Port Hedland Spoilbank Marina

Water Quality Modelling Report

26 February 2020 | 13143.201.R1.Rev0

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Port Hedland Spoilbank Marina

Water Quality Modelling Report

Prepared for:

Department of Transport

Department of Transport WA
Marine House
Fremantle WA

Contact: Jason Bradford
Phone: +61 8 6311 3400

Prepared by:

Baird. Innovation Engineered.

Baird Australia Pty Ltd as Trustee for the Baird Australia Unit Trust
ACN 161 683 889 | ABN 92 798 128 010

For further information, please contact
Jim Churchill at +61 8 6255 5080

www.baird.com

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B	7/11/2019	Draft	Issued for client review. Scope Task D, E, G	DT/ JC	DT	JC
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Executive Summary

Baird Australia Pty Limited (Baird) have been engaged by the Department of Transport (WA) under contract DOT404017c075 to undertake a water quality modelling study for the Spoilbank Marina Project. This study will support the application for environmental approvals that are required for the project.

The key objectives of the water quality modelling scope are:-

- Estimate the flushing (e-folding) times of the Spoilbank Marina and transport and fate of marine spills if they were to occur in the Spoilbank Marina; and
- Establish the fate of sediment suspended during construction of the marina by dredging and marine construction operations and predict the zones of impact in the marine environment.

The information gained from this body of work is intended to support the application for environmental approvals for the Spoilbank Marina Project.

The study adopted an integrated Delft-FM and Delft3D model system that was also adopted in the Spoilbank Marina Coastal Processes Study (Baird, 2020). The coupled 2D/3D hydrodynamic and wave model system has been systematically validated for wet and dry season conditions as documented in Section 4 of this report.

Water quality modelling has focused on flushing of the Spoilbank Marina. Ten separate 3D model simulations with different tide and wind conditions have been modelled to assess flushing and water exchange with the surrounding coastal waters. Overall, the Spoilbank Marina has a high flushing efficiency as there is generally net advection of water that flows out of the Spoilbank Marina during the ebb tide and overall recirculation is low. Flushing times, assessed as e-folding times (time to reach ≈37% of initial concentration), consistently range between 24-hours during spring tides up to 48 to 50 hours during neap tides. The potential for salinity and temperature enhancement in the marina and vertical stratification were also assessed with a combination of 2D and 3D modelling of temperature and salinity using a dynamic heat and evaporation model. The results from that assessment indicate that the potential for vertical stratification is low inside the SBM and salinity and temperature inside the basin are expected to be only slightly elevated from background coastal waters (+0.3^{o}C temperature, +0.3 ppt salinity).

Modelling of the generation and fate of suspended sediments released into the water column during dredging activities has been completed in Section 6 using 3D modelling with appropriate sediment source terms based on literature, including recommendations from the WAMSI dredging node and incorporating available geotechnical data at the site. The dredge plume modelling outcomes have been reported and analysed to assess the predicted zones of impact around the project site based on analysis of the modelled suspended sediment concentration through the construction period using the approach in Jones et al 2019 and Fisher et al 2019 (WAMSI). The modelling shows the impacts from the dredge plumes are largely confined to the project footprint and the section of nearshore between the western shoreline of the Spoilbank and the Goldsworthy Channel. The modelled results have been analysed against defined threshold values for corals (probable and possible effects) to determine spatially the Zone of High Impact (ZoHI) and Zone of Moderate Impact (ZoMI) through the dredging program that will be adopted in the environmental monitoring and dredge management program.

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1. Introduction

Baird Australia Pty Limited (Baird) have been engaged by the Department of Transport (WA) under contract DOT404017c075 to undertake a water quality modelling study for the Spoilbank Marina Project. This study will support the application for environmental approvals that are required for the project.

The following report documents the methods, data sources and outcomes for the Scope of Work under contract DOT404017c075. The report is presented with the following sections:

- Section 1: Introduction and background description of Spoilbank Marina (SBM) Project.
- Section 2: Summary of data inputs and sources.
- Section 3: Description of metocean environment.
- Section 4: Description and summary of validation of hydrodynamic and wave models adopted in this study.
- Section 5: Marina flushing and spill assessment.
- Section 6: Dredge plume modelling of the dredging works to construct the SBM.

1.1 Spoilbank Marina Development

In recent years the Town of Port Hedland, together with LandCorp and the Pilbara Development Commission, have been progressing planning for the development of a marina within Port Hedland. Following multiple iterations of the Port Hedland marina precinct concept the project received state government endorsement in 2018. A concept design was developed for a location on the western side of the Spoilbank, adjacent to the Port Hedland Yacht Club, incorporating 2 lanes of boat ramp and 20 boat pens. Several supporting studies, including preliminary environmental assessment, have been undertaken based on this initial concept presented in Figure 1.1.

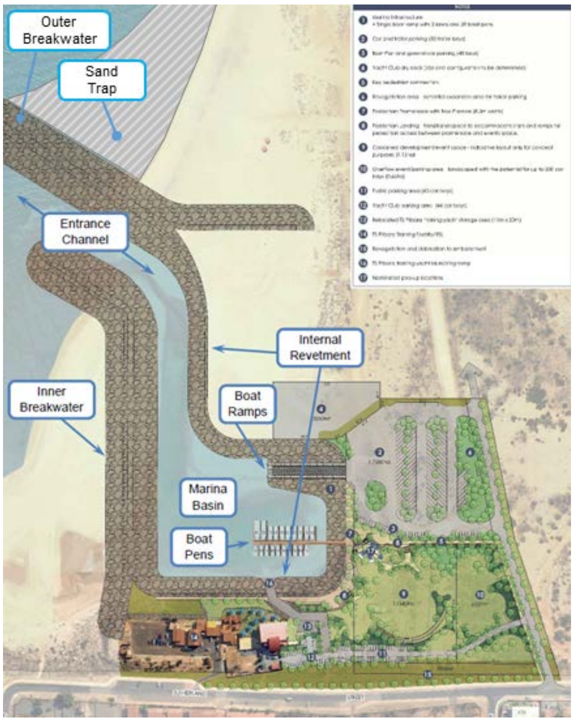


Figure 1.1: Initial Concept Layout plan for proposed Spoilbank Marina (TBB, June 2018)

The Spoilbank is an artificial landform created from the Port Hedland inner harbour and shipping channel dredging sediment disposal in the mid-1960s and early 1970s. Over the past 50 years, this artificially constructed area of land has migrated south and evolved from an offshore island to a shore connected sandspit peninsula. Multiple regional scale geomorphology and coastal engineering assessments confirmed that the Spoilbank is highly vulnerable to hydrodynamic forces. This man-made land feature has now stepped into a shrinking/eroding phase. Substantial erosion is anticipated to occur over forthcoming decades. Morphological changes are particularly pronounced during severe tropical cyclone storms, including the recent Tropical Cyclone Veronica event in March 2019.

The conditions at the proposed marina site are characterised by a high tidal range, strong tidal current, silty fine sediment, a continuously changing landform and exposure to cyclonic conditions.

1.2 Concept Design

The current project, co-ordinated by Department of Transport (DoT), is focused on design development of marine facilities for the Spoilbank Marina project. The water quality modelling study is one of several parallel investigations required to refine the concept design layout and specification.

1.2.1 Design Workshop

In June 2019, the DoT hosted an entrance design workshop, which was aimed at discussing and refining the marina concept layout to reduce the potential need for costly retrofitting and maintenance. During the workshop several items were discussed relating to the entrance configuration, and most importantly options to reduce the potential for sedimentation of the marina entrance channel and to minimise capital dredging works associated with the channel and marina basin. The DoT took the discussions on-board and further developed concept layout options for consideration in ongoing design and environmental assessments which were subsequently refined by the design engineers, M P Rogers and Associates (MRA). The three concepts that have been assessed in this report are presented in Figure 1.2.

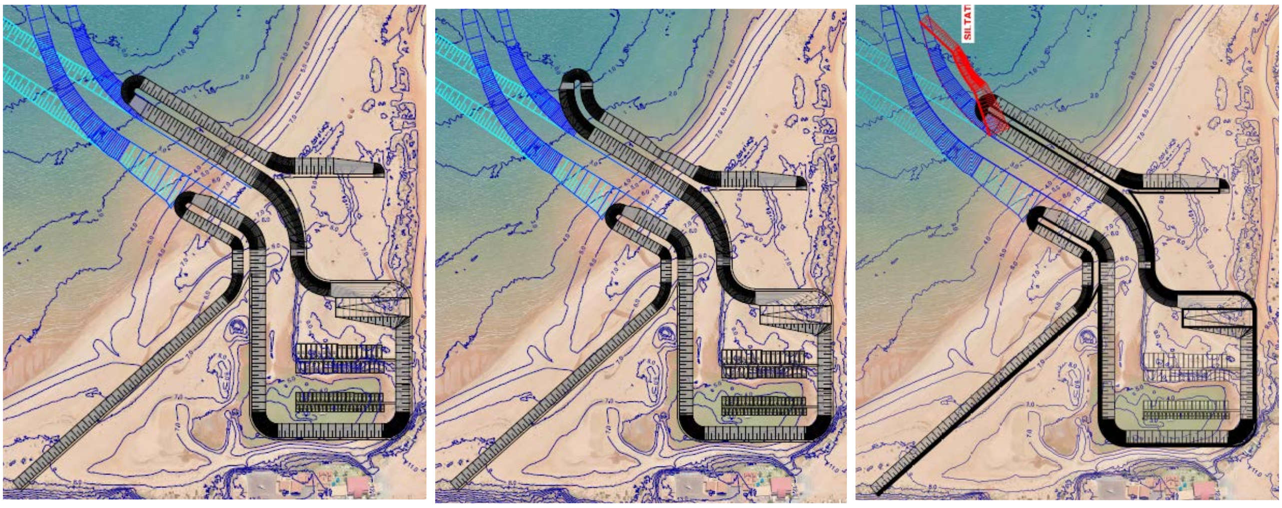


Figure 1.2: Spoilbank Marina Concept Layout Options. Left: Base Case, Centre: Option 1 (Breakwater Hook Design), Right: Option 2 (Base Case with Siltation Trap)

1.2.2 Marina Basin and Revetments

The marina concept (Figure 1.2) includes a basin of approximately 160 x 170m in dimension that will accommodate up to 80 vessels of sizes between 10 and 20m in length. A dual boat ramp is located in the north eastern corner with a fairway that runs along the northern extent of the basin to connect with the marina entrance channel. The marina basin will be contained by rock revetments on all sides with additional external revetments constructed to provide long term reclamations of the northern and western landside areas. These are required due the highly mobile and evolving nature of the Spoilbank land mass.

The northern and southern training walls are 200 m and 75 m in length (along the crest), respectively and will act to stabilise the entrance, provide protection from incident waves and act as sediment traps to inhibit nearshore sediment transport from infilling the entrance channel. The Option 1 layout includes a breakwater hook feature at the end of the northern training wall where most of the sediment bypass is expected to occur, to attempt to keep sedimentation away from the entrance channel.

1.2.3 Entrance Channel

The entrance channel starts from the marina basin in a north-south alignment before turning to a north westerly orientation through the entrance. It is protected through the shoreline and intertidal areas by two entrance training walls (Figure 1.2).

Offshore there are three entrance channel alignments that have been considered in the design phase. The channels are between 900 and 1000m in length and extend out to design depth on a final heading east-north east parallel the main Port Hedland shipping channel (Goldsworthy channel) so as to encourage separation of commercial and recreational vessels. The entrance channel is 30 m wide (at the channel toe) and will be maintained to -2 m CD. The channel will be dredged to -2.5 m CD including 0.5m over-dredge for sedimentation allowance to provide all tide access to all vessel sizes in the proposed marina fleet.

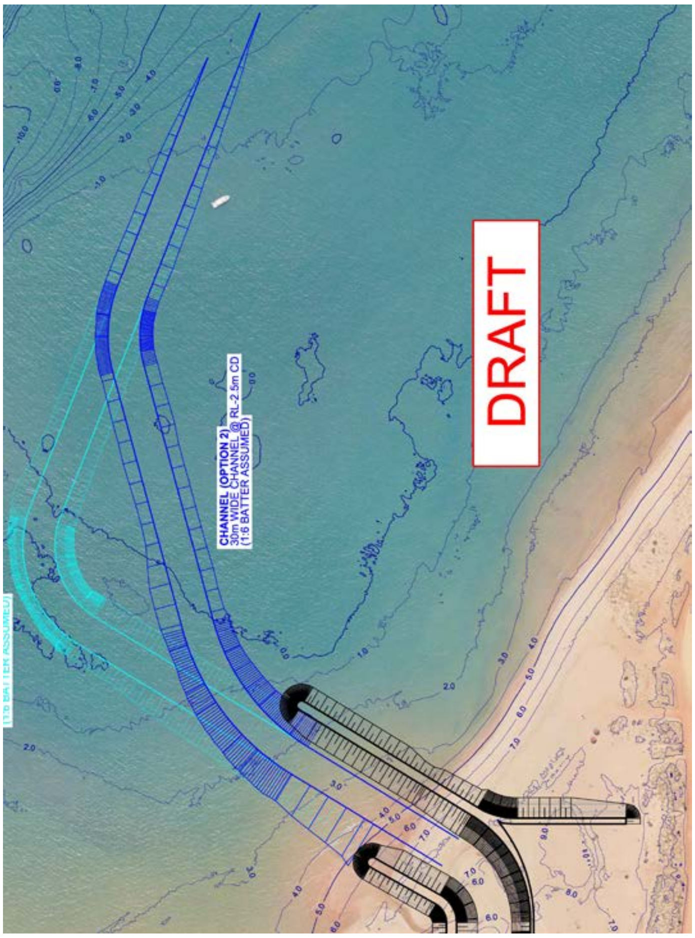


Figure 1.3: Entrance Channel Alignment Options. Option1 in Light Blue, Option 2 in Dark Blue.

1.3 Water Quality Modelling Scope

The key objectives of the water quality modelling scope are:-

- Estimate the flushing (e-folding) times of the Spoilbank Marina and transport and fate of marine spills if they were to occur in the Spoilbank Marina; and
- Establish the fate of sediment suspended during construction of the marina by dredging and marine construction operations and predict the zones of impact in the marine environment.

The information gained from this body of work is intended to support the application for environmental approvals for the SBM Project. It will also provide input into environmental monitoring and management plans.

The project is composed of the following tasks:

1. Project management and meetings;
2. Data gathering and review;
3. Wave and hydrodynamic model calibration;
4. Flushing assessment including an assessment of the transport and fate of marine spills; and
5. Sediment plume modelling.

This draft report presents updates from the previous interim report, specifically the inclusion of project Deliverable Items D, E and G comprised of the following:

- Item B - Data gathering summary and review as presented in Section 2;
- Item C - Description of the project site and characterization of regional metocean conditions as presented in Section 0.
- Item D – Model Calibration as presented in Section 4;
- Item E – Flushing Assessment Selection of Modelling Scenarios presented in Section 5; and
- Item G – Sediment Plume Modelling Assumptions presented in Section 6.

2. Background Data Summary

The background reports referenced in the development of the hydrodynamic model and application in the dredge plume modelling program are outlined in this section.

2.1.1 Site Specific Reports

- Baird (2020). Spoilbank Marina Metocean Design Criteria and Coastal Process Studies. Prepared for Department of Transport. Doc Ref: 13143.101.R1.Rev 0.
- Cardno (2011). Port Hedland Coastal Vulnerability Study. Final Report, Job Number: LJ15014, Report Number: Rep1022p
- Cardno (2019). Suspended Sediment Analysis, Port Hedland Spoilbank Marina, Prepared for Department of Transport, 5 September 2019 (CW105000)
- CMW, Spoilbank Marina Port Hedland WA, Factual Geotechnical Investigation Report, Report Prepared for Department of Transport, PER2019-0292AA RevA December 2019
- DoT (2019). SSC analysis of 60 water samples - measurements taken on 11 July 2019 near AWAC location DOT02 (provided via email from B Heijlen,26/7/2019)
- Golder Associates Pty Ltd (2009). Geotechnical Studies, Spoilbank Marina, Port Hedland. Report Prepared for MP Rogers, Report No. 097642244001 R Rev1
- O2 Marine (2019). Particle size distribution data for 3 surface grab samples (provided via email from B Heijlen, 4th October 2019)
- RPS (2014). Water Quality Report - Proposed Port Hedland Marina Development. Prepared for LandCorp. Report No: L1314906, Version/Date: Rev 0, August 2014
- Seashore Engineering (2019). Port Hedland Spoilbank Marina - Spoilbank Morphodynamics, Prepared for Department of Transport, Report SE078-01-Rev A
- Shorewater Marine Pty Ltd (2016). Proposed Port Hedland Spoilbank Marina, Report Prepared for LandCorp, SHOREWATER MARINE RFT0443, Undertaking of Jet Probing, Supply of Core Sampling, 26 May 2016
- BMT Western Australia Pty Ltd (2019). Sediment Sampling Results of 2 surface samples at the AWAC locations, Email K.Ghaly to B Heijlen, RE: [External] FW: Port Hedland - dredging requirements dated 15/5/2019

2.1.2 WAMSI Dredging Node

- Fisher R, Jones R, Bessell-Browne P, (2019). Effects of dredging and dredging related activities on water quality: Impacts on coral mortality and threshold development Report of Theme 4 - Project 4.9, prepared for the Dredging Science Node, Western Australian Marine Science Institution, Perth, Western Australia, 94 pp.
- Jones R, Fisher R, Bessell-Brown P, Negri A, Duckworth A (2019) Theme 4 | Synthesis Report: Defining thresholds and indicators of coral response to dredging-related pressures. Western Australian Marine Science Institution (WAMSI). Perth, Western Australia pp. 36.
- Kemps H and Masini R (2017) Estimating dredge source terms – a review of contemporary practice in the context of Environmental Impact Assessment in Western Australia. Report of Theme 2 – Project 2.2, prepared for the Dredging Science Node, Western Australian Marine Science Institution (WAMSI). Perth, Western Australia, 29pp.
- Mills D (2019) Predicting and measuring the characteristics of sediments generated by dredging. Synthesis Report of Theme 2 – prepared for the Dredging Science Node, Western Australian Marine Science Institution, Perth, Western Australia, 12 pp.

- Sun C, Shimizu K, Symonds G (2016) Numerical modelling of dredge plumes: a review. Report of Theme 3 - Project 3.1.3, prepared for the Dredging Science Node, Western Australian Marine Science Institution, Perth, Western Australia, 55 pp
- Sun C, Lowe R, Fearns P, Ghisalberti M, Branson P (2019), WAMSI Dredging Science Node Theme 3 I Synthesis Report: Characterisation and prediction of dredge-generated sediment plume dynamics and fate, prepared for the Dredging Science Node, Western Australian Marine Science Institution, Perth, Western Australia,

2.1.3 Key EPA Documents

- EPA 2016a, Statement of Environmental Principles, Factors and Objectives, EPA, Western Australia;
- EPA 2016b, Environmental Impact Assessment (Part IV Divisions 1 and 2) Administrative Procedures 2016;
- EPA 2018a, Environmental Impact Assessment (Part IV Divisions 1 and 2) Procedures Manual, EPA, Western Australia;
- EPA, 2016c, Environmental Factor Guideline – Marine Environmental Quality, EPA, Western Australia;
- EPA, 2016d, Environmental Factor Guideline – Benthic Communities and habitat, EPA, Western Australia;
- EPA, 2016f, Technical Guidance – Protecting the Quality of Western Australia's Marine Environment, EPA, Western Australia; and
- EPA, 2016g, Technical Guidance - Environmental Impact Assessment of Marine Dredging Proposals, EPA, Western Australia.

2.1.4 Other Policy and Guidance

- DoE, 2006, Pilbara Coastal Water Quality Consultation Outcomes – Environmental Values and Environmental Quality Objectives, Department of Environment (DoE), Government of Western Australia, Marine Series Report No. 1;
- ANZECC & ARMCANZ 2000, Australian and New Zealand Guidelines for Fresh and Marine Water Quality (Australian and New Zealand Environment and Conservation Council (ANZECC) & Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ);

2.2 Data Sources

2.2.1 Measured Data Sources

The key measured data sources are summarised in Table 2.1.

Table 2.1: Data Summary – Key Datasets

Dataset	Description
Sediment Sampling	Data set focused on Spoilbank Marina area as summarised in Section 2.2.2.1
Bathymetry Data	Data comprised of regional bathymetry data provided by the Australia Hydrographic Office, bathymetric survey data provided by BHP and the Pilbara Ports Authority (PPA) and LIDAR data collected by Department of Transport of the Spoilbank Marina. Summarised in Section 2.2.2.2.

Dataset	Description
Baseline Metocean Data	Detailed data set of Waves, Water Level, Currents, Atmospheric Pressure, Wind Speed collected by a range of organisations at a variety of sites. Summarised in Section 2.2.2.3.
Baseline Water Quality	Water quality baseline data is currently being collected at the site. Guidance on Baseline water quality information has been provided by O2Marine and Teal Solutions, developed from a range of historical Port Hedland reports.

2.2.2 Review of Data Sources and Application in the Study

2.2.2.1 Sediment and Geotechnical Data

Sources of historical geotechnical data provided for the project are shown in Figure 2.1 which comprises:

- Golder Associates Pty Ltd (2009) that included Jet Probing (110 onshore locations, 49 nearshore locations), Drilling (6 boreholes) and Test Pits (13 locations).
- Shorewater Marine Pty Ltd (2016) that included Jet Probing (321 locations) and Core Sampling (6 locations). Note that Baird has not received any data in relation to the core sampling of that campaign.
- WBM Western Australia Pty Ltd (2019) that include particle size distribution data for 2 surface grab samples.
- O2 Marine (2019) particle size distribution data for 3 surface grab samples (provided via email from B Heijlen, 4th October 2019) Data collected for the current project is shown in Figure 2.3.

Site specific geotechnical and sediment sampling information obtained across the project footprint in 2019 are as follows:

- O2 Marine and Teal Solutions (2019), comprehensive sediment sampling field investigation in Late September 2019 through the project footprint. PSD of samples (generally surface samples) via hand trowel, push core and vibracore (Figure 2.3).
- CMW Geosciences (2019), Spoilbank Marina Port Hedland Factual Geotechnical Investigation Report, with detailed geotechnical information from test pits and borehole locations through the development footprint (Figure 2.4).

Review of the available data suggests that surface sediments consist of coarse silts to fine sands with frequent occurrence of shell fragments in the intertidal and nearshore areas out to the navigation channel, however during more recent site investigations and sediment sampling a higher content of cobbles and rock has been identified along the Spoilbank shoreline.

Golder Associates Pty Ltd (2009) states "*calcarenite rock will be encountered during either dredging or excavation works for both the marina and entrance channel……. Strength properties of the calcarenite is variable, ranging from very low to high. This variation in strength is known to influence the efficiency of dredging and excavation of calcarenite*".

The coverage of geotechnical testing across the site is reasonably dense and there exists a suitable amount of data to produce a reasonable geotechnical ground model in particular the definition of level of calcarenite rock. Detailed particle size distribution data from both the seabed samples and the samples extracted at various levels through the boreholes provide a reasonable basis to understand sediment composition and characteristics across the site. This data has informed the calculation of material type and volume applied in the sediment transport models.

The Particle Size Distribution (PSD) data from the O2Marine and Teal Solutions (2019), BMT (2019) and O2Marine (2019) grab sample data, provides a useful dataset to inform the composition of near surface sediments that may be dredged. PSD data collected near the outer end of the proposed entrance channel (BMT, 2019 – see Figure 2.1) indicate that surface sediment consist of predominantly silty fine sands with some gravel present, with D50 values between 0.1 - 0.13 mm. Sediment sampling along the Spoilbank shoreline (O2Marine, 2019), indicate surface sediments comprise of rocky coarse sand with some shell and mud present with D50 values between 0.25 and 1 mm. It is noted that the high occurrence of gravel and cobbles at the surface during the O2Marine site visit (refer Figure 2.2) was not previously noted along the western shoreline of the Spoilbank and these layers are thought to have been exposed during Tropical Cyclone Veronica where significant volumes of sand were mobilised.

Borehole data and PSD below the surface from Golder 2009 provides a useful description of the depth of rock, thickness of rock and sediment properties below the rock layer at locations across the proposed marina basin (approximately between the layout entrance and the yacht club).

The understanding of the rock layer depth has been improved with the detailed geotechnical study completed by CMW Geosciences in late 2019 which was focussed on the onshore and offshore sections of the dredging footprint. The data collected across the site includes 14 boreholes and 20 test pits. A range of soil laboratory testing was completed including PSD from samples collected at a range of dredge depths. The borehole logs provide a detailed account of the sediment layers (overlying sand, calcarenite layer, below rock sediments) through the planned entrance channel alignment and onshore basin region on the Spoilbank.

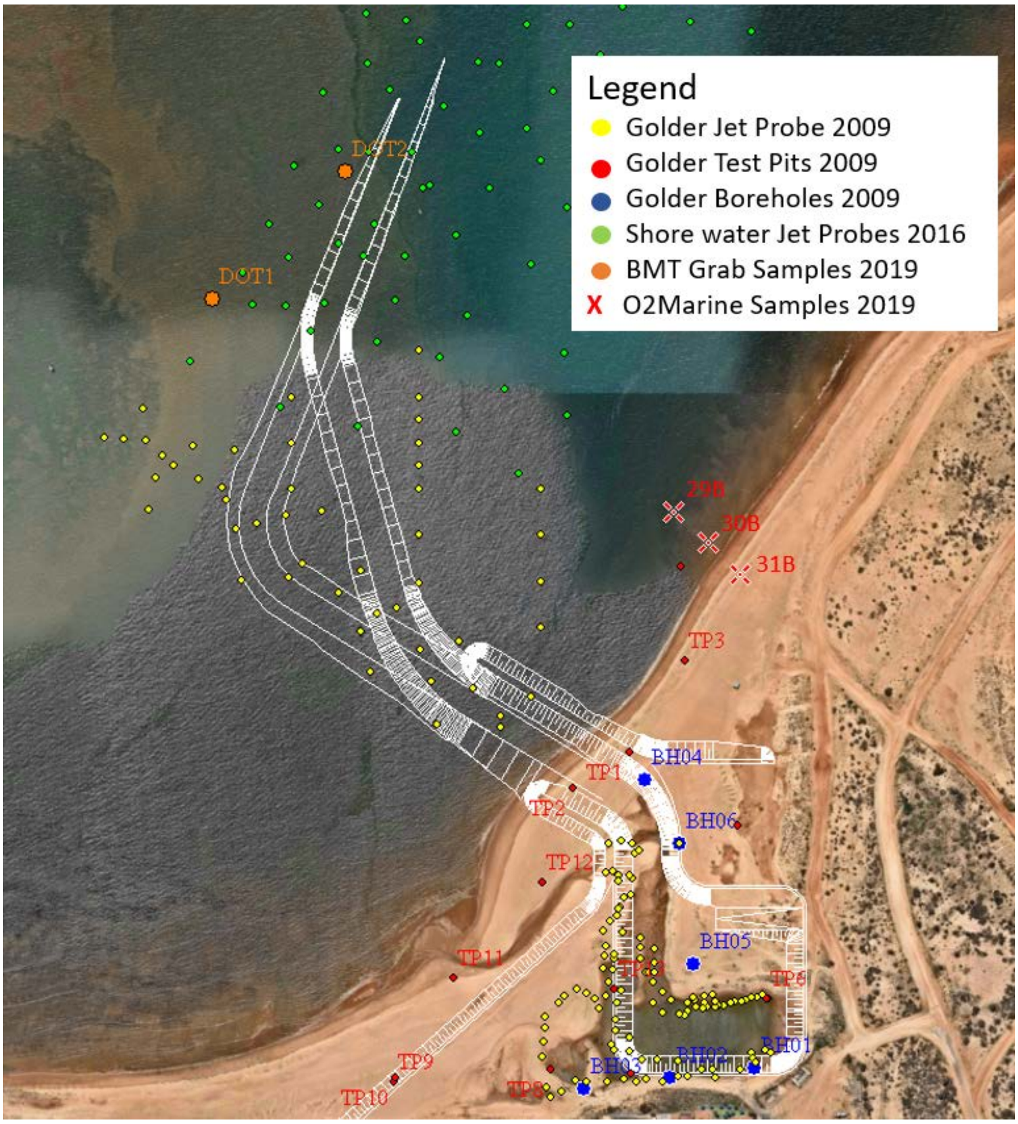


Figure 2.1: Location of Sediment and Geotechnical Data provided to date.

