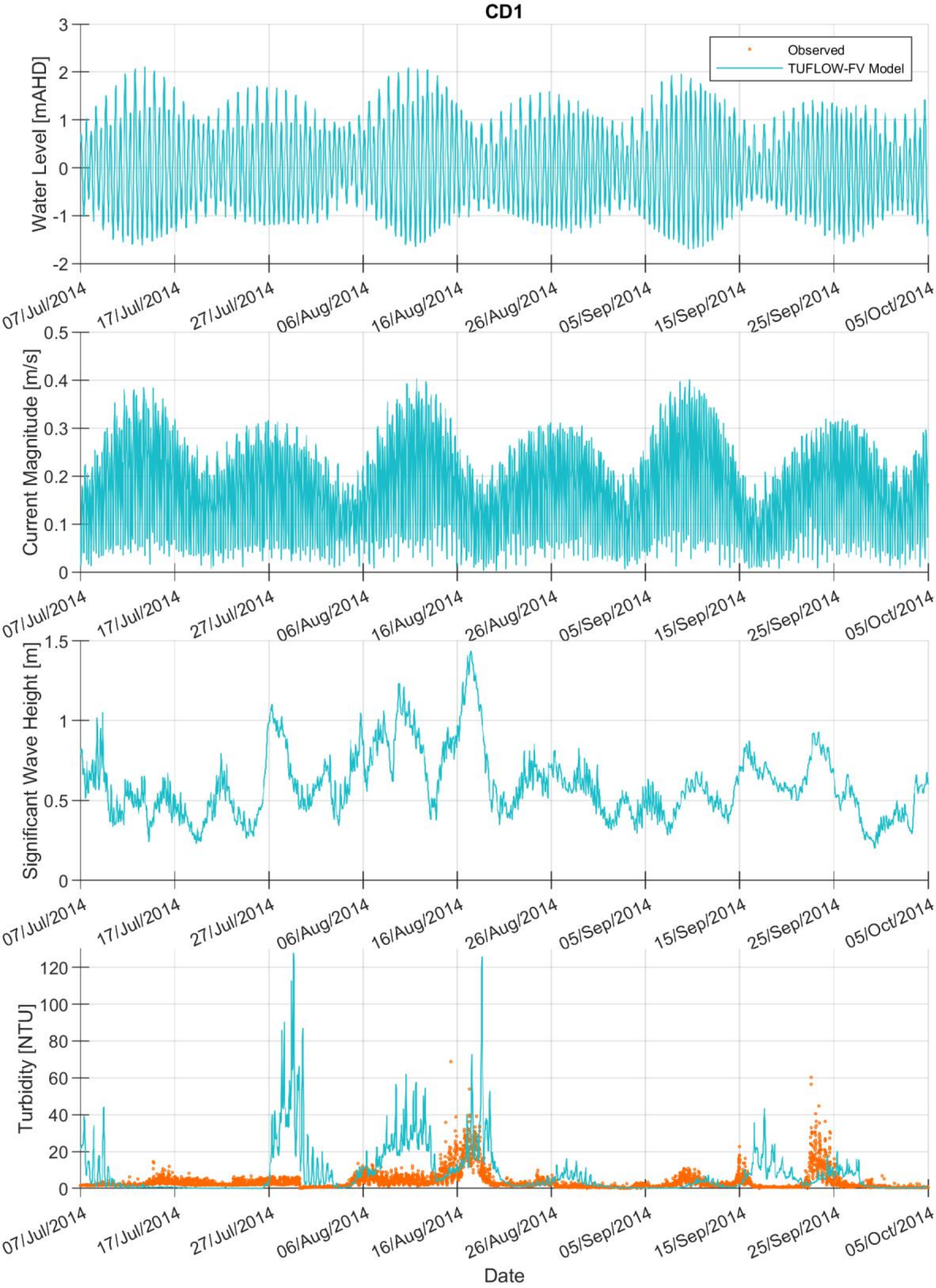

Figure 6-8 Time series Comparison of Modelled and Observed Water Level (Top), Current Magnitude (Centre Top), Sig. Wave Height (Centre Bottom) and Turbidity (Bottom) at CD1

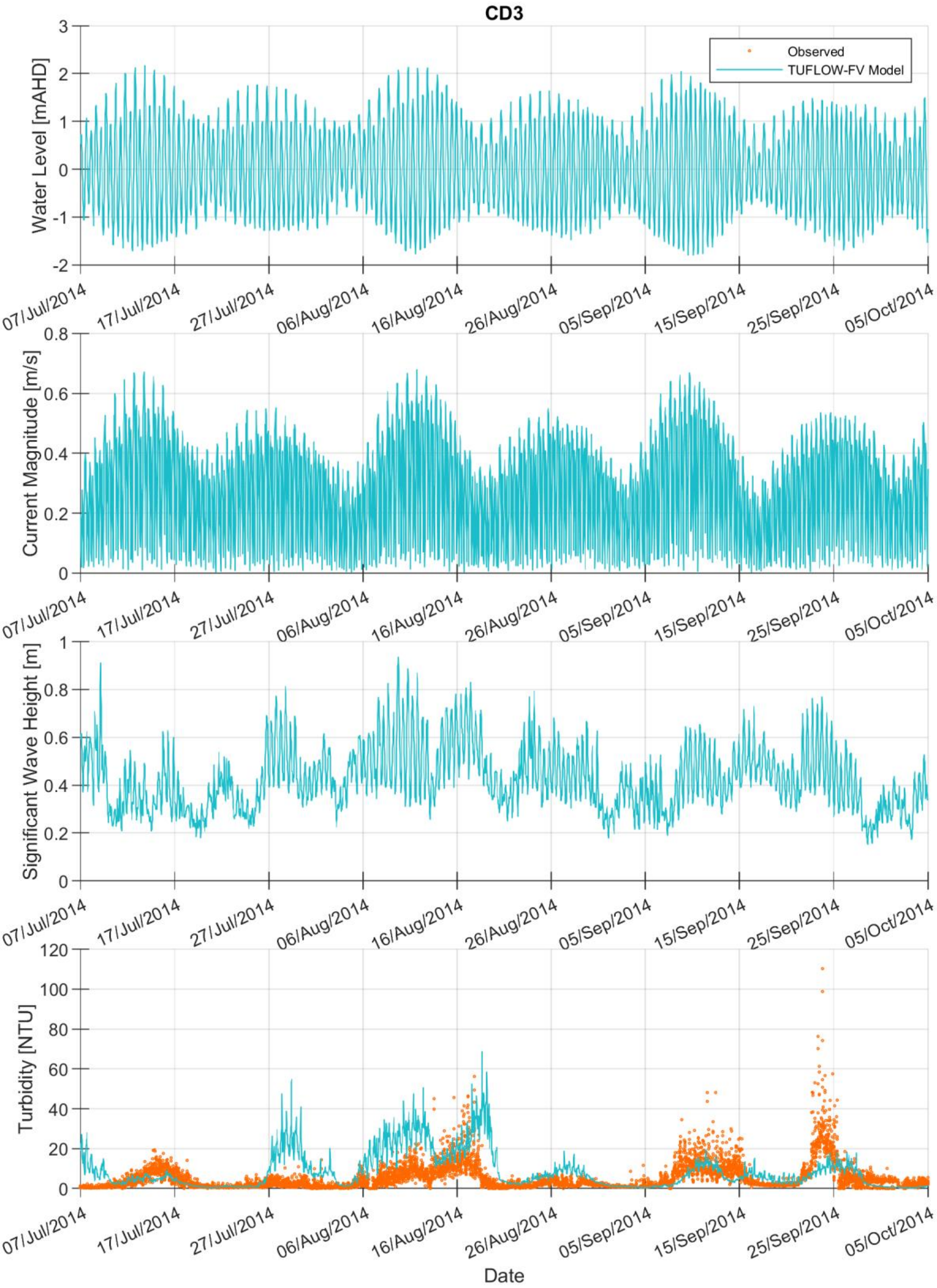

Figure 6-9 Time series Comparison of Modelled and Observed Water Level (Top), Current Magnitude (Centre Top), Sig. Wave Height (Centre Bottom) and Turbidity (Bottom) at CD3

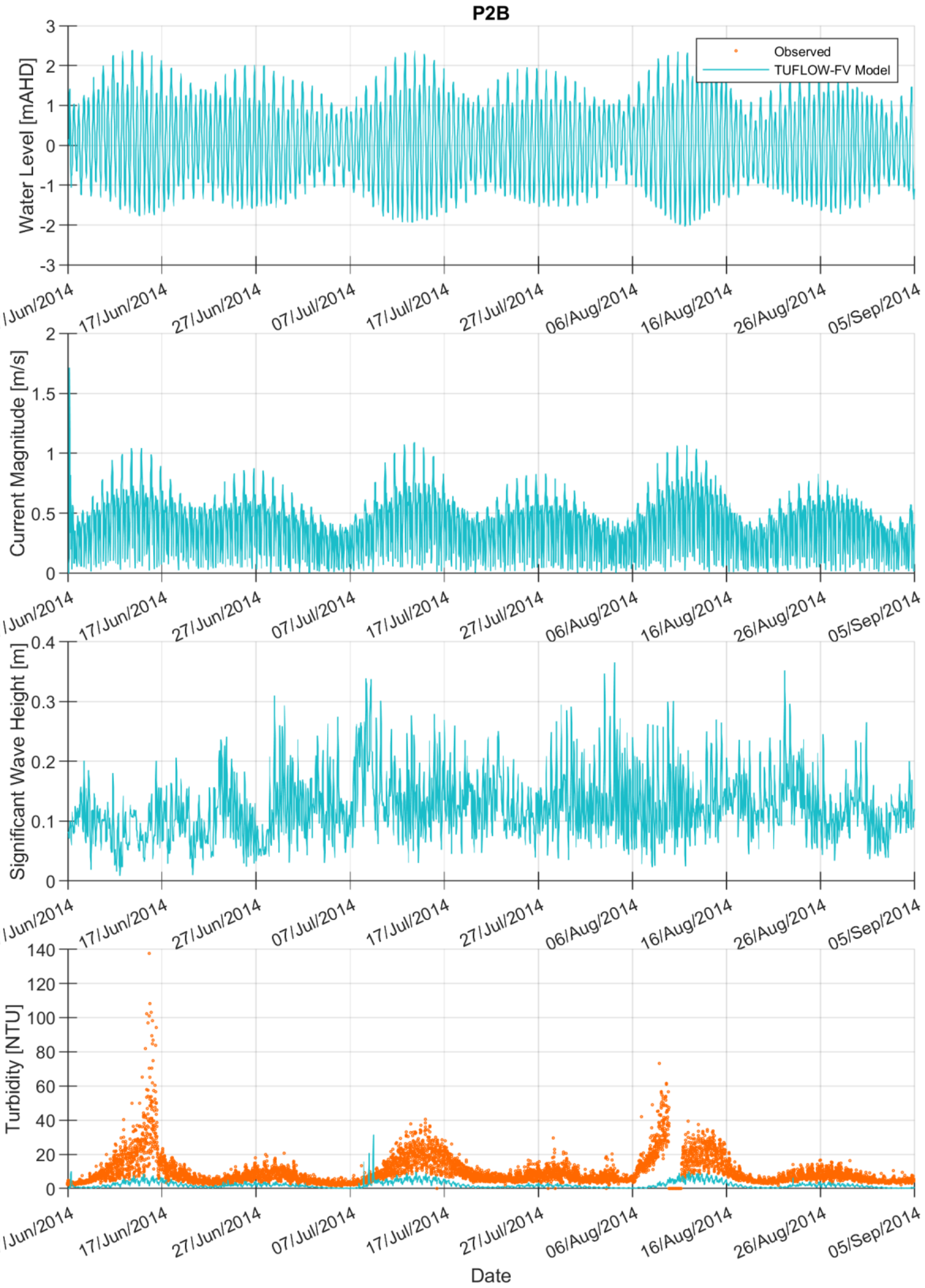

Figure 6-10 Time series Comparison of Modelled and Observed Water Level (Top), Current Magnitude (Centre Top), Sig. Wave Height (Centre Bottom) and Turbidity (Bottom) at WB50

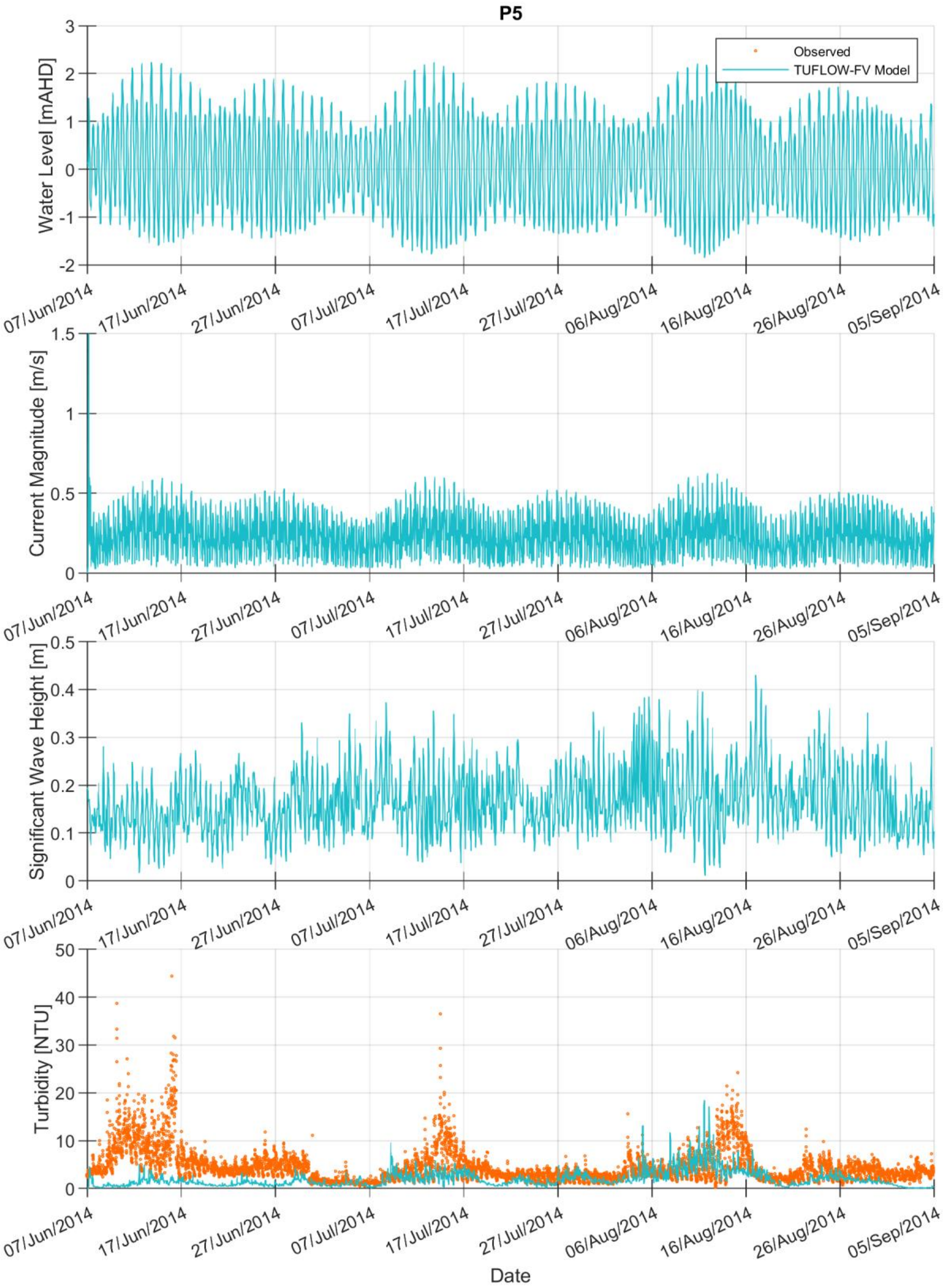

Figure 6-11 Time series Comparison of Modelled and Observed Water Level (Top), Current Magnitude (Centre Top), Sig. Wave Height (Centre Bottom) and Turbidity (Bottom) at MH10

7 Analysis of Modelled Net Sediment Transport Rates

The calibrated model results have been analysed to assess the estimated net flux of sediment into and out of the Port through each of the three main entrances (South Entrance, North Entrance, The Narrows), while noting the bias of the model towards overprediction of the net export of sediment from the Port. The results of the analysis are presented in Figure 7-1 to Figure 7-3.

The top panel of each figure shows the modelled significant wave height at the EBSDS, and the middle panel shows the modelled depth-averaged Total Suspended Solids (TSS) at the same location. The bottom panel of each figure shows the modelled cumulative sediment transport flux (in tonnes) through each transect, and the net cumulative flux into and out of the Port (cyan line).

It is apparent that the modelled cumulative flux through the biggest entrance (the South Entrance) is primarily driven by wind events during spring tides, since the trend in the net flux is not uniformly positive or negative, but shows a positive trend (into the Port) during periods of higher wave activity and a neutral (or slightly negative) trend during more quiescent periods. While this trend is likely to be realistic, it should be noted that the net predictions of the model may be biased towards export of sediment as explained in the calibration section (see Section 5). The model indicates a tendency to export sediment through the North Entrance on a fairly consistent basis (noting, though, that the model has a bias towards net export). The modelled flux through The Narrows was negligibly small for all three of the simulations, when compared to the flux through the other two entrances. Although the measured fluxes presented in Section 5 showed a similar net flux through The Narrows and the North Entrance, the fluxes at The Narrows are usually much smaller due to the smaller volume flux of water and the lower influence of wave events on the ambient turbidity. The overall net transport estimated by the model for the 2012-2013 simulation is around 280,000 tonnes net gain into the Port, which is higher than the net transport for the other two simulations due to the sediment flux associated with the January 2013 storm event (note that the mouth of the Boyne is outside the South Entrance transect, so much of the flood plume was advected into the Port). For the 2014-2015 period, the modelled influx was around 50,000 tonnes while for the 2018-2019 there was a modelled export of around 25,000 tonnes. Note, however, that these cumulative flux estimates are highly sensitive to the biases identified in the model calibration and the uncertainty in the modelled ambient sediment dynamics.

Figure 7-4 shows the location of the GBRMP boundary segment to the north of the EBSDS, and the GBRMP boundary segment to the east of the EBSDS. Figure 7-5 and Figure 7-6 show the cumulative transport of sediment across the GBRMP boundaries to the north and east of the EBSDS for the 2014-15 simulation, with and without dredging activity. It is apparent that there is a large net flux of ambient sediment from the south east to the north west, and dredging disposal activity causes only a minor increase in the total flux of sediment across the GBRMP boundary to the north of the EBSDS. Figure 7-7 and Figure 7-8 show equivalent results for the 2018-2019 simulation, and again the dredging disposal activity causes only a small increase to the cumulative net flux of sediment across the GBRMPA boundary to the north of the EBSDS.

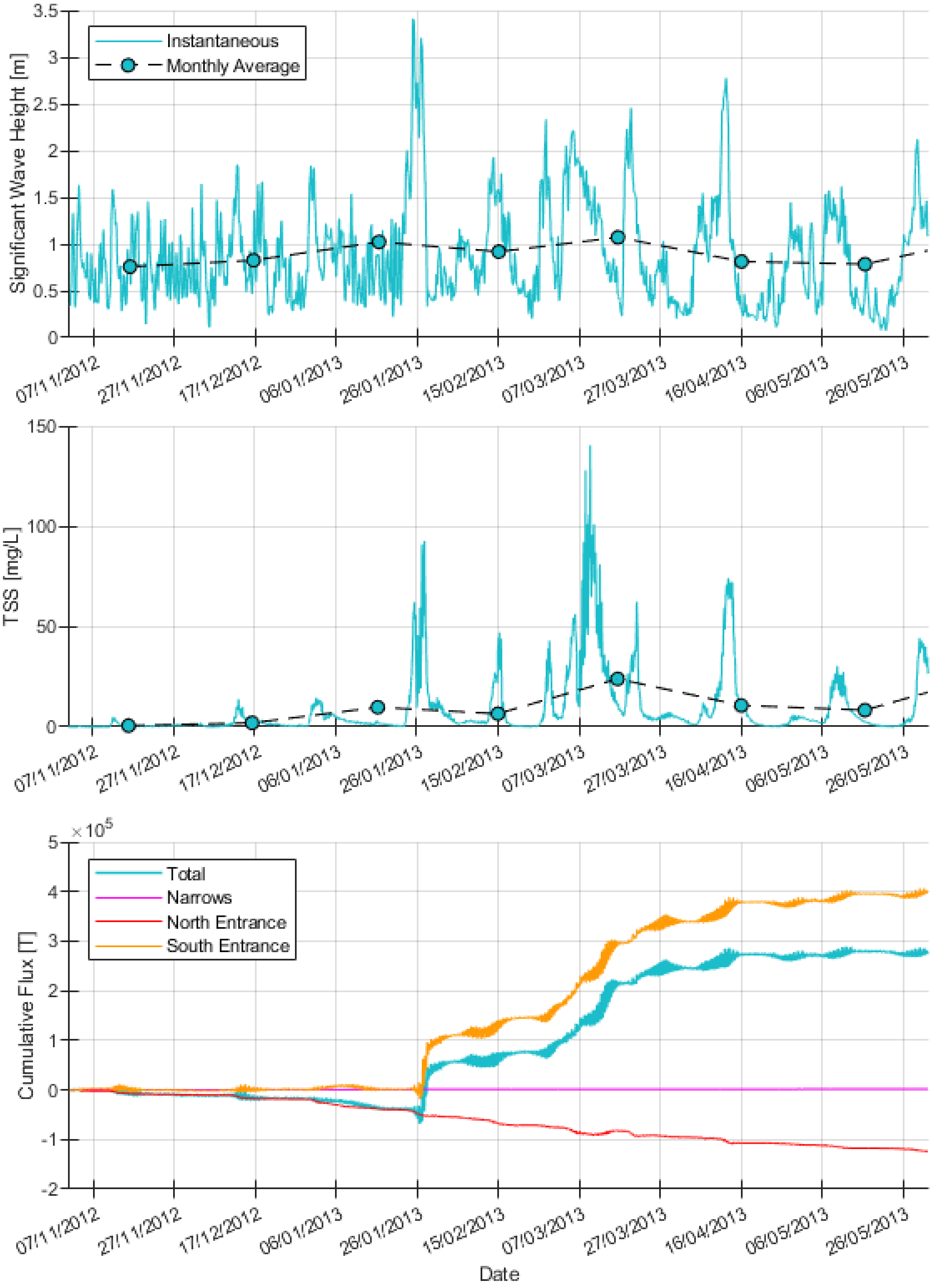

Figure 7-1 Modelled Wave Height (Top), TSS (Middle) and Cumulative Sediment Flux Across Port Entrance Transects (Bottom) for the 2012-2013 Simulation

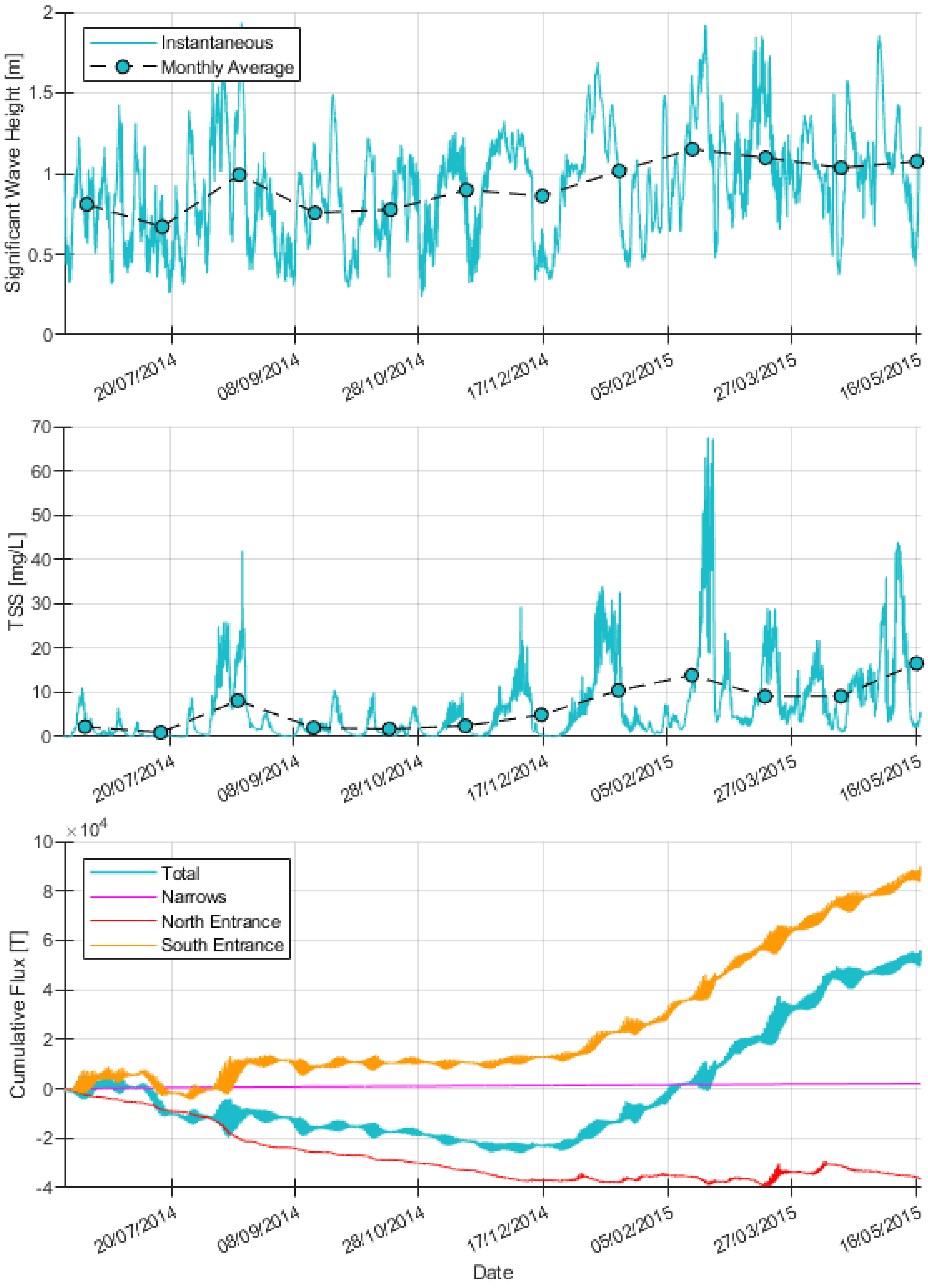

Figure 7-2 Modelled Wave Height (Top), TSS (Middle) and Cumulative Sediment Flux Across Port Entrance Transects (Bottom) for the 2014-2015 Simulation

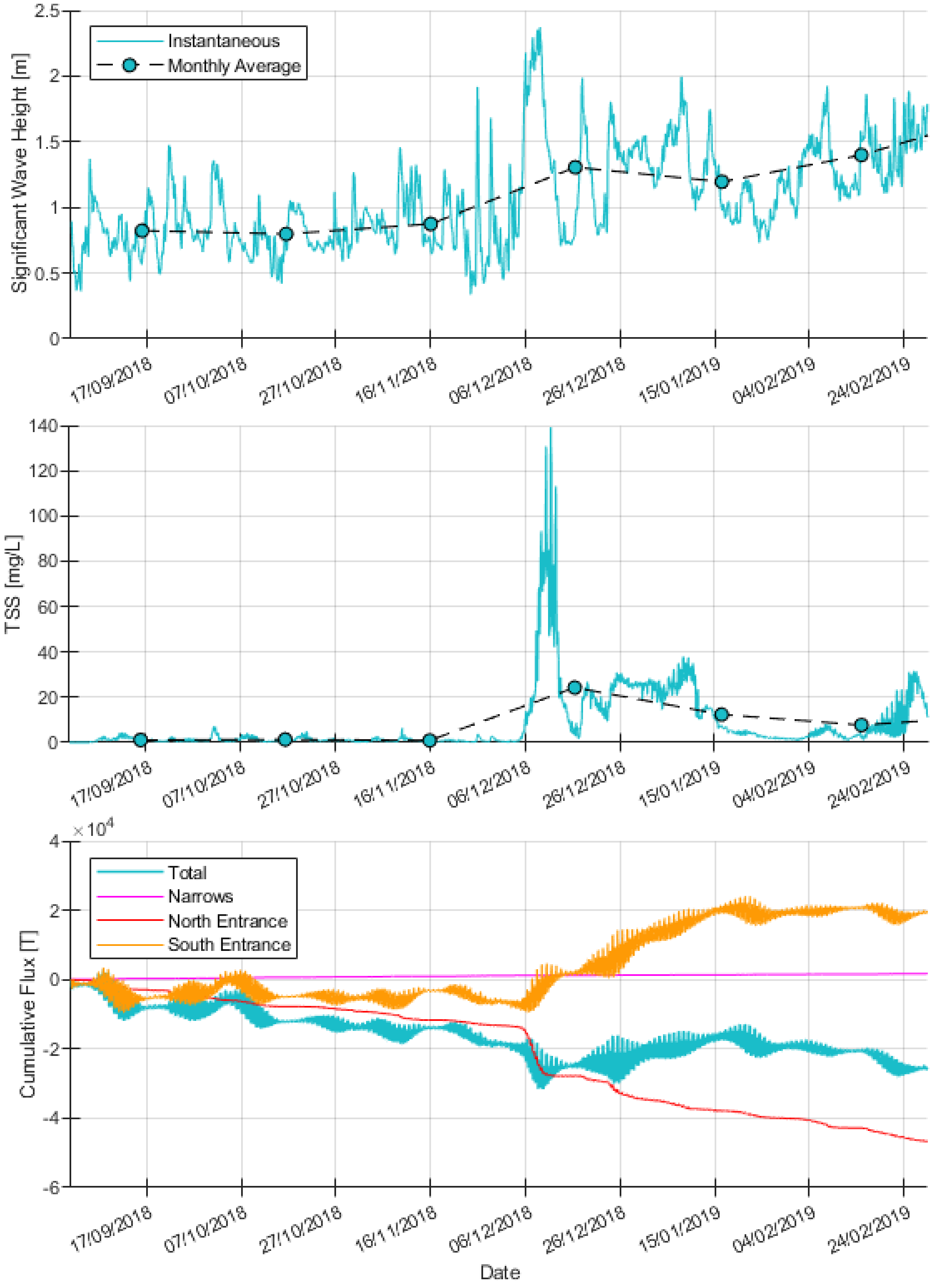

Figure 7-3 Modelled Wave Height (Top), TSS (Middle) and Cumulative Sediment Flux Across Port Entrance Transects (Bottom) for the 2018-2019 Simulation

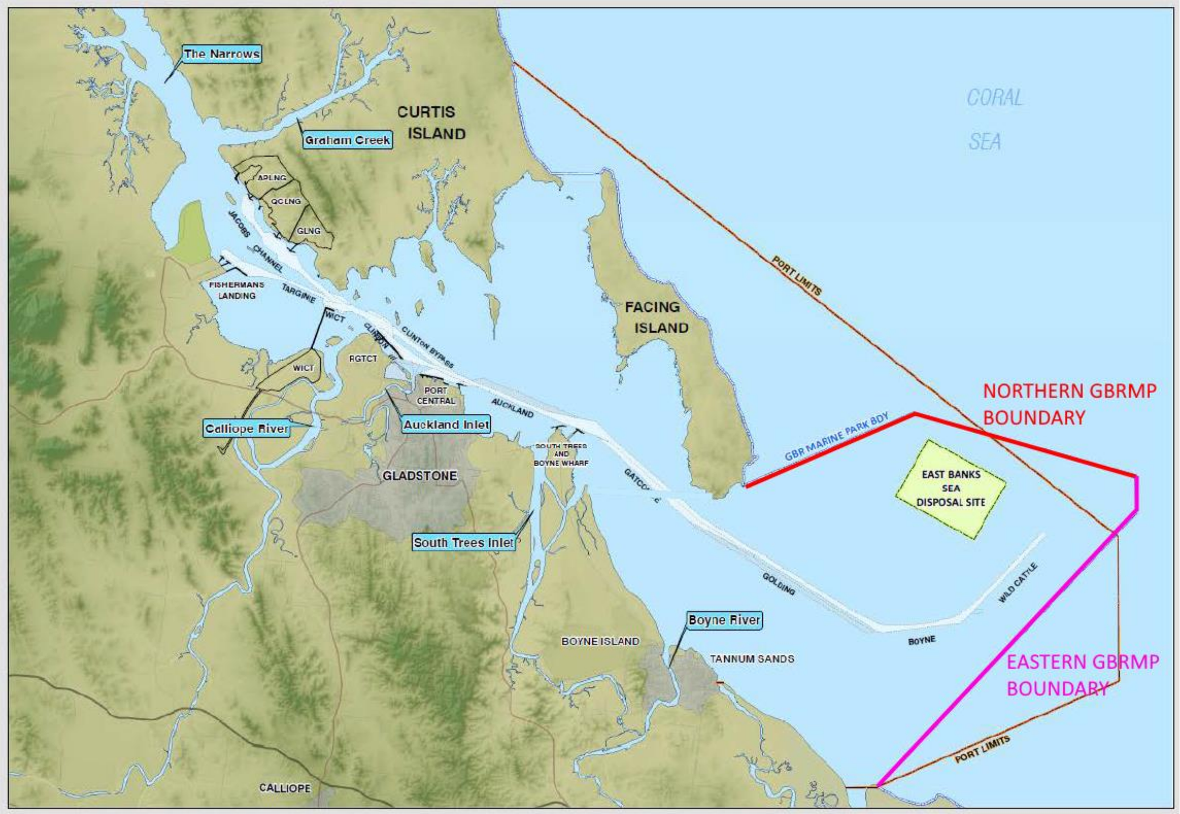

Figure 7-4 Location of Northern GBRMP Boundary (Red Line) and Eastern GBRMP Boundary (Purple Line)

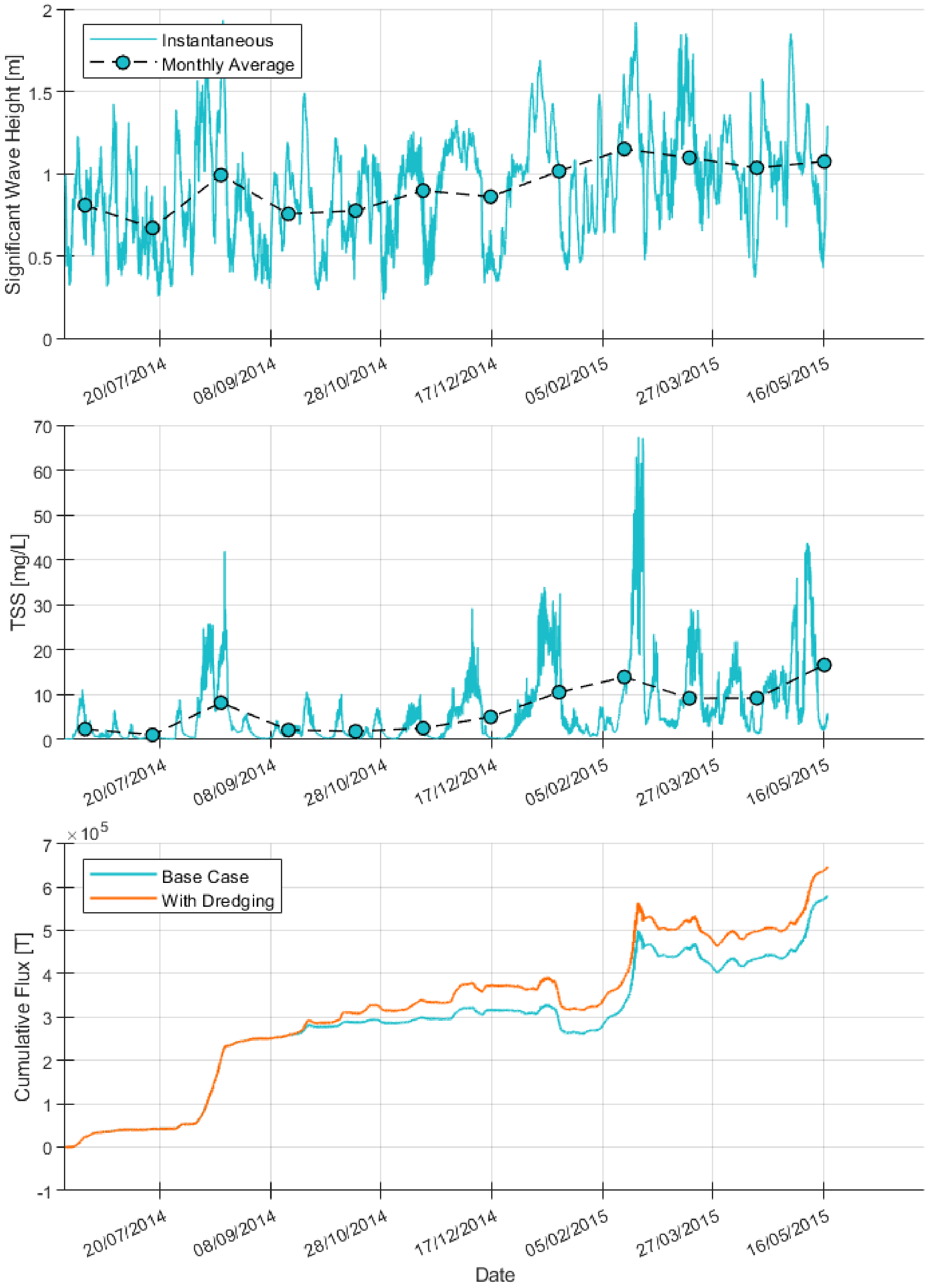

Figure 7-5 Modelled Wave Height (Top), TSS (Middle) and Cumulative Sediment Flux Across the Northern GBRMP Boundary (Bottom) for the 2014-2015 Simulation

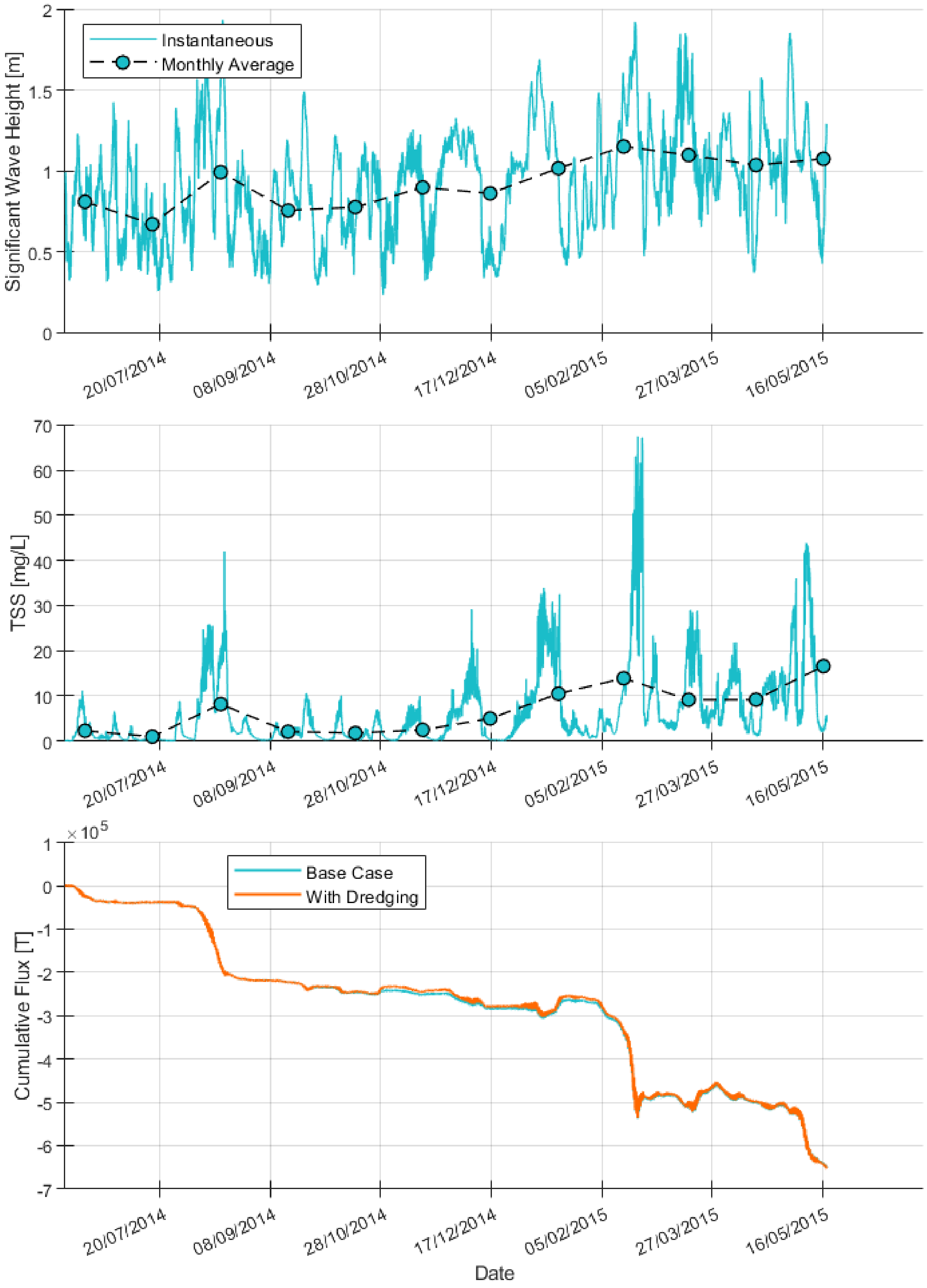

Figure 7-6 Modelled Wave Height (Top), TSS (Middle) and Cumulative Sediment Flux Across the Eastern GBRMP Boundary (Bottom) for the 2014-2015 Simulation

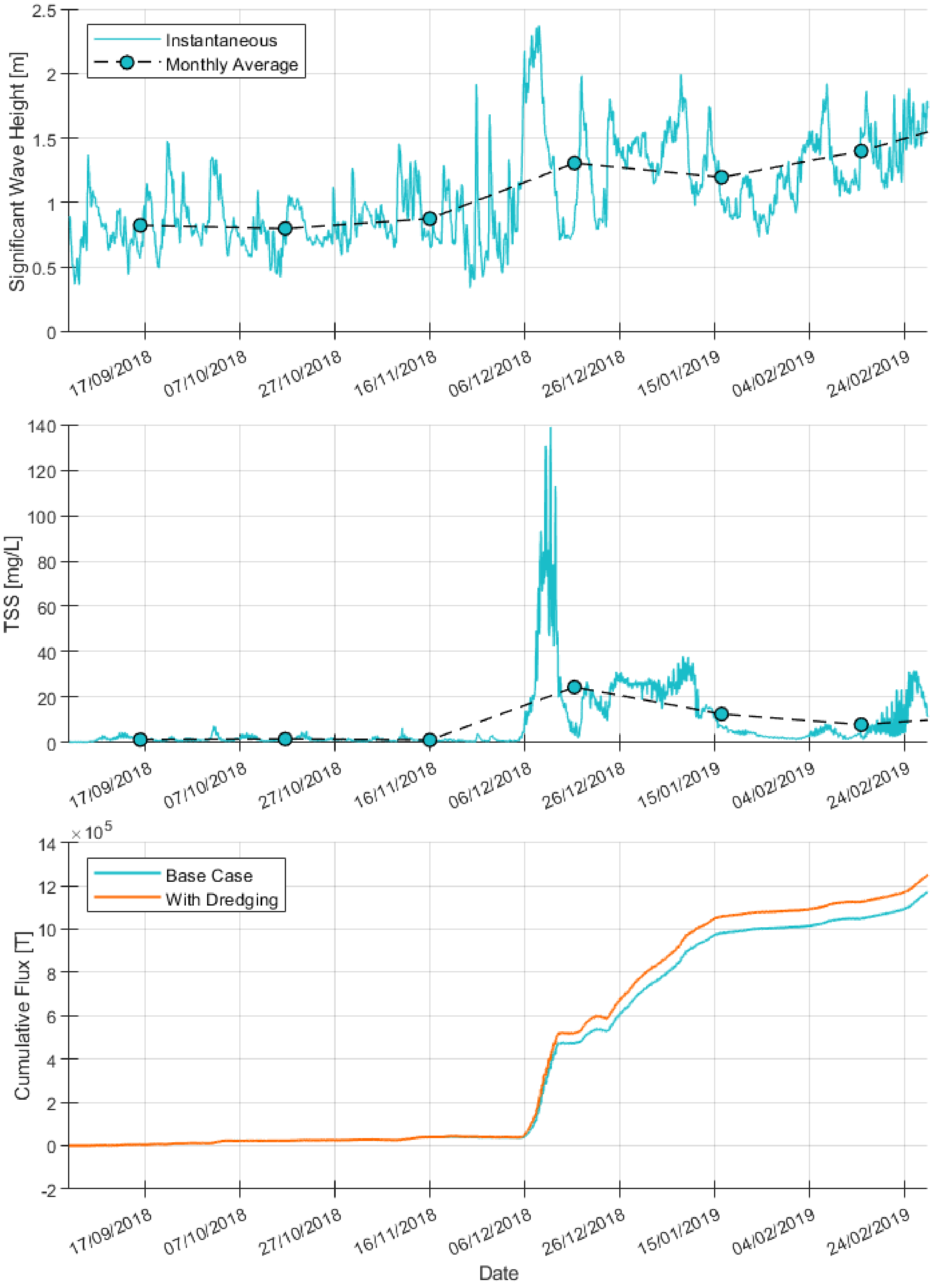

Figure 7-7 Modelled Wave Height (Top), TSS (Middle) and Cumulative Sediment Flux Across the Northern GBRMP Boundary (Bottom) for the 2018-2019 Simulation

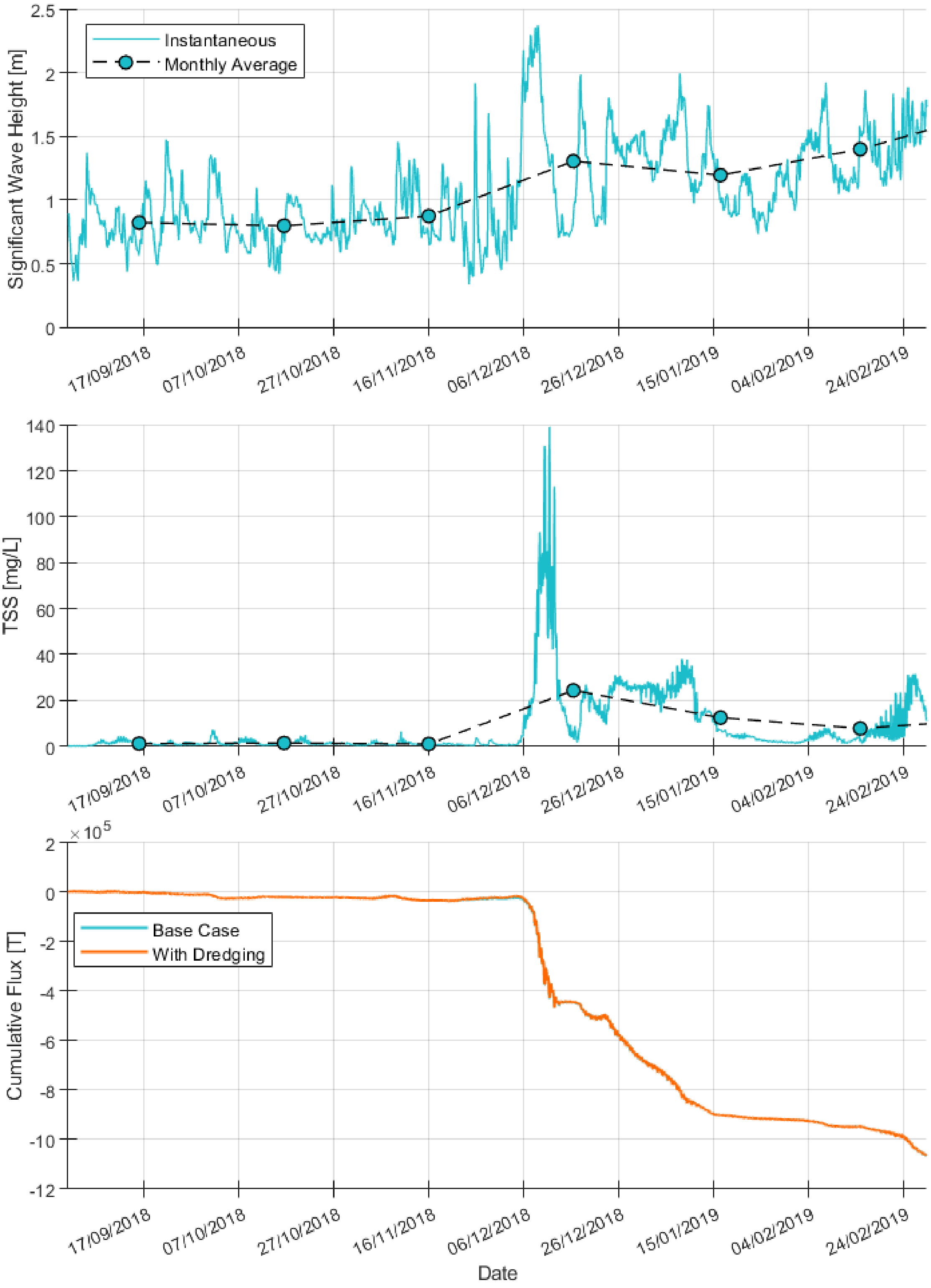

Figure 7-8 Modelled Wave Height (Top), TSS (Middle) and Cumulative Sediment Flux Across the Eastern GBRMP Boundary (Bottom) for the 2018-2019 Simulation

8 Conclusions

The Port of Gladstone TUFLOW FV hydrodynamic and sediment transport model has undergone additional calibration and validation to improve its representation of ambient sediment dynamics in the Port. The model outputs are being used to help develop a quantitative sediment budget for the Port, as part of GPC’s SSM Project.

Some key observations that can be made from the information presented in this report include:

- Modelling the ambient sediment dynamics is a very challenging task, and although the model does provide a reasonable representation of the sediment dynamics in the Port there remains significant uncertainty in the accuracy of the estimates produced by the model.
- In particular, it is very difficult to obtain accurate estimates of net sediment flux across transects. This can be attributed to a few issues:
  - The net flux is the difference between two large numbers – the gross flux into the Port on a flood tide and the gross flux out of the Port on an ebb tide. Because any estimate of each of those two large numbers has uncertainty associated with it, the net flux estimate is subject to large errors in both magnitude and sign (in/out of the Port).
  - There are limitations in the model accuracy due to the inherent complexity of the system, the limited data available for calibration and the imperfect representation of the physical processes in the Port.
  - The measurement methods used to derive the measured fluxes also have significant uncertainty due to the need to transform the measured ADCP backscatter into an equivalent TSS, and potential errors in the estimates of the volume flux.
- The model does provide useful indications of the overall mass balance of the system, including the relative significance of the three main entrances to the Port (The Narrows has a very minor influence on the overall sediment budget compared to the other two entrances).
- The results indicate that the overall magnitude and direction of the net flux into and out of the Port is likely to be event-driven, since the net flux is sensitive to the offshore ambient turbidity which is elevated during significant wave events.

9 References

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Appendix A ADCP Transect Measurement Report

Technical Memorandum

From:	Jessie Cullen and Paul Guard	To:	Gordon Dwane
Date:	15 January 2019	CC:	
Subject:	Gladstone Sediment Flux Measurements		

1 Background

BMT was commissioned to undertake measurements of water and sediment fluxes across transects at the Port of Gladstone as part of the ongoing Sustainable Sediment Management Project. The data will be used to refine and improve the Gladstone TUFLOW FV model and to assist in the development of a quantitative sediment budget for the Port. A summary of the data collection campaign and sediment flux measurement for each transect is presented below.

2 Data Collection

Water velocity and suspended sediment concentrations were measured across transects at three locations (see Figure 1) over complete tidal cycles during large spring tides (with range up to 4.5m) on the 7th, 8th and 10th September 2018 and again during 'average' tides on the 12th, 13th and 15th September 2018.

- Transect A from Gatcombe Heads to Lilly's Beach;
- Transect B from South End on Curtis Island to North Point on Facing Island; and
- Transect C across The Narrows at Black Swan Island.

A downward facing Acoustic Doppler Current Profiler (ADCP) mounted to the BMT vessel 'Resolution II' was used to measure both the velocity profile and the suspended sediment concentration profile under the boat as it traversed each transect repeatedly over a complete tidal cycle (12.5 hours).

A Campbell Scientific OBS-3A turbidity probe was used at several locations to measure the turbidity profile and water quality samples were taken at known depths on the profile for subsequent analysis to determine the total suspended solids (TSS) concentration. The turbidity profiles and TSS measurements were then correlated with ADCP backscatter measurements to allow conversion of the ADCP backscatter data into TSS concentration data across each transect.

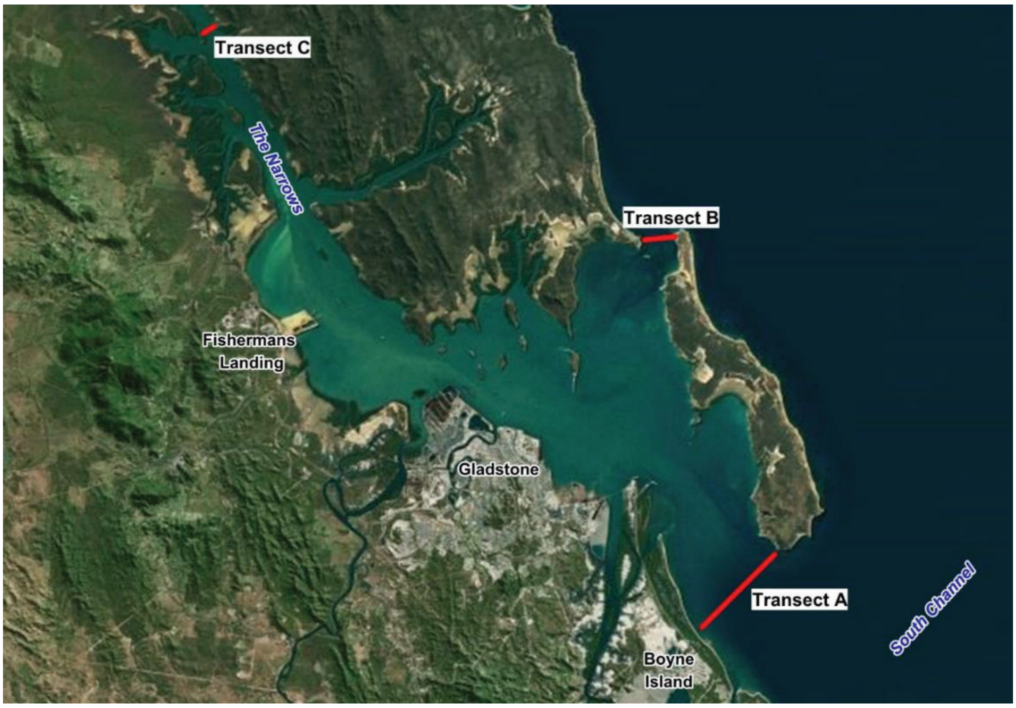


Figure 1 Transect Locations (Red Lines)

3 Data Presentation

For each of the measured transects, a curtain plot was developed which shows the calculated TSS concentrations along the transect as a function of chainage and elevation. Figure 2 shows an example of this curtain plot together with a plan view which shows the depth averaged TSS concentrations along the transect. The complete set of plots for the measured ADCP transects is presented in Appendix A.

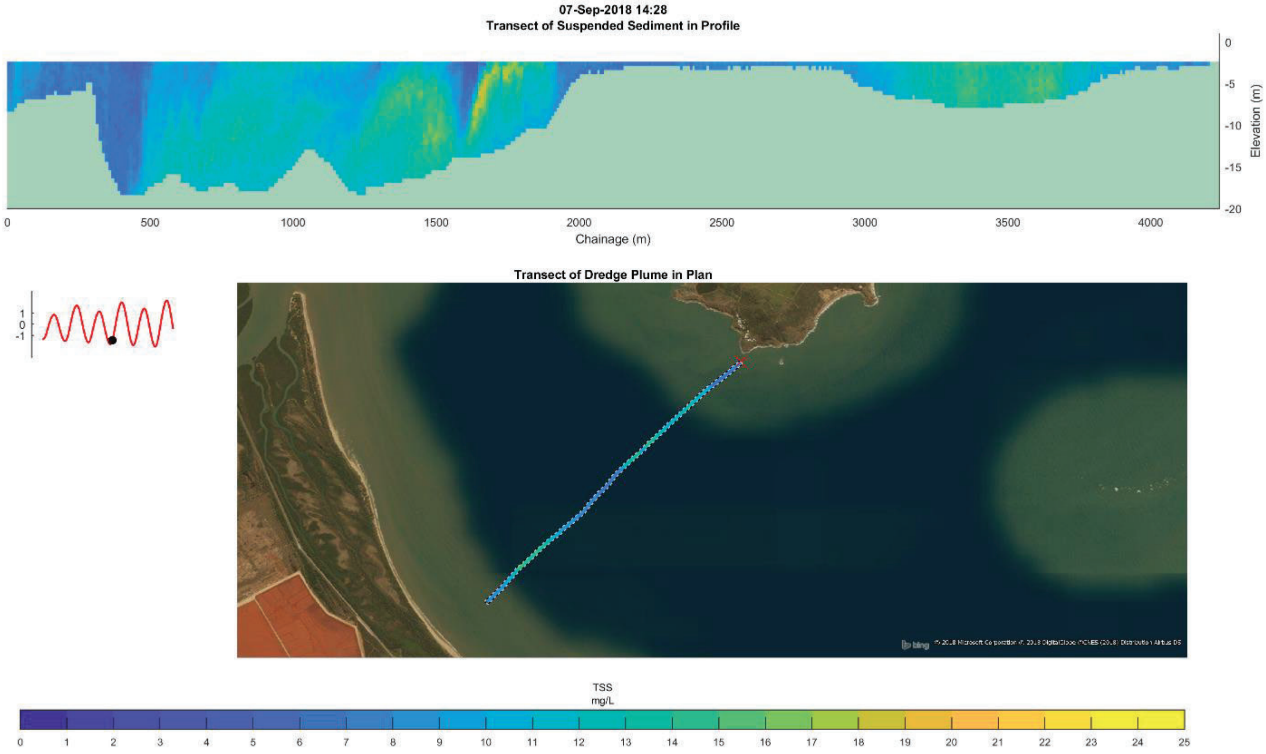


Figure 2 Example ADCP Transect Plot

3.1 Spring Tidal Range - Results

For each measured transect, the calculated TSS concentrations and water velocities were integrated to produce a measurement of the net sediment and water flux across the transect at that time. Time series of the total sediment flux and water level are presented in Figure 3 to Figure 5 for spring tidal range conditions. Accompanying each plot is tabulated data including the time of measurement, water level (relative to Mean Sea Level [m MSL]), total sediment flux, average sediment concentration and volumetric flow rate. Sediment flux and volumetric flow rate are positive into the harbour.

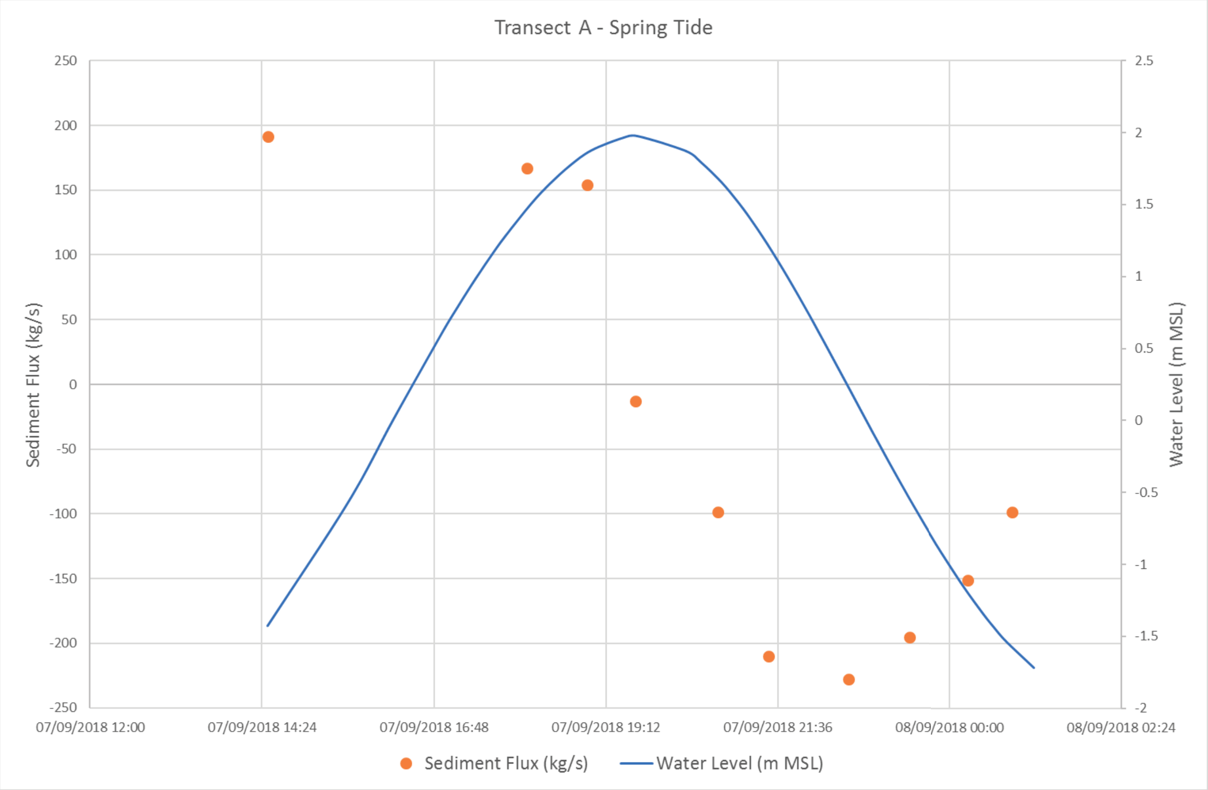


Figure 3 Sediment Flux – Spring Tide – Transect A

Table 1 Transect Data Collection Summary – Spring Tide – Transect A

Time	Water Level [m MSL]	Sediment Flux (kg/s)	Average Sediment Concentration (g/m³)	Volumetric Flow Rate (m³/s)
07/09/2018 14:28	-1.43	192	10	17,223
07/09/2018 18:06	1.47	167	6	24,562
07/09/2018 18:56	1.86	154	8	20,634
07/09/2018 19:36	1.97	-13	8	-4,071
07/09/2018 20:46	1.68	-99	5	-17,695
07/09/2018 21:28	1.21	-210	6	-32,437
07/09/2018 22:35	0.23	-227	7	-30,637
07/09/2018 23:26	-0.55	-195	7	-28,706
08/09/2018 00:15	-1.20	-151	6	-23,592
08/09/2018 00:52	-1.58	-98	5	-17,375

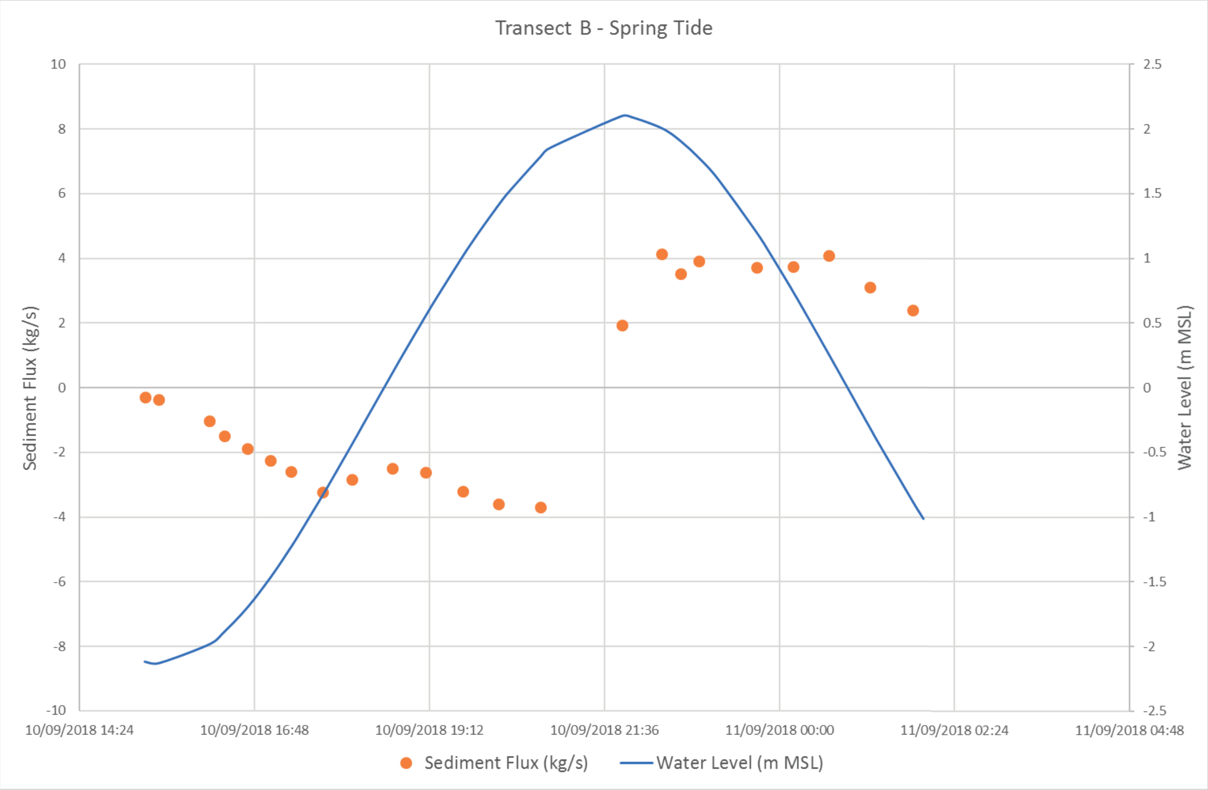


Figure 4 Sediment Flux – Spring Tide – Transect B

Table 2 Transect Data Collection Summary – Spring Tide – Transect B

Time	Water Level [m MSL]	Sediment Flux (kg/s)	Average Sediment Concentration (g/m^3)	Volumetric Flow Rate (m^3/s)
10/09/2018 15:18	-2.12	0	6	-55
10/09/2018 15:29	-2.13	0	6	-59
10/09/2018 16:11	-1.99	-1	3	-310
10/09/2018 16:23	-1.89	-1	3	-467
10/09/2018 16:42	-1.70	-2	3	-518
10/09/2018 17:01	-1.47	-2	4	-624
10/09/2018 17:17	-1.24	-3	3	-830
10/09/2018 17:44	-0.83	-3	3	-1,145
10/09/2018 18:08	-0.44	-3	2	-1,508
10/09/2018 18:41	0.11	-3	1	-1,893
10/09/2018 19:09	0.56	-3	1	-2,178
10/09/2018 19:39	1.02	-3	1	-2,420
10/09/2018 20:09	1.41	-4	1	-2,531
10/09/2018 20:43	1.79	-4	2	-2,265
10/09/2018 21:50	2.10	2	2	1,005
10/09/2018 22:23	2.01	4	1	2,985
10/09/2018 22:38	1.91	4	1	2,782
10/09/2018 22:54	1.78	4	1	3,207
10/09/2018 23:41	1.20	4	1	2,926
11/09/2018 00:11	0.74	4	2	2,188
11/09/2018 00:40	0.26	4	2	1,671
11/09/2018 01:14	-0.31	3	3	1,092
11/09/2018 01:49	-0.88	2	3	806

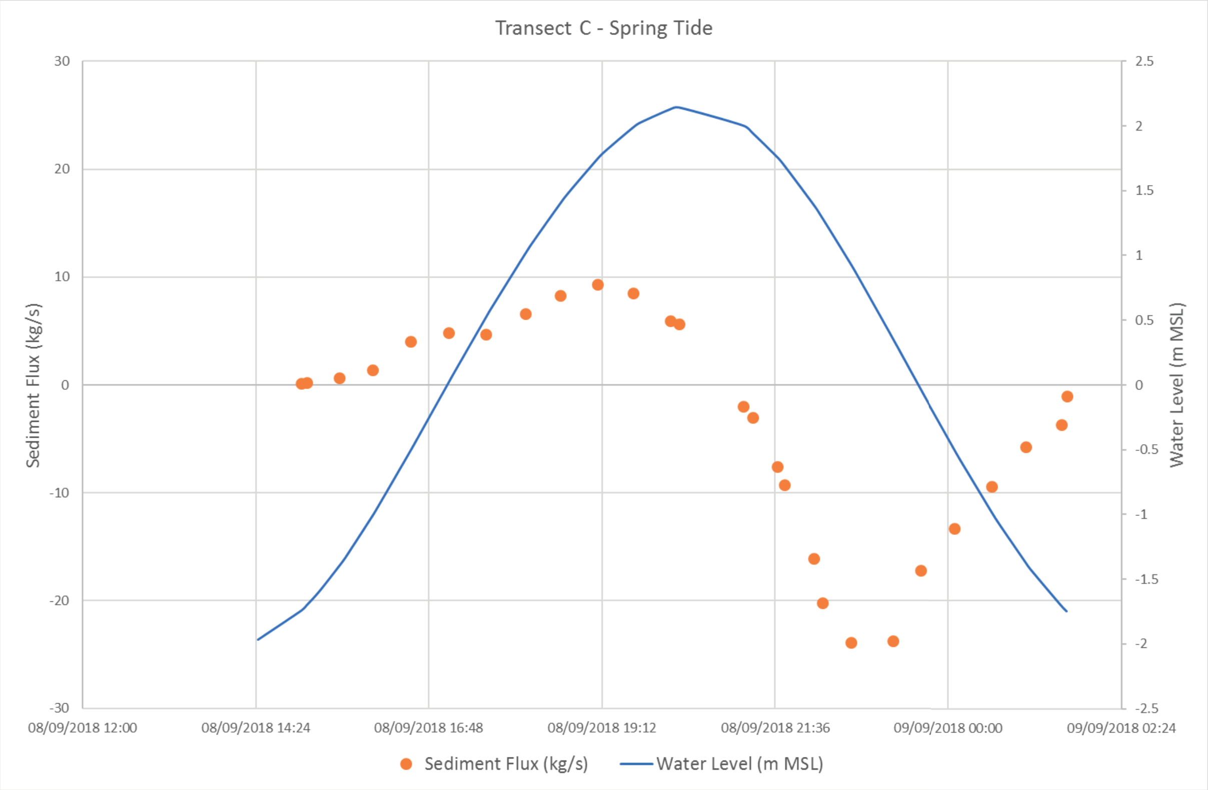


Figure 5 Sediment Flux – Spring Tide – Transect C

Table 3 Transect Data Collection Summary – Spring Tide – Transect C

Time	Water Level [m MSL]	Sediment Flux (kg/s)	Average Sediment Concentration (g/m³)	Volumetric Flow Rate (m³/s)
08/09/2018 15:02	-1.74	0	11	16
08/09/2018 15:06	-1.70	0	11	19
08/09/2018 15:33	-1.40	1	12	53
08/09/2018 16:00	-1.02	1	15	100
08/09/2018 16:32	-0.51	4	21	208
08/09/2018 17:04	0.01	5	18	267
08/09/2018 17:35	0.51	5	15	289
08/09/2018 18:07	1.01	7	18	360
08/09/2018 18:37	1.40	8	17	468
08/09/2018 19:07	1.74	9	17	536
08/09/2018 19:37	1.99	9	16	480
08/09/2018 20:08	2.13	6	15	392
08/09/2018 20:16	2.14	6	14	383
08/09/2018 21:09	2.00	-2	11	-189
08/09/2018 21:17	1.95	-3	11	-274
08/09/2018 21:37	1.76	-8	13	-627
08/09/2018 21:43	1.70	-9	13	-727
08/09/2018 22:08	1.39	-16	18	-920
08/09/2018 22:15	1.29	-20	20	-1,009
08/09/2018 22:38	0.93	-24	26	-883
08/09/2018 23:13	0.36	-24	33	-702
08/09/2018 23:36	-0.03	-17	33	-522
09/09/2018 00:05	-0.50	-13	31	-389
09/09/2018 00:36	-0.99	-9	35	-263
09/09/2018 01:04	-1.37	-6	33	-183
09/09/2018 01:34	-1.71	-4	29	-129
09/09/2018 01:38	-1.75	-1	31	-51

3.2 Average Tidal Range Conditions

Time series of the total sediment flux and water level across each transect during "average" tidal range conditions are presented in Figure 6 to Figure 8. Accompanying each plot is tabulated data including the time of measurement, total sediment flux, average sediment concentration and volumetric flow rate. Sediment flux and volumetric flow rate are positive into the harbour.

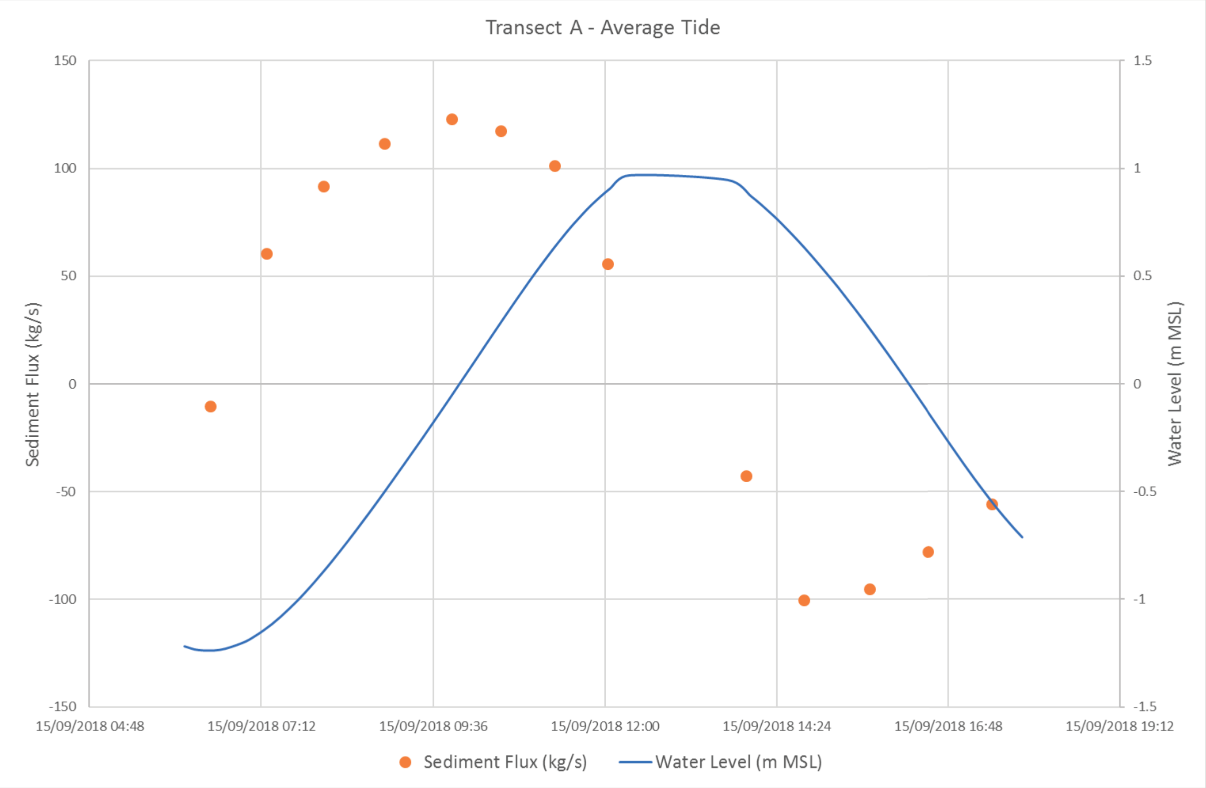


Figure 6 Sediment Flux – Average Tide – Transect A

Table 4 Transect Data Collection Summary – Average Tide – Transect A

Time	Water Level [m MSL]	Sediment Flux (kg/s)	Average Sediment Concentration (g/m³)	Volumetric Flow Rate (m³/s)
15/09/2018 06:29	-1.24	-10	8	-1,300
15/09/2018 07:16	-1.14	60	8	7,834
15/09/2018 08:04	-0.87	92	8	11,901
15/09/2018 08:55	-0.50	111	8	14,440
15/09/2018 09:51	-0.05	123	8	15,993
15/09/2018 10:32	0.28	117	8	15,343
15/09/2018 11:17	0.63	101	7	13,404
15/09/2018 12:02	0.90	56	6	9,539
15/09/2018 13:58	0.89	-43	6	-7,785
15/09/2018 14:46	0.64	-100	6	-18,459
15/09/2018 15:42	0.25	-95	6	-16,935
15/09/2018 16:31	-0.13	-78	6	-13,736
15/09/2018 17:24	-0.55	-56	6	-10,163

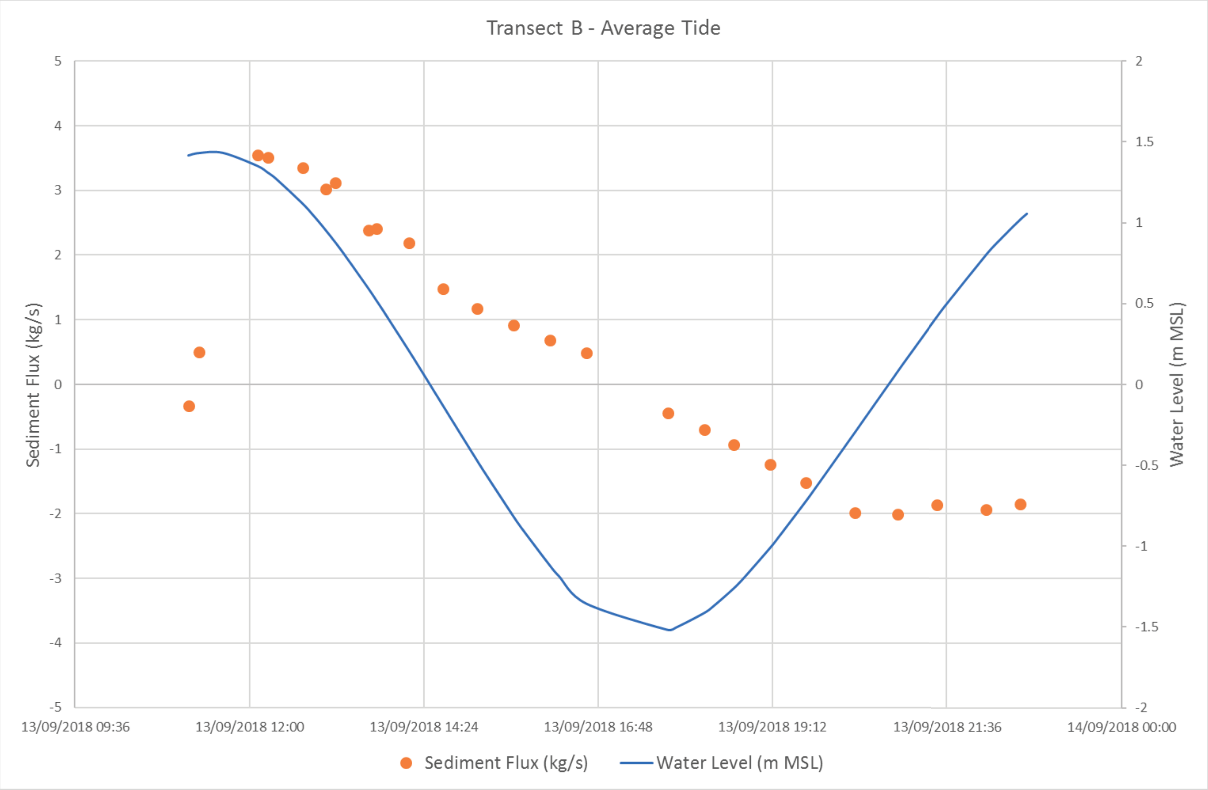


Figure 7 Sediment Flux – Average Tide – Transect B

Table 5 Transect Data Collection Summary – Average Tide – Transect B

Time	Water Level [m MSL]	Sediment Flux (kg/s)	Average Sediment Concentration (g/m³)	Volumetric Flow Rate (m³/s)
13/09/2018 11:09	1.42	-0.3	2.1	-152
13/09/2018 11:18	1.43	0.5	2.1	247
13/09/2018 12:06	1.35	3.5	1.6	2,244
13/09/2018 12:15	1.31	3.5	1.6	2,244
13/09/2018 12:44	1.12	3.3	1.5	2,188
13/09/2018 13:03	0.95	3.0	1.6	1,928
13/09/2018 13:11	0.88	3.1	1.6	1,992
13/09/2018 13:38	0.60	2.4	1.5	1,555
13/09/2018 13:44	0.52	2.4	1.6	1,535
13/09/2018 14:11	0.21	2.2	1.8	1,251
13/09/2018 14:39	-0.13	1.5	1.9	799
13/09/2018 15:07	-0.46	1.2	2.0	605
13/09/2018 15:37	-0.81	0.9	2.0	460
13/09/2018 16:08	-1.12	0.7	2.1	324
13/09/2018 16:38	-1.36	0.5	2.1	225
13/09/2018 17:45	-1.52	-0.4	2.0	-214
13/09/2018 18:15	-1.41	-0.7	1.8	-387
13/09/2018 18:39	-1.26	-0.9	1.7	-529
13/09/2018 19:09	-1.01	-1.2	1.7	-705
13/09/2018 19:39	-0.72	-1.5	1.6	-907
13/09/2018 20:19	-0.30	-2.0	1.7	-1,168
13/09/2018 20:55	0.08	-2.0	1.6	-1,228
13/09/2018 21:27	0.42	-1.9	1.6	-1,150
13/09/2018 22:08	0.80	-1.9	1.6	-1,178
13/09/2018 22:36	1.02	-1.8	1.7	-1,082

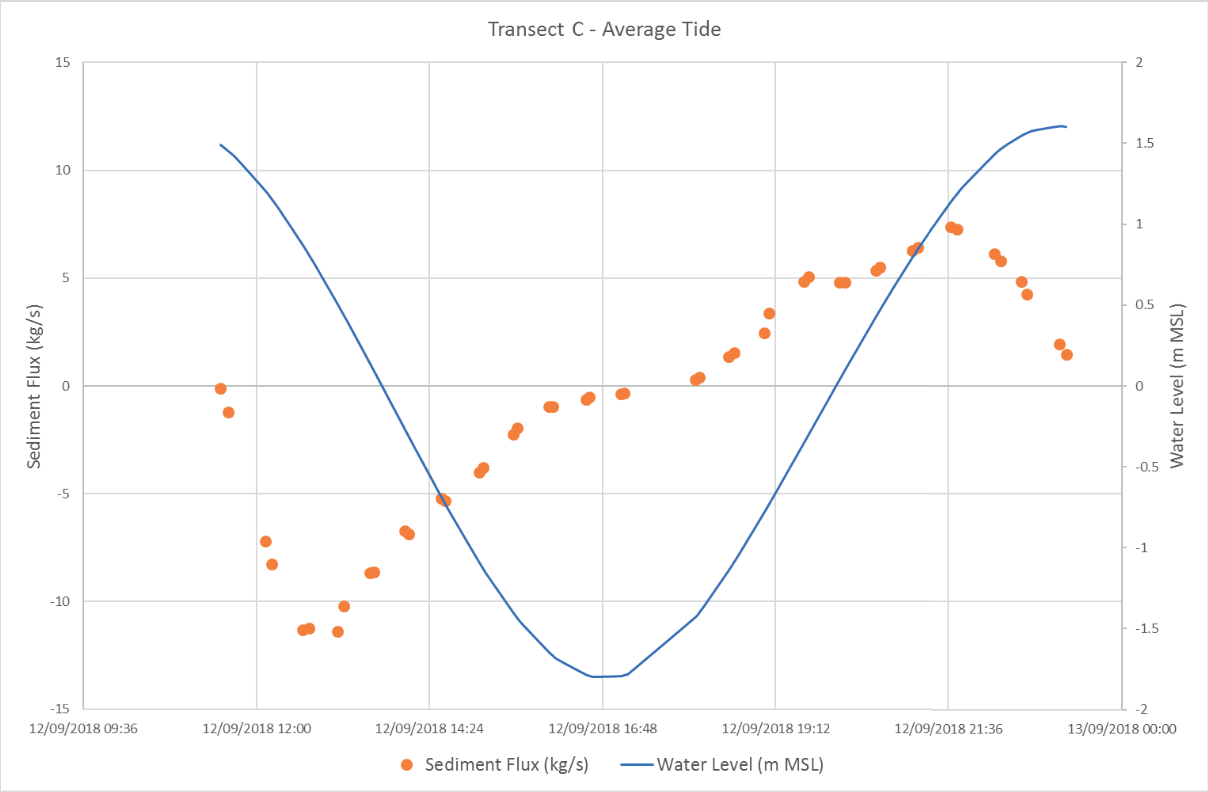


Figure 8 Sediment Flux – Average Tide – Transect C

Table 6 Transect Data Collection Summary – Average Tide – Transect C

Time	Water Level [m MSL]	Sediment Flux (kg/s)	Average Sediment Concentration (g/m^3)	Volumetric Flow Rate (m^3/s)
12/09/2018 11:30	1.49	0	19	-7
12/09/2018 11:36	1.45	-1	19	-63
12/09/2018 12:07	1.20	-7	18	-387
12/09/2018 12:12	1.15	-8	19	-434
12/09/2018 12:38	0.87	-11	22	-505
12/09/2018 12:43	0.81	-11	22	-507
12/09/2018 13:07	0.51	-11	23	-470
12/09/2018 13:12	0.44	-10	24	-421
12/09/2018 13:34	0.14	-9	24	-358
12/09/2018 13:37	0.09	-9	24	-356
12/09/2018 14:03	-0.27	-7	24	-278
12/09/2018 14:06	-0.32	-7	24	-281
12/09/2018 14:33	-0.69	-5	24	-213
12/09/2018 14:36	-0.73	-5	25	-213
12/09/2018 15:05	-1.09	-4	26	-154
12/09/2018 15:08	-1.13	-4	27	-143
12/09/2018 15:33	-1.41	-2	25	-93
12/09/2018 15:37	-1.43	-2	23	-85
12/09/2018 16:03	-1.65	-1	19	-49
12/09/2018 16:06	-1.67	-1	20	-49
12/09/2018 16:34	-1.79	-1	18	-33
12/09/2018 16:37	-1.79	-1	18	-29
12/09/2018 17:03	-1.79	0	17	-21
12/09/2018 17:05	-1.79	0	17	-20
12/09/2018 18:05	-1.43	0	18	16
12/09/2018 18:08	-1.40	0	18	22
12/09/2018 18:33	-1.14	1	21	65
12/09/2018 18:37	-1.09	2	20	76

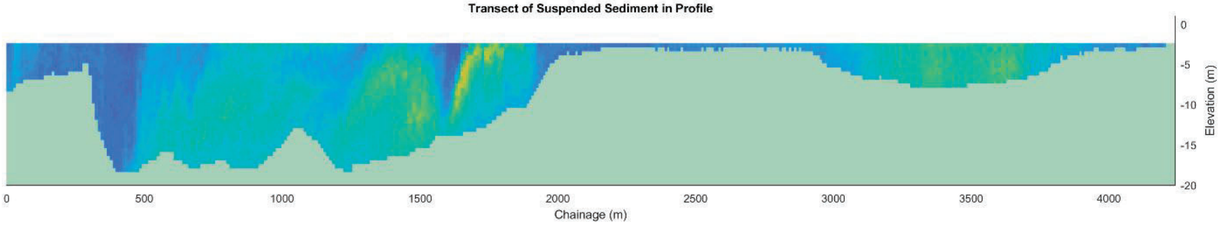
Time	Water Level [m MSL]	Sediment Flux (kg/s)	Average Sediment Concentration (g/m³)	Volumetric Flow Rate (m³/s)
12/09/2018 19:02	-0.78	2	24	124
12/09/2018 19:06	-0.73	3	23	154
12/09/2018 19:35	-0.35	5	23	220
12/09/2018 19:39	-0.30	5	23	228
12/09/2018 20:05	0.04	5	20	243
12/09/2018 20:09	0.10	5	19	242
12/09/2018 20:35	0.42	5	20	258
12/09/2018 20:38	0.47	6	20	261
12/09/2018 21:05	0.79	6	21	298
12/09/2018 21:10	0.84	6	21	296
12/09/2018 21:38	1.14	7	22	324
12/09/2018 21:43	1.19	7	21	327
12/09/2018 22:14	1.43	6	20	289
12/09/2018 22:19	1.46	6	20	276
12/09/2018 22:36	1.55	5	20	226
12/09/2018 22:41	1.56	4	20	200
12/09/2018 23:08	1.60	2	19	90
12/09/2018 23:13	1.60	1	19	65

Appendix A

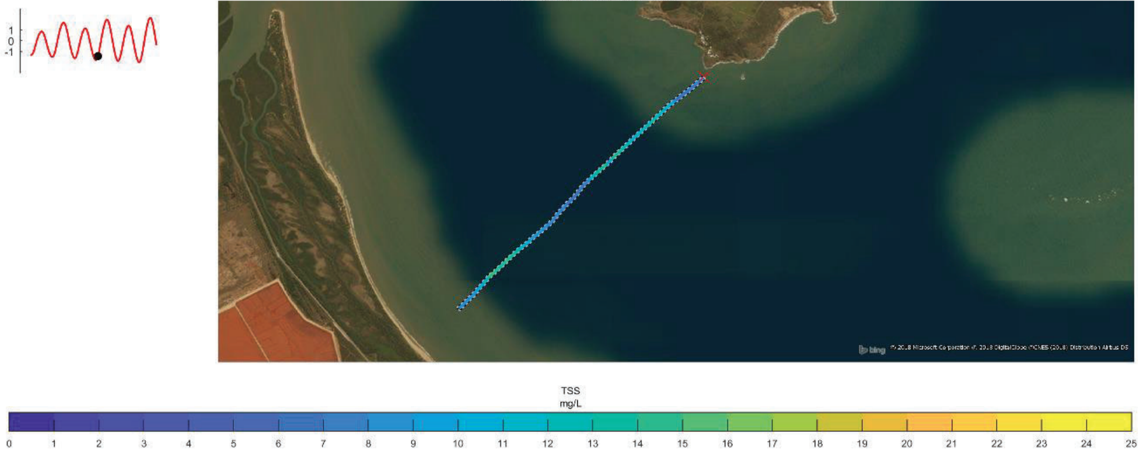
Transect A - Gatcombe Heads to Lilly's Beach – Spring Tide

