# Port of Bundaberg Sediment Budget: Model Development and Validation

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# Document Control Sheet

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| **Synopsis: Development and validation of TUFLOW FV and SWAN models for the Port of Bundaberg to assist with development of a quantitative sediment budget.** | | |

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# 1 Introduction

## 1.1 Background

GPC commissioned BMT to develop and validate a TUFLOW FV numerical hydrodynamic and sediment transport model to simulate the sediment dynamics within the Port of Bundaberg (PoB) to inform the PoB quantitative sediment budget.

## 1.2 Study Objectives and Scope

The objective of this study is to develop and validate the TUFLOW FV numerical hydrodynamic and sediment transport model for the PoB to demonstrate its suitability for use in developing a quantitative sediment budget. The model was calibrated using data from the 2020 monitoring campaign and 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 2020 monitoring campaign (29 April 2020 – 28 May 2020).
- Simulation of additional periods
    - Nov 2012 to Apr 2013 (inclusive) – 6 month wet season period which includes an extreme river discharge event (January 2013, the largest for Burnett River over last 10 years) and above average wave conditions; and
    - Nov 2014 to Nov 2015 (inclusive) – 12 month period that includes a low discharge wet season with a single large wave event (TC Marcia) and then a typical dry season. This 12 month period included a typical maintenance dredging campaign - 64,000 m$^3$ dredged in May/June.
- Extraction of net sediment mass fluxes for areas of interest, and across selected transects within the PoB.

# 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 TUFLOW FV model mesh is composed of a regional component (Figure 2-1) and a nested component (Figure 2-2). The boundary of the nested model is provided with water levels, temperature, salinity and suspended sediment outputs from the regional model.

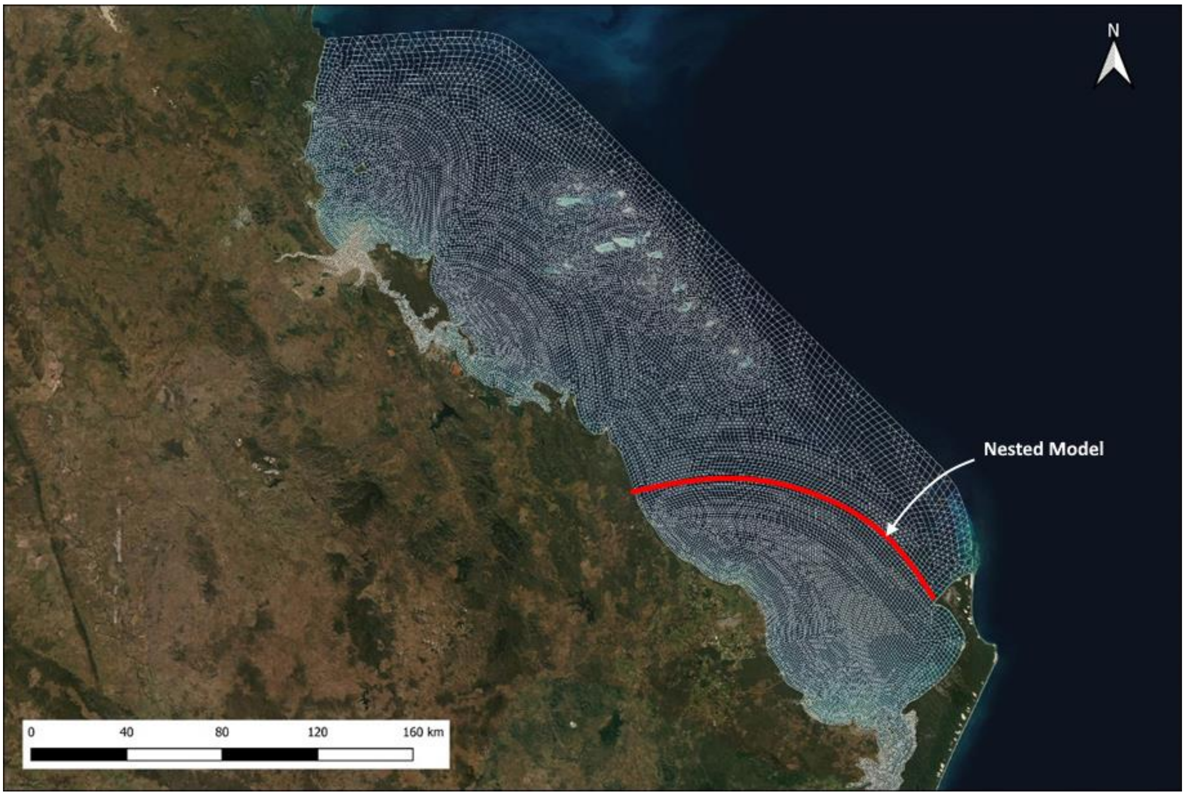

Figure 2-1 TUFLOW FV Model Mesh – Regional Model Domain

Figure 2-2 TUFLOW FV Model Mesh – Local Model Mesh

## 2.3 Bathymetric Data

Bathymetric data in the vicinity of the PoB was sourced from survey data and other publicly available datasets. Bathymetric data for the majority of the model domain was sourced from Project 3DGBR: a high-resolution depth model for the Great Barrier Reef and Coral Sea (Beaman 2018, 30m horizontal resolution). A number of hydrographic survey data sets collected by MSQ and BMT for the channel areas were compiled, and a unified DEM was developed which incorporated the best available data in each part of the model. 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 2-3 and Figure 2-4.

