Onslow Marine Support Base

Shoreline Impacts Assessment

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Onslow Marine Support Base

Shoreline Impacts Assessment

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Executive Summary

The Onslow Marine Support Base (OMSB) project will develop a major marine support base in Onslow that will provide maritime support services to commercial operations across a range of sectors. The OMSB will deliver a land backed wharf with a deep berth pocket for a range of vessel sizes, connected to Beadon Bay through a deepened, wider navigation channel which is planned to be dredged through the Beadon Creek entrance.

As part of the environmental approvals process for the OMSB project, the impact of the Stage 2 capital dredging to the Beadon Creek system is being referred to Western Australia's Environmental Protection Authority (EPA). This requires investigation of the changes that will occur to the coastal dynamics for the Beadon Creek entrance, shorelines and upstream areas.

A hydrodynamic model of the Onslow coastal region has been developed to support investigations into changes to the coastal processes associated with the planned capital dredging. The model has been validated against the available measured water level record from a tide gauge location within Beadon Creek and at an AWAC instrument northwest of the training wall, showing good agreement to the measured data for water level, current velocity and direction.

The modelling investigations indicate that whilst there is an increase in storage volume associated with the Stage 2 capital dredging, there is only a minor (<1%) increase to the overall tidal prism. The upstream impacts to water level and velocity in Beadon Creek show only negligible changes compared to the existing condition.

A quantitative assessment of sediment transport and sedimentation has been completed, with the hydrodynamic and wave models developed in the initial project phase applied to sediment transport modelling of the planned capital dredging. The modelled sedimentation volumes in the existing and post-dredging case have been assessed within ten distinct channel sections that have previously been used to assess dredging requirements for Beadon Creek (Oceanica 2014).

For the navigable areas of the OMSB footprint (navigation channel, entrance channel, turning circle and berth area) annual total sedimentation allowance of 38,000 m^3 is recommended based on the modelled outcomes. This value includes an allowance for cyclone impacts and assumes an eastward littoral transport rate of 24,000m^3 annually.

Modelling estimates of sedimentation in lower Beadon Creek (south of the OMSB footprint) post development recommend an allowance for 1800m^3 annually, which includes an allowance for sedimentation from cyclones.

An analysis of scour potential along the toe depth of the training wall indicates that current velocity will be reduced by 50% or more following the establishment of the dredged channel. This is directly related to the larger cross sectional area the developed case provides for flows through the entrance channel. Whilst the current velocity is significantly reduced through this section, further understanding of the sediment size at toe depth is recommended to fully understand the potential for scour in extreme events (eg cyclones).

In general, there is only minor annual sedimentation volumes predicted for the OMSB berth, turning circle and inner channel approach areas, with the largest sedimentation expected to occur within the OMSB navigation channel both offshore and on the lee side of the training wall as eastward littoral drift of sediment is trapped in the deep navigation channel. Maintenance dredging of the sediment that is directed into the navigation channel will be required to maintain navigable depth in this area, with some form of bypassing required that can restore the natural eastward supply of sand to the eastern shoal and eastern shoreline.

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1. Introduction

1.1 Project Overview

The Onslow Marine Support Base (OMSB) project involves the development of a major marine supply base in Onslow which will provide maritime support services to commercial operations across a range of sectors. The project site is located on an undeveloped section of the western Beadon Creek shoreline, north of the existing marine precinct. The OMSB will deliver a land backed wharf with a deep berth pocket for a range of vessel sizes, connected to Beadon Bay through a deepened, wider navigation channel which is planned to be dredged through the Beadon Creek entrance.

Phase One of the OMSB project is nearing completion which has involved initial dredging of the berth pocket and development of the land backed wharf. The Stage Two capital dredging works within Beadon Creek and the channel approach from Beadon Bay will significantly improve the access for commercial vessels, and will involve the removal of approximately 1 million cubic metres of dredge material which is planned for onshore reuse.

1.1.1 Project Location

The town of Onslow is on Australia's northwest coast approximately 1400km north of Perth (Figure 1.1). The OMSB site is located north of the Beadon Creek Maritime Facility which is on the western shoreline of Beadon Creek and managed by the Department of Transport (DoT). Currently the maritime facility supports commercial activities including the oil and gas industry and recreational and fishing charter operations. The OMSB site is well placed strategically to play a key role in servicing the current and future oil and gas operations on the north-west shelf.

Figure 1.1: Onslow Location and OMSB Project Area and Dredge Footprint (Google Earth)

1.2 Coastal Dynamics

The town of Onslow is sited adjacent to Beadon Creek. The Beadon Creek Maritime Facility has been operational since the 1960's. Over this time a number of modifications have been undertaken to the natural system. A training wall constructed in 1968 at the creek entrance was designed to formalise the channel opening, whilst the upstream catchment area of Beadon Creek was reduced by the development of the Onslow Salt Works in 1997. The Beadon Creek entrance channel is at a depth of approximately -1.6m CD (Figure 1.2).

Figure 1.2: Onslow Beadon Creek Site Overview and Key Reference Locations

The existing Beadon Creek navigation channel currently supports marine access to the Creek for a range of commercial and recreational activities, including the Beadon Creek Maritime Facility. Under the management of the Department of Transport (DoT), the channel depth has been maintained through periodic maintenance dredging, with an average of approximately 5,000m^3 per year of dredged sediment removed (Damara, 2010; Crawford, 1995).

There has been continual accumulation of sediment on the western side of the training wall since its construction in 1968. Sediment littoral transport is eastward under the prevailing longshore wave direction with net accretion rates along the shoreline west of the training wall estimated at 5,000 to 10,000m^3 annually (Damara, 2010). Damara (2010) estimates the total littoral drift to be between 35,000 and 85,000 m^3 per annum eastwards. The entrance channel is maintained to a depth of -1.6mCD largely by the natural tidal flows, with the eastern bank of the creek and the ebb tide shoal to the east of the entrance fed by the natural bypass capacity of the channel.

1.3 Study Scope and Approach

As part of the environmental approvals process for the OMSB project, the impact of the Stage 2 capital dredging to the Beadon Creek system is being referred to Western Australia's Environmental Protection Authority (EPA). This requires investigation of the changes that will occur to the coastal dynamics for the Beadon Creek entrance, shorelines and upstream areas.

This report details the hydrodynamic and morphological assessment of the existing Beadon Creek system, and investigates the potential changes to the coastal system that could occur following the planned Stage 2 capital dredging. A review of previous studies undertaken at the location is presented to provide a summary of the key factors influencing the coastal processes within the current Beadon Creek system. A hydrodynamic model has been developed to examine the changes to Beadon Creek associated with the modification to the system under the planned Stage Two capital dredging for the OMSB project. The hydrodynamic model is applied in sediment transport investigations that model morphological changes under general ambient conditions (wet and dry seasonal periods) and extreme conditions (cyclones) to provide quantitative assessment of changes to longshore transport rates at the offshore end of the western training wall, sedimentation in the navigation channel, sediment bypass rates, scour potential along the channel margins and entrance training wall.

The report is structured in the following sections:

- Section 2: Coastal processes summary based on review of existing literature
- Section 3: Hydrodynamic model setup, calibration and validation
- Section 4: Developed case layout and model setup
- Section 5: Hydrodynamic Assessment Results
- Section 6: Sediment Transport and Morphological Impact Assessment
- Section 7: Conclusions

2. Coastal Processes Summary

2.1 Oceanographic Conditions

Onslow is situated on the northwest coast of Australia in the Pilbara region. The location experiences a tropical climate with two distinct seasons – a dry season between the months April to October and wet season between the months November to March. The dry season is typically categorised by light winds from the south, southeast and east. In the wet season or monsoon, the winds are typically stronger with a strong sea-breeze effect in operation and wind directions around the southwest, west and northwest directions (DoT 2017).

Ambient wave conditions at the Onslow shore are relatively minor, with a total wave height lower than 1m and generally less than 0.5m throughout the year. The location is well protected from swell originating in the Southern and Indian Oceans due to the orientation of the coast and the shallow continental shelf, with swell wave height generally less than 0.25m in the period range 8-20 seconds. An active sea breeze cycle is present in summer with onshore winds driving local seas in the afternoon at periods 3-8 seconds (DoT 2017).

The Pilbara is an active tropical cyclone region and Onslow has been subjected to a significant number of Tropical Cyclones in its history. The cyclone season typically lasts from November through April, and the impact from cyclones can result in extreme water levels, waves and damaging winds. The most damaging cyclone in recent history was Tropical Cyclone Vance which impacted Onslow on 22 March 1999 as a Category 5 system creating an estimated storm surge of 4m (BOM).

A summary of the typical wet and dry season conditions is presented in Table 2.1.

Table 2.1: Meteorological and Oceanographic Summary – Wet and Dry Season

Season	Period	Description
Dry Season	April to October	Tendency for light winds from the S, SE and E Persistent low level background swell originating from the southern and Indian ocean (<0.25m)
Monsoon Season	November to March	Seabreeze System from SW, W and N-W directions. Generally stronger winds compared to dry season Seabreeze effect provides diurnal wave response. Waves are larger than dry Season Elevated water levels

Onslow experiences semi-diurnal tides with a spring tide range of 1.9m. The tides are shown in Figure 2.1 with the DoT submergence curve presented on Table 2.2.

Table 2.2: Beadon Creek Tidal Planes

Level	Height (m CD)
HAT	3.1
MHWS	2.5
MHWN	1.8
MSL	1.6
AHD	1.49
MLWN	1.3
MLWS	0.6
LAT	0.1

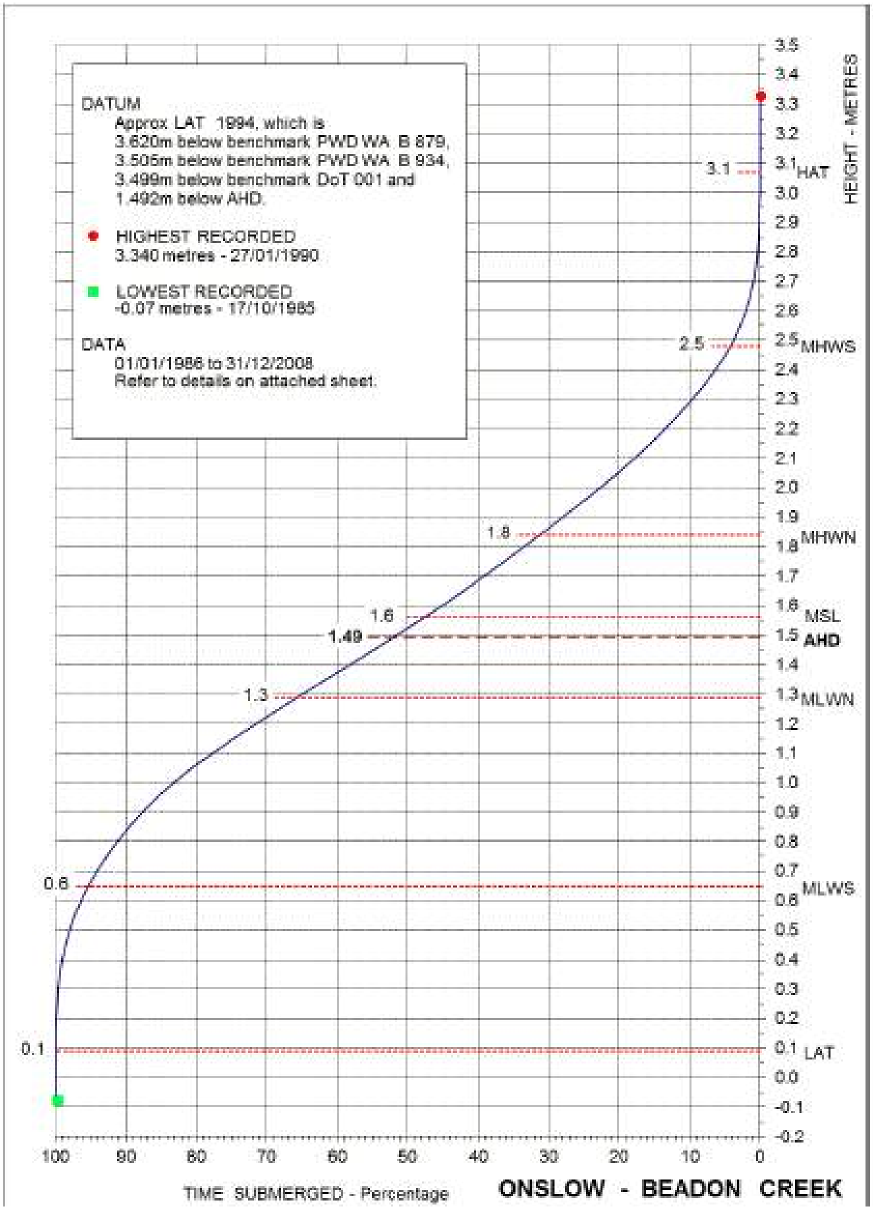

Figure 2.1: Onslow Beadon Creek Submergence Curve (DoT 2017)

2.2 Beadon Creek and Entrance Channel Dynamics

The tidal exchange and flows through Beadon Creek are controlled by the general tide regime, local bathymetry, the training wall at the entrance and the characteristics influencing the upstream tidal flats (Figure 2.2).

Figure 2.2: Influences on Beadon Creek and Entrance Channel Dynamics

The Onslow breakwater / training wall is a low-rise rubble mound structure that is designed to be overtopped under extreme cyclone events and high tide levels. The structure was built in 1968 in conjunction with a dredged channel through the bar for the purpose of maintaining a navigation channel to the maritime facility within Beadon Creek (DoT 2017).

Sediment littoral transport is eastward under the prevailing longshore wave direction with net accretion rates along the shoreline west of the training wall estimated at 5,000 to 10,000m^3 annually (Damara 2010). There has been continual accumulation of sediment on the western side of the training wall since its construction in 1968. The entrance channel is maintained to a depth of -1.6mCD largely by the natural tidal flows, with the eastern bank of the creek and the ebb tide shoal to the east of the entrance fed by the natural bypass capacity of the channel.

The upstream area of Beadon Creek was significantly modified as a result of the construction of the Onslow Salt levee banks in 1997 which served to greatly reduce the sediment transport impacts associated with large flooding events. Historically sedimentation as a result of large scale catchment flooding during extreme rainfall events and breakout of the Ashburton River impacted Beadon Creek, and this source of sediment supply has now been largely restricted. As part of its operation, Onslow Salt operate three seawater pumps from a tidal branch on the eastern side of the upstream Beadon Creek, extracting 12m^3/s when the water level in the creek is above 0.8mCD (Onslow Salt 2017). This extraction regime results in a difference between inflow and outflow volumes through Beadon Creek, with inflow exceeding outflow by approximately 35% during mean spring tides (HGM 1998).

The Beadon Creek entrance has generally maintained a stable cross section under the natural tidal regime, with this ‘quasi-equilibrium’ explained as evidence of a dynamically stable inlet system (HGM 1998). The inlet stability principle (Brunn 1979) is governed by the dynamics of the upstream area, tide regime and available sediment supply, and for Beadon Creek entrance a stable cross sectional area of 220-250m^2 was estimated, as measured below mean sea level (HGM 1998). This estimation of a stable cross sectional area is supported by analysis of the present bathymetry through the channel. Figure 2.3 presents the entrance channel bathymetry from recent multibeam survey (DoT 2016), with the cross-sectional area measured below 0m MSL calculated as approximately 250m^2. This concept has important implications for the planned deepening and widening of the channel through the entrance for the OMSB project, which will increase the cross-sectional area of the entrance beyond this dynamically stable level.

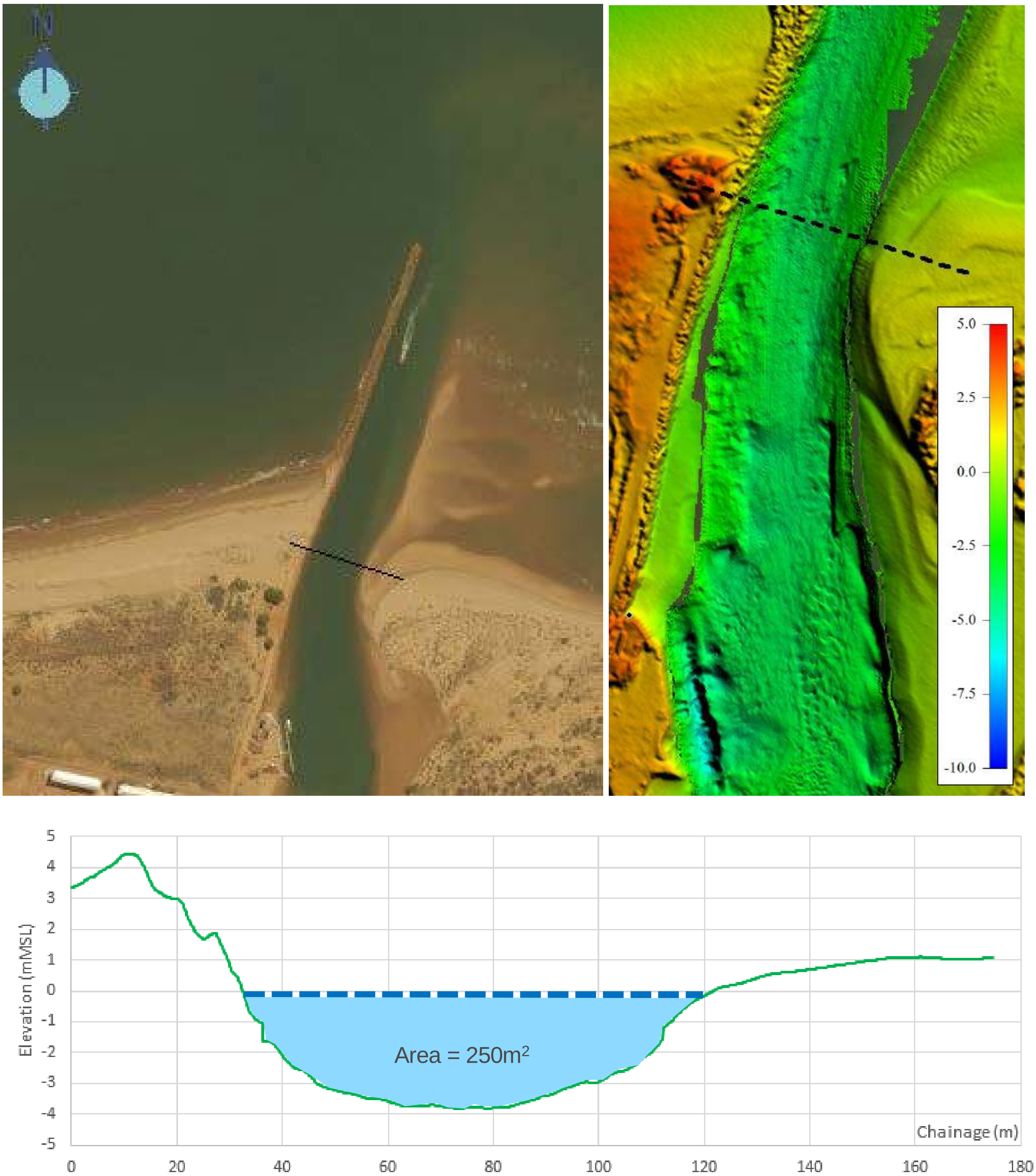

Figure 2.3: Analysis of Cross Sectional Area through the Entrance Channel (below m MSL).

A brief summary of the historical dredging requirements in Beadon Creek is provided in Table 2.3 (from BMT Oceanica 2014) with the dredging locations indicated on Figure 2.4.

Table 2.3: Dredging summary 1964 to 2013 (BMT Oceanica 2014)

Date	Volume (m^3)	Depth (m CD)	Disposal Site	Reference	Comments
1964-1968	Unknown	-0.7	Unknown	HGM 1998	Capital Dredging
1999	41,000	Bell Mouth: -1.6 Basin: -2.6	Dune Swale west rock wall and quarry	HGM 1999	Dredged Sand Bar and Mouth of Creek
2003	10,000	Bell Mouth: -1.6 Channel: -1.6	Dune Swale west rock wall	JFA 2004	Maintenance Dredging
2011	Unknown	Berth Pocket Adjacent to Channel	Onshore adjacent to berth pocket	Oceanica 2012	Small Scale Dredging
2012	40,000	Bell Mouth: -1.6 Channel:-1.5 to -2.6	Dune Swale west rock wall	BMT JFA 2013	Maintenance Dredging
2013	13,000	Channel: -1.5 to -2.6 Cyclone Moorings: -1.5	Dune Swale west rock wall		Maintenance Dredging
2013	5,000	Berth Pocket Adjacent to Channel: -1.6 to -2.65	Dune Swale west of entrance training wall		Small Scale Dredging

Figure 2.4: Location of Beadon Creek dredging areas – Bellmouth, mid-channel and basin (DoT 2017 from JFA 2013)

3. Model Setup and Calibration

A range of datasets have been sourced and used in the development of a suite of numerical models to describe the coastal processes in the region of Onslow and within Beadon Creek. The models are used to simulate the combined actions of tide, winds, waves and currents through Beadon Creek, and applied to understand modifications to the existing coastal system as a result of the planned capital dredging works.

A description of the input source data used to develop the numerical models is presented in this Section along with a detailed description of the model setup, calibration and validation to the existing condition of Beadon Creek.

3.1 Model Inputs

A digital elevation model (DEM) was developed for the project area from available bathymetric and elevation sources discussed in the following sections. All levels were adjusted to a datum of Mean Sea Level (MSL) for application in numerical model development.

3.1.1 Bathymetry Data and Elevation Data Sources

Bathymetry data sources used in the study are summarised in Table 3.1 and ranked in order of highest to lowest priority. It is noted the depth of the tidal creeks in the southern extent of the Beadon Creek tidal flats were not defined in available data and these were schematised based on extension of levels available in nearby areas and interpretation of aerial imagery.

Table 3.1: Bathymetry Sources for Model Development

Rank	Areas Covered	Data Type	Year	Source
1	Beadon Creek and Onslow Nearshore	Multibeam	2016	DoT
2	Beadon Creek and Onslow Nearshore	Multibeam	2017	DoT
3	Offshore Areas	Navigation Charts	-	Australian Hydrographic Service

Elevation data used for the model development is summarised in Table 3.2 and ranked in order of highest to lowest importance.

Table 3.2: Elevation Data Sources for Model Development

Rank	Areas Covered	Data Type	Year	Source
1	Beadon Creek and Onslow Coast Shoreline, Training Wall	LiDAR	2016	Chevron
2	Beadon Creek and Onslow Coast Shoreline	LiDAR	2015	Chevron
3	Beadon Creek and Shoreline	LiDAR	2012	LandCorp

It is noted the south-eastern extent of the Beadon Creek Tidal Flat was not defined by any of the available elevation data sources. The elevation in this region was schematised by adopting the general surface levels recorded by the LiDAR capture on the western side.

3.1.2 Measured Data

The meteorological and oceanographic measured data sources used in the project are summarised in Table 3.3 and shown on Figure 3.1.

Table 3.3: Sources of Measured Data

Instrument	Location	Data	Data Availability
Beadon Creek Tide Gauge (DoT)	Lon 115.13153 Lat -21.64967 Depth 3.7m	Water Level	1/1/1986 to 31/12/2016 at 5 minute frequency
AWAC North-west of Training Wall (DoT)	Lon 115.13080 Lat -21.637317 Depth 3.7m	Water Levels, Wave Height, Wave Period, Wave Direction, Current Speed and Direction through water column	03/11/2014 to 21/07/2016. Waves and Currents at 1 hour intervals
Wind Measurements Onslow Airport (BoM)	Lon 115.1092 Lat -21.6689 Height 10m Above Ground	Wind Speed, Wind Direction. Atmospheric Pressure	Nov 1997 to Dec 2016 Half Hour at 10m above Ground

Figure 3.1: Measured Data Sources and Locations

3.1.3 Sediment Sampling

Sediment sampling data from locations inside Beadon Creek, the proposed Turning Circle as well as the Inner and Outer Channel areas have been collected and analysed for particle size distribution (PSD) and sediment properties (O2 Marine 2017). The sediment sampling locations are shown on Figure 3.2.

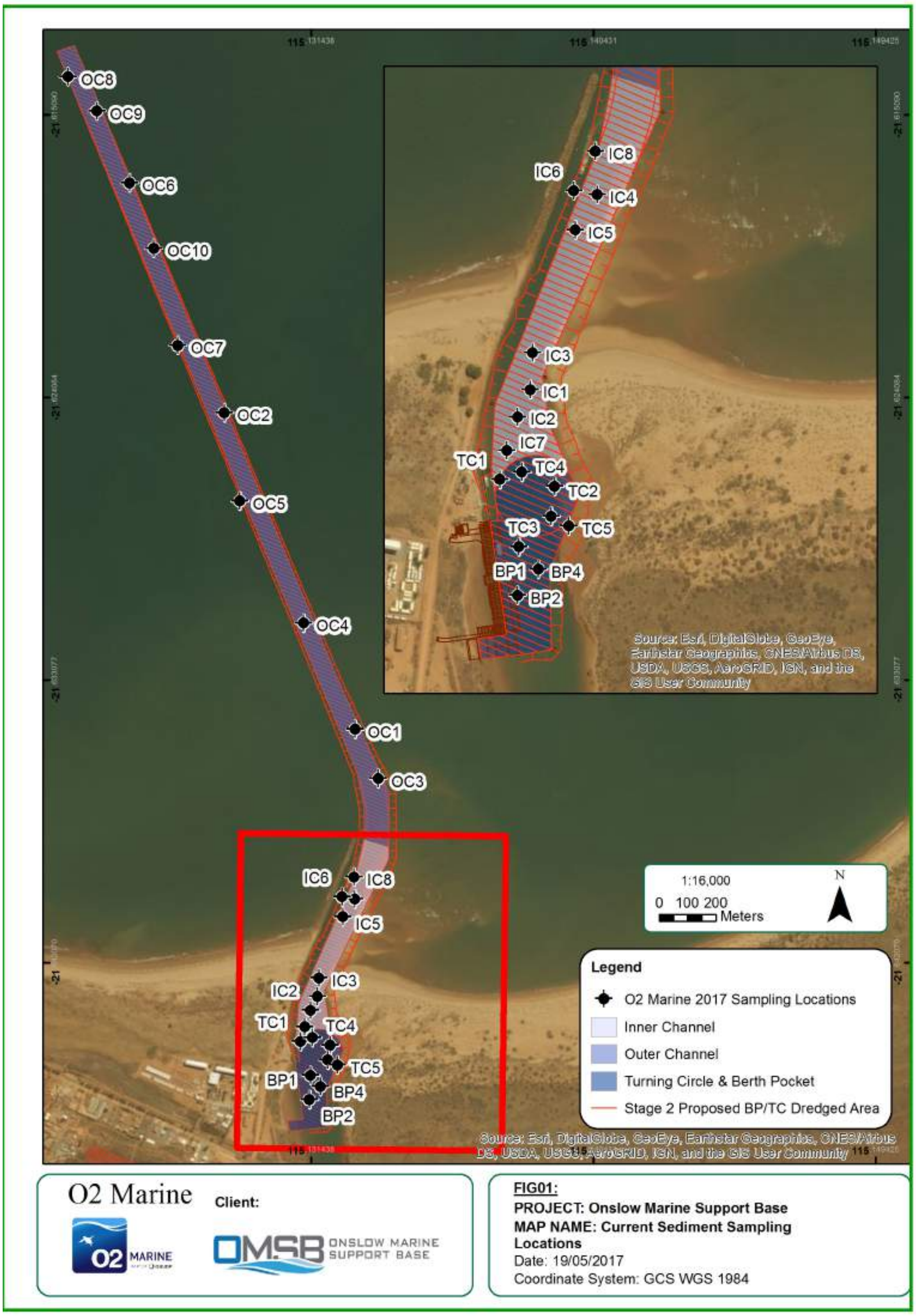

Figure 3.2: Sediment Sampling Locations (O2 Marine 2017)

3.2 Regional Scale Model

3.2.1 Model Setup

The regional model has been developed by Baird using the Delft-Flow Flexible Mesh (D-Flow FM) platform. The model extent is shown in Figure 3.3 extending across the entire northern coast of Western Australia. The model is driven by tidal constituents along its open boundaries with bathymetry defined from hydrographic chart data and local scale bathymetry sources where available.

Validation of the hydrodynamic model to predicted astronomical tide at standard port locations across the north-west region of Australia shows very good agreement to tidal constants in both amplitude and phase. Predicted and modelled water levels for March 2011 are shown on Figure 3.4 for six port locations across the model domain including Onslow.

For this project, winds and atmospheric pressure have been sourced from the NCEP Climate Forecast System (CFSR). The climatic conditions were then applied spatially in D-FLOW FM and updated hourly across the regional model in conjunction with the tides, so their influence was captured in the determination of hydrodynamic forces acting in the domain.

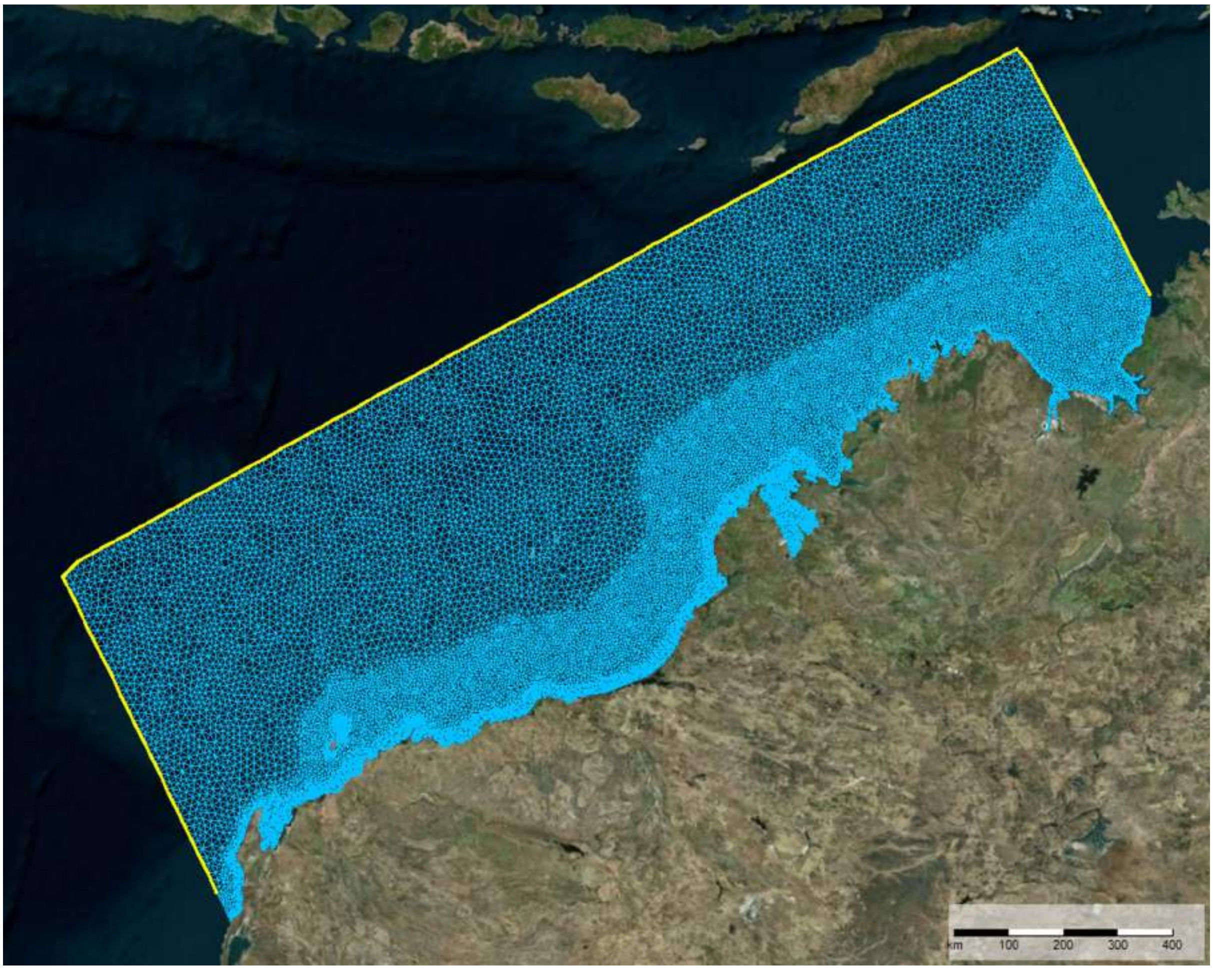

Figure 3.3: Regional Model Grid Extent shown in Delft-FM

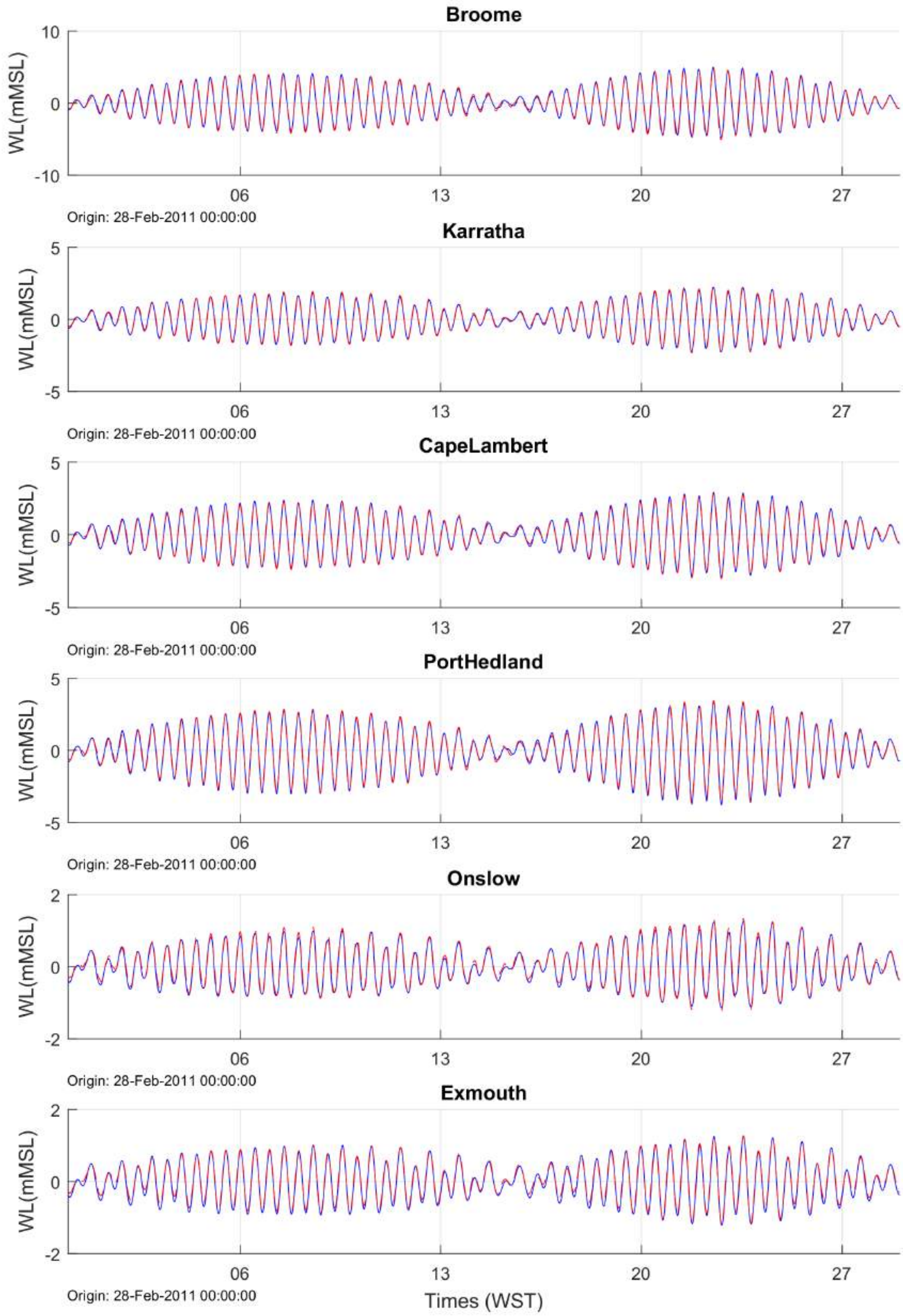

Figure 3.4: Regional Model Tidal Validation. Water Levels Shown: Modelled Blue, Predicted Red.

3.3 Local Model Setup

3.3.1 Grid and Bathymetry

The local model was developed to describe in fine detail the coastal processes acting along the Onslow coastal region, focussed on the key area of interest through Beadon Creek. The model was developed in the Delft3D-FLOW model system using a curvilinear grid extending approximately 17km offshore and 13km along the shore (Figure 3.5).

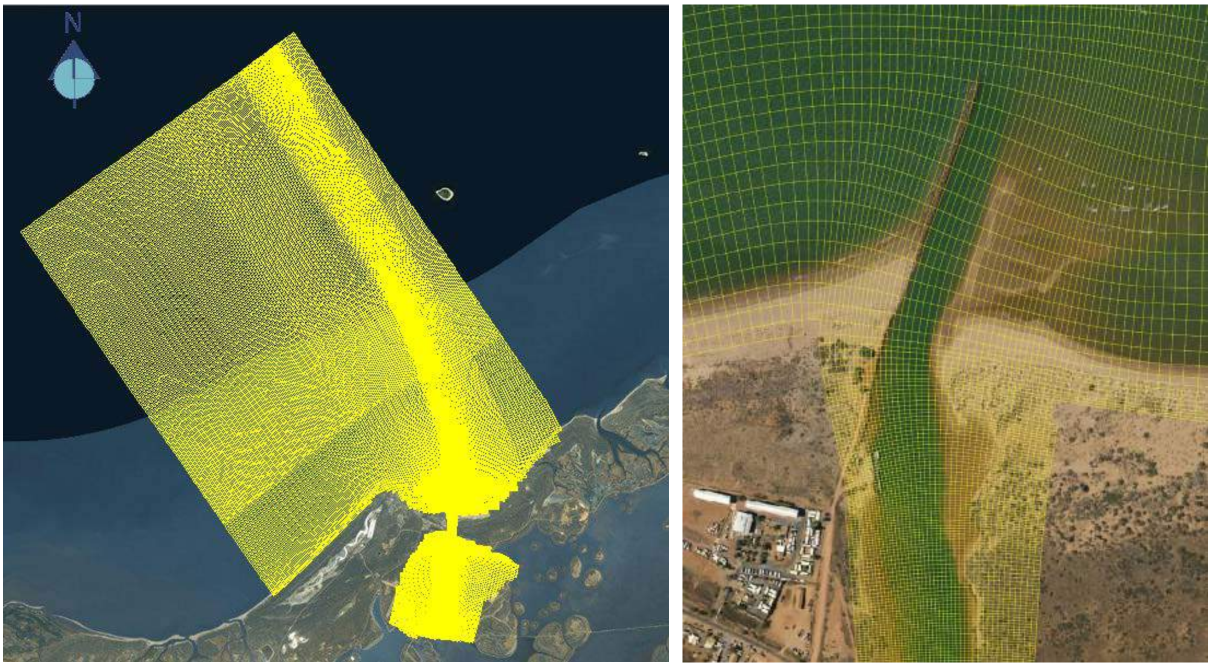

Figure 3.5: Local Model Grid

The curvilinear grid optimises model performance allowing varying grid resolution through the domain achieving high resolution in the nearshore areas through Beadon Creek (6m), with less detail in the offshore regions (180m).

The model bathymetry was assigned from the bathymetry and elevation data sets outlined in Section 3.1.1. All data sets were converted to the model datum of mean sea level (m MSL)

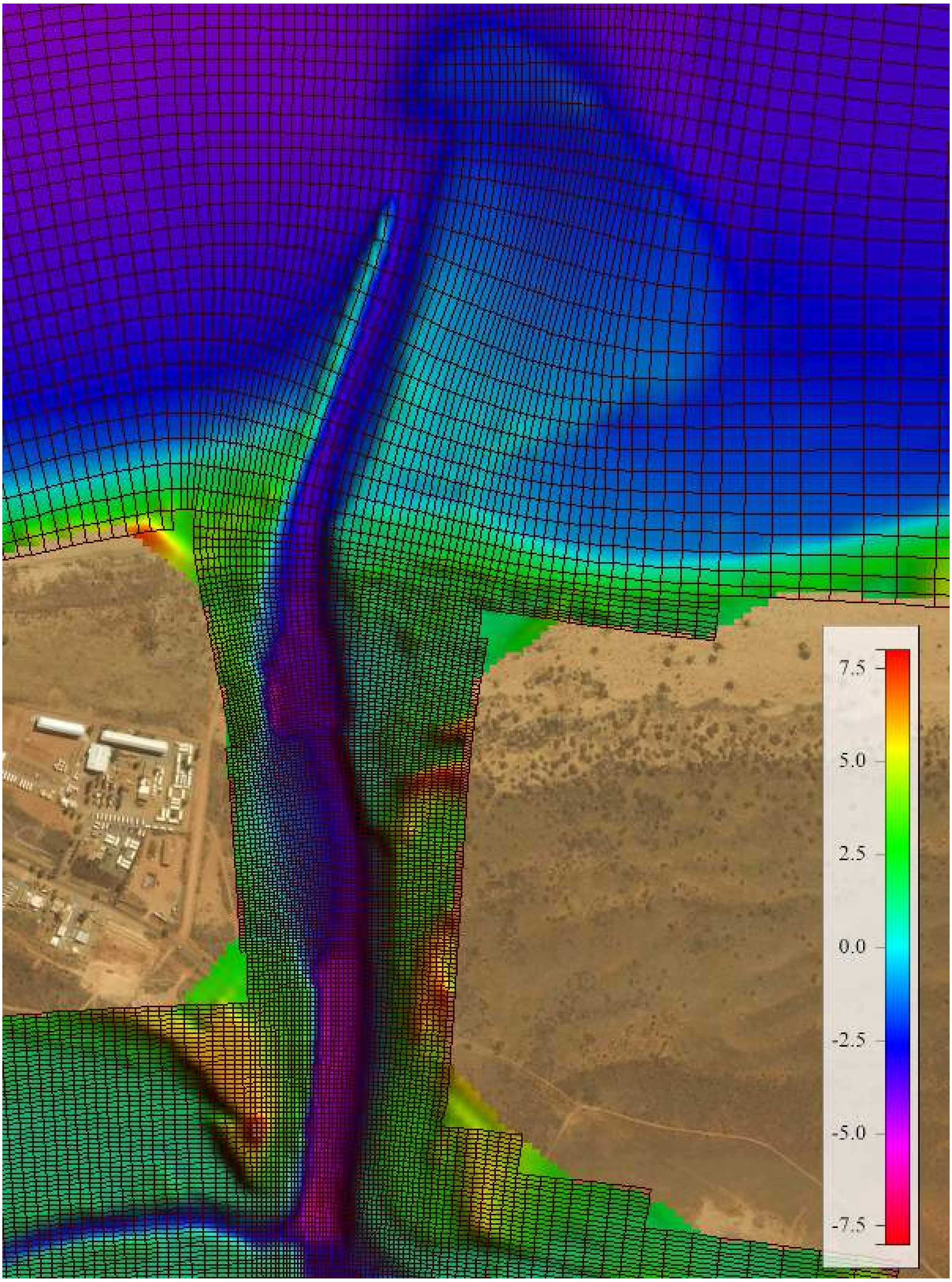

Figure 3.6: Local Model Grid through Beadon Creek Entrance with Existing Bathymetry (datum m MSL)

3.3.2 Boundary Conditions

The local model is driven by three offshore boundaries that control the hydrodynamics. The boundary conditions for the local model have been defined from the regional scale model as shown in Figure 3.7; summarised as follows:

- The eastern and western boundaries are discharge boundaries which input flow volumes (in m^3/s) across the boundary with direction reversing through the ebb tide and flood tide cycle
- The northern boundary is a water level boundary applying time series water level change at the boundary under the general tidal cycle.

Local winds act over the model domain and are input half hourly based on the Onslow Airport measured wind speed and direction (BOM).

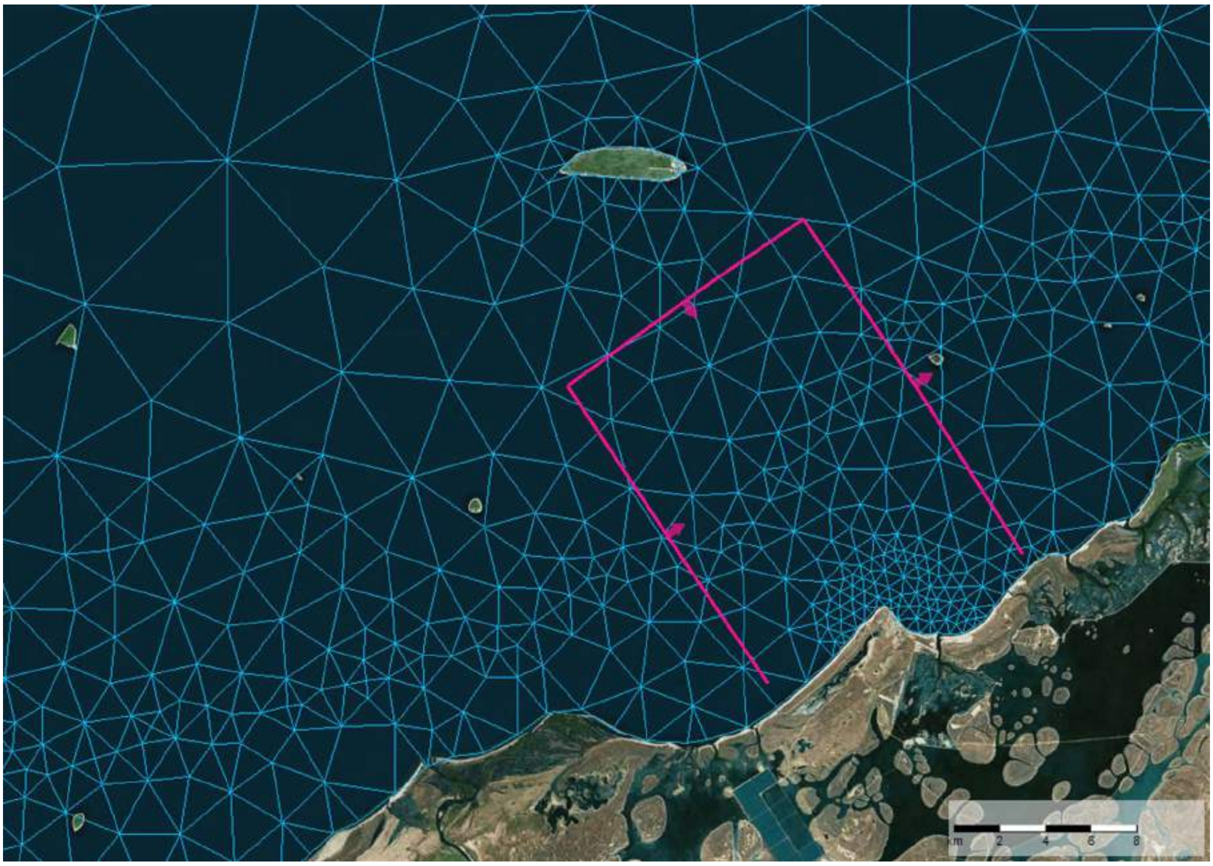

Figure 3.7: Local Model Domain (shown in magenta) nested inside Regional Model Domain Flexible Mesh Grid (shown in Blue)

3.3.3 Discharge for the Onslow Salt Operations

Onslow Salt pumps seawater out of the Beadon Creek system using three pumps located on one of the tidal branches that extend through the eastern side of the tidal flats. The extraction of seawater has been included in the model based on a total pumping rate of $12m^3$ per second whenever the water level in the creek is higher than 0.6mCD, based on the stated operational procedure in Gulf Holdings (1990). Recent advice from Onslow Salt confirms their current pumping operation continues to extract a total of $12m^3$ per second when the tide level in the creek is above 0.8mCD (Onslow Salt 2017). It is noted the chart datum referred in the Gulf Holdings (1990) reference differs slightly from the present tidal datum accounting for the difference in pumping cutoff rates, and the model is representative of the current Onslow Salt pumping operation.

An assessment of the modelled volume of tidal inflow and outflow exchanged through the Beadon Creek entrance shows there is a significantly larger inflow volume to Beadon Creek with the intake operating. A comparison of the discharge rates through the entrance with and without the pump active is shown in Figure 3.8. The intake pumps draw a larger volume of water into Beadon Creek in the flood tide with the discharge rate for inflow increasing from approximately 175m³/s to 200m³/s, an increase of approximately 15% through the peak. The total modelled inflow and outflow volumes through the Beadon Creek entrance were calculated for a four week period. With the seawater pumps active the inflow volume was approximately 25% greater than the outflow through the entrance. This finding corresponds to work presented by HGM (1998).

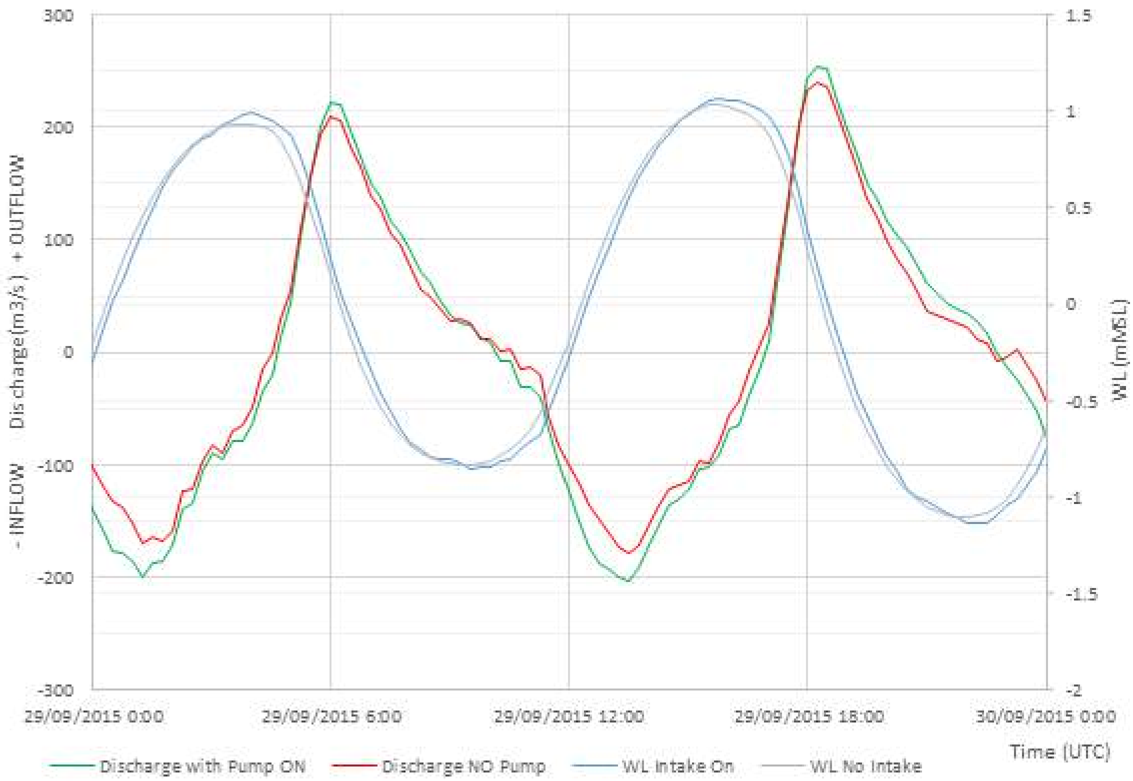

Figure 3.8: Modelled Discharge and Water level through the Beadon Creek Entrance Channel with and without the Onslow Salt Intake pump, spring tide conditions.