Figure 2.2: Site photo from September 28 showing high occurrence of gravel and cobbles at the surface in the shoreline (photos source O2 Marine)

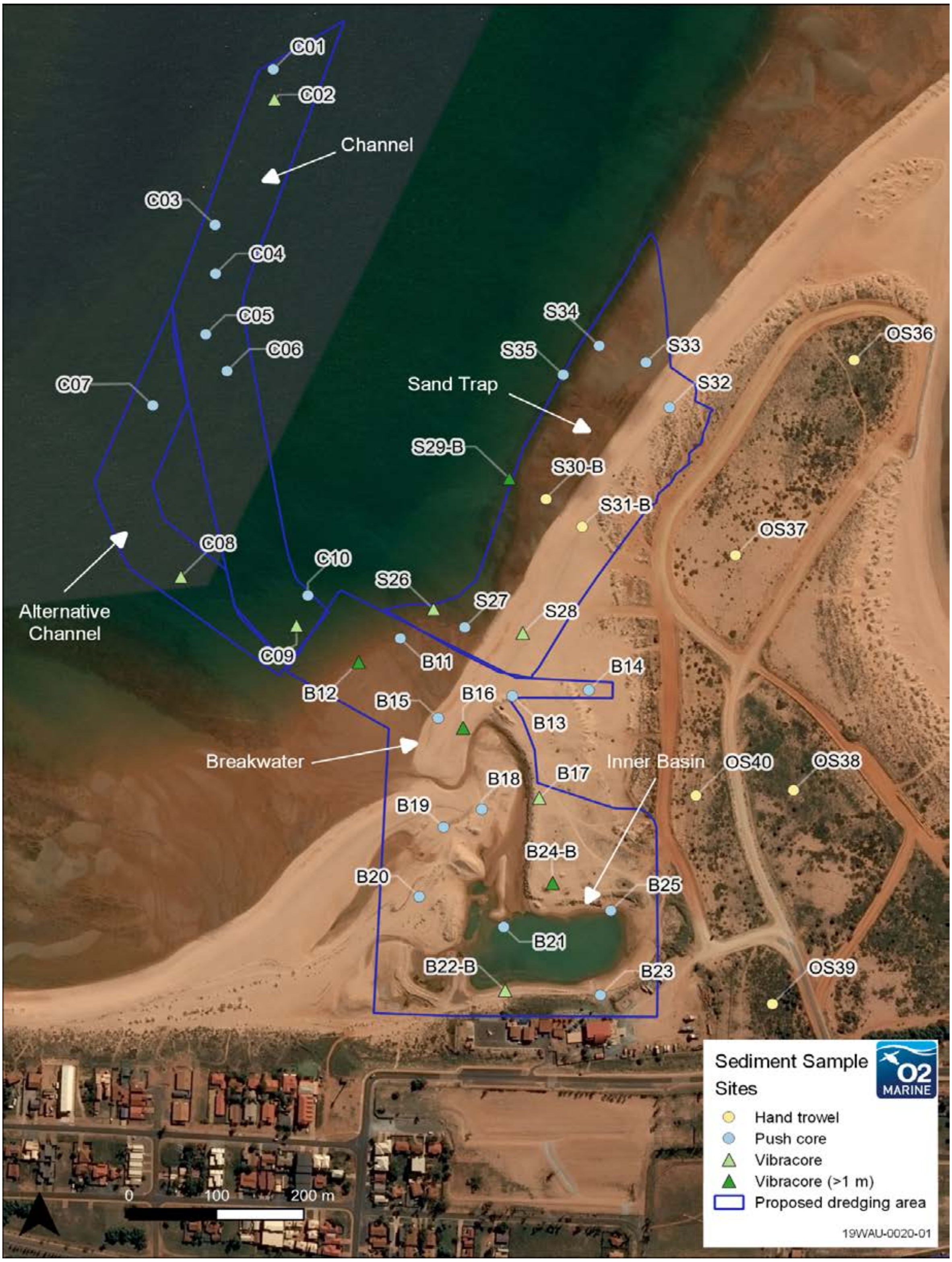


Figure 2.3: Sediment sampling locations, September 2019 (O2 Marine, Teal Solutions)

Figure 2.4: Borehole and Test Pit Locations, CMW 2019

2.2.2.2 Bathymetry Data

Two bathymetric datasets were provided by DoT, collected over the Spoilbank and surrounding intertidal/nearshore areas on the 14-Aug-2018 and 12-May-2019. No metadata or survey report were provided however the following was provided by the DoT (email) or can be obtained from the folder naming:

- Vertical datum: Chart Datum

- Horizontal datum: MGA50, GDA94
- Survey date(s): 14-Aug-2018 and 12-May-2019
- Resolution: 1 x 1 m

The vertical units are assumed to be meters and the 1m resolution points are an average of the full resolution multi-beam data within 1 x 1 m areas.

Baird have on file bathymetric datasets covering the full extent of Port Hedland Inner Harbour (including tidal creeks) and offshore shelf areas. The latest survey data from DoT was be incorporated and prioritised within a bathymetric/topographic DTM of the region for inclusion in numerical model setups.

2.2.2.3 Metocean Data

Metocean data, collected by the Pilbara Port Authority (PPA), Bureau of Meteorology (BoM) and DoT, was made available for this project and provides a description of the site specific metocean conditions. Metocean parameters for water levels, waves, currents and winds over period (approx.) between December 2018 and July 2019, were provided across 10 locations, including:

- Port Beacon C2 (PPA) – Waves (DWR)
- Port Beacon 15 (PPA) – Waves (DWR)
- Port Beacon 16 (PPA) – Waves, Currents (AWAC), Winds (Met Station)
- Port Beacon 17 (PPA) – Water Level (Tide Gauge)
- Port Beacon 31 (PPA) - Water Level (Tide Gauge)
- Port Beacon 47 (PPA) – Waves, Current (AWAC), Water Level (Tide Gauge)
- Port Hedland Tower (PPA) – Wind (Met Station)
- HD01 (DoT) – Waves, Water Level, Currents (AWAC)
- HD02 (DoT) – Waves, Water Level, Currents (AWAC)
- Port Hedland Airport (BoM) – Wind (Met Station)

The locations of the metocean measurements is presented in Figure 2.5.

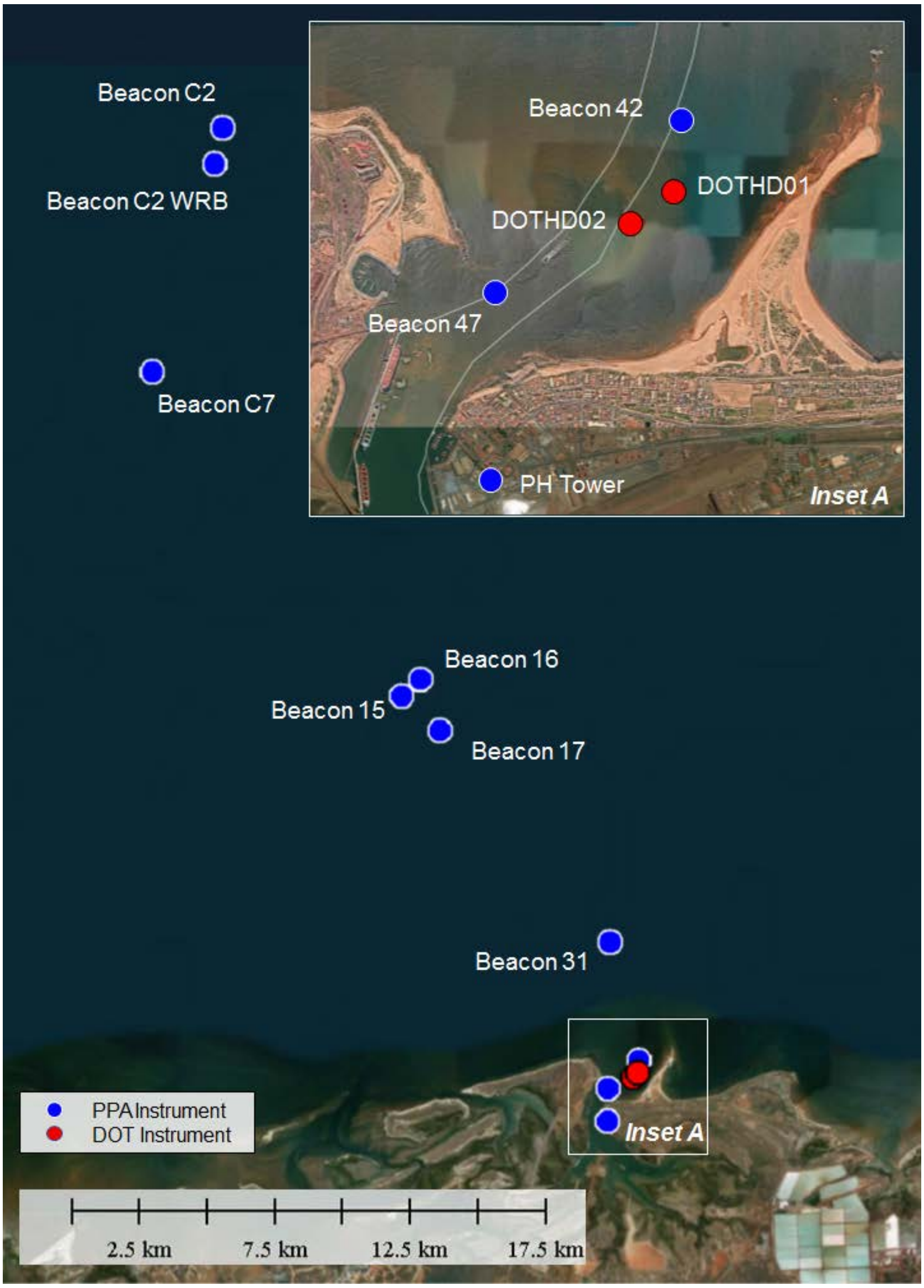


Figure 2.5: Location of Metocean Measurements from PPA and DoT

A review of the data from the datasets covering December 2018 to 4 July 2019 (wet season and dry season data) indicates:

- The data collected between December 2018 to April 2019 provides a good characterisation of wet season conditions and include data collected during a severe tropical cyclone, TC Veronica.
- A good characterisation of dry season conditions at the site has been made possible from the May 2019 to July 2019 data.

Validation of the numerical models based on the wet season and Dry season data is completed in Section 4.2.2 from these measured data sources

Based on the outcomes reported in the *Port Hedland Spoilbank Marina Coastal Process Study* (Baird, 2020) and work presented in this report in Section 4.3 the measured current and wave data from DOTHD01 and DOTHD02 provide the primary characterisation of currents and waves which influence the Spoilbank Marina site.

Water temperature data measured by the AWAC instruments at Locations HD01 and HD02 (see Figure 2.5) was provided for a period from April 2019 through to July 2019. This period covered the transition from wet season conditions characterised by water temperatures greater than 28 ^{o}C and then water temperatures in the range of ≈20 ^{o}C in July. The measured water temperatures at the DoT instrument sites in 2019 have good agreement with the seasonal water temperature near the entrance to Port Hedland reported in BHP (2009).

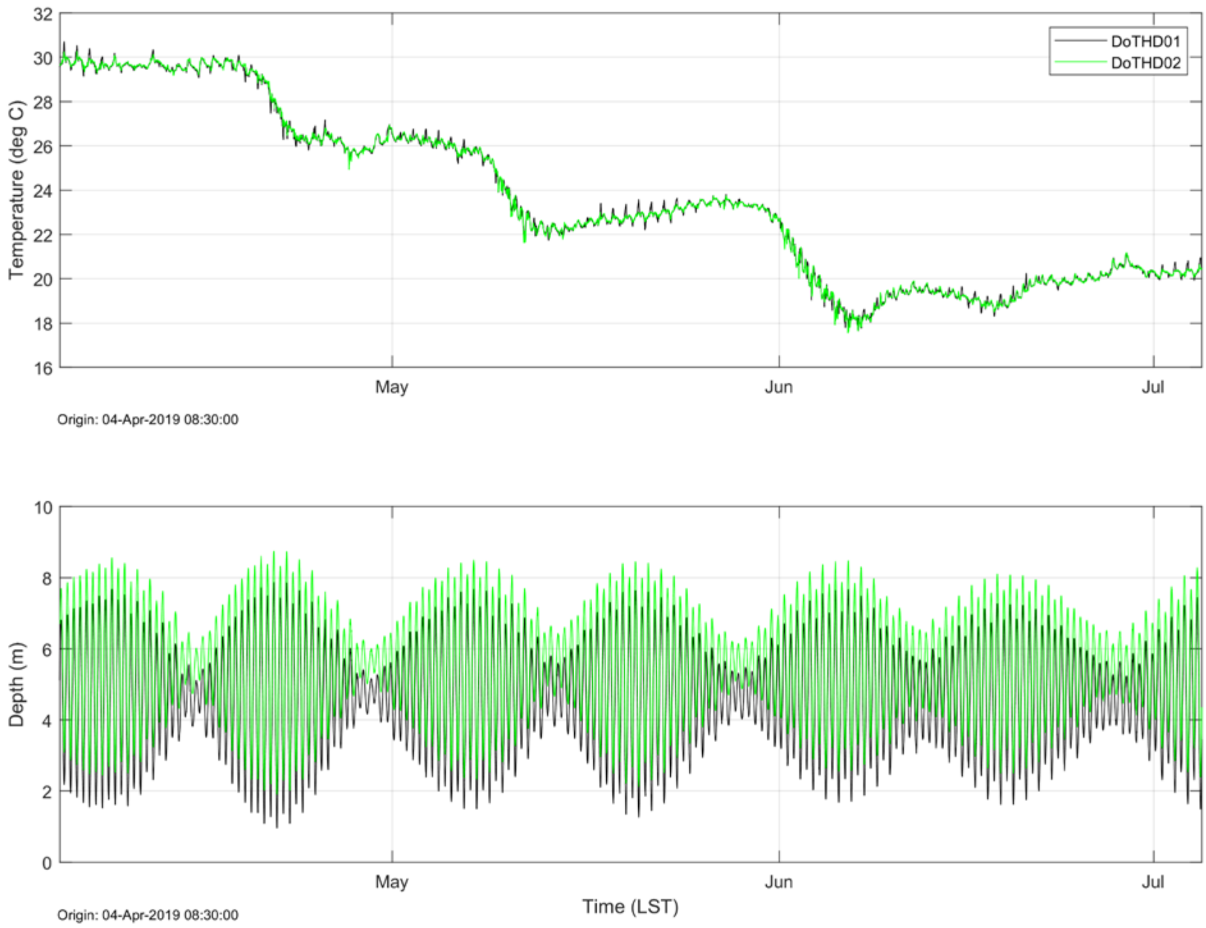


Figure 2.6: Measured water temperature (near seabed) and depth at Locations DoT HD01 and HD02: Apr 2019 to Jul 2019.

3. Metocean Environment

3.1 Project Location

Port Hedland is located off the Northwest Shelf (NWS) of Australia approximately 190km East-Northeast of Karratha and 460km Southwest of Broome, as shown in Figure 3.1. The metocean climate has strong seasonality of winds and waves, however is generally characterised by its macrotidal, semi-diurnal tides and low ambient wave climate. Being at a latitude of -20.3 degrees, the region is subject to the Australian monsoon during the summer months (November through April) characterised by high rainfall and tropical cyclones, with three events per year, on average, influencing the metocean conditions at Port Hedland.

The proposed marina is located at the southwestern corner of the Port Hedland Spoilbank, an artificial mobile landform, that is located on the eastern side of the main Goldsworthy shipping channel just outside of the Port Hedland Inner Harbour. This site provides a relatively sheltered position from offshore conditions, between the Port Hedland Spoilbank landform and the Goldsworthy shipping channel, with the nearshore area consisting of naturally shallow, relatively flat, seabed conditions.

Figure 3.1: Locality Map of the proposed Port Hedland Spoilbank Marina

3.2 Local Setting and Metocean Influences

The dominant metocean processes at the site are as follows:

- Large tide range which govern water level variations and most of the currents that are observed in the nearshore area surrounding the Spoilbank Marina;
- Prevailing westerly seabreeze during the wet season (summer) months that dominate the local sea waves which impact on the Spoilbank, promoting southerly sediment transport in the nearshore along the western shore of the Spoilbank;

- Prevailing small amplitude long period swells during the dry season (winter) months that impact on the Spoilbank, promoting southerly sediment transport in the nearshore of the western side of the Spoilbank; and
- Frequent cyclone events, including moderate to severe events every 5 to 10 years which cause extreme event winds, waves, water levels, currents and sediment transport that can be significantly higher than during ambient conditions.

3.3 Wind Climate

Wind conditions at Port Hedland are seasonal with clear differences in the prevailing winds during the Summer and Winter months. North-westerly winds generally blow during the summer Wet Season followed by strong easterlies/south-easterlies over winter Dry Season months before a gradual return to north-westerly conditions in spring. These general trends are reinforced by land and sea breezes induced by temperature differences between land and water. Figure 3.2 presents the seasonal wind roses from the Port Hedland Airport that clearly identifies the seasonal differences in the wind climate.

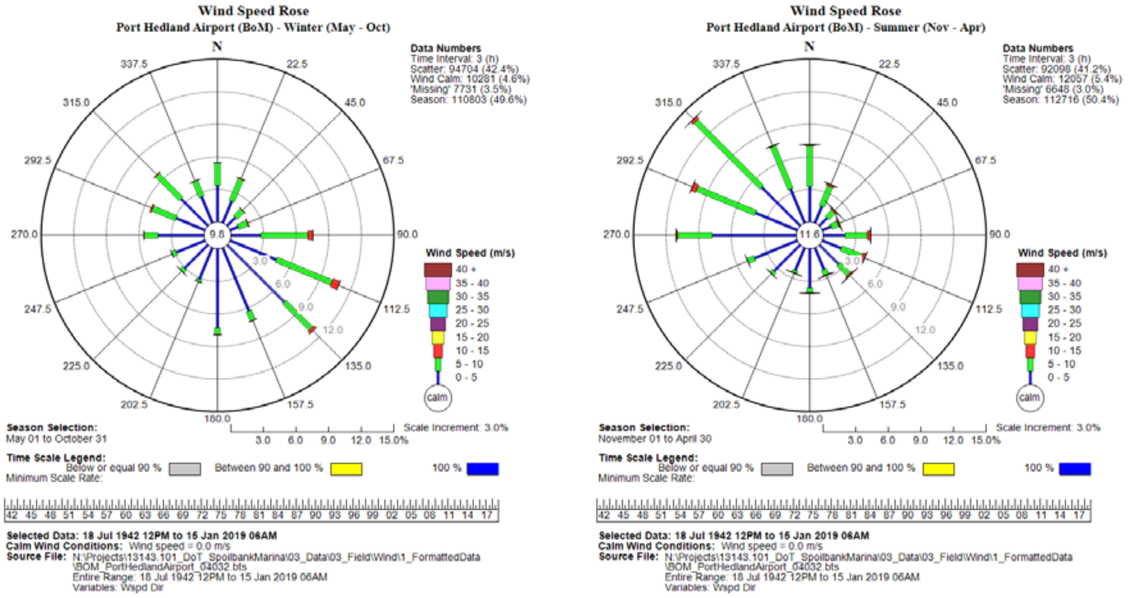


Figure 3.2: Wind Speed Roses at the Port Hedland Airport Station (BoM) for Winter months (left) and Summer months (right). Analysis of BoM data from 1942 to 2019.

3.4 Water Levels

The Port Hedland region is a macro-tidal environment and is subject to large, semi-diurnal tides which drive water level variations over an approximate two-week spring-neap cycle. Tidal ranges vary between 1.4 m during mean neap tides, 5.4 m during mean spring tides and up to 7.5m during very large spring tide periods. A summary of tidal planes at Port Hedland is provided in Table 3.1.

Table 3.1: Port Hedland Tidal Planes (DoT, 2019)

Tidal Plane		Level (m LAT - 2005)	Level (m AHD)
HAT	Highest Astronomical Tide	7.61	3.72
MHWS	Mean High Water Springs	6.73	2.84
MHWN	Mean High Water Neaps	4.67	0.78
MSL	Mean Sea Level	4.00	0.11
MLWN	Mean Low Water Neaps	3.33	-0.56
MLWS	Mean Low Water Springs	1.27	-2.62
LAT	Lowest Astronomic Tide	0.07	-3.82

In addition to tides, mean water levels in the region are influenced by a range of other processes, including oceanographic currents, low pressure systems and inter-annual variability associated with the El Niño–Southern Oscillation, resulting in residuals in the range of +/-0.2m, typically (Cardno, 2011). However, the largest amplitude contributor to water level residuals is storm surge which can accompany tropical cyclone events and increase the water level by over 1m above highest astronomical tide (HAT).

3.5 Tidal Currents

Due to the large tidal range which is present at Port Hedland and the large tidal prism which exists inside the Inner Harbour, peak tidal currents within the harbour can reach velocities in excess of 1.5 knots, with maximum velocities in the narrowest part of the Harbour near Hunt Point exceeding 2.5 knots (depth-averaged) on occasion. The tidal flow patterns outside and within the Inner Harbour are extremely complex, due to the large range in depths and the storage within the multitude of creeks which can extend several kilometres inland.

Current flows past the SBM site are tidally dominated and heavily influenced by the presence of the Goldsworthy Channel that acts as the main conveyance of flow in and out of the Port Hedland Inner Harbour. As a result, there is a strong tidal inequality between flood and ebb tide flows, with markedly stronger flows associated with a flood tide, due to the fact that the majority of ebb tide flow is constrained to the channel, particularly at lower tide levels. Figure 3.3 presents current speed roses from measured data at the DoT AWAC locations (DoTHD01 and DoTHD02) for wet season conditions (Dec 2018 to Apr 2019). Peak flood tide currents speeds of up to 0.7m/s are observed, with peak current speeds of 0.8m/s measured under TC Veronica. Figure 3.4 presents current speed roses from measured data at the DoT AWAC locations (DoTHD01 and DoTHD02) for dry season conditions (May 2019 to Jul 2019). Peak flood tide currents speeds of up to 0.6m/s are observed.

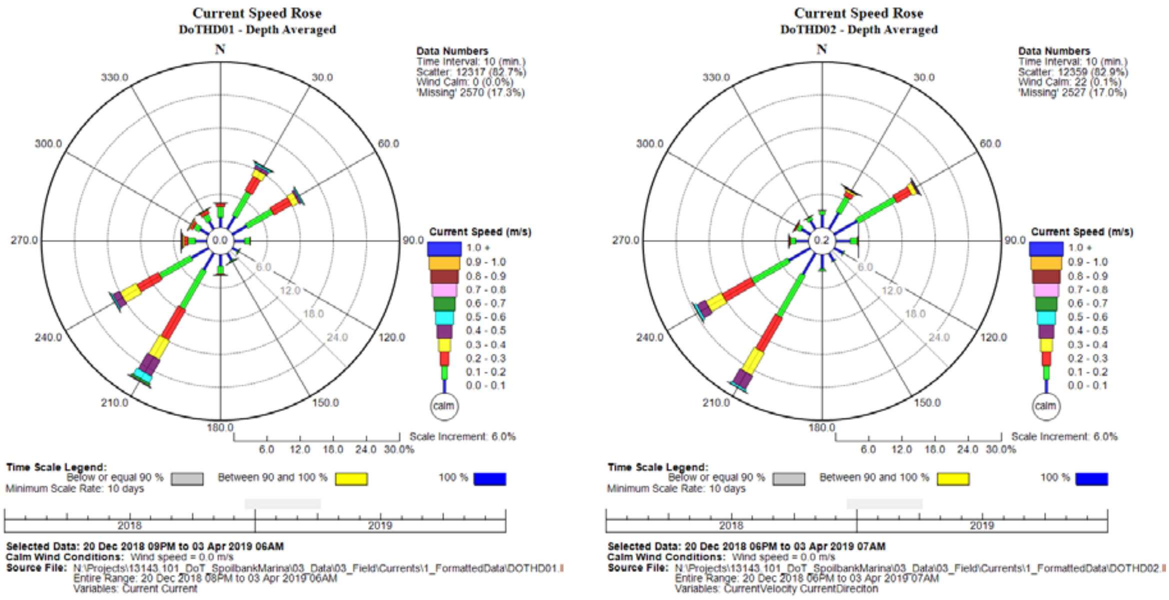


Figure 3.3: Current Speed (Depth-averaged) Roses at the DoTHD01 (left) and DotHD02 (right) AWAC Locations over the period 20 December 2018 to 3 April 2019 – Wet Season. Direction convention is shown as 'Direction Going to'.

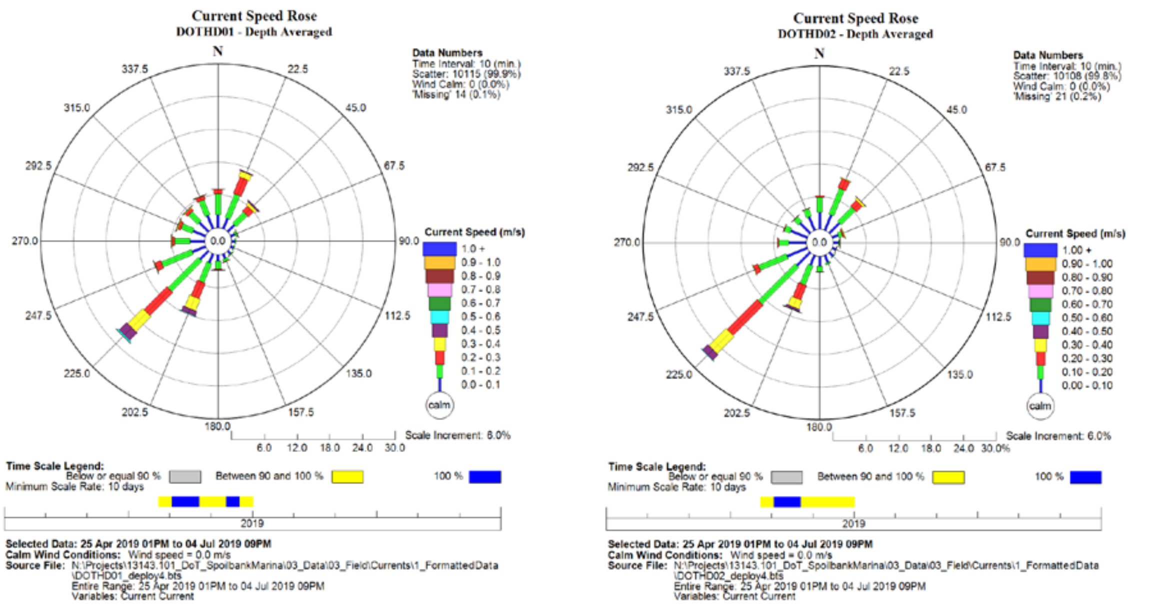


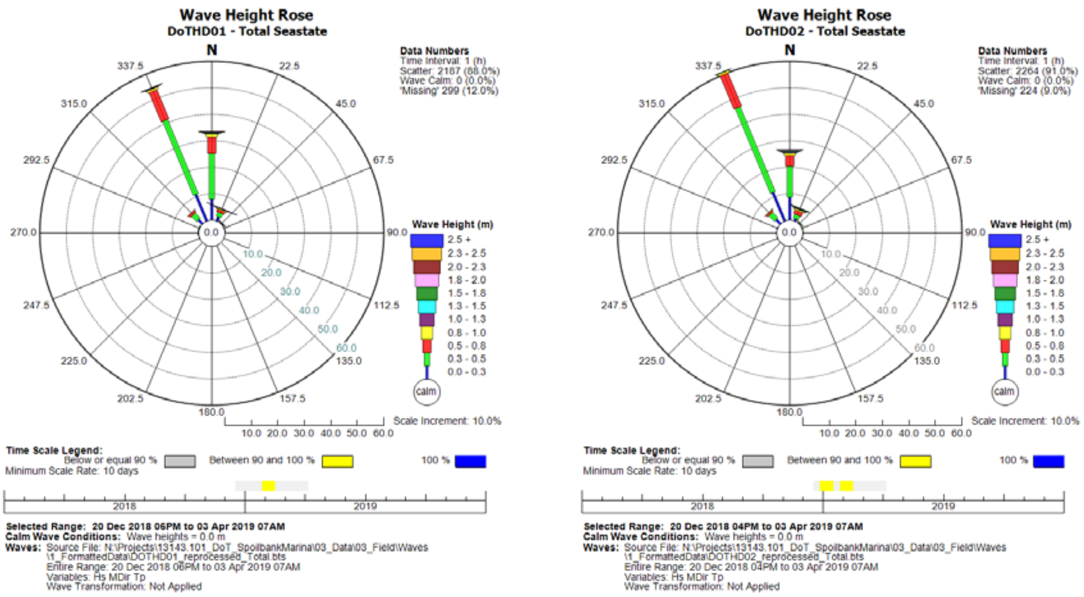
Figure 3.4: Current Speed (Depth-averaged) Roses at the DoTHD01 (left) and DotHD02 (right) AWAC Locations over the period 25 April 2019 to 4 July 2019 – DrySeason. Direction convention is shown as 'Direction Going to'.