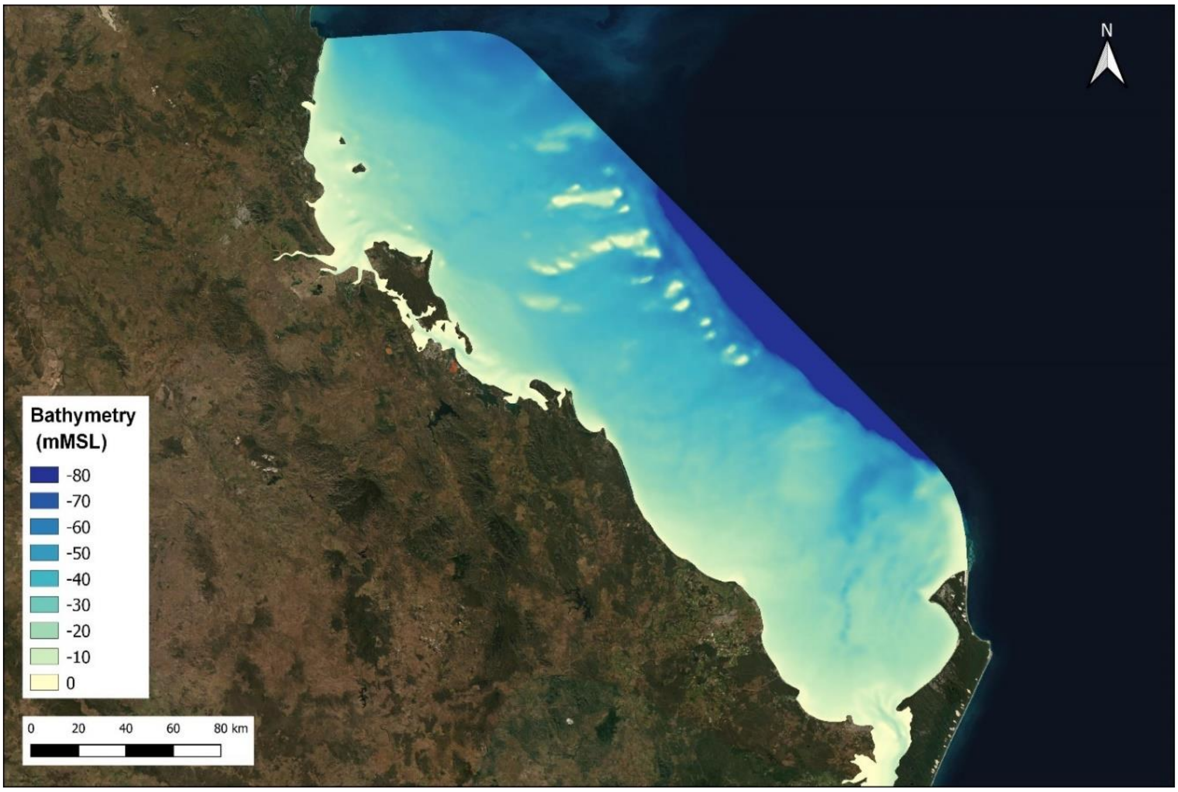

Figure 2-3 Model Bathymetry – Regional Model Domain

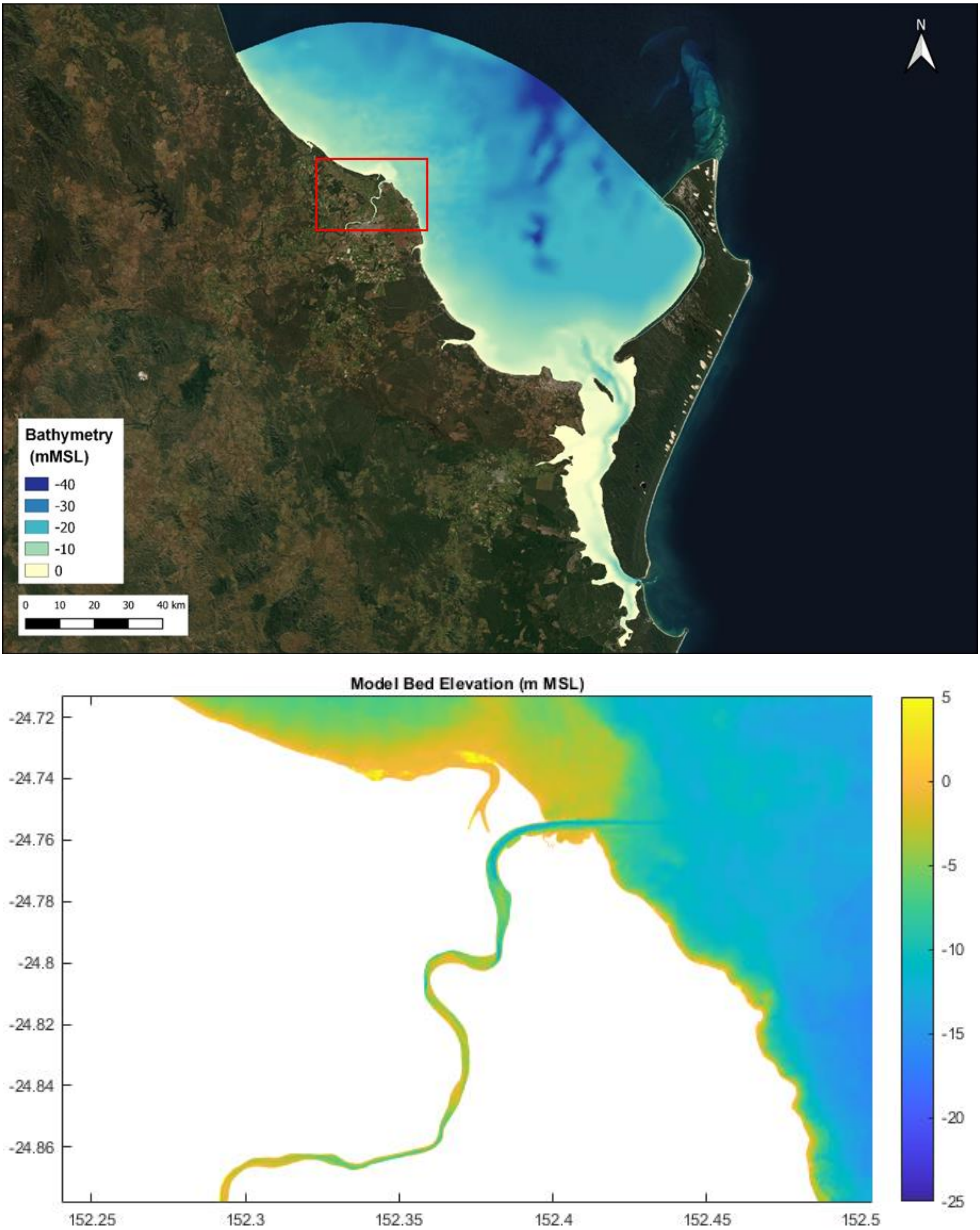

Figure 2-4 Model Bathymetry – Local Model Domain (Bottom Panel Domain is Red Box in Top Panel)

# 3 Wave Model Description

A wave model 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 (~500 m resolution), and a nested local-scale grid (~100 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.

### 4.1.5 Swell

The regional-scale wave model was supplied with swell boundary conditions from the ECMWF ERA-5 model.

### 4.1.6 Freshwater Inflows

Freshwater inflows from the Burnett River are included in the model. Freshwater inputs for the model calibration and validation periods were obtained from DNRM data (Department of Natural Resources and Mines, 2019). The sediment fluxes associated with these freshwater flows were also included in the ambient sediment dynamics modelling (and calibration process).

# 5 Model Calibration

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 |
|---|---|---|
| Bundaberg Wave Buoy | Wave buoy with integrated parameters | 01/01/2020 – 31/03/2020 |
| Port of Bundaberg GPC AWAC | Water levels, vertically resolved current speeds and direction, turbidity data | 28/04/2020 – 28/05/2020 |
| ADCP Transects | Flow rate and sediment flux across channel, velocity magnitude and direction | 08/05/2020 – 09/05/2020 |
| Bundaberg (Burnett Heads) Tide Gauge | Recorded water level | 01/01/2020 – 02/09/2020 |

A BMT report describes the turbidity data collected by GPC along with other turbidity datasets (BMT, 2020a). A description of the ADCP boat-mounted transect measurements that were undertaken by BMT in early May 2020 is also provided in a separate technical report (BMT, 2020b).

The hydrodynamic model performance was assessed by comparing the water level and depth-averaged current velocity output to the data collected by GPC in April - May 2020. The water level and flow velocity comparison at the GPC Port of Bundaberg AWAC (for location see Figure 5-1) is provided in Figure 5-2. The model reproduces the observed tidal variation of water levels very well, with only minor differences in tidal range between the model and measurements. The depth-averaged flow velocity is also very well reproduced by the model.

The performance of the SWAN wave model was assessed by comparing the modelled significant wave height, peak period and peak wave direction with the measurements from the Bundaberg Waverider Buoy (maintained by the Queensland Department of Environment and Science). The model reproduces the measured wave parameters accurately, as shown in Figure 5-3, with only a occasional periods where the modelled significant wave height is lower than the measurements.

The top panel of Figure 5-4 shows the modelled flow rate across the transect compared to the flows measured using a boat-mounted ADCP. Positive flow/flux is into the Port, negative flow/flux is out of the Port. The modelled and measured flow rate corresponds fairly well, although the model appears to underestimate the ebb tidal flow rate and underestimates the duration of the incoming flood tide.

The bottom panel of Figure 5-4 shows the modelled and measured sediment flux across the transect. The model estimates the time series of the sediment flux reasonably well, considering the difficulty of characterising the complexity of the sediment transport processes in the model.

Figure 5-5 shows the modelled and measured turbidity at the Port of Bundaberg GPC AWAC deployment location. The modelled TSS was converted to an equivalent turbidity using the relationship 1 NTU = 1.687 mg/L, which was the best fit relationship from comparisons between measured turbidity and lab measurements of TSS from samples collected during the field work in

Bundaberg. An additional offset of 3 NTU was applied to the model output to represent a base level of turbidity apparent in the measurements that could be attributed to organic matter. The model reproduces the spring-neap variability in the suspended sediment concentrations moderately well but tends to underestimate the observed variation during the tidal cycle.

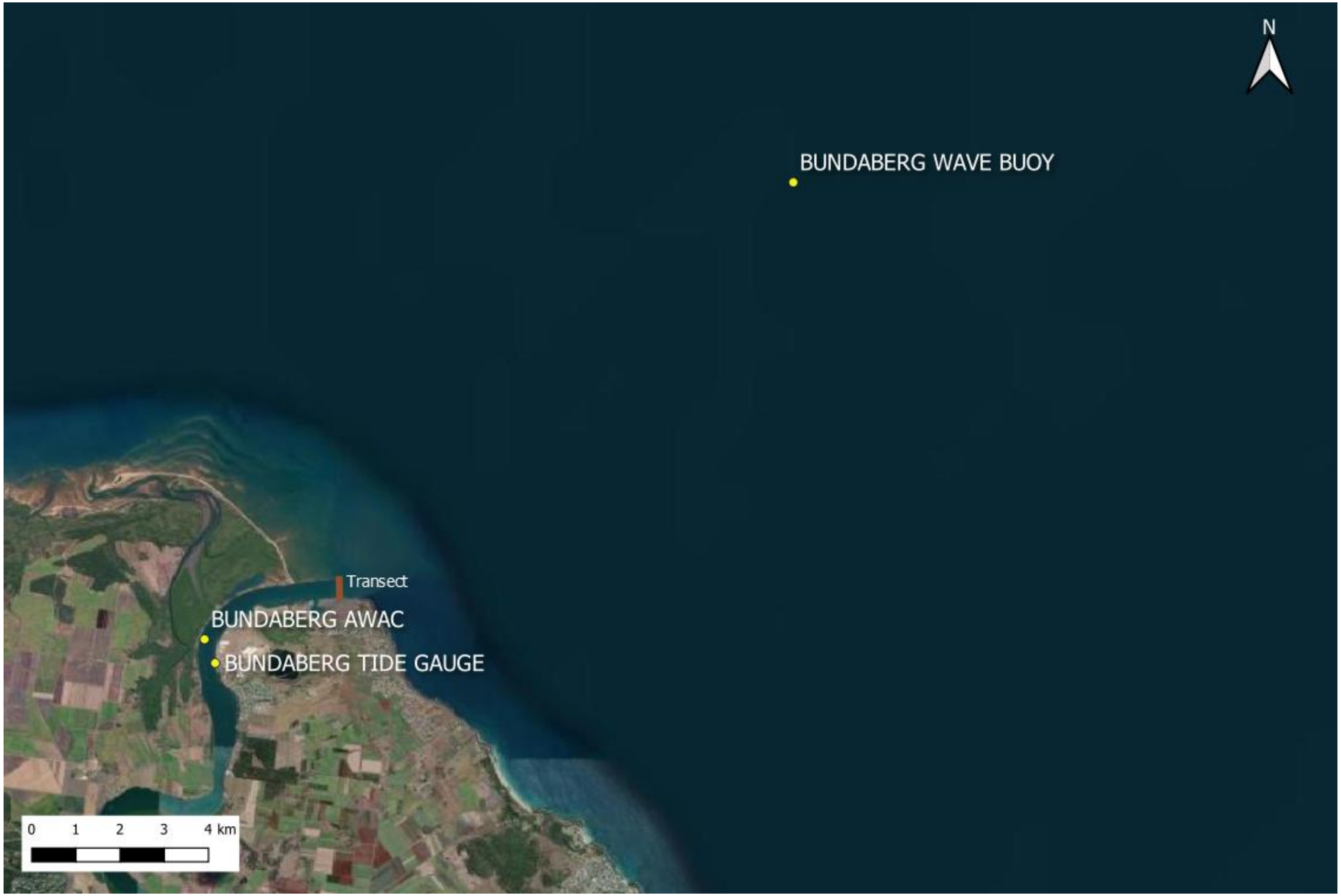

Figure 5-1 Calibration and Reporting Points

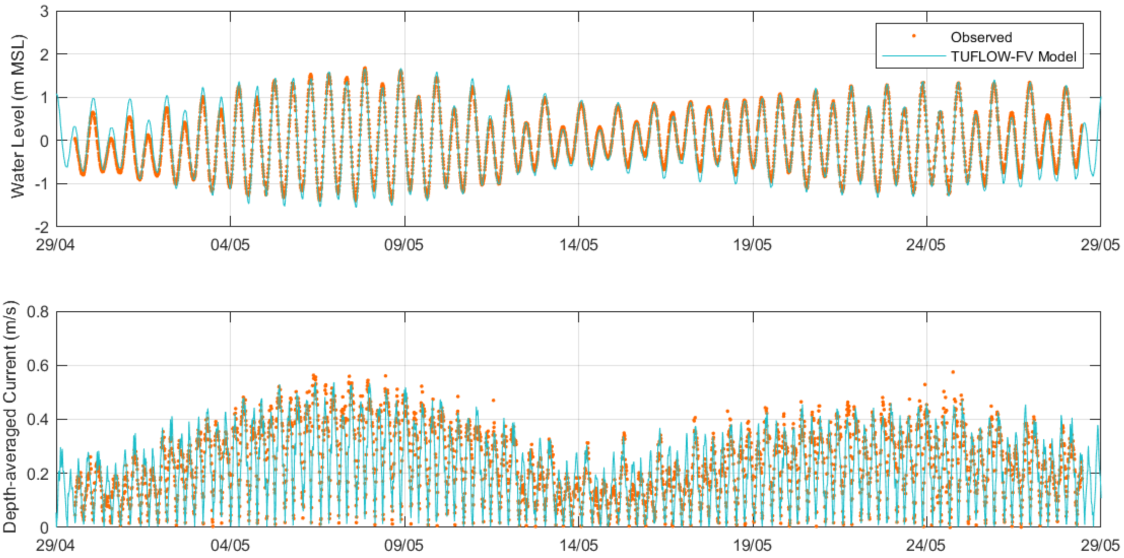

**Figure 5-2 Timeseries comparison of modelled and observed Water Level (Top) and Current Magnitude (Bottom) at Port of Bundaberg GPC AWAC**