3.3.4 Calibration Terms

Bed roughness has been assigned in the model based on the Chezy formulation with varying roughness through the model domain specified by landform type and depth (Figure 3.9). Higher Chezy values indicate less roughness in the model with a summary of assigned values as follows:

- Offshore coastal areas: 40-75
- Beadon Creek and Channel branches: 40
- Mangrove Areas: 5
- Tidal Flats: 25

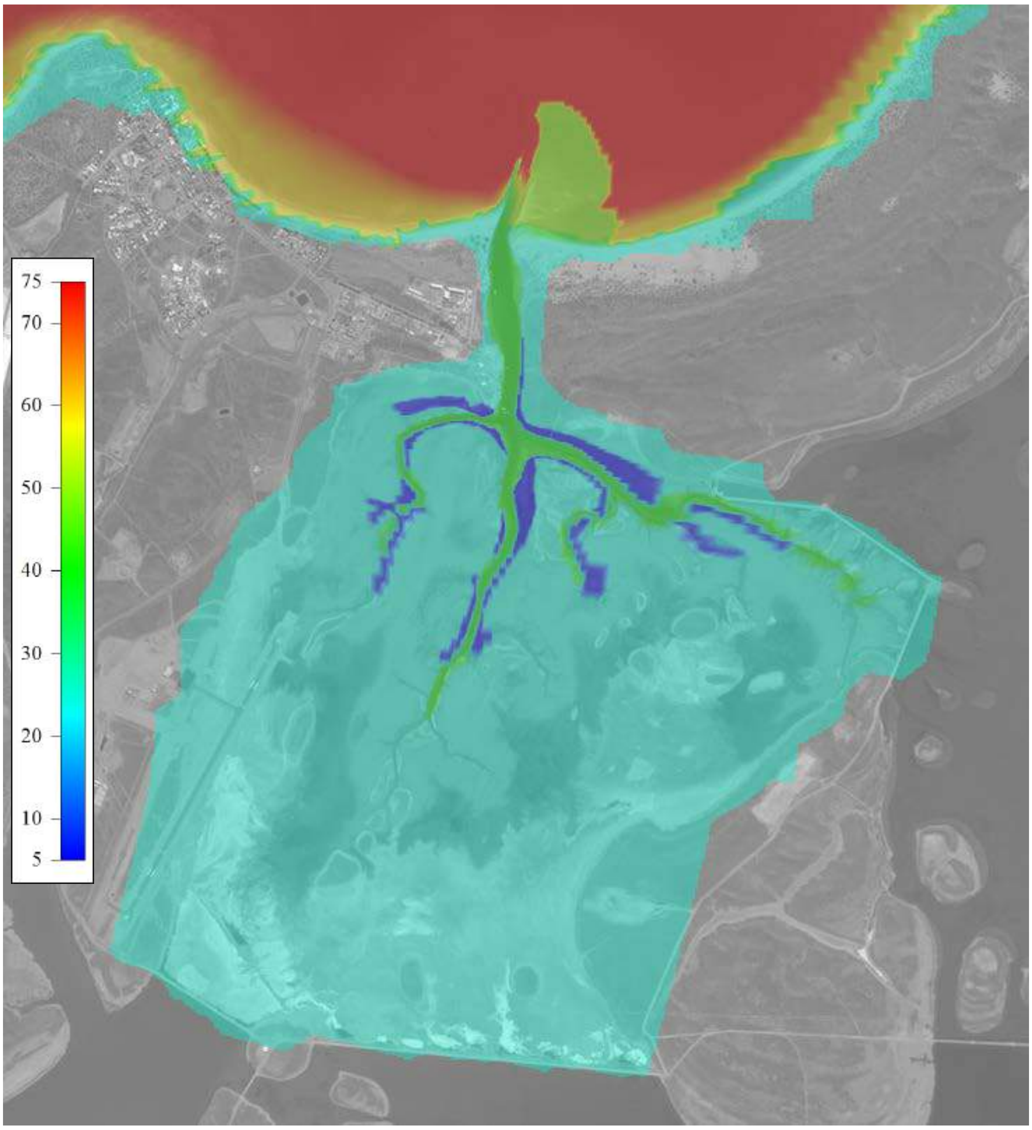

Figure 3.9: Roughness Map from Delft-3D Model

Eddy viscosity was used to dampen oscillations in the model and spatially varying values were applied in the model ranging from 100 at the open boundary sections to 10 within the general model domain.

3.4 Model Validation

3.4.1 Simulation Periods

To recognise seasonal conditions affecting coastal processes in the study area, one month of representative Dry Season and Wet Season conditions were identified for model investigations as follows:

- Monsoon Season: 1 to 31 March 2016
- Dry Season: 25 September to 23 October 2015

The representative seasonal periods were selected at times corresponding with large spring tides when measured data was available (Section 3).

3.4.2 Model Comparison – Monsoon Season

The monsoon season model comparisons are shown on Figure 3.10 with validation against the measured data. Water level comparisons within Beadon Creek and at the AWAC location show very good agreement to phase. The model shows a slight offset in water levels, particularly in the first half of the simulation period, noting that February is the period of highest regional residuals across the North-West Shelf with typically 0.2m additional water level residual. At the AWAC location the trend in current speeds and directions are generally well described. Spikes in the measured current velocity data are not replicated in the model and are considered a result of the eddy shedding from the end of the training wall (further discussed in Section 3.4.4).

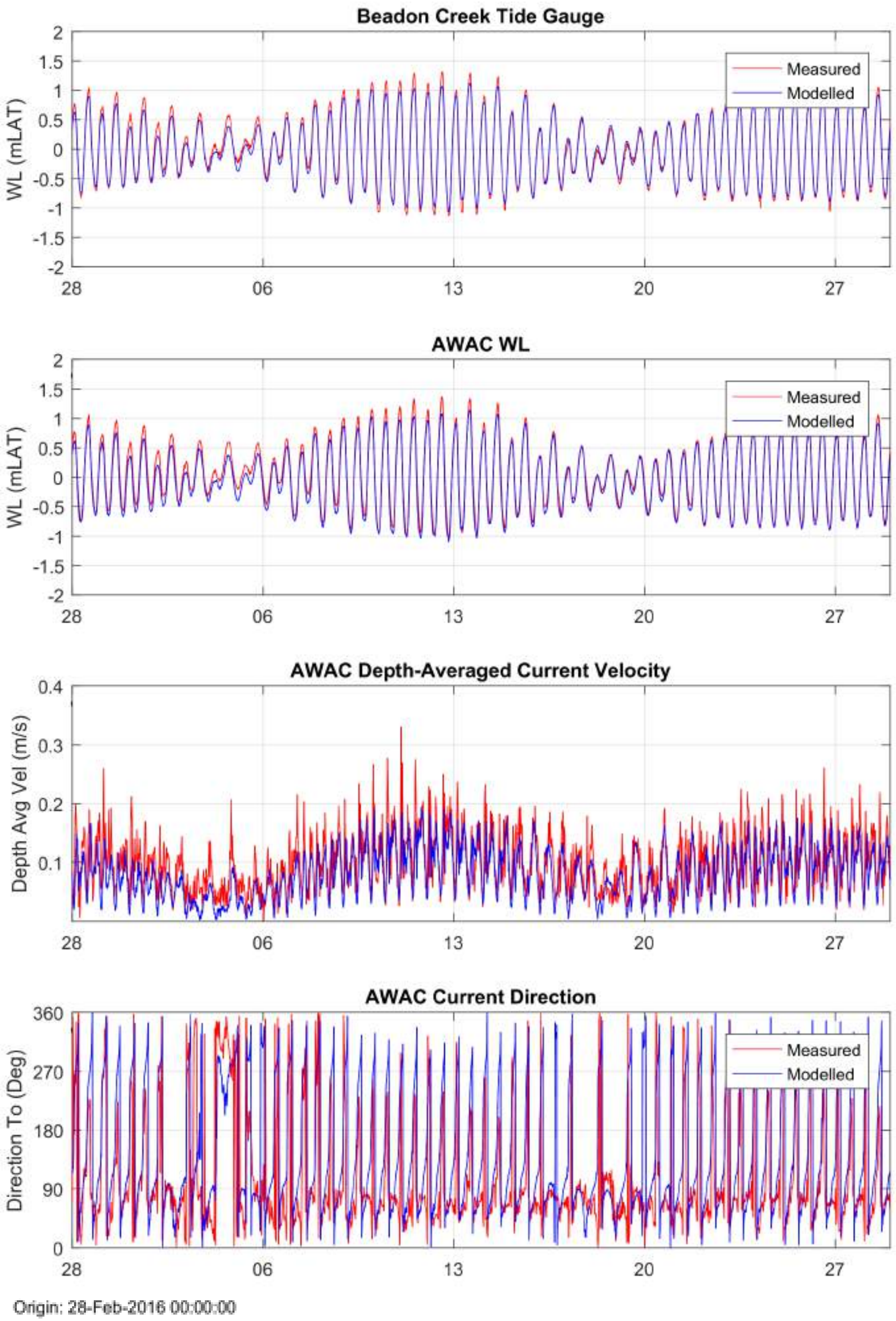

Figure 3.10: Model Validation – Representative Monsoon Season, 28 Feb 2016 – 28 Mar 2016

3.4.3 Model Comparison – Dry Season

The dry season model comparisons are shown on Figure 3.11 with validation against the measured data. Water level comparisons within Beadon Creek and at the AWAC location show very good agreement to phase and water level magnitude. At the AWAC location the trend in current speeds and directions are generally well described. As noted for the monsoon season simulation, peaks in the measured current velocity data are a result of eddy shedding from the end of the training wall and are not replicated in the model (further discussed in Section 3.4.4).

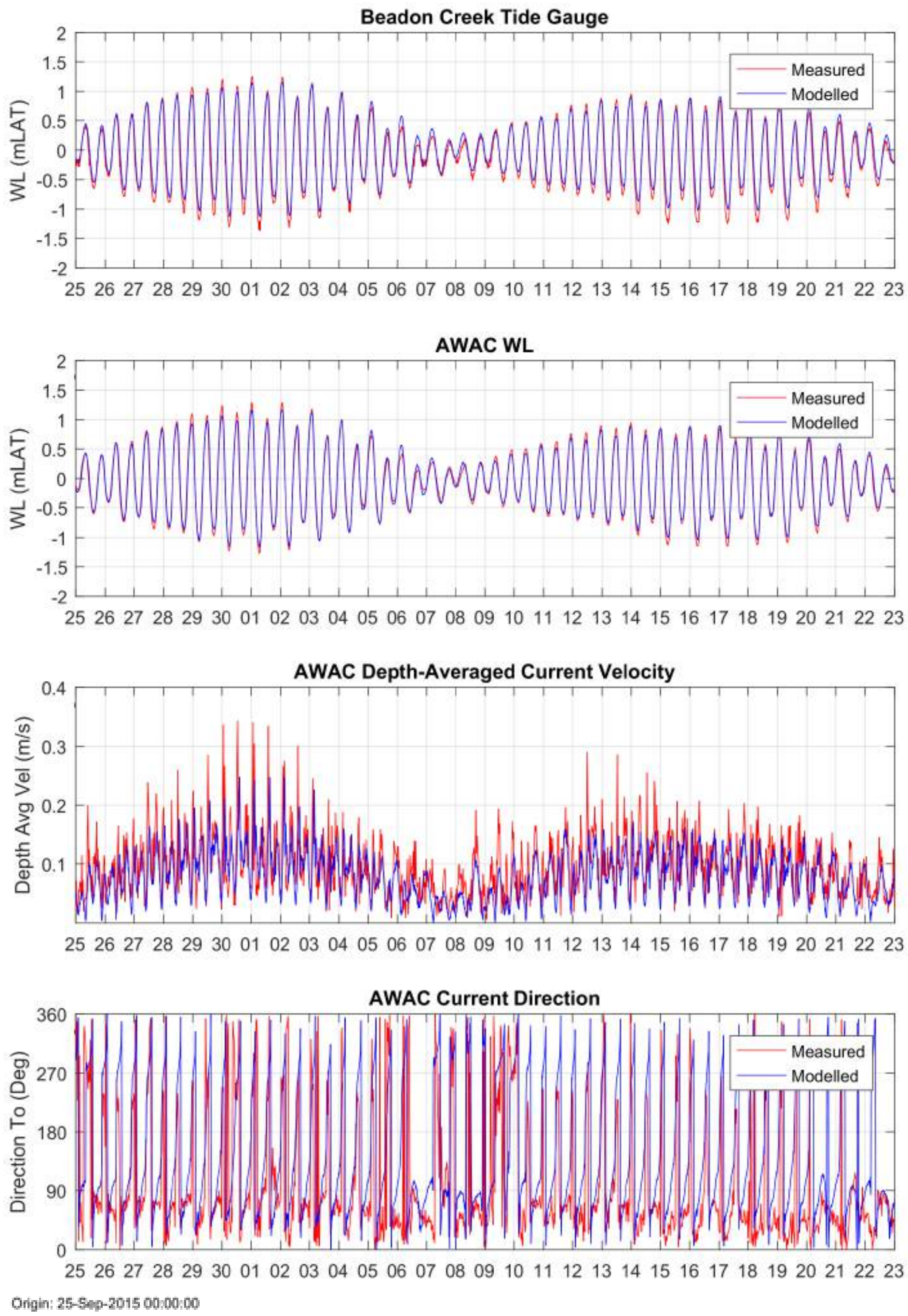

Figure 3.11: Model Validation –Representative DrySeason, 25 Sep 2015 – 23 Oct 2015

3.4.4 Eddy Shedding

On the ebb tide, water passes through the entrance channel and around the end of the training wall in the northwest direction. This process results in eddy structures that form in the nearshore area with local currents that turn anti-clockwise changing in scale and magnitude as the proximity to the entrance training wall increases and the stage of the tide changes. The aerial image, presented in Figure 3.12, clearly shows the eddy shedding on northwestern side of the entrance training wall, highlighted by the suspended sediment in the water column. Model outcomes presented alongside the aerial image in Figure 3.12 indicate the broader eddy structures are replicated in the model.

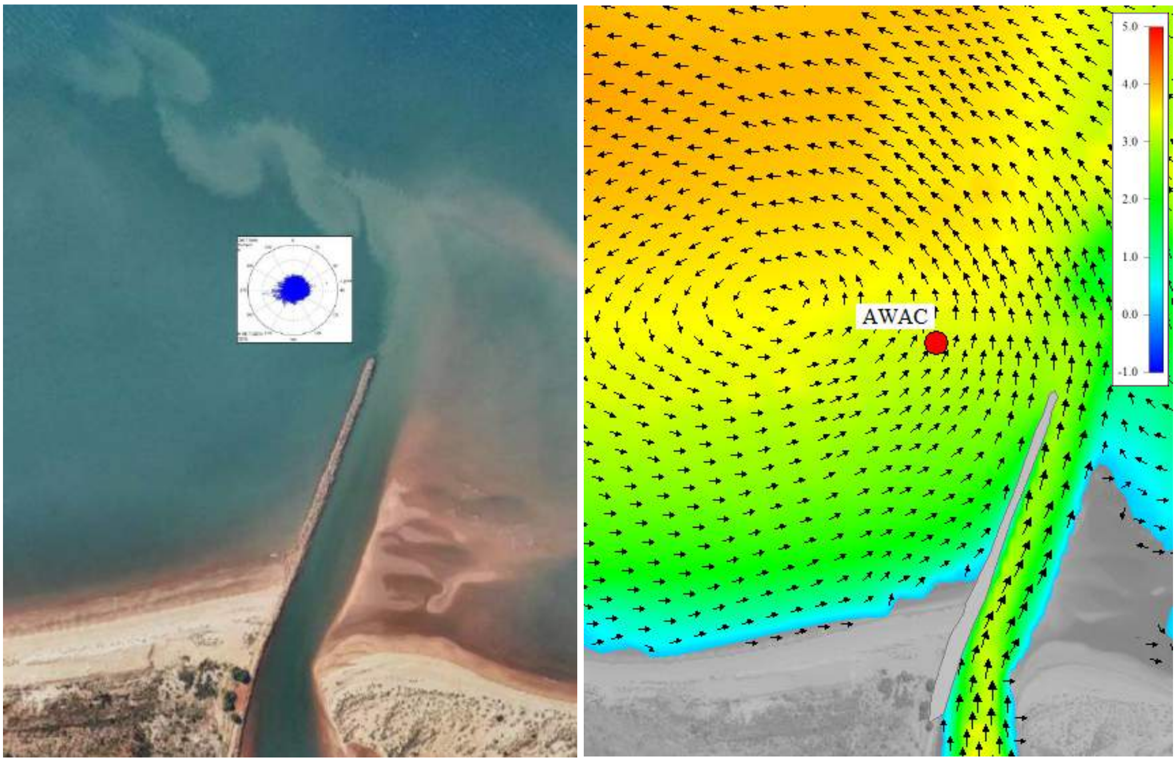

Figure 3.12: Model Validation – Eddy Shedding from Training Wall on Ebb Tide. Left Aerial Image, Right: 1 October 2015 0900 modelled ebb tide level (m MSL) and flow direction (depth averaged).

One of the outcomes of the eddy formation in the nearshore area is that it will setup a very localised gradient in the velocities, where large differences in velocity magnitude can exist across comparatively short distances. This has been investigated in the model to understand if this is the cause of the very large velocity spikes in the measured record.

In Figure 3.13 the modelled velocity gradients at the AWAC location are compared to current velocity magnitude at a location 125m north. This shows the velocity magnitudes are higher than at the AWAC location and supports the theory that velocity gradients exist across this area making point comparisons of modelled and measured data highly sensitive to the exact location and model resolution. Overall, the model is representing the turbulent processes near the entrance to a similar magnitude, although the exact location of eddies and vortices differ to some of the observations. In part, the resolution of the hydrodynamic model will limit the ability to exactly replicate the eddy length scales that may be present at the site and it is computationally expensive to refine the model to a resolution that could capture those processes.

Overall, the exact locations of the eddies near the entrance to Beadon Creek is a localised phenomenon that is not a key variable in the larger scale coastal processes at the site. The model achieves very good agreement to the general trend of the measured velocity magnitude and phasing at the AWAC which provides confidence the model is accurately reproducing the overall hydrodynamics for the location.

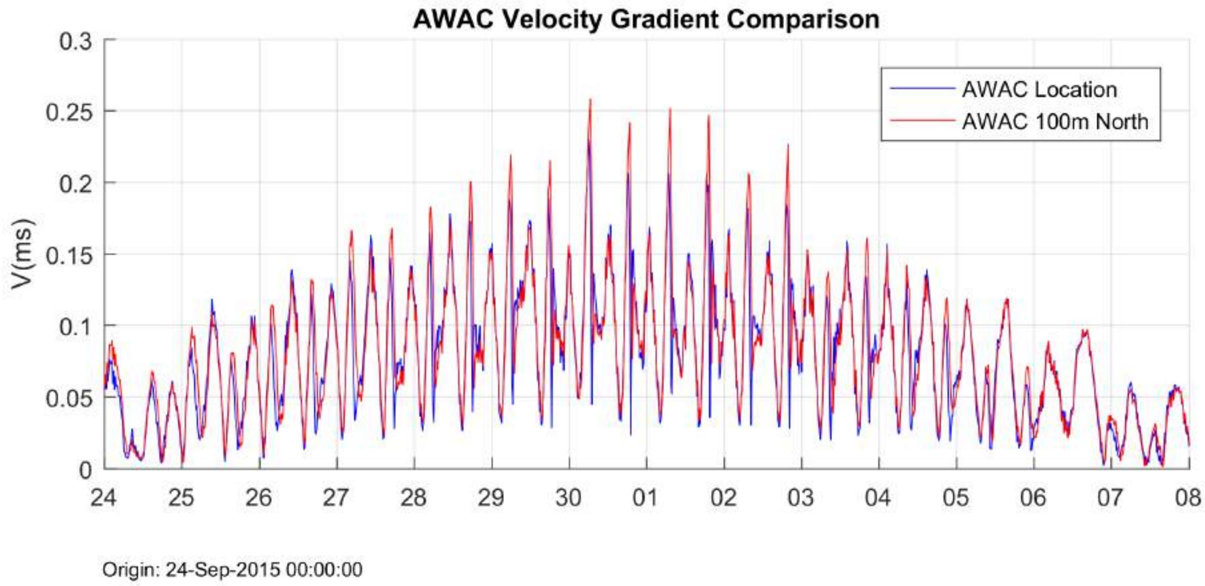

Figure 3.13: Comparison of modelled current velocity gradient at the AWAC location

4. Developed Case Layout

The Stage 2 design drawings showing the concept plan as at 14 March 2017 are provided in Appendix A. Figure 4.1 indicates the key design features that have been incorporated in the design with features and dimensions summarised as follows:

- a land backed wharf with land reclaim constructed from dredge spoil
- a berth pocket with dimensions of 240m x 40m and dredge level of -8.0m CD
- a turning circle with a 70m radius and dredge level of -6.0m CD
- a navigation channel through the Beadon Creek Entrance, dredged to -6m CD, with a width of 75m at the training wall turn narrowing to 55m through the lee side of the entrance channel entering Beadon Creek
- Batter slopes to natural levels at approximately 1V:3H
- An offshore navigation channel with a width of 55m dredged to a level of -6m CD and extending approximately 2.5km into Beadon Bay.

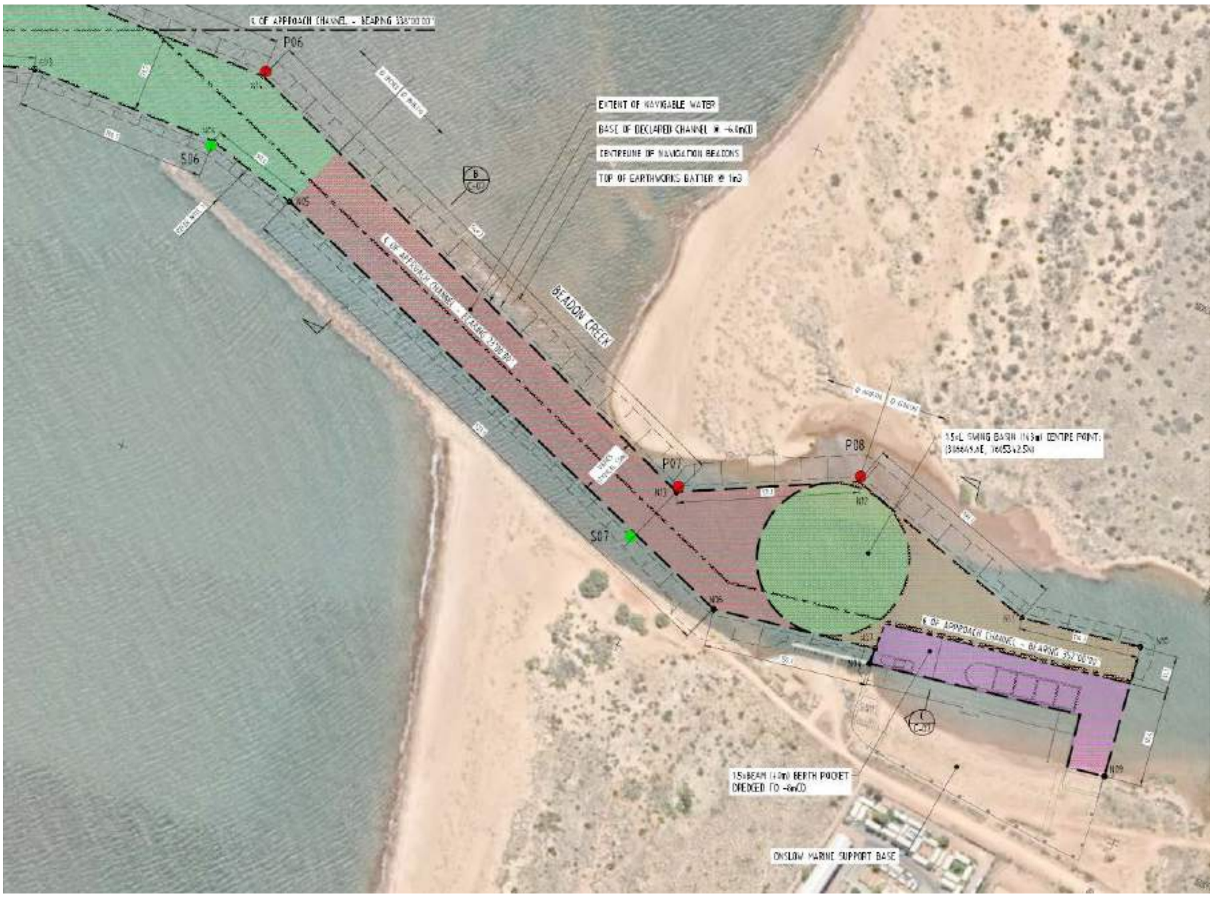

Figure 4.1: Marine supply Base Concept (APH170162 C-05 RevB)

The estimated dredge volume for Stage 2 is 0.93 million m^3 with the preferred option to re-use the dredge spoil in land areas shown in Figure 4.2. This approach is currently being negotiated with the Shire of Ashburton.

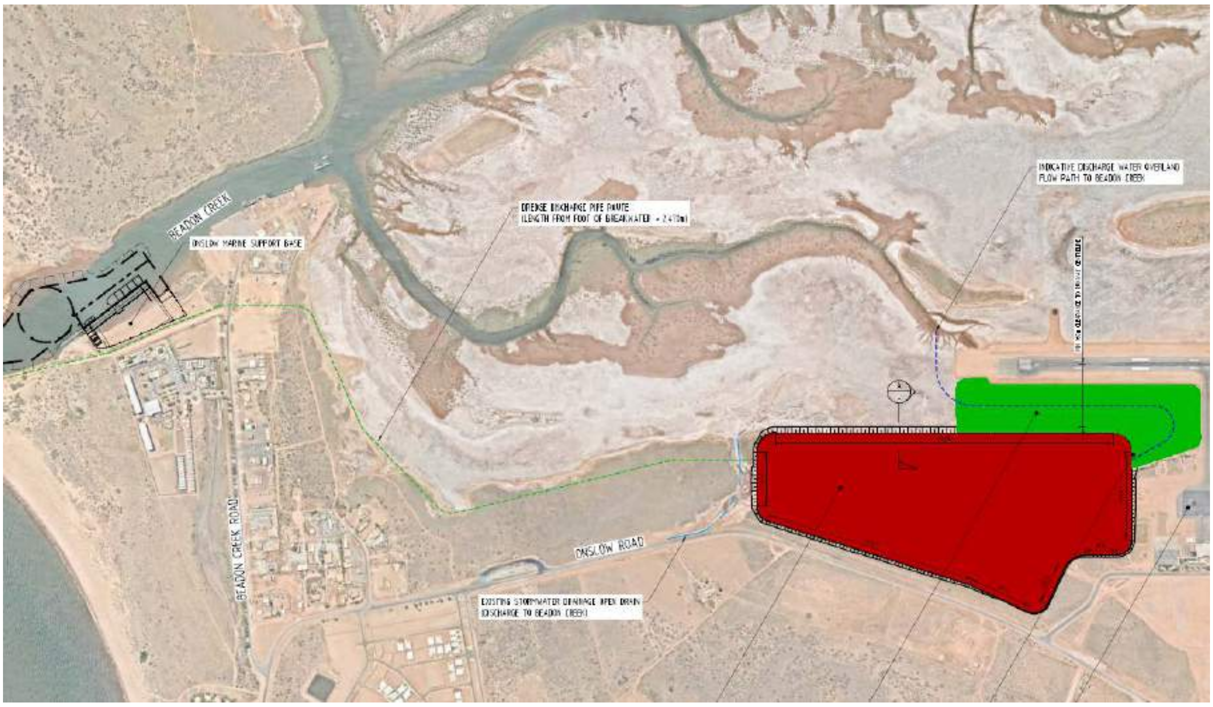

Figure 4.2: Re-use areas for Dredge Spoil (APH170162 C-06 RevC, 17 Jul 2017)

4.1 Developed Case Model Bathymetry

The dredged levels shown in the concept design were adjusted to the model datum (m MSL) and updated in the model bathymetry to define the developed case layout.

5. Hydrodynamic Assessment Results

5.1 Model Reporting Locations

The model reporting locations are summarised on Table 5.1 and shown for the Beadon Creek Entrance on Figure 5.1, the central Beadon Creek section in Figure 5.2 and the lower Beadon Creek area across the tidal flats in Figure 5.3.

Table 5.1: Model Reporting Locations

Location ID	Location Description
T0 – T4	Training Wall channel section
ES0 – ES2	Eastern Shoal
DE1 – DE3	Developed Case Channel
EB1 – EB4	Eastern Bank of Beadon Creek
C1-C6	Main Channel Central Beadon Creek Section
B1-B2	OMSB Berth Pocket
CK1-CK4	Beadon Tidal Creeks
M1-M4	Mangrove Areas in Beadon Creek Tidal Flats
F1-F3	Tidal Flats

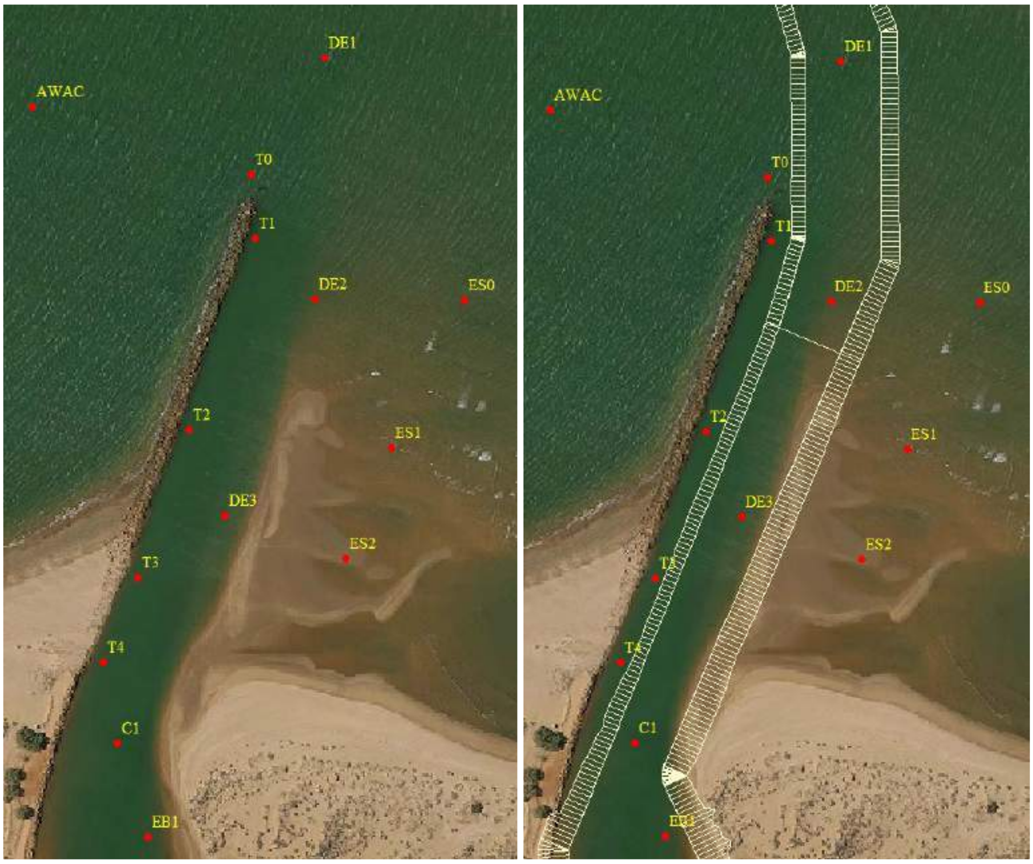

Figure 5.1: Model Reporting Locations – Beadon Creek Entrance

Figure 5.2: Model Reporting Locations – OMSB Site and Central Beadon Creek

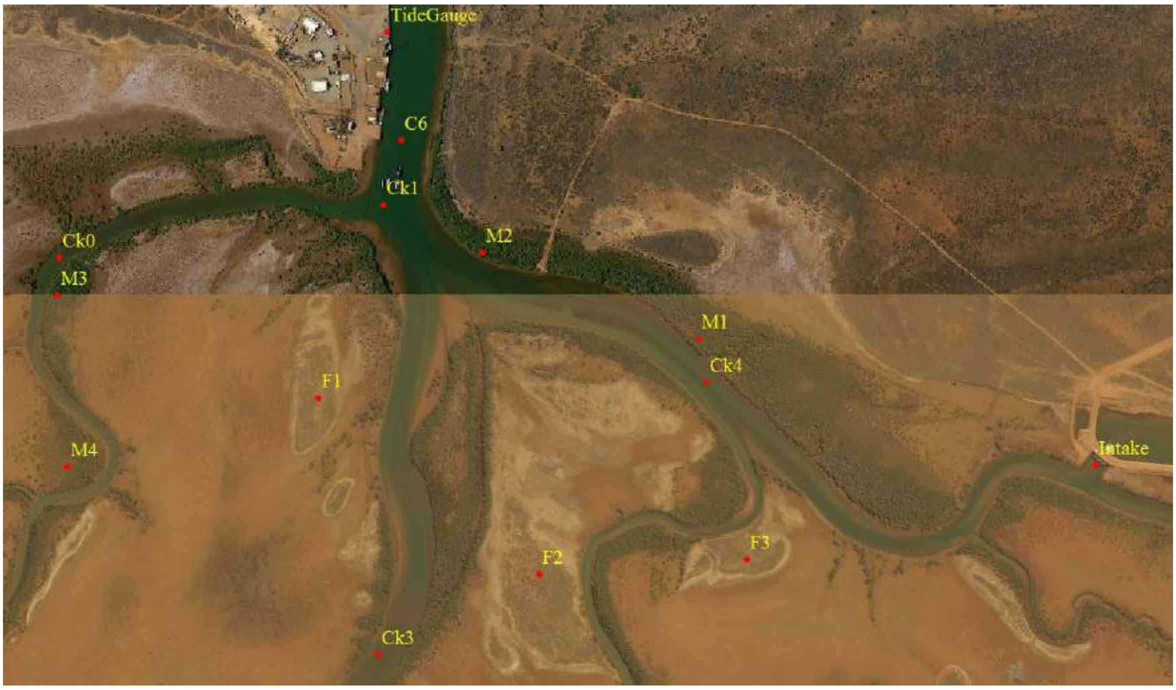

Figure 5.3: Model Reporting Locations – Beadon Creek Tidal Flats

5.2 Change to Beadon Creek Tidal Prism

The storage volume of Beadon Creek will increase following the Stage 2 capital dredging. Calculated from the tip of the Entrance Channel through into the OMSB site, the dredging will result in an estimated 670,000m^3 of additional storage volume in Beadon creek.

The dredging will alter the tidal prism of the creek as a result of both the increased available volume and the modification to the entrance which will make the exchange of flows in and out of the entrance more efficient. The change in the tidal prism volume was assessed by analysing the inflow and outflow through the entrance channel in the existing and developed (ie dredged) scenario model. The discharge through two spring tide cycles is shown in Figure 5.4.

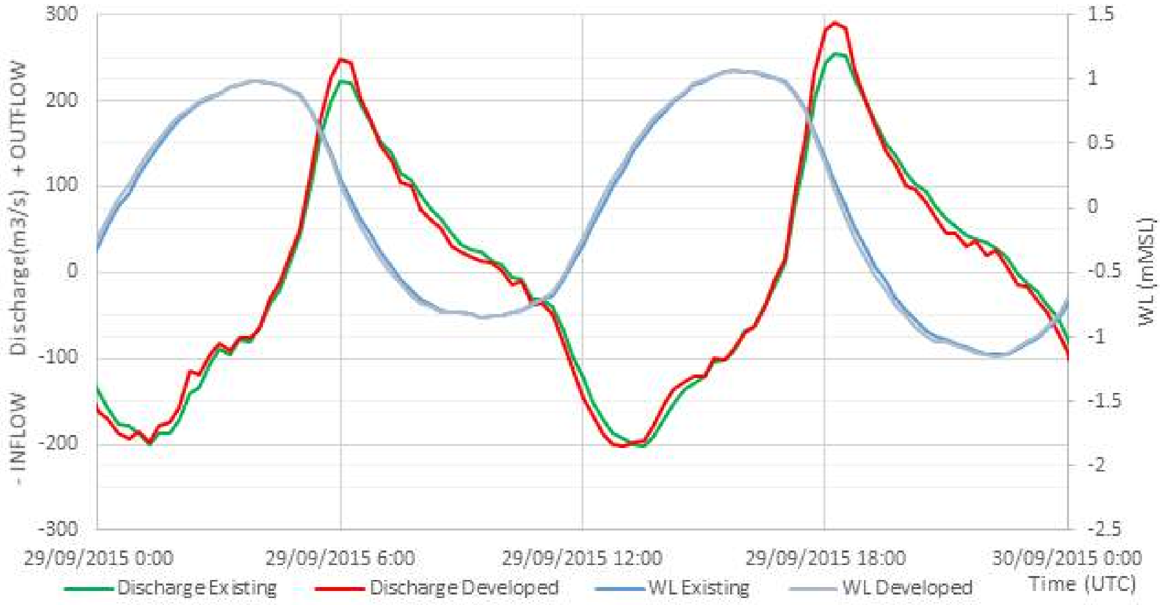

Figure 5.4: Modelled discharge rates for inflow and outflow through the Entrance Channel during a large spring tide.

On Figure 5.4 the outflow rate increases under the developed scenario when compared to the existing with the outflow rate increasing at the peak of the ebb tide from approximately 220m^3/second to 250m^3/second. On the incoming flood tide the inflow rate is largely unchanged, however the more efficient dredged channel allows the water to reach a peak discharge rate slightly earlier. The water level comparisons shown on Figure 5.4 between the existing and developed cases show the magnitude of the peak and trough remains unchanged at the entrance location. Due to the increased channel efficiency for transferring the tide in the developed case, the timing of the water level is slightly quicker in the ebb and flood for the developed case, in line with the discharge rate increases. The difference in timing of the water level at the entrance is approximately 10 minutes earlier for the developed case mid stage of the ebb and flood tide.

The difference in cumulative discharge over a full month tidal cycle for the existing and developed case was assessed in the model for the Dry Season (23/9/2015 – 23/10/2015). The results are presented in Table 5.2 and indicate approximately 100 Gigalitres of inflow to Beadon Creek and approximately 75 Gigalitres of outflow occurred for the approximate 4 week period, resulting in a negligible increase in discharge volume through the entrance under the developed case scenario. Based on this four week period, the increase to the tidal prism of Beadon Creek is approximately 1%.

Table 5.2: Increase to Tidal Prism Calculation Based on one Month of modelled Tides at the Beadon Creek Entrance for the Existing and Developed Case.

	Existing	Developed		Existing	Developed	% Diff	Pump Volume[2]
	Total INFLOW		% Diff	Total OUTFLOW		% Diff	Inflow-Outflow
Total (GL)[1]	101.2	102.1	+1%	74.8	75.6	+1%	26.4

1. 1 Gigalitre = 1 million m^3
2. The salt intake pump for Onslow Salt accounts for the volume difference of Total Inflow - Outflow

It is important to remember that whilst discharge rates are increasing through the ebb tide under the developed scenario, the cross-sectional area at the entrance is larger for the developed case. A representative cross section at the entrance is shown to illustrate this on Figure 5.5.

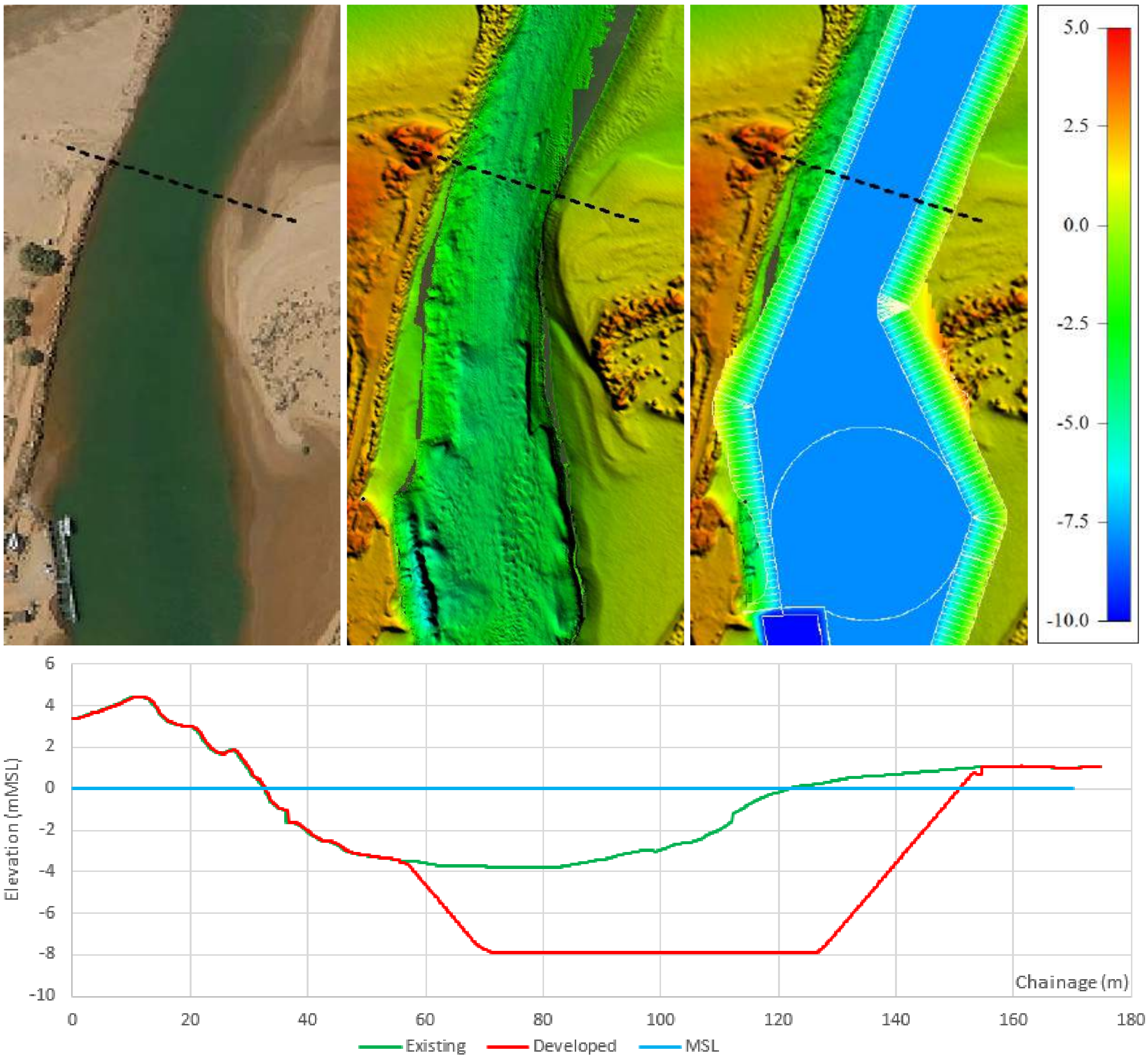

Figure 5.5: Cross Sectional Area of Entrance Channel under pre and post-dredge condition. Levels shown from 2016 LiDAR and Bathymetry (mMSL)

A calculation of the cross-sectional area for the existing and developed channel shown on Figure 5.5 (as measured below 0m MSL) indicates the cross-sectional area would increase from approximately 250m^2 to 650m^2. This increase in cross sectional area associated with the increased channel depth and width reduces the current velocity despite the increased peak discharge rates through the channel. Similarly, a reduction in the velocity magnitude will be expected for all reporting locations where dredging has deepened the seabed level.

5.3 Spatial Plots for Current Velocity and Direction

Modelled spatial current velocity and direction is presented for dry season ebb and flood tide to examine changes to the velocity structure and magnitude under the post development scenario.

For the peak spring flood tide case the modelled current velocity and magnitude is presented for the existing case on Figure 5.6 and on Figure 5.7 for the developed case. A comparison of the existing and developed cases in the Beadon Creek central section is shown in Figure 5.8.

The additional depth associated with the dredging reduces the current speeds through the entrance channel and central section of Beadon Creek in the flood tide conditions. It is noted that minor differences in inundation may be observed between the existing and developed cases presented on Figure 5.6 and Figure 5.7 due to the dredged entrance being more efficient at transmitting the tide in and out in the developed case as discussed in Section 5.2. In effect, the developed cases are at a moderately more advanced stage of the tide cycle.

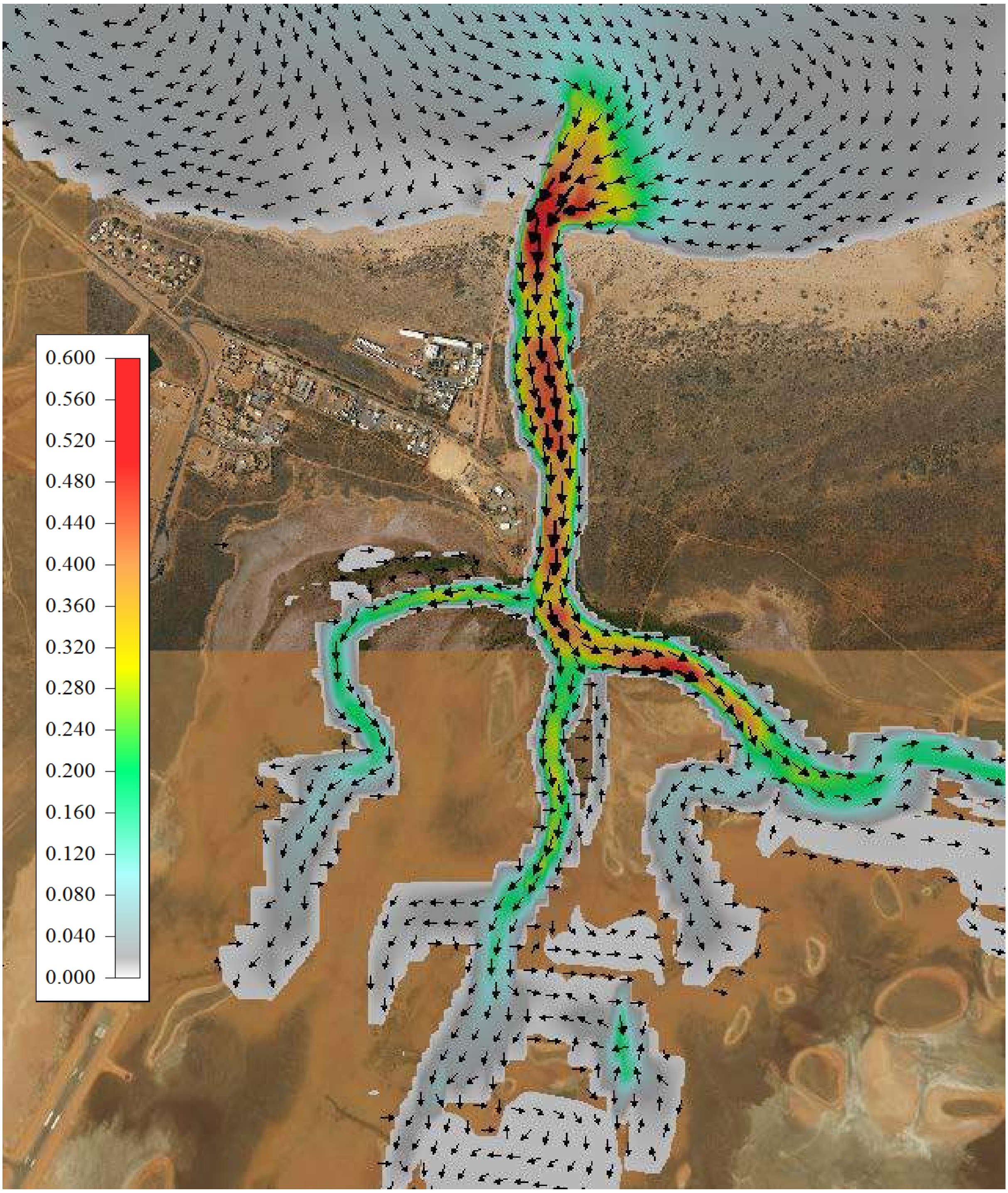

Figure 5.6: Existing case modelled depth average current speed through the Entrance Channel during a large flood tide (1 October 2015 1100 WST).