3.6 Wave Conditions

The ambient wave climate at Port Hedland is largely described by a persistent north-westerly swell which propagates long distances to the Pilbara coast from the Indian Ocean. These swell waves generally arrive with peak periods of 12 to 18 seconds and are most prevalent during the winter months, though present throughout the entire year. Due to the broad shelf offshore of Port Hedland, swell at the entrance to Port Hedland is normally negligible (Hs<0.1m) and even 15 km offshore, at the Beacon 15/16 wave measurement locations, swell heights (Hs) are normally less than 0.3m.

Locally generated sea waves are also prevalent from the north-west quadrant throughout the year with peak periods of 2 to 9 seconds, typically. These shorter period waves can be comparatively energetic with offshore significant wave heights in excess of 2m during the monsoonal months due to the frequent passage of tropical lows and occasional extreme cyclonic events. During the period from October to April each year, strong westerly sea breezes develop along the coastal waters of the Pilbara which are frequently 15 to 20 kts and can generate westerly seas of 1 to 1.5m (Hs). Wave penetration to the SBM entrance is limited by seabed features such as the Spoilbank land mass and Goldsworthy shipping channel.

Figure 3.5 presents the wave height roses for the DoT AWAC locations for wet and dry season measurement periods. Measured data at the DoT AWAC locations, collected over a 3-month period during the Wet season, indicate that wave conditions are below 1m (Hs) approximately 98% of the time, with wave conditions only exceeding 1m (Hs) during TC Veronica between the 22nd and 26th of March 2019. Ambient wave conditions approach the measurement locations from an almost exclusively North-northwest direction, however notably the larger wave heights during TC Veronica propagate from the North, as demonstrated by the wave height intensity rose in Figure 3.6. During the dry season months (winter), winds are typically easterly, a direction from which the SBM location is protected due to the presence of the Spoilbank and the corresponding wave climate is milder (see Figure 3.5 lower plots).



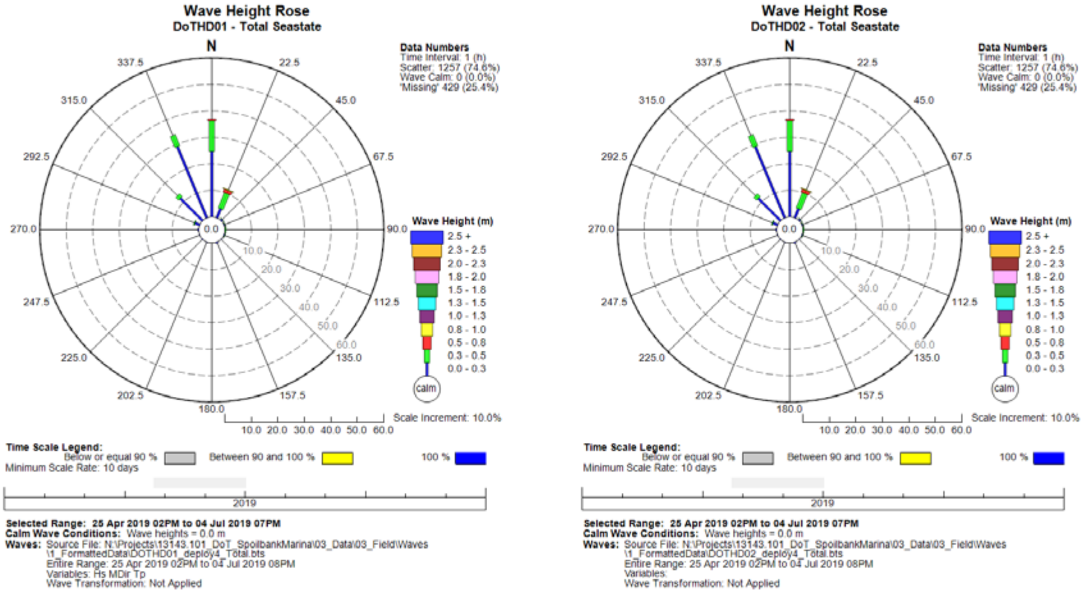


Figure 3.5: Wave Height Roses at the DoTHD01 (left) and DotHD02 (right) AWAC Locations for Wet Season (Summer, top) and Dry Season (Winter, bottom) deployments.

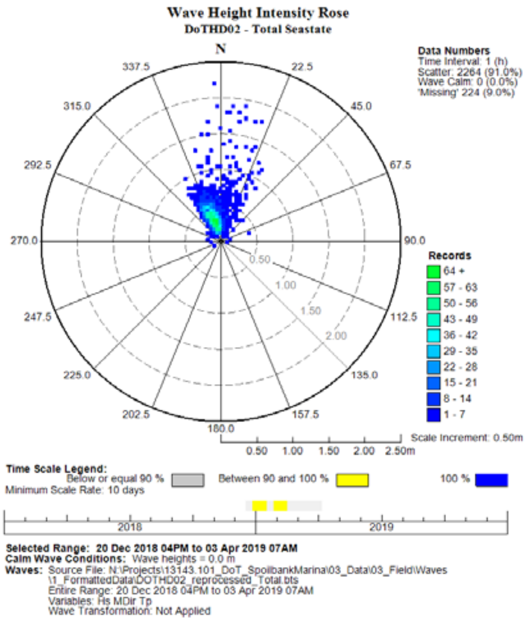


Figure 3.6: Wave Height Intensity Rose at the DoTHD02 AWAC Location over the period 20 December 2018 to 3 April 2019.

3.7 Tropical Cyclones

The Pilbara coastline is the most cyclone-prone region of the Australian mainland, with the area immediately surrounding Port Hedland having the highest frequency of Category 4 and 5 cyclones that make landfall. Approximately 3 cyclones per year, on average, influence the metocean conditions at Port Hedland. Events of this magnitude govern the design criteria for engineering works in the Port Hedland region, including design wave heights and water levels.

3.8 Seasonal Variation

Baird reviewed the latest metocean data set received from the DoT on 2 October 2019 and characterised the seasonal variation in currents and waves for selection of representative wet and dry season conditions. A summary of the seasonal variation of the key metocean parameters is summarised below:-

- Wind: The wet season is dominated by westerly winds which can be particularly strong in the afternoon. The dry season is dominated by east-southeast winds.
- Water Levels: Water levels are dominated by astronomical tide and as a result seasonal processes are minor. There is a trend of higher residual water levels during the mid to late wet season months (Jan-Mar), and reduced residuals in winter. The astronomical tide cycle is governed by the solar-lunar cycle and there are consistent large tide events during particular phases of the annual solar-lunar cycle.
- Currents: Currents are dominated by tide and as a result currents in nearshore areas surrounding the Spoilbank are dominated by astronomical tide with only small seasonal influences.
- Tropical Cyclones: Tropical cyclones typically occur between November and April, although may occur as late as May.

4. Hydrodynamic and Wave Models

This study has utilised a set of hydrodynamic and wave models that were developed for the *Coastal Processes Study (*Baird, 2020) and further expanded the validation of the models including validation of 3D currents. The following sections summarise the setup and validation of the hydrodynamic and wave models.

4.1 Model Systems and Validations

The following numerical models wave been adopted for this study:-

- Shelf-scale Hydrodynamic model (Delft-FM);
- Local-scale Coupled Hydrodynamic and Spectral Wave model (Delft3D FWF) which can be run in coupled FLOW-WAVE-FLOW model, or separately as a hydrodynamic model (FLOW) or wave model (WAVE).

The various modelling components have previously been applied by Baird for a number of coastal processes and design criteria studies at coastal locations on the North West Shelf (NWS), including Port Hedland. The models have been adopted in the Coastal Processes Study for the Spoilbank Marina project (Baird, 2020).

Validation of the numerical model systems and methods has focussed on hydrodynamic and wave conditions that were observed during a metocean data collection deployment completed by the DoT over a 27-week period (approx.), between December 2018 and early July 2019. The validation of the models in this report is focused on ambient, season conditions but the measured data period includes observations from TC Veronica (March 2019) and validation of the hydrodynamic and wave models for that extreme event is presented in Baird (2019).

4.2 Regional Hydrodynamic Model

Baird's regional hydrodynamic model was established using the Delft3D Flexible Mesh Suite (Delft3D FM). A summary of the key features are as follows (from Deltares, 2018):

- Delft3D FM Suite is a multi-dimensional (1D, 2D and 3D) hydrodynamic (and transport) simulation program which calculates non-steady flow and transport phenomena that result from tidal and meteorological forcing on structured and unstructured boundary fitted grids;
- The Delft3D FM Suite can simulate storm surges, cyclones, tsunamis, detailed flows and water levels, waves, sediment transport and morphology, water quality and ecology, and is capable of handling the interactions between these processes;
- D-Flow FM implements a finite volume solver on a staggered unstructured grid. The higher-order advection treatment and near-momentum conservation make the solver very suitable for supercritical flows, bores and dam breaks. The handling of wetting-and-drying makes it suitable for flooding computations; and
- The continuity equation is solved implicitly for all points in a single combined system. Coriolis forcing, horizontal eddy viscosity, tide generating forces and meteorological forcing are incorporated, making the system suitable for tidal, estuarine or river computations.

4.2.1 Model Setup

The Delft3D-FM numerical model grid extent is shown in Figure 4.1. A summary of the Delft3D-FM hydrodynamic model grid and bathymetry setup is as follows:

- The model domain extends across approximately 2000 km of coast and offshore up to 800km.

- A flexible mesh triangular grid with increasing resolution from the offshore to the nearshore areas maximises computational efficiency. Approximate size in offshore areas is 20 km reducing to 500m to 1000m nearshore.
- Bathymetry in the model has been assigned from measured bathymetry and navigational chart information, at a common datum across the model of mean sea level (MSL).
- The model has three offshore boundaries driven by 14 key tidal constituents derived from TOPEX8 (http://volkov.oce.orst.edu/tides/tpxo8_atlas.html, http://volkov.oce.orst.edu/tides/region.html) . The tidal constituents are A0, M2, S2, N2, K2, K1, O1, P1, Q1, M4, MS4, MN4, MM and MF.
- Bed friction is applied in the model as Manning's roughness values

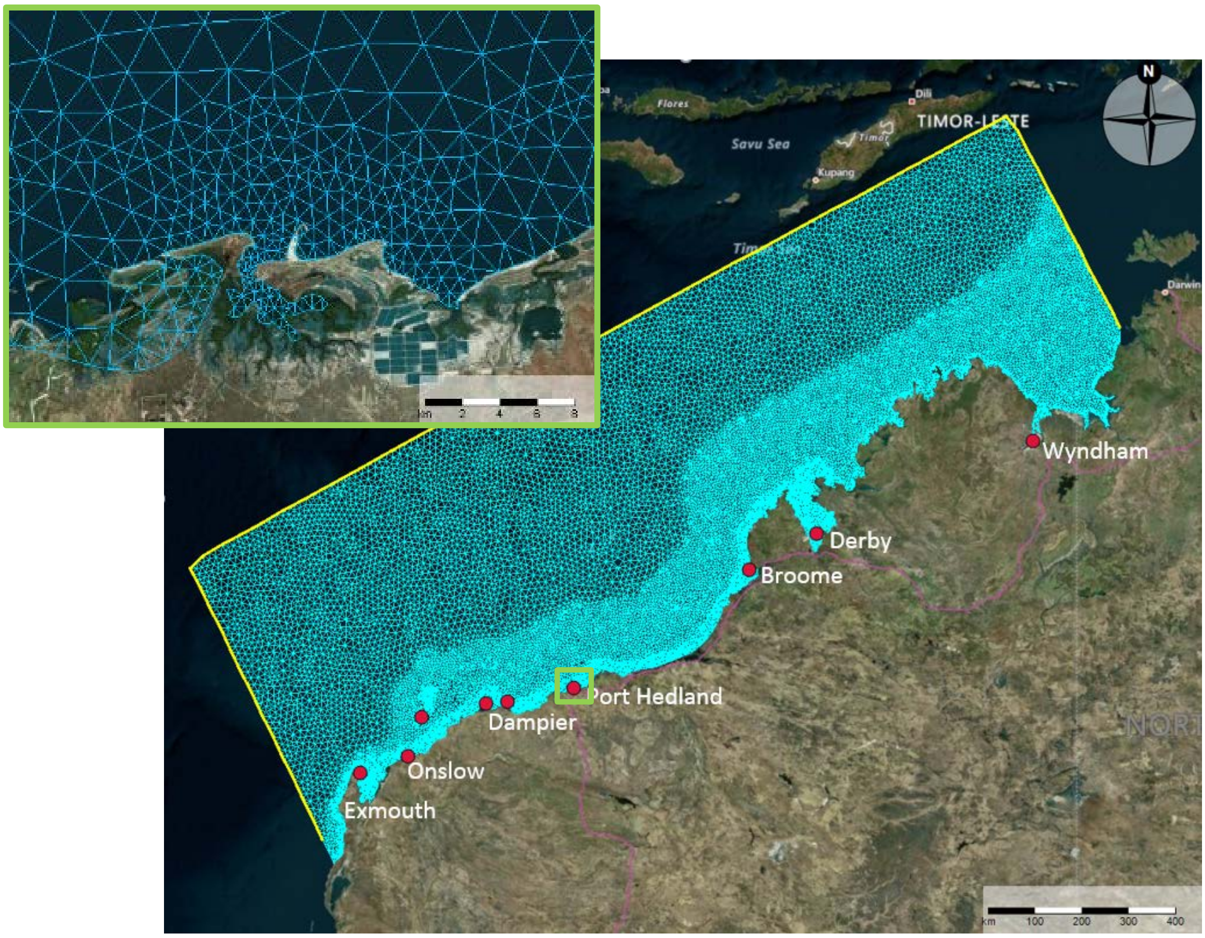


Figure 4.1: Delft3D Flexible Mesh (D-FM) Model Domain of the North West Shelf with detail of model mesh around Port Hedland (insert)

4.2.2 Model Validation – Tidal Hydrodynamics

The regional hydrodynamic model has been validated for general tides at Port Hedland and many other key port locations across the north west shelf. A comparison of predicted and modelled tides is shown in Figure 4.2 indicating excellent agreement across the northwest shelf.

The comparison of modelled water level amplitude and phasing against the reported National Tide Centre (NTC) components for the seven primary tidal constituents is shown on Table 4.1 for Port Hedland based on 1 year of tides (2011). The modelled amplitude and phasing results presented in Table 4.1 show very good agreement to the NTC constituents at the port, providing confidence that the model can accurately simulate the astronomical tide across the Port Hedland region.

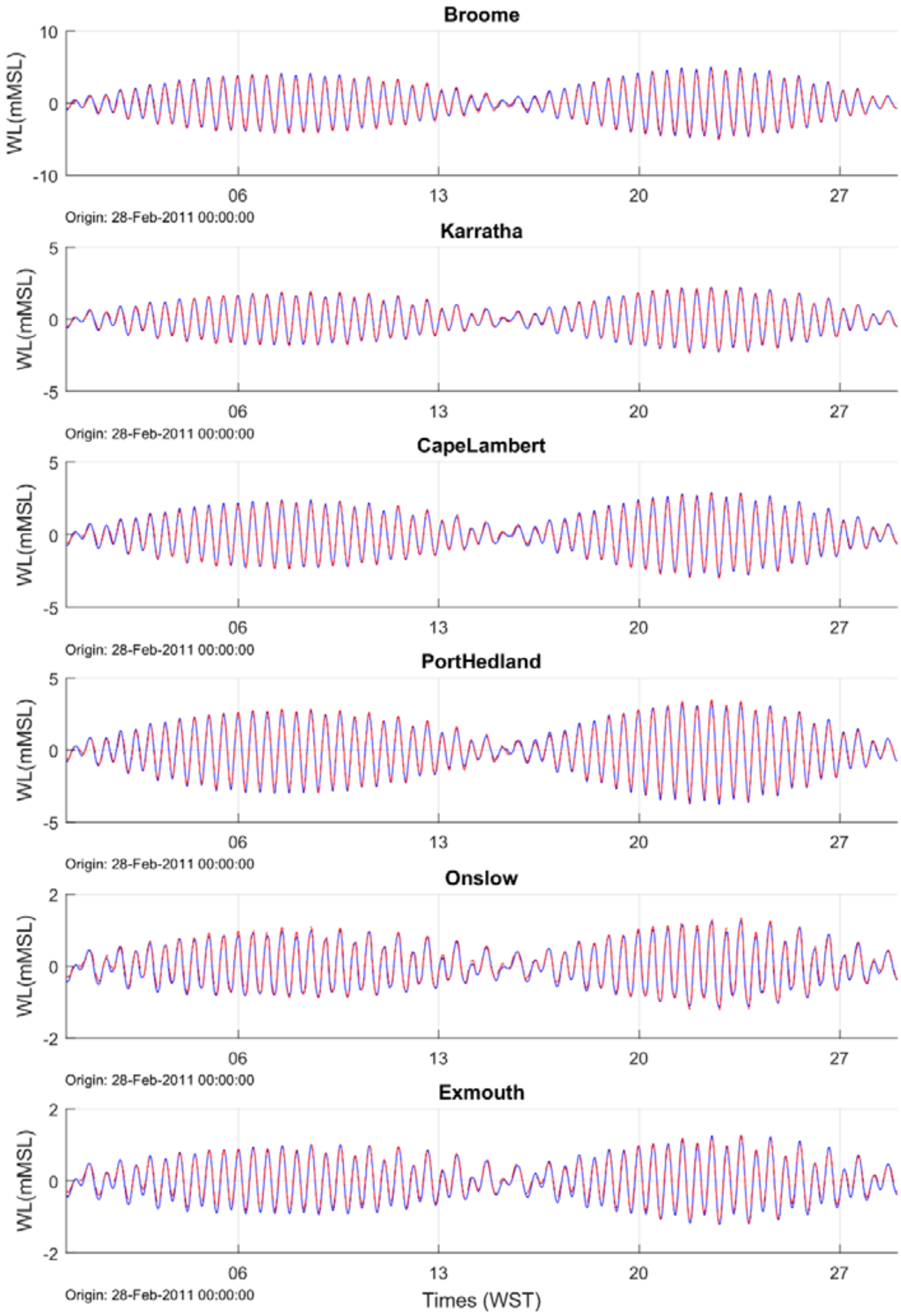


Figure 4.2: Delft3D-FM Hydrodynamic Model Validation: Water Level Comparisons at Six Port Locations on the North West Shelf. Predicted (blue) Modelled (red)

Table 4.1: Model Tidal Validation against NTC Components at Port Hedland

Tidal Constituent	NTC Amplitude	Model Amplitude Difference	Model Phase Difference
M2	1.70	0.7%	-1.3%
S2	1.03	-0.8%	-0.7%
N2	0.29	1.3%	-2.1%
K2	0.29	-1.1%	-0.7%
K1	0.24	0.5%	-0.6%
O1	0.15	4.7%	-0.6%
P1	0.07	8.9%	-0.6%
Q1	0.03	9.3%	-0.6%

4.3 Local Scale Hydrodynamic and Wave Model

To accurately model the joint occurrence and interaction of water levels and waves, a coupled hydrodynamic and wave modelling approach was applied for local scale modelling over the Port Hedland coastal region and SBM site. The Delft3D model system was employed which has previously been adopted by Baird in numerous similar studies and demonstrated to accurately model the storm tide processes at Port Hedland and other coastal locations on the NWS.

4.3.1 Delft3D Flow Wave Flow (FWF)

The local scale Delft3D model allows for coupling of the wave conditions and hydrodynamics through the duration of a cyclone simulation. The modelling approach is termed 'Flow-Wave-Flow' (FWF) with the water levels in the model evaluated in the hydrodynamic model (Flow) and the wave conditions separately evaluated in the waves module (Wave). The key processes affecting water level including radiation stresses are passed across and updated in the hydrodynamic model during the simulation. The FWF process runs continuously through simulation to update and interchange wave and water level information. The effect of waves on current (via forcing, enhanced turbulence and enhanced bed shear stress) and the effect of flow on waves (via set-up, current refraction and enhanced bottom friction) are accounted for within this coupled modelling approach (Deltares, 2015).

Spatial wind and pressure fields active over the model domains influence the wind growth of waves and wind/pressure setup of the water level in the hydrodynamics. Baird's approach is to update spatial wind and pressure fields every 30 minutes for cyclonic conditions and 120 minutes for ambient conditions, and to align coupling interval of hydrodynamics and waves with the input forcing.

4.3.2 Delft3D-Flow Model Setup

The layout of the Delft3D-Flow model is shown in Figure 4.3 and summarised as follows:

- The hydrodynamic model setup is established as a Domain Decomposition model, which allows dynamic two way coupling of structured domains, to maximise the efficiency of the model simulations, with three hydrodynamic grids that increase in resolution from offshore into the SBM site at the entrance to Port Hedland and a fourth covering the Inner Harbour:

- Outer 315m Grid - extending 40km offshore and approx. 35km east and west of the site;
- Nearshore 45m Grid – extending to the 10m (approx.) offshore depth contour. Total Grid area 10km x 5km;
- Local 15m Grid - overlays the Spoilbank and adjacent nearshore and channel areas. Total Grid Area 3.5km x 4km.
- Inner Harbour 45m Grid – covering the Port Hedland Inner Harbour and intertidal tributaries.

- Boundary conditions at the outer boundary are derived from hydrodynamic output from the regional scale hydrodynamic model (see Figure 7). These are input as time series of water levels across boundary points at approximately 5km interval around the outer domain;
- A model timestep of 0.25 minutes (15 seconds) was adopted.

The model bathymetry has adopted the survey data specified in Section 0 and other regional scale data set that Baird had available. A digital bathymetry model was developed during the *Coastal Processes Study* (Baird, 2019) and the model bathymetry adopted in the Delft3D for this study is the same as Baird (2019).

Previous validation of a local scale Delft3D coupled hydrodynamic/wave model for Mermaid Sound (Karratha) determined that a change in the model wind drag coefficients produced improved validation for storm surge and tide for historical cyclone cases. Full details are documented in Churchill et al (2017). The same wind drag parameterisation was therefore applied to both the Delft3D Flow and regional scale Delft-FM models for this study. The adopted wind drag coefficient, as a function of wind speed, was:

- Wind Speed (m/s) = 0 20 60
- Wind Drag Coefficient (Cd) = 0.001 0.0025 0.0025

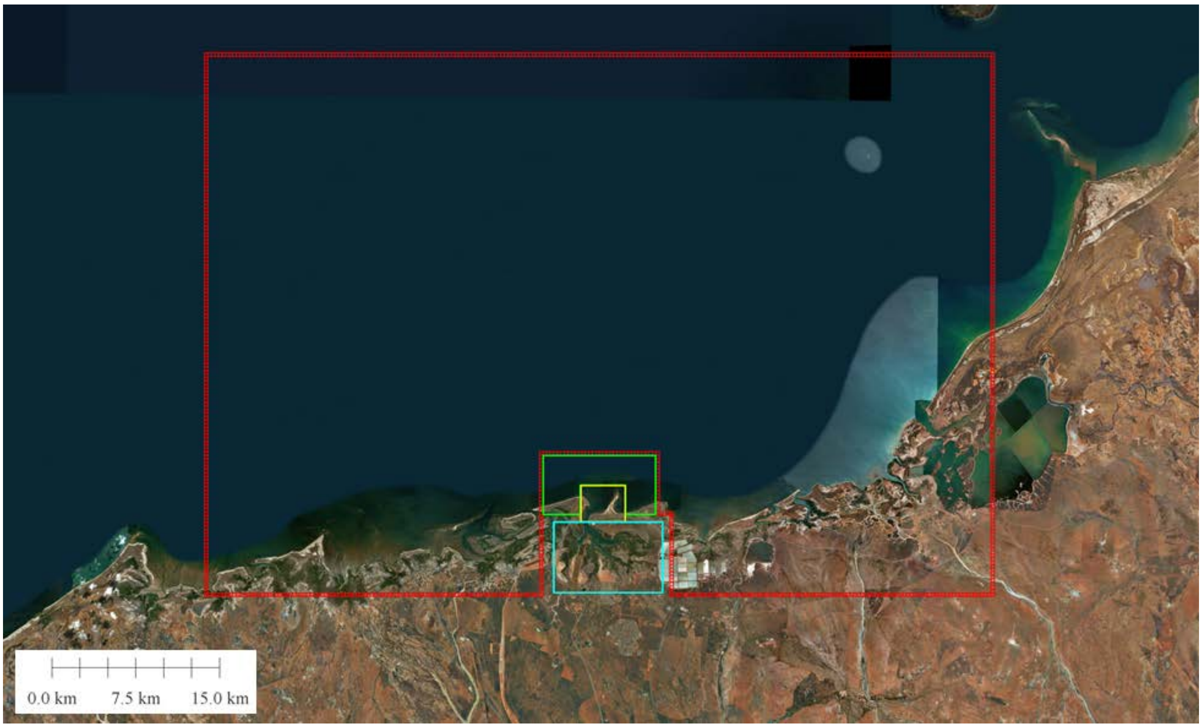


Figure 4.3: Local Delft3D Flow-Wave-Flow Model Layout. Outer grid (red) is 315m resolution, Nearshore grid (green) is 45m resolution, Local grid (yellow) is 15m resolution and the Inner Harbour grid (blue) is 45m resolution.

A 3D version of the Delft3D model has been developed for the water quality modelling study that has adopted a six (6) vertical (sigma) layer model schematisation for the Local grid area defined in Figure 4.3. The vertical layer thickness is variable with smaller vertical (higher resolution) near the surface and seabed where stress gradients are larger. The layer thickness as a proporation of water depth (top to bottom) that has been adopted is: 10%, 15%, 25%, 25%, 15% and 10%.

4.3.3 Delft3D-Wave Model Setup

The Delft3D-Wave system applies the Deltares SWAN (Simulating WAves Nearshore) model which is a 3rd generation spectral model. The SWAN model was used to both transfer wave conditions from offshore and develop locally generated wave conditions and propagate the resulting wave energy to the Mermaid Sound facilities under extreme cyclonic wind forcing.