07-Sep-2018 14:28

Transect of Suspended Sediment in Profile

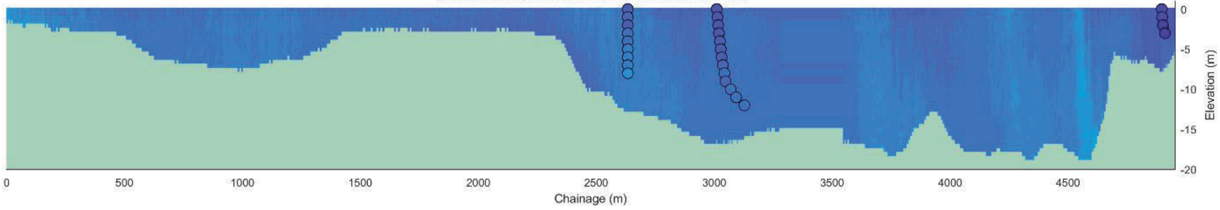


Transect of Dredge Plume in Plan

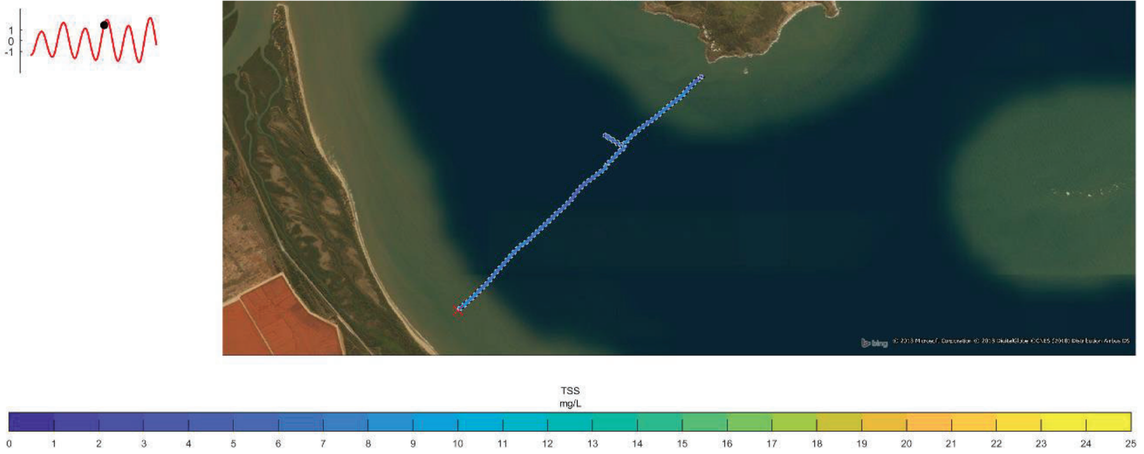


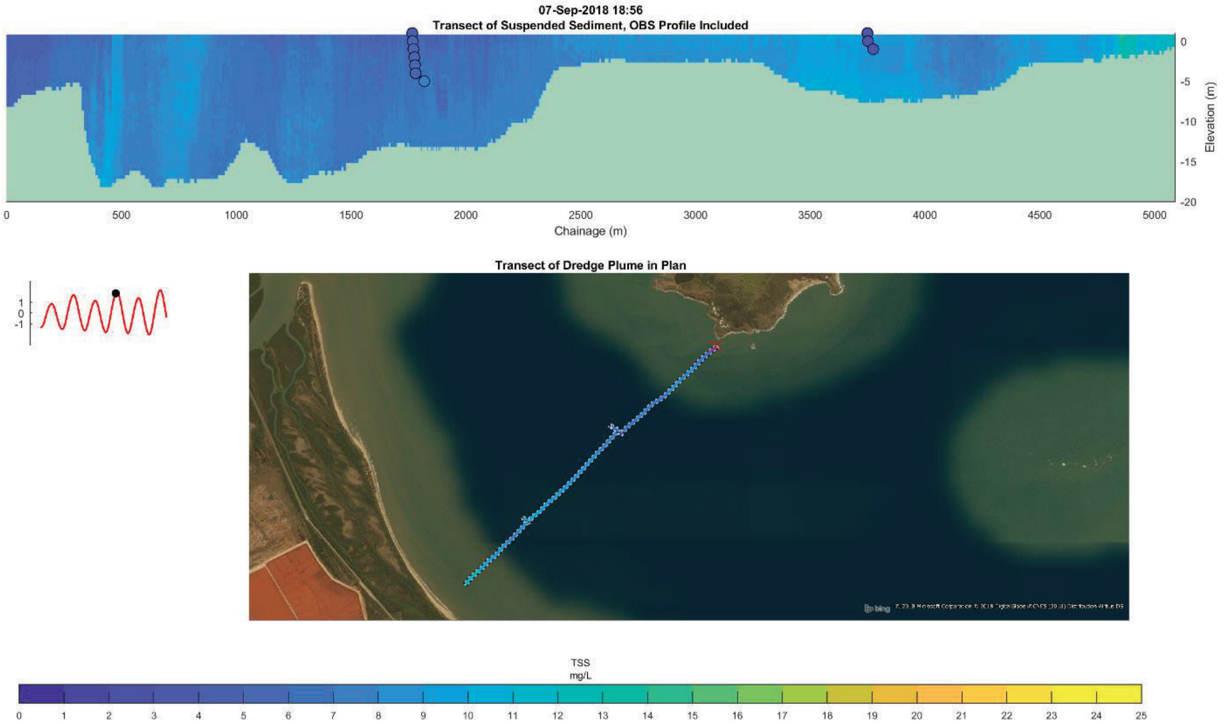
07-Sep-2018 18:06

Transect of Suspended Sediment, OBS Profile Included



Transect of Dredge Plume in Plan

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-20
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500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Chainage (m)
1
0
-1
Transect of Dredge Plume in Plan
TSS
mg/L
0
1
2
3
4
5
6
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8
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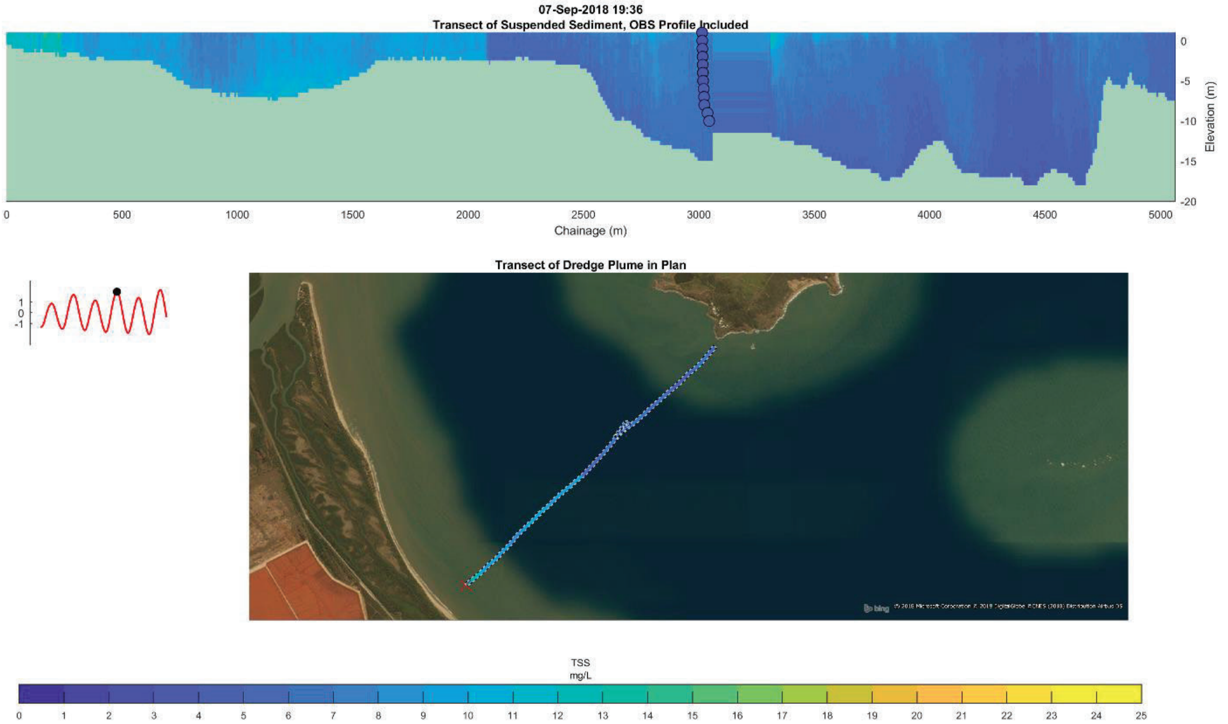
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1500
2000
2500
3000
3500
4000
4500
5000
Chainage (m)
1
0
-1
Transect of Dredge Plume in Plan
TSS
mg/L
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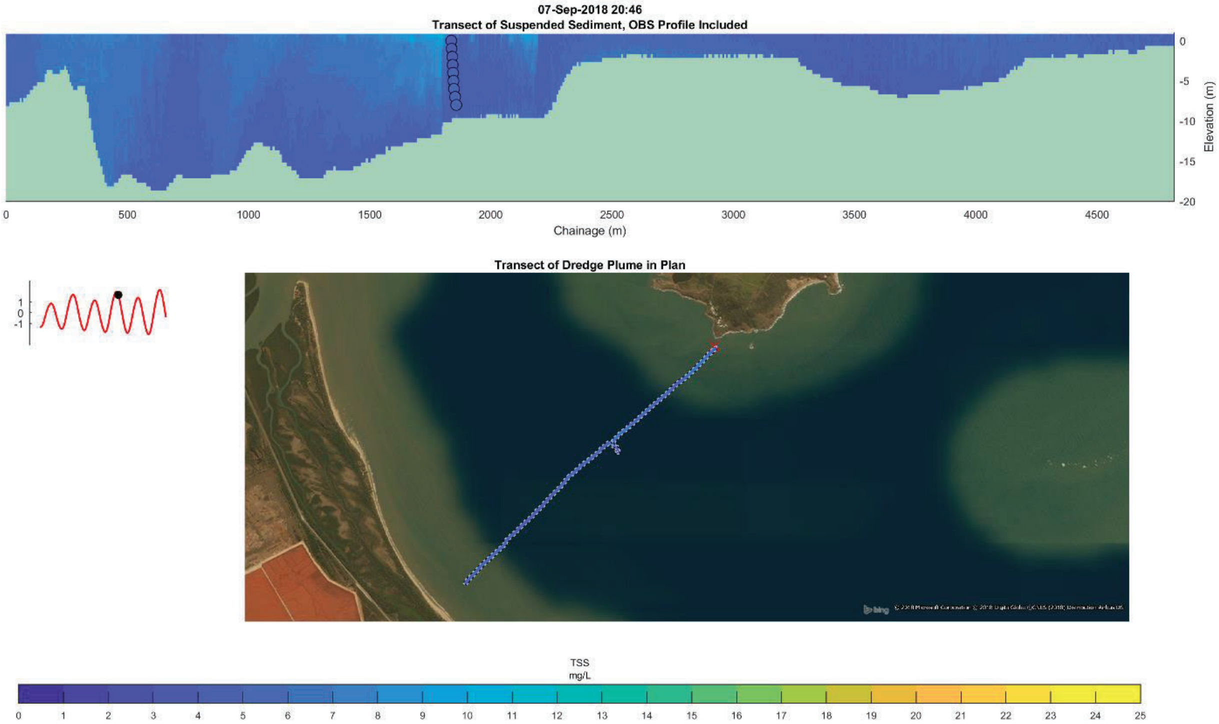
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2500
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4000
4500
Elevation (m)
0
-5
-10
-15
-20
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-1
Transect of Dredge Plume in Plan
TSS
mg/L
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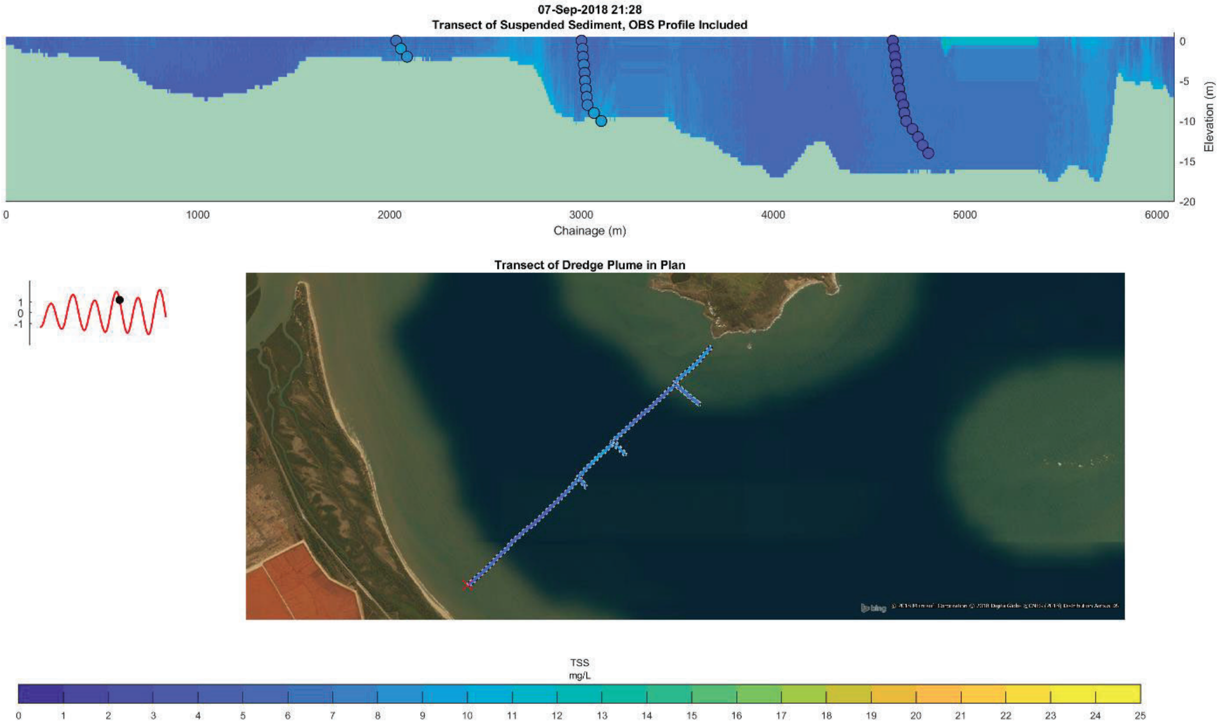
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4000
5000
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Elevation (m)
0
-5
-10
-15
-20
1
0
-1
Transect of Dredge Plume in Plan
TSS
mg/L
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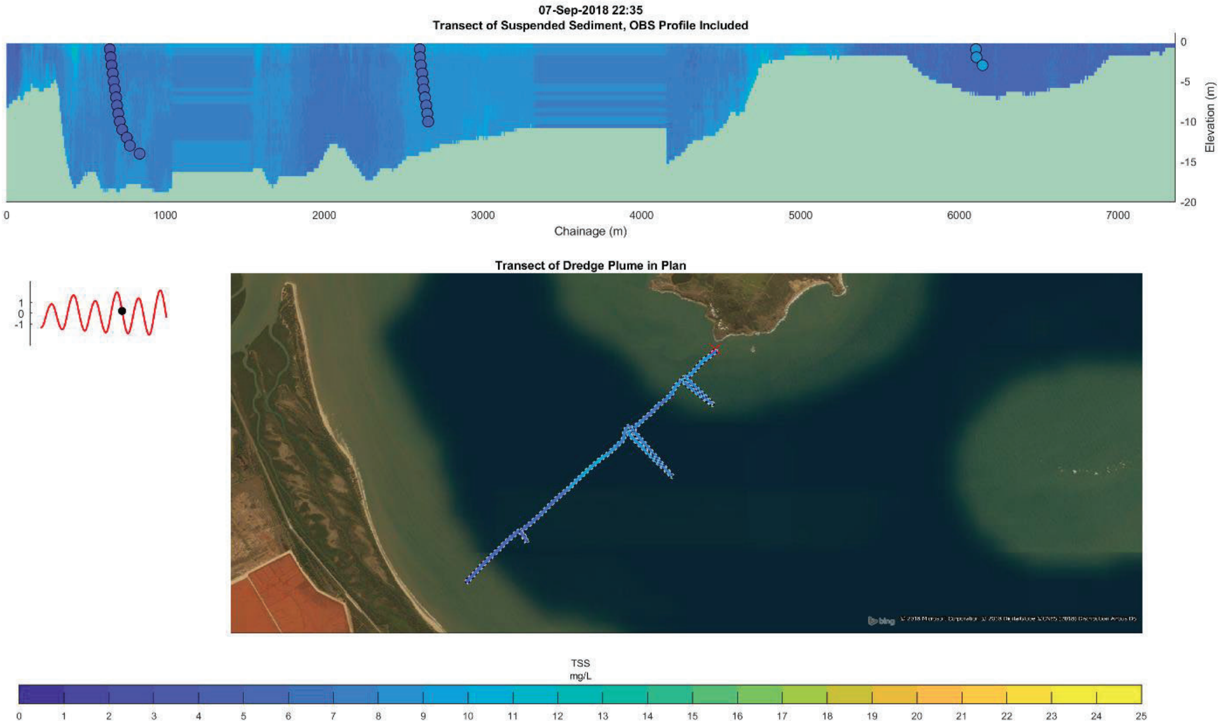
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Elevation (m)
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2000
3000
4000
5000
6000
7000
Chainage (m)
Transect of Dredge Plume in Plan
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-1
TSS
mg/L
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1
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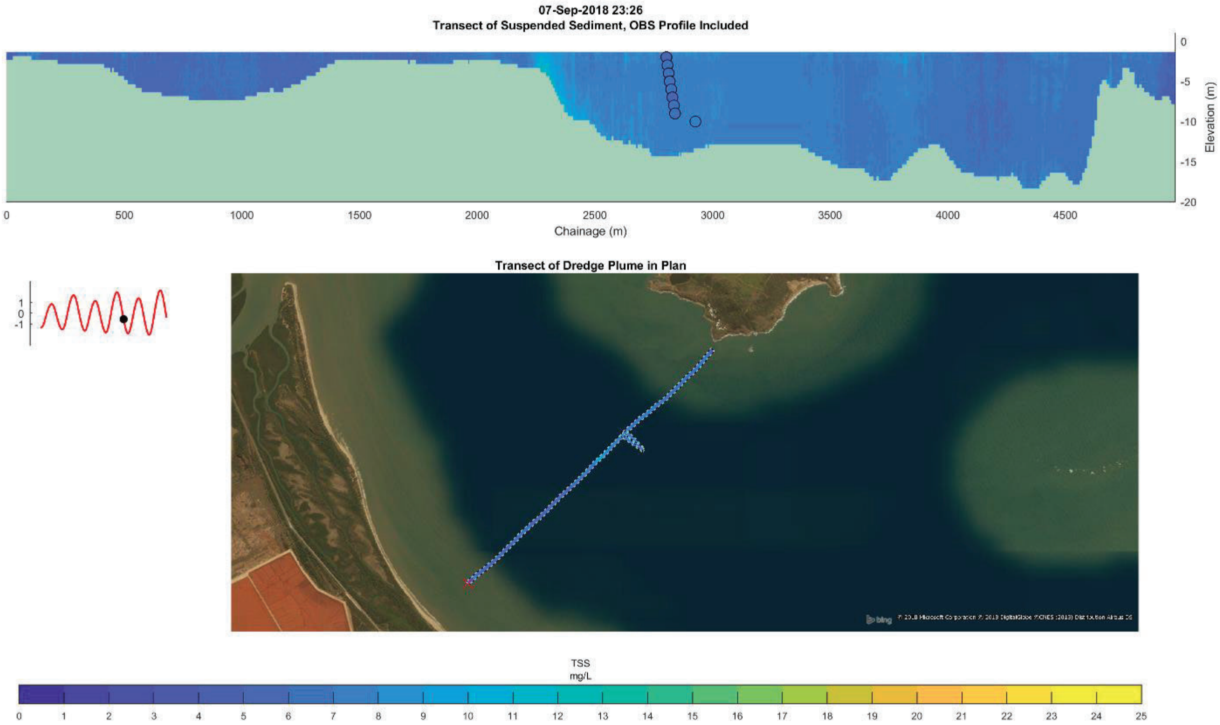
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1500
2000
2500
3000
3500
4000
4500
Chainage (m)
Transect of Dredge Plume in Plan
1
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-1
TSS
mg/L
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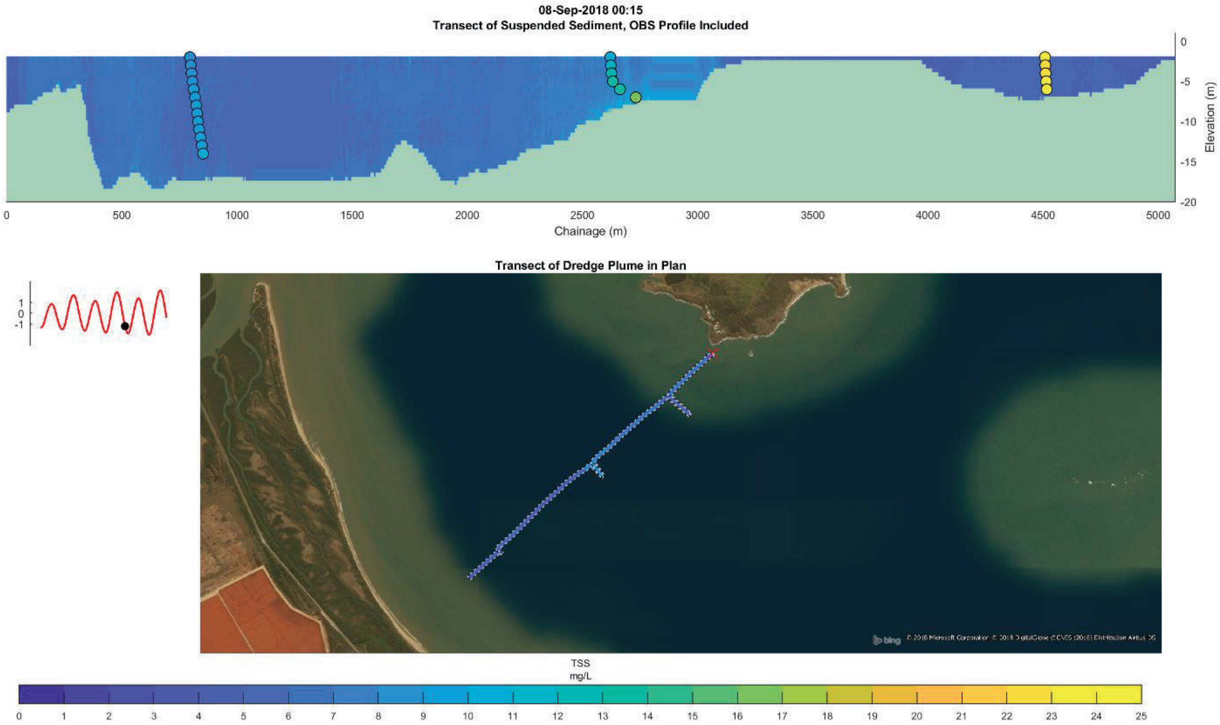
08-Sep-2018 00:15
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1500
2000
2500
3000
3500
4000
4500
5000
Chainage (m)
Transect of Dredge Plume in Plan
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© 2018 Microsoft Corporation © 2018 DigitalGlobe ©CNES (2018) Distribution Airbus DS
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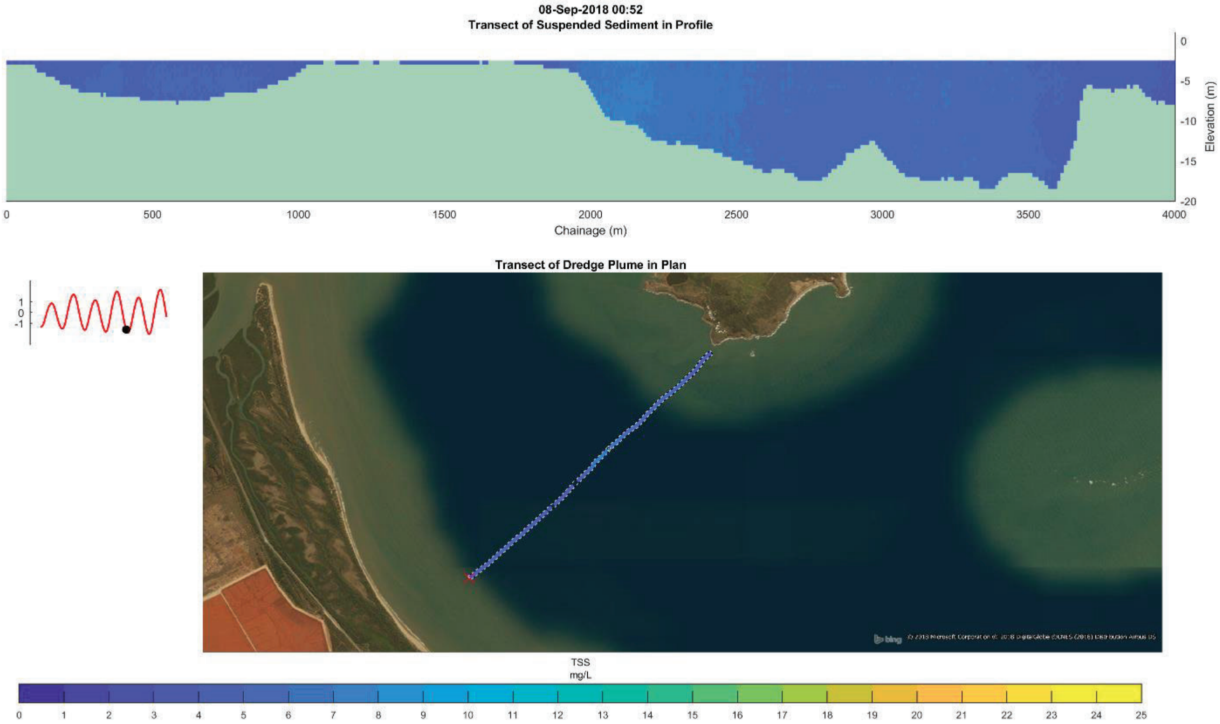
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1000
1500
2000
2500
3000
3500
4000
Chainage (m)
Transect of Dredge Plume in Plan
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-1
© 2018 Microsoft Corporation © 2018 DigitalGlobe ©CNES (2018) Distribution Airbus DS
TSS
mg/L
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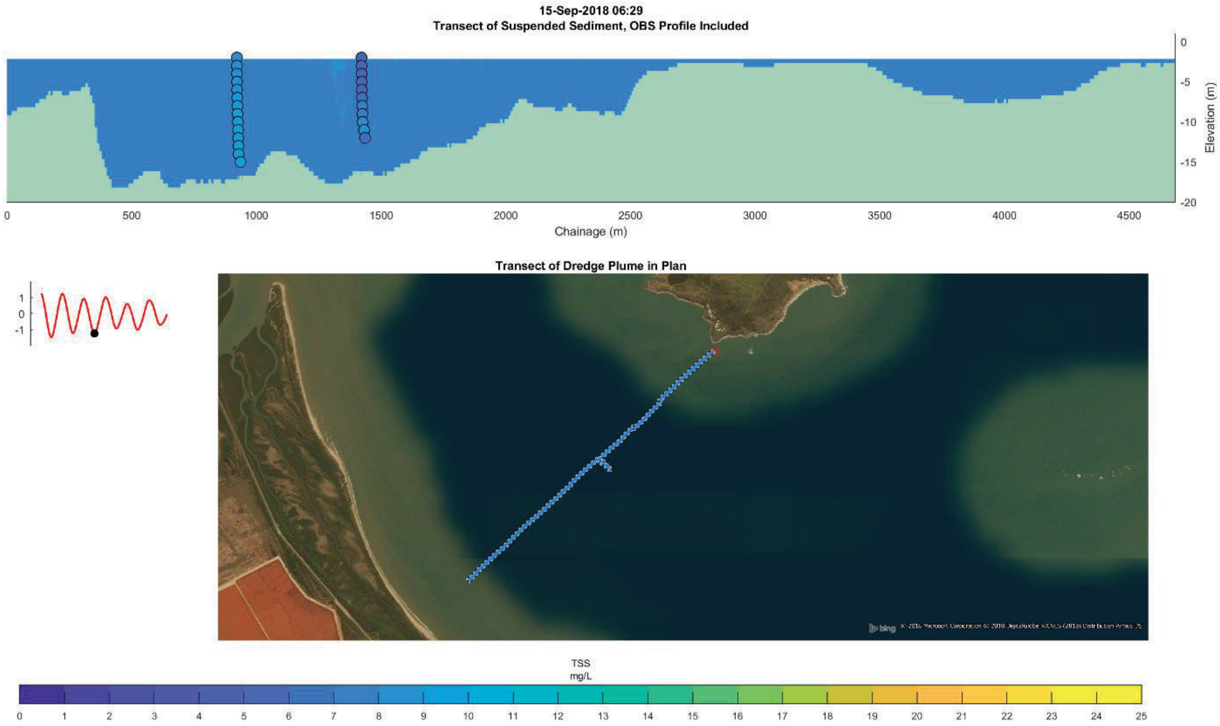
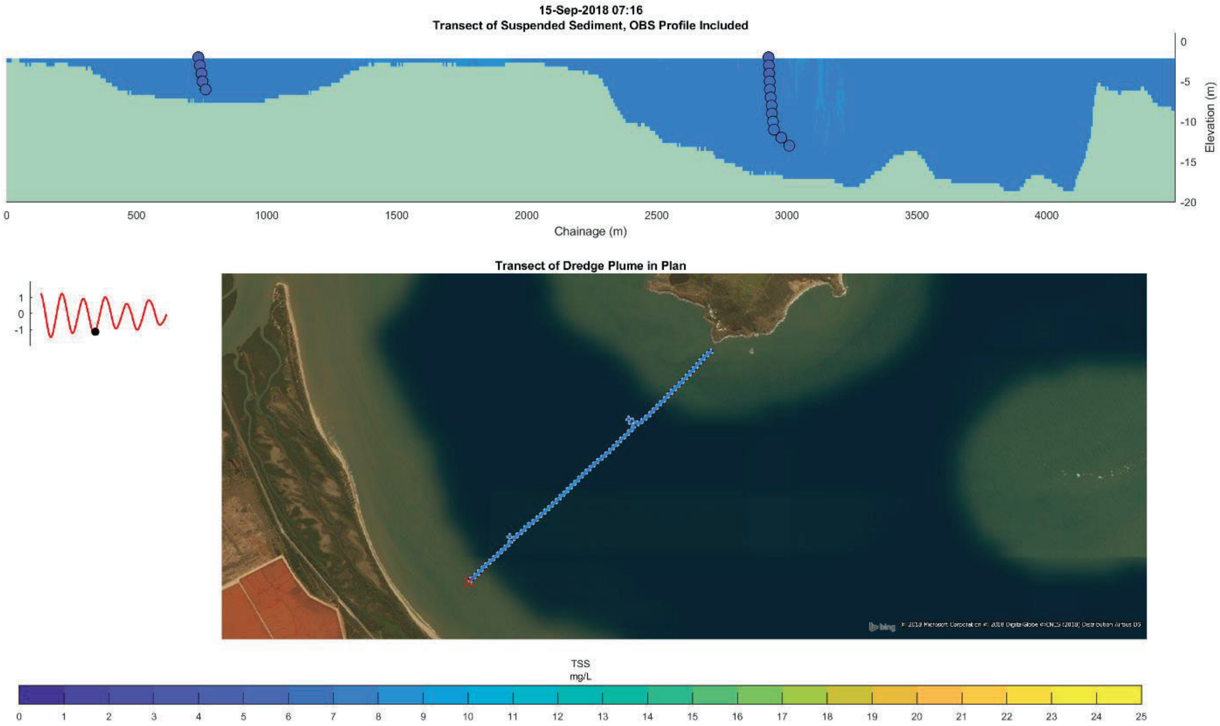
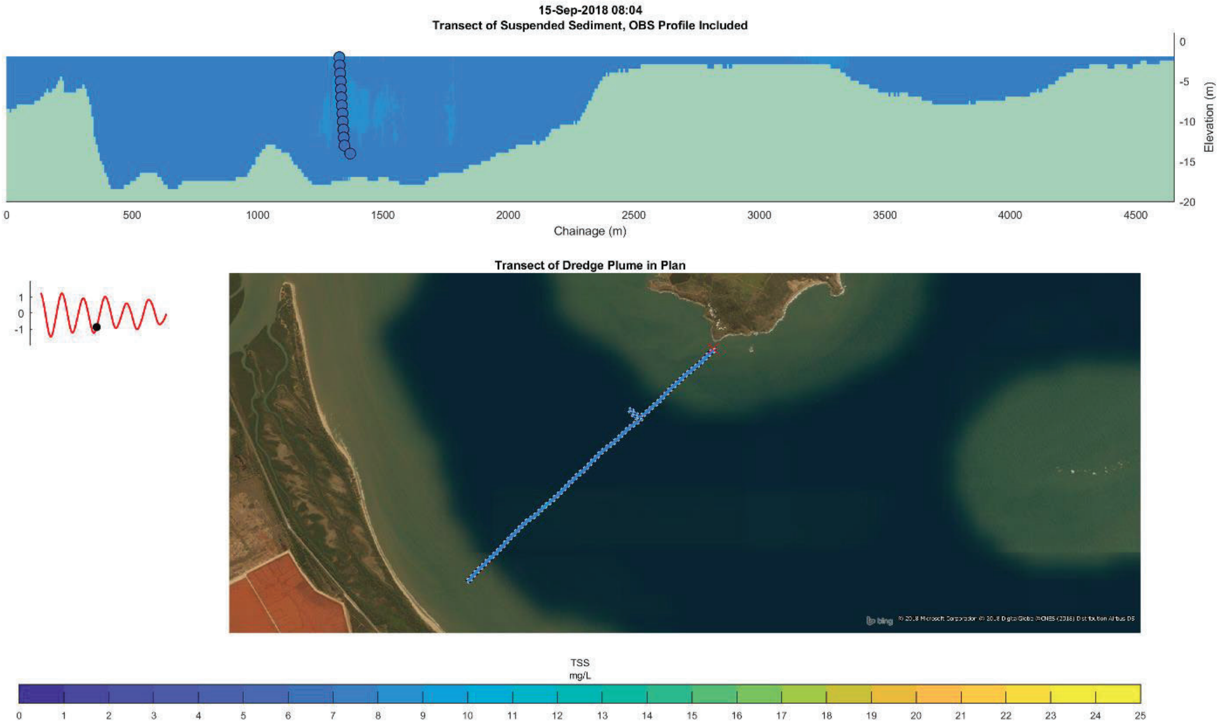
Transect A - Gatcombe Heads to Lilly's Beach – Average Tide


15-Sep-2018 06:29
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan


15-Sep-2018 07:16
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan


15-Sep-2018 08:04
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0
-5
-10
-15
-20
Elevation (m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
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24
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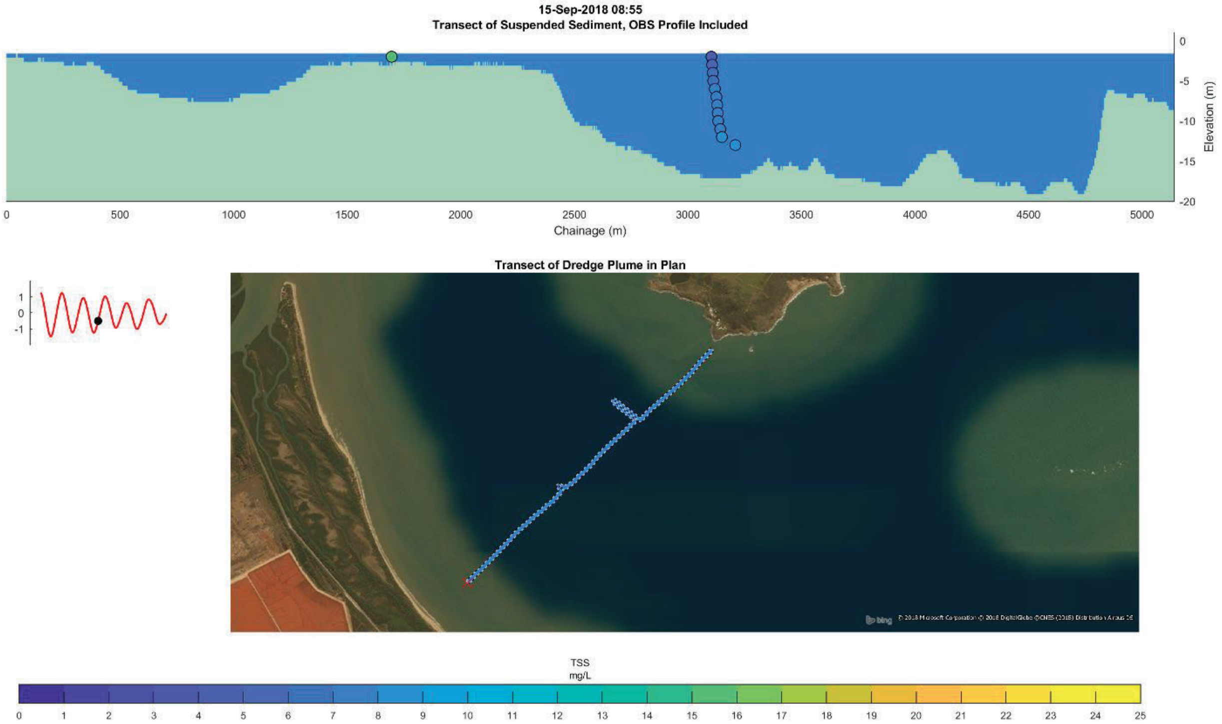
15-Sep-2018 08:55
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-5
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-15
-20
Elevation (m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
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24
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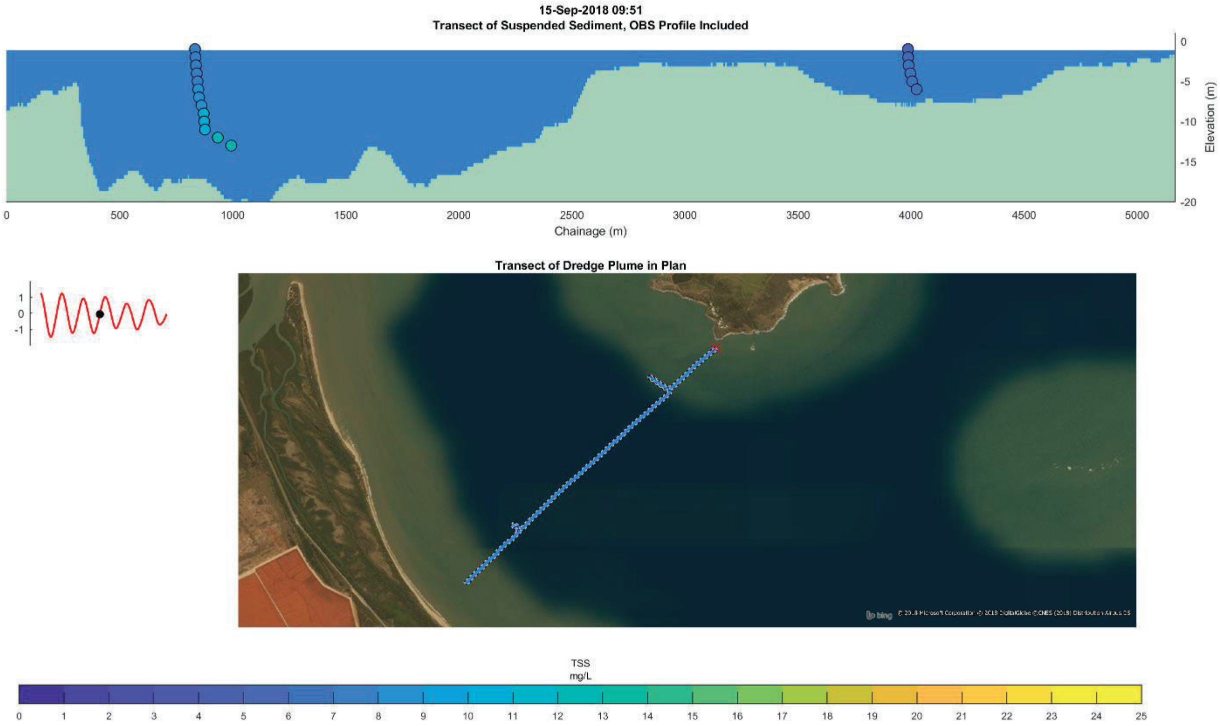
15-Sep-2018 09:51
Transect of Suspended Sediment, OBS Profile Included
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-5
-10
-15
-20
Elevation (m)
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500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
8
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10
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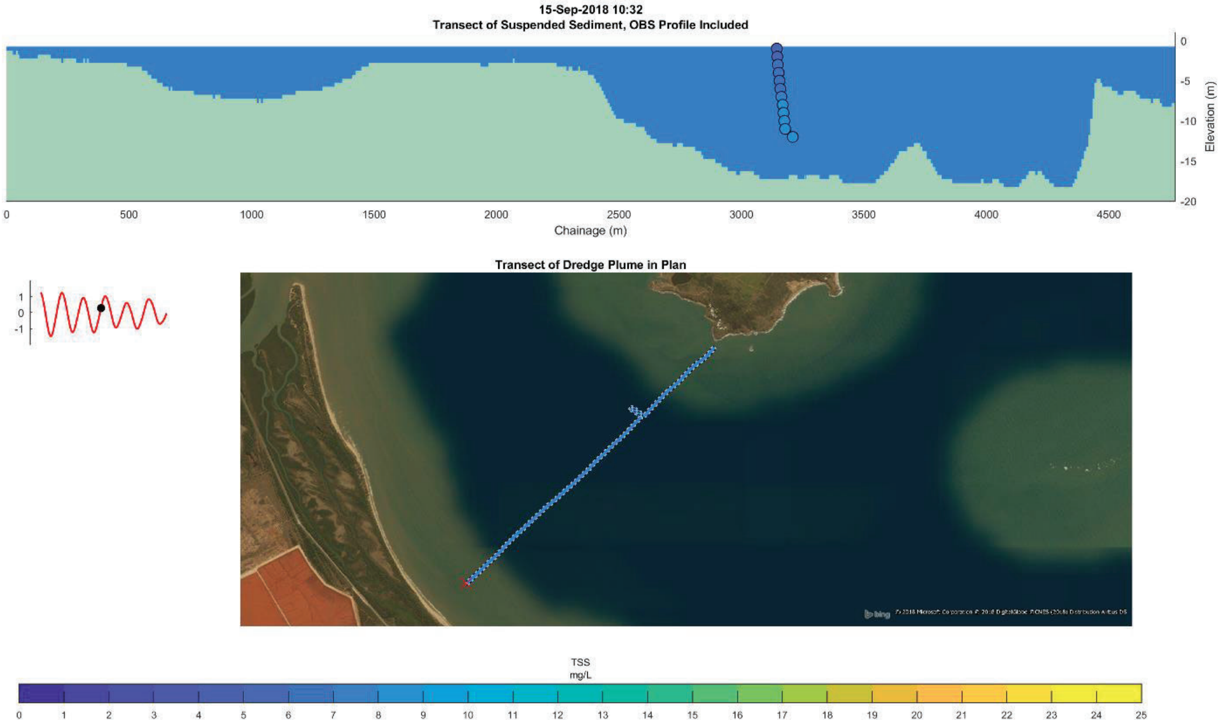
15-Sep-2018 10:32
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-5
-10
-15
-20
Elevation (m)
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500
1000
1500
2000
2500
3000
3500
4000
4500
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
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9
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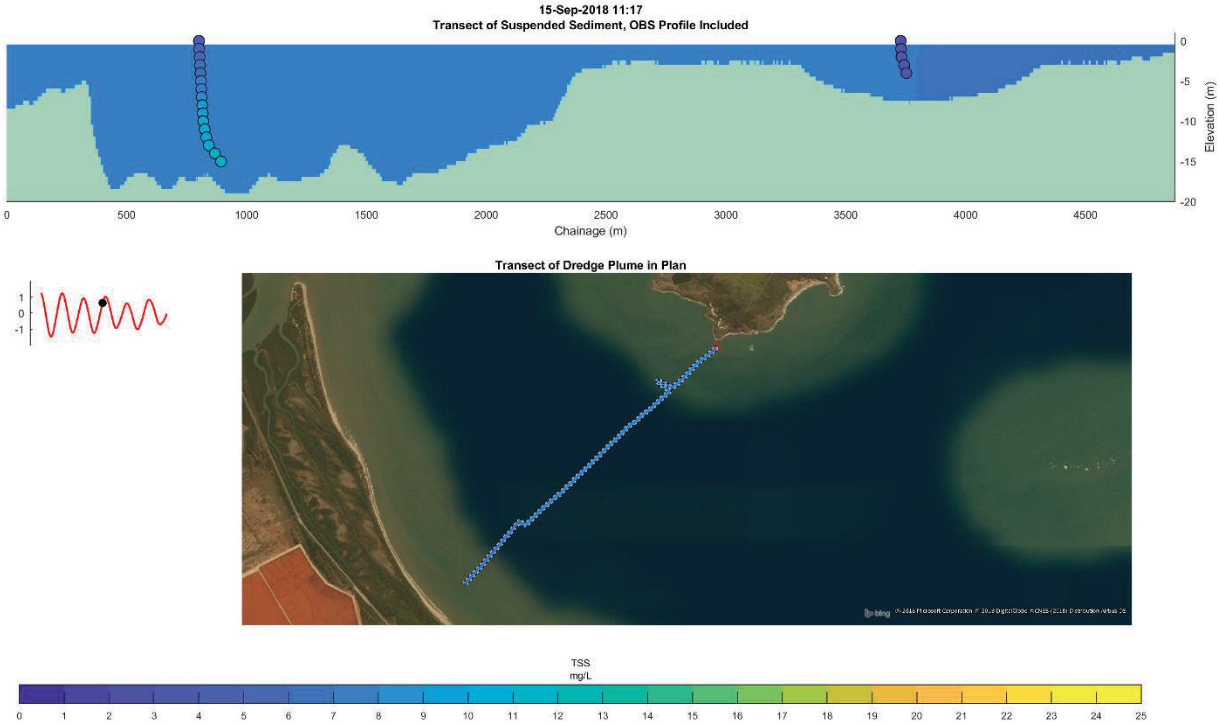
15-Sep-2018 11:17
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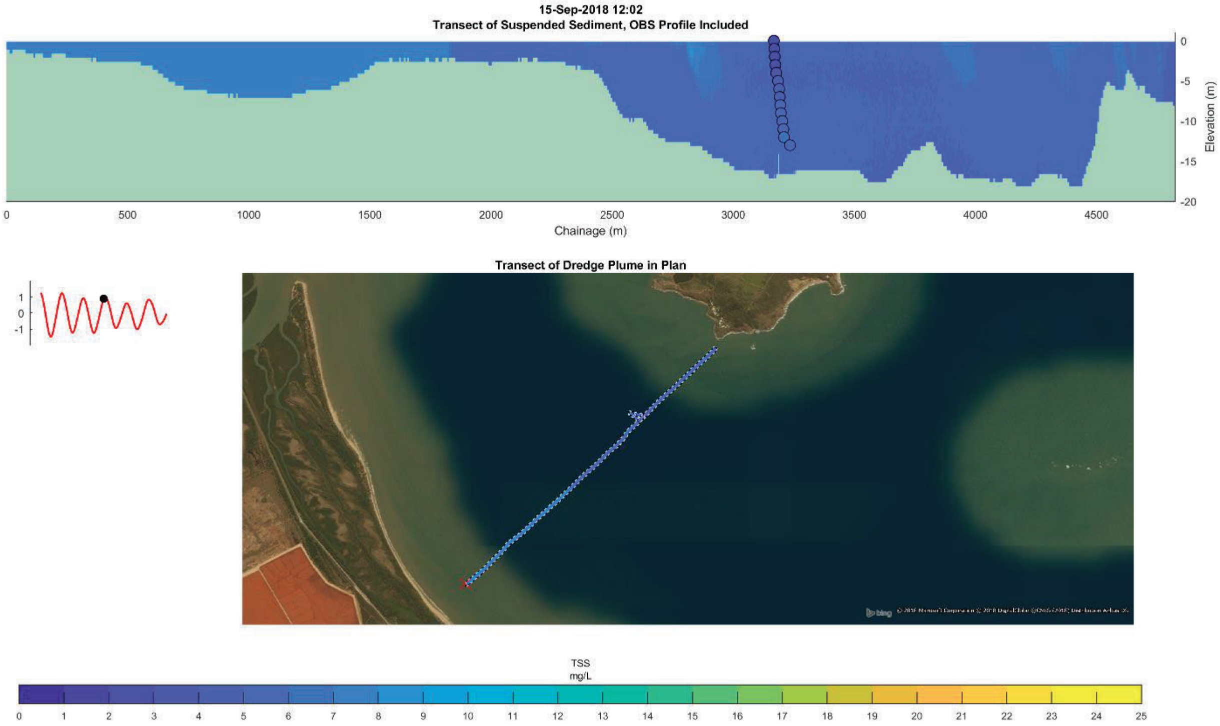
-5
-10
-15
-20
Elevation (m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25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-5
-10
-15
-20
Elevation (m)
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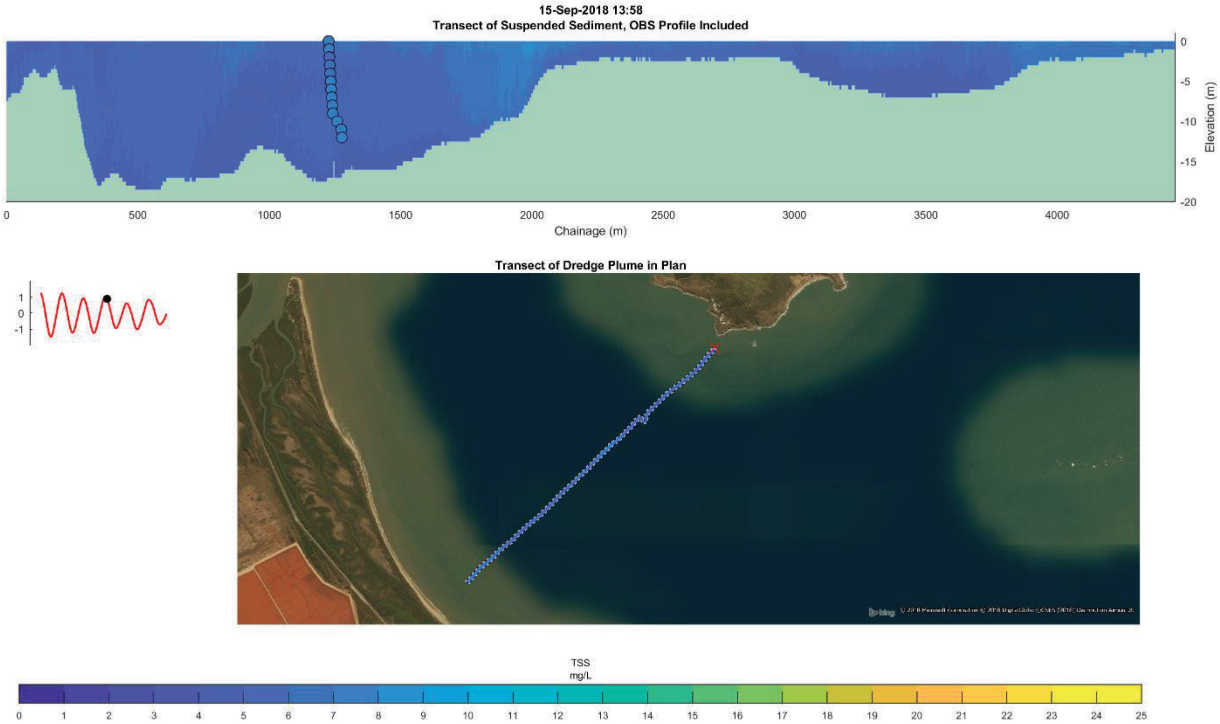
500
1000
1500
2000
2500
3000
3500
4000
4500
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25


15-Sep-2018 13:58
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Elevation (m)
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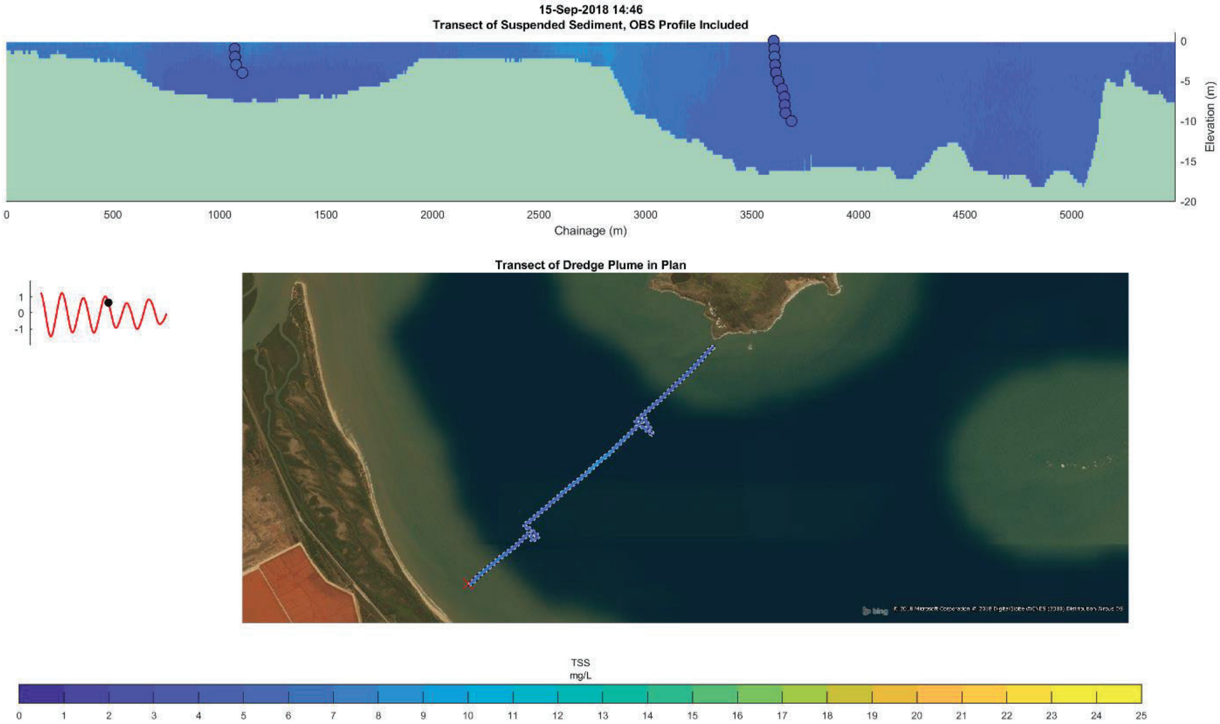
-5
-10
-15
-20
Chainage (m)
0
500
1000
1500
2000
2500
3000
3500
4000
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25


15-Sep-2018 14:46
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Elevation (m)
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-5
-10
-15
-20
Chainage (m)
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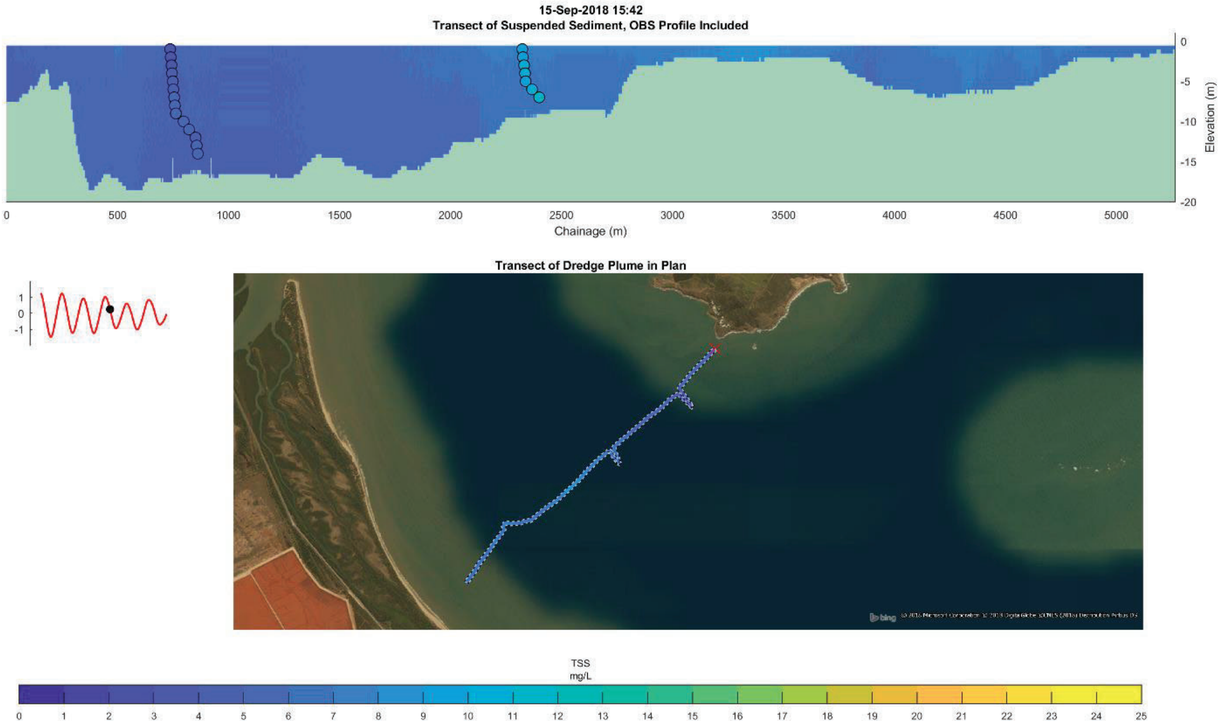
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25


15-Sep-2018 15:42
Transect of Suspended Sediment, OBS Profile Included
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-5
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-15
-20
Chainage (m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
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3
4
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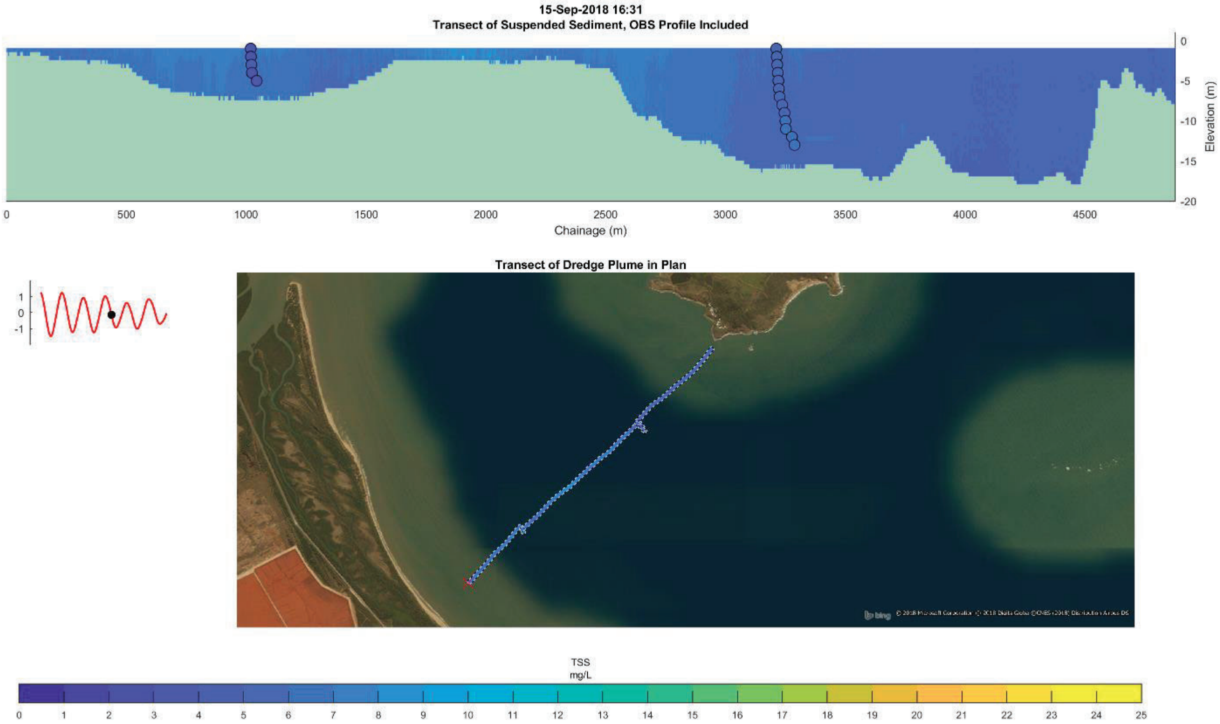
15-Sep-2018 16:31
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-5
-10
-15
-20
Chainage (m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
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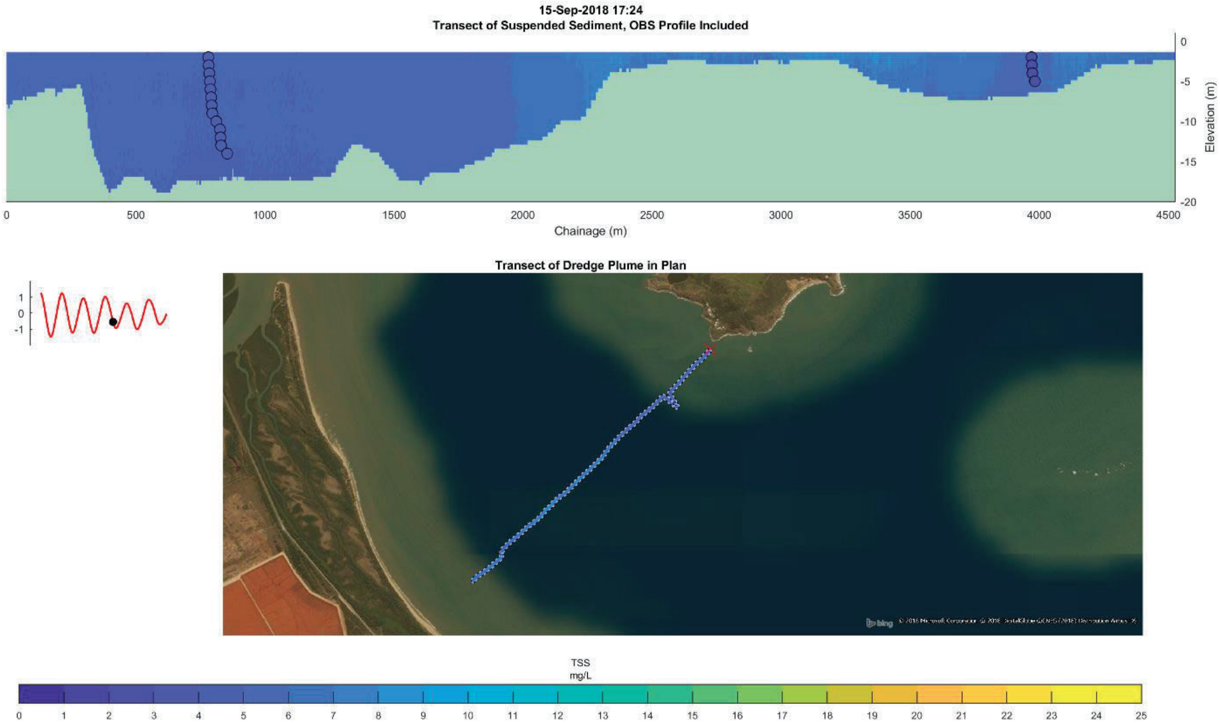
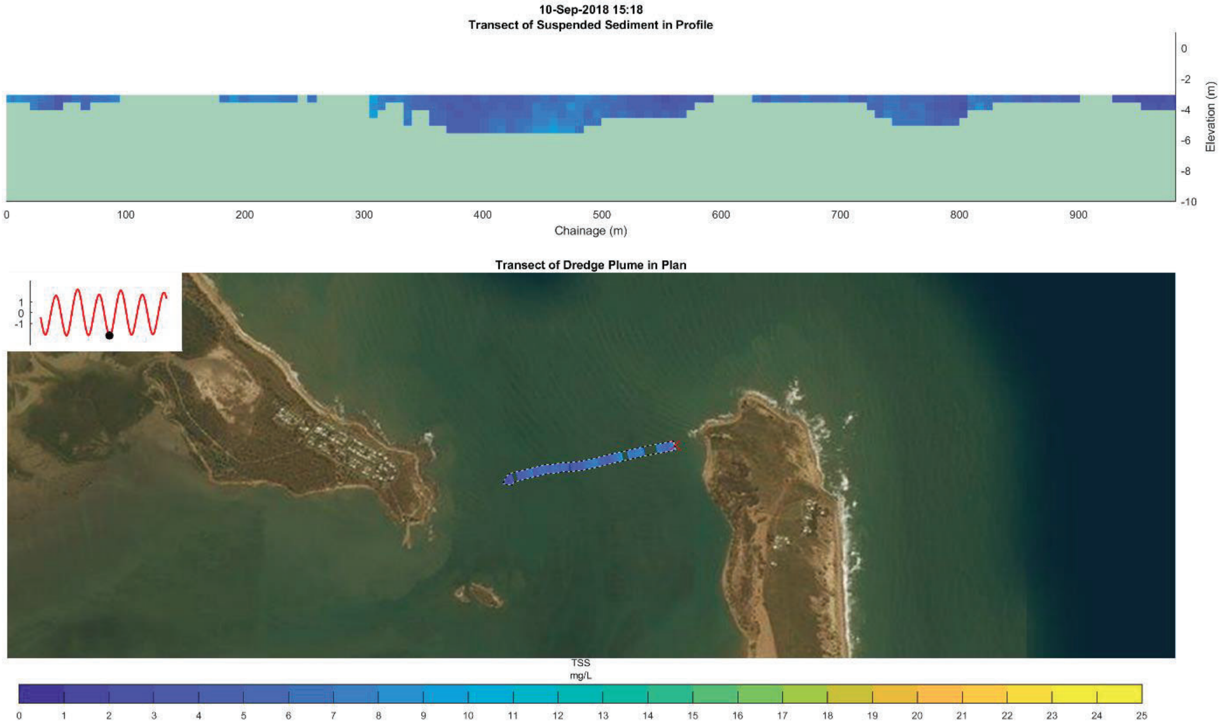


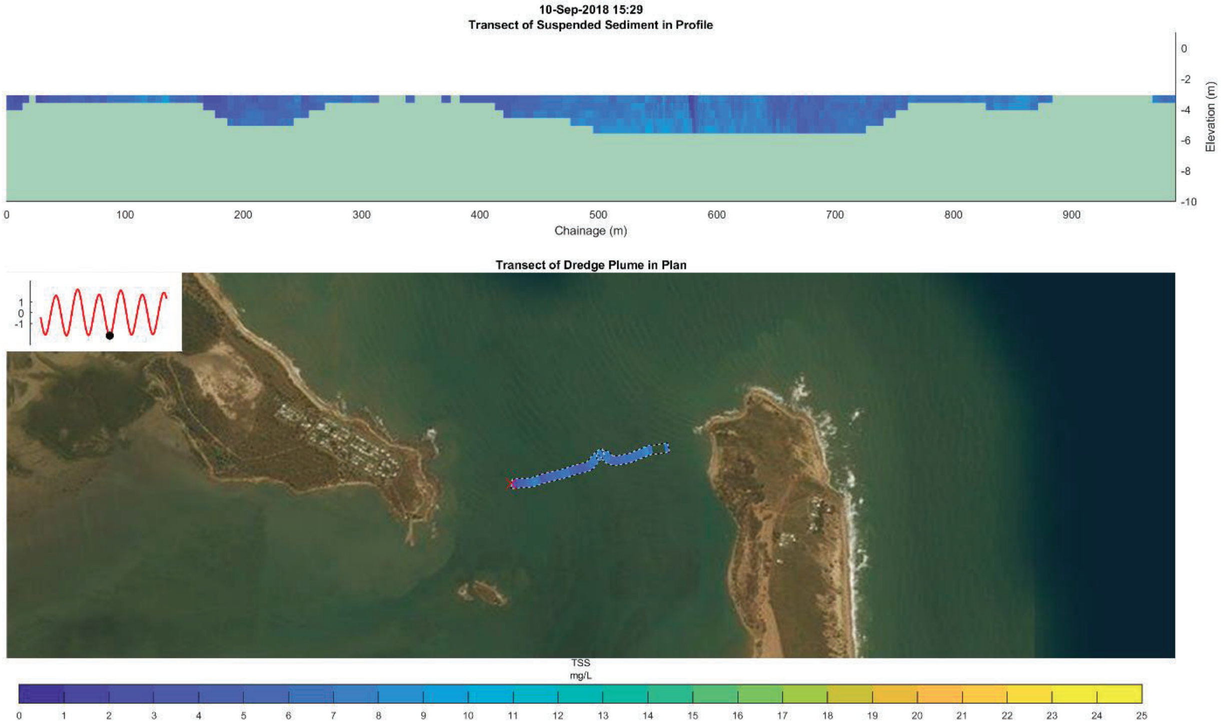
15-Sep-2018 17:24

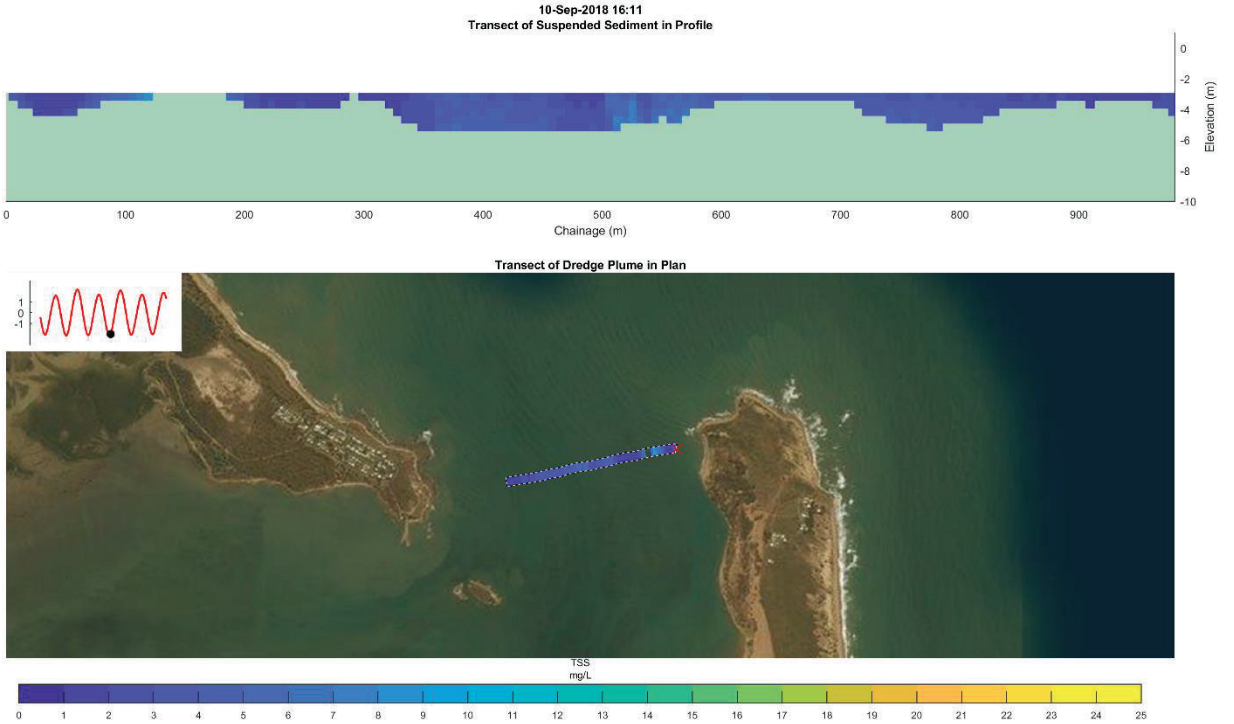
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan

Transect B - South End on Curtis island to North Point on Facing Island – Spring Tide

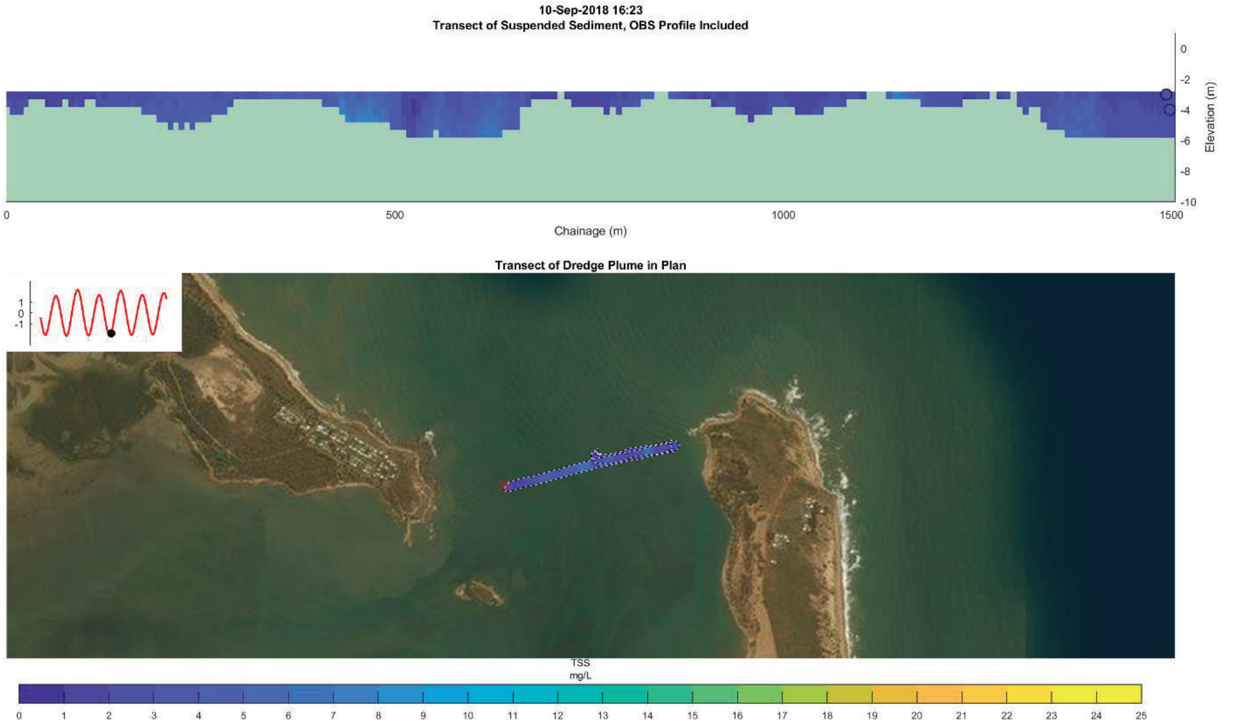






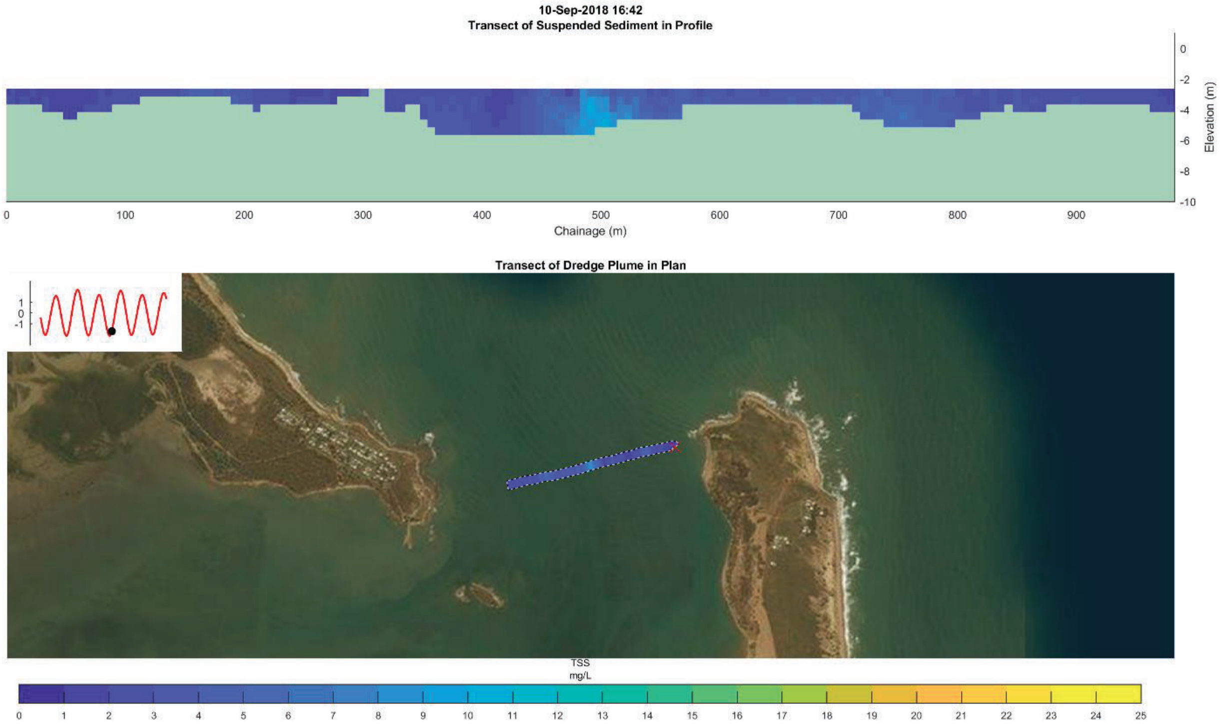
10-Sep-2018 16:11
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan



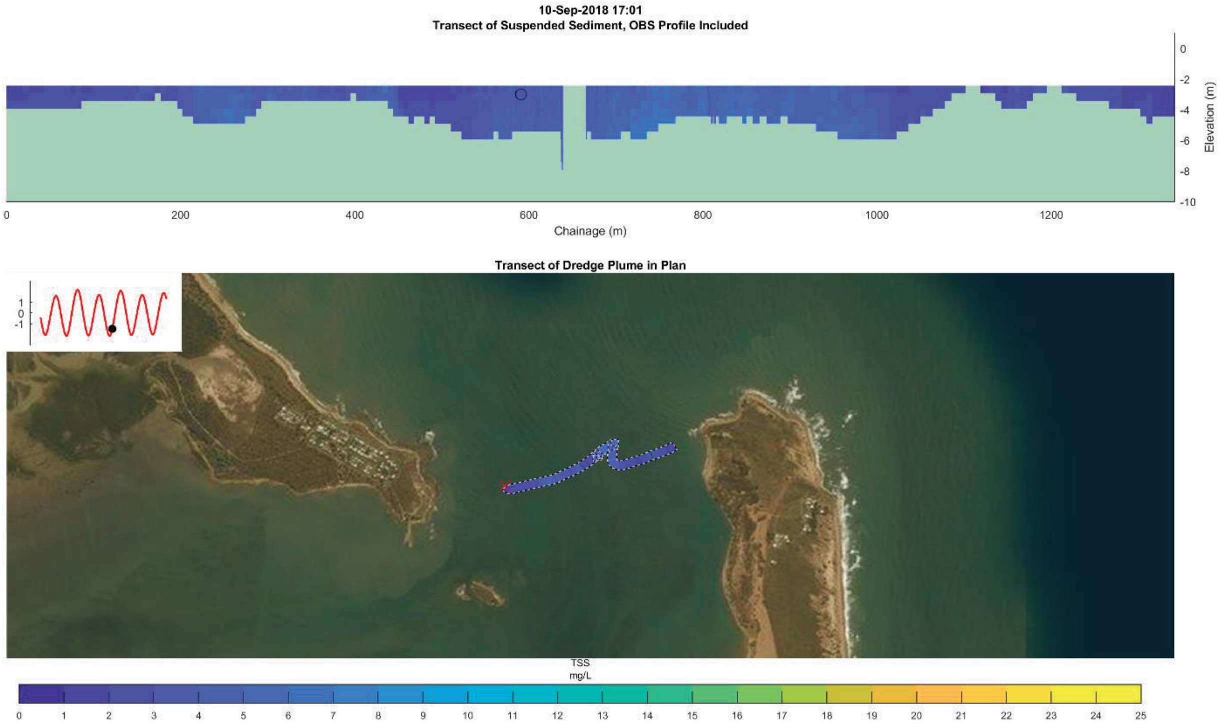
10-Sep-2018 16:23
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan



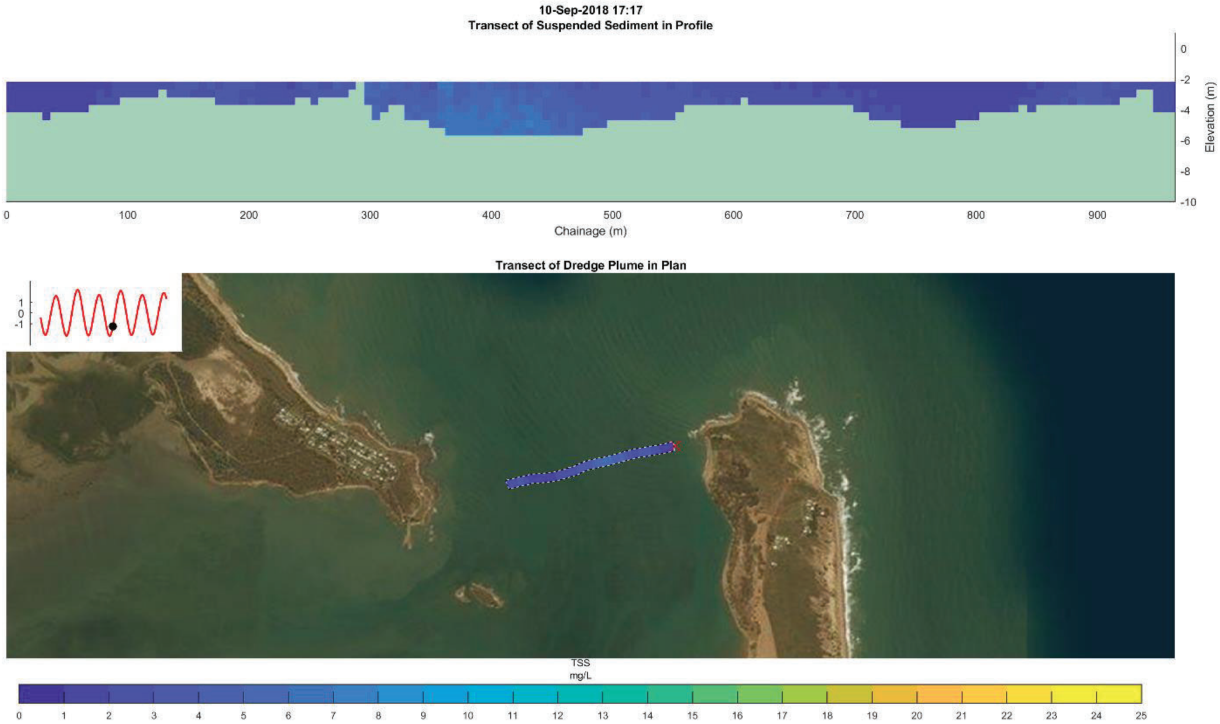
10-Sep-2018 16:42
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan



10-Sep-2018 17:01
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan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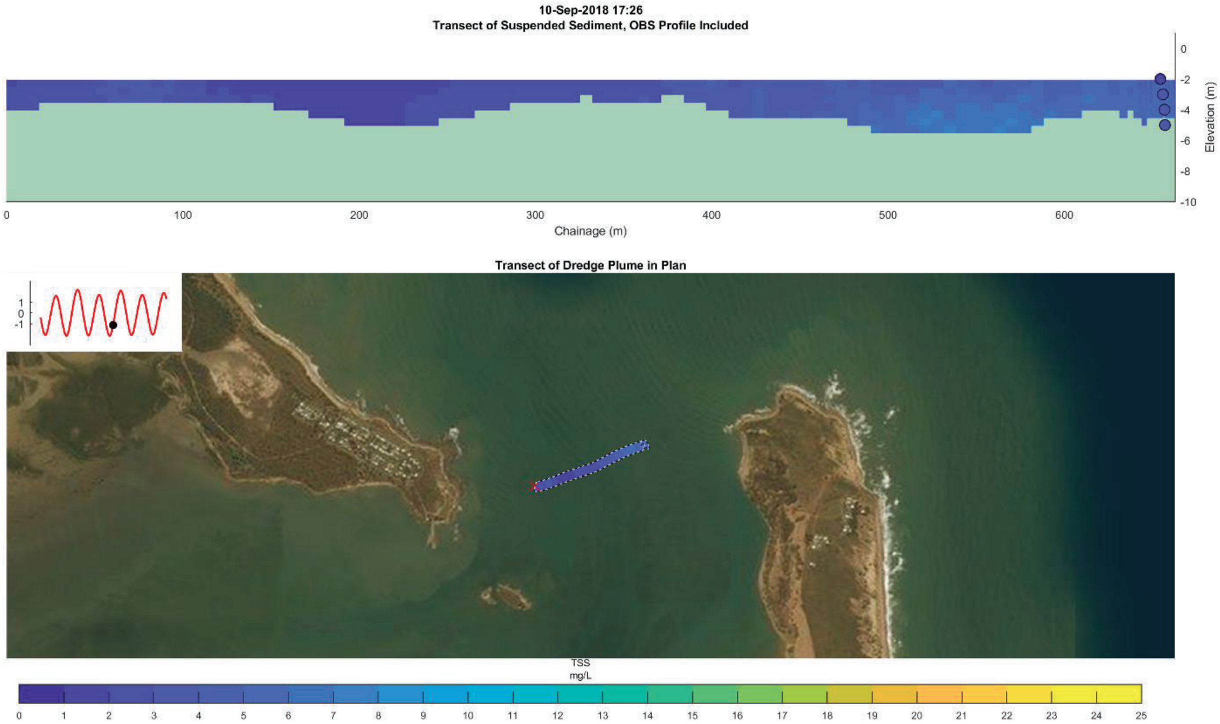
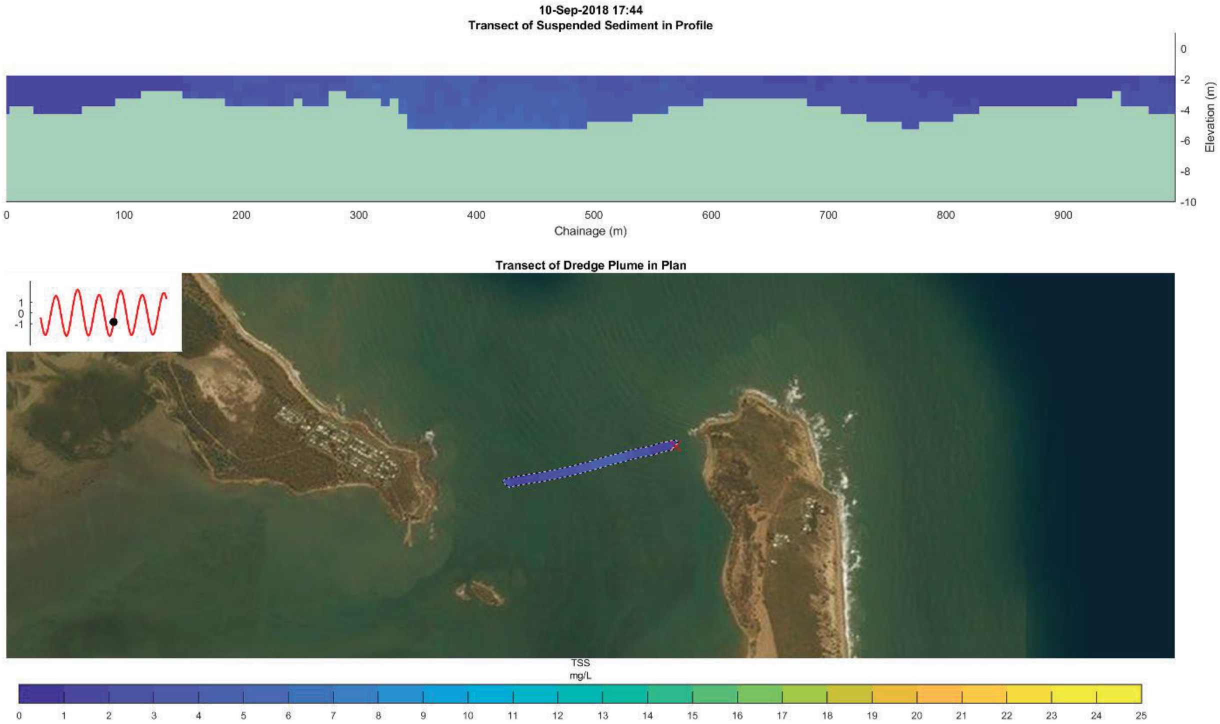
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan