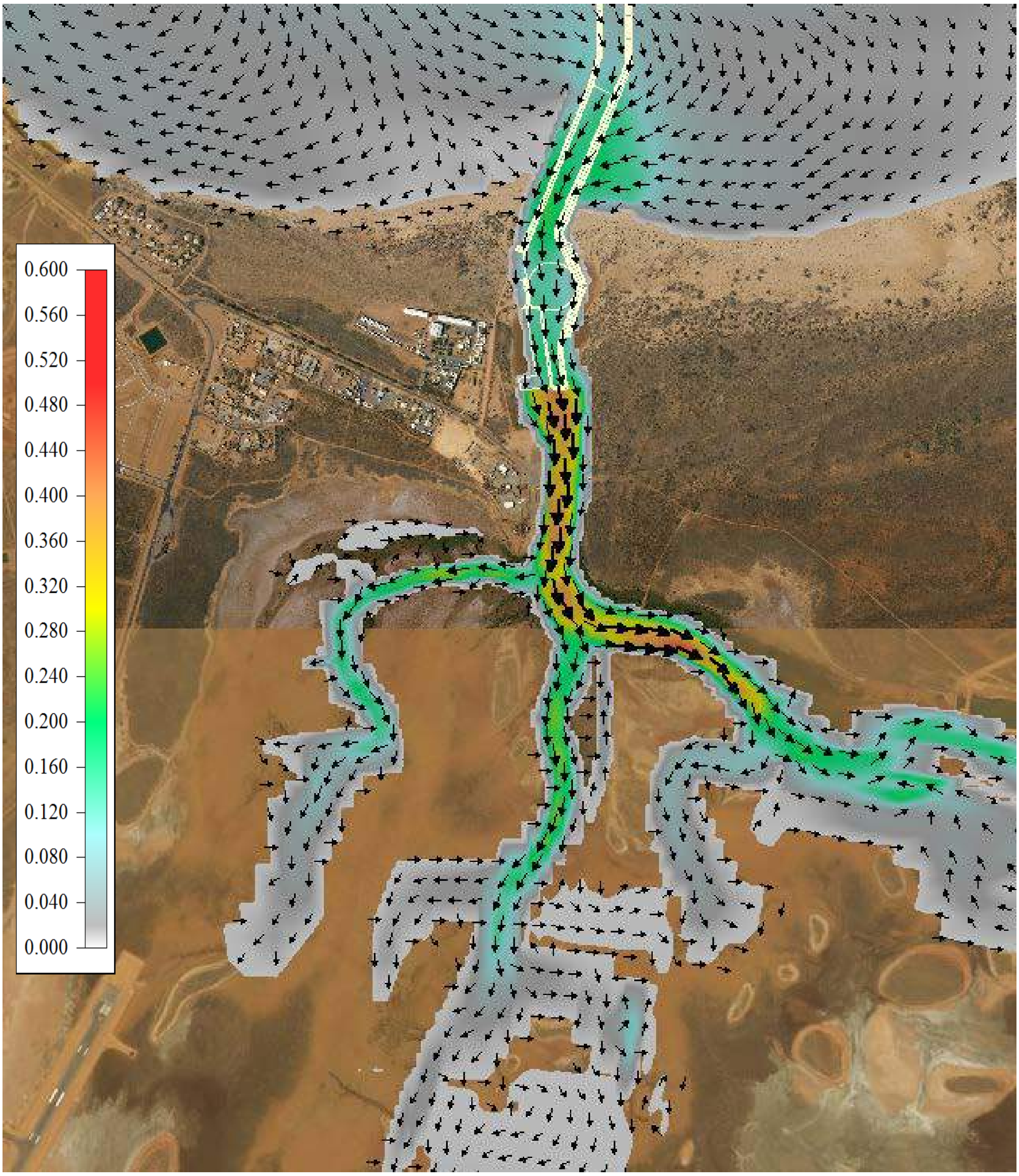

Figure 5.7: Post development modelled depth average current speed through the Entrance Channel during a large flood tide (1 October 2015 1100 WST).

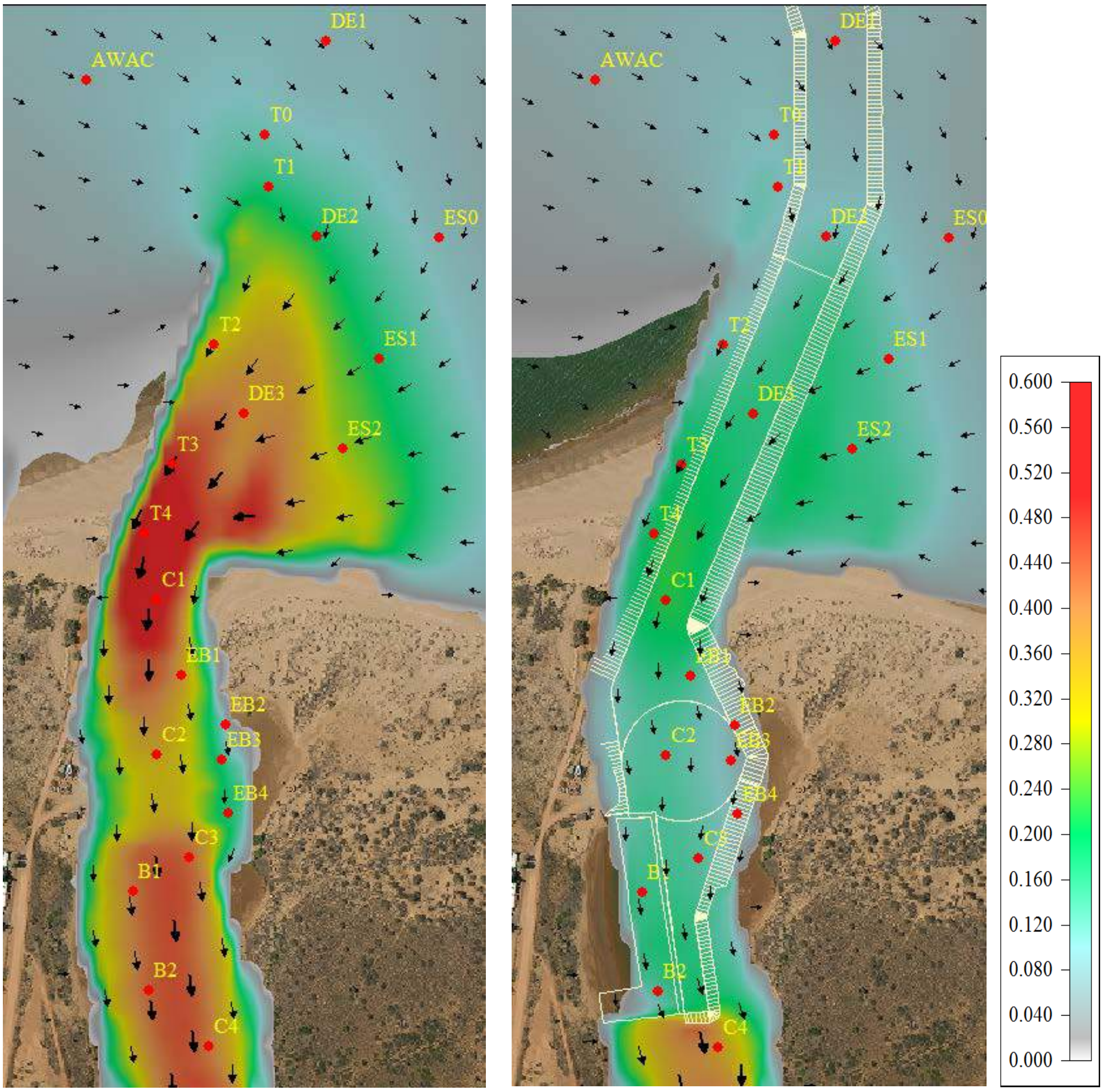

Figure 5.8: Comparisons of depth averaged current speed through Beadon Creek entrance during a large flood tide for the existing (left) and developed (right) case (1 October 2015 1100 WST).

For the peak spring ebb tide case, the modelled changes to current velocity and magnitude is presented in Figure 5.9 for the existing case and on Figure 5.10 for the developed case. A comparison of the existing and developed cases in the Beadon Creek central section is shown in Figure 5.11.

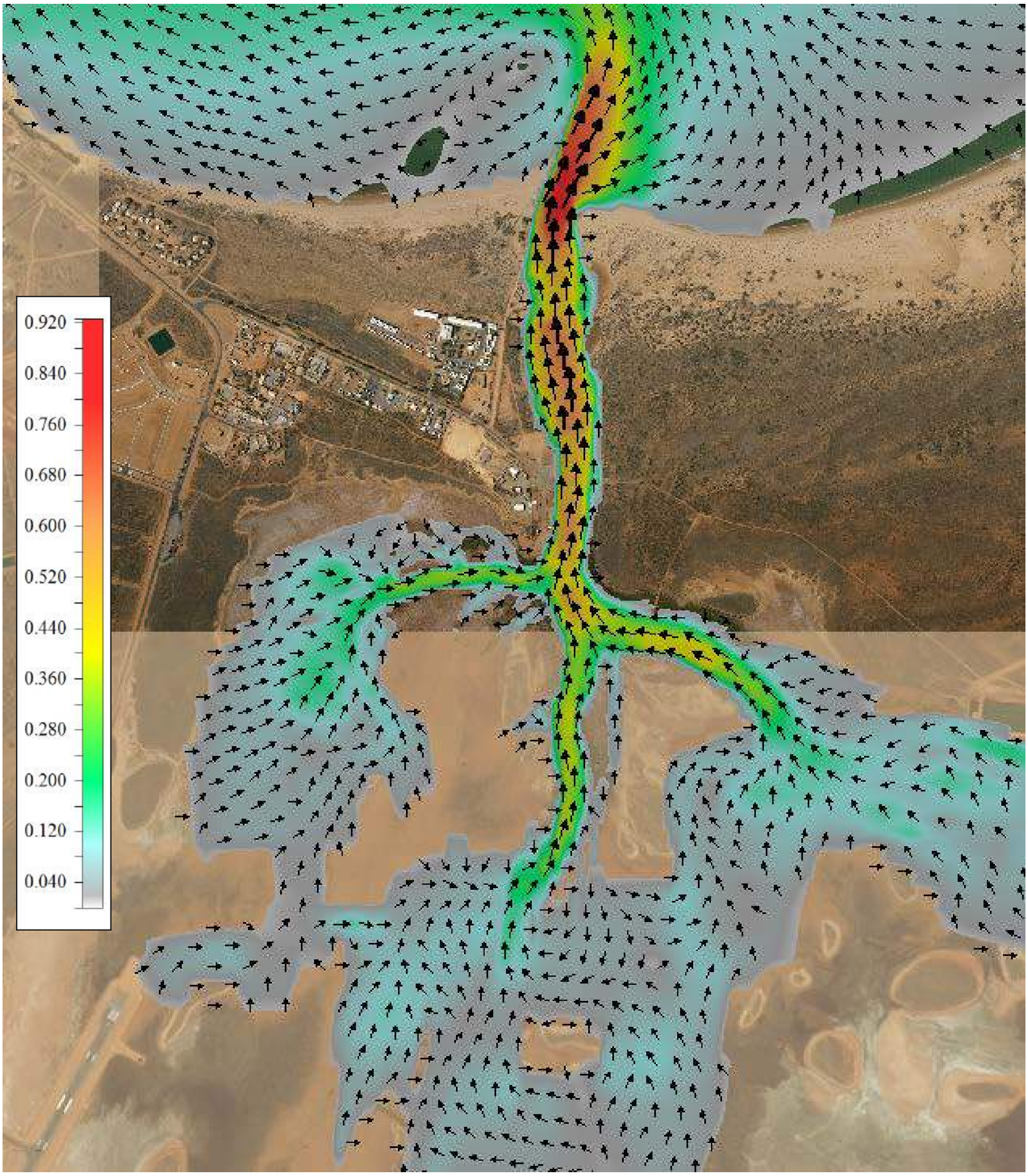

Figure 5.9: Existing condition modelled depth average current speed through the Entrance Channel during a large ebb tide (1 October 2015 0230 WST).

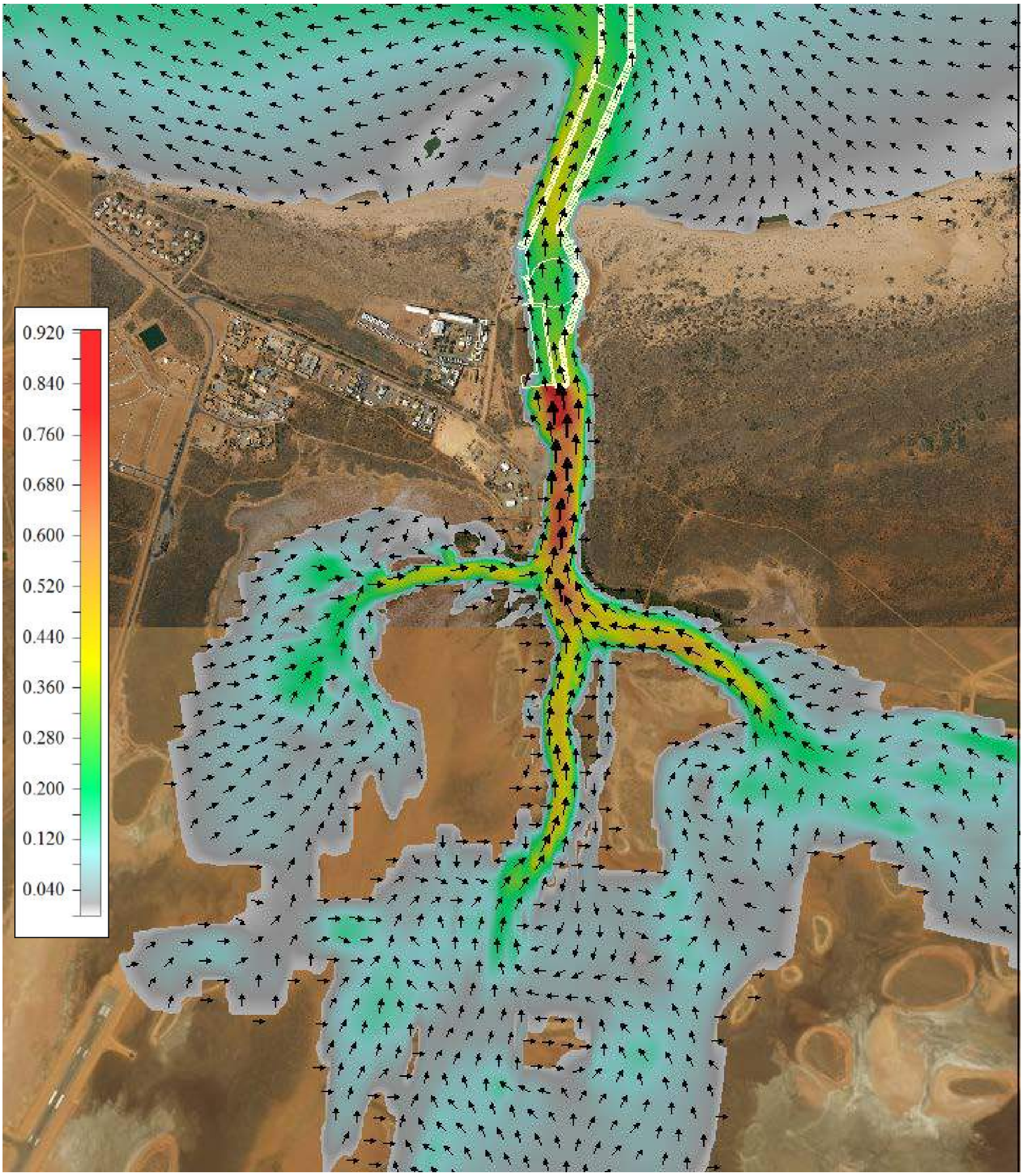

Figure 5.10: Post development modelled depth average current speed through the Entrance Channel during a large ebb tide (1 October 2015 0230 WST).

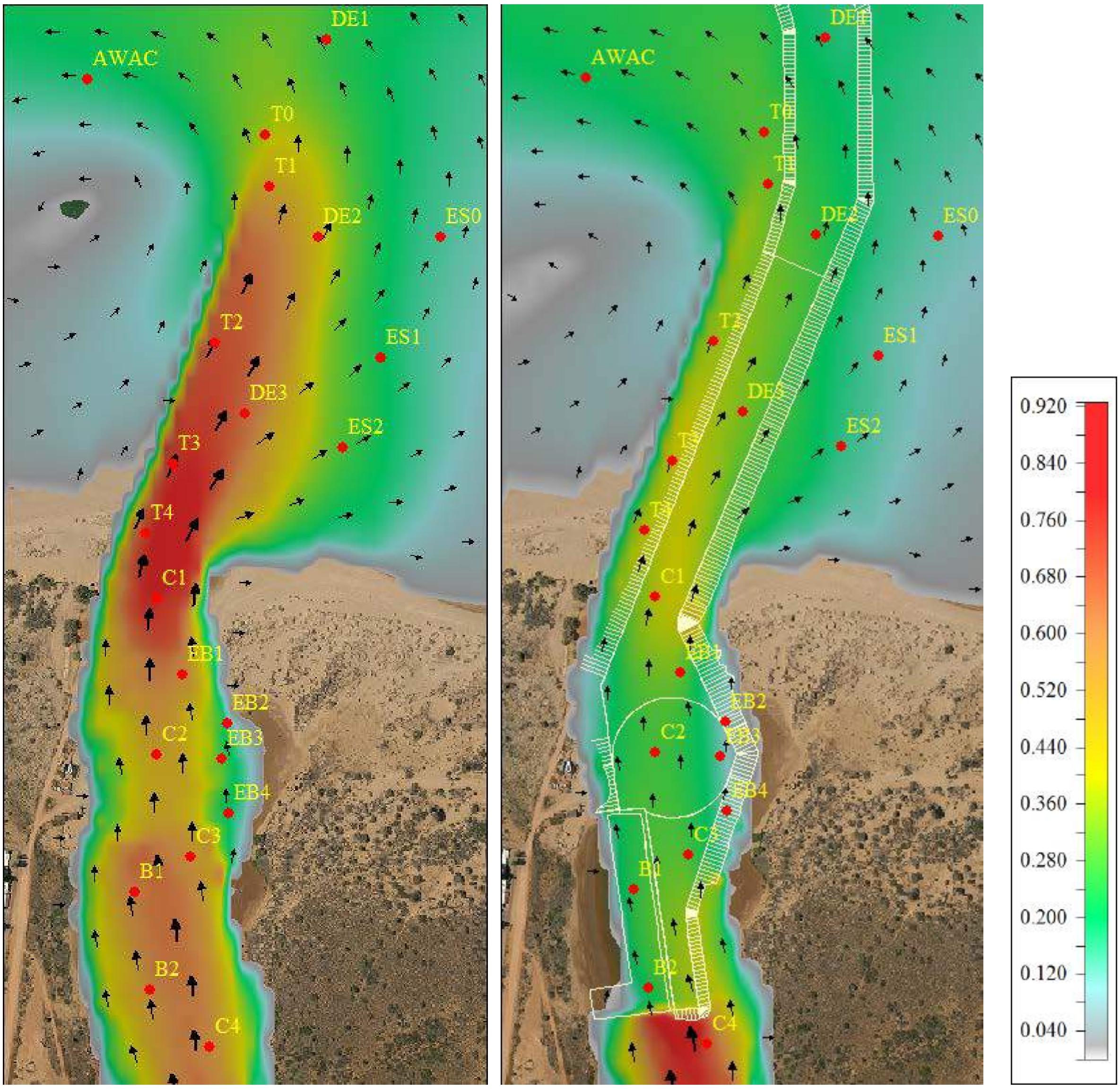

Figure 5.11: Comparisons of depth averaged current speed through the central Beadon Creek Channel section during a large ebb tide for the existing (left) and developed (right) case (1 October 2015 0230 WST).

5.4 Changes to Current Velocity at Key Locations

For the model reporting locations in Table 5.1, comparisons of the pre and post development current velocities modelled through the neap - spring cycle during the Dry Season are shown below.

For the Training Wall Locations T0 to T4 the modelled current speed comparisons are shown on Figure 5.12. The depth averaged current velocities reduce by between 40 to 60% following the establishment of the deeper channel to the east of the training wall location.

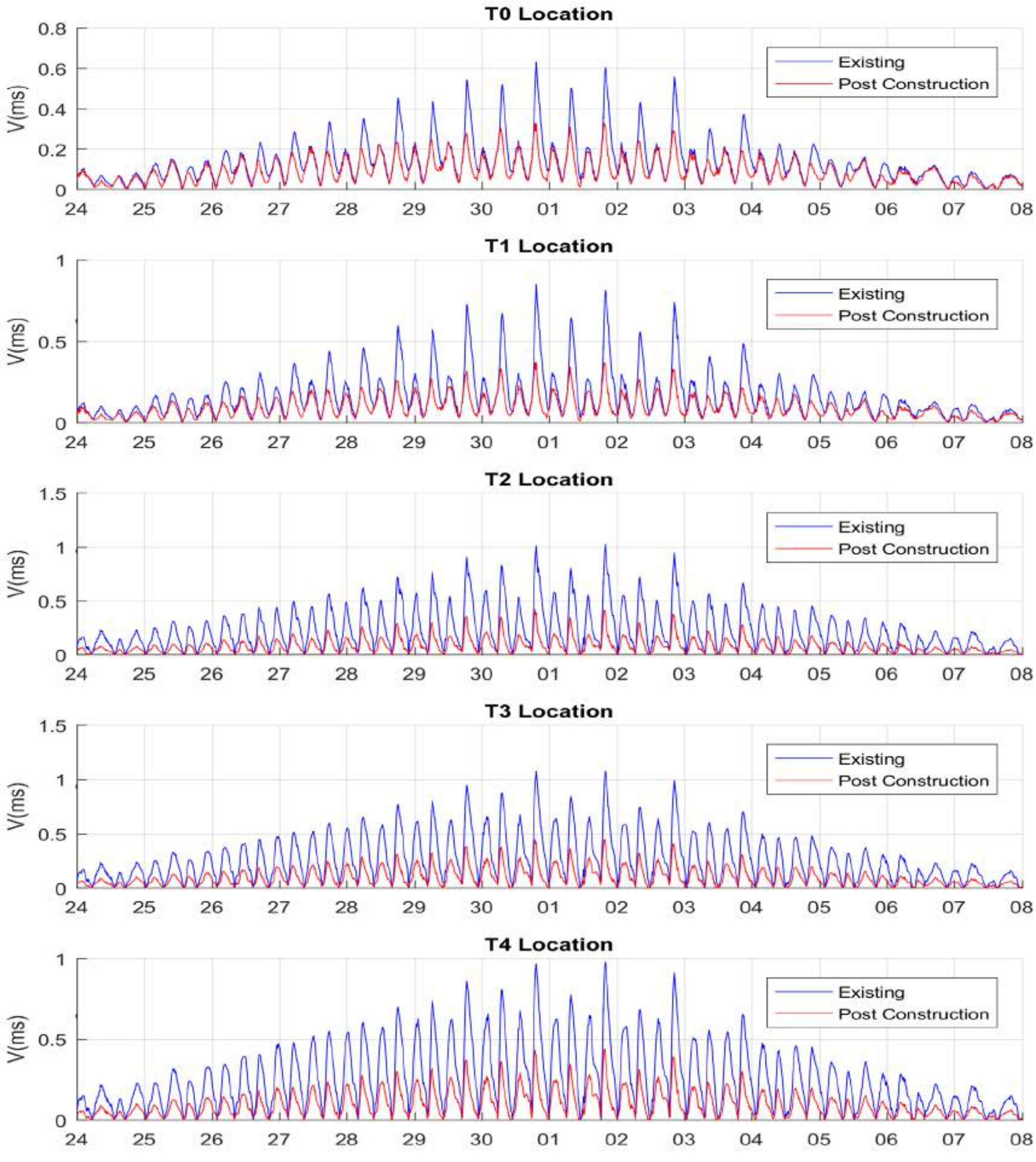

Figure 5.12: Modification to flow velocities along the Training wall post construction (Spring Tide 24 Sep to 8 Oct 2015)

For the Eastern Shoal Locations ES1 to ES3 the modelled current speed comparisons are shown on Figure 5.13. The modelled depth averaged current velocity remains largely unchanged between the existing and post construction scenario for location ES0. For locations ES1 and ES2 a reduction in the velocity magnitude through the peak of the spring tide is noted, whilst through the neap phase these are generally unchanged.

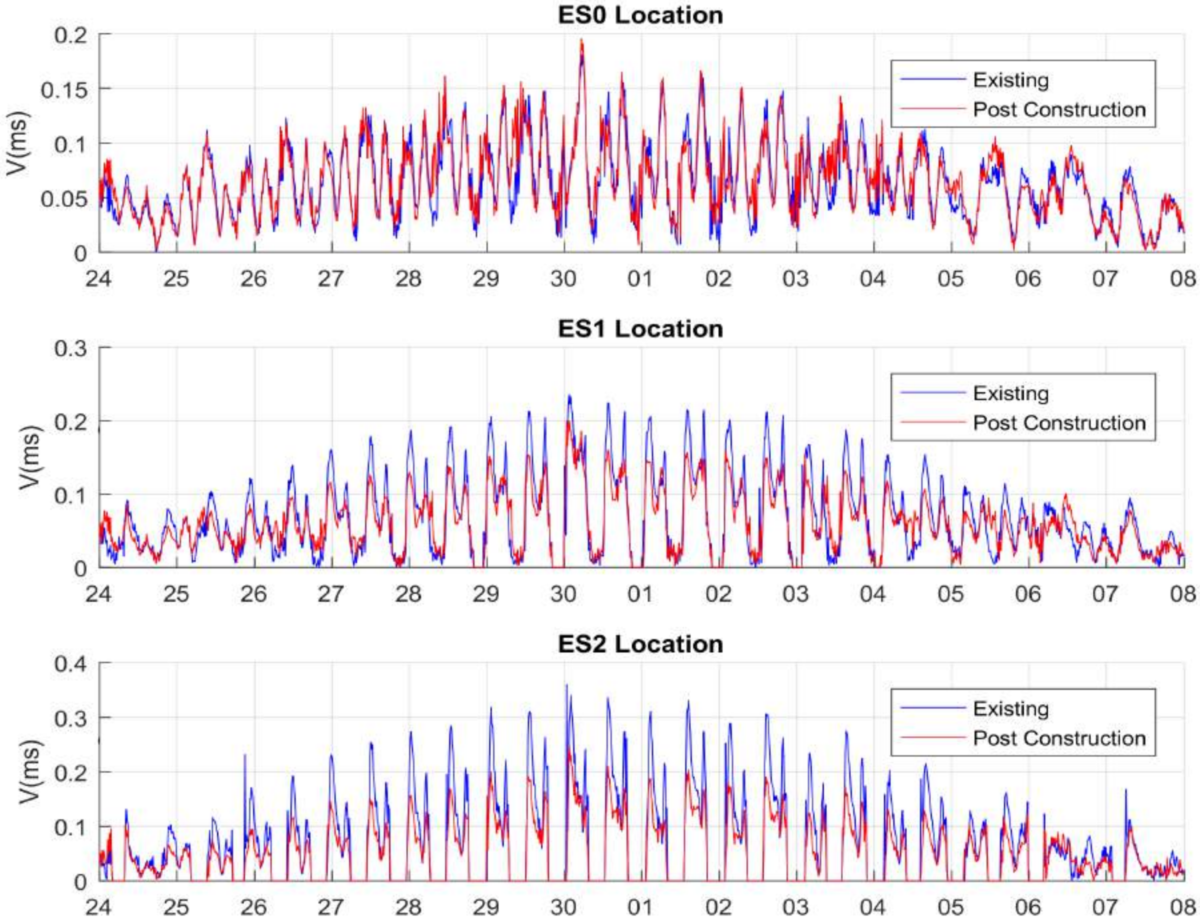

Figure 5.13: Modification to flow velocities on the eastern shoal post construction (Spring Tide 24 Sep to 8 Oct 2015)

For the main Channel section of Beadon Creek, reporting locations C1 to C6 modelled current speed comparisons are shown on Figure 5.14. The modelled depth averaged current velocity reduces markedly following the establishment of the deeper channel for the C1, C2 and C3 locations positioned inside the dredged footprint (Figure 5.2). For the lower sections of the creek at C4, C5 and C6 there is a minor increase in the velocity magnitude post construction, through the peak spring tide currents period. There is negligible difference in current velocity magnitude during the neap phase.

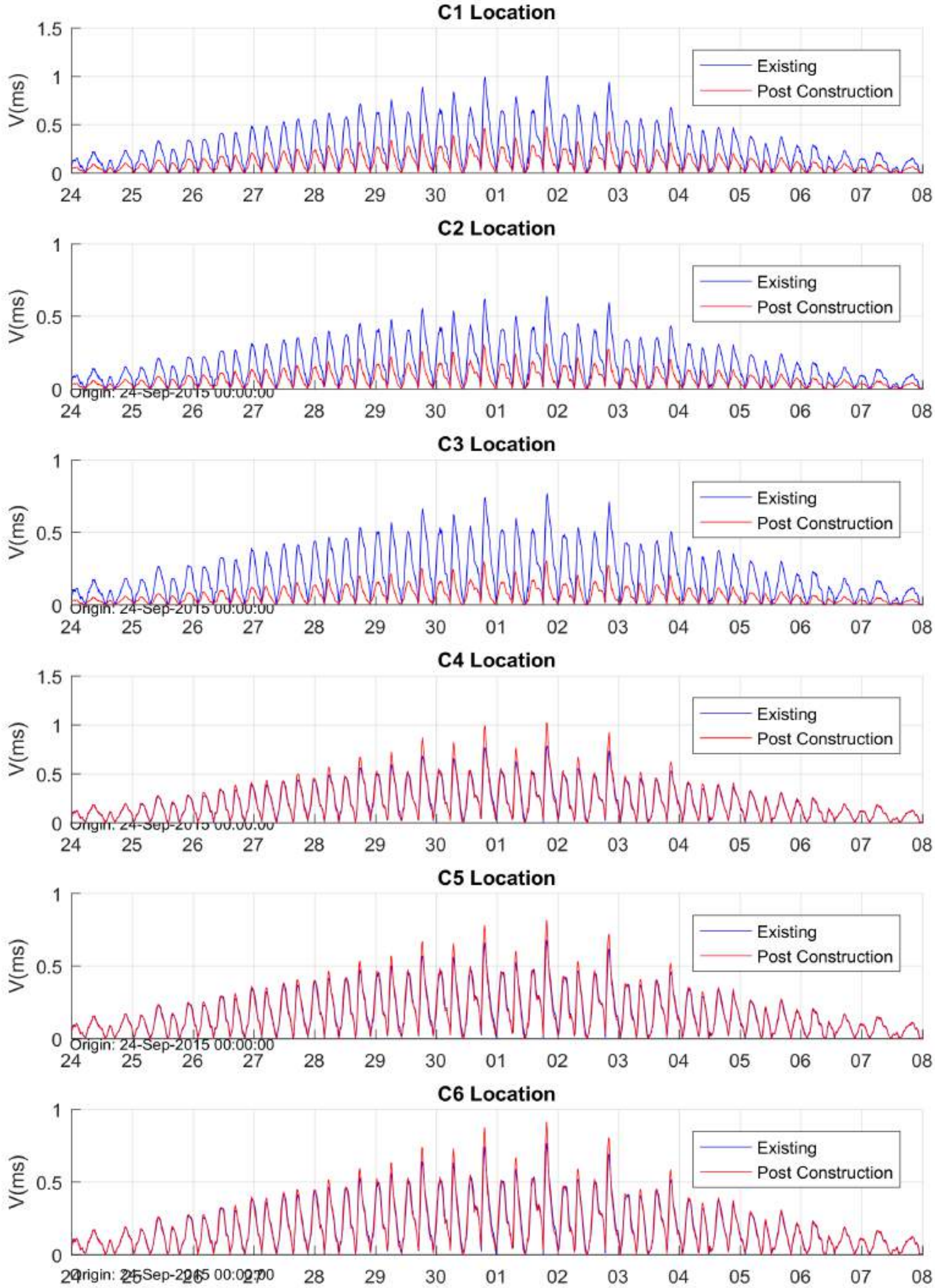

Figure 5.14: Modification to flow velocities in the Main Channel of Beadon Creek Post Construction (Spring Tide 24 Sep to 8 Oct 2015)

For the Beadon tidal creek branches in locations CK0 to CK4 the modelled current speed comparisons are shown on Figure 5.15. The modelled depth averaged current velocity is largely unchanged through the neap phase of the month, however during the spring tide phase the current magnitude increases in the post-development case. This is considered to be due to the increased efficiency of the entrance channel, as discussed in Section 5.2, which moves the water through the entrance more easily, with the upstream flow velocities in turn increased. The increase in current speeds in the upper creek has the potential to increase the risk of erosion in this area is examined in detail in the morphological modelling presented in Section 6.

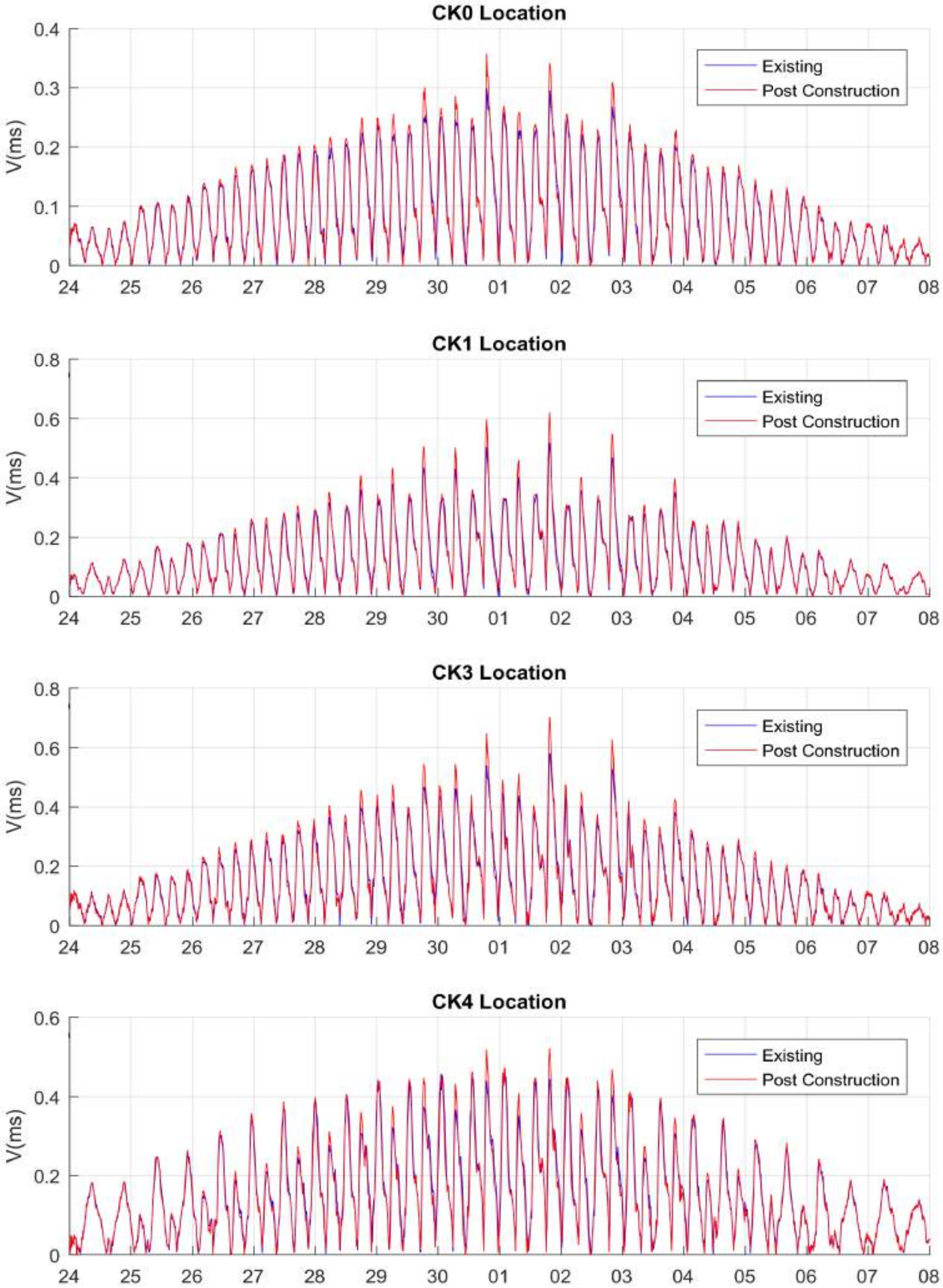

Figure 5.15: Modification to flow velocities in the Beadon Creek Tidal Branches Post Construction (Spring Tide 24 Sep to 8 Oct 2015)

For the OMSB berth pocket, the modelled current speeds under the post-development scenario are presented for reference on Figure 5.16. The current speeds through the berth pockets through the peak of the spring tide ebb are approximately 0.2ms^{-1}.

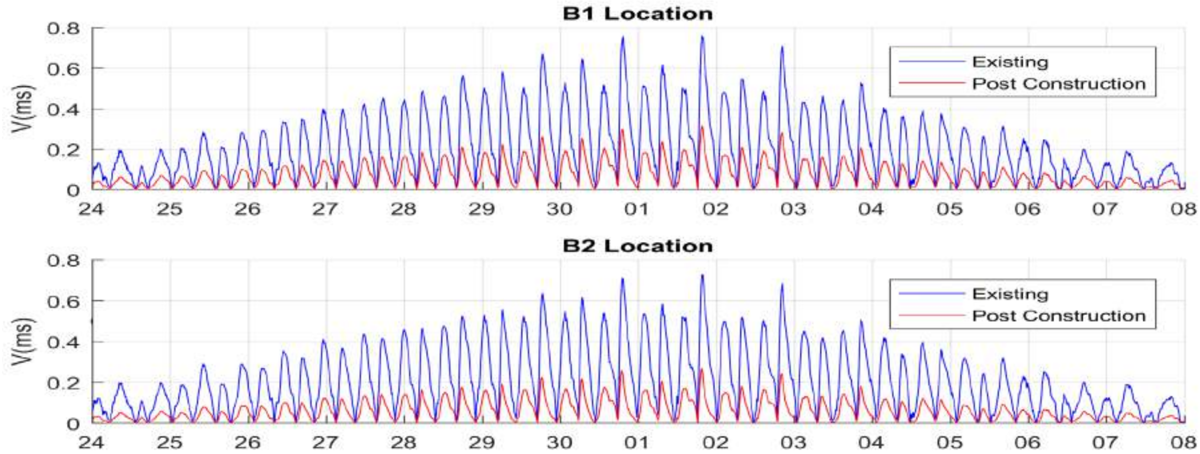

Figure 5.16: Flow velocities during the neap-flood phase in the Berth Pocket Post Construction (Spring Tide 24 Sep to 8 Oct 2015)

For the developed case dredged navigation channel into Beadon Creek east of the training wall, velocity changes are shown for reporting locations on Figure 5.17. The current magnitude peaks at 0.2 - 0.3 ms^{-1} through the spring tide peak, compared to 0.6 to 0.9 ms^{-1} for the present seabed condition. The high pre-development velocities modelled for the locations DE1, DE2 and DE3 are due to the lower bed levels and the tidal current being directed through the edge of the channel in this area, and are similar to the magnitude modelled at the training wall locations shown on Figure 5.12.

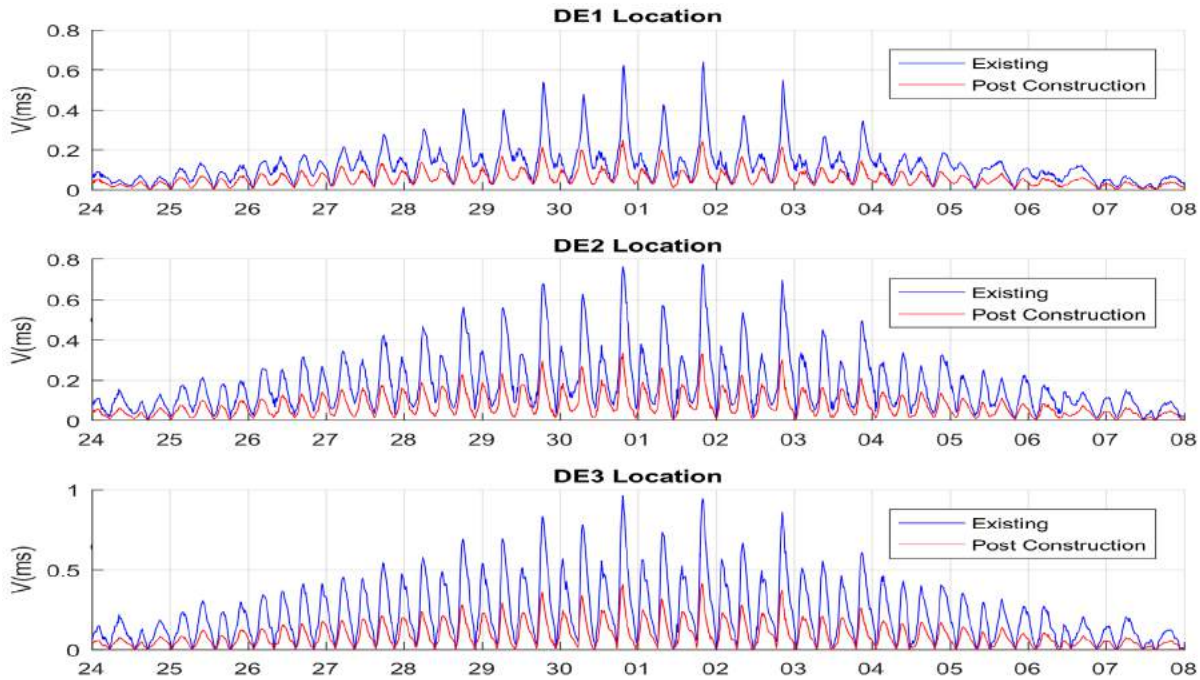

Figure 5.17: Flow velocities during the neap-flood phase in the Main Access Channel Post Construction (Spring Tide 24 Sep to 8 Oct 2015)

5.5 Submergence Curves

For the Beadon Creek upstream reporting locations, shown in Figure 5.3, the modelled water level time series information for the four week representative Dry Season period has been used to produce submergence curves. These indicate the length of time that a nominated water level occurs at a point location. The submergence curves would indicate if there is a significant change to the inundation characteristics post construction of the OMSB.

For the Salt intake location the submergence curve is presented in Figure 5.18. Post construction water levels result in minor changes to the submergence curve.

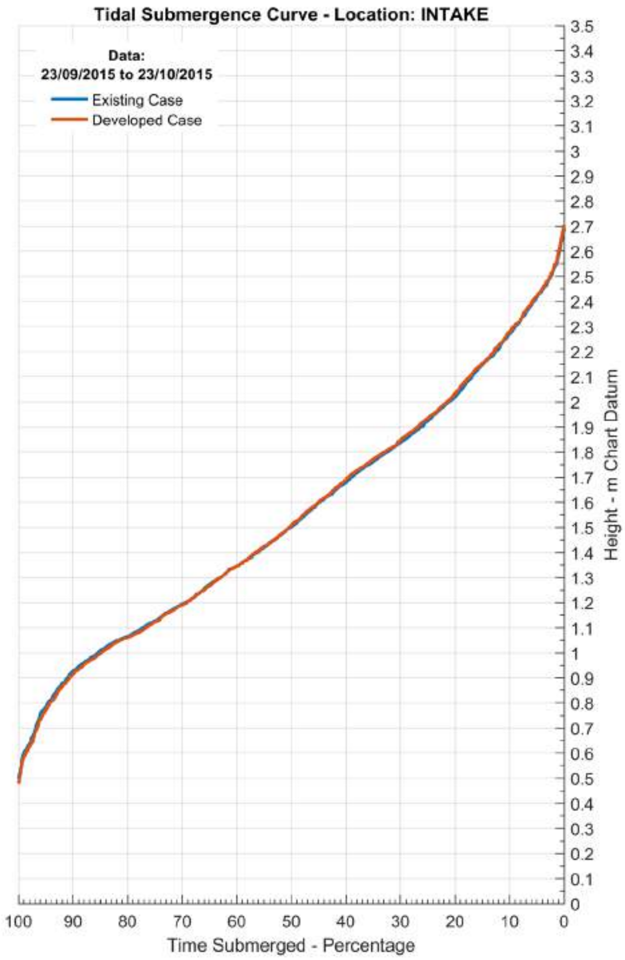

Figure 5.18: Submergence Curve for the Salt Intake location for the existing and post construction scenario

The submergence curve for the east and west Tidal Branch locations CK0 and CK4 are shown in Figure 5.19. The outcomes post construction indicate minor changes to the submergence characteristics.

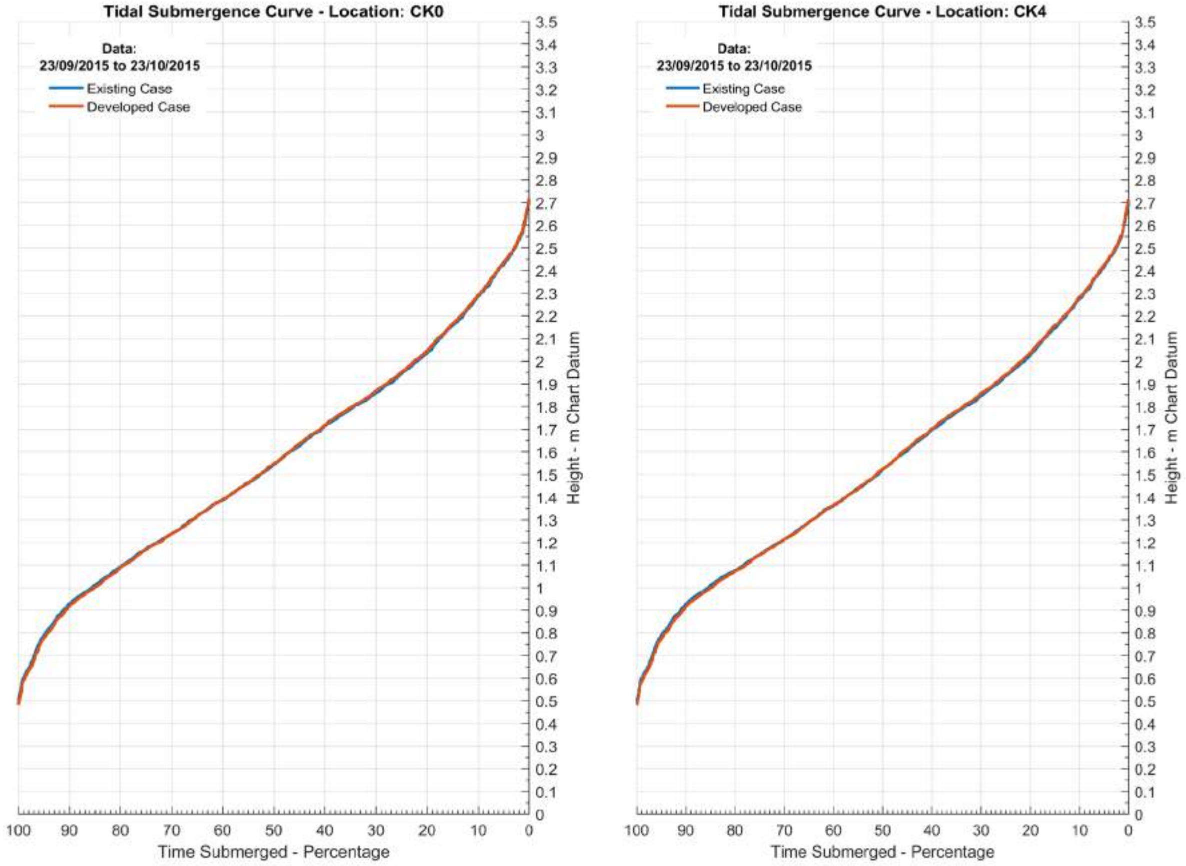

Figure 5.19: Submergence Curve for the east and west Beadon Creek Tidal Branches CK0 and CK4 respectively under the existing and post construction scenario

For the Mangrove location M1 and M2 on the eastern side of the Beadon Creek tidal flats the submergence curve is presented in Figure 5.20. For these locations which are located at elevations of 1.8mCD and 1.6mCD, the submergence curves indicate a slight reduction in the time submerged, and are generally unchanged between the existing and develop cases.

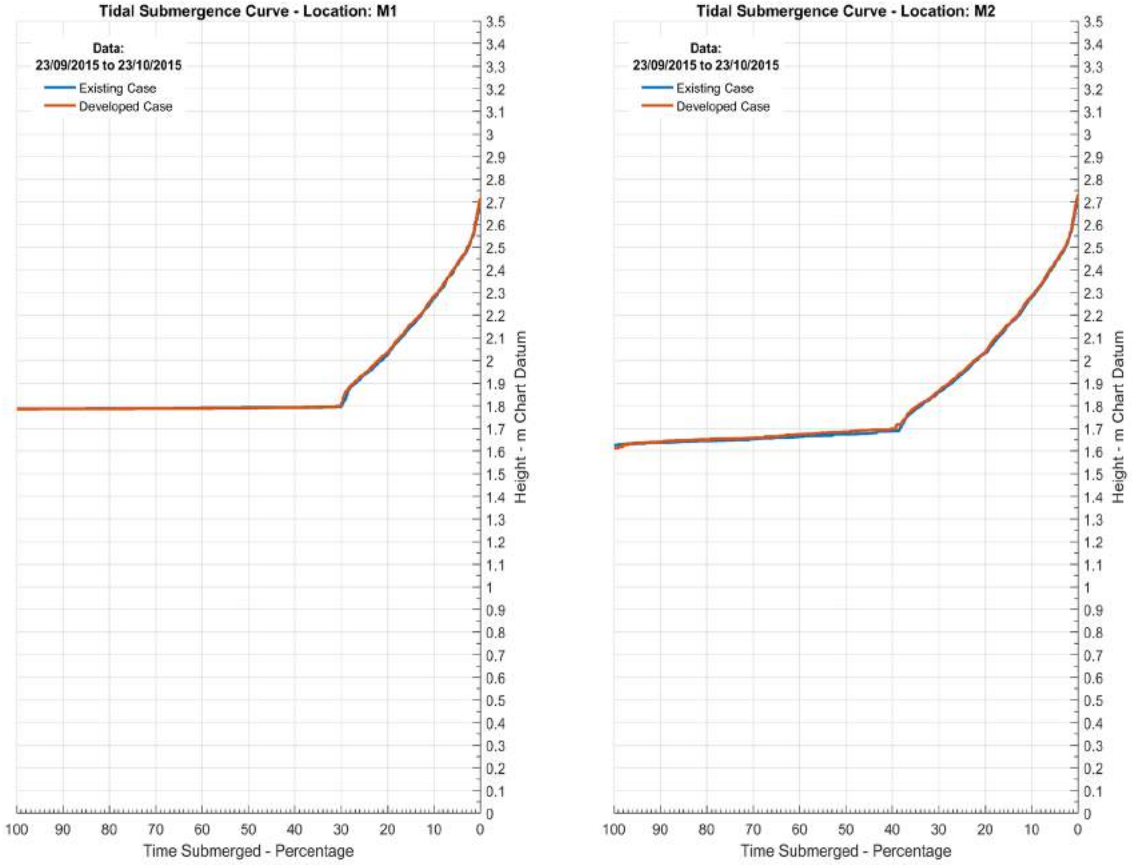

Figure 5.20: Submergence Curve for the Mangrove Location M1 and M2 for the existing and post construction scenario

6. Sediment Transport and Morphological Impact Assessment

6.1 Description of Sediment Transport Processes

A quantitative assessment of sediment transport and sedimentation mechanisms are presented in this section based on analysis of available information and review of previous studies. The key processes influencing the behaviour of the shoreline and within Beadon Creek are:

- Hydrodynamic processes (astronomical tides discussed in Section 5)
- Shoreline processes (evidenced through historical shoreline evolution)
- Littoral Transport
- Aeolian Transport
- Erosion and accretion of the tidal flats and mangrove creek system
- Tropical Cyclone impacts (waves, storm surge, inundation)

The processes are shown conceptually on Figure 6.1. Despite these various influences there has been minimal requirement for maintenance dredging of Beadon creek (refer Table 2.3). The locations of historical maintenance dredging are indicated in Figure 6.1.