The SWAN model can account for the following physics (Deltares, 2015):

- wave refraction over a bottom of variable depth and/or a spatially varying ambient current;
- depth and current-induced shoaling;
- wave generation by wind;
- dissipation by whitecapping;
- dissipation by depth-induced breaking;
- dissipation due to bottom friction (three different formulations);
- nonlinear wave-wave interactions (both quadruplets and triads);
- wave blocking by flow;
- transmission through, blockage by or reflection against obstacles; and
- diffraction.

The model grid layout and resolution replicate the Delft3D flow model, increasing in resolution from offshore to the Spoilbank area (see Figure 4.3), however the Inner Harbour grid is excluded.

- The bed friction in the model is based on a JONSWAP bottom friction formulation value of 0.067 m^2/s^3 which was found to be suitable for cyclonic wind sea conditions (consistent with Deltares 2018);
- Offshore boundary conditions were applied as directional spectra derived from the WW3 model. The boundary points were spaced at approximately 5km interval around the outer domain.

4.3.4 Model Validation – 2D Ambient Hydrodynamics

Validation of the tidal hydrodynamics was completed for a spring neap phase during typical 'wet' season ambient conditions that occurred in January 2019. Comparisons of the modelled water level and currents at the DoTHD01 AWAC location (see Figure 2.5) is presented in Figure 4.4, and at the DoTHD02 AWAC location presented in Figure 4.5. Model validation statistics are included in Figure 4.4 and Figure 4.5. To provide a like-for-like comparison of current speeds, the depth averaged values from the model were adjusted to reflect the 0.6m blanking distance between the seabed and the lowest recorded depth from the AWAC. The resulting comparisons show good agreement for current speed and direction.

Dry season model validation time series and statistics for a model simulation period covering June 2019 are presented in Figure 4.6 and Figure 4.7. The resulting comparisons show good agreement for depth-averaged current speed and direction during dry season conditions.

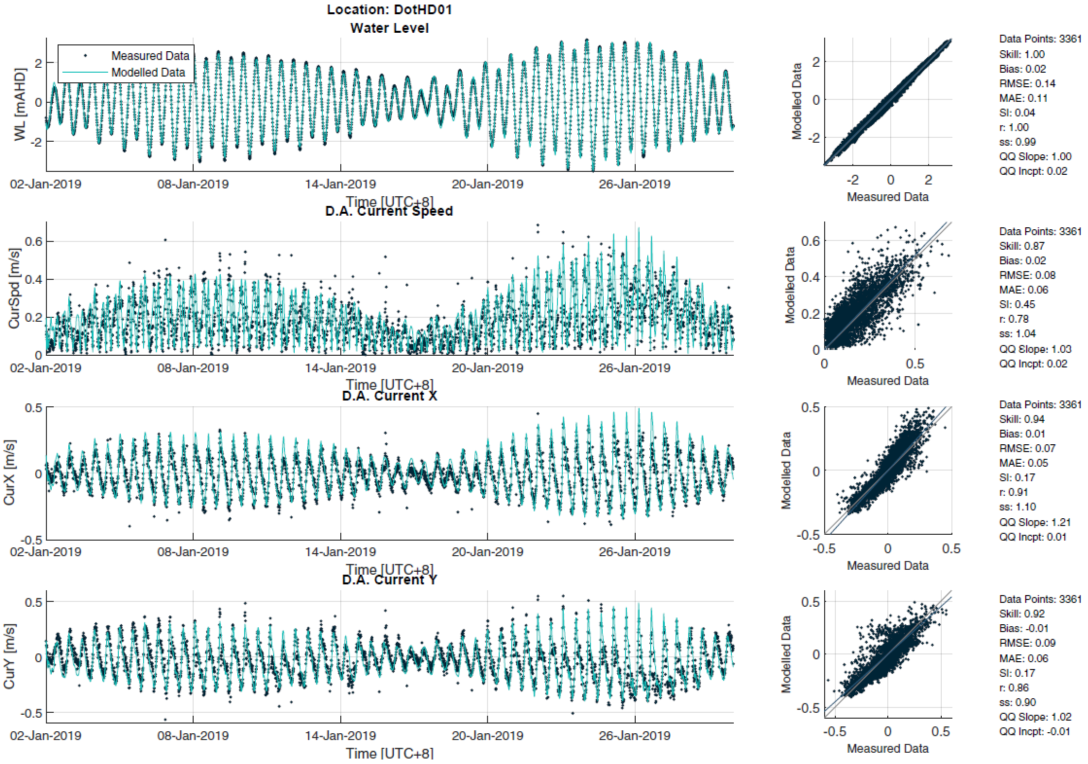


Figure 4.4: Water level and 2D (depth-averaged) Current (Mag, U, V directions) validation at the DoTHD01 AWAC location: Wet Season Conditions

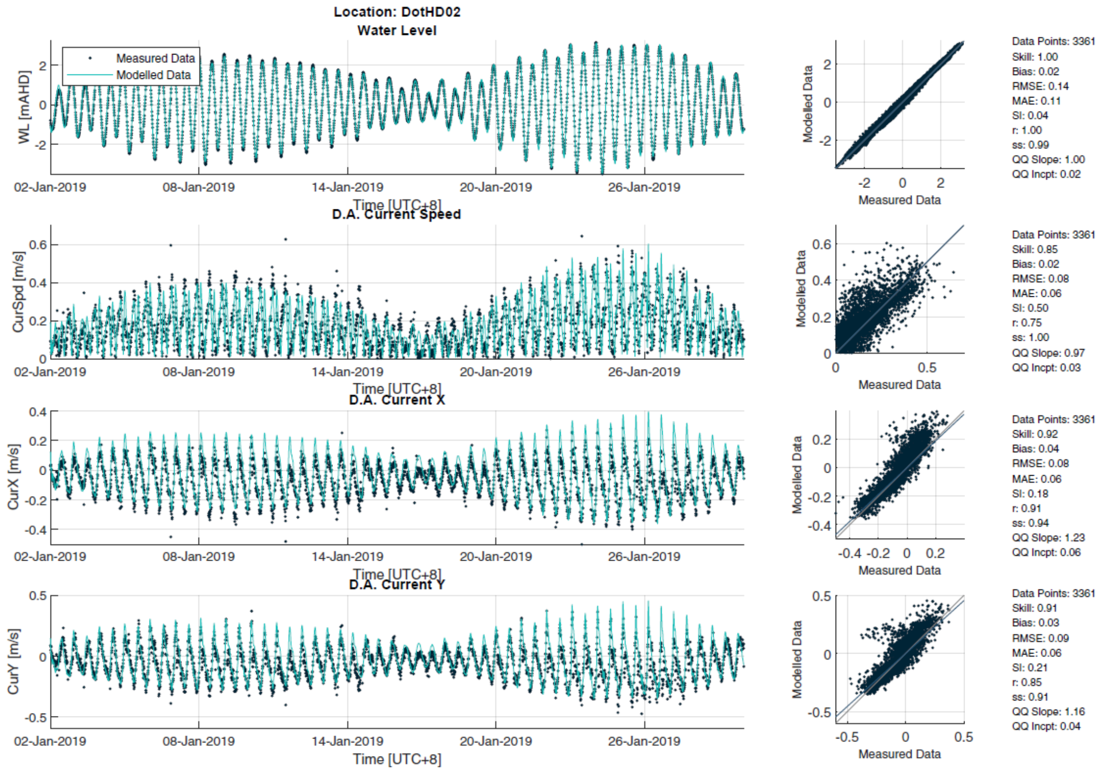


Figure 4.5: Water level and 2D (depth-averaged) Current (Mag, U, V directions) validation at the DoTHD02 AWAC location: Wet Season Conditions

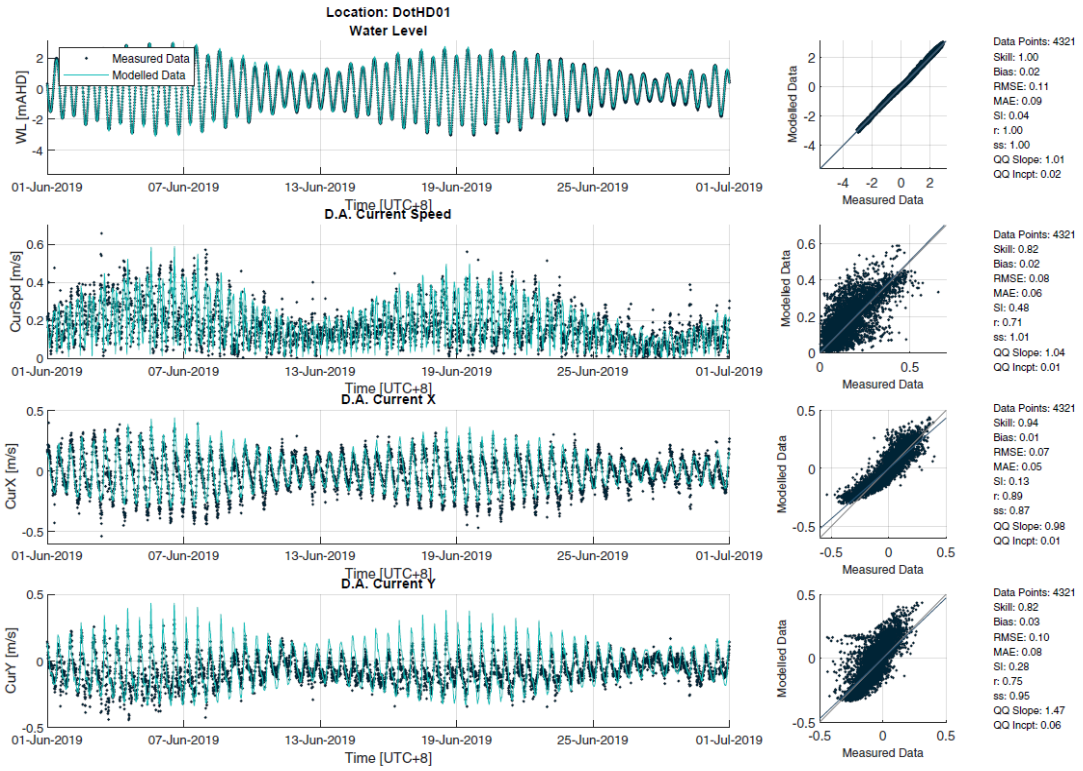


Figure 4.6: Water level and 2D (depth-averaged) Current (Mag, U, V directions) validation at the DoTHD01 AWAC location: Dry Season Conditions

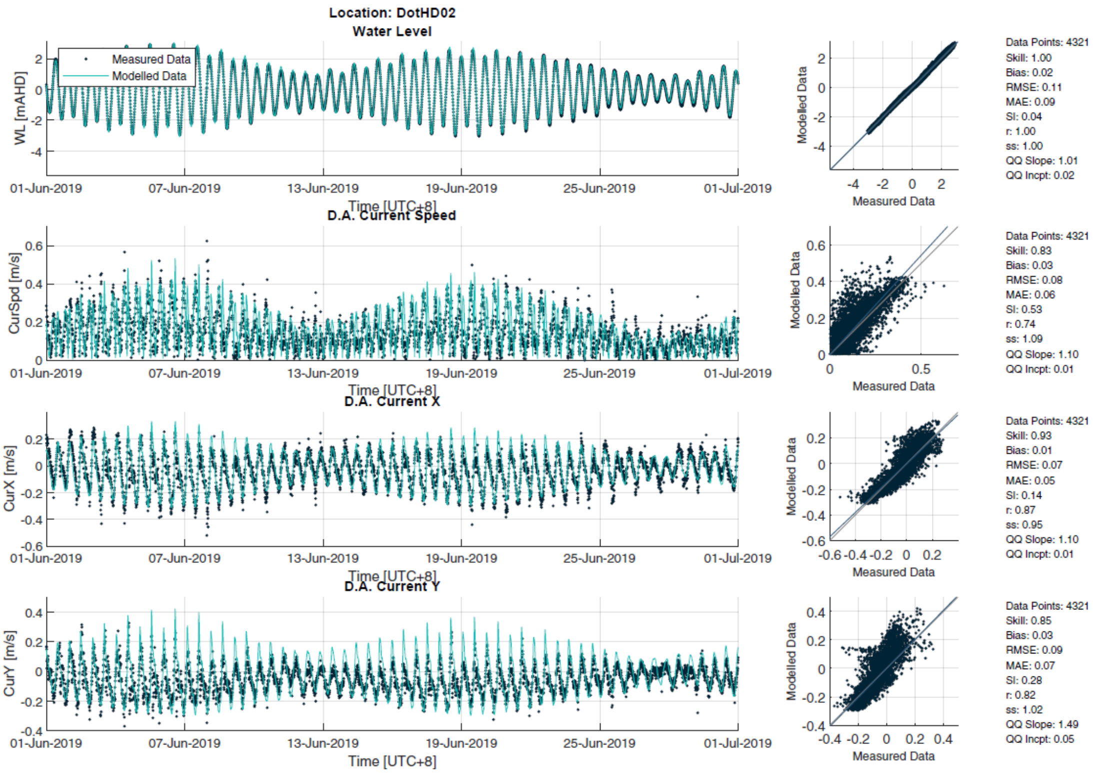


Figure 4.7: Water level and 2D (depth-averaged) Current (Mag, U, V directions) validation at the DoTHD02 AWAC location: Dry Season Conditions

4.3.5 Model Validation – 3D Ambient Hydrodynamics

Validation of the tidal hydrodynamics for 3D has been completed and is summarised below for the January 2019 model simulation period. For comparison with modelled data, it was observed that the measured data from the highest elevation (above seabed) bin could be variable and appeared unreliable at times. As a result, the model comparisons have focused on the 'near-surface' level which presents the upper 10% to 25% of the water column. The AWAC instrument has a blanking distance above the seabed and therefore cannot measure at seabed currents. Similarly, the 'near-bed' data is based on modelled and measured currents from the lower 10% to 25% of the water column.

Figure 4.8 and Figure 4.9 present comparisons of modelled and measured near-surface (model layer 2) and near-bed (model layer 5) current magnitude and direction at locations DoTHD01 and DoTHD02 respectively. At both sites, the modelled relative variation between near-bed and near-surface currents is reasonably consistent with near-surface currents approximately 20% higher than the near-bed currents. This variation between modelled near-bed and near-surface currents agrees well with the normal trend observed in the measured data.

Appendix A.1 present complete time series and validation metrics for near-surface and near-bed modelled and measured currents at locations DoTHD01 and DoTHD02 respectively for the 1-month wet and dry season model validation period wet season simulation period between 2 January 2019 and 31 January 2019. Model validation at both sites and for all layers in the water column is good and reasonably consistent for the two model sites.

Appendix A.2 present complete time series and validation metrics for near-surface and near-bed modelled and measured currents at locations DoTHD01 and DoTHD02 respectively for the dry season simulation period between 1 June 2019 and 1 July 2019. Model validation at both sites and for all layers in the water column is good and reasonably consistent for the two model periods. In most situations, the Delft3D model has a 20% variation in current magnitude between near-bed and near-surface.

Figure 4.8: 3D model validation at the DoTHD01 AWAC location: comparison of modelled and measured near-surface and near-bed current magnitude and direction.

Figure 4.9: 3D model validation at the DoTHD02 AWAC location: comparison of modelled and measured near-surface and near-bed current magnitude and direction.

4.3.6 Model Validation – Ambient Wave Conditions

Validation of the wave conditions near the Spoilbank Marina development has been completed using the coupled Delft3D-FWF model described in Section 4.3.1. Baird (2020) demonstrated that waves in the nearshore areas offshore of the western shoreline of the Spoilbank are significantly modulated by tide and therefore to model the effect of wave forcing it is essential that the water level variation is included in the wave model.

Modelled and measured wave at the DoTHD01 and DoTHD02 AWAC locations is presented for the December 2018 period in Figure 4.10 and Figure 4.11. Model validation metrics are included in the plots. December wind conditions are typically dominated by prevailing westerly seabreezes which generate seas from the west to northwest and those conditions are most significant with respect to the local sea wave climate impacting on the Spoilbank Marina development site. Overall model validation is reasonable and suitable for the purposes of dredge plume and water quality modelling. The wave climate is mild at the site and characterised by short period seas.

Modelled and measured wave at the DoTHD01 and DoTHD02 AWAC locations is presented for the June 2019 period in **Figure 4.12** and **Figure 4.13**. Model validation metrics are included in the plots. June wind conditions are typically dominated by prevailing south-easterly winds which generate seas from the north at the Spoilbank Marina development site. Also, during the winter period small amplitude long period swells can dominate during calm wave periods. Overall model validation is good for the dry season conditions and suitable for the purposes of dredge plume and water quality modelling. The wave climate is mild at the site and characterised by short period seas.

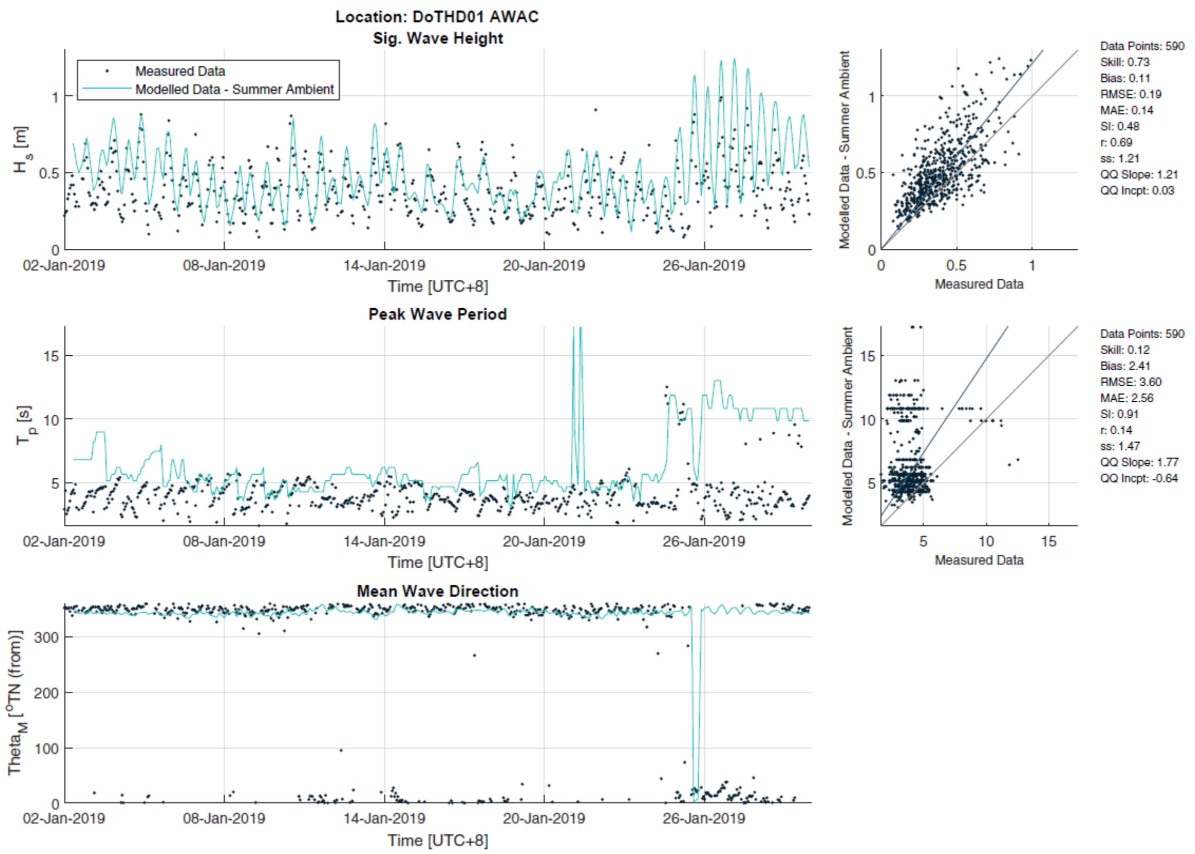


Figure 4.10: Wave height, period and direction validation at the DoTHD01 AWAC location: Wet Season Jan 2019.

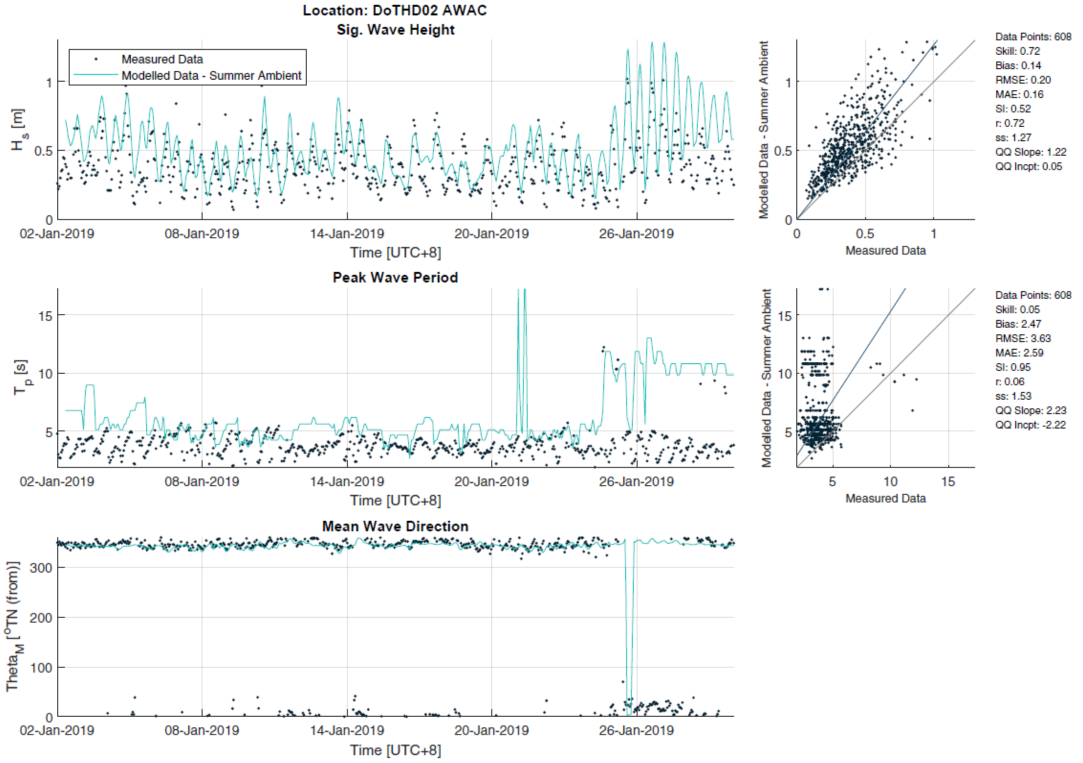


Figure 4.11: Wave height, period and direction validation at the DoTHD02 AWAC location: Wet Season Jan 2019.

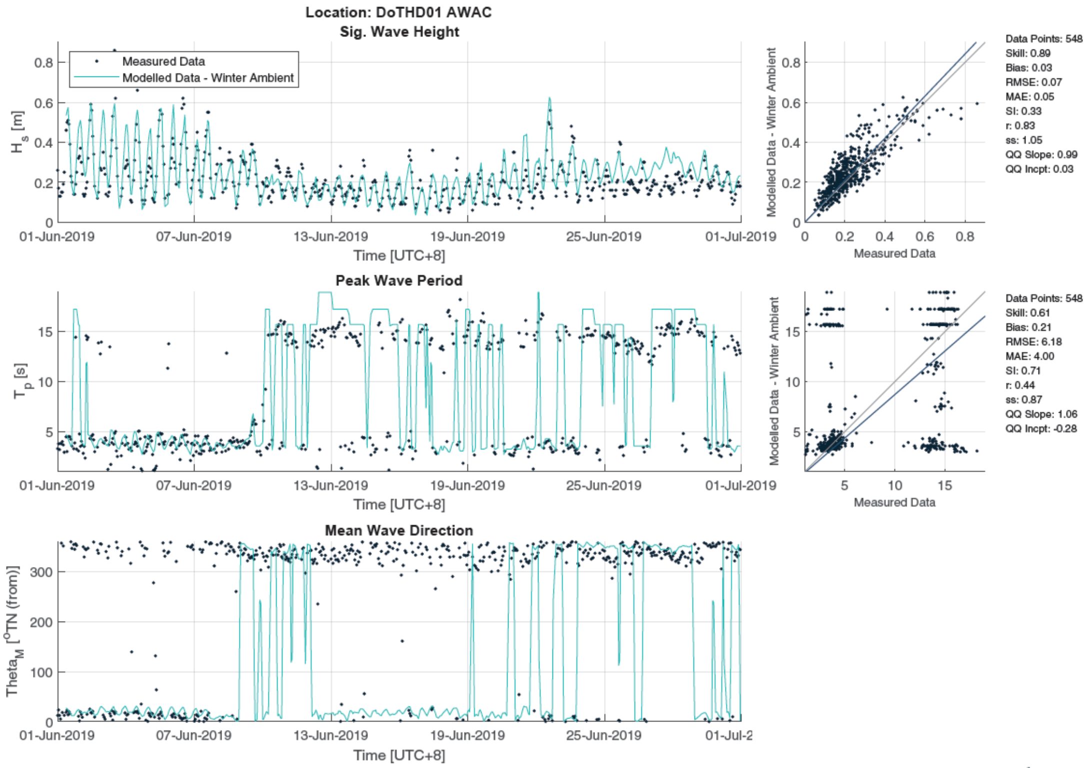


Figure 4.12: Wave height, period and direction validation at the DoTHD01 AWAC location: Dry Season Jun 2019.

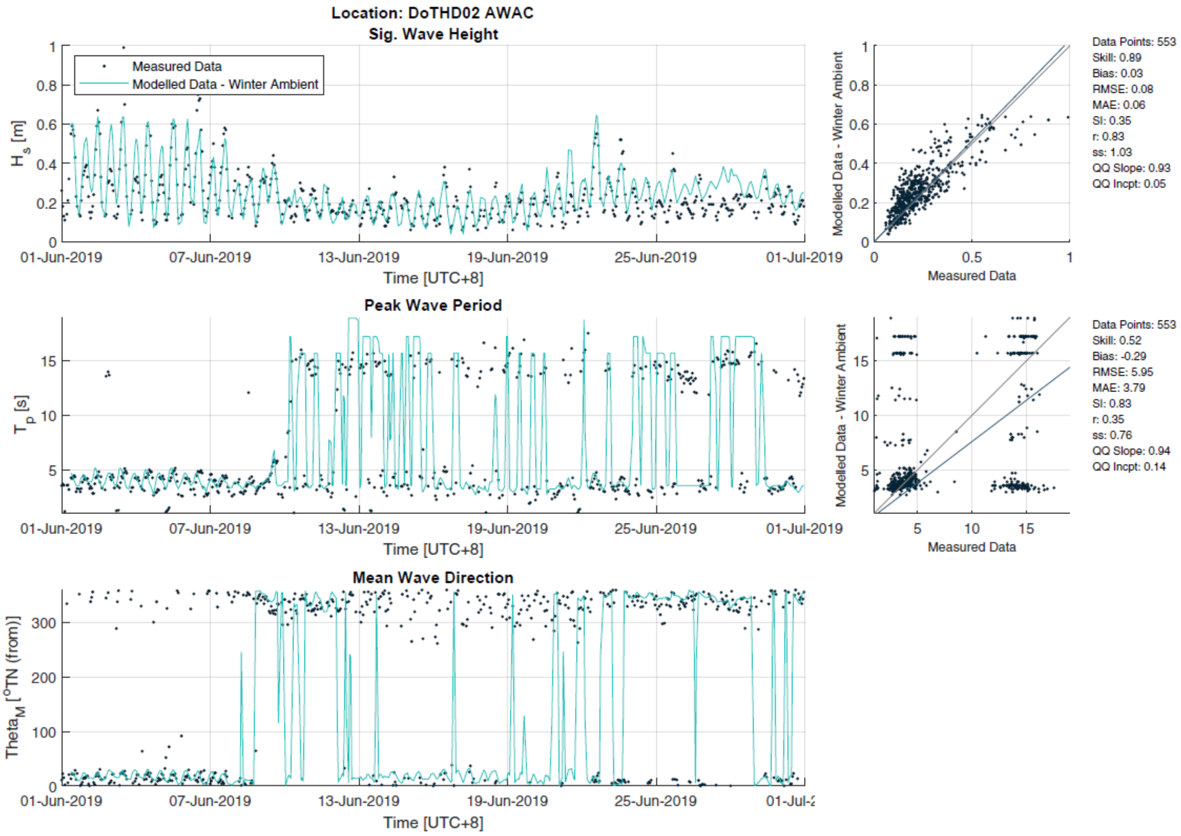


Figure 4.13: Wave height, period and direction validation at the DoTHD02 AWAC location: Dry Season Jun 2019.