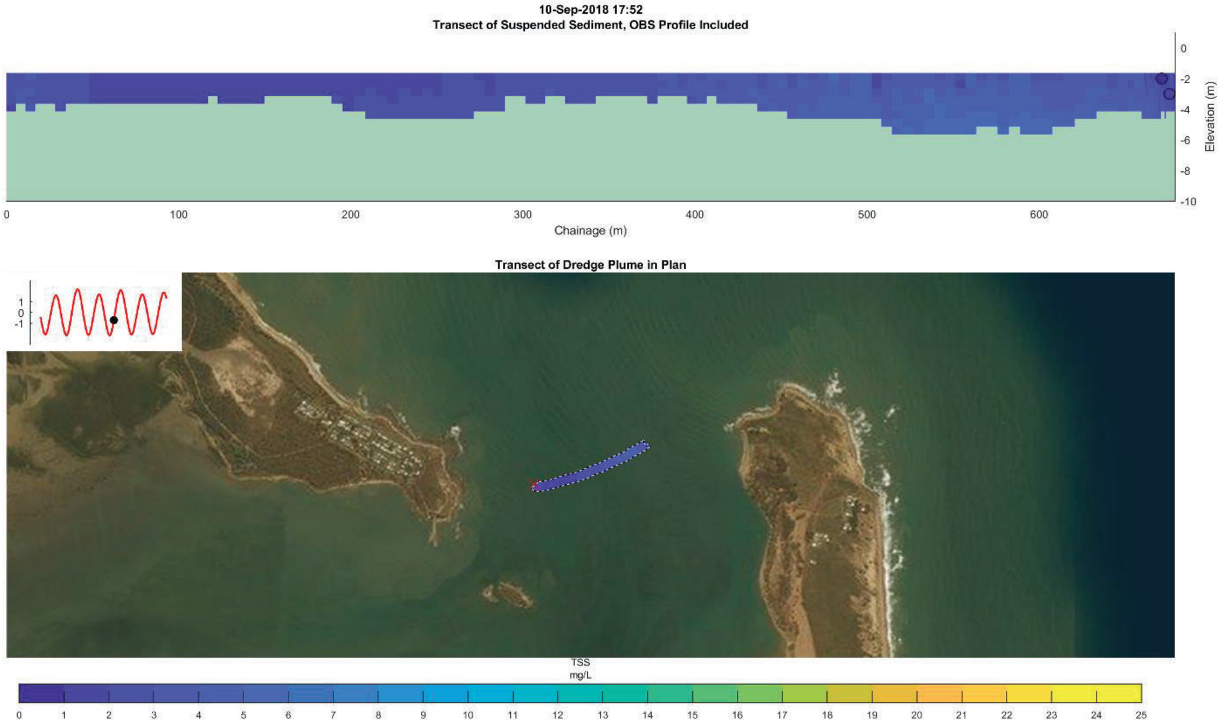

10-Sep-2018 17:26
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan


10-Sep-2018 17:44

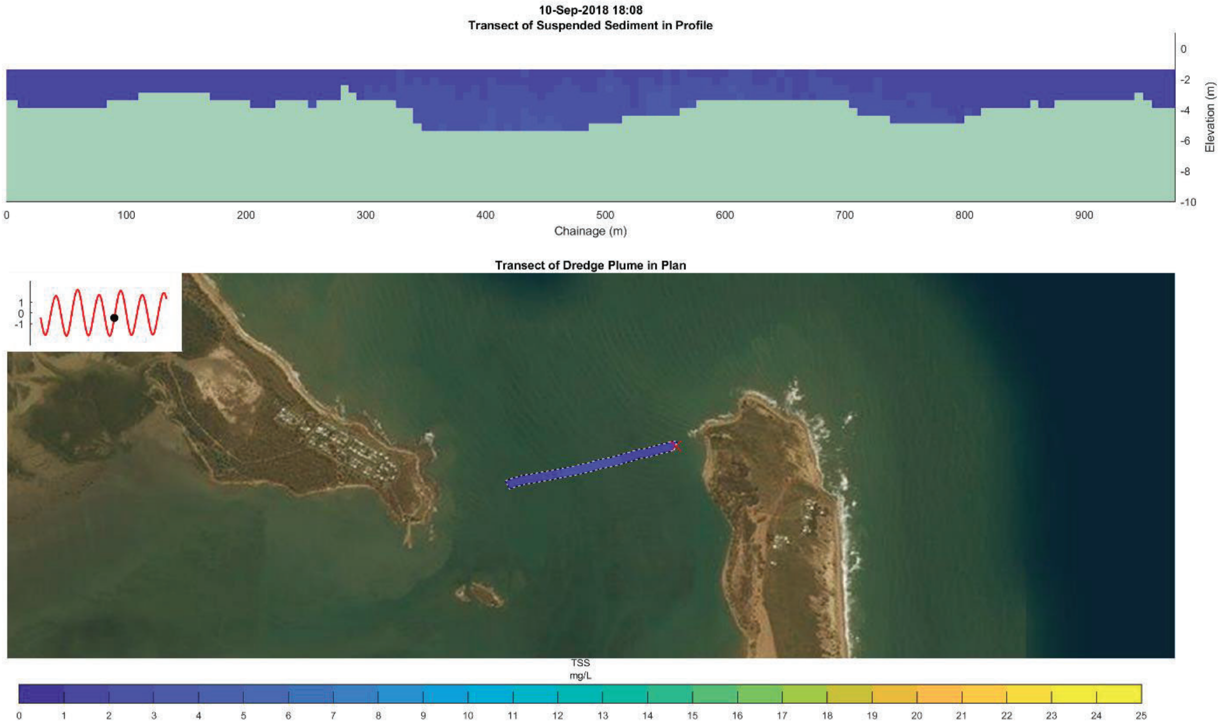
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan


10-Sep-2018 17:52

Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan


10-Sep-2018 18:08
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
100
200
300
400
500
600
700
800
900
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
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24
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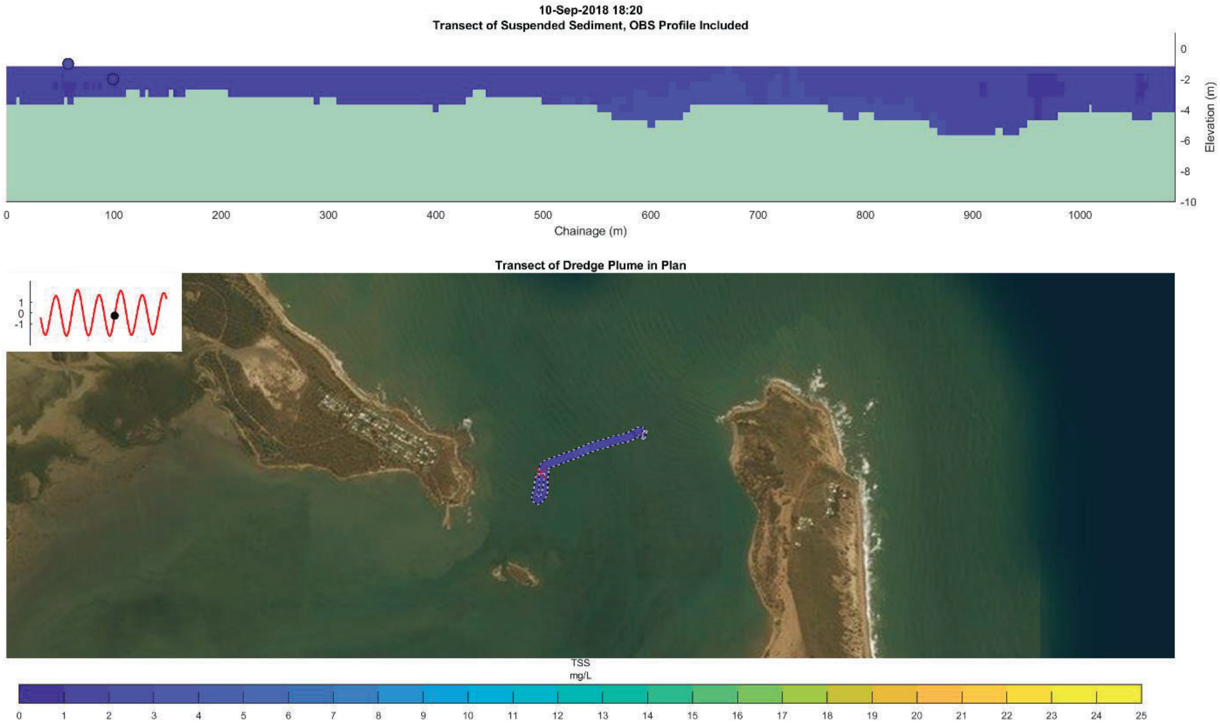
10-Sep-2018 18:20
Transect of Suspended Sediment, OBS Profile Included
0
-2
-4
-6
-8
-10
Elevation (m)
0
100
200
300
400
500
600
700
800
900
1000
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
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24
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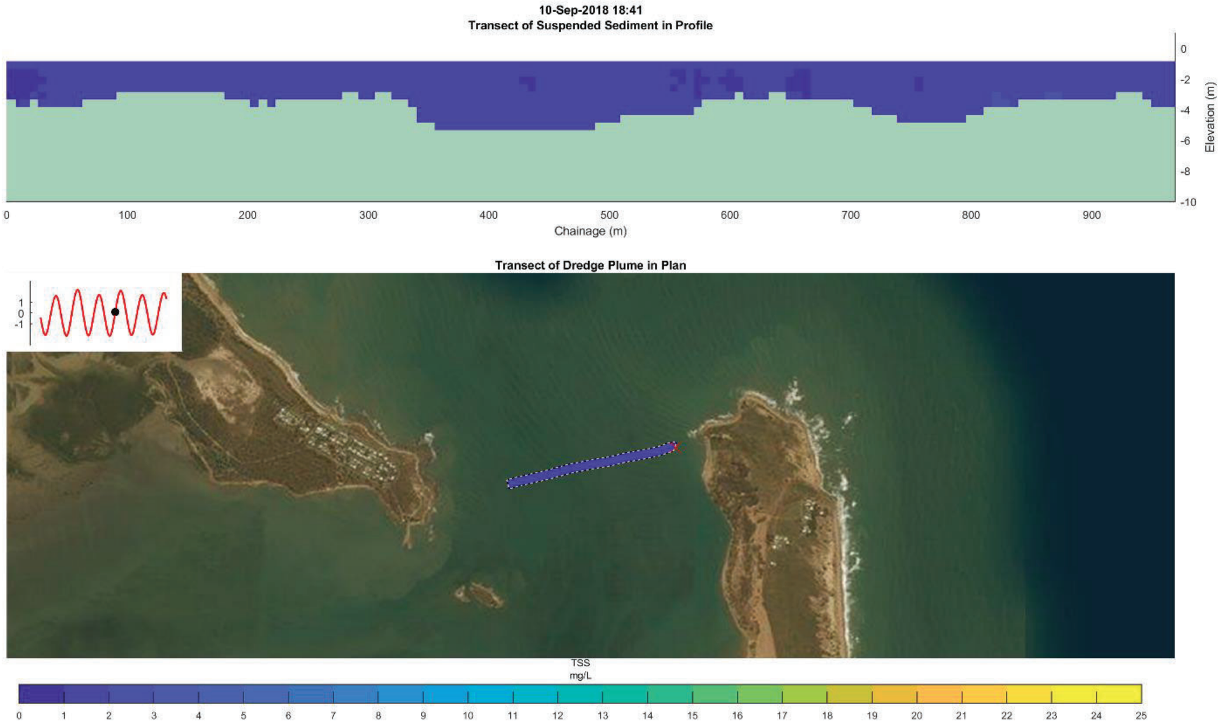
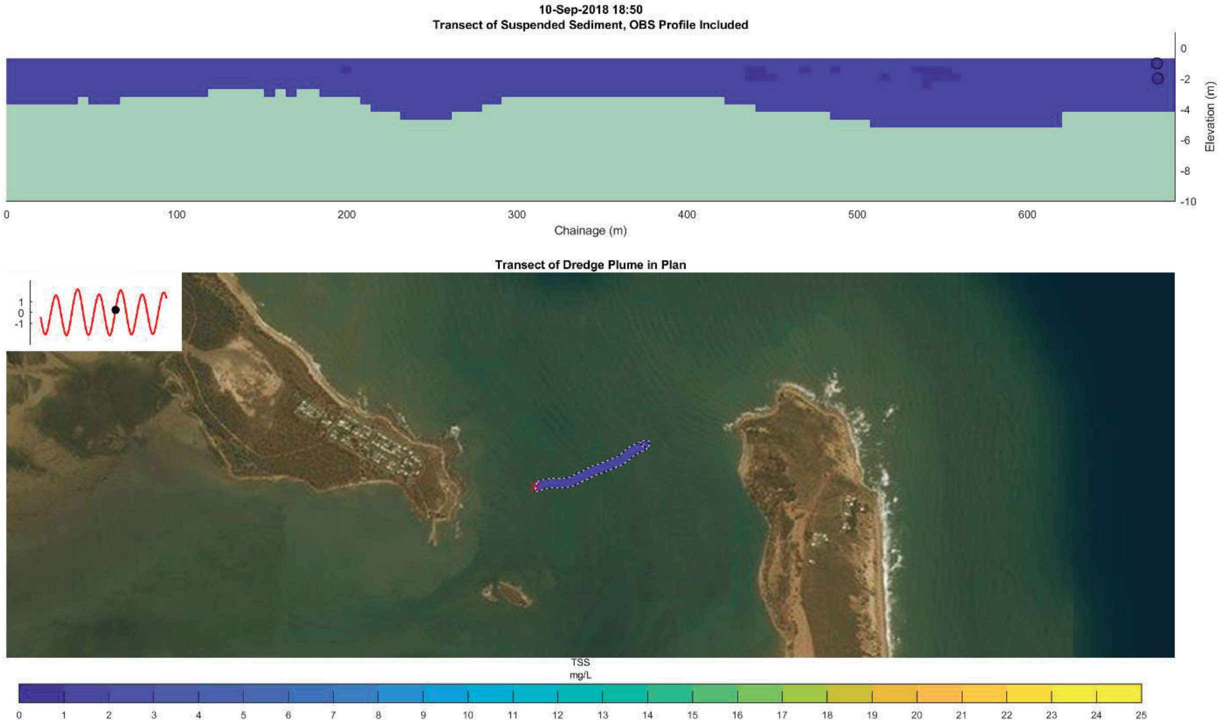

10-Sep-2018 18:41

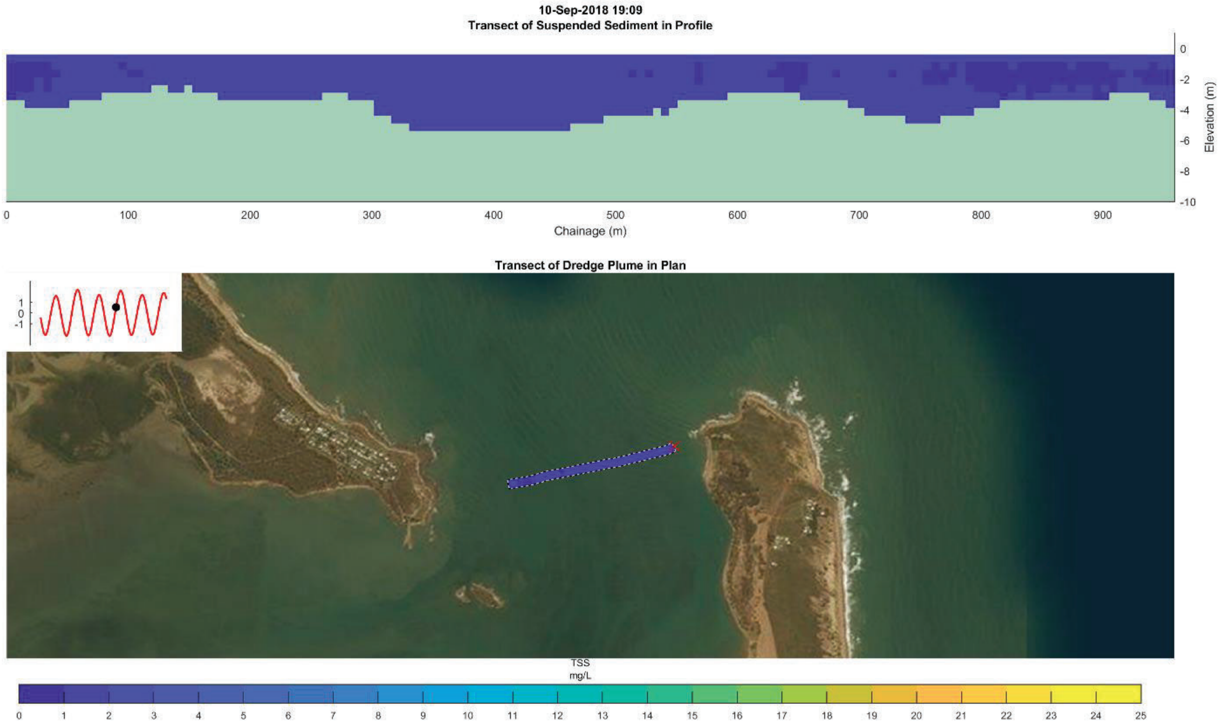
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan


10-Sep-2018 18:50

Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan


10-Sep-2018 19:09
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
100
200
300
400
500
600
700
800
900
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
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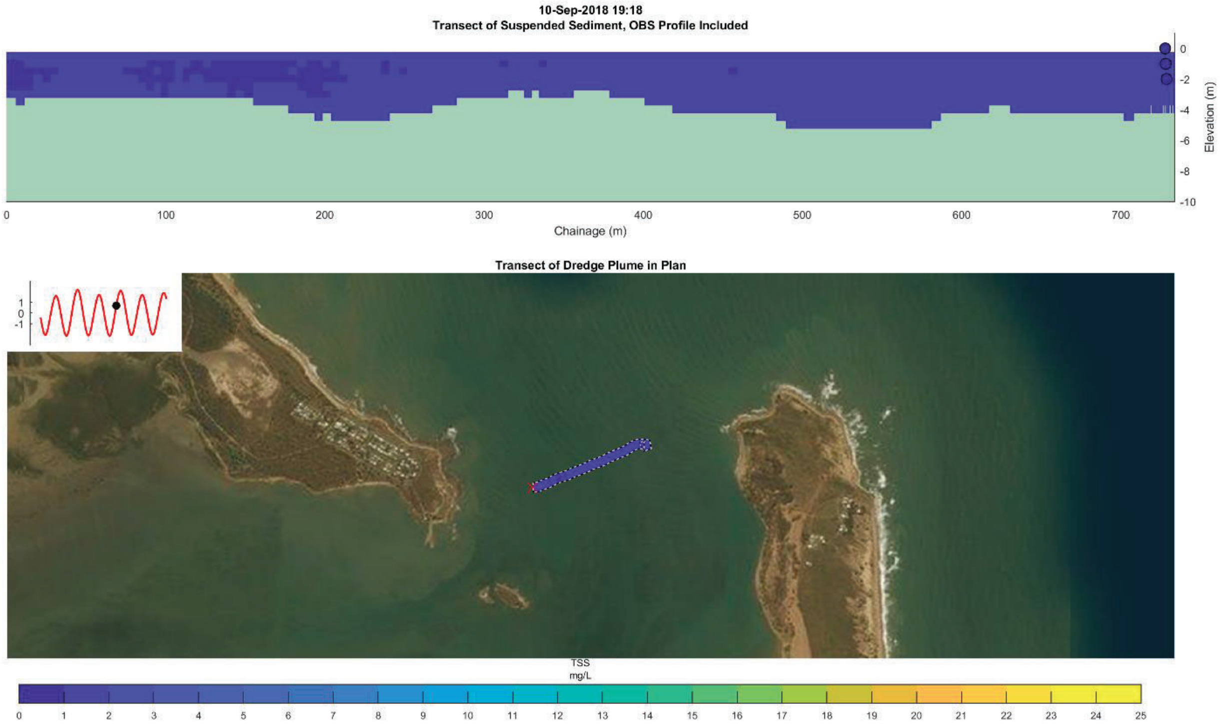
10-Sep-2018 19:18
Transect of Suspended Sediment, OBS Profile Included
0
-2
-4
-6
-8
-10
Elevation (m)
0
100
200
300
400
500
600
700
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
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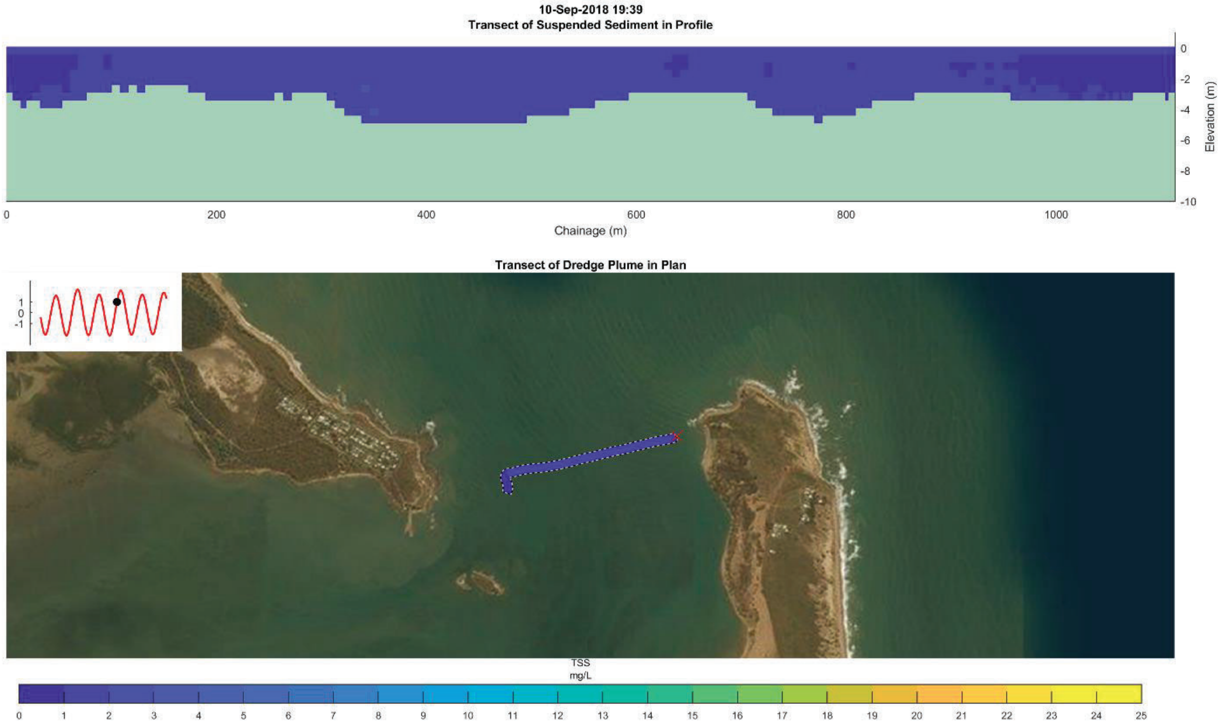
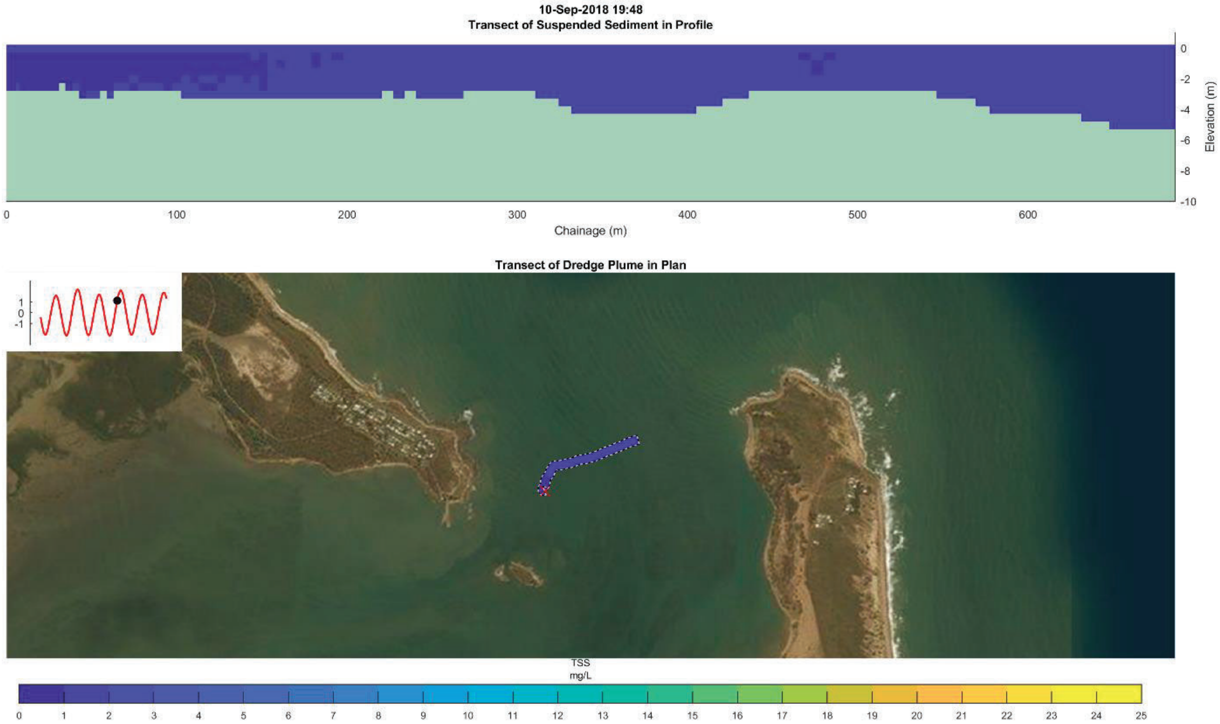


10-Sep-2018 19:39

Transcect of Suspended Sediment in Profile

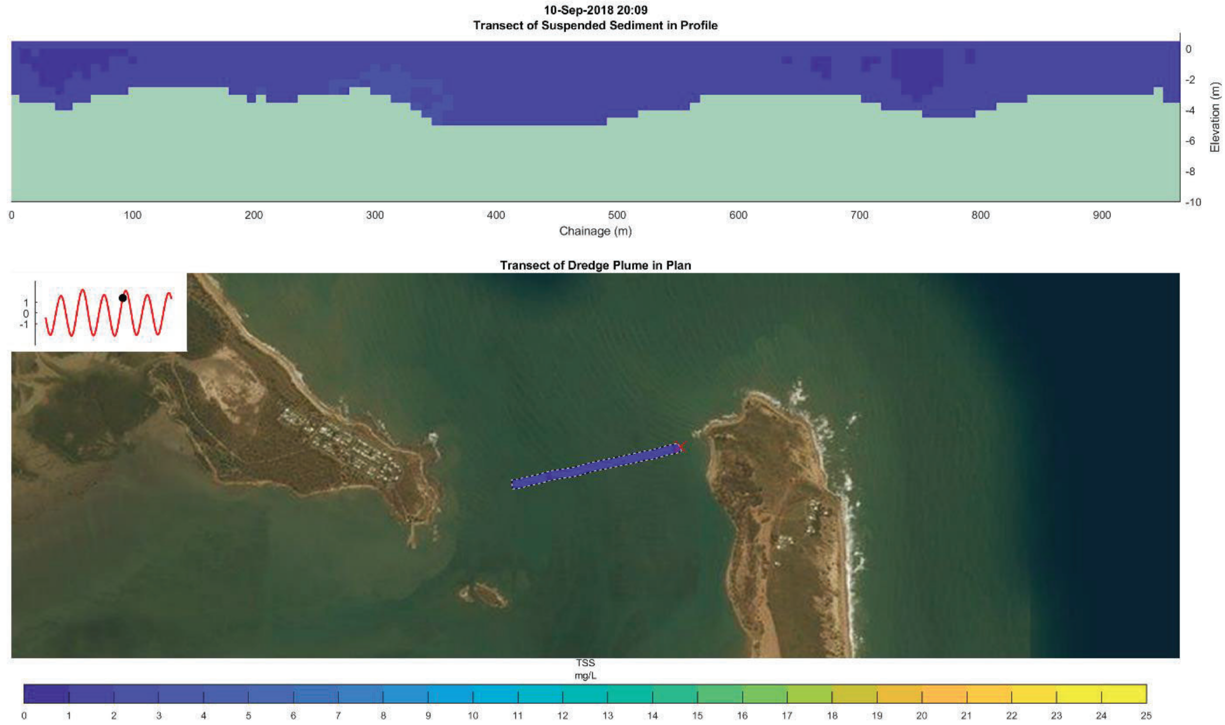
Transect of Dredge Plume in Plan



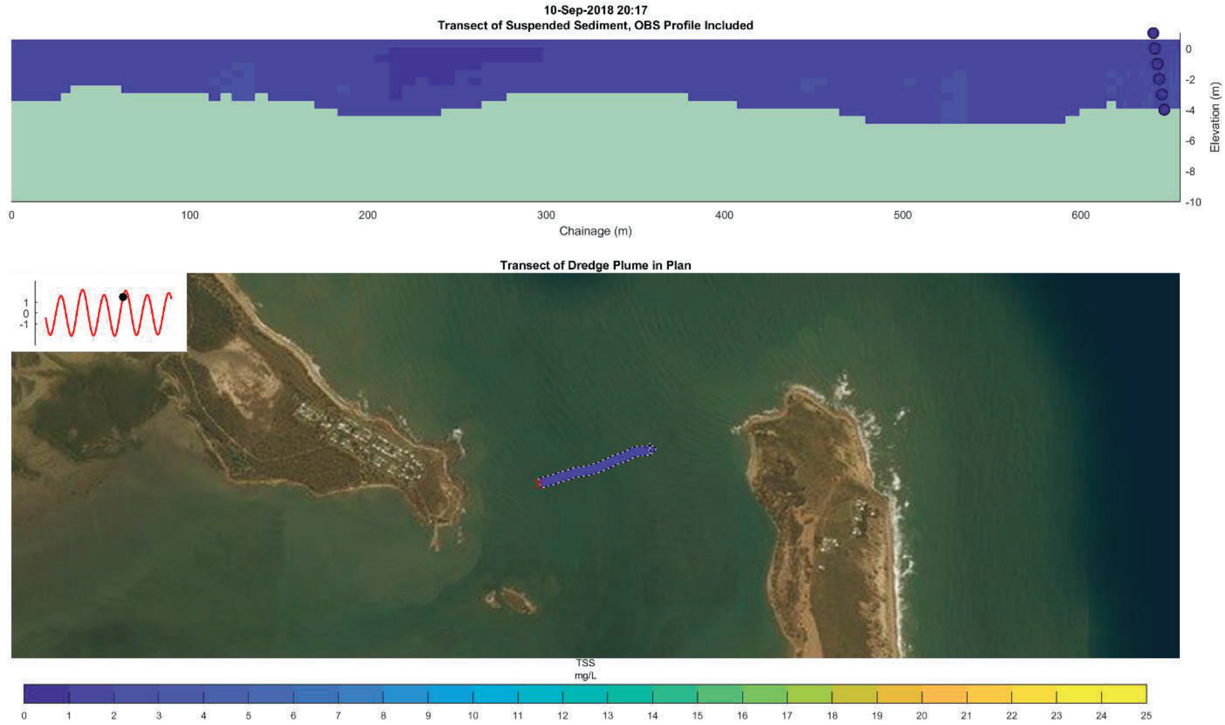
10-Sep-2018 19:48

Transcect of Suspended Sediment in Profile

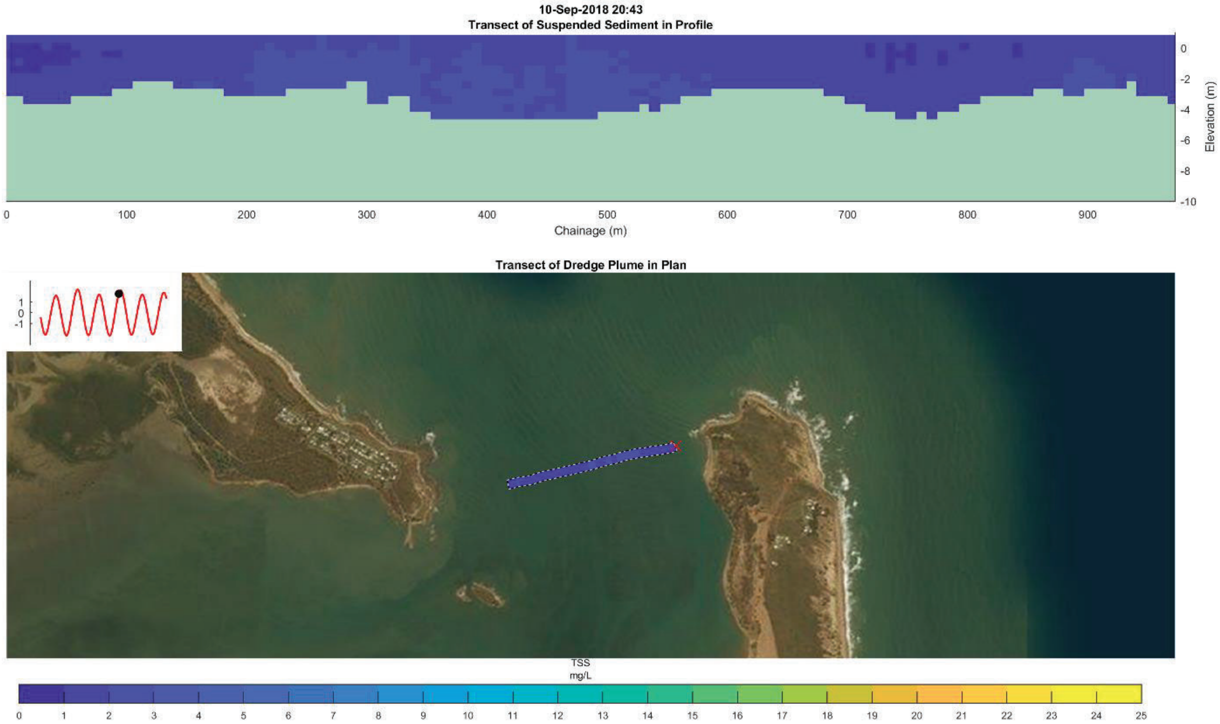
Transect of Dredge Plume in Plan


10-Sep-2018 20:09
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan

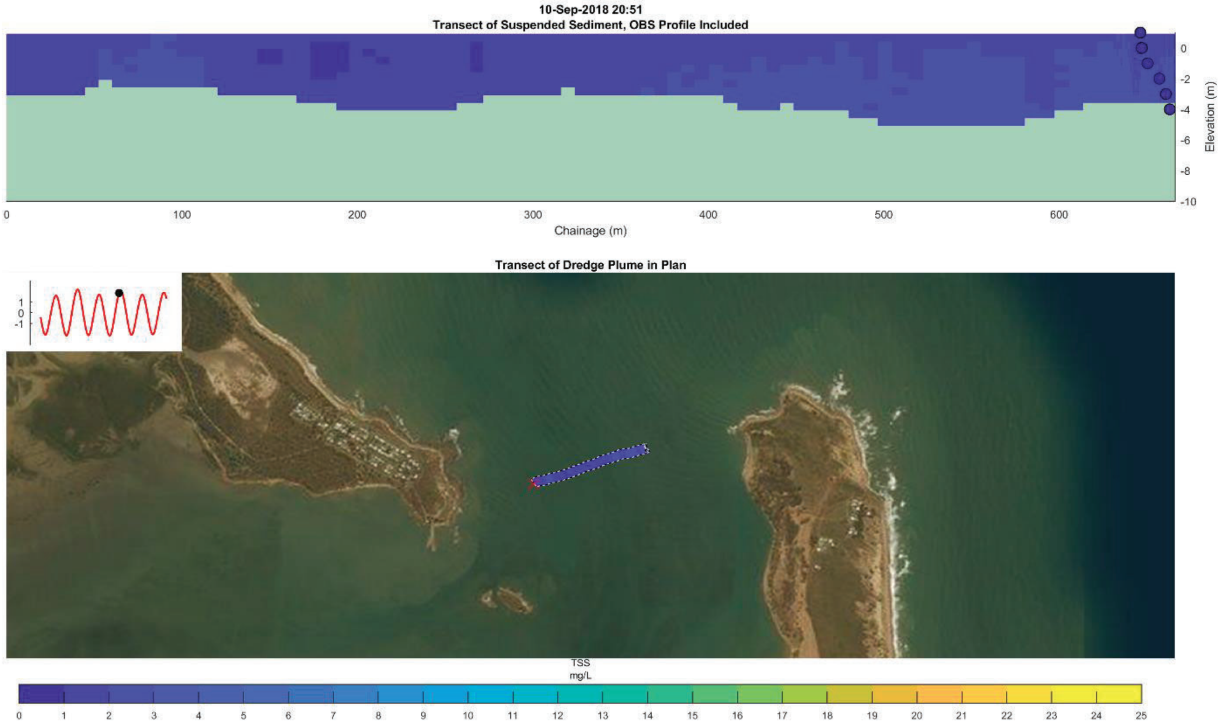

10-Sep-2018 20:17
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan


10-Sep-2018 20:43

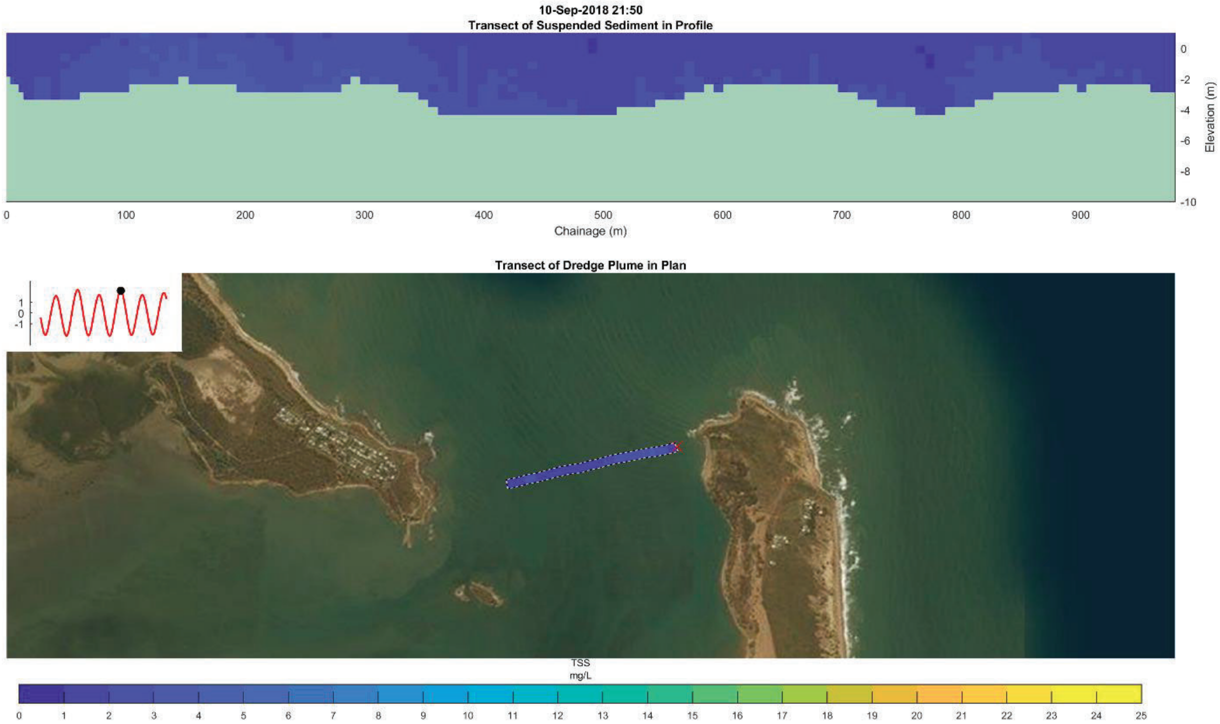
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan


10-Sep-2018 20:51

Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan


10-Sep-2018 21:50
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
100
200
300
400
500
600
700
800
900
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
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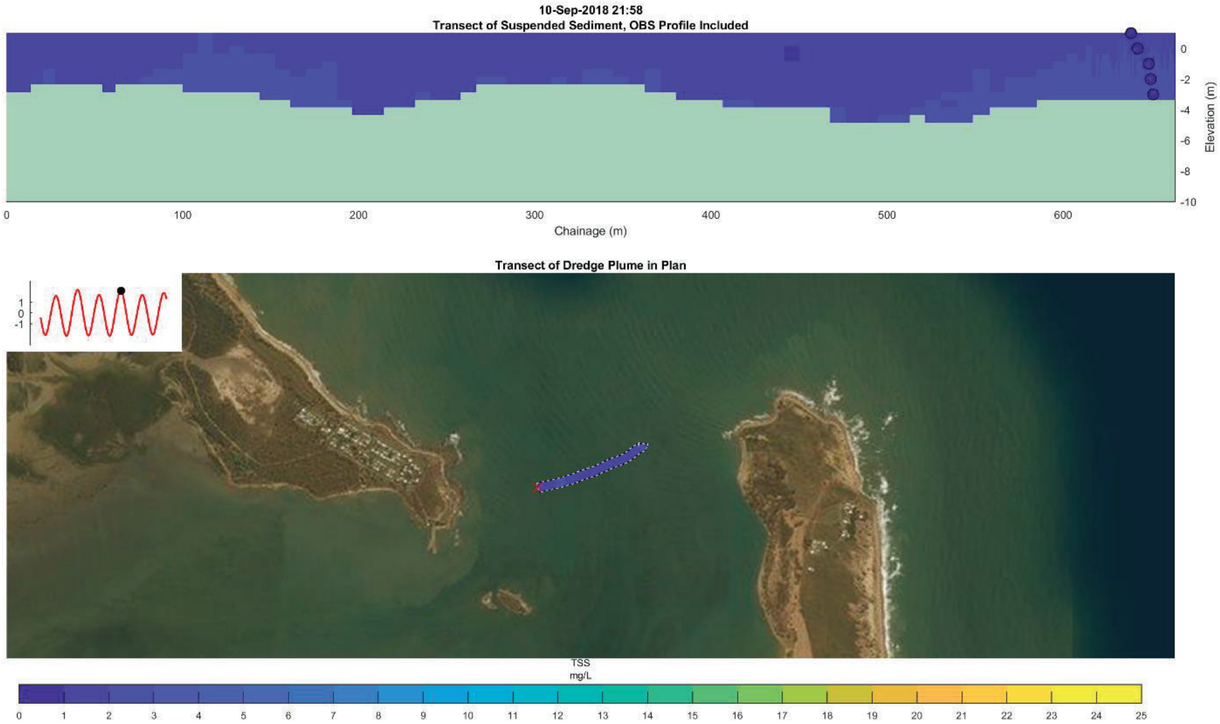
10-Sep-2018 21:58
Transect of Suspended Sediment, OBS Profile Included
0
-2
-4
-6
-8
-10
Elevation (m)
0
100
200
300
400
500
600
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
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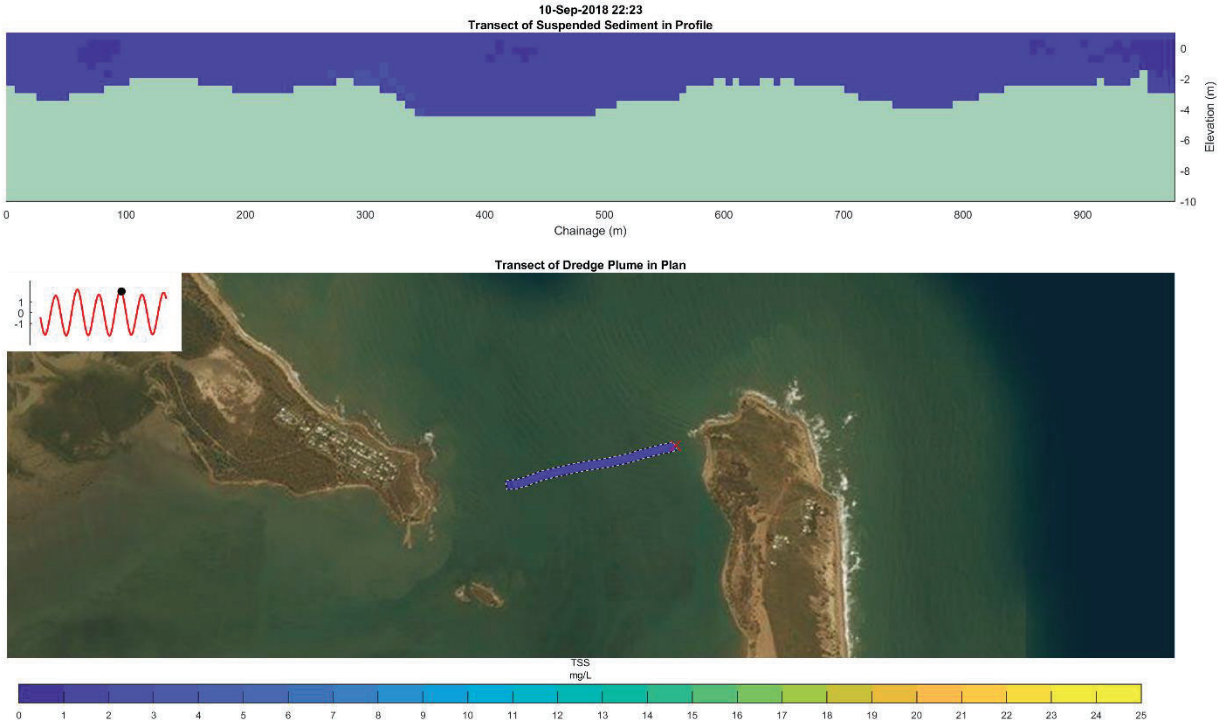
10-Sep-2018 22:23
Transect of Suspended Sediment in Profile
Elevation (m)
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-2
-4
-6
-8
-10
Chainage (m)
0
100
200
300
400
500
600
700
800
900
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
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4
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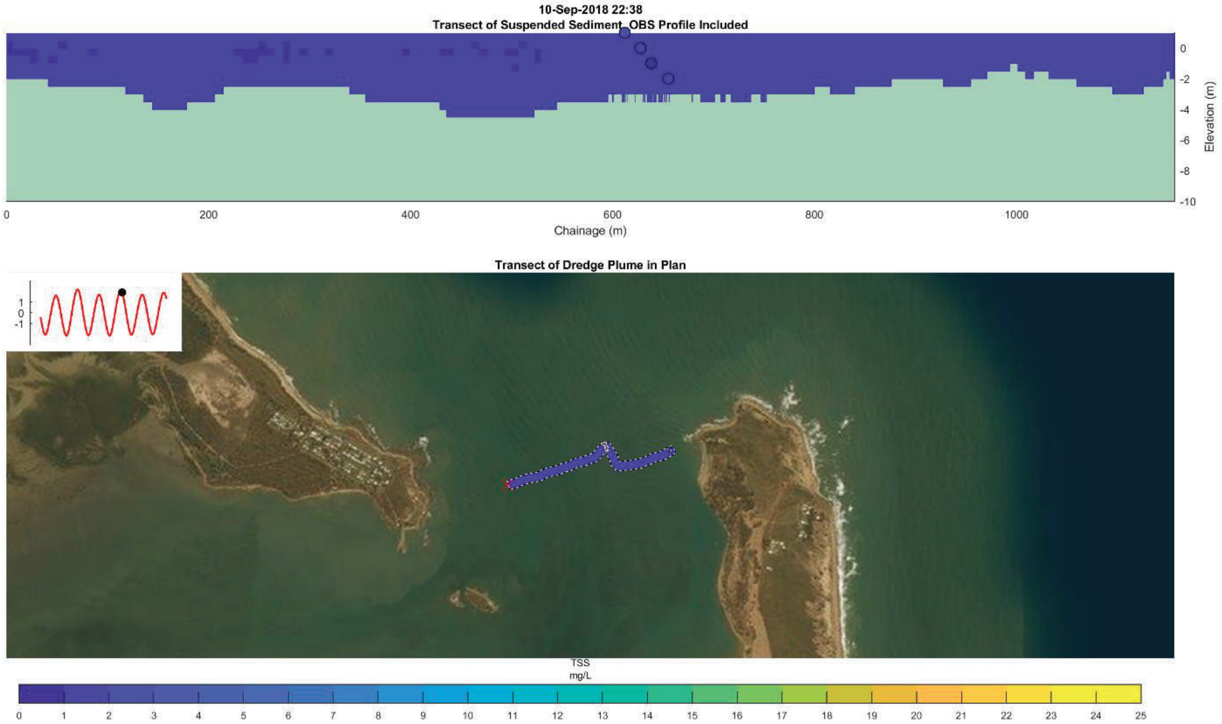
10-Sep-2018 22:38
Transect of Suspended Sediment, OBS Profile Included
Elevation (m)
0
-2
-4
-6
-8
-10
Chainage (m)
0
200
400
600
800
1000
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
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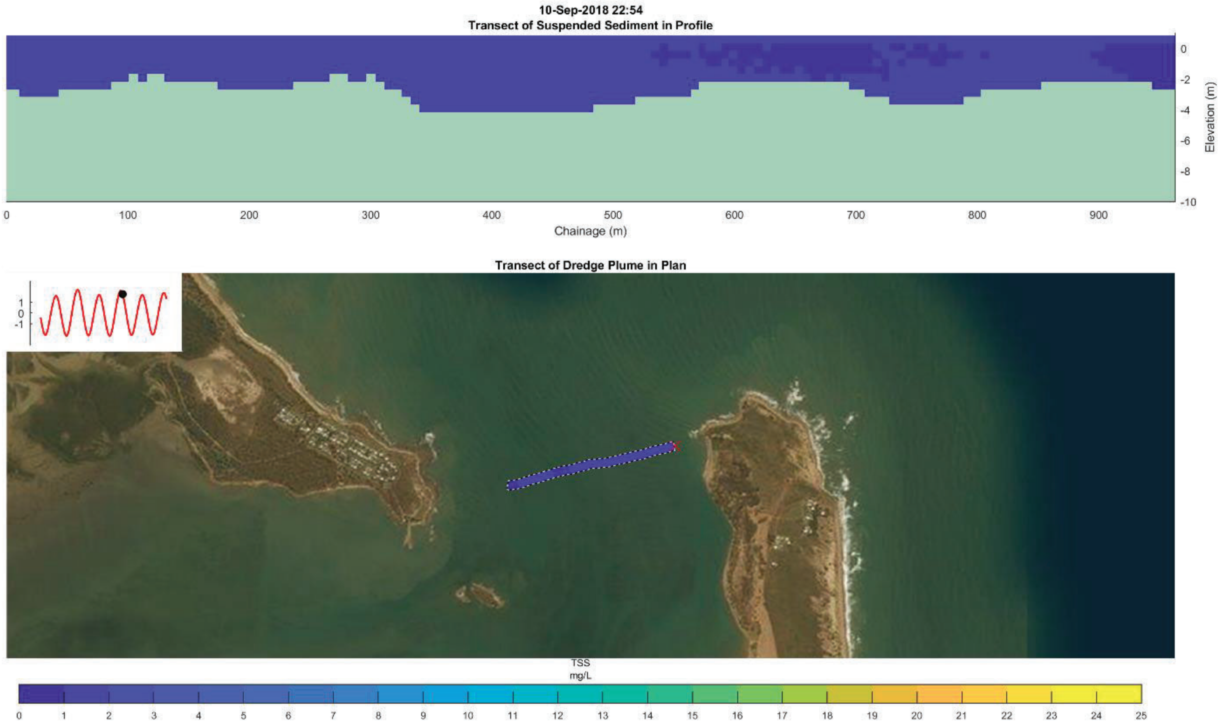
10-Sep-2018 22:54
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
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100
200
300
400
500
600
700
800
900
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
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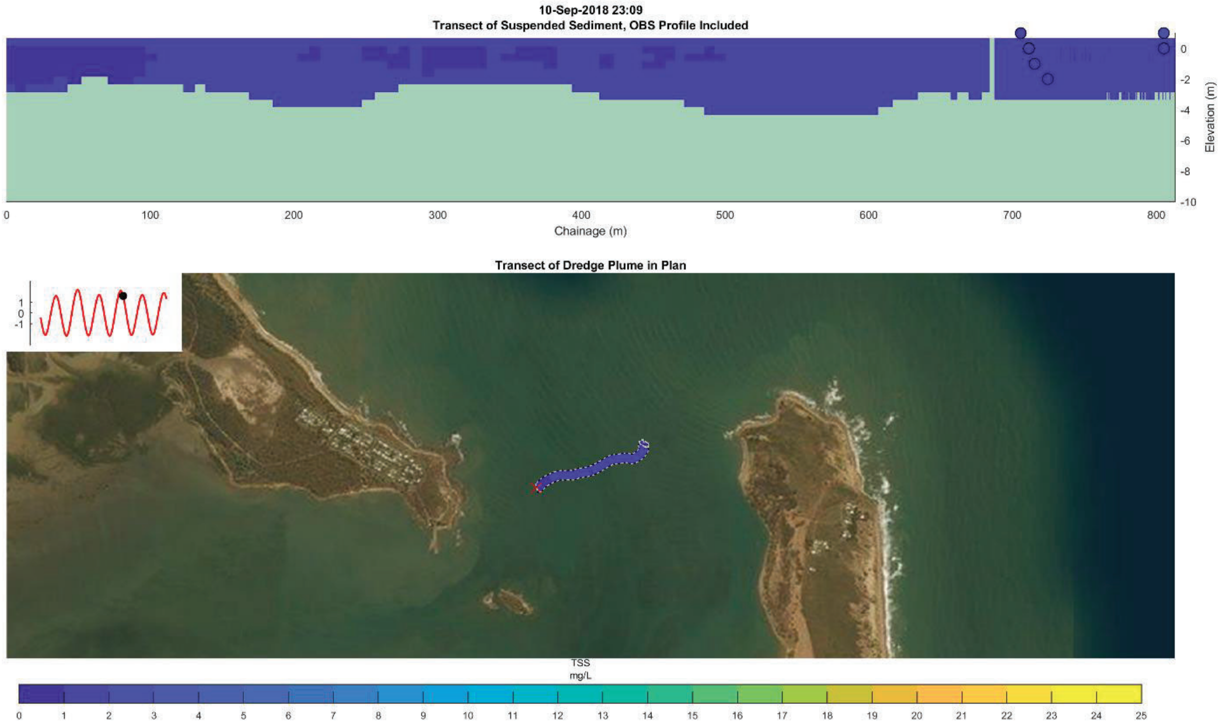
10-Sep-2018 23:09
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-2
-4
-6
-8
-10
Elevation (m)
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100
200
300
400
500
600
700
800
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
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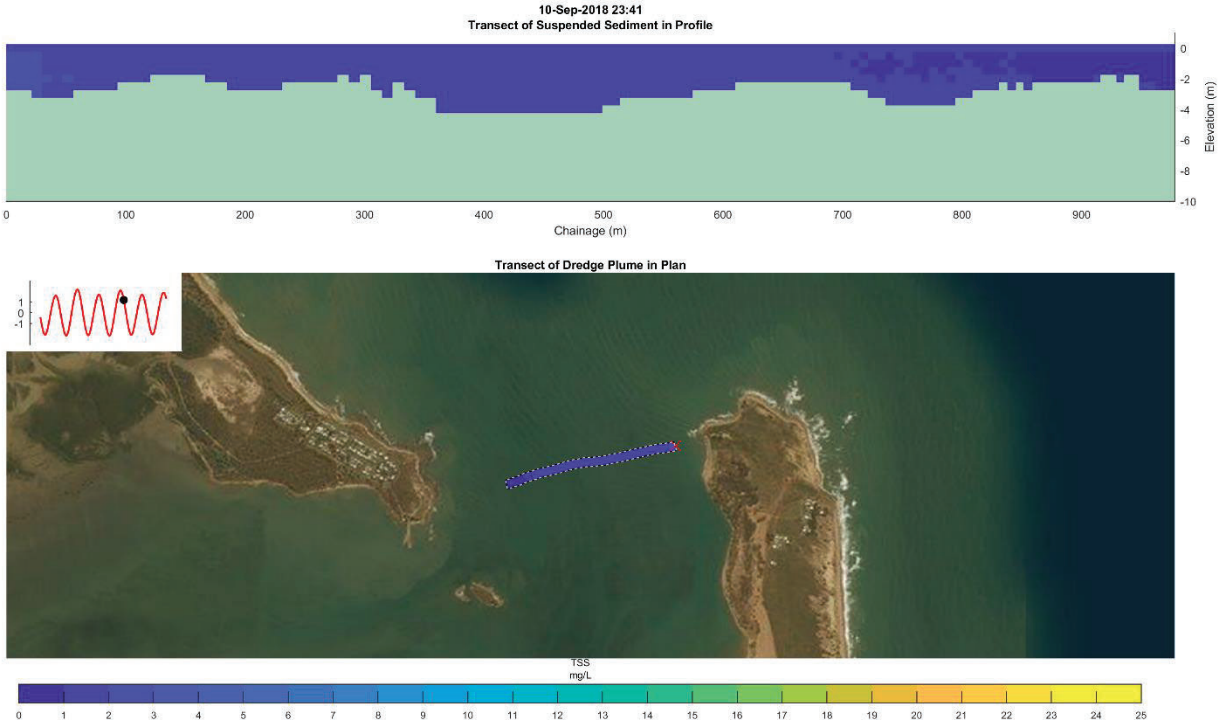
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-10
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100
200
300
400
500
600
700
800
900
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
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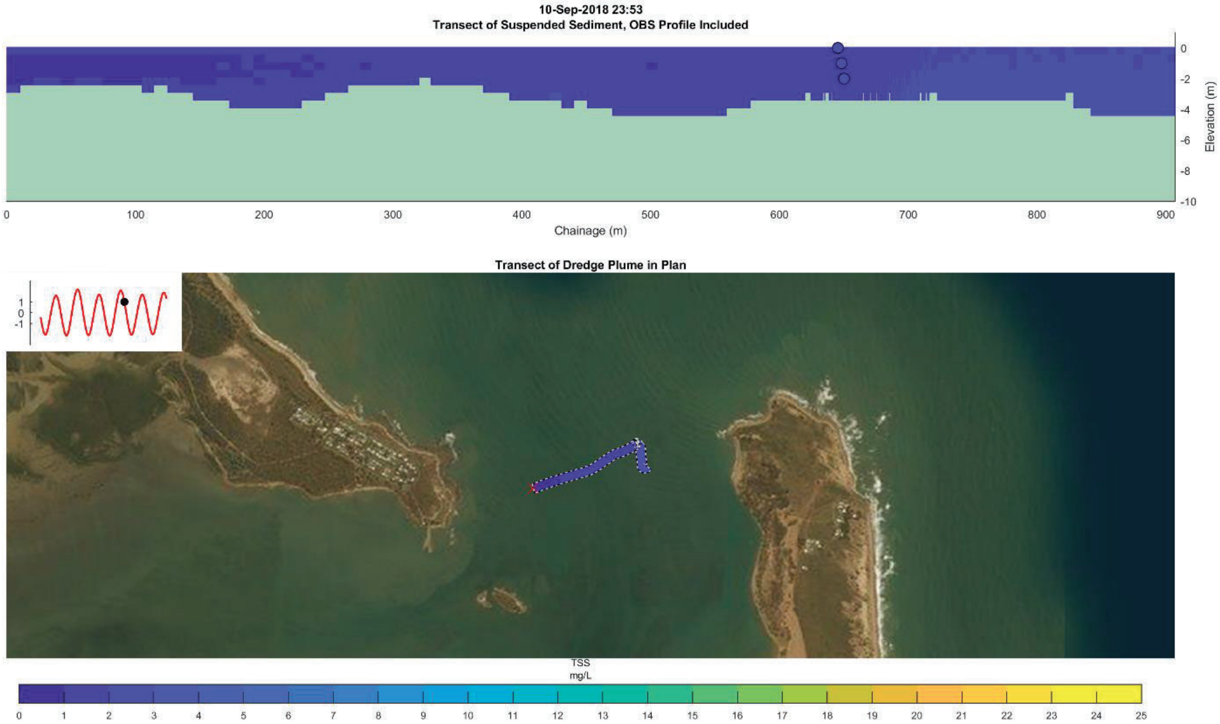
10-Sep-2018 23:53
Transect of Suspended Sediment, OBS Profile Included
Elevation (m)
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-2
-4
-6
-8
-10
0
100
200
300
400
500
600
700
800
900
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
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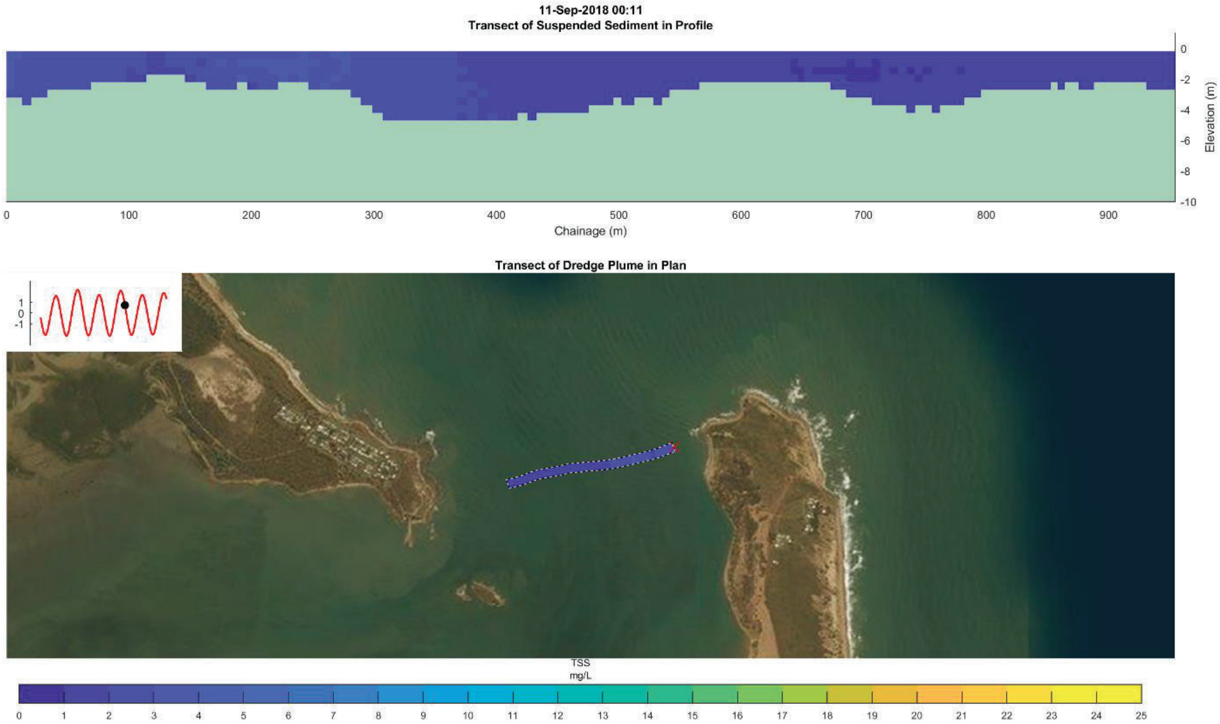
11-Sep-2018 00:11
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-4
-6
-8
-10
Elevation (m)
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100
200
300
400
500
600
700
800
900
Chainage (m)
Transect of Dredge Plume in Plan
1
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-1
TSS
mg/L
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1
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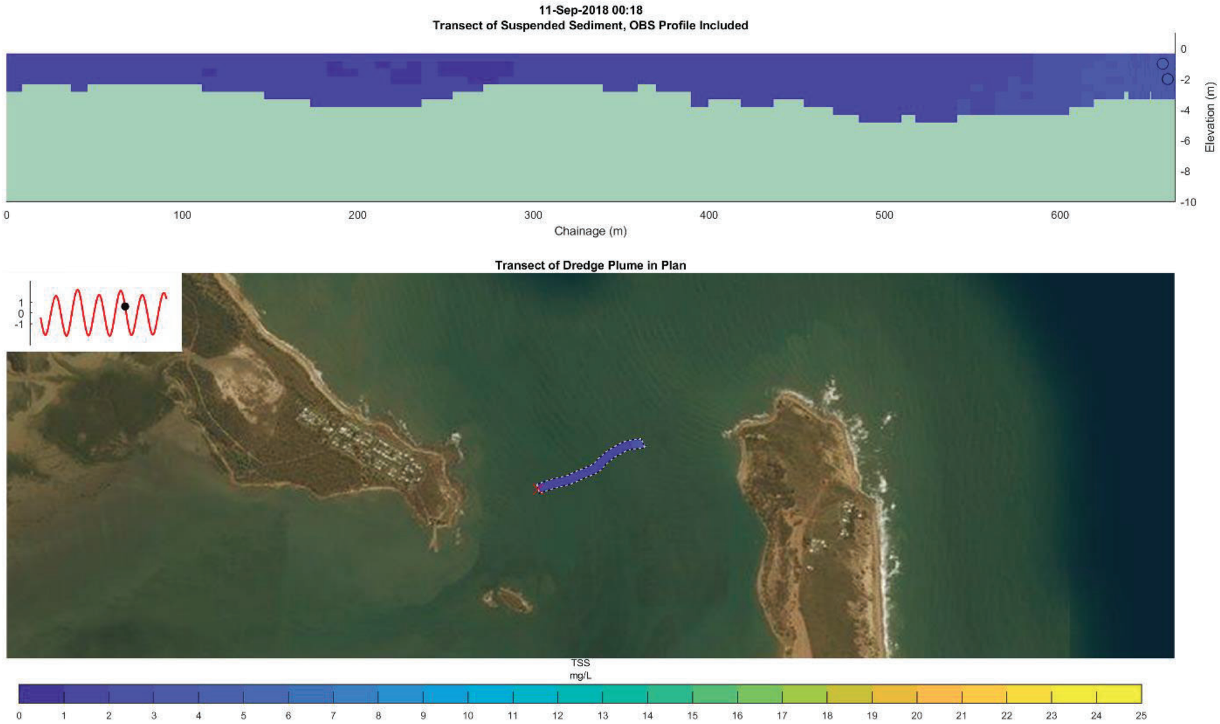
11-Sep-2018 00:18
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-10
Elevation (m)
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200
300
400
500
600
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
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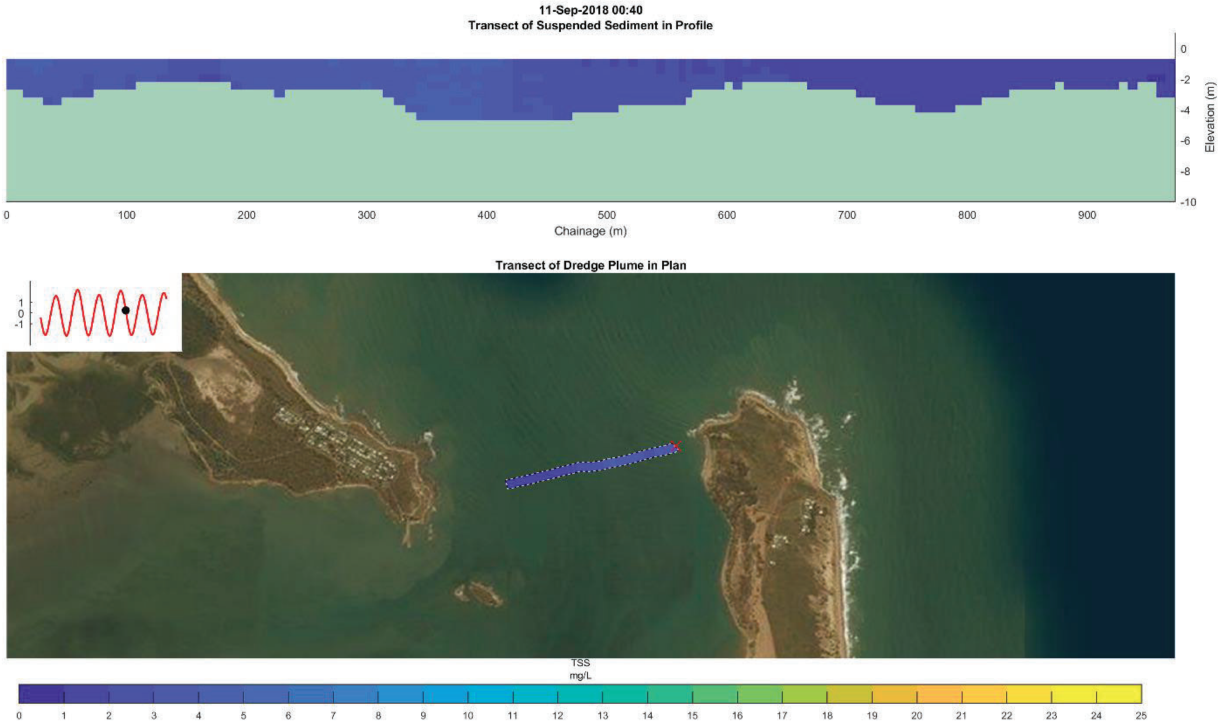
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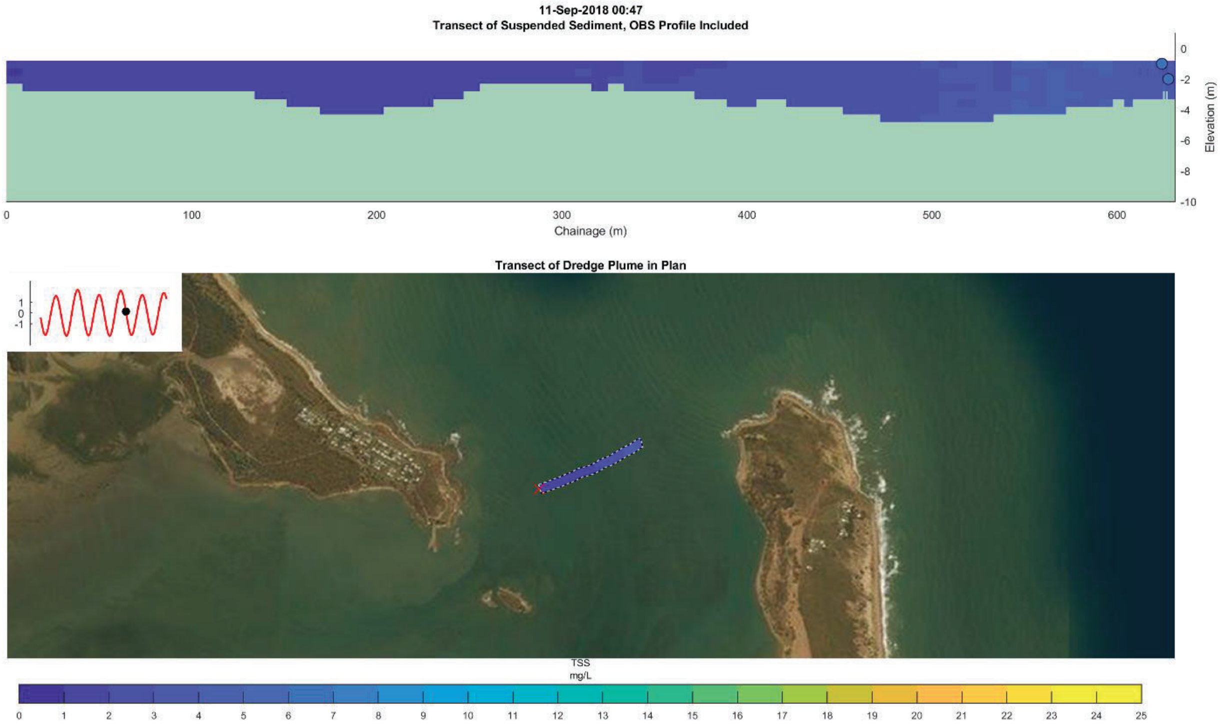
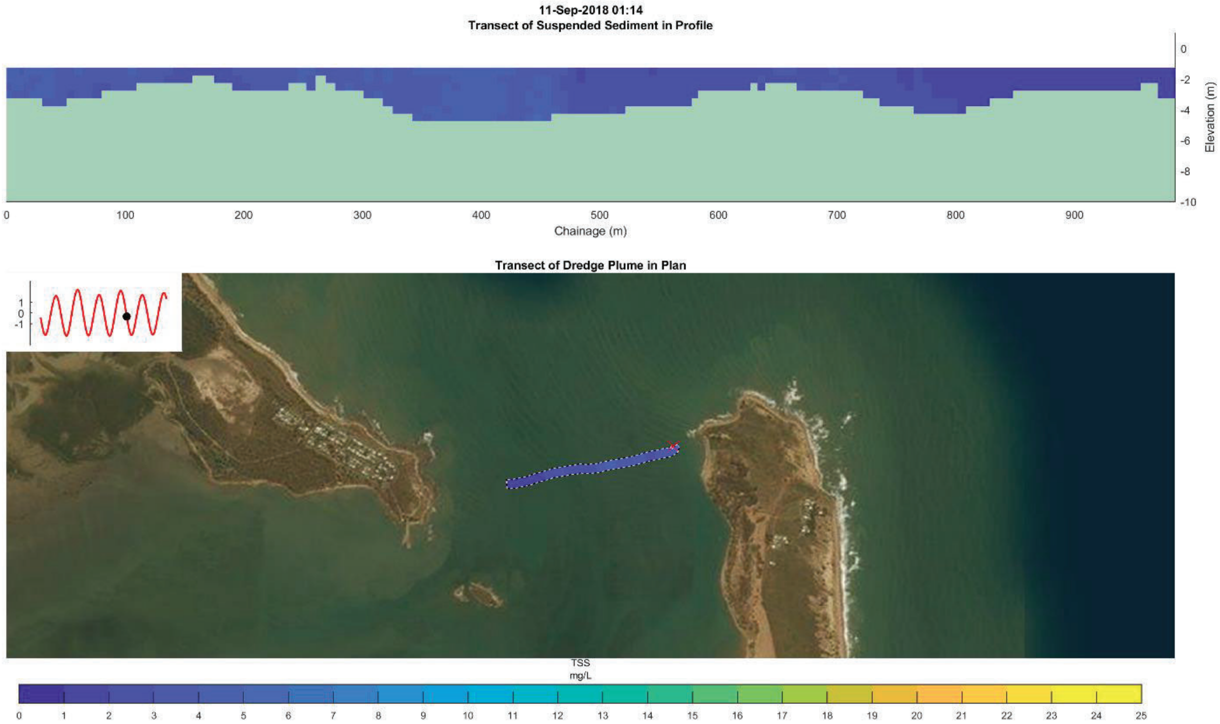
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan


11-Sep-2018 00:47

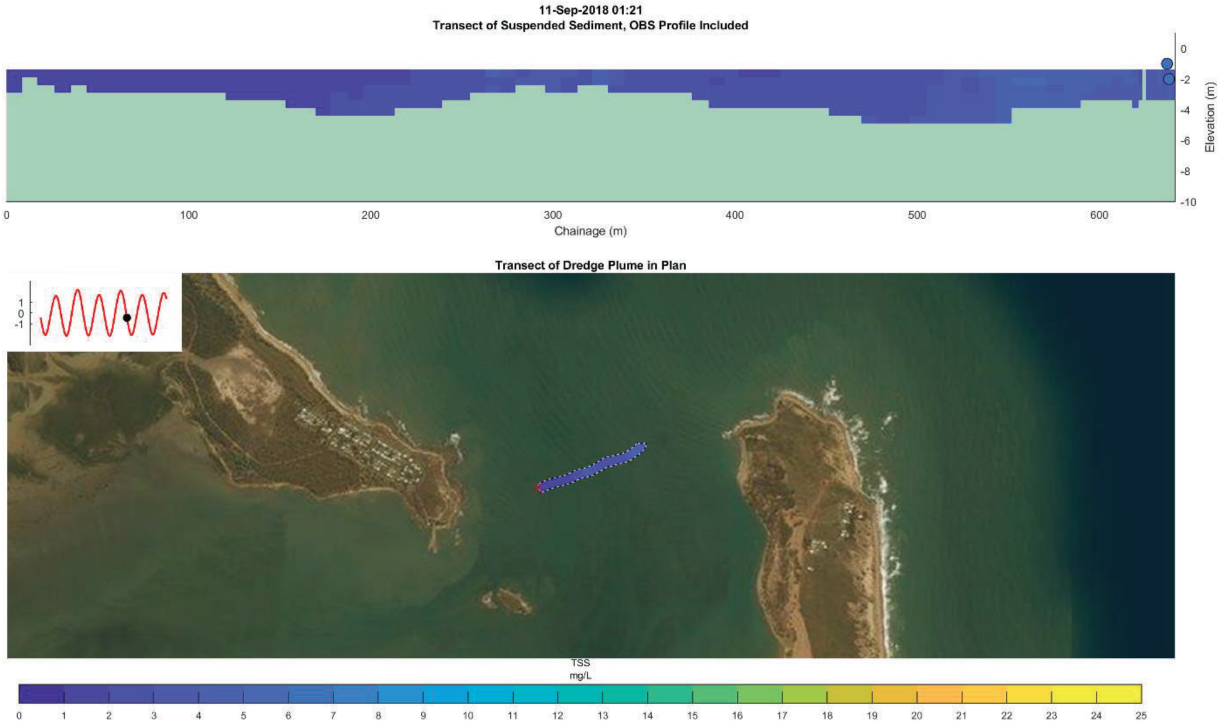
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan



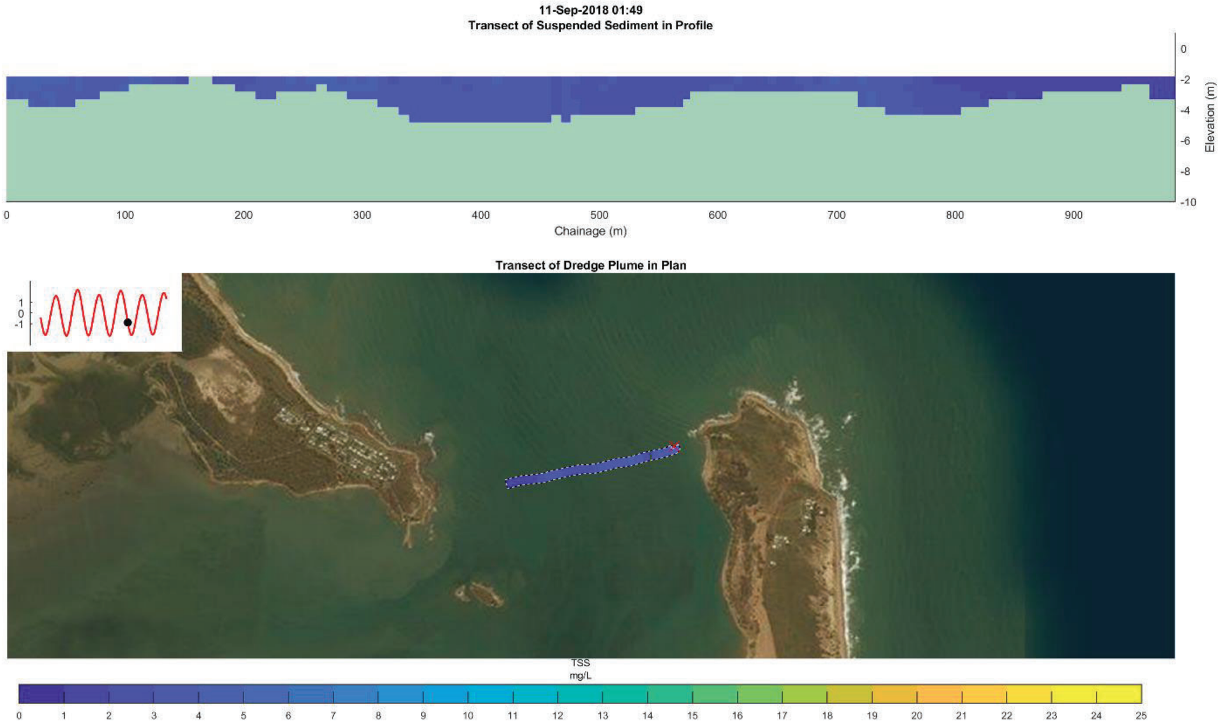
11-Sep-2018 01:14
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan



11-Sep-2018 01:21
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan


11-Sep-2018 01:49
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Elevation (m)
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100
200
300
400
500
600
700
800
900
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
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4
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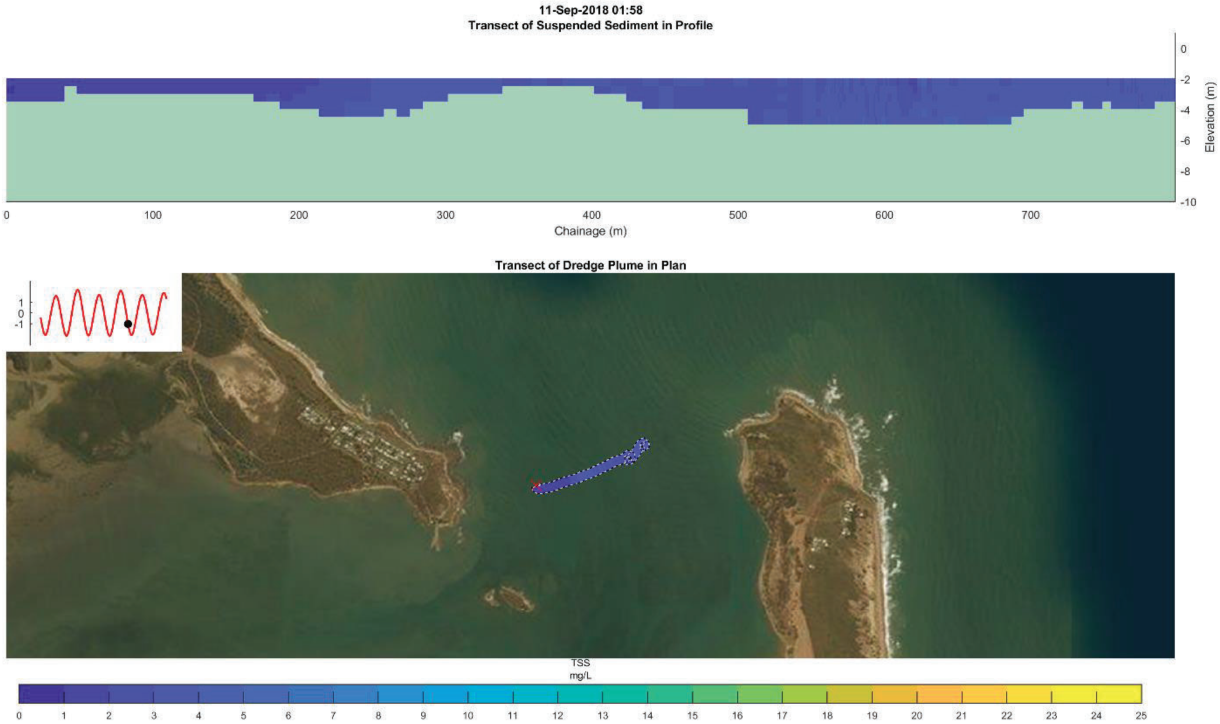
11-Sep-2018 01:58
Transect of Suspended Sediment in Profile
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Elevation (m)
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200
300
400
500
600
700
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
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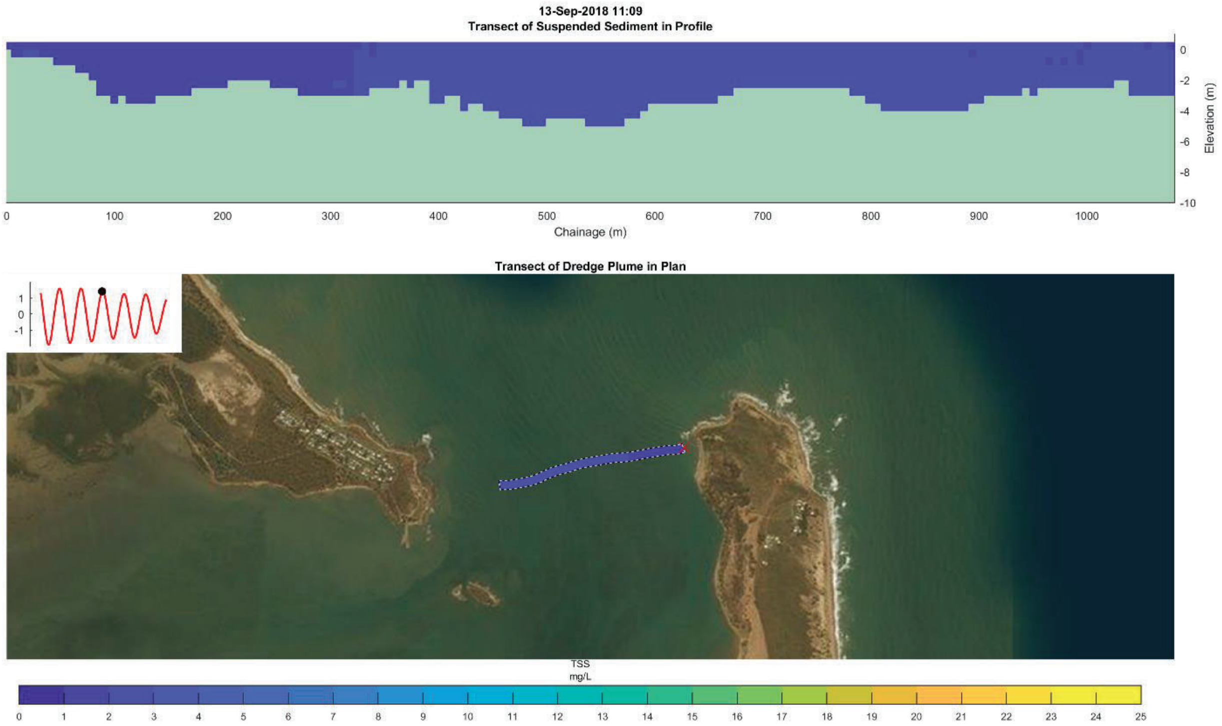
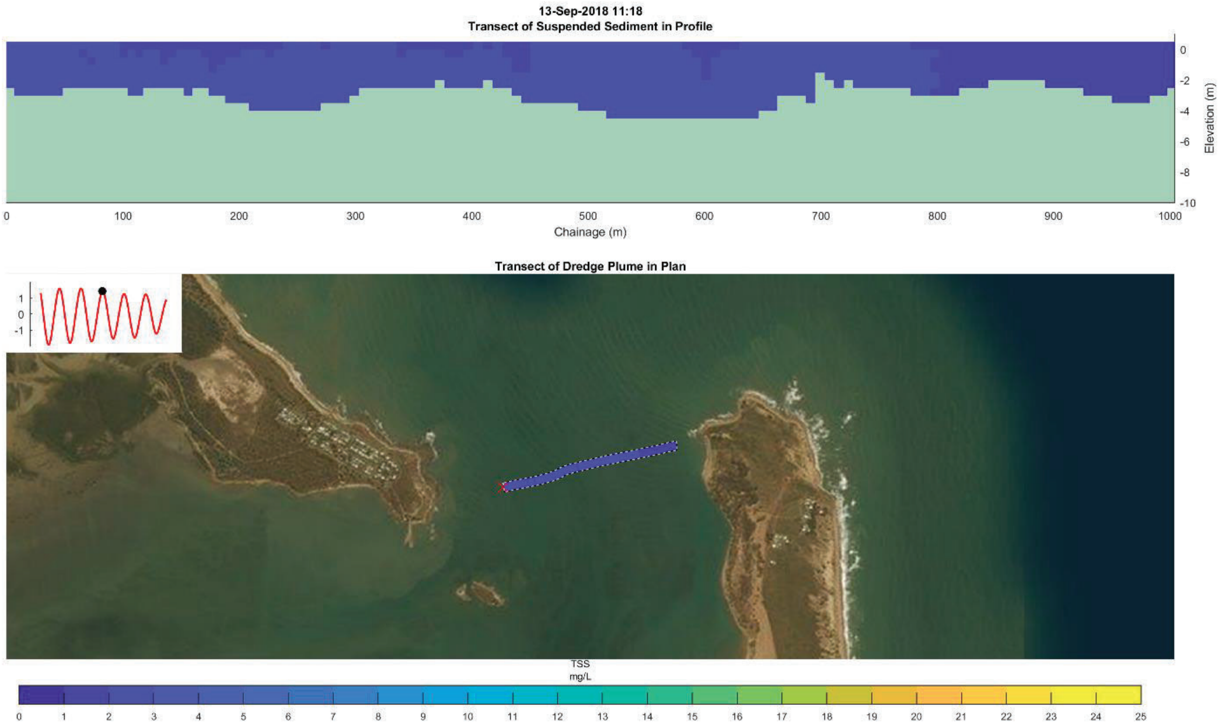
Transect B - South End on Curtis island to North Point on Facing Island – Average Tide