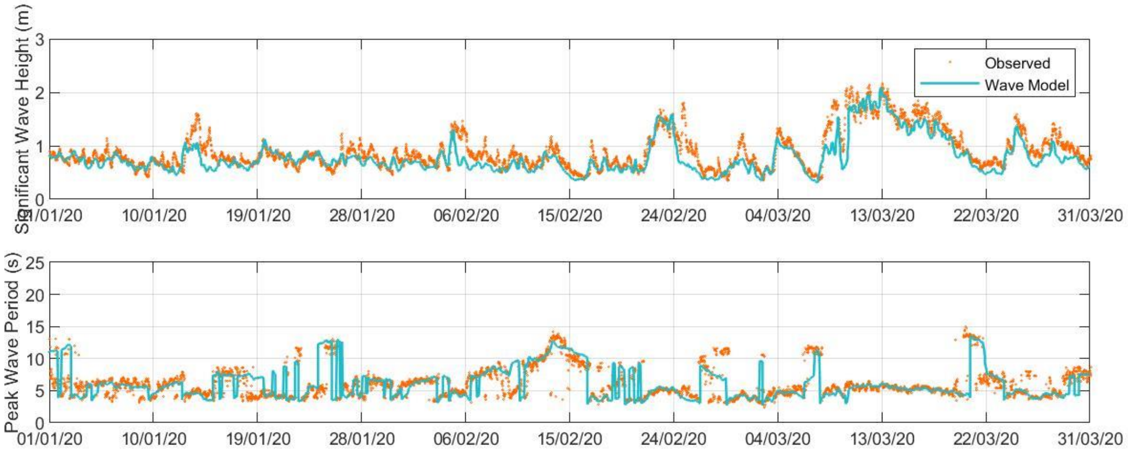

**Figure 5-3 Time series Comparison of Modelled and Observed Significant Wave Height (Top), Peak Wave Period (Bottom) at the Bundaberg Wave Buoy**

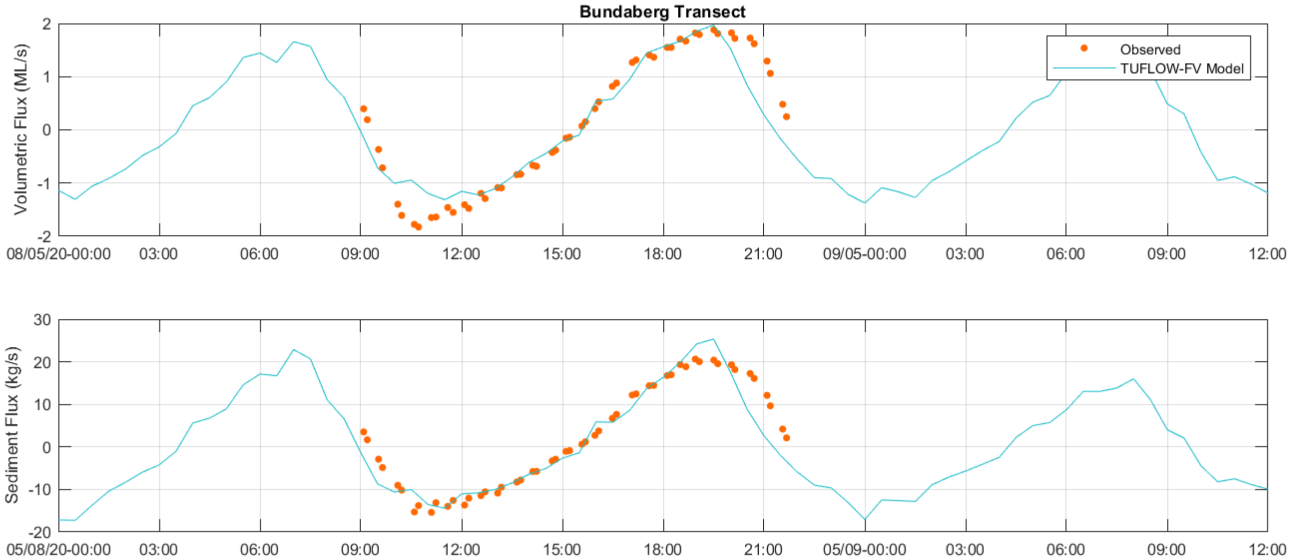

Figure 5-4 Time Series Comparison of Modelled and Observed Transect Flow Rate (Top) and Sediment Mass Flux (Bottom) (Ref Figure 5-1 for Location)

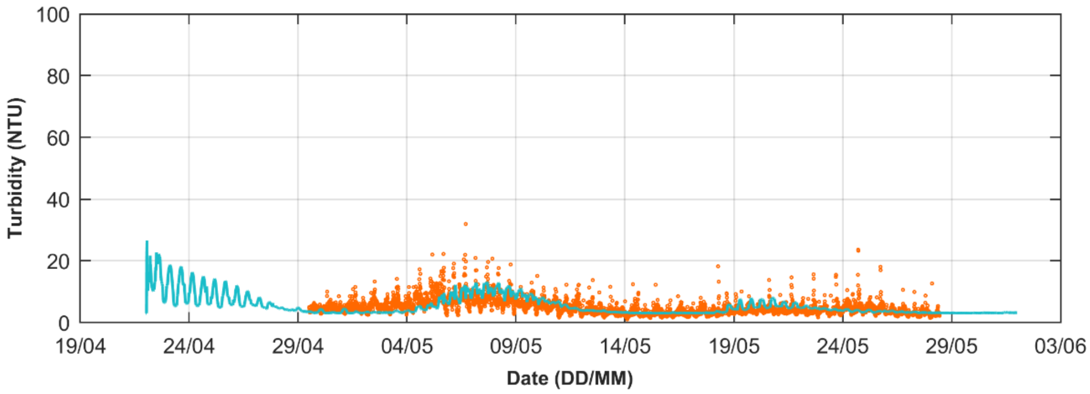

Figure 5-5 Modelled vs Measured Turbidity (at Port of Bundaberg GPC AWAC)

# 6 Model Hindcasts

Two additional hindcast simulations for the PoB 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 (01/11/2012 – 01/05/2013) included an extreme rainfall event in late January in the PoB region associated with ex-tropical cyclone Oswald, which resulted in significant discharge of turbid water from river systems including the Burnett. The inflow hydrograph from the Burnett River from the simulation period is shown in Figure 6-1.

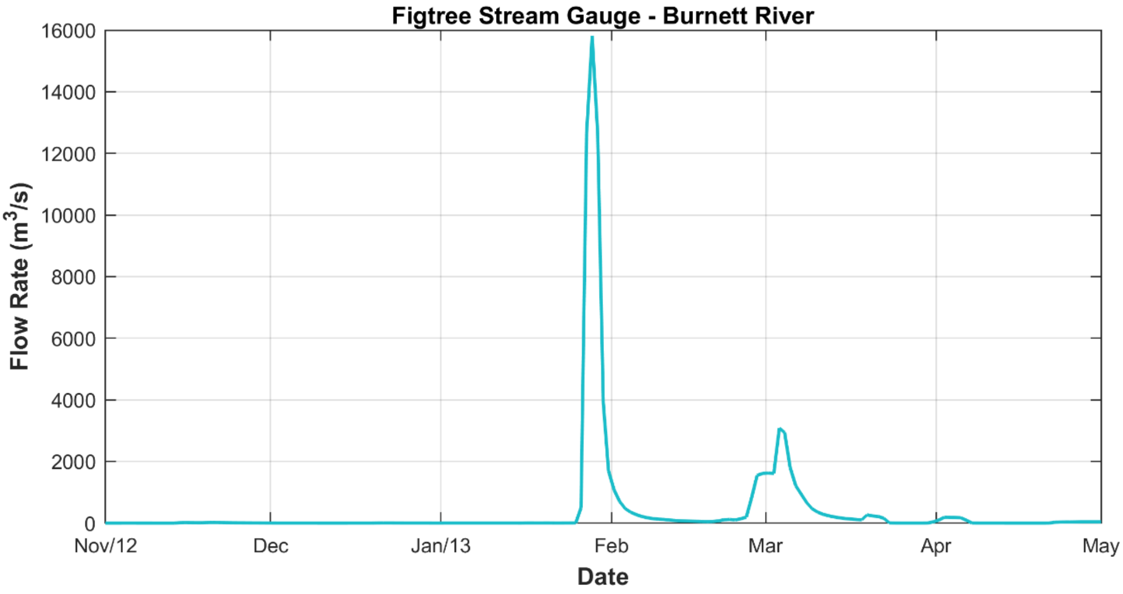

**Figure 6-1 Burnett River Hydrograph from the Figtree Gauge 2012-2013 (Department of Natural Resources and Mines, 2019)**

Time series of modelled output parameters at the GPC AWAC deployment location are provided in Figure 6-2. The influence of the passage of ex-tropical cyclone Oswald is readily apparent in the water level, current speed and wave height time series, and it also generated a very large increase in the modelled depth-averaged TSS.