5. Marina Flushing and Spill Assessment

5.1 Marina Flushing Assessment

The following section presents an assessment of the marina flushing for a range of tide and wind forcing conditions. Flushing time can be estimated by introducing a conservative tracer, such as dye, at a constant concentration into the system and examining the rate at which the concentration decays. Concentrations will decrease approximately exponentially as tracer is flushed from the SBM system under the general tidal regime in conjunction with wind forcing. The time required for tracer concentration to attain e^{-1} times (≈37%) its initial concentration, is referred to as the e-folding time (Te) and is an estimator of the flushing time.

The model simulations have adopted the following:

- Initial conservative tracer concentration of 100 (relative units) inside the SBM basin and entrance channel.
- The 6-layer 3D model grid specified for the Local 15m Grid (see Section 4.3.2);
- The base case entrance layout for the Marina basin as specified in Figure 1.2; and
- The basin layout and bathymetry as specified in Figure 5.1.

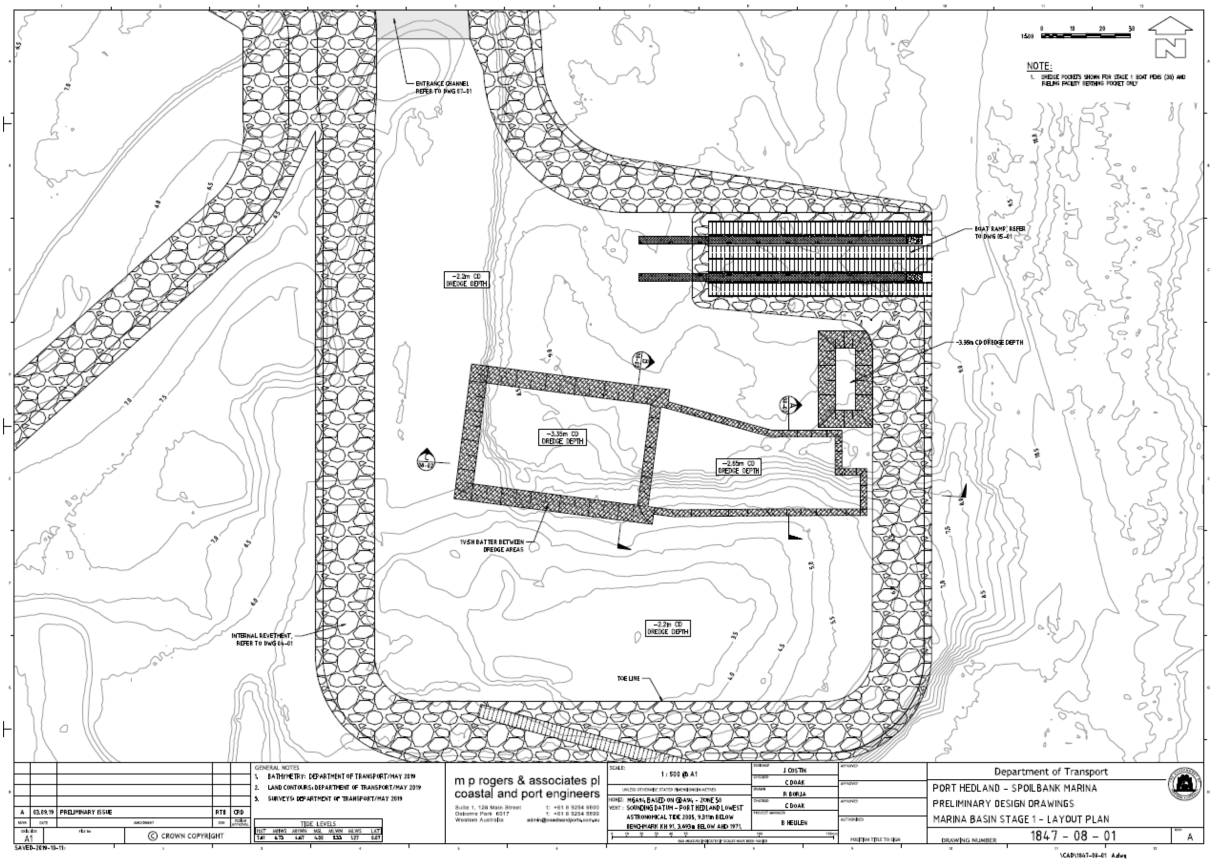


Figure 5.1: Marina Basin Updated Design (Ref: DWG 1847-08-01.pdf)

5.1.1 Modelling Scenarios

The two key metocean forcing processes for flushing of the marina will be tide conditions and local winds.

To investigate the flushing of the marina basin 10 metocean scenarios have been assessed in the model investigation to represent a range of flushing conditions:

- Normal (mean) spring tide conditions:
  1. Typical wet season wind conditions;
  2. Typical dry season wind conditions;
- Normal (mean) neap tide conditions with typical wet and dry season wind conditions and 'calm' wind conditions;
  3. Typical wet season wind conditions;
  4. Typical dry season wind conditions;
  5. Calm wind conditions;
- Extreme neap tide condition (small variation LW to HW) with typical wet and dry season wind conditions and 'calm' wind conditions:
  6. Typical wet season wind conditions;
  7. Typical dry season wind conditions;
  8. Calm \wind conditions;
- Alternative tide scenarios:
  9. Spring with typical dry season conditions; Typical wet season wind conditions;
  10. Neap with typical dry season conditions.

Analyses from historical data to characterise typical and worst-case wet and dry season tides has been completed to determine the cases to model for the flushing assessment. The case selection is summarised in Table 5.1.

The Port Hedland tidal planes are shown in Table 5.1. Based on the tidal planes the spring tide range is on average 5.4 m and the neap tide range is on average 1.4 m. The probability of occurrence for the cases is shown in Figure 5.2 based on analysis of the water level from Berth 3 over the period 2011 to 2018 (8 years).

The measured winds from the BoM location at Port Hedland Airport have been analysed to characterise the dry season and wet season wind conditions for model simulations. Winds have been applied as constant 50%-percentile wind speeds for the seasonal conditions and as demonstrated in the results (see Sections 5.1.2 and 5.2.3) the local wind conditions are not significant in terms of the flushing of the marina with respect to water exchange and mixing with surrounding coastal waters and also vertical mixing of the water column inside the marina. The winds speeds adopted for the simulations are:

- Wet Season: 5.7 m/s @ 315^{o}TN; and
- Dry Season: 4.6 m/s @ 135^{o}TN.

For the calm scenarios, no wind was applied in the model cases based on the potential for the developed case breakwater structures to completely shield the marina basin and entrance channel from wind.

Table 5.1: Flushing Simulations Case Selection

Case	Water Level Range	Date	Winds
1. Normal Spring Tide – Typical Wet Season Wind	5.4m	14th Jan 2010 (Figure 5.3)	Based on P50 Winds, with direction dominated from NW
2. Normal Spring Tide – Typical Dry Season Wind	5.4m	14th Jan 2010 (Figure 5.3)	Based on P50 Winds, with direction dominated from E SE
3. Normal Neap Tide – Typical Wet Season Wind	1.4m	14th Jan 2010 (Figure 5.3)	Based on P50 Winds, with direction dominated from NW
4. Normal Neap Tide – Typical Dry Season Wind	1.4m	14th Jan 2010 (Figure 5.3)	Based on P50 Winds, with direction dominated from E SE
5. Normal Neap Tide – Calm Wind	1.4m	14th Jan 2010 (Figure 5.3)	No wind
6. Extreme Neap – Typical Wet Season Wind	0.04m	8th October 2004 (Figure 5.5)	Based on P50 Winds, with direction dominated from NW
7. Extreme Neap – Typical Dry Season Wind	0.04m	8th October 2004 (Figure 5.5)	Based on P50 Winds, with direction dominated from E SE
8. Extreme Neap – Calm Wind	0.04m	8th October 2004 (Figure 5.5)	No wind
9. Alternative Spring Tide – Typical Dry Season Wind	5.4m	4th January 2010 (Figure 5.6)	Based on P50 Winds, with direction dominated from E SE
10. Alternative Neap Tide – Typical Dry Season Wind	1.4m	9th January 2010 (Figure 5.6)	Based on P50 Winds, with direction dominated from E SE

The modelling examines flushing conditions for the range of conditions. The water level timeseries for the various scenarios are presented in Figure 5.3, Figure 5.4, Figure 5.5 and Figure 5.6.

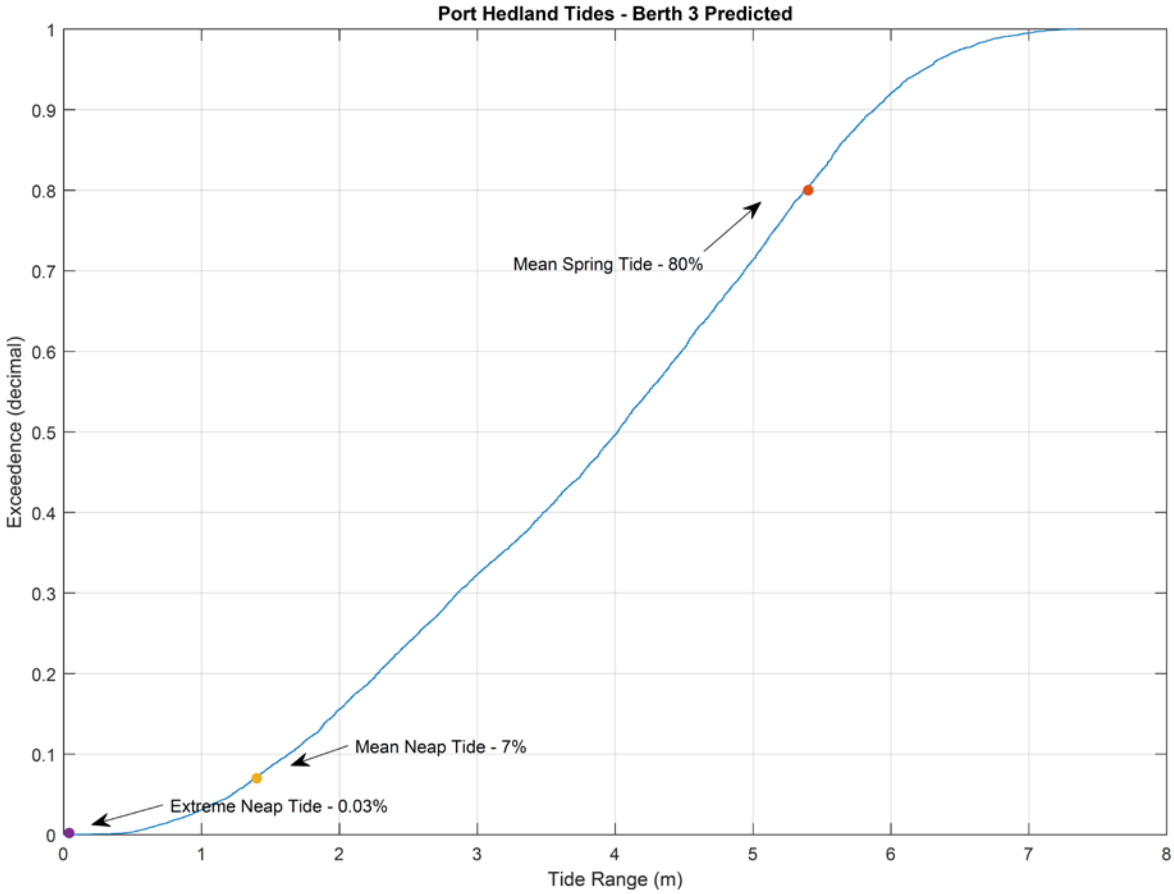


Figure 5.2: Analysis of water levels from Berth 3 to determine probability of Exceedence for mean spring tide range, neap tide range and extreme neap tide scenarios

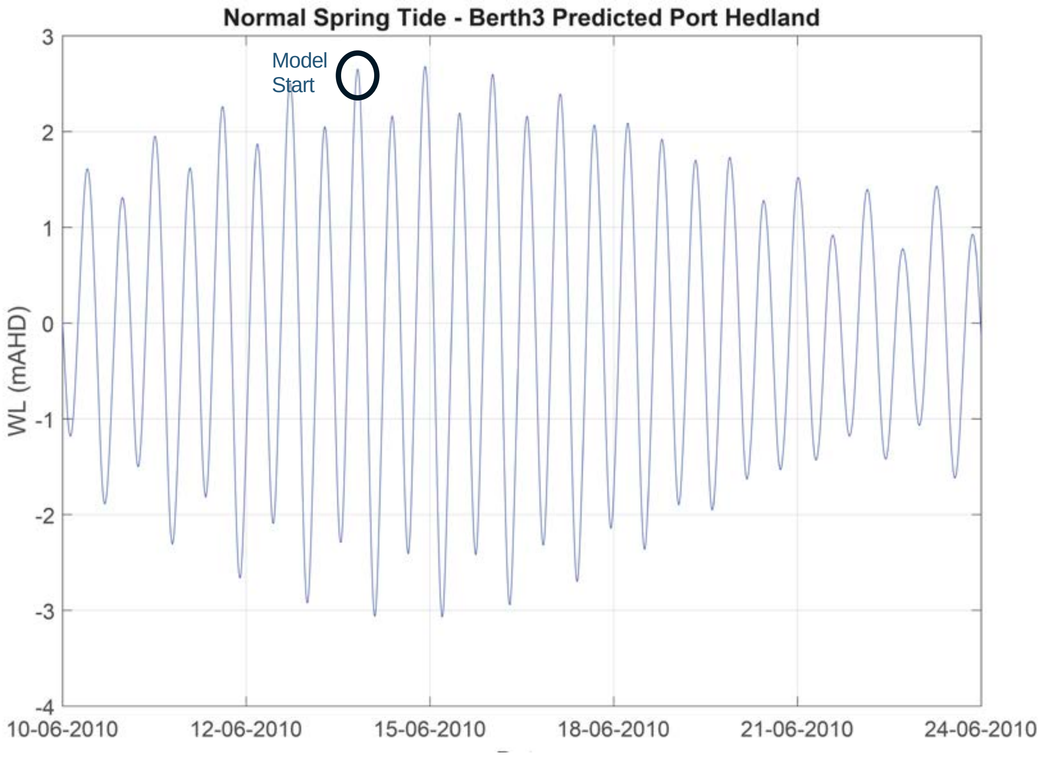


Figure 5.3: Normal Spring tide Case, Dry Season. Water Level time series with target spring tide condition shown at 22 June 2001.

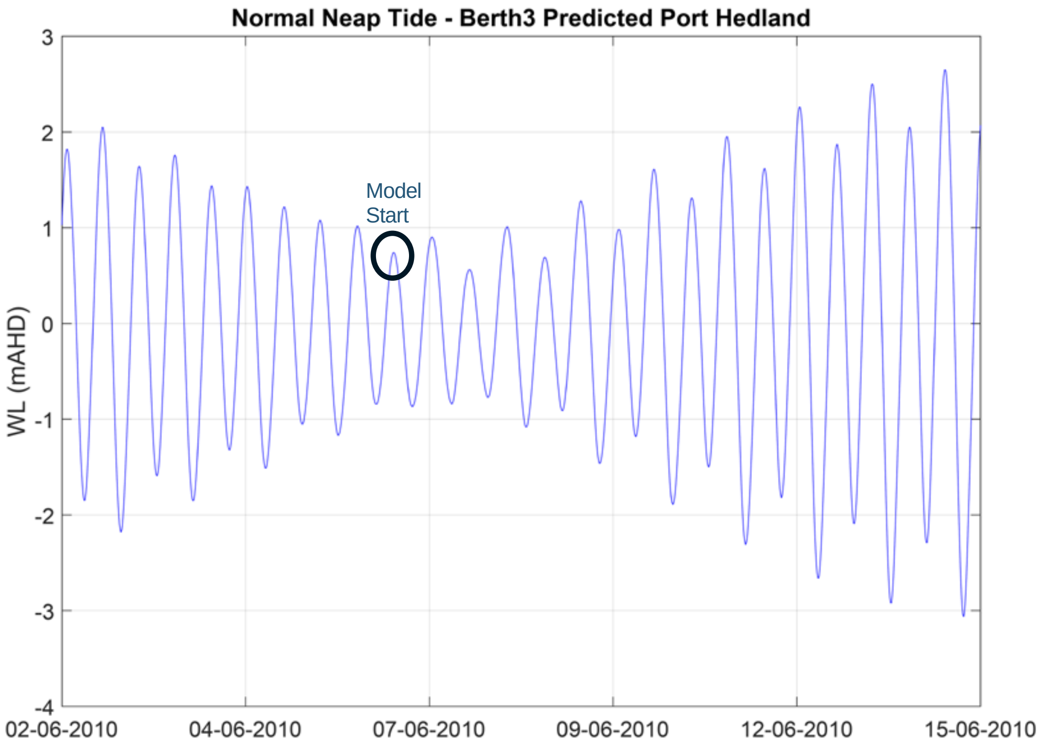


Figure 5.4: Normal Neap Tide Case, Wet Season. Water Level time series with target spring tide condition shown at 6 June 2010 2003.

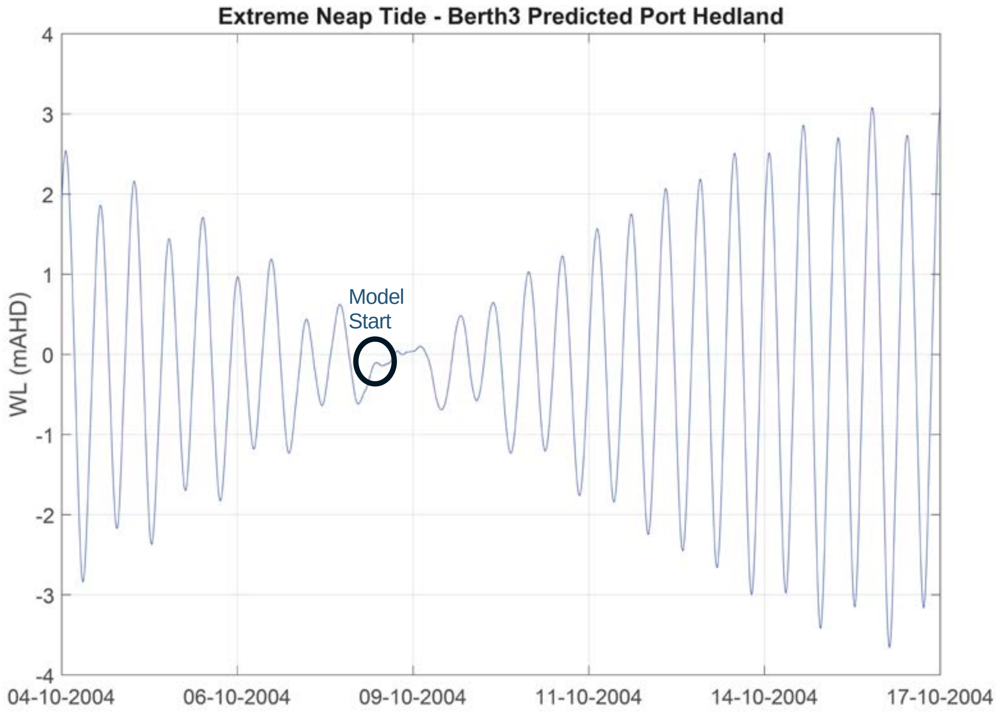


Figure 5.5: Extreme Neap Tide Case. Water Level time series with target extreme neap condition shown at 9 October 2004.

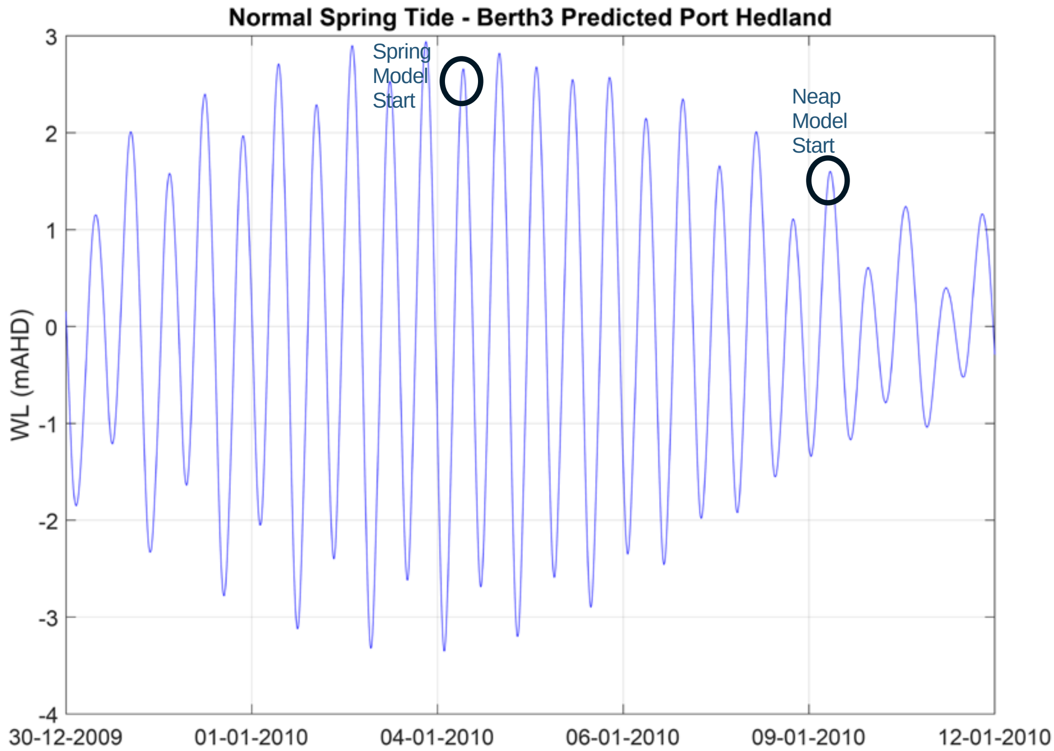


Figure 5.6: Alternative Normal Spring and Neap Tide Cases. Water Level time series with target spring and neap tide conditions.

5.1.2 Flushing Results

The flushing simulations have identified that e-folding times of the marina basin are short, ranging between 24-hours for spring tides up to 50-hours for small neap tides. Overall, local wind conditions have a small effect compared to tides on the overall flushing of the marina.

Figure 5.7, Figure 5.8, Figure 5.9, Figure 5.10 and Figure 5.11 present time series of water level and tracer concentrations for the ten flushing scenarios summarised in Table 5.1. A summary of e-folding time for three locations inside the marina basin is presented in Table 5.2. Appendix B presents spatial plots of tracer concentration (mid-depth) for spring (Case 2), neap (Case 4) and extreme neap (Case 7) tide scenarios. For extreme neap tide conditions, flushing rates increase significant after the first 18-hours when advection of water out of the marina basin is low. Overall, flushing times are small for all tide conditions and recirculation of marina water, characterised by water which exits the marina on the ebb tide and returns on the following flood tide, is low.