13-Sep-2018 11:09

Transect of Suspended Sediment in Profile

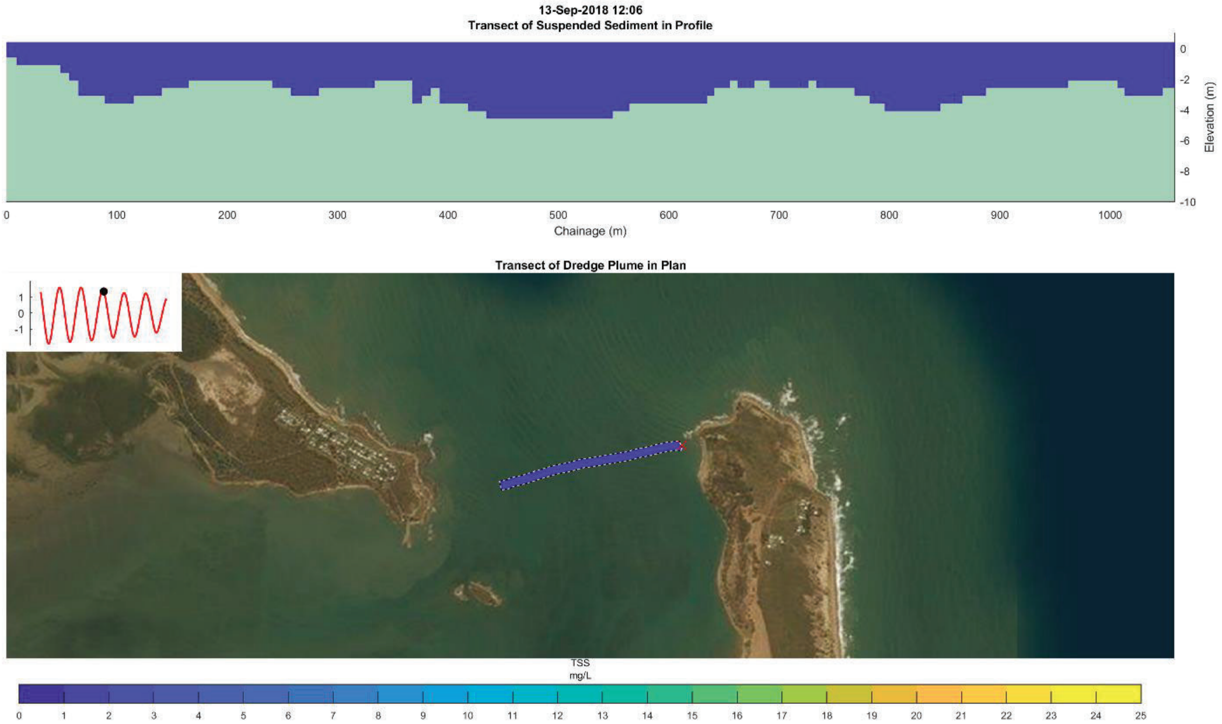
Transect of Dredge Plume in Plan



13-Sep-2018 11:18

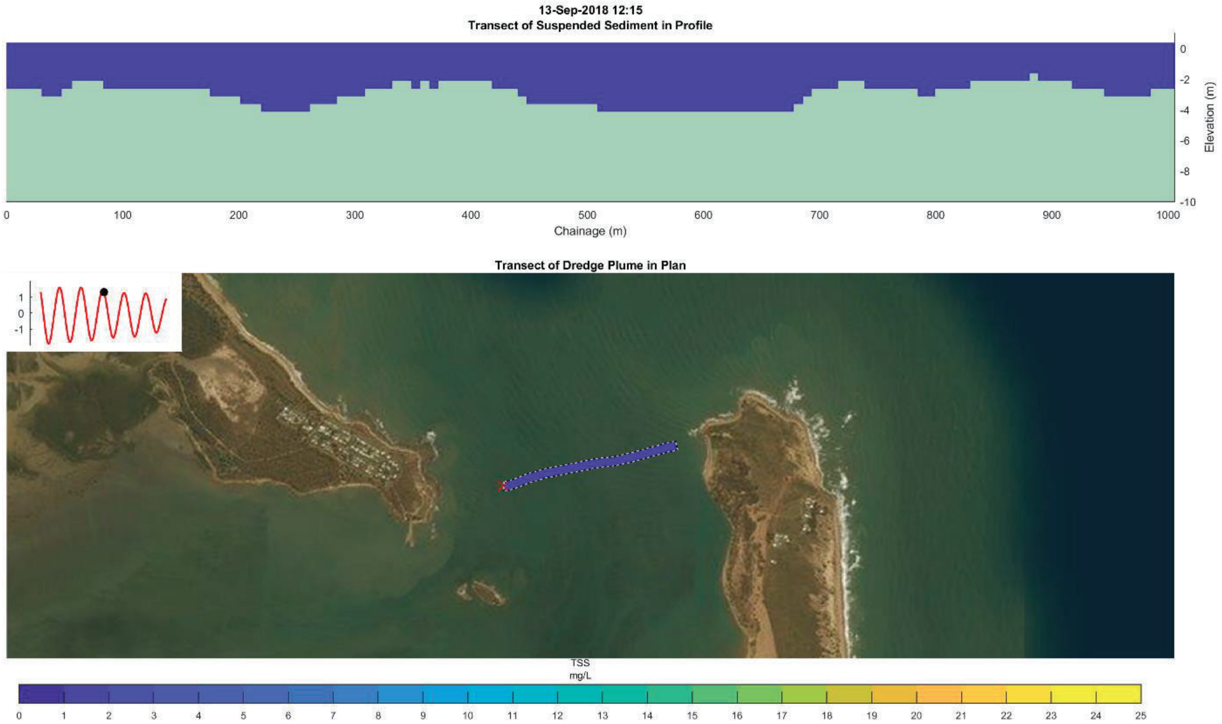
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan



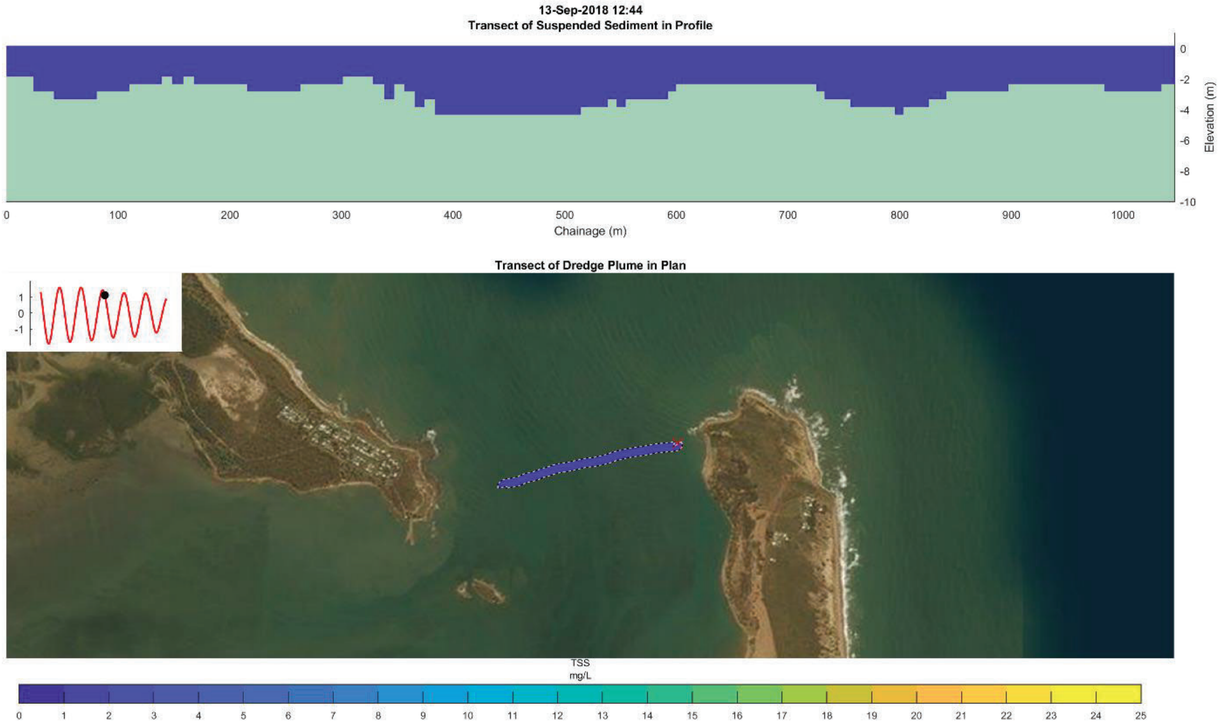
13-Sep-2018 12:06
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan



13-Sep-2018 12:15
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan


13-Sep-2018 12:44
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-4
-6
-8
-10
Elevation (m)
0
100
200
300
400
500
600
700
800
900
1000
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
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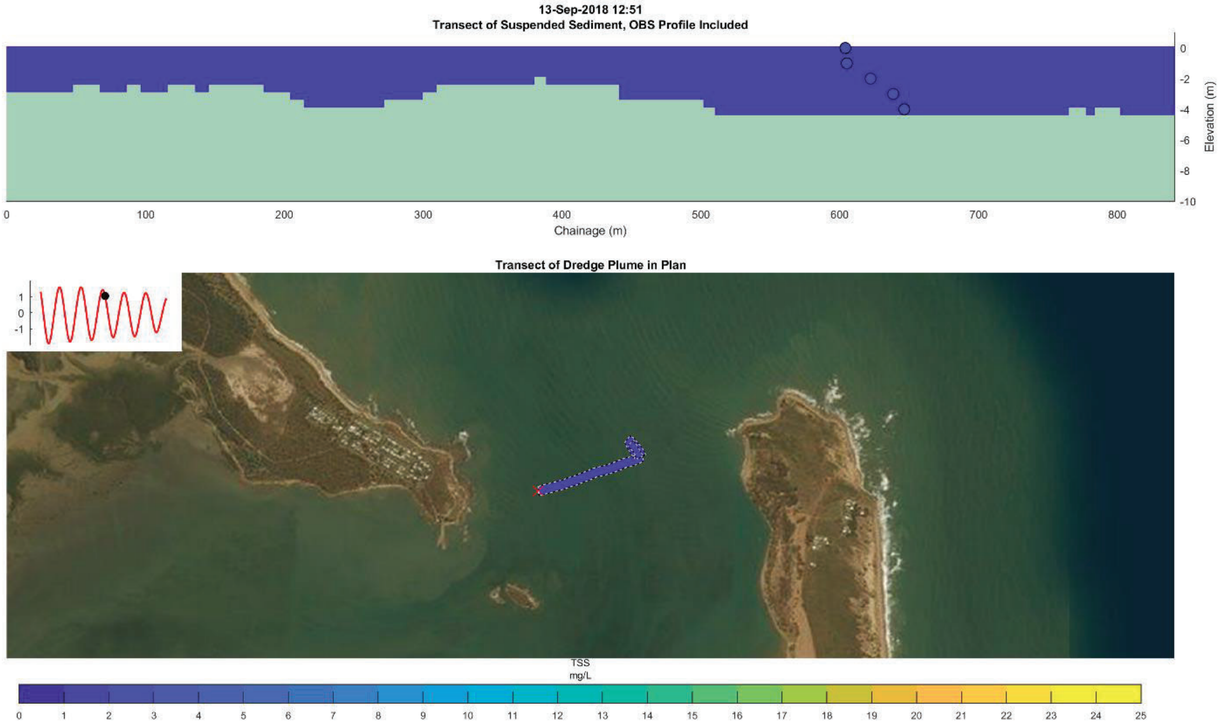
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Elevation (m)
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200
300
400
500
600
700
800
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
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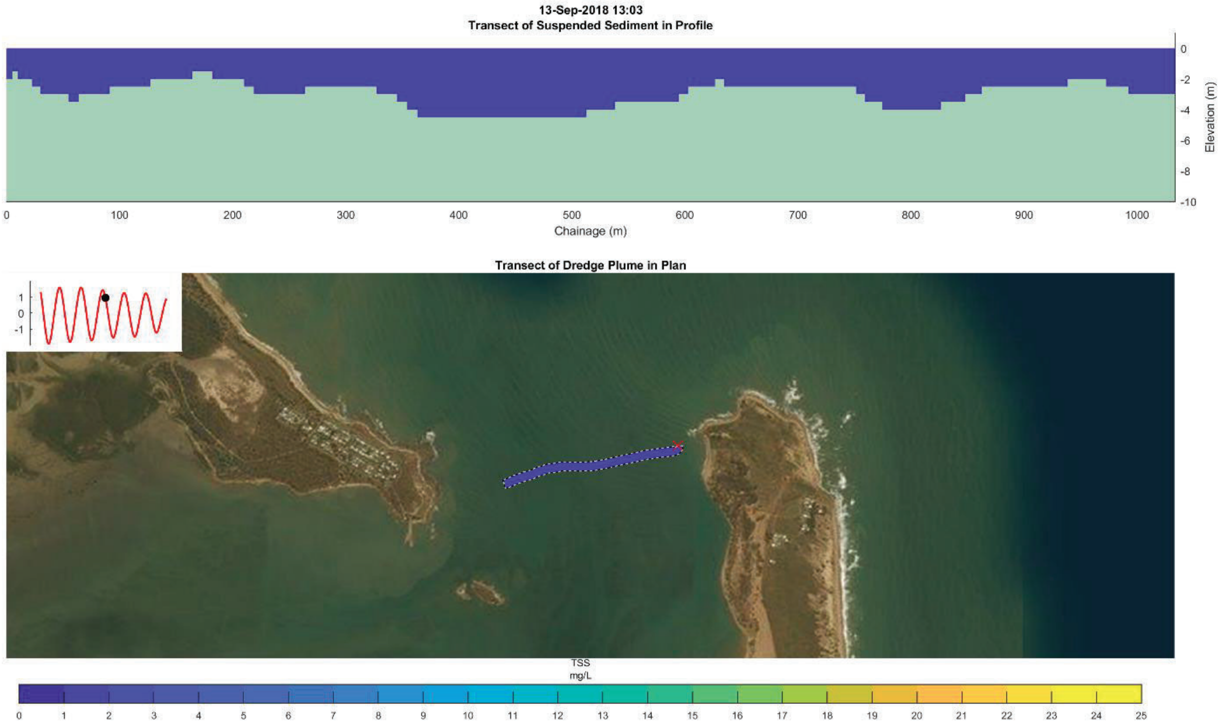
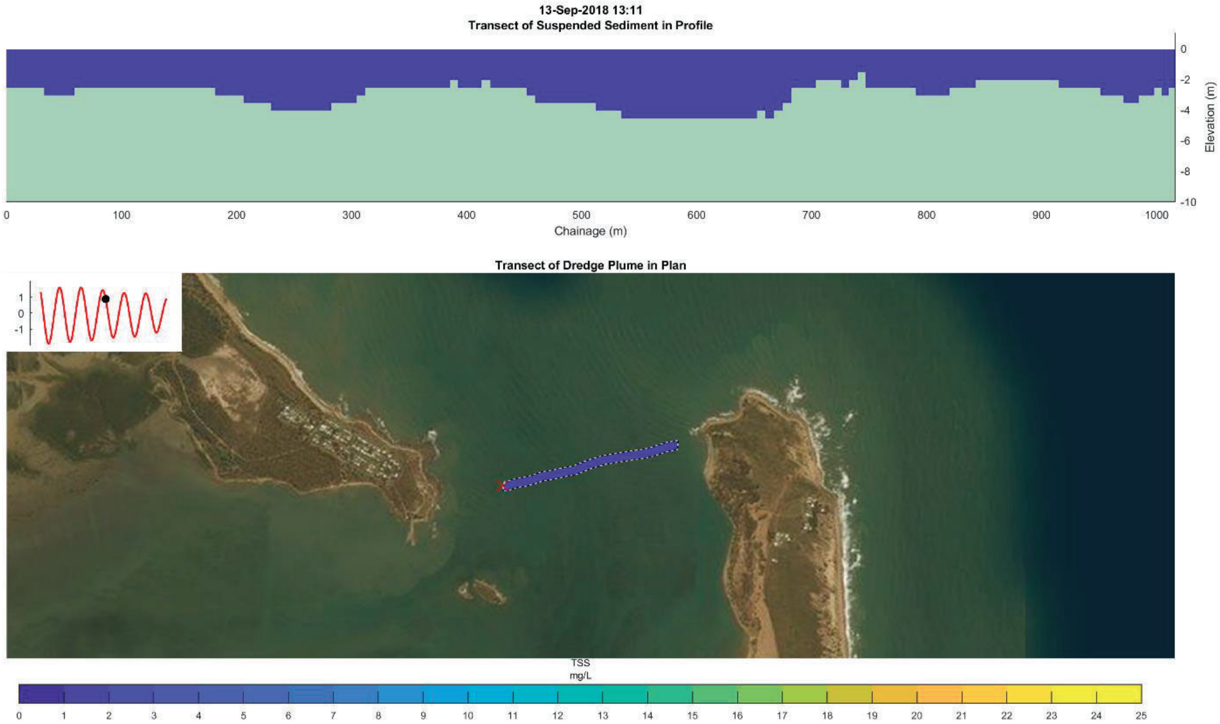


13-Sep-2018 13:03

Transcect of Suspended Sediment in Profile

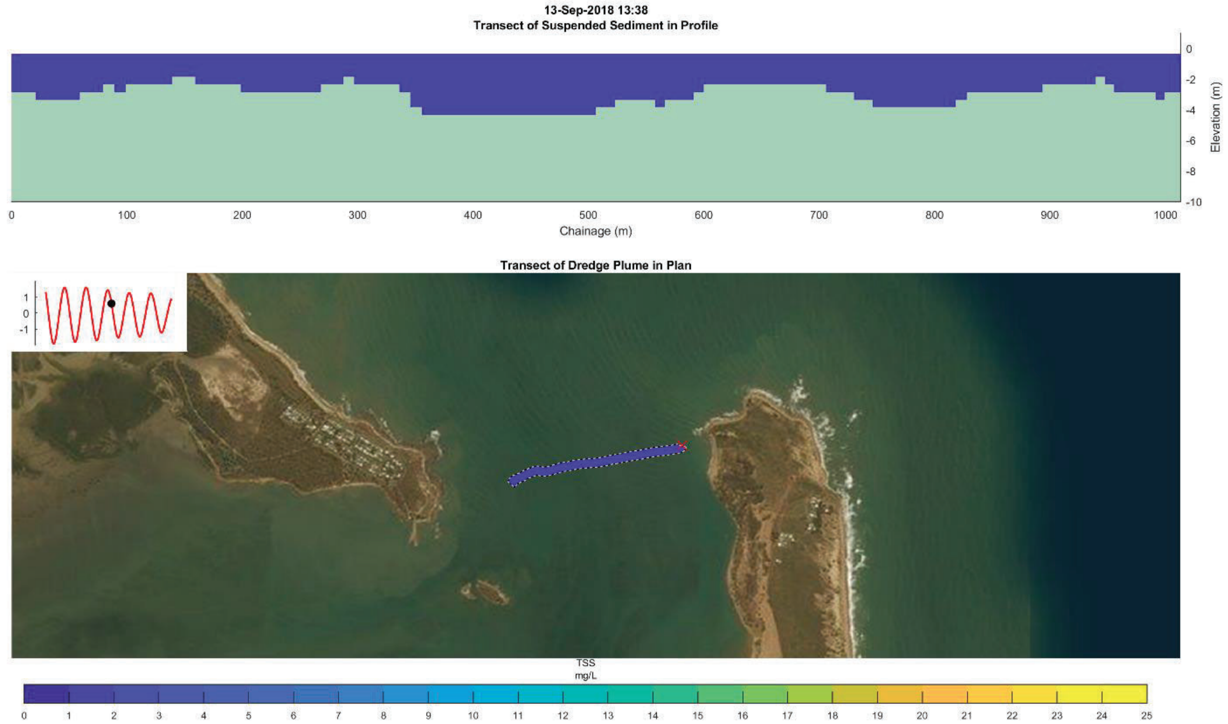
Transect of Dredge Plume in Plan



13-Sep-2018 13:11

Transcect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan


13-Sep-2018 13:38
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
100
200
300
400
500
600
700
800
900
1000
Chainage (m)
Transect of Dredge Plume in Plan
1
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-1
TSS
mg/L
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1
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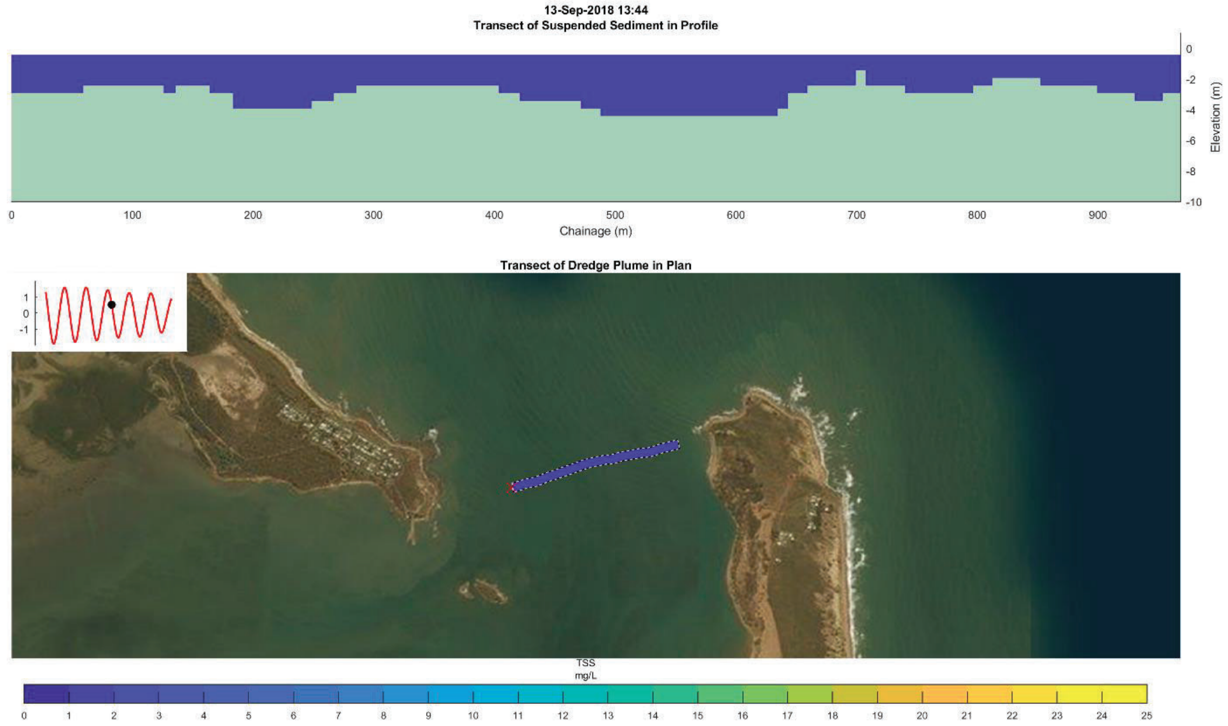
13-Sep-2018 13:44
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
100
200
300
400
500
600
700
800
900
Chainage (m)
Transect of Dredge Plume in Plan
1
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-1
TSS
mg/L
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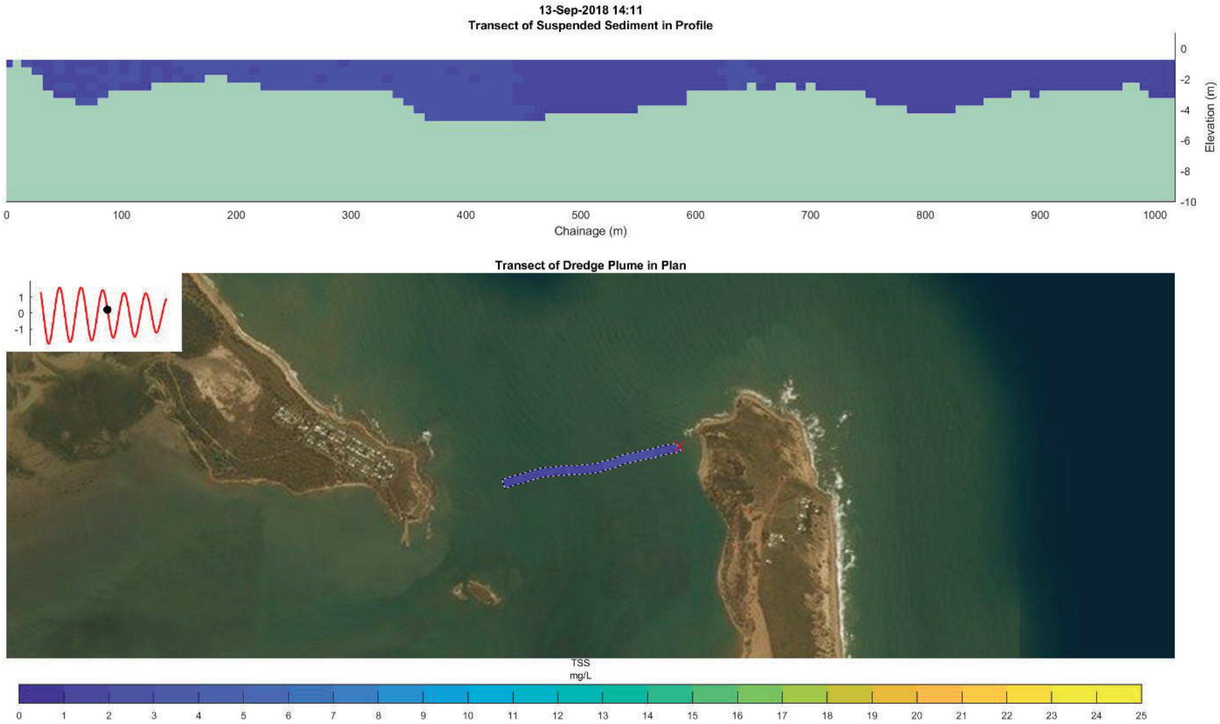
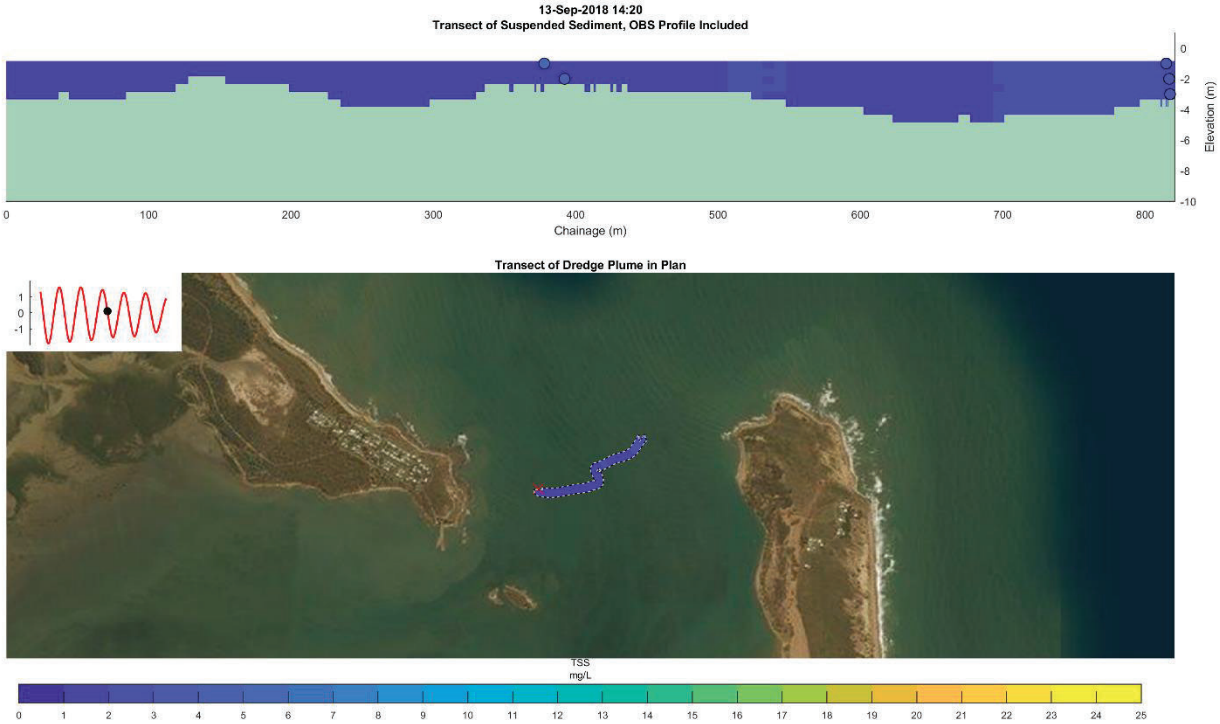


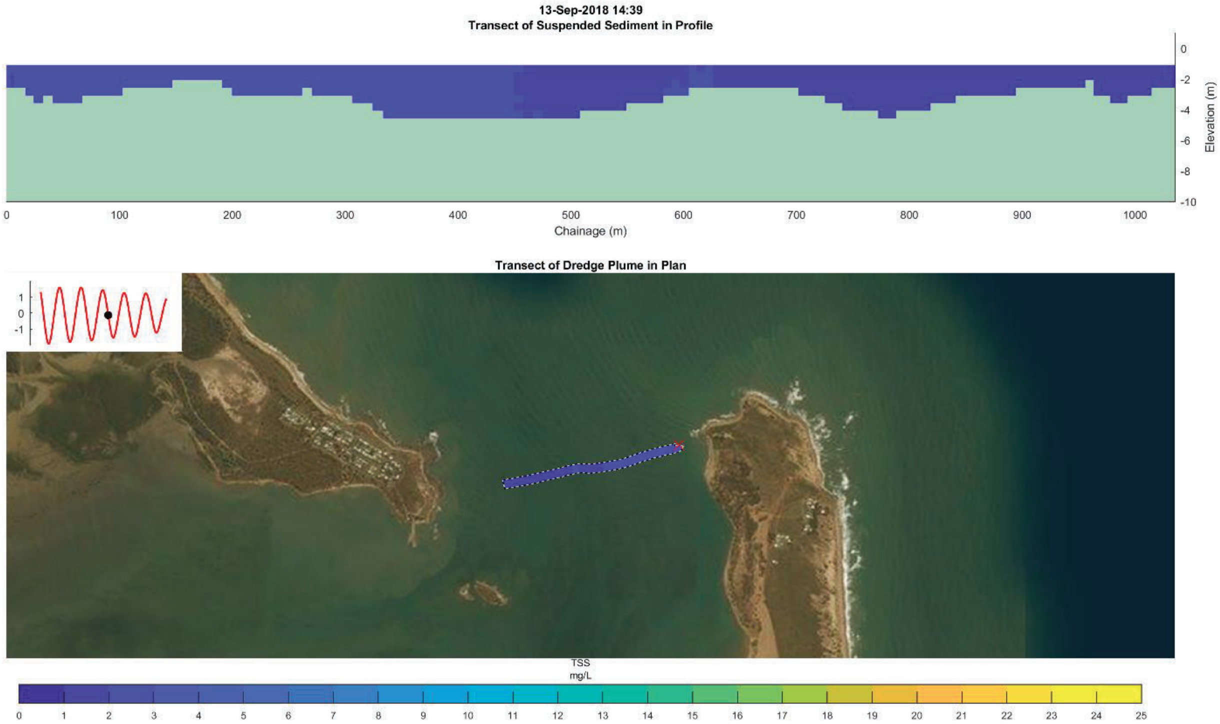
13-Sep-2018 14:11
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan



13-Sep-2018 14:20
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan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Elevation (m)
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200
300
400
500
600
700
800
900
1000
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
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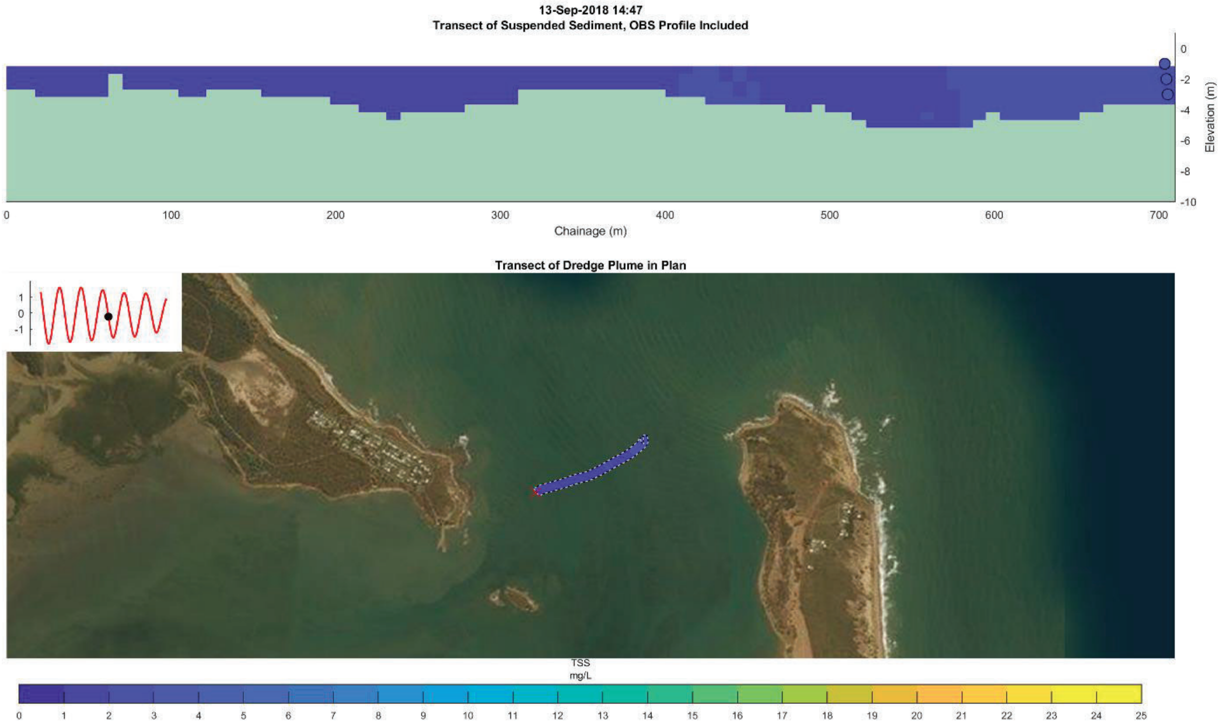
13-Sep-2018 14:47
Transect of Suspended Sediment, OBS Profile Included
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-10
Elevation (m)
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600
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Chainage (m)
Transect of Dredge Plume in Plan
1
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-1
TSS
mg/L
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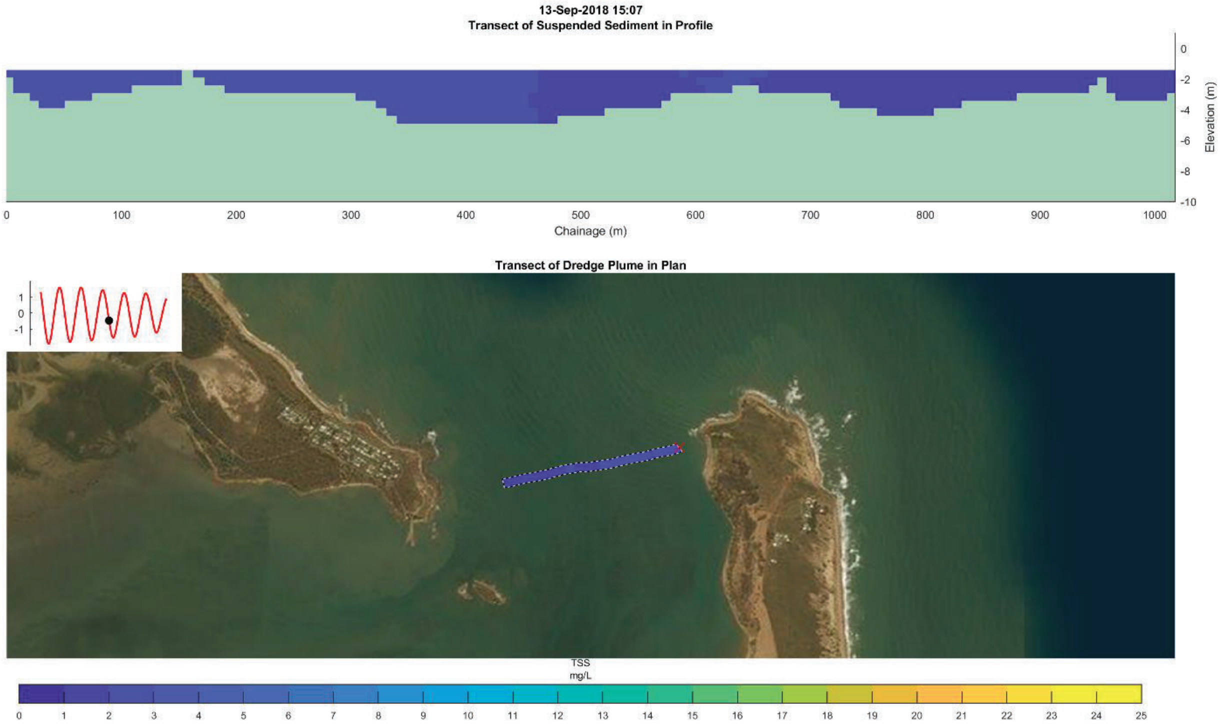
13-Sep-2018 15:07
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Elevation (m)
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700
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900
1000
Chainage (m)
Transect of Dredge Plume in Plan
1
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-1
TSS
mg/L
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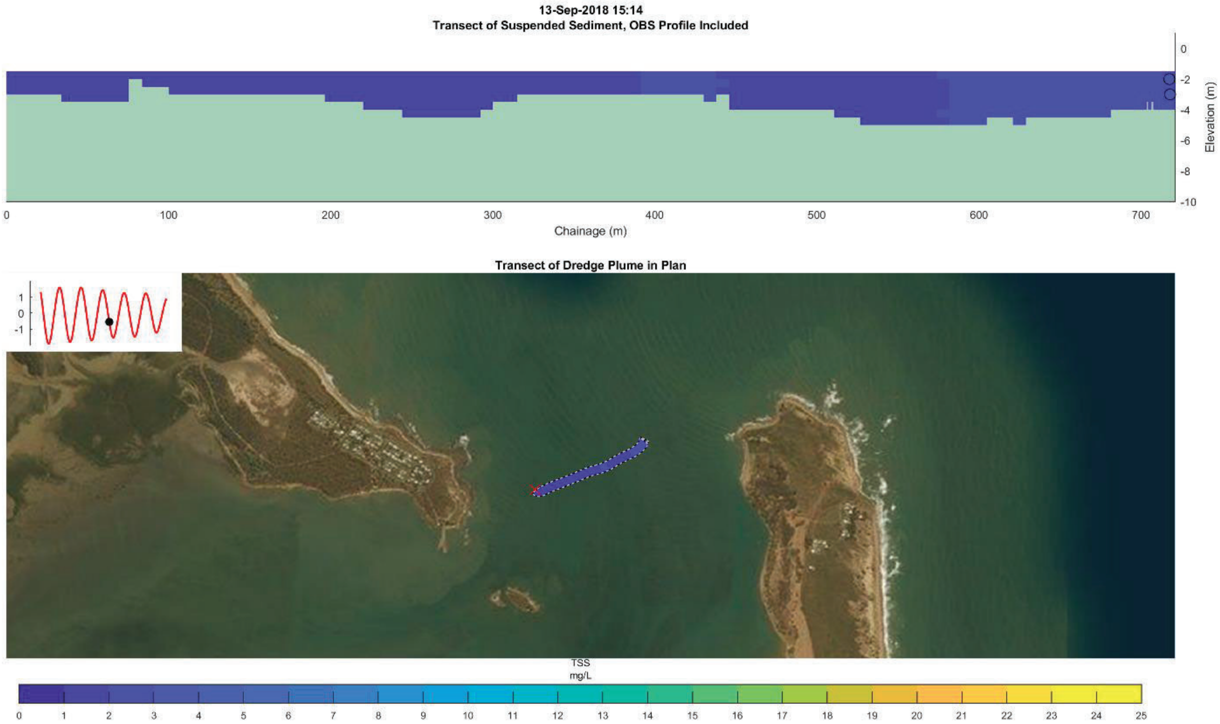
13-Sep-2018 15:14
Transect of Suspended Sediment, OBS Profile Included
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Elevation (m)
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200
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Chainage (m)
Transect of Dredge Plume in Plan
1
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-1
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mg/L
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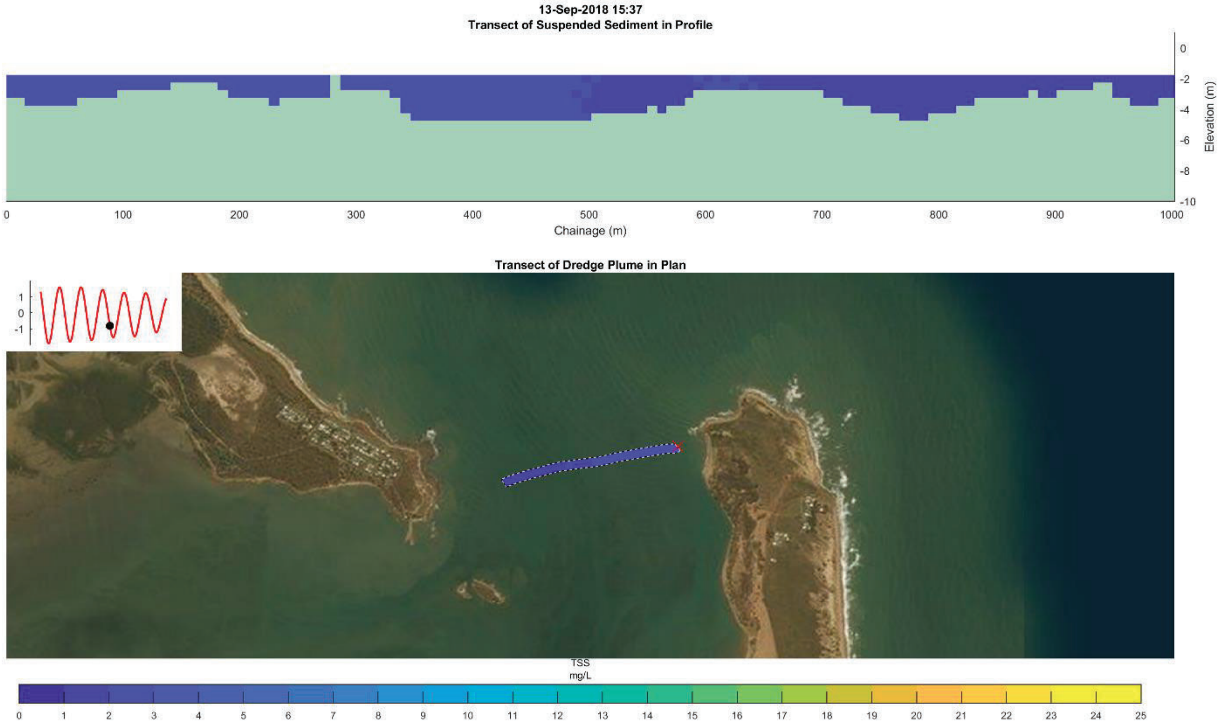
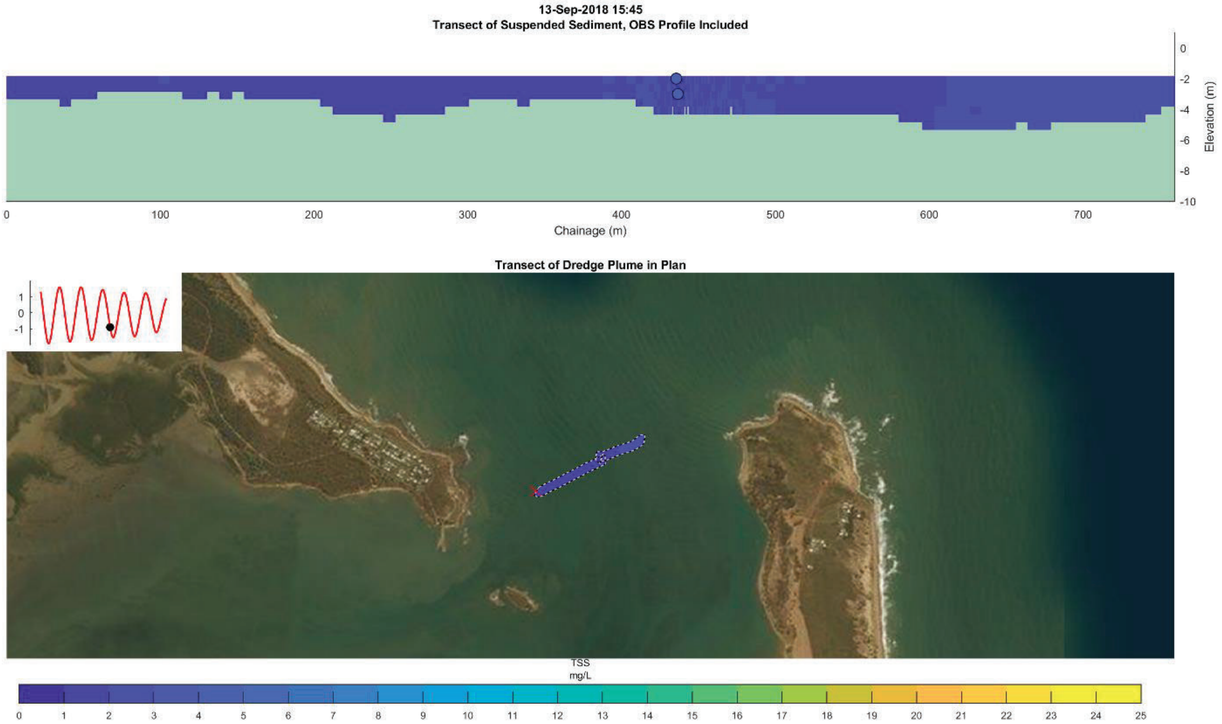


13-Sep-2018 15:37

Transect of Suspended Sediment in Profile

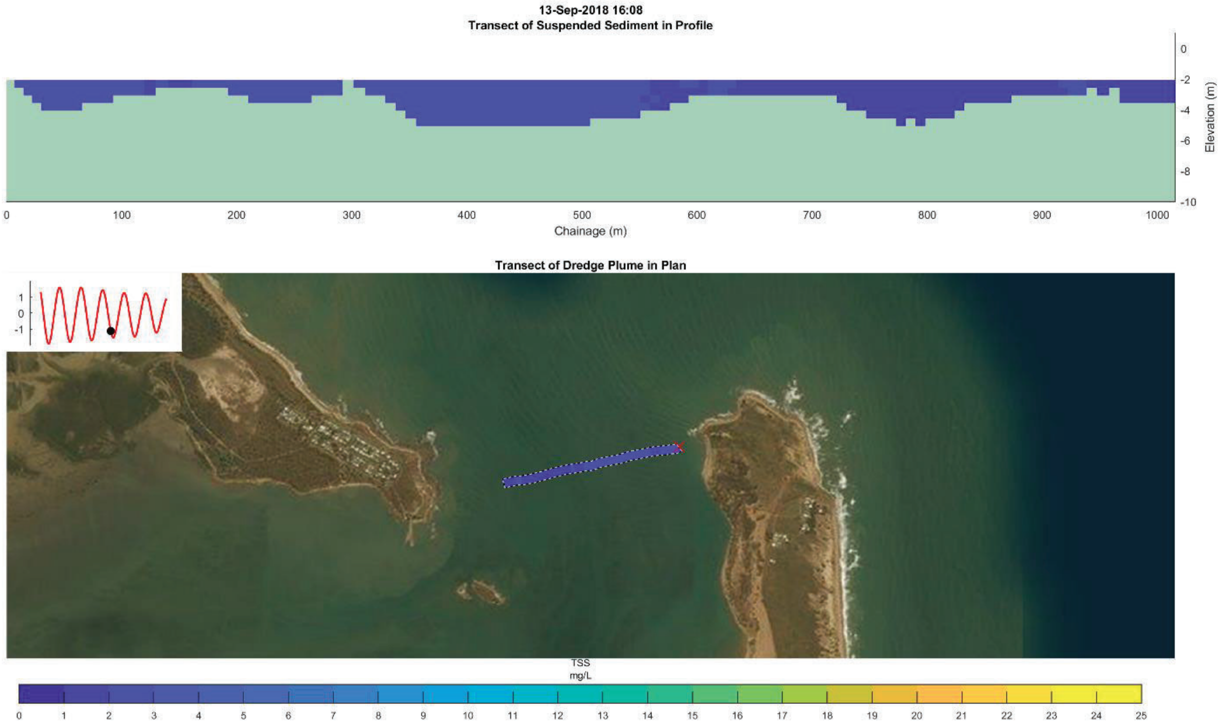
Transect of Dredge Plume in Plan



13-Sep-2018 15:45

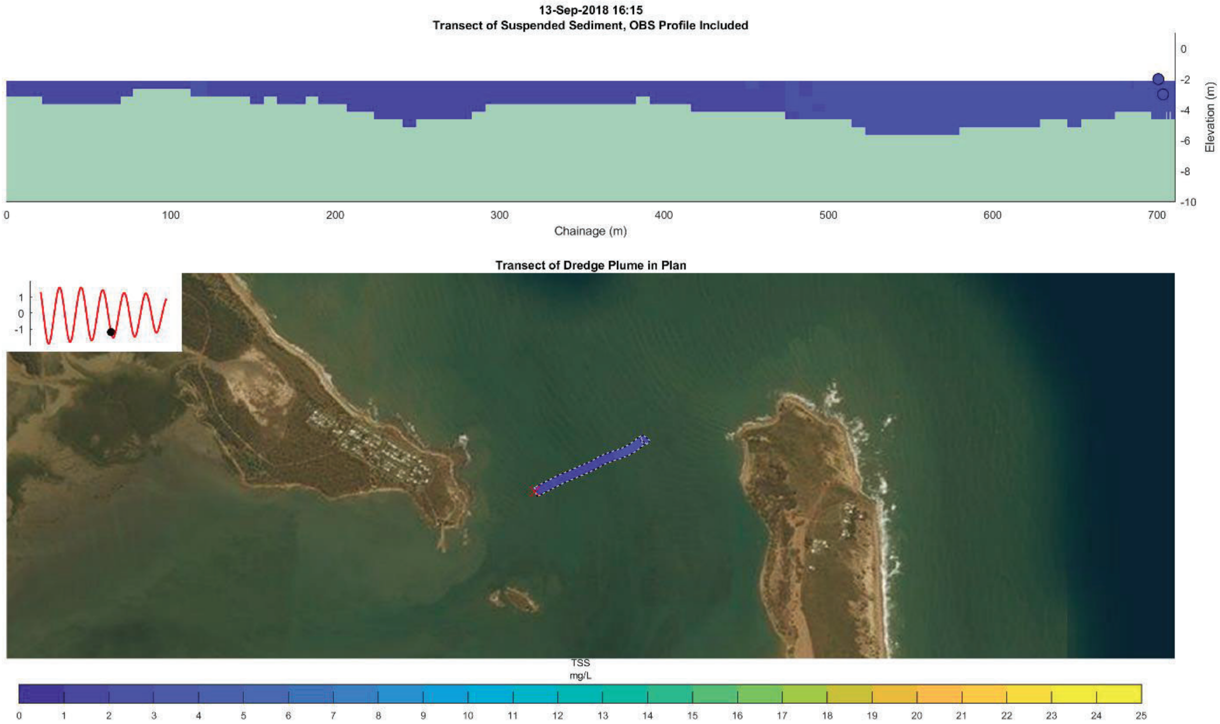
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan



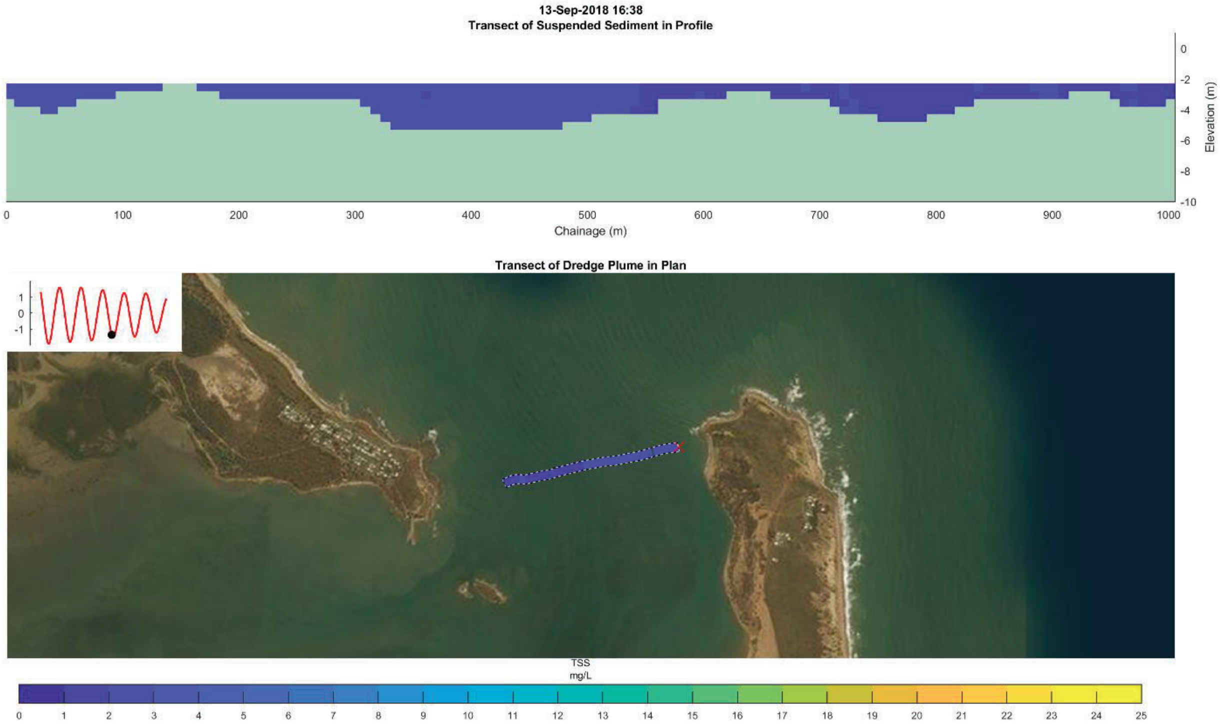
13-Sep-2018 16:08
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan



13-Sep-2018 16:15
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan


13-Sep-2018 16:38
Transect of Suspended Sediment in Profile
0
-2
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-6
-8
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Elevation (m)
0
100
200
300
400
500
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700
800
900
1000
Chainage (m)
Transect of Dredge Plume in Plan
1
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-1
TSS
mg/L
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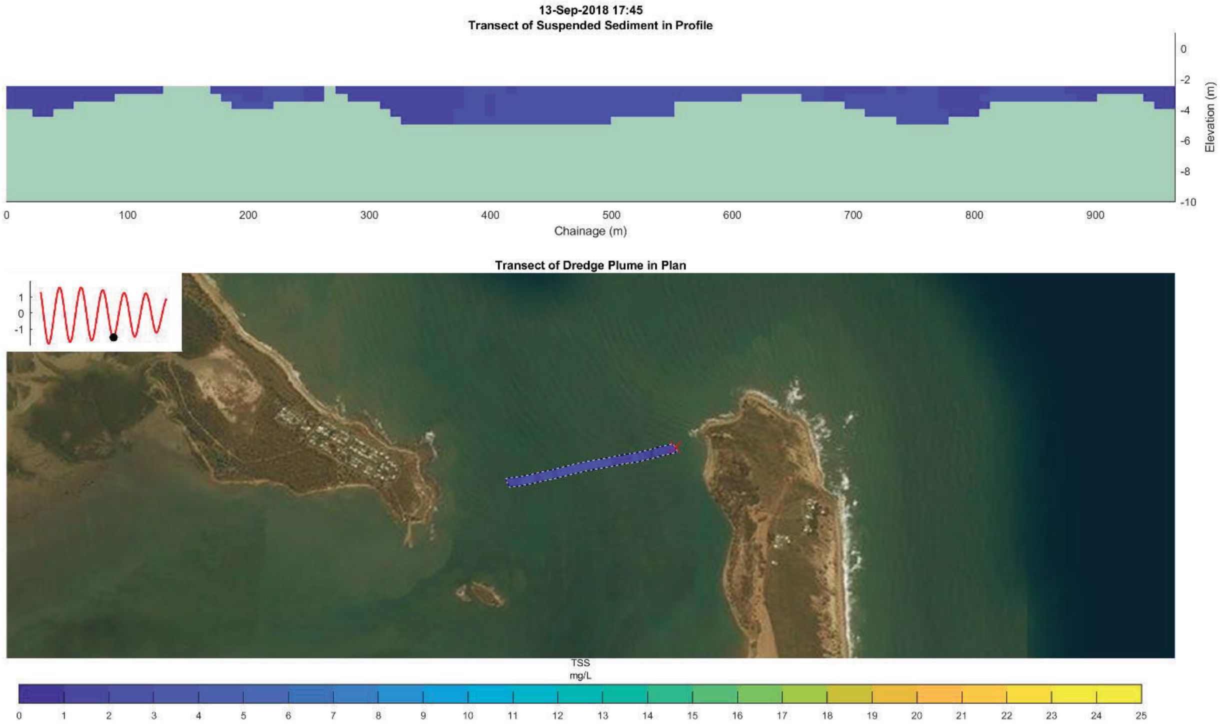
13-Sep-2018 17:45
Transect of Suspended Sediment in Profile
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Elevation (m)
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Chainage (m)
Transect of Dredge Plume in Plan
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TSS
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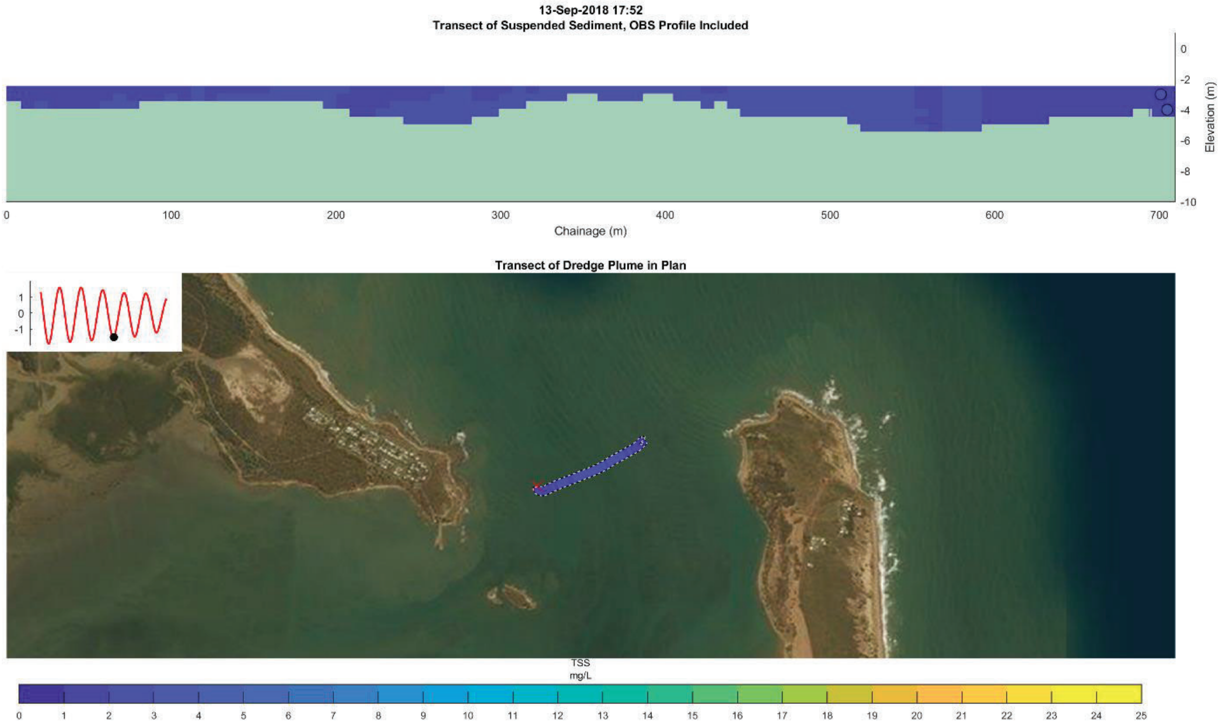
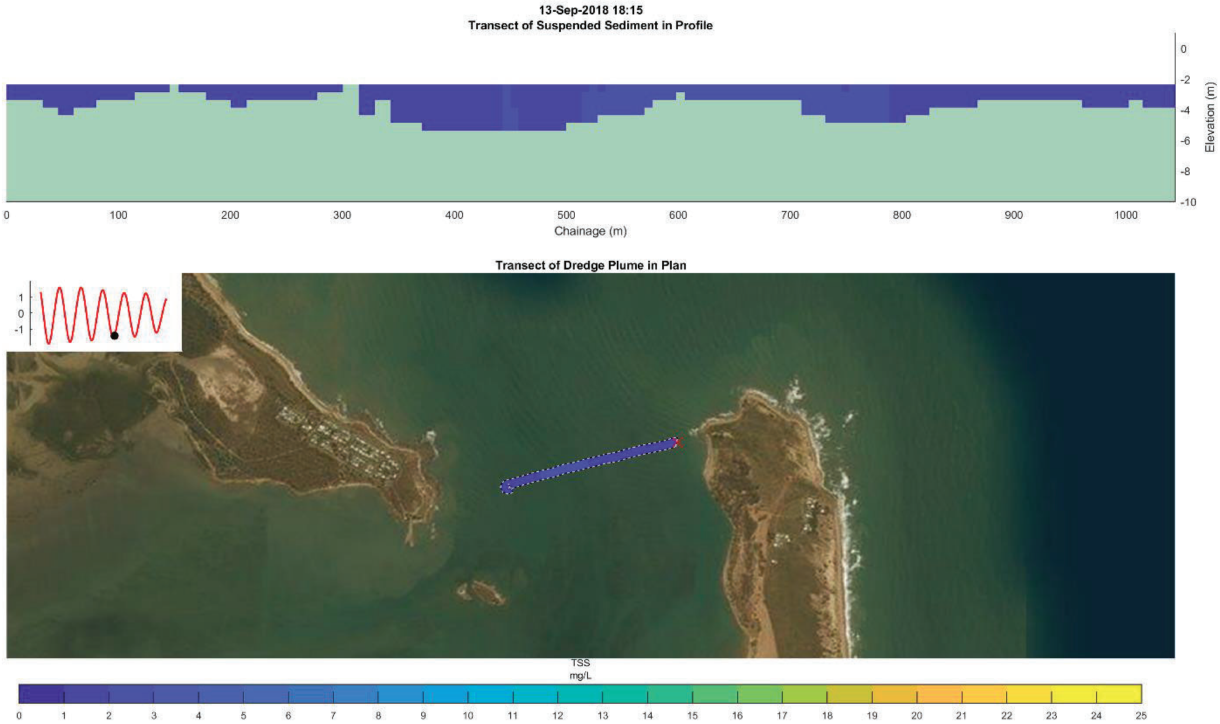


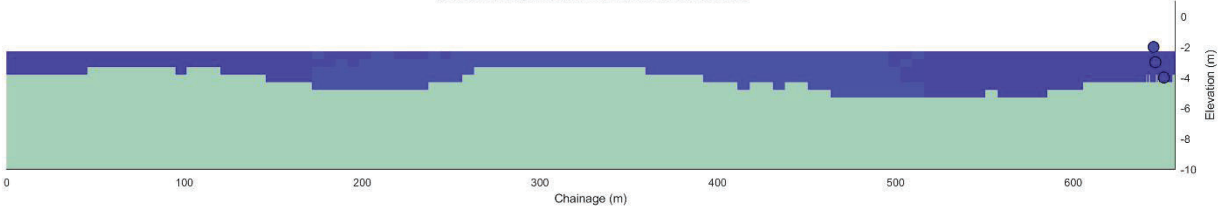
13-Sep-2018 17:52
Transect of Suspended Sediment, OBS Profile Included

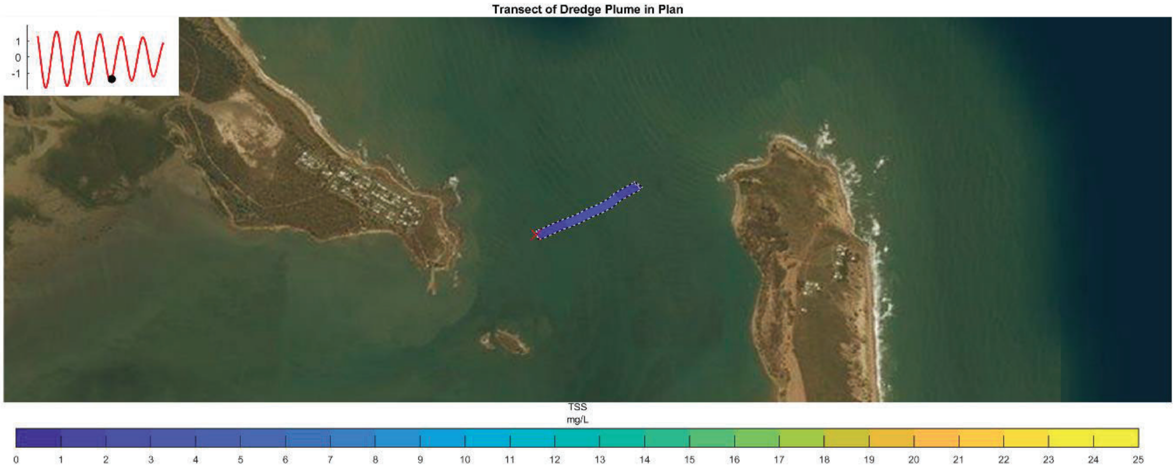
Transect of Dredge Plume in Plan

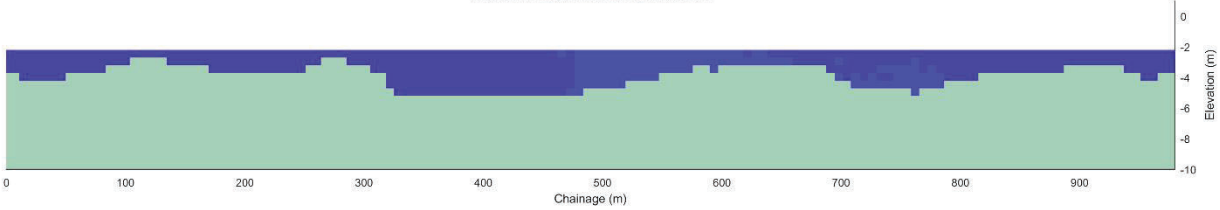


13-Sep-2018 18:15
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan


13-Sep-2018 18:23
Transect of Suspended Sediment, OBS Profile Included


Transect of Dredge Plume in Plan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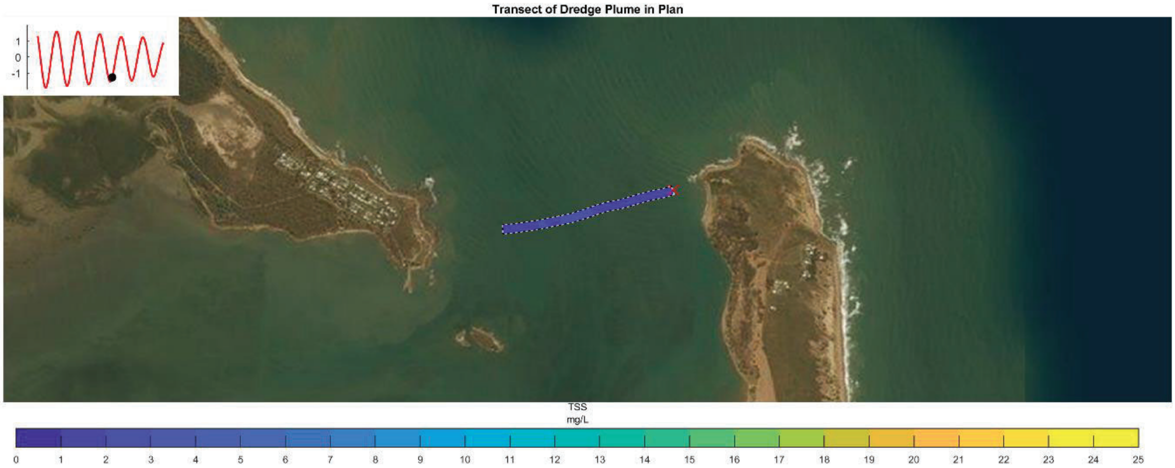
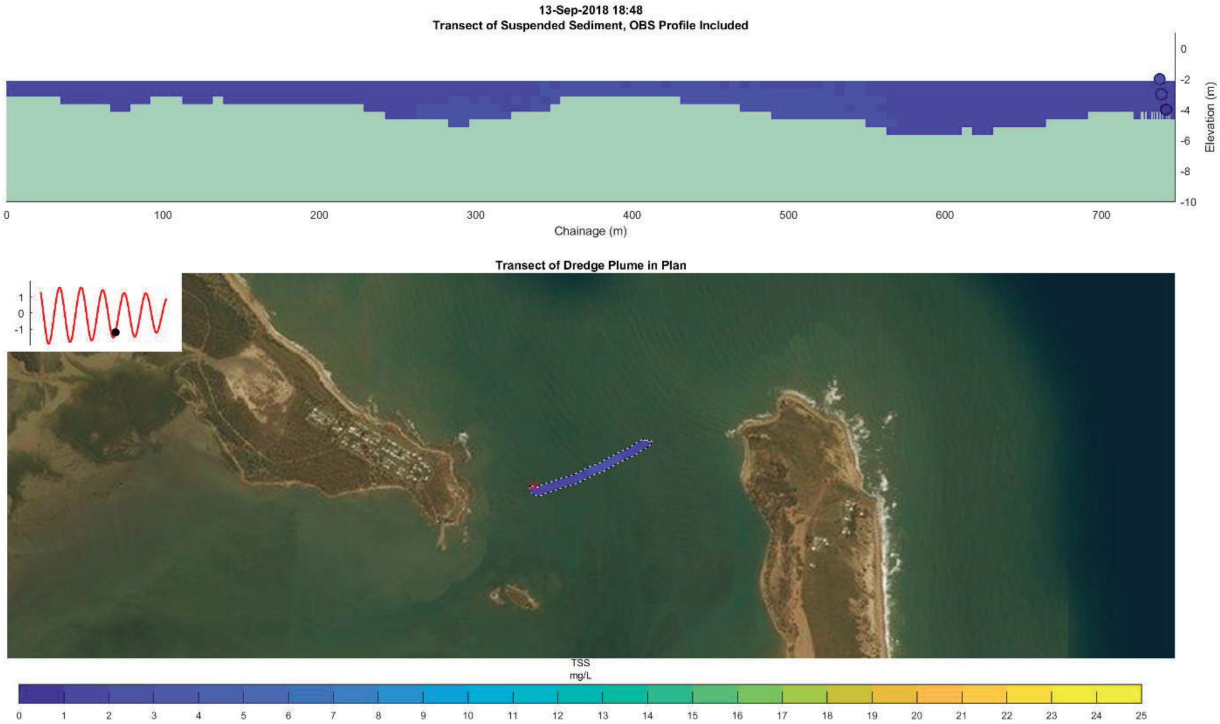
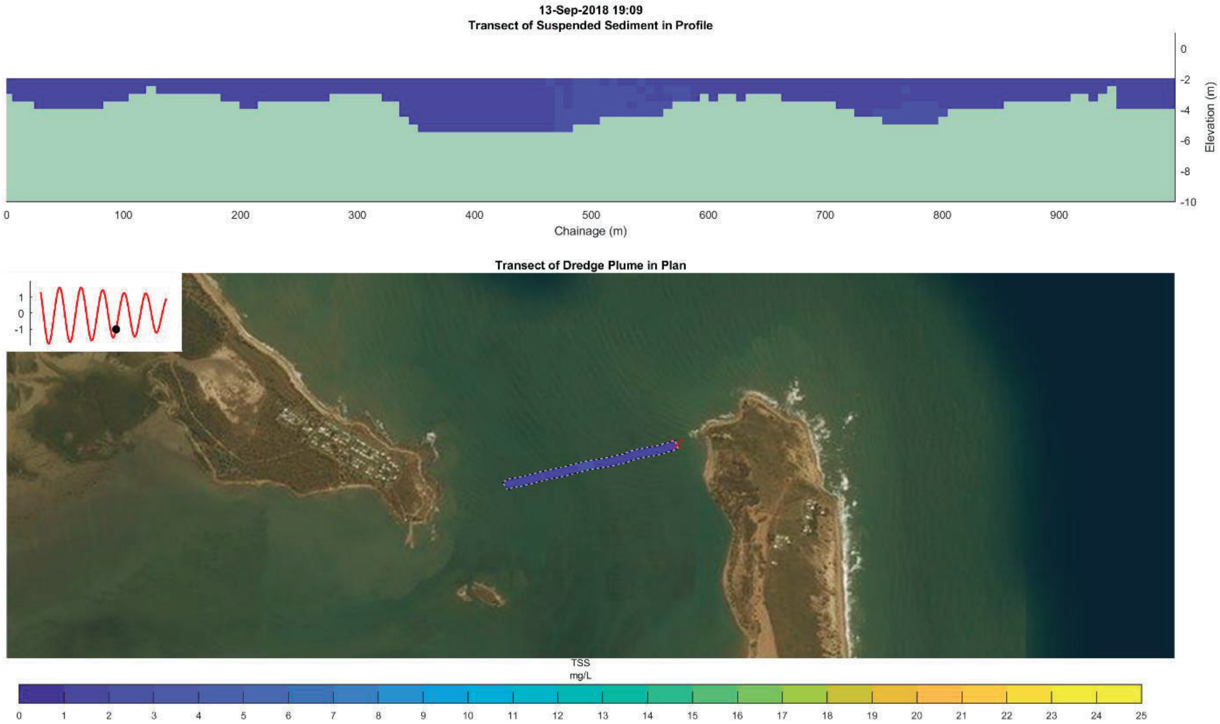
Transect of Suspended Sediment in Profile


Transect of Dredge Plume in Plan



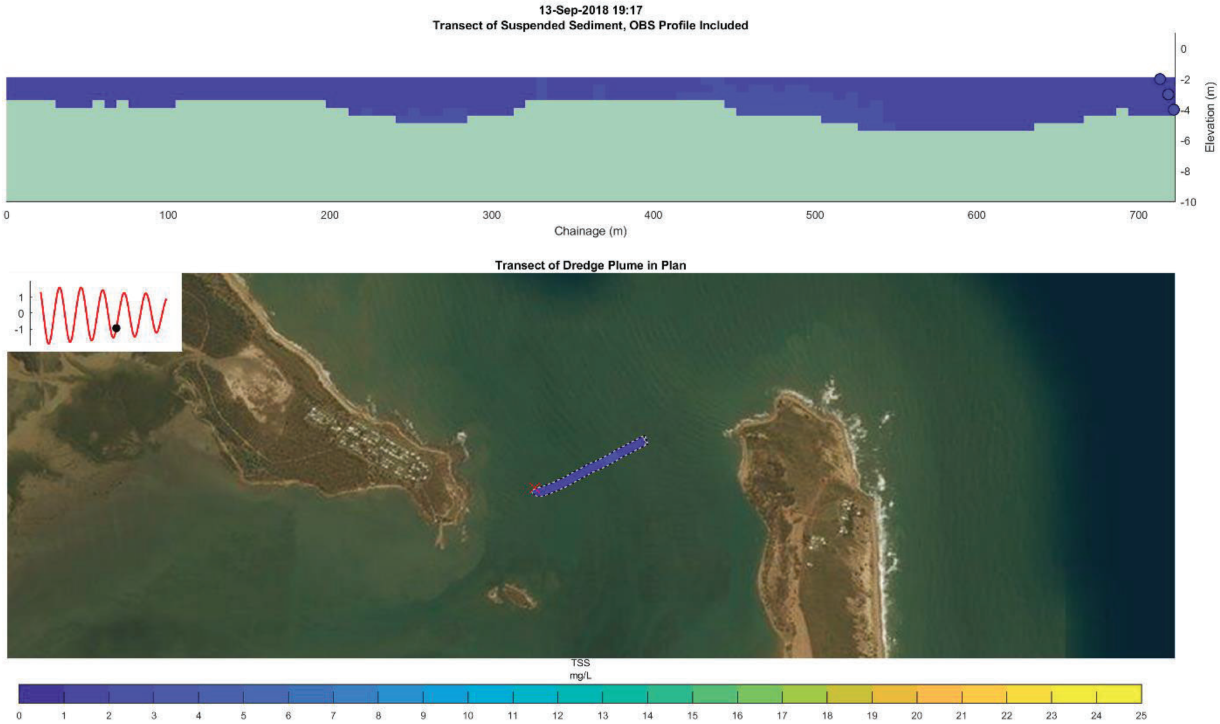
13-Sep-2018 18:48
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan



13-Sep-2018 19:09
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan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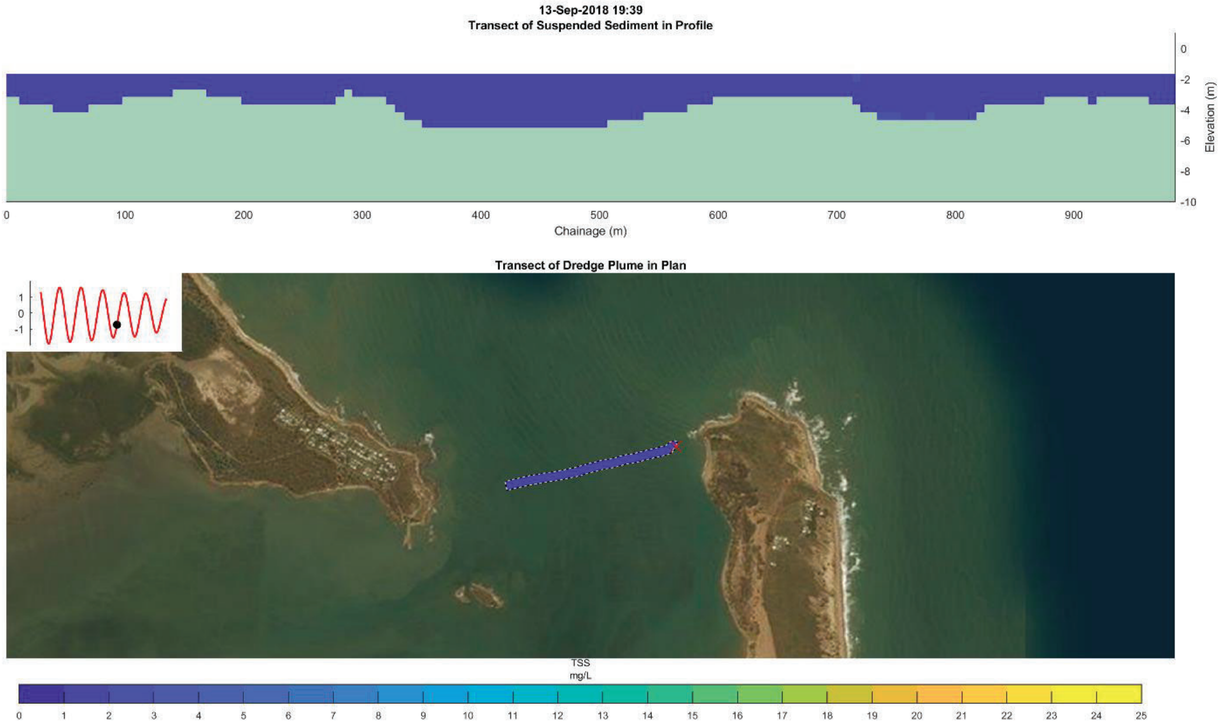
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan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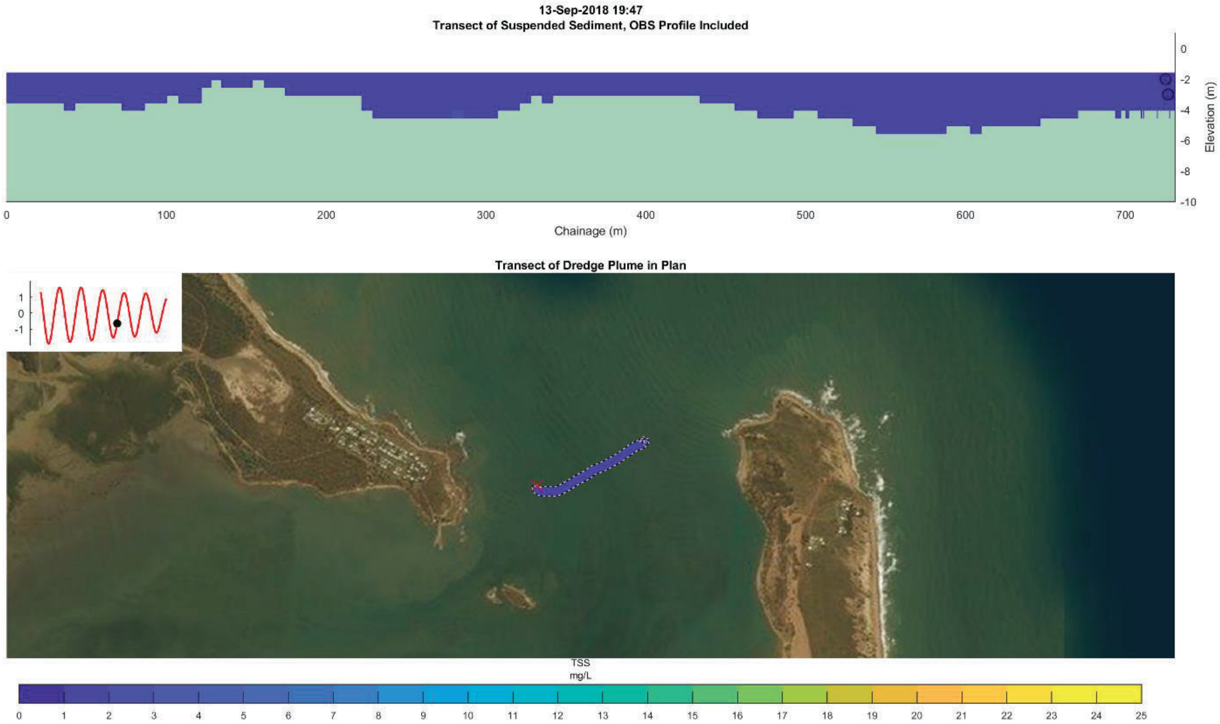
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan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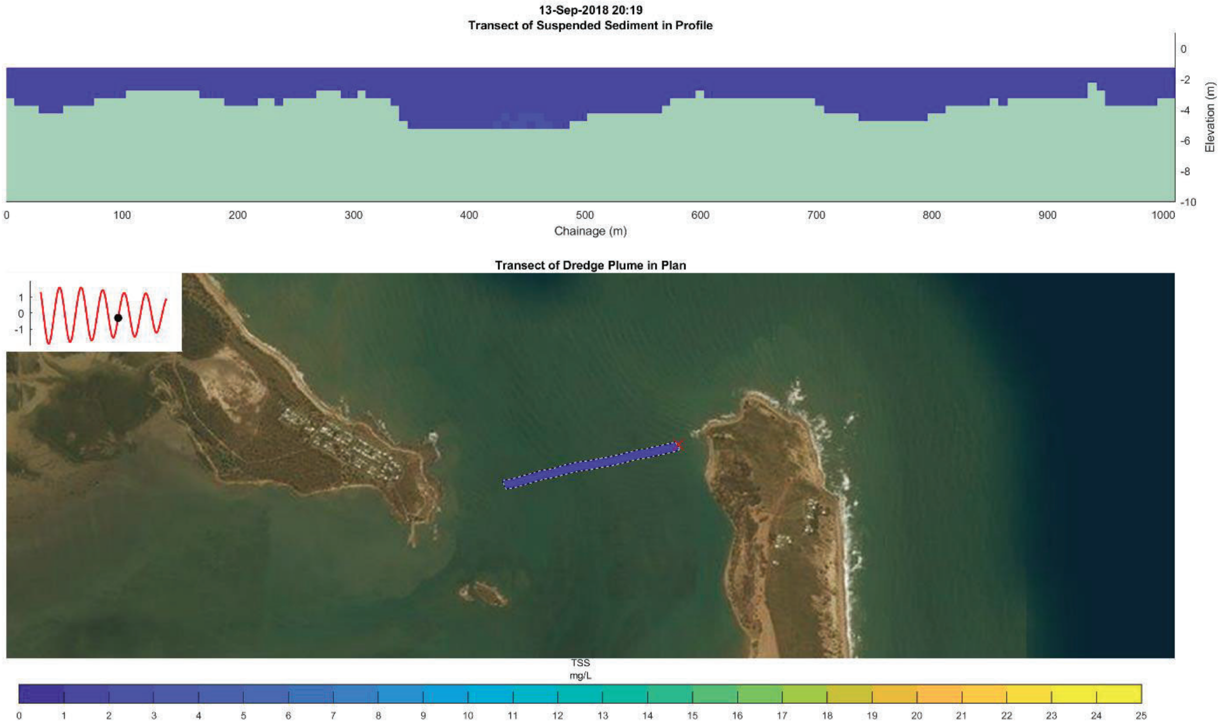
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan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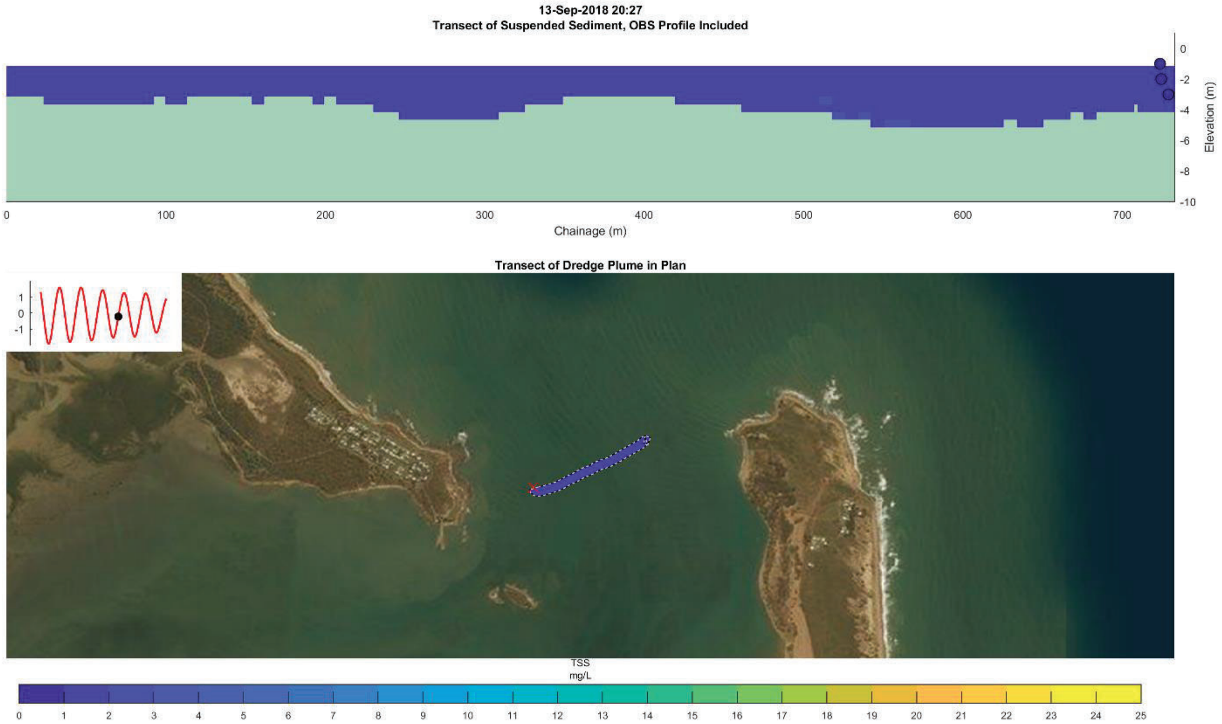
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan



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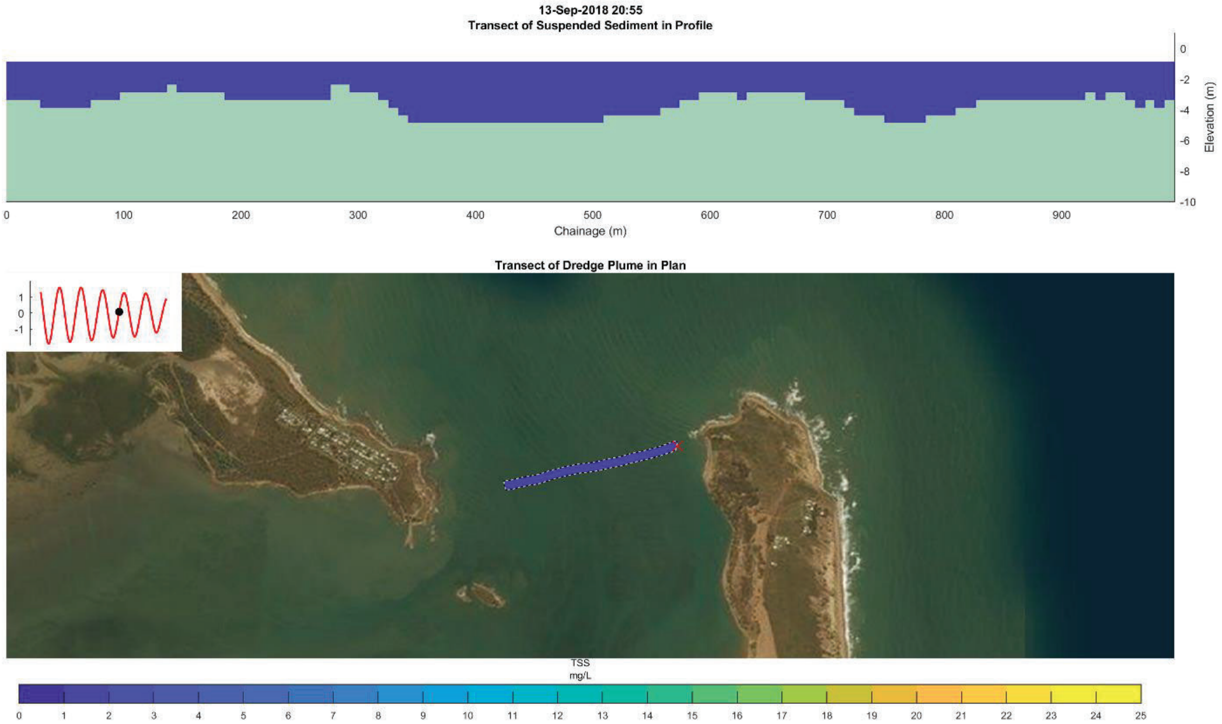
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan



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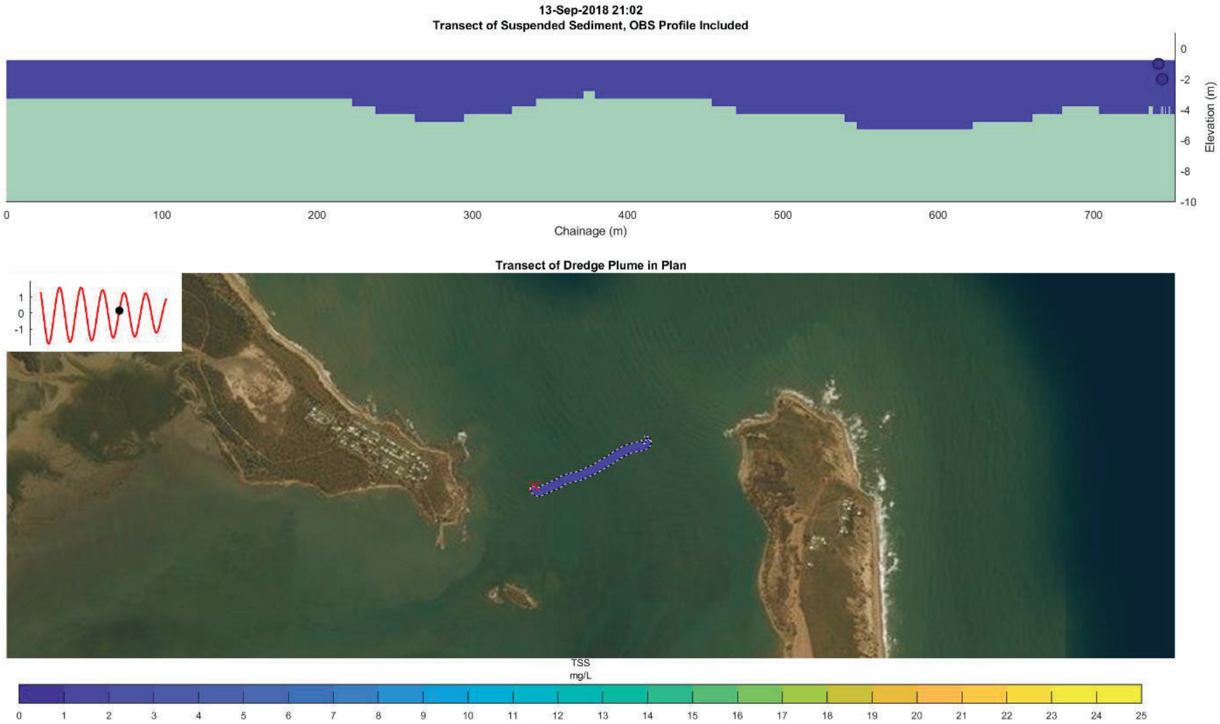
Transect of Suspended Sediment in Profile