The time series of modelled output parameters at the Bundaberg Waverider Buoy location are provided in Figure 6-3. Again the influence of the passage of ex-tropical cyclone Oswald is readily apparent in the current speed and wave height time series, and the modelled depth-averaged TSS also showed a very large increase during the event at this offshore location.

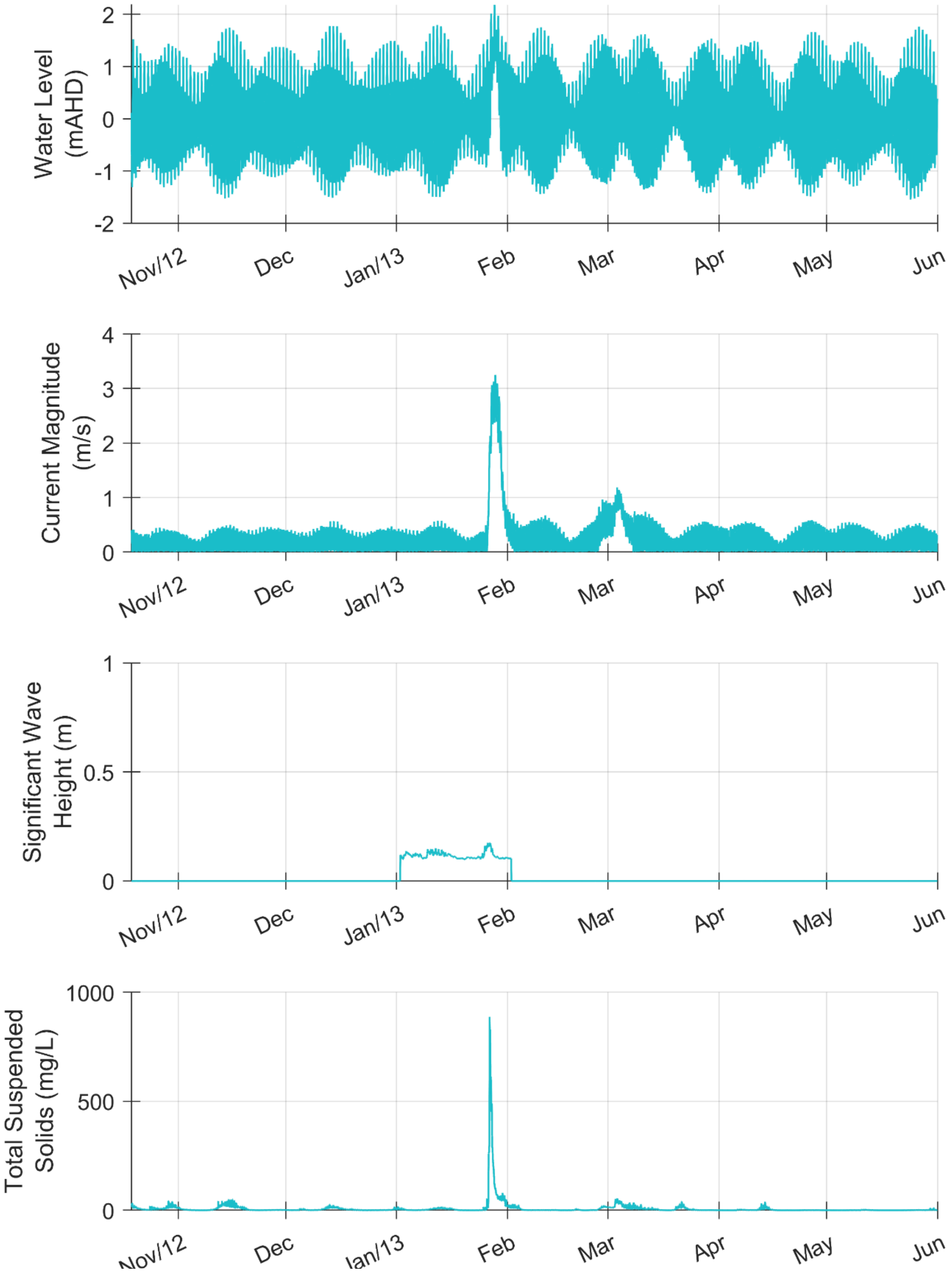

Figure 6-2 Time Series of Water Level (Top), Current Magnitude (Second Panel), Significant Wave Height (Third Panel), and Total Suspended Solids (Bottom) at the GPC AWAC Reporting Location for the 2012-2013 Simulation Period

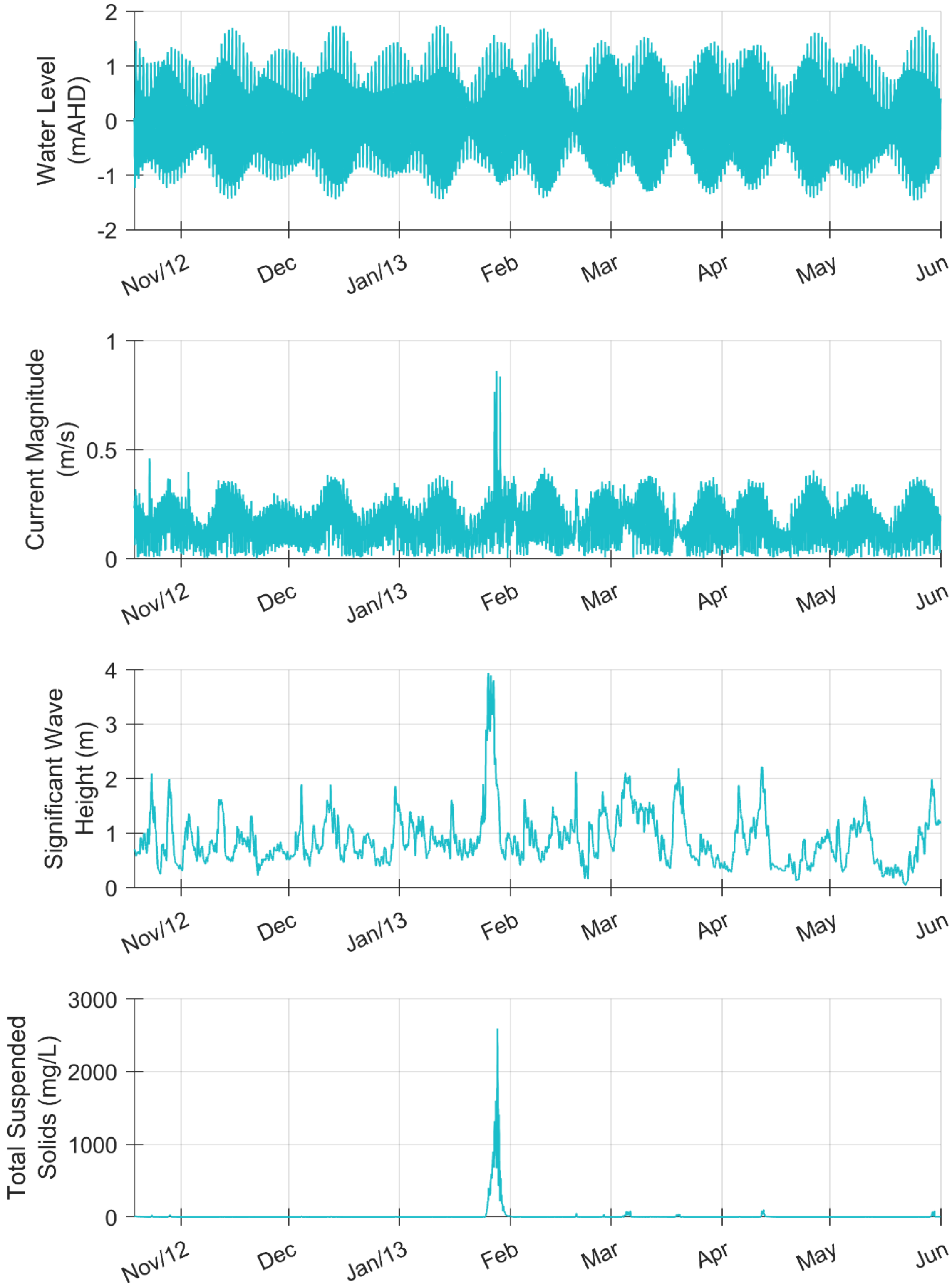

**Figure 6-3 Time Series of Water Level (Top), Current Magnitude (Second Panel), Significant Wave Height (Third Panel), and Total Suspended Solids (Bottom) at the Bundaberg Waverider Buoy Reporting Location for the 2012-2013 Simulation Period**

## 6.2 2014 – 2015 Hindcast

The 2014-2015 hindcast period (01/11/2014 – 01/12/2015) is characterised as a typical year for meteorological conditions at the PoB. The inflow hydrograph from the Burnett River from the simulation period is shown in Figure 6-4. The flow event in late February 2015 was associated with the passage of ex-tropical cyclone Marcia.