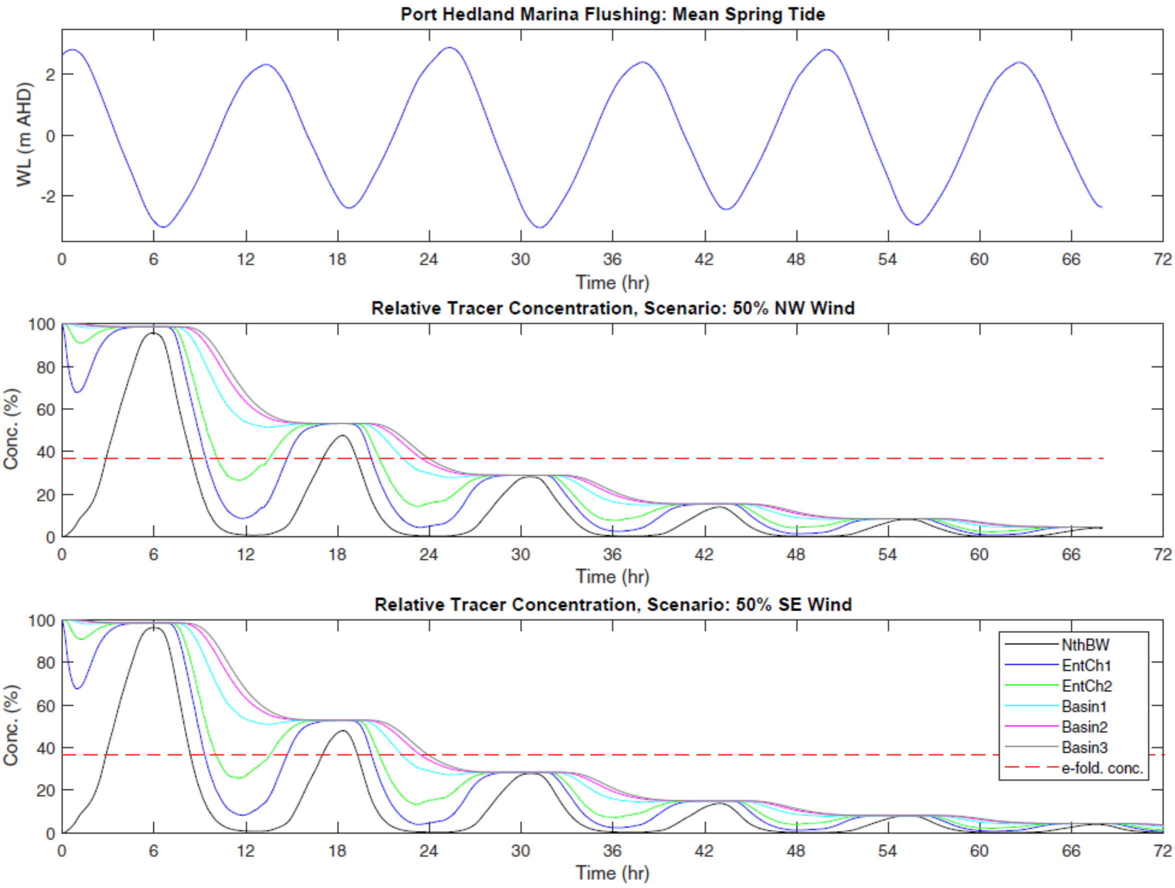


Figure 5.7: Tracer concentration time series (mid-depth): Mean Spring Tide Scenarios (Cases 1, 2)

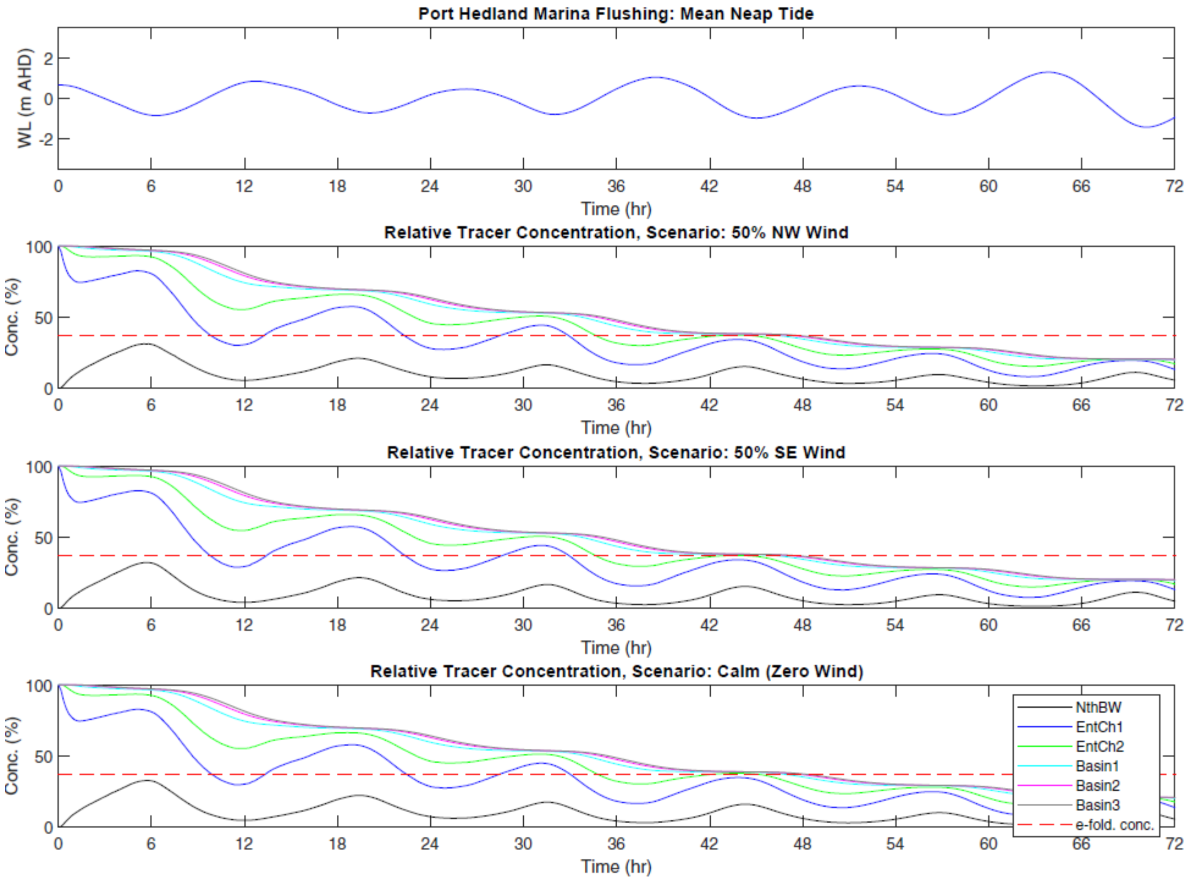


Figure 5.8: Tracer concentration time series (mid-depth): Mean Neap Tide Scenarios (Cases 3, 4, 5)

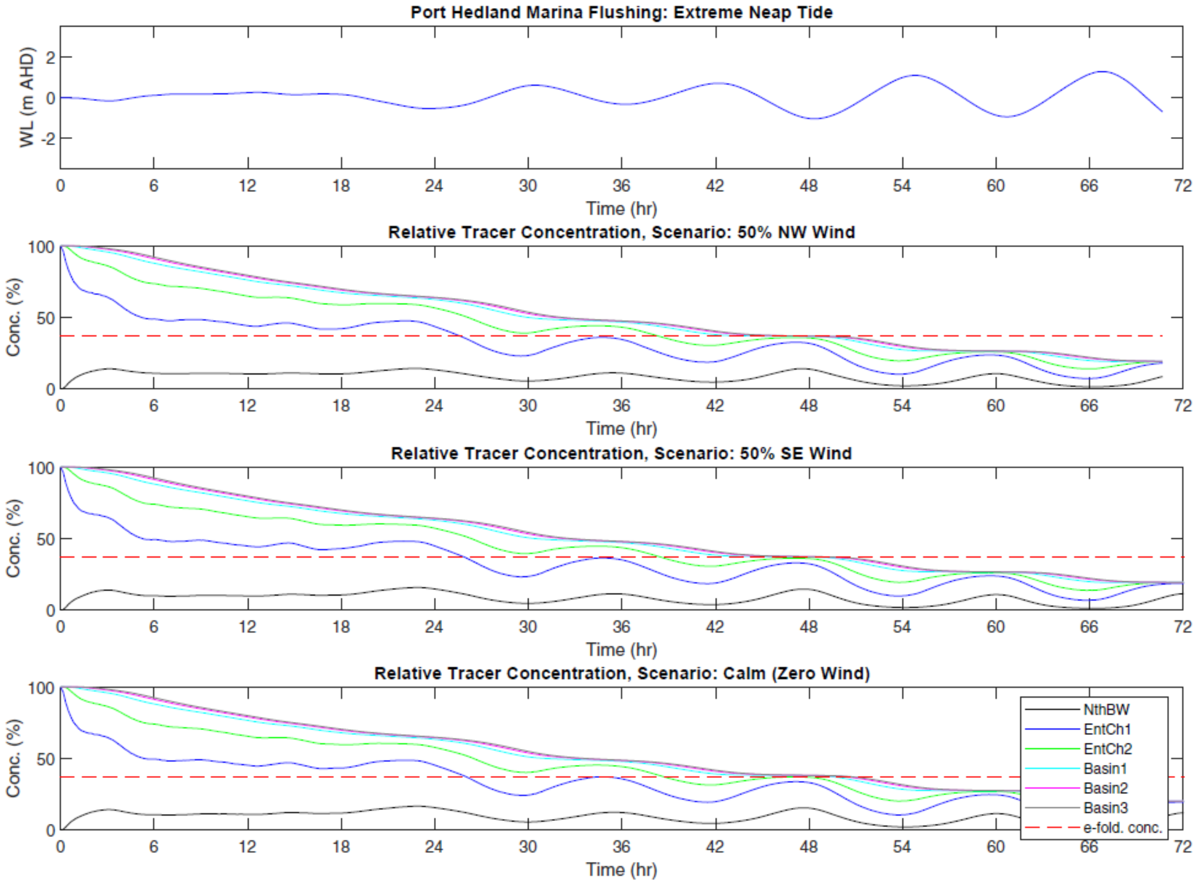


Figure 5.9: Tracer concentration time series (mid-depth): Extreme Neap Tide Scenarios (Cases 6, 7, 8)

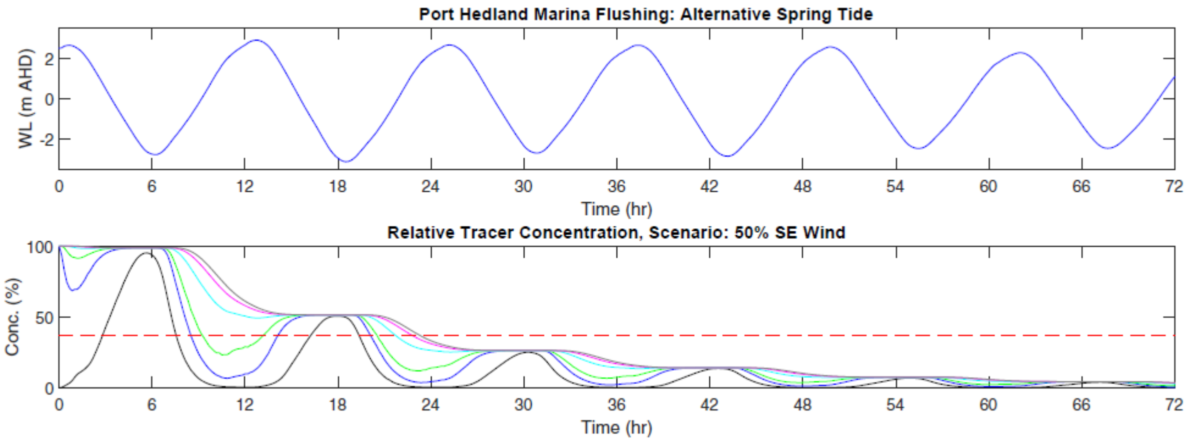


Figure 5.10: Tracer concentration time series (mid-depth): Alternative Neap Tide Scenario (Case 9)

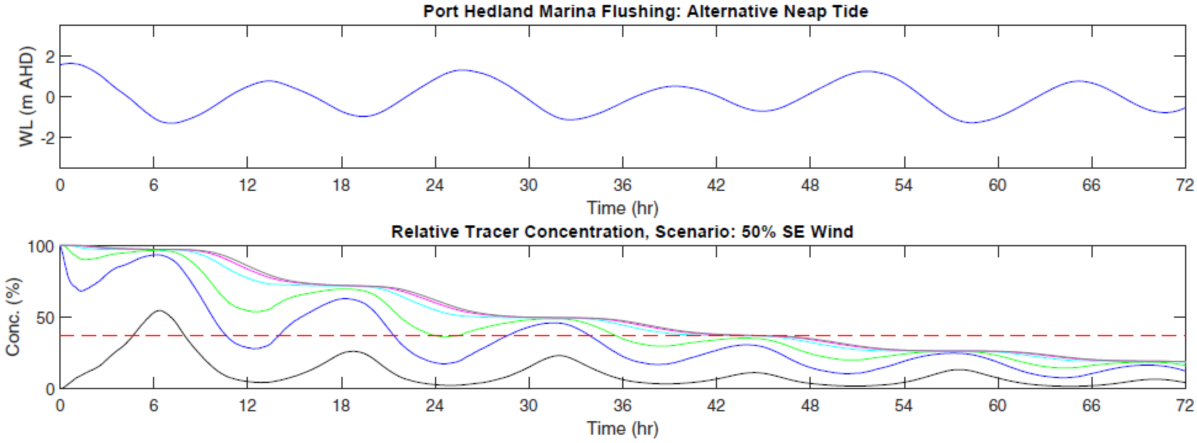


Figure 5.11: Tracer concentration time series (mid-depth): Alternative Neap Tide Scenario (Case 10)

Table 5.2: E-Folding Time (Mid-depth) – Flushing Scenarios

Case	WL Range	Basin 1 – NE	Basin 2 – Centre	Basin 3 – SE	Average
		e-Folding Time (hr)			
1. Normal Spring Tide – Typical Wet Season Wind	5.4m	23.5	23.5	24.0	**23.7**
2. Normal Spring Tide – Typical Dry Season Wind	5.4m	22.3	23.5	24.0	**23.3**
3. Normal Neap Tide – Typical Wet Season Wind	1.4m	46.7	47.7	48.0	**47.4**
4. Normal Neap Tide – Typical Dry Season Wind	1.4m	46.5	47.5	47.8	**47.3**
5. Normal Neap Tide – Calm Wind	1.4m	47.2	48.0	48.5	**47.9**
6. Extreme Neap – Typical Wet Season Wind	0.04m	47.5	48.7	49.0	**48.4**
7. Extreme Neap – Typical Dry Season Wind	0.04m	48.8	49.7	50.2	**49.6**
8. Extreme Neap – Calm Wind	0.04m	49.8	50.7	51.0	**50.5**
9. Alternative Spring Tide – Typical Dry Season Wind	5.4m	21.8	22.8	23.3	**22.7**
10. Alternative Neap Tide – Typical Dry Season Wind	1.4m	43.8	45.2	45.5	**44.8**

5.2 Potential for Salinity and Temperature Enhancement within the Marina Basin

5.2.1 Water Quality Statistics

A summary of the measured water temperature and salinity statistics from available measured data near the entrance to Port Hedland (BHP, 2009, site HPD) is shown in Table 5.3. These have been adopted for offshore boundary conditions in the 2D/3D numerical modelling presented in the following sections. Water temperatures in Table 5.3 agree with the data measured by DoT in 2019 near the entrance to the SBM as presented in Figure 2.6.

Table 5.3: Salinity and Temperature Statistics (BHP 2009)

Percentile	Wet Season		Dry Season	
	Salinity	Temperature	Salinity	Temperature
P20	37.3 ppt	24.1 deg	32.0 ppt	20.4 deg
P50[1]	38.3 ppt	28.4 deg	36.0 ppt	24.5 deg
P80	39.3 ppt	32.8 deg	39.9 ppt	28.5 deg

1. Inferred from Average of P20 and P80

5.2.2 2D Modelling of Salinity and Temperature

Initial modelling of temperature and salinity processes was undertaken using a localised 2D model (Local Grid, Figure 5.12) to examine the potential for temperature and salinity enhancement within the SBM. The modelling adopted a dynamic heat model (solar radiation, temperature and evaporative transfer) and salinity model that includes evaporative losses.

Modelling of potential salinity and temperature enhancements within the Marina basin was undertaken using the local grid of the validated Delft3D model covering the Spoilbank and shipping channel. The model extent is presented in Figure 5.12. The model configuration included the following:

- The 2D model was run for a year over a predicted tide for 2018 with the model inputs described in sTable 5.4 and included wind, air temperature, relative humidity, radiation and evaporation processes;
- The 50th percentile salinity and water temperature values for wet and dry seasons (see Table 5.3) were adopted as initial conditions and also open boundary conditions;
- Modelled wet season period is defined as between December to March and the dry season between June to September with the interpolation of salinity and temperature values in the periods between the seasons; and
- Preliminary simulations were undertaken in both 2D and 3D, however as there was minimal vertical stratification seen in the 3D model, the 2D model was determined to have sufficient description of the salinity and temperature at the site.

sTable 5.4: Data Sources used in the Flushing Model for Salinity Differences in the Marina Basin

Variable	Description	Source
Water Levels	Predicted water levels for all of 2018 generated from T-tide analysis of measured tide at Beacon 31 at Port Hedland from 20/12/18 - 30/04/19	PPA
Salinity	Average baseline measured salinity values for the wet and dry seasons from the Water Quality and Cora Health Report	BHP Billiton. (2009). Rgp6 Port Facilities Baseline Water Quality and Coral Health Report.
Water Temperature	Average baseline measured temperature values for the wet and dry seasons from the Water Quality and Cora Health Report	BHP Billiton. (2009). Rgp6 Port Facilities Baseline Water Quality and Coral Health Report.
Wind	Measured wind speed and directions at 30 min intervals from Port Hedland Airport for 2018 for initial local grid 2D simulations. Spatial CFSR winds for 3D simulation of Jan 2018.	BoM, NCAR
Air Temperature, Relative Humidity, Net Radiation	Measured air temperature, relative humidity, and net radiation at 30 min intervals from Port Hedland Airport for 2018	BoM
Evapotranspiration	Measured Daily Evapotranspiration for Port Hedland Airport for 2018 interpolated as mm/hr	BoM

Model outputs for the first three months of the simulation (all within the simulated wet season) were extracted for comparisons of salinity and temperature at two locations, from within the marina basin and outside the marina in the shipping channel, as presented in Figure 5.13. The comparisons indicate: -

- The maximum depth-averaged salinity within the marina basin was 38.5 ppt compared to the maximum ambient salinity within the model of 38.3 ppt; and
- Temperatures within the marina basin over the first three months of the model run were 30.8 deg, being 1.9 deg higher than the maximum in the channel of 28.9 deg.

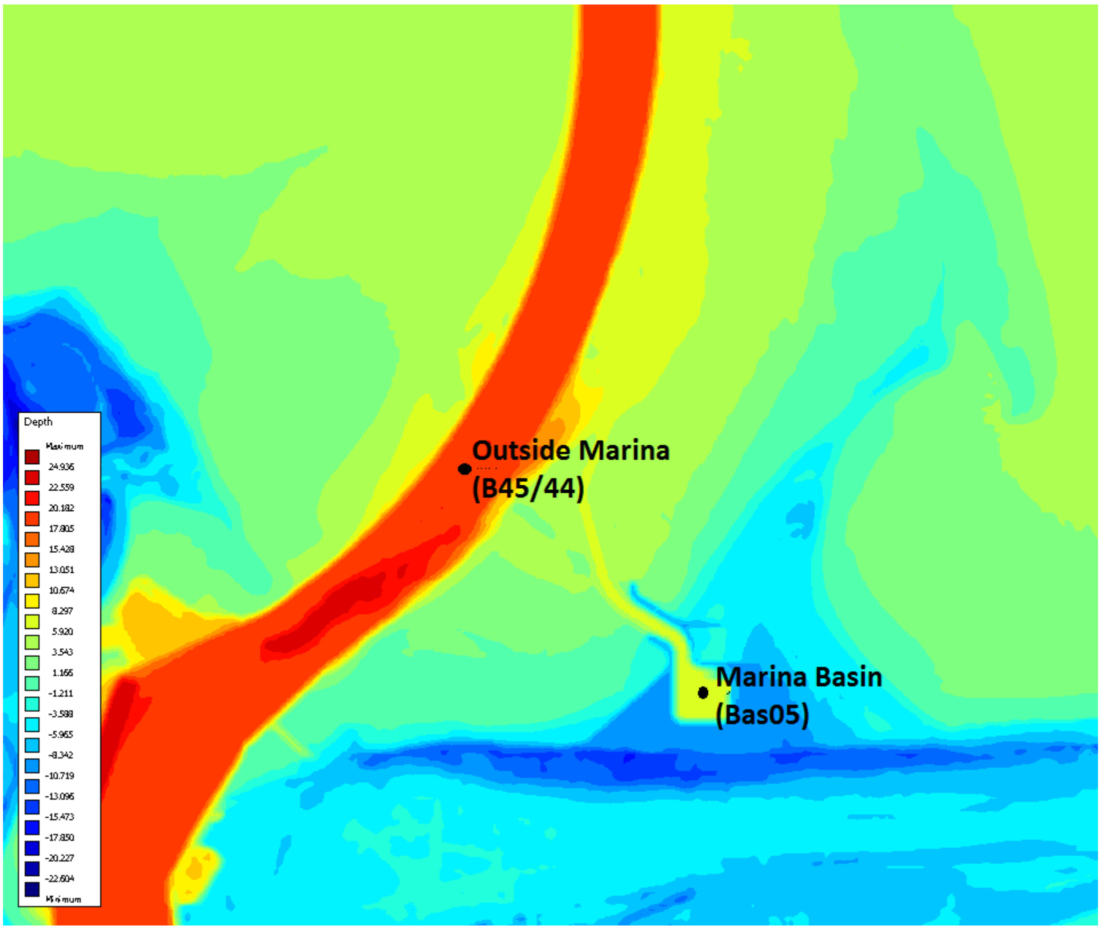


Figure 5.12: Location of Observation Points in the 2D Local Grid Salinity Model (15 m grid resolution).

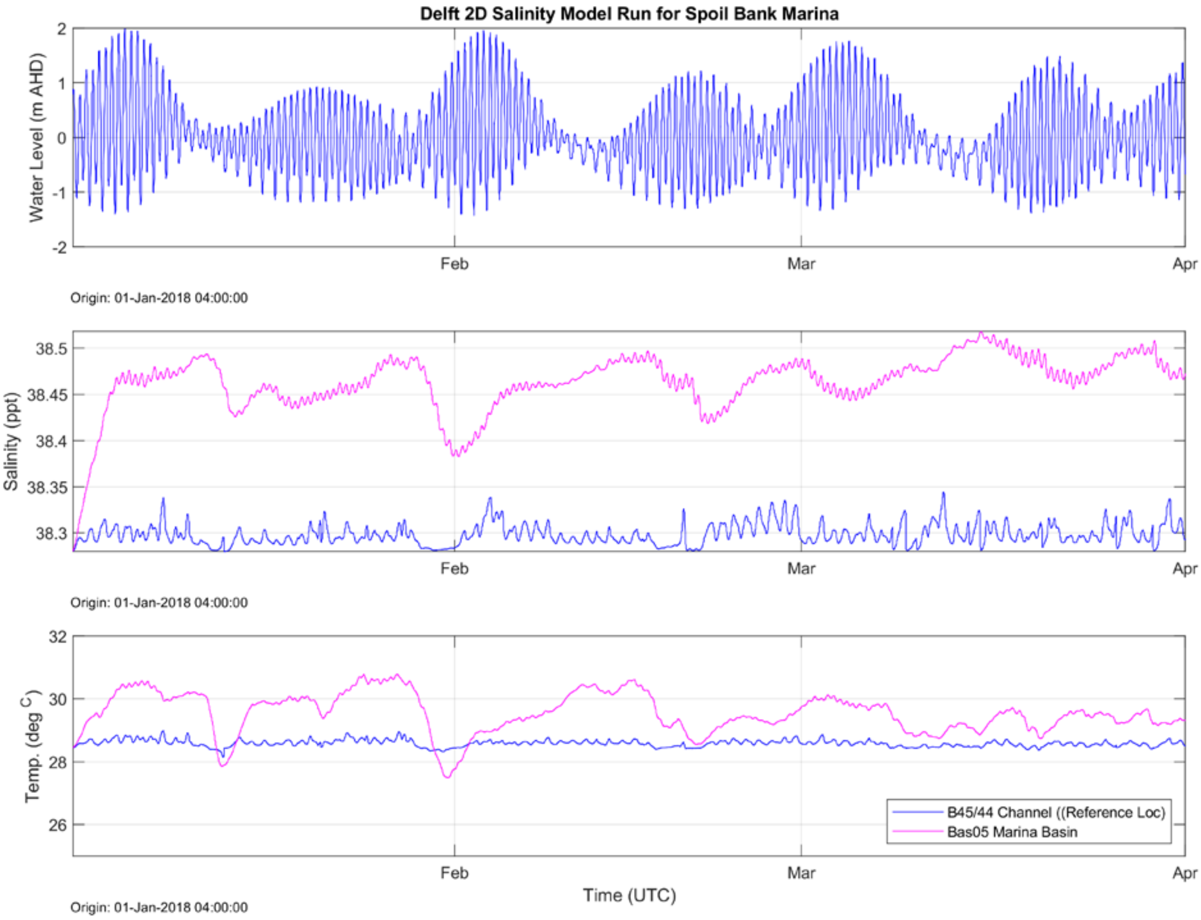


Figure 5.13: Modelled Depth Averaged Salinity and Temperature within and outside the Spoilbank Marina for the Wet Season

5.2.3 3D Modelling of Salinity and Temperature – Wet Season

The 2D modelling indicated that the middle of the wet season was when the greatest potential for salinity and temperature enhancement was likely to occur in the marina basin. As such, detailed 3D hindcast modelling was completed for January 2018 with the full Delft3D model specified in Section 4.2.1 including the Local Grid with 6-vertical layers. The forcing for the heat and salinity model was consistent with the 2D model summarised sTable 5.4. The full Delft3D model provides a more suitable model domain to model the heat enhancement that occurs over the inner NWS during the wet season. The open offshore boundaries adopted the 50% temperature and salinity values as presented in Table 5.3

Figure 5.14 presents the mid-depth time serious of temperature and salinity inside and outside the Marina basin. The model indicates a steady increase in temperature and salinity over a 7-day warm up period (from background initial conditions), before a stable variation in temperature and salinity is observed. Maximum variations of salinity and temperature from within the marina basin are approximately +0.3 ppt and +0.3°C respectively, compared to the reference location outside the basin.

The 3D model simulation has indicated that the vertical water column is generally well mixed for the January 2018 simulation period. Figure 5.15 presents a time series of vertical temperature profile in the middle of the SBM basin, and Figure 5.16 is a similar plot for vertical salinity profile. The large tidal exchange, even during neap tides promotes vertical mixing. The salinity and temperature range during the modelled January 2018 are typically between the 50th-percentile and 80th-percentile values for the coastal waters near the entrance to Port Hedland as presented in Table 5.3.

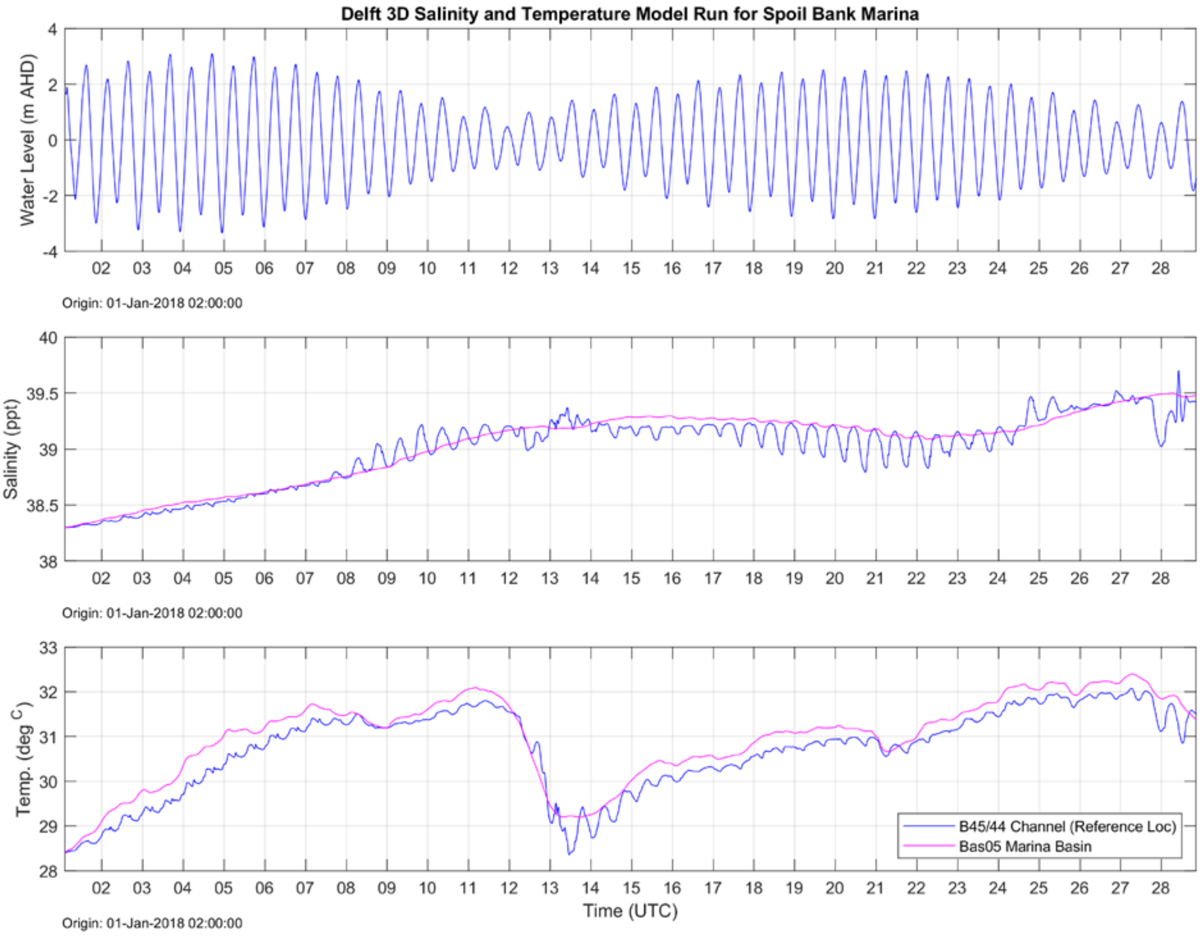


Figure 5.14: Modelled Mid-Depth Salinity and Temperature within and outside the Spoilbank Marina for January 2018 conditions.