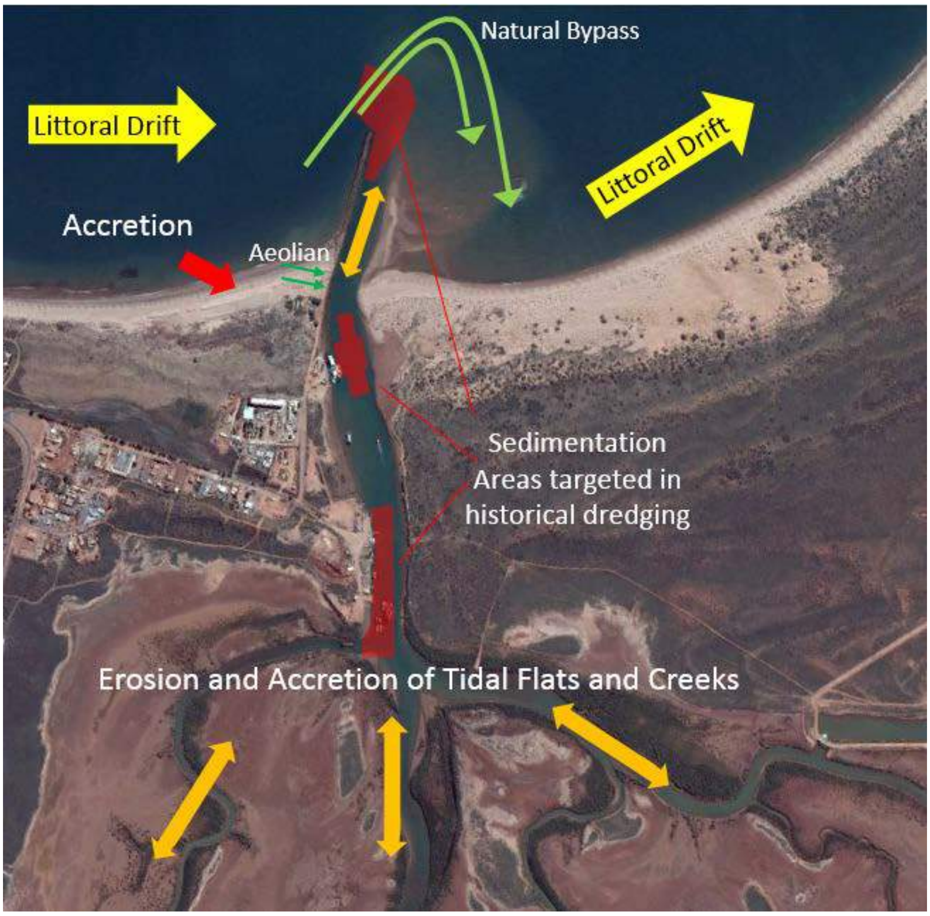

Figure 6.1: Conceptual summary of sediment transport

6.1.1 Shoreline Processes - Historical Shoreline Position

The training wall was constructed in 1968 on the western sand spit at the entrance to Beadon Creek as shown in Figure 6.2 (Seashore, 2017). This feature has played a critical role in stabilising the entrance and reshaping the coast on the western shore.

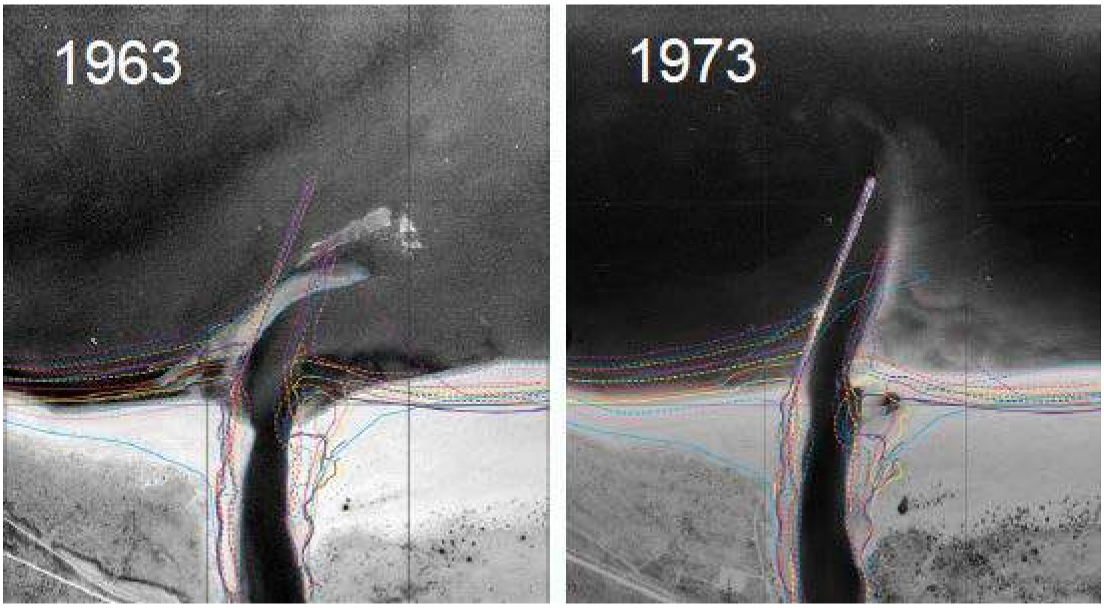

Figure 6.2: Historical aerials showing construction of the training wall on the western sand spit at the entrance to Beadon Creek (Seashore 2017)

Following the establishment of the Beadon Creek training wall, the shoreline on the western side of the training wall has continually accreted. Shoreline position based on analysis of aerial imagery presented in MRA (2012) and Cardno (2017) is shown for the western side of the training wall on Figure 6.3. The shoreline position is indicated using the vegetation line on the foredune in the aerial imagery as a proxy for the shoreline position. On Figure 6.3 it can be seen the western shoreline has accreted between 40m and 200m over the 52 year period (1963 to 2015) through the central section, and at the training wall by approximately 320m.

Figure 6.3: Historical shoreline position on the western side of the training wall

Following the impacts to the western shoreline associated with Tropical Cyclone Vance in 1999, the shoreline position in the vicinity of the training wall eroded by as much as 20m from its 1993 position, however these impacts showed full recovery by 2004. The rate of shoreline movement has decreased in the past 20 years and in recent aerial imagery (2004 to 2015) the vegetation line has remained largely unchanged in the shoreline adjacent the training wall. For coastal hazard risk presented in Cardno (2017), the coastal processes allowance for this section of the western shore recommended an accretion value of 2.8m annually.

For the eastern side of the Beadon Creek entrance, analysis of recent aerial imagery was undertaken by Baird as shown on Figure 6.4. Similar shoreline position analysis reported for the Wheatstone project is shown on Figure 6.2 (Seashore, 2017). The shoreline on the eastern shore was located further seaward from its current position in the 1966 aerial image before the training wall construction. The realignment of the coastline position is shown in the aerial images 1991 to 2015 with recent imagery showing relative stability along this section of coast. Immediately following Tropical Cyclone Vance in 1999, the shoreline vegetation line was eroded by up to 60m at the eastern side of the entrance. Shoreline recovery was noted and shown in the 2002 and 2007 aerial imagery.

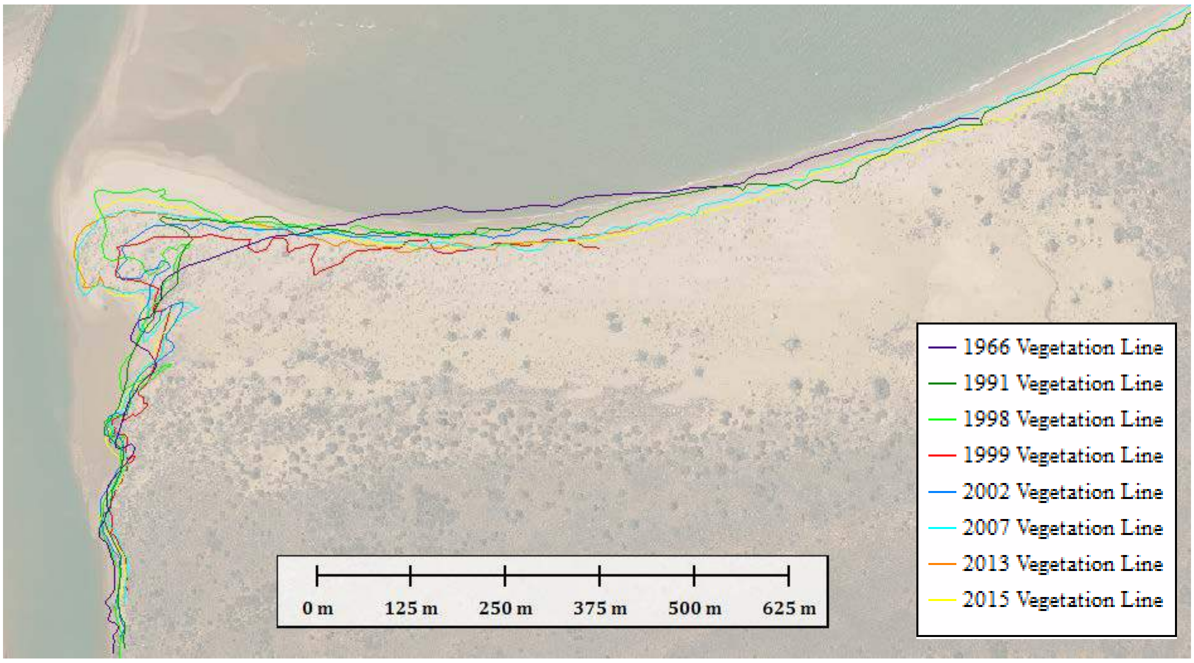

Figure 6.4: Historical shoreline position on the eastern side of the training wall

The eastern shoal has been a constant feature of the shoreline through the historical aerial record as shown on Figure 6.5. The feature developed following the construction of the training wall and whilst its form has been reshaped over time its footprint appears in the aerial images as generally constant over its recent history.

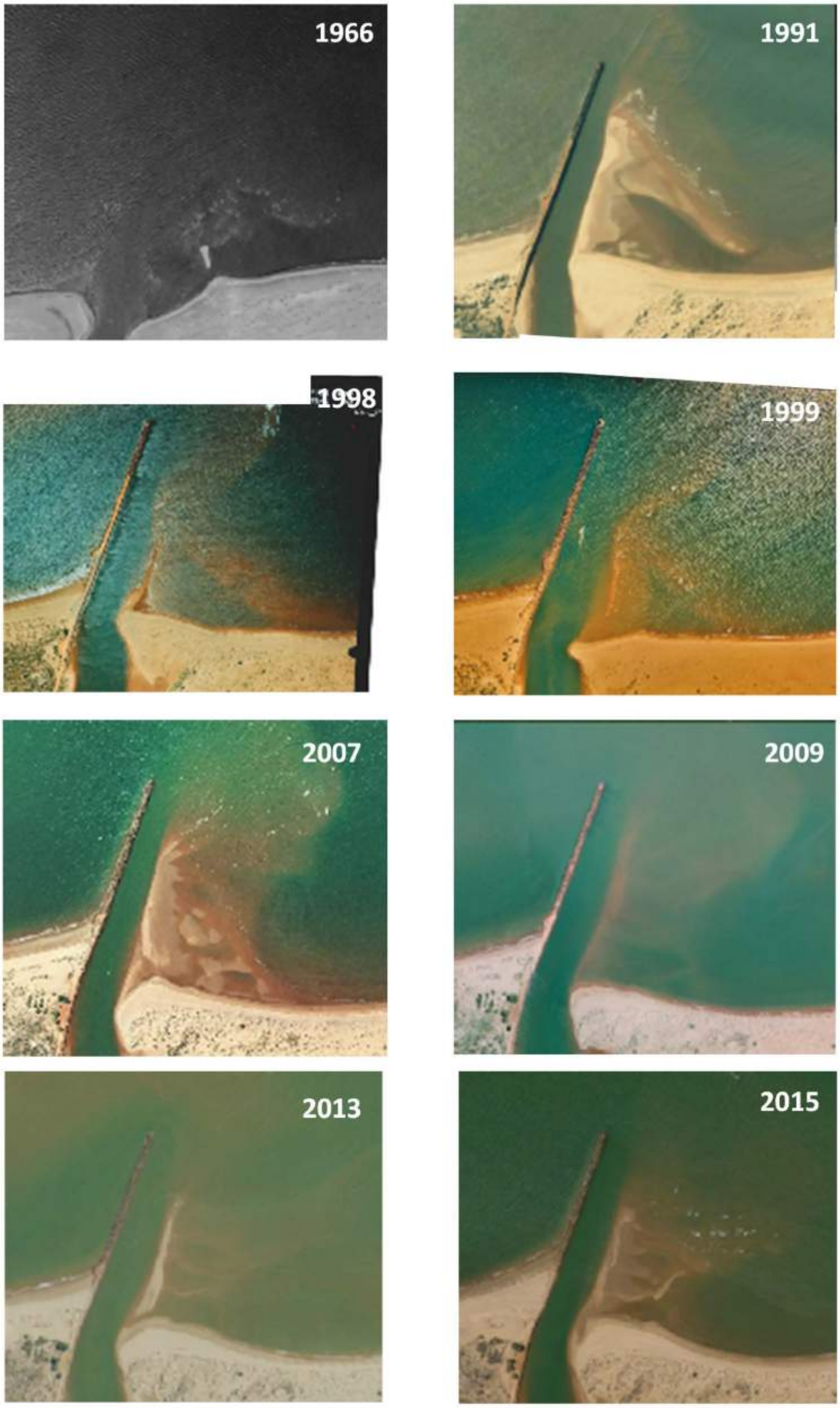

Figure 6.5: Eastern shoal feature shown in historical aerial 1966 to 2015

Multibeam bathymetry data (DoT 2017) is shown on Figure 6.6 to illustrate the seabed levels for features around the Beadon Creek entrance and training wall. Observations of note include:

- The elevation of the training wall is approximately +1mAHD with the navigation channel clearly defined along the lee side at a depth of over -3.0m AHD.
- The outer section of the eastern shoal feature is in the depth range -1mAHD to -2mAHD. The nearshore section is at depths higher than -1mAHD which are not described by the multi-beam data.
- On the western side of the training wall there is a wide shallow shoreline as a result of sediment that is moving eastward under littoral forcing being trapped by the training wall.
- The main channel is shown as the deep section (in green on Figure 6.6) running along the eastern side of the training wall. The deep navigable section of channel narrows around the tip off the training wall. Maintenance dredging has been focussed through this ‘Bell Mouth’ entrance area historically.
- A degree of ‘natural bypassing’ of the sediment from the western side of the training wall to the eastern shoal is occurring, with sediment passing across the narrow navigation channel section at the tip of the training wall being redistributed onto the eastern shoal under hydrodynamic and wave forcing.

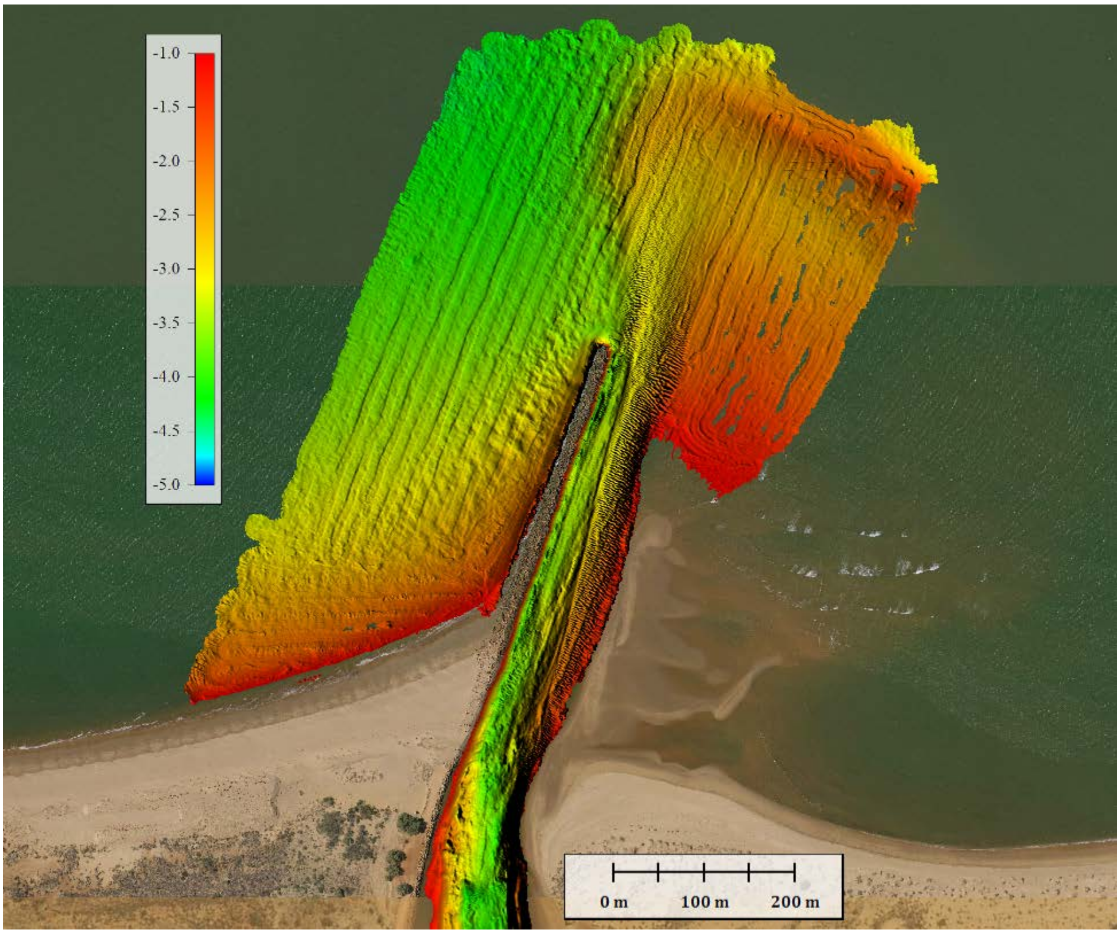

Figure 6.6: Multi-beam bathymetry showing seabed elevation at the Beadon Creek Entrance (Datum mAHD)

On Figure 6.7, the eastern shoreline at the entrance to Beadon Creek is shown with the proposed dredge footprint overlain for reference, indicating the erosion of the shoreline and proximity of the eastern bank to the turning circle area. Of note, the aerial images in 1991, 1999 and 2001 show the impact from tropical cyclone Vance (March 1999) and the reshaping of this spit feature. In the most recent aerial imagery (2009 to 2015) the shoreline has remained stable, noting that no major cyclones have made landfall along the Onslow coast since tropical cyclone Dominic in January, 2009. The eastern shoreline will play a key role in naturally protecting the entrance channel and turning circle areas.

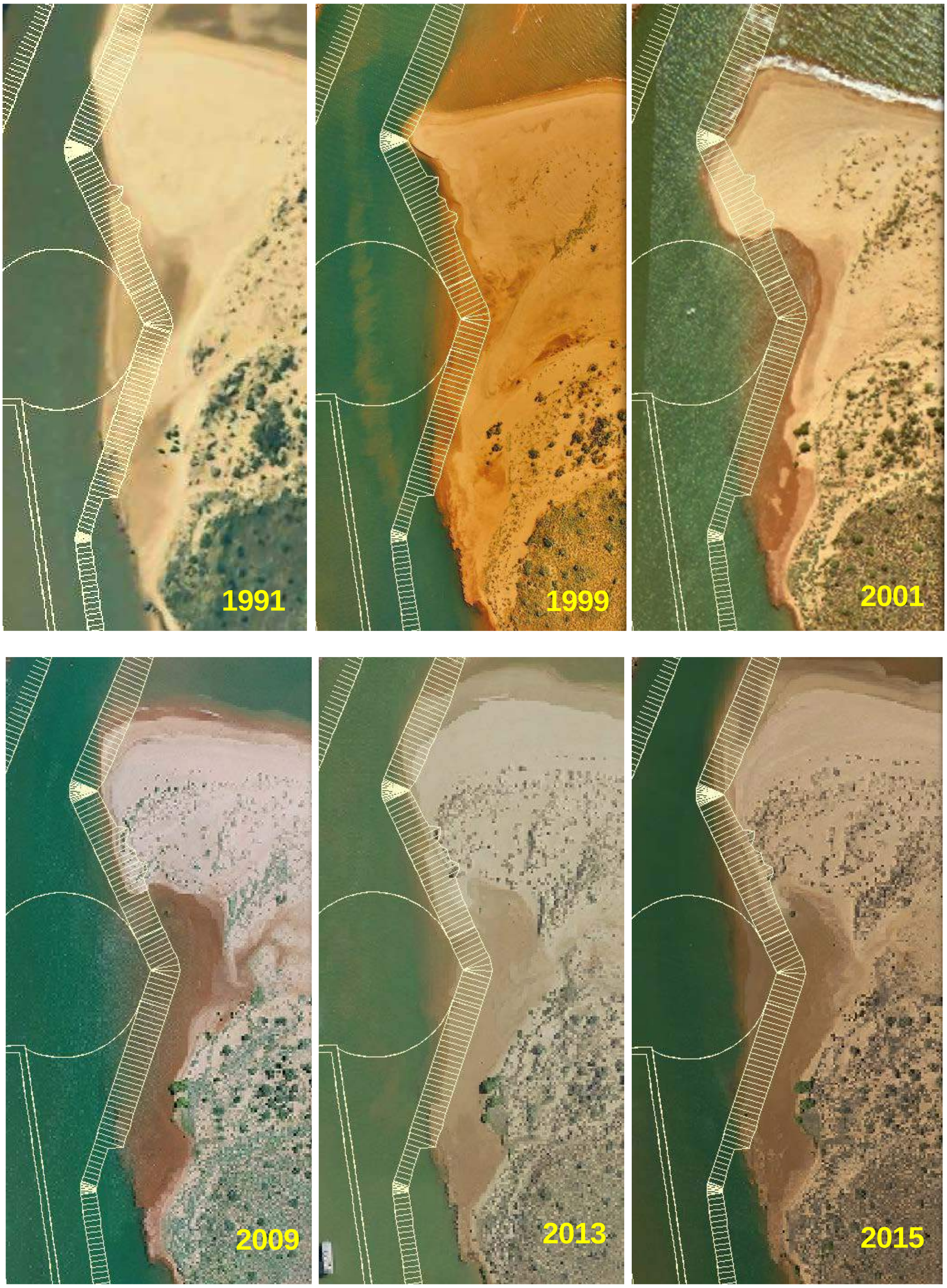

Figure 6.7: Eastern shoreline with aerial imagery overlain with proposed dredge area footprint for years 1991, 1999 (post cyclone TC Vance), 2001, 2009 (post TC Dominic), 2013 and 2015.

6.1.2 Littoral Transport

Littoral transport along the shoreline is predominantly to the east under the general wave direction, with a minor seasonal reversal for short periods. The net volume of sediment transport has been estimated at between 10,000 m^3 to 15,000m^3 annually travelling east (Seashore, DoT).

Baird has applied the DHI LITDRIFT model to investigate the potential for littoral transport along the western shoreline of Onslow.

For the Onslow location, a cross shore profile based on the LiDAR and multi-beam data was setup for a section of the shoreline approximately 1km west of the training wall as shown on Figure 6.8. Measured AWAC data for a one year period (wave height, wave period and direction) was applied in the model to assess the potential alongshore transport rates. Sediment characteristics in the model were based on sediment samples measured on the shoreline.

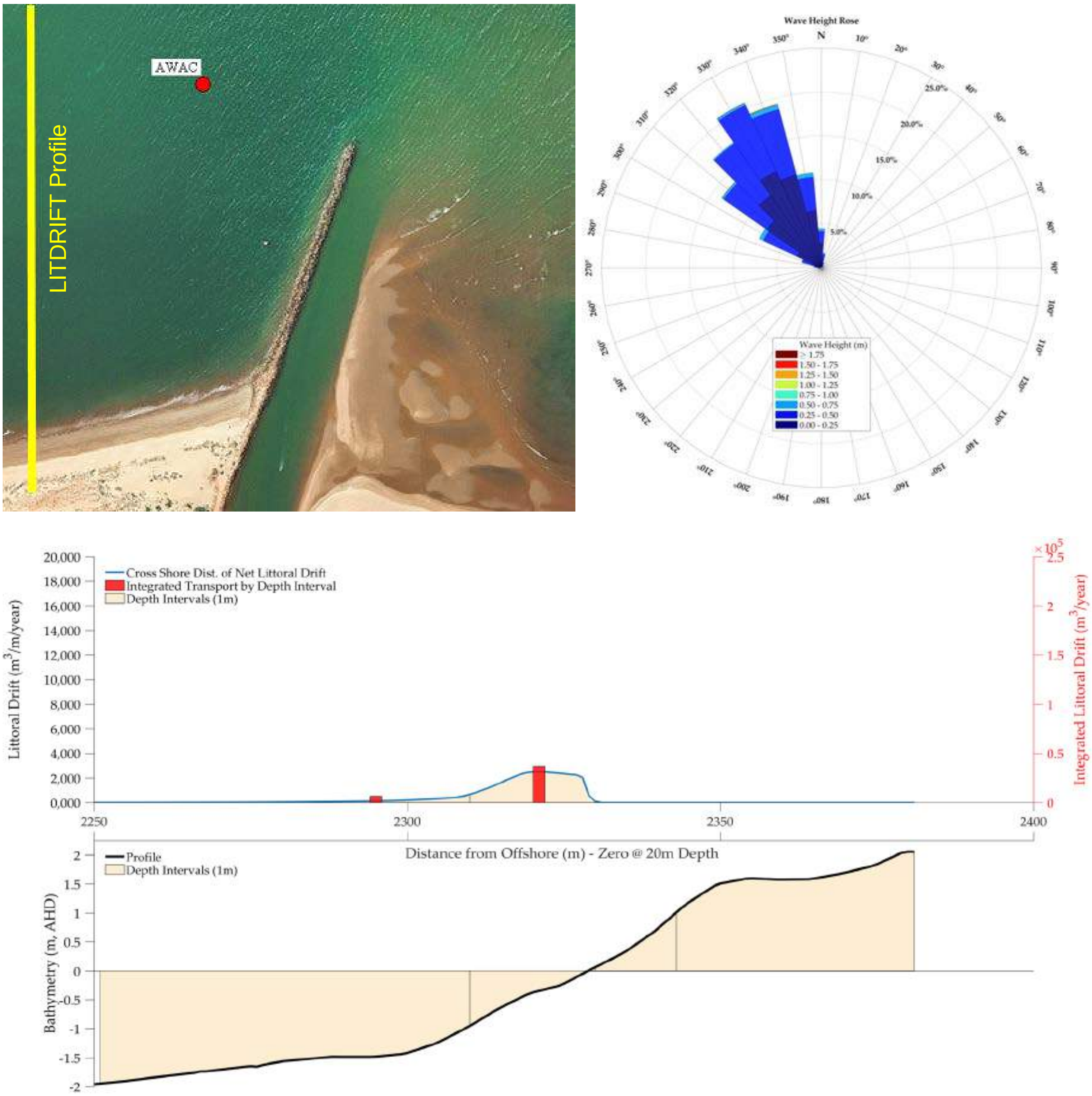

Figure 6.8: Littoral transport modelling for the western shoreline using the LITDRIFT model.

The model results are shown in Figure 6.8 and indicate the *potential* alongshore transport rate is 45,000m^3 in an eastward direction annually. It is noted that this is the potential rate of transport assuming alongshore profile uniformity and infinite sand supply availability. The actual rate of longshore transport is likely less than half this potential value. The results on Figure 6.8 show that sediment transport is largely concentrated in the active wave breaking zone approximately -1.5mMSL to 0mMSL on the profile.

The LITDRIFT result compares well to transport rates reported in DHI (2012) for the Wheatstone project for similarly north to north-east aligned coastlines which indicated potential transport rates of 50,000m^3 to 75,000 m^3 annually. Similarly, Damara 2010 estimated the total littoral drift in the range 35,000m^3 to 85,000 m^3 per annum eastwards for the Onslow shoreline west of the training wall. The large ranges in transport potential are attributable to cross shore profile alignment and the time period (metocean forcing) that is considered, and it is noted that the estimate for Onslow in this study has been determined from just one year of data and over the longer term this would be expected to vary.

The exact rate of littoral transport eastwards is unknown and will vary each year depending on the forcing conditions and available sediment. A range of littoral transport values have been applied in the sediment transport modelling to understand sedimentation impacts for the existing and post-dredged scenarios.

Littoral Sediment on the Western Side of Beadon Creek Training Wall

Using methods described in Kamphuis (2010), the accretion rate on the western shoreline was assessed, to estimate what proportion of the eastward bound sediment is trapped on the western side of the training wall annually. The Kamphuis method uses a cross shore profile assessment to estimate the volume change across the profile as the shoreline moves seaward. Local inputs describing wave conditions and sediment size (D_{50}) were applied to determine the equilibrium beach profile and closure depth. Shoreline volume changes were estimated by integrating the area below the accreting shoreline to the closure depth.

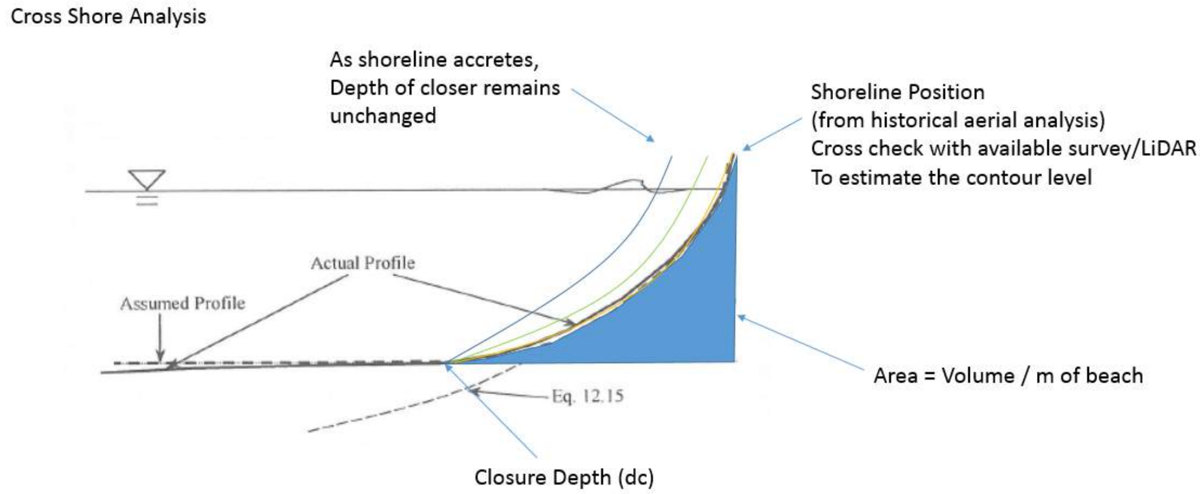

Figure 6.9: Schematic of Cross Shore Profile Analysis based on the equilibrium profile concept in Kamphuis (2010)

The LiDAR data captured along the western side of the training wall was analysed for the period 2010 to 2016 to quantify the change at the shore with the volume of seaward accretion based on the movement of the 0mAHD contour in the two datasets, as shown on Figure 6.10. The section of beach over which progradation of the shoreline has been observed (extending approximately 1km west of the training wall) was analysed across 10 transects showing the annualised rate of change to be 2m on average. The results from this analysis are summarised on Table 6.1.

Applying the equilibrium profile method for the calculated shoreline changes, the progradation of the shoreline area accounts for approximately 2,700m^3 of sediment annually. This only accounts for the area below the 0mAHD contour extending offshore to closure depth. Changes to the upper beach area were assessed through analysis of the LiDAR datasets to examine the volume change between surveys and showed that from 0mAHD up to the approximate berm level of 1.5mAHD there was on average 1,800m^3 of sand accretion annually.

In total, it is estimated that the training wall trapped approximately 4,500m^3 of sediment on its western side annually over the six-year period 2010 to 2016. This compares with the lower bound of estimates presented in Damara (2010) of between 5,000m^3 and 10,000m^3 of annual accretion, noting the analysis in the current study is only six years for this study (2010 to 2016) and there appears to have been a reduction in the rate of shoreline accretion in this section of coast in recent years based on the historical shoreline positions presented in Figure 6.3.

Table 6.1: Shoreline changes west of training wall - transect analysis 2010 to 2016 LiDAR

Transect	2010-2016 Change	Annual Rate Change	Distance Between
0	0	0	0
1	7.8	1.3	100
2	8.2	1.4	100
3	9.8	1.6	100
4	10	1.7	100
5	13.1	2.2	100
6	13.6	2.3	100
7	14.5	2.4	100
8	16.9	2.8	100
9	12.1	2.0	100
10	0	0.0	65

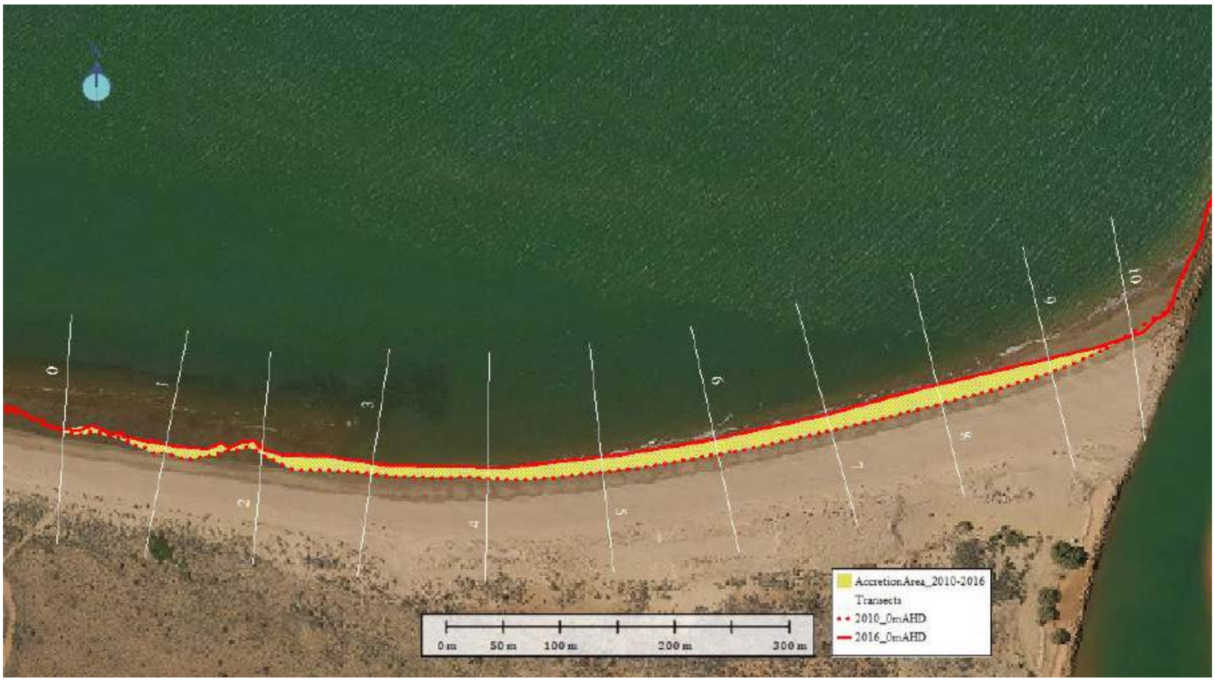

Figure 6.10: Assessment of shoreline change based on 2010 and 2016 LiDAR

6.1.3 Aeolian Transport

Aeolian transport of sediment (carried by the wind) is occurring along the Onslow shoreline, with sediment moved in an eastward direction under the prevailing wind direction, evidenced by site photos and anecdotal information of sediment along the crest of the training wall (Figure 6.11). This wind-blown sand enters the Beadon Creek channel along the exposed section at the landward edge of the training wall, through either wind forcing or during large flood tides (Figure 6.11).

A calculation of the potential for wind blown sand volumes along this section of the coast was undertaken based on the Hsu (1986) equation for wind blown sand transport as summarised in the Coastal Engineering Manual (USACE, 2006). The calculation of transport potential was completed assuming a D_{50}=0.25mm, and using half-hourly data from Onslow Airport between 20-Oct-2012 to 13-Dec-2016.

For the site, the calculated easterly sand transport potential was an annual average off 7.6 m^3/m of beach width. The exposed beach width along the training wall at Beadon Creek is approximately 160m (Figure 6.11) and this would result in a potential annual wind blown rate across the training wall of 1,200m^3 to the east. This Aeolian transport rate was applied as a sediment source along the 160m training wall length in the numerical modelling (see Section 6.2).

Figure 6.11: Aeolian transport assessment. (left) Sand overlaying the training wall (Seashore 2017), (right) exposed beach width and entry point into Beadon Creek

6.1.4 Beadon Creek Tidal Flats – Catchment Flooding

There is the potential for sediments in the tidal flats of the upstream tributaries of Beadon Creek to be mobilised under large runoff events and extremely high water levels (e.g. large spring tides and storm surge events). Whilst the availability of sediment supply in these large events has been greatly reduced by the reduction in the upstream catchment area following the construction of the Onslow Salt operations, there still exists a potential for erosion and sedimentation of fine sediments during these extreme events. The inundation of the tidal creeks and tidal flats under large spring tides is modelled in this study (and associated erosion and sedimentation), however large scale catchment flooding from rainfall events is not included in the sediment transport model.

6.1.5 Vessel Effects

There are two mechanisms by which the vessels that use the port can influence the sedimentation and erosion behaviour in the entrance channel and within Beadon Creek. Vessel wake associated with the vessels that enter and exit the entrance channel can influence the sedimentation processes through the resuspension of fine material. Alternatively, the deep draught vessels which move through the navigation channel with minimal under-keel clearance have the potential to scour out the sediments on the seafloor. These two processes are not considered in the modelling process presented in this report, but could be further assessed as part of the port risk assessment and the risk may be mitigated through operational practices (e.g. limiting vessel speeds).

6.2 Sediment Transport Model

The sediment transport modelling was undertaken using the Delft3D hydrodynamic model presented in Section 5 to examine bedform changes under the hydrodynamic conditions.

A brief description of the modelling process is given in the section following with additional model detail and validation provided in Appendix A. The model has been applied to determine projected sedimentation volumes and dredging requirements for the OMSB project (navigation channels etc.) and the existing areas within Beadon Creek managed by the DoT.

6.2.1 Model Summary

The Delft3D Online Sediment model has been applied in the sediment transport investigations to investigate the sediment transport and morphology changes from both sand and fine sediments in the following ranges:

1. The sand fraction represents sediment sizes in the range 0.1mm to 0.4mm (100-400µm)
2. Fine sediments represented by clay, silt and coarse silt in the range (4-55µm)

The model is forced by hydrodynamic conditions for the representative wet season and dry season period (refer Section 3.4). The wet and dry seasons are run for one month respectively in the model and bed level changes are extrapolated to be representative of the annual bedform changes. The morphological changes at the seabed are driven by the hydrodynamic forcing (water levels, winds, waves, currents) with erosion, resuspension and deposition of sediment.

A spatially varying sediment grain size description is specified in the model based on sediment sampling data (O2, 2017) and spatially varying seabed roughness is applied using Chezy roughness values. The model assumes there is sediment available at the seabed that can be eroded under sufficient bed shear stress, except along the training wall where rock is assumed fixed (see Appendix A).

The morphological changes modelled are representative of one year with the following processes incorporated:

- Representative dry season and monsoon season hydrodynamic conditions are applied. This includes time varying winds, waves, currents and tides.
- The salt intake from Onslow Salt removes 12m^3sec^{-1} via three pumps operating on the eastern side of Beadon Creek tidal flats whenever the water level is above 0.8m CD.
- Aeolian transport of 1200m^3 annually is input to the channel at the exposed landward section of the training wall, adopting a sediment size of 0.25mm.
- Easterly Littoral drift of sediment around the training wall input to the model is input at three different annual rates; 8,000m^3, 16,000m^3 and 24,000m^3. A sediment size of 0.2mm is adopted.
- Sedimentation is modelled for sand fractions and fine sediments (clays,silts)

The modelling does not include:

- The impacts from passing ships through either vessel wakes resuspending sediments (fine sediments) or through scouring of the sediment from the seabed in the event of limited underkeel clearance from large vessels.
- Significant rainfall events or king tides mobilising / resuspending material in the Beadon Creek tidal flats area.

There is a noted limitation in extrapolation of the results from one month of modelled seasonal conditions (wet season and dry season) across the whole year, however to achieve reasonable model run times this approach was required and the modelled periods provide a sound representation of the general sediment transport processes and pathway trends.

6.2.2 Model Validation

The modelled sedimentation rates for the existing Beadon Creek case have been quantified within the channel sections from Hydrographic Chart AUS0069. The modelled results are compared against two historical sedimentation rate estimates:

1. Estimate 1: The 2012 pre-dredge assessment of annual sedimentation within each channel section in the period following the dredging campaigns of 1999 and 2012 (Oceanica, 2014).
2. Estimate 2: Recent multibeam survey of Beadon Creek (DoT, 2016) was analysed to estimate the bed level changes that have occurred in the period following the maintenance dredging campaign completed in 2012-2013 (based on target design depths of that campaign).

The channel sections that are used for the analysis are shown on Figure A.11. All calculations for sedimentation within the channel sections only includes the sedimentation, and does not consider the erosion within the region which is understood to be consistent with Oceanica (2014).

Figure 6.12: Channel sections analysed for bed level changes (Oceanica, 2014)

The sediment transport model results for the existing case are shown in Figure 6.13. This result incorporates the sand fractions and fine sediments and includes littoral transport based on an assumed rate of 8,000m^3 and aeolian transport rate of 1,200m^3, annually. The historically observed sedimentation rates within each of the channel sections is presented in Table 6.2 compared against those derived from the modelled outcomes.

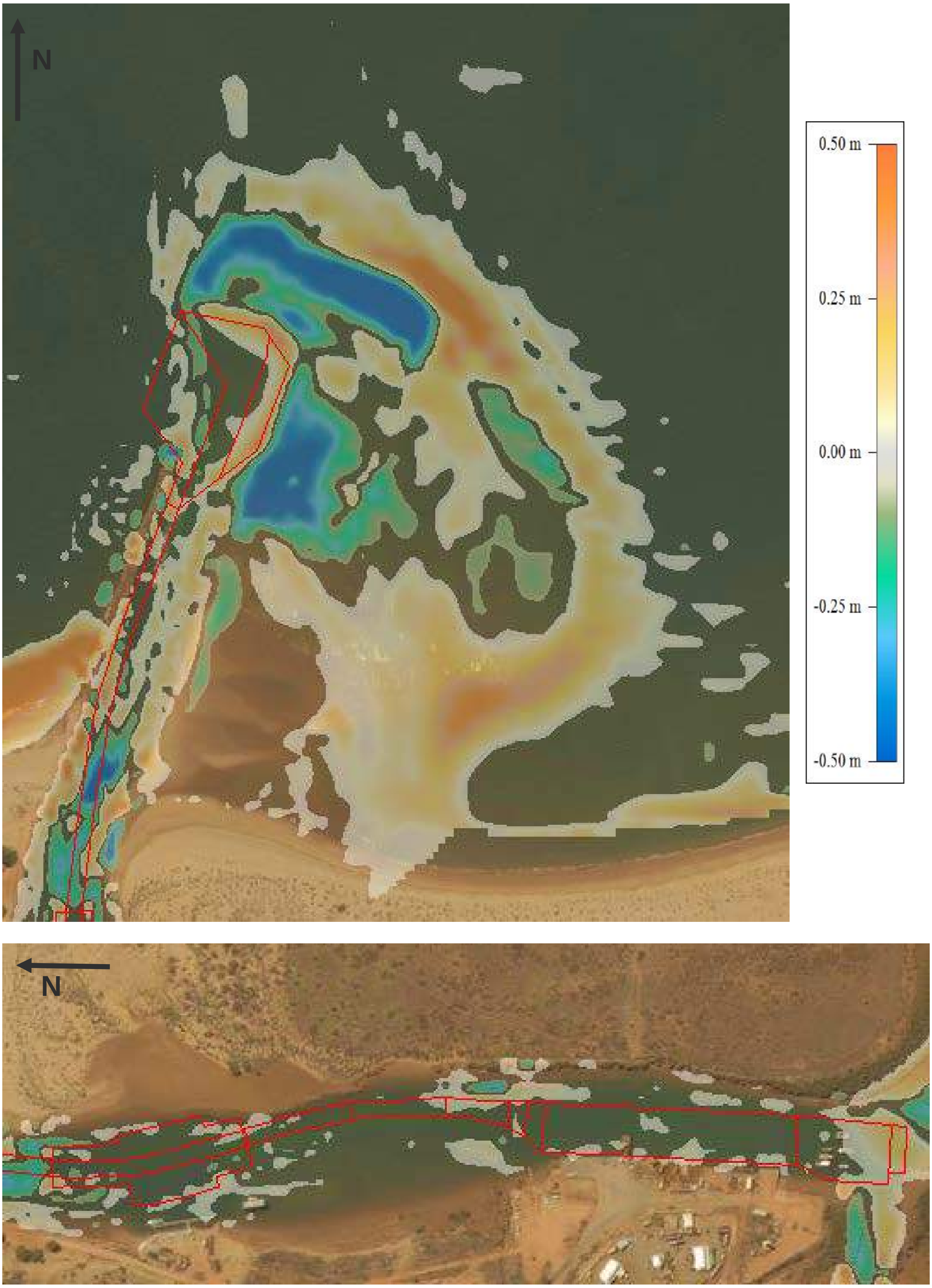

Figure 6.13: Modelled annual erosion and sedimentation for the existing case. Outer channel (upper) and inside Beadon Creek (lower) areas with channel sections overlaid.

Table 6.2: Annual Sedimentation Rates (m³/yr) for Channel Sections – Historical vs Modelled

No.	Description	Design Depth	Estimate 1 [1]	Estimate 2 [2]	Modelled Estimate [3]
1	Bell Mouth	-1.6mCD	*510*	*250*	490
2	Bell Mouth Silt Trap	-1.6mCD	*2240*	*1570* [4]	1580
3	Outer Entrance Channel	-1.6mCD	*60*	*10*	140
4	Mid Entrance Channel A	-1.6mCD	*1190*	*270* [5]	350
5	Mid Entrance Channel B	-1.6mCD	*30*	*10*	50
6	Inner Entrance Channel	-1.6mCD	*40*	*10*	10
7	Inner Entrance Channel	-1.6mCD –	*20*	*0*	40
8	Basin	-2.2mCD to	*870* [6]	*125*	120
9	Cyclone Moorings	Varies [7]	*620*	-	415
10	Basin Silt Trap	-1.5mCD	*130*	*25*	145
	TOTAL		*5700*	*2270*	3340

Notes

1. Estimate 1: 2003 to 2012 Average Annual Sedimentation calculated from rates reported in Oceanica (2014)
2. Estimate 2: 2012/13 to 2016 Average Annual Sedimentation calculated from changes to post dredging seabed depth (Oceanica, 2014) and analysis of 2016 multibeam data (DoT, 2016)
3. Modelled Annual Sedimentation Existing Case (Baird sediment transport model – sand and fines fractions combined). Littoral transport is modelled based on an annual rate of 8,000m³
4. Bellmouth area is not completely described by the 2016 LiDAR data. Approximately 30% of the eastern side is not captured in the LiDAR
5. Dredging occurred for the nearshore berth adjacent the Mid Channel Section during this time period and may have impacted dredge volumes and / or creek dynamic in this section
6. Basin area was dredged in 1999 campaign, but not in 2003. Assessment based on 13 years
7. The design / target depth was not determined for the Cyclone Moorings in Oceanica 2014 so calculations from the LiDAR data were not completed

Comparison of the modelled outcomes for erosion and sedimentation in the existing case against survey comparisons is presented in Figure 6.14 with the following noted:

- The modelled case outcome in Figure 6.14 compares to the 2003 to 2008 survey differences with comparable areas of sedimentation in the Bell mouth area and Bell mouth silt trap. The erosion and deposition areas at the tip of the training wall and northern extent of the ebb shoal show reasonable agreement between the modelled and survey results.
- Along the training wall the model outcomes show areas of sedimentation through the northern section of the approach channel, stable through the lower section and areas of erosion through the southern portion leading into Beadon Creek. This is in general agreement to the survey outcomes in the 2003 to 2008 period.
- For areas on the eastern side of the channel there is erosion shown in the 2003 to 2008 survey, and sedimentation in the 1999 to 2015 survey outcomes. The modelled result shows sedimentation in this section.

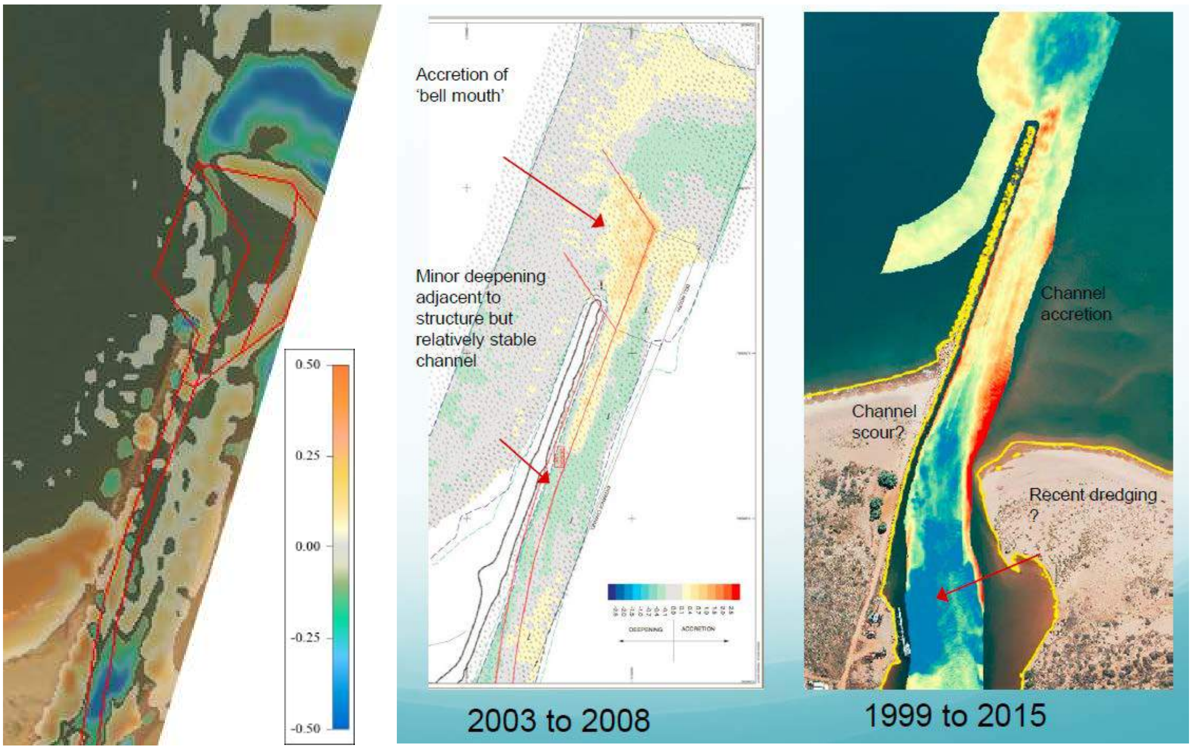

Figure 6.14: Beadon Creek Entrance (left) modelled existing case annual sedimentation, (middle) 2003 to 2008 measured changes, (right) 1999 to 2015 measured changes (from Seashore 2017).