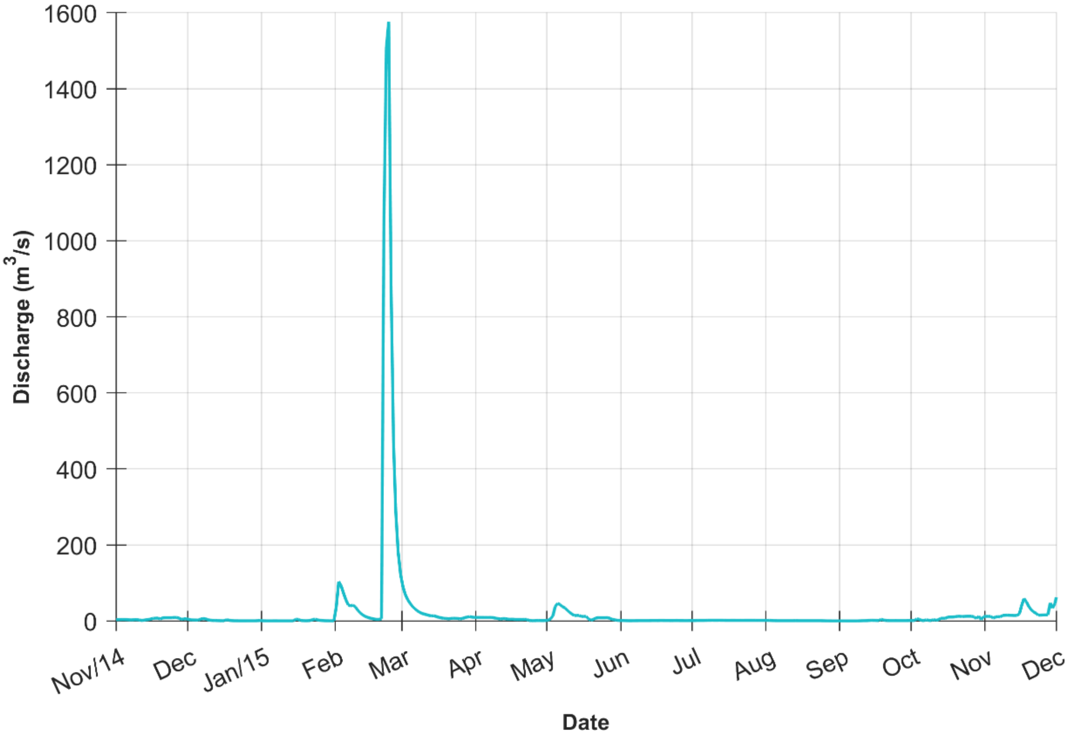

**Figure 6-4 Burnett River Hydrograph from the Figtree Gauge 2014-2015 (Department of Natural Resources and Mines, 2019)**

A maintenance dredging campaign was included as part of the simulation. This was a campaign that was simulated to occur in May-June 2015 based on a historical dredge log representing a volume of 64,000m$^3$ of sediment removed from the shipping channels and placed at the DMPA.

The campaign involved the TSHD Brisbane and included the following assumptions:

- Dry mass in each load defined by the dredge log (46 loads in total);
- Dredge cycle time defined by the dredge log;
- Total dredging campaign duration of 7 days;
- Dredging locations based on the dredging log:
  - 28% of dredging in the berths and swing basin;
  - 44% in the Sea Reach of the channel; and
  - 28% in the Inner and Middle Reaches.

- Placement took 10 minutes per load at defined locations within the boundaries of the DMPA;
- The plume generation rates were estimated based on available data and previous modelling work undertaken for the TSHD Brisbane. The basic assumptions were:
  - Assumed composition of material: 68% sand, 21% silt, 11% clay
  - Proportion of fines being dredged forming a passive plume at the draghead: 2%
  - Proportion of fines being dredged lost during overflow dredging operations: 80%
    - 15% of which forms a passive plume of fine sediment in the model
  - Proportion of sand being dredged lost during overflow dredging operations: 25%
    - 15% of which forms a passive plume of fine sediment in the model
  - Proportion of fines that form a passive plume during placement: 10%
  - Proportion of sand that form a passive plume during placement: 2%

Time series outputs of key model output parameters at the GPC AWAC deployment location are provided in Figure 6-5. As noted for the 2012-2013 simulation, the current speed and TSS concentration at that location was influenced by freshwater inflow events including the passage of ex-tropical cyclone Marcia.

Figure 6-6 shows time series outputs of key model output parameters at the Bundaberg waverider buoy location. The passage of ex-tropical cyclone Marcia was also the most significant event during the simulation at this location, since it was associated with elevated significant wave height and higher levels of TSS concentration.

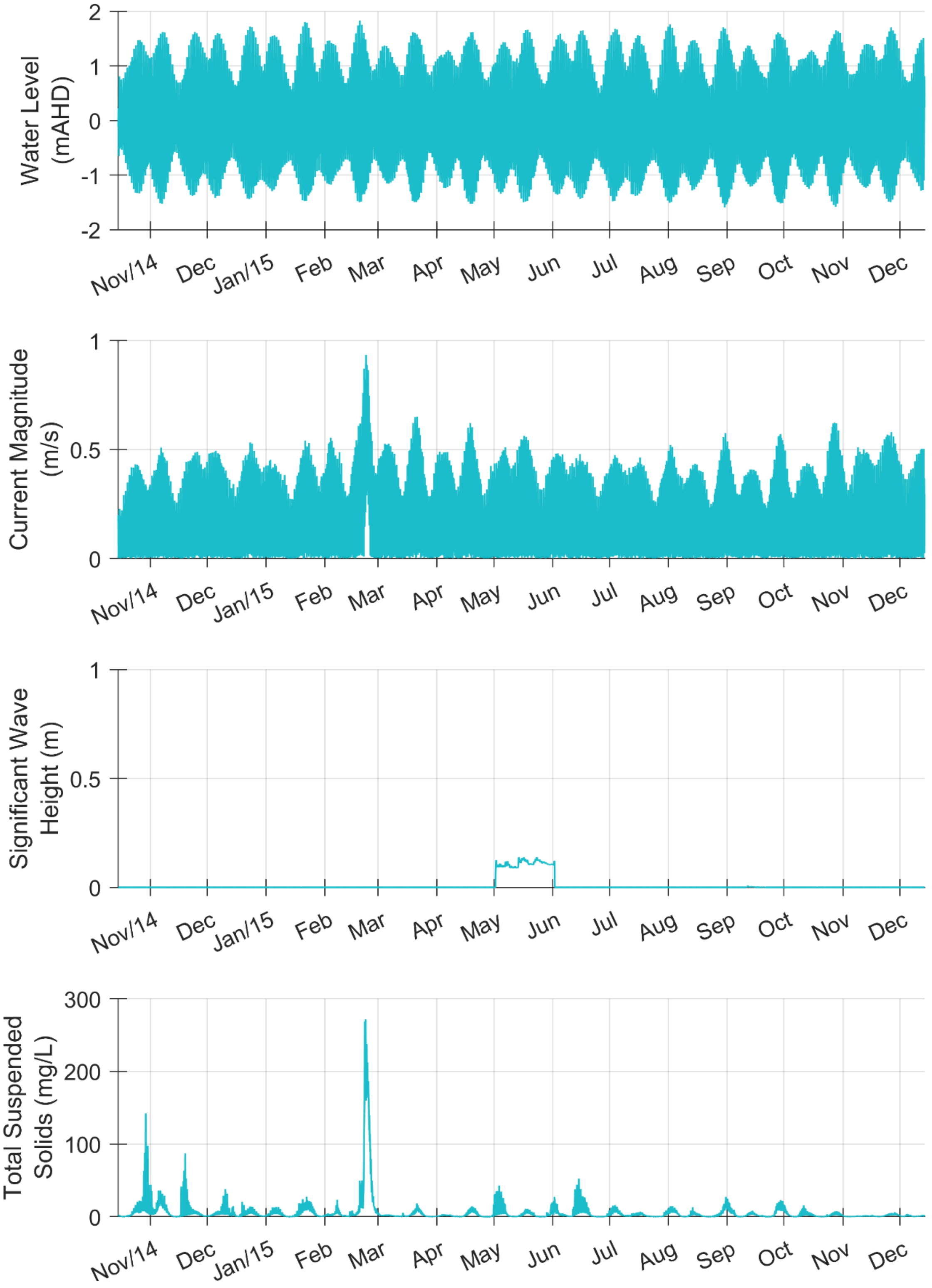

**Figure 6-5 Time Series of Water Level (Top), Current Magnitude (Second Panel), Significant Wave Height (Third Panel), and Total Suspended Solids (Bottom) at the GPC AWAC Reporting Location for the 2014-2015 Simulation Period**

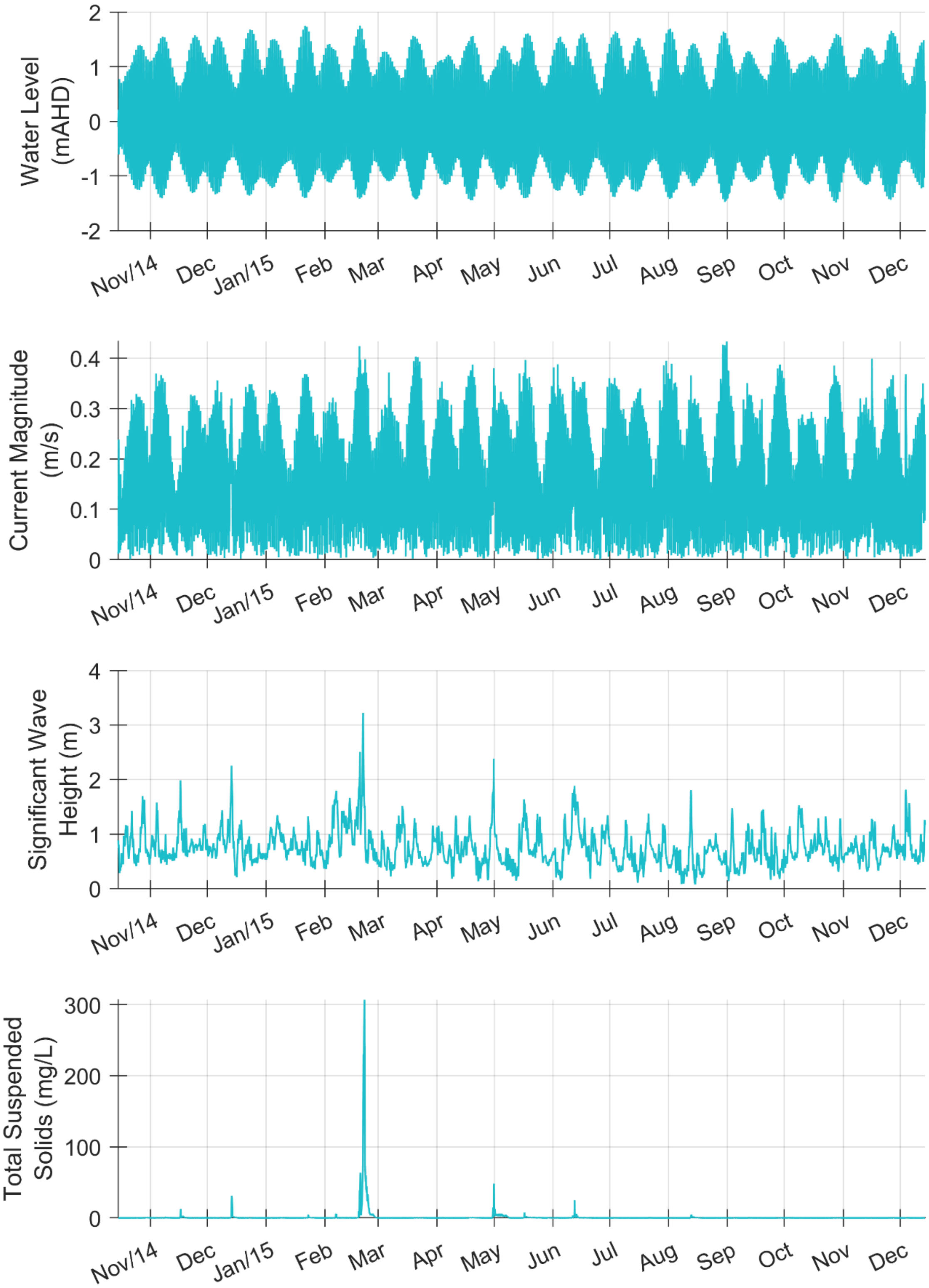

**Figure 6-6** Time Series of Water Level (Top), Current Magnitude (Second Panel), Significant Wave Height (Third Panel), and Total Suspended Solids (Bottom) at the Bundaberg Waverider Buoy Reporting Location for the 2014-2015 Simulation Period

## 6.3 2020 Hindcast

The 2020 hindcast period (06/02/2020 – 01/06/2020) corresponded to a period of relatively mild conditions at the PoB. The inflow hydrograph from the Burnett River from the simulation period is shown in Figure 6-7.