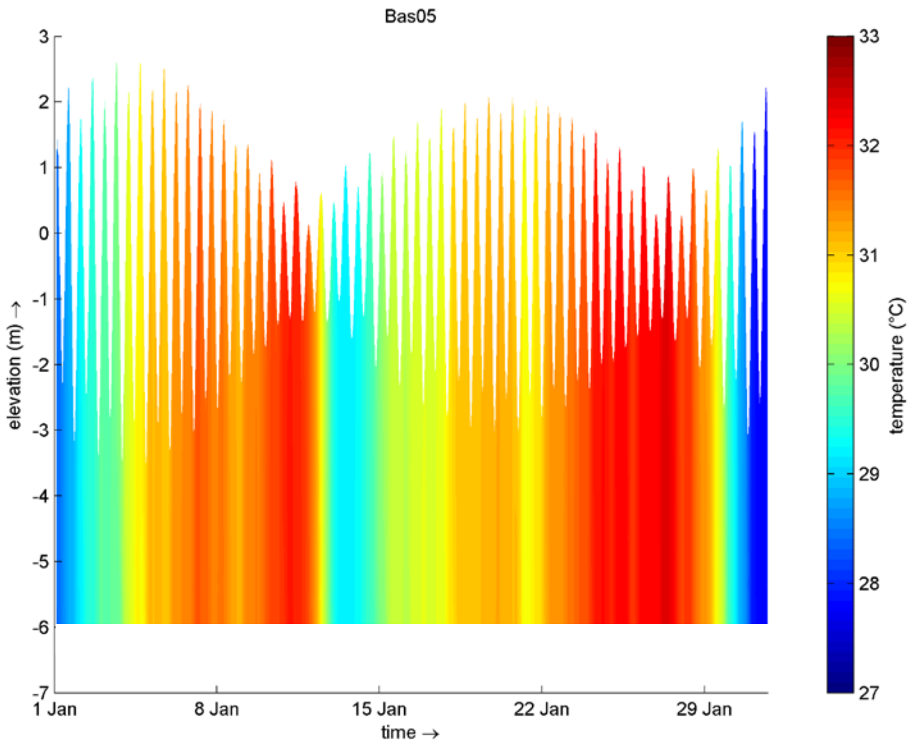


Figure 5.15: Modelled vertical temperature profile inside marina basin for January 2018 conditions.

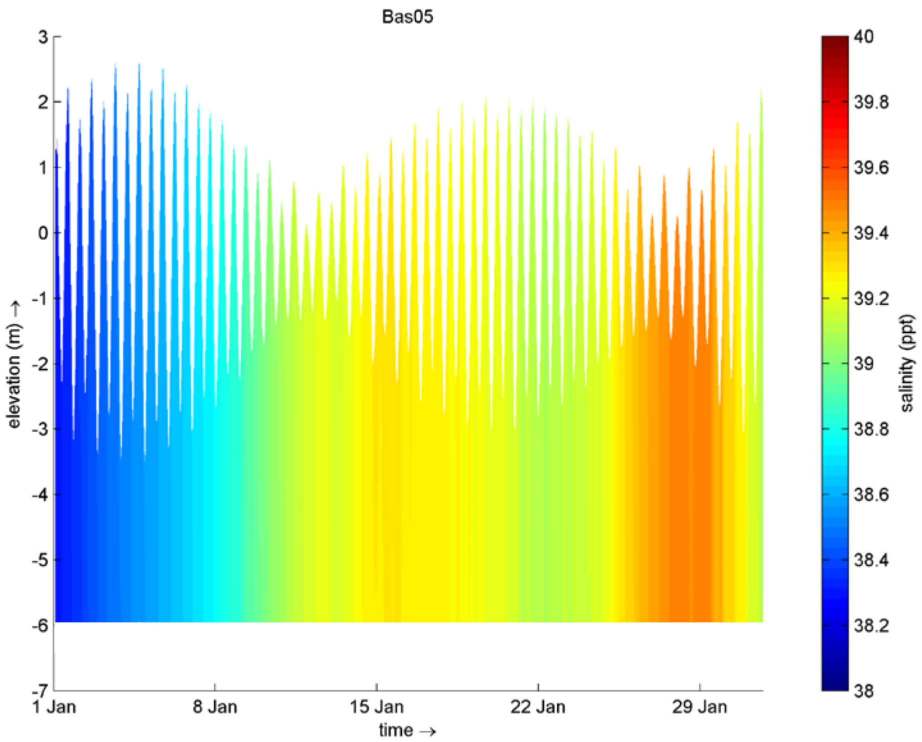


Figure 5.16: Modelled vertical salinity profile inside marina basin for January 2018 conditions.

6. Sediment Plume Modelling

The planned dredging activities and breakwater construction associated with the construction of the Marina will result in impacts to the water quality through the generation of dredge plumes that have the potential to affect the marine environment including corals and seagrasses.

The numerical model detailed in Section 4.3 was adopted as the basis for assessment of the impacts from dredge plumes generated as a result of construction activities. The modelling examines the fate of sediment released into the water column from a range of construction sources analysing the suspended sediment concentration (SSC) spatially and temporally as the sediment plume disperses from the source.

A construction schedule has been developed to complete the requirements of the project which incorporates a range of assumptions for the plant and equipment (eg production rates, working hours). The proposed schedule has been implemented in model simulations developed from a range of local information including survey data and geotechnical information.

The dredge plume modelling outcomes have been analysed to assess the predicted impact around the project site based on the analysis method described in Jones et al 2019 and Fisher et al 2019 (WAMSI). This approach is based on evaluating the running mean SSC through the dredge program against threshold values at 7-day, 14-day and 28-day periods at which impacts to corals are possible and/or probable respectively. The analysis technique has been used to determine the zones of influence (ZoHI, ZoMI) through the dredging program that will be used in the environmental monitoring and dredge management program.

6.1 Model System

The Delft3D hydrodynamic model outlined in detail in Section 4.3 has been adopted as the platform for the dredge plume modelling. The Delft3D Online Sediment model (Online-MOR) has been activated in the model to investigate the transport of sand and fine sediments released through the dredging program. The sediment transport model operates in conjunction with coupled hydrodynamic and wave forcing active throughout the model simulations.

The dredge plume model simulations examine the fate of suspended sediments under the hydrodynamic forcing (water levels, winds, waves, currents) with erosion, resuspension and deposition of the dredge material permitted in the model based on bed shear stress. The existing (initial) layer of sediment at the seabed in the models is not erodible.

6.2 Project Location and Construction Requirements

The existing seabed level offshore of Port Hedland is shown in Figure 6.1. There are two notable features that influence the hydrodynamics around the planned Marina location for the sediment fate modelling:

- The Goldsworthy shipping channel which is used for vessels navigating in and out of Port Hedland with a maintained depth of -14.3mCD
- The Spoilbank, an artificial landform created from the Port Hedland inner harbour and shipping channel dredging sediment disposal in the mid-1960s and early 1970s, It can be seen in Figure 6.1 as a feature extending a significant distance offshore in the seabed bathymetry.

The Spoilbank Marina breakwaters and channel are shown in Figure 6.2 and include:

- Entrance channel dredged to -2.5mCD with batters to the natural seabed. The depth includes a 0.5m overdredge allowance;
- Marina Basin dredged to -2.5mCD with berth pockets at -2.65mCD and -3.35mCD; and
- Northern Breakwater and Southern Breakwater structures

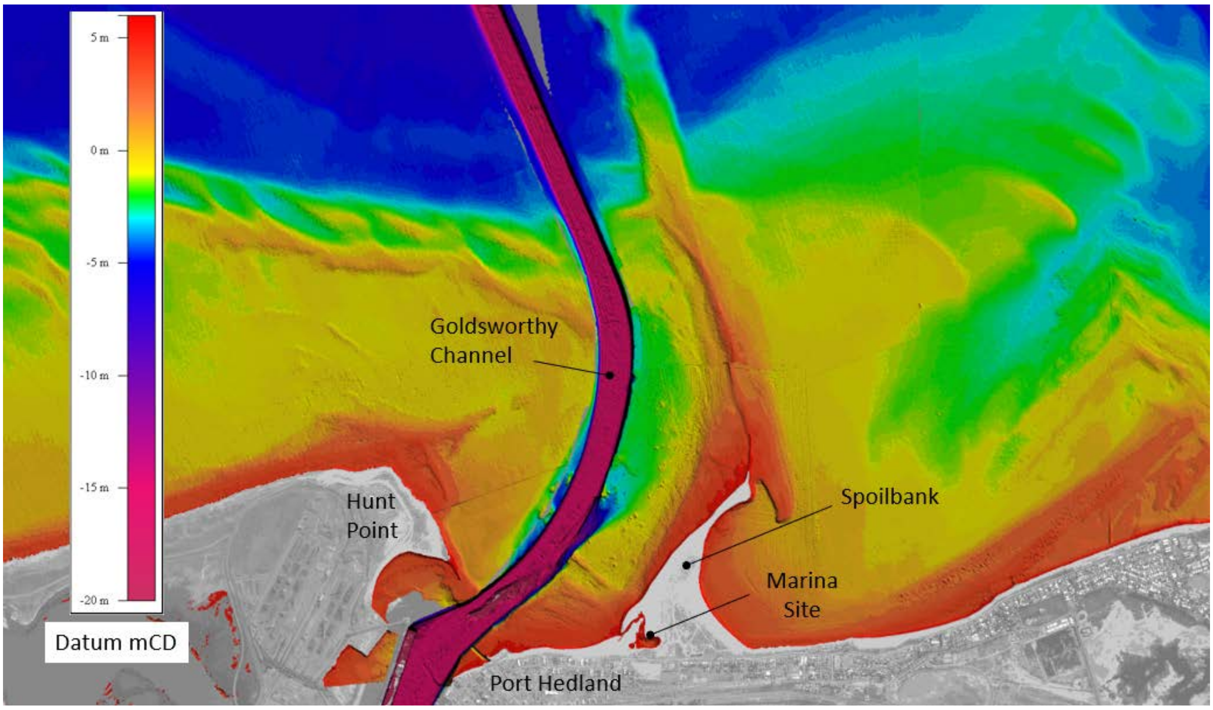


Figure 6.1: Existing seabed bathymetry offshore of project location (datum mCD)

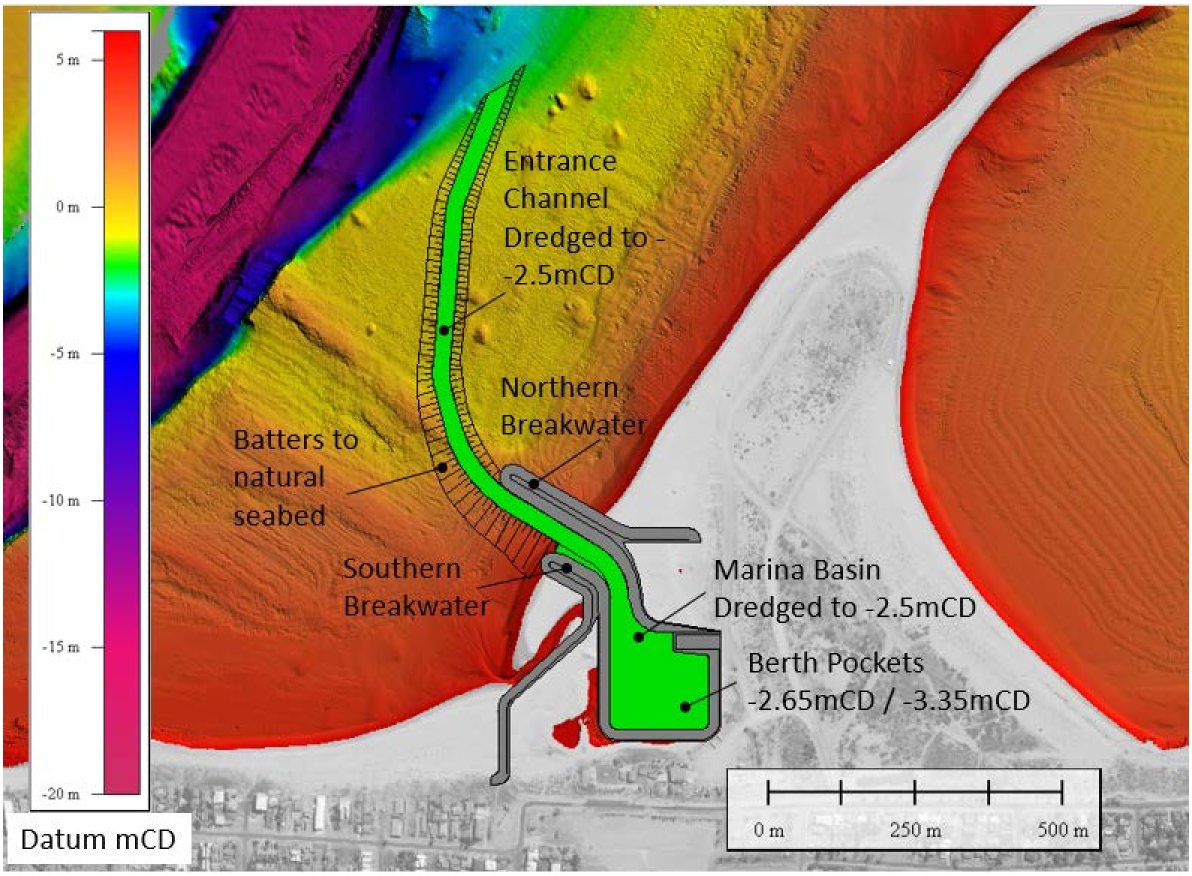


Figure 6.2: Overview of the Construction Elements for the Spoilbank Marina and Entrance Channel. Concept is shown over the existing seabed bathymetry (Datum mCD)

6.3 Construction Methodology and Modelling Assumptions

6.3.1 Dredging Methodology and Assumptions

Based on information provided for the preliminary construction schedule (MPRA 2019a, MPRA 2019b, MPRA 2019c) and discussions with DoT the following construction approach has been adopted for the purposes of modelling:

1. The entrance channel and Marina Basin will be dredged to a depth of -2.5m CD. This includes an over dredge allowance of 0.5m. Two berth pockets in the marina basin will be dredged to a depth of -2.65mCD and 3.35mCD (refer Figure 5.1);
2. All dredging required on the site (entrance channel and marina basin) will be completed by a medium size cutter suction dredge (CSD);
3. The dredge is scheduled to commence at the offshore extent of the channel and work towards the marina basin;
4. For the basin excavation works a silt curtain may be required across the entrance to the waterway, though the effectiveness of this in the tidal range on site would need to be examined. Alternatively, a bund across the entrance could be implemented suited to the location;
5. Based on information provided by DoT, during the turtle nesting season in Port Hedland between December and March (inclusive) there will be no dredging. The dredge program is scheduled to be delivered outside of these months (ie dry season).
6. A total of 491,500m^3 will be dredged from the channel and basin of which approximately 337,200m^3 is sand and 154,300m^3 is estimated to be rock;
7. Dredging of the entrance channel represents 132,200m^3 of the total. The dredging of the Marina basin and entrance will require 359,300m^3 of material to be removed. No land-based excavation has been considered in the construction program;
8. All excavated material is to be placed onshore and intended for use as construction fill;
9. A longreach excavator will operate on a bund removing sediment from the seabed at the site of the northern and southern breakwater structures prior to the breakwater construction;
10. The dumping of core material in the shoreline to construct the northern and southern breakwaters will be done by trucks along breakwater centreline. Dumping will commence from the landside and progressively move seaward with a tipping rate of 1,500m^3 a day assumed.
11. A dewatering pond will be established on the Spoilbank and used for settling the fines material, with discharge back into the nearshore on the northern side of the Northern Breakwater. The discharge concentration is assumed to be 25mg/L, comprising 50% clay and 50% fine silt, discharging at a constant rate throughout the entire dredging period.
12. Production rates have been adopted based on upper limit estimates from previous similar projects.as:
    - 10-hour dredge operations (daylight hours 8am to 6pm) over a 6-day working week (Monday to Saturday); and
    - dredge rates (in m^3/day) for the medium sized CSD assumed as 3,300m^3/day for sand, 630m^3/day for rock, 1250m^3/day for red beds
    - dredge rates (in m^3/day) for the longreach excavator are assumed as 1,000m^3/day for sand and red beds.
    - Rock placement for the core material will be adopted as 1,500 to 2,000 tonnes a day

6.3.2 Model Assumptions for Dredge Plume Modelling

A summary of the key considerations for dredge plume modelling is summarised in Table 6.1.

Table 6.1: Dredging Method - Considerations for Dredge Plume Modelling

Dredge Design	Entrance Channel	Harbour Basin
Total Length	800m	-
Design Depth	-6.4m AHD (-2.5m CD)	-6.4m AHD (-2.5m CD). Berth Pockets (-2.65mCD -3.35mCD)
Design Width	30m at Floor	160m x 160m Basin Area
Batters	Minimum 1V:10H (sand) and 1V:2H (Rock)	Minimum 1V:6H (sand)
Dredge Volume	100,400m^3 Sand 31,800m^3 Rock	158,700m^3 Sand 122,500m^3 Rock 78,100m^3 Red Beds
Construction Method		
Dredge Plant	Medium Cutter Suction Dredge	Longreach Excavator (40T)
Excavation Rate (daily)	3,300m^3 for sand 630 m^3 for rock 1250 m^3 for red beds	1000m^3 day sand and red beds. Working radius 10m
Landside Placement Rate for Structural Elements	Placement of core – 1,500 tonnes a day	
Operating Hours	Daytime Operations 0800 - 1800 10 Hour continuous Shift x 6 days a week	
Operational Constraints	No dredging to occur in turtle season December – March inclusive	
Dredge spoil disposal method	CSD to dispose of all material on-shore to be used as fill. Dewatering in shoreline - settling ponds on shoreline for settlement of fines	

6.3.3 Indicative Construction Program

An indicative construction program is summarised in Table 6.2 which has been adopted in the modelling process. This incorporates production rates stated in Table 6.1 and the requirement to complete works outside of the December to March turtle season.

It is noted that the construction methodology and dredging strategy will ultimately be determined by the contractor. The dredge plume modelling approach adopted in this study has been developed to present a conservative (ie 'worst case') assessment of dredge plumes generated through the construction program assuming:

- High production rates for the dredging and construction activities will be achieved on site (upper limit rates based on similar scale projects); and
- No downtime will occur during the production schedule

Table 6.2: Proposed Construction Schedule Adopted in Model Program

Activity	Indicative Month
Site establishment Year 1	M1 April Year 1
Entrance Channel Dredging (CSD)	M2 – M5 (May – Aug) Year 1
Landside Breakwater Structures (Excavator)	M5 – M8 (Aug – Nov[2]) Year 1
Marina Basin Dredging (CSD)[1]	M1 – M8 (April – Nov[2]) Year 2

1. Assumption that no land-based excavation is undertaken inside Marina Basin. Work may catty over to year 3
2. Assumption that dredging cannot occur in Turtle Season, Dec – Mar Inclusive

6.3.4 Plume Discharge Sources

Sediment plumes will be generated during the breakwater construction and entrance channel dredging at different scales. The sediment plume generation sources are summarised in Table 6.3 for the dredging activities and Table 6.4 for the works associated with construction of the breakwater structures. Assumptions adopted in the modelling are based on literature and studies as referenced.

Table 6.3: Model Assumptions – Plume Generation Sources from Dredging Activities

Plume Source	Approach to define plume generation in model	Model Assumption
Mobilisation of fine sediments at the seabed by CSD head	Sediment material excavated is mobilised at the seabed and released into the far-field model from around the rotating cutter head. The model source is distributed vertically within a few metres of the seabed.	6% of total volume of fine sediments (<130µm) excavated[1]
Dewatering discharge	Dewatering of fines from CSD throughout the program. Source for far-field plume is discharge point of settlement pond.	The dewatering discharge is modelled as a point source north of the breakwater in the sediment trap location The SSC is modelled as 25mg/L discharged constantly through the dredge program (50% clay and 50% silt)
Generation of rock flour by cutter head on calcarenite material.	Fine rock is mobilised at the seabed based on grinding of the CSD cutter head against rock. The source for the far-field plume is from around the rotating cutter distributed vertically within a few metres of the seabed.	Rock flour risk is considered low, however a sensitivity case with rock flour has been modelled based on 1% to 5% of the total rock volume dredged [2]

Notes and Assumptions

1. Based on range reported in projects predominantly involving dredging of unconsolidated or weakly consolidated sediments (Range of values 5-7.5% of fines generated, Kemps and Mansini 2017)
2. Refer Section 6.4.3. Assumptions verified against the 2019 CMW Geotechnical data collected from boreholes across the Spoilbank
3. Advice based on similar projects (Teal / DoT)

Table 6.4: Plume Generation Mechanisms from Construction of Breakwaters

Plume Source	Approach to define plume generation in model	Model Assumption
Construction of Temporary Bunds for access to northern and southern breakwaters during construction	Bunds to be constructed from material excavated from the Spoilbank,assumed sand and rock with low fines content. Plumes are generated from the fines in the placed material as it is released in the shoreline.	Assumed negligible fines content released at seaward extent of bunds as they are constructed / removed. Plume impacts minimal when compared to plume generation from dredging of channel. Not included in model.
Long Reach Excavator operating on bund removing sediment prior to breakwater construction.	The bucket will mobilise fines at the seabed (<130µm) and through the water column as it raises to the surface and is released into truck. Assumed coarse material >130µm will fall out of suspension locally at the source. Far-field plume source distribution vertically through the water column.	4% of fines (<130µm) by mass for the sediment being excavated from seabed[1]
Dumping of Core material in shoreline – Northern Breakwater; and Southern Breakwater	Fines in the core material is released in the shoreline. Assumed tipped by trucks along breakwater centreline with source for far-field plume the seaward extent of construction distributed vertically through the water column.	Assumed as 2% of total core material (0.5% Clay, Fine Silt, Coarse Silt, Fine Sand)[2]
Place Armour Stone on Breakwater	A percentage of the fines in the placed material is released in the shoreline. Source for far-field plume is seaward extent of dumping.	Assumed negligible % of fines <130µm in Armour stone. Not included in model.

Notes and Assumptions

1. Based on median of range for backhoe dredge, WAMSI document Sun et al 2017
2. Based on assumptions in landside placement production rates (MPRA, Table 6.1) and core dumping approach outlined in similar MPRA project methodology reported in RPS 2019

6.4 Dredge Material - Sediment Sampling Data Sources and Analysis

6.4.1 Dredging Sequences

The largest generation of dredge plumes will be associated with the CSD operating over the four-month period dredging of the entrance channel. The sediment plume modelling of the offshore channel and Marina basin dredging is sequenced through seven Zones shown in Figure 6.5 which extend from the offshore extent of the channel (Zone 19) into the basin (Zone 11 / Zone 13).

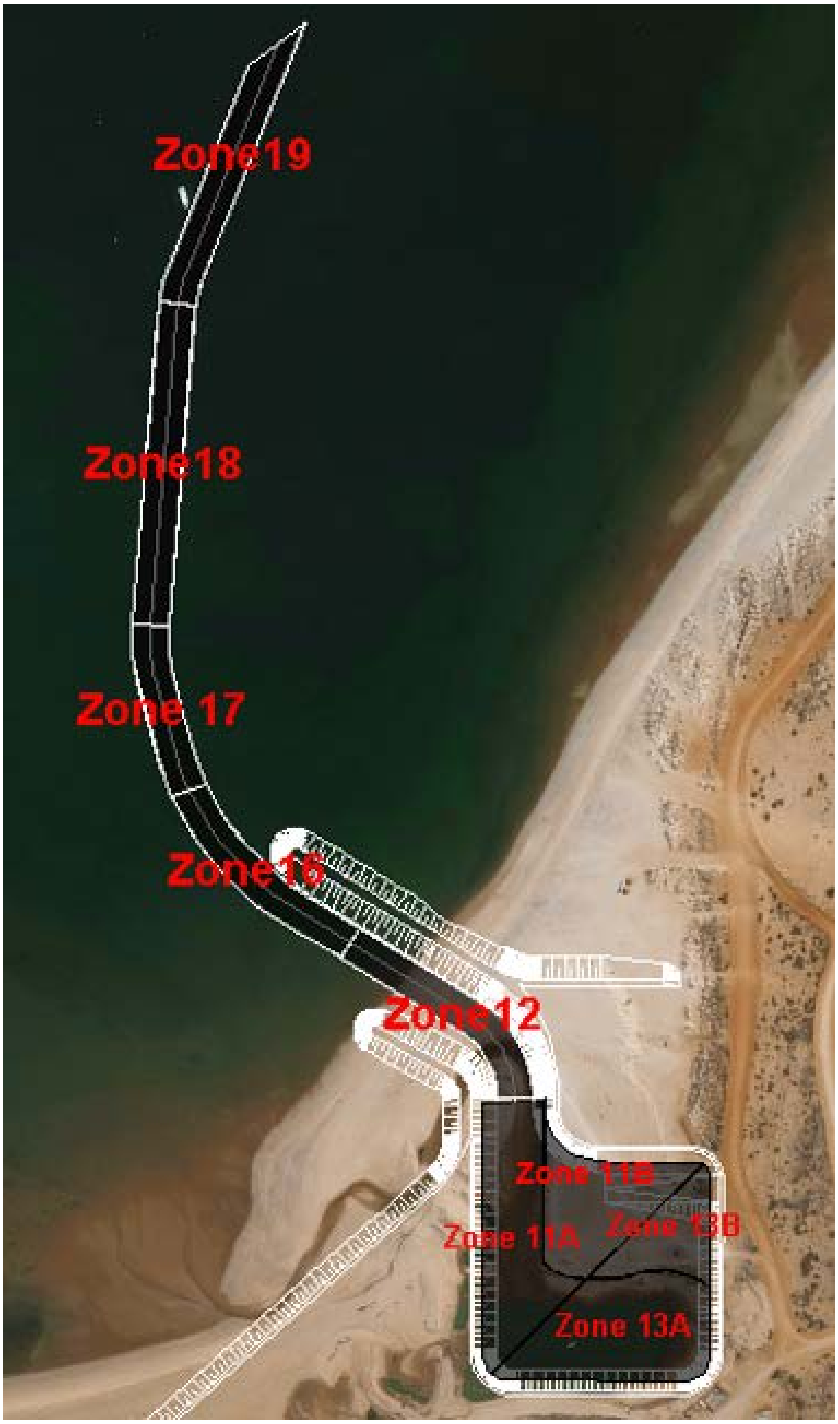


Figure 6.3: Dredging Sequences by Cutter Suction Dredge. Zones adopted in numerical modelling of dredge program commences at the outer end of the channel (Zone 19) and finishes in the Basin.

The entrance channel and basin are dredged to -2.5mCD which includes an overdredge allowance of 0.5m. A summary of the volume of dredge material by Zone is provided in Table 6.5 for the offshore channel sections (Zone 19, Zone 17, Zone 16, Zone 12) and the Marina basin (Zone 11, Zone 13) in Table 6.6. The borehole data from the reference geotechnical data has been used to determine the depth of the rock layer and the sediment present above the rock, in the rock layer and below the rock layer in each respective section in the tables.

Table 6.5: Summary of Dredge Volume by Zone – Channel Entrance

Dredge Zone	Total Dredge Volume	Sediment Above Rock	Rock	Sediment Below Rock	Depth of Rock Layer
Z19	9,800 m^3	100%	0%	0%	-
Z18	21,400 m^3	100%	0%	0%	-
Z17	12,500 m^3	43%	57%	0%	-1.25 mCD
Z16	28,700 m^3	27%	43%	30%	+ 0.2 mCD
Z12	59,800 m^3	60%	21%	19%	+ 1 mCD
TOTAL	132,200 m^3	-	-	-	-

Table 6.6: Summary of Dredge Volume by Zone – Marina Basin

Dredge Zone	Total Dredge Volume	Sediment Above Rock	Rock	Sediment Below Rock	Depth of Rock Layer
Z11A	89,900 m^3	45%	36%	19%	+ 2 mCD
Z11B	98,600 m^3	55%	33%	13%	+ 2 mCD
Z13A	74,700 m^3	43%	39%	18%	+ 3 mCD
Z13B	96,100 m^3	33%	30%	37%	+ 3 mCD
TOTAL	359,300 m^3	-	-	-	-

Detailed dredge logs have been developed that cover the dredging sequences in the modelling study. The methodology adopted is that the CSD completes the dredging to design depth in each respective zone before moving to the next zone landward.