Comparison between the surveyed and modelled outcomes in Figure 6.14 and Table 6.2 show the model is generally representative of the sedimentation and erosion through Beadon creek. It is important to note the sedimentation outcomes from the model are highly dependent on the metocean conditions applied in the model, the initial bathymetry at the start of the modelling, and the sediment size at the seabed and the model cannot perfectly represent all processes given the limitations in the accuracy of those input data. However, the agreement between the surveyed and modelled outcomes indicates the model is describing the erosion and sedimentation processes for the existing creek entrance configuration.

6.2.3 Model Limitations

The following limitations are noted in the model:

- Sediment size has been assigned in the model based on sediment sampling completed for the project and for many areas in Beadon Creek the sediment size (D50) are a best estimate due to lack of available data. The adopted sediment sizes have a significant influence on the sediment transport outcomes from the model.
- The description of sediment transport processes over areas that experience wetting and drying (e.g. the ebb tide shoal) are limited by model parameterisation that limits erosion to areas with a water depth of at least 0.5m. Over a spring-neap tide cycle the impact of this limit is thought to be insignificant in representing the overall sediment transport pathways.

6.2.4 Summary of Projected Sedimentation

The sedimentation model results for the developed case are examined in the dredge footprint areas described in Figure 6.15 with the modelled results shown spatially in Figure 6.16 and Figure 6.17.

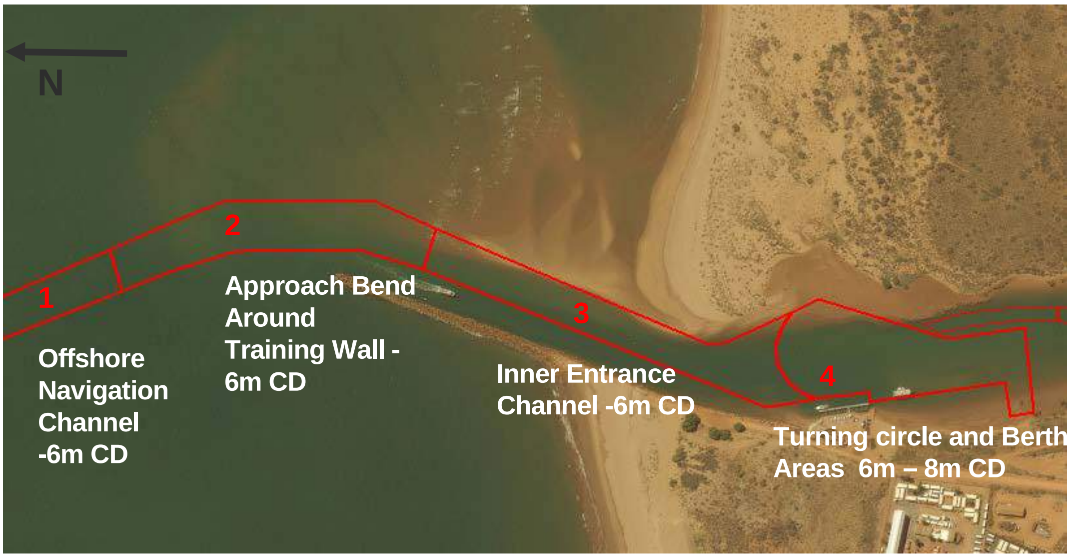

Figure 6.15: Channel sections analysis regions for developed case

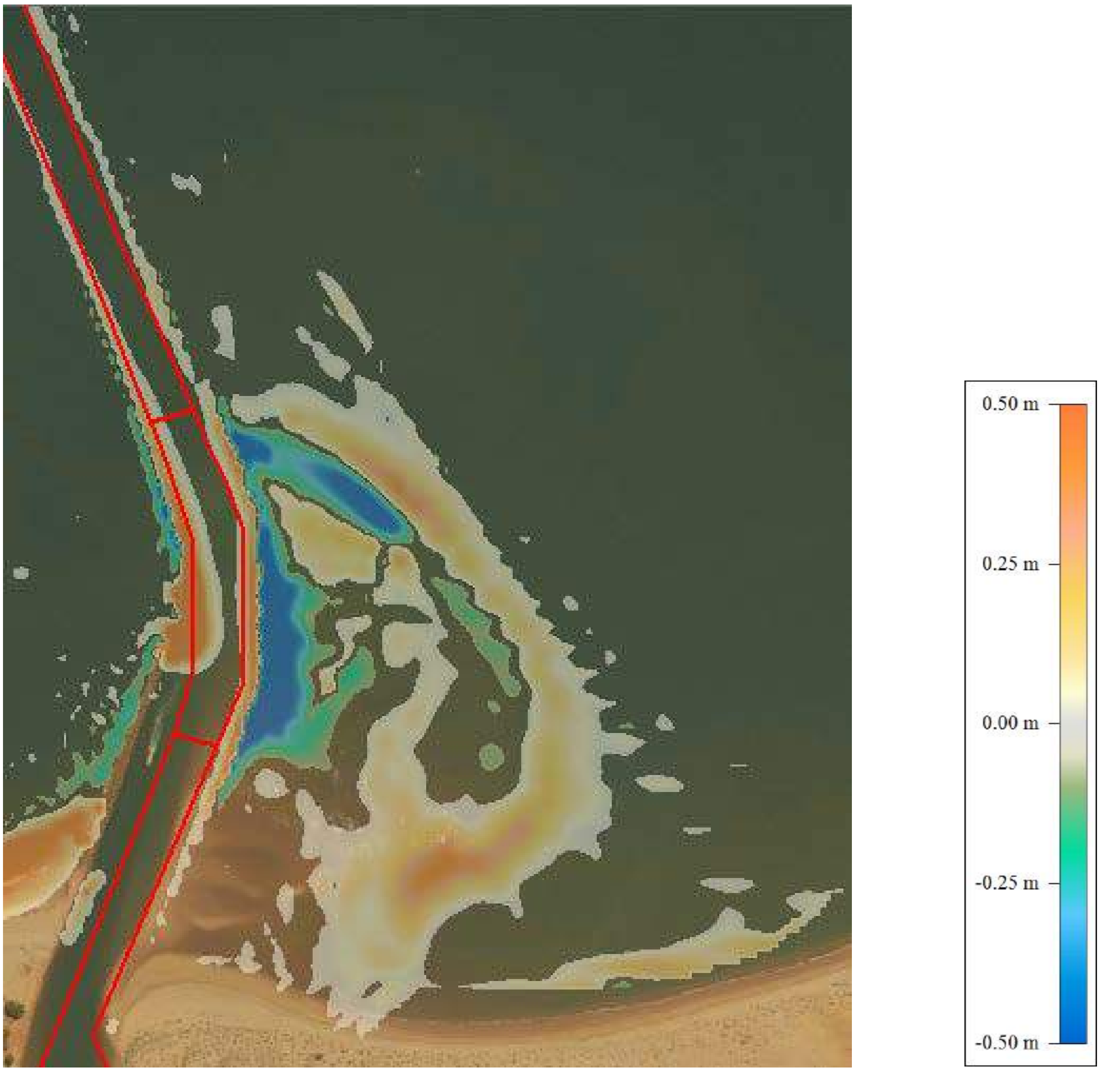

Figure 6.16: Modelled annual erosion and sedimentation for the developed case outer channel section

Figure 6.17: Modelled annual erosion and sedimentation for the developed case inside Beadon Creek with channel sections overlaid

The projected annual sedimentation for navigable areas of the OMSB footprint (entrance channel, turning circle and berth area) and the section of Beadon Creek below the development are summarised in Table 6.3 based on the sediment transport modelling.

Table 6.3: Summary of Projected Annual Sedimentation Volumes (m^3/yr) for Developed Case

Region	Sector Name	Total Sedimentation Annually
Lower Beadon Creek Areas Controlled by DoT	6. Inner Entrance Channel A	30 m^3
	7. Inner Entrance Channel B	110 m^3
	8. Basin	410 m^3
	9.Cyclone Moorings	400 m^3
	10. Basin Silt Trap	250 m^3
	TOTAL	**1,200 m^3**
OMSB Dredge Footprint Areas	1. Offshore Navigation Channel	4,780 m^3
	2. Approach Bend Around Training Wall	13,100 m^3
	3. Inner Entrance Channel	1,740 m^3
	4. Turning Circle and Berth Areas	80 m^3
	TOTAL	**19,700 m^3**

The outcomes in Table 6.3 indicate the projected dredge volumes post development in the lower Beadon Creek section will be 1,200m^3 annually. This is an increase of approximately 500m^3 from the equivalent sections of the channel modelled in the existing case (Table 6.2). The increase in sedimentation is a direct result of the seabed responding to the change in the hydrodynamic regime (i.e. the dredging for the entrance and turning circle areas) and the sedimentation rate would likely decrease over time as the seabed adjusted to a new equilibrium condition.

The projected annual sedimentation rate for the OMSB dredge footprint areas shown in Table 6.3 is 19,700m^3, and as indicated in Table 6.3 the majority of the sedimentation (13,100m^3) is directed into the approach bend around the training wall (Section 2).

The sedimentation estimate for the OMSB footprint areas is based on an assumed littoral transport rate of 8,000m^3 annually, the majority of which is directed into Section 2 with a small proportion directed in to Section 1. These projections include an allowance for westerly directed littoral drift during seasonal reversal (2% of easterly rate based on LITPROF, refer Section 6.1.2) that is assumed as being deposited directly into the dredged channel.

The actual littoral transport rate is unknown and will vary from year to year depending on metocean conditions and available sediment supply, and a range of values is provided here for comparison, noting any additional littoral transport volume is entirely directed into the dredged navigation channel. For example:

- applying a littoral transport rate of 16,000m^3 annually (net eastward) the sedimentation total in the OMSB dredged footprint would increase to 28,000m^3.
- applying a littoral transport rate of 24,000m^3 annually the sedimentation total would increase to 36,300m^3 in the OMSB footprint areas.

In summary, the key driver of sedimentation for the OMSB navigation channel is expected to be the eastward littoral drift. This sedimentation is likely to be most concentrated in the channel bend section of the OMSB channel near the end of the training wall (Section 2) as shown in Figure 6.16. Maintenance dredging of the sediment that is directed into the navigation channel will be required to maintain navigable depth in this area. The rate at which sediment accumulates is expected to vary seasonally and annually.

A form of bypass for the sedimentation in the OMSB navigation channel is recommended that can restore the natural eastward supply of sand to the eastern shoal and eastern shoreline. Restoring this natural sediment supply to the eastern shore will be important to ensure that the existing observed stability along this section of shoreline is preserved which provides a natural barrier to Beadon Creek (refer Figure 6.7).

Bypassing options have not been investigated as part of this scope, however it is anticipated the material will be predominantly clean sand material well suited to standard dredging operations. Further analysis of the sediment transport process to support detailed design is recommended adopting finer scale model resolution. Refinement of the sediment transport model would also be applicable for the design of the maintenance dredging strategy and options for bypassing the material to the eastern side of the channel.

6.3 Sedimentation from Extreme Cyclonic Events

Onslow is located in one of the most cyclone prone areas of the Australian coast. The sediment transport model was applied to assess the potential sedimentation impacts for the OMSB developed footprint from a severe tropical cyclone event. Two recent cyclones that have impacted Onslow were investigated; TC Olwyn (2015) and TC Vance (1999). The modelling approach is outlined in detail in Appendix A. A summary of the sedimentation volumes is presented in Table 6.4 showing the sedimentation in each respective channel section (erosion rates are not considered in the overall total).

The results in Table 6.4 show the cyclone impacts vary for the two events with significant differences through the channel sections examined. Modelling outcomes of TC Vance indicate that this event with very high water levels through Beadon Creek associated with a large storm surge can cause sedimentation impacts to the Turning Circle and Berth Area. The results from modelling of TC Olwyn indicate extreme waves from a northerly direction through the peak will cause higher sedimentation impacts to the offshore channel.

Table 6.4: Modelled Sedimentation Rates (m^3) for OMSB Developed Case Dredged Footprint Area and Lower Beadon Creek Section for Cyclone Cases

No.	Description	TC Olwyn	TC Vance
1	Offshore Navigation Channel	4600 m^3	1500 m^3
2	Approach Bend Around Training Wall	1400 m^3	1250 m^3
3	Inner Entrance Channel	620 m^3	590 m^3
4	Turning Circle and Berth Areas	120 m^3	1330 m^3
OMSB Dredged Footprint Area Total		**6740 m^3**	**4670 m^3**
6-10	Lower Beadon Creek. Total for All Areas	120 m^3	910 m^3

An annual allowance for tropical cyclone sedimentation impacts in the OMSB dredged footprint and lower Beadon Creek has been determined through:

- adopting the worst outcome (i.e. highest sedimentation) by channel section shown in Table 6.4 for the two cyclone events
- assuming a design event cyclone will impact the location once every 5 years. The annual sedimentation projection represents 20% of the sedimentation impacts from the ‘worst case’ design cyclone. This is considered a very conservative assumption, but with the limited number of events examined and the identified variation in the associated impacts, a cautious approach is considered warranted.

In summary the annual allowance for sedimentation associated with cyclone impacts is 200m^3 for the Lower Beadon creek section (areas 6 to 10) and 1600m^3 for the OMSB dredged footprint.

7. Scour of Training Wall Toe Section

The impacts to current velocities through the entrance and along the training wall following the dredging for the OMSB development have been investigated using the hydrodynamic model presented in Section 5, with a focus on identifying the potential for increased scour along the toe section of the training wall.

7.1 Current speeds through the Entrance and Training Wall

To investigate changes in the current velocities along the training wall, a total of 15 cross sections were examined at 50m chainage extending through the length of the training wall to the head of the structure (Figure 7.1).

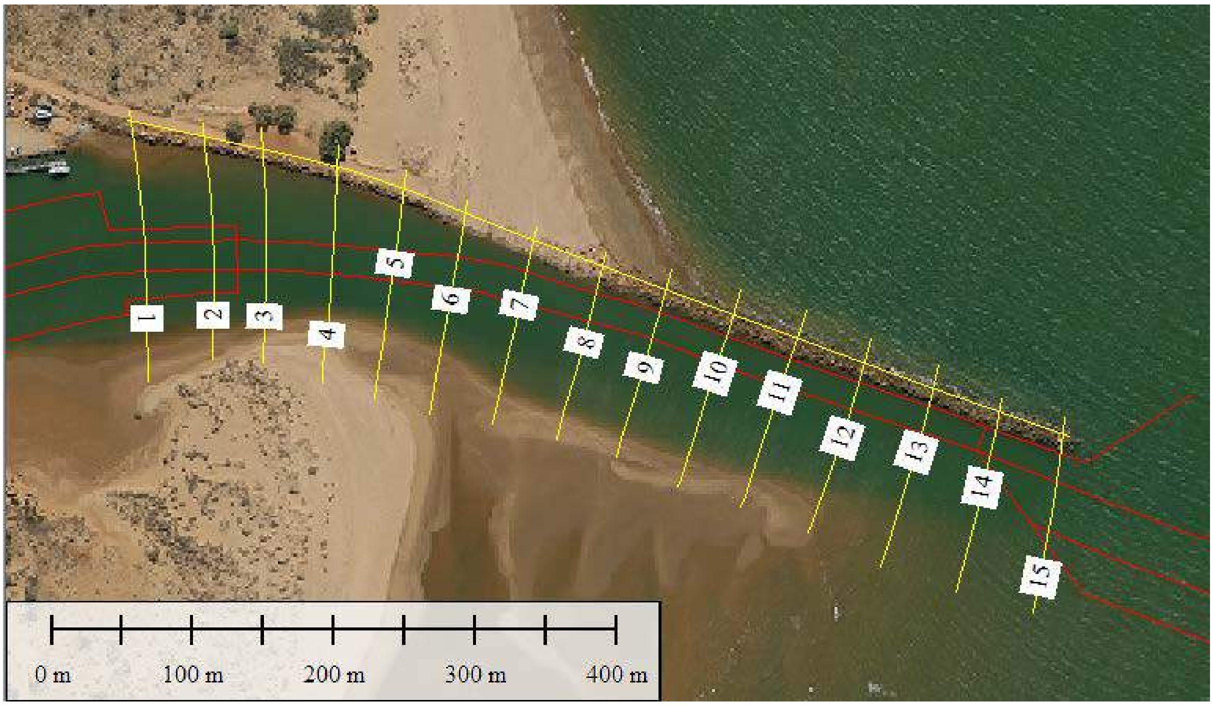

Figure 7.1: Cross Sections Examined for Velocity Changes under Existing and Developed Case

Ebb tide velocities are stronger than flood tide velocities through this section. For the existing and developed cases, the modelled velocity profile through the section and along the training wall was compared for two representative design cases – a large spring tide ebb tide and the ebb tide following a severe tropical cyclone induced storm surge event (TC Vance 1999).

7.1.1 Examination of Tidal Currents – Large Spring Ebb tide

The largest spring tide modelled for the dry season occurs on 1 October 2015 at 1900UTC (refer Figure 5.12) and this was selected for closer assessment within each of the cross sections. For each of the 15 cross sections shown in Figure 7.1, the current speed profile was extracted from the model for both the existing and developed case and is presented in Appendix B. The result from Cross Section 6 is presented in Figure 7.2.

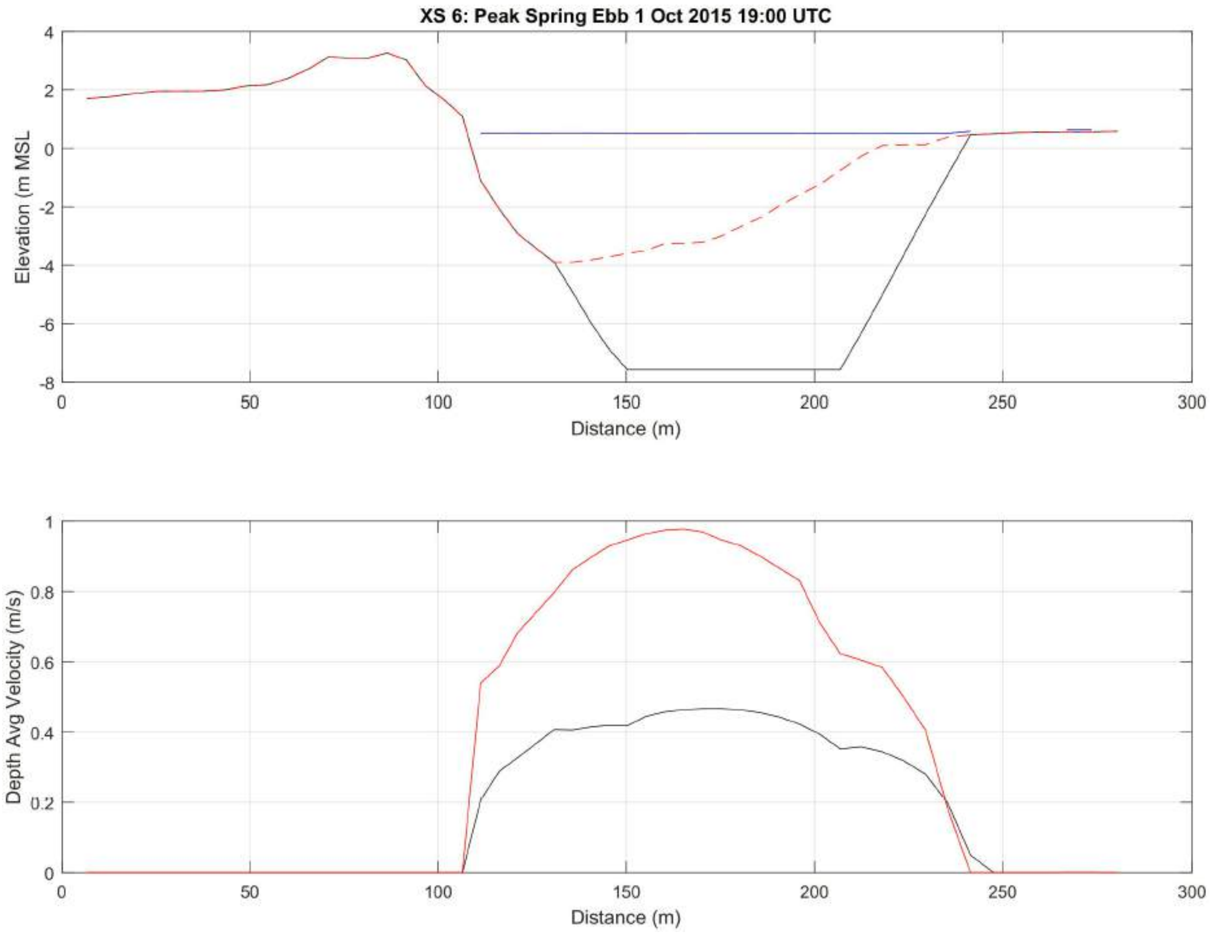

Figure 7.2: Cross Section 6 Comparison of Tidal Current Velocity for Existing (red) and Developed (black) Case at peak Spring Tide Ebb

The existing cross section is shown in the upper plot of Figure 7.2 in red, with the dredged channel in black indicating additional depth of approximately 2m and additional cross sectional area of approximately 150%. In the lower plot the depth averaged current speed at the time of the peak spring tide ebb current is shown in red for the existing cross section and black for the developed cross section. The current velocities are highest through the central deep section of the channel, tailing off in the shallower nearshore sections. Examination of the pre and post development current velocities show there is a marked reduction in the current velocity with velocities generally halved post development. Current velocity peaks at approximately 1ms^{-1} under existing conditions in the centre of the channel, while along the training wall toe (approximately -2m MSL) the current velocity is approximately 0.6ms^{-1}. For the developed case the equivalent locations show current speeds are approximately 0.5ms^{-1} through the central channel and 0.3ms^{-1} along the toe depth of -2m MSL. This is a direct result of the larger cross sectional area over which the ebb tide is released in the developed case.

7.1.2 Examination of Currents in Extreme Storm Surge Ebb Tide – TC Vance

The highest tidal currents modelled through the entrance channel cross sections during the ebb flow following the peak of the storm surge from TC Vance 1999 are shown in Appendix C. The storm surge peak modelled during the event was 2.1m MSL, with the peak water level in Beadon Creek approximately 0.5m above the HAT level. The current velocity at Cross Section 6 through the peak of the event is shown in Figure 7.3.

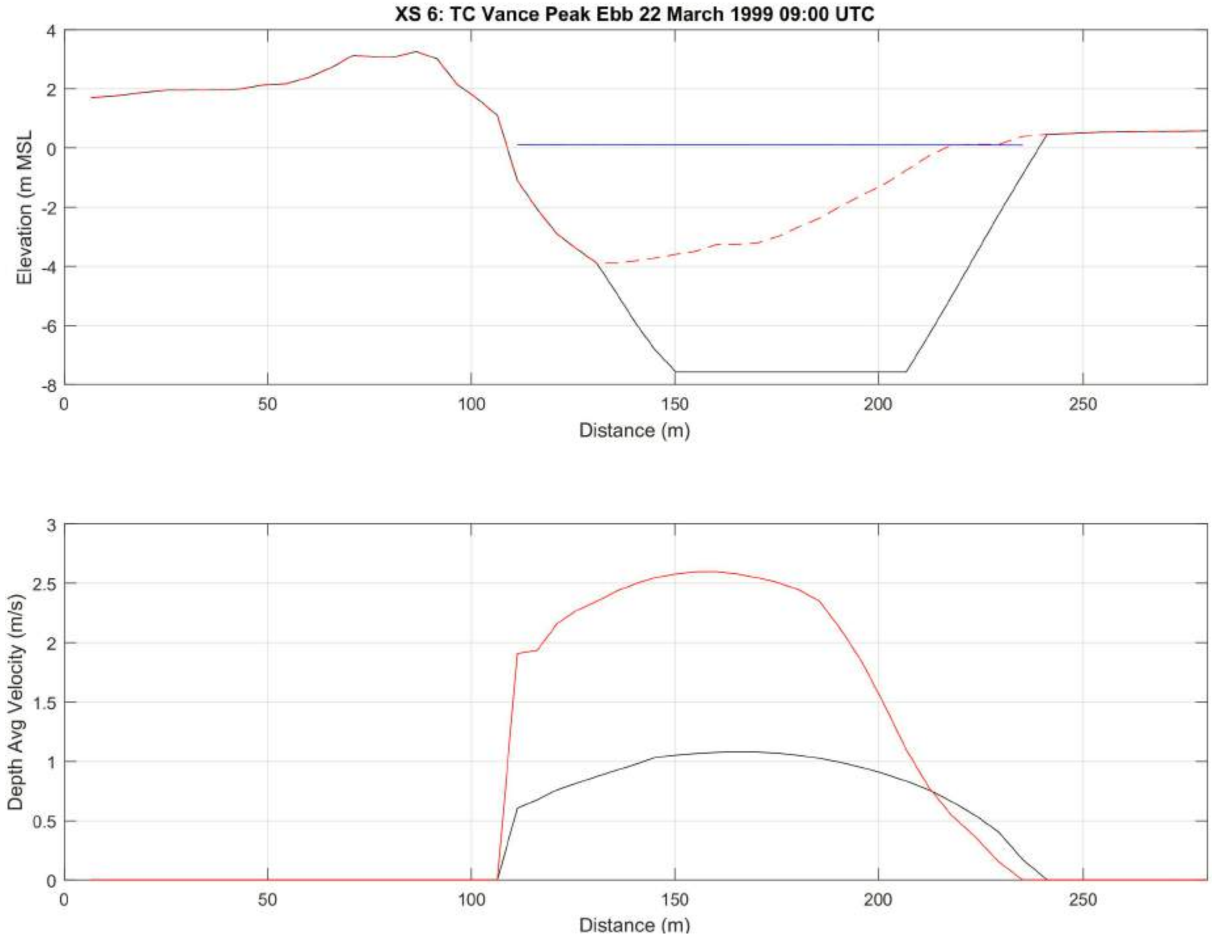

Figure 7.3: Cross Section 6 Comparison of Current Velocity for Existing (red) and Developed (black) Case at peak Ebb Tide during TC Vance

The current velocities for the 15 cross sections in Appendix C show there are very high current speeds through the channel during the ebb tide of TC Vance under the existing entrance channel conditions. For the Cross Section 6 case in Figure 7.3, current velocity peaks at approximately 2.5ms^{-1} under existing conditions through the centre of the channel, while along the training wall toe (-2m MSL) the current velocities are approximately 2ms^{-1}. For the developed case the equivalent locations show current speeds are approximately 1ms^{-1} through the central channel and 0.7ms^{-1} along the toe depth of -2m MSL.

7.1.3 Summary - Velocity through the entrance channel

The key points from the modelled hydrodynamics of velocities in the channel are:

- Current speeds are highest in the deep section of the channel and taper off at the shallow edge of the creek, that is, current speeds are inversely proportional to the depth/cross-sectional area and effective friction.
- Both the spring tide ebb and cyclone cases clearly show the reduction in current velocity associated with the developed case channel profile. Current velocities are generally halved due to the greatly increased cross sectional area of the channel (see Figure 7.2 and Figure 7.3).
- Tidal velocities through the channel for large spring tide ebb conditions show that at the toe depth of the training wall (-2m MSL) the current speeds are between 0.3ms^{-1} and 0.4ms^{-1} in the developed case.
- For the extreme event of TC Vance the highest current speeds modelled at the toe depth of the training wall (-2m MSL) reduce from 2ms^{-1} in the existing case to below 0.7ms^{-1} in the developed case.

- Whilst the developed case velocities along the toe depth reduce by 50% or more when compared to the existing case, there is still potential for scour in this area depending on the sediment size. The critical threshold for erosion is dependent on sediment size (i.e. D_{50}) and this is not well defined along the toe of the breakwater length from the sediment sampling. Further understanding of sediment size would be beneficial in understanding potential for scour risk along the training wall structures.

8. Conclusions

The Onslow Marine Support Base (OMSB) project involves the development of a major marine support base in Onslow which will provide maritime support services to commercial operations across a range of sectors. The OMSB will deliver a land backed wharf with a deep berth pocket for a range of vessel sizes, connected to Beadon Bay through a deepened, wider navigation channel which is planned to be dredged through the Beadon Creek entrance.

As part of the environmental approvals process for the OMSB project, the impact of the Stage 2 capital dredging to the Beadon Creek system is being referred to Western Australia's Environmental Protection Authority (EPA). This requires investigation of the changes that will occur to the coastal dynamics for the Beadon Creek entrance, shorelines and upstream areas. A hydrodynamic model of the Onslow coastal region has been developed to support investigations into changes to coastal processes associated with the planned capital dredging. The model has been validated against the available measured water level record from a tide gauge location within Beadon Creek and at an AWAC instrument northwest of the training wall, showing good agreement to the measured data for water level, current velocity and direction. Representative dry season and wet season conditions have been simulated with the model, with a four week period for each seasonal scenario applied to the existing coastal region as part of the model validation.

The hydrodynamic model has been used to assess changes within Beadon Creek under the planned Stage 2 capital dredging works. At key reporting locations within the Beadon Creek system, training wall and lower tidal creek network, the impacts to tidal velocities and the characteristics of the tidal plane and inundation were examined.

The key outcomes from the hydrodynamics assessment are summarised in the following bullet points:-

- Total discharge volume through the channel entrance was examined for the developed case to investigate changes to the tidal prism against the existing condition. For a four week period of modelled tides, the total inflow to the Beadon Creek system was estimated at 101GL and the total outflow volume 75GL. The difference in the inflow and outflow volume is due to the extraction of seawater from the Beadon creek system for the Onslow Salt pond operations, which have been included in the hydrodynamic model description. Under the developed scenario, the Beadon Creek tidal prism remains largely unchanged with total inflow and outflow volumes estimated to increase by only 1% based on the one month of modelled tides. There was an increase in the discharge rate at the channel entrance during ebb tides for the developed case, as the deeper wider channel allows more conveyance of the ebb tide flows;
- The channel entrance cross sectional area will increase from the current cross sectional area of approximately 220m^2-250m^2 (below MSL) to over 600m^2 as a result of the channel dredging. Model comparisons for the developed case against the existing case indicate that whilst discharge rates increase through the Beadon Creek entrance in the ebb tide cycle, the larger cross section of the developed case channel results in overall reduced velocity magnitude through the channel entrance. Based on historical assessments of the entrance, the present 220-250m^2 area has been estimated to be representative of a 'stable' inlet dimension with respect to the tidal prism upstream and the increase in the cross section under the developed scenario will likely result in an increased sedimentation rate for the navigation channel as the entrance system tries to move towards a new dynamic equilibrium based on the sediment supply and tidal prism;
- The change to current velocities post construction through the spring-neap cycle was examined using the hydrodynamic model at key areas of interest in Beadon Creek. For the dredged areas through the entrance channel and central Beadon Creek the current speeds reduce for the developed case. Along the eastern side of the training wall the current speeds reduce from ebb tide peaks of approximately 1 ms^{-1} in the existing condition to less than 0.5 ms^{-1} post construction. Within the lower section of Beadon Creek the current magnitude increases slightly post construction, likely due to the increased efficiency of the dredged entrance channel to convey ebb tide peak flows;

- At locations upstream of the OMSB dredging footprint, including the Beadon Creek Tide gauge, mangrove areas and tidal branches of Beadon Creek submergence curves were compared between the existing and post construction scenarios and showed there was negligible change to the estuary tide plane post-construction.

The Delft3D and LITDRIFT modelling suites were applied in sediment transport and morphology investigations. Modelling was supported by the analysis of historical aerial imagery available from the site since the 1960's to track the rate of existing shoreline movement. Morphological changes in the coastal system associated with the modification of the seabed and entrance channel dynamics under the Phase 2 capital dredging program were completed based on a representative year of simulations derived from dry season and monsoon conditions and for two cyclone events, with the following key outcomes:

- Analysis of aerial imagery has been used to investigate shoreline movement at the shorelines east and west of Beadon Creek entrance. For the shoreline adjacent to the western side of the entrance channel, accretion of over 300m has been observed since the construction of the training wall. The analysis of shoreline position in recent historical aerial imagery suggests the rate of accretion has slowed in the past 10 years and this region is accreting at approximately 2m a year currently. This accretion is the direct result of trapped eastward bound littoral transport;
- Analysis of the shoreline east of the Beadon creek entrance using the available historical imagery indicates this section of the shoreline moved landward following the formalisation of the Beadon Creek entrance, but that the shoreline has remained reasonably stable over the past 25 years;
- The rate of littoral transport along the shoreline to the west of the training wall was assessed by applying one year of data from the AWAC instrument to the LITDRIFT model. The *potential* rate of transport was estimated at 45,000m^3 annually, noting that this represents the total volume of sediment that could be transported eastward if unlimited sand supply was available. The actual average net rate of eastward littoral drift at the location is estimated to be lower, and the rate would vary on an annual and seasonal basis depending on the wave conditions at the site (one representative year was assessed in this study);
- Analysis of LiDAR data captured for the shoreline west of the training wall between 2010 and 2016 was used to estimate the volume of sediment trapped on the western side of the training wall as approximately 4,500m^3 annually;
- Analysis of the aeolian transport potential from the upper beach section adjoining Beadon Creek indicates up to 1200m^3 annually could be transferred to the east and into Beadon Creek through this mechanism.
- The existing form of the Beadon Creek entrance channel has the capacity to 'naturally bypass' a proportion of the net eastward bound littoral drift. This is directed by the action of spring tide current velocities on the ebb and flood tide which redistribute sediment that falls into the existing channel around and onto the eastern shoal, assisted by wave action. The ability for the system to 'naturally bypass' will be significantly reduced under the developed case as the deepened channel becomes a trap for the eastward and westward littoral drift. The deeper channel and associated reduced tidal velocities will not have the same capacity to move the sediment from the seabed;
- Eastward littoral drift rates at the Beadon Creek entrance have been estimated in previous studies as approximately 10,000m^3 – 15,000 m^3 annually. This rate will vary on a seasonal and annual basis depending on available sediment supply and metocean forcing conditions. For this study the littoral transport rate has been assessed and modelled in the range of 8,000m^3 – 24,000m^3 annually. The majority of this sediment would be deposited in the dredged navigation channel on the lee side of the breakwater, and is the main driver of sedimentation in the developed case.;
- Sediment samples collected in the Beadon Creek entrance and nearshore areas indicate the dredged areas in the existing navigation channel and inside Beadon Creek consist of generally coarser sediments than offshore regions, likely as a result of the winnowing of the seabed material from tidal velocities acting through these areas in spring tides. It is expected the dredged channel would have a low capacity to continue this process based on the hydraulic and sediment conditions in the channel;
- The sediment transport model has been developed from the validated hydrodynamic model. The sediment transport results incorporate analysis of both sand fractions and fine sediments (clays, silts).

The final outcomes for sedimentation from the model are based on sedimentation rates only, and erosion is not included. The model results are representative of a one year period, based on extrapolation of outcomes from 4 week representative conditions for the wet season and dry season respectively. The modelling adopts a spatially varying sediment size and roughness across the seabed, and includes the littoral transport and aeolian transport rates determined for the site;

- The sediment transport model was validated by comparing the modelled sedimentation volumes against historically reported sedimentation rates for maintenance dredging between 2002 and 2012 (Oceanica, 2014) and from survey comparisons between 2012 to 2016 (DoT LiDAR). The model outcomes are generally representative of the historical observations, within the constraints of representing a 'like for like' comparison of actual and modelled parameters (bathymetry, sediment size, metocean conditions) in each representative time period;
- The projected annual sedimentation rate for lower Beadon Creek following dredging is 1,200m^3 annually. This is an increase of approximately 500m^3 from the equivalent sections of the channel modelled in the existing case with the increase a direct result of the seabed responding to the change in the hydrodynamic regime (i.e. the dredging for the entrance and turning circle areas). The sedimentation rate would likely decrease over time as the seabed adjusted to a new equilibrium condition.
- The projected annual sedimentation rate for the OMSB dredge footprint areas is 36,300m^3 with the majority of the sedimentation (29,800m^3) in the section of the approach bend around the training wall (Section 2). This is considered a conservative (i.e. high) estimate under the assumption there is net littoral transport of 24,000m^3 directed eastward annually which is bypassed by the current existing channel but trapped by the dredged channel. Understanding the true littoral transport rate will be a key factor in the design of the dredging maintenance program for the developed case;
- The potential sedimentation impacts for the OMSB developed footprint from a severe tropical cyclone event was assessed based on sediment transport modelling of TC Olwyn (2015) and TC Vance (1999). This analysis recommended that an annual sediment allowance of 1,600m^3 in the OMSB footprint and 200m^3 for lower Beadon Creek be adopted based on a significant event impacting the site every 5 years;
- The key driver of sedimentation for the OMSB navigation channel is expected to be eastward littoral drift of sediment. This sedimentation is likely to be most concentrated in the channel bend section of the OMSB channel near the end of the training wall (Section 2). Maintenance dredging of the sediment that is directed into the navigation channel will be required to maintain navigable depth in this area. A form of bypass for the sedimentation in the OMSB navigation channel is recommended that can restore the natural eastward supply of sand to the eastern shoal and eastern shoreline. Restoring this natural sediment supply to the eastern shore will be important to ensure there is future stability along this section of the shoreline which provides the natural barrier to Beadon Creek;
- Bypassing options have not been investigated as part of this scope, however it is anticipated the material will be predominantly clean sand material well suited to standard dredging operations. Further modelling at finer resolution is recommended to support detailed design and development of the maintenance dredging strategy including options for bypassing sediment to the eastern side of the channel; and
- Examination of the scour potential at cross sections along the training wall for extreme ebb tide cases (spring tide and cyclone) indicate that the developed channel will significantly reduce the current velocity at the toe depth (approximately -2m MSL). Whilst the channel velocity was shown to reduce by 50% at the toe depth for the cases examined, there is still a potential for scour along this section depending on the actual sediment size (i.e. D_{50}) which is not well defined from sediment sampling to date. Future sediment sampling at toe depth would assist in understanding the scour potential in the developed case.

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Appendix A

Sediment Transport Modelling Detail

A.1 Sediment Transport Model

The sediment transport model developed for Beadon Creek is an extension of the hydrodynamic model that has been presented in Section 5 of the main report. The sediment transport model was required to assess both fine sediments and sand fractions.

Historical aerial imagery from the Beadon Creek entrance can be used to illustrate the presence of fine sediments and sand fractions. In Figure A.1 the eastern shoal is shown at mid-tide with reworking of the sand fractions occurring at the seabed under wave action and tidal current induced shear stresses. On Figure A.2 the presence of fine suspended sediments in the water column is evident by the turbidity in the water column.

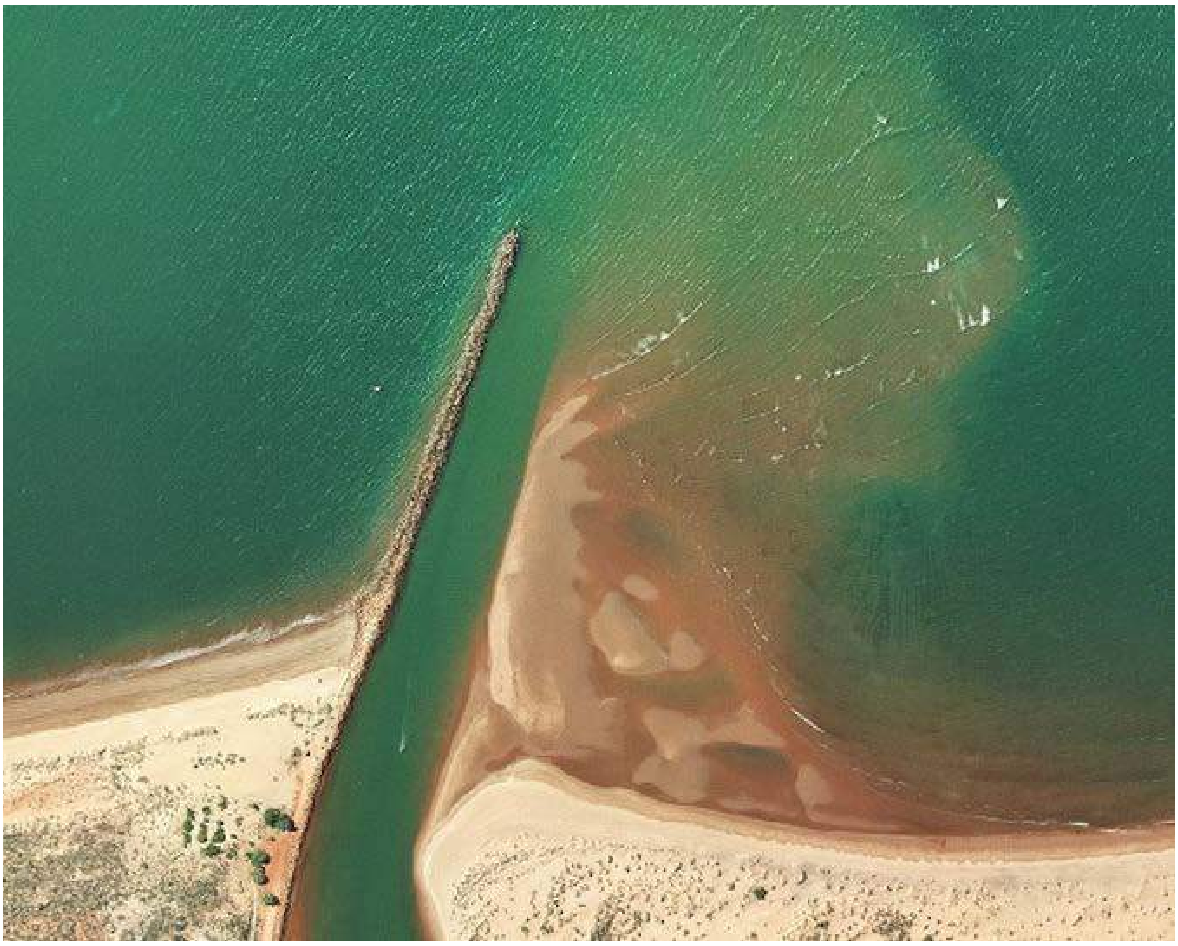

Figure A.1: Example of sand fractions at the Beadon Creek entrance (image 2013)

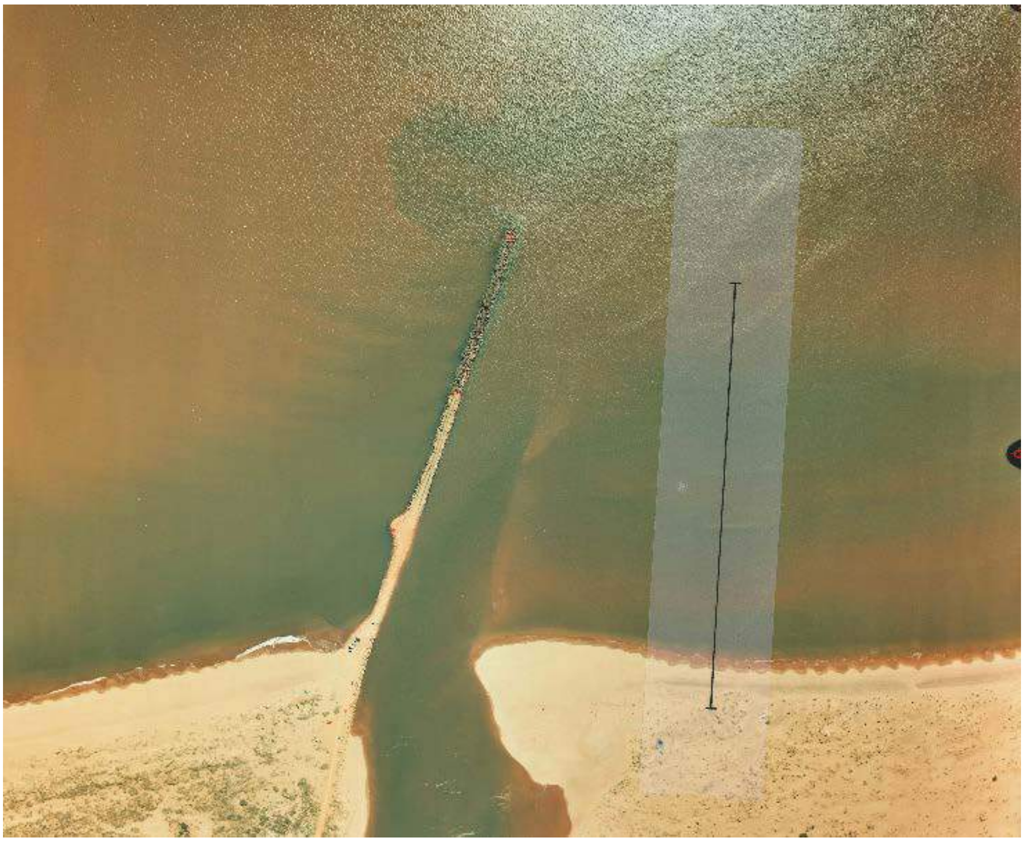

Figure A.2: Example of suspended fine sediments at the Beadon Creek entrance (image 1991)

A.1.1 Sediment Transport Model Description

The Delft3D Online Sediment model has been applied in the sediment transport investigations to examine the sediment transport and morphology changes from both sand and fine sediments. Based on the hydrodynamic model that has been presented in Section 5 of the main report, the sediment transport was developed by upgrading the model grid and refining the grid size across the region of the training wall and Beadon Creek entrance to approximately 5m x 5m.

A.1.1.1 Hydrodynamic and Wave Validation

A representative year is evaluated in the sediment model by applying the dry season and wet season periods discussed in Section 3.4. The model evaluates sediment transport over a 4-week period for each of the seasonal conditions and results are adjusted using a morphological factor in Delft3D so that the overall outcomes represent a one year period.

Further to the hydrodynamic model validation presented in Section 3.4 of the main report, a comparison of the measured and modelled dry season and wet season conditions for waves, winds and atmospheric pressure is presented on Figure A.3 and Figure A.4.

The comparisons show that the model agreement to the measured data is generally good for wave conditions, with modelled wave heights moderately higher than the AWAC measured wave height. The peak period comparisons show variability, and it is noted that the derivation of this parameter is subject to differing interpretations in the AWAC instrument and model, with the general range for peak period noted as being consistent across the measured and modelled data. Wind conditions and atmospheric pressure are represented well in the model when compared against the measured data.

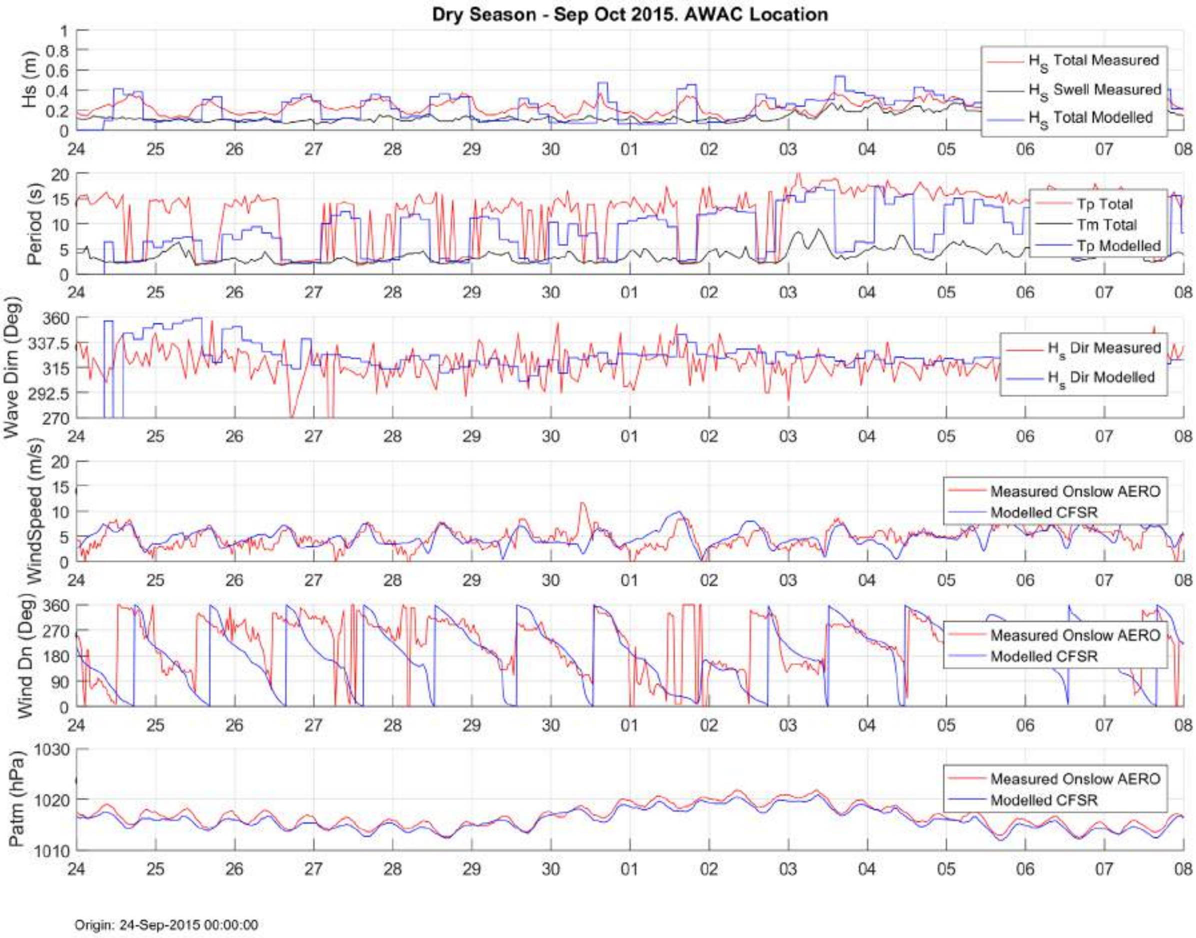

Figure A.3: Dry season comparison of measured and modelled wave, wind and atmospheric pressure conditions

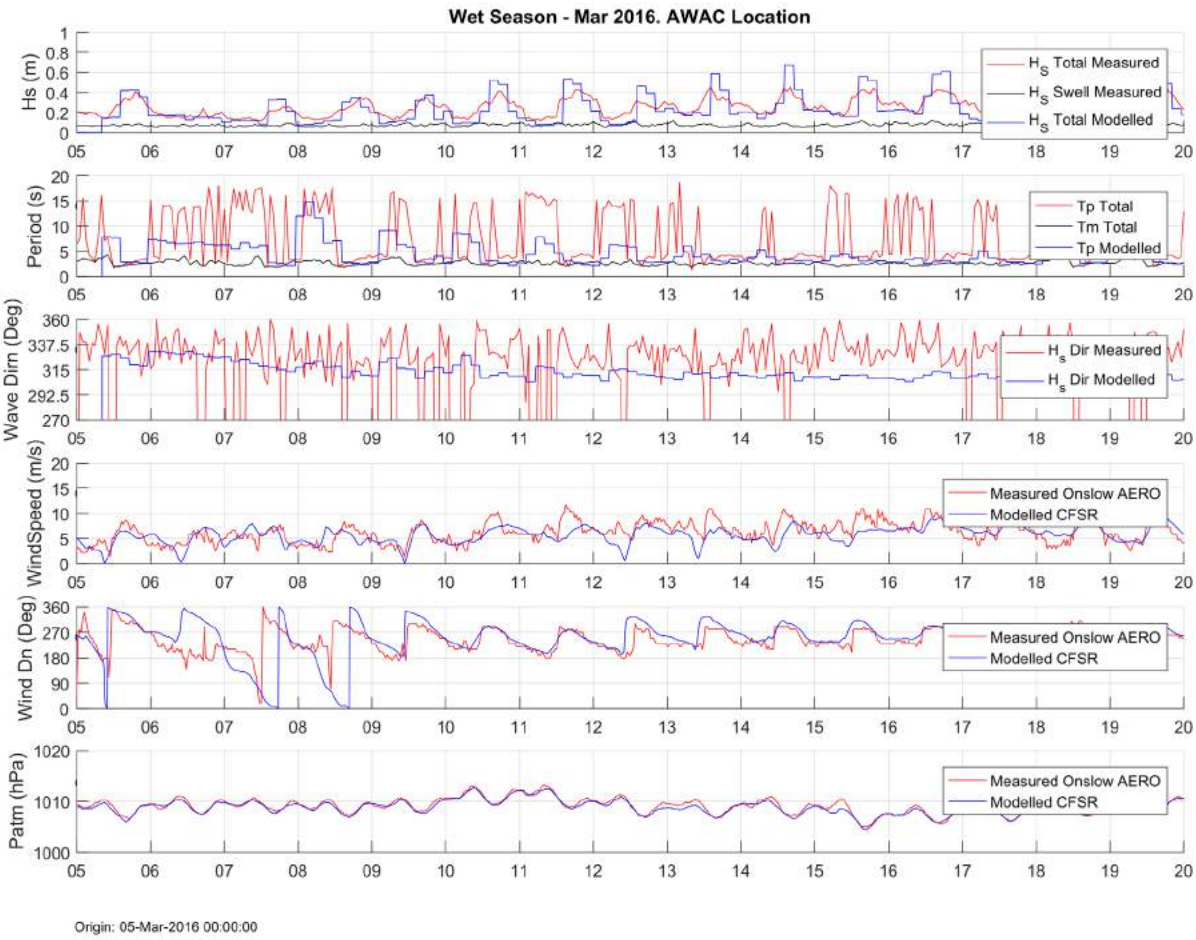

Figure A.4: Wet season comparison of measured and modelled wave, wind and atmospheric pressure conditions

A.1.1.2 Sediment Transport Parameterisation Models

The sediment transport model examines components within two categories:

1. The sand fraction which represents sediment sizes in the range 0.1mm to 0.4mm (100-400µm)
2. Fine sediments represented by clay, silt and coarse silt in the (4-55µm)

Sand Fraction Modelling

For the sand fraction, the TRANMOR 2004 sediment transport model for non-cohesive sediments has been applied. This sand transport model has been documented recently in van Rijn (2007) and van Rijn et al (2007). The TR2004 model is significantly more accurate and robust compared to earlier sediment transport models. The key changes in the TR2004 model, compared to earlier transport models such as the van Rijn 1993 model, are associated with:

- Bed roughness;
- Bed forms;
- Wave-induced transport; and
- Reference concentration above the seabed.