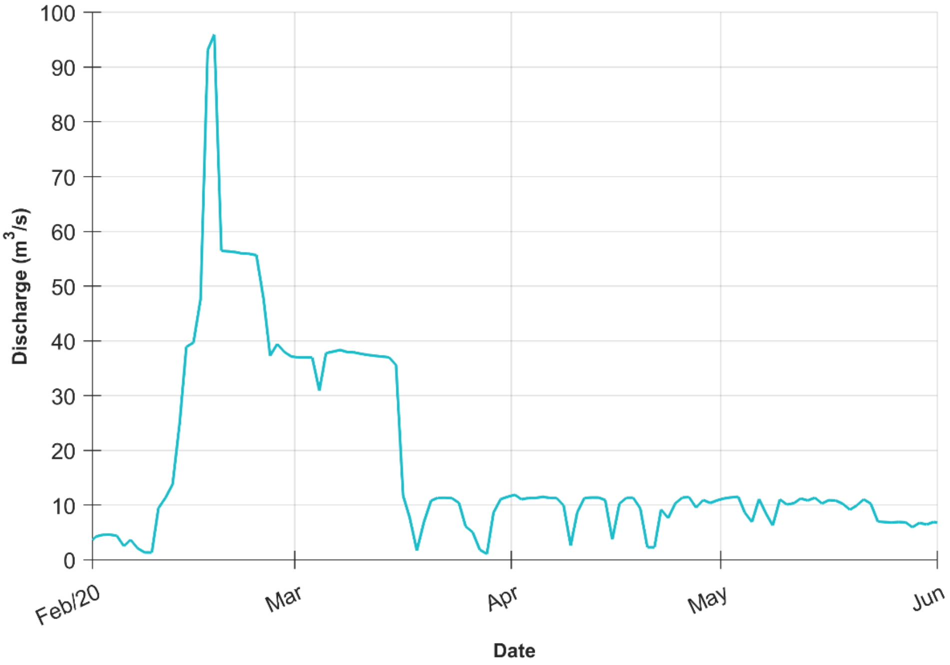

**Figure 6-7 Burnett River Hydrograph from the Figtree Gauge 2020 (Department of Natural Resources and Mines, 2019)**

Time series outputs of key model output parameters at the GPC AWAC deployment location are provided in Figure 6-8, and at the Bundaberg waverider buoy locations in Figure 6-9. A wind and wave event in mid-March generated elevated TSS concentrations at the waverider buoy location. The TSS concentrations at the GPC AWAC location show a strong correlation with the spring-neap tidal magnitude variation, however the influence of the offshore wave event in March is also evident due to advection into the Port area.

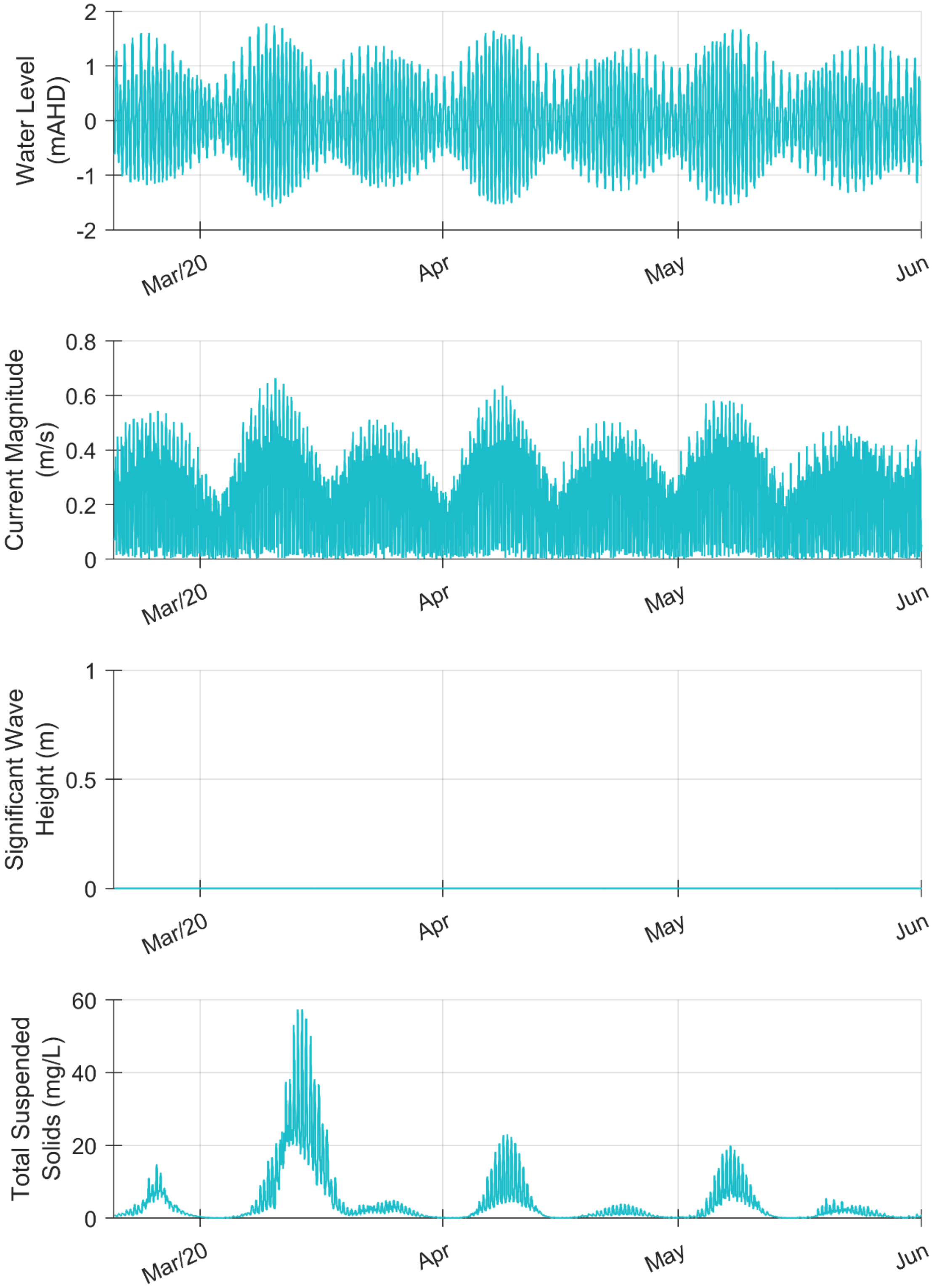

**Figure 6-8 Time Series of Water Level (Top), Current Magnitude (Second Panel), Significant Wave Height (Third Panel), and Total Suspended Solids (Bottom) at the GPC AWAC Reporting Location for the 2020 Simulation Period**