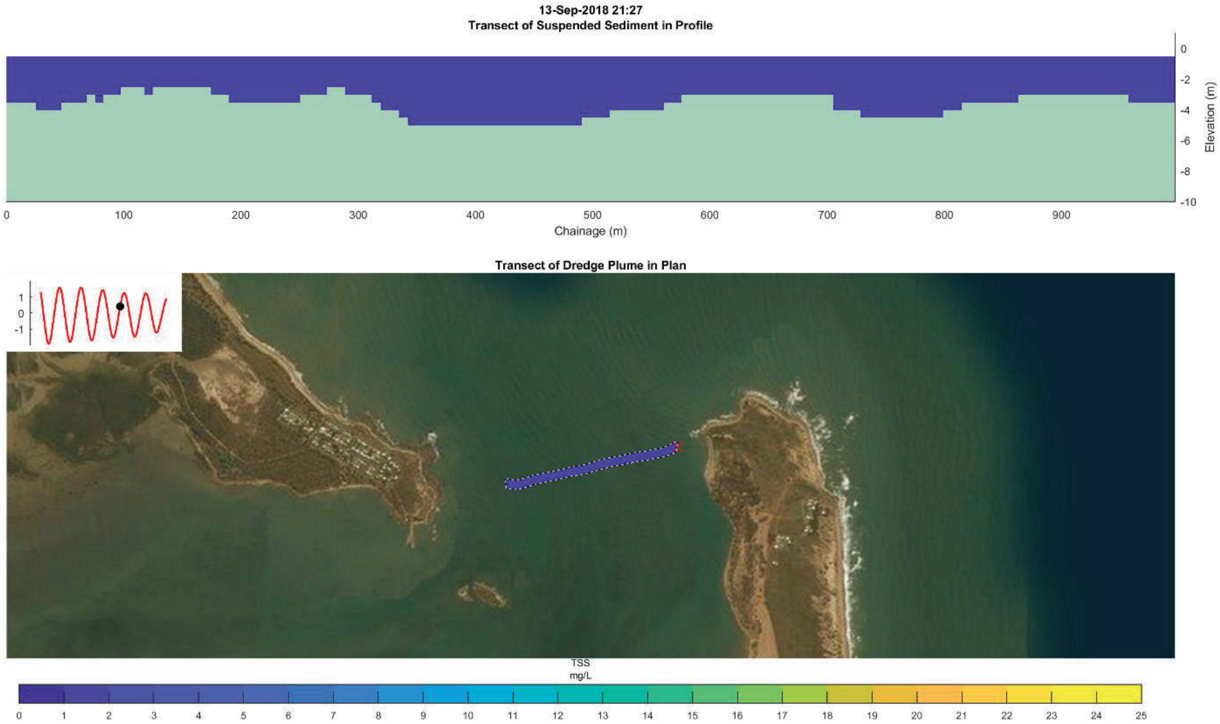
Transect of Dredge Plume in Plan



13-Sep-2018 21:02

Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan



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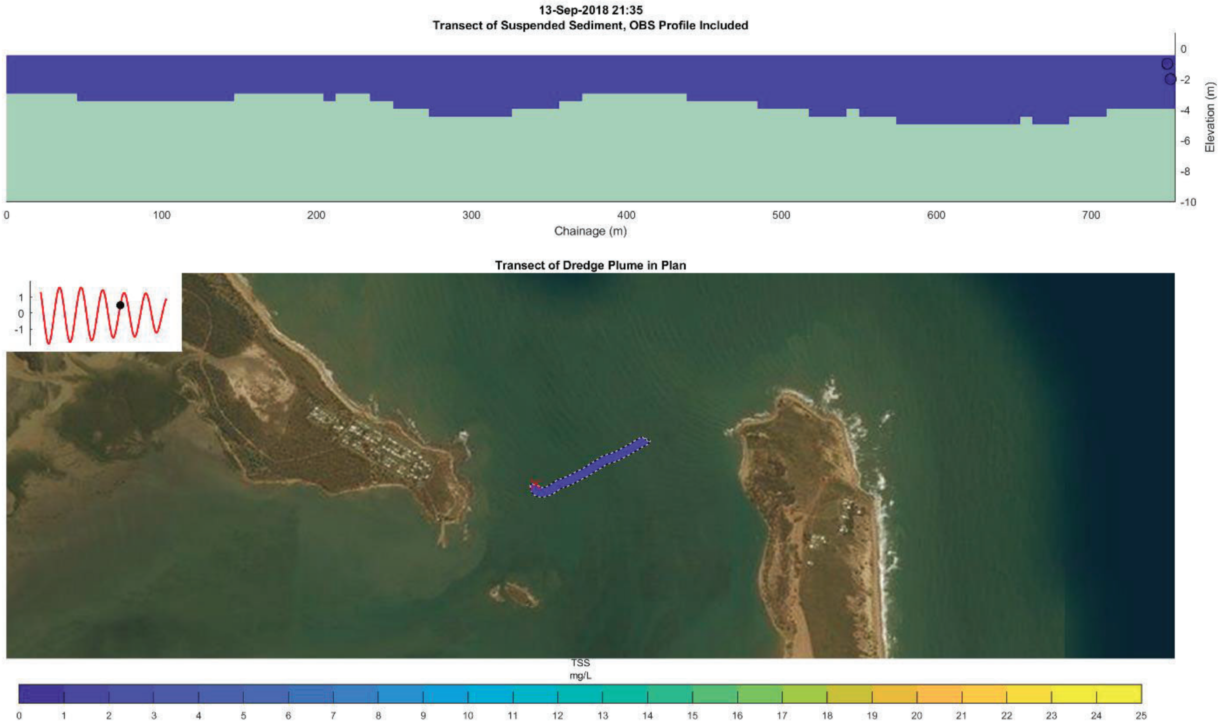
Transect of Suspended Sediment in Profile

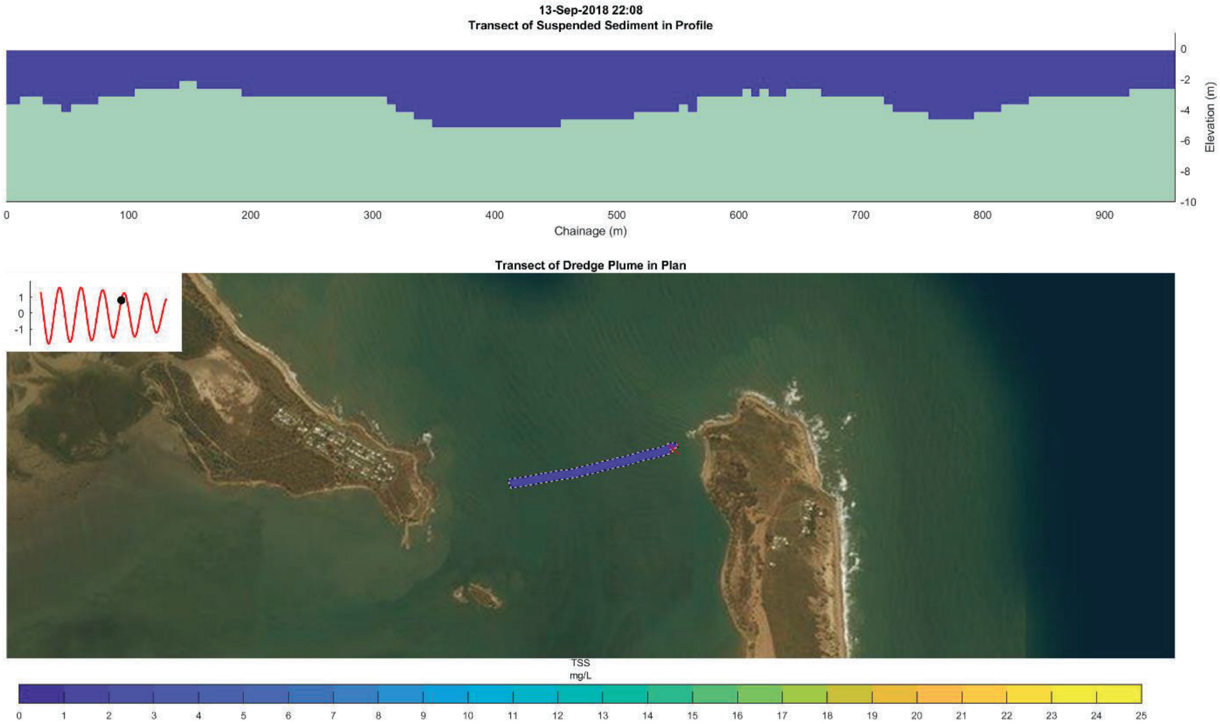
Transect of Dredge Plume in Plan



13-Sep-2018 21:35

Transect of Suspended Sediment, OBS Profile Included

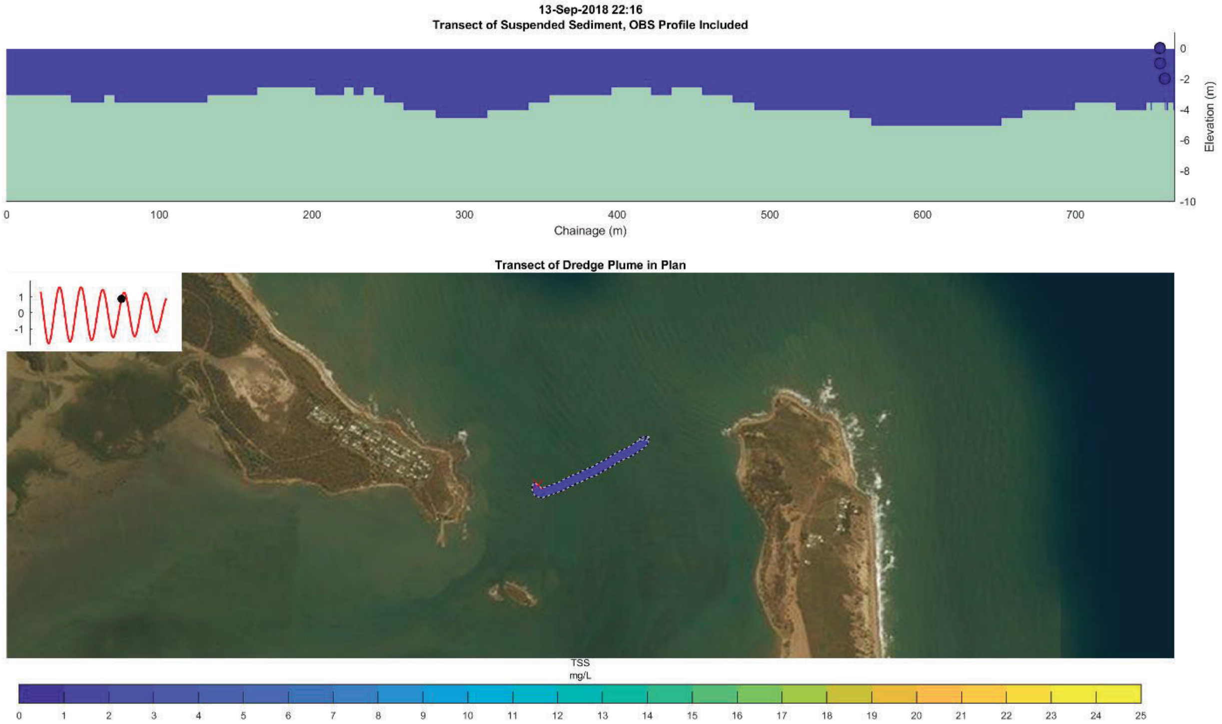
Transect of Dredge Plume in Plan



13-Sep-2018 22:08

Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan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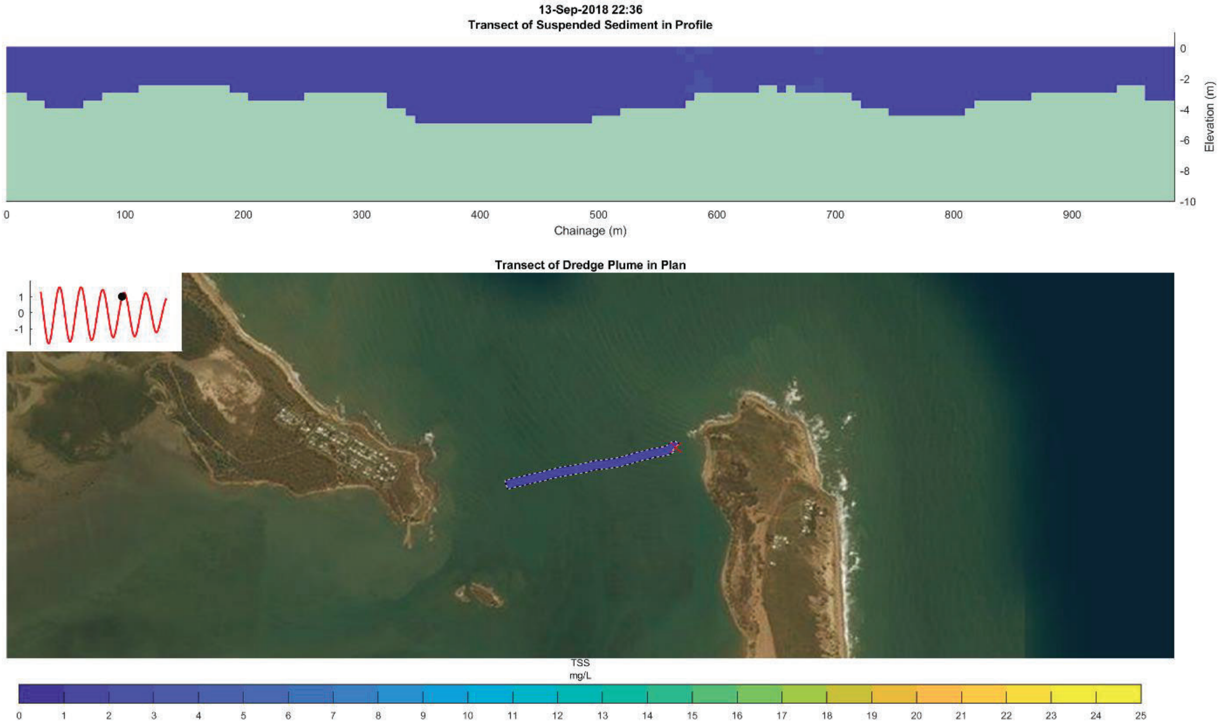
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan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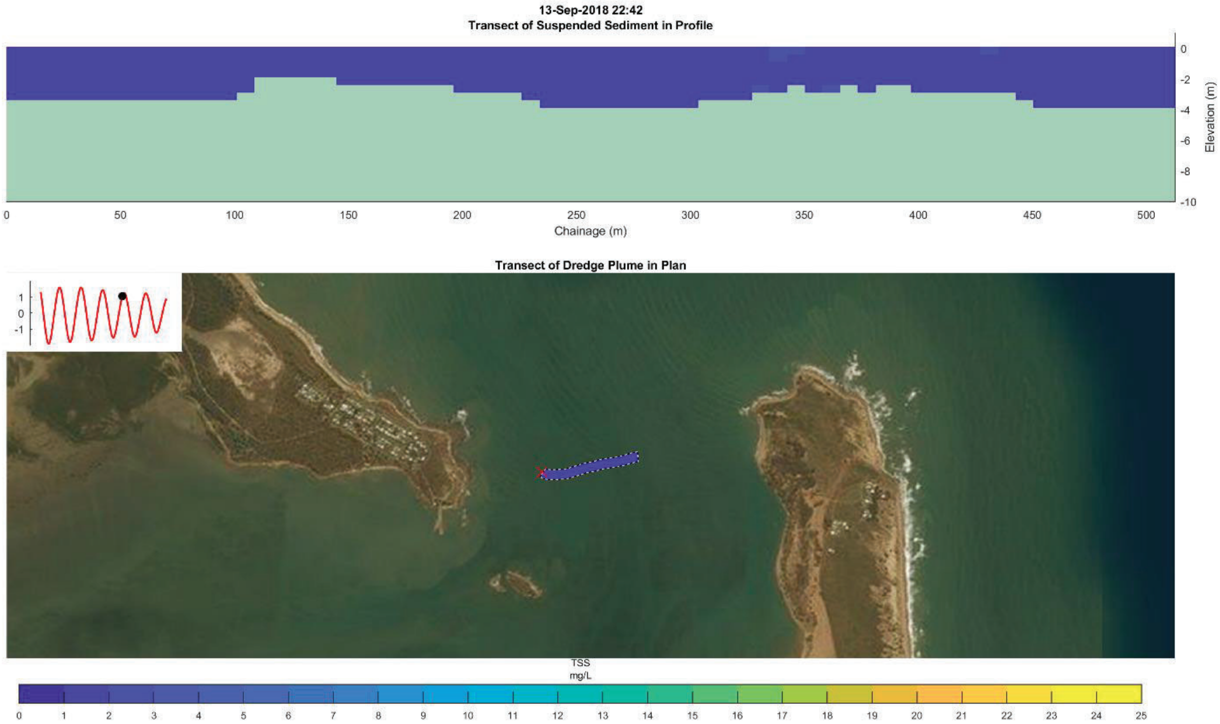
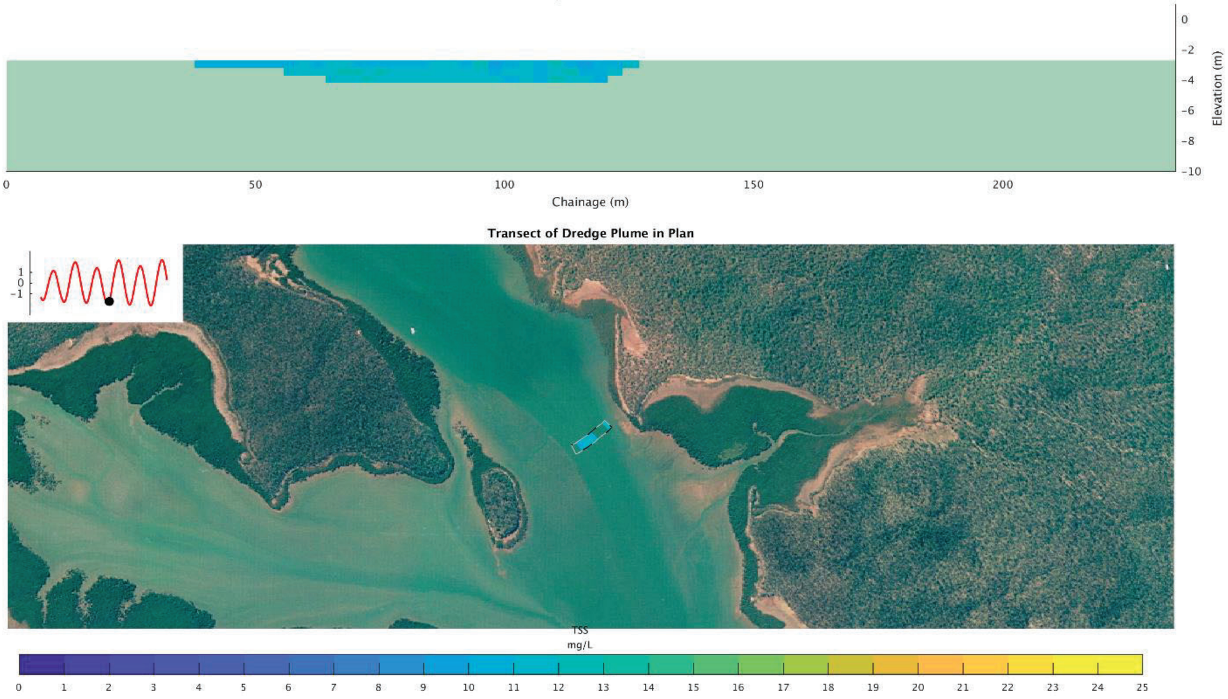
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan


13-Sep-2018 22:42
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
300
350
400
450
500
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25

Transect C – The Narrows– Spring Tide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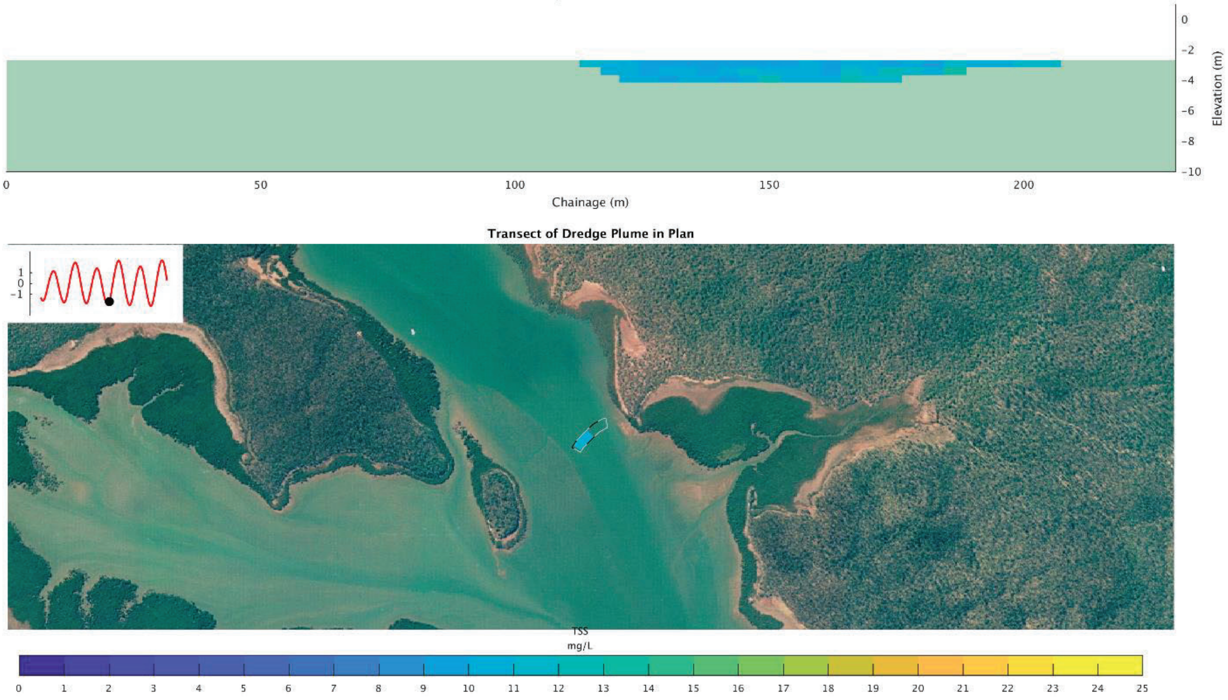
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan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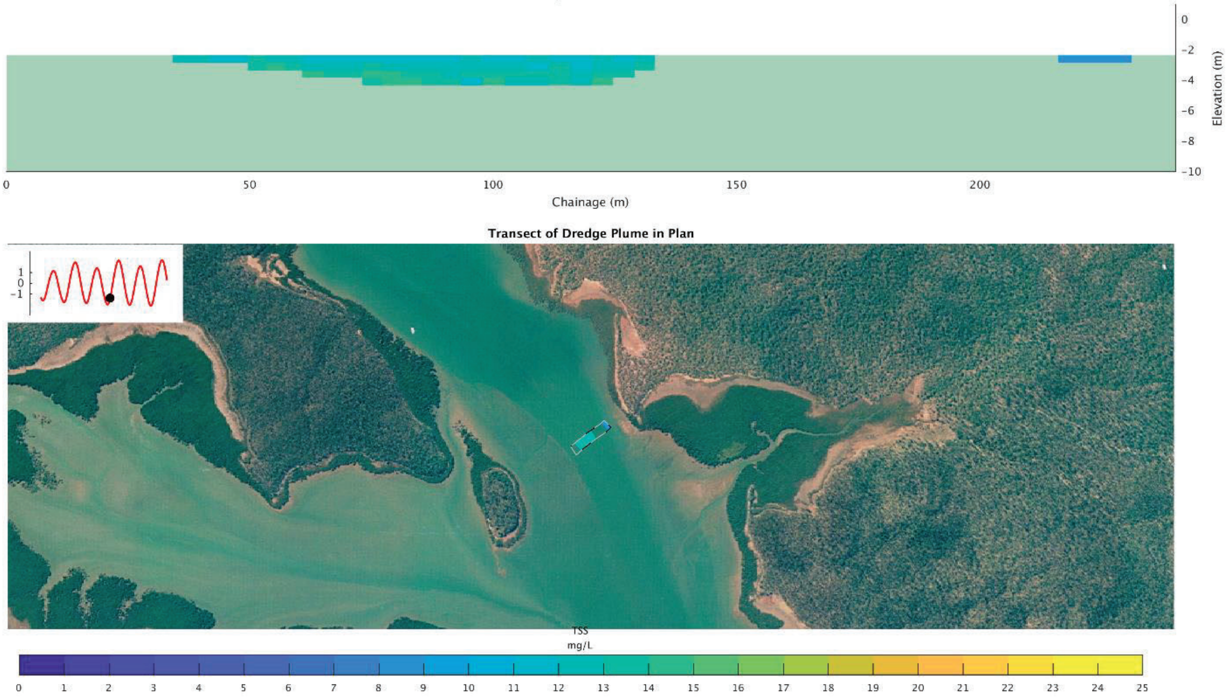
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan

08-Sep-2018 15:33
Transect of Suspended Sediment in Profile



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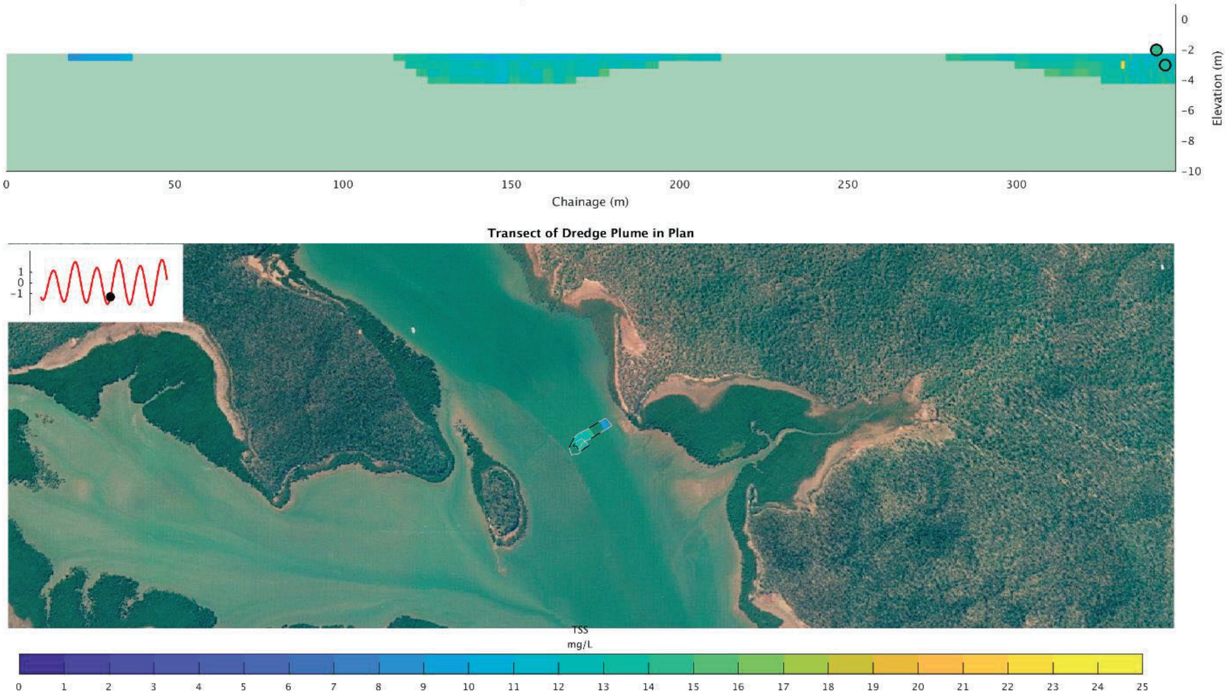
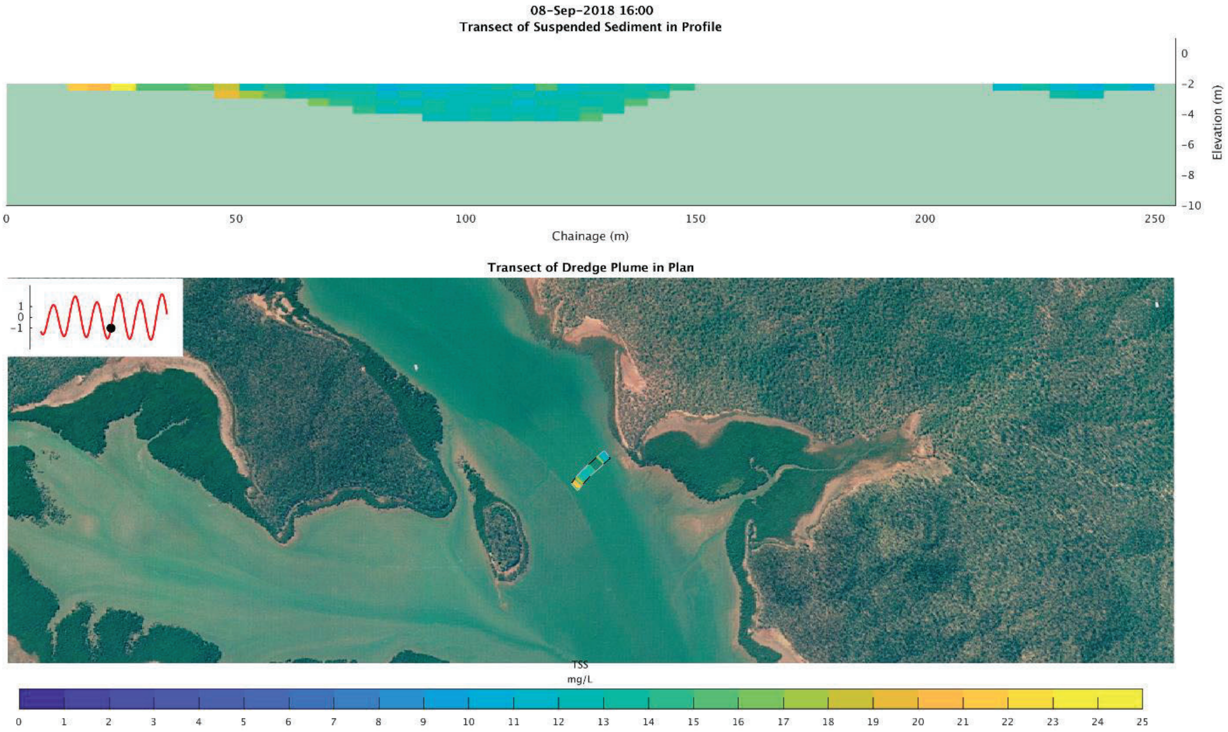
Transect of Suspended Sediment, OBS Profile Included

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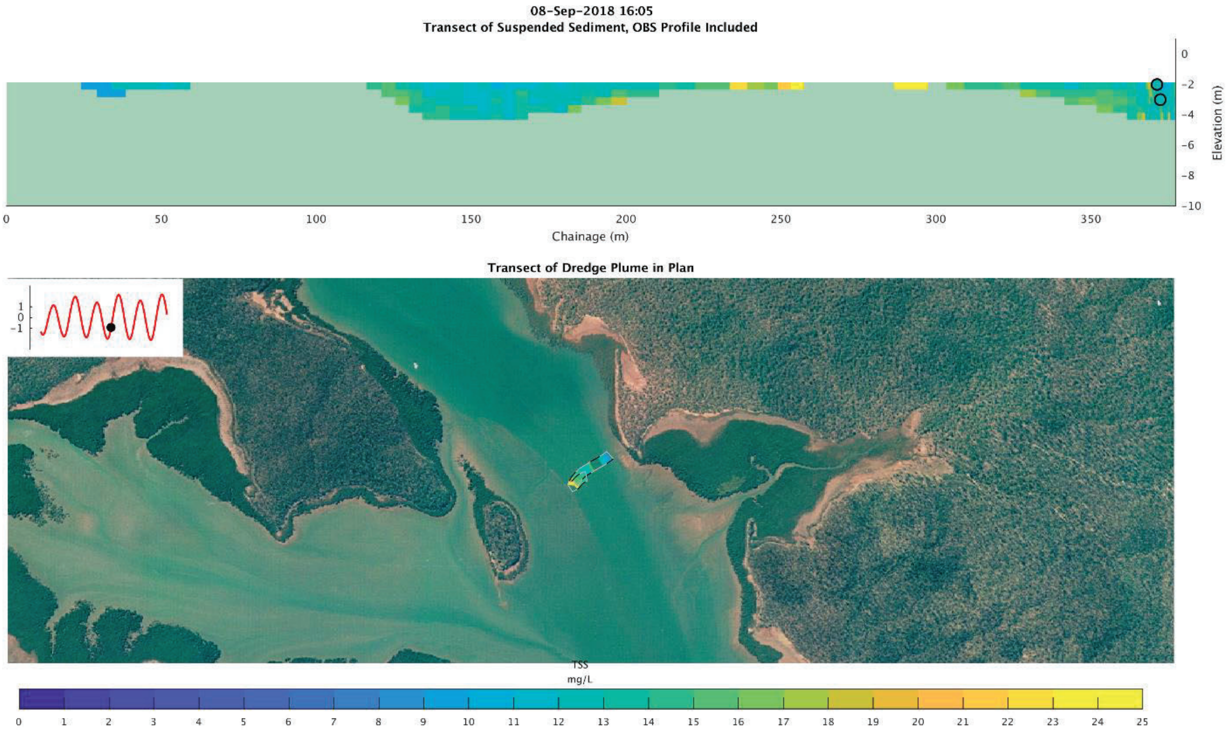
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan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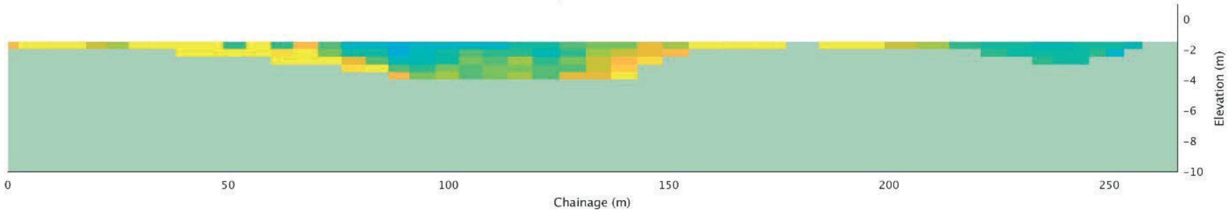
Transect of Suspended Sediment, OBS Profile Included

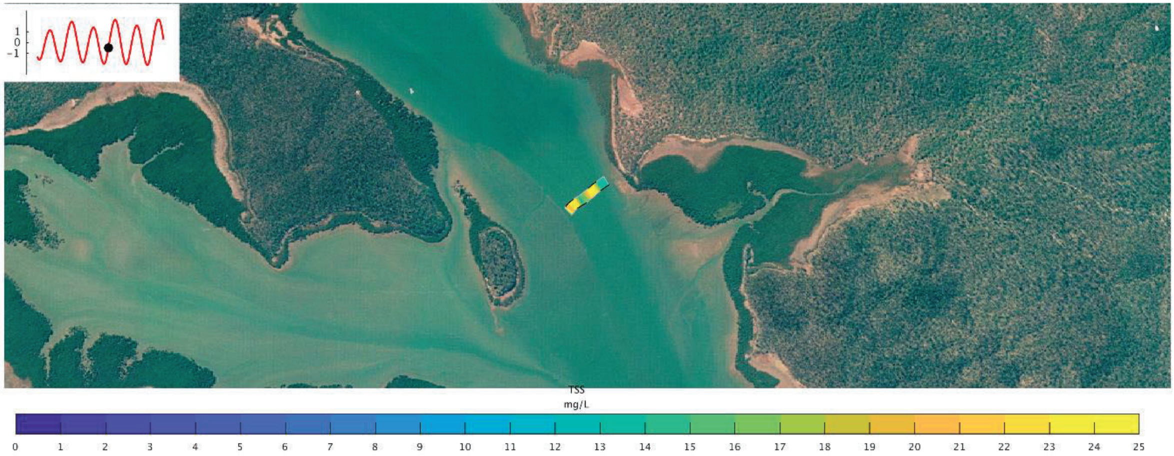
Transect of Dredge Plume in Plan

08-Sep-2018 16:32

Transect of Suspended Sediment in Profile



Transect of Dredge Plume in Plan



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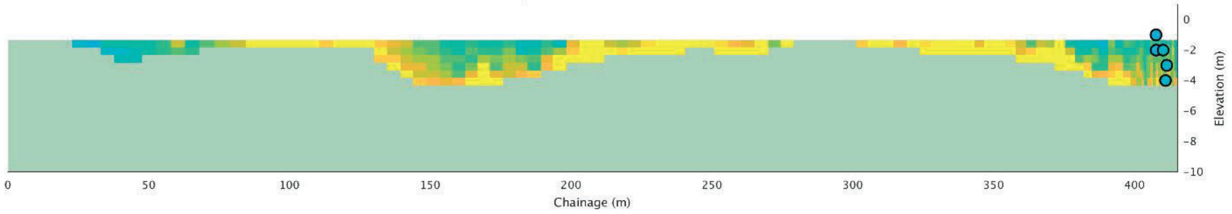
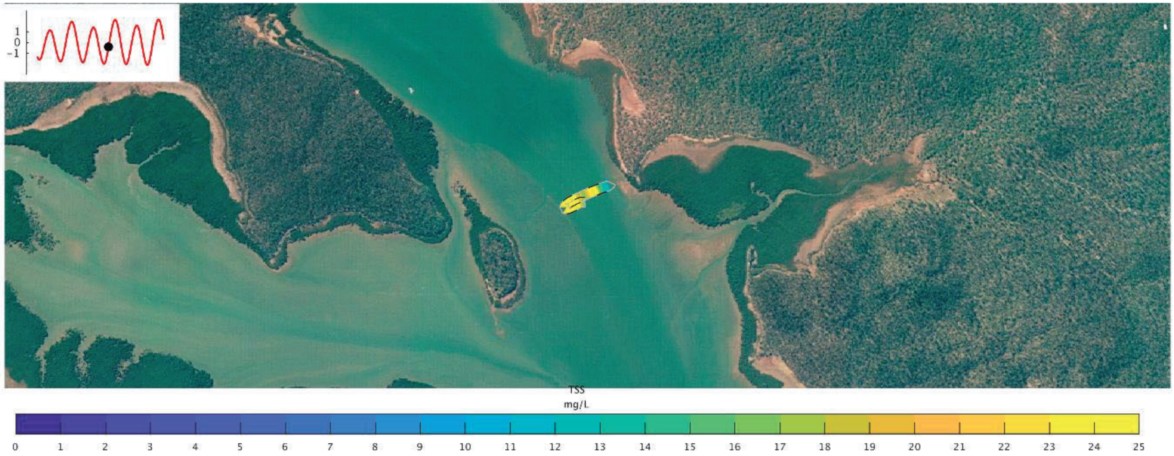
Transect of Suspended Sediment, OBS Profile Included



Transect of Dredge Plume in Plan



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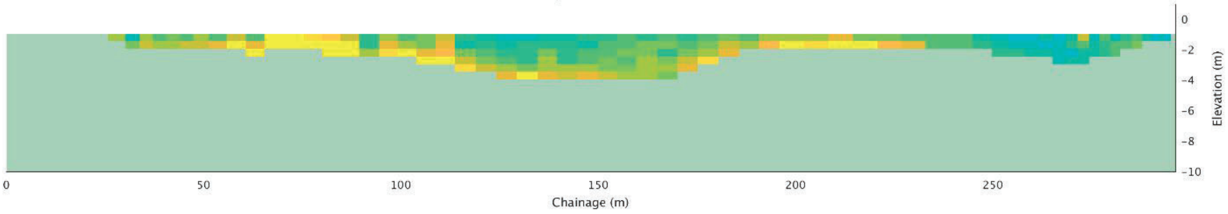
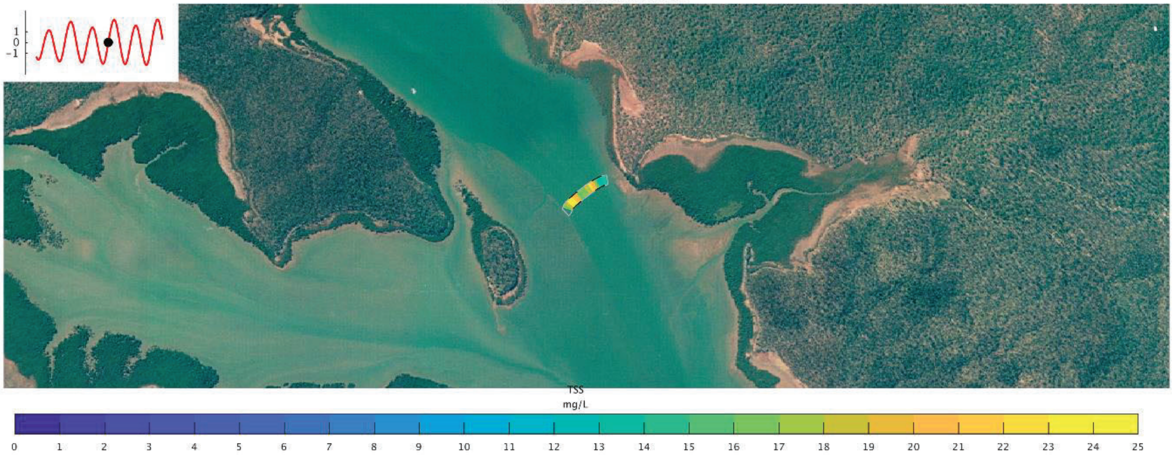
Transect of Suspended Sediment in Profile



Transect of Dredge Plume in Plan



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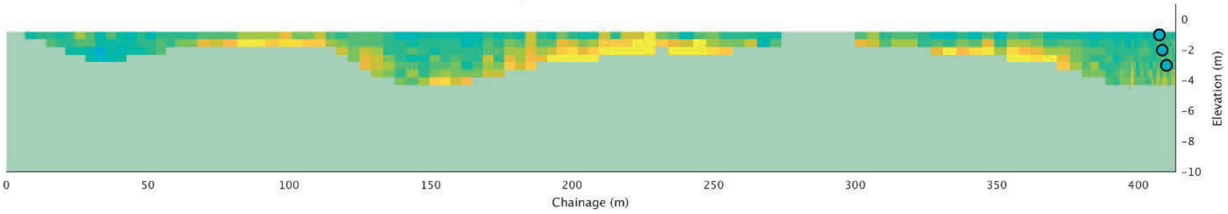
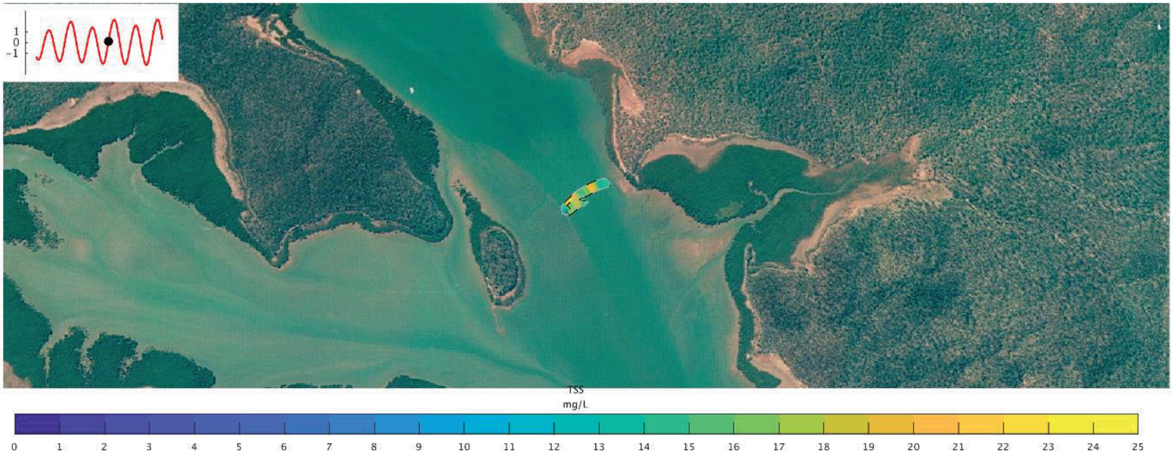
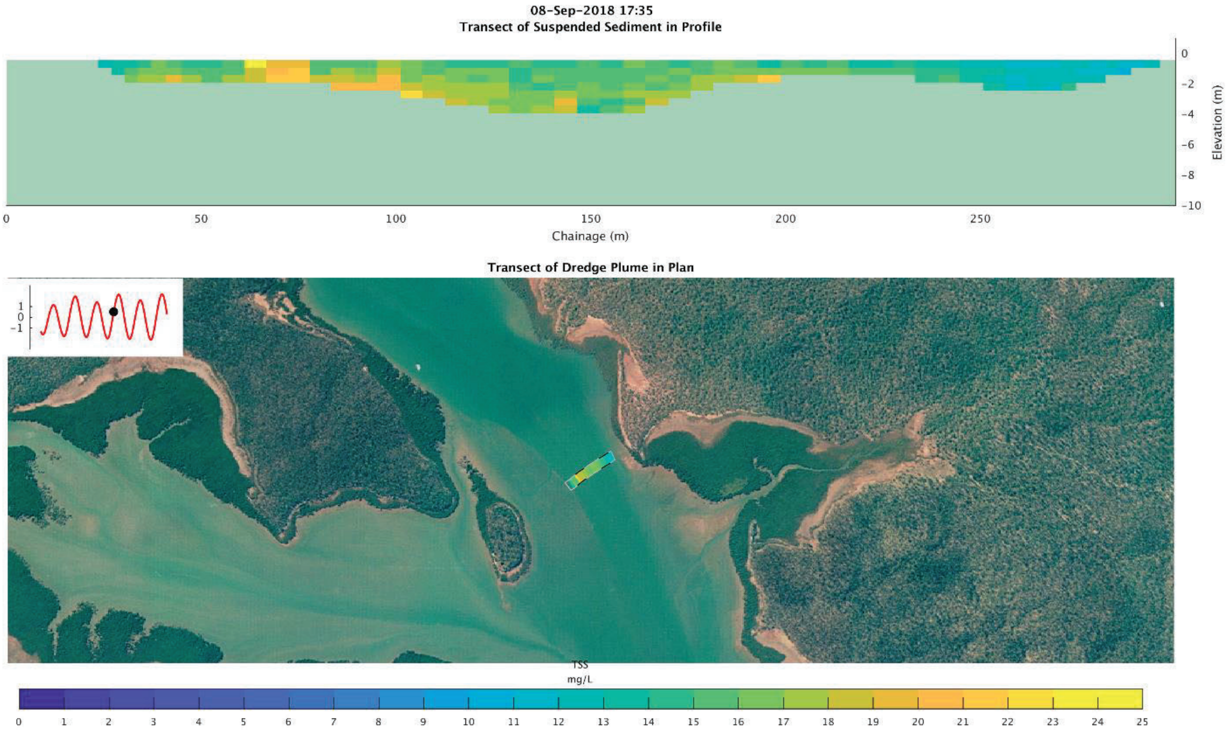
Transect of Suspended Sediment, OBS Profile Included



Transect of Dredge Plume in Plan





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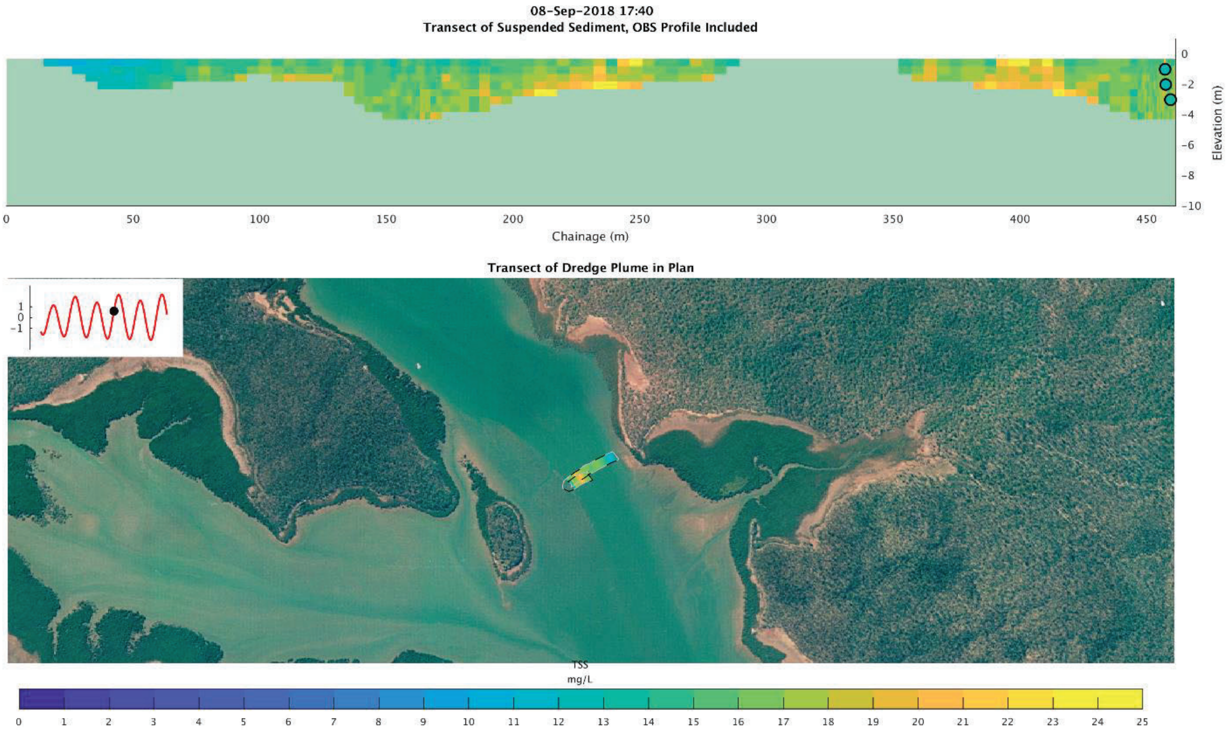
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan



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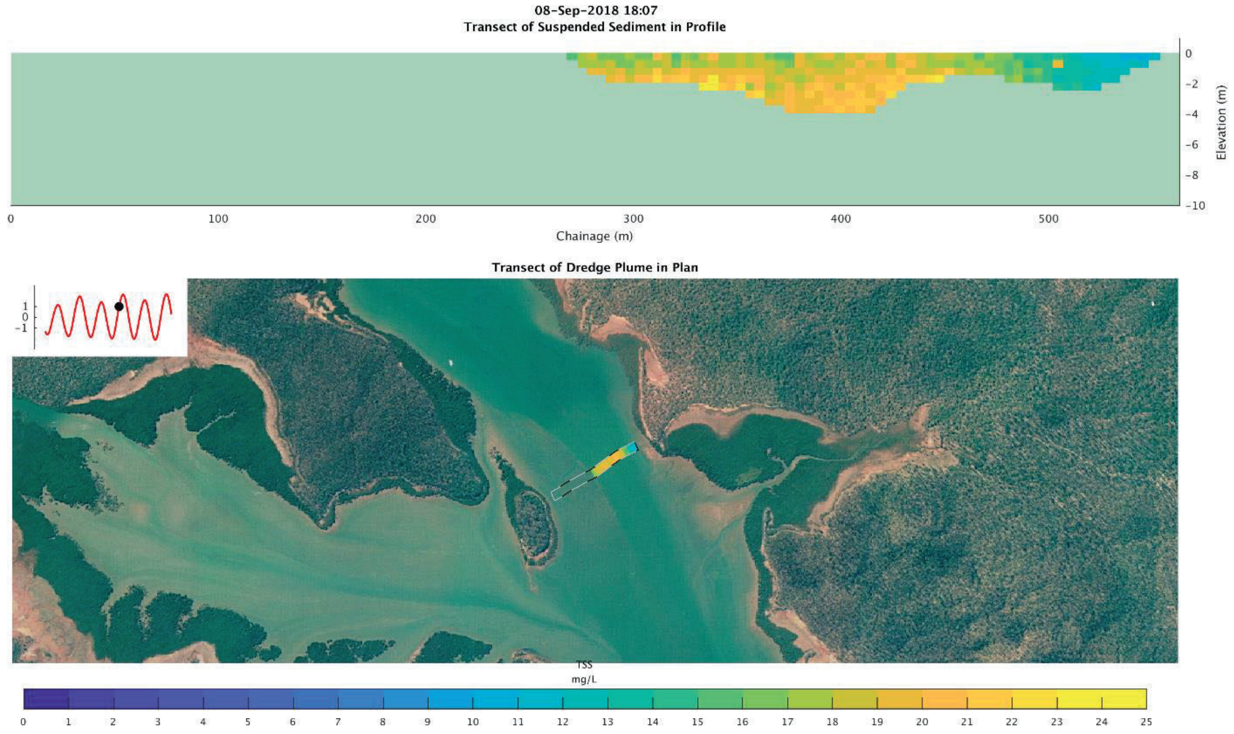
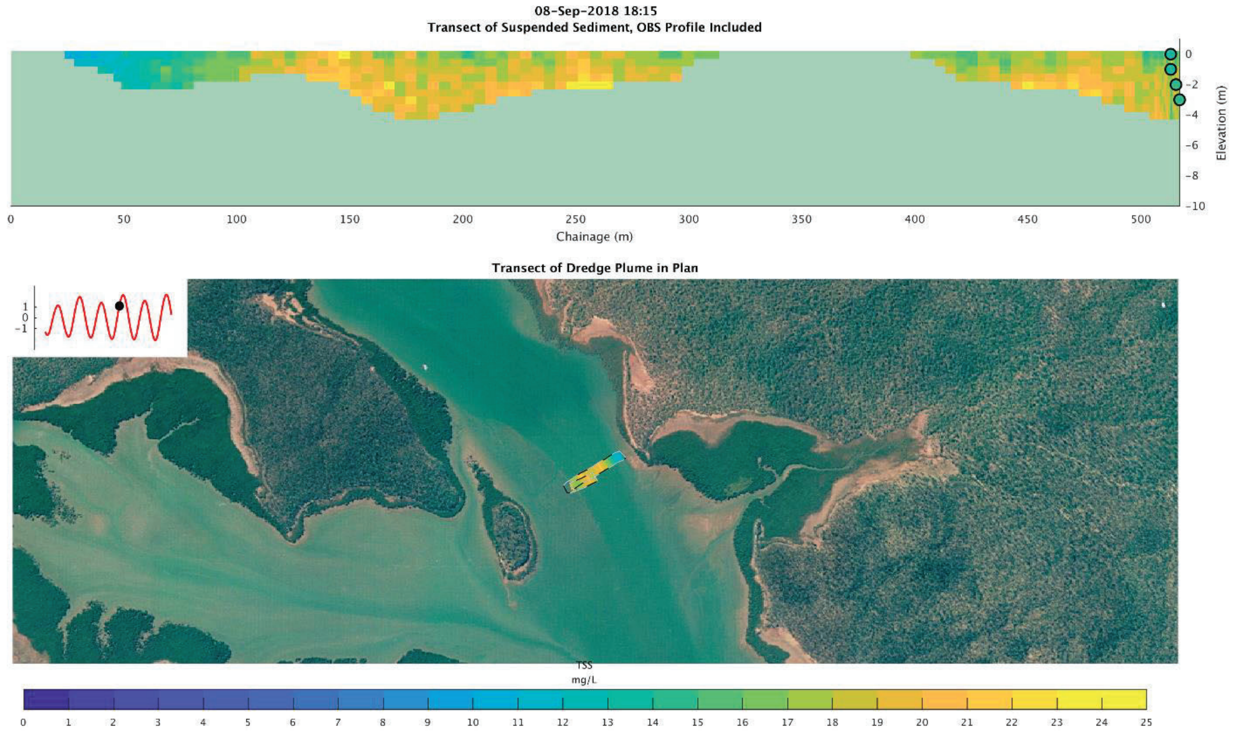
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan


08-Sep-2018 18:07
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
100
200
300
400
500
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25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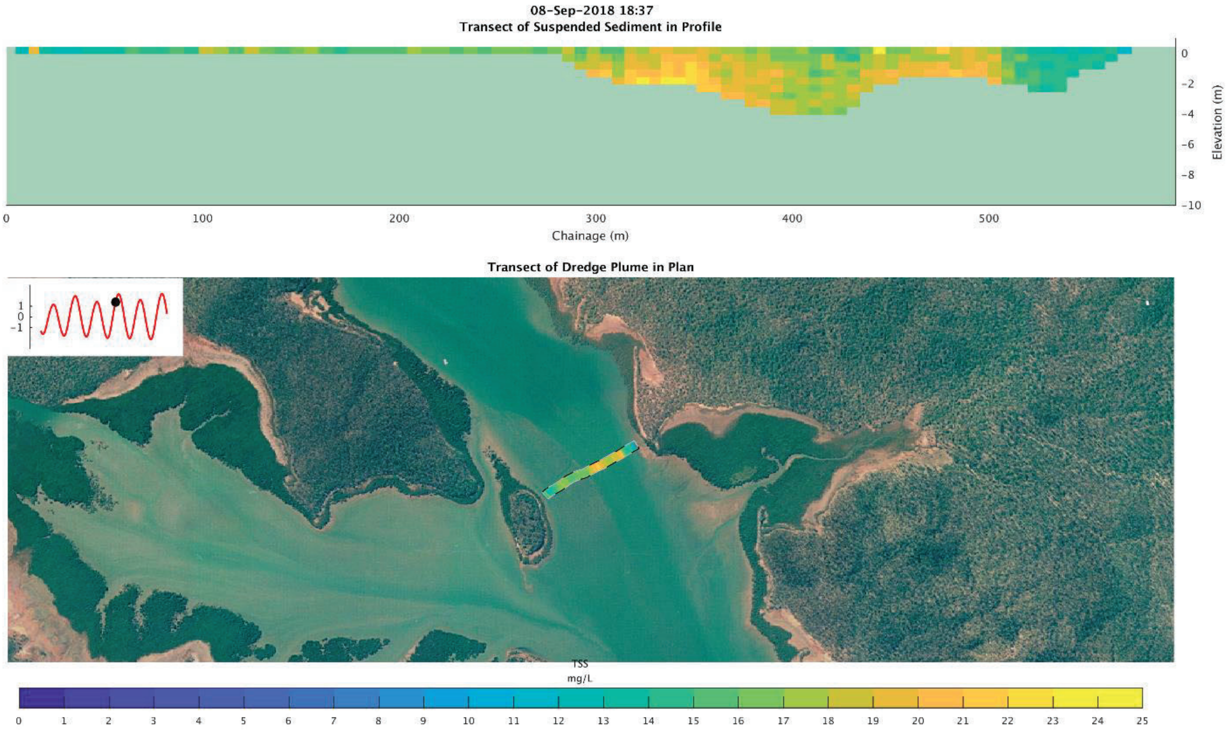
Transect of Suspended Sediment, OBS Profile Included
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
300
350
400
450
500
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25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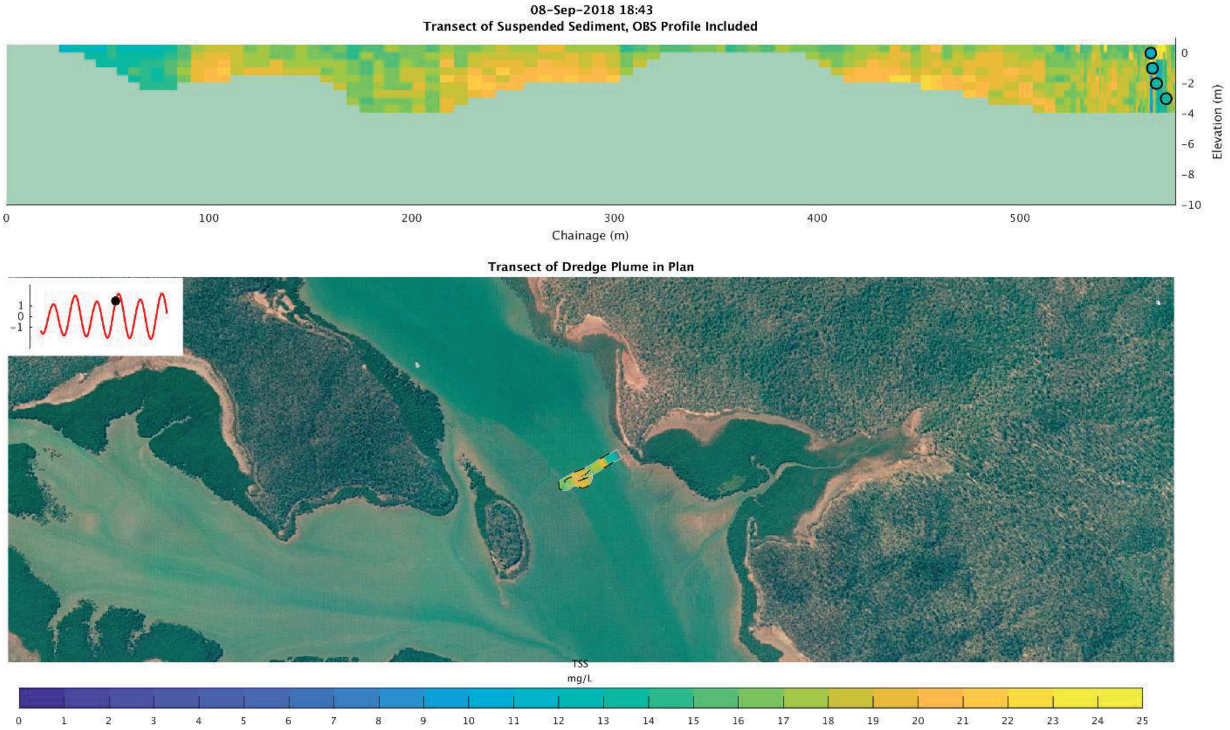
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan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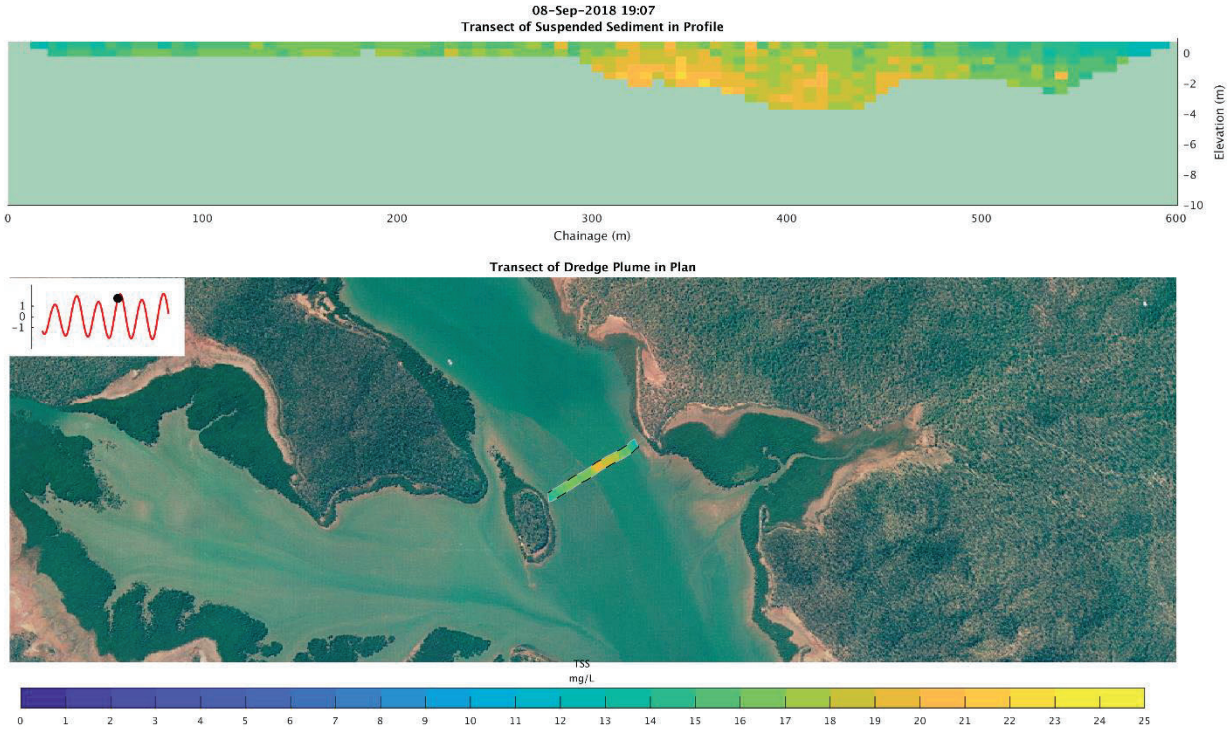
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan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Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
100
200
300
400
500
600
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
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18
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20
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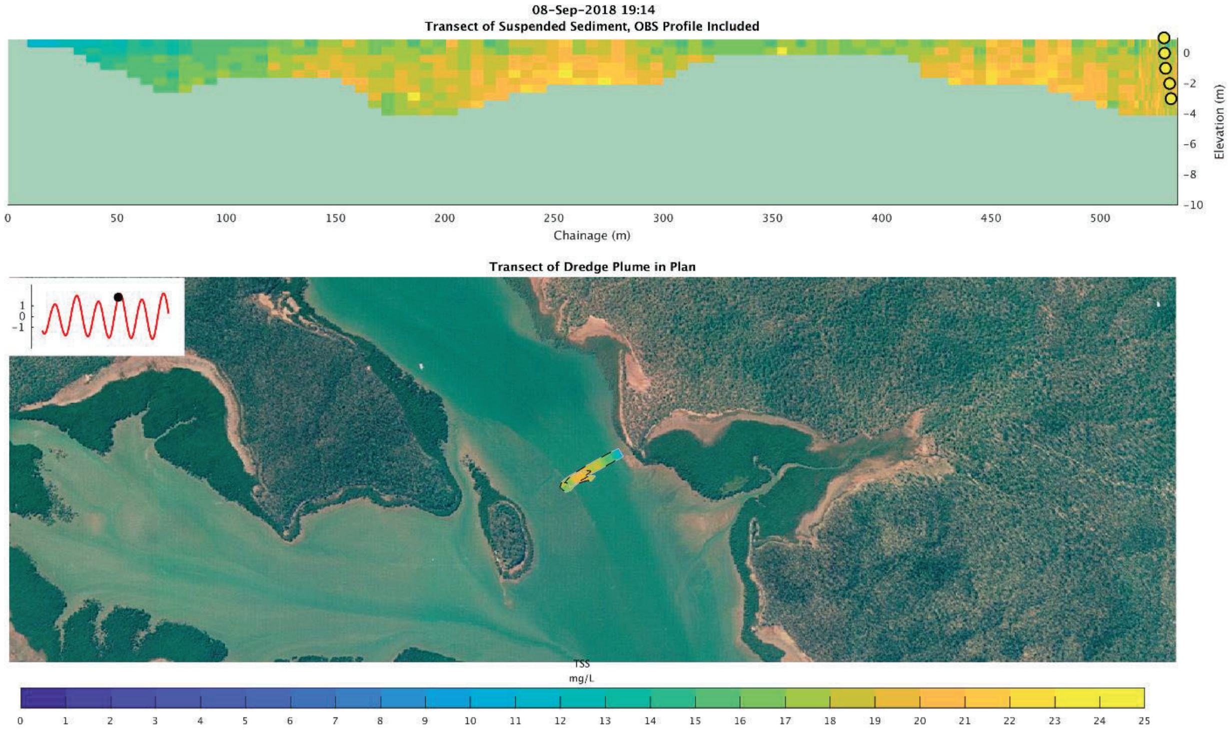
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Transect of Suspended Sediment, OBS Profile Included
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
300
350
400
450
500
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
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10
11
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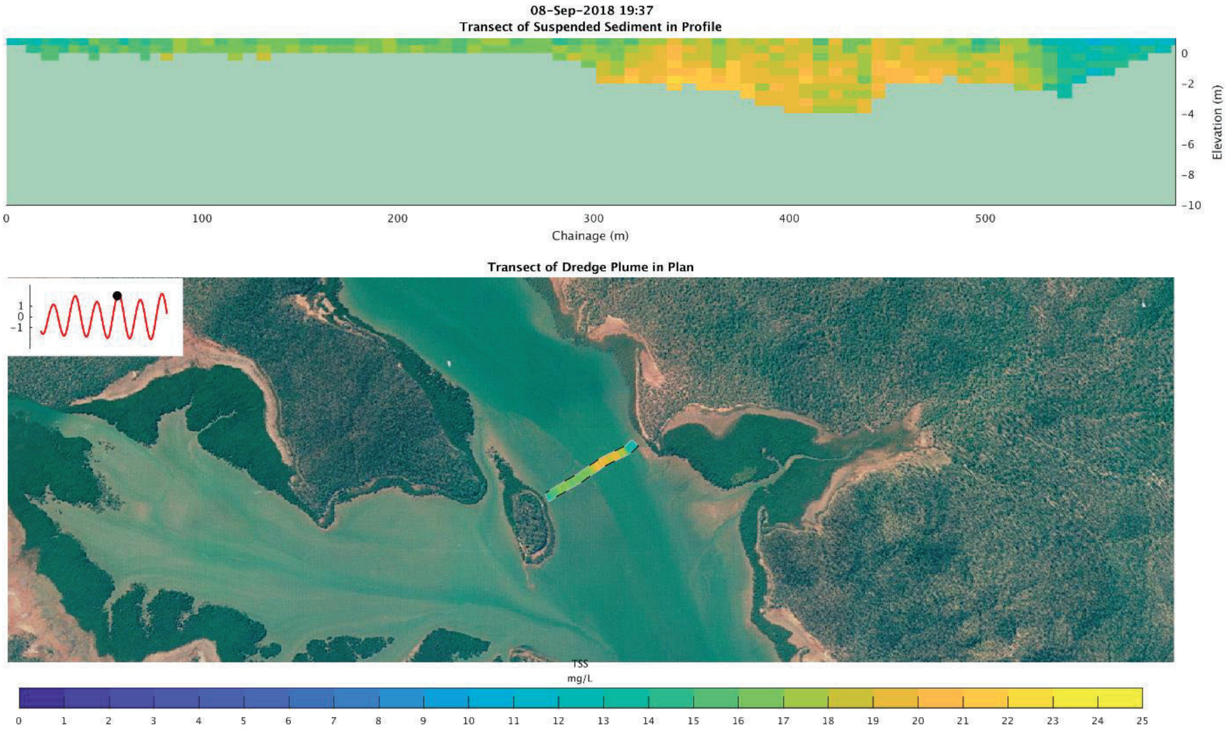
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Transect of Suspended Sediment in Profile
Elevation (m)
0
-2
-4
-6
-8
-10
Chainage (m)
0
100
200
300
400
500
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
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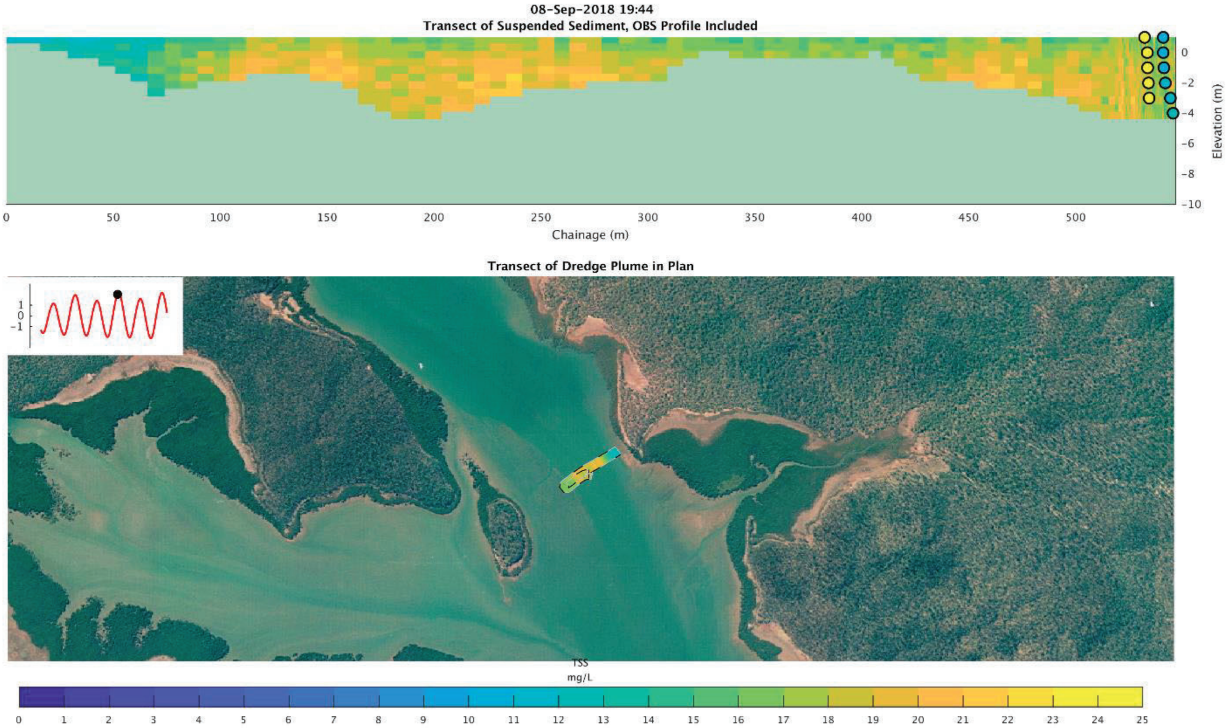
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Transect of Suspended Sediment, OBS Profile Included
Elevation (m)
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-2
-4
-6
-8
-10
Chainage (m)
0
50
100
150
200
250
300
350
400
450
500
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
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16
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23
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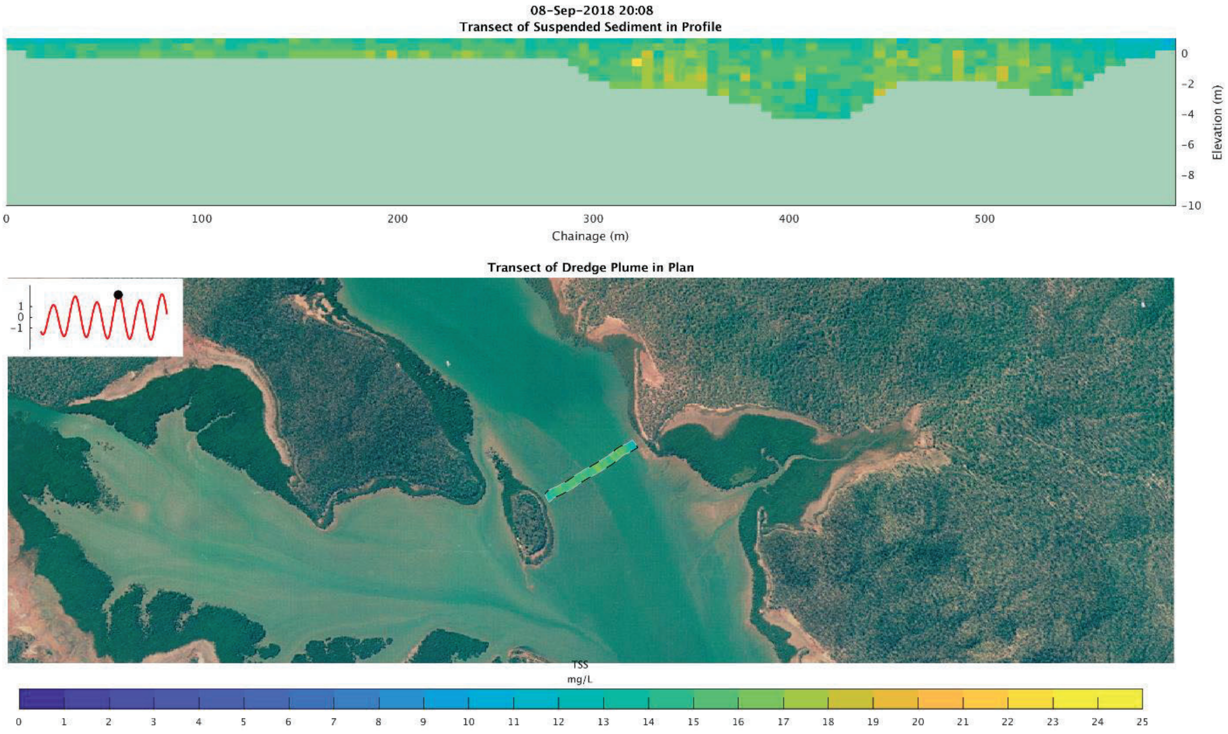
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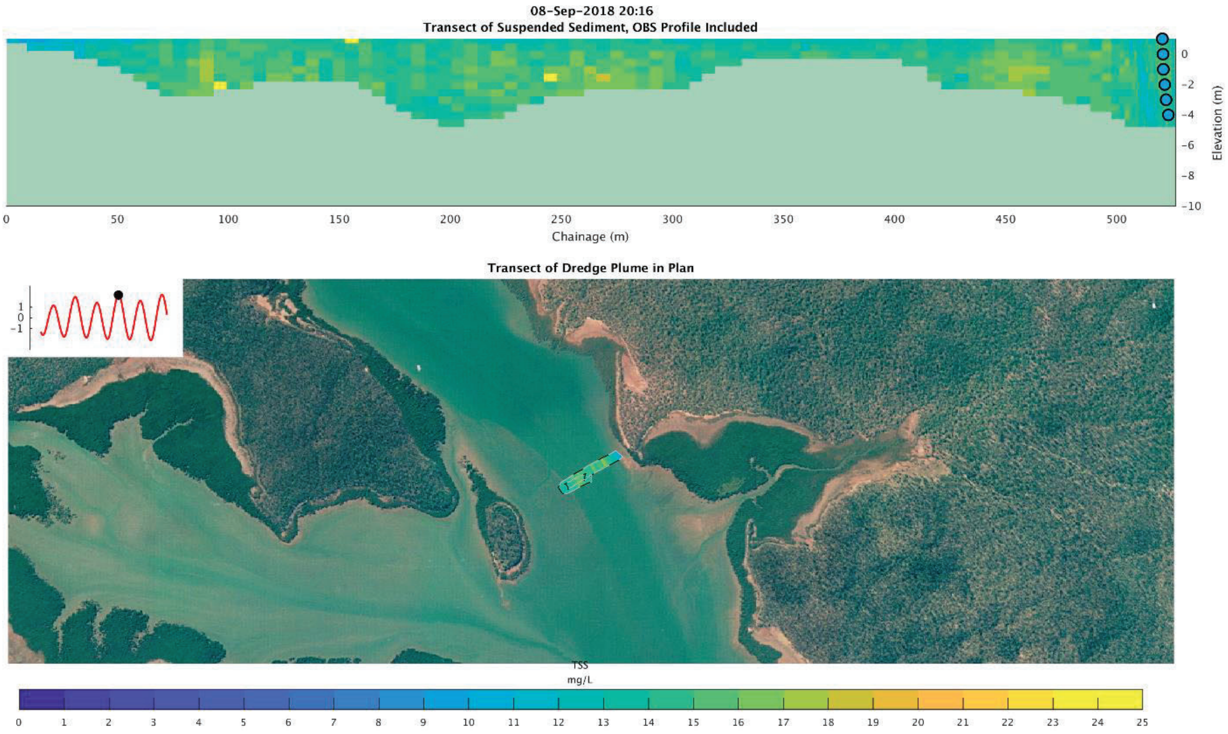
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan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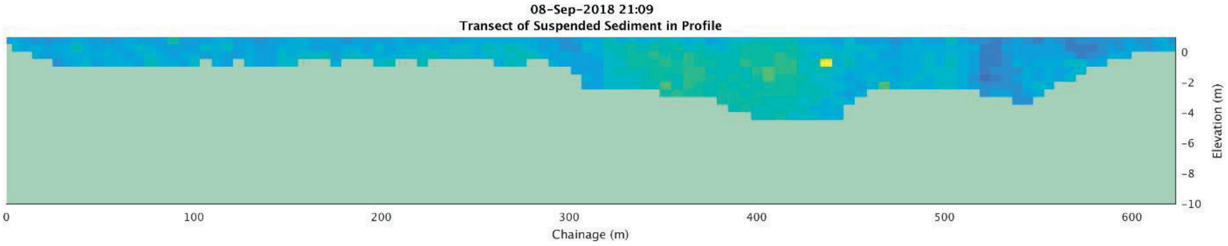
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan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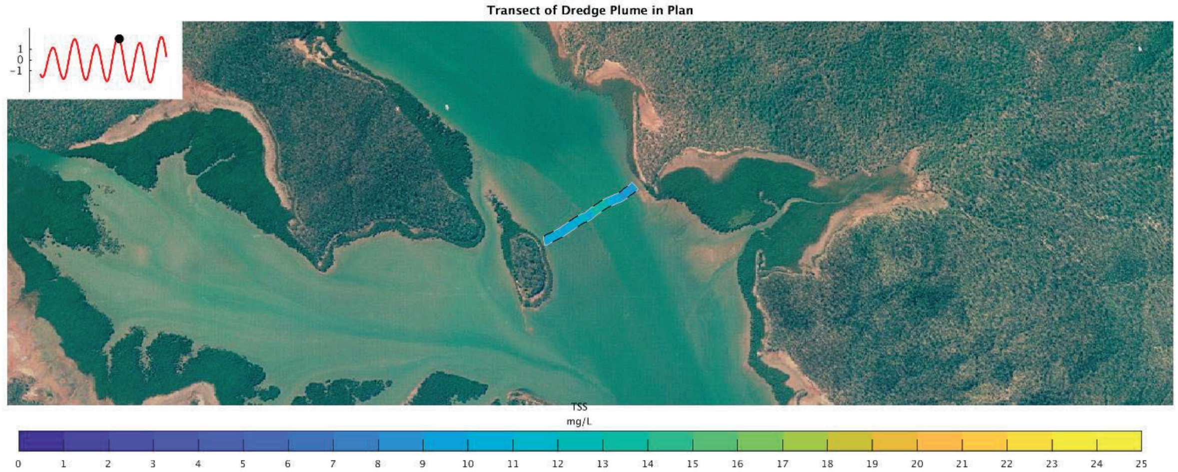
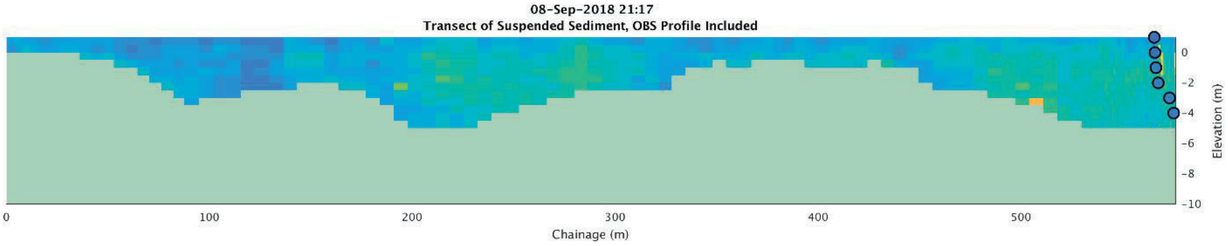
Transect of Suspended Sediment in Profile


Transect of Dredge Plume in Plan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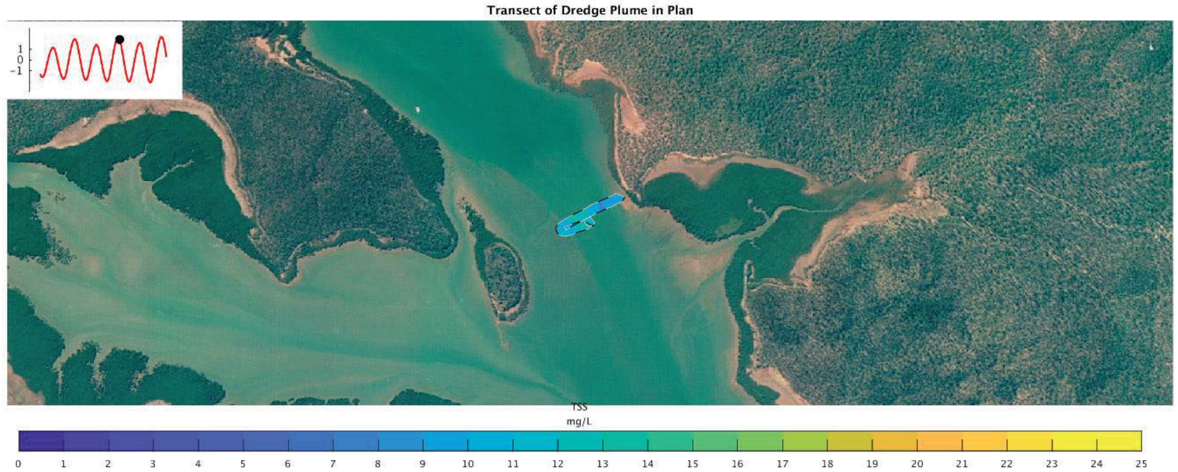
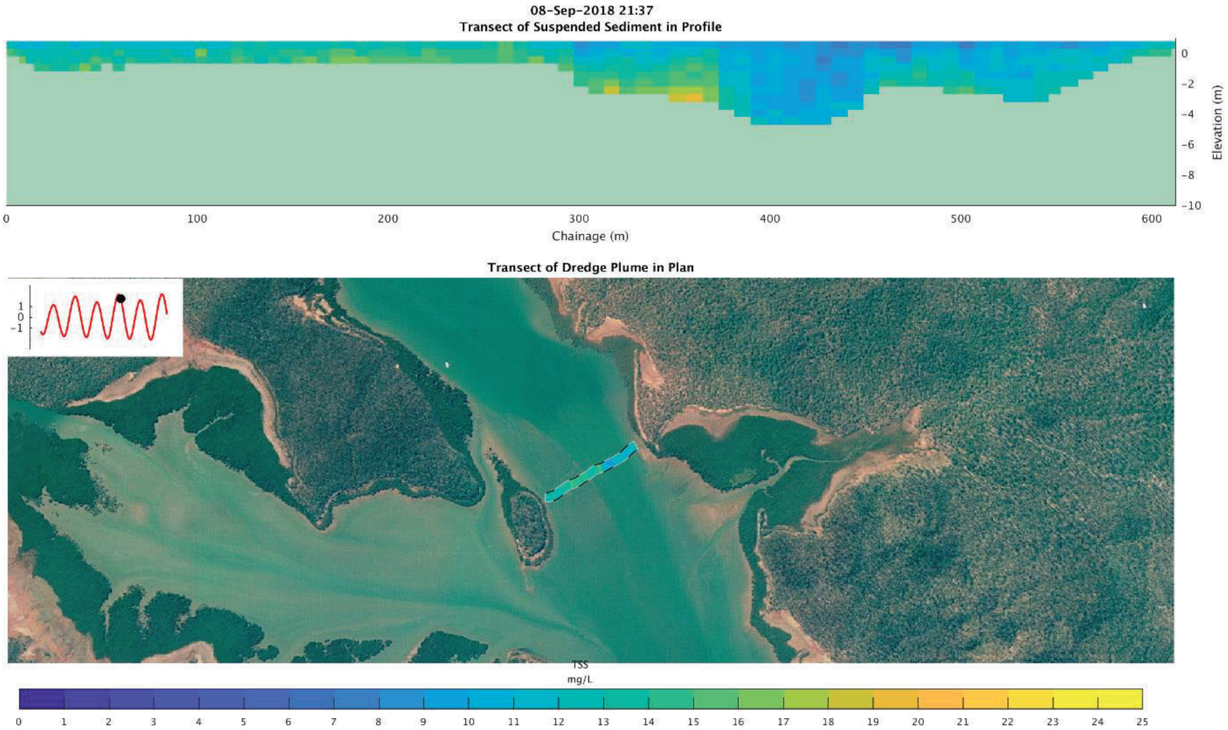
Transect of Suspended Sediment, OBS Profile Included