Delft3D and the TRANMOR 2004 model has been used in a number of entrance and channel morphology studies over the last ten years including well validated models that have been developed for dynamic entrances with wave-current interactions. Two such studies of note, with publicly available reports, include the Brisbane Water (NSW) estuary processes study the Lake Illawarra Entrance Study. At Lake Illawarra, revalidation of the Deflt3D entrance morphological model using the TR2004 sediment transport model demonstrated substantially improved agreement between modelled and measured entrance morphological changes (Taylor et al, 2008). The model system was also applied in the coastal processes investigations for the Port Hedland Outer Harbour project.

In this study, bed roughness due to bed forms was included in the sediment transport and hydrodynamic model processes. The bed form roughness model is based on van Rijn (1993).

Sand Fraction Input Parameters

Sediment size at the seabed was assigned based on the sediment sampling results reported in O2 (2017). The sediment size map is shown in Figure A.5 for the existing case model, based on the sediment sampling undertaken to support the project (O2, 2017). The median sediment sizes (D_{50} values) are largest in the navigation channel through the entrance in comparison to other areas, in the range 0.30mm to 0.40mm due to scouring of this section.

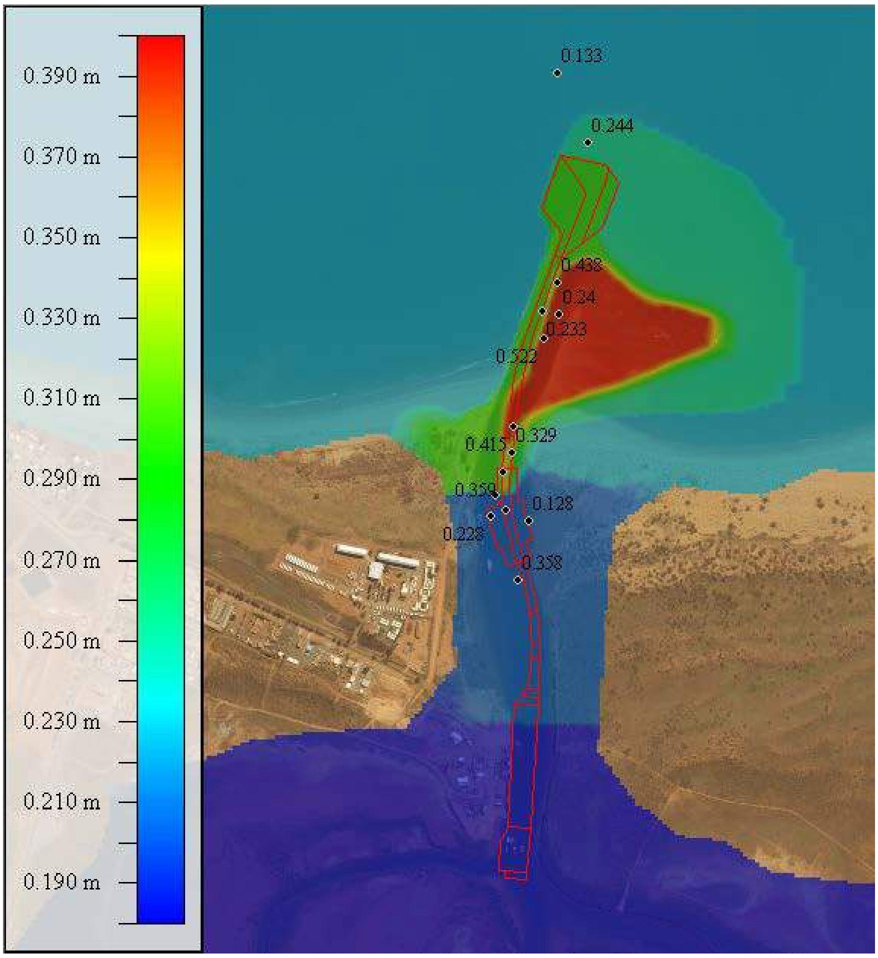

Figure A.5: Sediment size map adopted in the Deft3D model through the Beadon Creek entrance with locations of measured sediment samples (all data shown in mm)

Fine Sediment Modelling

Fine sediments were modelled using the Partheniades-Krone formulations (Partheniades, 1965) for cohesive sediment. This model calculates the sediment fluxes between the water phase and the bed. The Partheniades-Krone formulations require the specification of the critical shear stresses for erosion and sedimentation, the maximum erosion rate and a hindered settling velocity. A review of van Rijn (2006) was undertaken to define the critical shear stress and maximum erosion rate for the defined silt fractions. Fall velocities were based on the sediment fraction particle size and adopted from appropriate literature as summarised in Table A.1. Critical shear stresses were adopted from literature (i.e. van Rijn 2006) and adjusted during model calibration. The critical shear stress for erosion was specified as 0.2 N/m^2 and the critical shear stress for deposition was specified as 0.06 N/m^2. Flocculation is not a significant process when suspended sediment concentrations are low, and salinity variations are minimal.

Table A.1: Three Fine Sediment Fractions Parameters

Sediment Fraction	Nominal Particle Size	Composition	Critical Shear Stress – Erosion $T_{cr,e}$ (N/m^2)	Fall Velocity – Stokes Law (mm/s)	Modelled Dry Bed Density (kg/m^3)
Clay	4µm	33%	0.2	0.004	400
Fine Silt	20µm	33%	0.2	0.06	900
Coarse Silt	55µm	33%	0.2	1.7	1100

Fine Sediment Input Parameters

The suspended fine sediment fractions in the model have been determined by examining turbidity measurements in the Onslow region for NTU and correlating these to a suspended sediment value (TSS). The Wheatstone Baseline Reporting (Chevron, 2013) reported baseline NTU values (Nephelometric Turbidity Units) for seasonal periods across several sites over a two-year period from May 2011 to April 2013.

Two sites reported in the Wheatstone data were selected within the Delft model domain to describe NTU values nearshore and offshore for input to D-FLOW Model Boundary as follows:

- Inshore: Ward Reef
- Offshore: Weeks Shoal

The selected locations are indicated relative to the Sediment transport model domain in Figure A.6 and the outcomes from the baseline monitoring summarised in Table A.2.

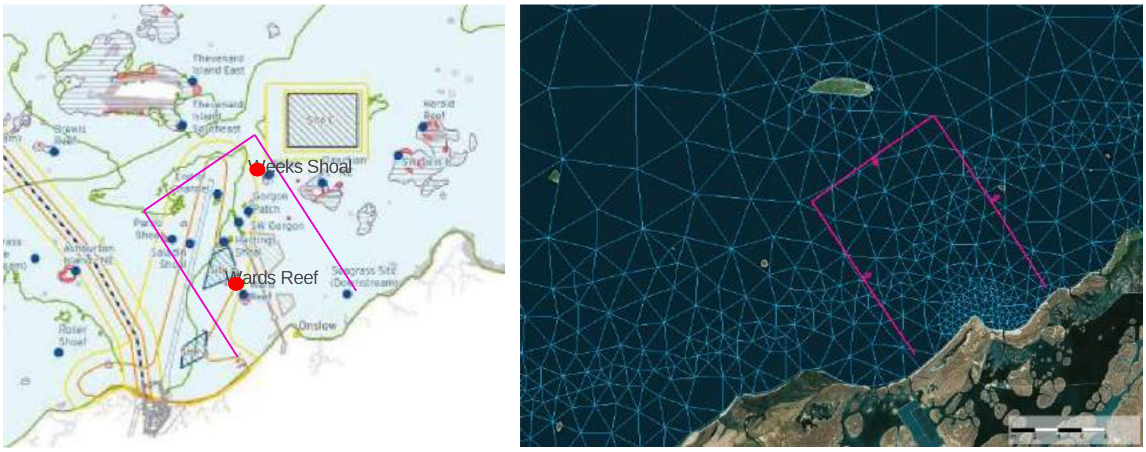

Figure A.6: Baseline monitoring locations for NTU (Wheatstone 2013) shown relative to the Delft-FLOW model boundaries.

Table A.2: Baseline monitoring locations for turbidity within the model domain (Wheatstone 2013)

	D3D Model BND	D3D Model Season	Wheatstone Season	NTU P20	NTU Median	NTU P80
Ward Reef	Inshore	Wet	Summer	1.3	2.3	4.7
Ward Reef	Inshore	Dry	Spring	1.1	1.8	2.8
Weeks Shoal	Offshore	Wet	Summer	0.9	1.4	2.5
Weeks Shoal	Offshore	Dry	Spring	0.7	1	1.3

The process to apply the measured values in Table A.2 to the model boundaries is summarised as follows:

- NTU was converted to TSS by adopting 1NTU = 1mg/L (1mg/L = 0.001 kg/m^3)
- The NTU value was divided between the three sediment fractions equally (Silt, Fine Silt, Clay)
- A time series file for each model boundary was defined to reproduce the statistics for the P20, P50 and P80 values within each respective seasonal period (dry / monsoon).

A.1.2 Longshore Sediment Transport Bypassing

Modelling of longshore transport (littoral drift) has been included in the modelling of sand fractions. This process directs sediment in a generally eastward direction under the prevailing wave conditions. There is a 'natural bypassing' of the sediment across the present Beadon Creek channel which directs the sediment around and over the eastern shoal ultimately feeding the shoal feature and the eastern shoreline. For the developed case, it is expected that the ability to naturally bypass sediment will be inhibited due to the reduction of velocities and seabed shear stresses through the deeper wider channel.

To assess the natural bypass mechanism of the existing channel, the sediment transport model adopted a sediment discharge node located on the north-western tip of the breakwater, with a fixed rate of sediment volume, to replicate the annual littoral bypass rate of the breakwater. The bypass sediment volume was then tracked through the model domain to investigate the sediment pathways and the resulting distribution of sediment deposition. For these simulations seabed morphology was not activated in the model, so that the longshore transport bypass process could be examined in isolation.

Simulations were run for 1 month of dry and monsoon season conditions and results proportionally combined and shown in Figure A.7 as the distribution of this bypass volume. The modelled outcomes indicate the sediment is redistributed through the model under the forcing conditions along four general pathways summarised in Table A.3.

Table A.3: Summary of littoral transport pathways and driving mechanisms

Pathway	General Forcing Mechanism
Into Lee (Eastern) Side of Breakwater	Easterly directed wave action. Once in the lee of breakwater the sediment either falls: • into the navigation channel at the Bell Mouth and then may be subject to tidal current resuspension • in the lee of the breakwater structure where tidal and wave stresses are minimal and deposition occurs
Around Eastern Shoal	Sediment at the bed subjected to high spring tide and flood tide velocities is mobilised and

Pathway	General Forcing Mechanism
	directed eastward under associated wave forcing. Sediment can move onto the shoal directly on the eastern side, but is predominantly directed around the northern deeper section of the shoal, and continues all the way to the eastern shoreline under wave forcing down the eastern side of the shoal.
Into Beadon Creek Entrance	A small amount of the sediment that is deposited in the navigation channel and shoal margins is resuspended in spring flood tides and directed into Beadon Creek where sedimentation will occur in areas of low bed shear stress.
Redistributed Westward	Under certain wave forcing conditions, the prevailing longshore transport direction reverses and sediment is moved back to the west. Additionally, material that is driven westerly on a strong ebb tide out of the range of the eastern shoal natural bypass mechanism may occur. The sediment will eventually be redirected back eastward with the prevailing littoral transport direction.

The modelled results for the existing case are shown in Figure A.7. While the limitation in describing the long-term littoral transport processes with a one month simulation is noted, the outcomes in Figure A.7 clearly demonstrate the four sediment pathways. The natural bypass mechanism as sediment is transported around the eastern shoal along its northern extent and onto the eastern shoreline is evident. There is a concentration of sedimentation on the lee of the breakwater in the bell mouth, silt trap area and adjacent the training wall. Westward redistribution of sediment is also observed.

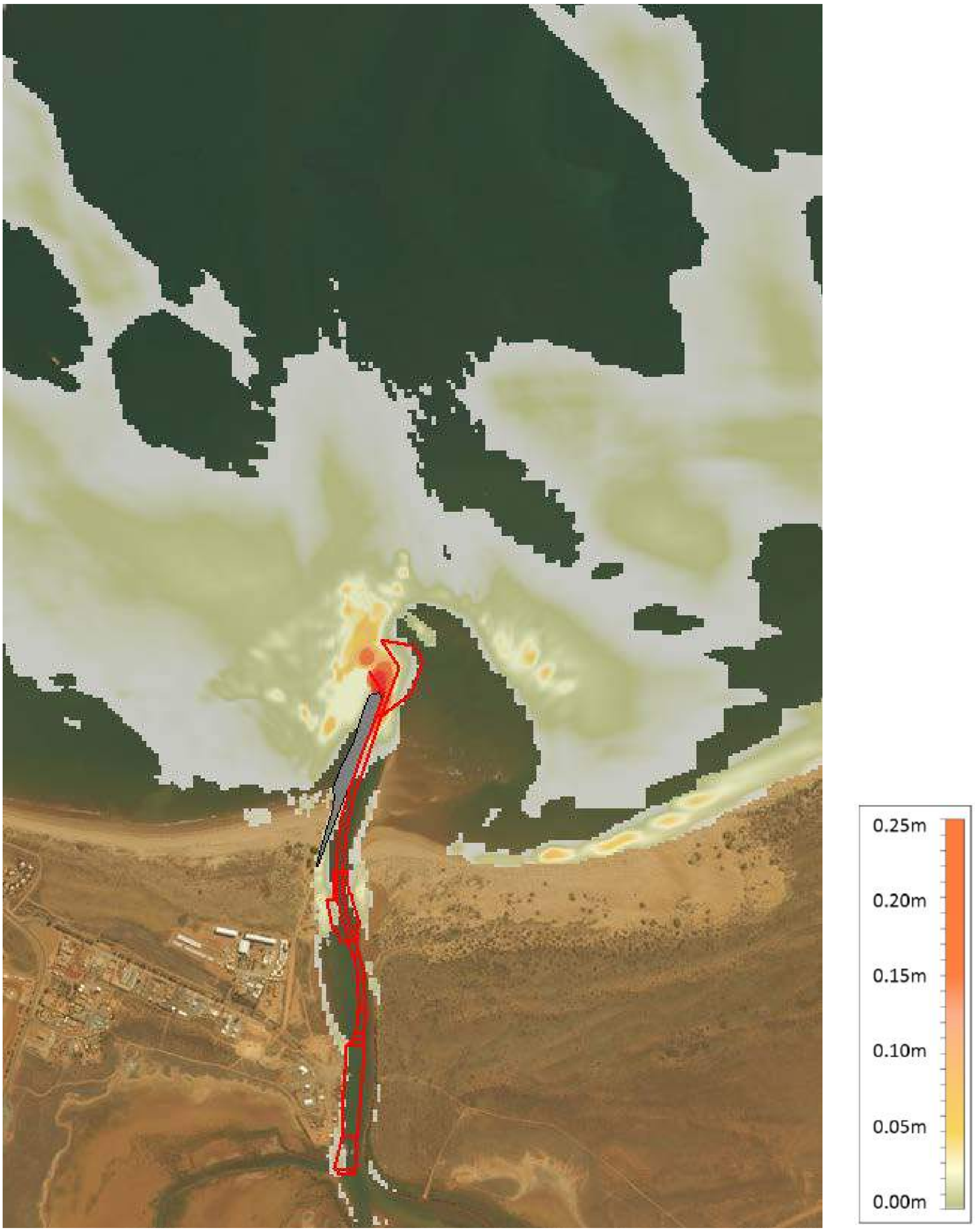

Figure A.7: Distribution of Littoral Drift Volume that Bypasses the Training Wall Structure under existing conditions

To examine the impacts to the natural bypass mechanism in the developed case, the sediment transport model was applied to the developed case that included the dredged channel footprint. The resulting sediment transport distribution are presented in Figure A.8, and show that the impact of the dredged channel effectively stops the eastward directed longshore transport pathway around the eastern shoal feature. The deepened channel becomes a trap for the eastward littoral drift and the deeper channel and associated reduced tidal velocities do not have the same capacity to move the sediment from the seabed as observed for the existing case.

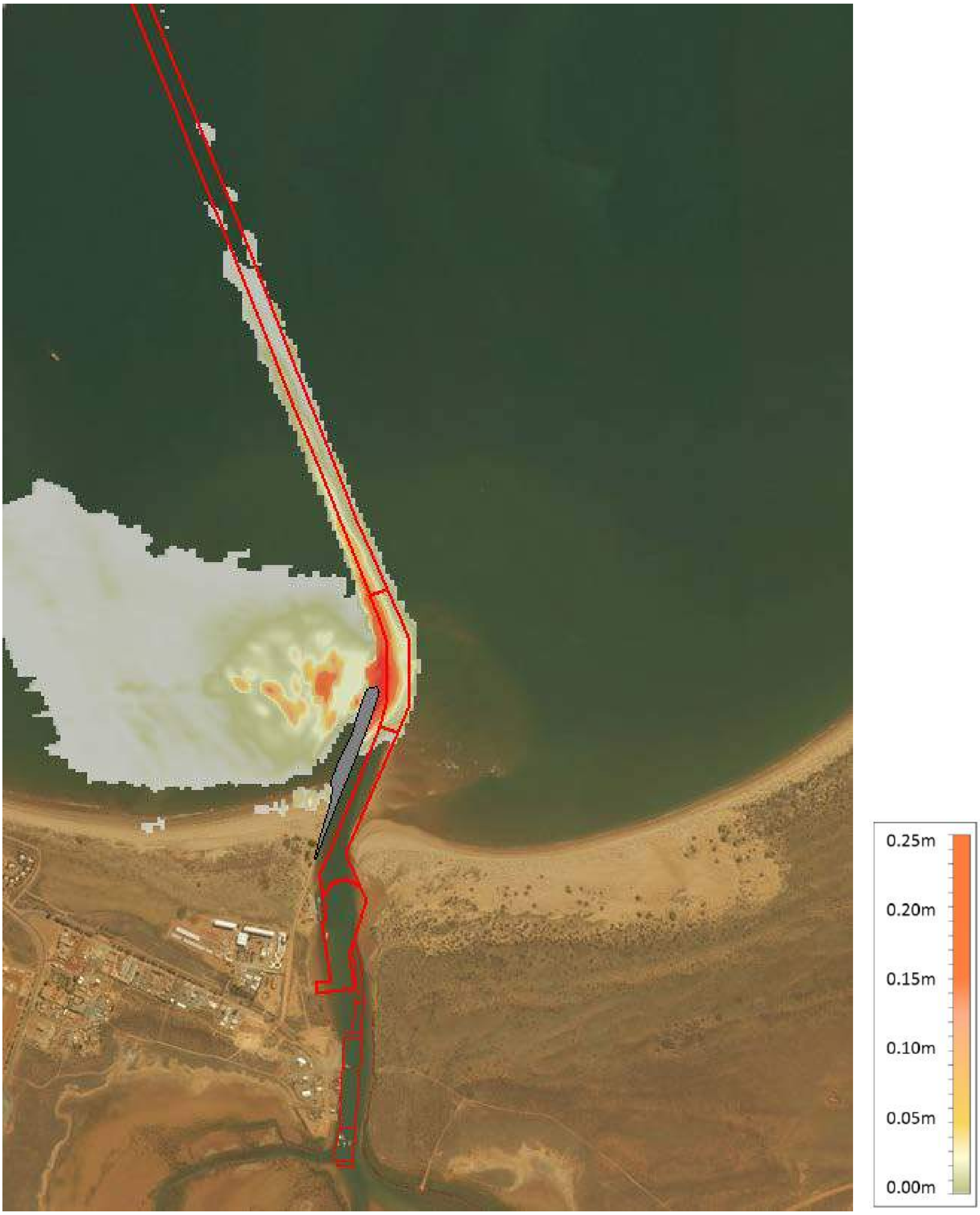

Figure A.8: Distribution of Littoral Drift Volume that Bypasses the Training Wall Structure under developed conditions

A comparison of the modelled sediment volumes for the existing and developed cases is summarised on Table A.4, indicating the proportion of sediment volume that is directed through each of the sediment pathways discussed in Table A.3.

Table A.4: Littoral Transport Sediment Deposition Summary

Pathway	Existing		Developed	
Lee Side of Breakwater	37%	28% Bell Mouth and Silt Trap 9% Training Wall at Channel Margin	83%	5% Section 1 Channel Offshore 54% Section 2 Channel Turn 24% Training Wall at Channel Margin
Around Eastern Shoal	48%		0%	
Southwards into Beadon Creek	1%		0%	
Westwards Redistribution	14%		17%	

The following is noted:

- the volume of sediment transported around the eastern shoal reduces from 48% in the existing case to 0% in the developed case as the deeper wider channel effectively traps all eastward bound sediment;
- for the existing case 37% of the sediment is trapped in the areas on the lee side of the breakwater, with the majority in the Bell Mouth and Bell Mouth Silt Trap areas (28%) and a smaller proportion (9%) deposited at the section between the training wall and entrance channel, which may move into the navigation channel over a longer time period;
- for the developed case, 83% of the total sediment volume is trapped between the training wall and the eastern side of the dredged channel. This sedimentation volume is predominantly in the dredged channel area of Section 2 (54%) with the offshore section of the channel (Section 1) accumulating 5% as sediment trapped in the deeper dredged channel section redistributed northwards. In the lee of the training wall between the training wall and western edge of the dredged channel, 24% of the sedimentation volume accumulates and this would be likely to move east and into the deeper channel over time
- westward redistribution is largely consistent between the existing and developed cases (14% existing compared with 17% developed) with the marginally higher developed case outcome likely due to the deeper channel of the developed case influencing the approach angle of waves at the training wall tip;
- for the existing case, approximately 1% of the overall sediment volume is transported through the Beadon Creek entrance and distributed inside Beadon Creek. No transport through Beadon creek occurs under the developed case, considered to be due to the reduced flood tide velocities through the entrance channel in the deeper dredged channel which do not have the capacity to resuspend and drive sediment through the entrance.

A.1.3 Fine Sediment Deposition

The modelled outcomes for the fine sediment fractions for the existing and developed case over a one year period is shown in Figure A.9, with a closer view of the OMSB footprint provided on Figure A.10. The model applies suspended sediments as boundary conditions defined for the three fine sediment categories outlined in Table A.2, with an allowance at the seabed for erosion of fine material locally. Shear stresses acting through the domain erode fine material from the seabed areas, with mobilised material transported under the hydrodynamic forcing through the water column and then deposited in more tranquil regions (i.e. deep channels and protected areas). The following is noted for the modelled fine sediment:

- All navigation areas in the development footprint are likely to experience sedimentation of fine materials (< 64um), at a rate of up to 0.1 m per year. This material may be redistributed away from areas where propeller wash or vessel induced flows can mobilise fine materials in low tide conditions.

- Sedimentation in the existing case shown in Figure A.9 for Beadon Creek and the lower tidal creeks is concentrated at the edges of the waterway. There is a minor reduction in the sedimentation rate noted in the lower tidal creeks for the developed case, likely as a result of the slightly elevated spring tide current speeds in this area reported in Figure 5.15.

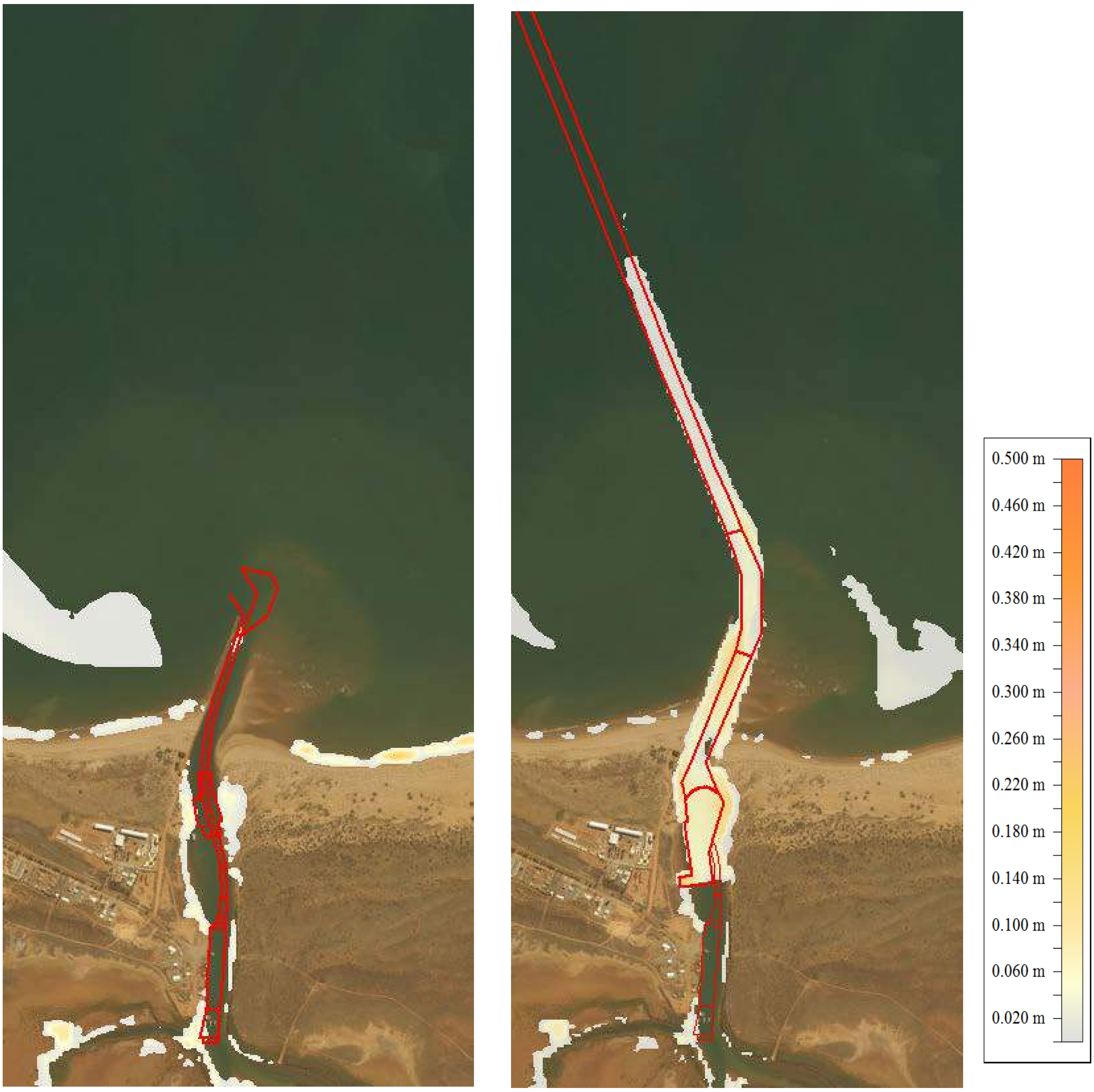

Figure A.9: Fines Accumulation – total annual sedimentation for Existing Case (left), Developed Case (right)

It is noted that baseline water quality monitoring for Wheatstone (MSC 2009) reported a higher NTU to TSS relationship (TSS = 2.04+1.07*NTU) than adopted for the model boundaries in this study. Because the modelled suspended sediment concentration in the water column at the OMSB site is dominated by the local erosion of fine material, adopting this higher NTU to TSS conversion from would not impact the reported sedimentation volumes.

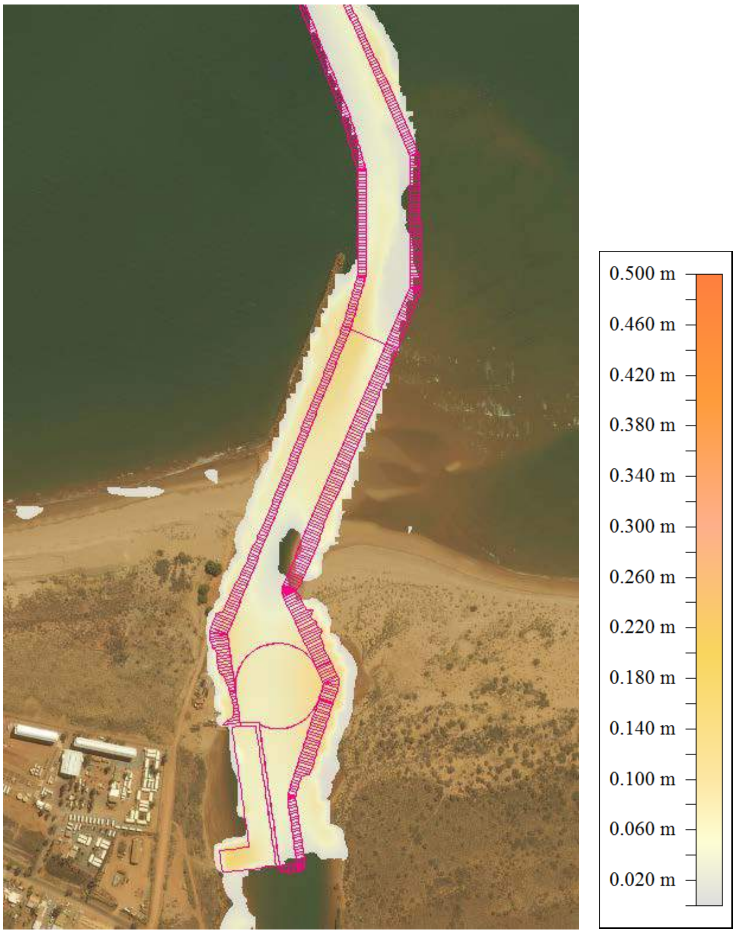

Figure A.10: Fines Accumulation – total annual sedimentation for Channel Entrance and OMSB area

A.1.4 Seabed Morphology under Existing Conditions

The sediment transport model was run for the representative monsoon and dry seasons and the outputs combined to produce the sediment transport results.

The morphological changes modelled are representative of one year with the following processes incorporated:

- Representative dry season and monsoon season hydrodynamic conditions are applied. This includes time varying winds, waves, currents and tides.
- The salt intake from Onslow Salt removes $12m^3sec^{-1}$ via three pumps operating on the eastern side of Beadon Creek tidal flats whenever the water level is above 0.8m CD.
- Aeolian transport of $1200m^3$ annually is input to the channel at the exposed landward section of the training wall, adopting a sediment size of 0.25mm.
- Easterly Littoral drift of sediment around the training wall input to the model is input at three different annual rates; $8,000m^3$, $16,000m^3$ and $24,000m^3$. A sediment size of 0.2mm is adopted.

The modelling does not include:

- The impacts from passing ships through either vessel wakes resuspending sediments (fine sediments) or through scouring of the sediment from the seabed in the event of limited underkeel clearance from large vessels.

- Significant rainfall events or king tides mobilising / resuspending material in the Beadon Creek tidal flats area.

The modelled sedimentation rates for the existing Beadon Creek case have been quantified within the channel sections that were reported in Oceanica (2014). The modelled results are compared against two historical sedimentation rate estimates:

1. Estimate 1: The 2012 pre-dredge assessment of annual sedimentation within each channel section in the period following the dredging campaigns of 1999 and 2002 (Oceanica, 2014).
2. Estimate 2: Recent multibeam survey of Beadon Creek (DoT, 2016) was analysed to estimate the bed level changes that have occurred in the period following the maintenance dredging campaign completed in 2012-2013 (based on target design depths of that campaign).

The channel sections that are used for the analysis are shown on Figure A.11.

Figure A.11: Channel sections analysed for bed level changes (Oceanica, 2014)

The combined model results (sand fractions and fine sediment) are shown in Figure A.13. A summary of the contribution from each modelled sediment transport process is provided in Table A.5.

The historically observed sedimentation rates within each of the channel sections is presented in Table A.6 compared against those derived from the combined modelled outcomes as shown in Figure A.13.

Table A.5: Contribution of Sediment Transport Processes to Overall Sedimentation (m³/yr)

Channel Sections		Fines	Sand Transport	Aeolian	Longshore Transport	TOTAL
1	Bell Mouth	0	340	50	100	490
2	Bell Mouth Silt Trap	0	1550	20	10	1580
3	Outer Entrance Channel	0	130	10	0	140
4	Mid Entrance Channel A	10	330	10	0	350
5	Mid Entrance Channel B	0	50	0	0	50
6	Inner Entrance Channel A	0	10	0	0	10
7	Inner Entrance Channel B	0	40	0	0	40
8	Basin	0	120	0	0	120
9	Cyclone Moorings	5	410	0	0	415
10	Basin Silt Trap	5	140	0	0	145
	TOTAL	**20**	**3120**	**90**	**110**	**3340**

For comparison, the observed changes to bed level are shown over a series of time periods in Figure A.12. The comparison periods are summarised as:

- 2003 to 2008. No major cyclone impacts understood to have occurred in Onslow.
- 1999 to 2015: Notable cyclones include TC Vance (March 1999) and TC Olwyn (March 2015)
- 2016 to 2017: No notable cyclone impacts occurred at Onslow.

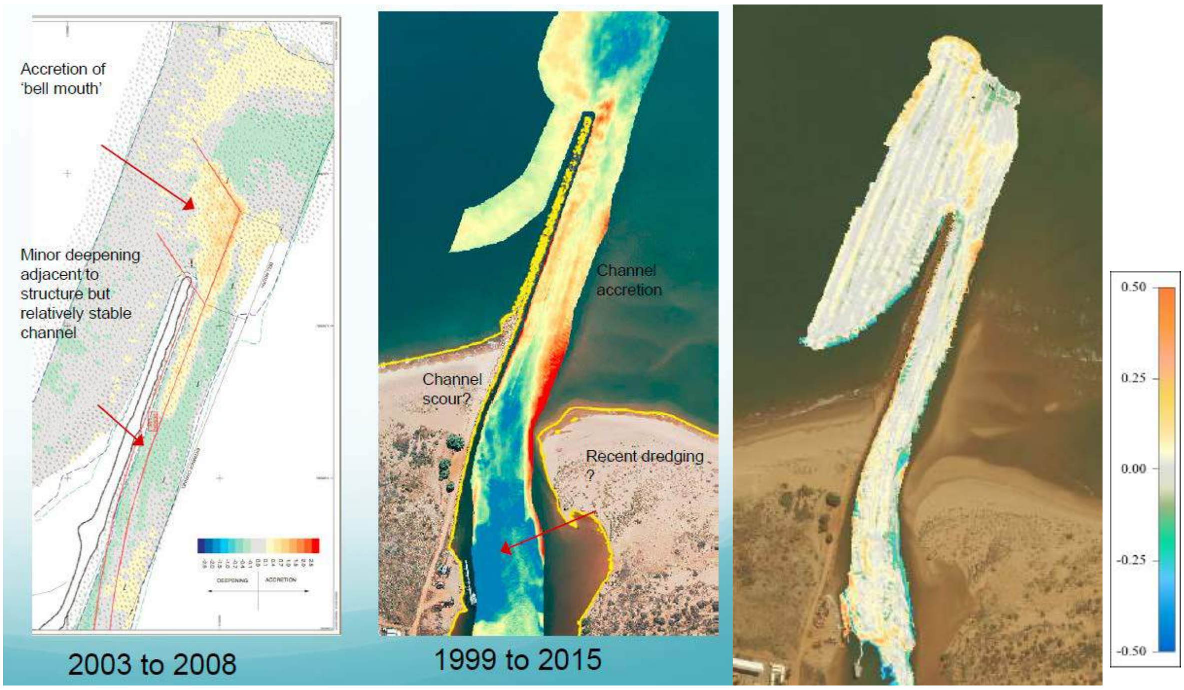

Figure A.12: Beadon Creek Entrance (left) 2003 to 2008, (middle) 1999 to 2015 (from Seashore 2017), (right) August 2016 to March 2017 calculated from multibeam data (DoT).

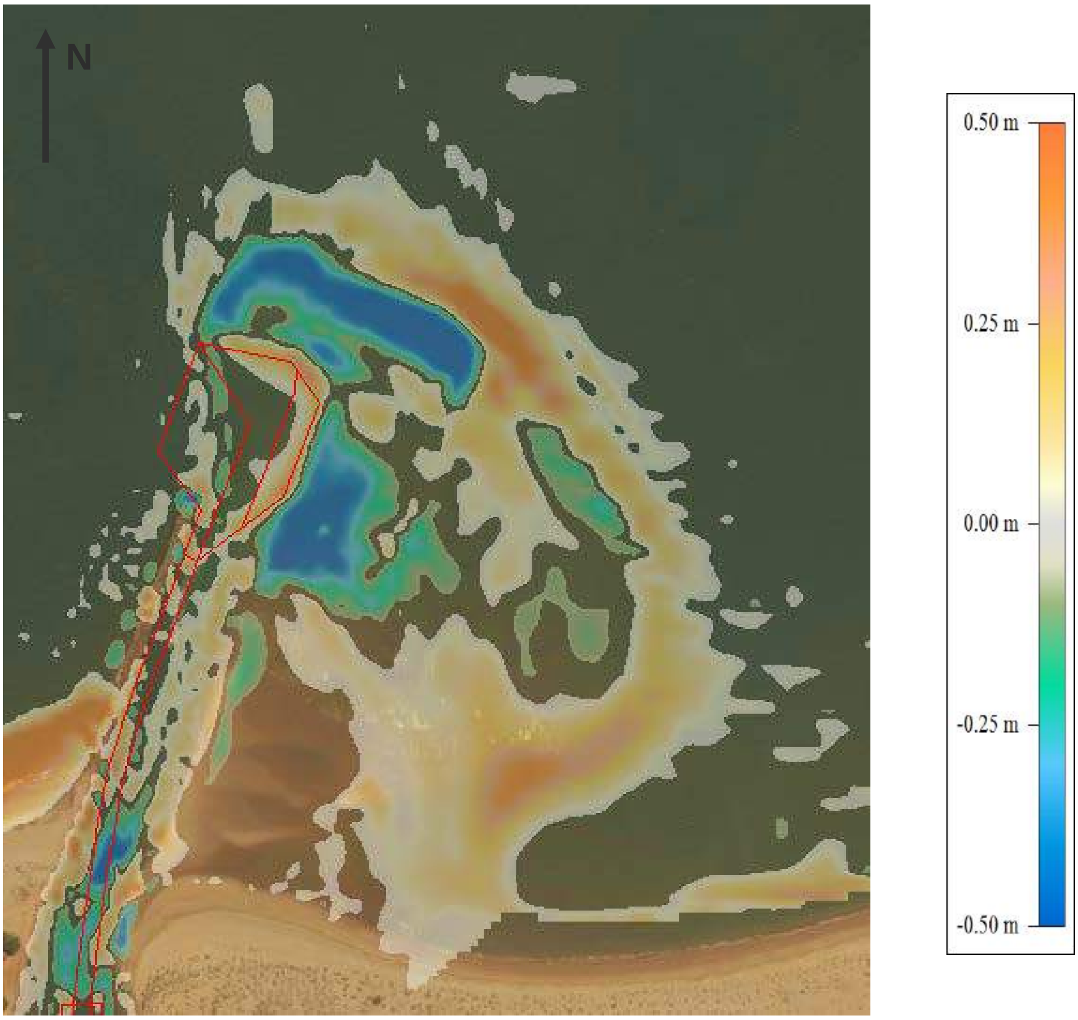

Figure A.13: Modelled annual erosion and sedimentation for the existing case. Outer channel (upper) and inside Beadon Creek (lower) areas with channel sections overlaid.

Table A.6: Annual Sedimentation Rates (m^3/yr) for Channel Sections – Historical vs Modelled

No.	Description	Design Depth	Estimate 1 [1]	Estimate 2 [2]	Modelled Estimate [3]
1	Bell Mouth	-1.6mCD	*510*	*250*	490
2	Bell Mouth Silt Trap	-1.6mCD	*2240*	*1570* [4]	1580
3	Outer Entrance Channel	-1.6mCD	*60*	*10*	140
4	Mid Entrance Channel A	-1.6mCD	*1190*	*270* [5]	350
5	Mid Entrance Channel B	-1.6mCD	*30*	*10*	50
6	Inner Entrance Channel A	-1.6mCD	*40*	*10*	10
7	Inner Entrance Channel B	-1.6mCD – 1.9mCD	*20*	*0*	40
8	Basin	-2.2mCD to -2.6mCD	*870* [6]	*125*	120
9	Cyclone Moorings	Varies [7]	*620*	-	415
10	Basin Silt Trap	-1.5mCD	*130*	*25*	145
	TOTAL		*5700*	*2270*	3340

Notes

1. Estimate 1: 2003 to 2012 Average Annual Sedimentation calculated from rates reported in Oceanica 2014
2. Estimate 2: 2012/13 to 2016 Average Annual Sedimentation calculated from changes to post dredging seabed depth (Oceanica 2014) and analysis of 2016 multibeam data (DoT 2016)
3. Modelled Annual Sedimentation Existing Case (Baird sediment transport model). Includes Sand fractions and Fine Sediment modelling outcomes, including littoral drift (8000m3/yr) and Aeolian transport (1200m3 / yr)
4. Bellmouth area is not completely described by the 2016 LiDAR data. Approximately 30% of the eastern side is not captured in the LiDAR
5. Dredging occurred for the nearshore berth adjacent the Mid Channel Section during this time period and may have impacted dredge volumes and / or creek dynamic in this section
6. Basin area was dredged in 1999 campaign, but not in 2003. Assessment based on 13 years
7. The design / target depth was not determined for the Cyclone Moorings in Oceanica 2014 so calculations from the LiDAR data were not completed

For the comparisons shown in Table A.6 and presented in Figure A.13 the model is considered to provide a reasonable representation of the sedimentation with the following points noted:

- Each sedimentation estimate is based on a different time period and therefore a result of different hydrodynamic forcing conditions. Further, the modelled result is equivalent to a single representative year (from two seasonal month simulations) and will therefore not account for longer term seasonal and inter-annual variability.
- The eastern shoal is an active area with constant reworking under wave and tidal action causing localised erosion and deposition. Eroded sediment at the western side of the shoal is deposited at the channel margins of the existing navigation channel and mobilised to the Bell Mouth area and Silt Trap.
- For the Outer Channel Entrance area (Section 3) the model shows higher sedimentation in this region (140m^3) than has been historically noted. The model has made assumptions on sediment size in this region which directly influence the erodibility of the seabed, and corresponding deposition in the Outer Channel Entrance area. The sedimentation in the Outer Channel entrance is close to the Bell Mouth area and overtime would likely mobilise in large spring tide ebb currents through the channel and be directed into the Bell Mouth;
- For the Mid Entrance Channel A (Section 4) the modelled rate of annual sedimentation of 350m^3 is within the range of sedimentation values observed in this section of Beadon Creek historically;
- For the central Beadon Creek sections (Sections 5, 6 and 7) there is very minor sedimentation noted in the historical data, and this is also observed in the modelled results in these sections (50m^3, 10m^3 and 40m^3 respectively);
- In the Basin area (Section 8) the modelled annual sedimentation rate of 120m^3 compares to the lower end of the historical range of 125m^3 to 870m^3;
- In the Cyclone Moorings (Section 9) the modelled annual sedimentation rate of 415m^3 is lower than the historical rate of 620m^3, however the modelled outcome is considered a reasonable description of the magnitude of sedimentation in this region noting the influence of seasonal and inter-annual variability on the comparisons; and
- Modelled sedimentation in the Basin Silt Trap (Section 10) is marginally higher than historical rates, however the modelled outcome is considered a reasonable description of the processes occurring in this section of Beadon Creek. It is noted the upstream bathymetry of Beadon Creek tidal creeks was estimated in the model as site specific data was unavailable and this may influence erosion and sedimentation outcomes.

A.1.5 Seabed Morphology under Developed Conditions

For the developed case, the modelled outcomes for the dredged footprint area are examined in four sections:

1. Offshore navigation channel (section extends to offshore limit)
2. Approach Bend Around Training Wall
3. Inner Entrance Channel
4. Turning Circle and Berth Areas

The sedimentation model results for the developed case are examined in the dredge footprint areas described in Figure A.14 with the modelled results shown spatially in Table A.7.

Figure A.14: Channel sections analysis regions for developed case

Table A.7: Annual Sedimentation rates (m^3/yr) for Developed case dredged footprint areas

No.	Description	Design Depth	Modelled Annual Sedimentation Developed Case
1	Offshore Navigation Channel	-6mCD	4,780
2	Approach Bend Around Training Wall	-6mCD	13,100
3	Inner Entrance Channel	-6mCD	1,740
4	Turning Circle and Berth Areas	-6mCD to -8mCD	80
	Total		19,700

Under the developed case the modelled sedimentation total in the dredged footprint is estimated as 19,700m^3 annually. The following points are noted of the outcomes on Table A.7:

- The sediment that is eroded and deposited on the dredged batters is expected to move into the deeper dredged areas over time. This material has been included in the total dredge volumes presented on Table A.7;
- In general the sedimentation rates increase in this lower section of Beadon Creek when compared to the existing case, with increased current speeds in the ebb tide leading to higher bed shear stresses, which drive erosion and associated deposition increases. This erosion/sedimentation process is likely to reduce over time as the bathymetry through the transition area (shown in **Error! Reference source not found.**) adjusts to the new hydrodynamic regime. As this process occurs the sedimentation rate is expected to move within the historical range.

Table A.8: Sedimentation rates (m^3/yr) for developed case in lower Beadon Creek

No.	Description	Design Depth	Historical Range of Annual Sedimentation	Modelled Annual Sedimentation Existing Case	Modelled Annual Sedimentation Developed Case
6	Inner Entrance Channel A	-1.6mCD	10 - 40	10	30
7	Inner Entrance Channel B	-1.6mCD – 1.9mCD	0 -20	40	110
8	Basin	-2.2mCD to -2.6mCD	125 - 870	120	410
9	Cyclone Moorings	Varies [4]	620	415	400
10	Basin Silt Trap	-1.5mCD	25 - 130	145	250
	TOTAL		1710	730	1200

For the sedimentation rates presented in Table A.8 it is noted:

- For the Inner Entrance Channel A (section 6) the sedimentation is consistent in the developed case
- Sedimentation in the Basin area is modelled at 410m^3 which is higher than the existing case, but comparable with the range of observed annual sedimentation rates reported for this section (125m^3 to 870m^3). The increase in sedimentation in the Basin is partly the result of increases in current speed in this section and the reshaping of the natural bed level under increased shear stresses, with some sediment likely originating from the eroded material at the transition of the dredged footprint area previously discussed;
- Modelled sedimentation in the Basin Silt Trap (Section 10) increases from 145m^3 to 250m^3 annually, with increases in current speeds in the developed case and associated increased bed shear stresses being the likely driver of this increase.

A.1.6 Sedimentation from Extreme Cyclonic Events

Onslow is located in one of the most cyclone prone areas of the Australian coast. The sediment transport model was applied to assess the potential sedimentation impacts for the OMSB developed footprint from a severe tropical cyclone event. Two recent cyclones that have impacted Onslow were investigated; TC Olwyn (2015) and TC Vance (1999), as summarised on Table A.9. For TC Olwyn, a range of measured data was available as shown on Table A.9, whilst for TC Vance there was limited data available through the event.