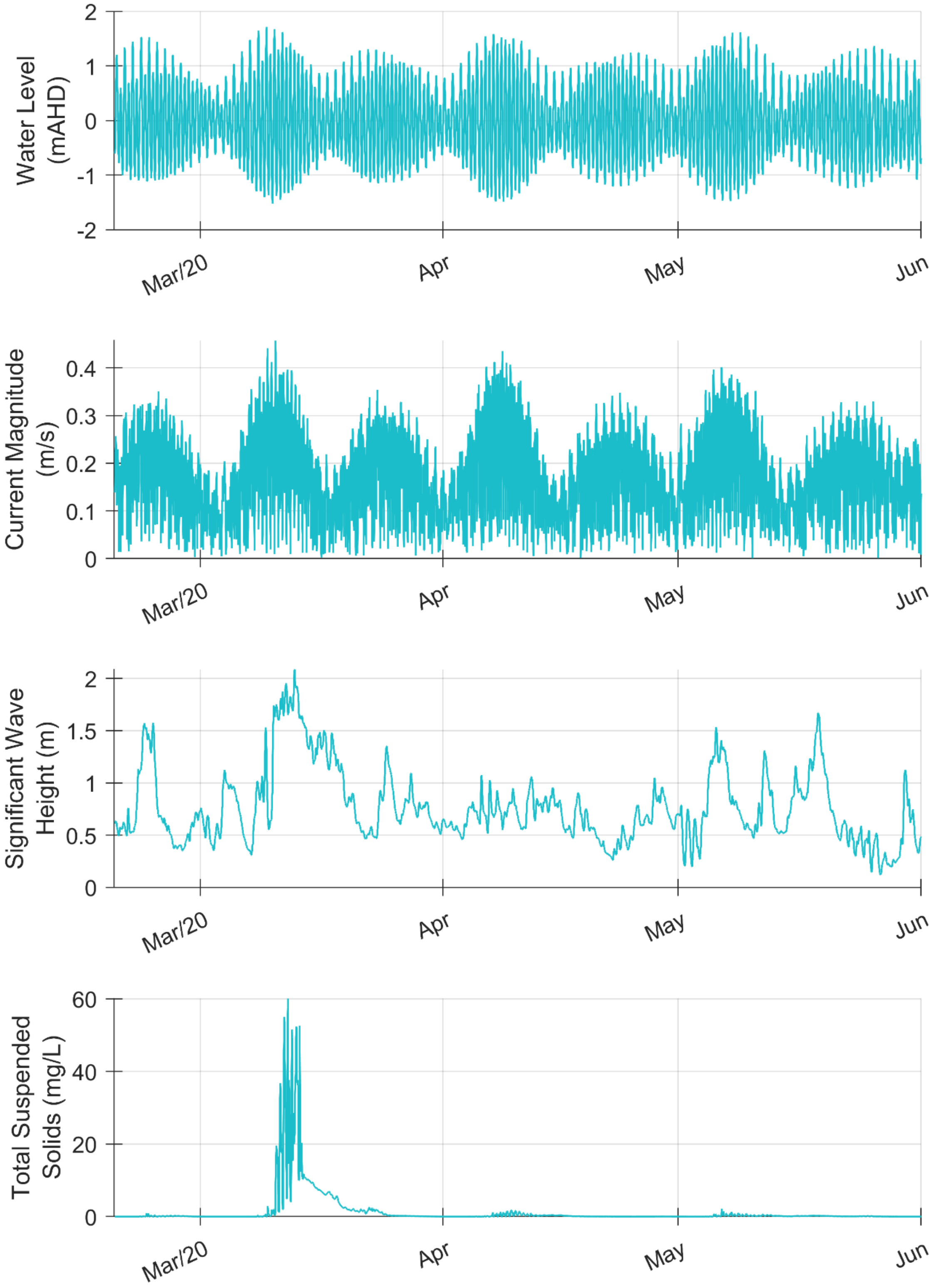

**Figure 6-9** Time Series of Water Level (Top), Current Magnitude (Second Panel), Significant Wave Height (Third Panel), and Total Suspended Solids (Bottom) at the Bundaberg Waverider Buoy Reporting Location for the 2020 Simulation Period

# 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. The results from the model hindcast simulations have been analysed to assess the estimated net flux of sediment into and out at the Port (PoB Inner), at the mouth of the Burnett River (PoB Outer), at a transect near the DMPA, and across a transect which captures the shore-parallel transport (Barubbra Is). For locations of the transects, see Figure 7-1.

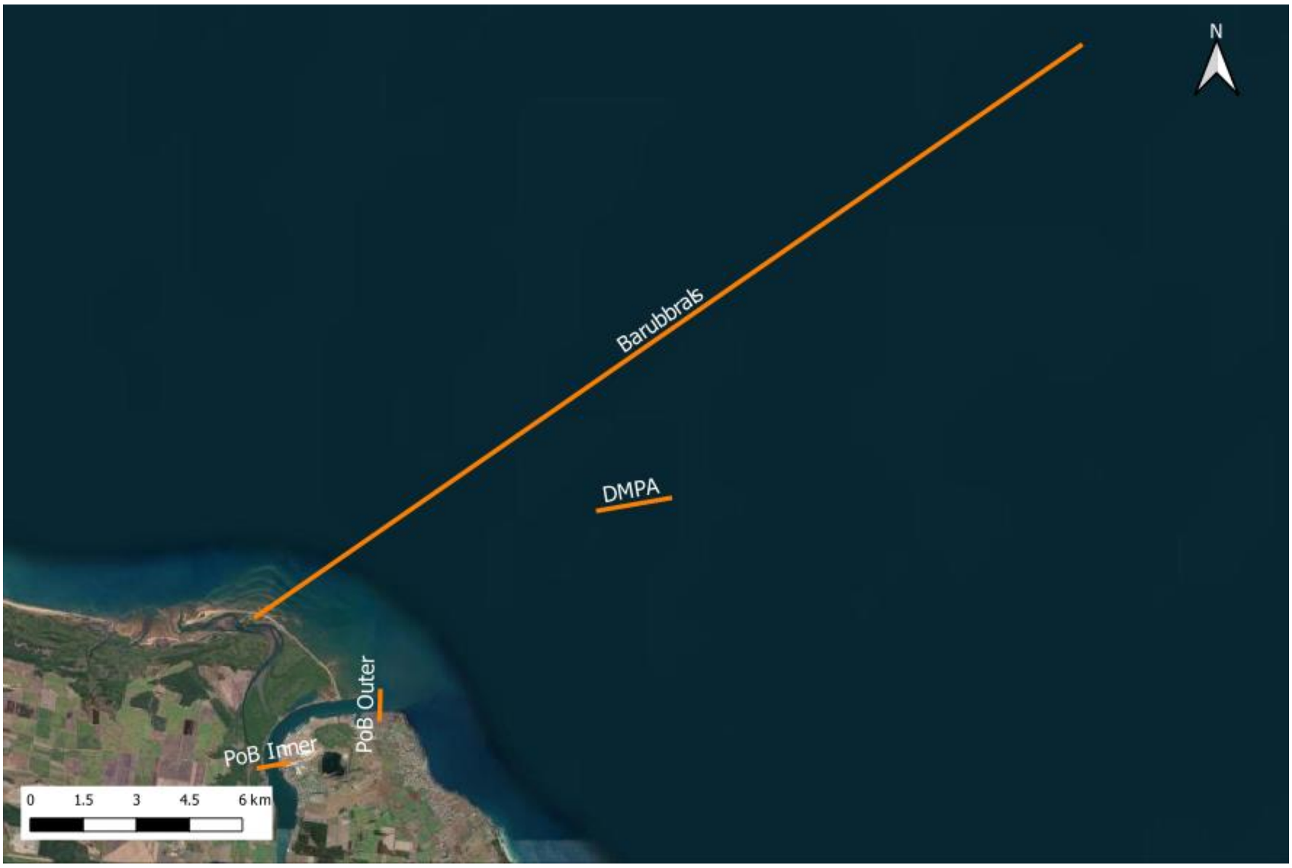

Figure 7-1 Location of Transects Analysed for Net Sediment Flux

The results of the analysis are presented in Figure 7-2 to Figure 7-4. The top panel of each figure shows the modelled significant wave height at the AWAC location, the centre panel shows the modelled Total Suspended Solids concentration at the AWAC recording location, and the bottom panel shows the cumulative sediment transport flux (in kg) through each transect. In each case the transect flux has been processed so that positive flux is either flowing out of the estuary, or flowing northwards parallel to the coastline in the case of the DMPA and Barubbra Island transects.

The model results indicate that there is a large net sediment transport flux northwards through the Barubbra Island transect in all of the simulations due to the resuspension of accumulated sediment offshore by wave and current action and transport by the prevailing currents.

In the 2012-2013 simulation, the net sediment flow out of the Burnett River associated with the passage of ex-tropical cyclone Oswald is evident. The total modelled flux at the Barubbra Island transect is larger than the modelled flux out of the river, indicating a significant contribution from the resuspension of sediment in nearshore areas.

In the 2014-2015 simulation, the passage of ex-tropical cyclone Marcia did not cause a significant net northward flux of sediment at the Barubbra Island transect despite the significant outflow of sediment from the Burnett River, likely because the wind direction during the passage of the storm was from the north. Wave events later in the simulation did generate significant fluxes to the north, much larger than the total net flux of sediment from the Burnett River. The fluxes of dredged sediment associated with maintenance dredging at each transect were much smaller than the modelled ambient fluxes (around 100 times smaller – note the different y-axis scales in the plot).

In the 2020 simulation there is again a large northward sediment flux at the Barubbra Island transect associated with the March 2020 wave event. Sediment fluxes at each transect for the remainder of the simulation were relatively small.

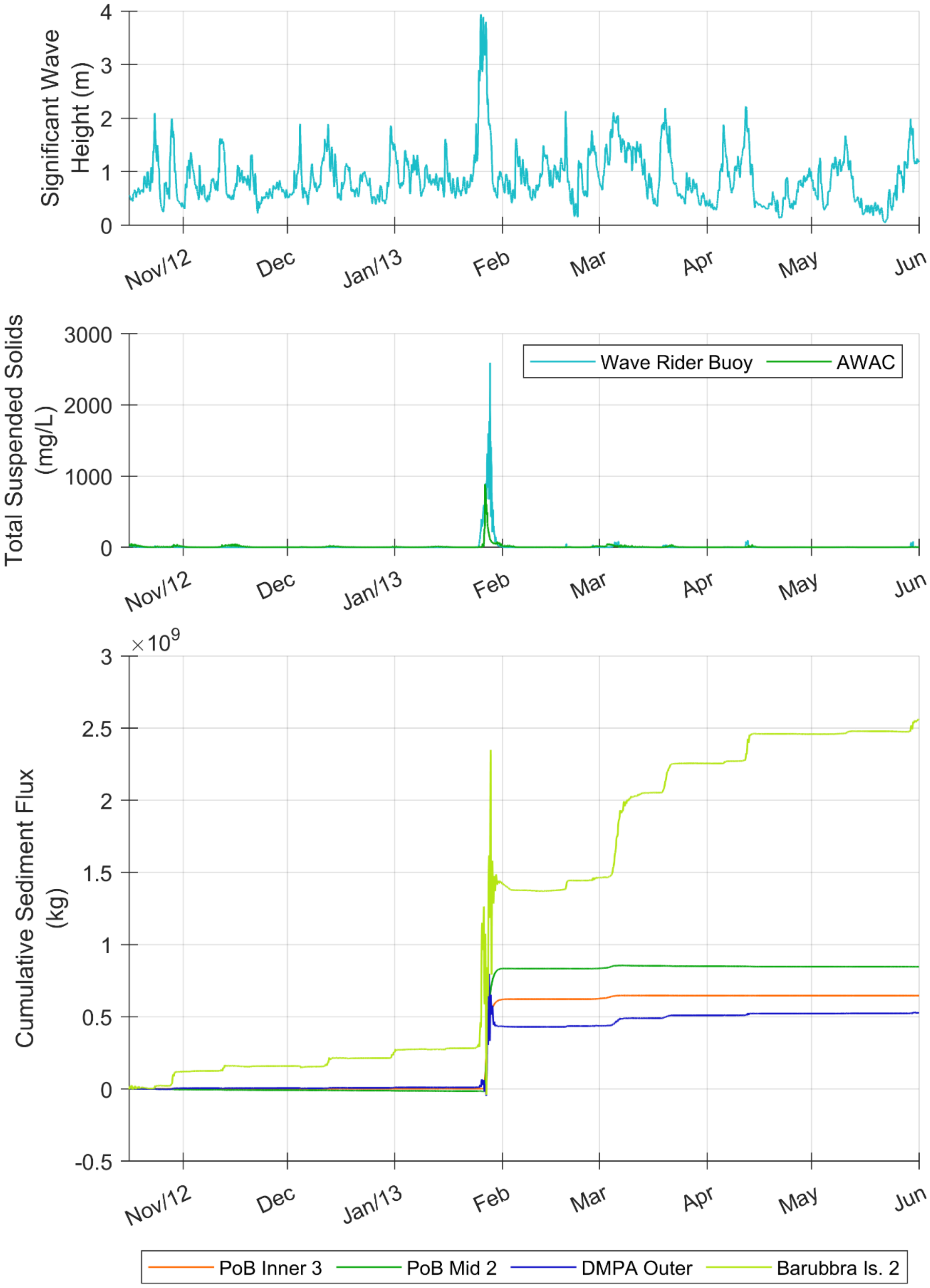

**Figure 7-2 Modelled Wave Height (Top), TSS (Middle) and Cumulative Sediment Flux Across Port Transects (Bottom) for the 2012-2013 Simulation**