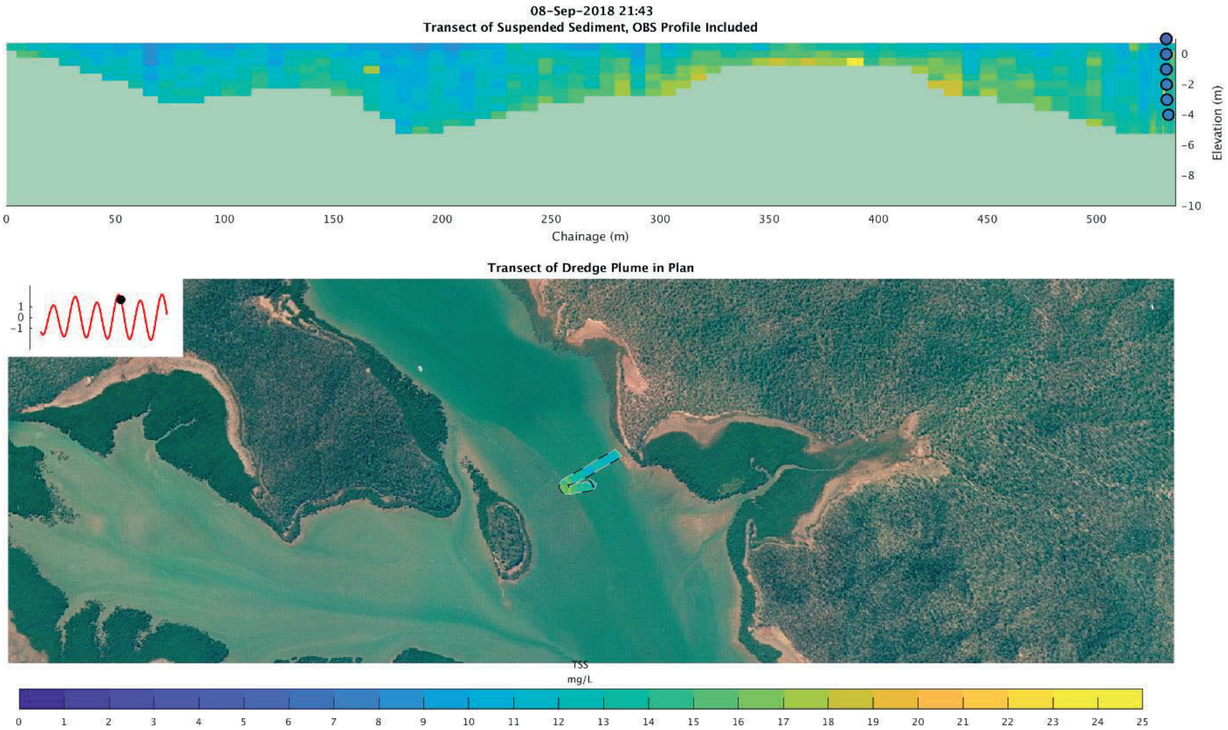

Transect of Dredge Plume in Plan



08-Sep-2018 21:37

Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan



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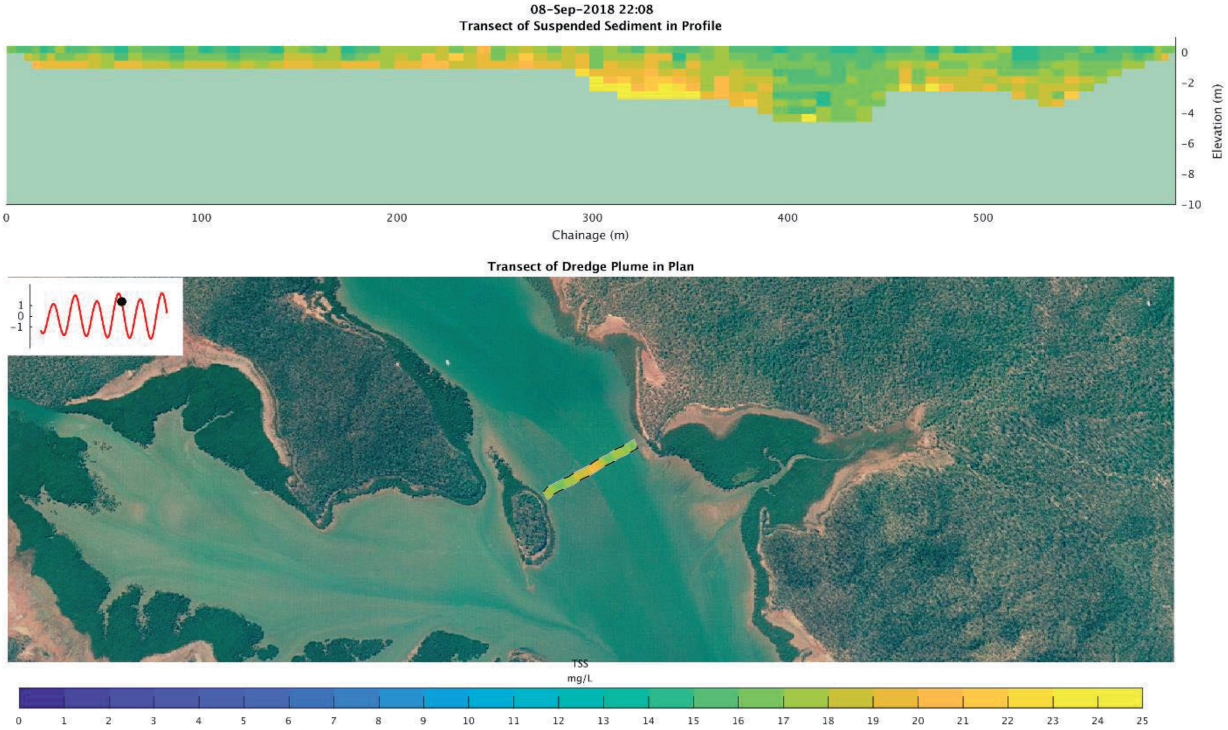
Transect of Suspended Sediment, OBS Profile Included

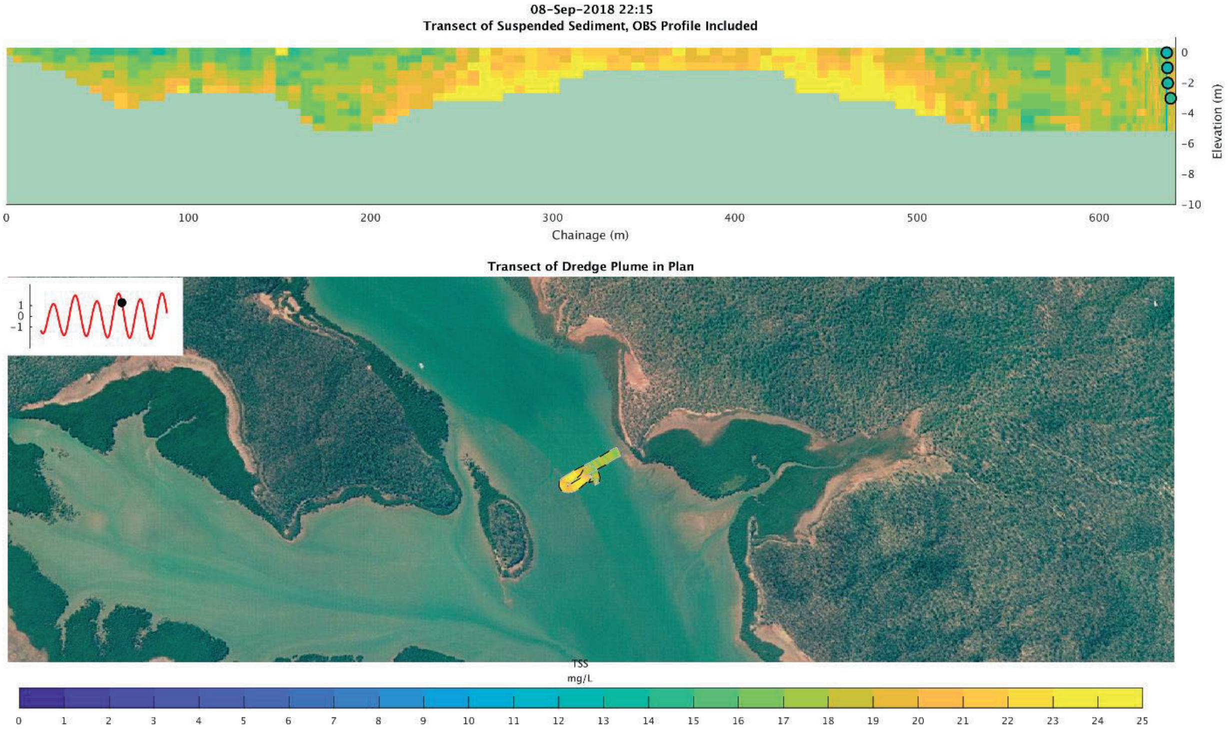
Transect of Dredge Plume in Plan



08-Sep-2018 22:08

Transect of Suspended Sediment in Profile

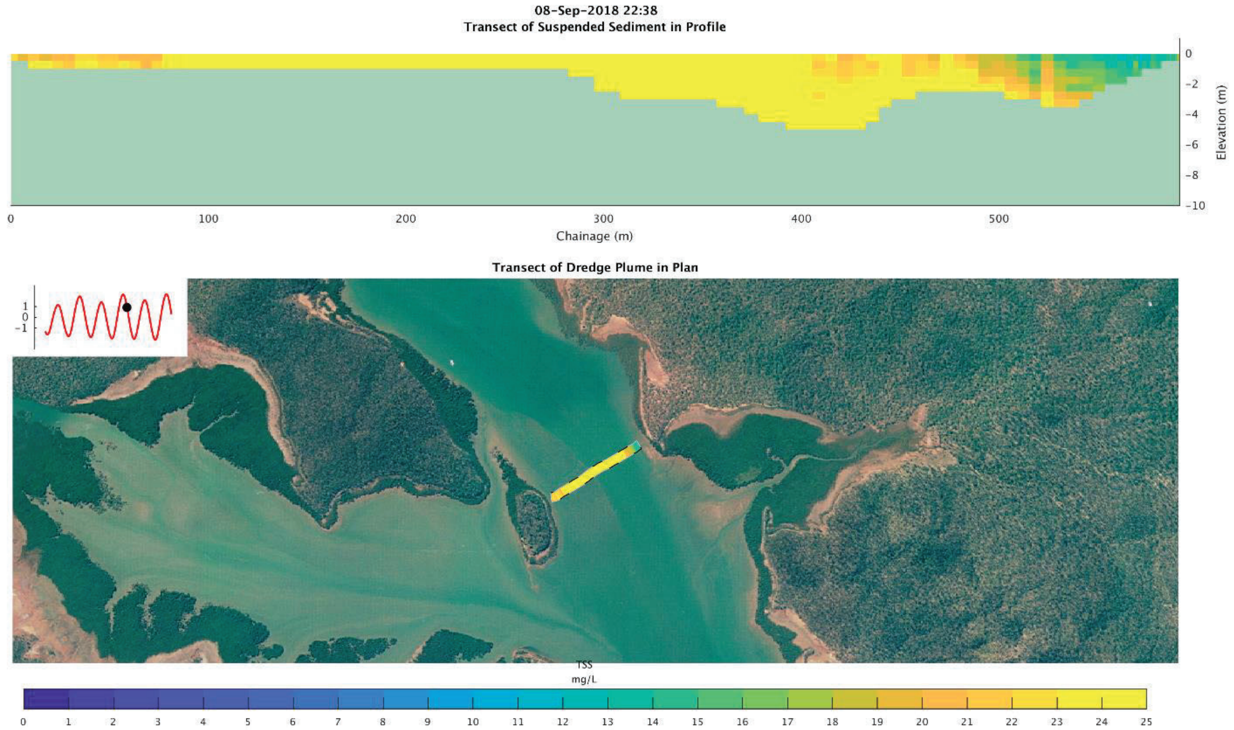
Transect of Dredge Plume in Plan



08-Sep-2018 22:15

Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan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Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
100
200
300
400
500
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
8
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10
11
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20
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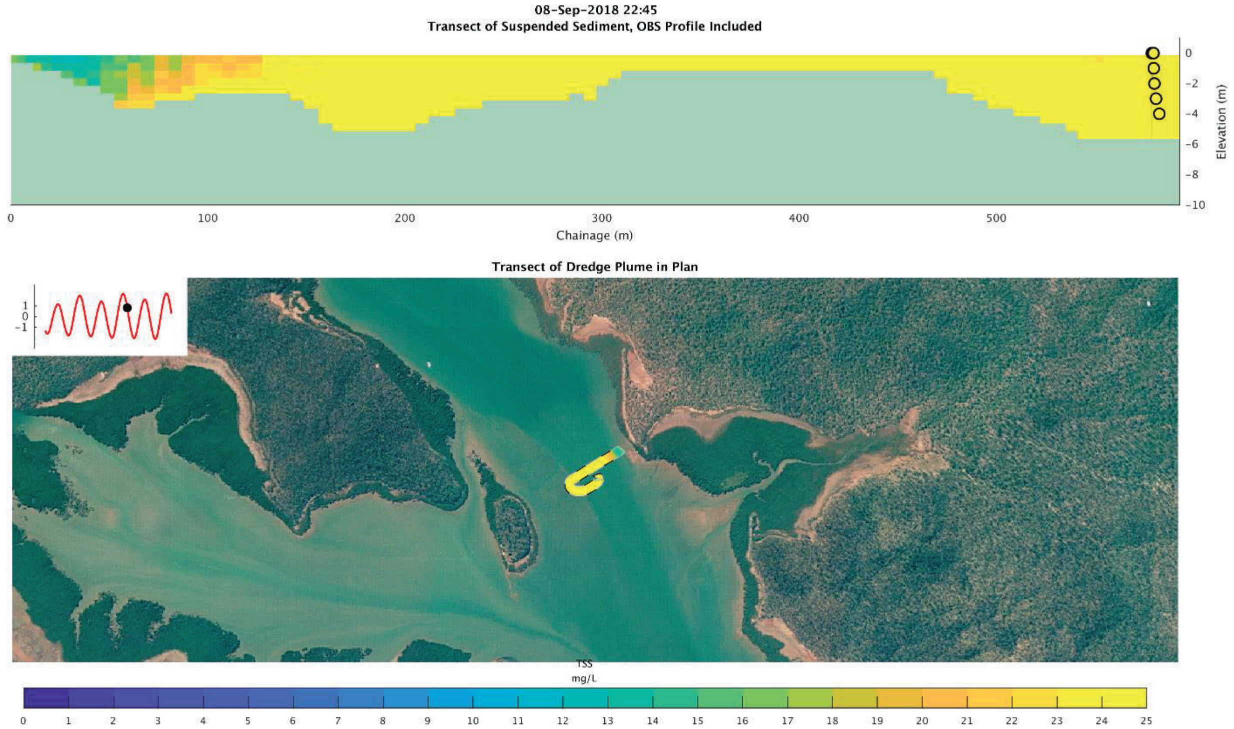
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Transect of Suspended Sediment, OBS Profile Included
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-2
-4
-6
-8
-10
Elevation (m)
0
100
200
300
400
500
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
8
9
10
11
12
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24
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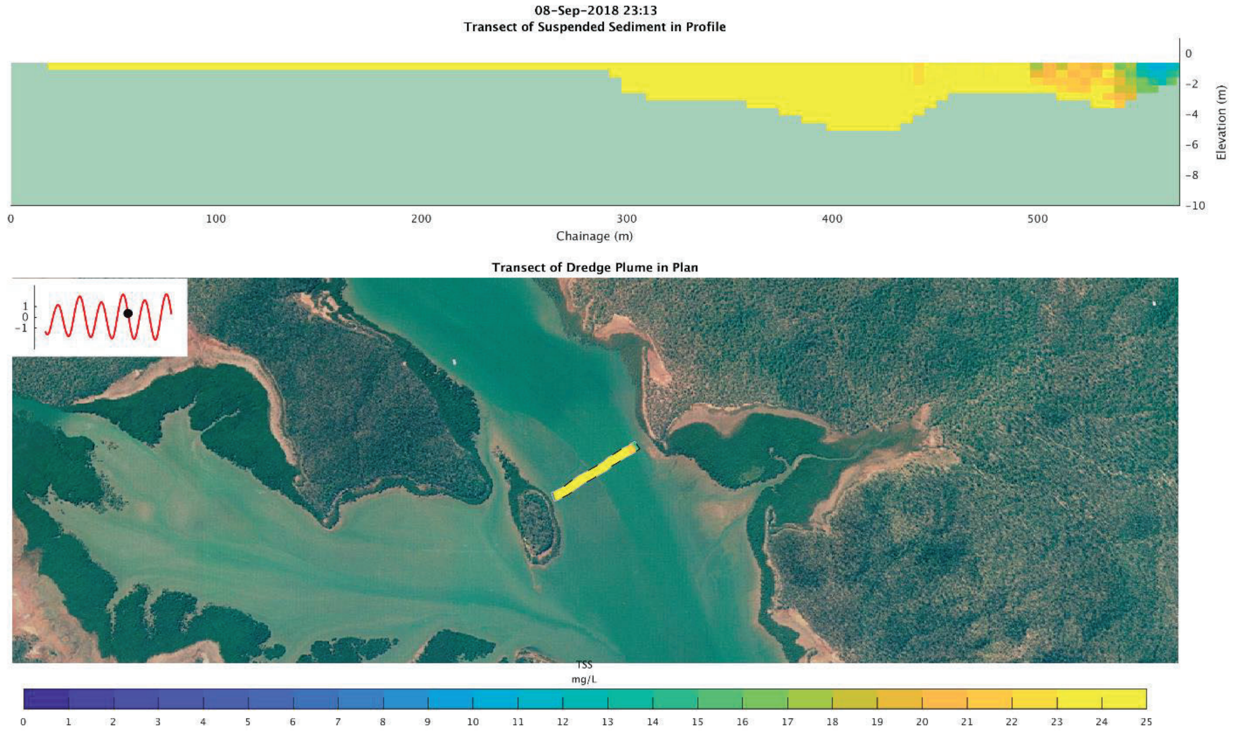
08-Sep-2018 23:13
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
100
200
300
400
500
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
8
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10
11
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14
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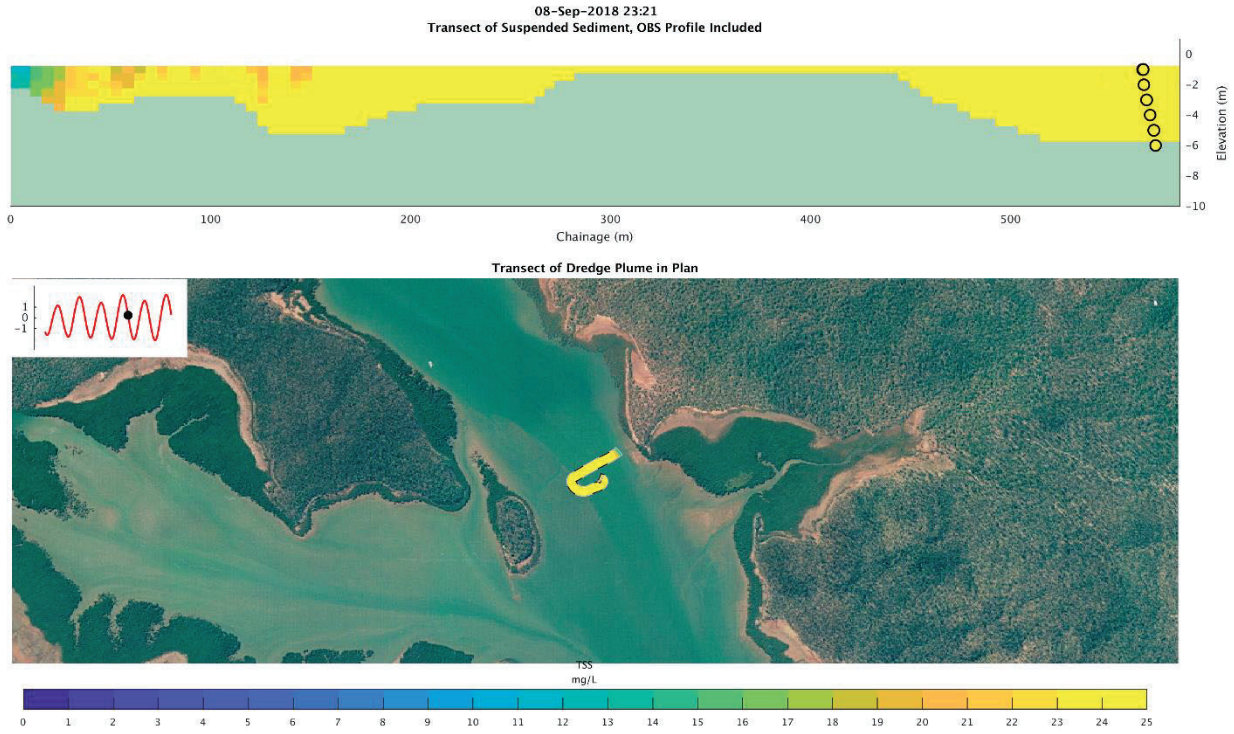
08-Sep-2018 23:21
Transect of Suspended Sediment, OBS Profile Included
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-2
-4
-6
-8
-10
Elevation (m)
0
100
200
300
400
500
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
8
9
10
11
12
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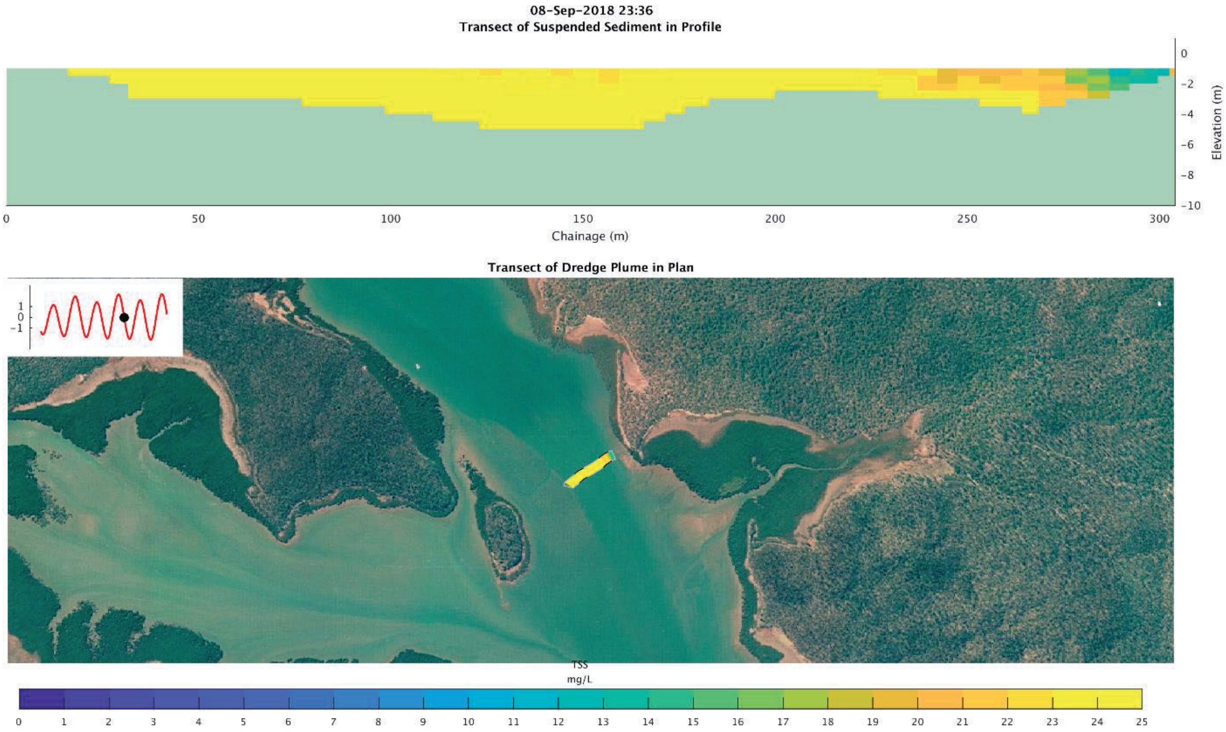
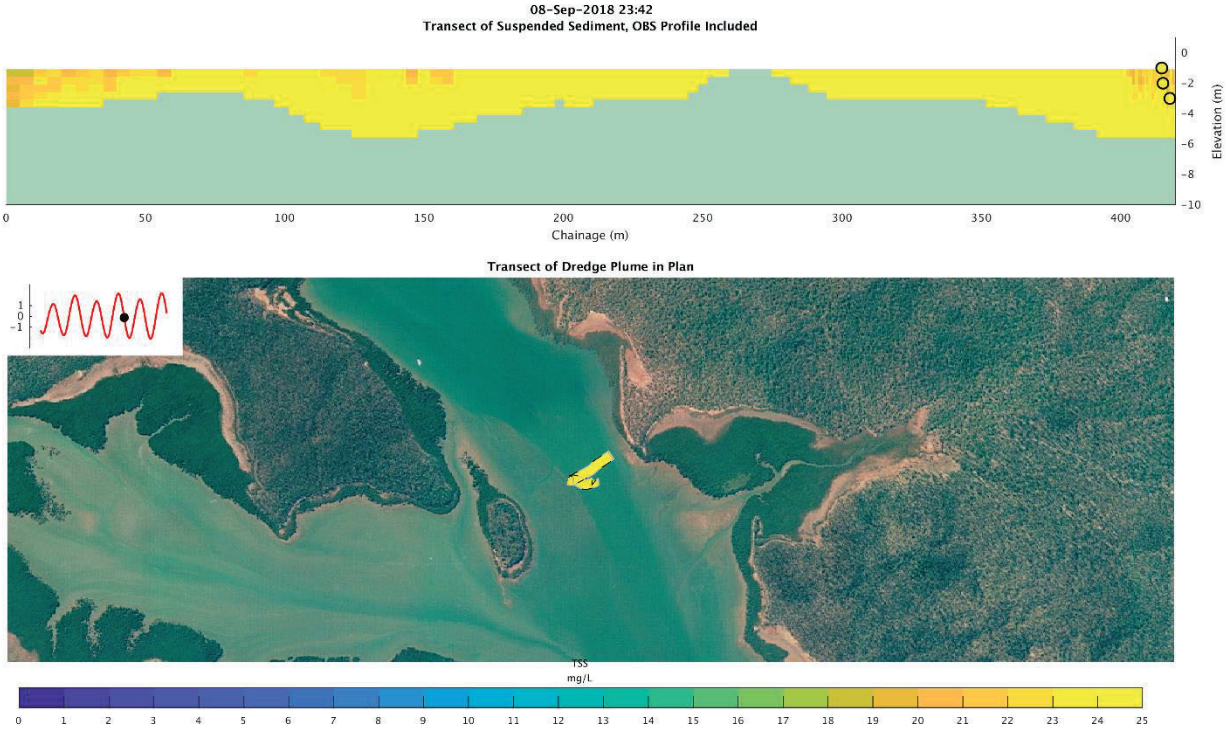


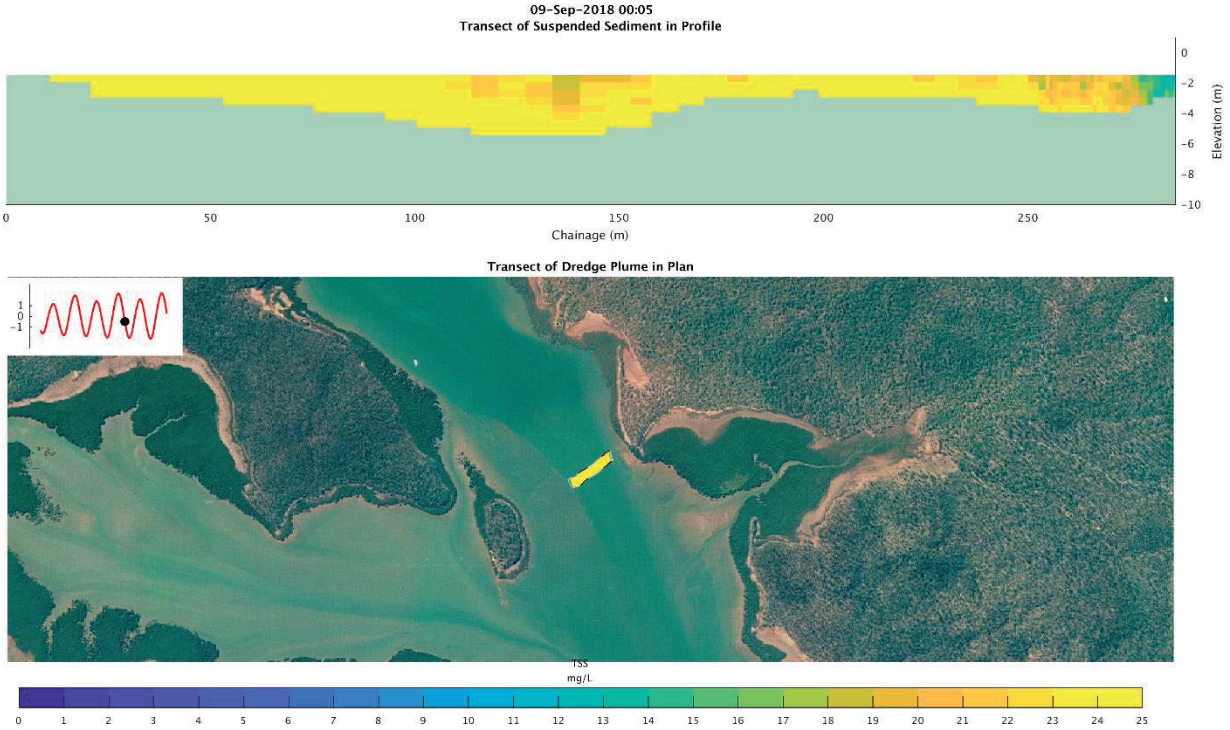
08-Sep-2018 23:36
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan



08-Sep-2018 23:42
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan


09-Sep-2018 00:05
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
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17
18
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24
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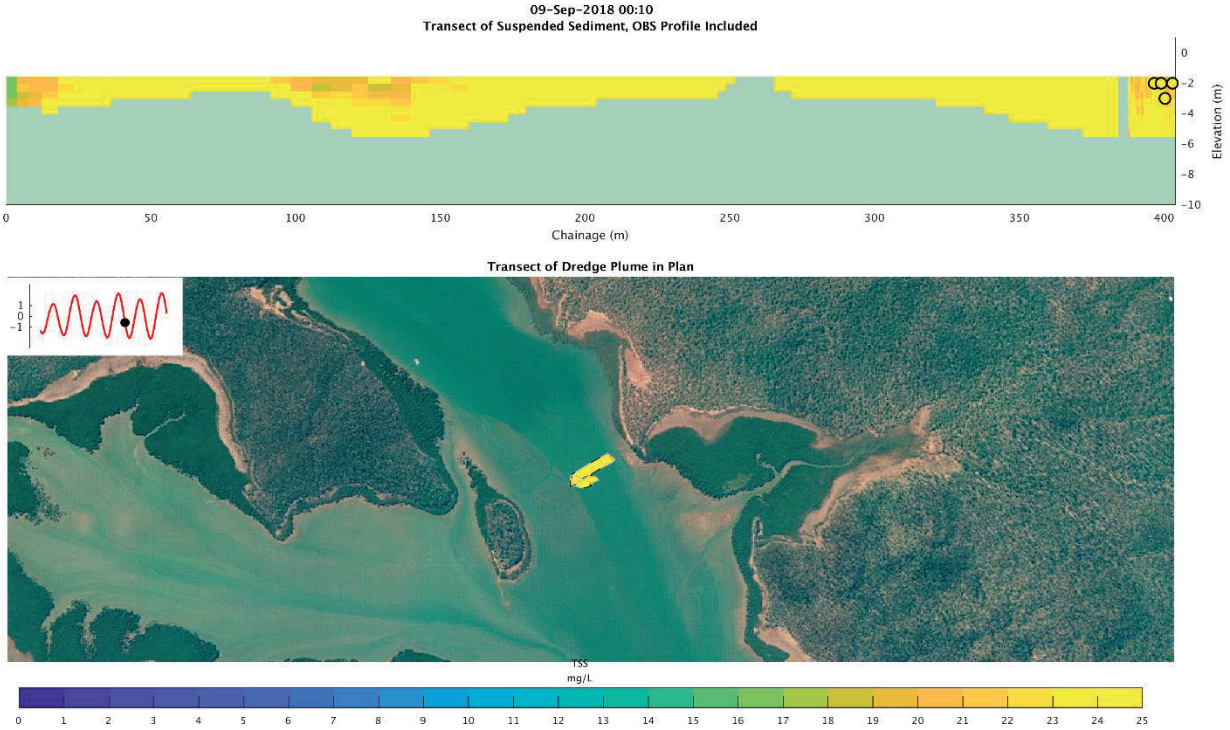
09-Sep-2018 00:10
Transect of Suspended Sediment, OBS Profile Included
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-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
300
350
400
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
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9
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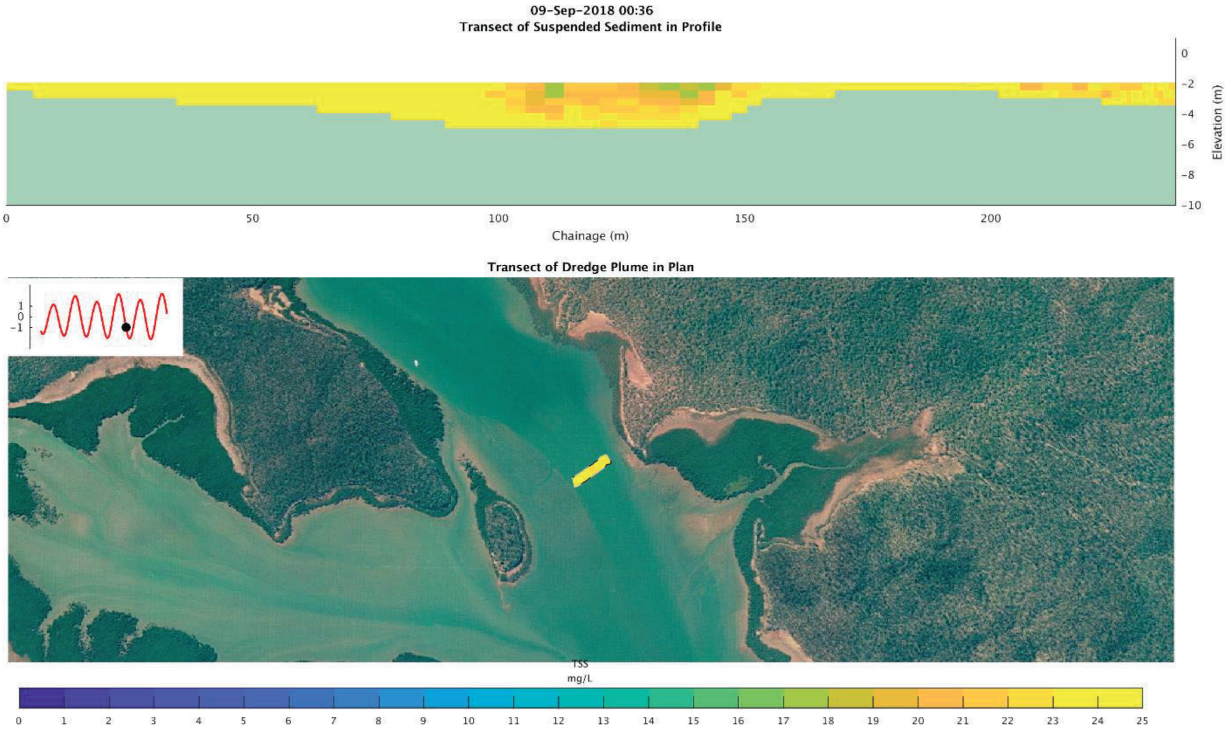
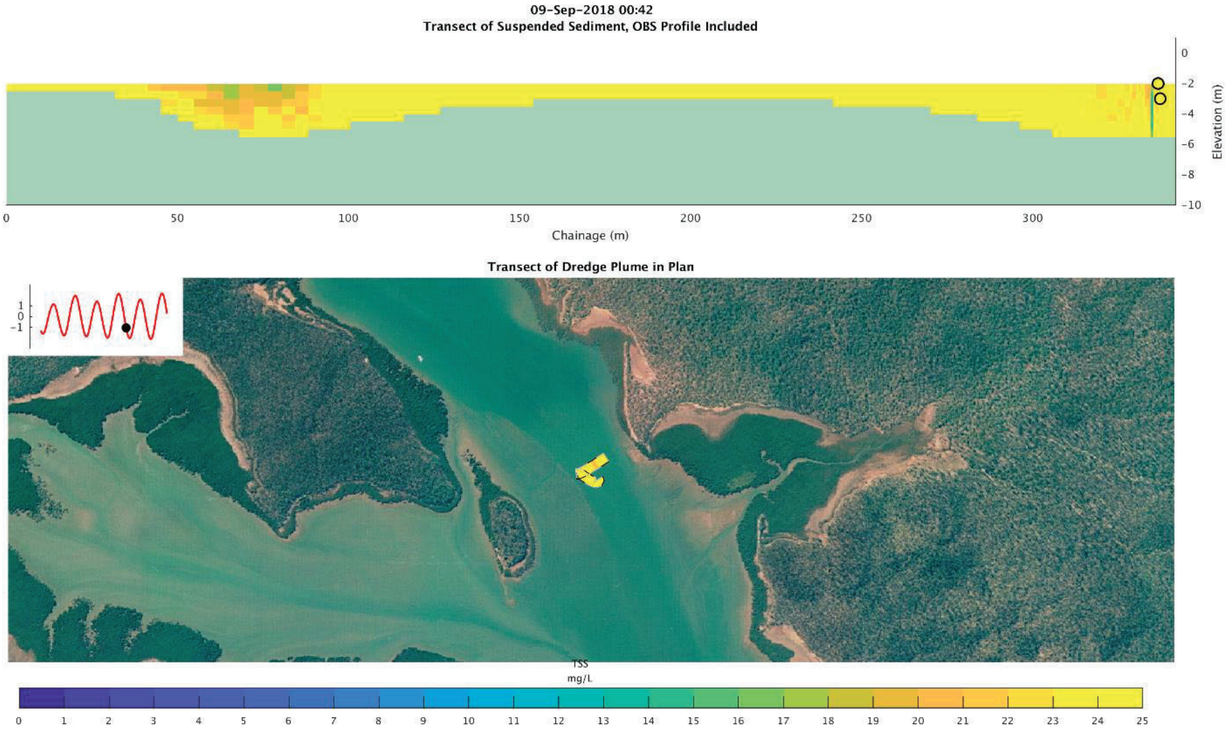


09-Sep-2018 00:36

Transect of Suspended Sediment in Profile

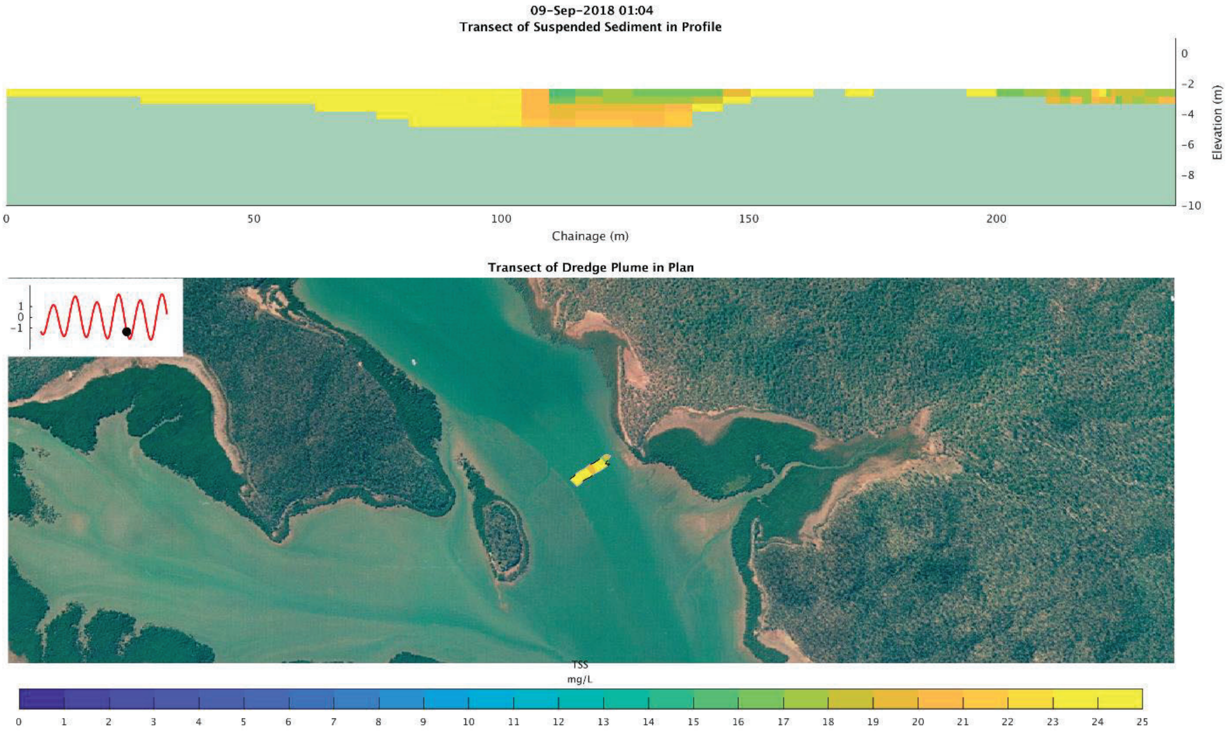
Transect of Dredge Plume in Plan



09-Sep-2018 00:42

Transect of Suspended Sediment, OBS Profile Included

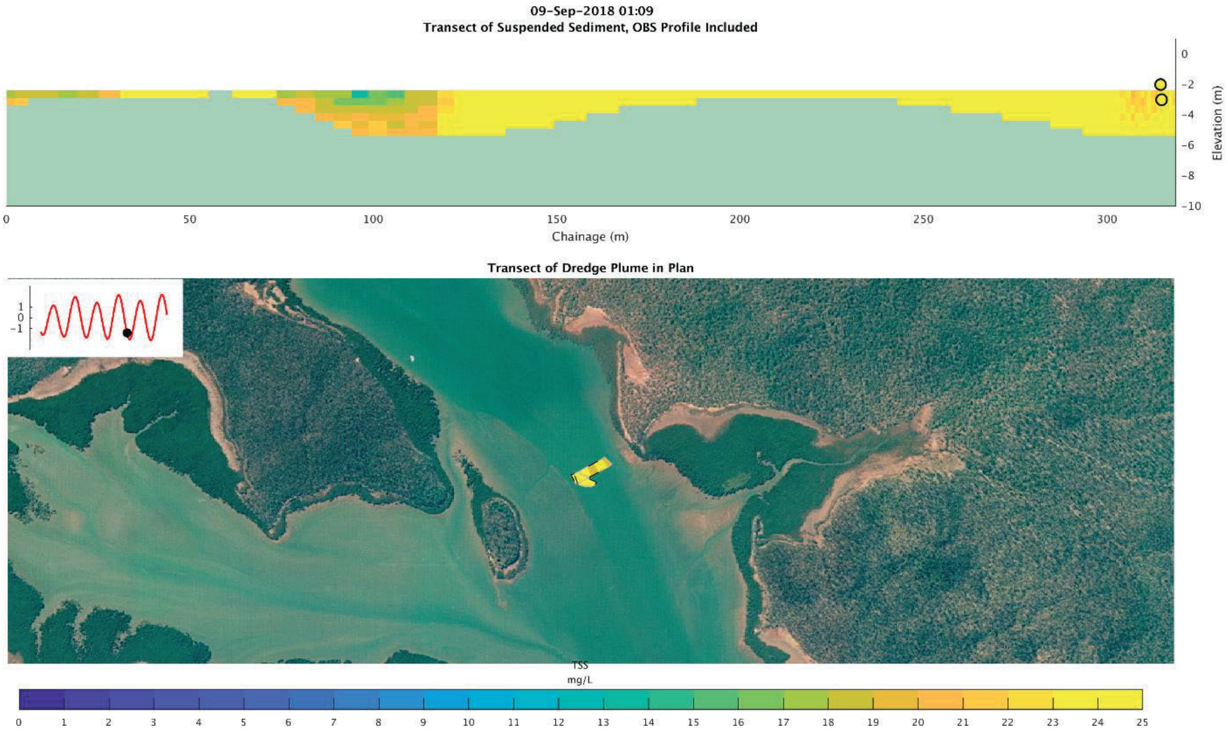
Transect of Dredge Plume in Plan



09-Sep-2018 01:04

Transect of Suspended Sediment in Profile

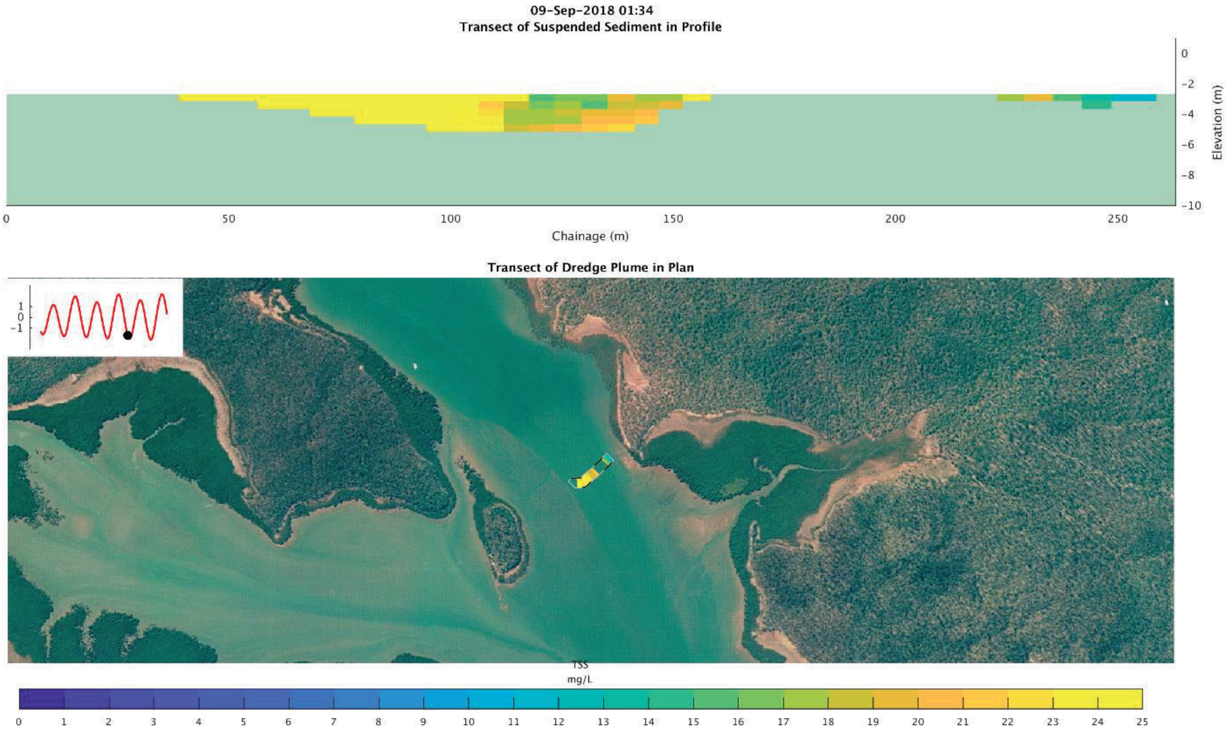
Transect of Dredge Plume in Plan



09-Sep-2018 01:09

Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan


09-Sep-2018 01:34
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
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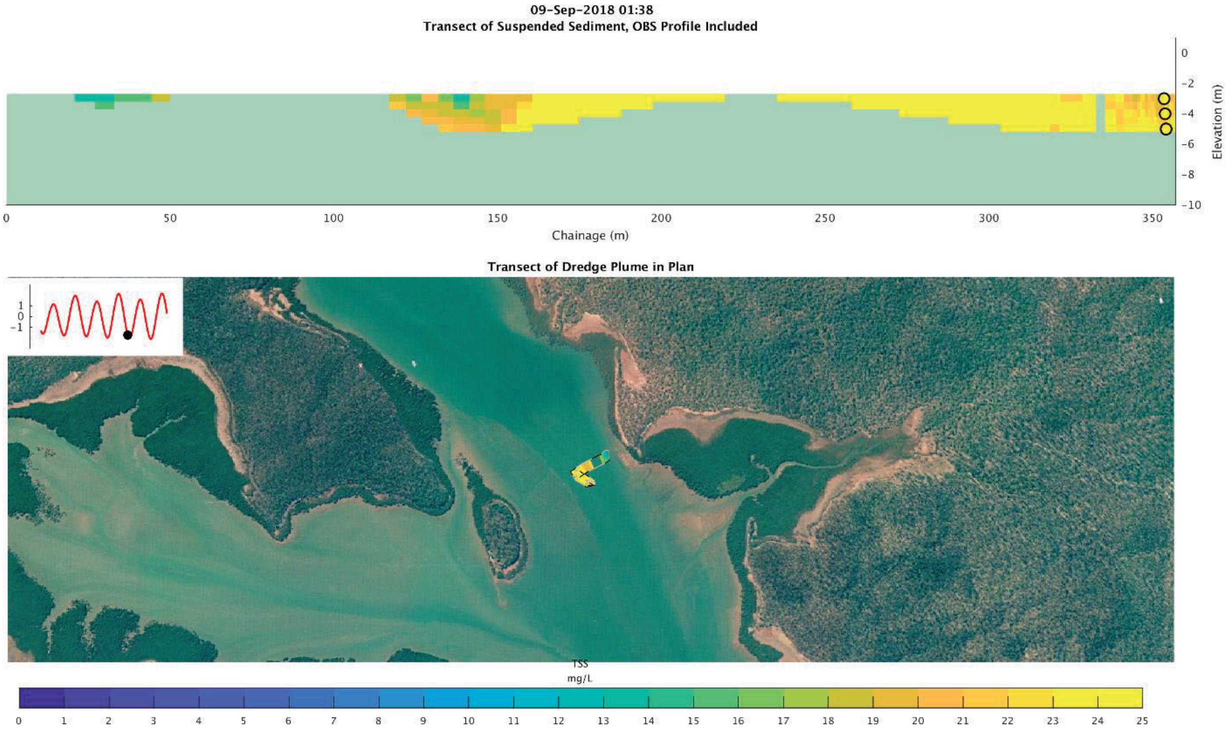
09-Sep-2018 01:38
Transect of Suspended Sediment, OBS Profile Included
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
300
350
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
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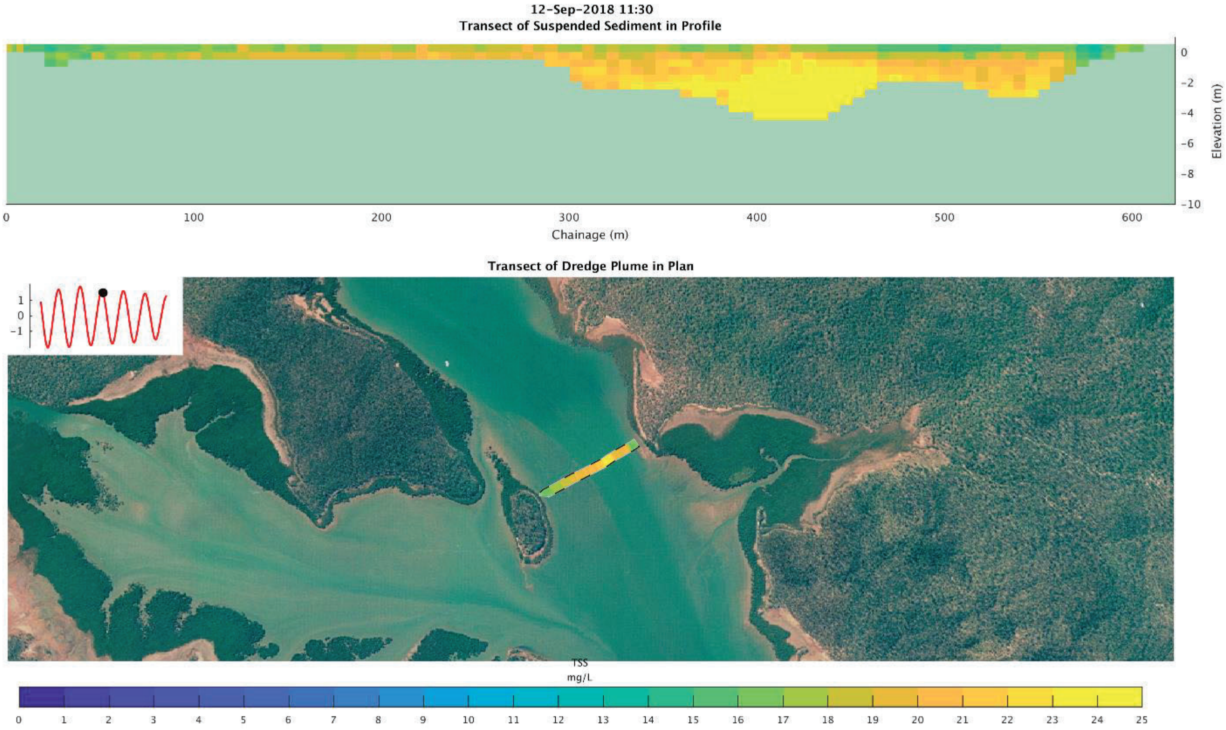
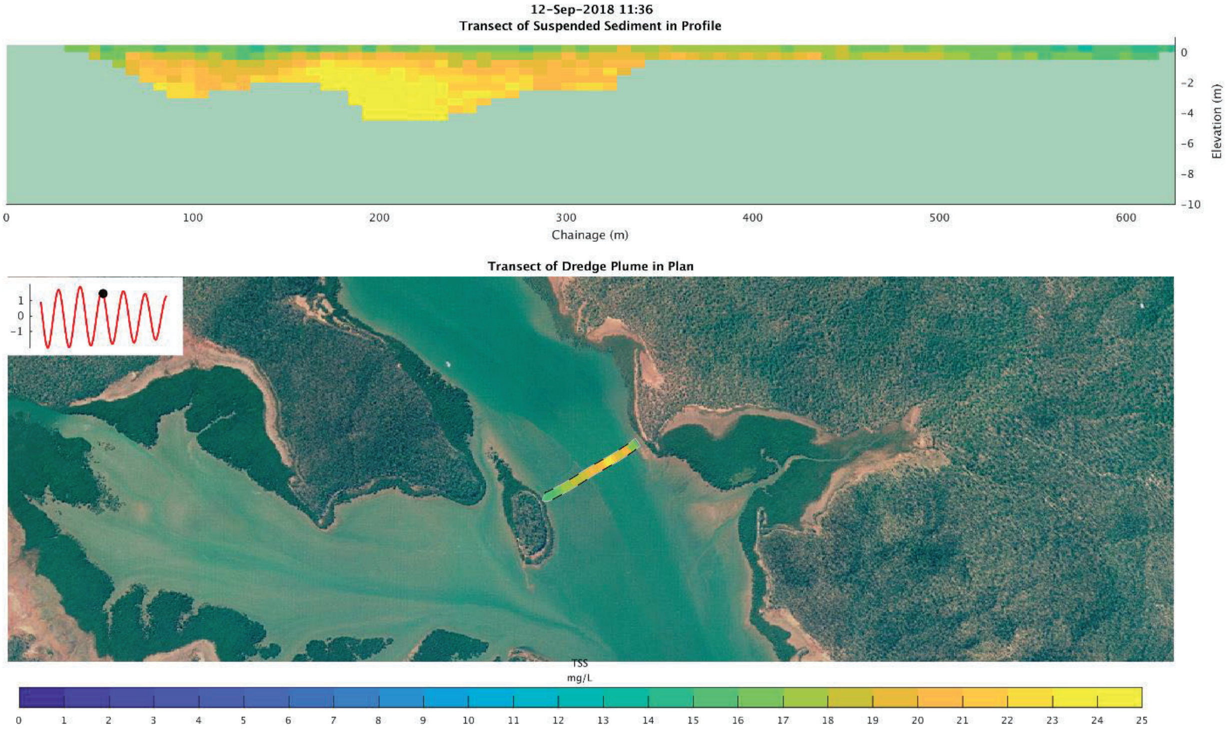
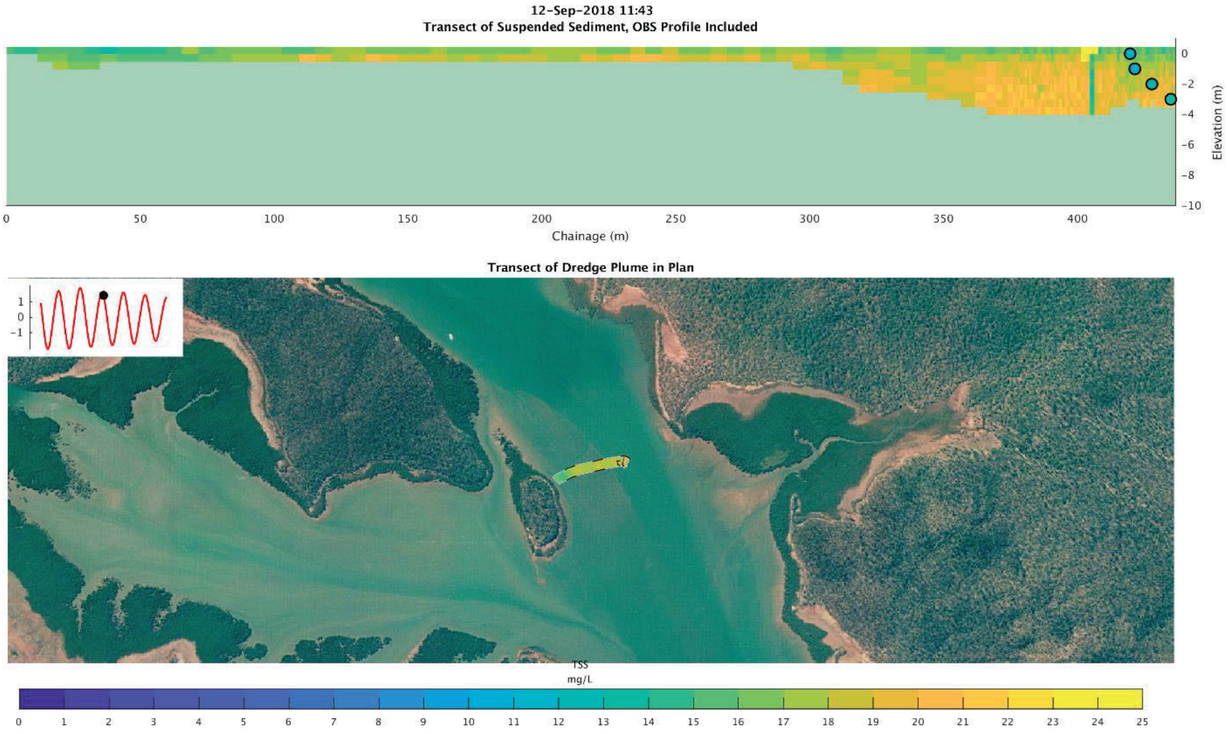
Transect C – The Narrows– Average Tide



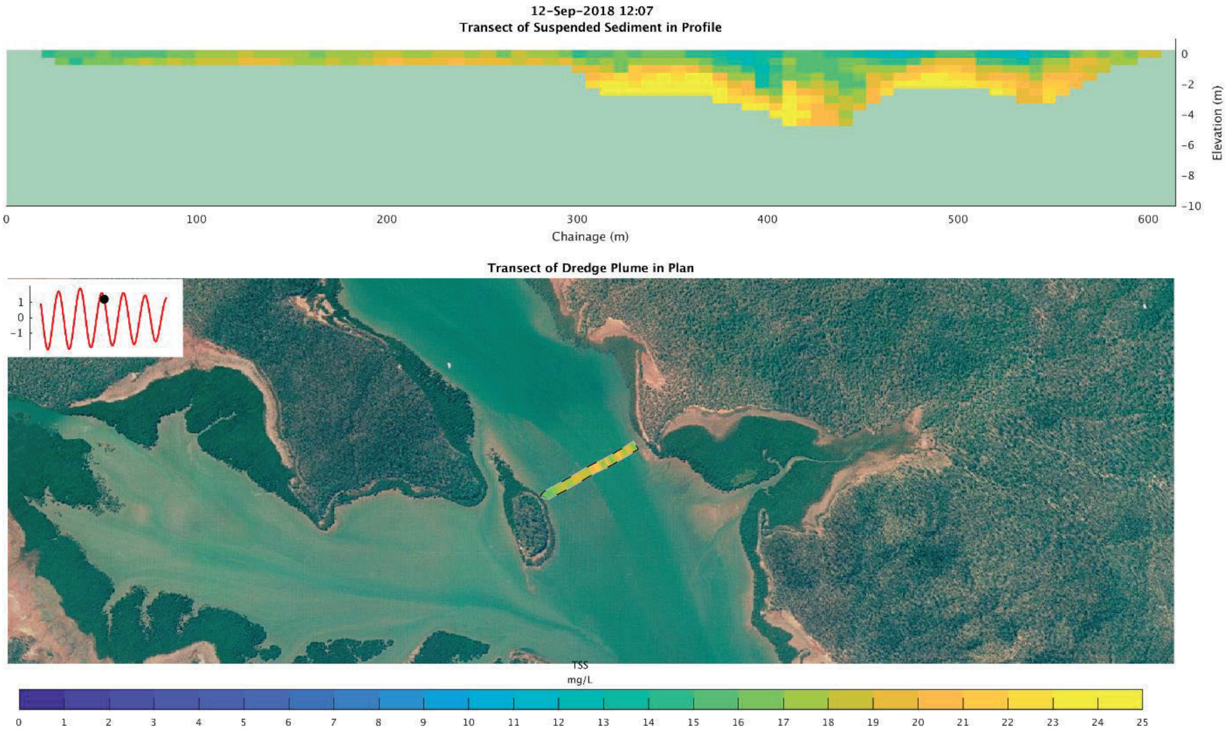




12-Sep-2018 11:43

Transect of Suspended Sediment, OBS Profile Included

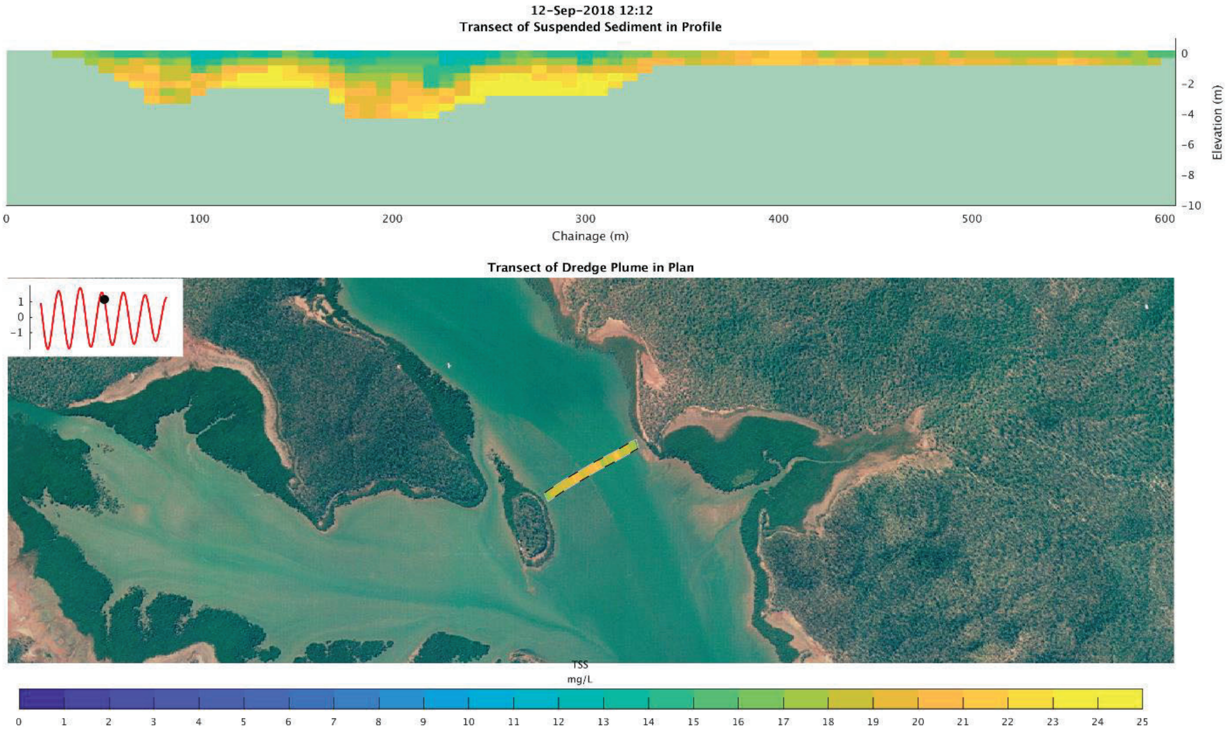
Transect of Dredge Plume in Plan

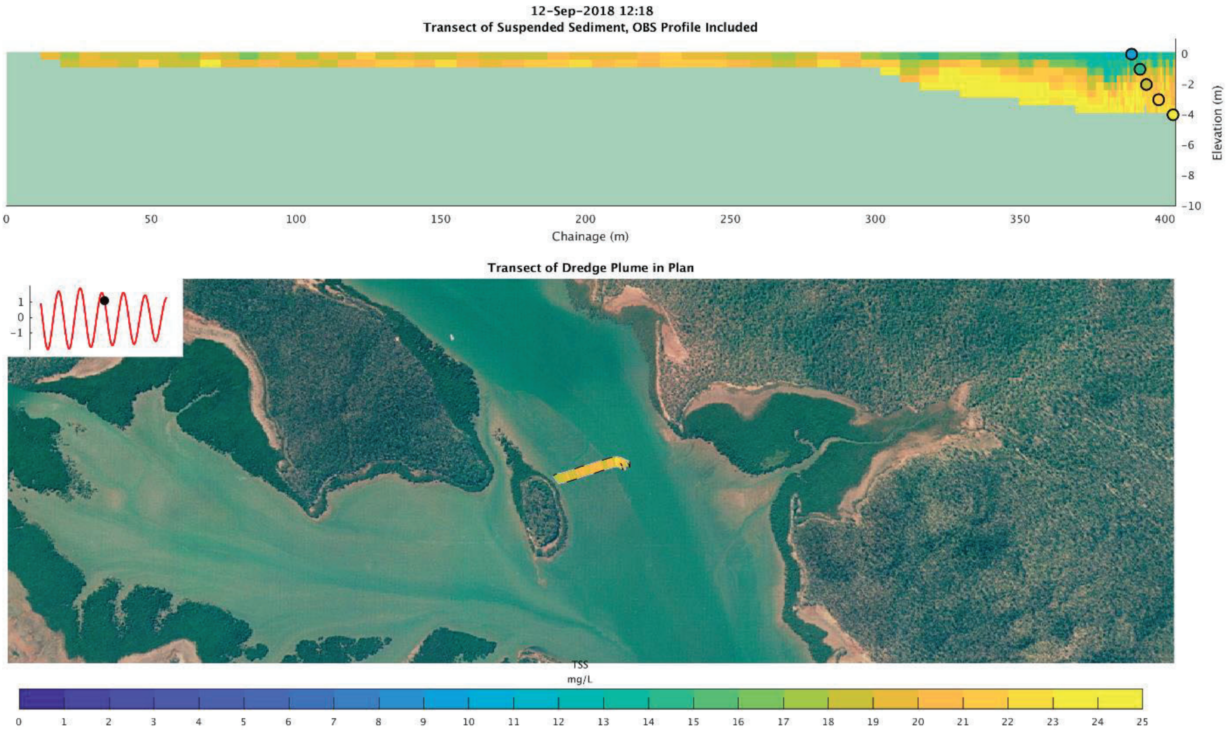


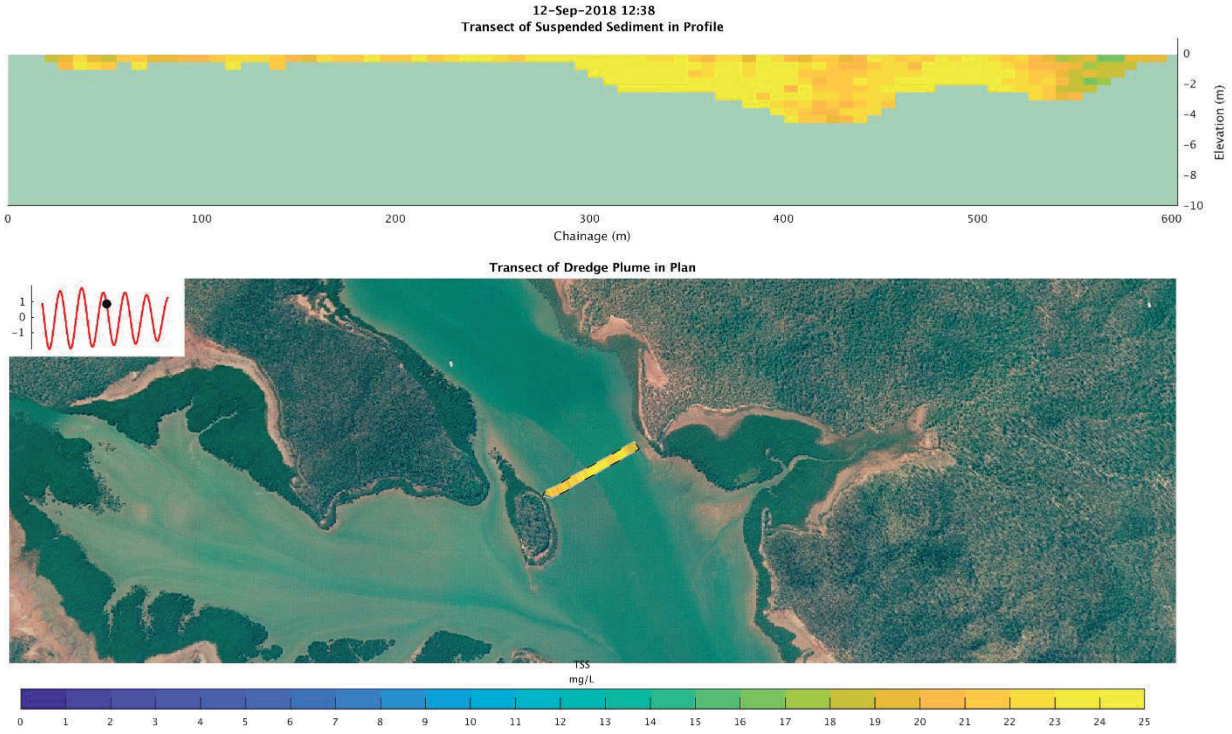
12-Sep-2018 12:07

Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan


12-Sep-2018 12:12
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
100
200
300
400
500
600
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25


12-Sep-2018 12:18
Transect of Suspended Sediment, OBS Profile Included
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
300
350
400
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25


12-Sep-2018 12:38
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
100
200
300
400
500
600
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
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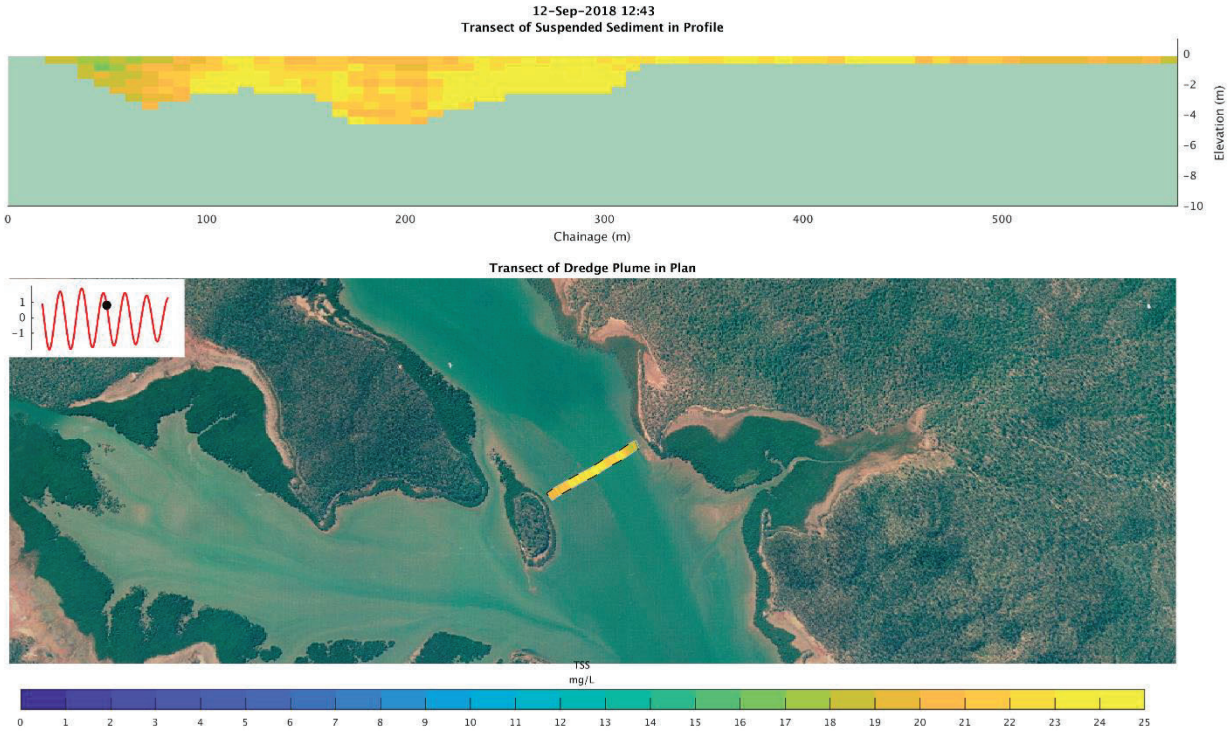
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Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
100
200
300
400
500
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
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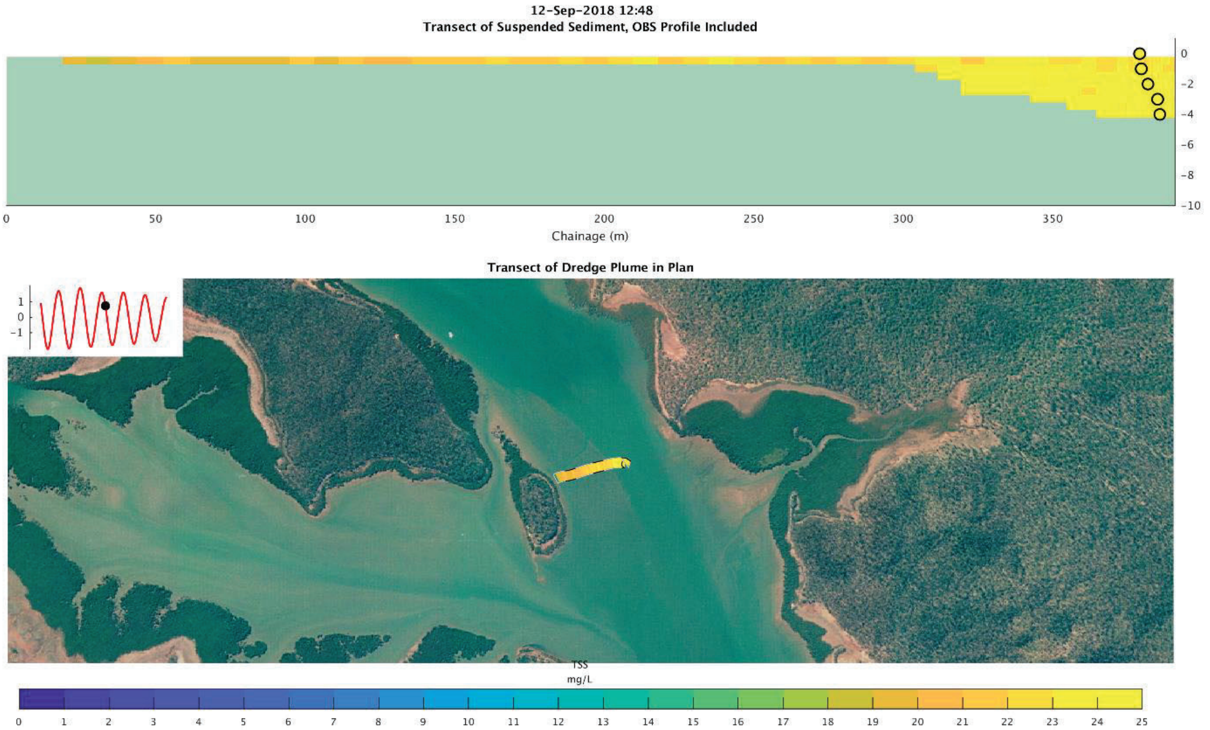
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-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
300
350
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
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4
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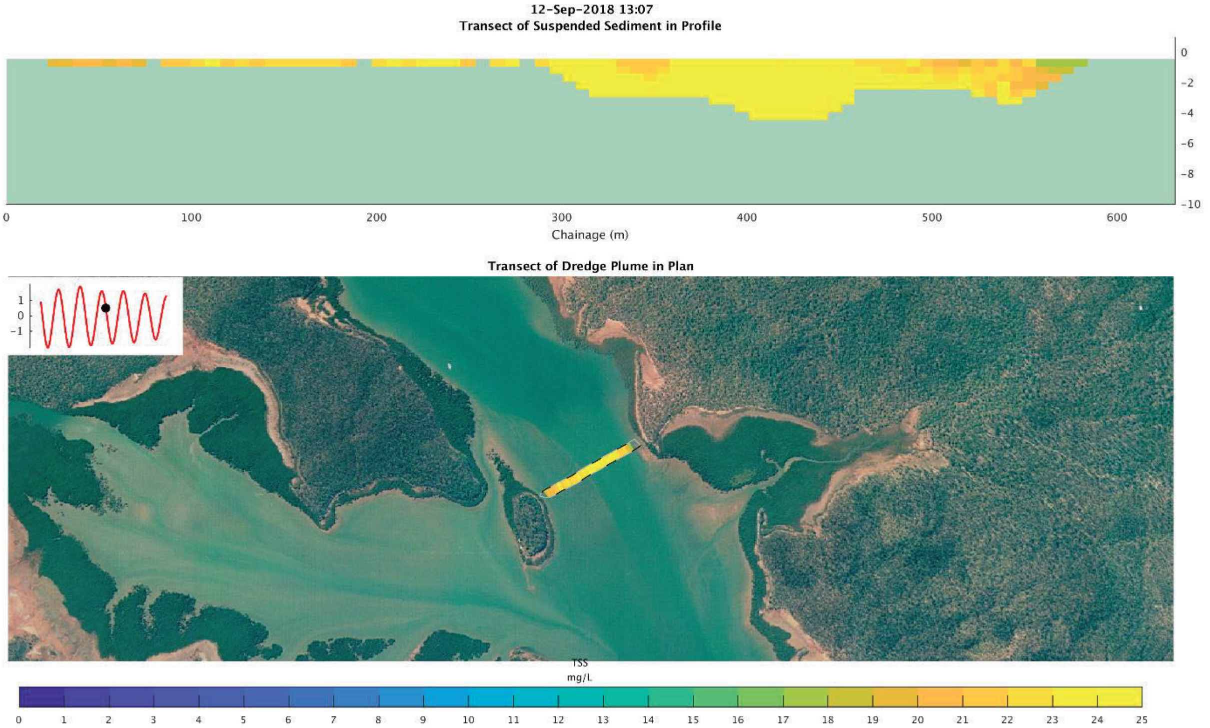
12-Sep-2018 13:07
Transect of Suspended Sediment in Profile
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-6
-8
-10
Elevation (m)
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200
300
400
500
600
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
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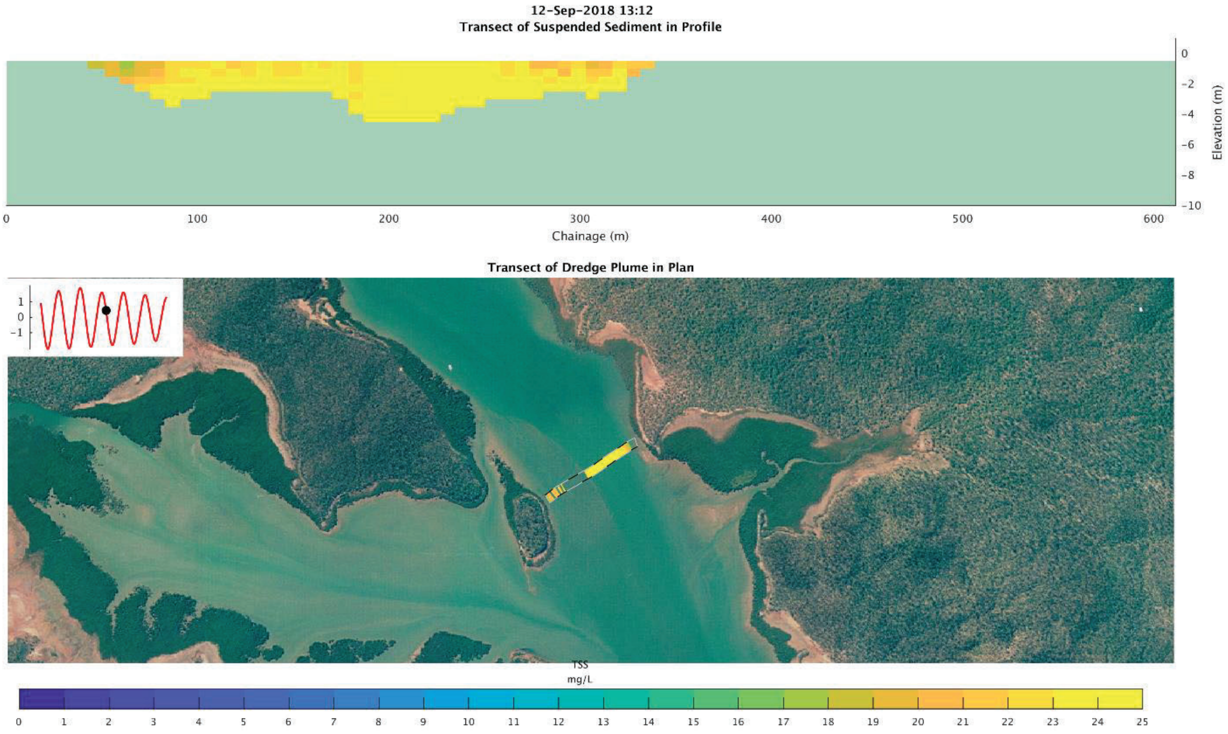
12-Sep-2018 13:12
Transect of Suspended Sediment in Profile
0
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-6
-8
-10
Elevation (m)
0
100
200
300
400
500
600
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
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1
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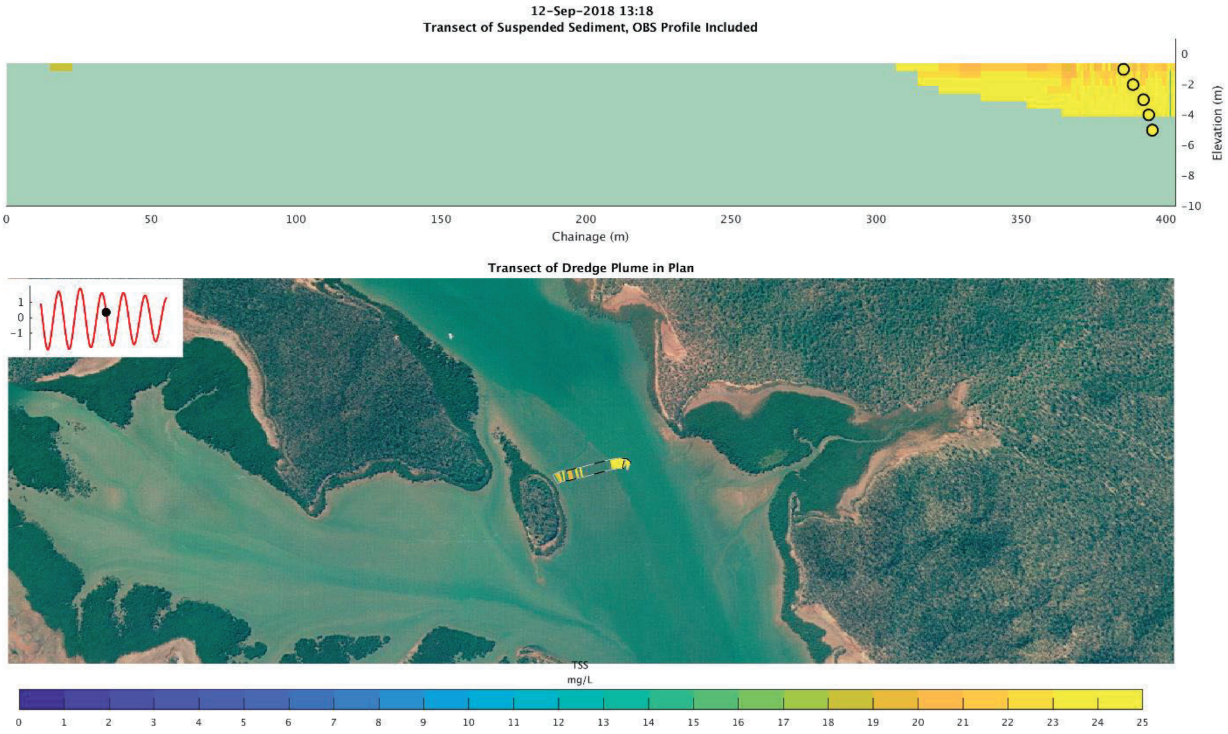
12-Sep-2018 13:18
Transect of Suspended Sediment, OBS Profile Included
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
300
350
400
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
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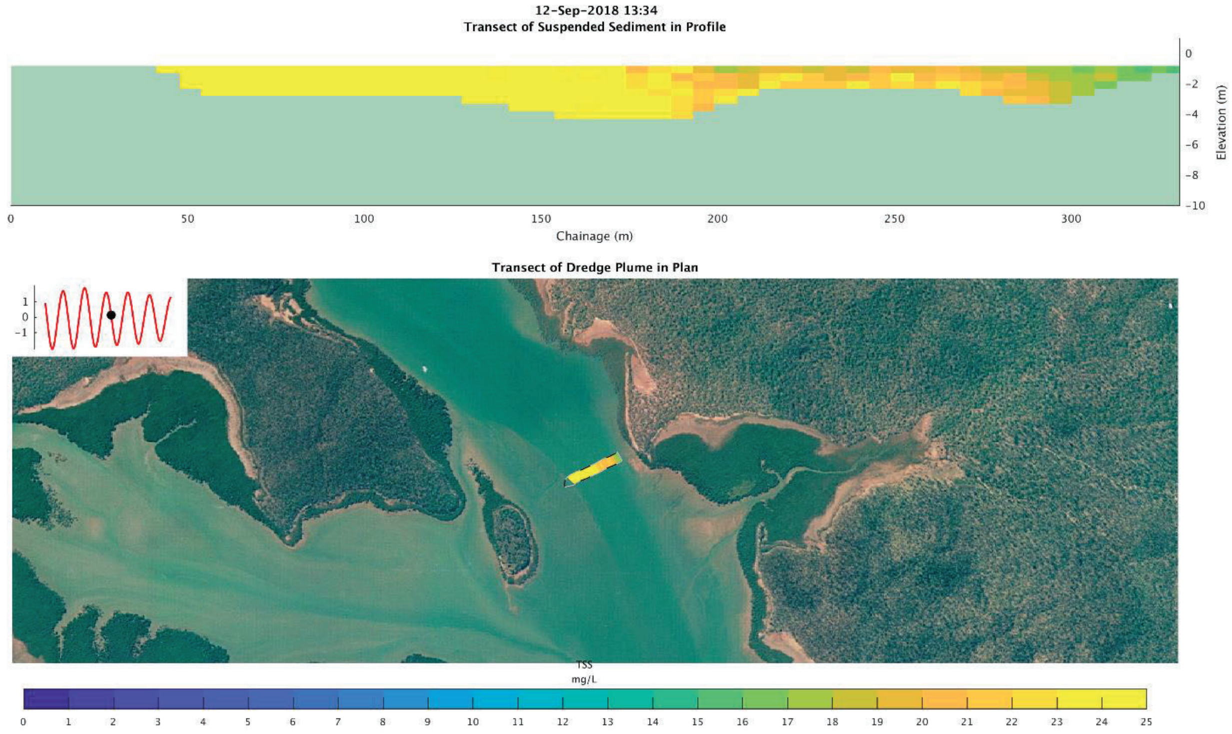
12-Sep-2018 13:34
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
300
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
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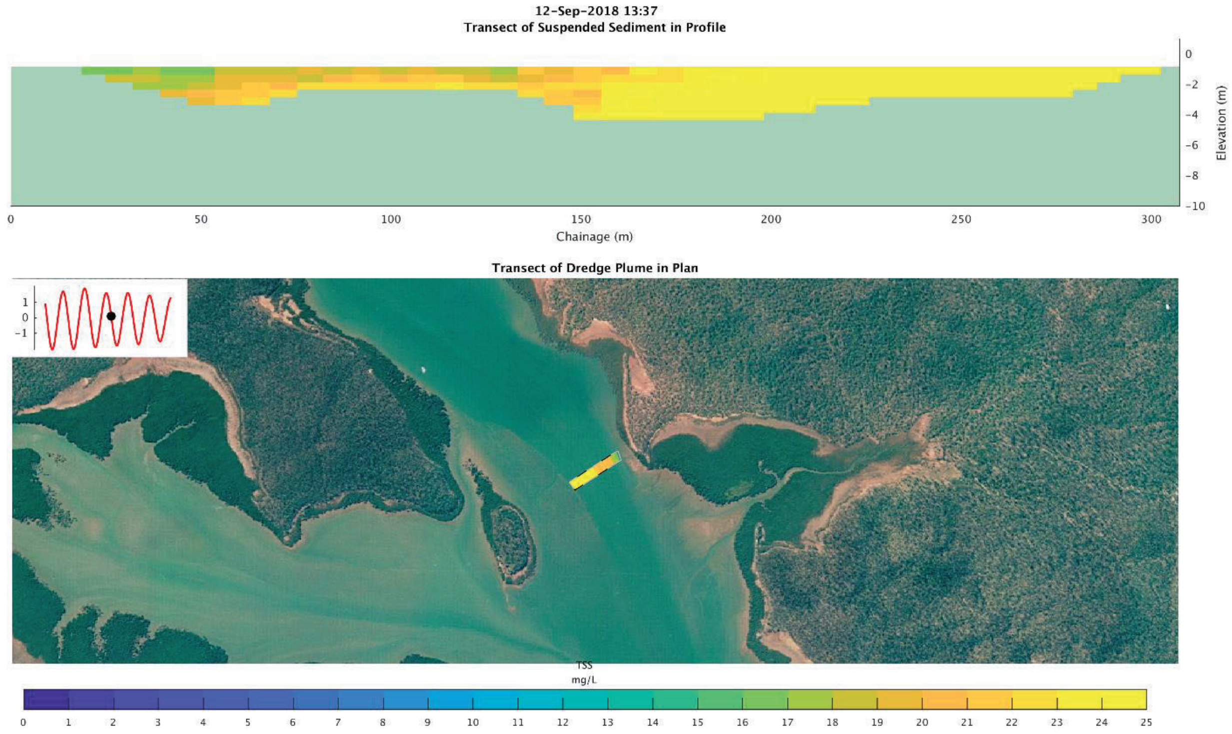
12-Sep-2018 13:37
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
300
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
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4
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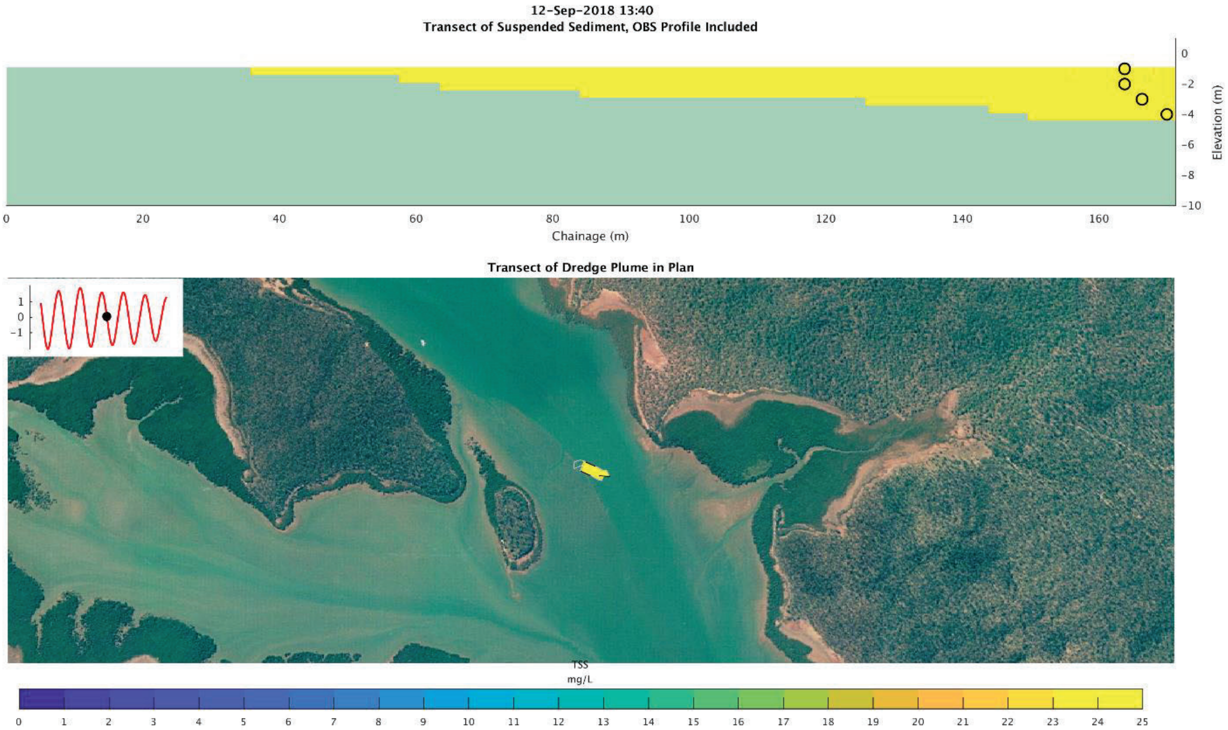
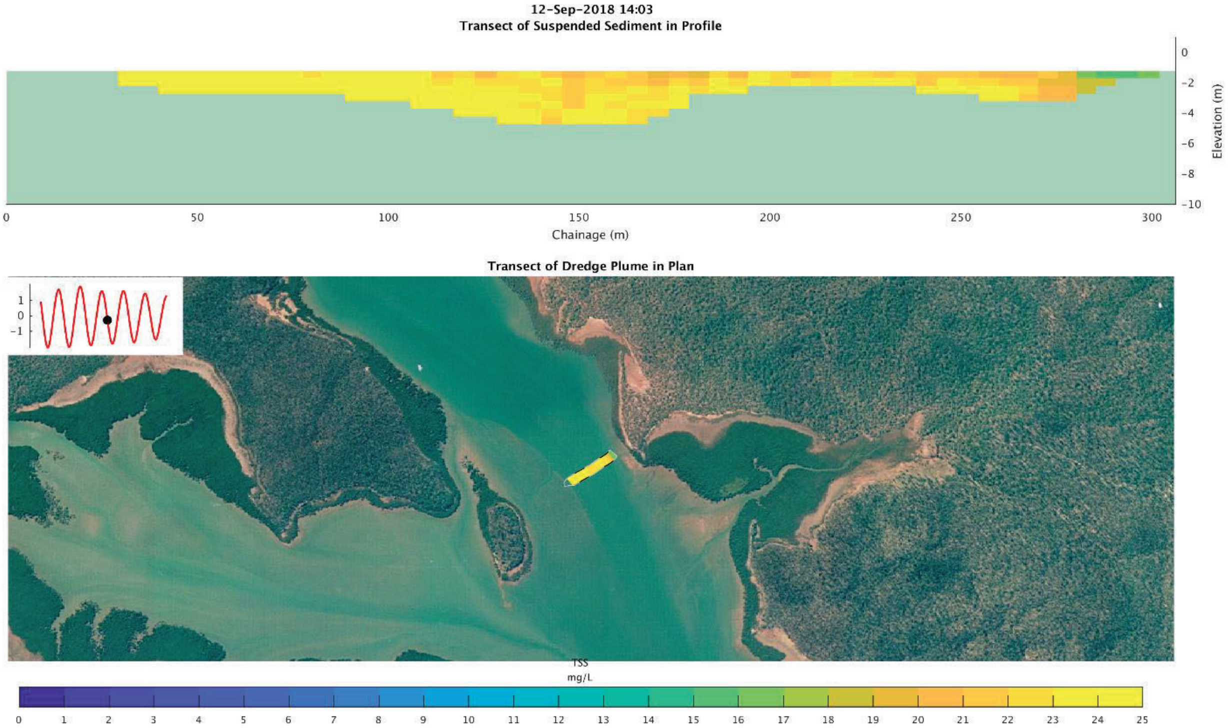