Table A.9: Modelled Tropical Cyclone Summary

Cyclone Event	Dates	Measured Data	Brief Summary
TC Olwyn	9–14 March 2015	• Beadon Creek Tide Gauge • Onslow Airport BOM data • AWAC – Wave measurements available but not continuous through the peak of event	TC Olwyn tracked approximately 100km west of Onslow along the western side of northwest Cape and continued south. The cyclone reached Category 3 scale. There is good availability of measured data for this event at Onslow (winds, water levels, currents, waves) and validation of the model was undertaken for this case.
TC Vance	18-24 March 1999	• Beadon Creek Tide Gauge – stopped working in lead up to the event peak • Onslow Airport BOM data – Instrument Failure • AWAC – not installed	TC Vance was one of the most destructive cyclones to make landfall on Western Australia's coastline (Figure A.15). The cyclone made landfall near Exmouth as a Category 5 system, with the eye of the cyclone passing through the Exmouth Gulf approximately 80 kilometres to the west of Onslow during Monday morning 22nd March 1999 (WST). The maximum recorded wind gust at Onslow was 174 kilometres per hour, and storm surge west of Onslow was estimated at over 5m (BOM 2017b).

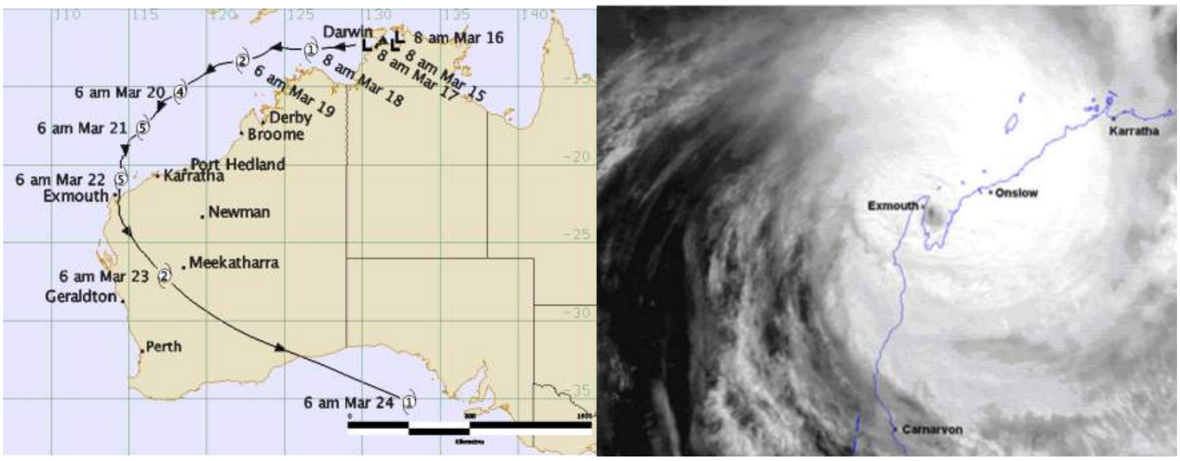

Figure A.15: TC Vance Track (left) and satellite image (right) (Source BOM 2017b)

For the extreme cyclonic simulations, cyclonic wind and pressure fields associated with the two respective cyclones were modelled with Baird's in-house *Cycwind* program which combines a Holland et al. (2010) vortex model blended into Climate Forecast System Reanalysis (CFSR) regional scale atmospheric fields.

The hydrodynamic model was run with the astronomical tide updating every 10 minutes and the wind and pressure fields updated every 30 minutes. The hydrodynamic model is coupled to the wave model which updates wave conditions hourly. Storm surge in the model is generated through wind and wave setup as well as the response to atmospheric pressure (inverse barometer effect). Erosion and sedimentation associated with extreme water levels, waves and currents in the model are simulated for the sand fractions through each modelled event.

Validation of the model against the measured data for the TC Olwyn event is presented in Figure A.16 with a brief summary as follows:

- the model shows good agreement to the measured conditions for water level with a peak water level of approximately 1.5m MSL (3.1m CD) which corresponds to highest astronomical tide level (HAT);
- the wind speed and direction in the model show good agreement to the measured data, and through the peak of the event wind speeds are in the range of 20 to 25ms^{-1} with wind direction from the north-east;
- the peak modelled wave height at the AWAC location was approximately 2.0m. The wave heights are not measured through the peak of the event but agree well with modelled Hs in the lead up and post cyclone peak;
- at the AWAC location the peak wave direction is from the north through the peak of the event; and
- modelled peak wave period (Tp) is in the range of 8 to 9 seconds.

The modelled metocean conditions for TC Vance are presented in Figure A.17, with a summary as follows:

- peak water level in the model is approximately 2m MSL (3.6m CD) which is 0.5m above HAT;
- peak modelled wind speed is 33ms^{-1} with winds from due east leading up to the peak;
- wave period is modelled in the range of 3 to 5 seconds through the peak of the event; and
- wave direction is from the northeast leading into the peak, then turns through north at the peak of the event

Sedimentation inside the OMSB footprint and Channel sections presented previously have been estimated for the two cyclone cases as summarised in Table A.10.

Table A.10: Modelled Sedimentation Rates (m^3) for OMSB Developed Case Dredged Footprint Area and Lower Beadon Creek Section for Cyclone Cases

No.	Description	TC Olwyn	TC Vance
1	Offshore Navigation Channel	4600 m^3	1500 m^3
2	Approach Bend Around Training Wall	1400 m^3	1250 m^3
3	Inner Entrance Channel	620 m^3	590 m^3
4	Turning Circle and Berth Areas	120 m^3	1330 m^3
OMSB Dredged Footprint Area Total		**6740 m^3**	**4670 m^3**
5-10	Lower Beadon Creek. Total for All Areas	120 m^3	910 m^3

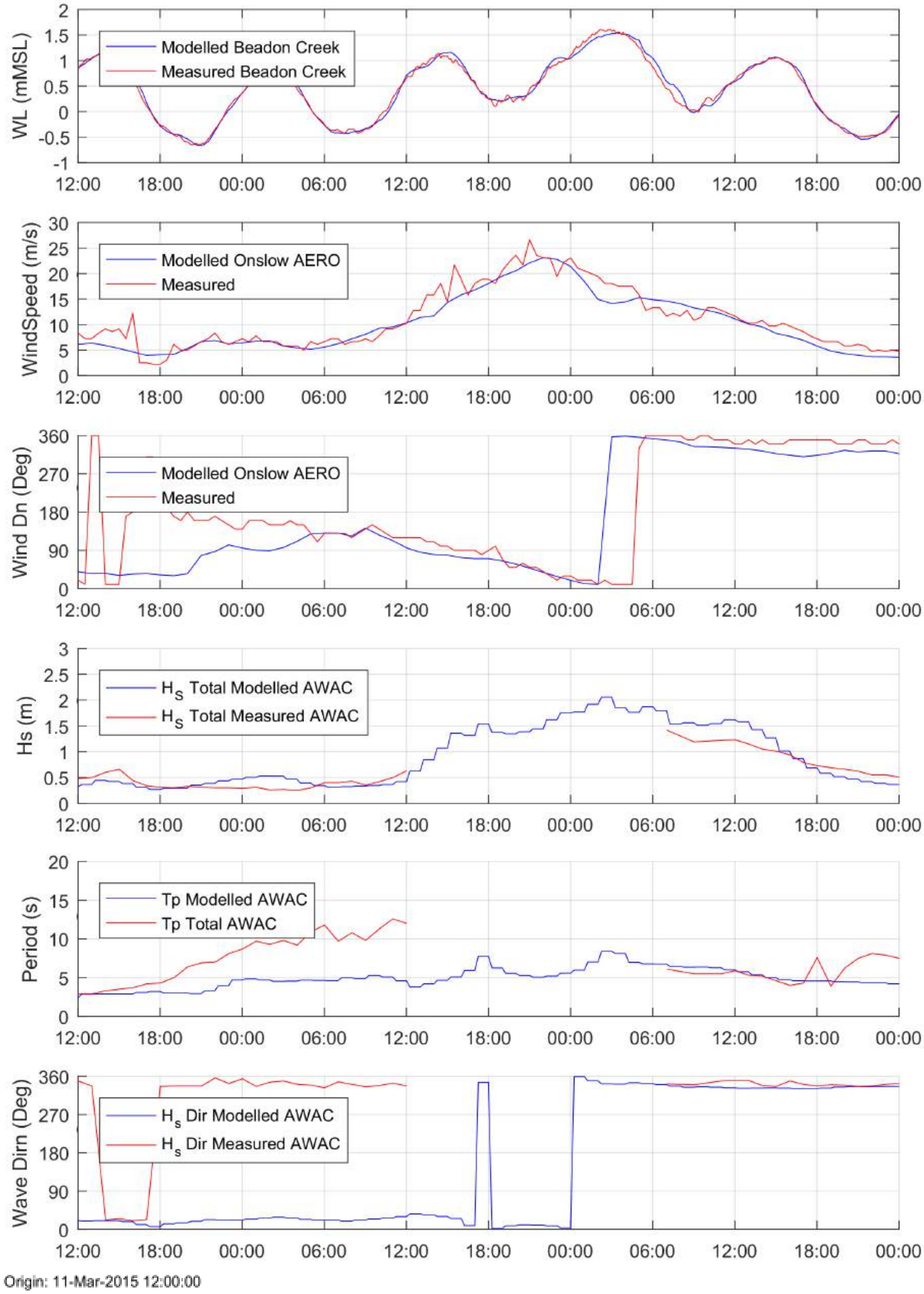

Figure A.16: TC Olwyn 2015 Modelled Metocean Conditions (Local Time)

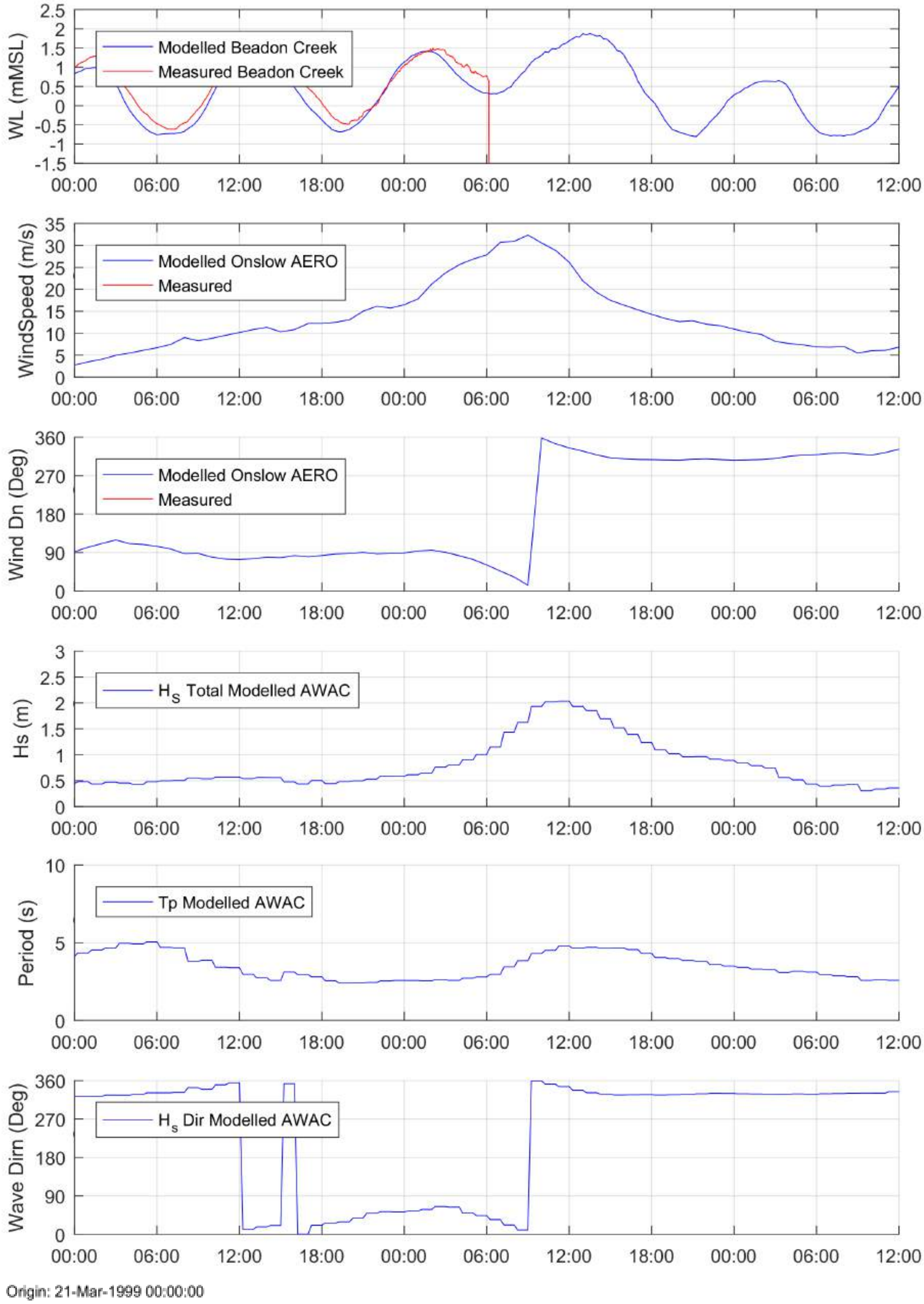

Figure A.17: TC Vance 1999 - Modelled Metocean Conditions (Local Time)

A summary of the sedimentation in the cyclone cases is as follows:

- the sedimentation volume reported in Table A.10 indicate modelled sedimentation for the OMSB footprint area of 6740m^3 under TC Olwyn and 4670m^3 for TC Vance;
- For TC Olwyn, the majority of the sedimentation occurs in the offshore navigation channel (4600m^3), with very minor sedimentation of the turning circle and berth areas (120m^3). Wave direction from a more northerly direction in the lead up and peak of the event, is likely the cause of higher sedimentation in the offshore navigation channel in TC Olwyn;
- For TC Vance the sedimentation volume is higher in the turning circle (1330m^3) when compared to the TC Olwyn case (120m^3), but there is much lower sedimentation in the offshore navigation channel (1500m^3) compared to TC Olwyn. The ebb tide immediately following the peak of the water level in TC Vance causes significant erosion and re-deposition of sediment in the turning circle and berth areas. The large velocities through the navigation channel entrance during this ebb tide cause the erosion seen on the eastern channel batter in Figure A.19;
- For lower Beadon Creek (channel sections 5 to 10) there is 120m^3 of sedimentation modelled in TC Olwyn and 910m^3 in TC Vance, largely concentrated in the Cyclone Moorings and Basin Silt Trap. The larger sedimentation volumes for TC Vance are a direct result of the ebb tide immediately following the peak of the water level, which causes extremely high current speeds and erosion of the creek bed.

The modelled results for the cyclone cases are presented in Figure A.18 and Figure A.19 for TC Olwyn and TC Vance respectively.

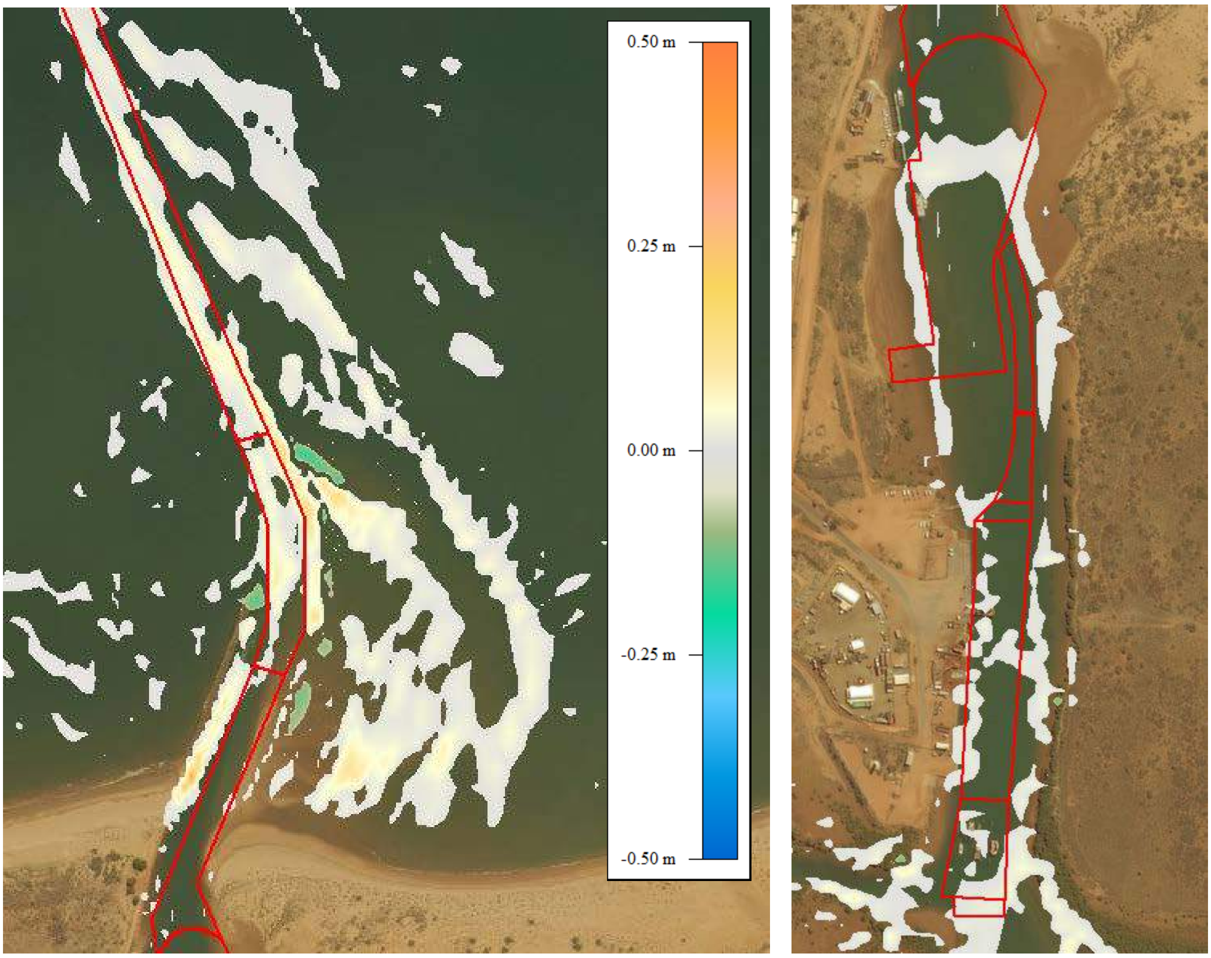

Figure A.18: TC Olwyn 2015, Sand fraction modelled erosion and sedimentation for the developed case. Outer channel (left) and inside Beadon Creek (right) areas with channel sections overlaid.

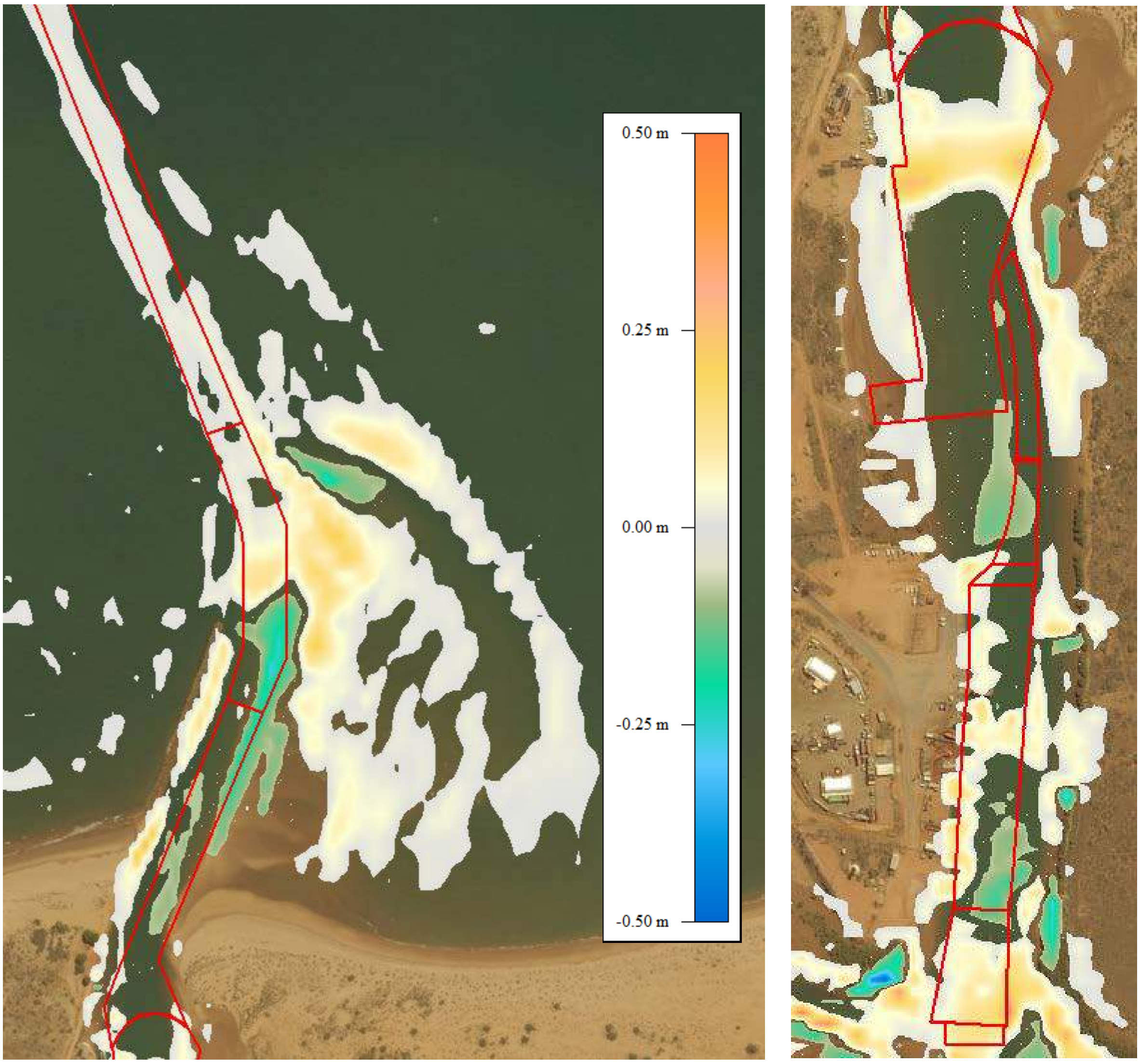

Figure A.19: TC Vance 1999, Sand fraction modelled erosion and sedimentation for the developed case. Outer channel (left) and inside Beadon Creek (right) areas with channel sections overlaid.

Appendix B

Ebb Tide Current Cross Sections – Spring Tide

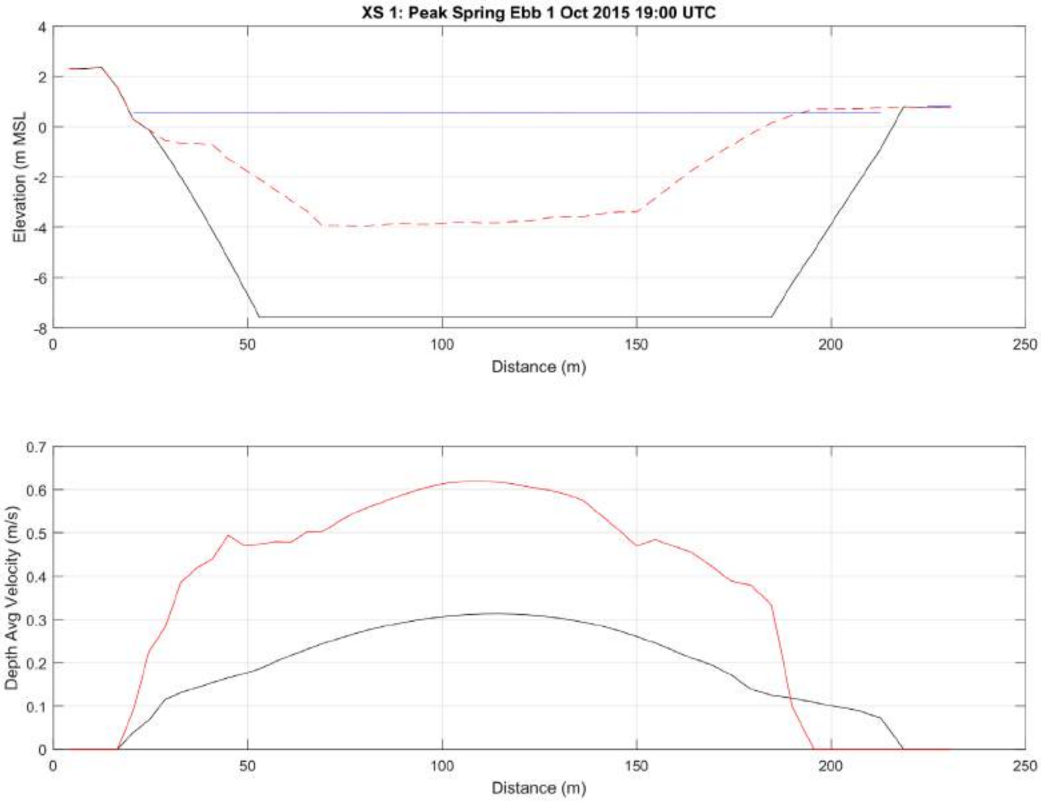

Figure B.1: Tidal Current Velocity for Existing and Developed Case at Peak Spring Ebb Tide (Cross Section 1)

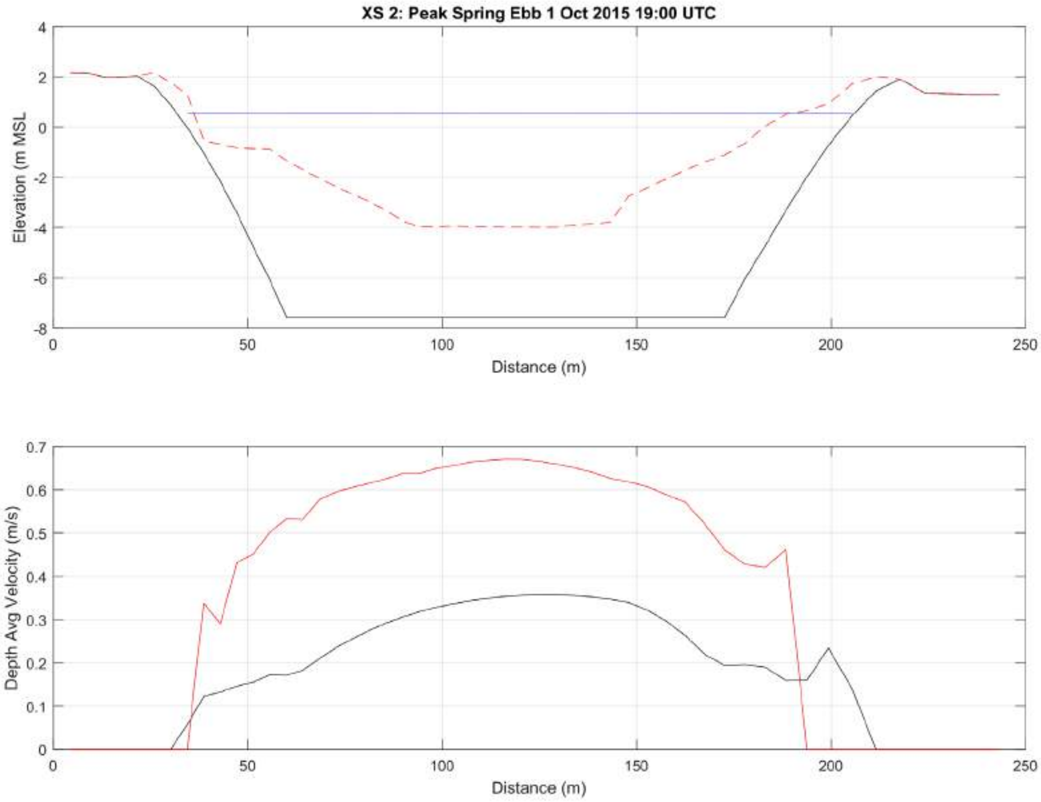

Figure B.2: Tidal Current Velocity for Existing and Developed Case at Peak Spring Ebb Tide (Cross Section 2)

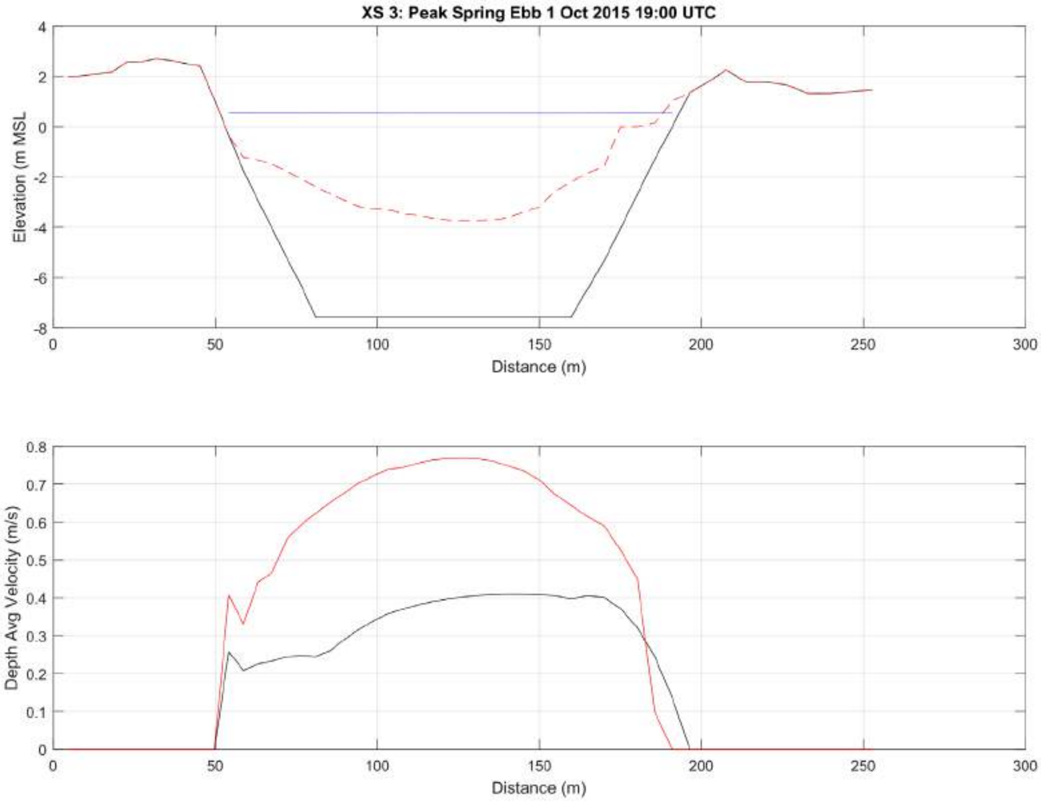

Figure B.3: Tidal Current Velocity for Existing and Developed Case at Peak Spring Ebb Tide (Cross Section 3)

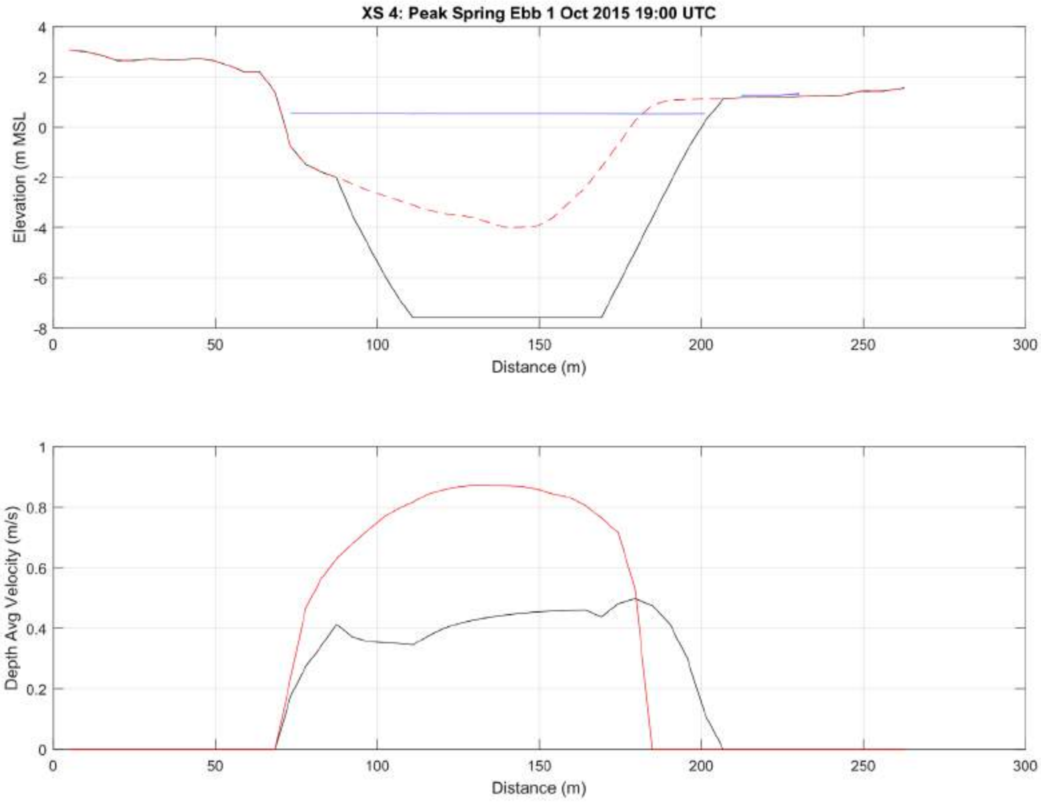

Figure B.4: Tidal Current Velocity for Existing and Developed Case at Peak Spring Ebb Tide (Cross Section 4)

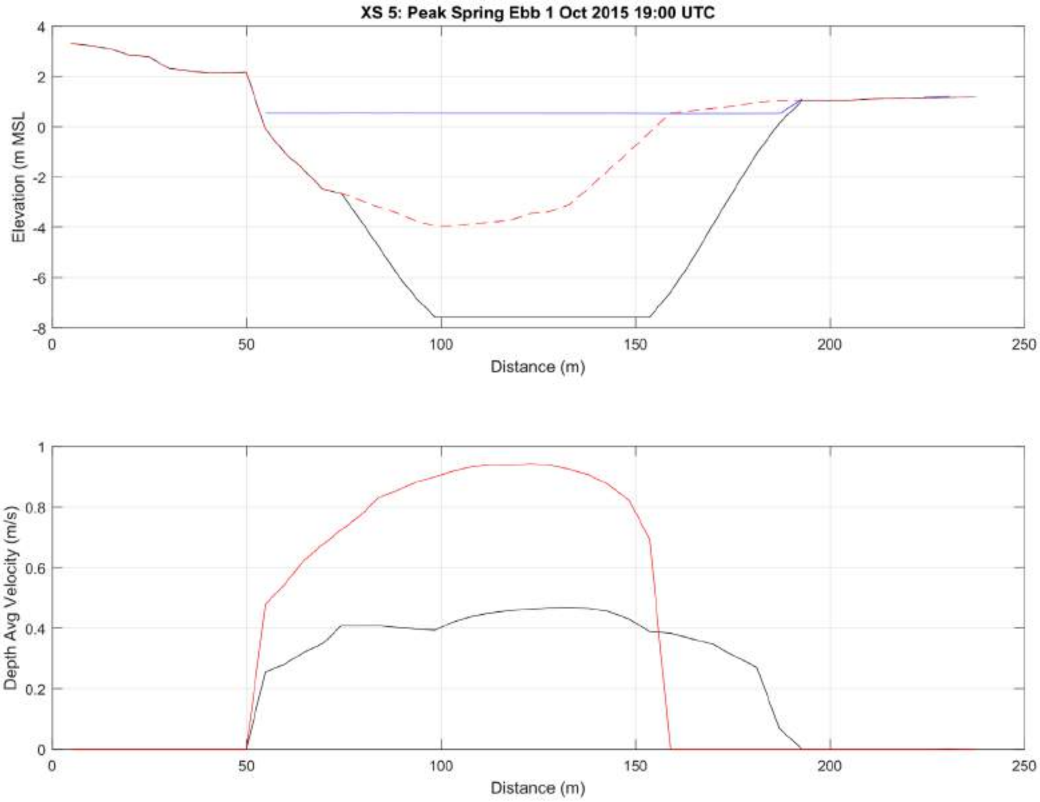

Figure B.5: Tidal Current Velocity for Existing and Developed Case at Peak Spring Ebb Tide (Cross Section 5)

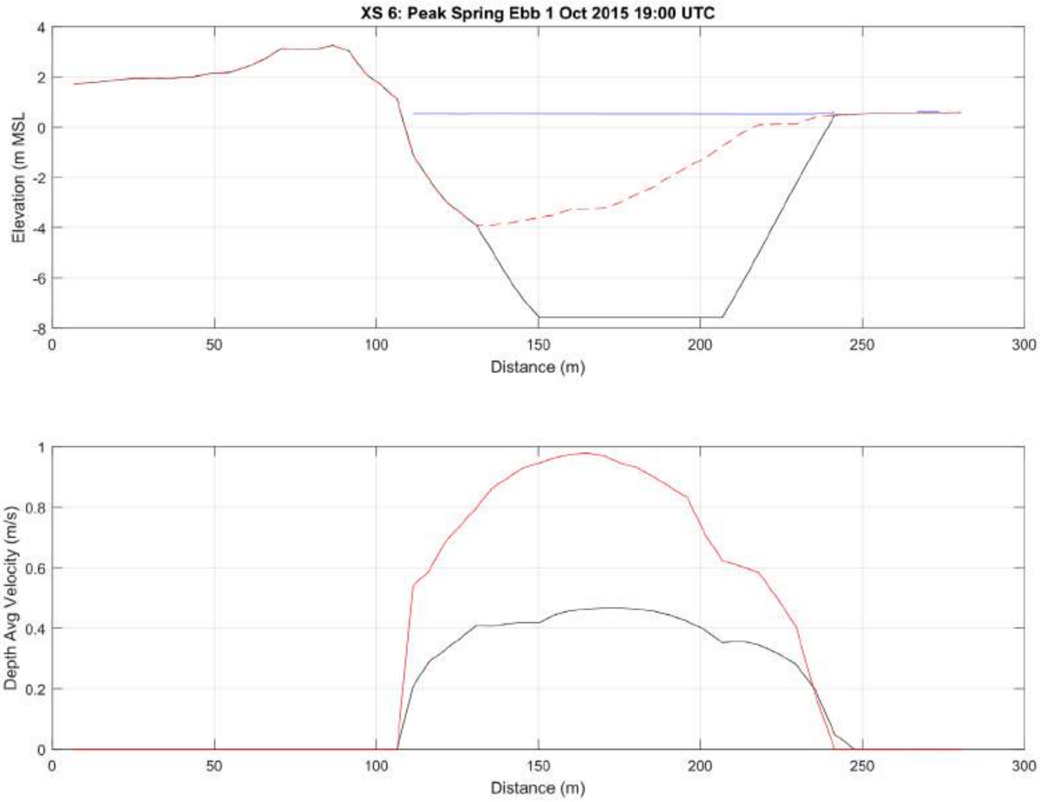

Figure B.6: Tidal Current Velocity for Existing and Developed Case at Peak Spring Ebb Tide (Cross Section 6)

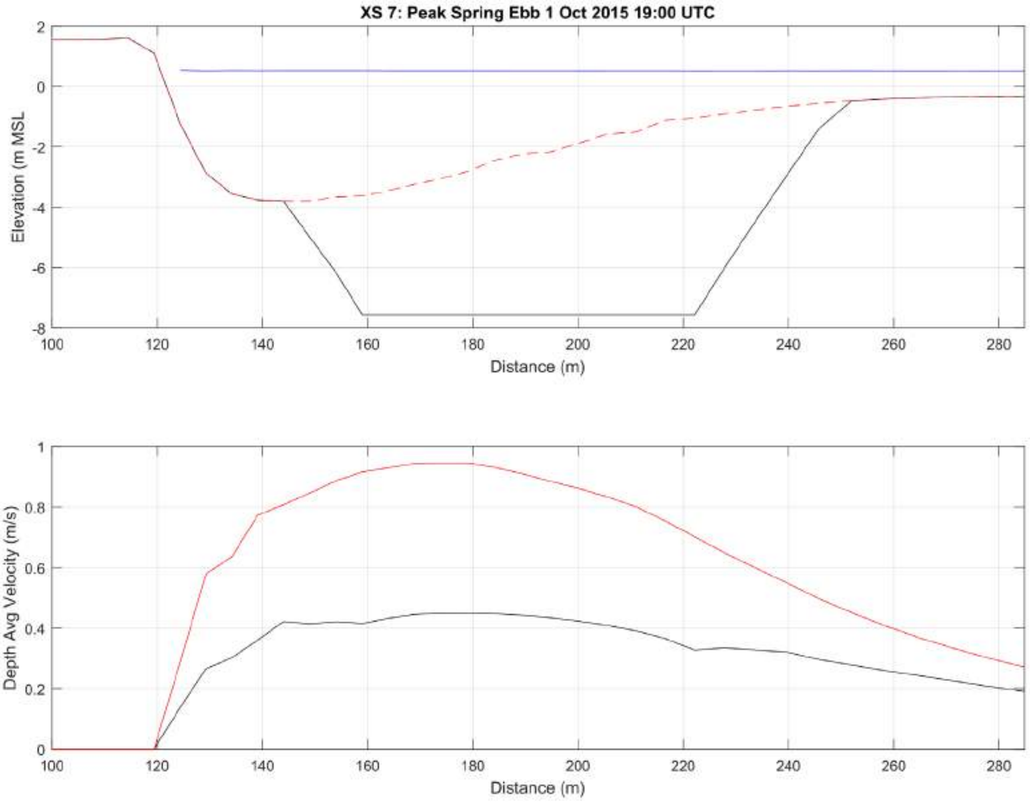

Figure B.7: Tidal Current Velocity for Existing and Developed Case at Peak Spring Ebb Tide (Cross Section 7)

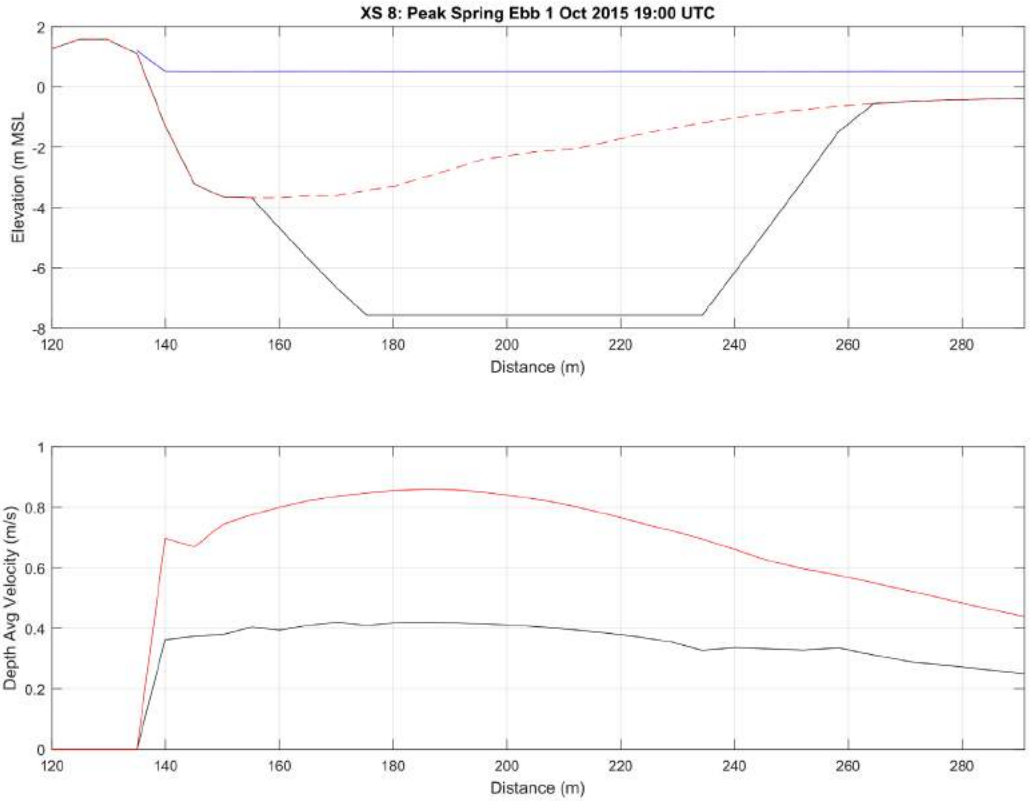

Figure B.8: Tidal Current Velocity for Existing and Developed Case at Peak Spring Ebb Tide (Cross Section 8)

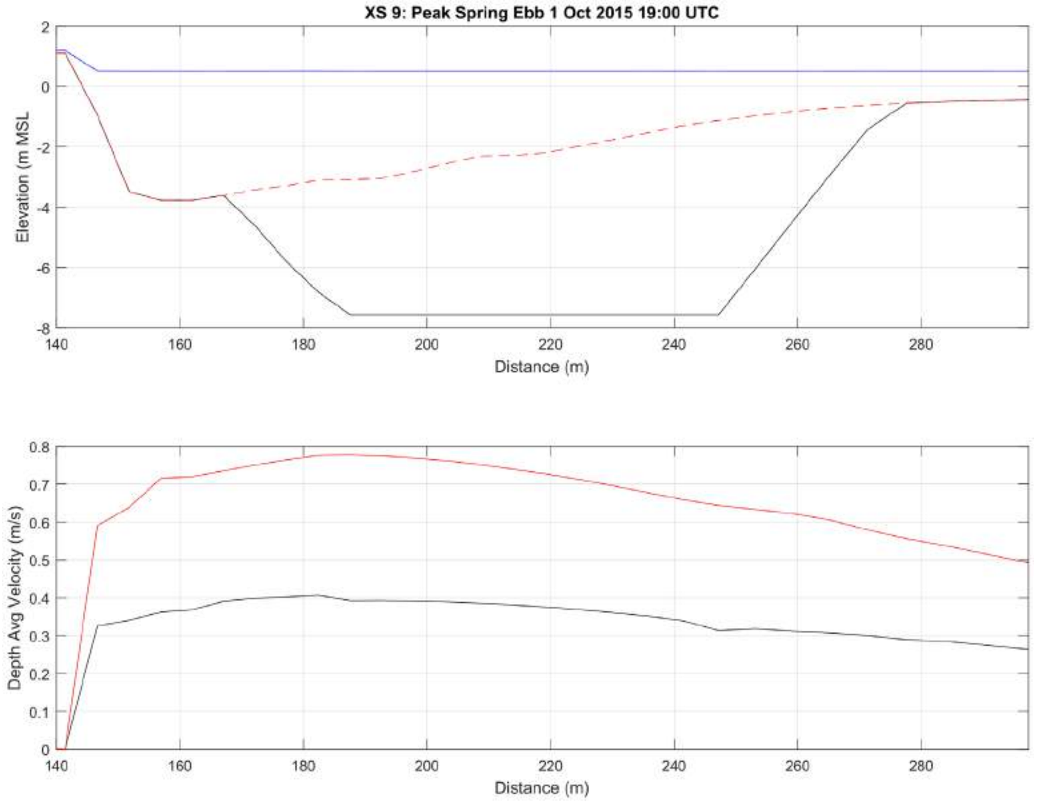

Figure B.9: Tidal Current Velocity for Existing and Developed Case at Peak Spring Ebb Tide (Cross Section 9)

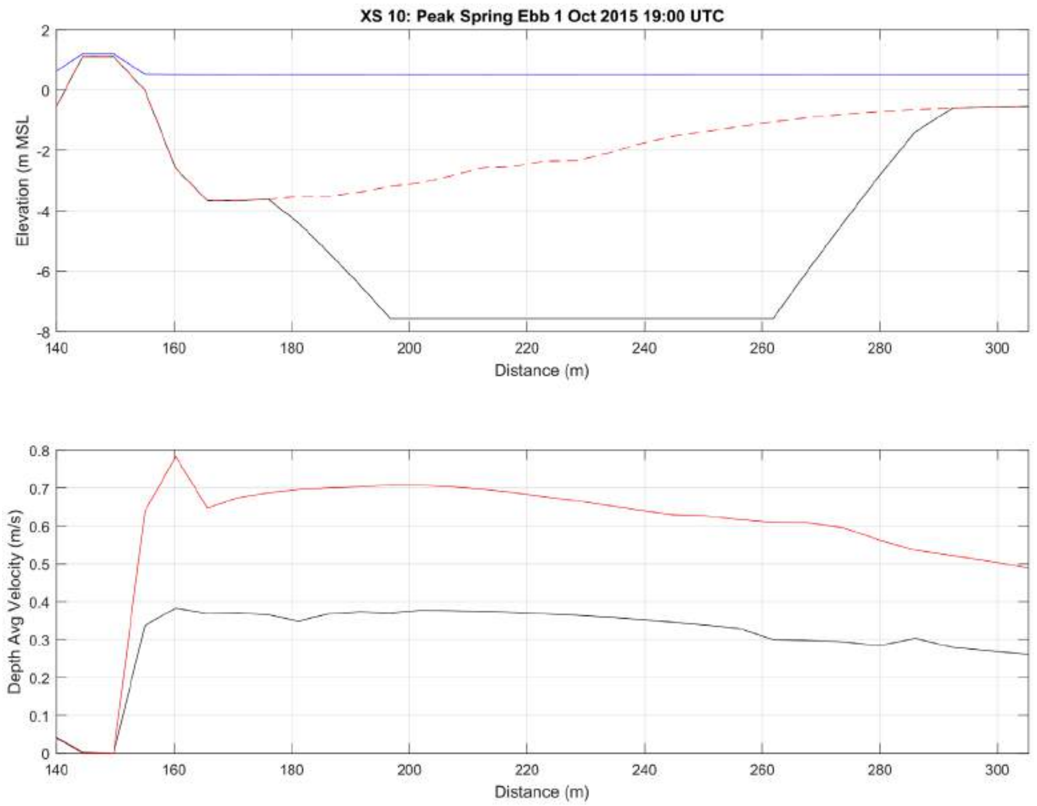

Figure B.10: Tidal Current Velocity for Existing and Developed Case at Peak Spring Ebb Tide (Cross Section 10)