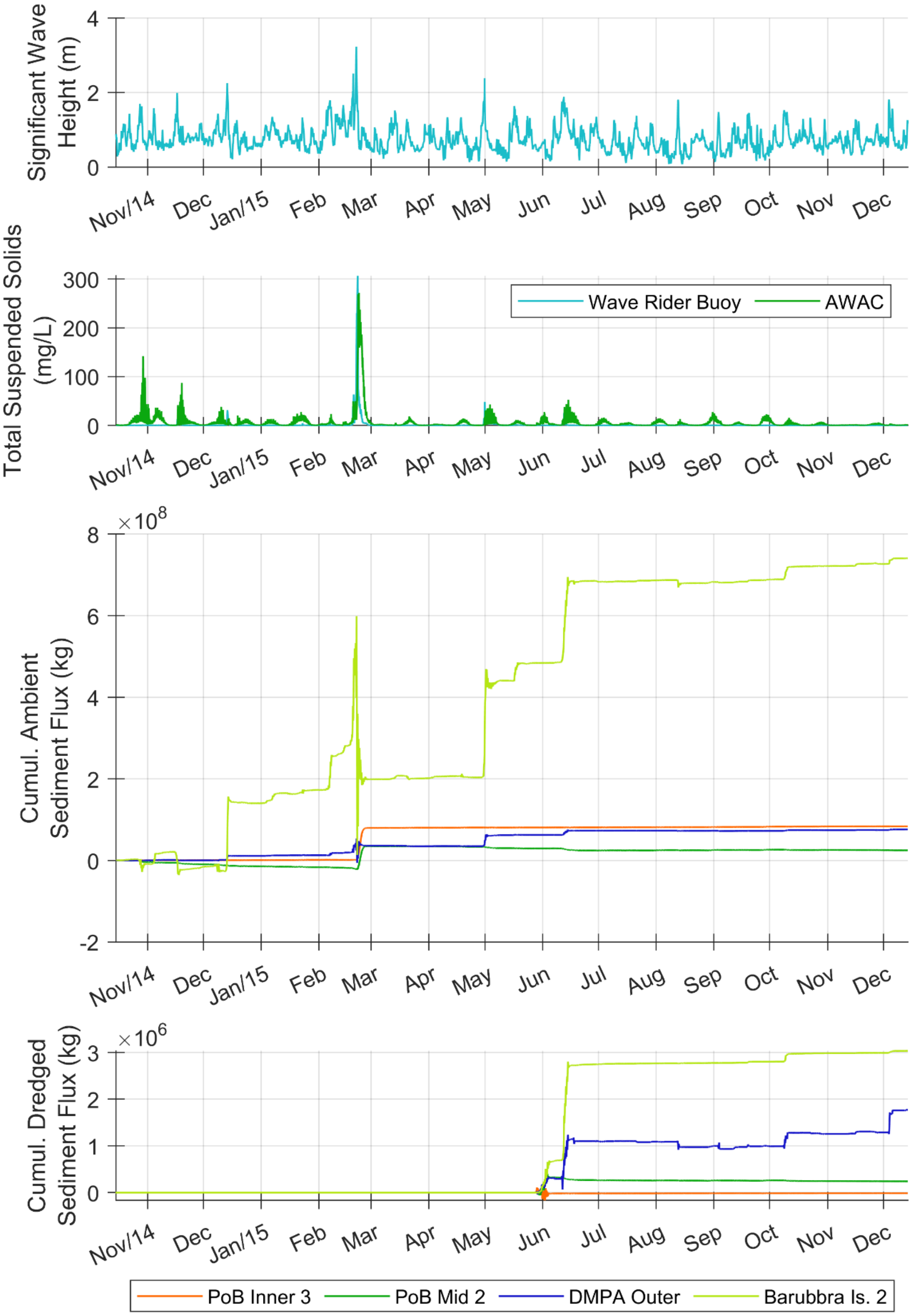

Figure 7-3 Modelled Wave Height (Top), TSS (Middle) and Cumulative Sediment Flux Across Port Transects (Bottom) for the 2014-2015 Simulation

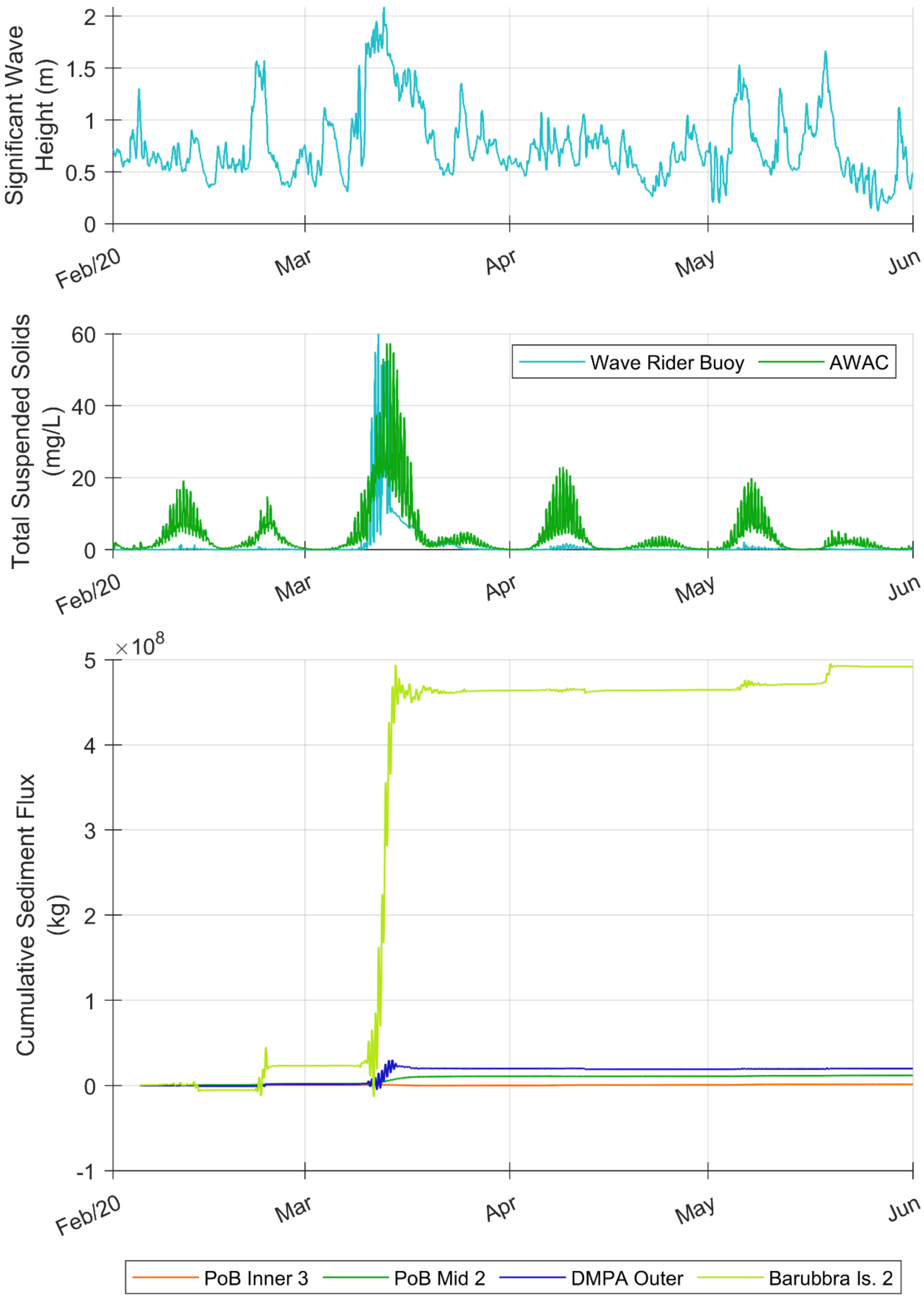

**Figure 7-4 Modelled Wave Height (Top), TSS (Middle) and Cumulative Sediment Flux Across Port Transects (Bottom) for the 2018-2019 Simulation**

# 8 Conclusions

The Port of Bundaberg TUFLOW FV hydrodynamic and sediment transport model has undergone calibration and validation to represent the ambient sediment dynamics in the Port. The model outputs are being used to help develop a quantitative sediment budget for the Port.

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

- There was limited data available for model calibration so the analyses need to be interpreted with some care. However, since the key physical processes and sources and sinks of sediment are included and comparisons with available data show good correlation the model does provide a reasonable representation of the patterns of sediment dynamics in the Port.
- In general, 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 dredging loads, river flows including flood loads and offshore ambient sediment transport loads. The modelled offshore sediment transport flux is much larger than the river-associated flux, and much larger than the fluxes associated with dredging (~100 times larger).
- The results indicate that the overall magnitude of the net flux out of the Port is event-driven. Offshore wave events can cause elevated turbidity at the sheltered Port location due to advection of suspended sediment on incoming tides.

# 9 References

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