12-Sep-2018 13:40

Transect of Suspended Sediment, OBS Profile Included

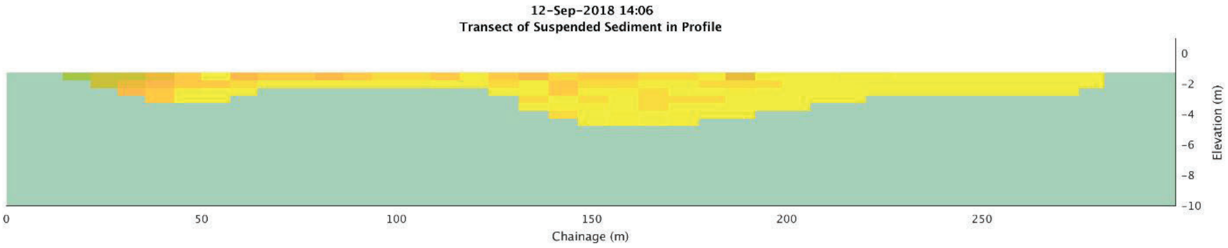
Transect of Dredge Plume in Plan



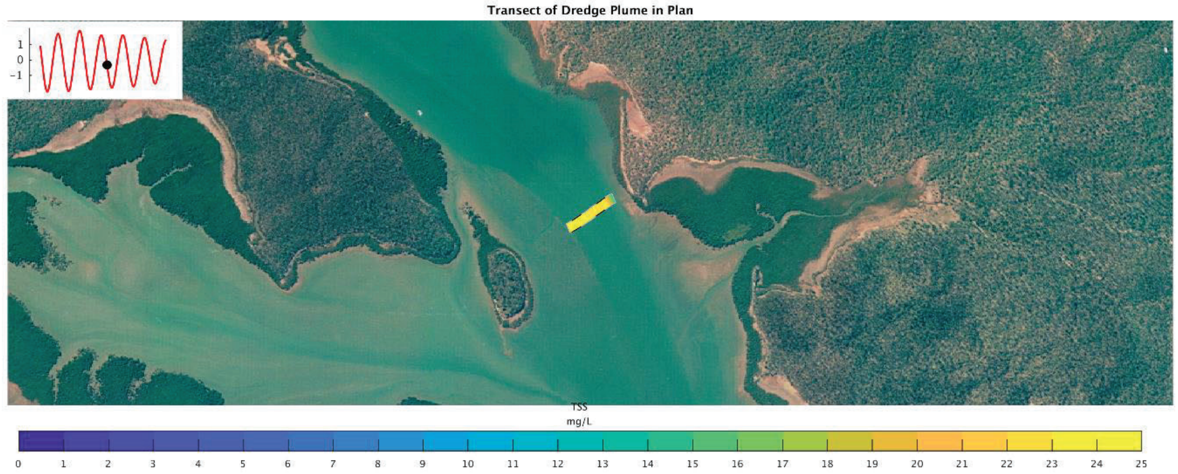
12-Sep-2018 14:03

Transect of Suspended Sediment in Profile

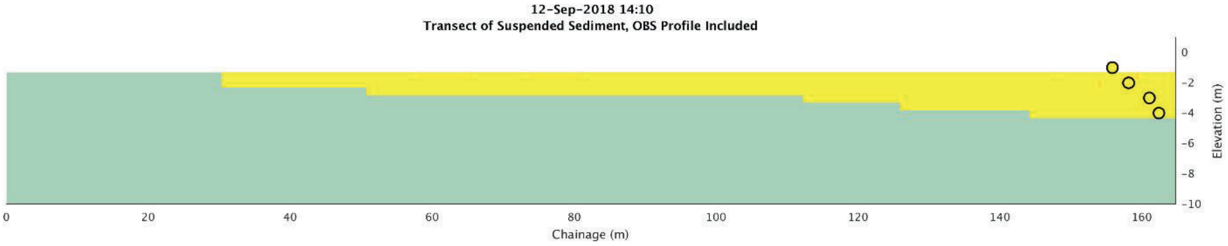
Transect of Dredge Plume in Plan



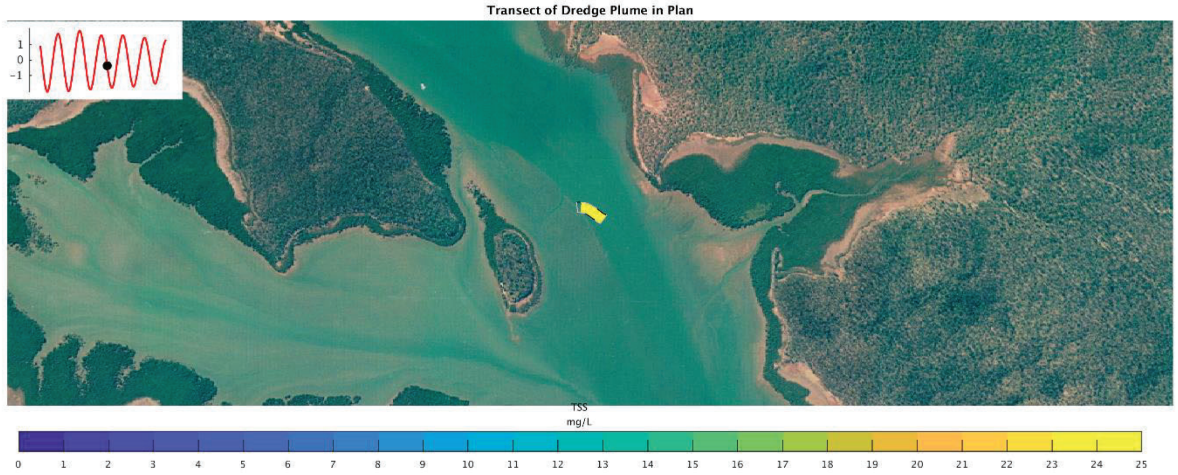
12-Sep-2018 14:06
Transect of Suspended Sediment in Profile



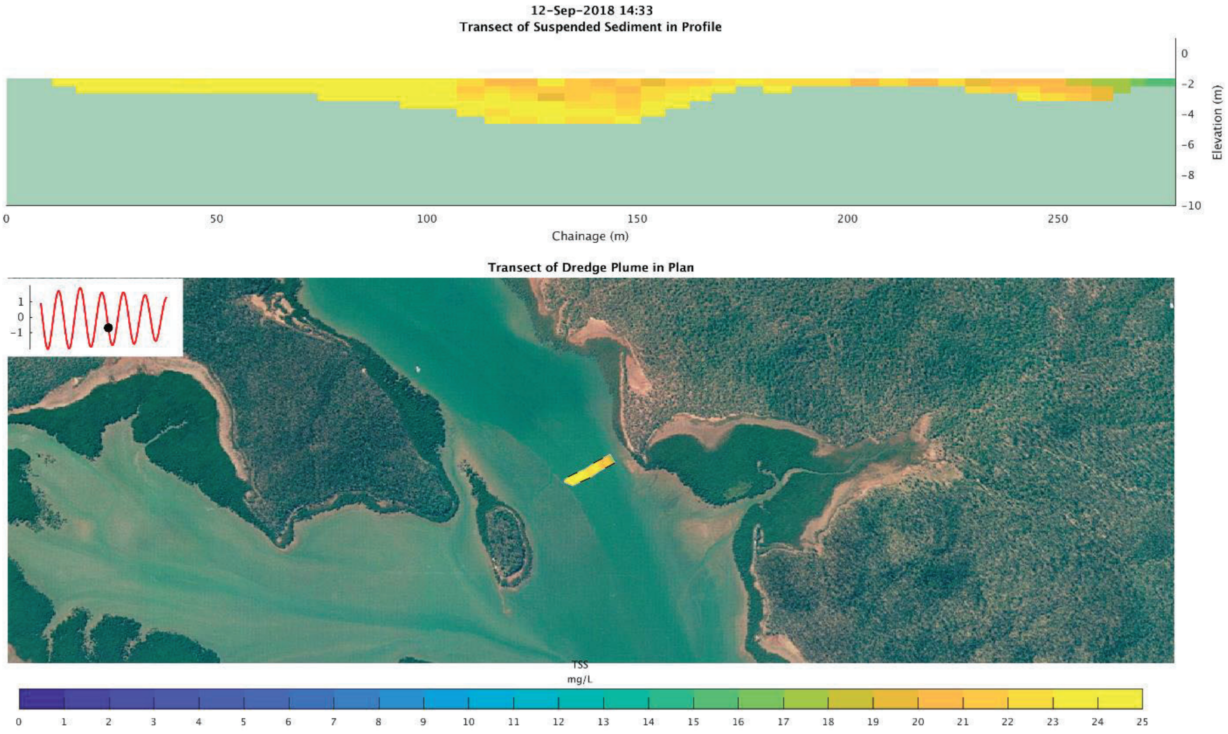
Transect of Dredge Plume in Plan



12-Sep-2018 14:10
Transect of Suspended Sediment, OBS Profile Included



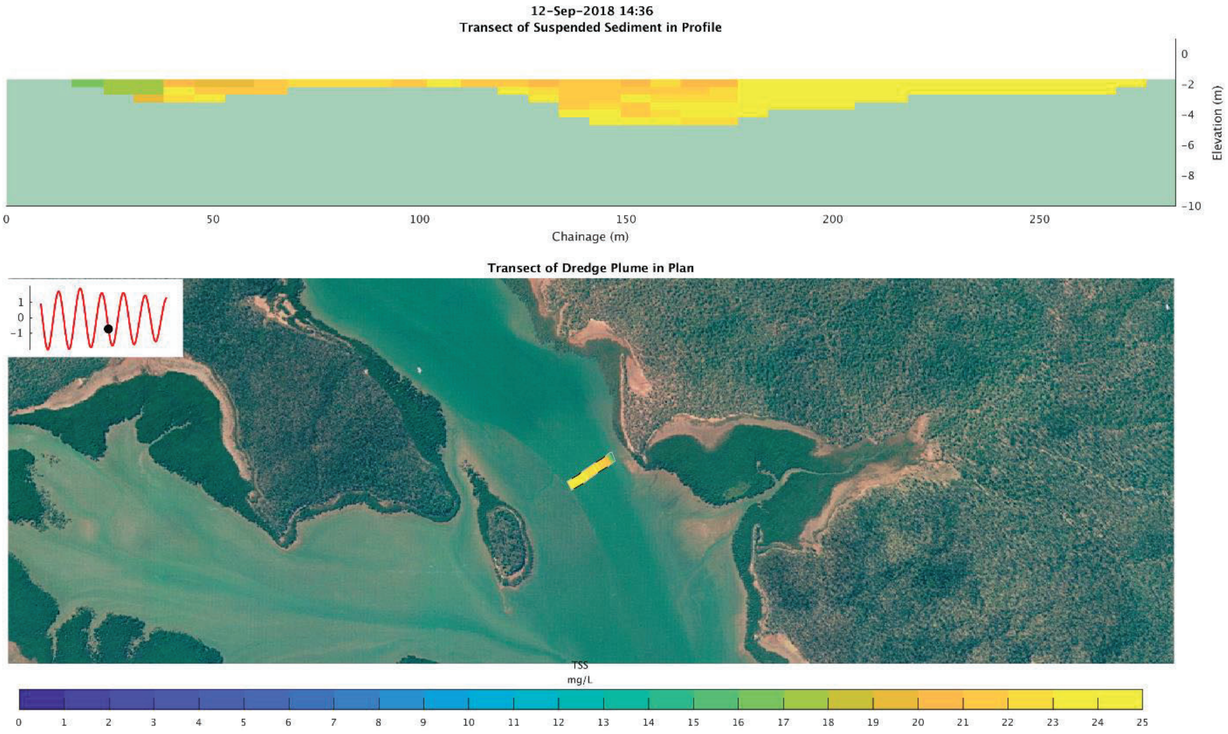
Transect of Dredge Plume in Plan



12-Sep-2018 14:33

Transect of Suspended Sediment in Profile

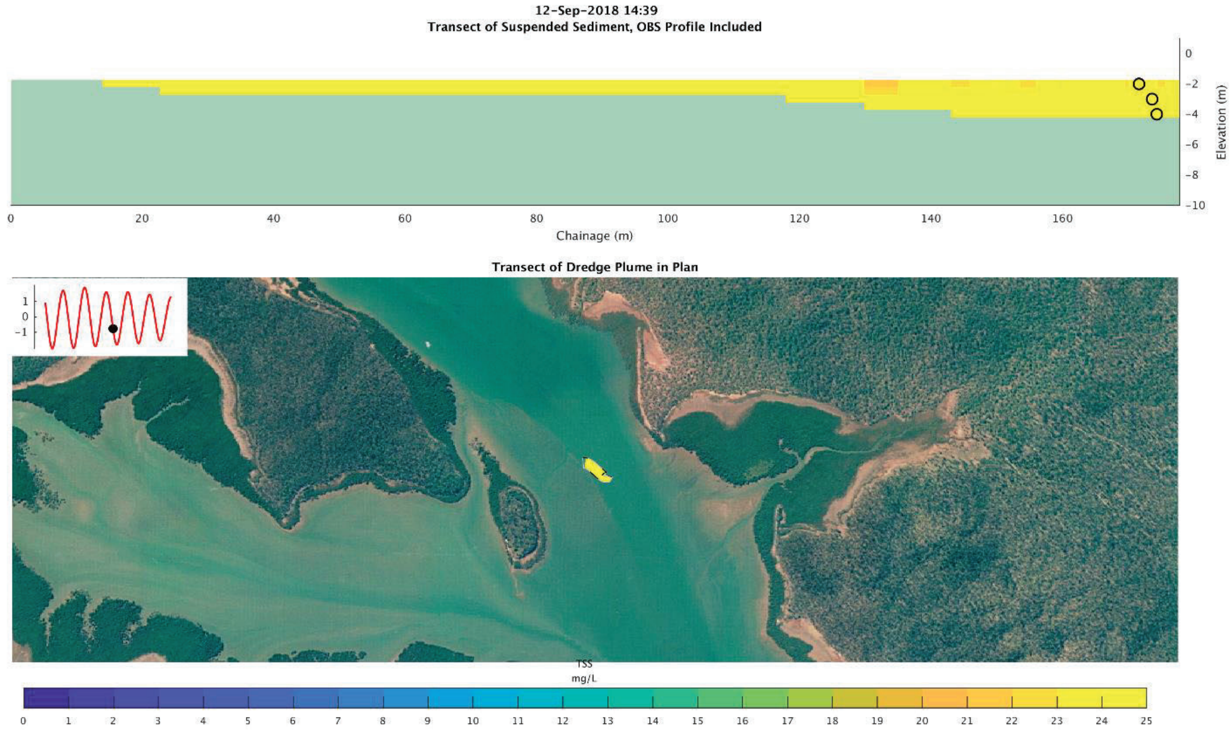
Transect of Dredge Plume in Plan



12-Sep-2018 14:36

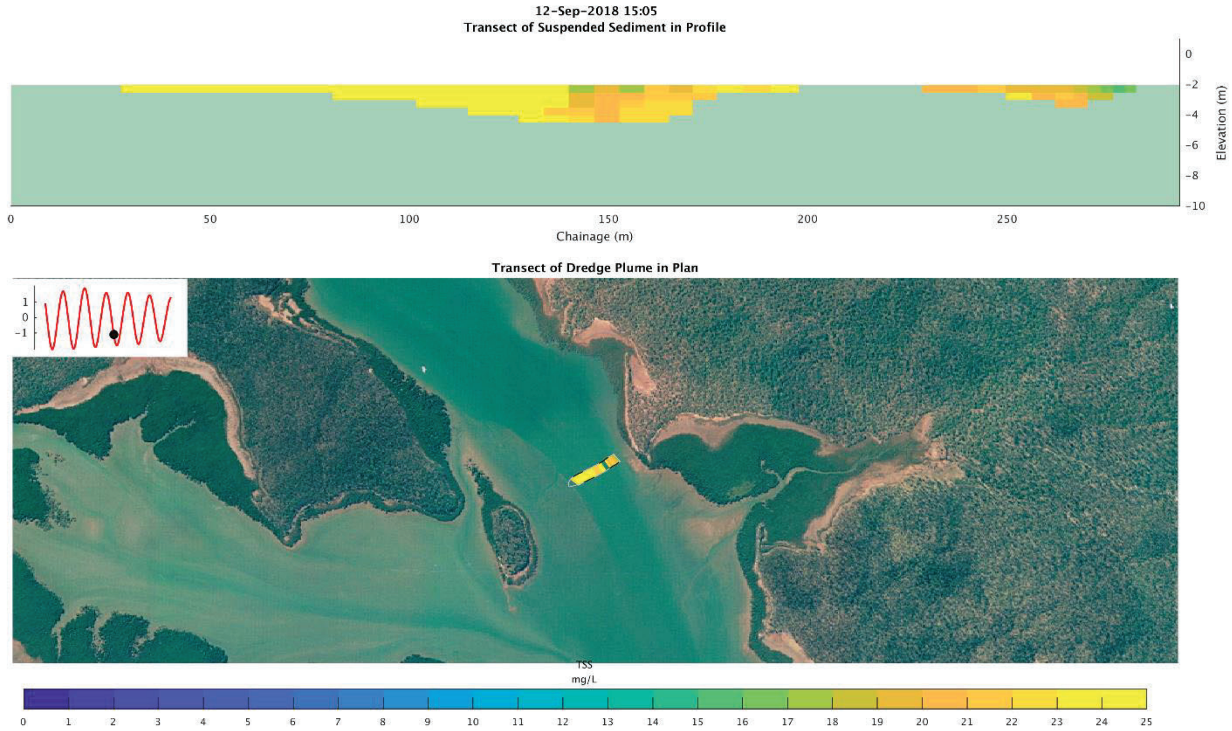
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan



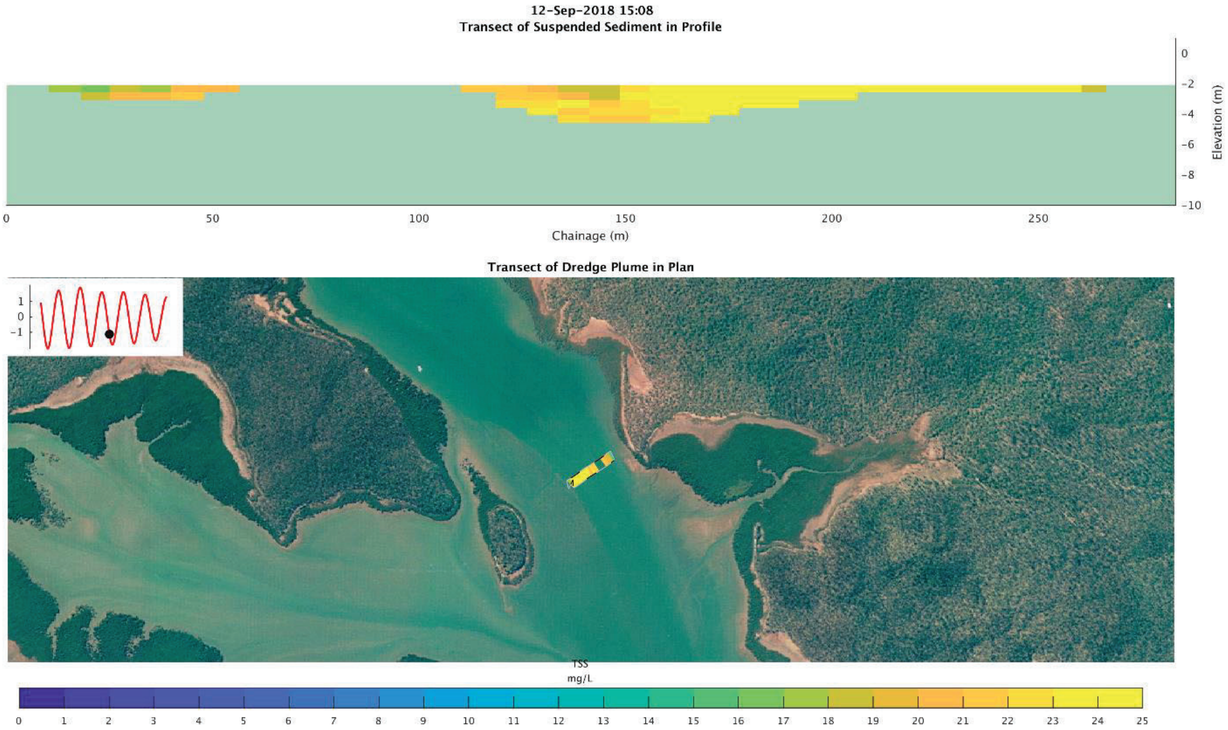
12-Sep-2018 14:39
Transect of Suspended Sediment, OBS Profile Included

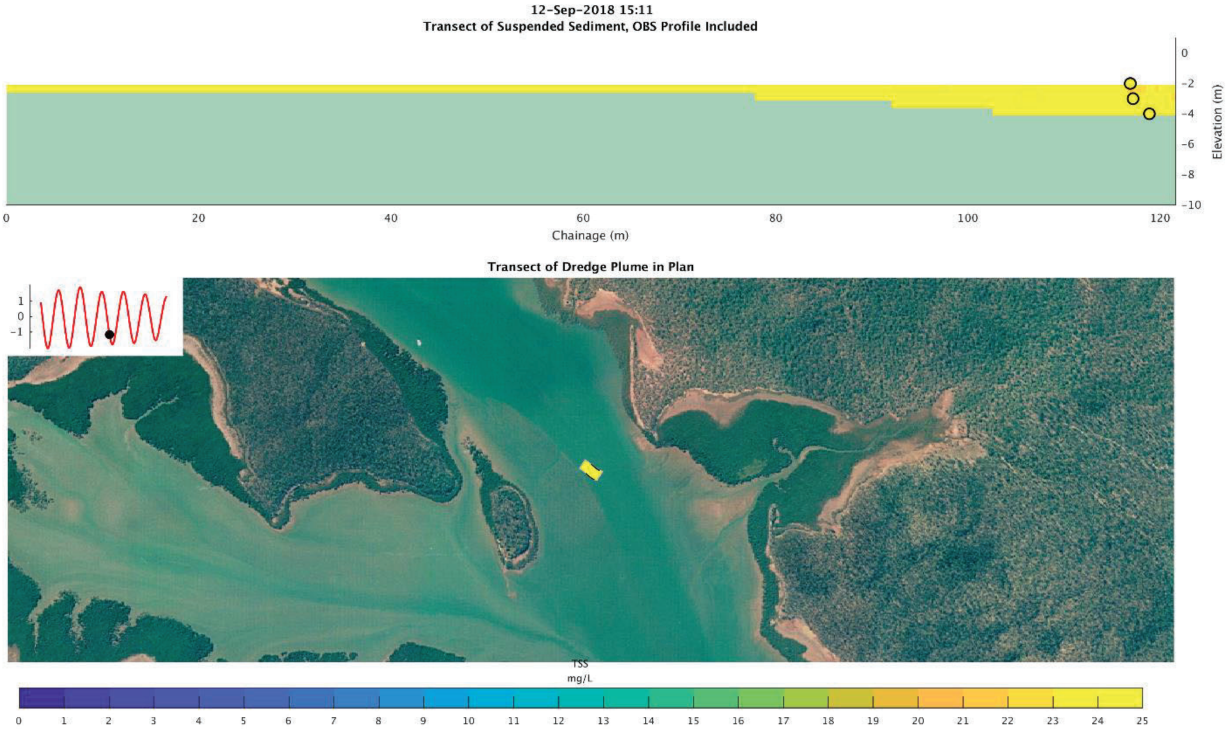
Transect of Dredge Plume in Plan



12-Sep-2018 15:05
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan


12-Sep-2018 15:08
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25


12-Sep-2018 15:11
Transect of Suspended Sediment, OBS Profile Included
0
-2
-4
-6
-8
-10
Elevation (m)
0
20
40
60
80
100
120
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
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20
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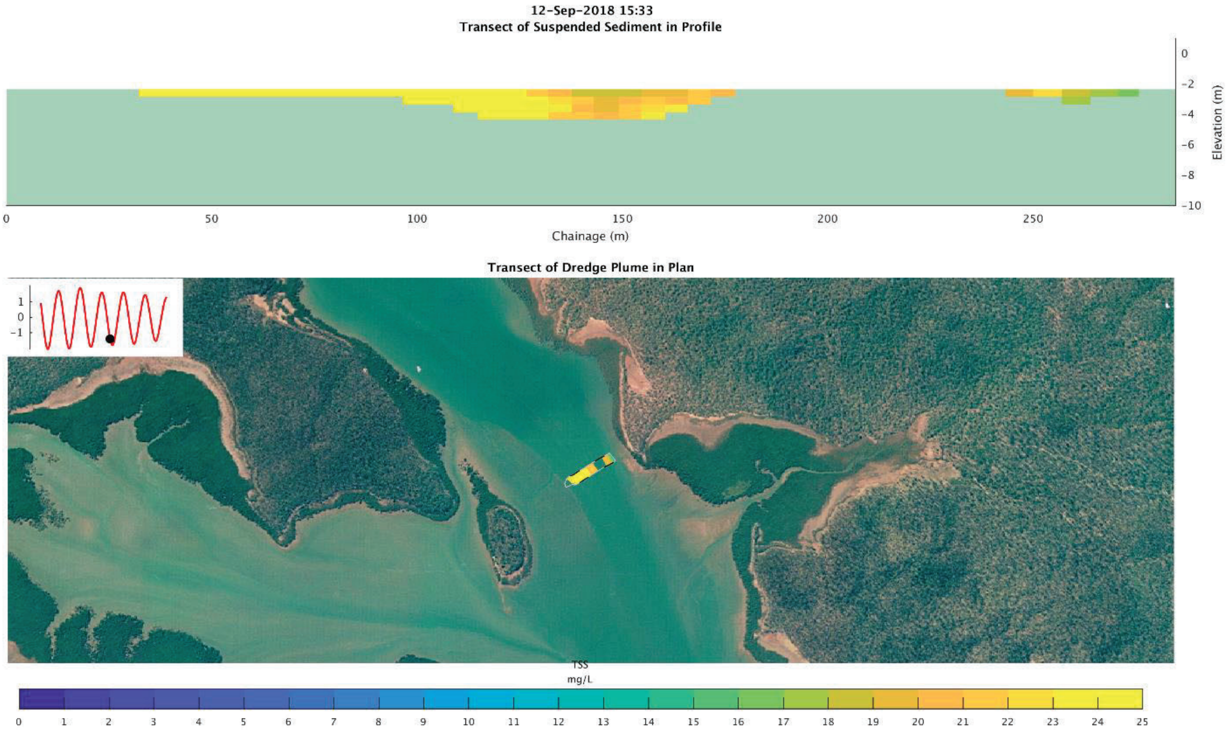
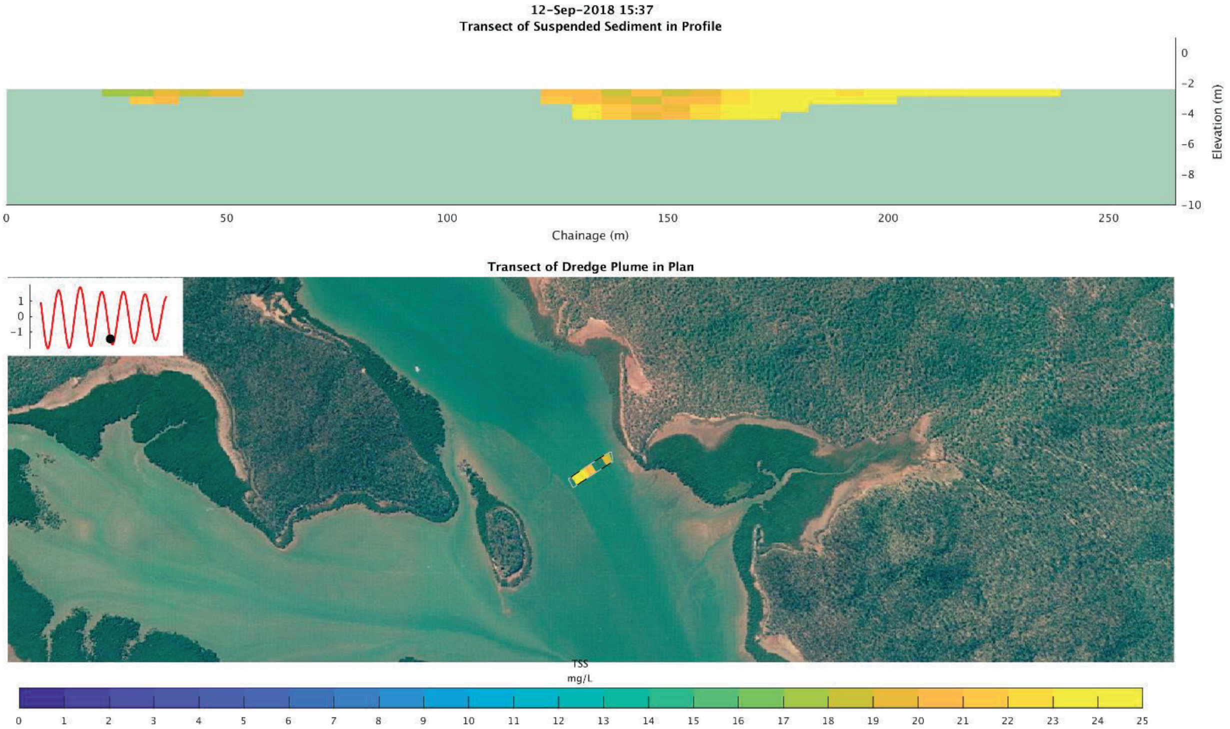
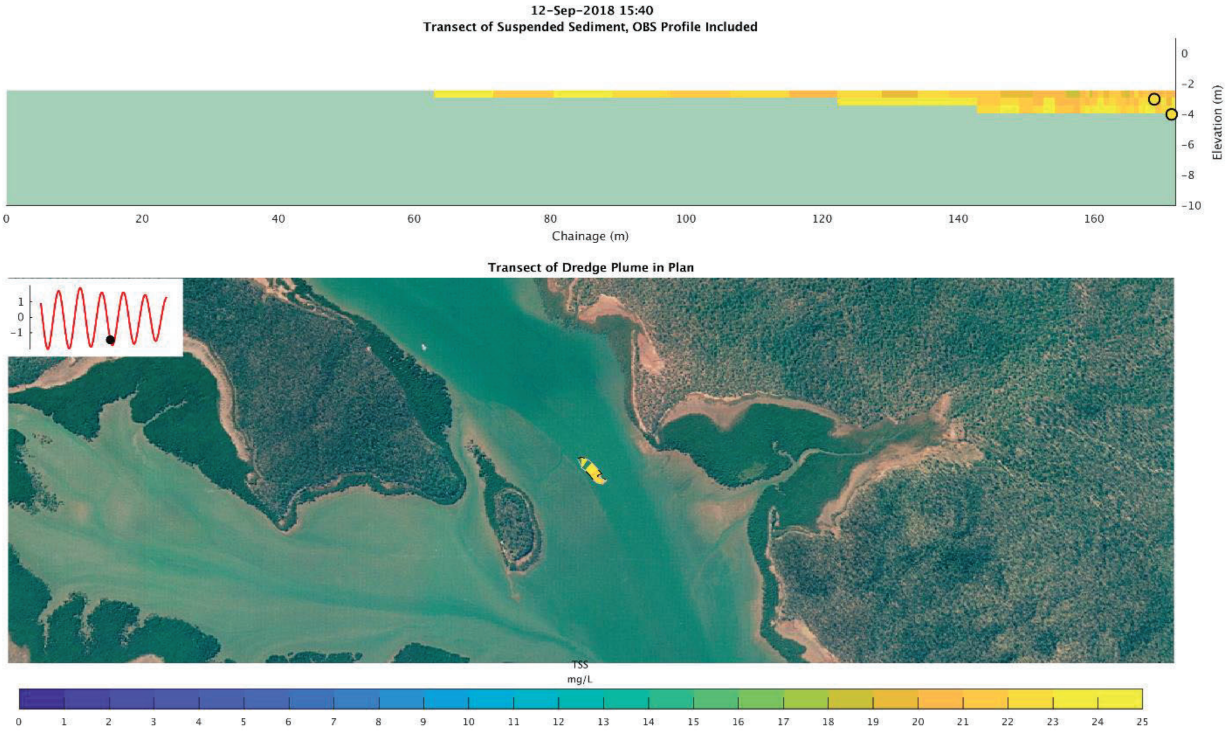
24
25


12-Sep-2018 15:33
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan

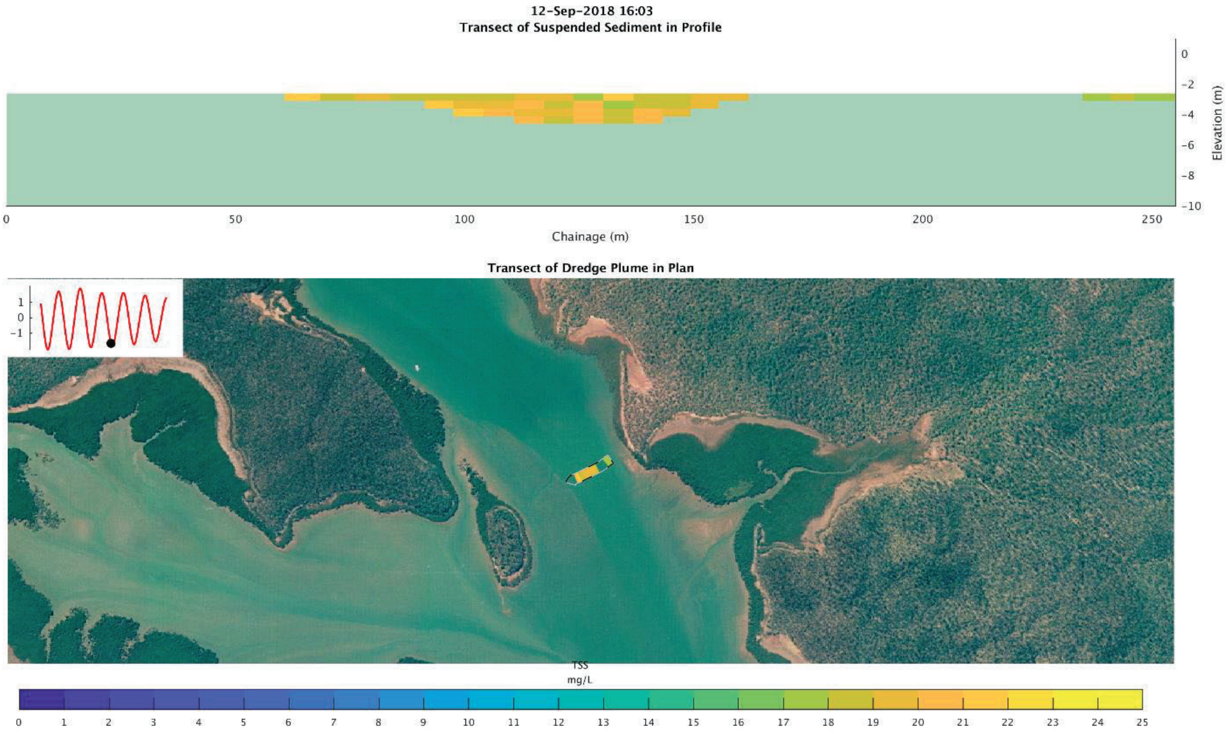

12-Sep-2018 15:37
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan



12-Sep-2018 15:40
Transect of Suspended Sediment, OBS Profile Included

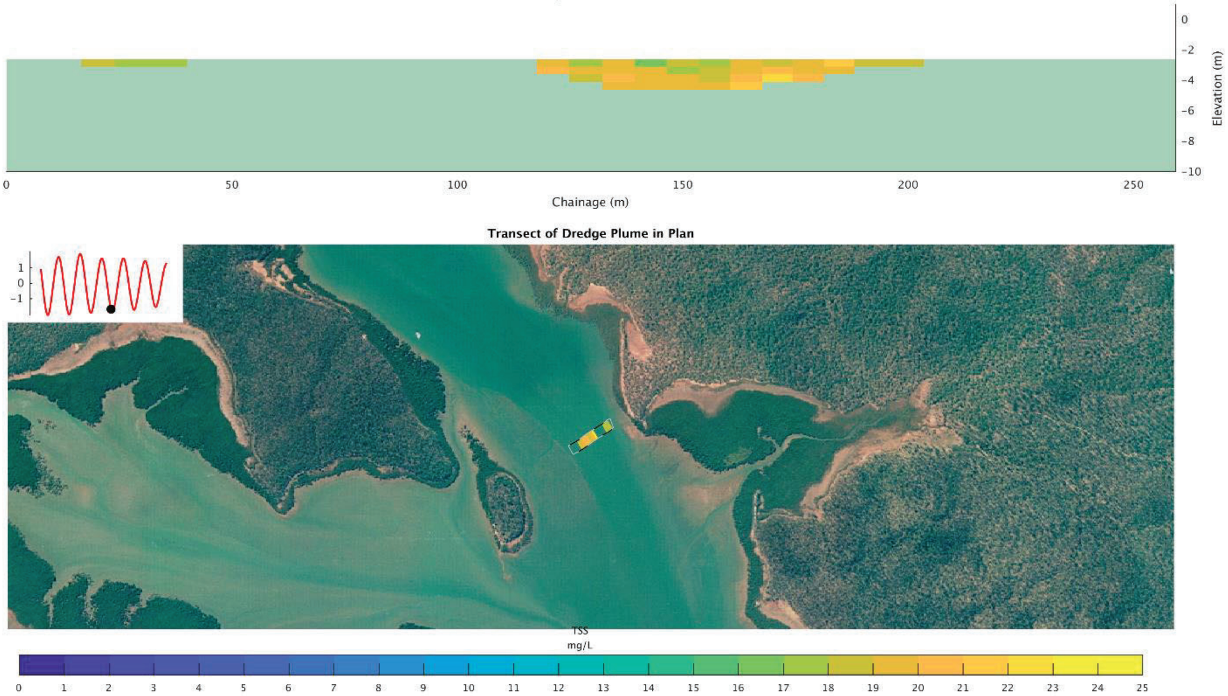
Transect of Dredge Plume in Plan



12-Sep-2018 16:03
Transect of Suspended Sediment in Profile

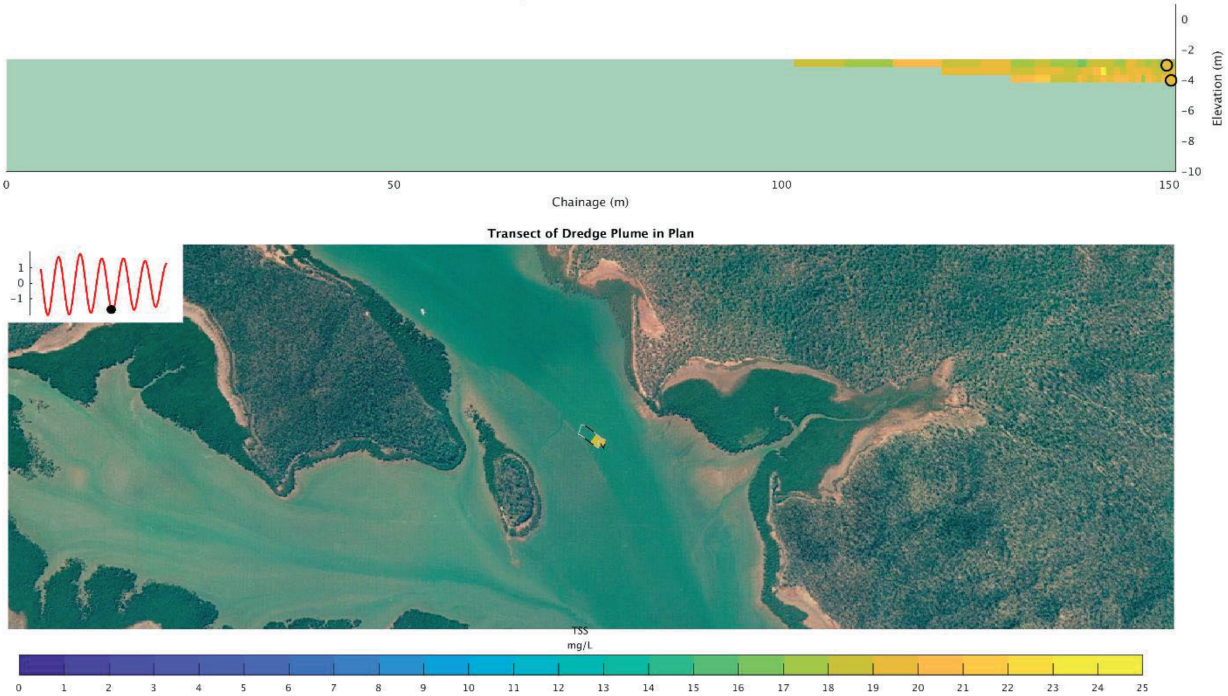
Transect of Dredge Plume in Plan

12-Sep-2018 16:06
Transect of Suspended Sediment in Profile

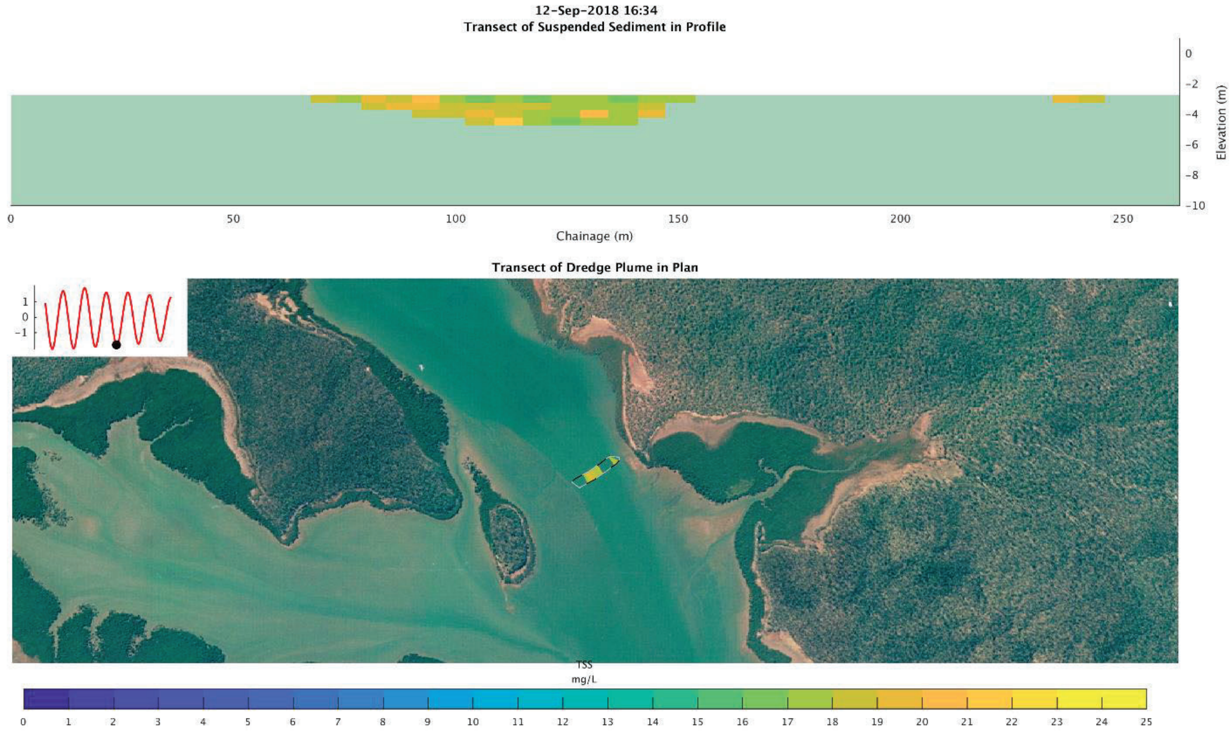


Transect of Dredge Plume in Plan

12-Sep-2018 16:09
Transect of Suspended Sediment, OBS Profile Included



Transect of Dredge Plume in Plan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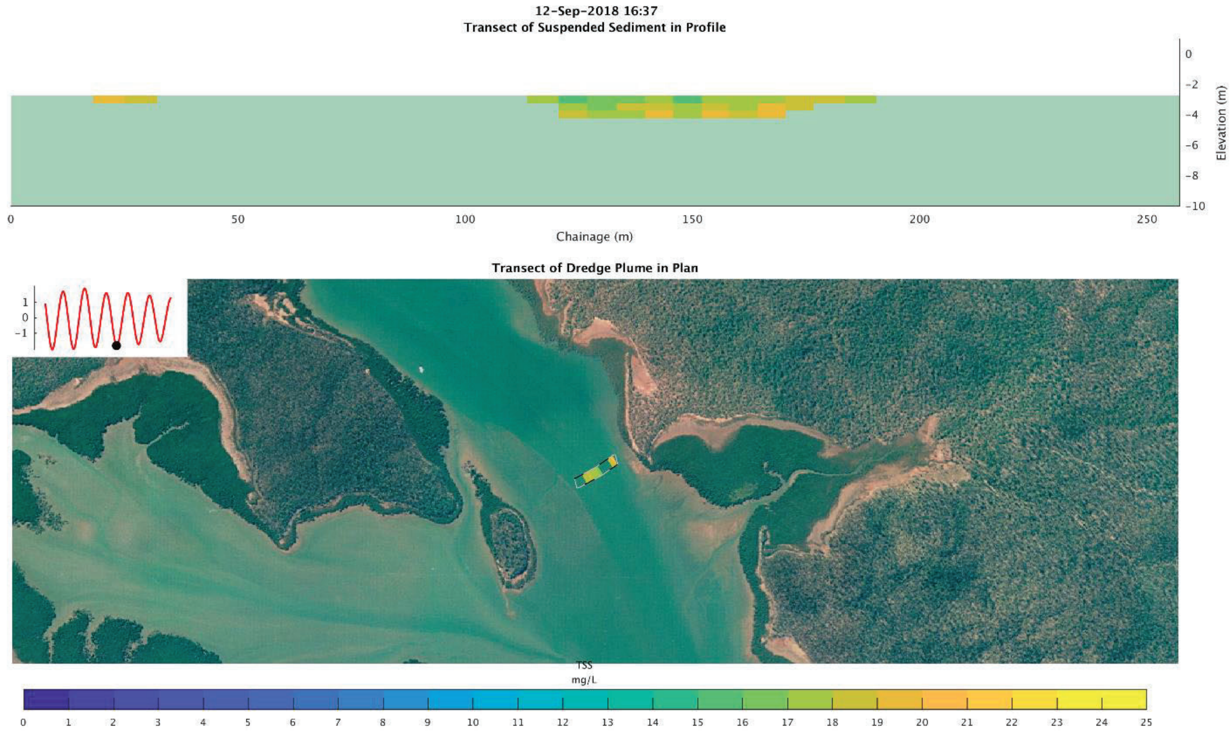
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan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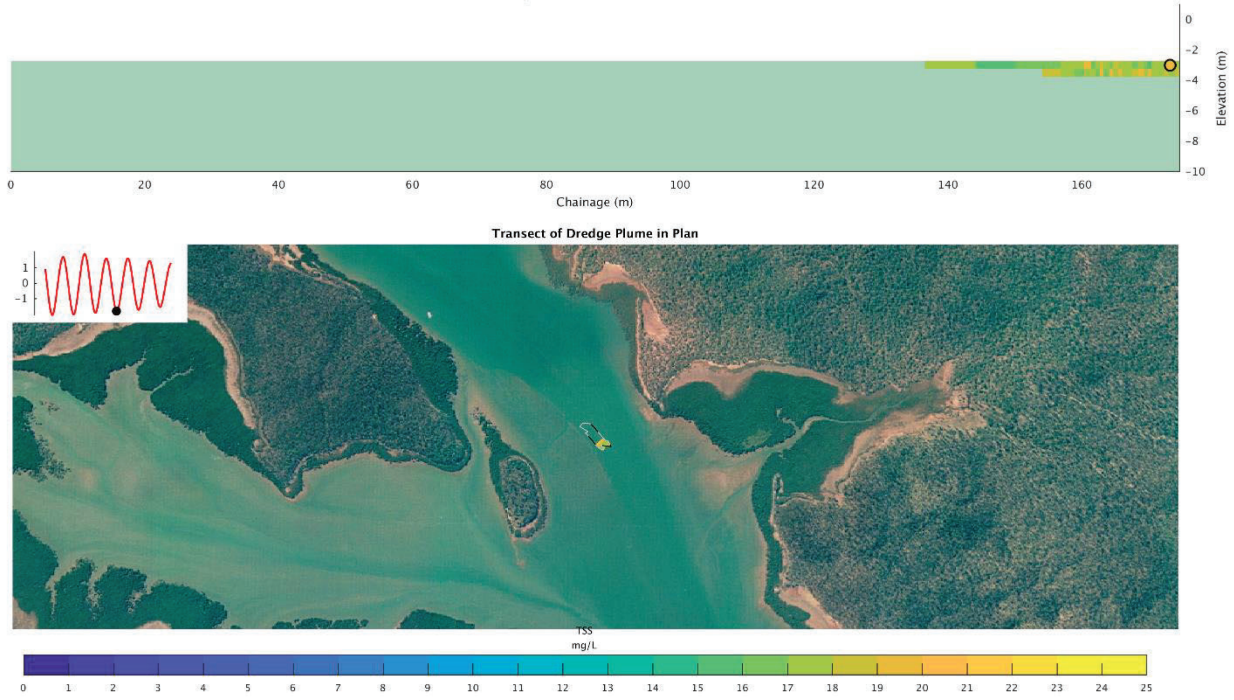
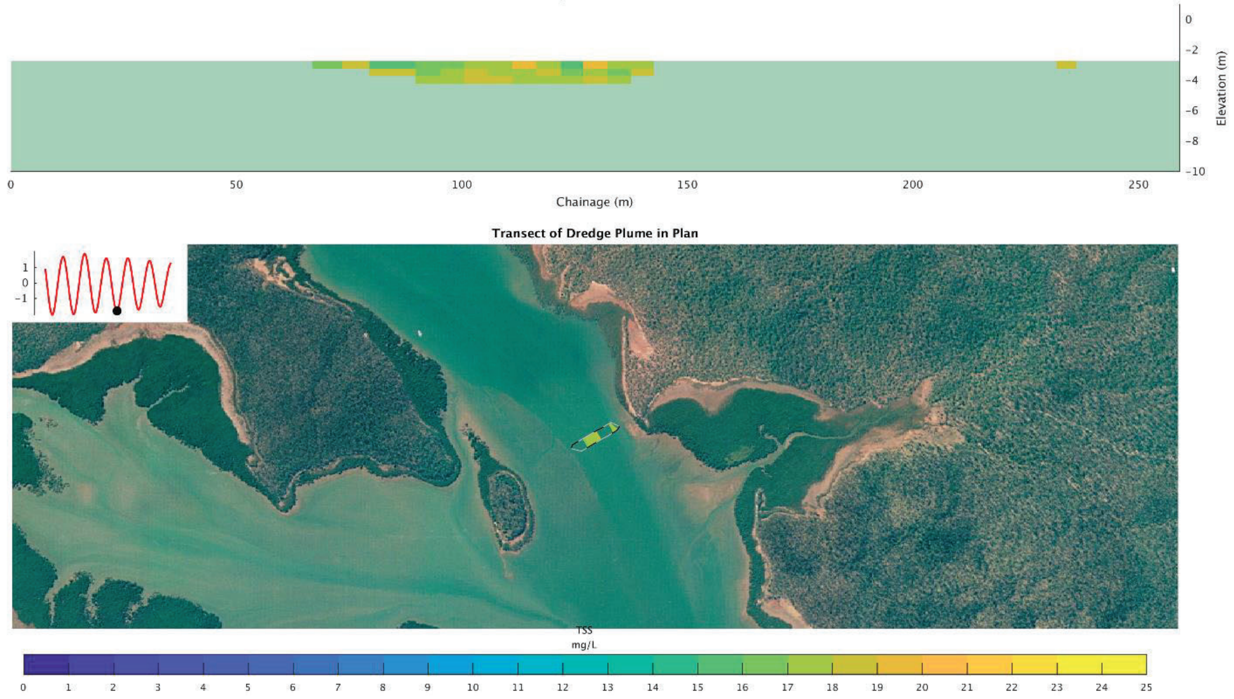
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan



12-Sep-2018 16:40
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan



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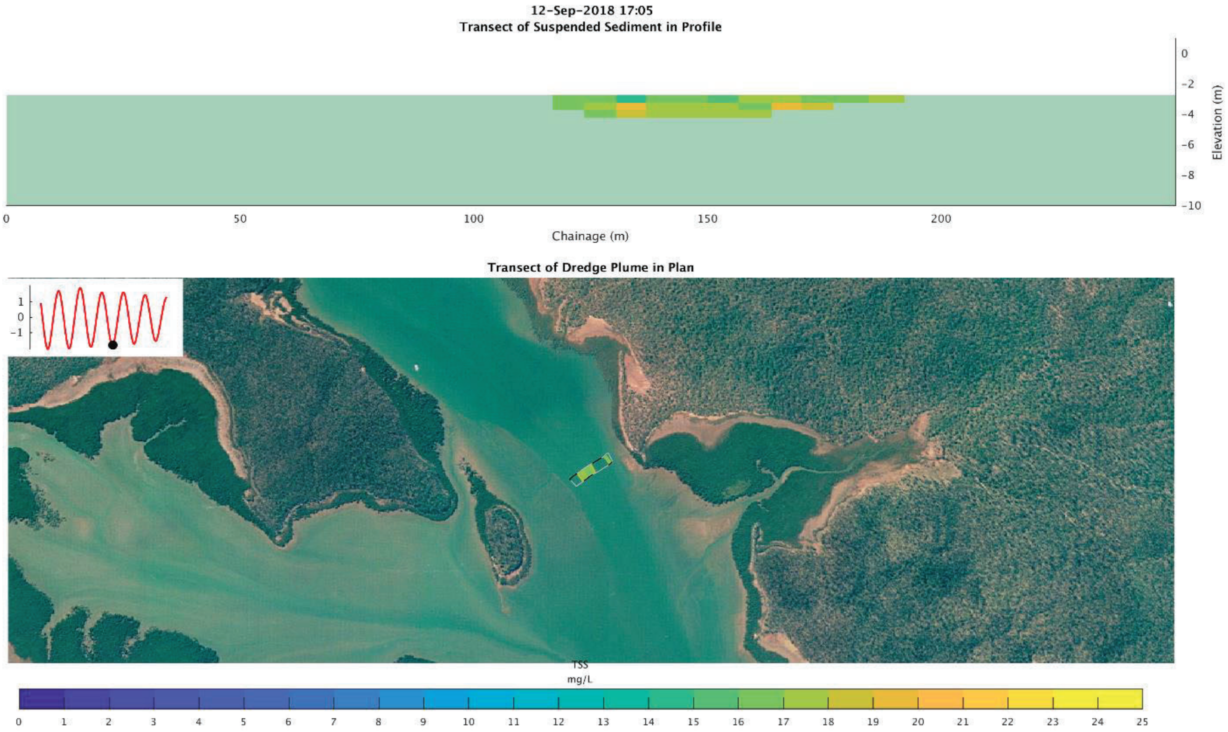
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan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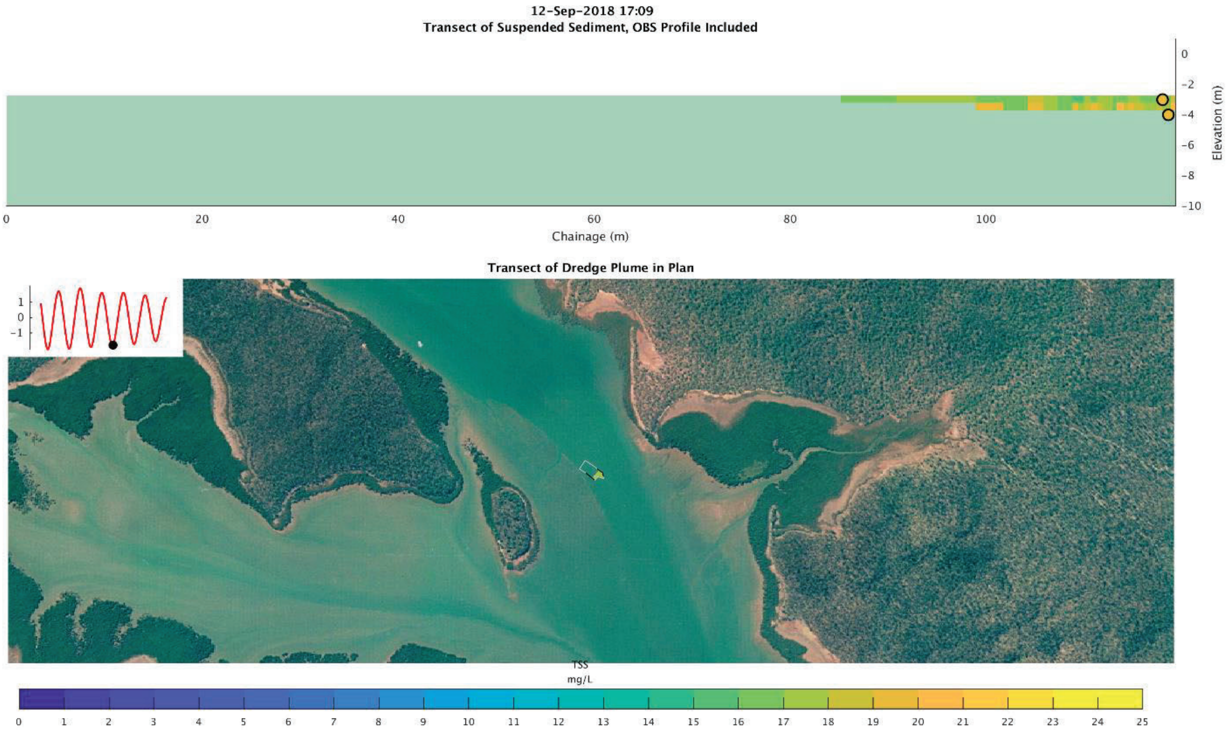
Transect of Suspended Sediment in Profile
Transect of Dredge Plume in Plan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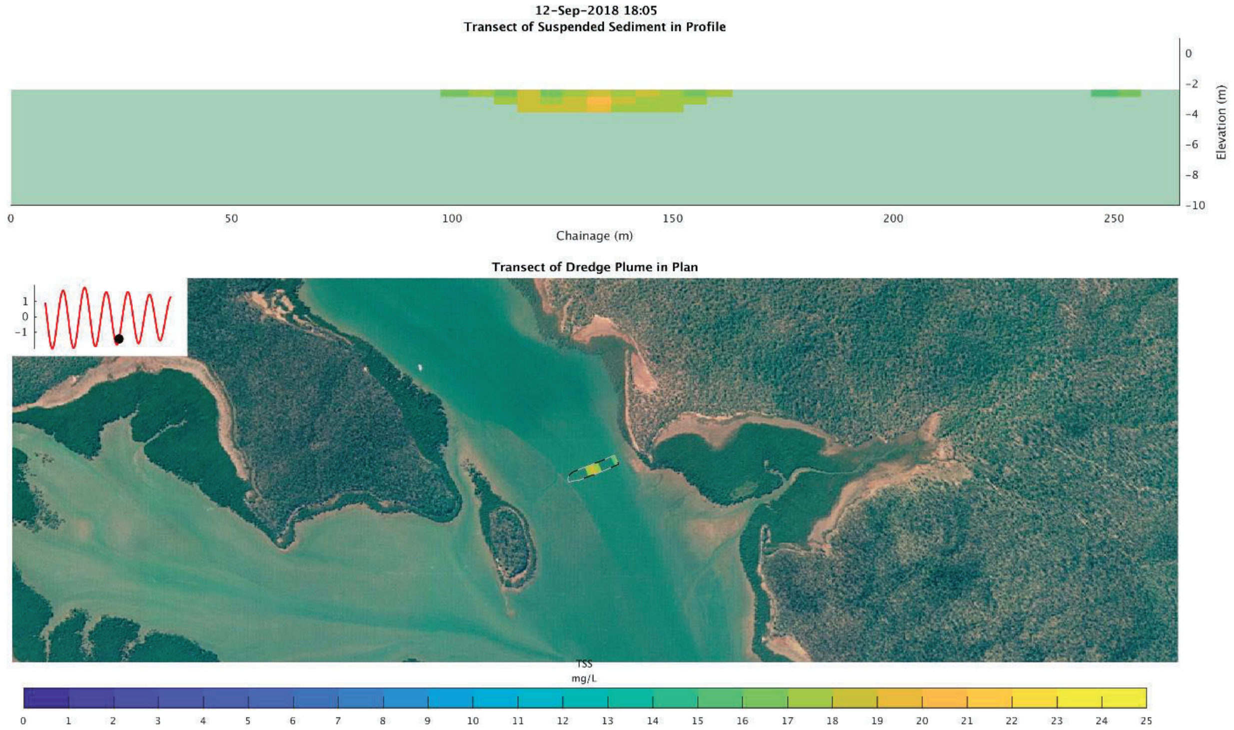
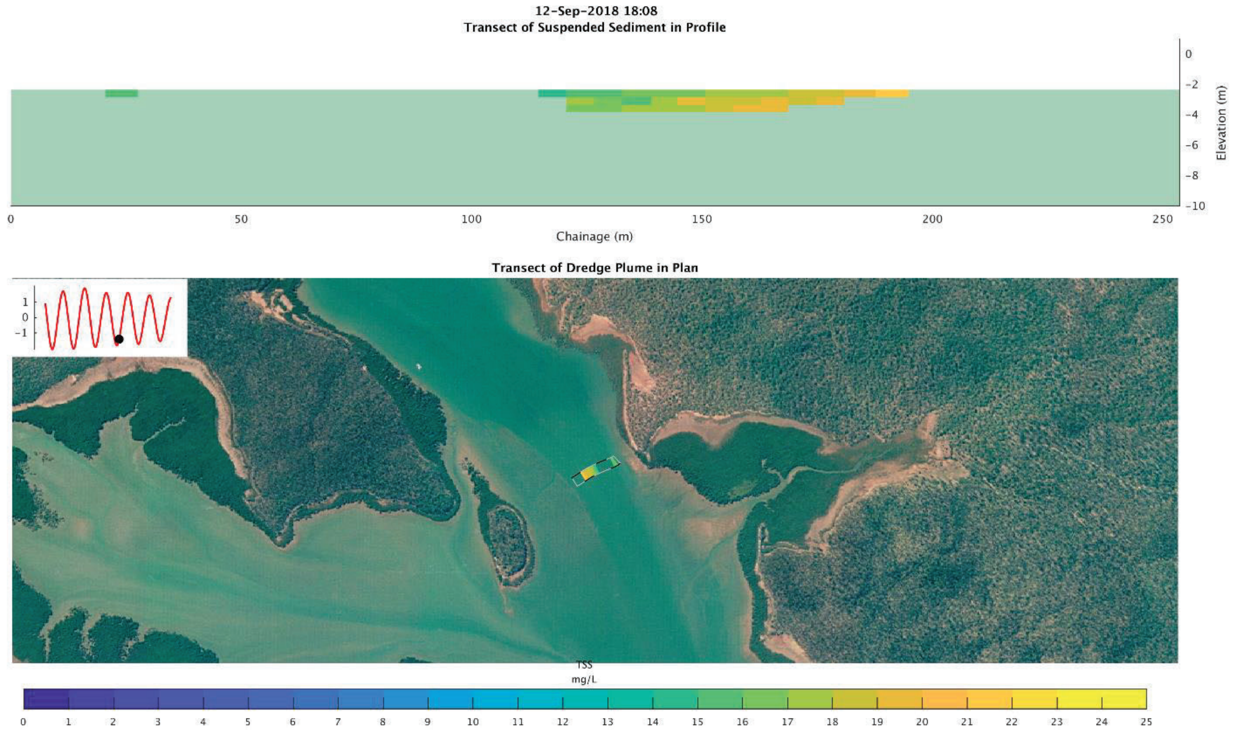
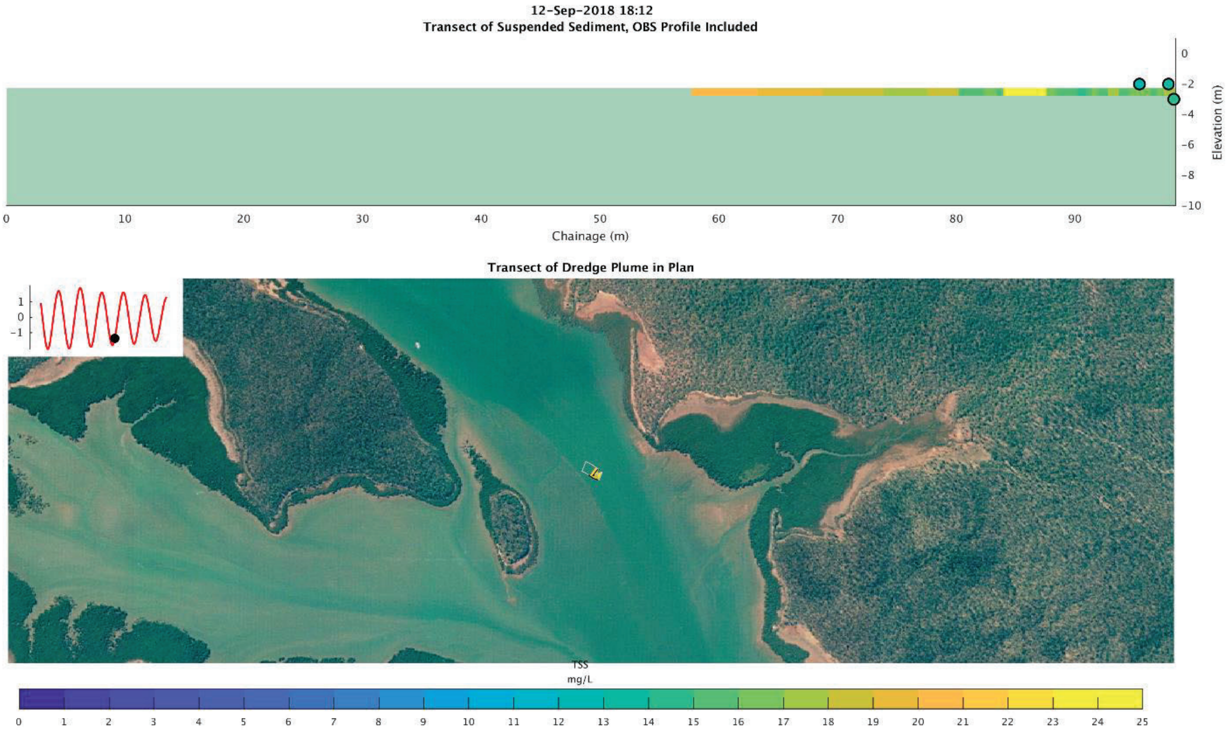
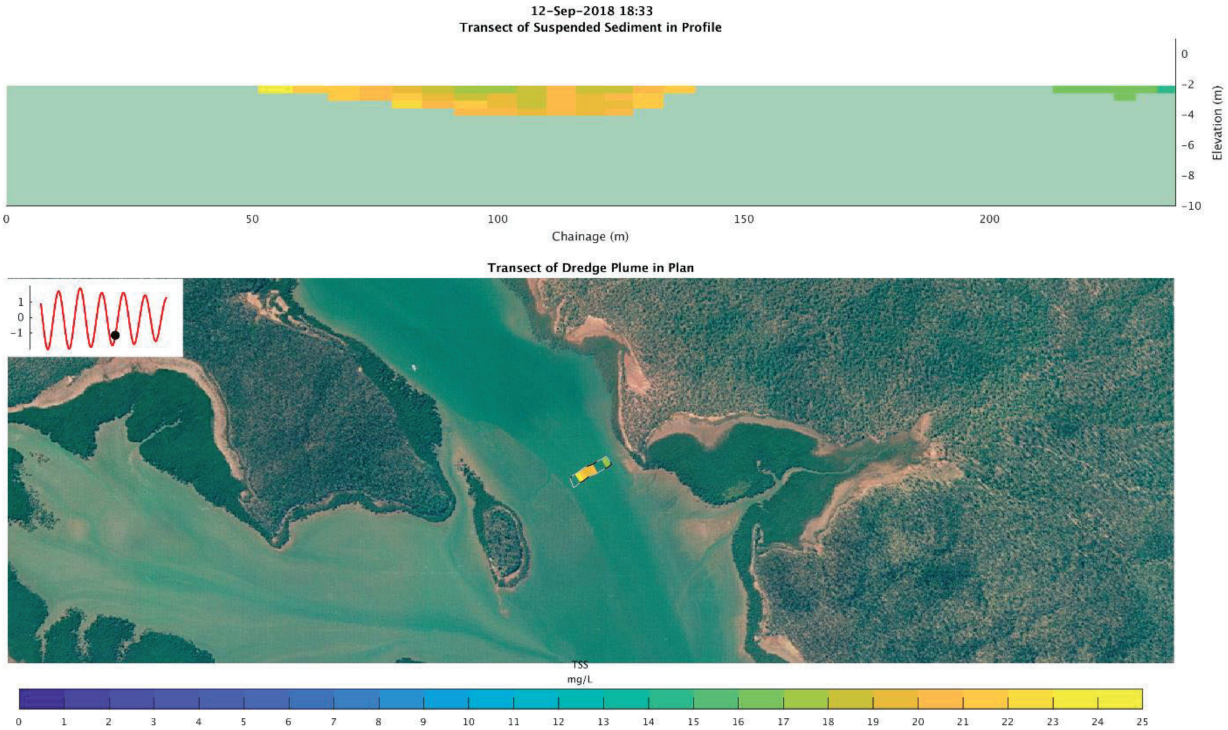
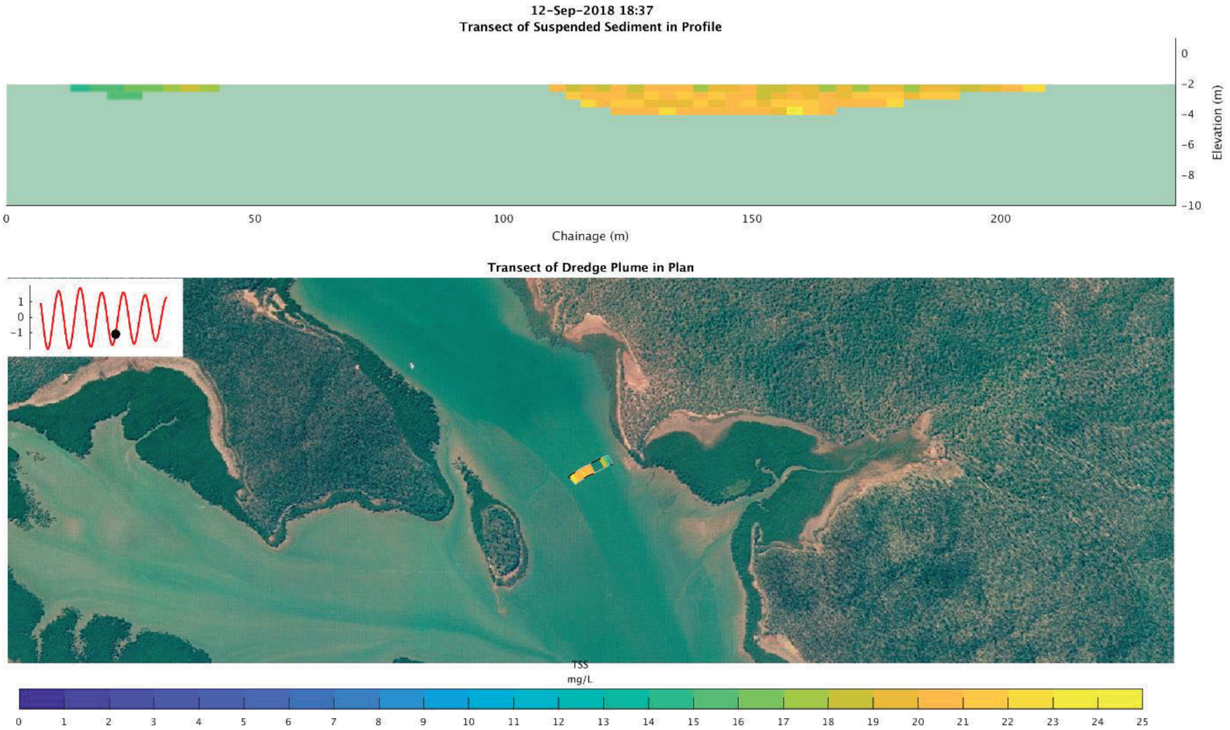
Transect of Suspended Sediment, OBS Profile Included
Transect of Dredge Plume in Plan


12-Sep-2018 18:05
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25


12-Sep-2018 18:08
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25


12-Sep-2018 18:12
Transect of Suspended Sediment, OBS Profile Included
0
-2
-4
-6
-8
-10
Elevation (m)
0 10 20 30 40 50 60 70 80 90
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25


12-Sep-2018 18:33
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0 50 100 150 200
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25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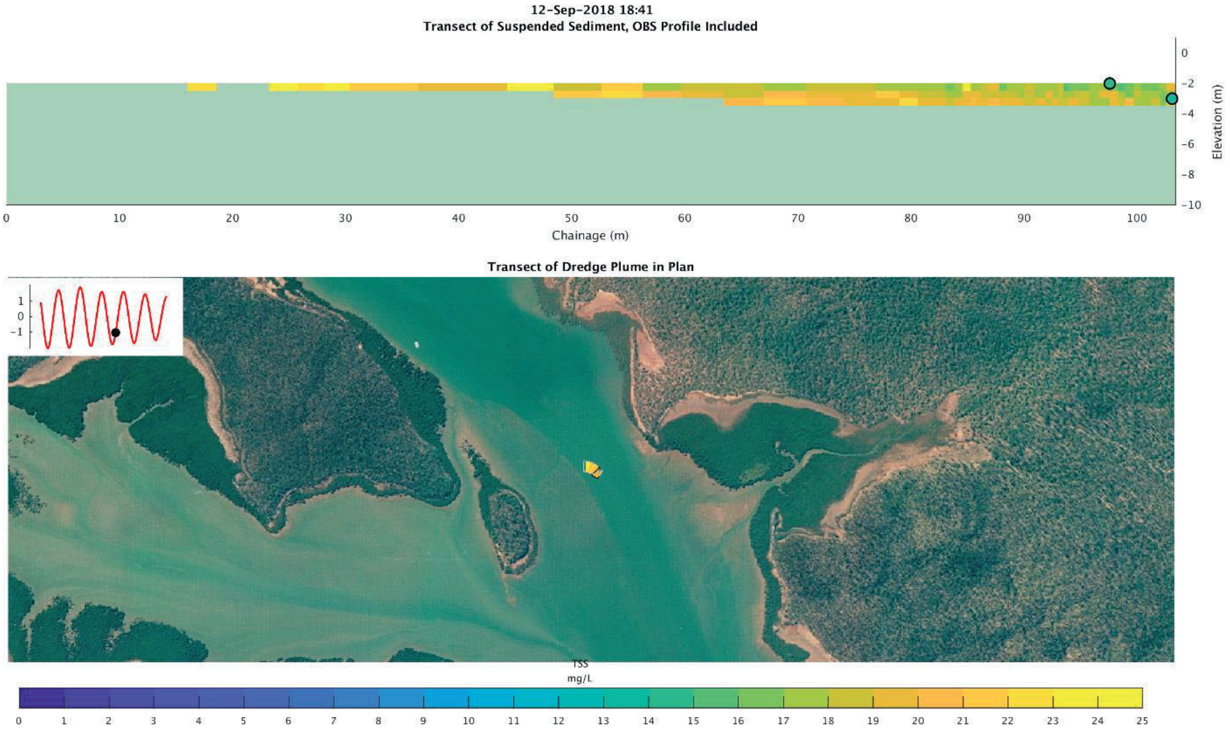
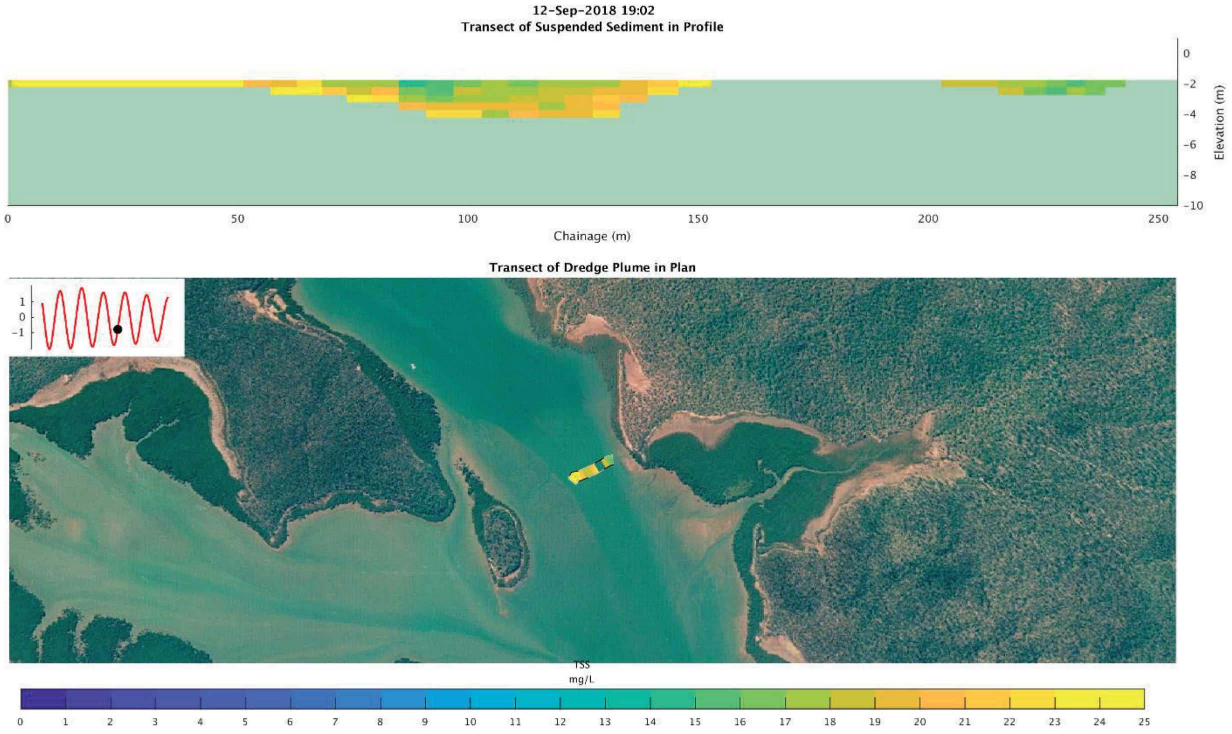
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan


12-Sep-2018 18:41
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan


12-Sep-2018 19:02
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
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20
21
22
23
24
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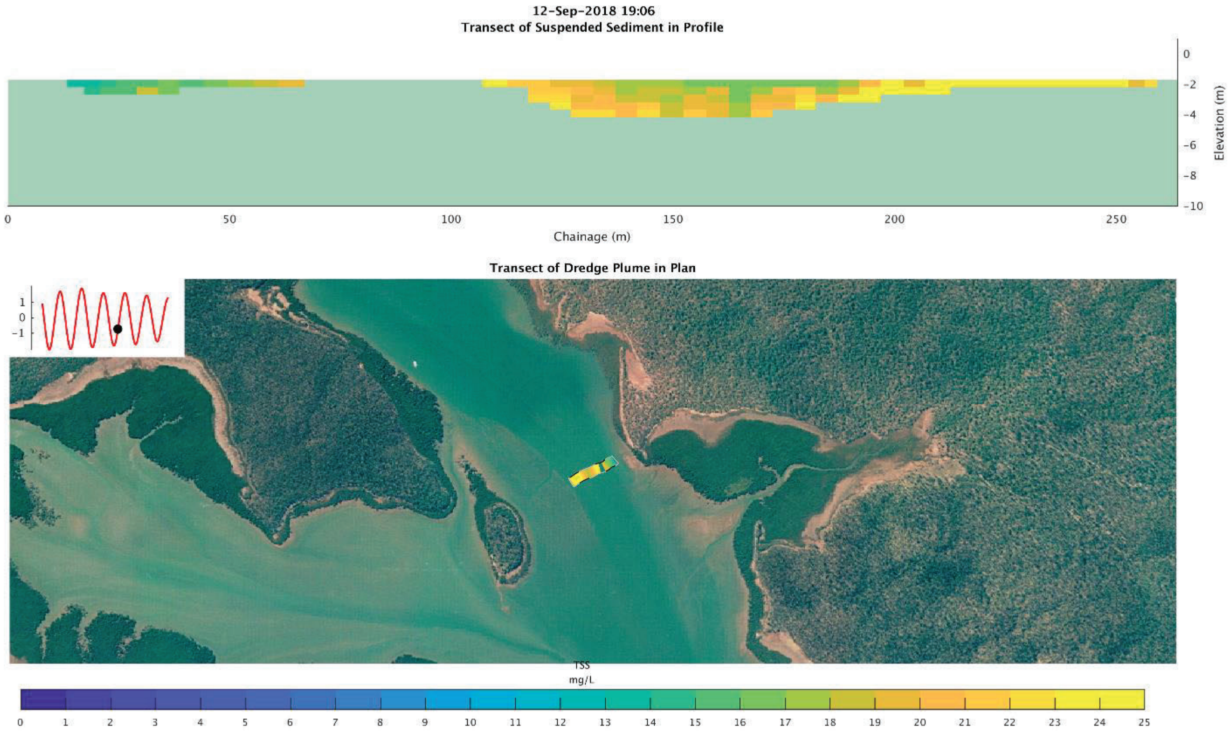
12-Sep-2018 19:06
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
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18
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20
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22
23
24
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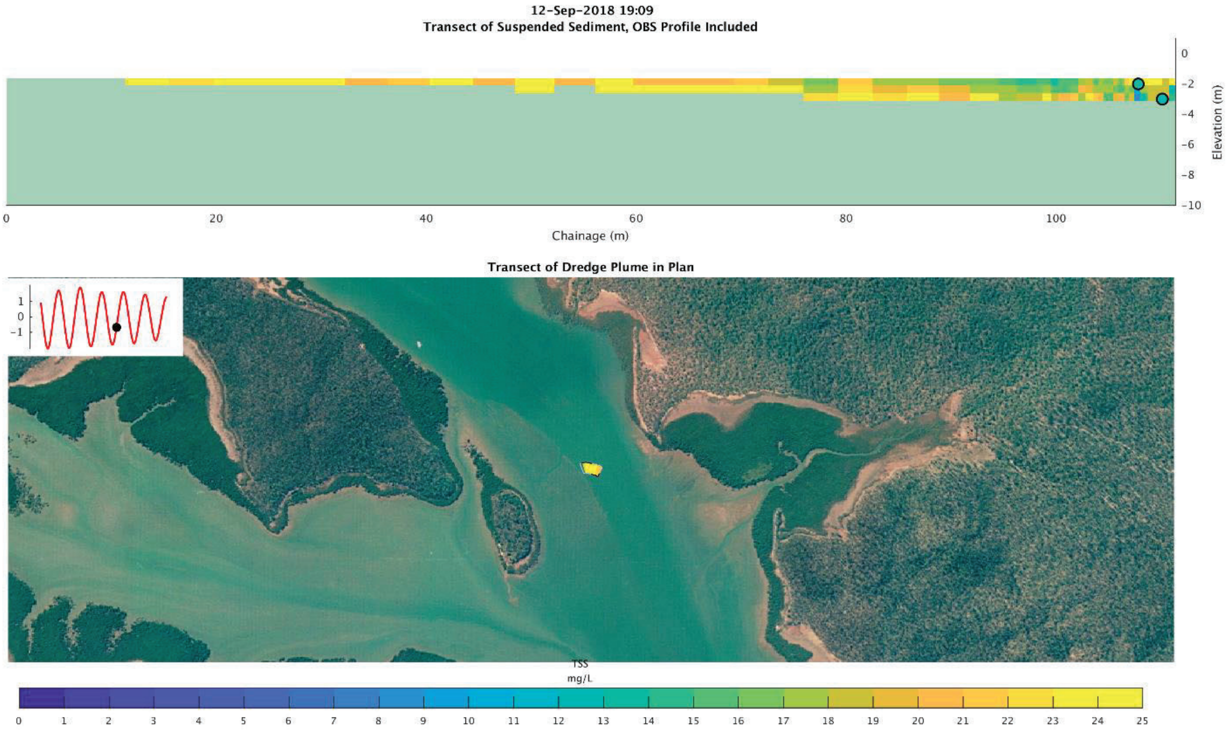
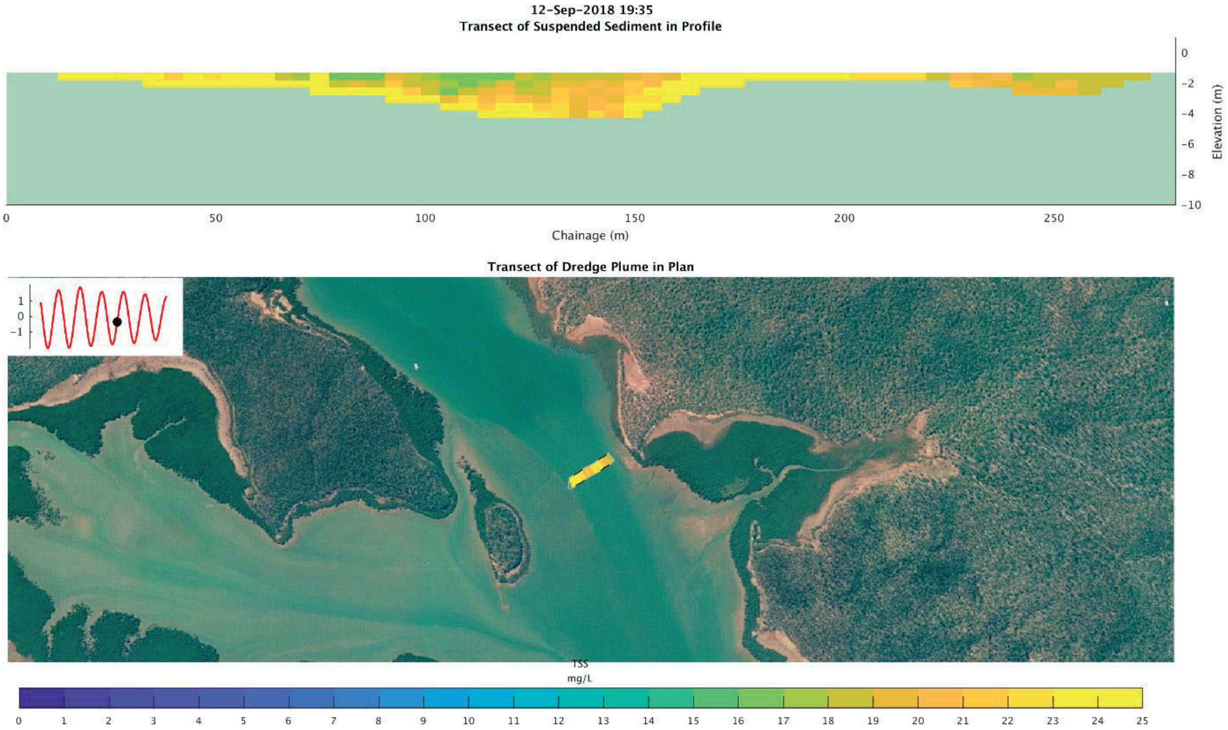