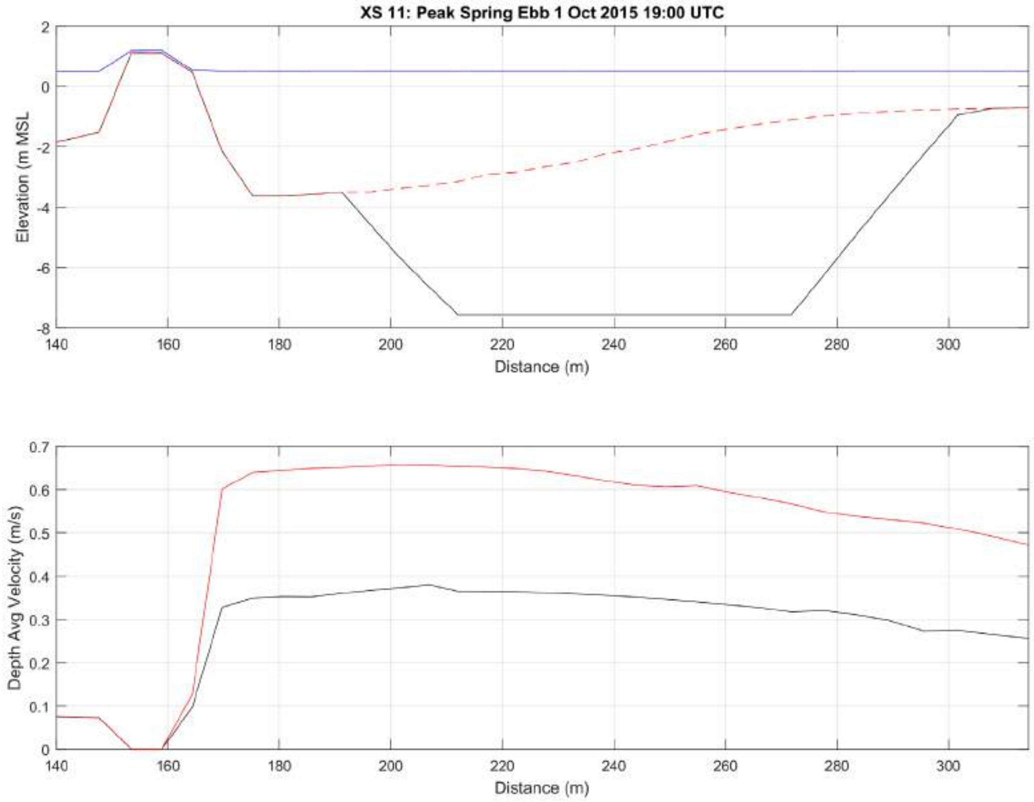

Figure B.11: Tidal Current Velocity for Existing and Developed Case at Peak Spring Ebb Tide (Cross Section 11)

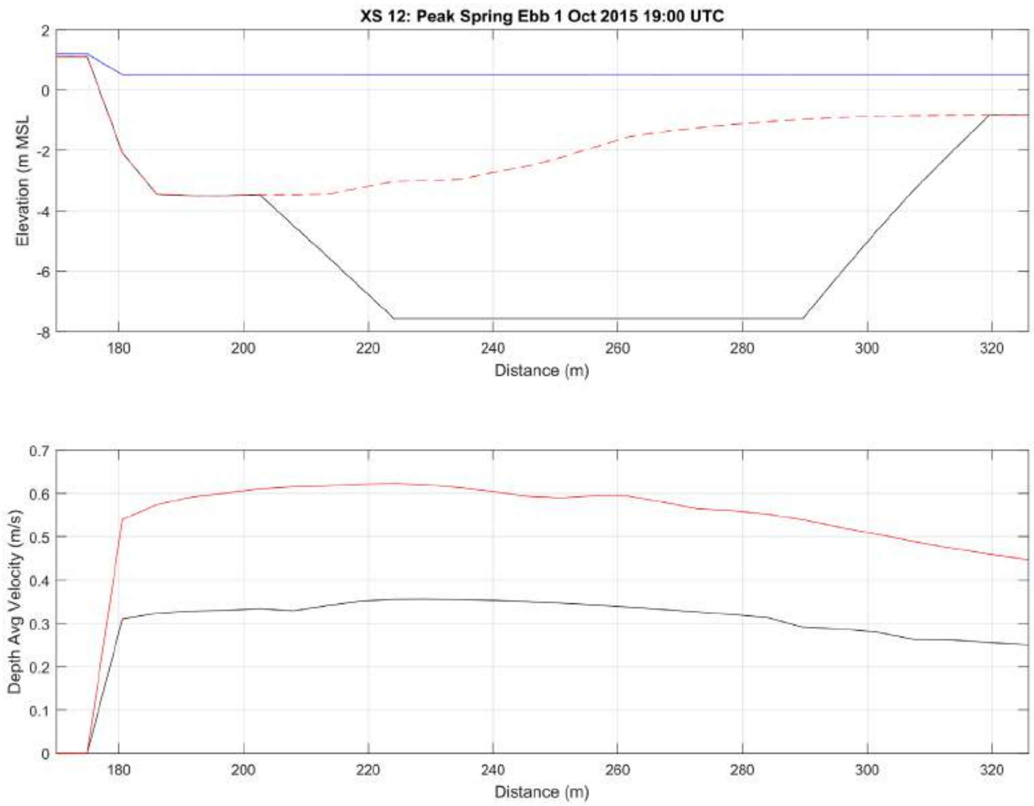

Figure B.12: Tidal Current Velocity for Existing and Developed Case at Peak Spring Ebb Tide (Cross Section 12)

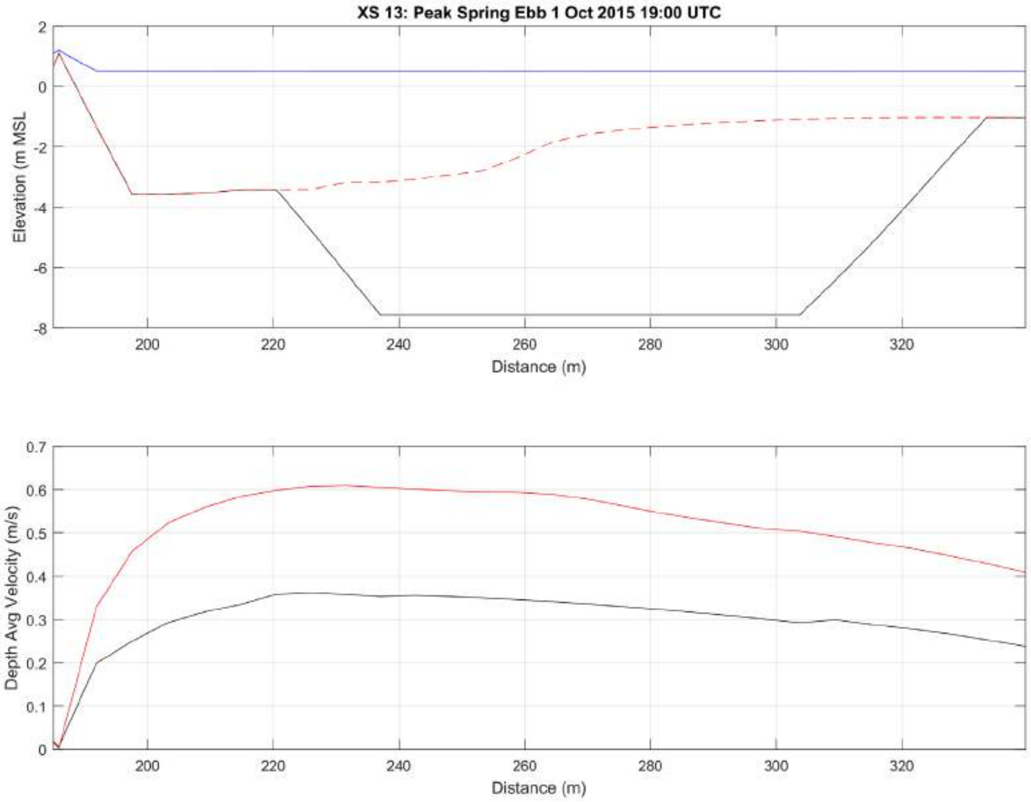

Figure B.13: Tidal Current Velocity for Existing and Developed Case at Peak Spring Ebb Tide (Cross Section 13)

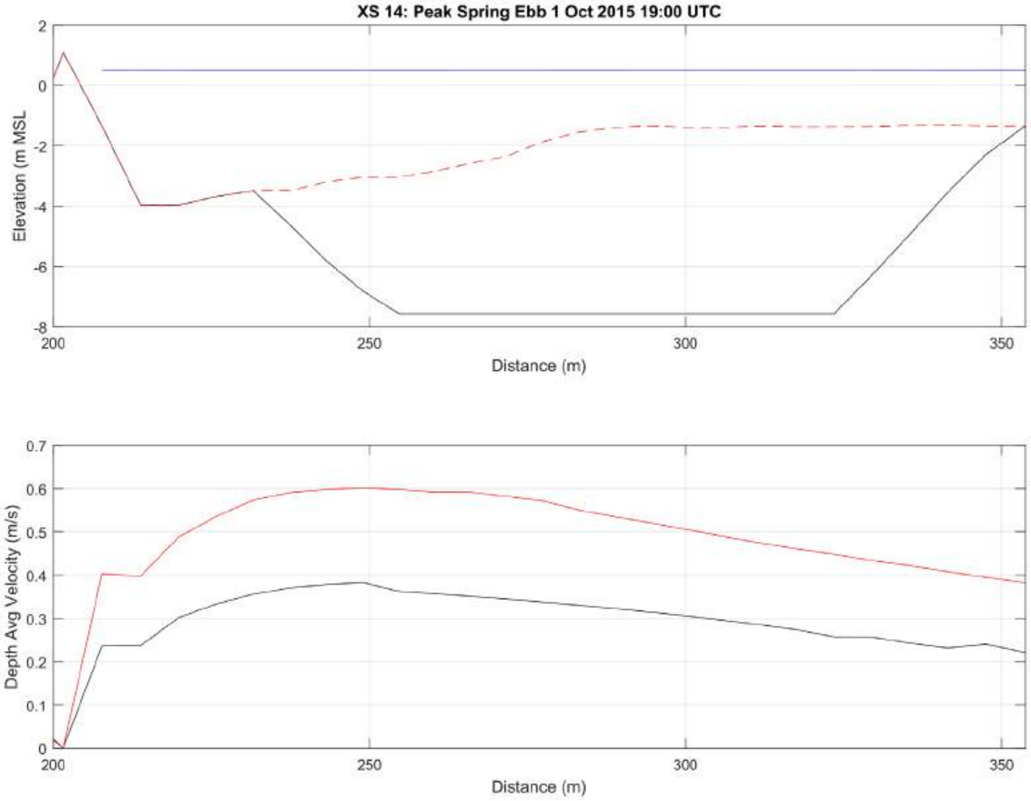

Figure B.14: Tidal Current Velocity for Existing and Developed Case at Peak Spring Ebb Tide (Cross Section 14)

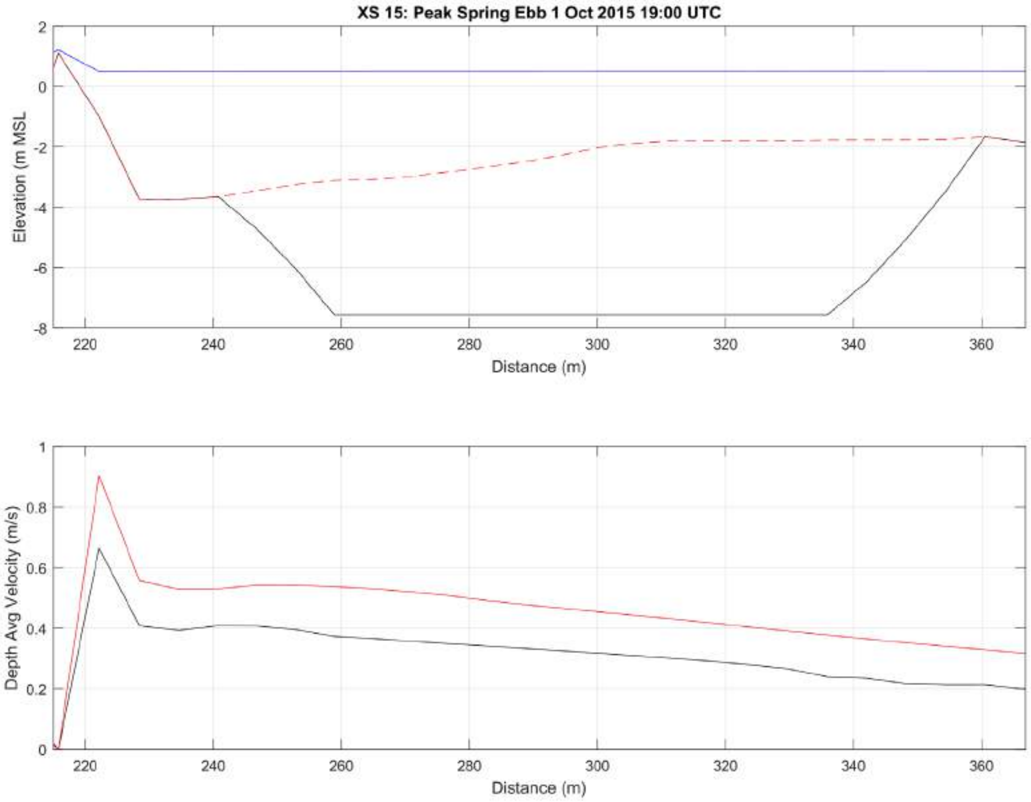

Figure B.15: Tidal Current Velocity for Existing and Developed Case at Peak Spring Ebb Tide (Cross Section 15)

Appendix C

Ebb Tide Current Cross Sections – TC Vance

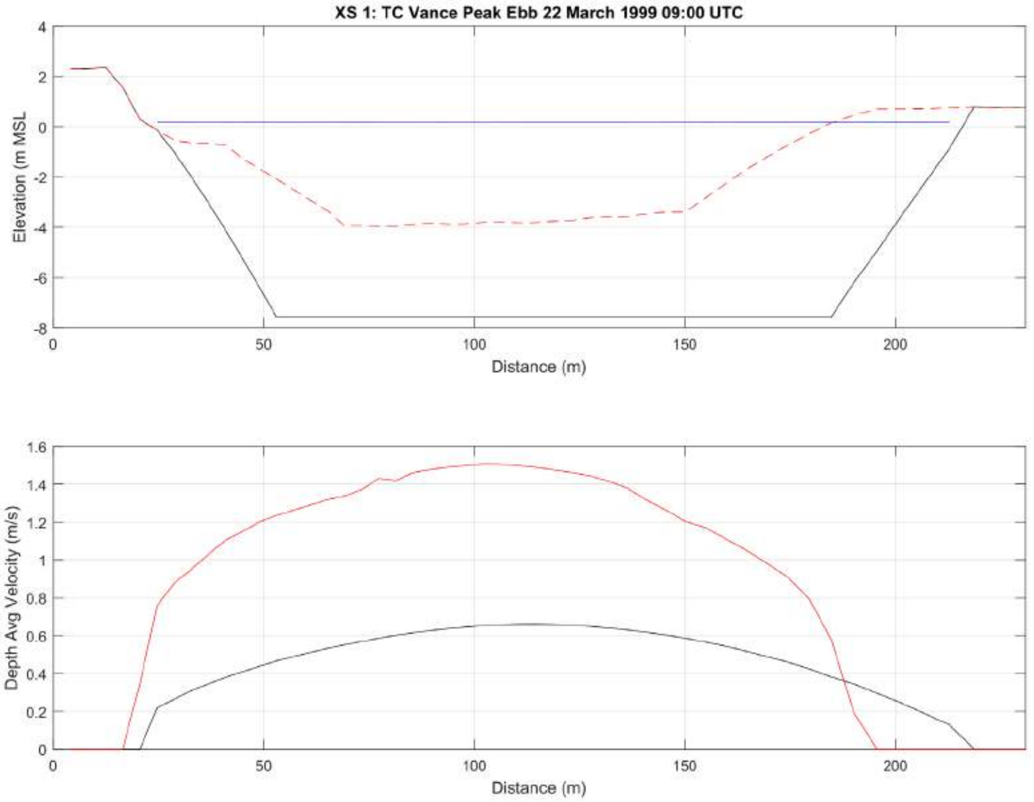

Figure C.1: Tidal Current Velocity for Existing and Developed Case at Peak Ebb Tide – TC Vance (Cross Section 1)

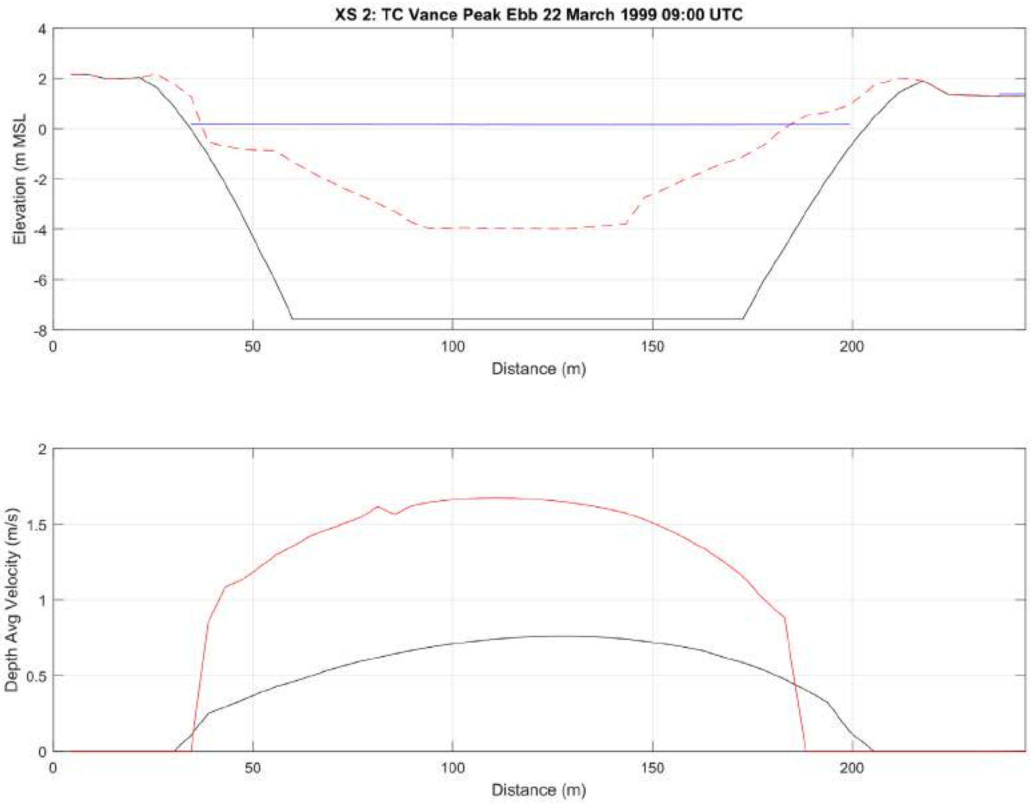

Figure C.2: Tidal Current Velocity for Existing and Developed Case at Peak Ebb Tide – TC Vance (Cross Section 2)

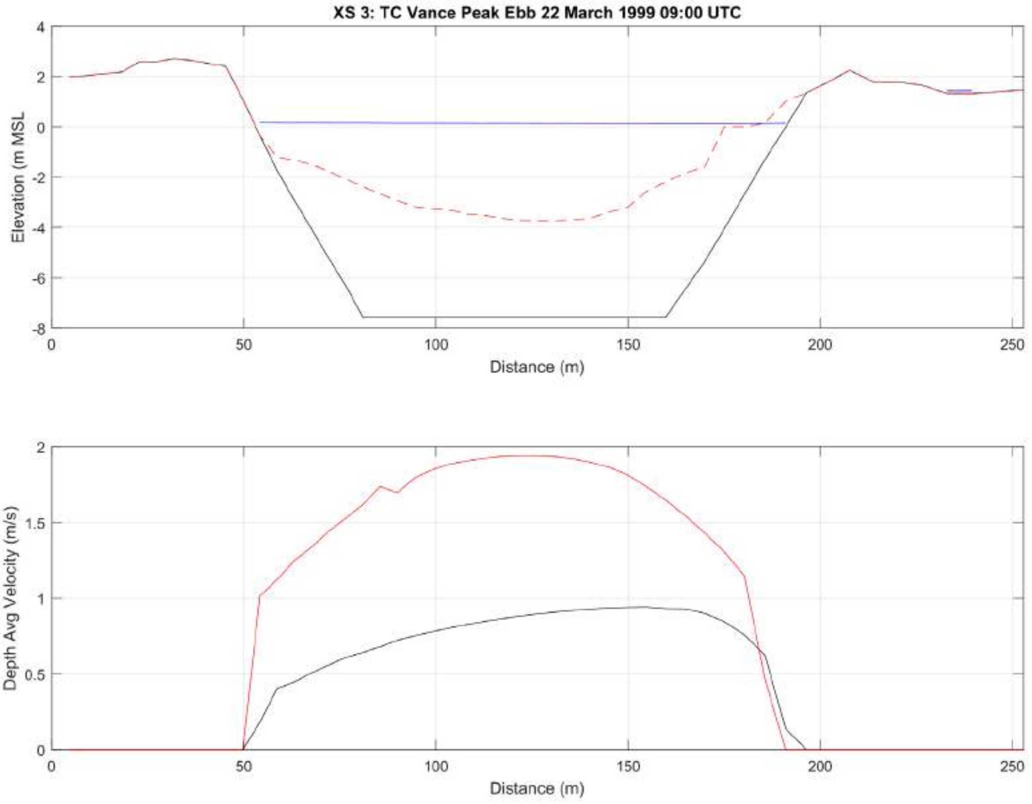

Figure C.3: Tidal Current Velocity for Existing and Developed Case at Peak Ebb Tide – TC Vance (Cross Section 3)

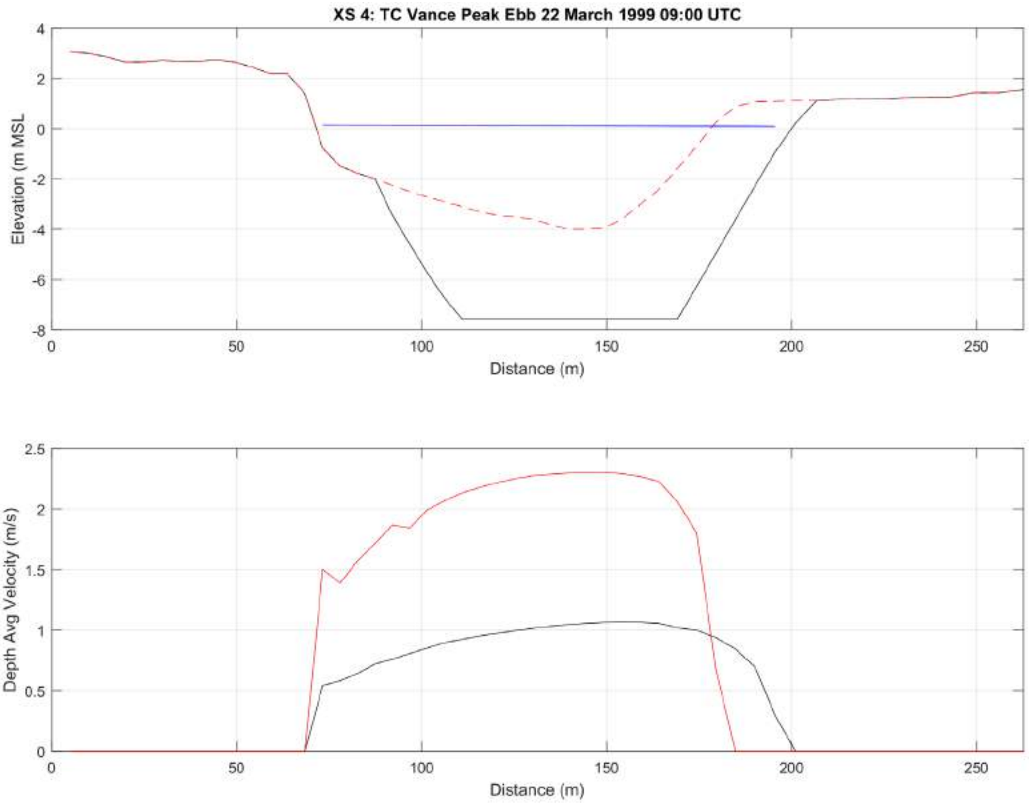

Figure C.4: Tidal Current Velocity for Existing and Developed Case at Peak Ebb Tide – TC Vance (Cross Section 4)

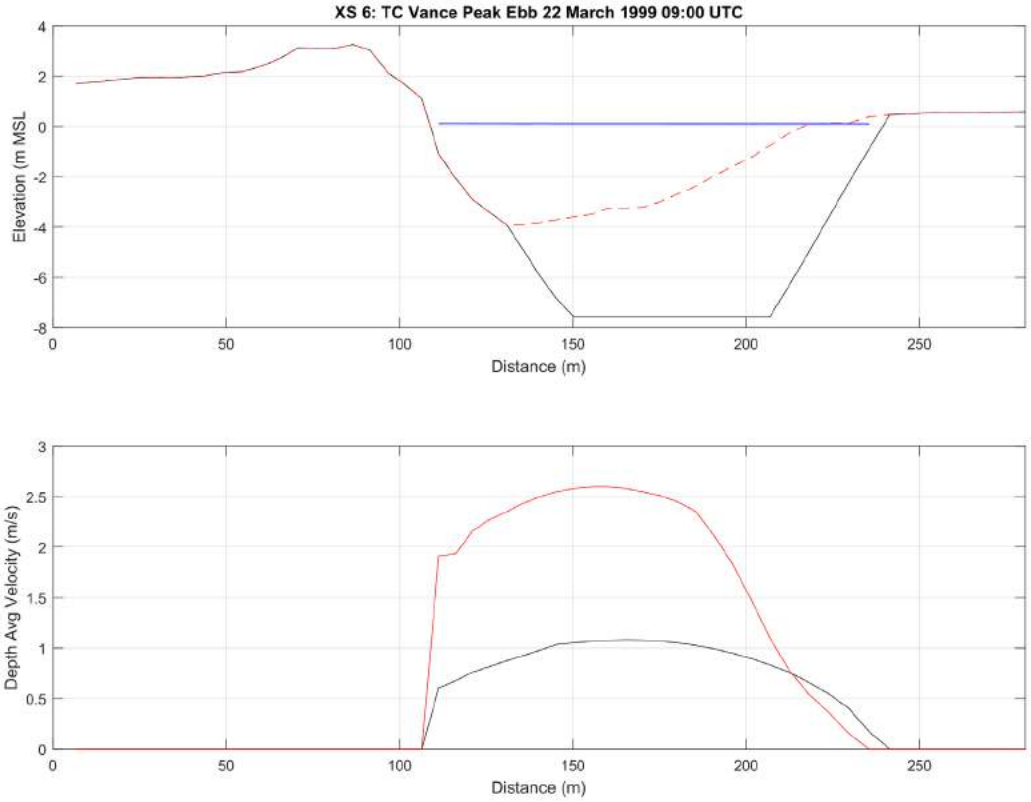

Figure C.6: Tidal Current Velocity for Existing and Developed Case at Peak Ebb Tide – TC Vance (Cross Section 6)

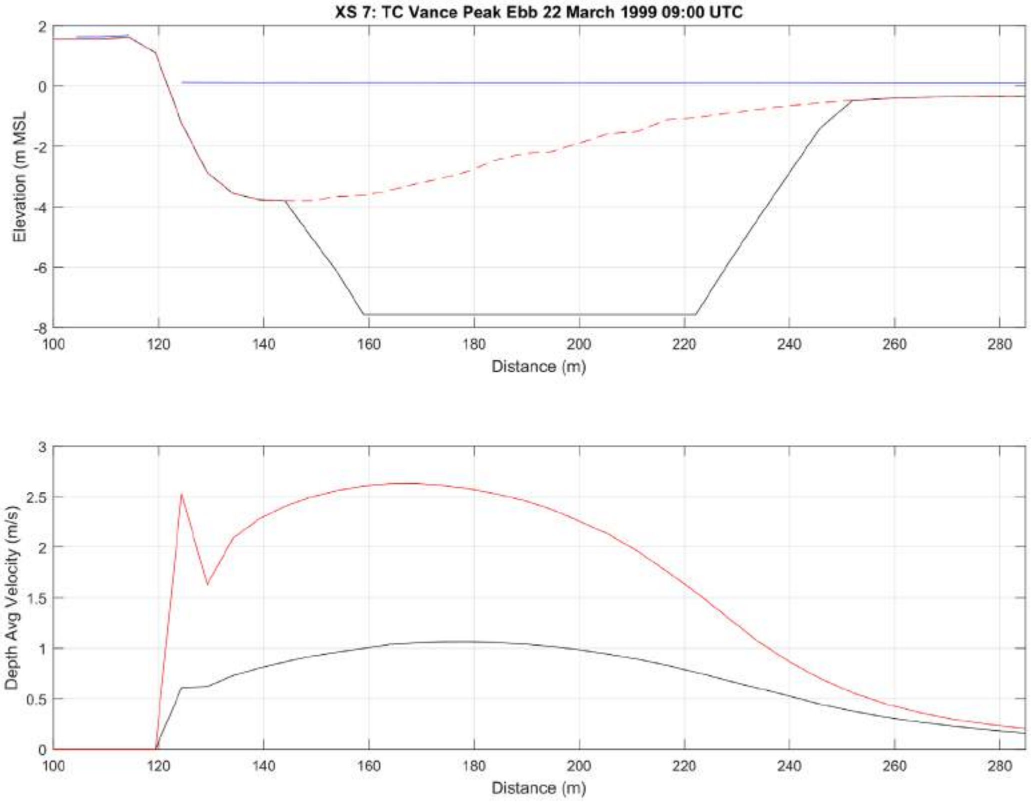

Figure C.7: Tidal Current Velocity for Existing and Developed Case at Peak Ebb Tide – TC Vance (Cross Section 7)

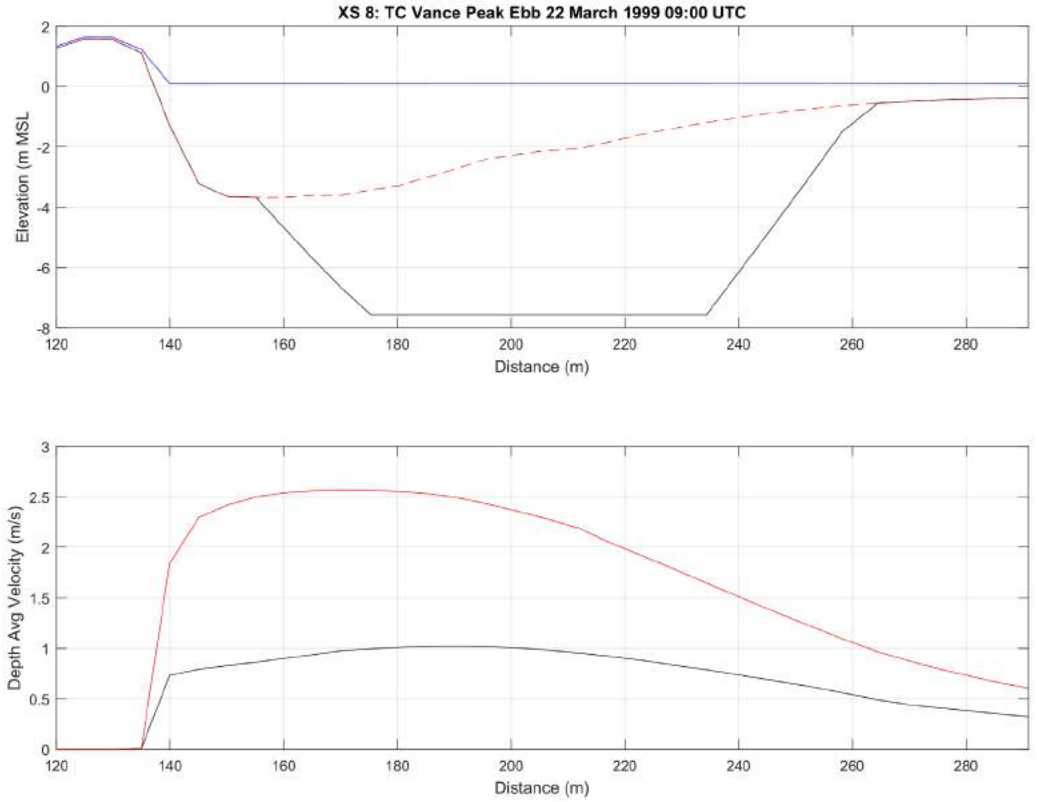

Figure C.8: Tidal Current Velocity for Existing and Developed Case at Peak Ebb Tide – TC Vance (Cross Section 8)

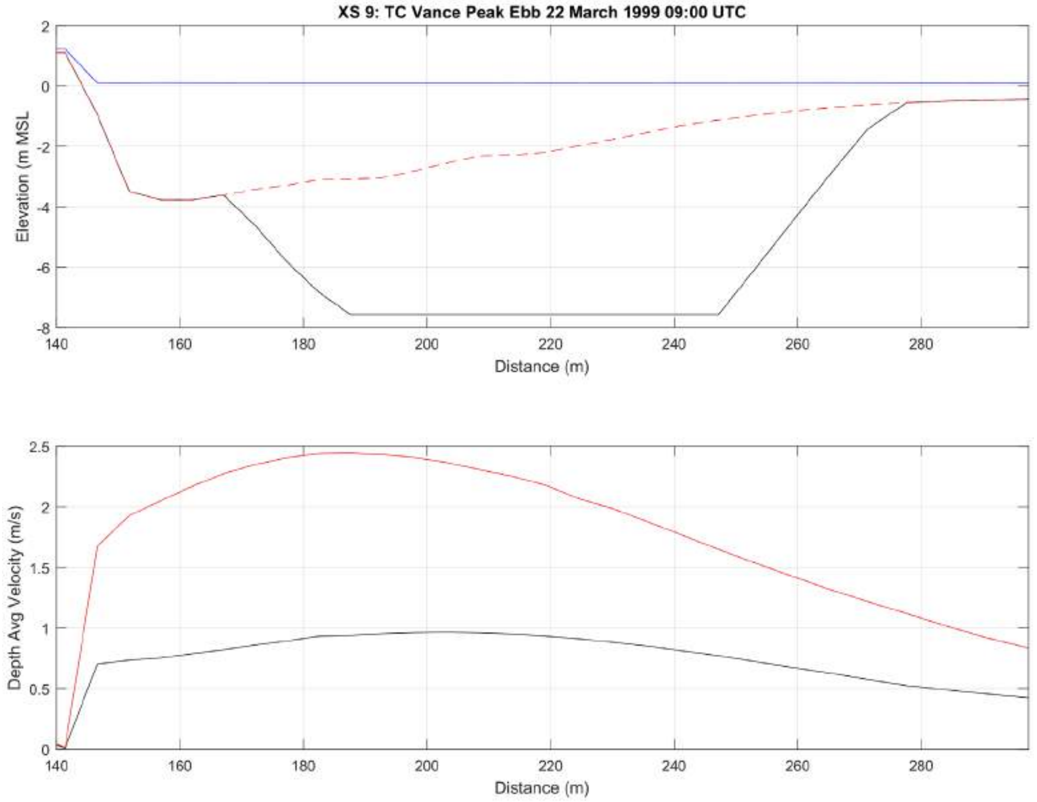

Figure C.9: Tidal Current Velocity for Existing and Developed Case at Peak Ebb Tide – TC Vance (Cross Section 9)

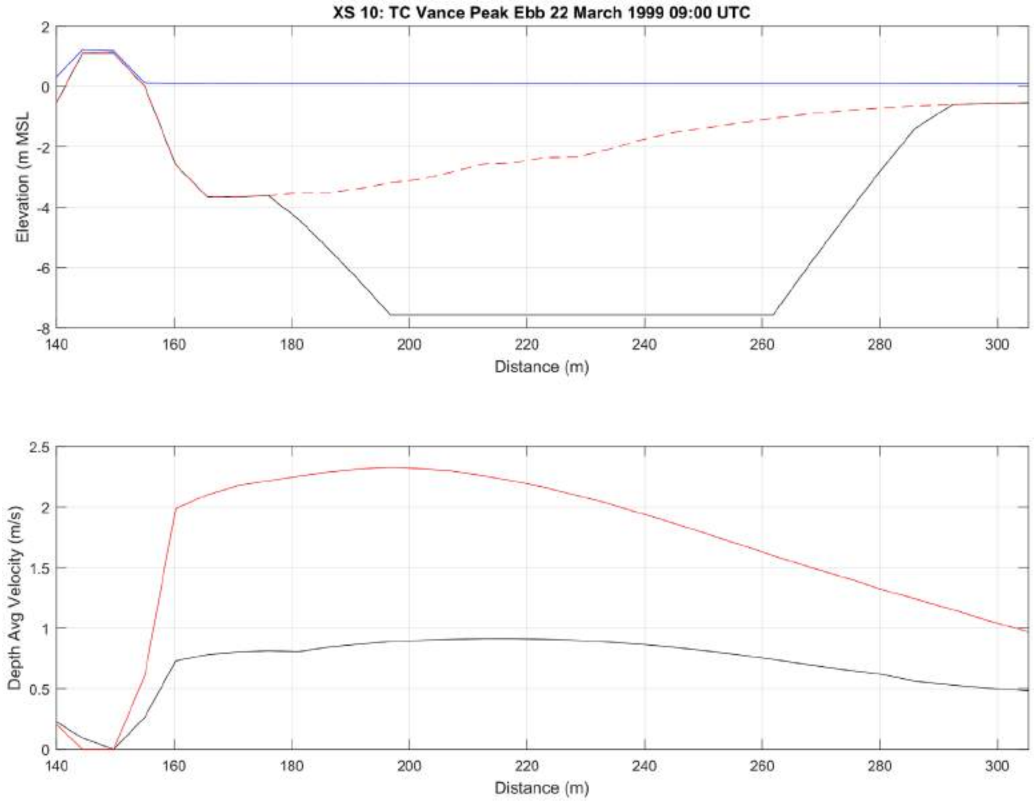

Figure C.10: Tidal Current Velocity for Existing and Developed Case at Peak Ebb Tide – TC Vance (Cross Section 10)

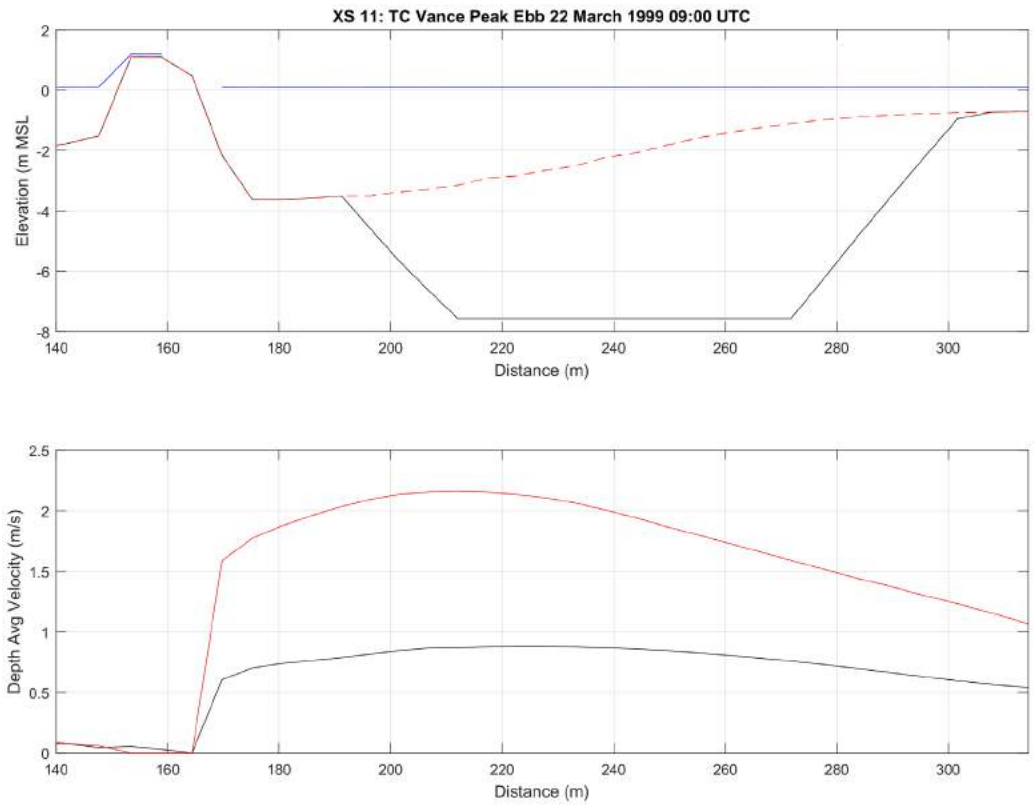

Figure C.11: Tidal Current Velocity for Existing and Developed Case at Peak Ebb Tide – TC Vance (Cross Section 11)

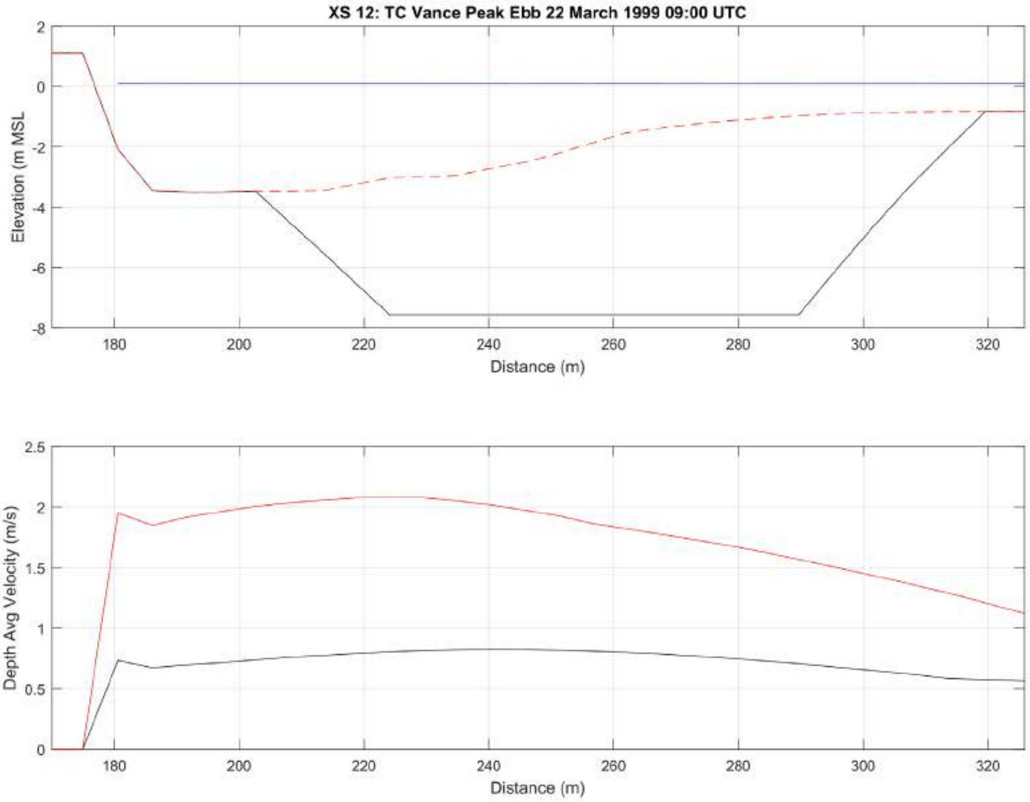

Figure C.12: Tidal Current Velocity for Existing and Developed Case at Peak Ebb Tide – TC Vance (Cross Section 12)

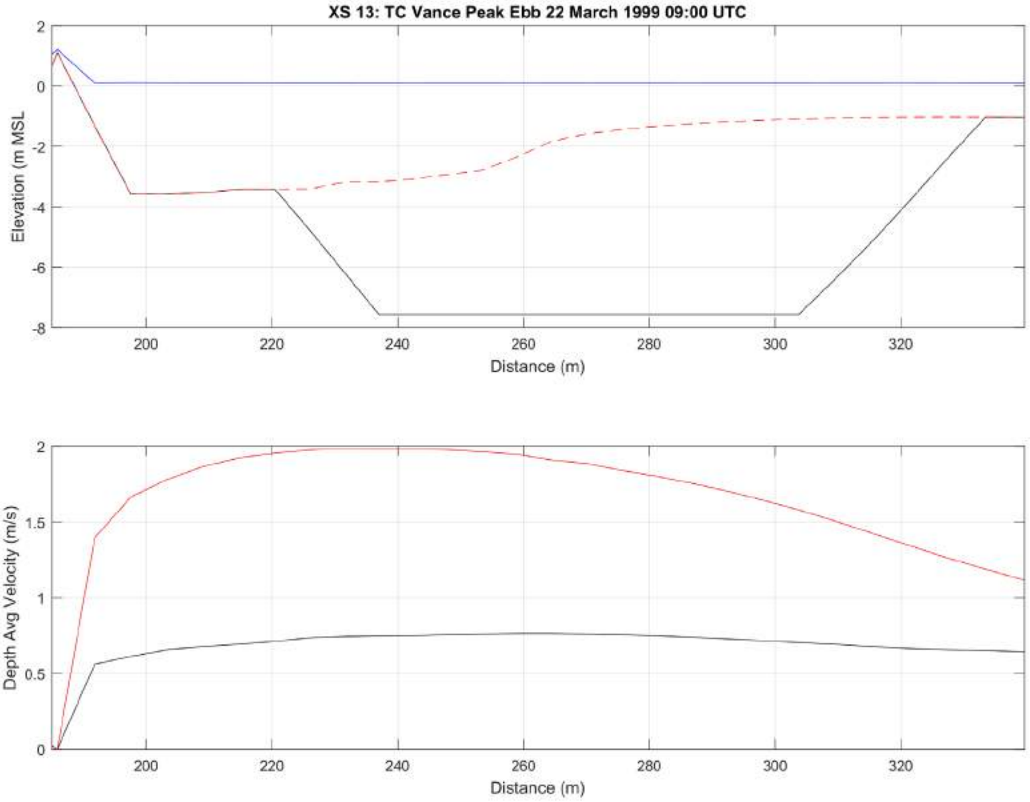

Figure C.13: Tidal Current Velocity for Existing and Developed Case at Peak Ebb Tide – TC Vance (Cross Section 13)

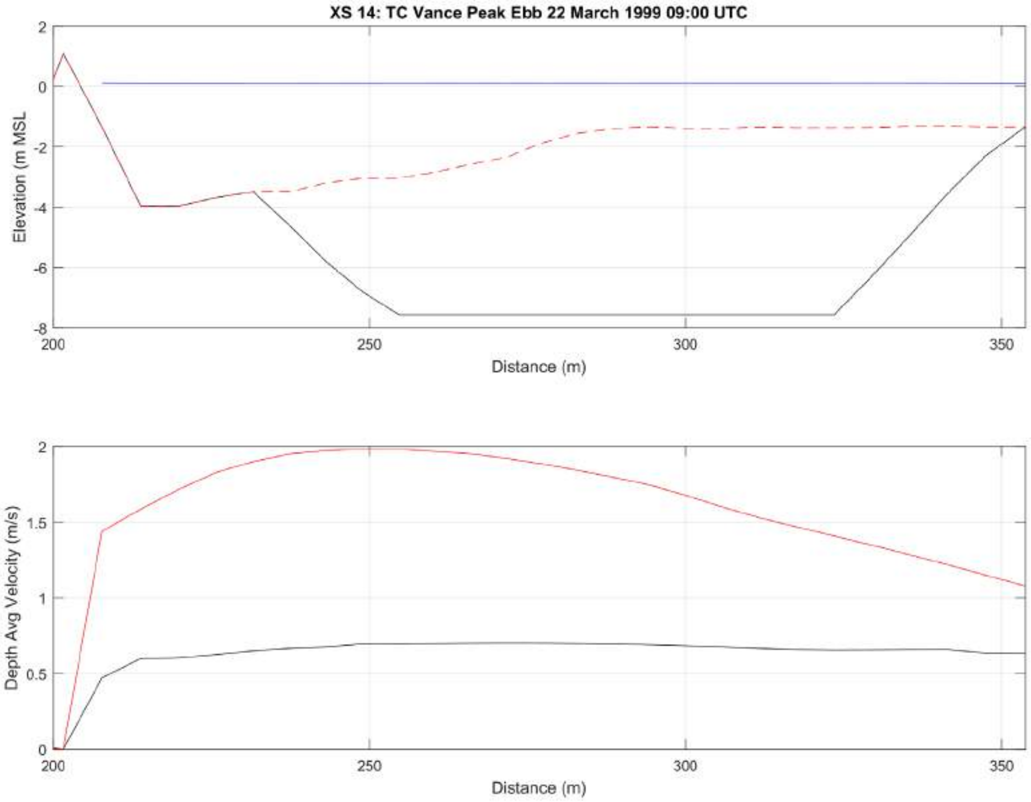

Figure C.14: Tidal Current Velocity for Existing and Developed Case at Peak Ebb Tide – TC Vance (Cross Section 14)

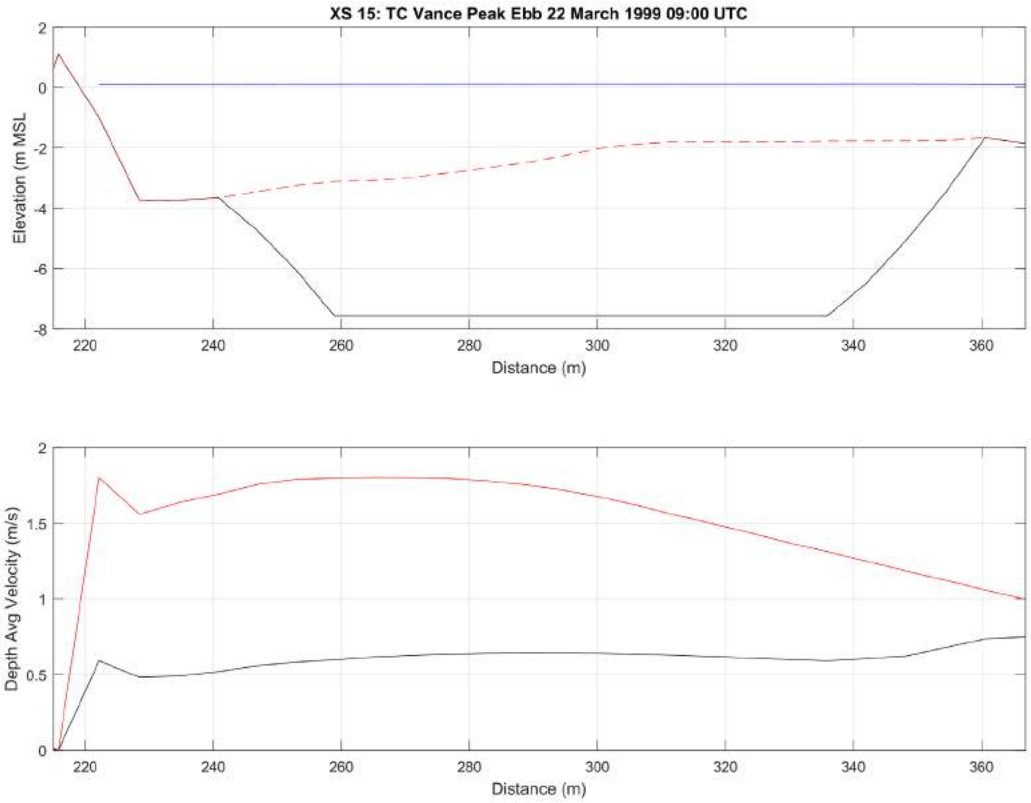

Figure C.15: Tidal Current Velocity for Existing and Developed Case at Peak Ebb Tide – TC Vance (Cross Section 15)