12-Sep-2018 19:09
Transect of Suspended Sediment, OBS Profile Included

Transect of Dredge Plume in Plan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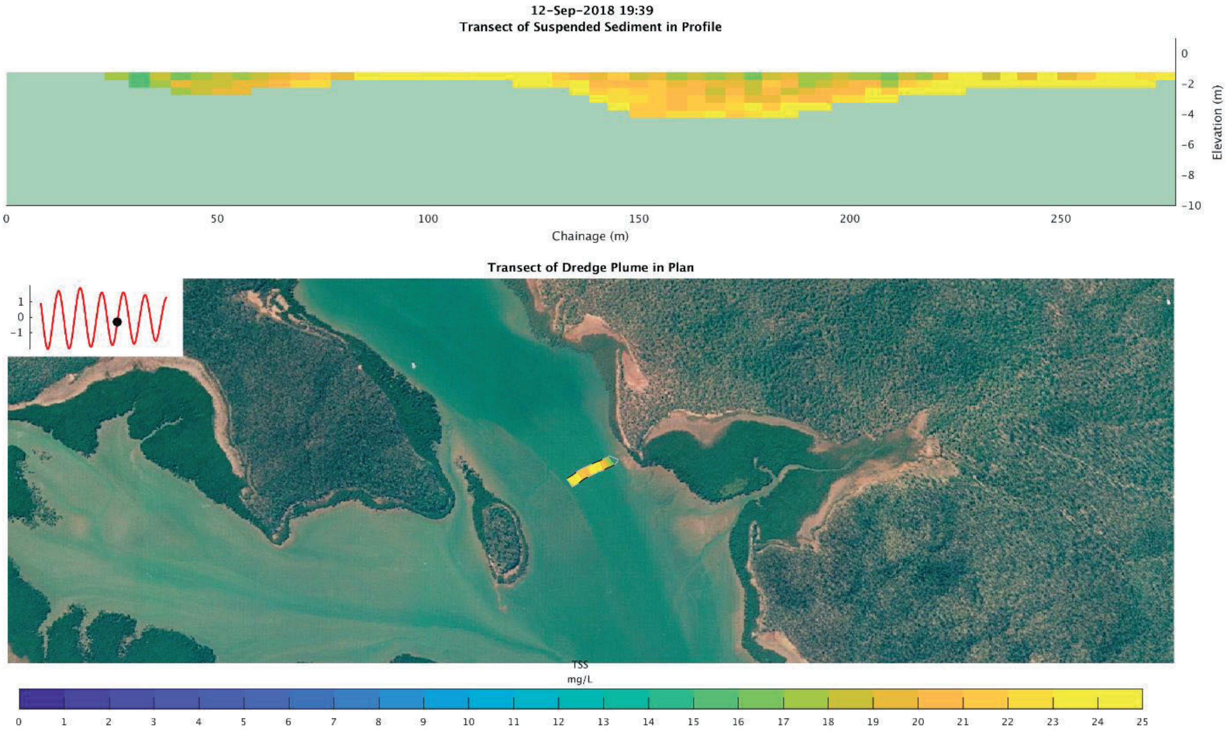
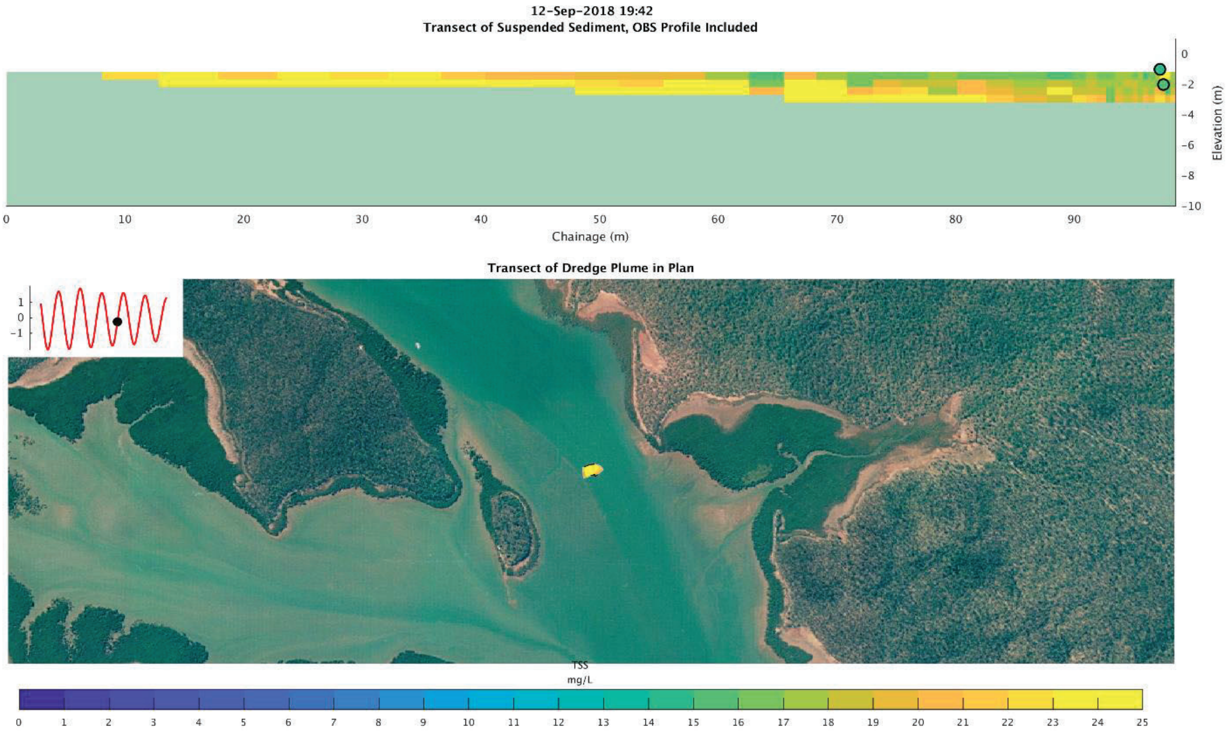
Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan


12-Sep-2018 19:39
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25


12-Sep-2018 19:42
Transect of Suspended Sediment, OBS Profile Included
0
-2
-4
-6
-8
-10
Elevation (m)
0
10
20
30
40
50
60
70
80
90
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
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20
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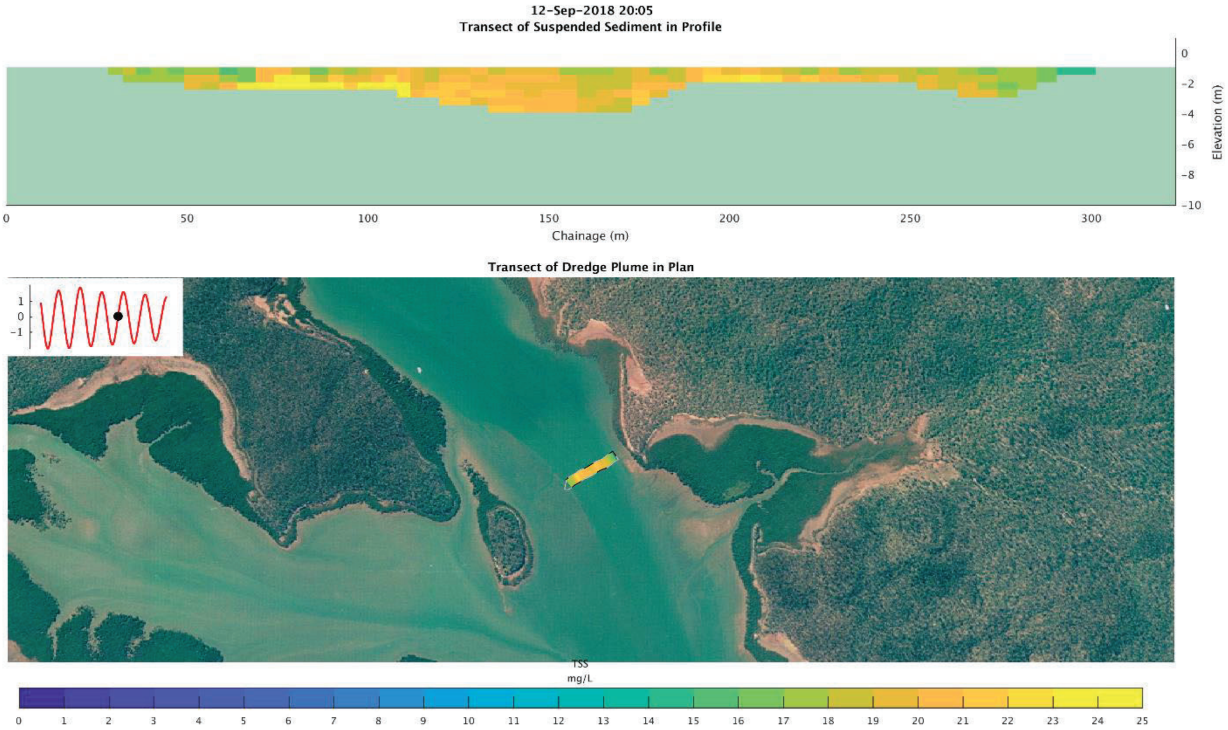
22
23
24
25


12-Sep-2018 20:05
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
300
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
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24
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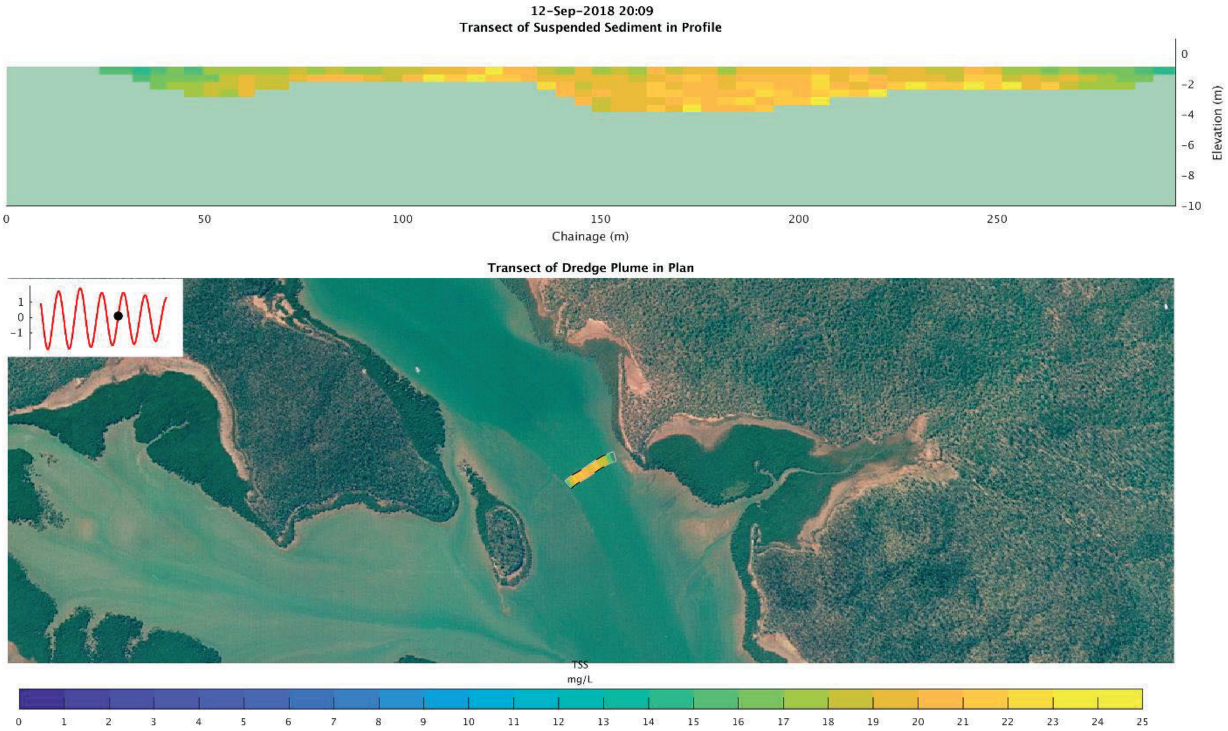
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Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
8
9
10
11
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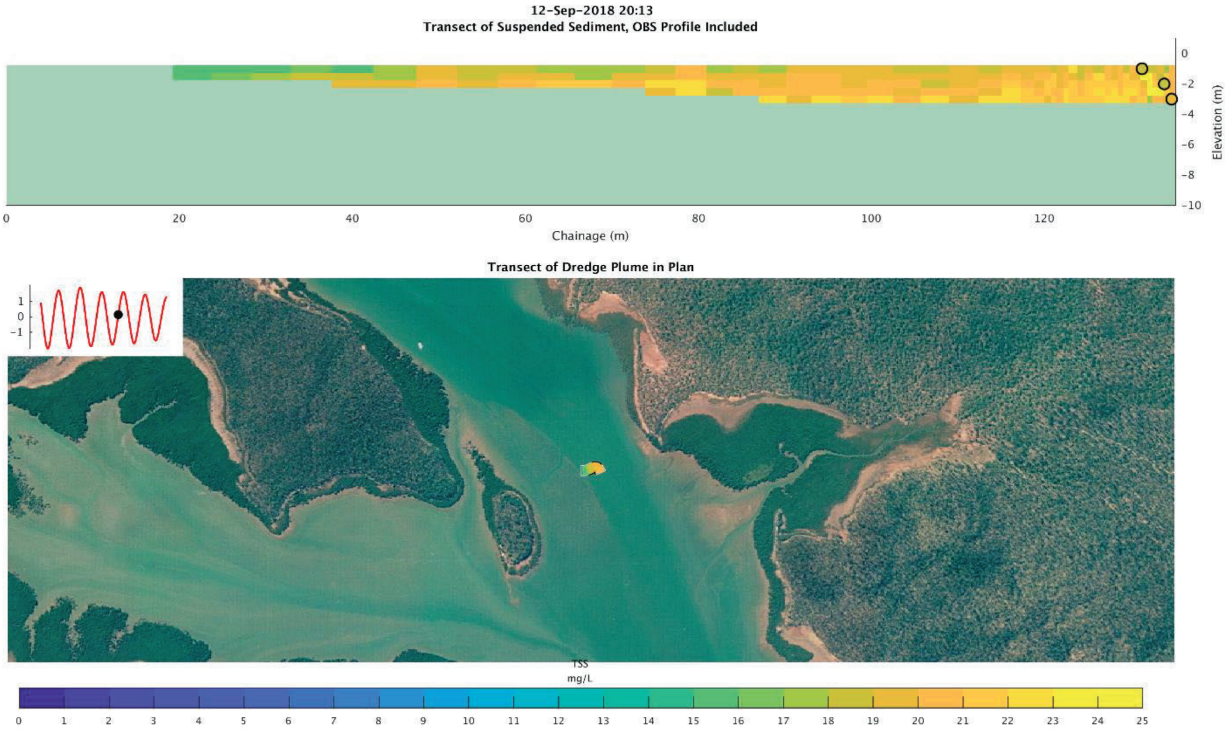
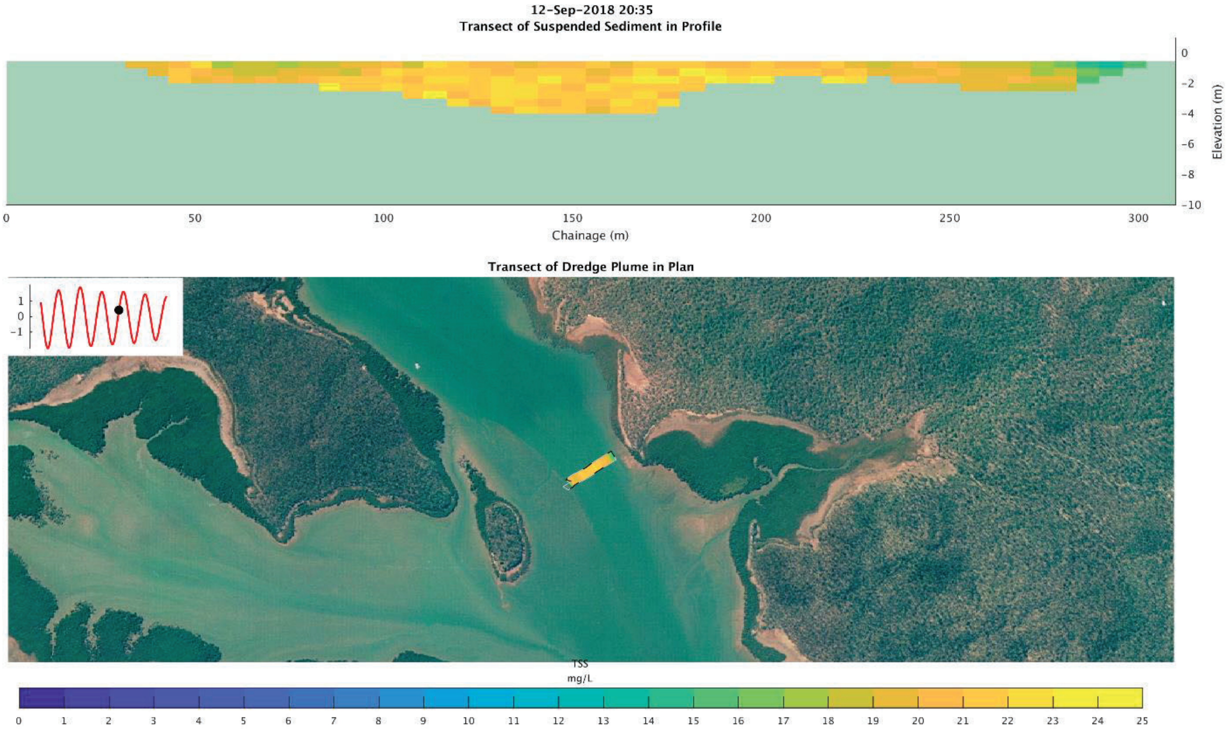


12-Sep-2018 20:13

Transect of Suspended Sediment, OBS Profile Included

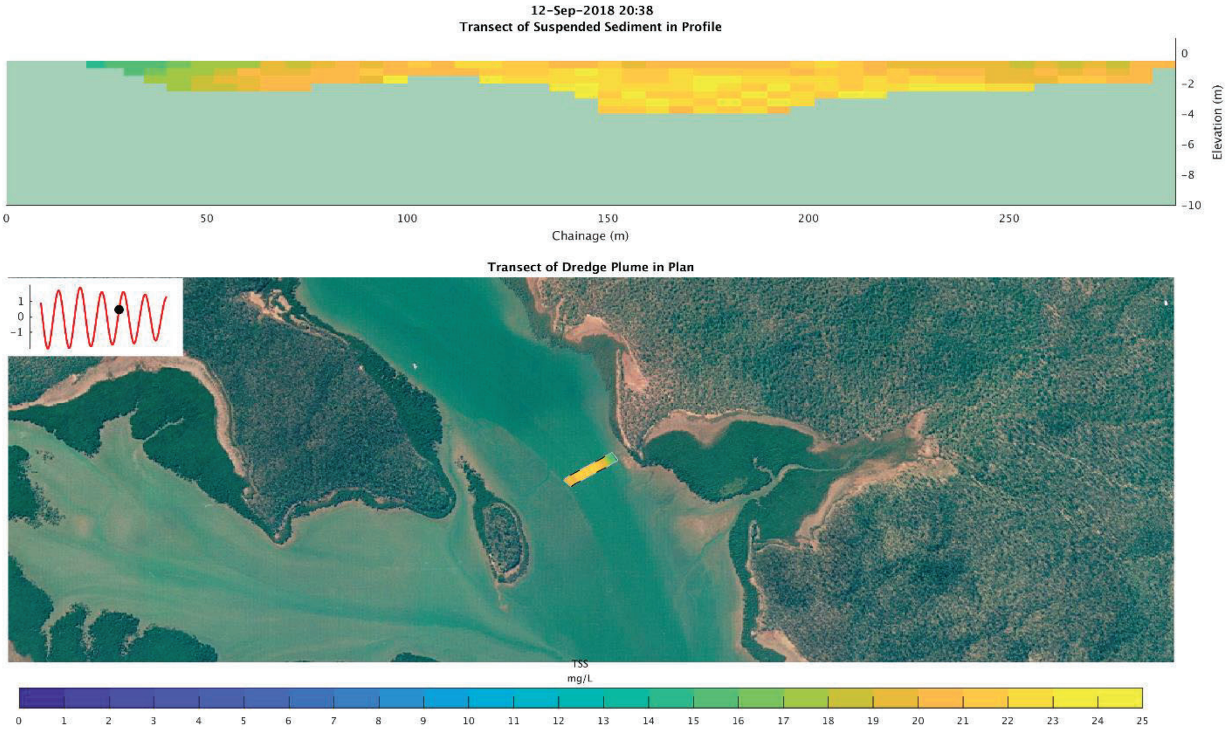
Transect of Dredge Plume in Plan

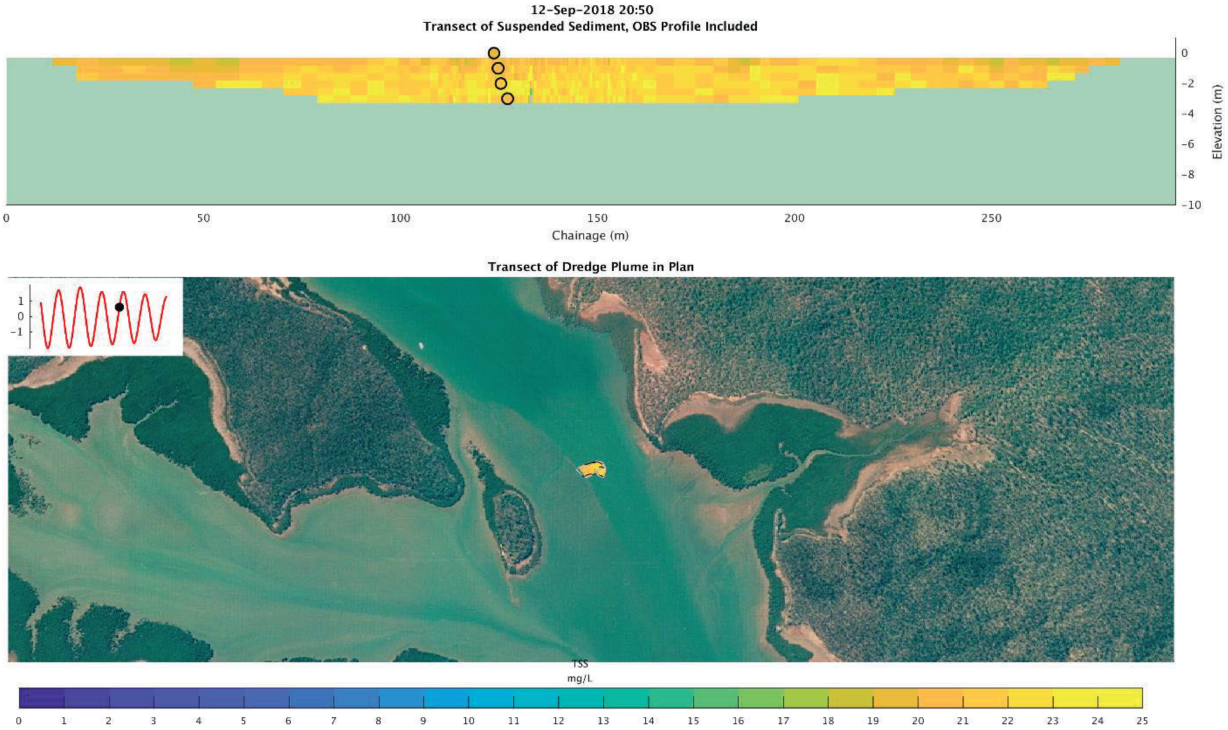


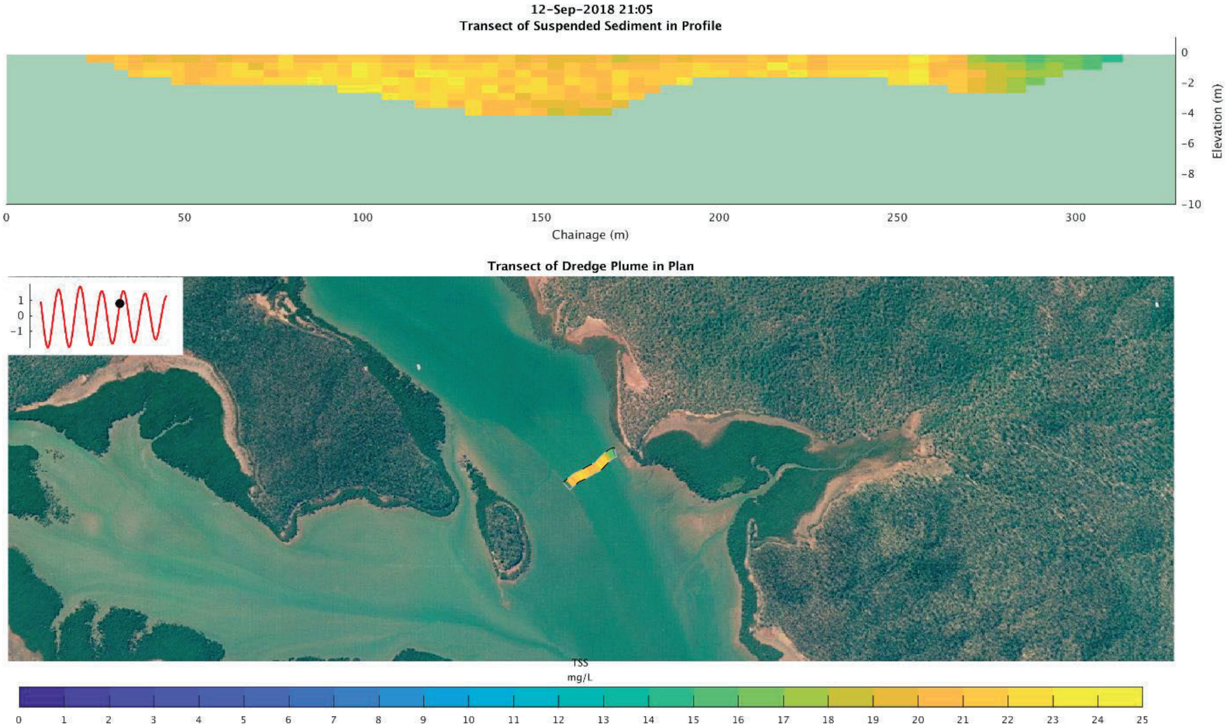
12-Sep-2018 20:35

Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan


12-Sep-2018 20:38
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

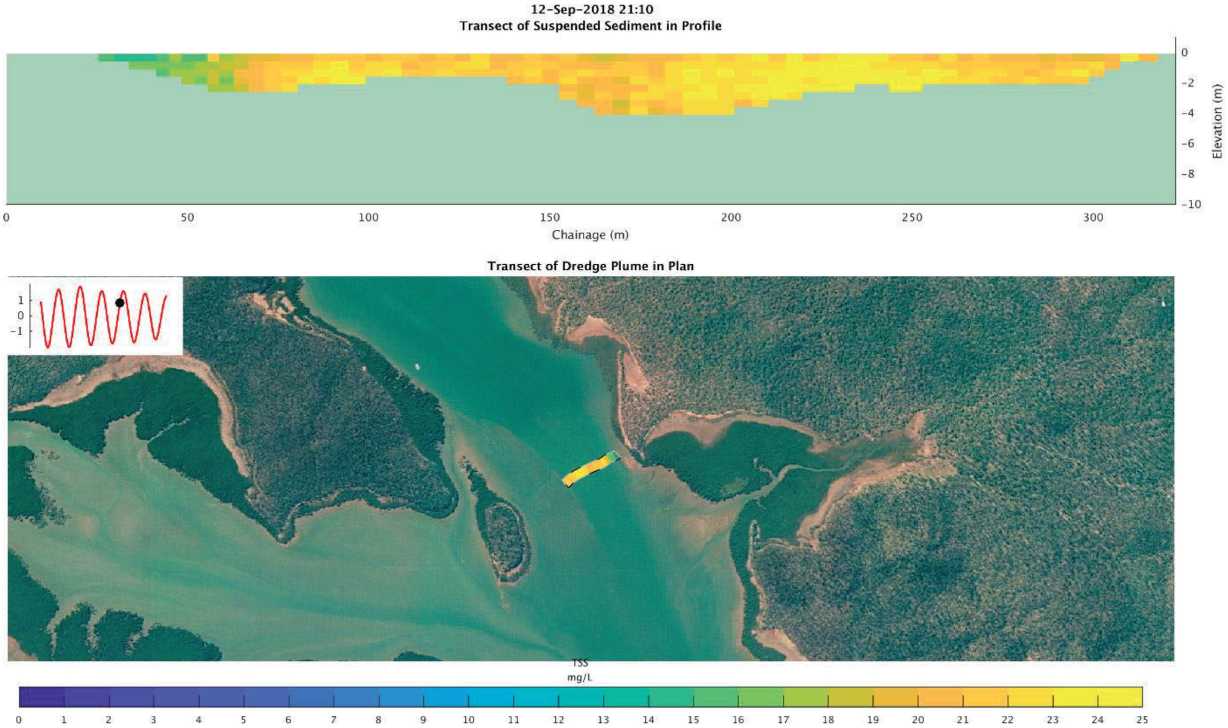

12-Sep-2018 20:50
Transect of Suspended Sediment, OBS Profile Included
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25



12-Sep-2018 21:05

Transect of Suspended Sediment in Profile

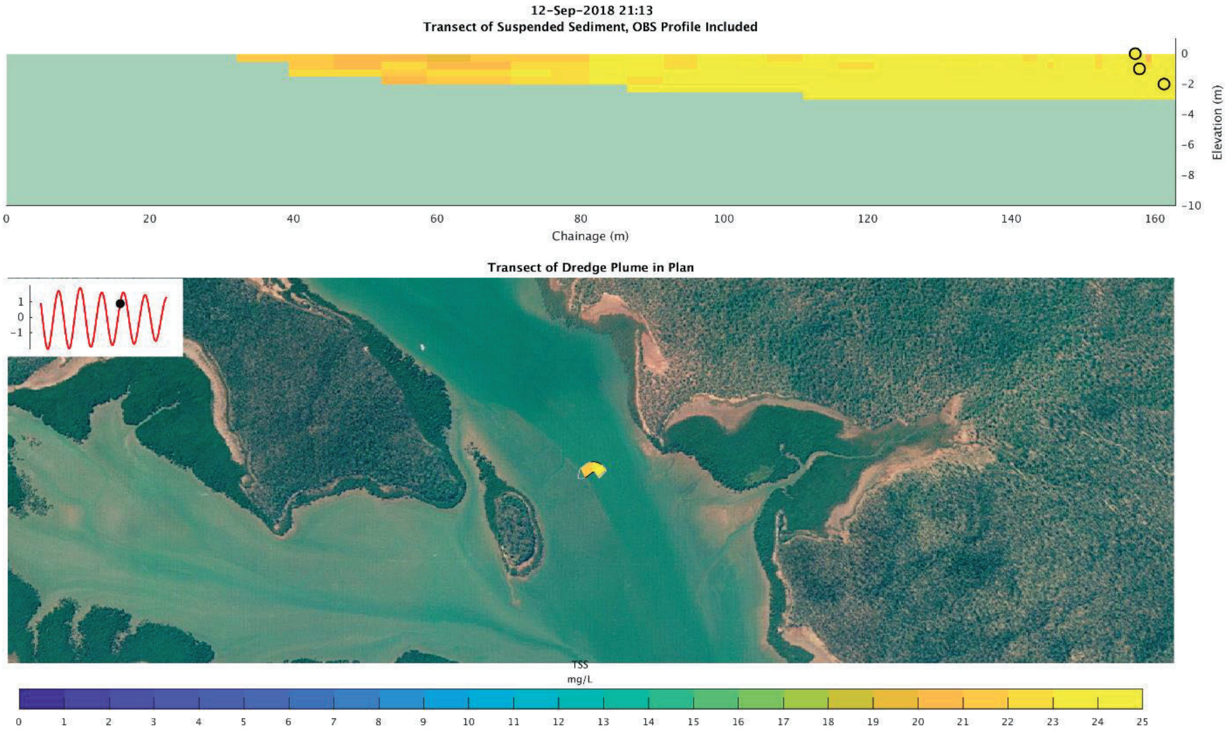
Transect of Dredge Plume in Plan



12-Sep-2018 21:10

Transect of Suspended Sediment in Profile

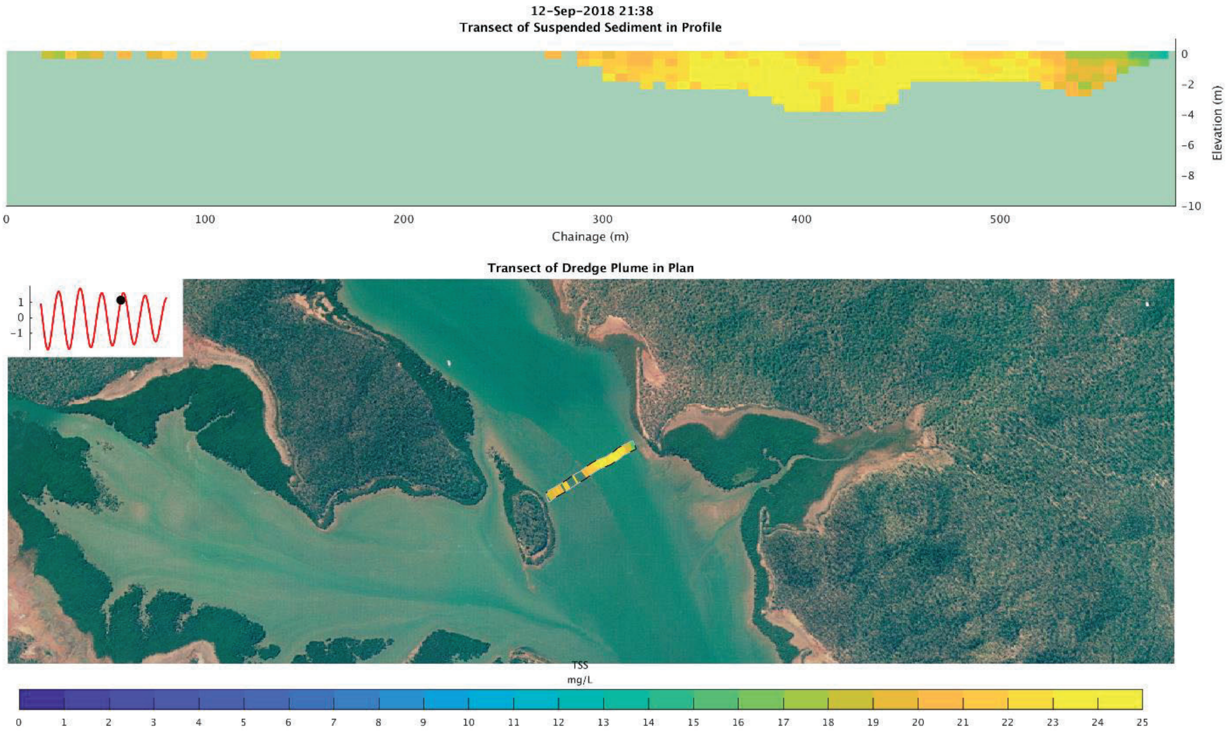
Transect of Dredge Plume in Plan



12-Sep-2018 21:13

Transect of Suspended Sediment, OBS Profile Included

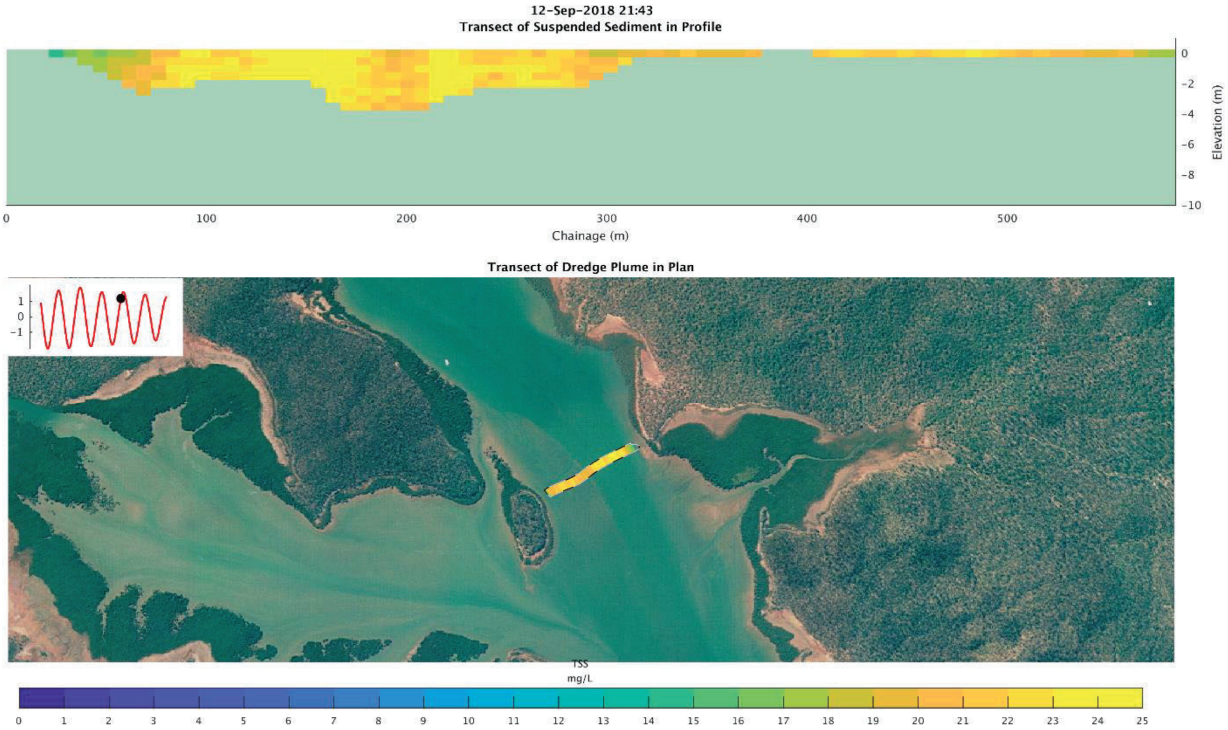
Transect of Dredge Plume in Plan



12-Sep-2018 21:38

Transect of Suspended Sediment in Profile

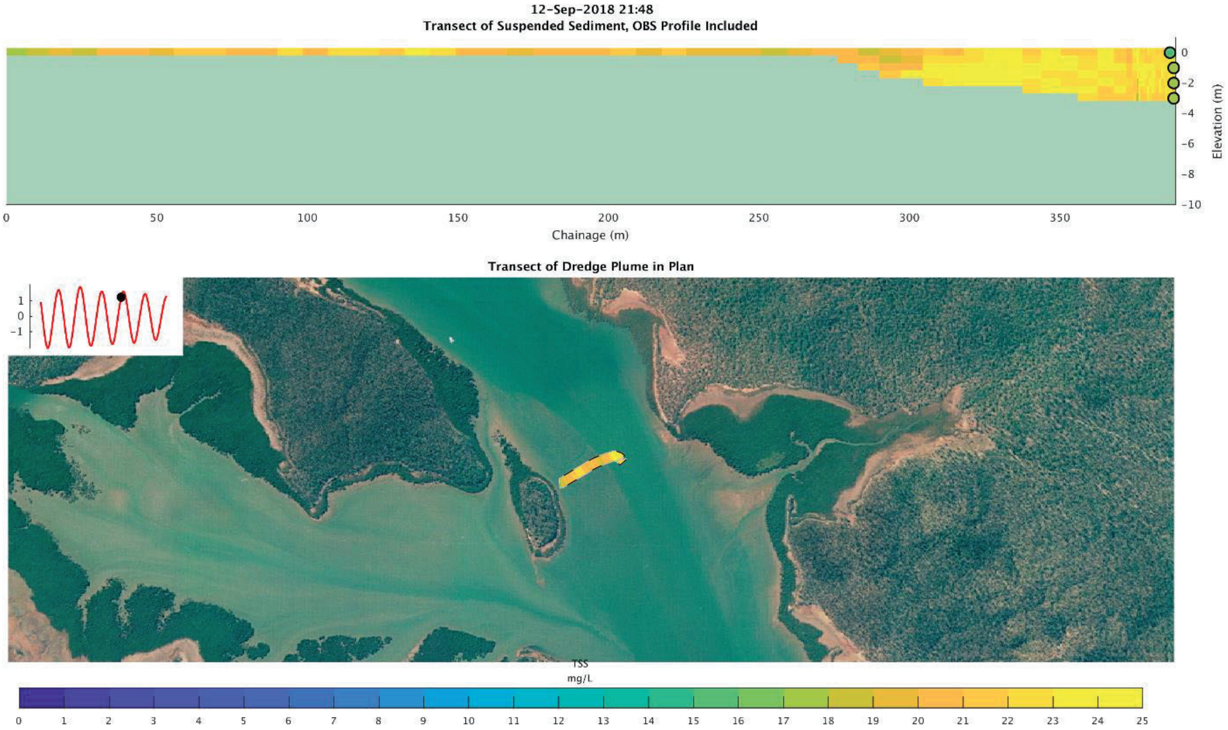
Transect of Dredge Plume in Plan



12-Sep-2018 21:43

Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan



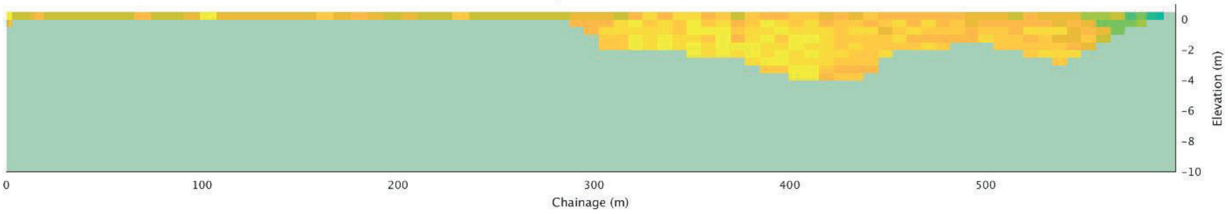
12-Sep-2018 21:48

Transect of Suspended Sediment, OBS Profile Included

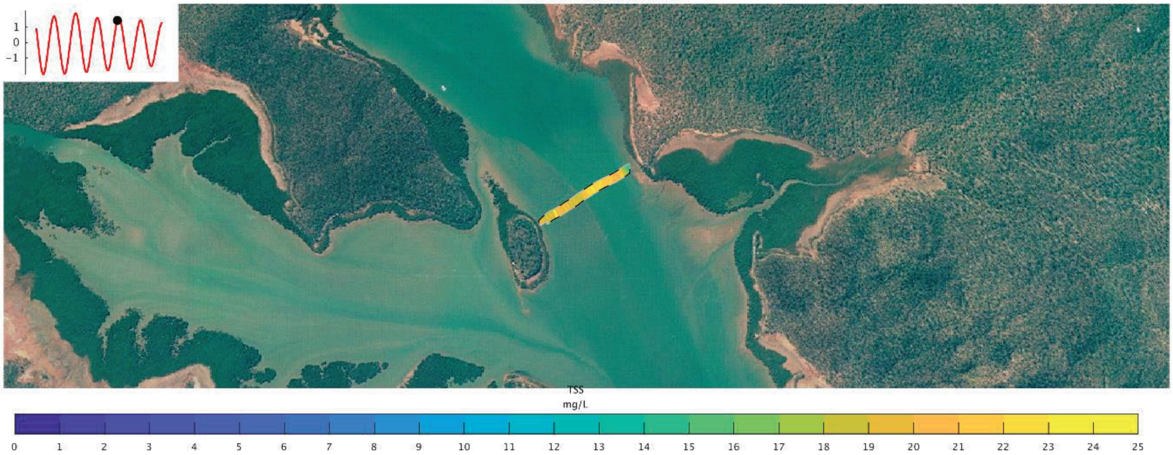
Transect of Dredge Plume in Plan

12-Sep-2018 22:14

Transect of Suspended Sediment in Profile

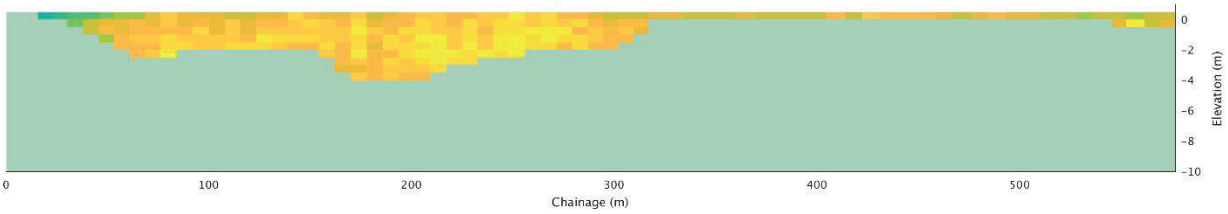


Transect of Dredge Plume in Plan

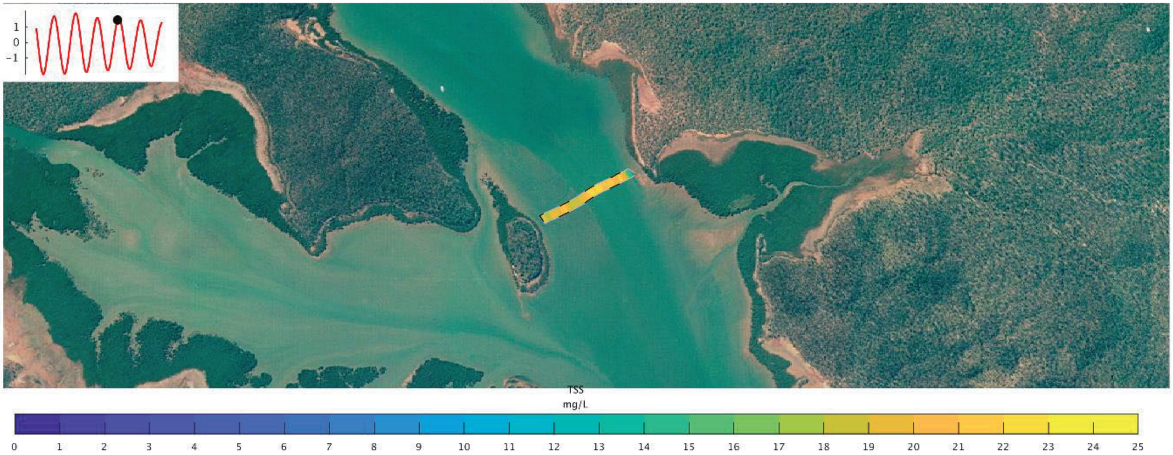


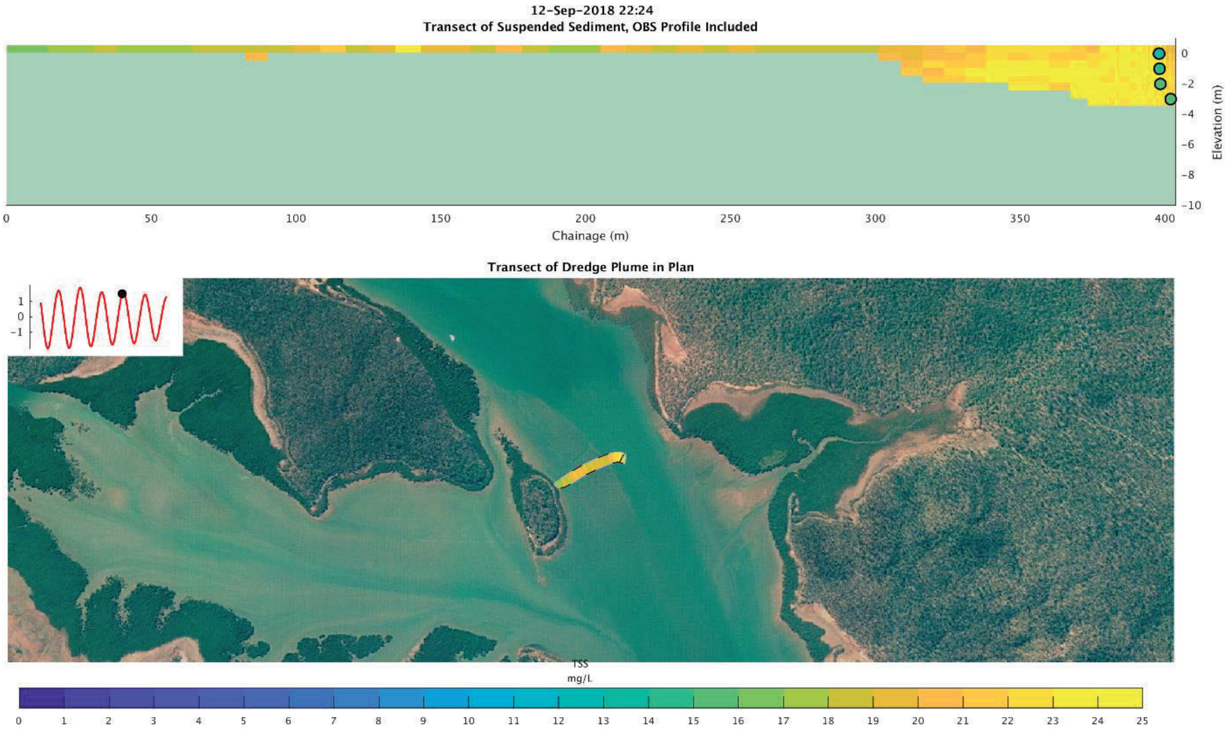
12-Sep-2018 22:19

Transect of Suspended Sediment in Profile



Transect of Dredge Plume in Plan

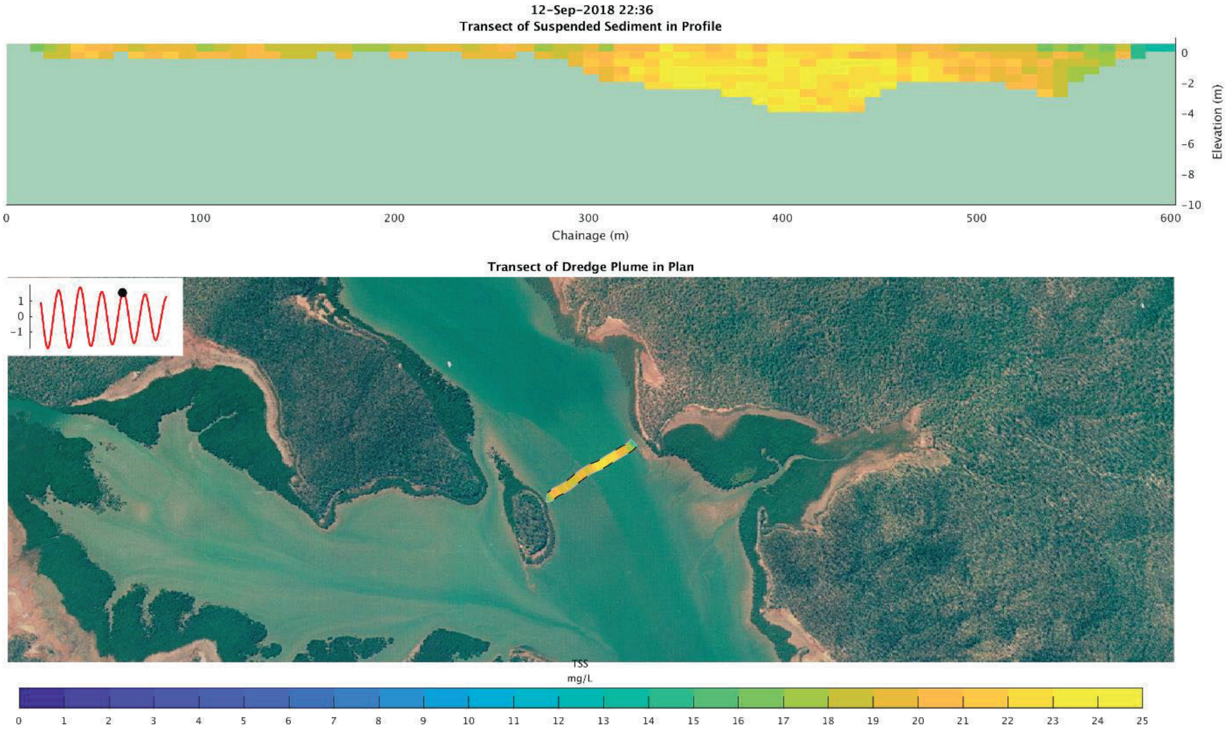




12-Sep-2018 22:24

Transect of Suspended Sediment, OBS Profile Included

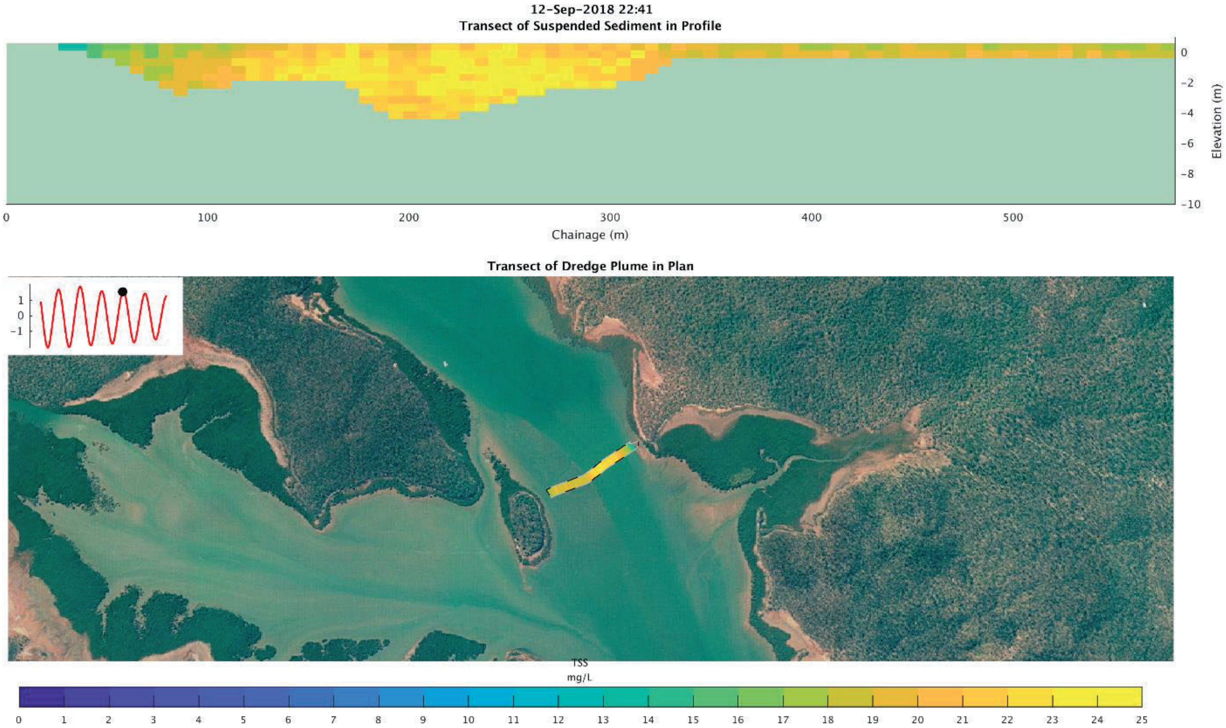
Transect of Dredge Plume in Plan

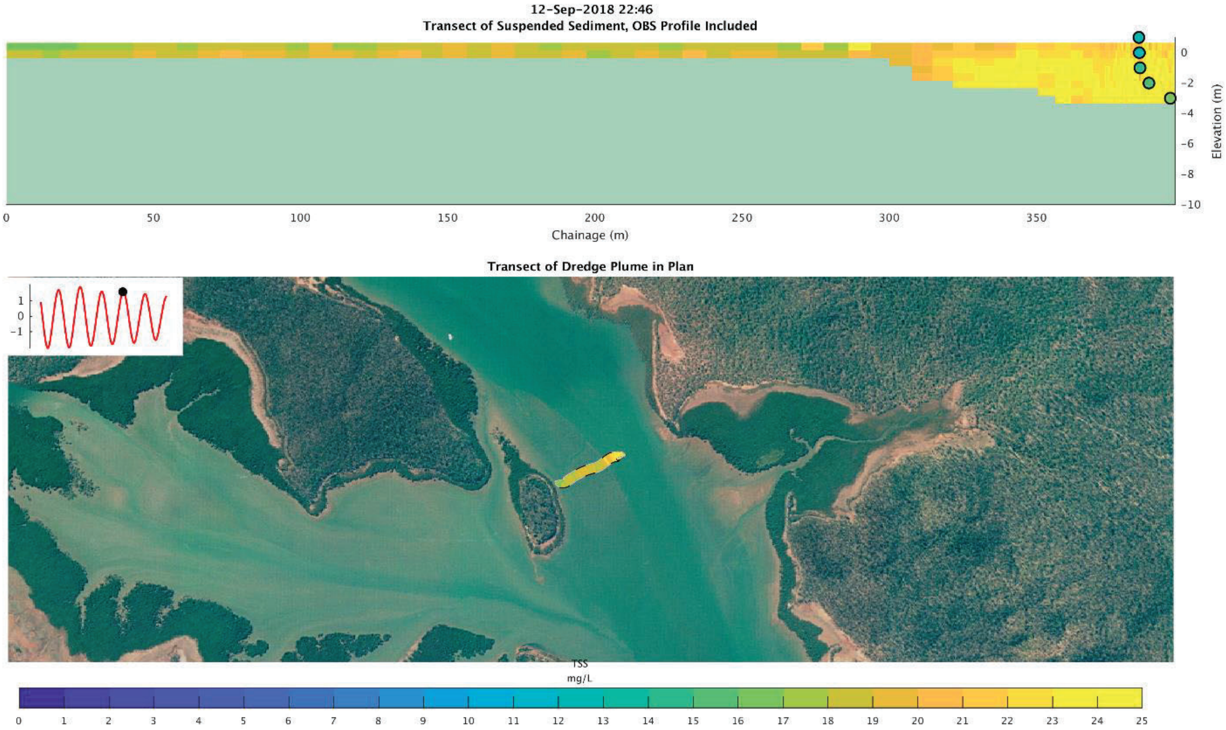


12-Sep-2018 22:36

Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan


12-Sep-2018 22:41
Transect of Suspended Sediment in Profile
0
-2
-4
-6
-8
-10
Elevation (m)
0
100
200
300
400
500
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25


12-Sep-2018 22:46
Transect of Suspended Sediment, OBS Profile Included
0
-2
-4
-6
-8
-10
Elevation (m)
0
50
100
150
200
250
300
350
Chainage (m)
Transect of Dredge Plume in Plan
1
0
-1
TSS
mg/L
0
1
2
3
4
5
6
7
8
9
10
11
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13
14
15
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17
18
19
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24
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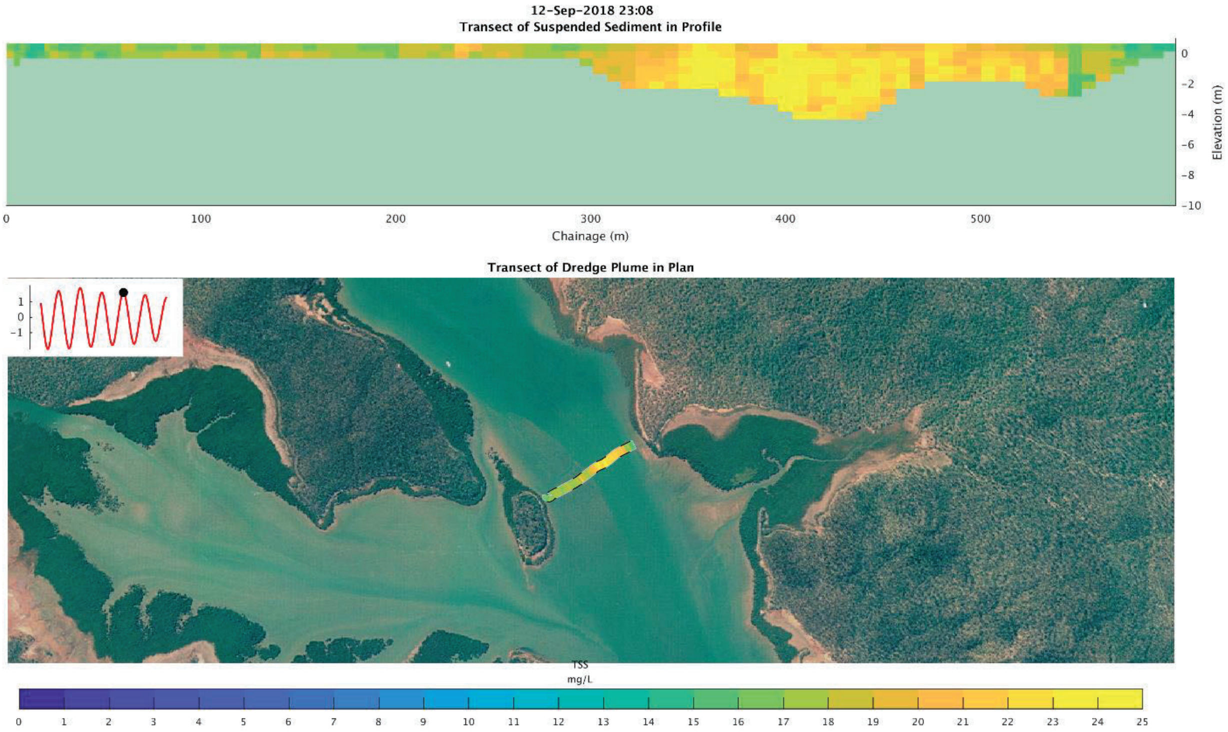
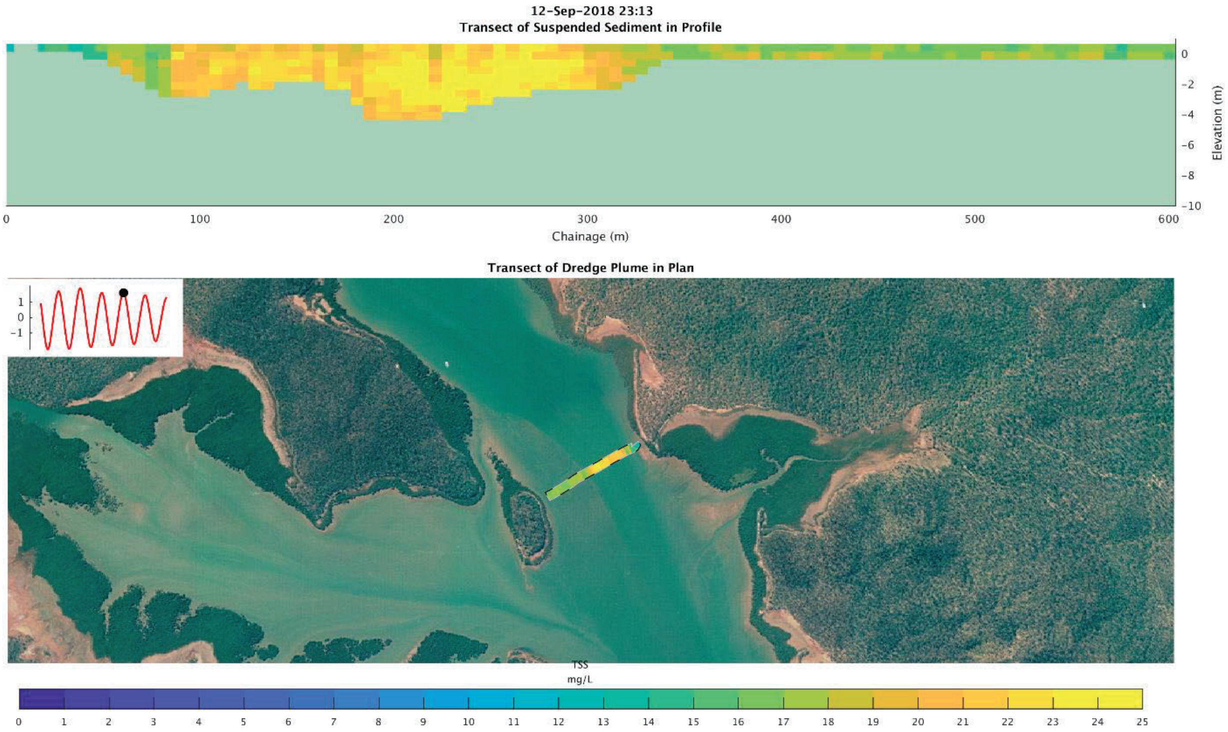


12-Sep-2018 23:08

Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan



12-Sep-2018 23:13

Transect of Suspended Sediment in Profile

Transect of Dredge Plume in Plan

Appendix B Additional Validation Plots

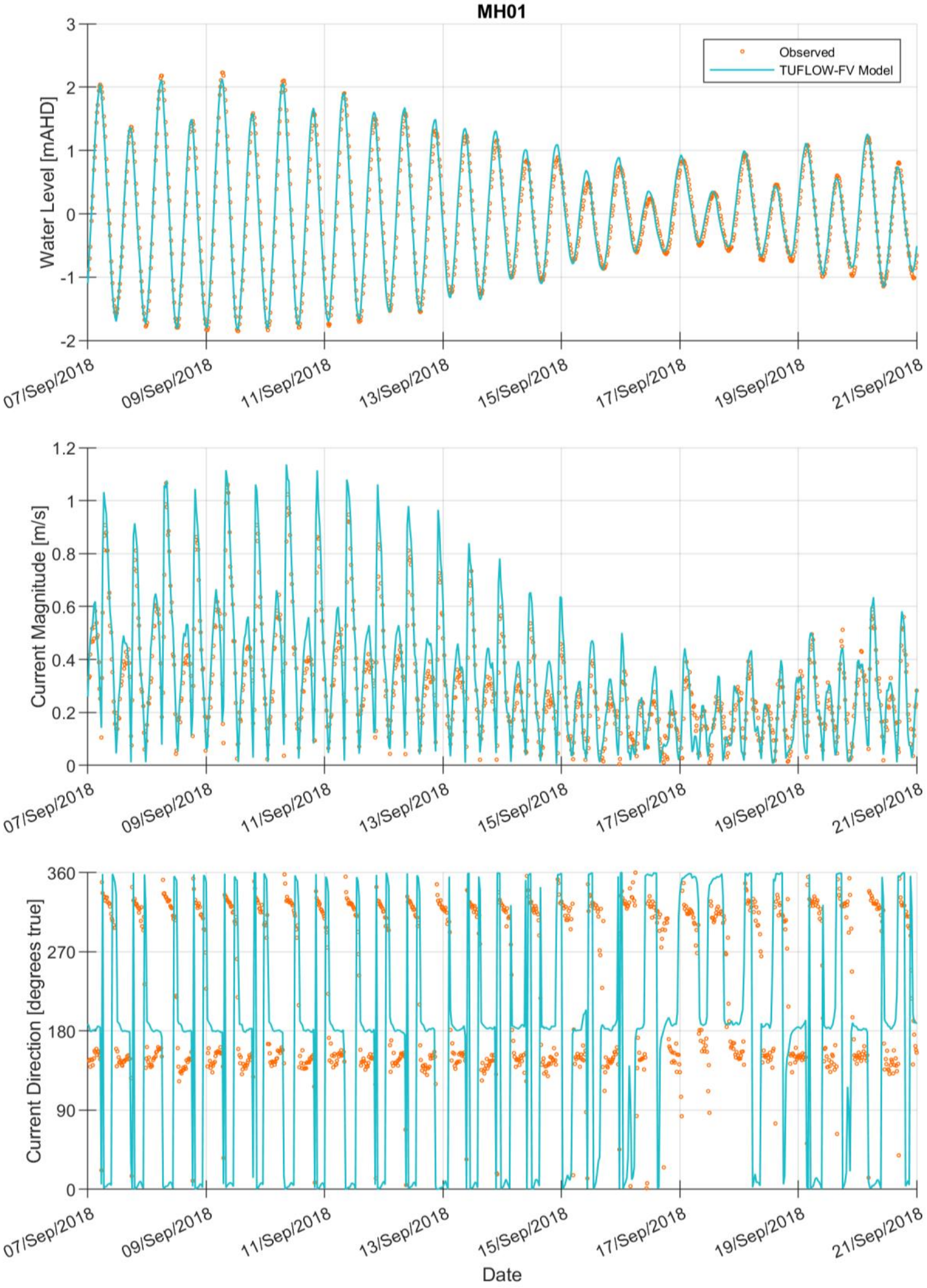


Figure B-1 Time series comparison of modelled and observed Water Level (Top), Current Magnitude (Centre) and Current Direction (Bottom) at MH01

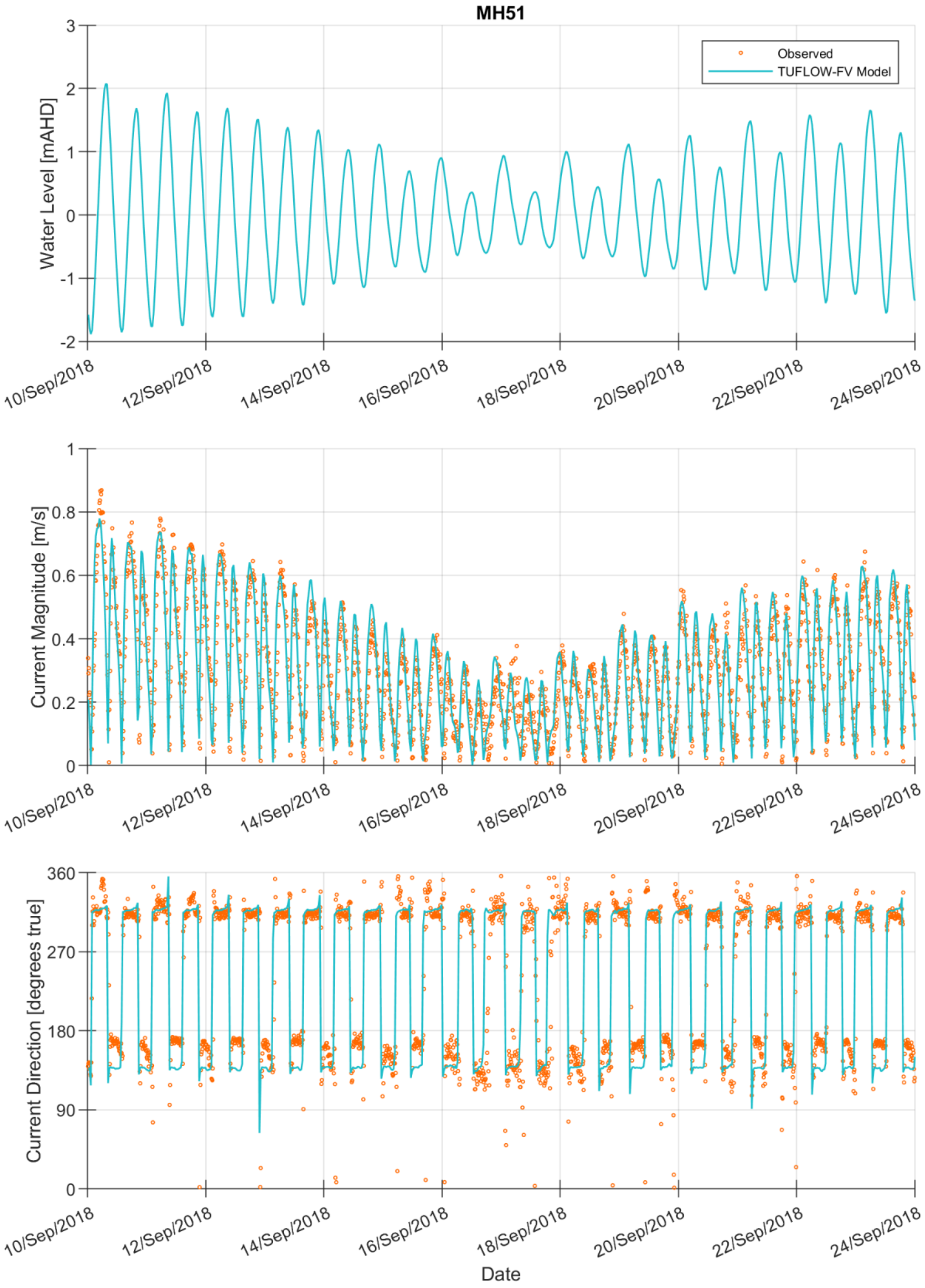


Figure B-2 Time series comparison of modelled and observed Water Level (Top), Current Magnitude (Centre) and Current Direction (Bottom) at MH51

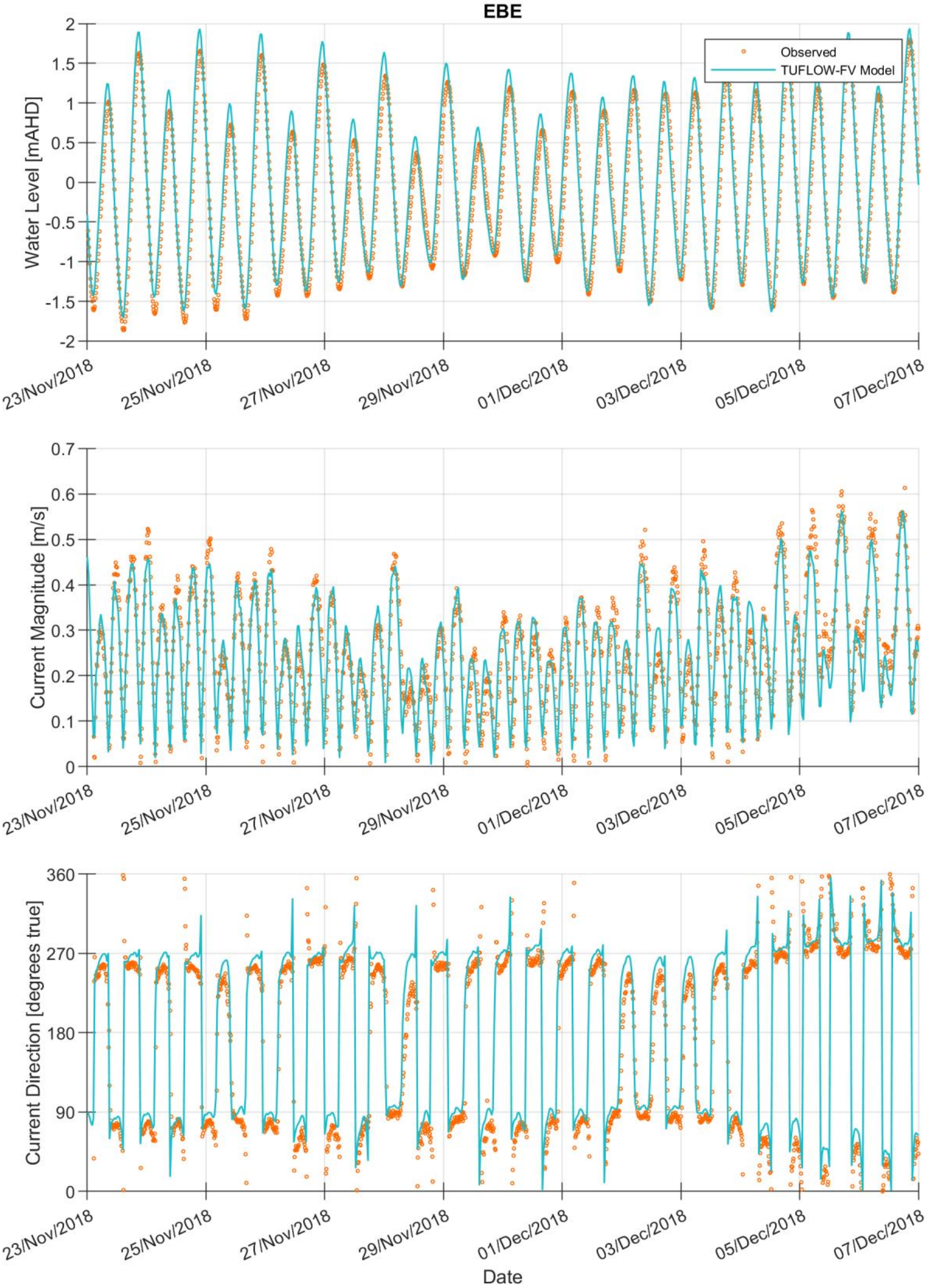


Figure B-3 Time series comparison of modelled and observed Water Level (Top), Current Magnitude (Centre) and Current Direction (Bottom) at EBE

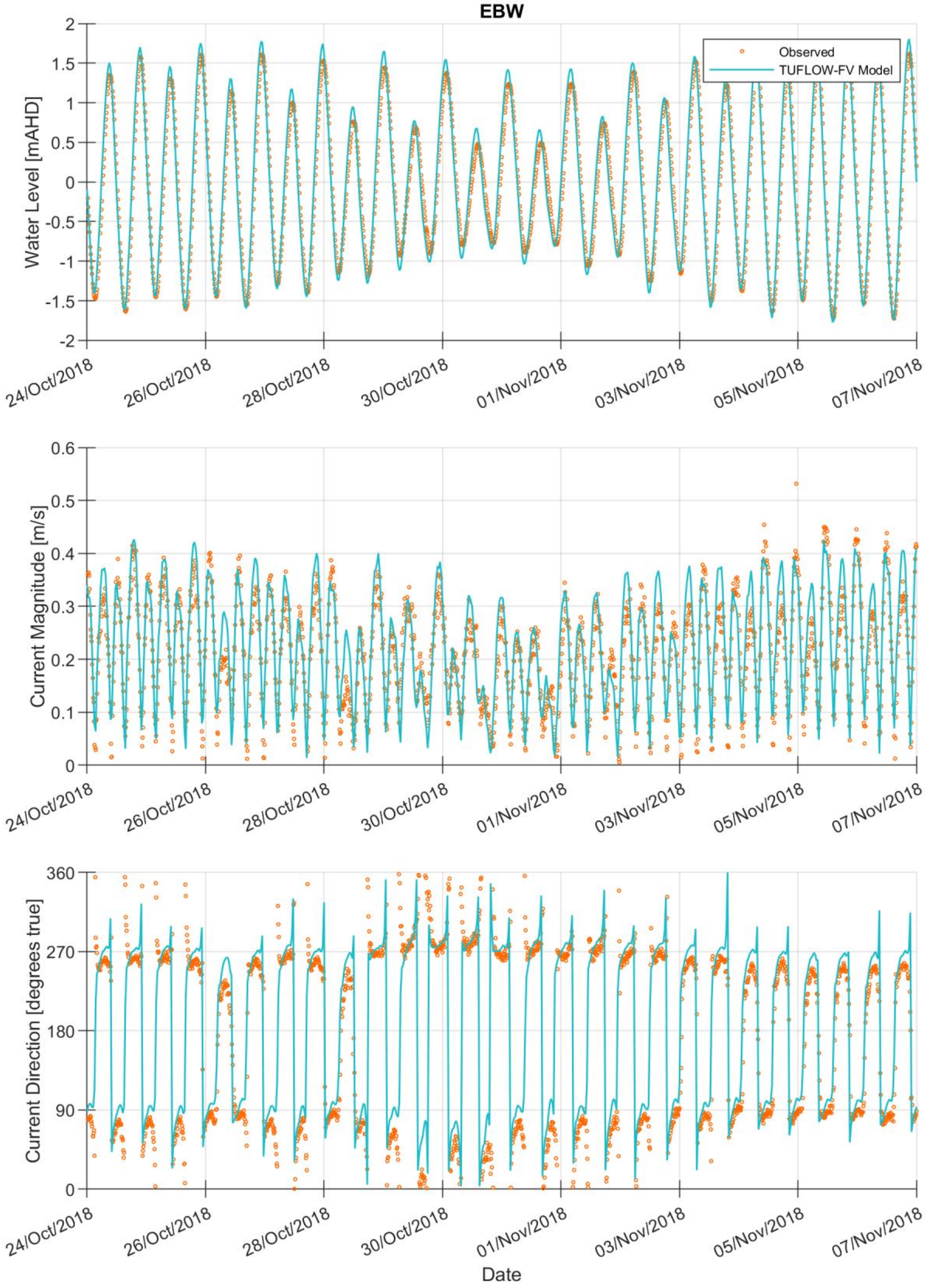


Figure B-4 Time series comparison of modelled and observed Water Level (Top), Current Magnitude (Centre) and Current Direction (Bottom) at EBE

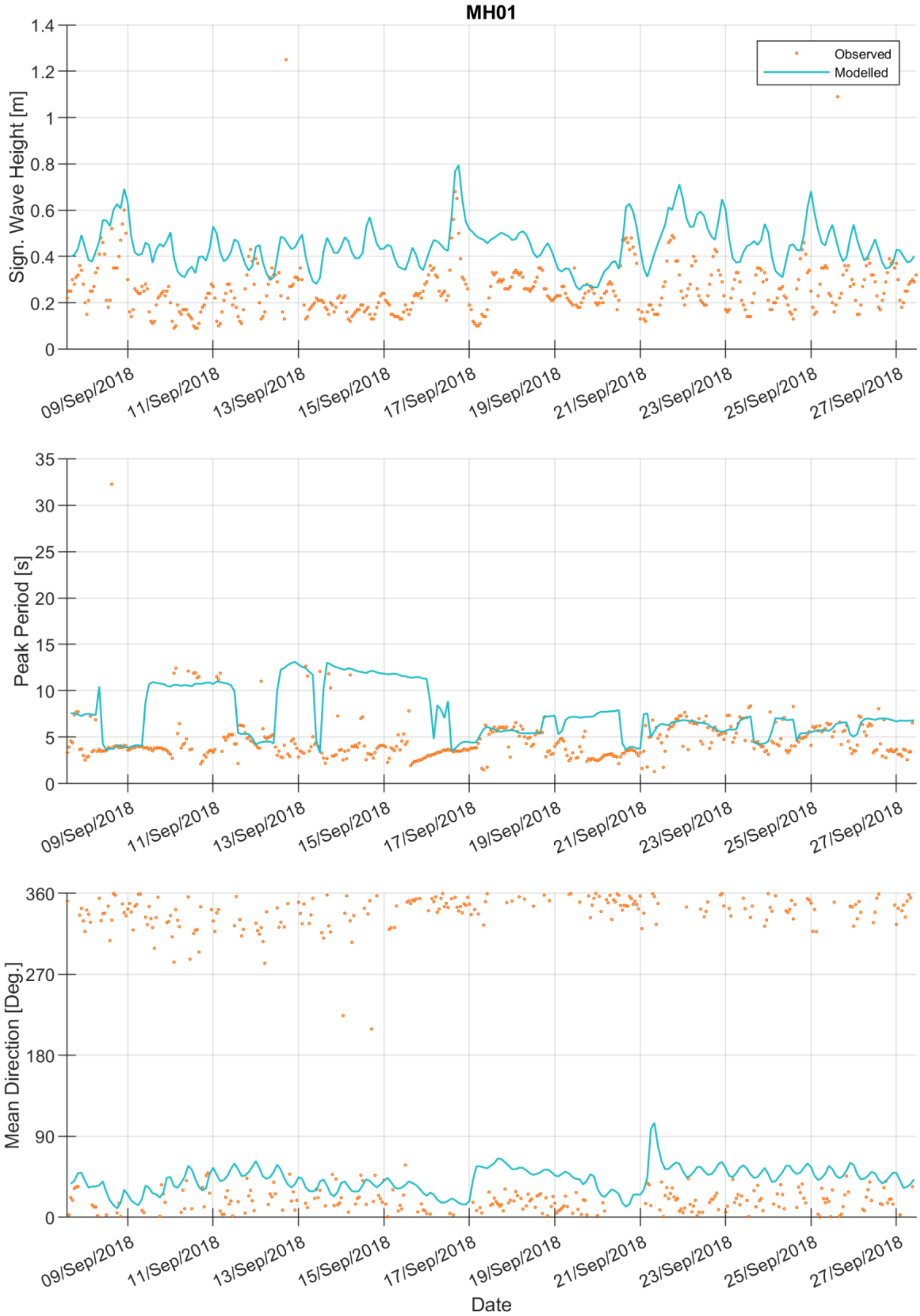


Figure B-5 Timeseries comparison of modelled and observed Wave Height (Top), Peak Period (Centre) and Peak Direction (Bottom) at MH01

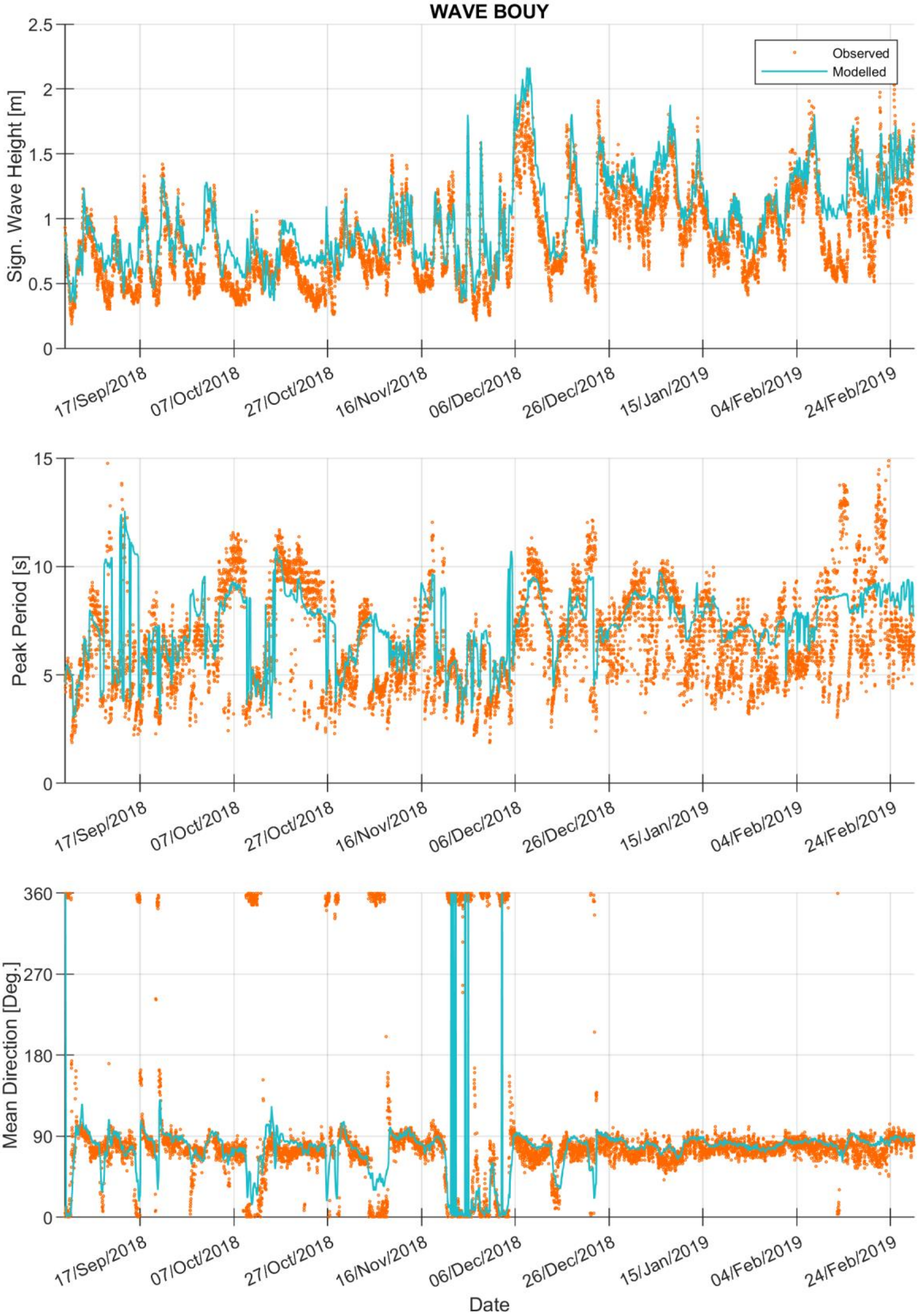


Figure B-6 Timeseries comparison of modelled and observed Wave Height (Top), Peak Period (Centre) and Peak Direction (Bottom) at Gladstone Wave Buoy

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