- For the offshore zones, Zone 19 and Zone 18 only sand is dredged from the seabed as the rock layer is below the design depth.
- For sections Zone 17, the rock layer is present at a depth shallower than design depth. In these sections all of the sand in the zone overlying the rock is removed first by the CSD and following this the rock is then removed from the section.
- For offshore Zone 16 / Zone 12 and Marine Basin Zone 11 and Zone 13, there is sand overlying rock and then a layer of sediment below the rock layer with high fines content locally termed ‘red beds’. In each zone the respective layers are removed in full before moving on to the next layer (ie overlying sand, rock layer, red beds layer) until the CSD achieves the design depth.

There are different production rates assigned to the three layers as noted in Table 6.1. For sand the CSD is able to dredge 3,300m^3 a day, for rock the dredge rate is 630m^3 a day and for the sediments below the rock layer (‘red beds’) the dredge rates are 1,250m^3 a day.

The dredge logs have been developed based on the calculated dredge volume in each zone, the production rates assumed by sediment class and a 6-day working week in daylight hours (10-hour shift in daylight hours) as outlined in Table 6.1.

6.4.2 Sediment Classifications in Model

The sediment classifications considered in the modelling are based on the range of sizes described in Table 6.7. The dredge plume modelling examines fine cohesive sediments (clays, silts) and also considers non-cohesive fine sand. The sediment classifications larger than fine sand are not included in the sediment transport modelling. It is assumed that these will fall out of suspension and be deposited at the seabed rapidly a short distance from their source.

Table 6.7: Summary of Sediment Classes in Model (Wentworth Scale)

Sediment Class	Size Range (µm)	Model Assumptions
Gravel, Cobbles	>2mm	Not considered in the model. Assumed that these larger sediments will fall to the seabed locally from the source location.
Medium to Coarse Sand	0.25mm – 2mm	
Fine sand	62µm – 0.25mm	Modelled as non-cohesive sediment with Median Sediment D_{50} = 100µm
Coarse Silt	16µm to 62µm	Modelled as cohesive sediment, Settling Velocity 1.7mm/s
Fine Silt	4µm to 16µm	Modelled as cohesive sediment, Settling Velocity 0.06 mm/s
Clay	< 2µm	Modelled as cohesive sediment, Settling Velocity 0.004 mm/s

A key determinant of the dredge plume dispersion and settlement in the model is the settlement rate parameter for the fine fractions. According to Stoke's Law, the settling rate of particles is affected by the gravitational force exerted on the particle, the density of the particle relative to the density of the medium, and the viscosity (resistance to flow-settling) of the medium.

For the modelled fine fractions, the following settlement rate has been adopted:

- Coarse Silt = 1.7 mm/s
- Fine Silt = 0.06 mm/s
- Clay = 0.004 mm/s

These values fall within the ranges of settling velocity adopted in similar modelling studies (Sun et al 2016).

6.4.3 Sediment Composition of Dredge Material

The sediment descriptions for dredged material released in the model through the dredging schedule has been developed from the Geotechnical information and sediment sampling completed across the project footprint outlined in Section 2.2.2.1 incorporating:

- the surface sample PSD in offshore sections where the dredging is concentrated in the upper seabed layer.
- the borehole data (CMW, 2019) in the channel entrance to determine the depth of rock, thickness of the rock layer as well as sediment description below the rock layer (from PSD).
- over the Spoilbank where the channel and marina basin dredging is undertaken the sediment descriptions are extracted from the detailed borehole and sediment samples from the surface layer and below rock ‘redbeds’ layer (CMW, 2019).

A summary of the sediment composition in each zone shown in Figure 6.3, with the reference borehole or sediment sample location used to develop the assumptions is presented in Table 6.8 for the channel section and Table 6.9 for the Marina basin. These sediment descriptions have been applied in the sediment transport model.

Table 6.8: Sediment Composition of dredged material by Zone – Offshore Channel Entrance

	Above Rock					Below Rock				
Dredge Zone	**Ref. Sample**	**Clay %**	**Silt %**	**Sand %**	**Gravel %**	**Borehole Sample**	**Clay %**	**Silt %**	**Sand %**	**Gravel %**
Z19	C02	18	20	61	1	BH12	-	-	-	-
Z18	C06	9	10	79	2	BH12	-	-	-	-
Z17	C08	11	3	78	8	BH12	-	-	-	-
Z16	C10	12	7	79	2	BH12	20	24	55	1
Z12	B15	5	0	54	41	BH12	20	24	55	1

Table 6.9: Sediment Composition of dredged material by Zone – Marina Basin

	Above Rock					Below Rock (red beds)				
Dredge Zone	**Ref. Sample**	**Clay %**	**Silt %**	**Sand %**	**Gravel %**	**Borehole Sample[1]**	**Clay %**	**Silt %**	**Sand %**	**Gravel %**
Z11A	B18	5	1	89	6	BH4 Golder (2009), BH11 CMW (2019), BH21 CMW (2019)	21	11	11	58
Z11B	B24-B	3	2	55	40		21	11	11	58
Z13A	B21	5	1	74	20		21	11	11	58
Z13B	B25	4	3	50	43		21	11	11	58
Z11A	B18	5	1	89	6		21	11	11	58

1. The sediment PSD for red beds was adapted from three borehole descriptions, residing near the entrance of the basin.

The sediment composition varies considerably across the zones and by depth:

- offshore section Zone 19 has a high fines content of 38% (clays and silts);
- offshore sections Zone 18, Zone 17 and Zone 16 have 14% - 19% fines;
- the entrance section (Zone 12) and zones across the Spoilbank (Zone 11 and Zone 12) have very low fines content in the dredge material (5% and 7%) and are predominantly sand and gravel;
- the sediments below the rock layer termed as 'red beds' have been modelled as having between 33% and 44% fines.

6.4.4 Rock Flour

The term 'rock flour' describes the very fine rock particles that can be generated when the CSD cutter head grinds the material in the rock layer, with the potential for sediment plumes to be produced by the fine rock particles. Baird have reviewed the available geotechnical data and from the description of the calcarenite in the CMW (2019) and Golder (2009) reports it is difficult to conclude whether rock flour will present an issue when the CSD cutter head is breaking through the calcarenite layer. There are several comments that can be made from information regarding rock flour generation from dredging activities:

- In the Golder borehole data the strength of the rock layer was measured at a number of sites in the range of Unconfined Compressive Strength (UCS) 0.88 to 9.7MPa and Point Load Index (PLI) strength 0.06 to 1.6MP. Accompanying notes state the strength properties of the calcarenite as variable ranging from 'very low' to 'high';
- The borehole data collected by CMW 2019 notes the presence of 'Calcarenite (carbonate sandstone) /Detrital Limestone in the rock layer. The rock material Uniaxial Compressive Strength (UCS) varies through the core in the range of 'Low' (2-6 MPa) to 'High' (20 to 60 MPa). An example of the rock layer from Borehole 12 is shown in Figure 6.4 with the layer observable between 5.5m and 6.0m.
- The generation of rock flour had a major environmental impact during capital dredging at Geraldton in 2002 and 2003. The majority of that dredging project involved dredging of limestone material, whereas the Spoilbank Marina borehole data indicates calcarenite layers are typically between 'Silty Sand' and

'Clayey Sand' layers. It was noted in SKM (2003) that the "presence of clays in the calcarenite tends to bind any fine material' reducing the potential for generation of rock flour.

- Dredging method has a significant impact on the potential generation of rock flour. Experience indicates that lower powered Cutter Suction Dredgers (CSD) have the greatest potential for the generation of rock flour as they grind harder rock into small particles whereas higher powered CSD's tend to fracture rock (Woodside, 2008). Backhoe dredging also tends to have lower potential for generating rock flour plumes compared to CSD's.

Based on the available information, rock flour is considered a low risk for the Spoilbank Marina dredging.

The sediment transport model has considered rock flour as a sensitivity that is tested in the model cases. At locations in the dredging program where the CSD cuts through the rock layer:

- The amount of rock flour generation has been tested for sensitivity cases at 1% and at 5% of the total volume of rock excavated. In the dredge log under assumed production rates, the rock layer is excavated at 63m^3 per hour. Under the 1% assumption this equates to 0.63m^3 of rock flour generation per hour in the model, and under the 5% sensitivity this equates to 3.15m^3 of rock flour generation per hour;
- The mass of the rock flour in the model is based on core sample data analysed through the calcarenite layer in Borehole 11 at approximately 7m depth (refer Figure 2.4, Figure 6.4). The uniaxial compressive strength test of the sample reports a high UCS of 8.7MPa with bulk density of the rock measured at 2150 kg/m^3. The rock flour density is higher than the density of the sand and fines in the model which are assumed at 1600 kg/m^3.
- The rock flour component is modelled as a very fine particle with settlement properties similar to the clay component (settlement rate of 0.004 mm/s).
- Discharge in the model is from the lower seabed level where the CSD head is active

Figure 6.4: Core Sample from Borehole 11 at depth 5m to 10m below surface (CMW 2019). The Calcarenite layer is the grey region shown in the 7.0m range

6.4.5 Dewatering

The dewatering discharge is modelled as a point source north of the breakwater in the sediment trap location. The SSC is modelled as 25mg/L discharged constantly through the dredge program (50% clay and 50% silt).

6.5 Model Approach and Outcomes

6.5.1 Simulations and Bathymetry

The validated Delft3D model for the dry season outlined in detail in Section 4.3.5 was used as the basis for the modelling program. The dredge program was assigned across discrete model simulations of 4-week duration which were simulated in the model based on the dry season validation case presented in Section 4.3.4 and Section 4.3.5.

The model grid resolution through the key area of interest around the Spoilbank region is 15m x 15m, with dredge plume model cases executed in 3D with 5 vertical layers through the water column ensuring the local bathymetric features and hydrodynamic influences on the dredge plume were reproduced.

The model bathymetry on the western side of the Spoilbank is based on high resolution nearshore multibeam captured from the location in 2019. This initial 'existing case' bed level was used at the commencement of the dredge modelling from the offshore extent of the channel and was updated in subsequent simulation cases through the program to represent the progress on the dredged entrance channel through the schedule. An example of the updates to bathymetry cases through the entrance channel dredge model sequence is presented in Figure 6.5.

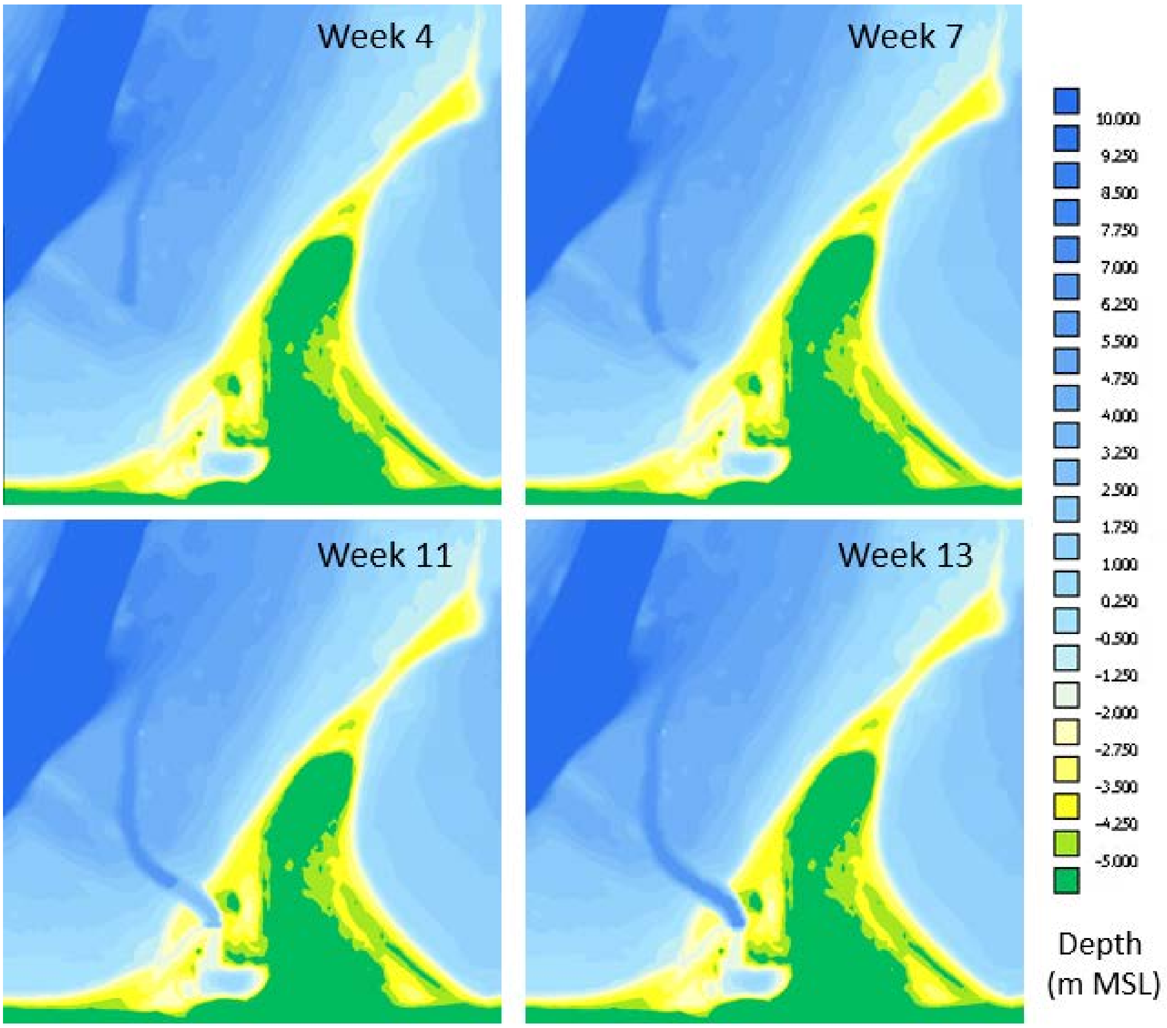


Figure 6.5: Developed Case Bathymetry updated through the model program to represent the dredging of the entrance channel from offshore to inshore.

6.5.2 Dynamic modelling of sediment released at Cutter Suction Dredge

The sediment is discharged into the 3D dredge plume model at the position of the CSD cutter head in the first few metres above the seabed layer in the model. The position of the CSD cutter discharge moves dynamically through the model domain following the dredge channel. The modelled time spent in each location is based on the volume of material required to reach design depth (-2.5 mCD), the type of sediment (sand, rock, red beds) and the assumed production rates in Table 6.1.

6.5.3 Dynamic modelling of the Dewatering Discharge

The dewatering discharge is modelled as a point source north of the breakwater in the sediment trap location. The SSC is modelled as a 25mg/L discharge that is constant through the dredge program made up of the fine sediment fractions (assume as 50% clay and 50% silt).

6.5.4 Plume Behaviour

The dredge plume modelling outcomes demonstrate the strong influence of the Goldsworthy Channel in restricting the impacts from the dredge plumes to the area on the western side of the Spoilbank. The nearshore area from the western shoreline of the Spoilbank to the Goldsworthy channel is shown in detail in Figure 6.1 and Figure 6.2. The entrance channel dredging is executed across a relatively shallow and flat seabed area of approximately +1mCD to -1mCD. In this region the dredge plume effects are the most pronounced along the entrance channel alignment with maximum SSC at the source of the CSD and then reducing SSC plumes directed into the ebb and flood current direction. The stratification of the plume is most pronounced adjacent the generation source with the SSC approaching uniform distribution through the water column at a distance away in the model.

At the Goldsworthy navigation channel, the seabed descends rapidly from approximately 0mCD to approximately over -15mCD. The majority of the tidal flow is directed through the deepwater channel and to a lesser degree along the western shoreline of the Spoilbank. the strong current velocity coupled with the increased depth of the Goldsworthy channel result in a rapid dispersion of the sediment plume. The suspended sediment that reaches the Goldsworthy channel is driven north under ebb tide current forcing and south into the inner harbour along the axis of the channel. The modelling indicates that once the suspended sediment enters the deepwater channel it does not return to the western side of the Spoilbank.

The Spoilbank feature can be clearly seen onshore and offshore in Figure 6.1, with an elevated ridge at the seabed extending northwards in the bathymetry for over 3km beyond the visible tip. This has an influence on flows around the Spoilbank. From the model outcomes the sediment plumes directed northwards in the ebb tide currents stay within the key flow path from the Goldsworthy channel to the western side of the Spoilbank feature and are directed offshore. The model confirms that suspended sediment from the dredge plumes (SSC) is not directed around the visible tip of the Spoillbank feature to the eastern side of the Spoilbank.

Example spatial plots of the dredge plumes are presented in Figure 6.6 for ebb tide and Figure 6.10 flood tide cases in the initial dredging sequence offshore of the entrance channel. The dredge plume is clearly directed by the currents and the SSC reduces rapidly once the plume encounters the deepwater navigation channel for Port Hedland Harbour (Goldsworthy Channel). The hydrodynamics of the western Spoilbank assist the plume in rapidly dispersing under the high current speeds through the channel where flows are directed.

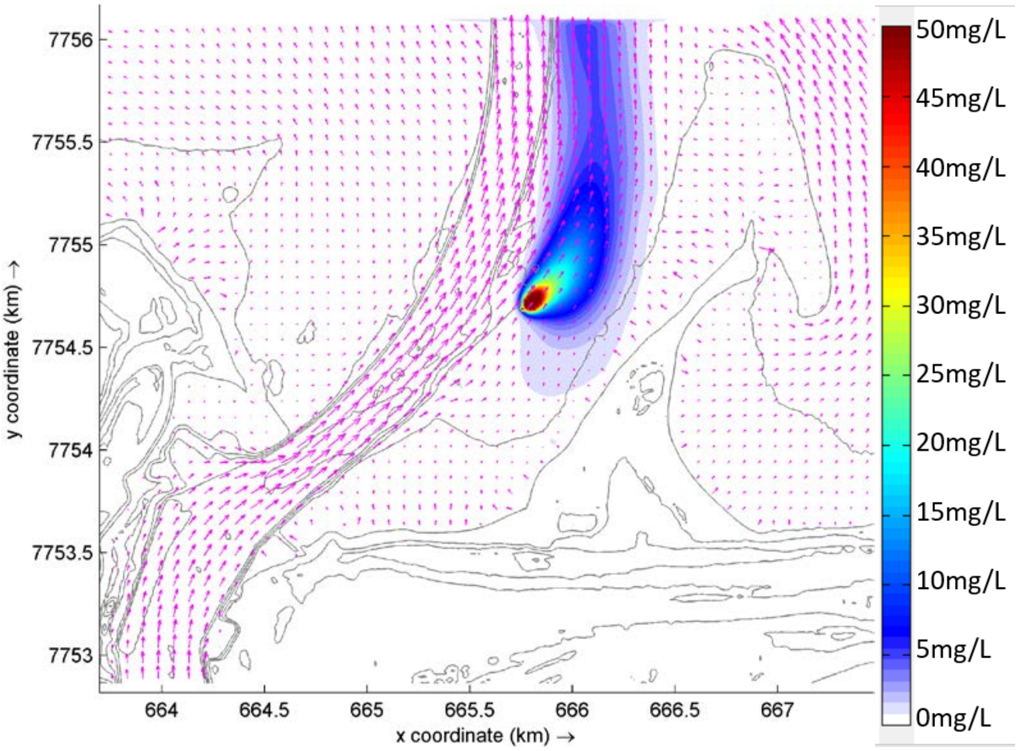


Figure 6.6: Modelled dredge plume on ebb tide. Suspended sediment concentration during the initial dredging sequence of the entrance channel at the offshore extent. Depth averaged currents are overlayed steering the plume along the alignment of the Goldsworthy Channel.

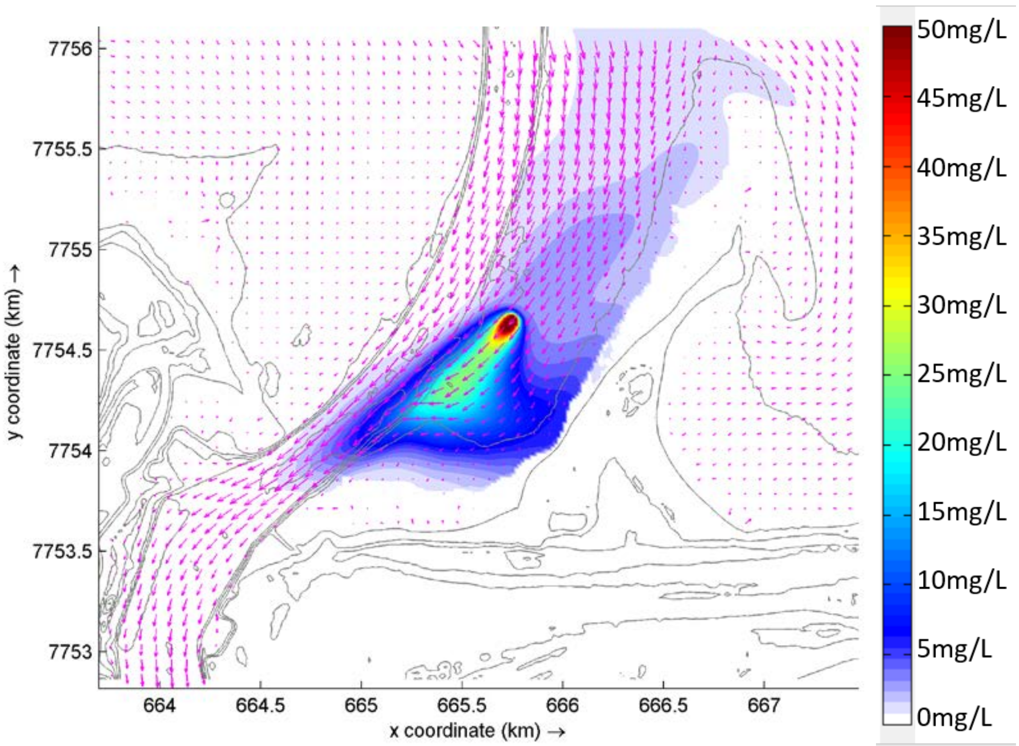


Figure 6.7: Modelled dredge plume on flood tide. Suspended sediment concentration during the initial dredging sequence of the entrance channel at the offshore extent. Depth averaged currents are overlayed steering the plume towards the Goldsworthy Channel.

A map showing the modelled 99th percentile value for SSC through the offshore dredging period (May – Aug) is presented in Figure 6.8 (no rock flour case). It is noted that this map does not represent an individual timestep, instead it is a composite of the 99th percentile value for each grid cell over the period. The 99th percentile case reflects conditions that would be present for approximately 24 hours over the approximately 4-month entrance channel dredging period.

The 99th percentile map in Figure 6.8 illustrates how the largest SSC impacts are within the Marina channel footprint and the approximately 300m area outside of where dredging with values of 25mg/L to > 100mg/L above background. Outside of this region in the shallow nearshore areas between the western Spoilbank and into the Goldsworthy channel the increase above background SSC drops to be in the range of 2mg/L to 5mg/L. At the Goldsworthy channel the dispersion of the plume is evidenced by the rapid reduction in modelled SSC impact reducing to be lower than 2mg/L above background.

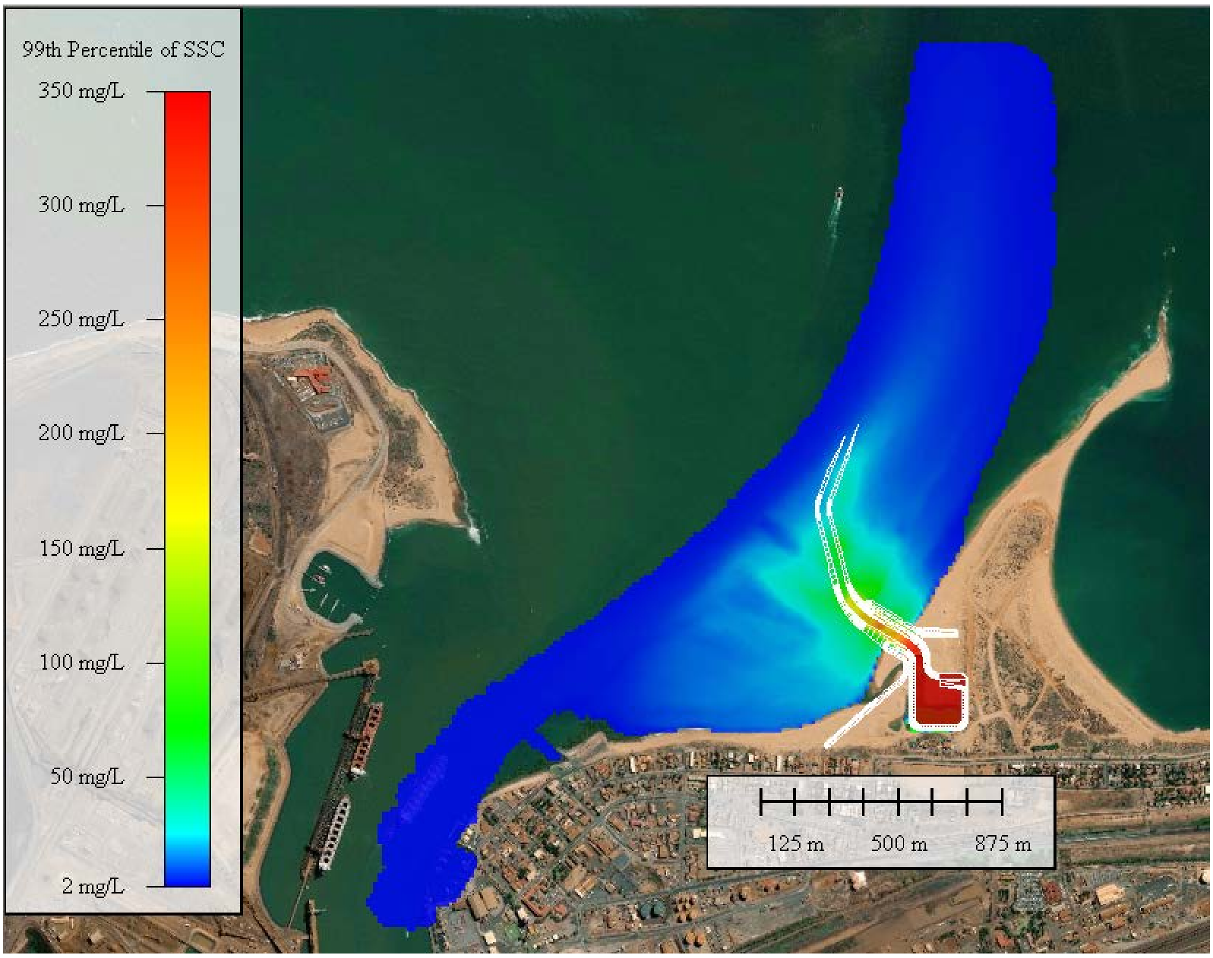


Figure 6.8: Modelled values of 99th percentile SSC through the 100 day offshore channel dredging period. Values represent excess above background SSC.

6.5.5 Model Analysis

The modelled dredge sequences were compiled to provide a continuous time series of the approximate 4-month dredging program for detailed analysis. The model simulations were executed with no background suspended sediment concentration and model results represent the excess above the background SSC.

Natural background SSC at Port Hedland will vary due to a range of factors. O2Marine reviewed the available measured data from the location to provide guidance for two scenarios for the background SSC that would be applied in the analysis that could reasonably approximate the ‘best case’ and ‘worst case’ conditions for the dredge monitoring plans.

The analysis of the modelled data has been undertaken adopting:

1. a median background (50th percentile, P50) SSC value of 7.8mg/l defined to represent the ‘Best Case’
2. a higher background (95th percentile, P95) SSC value of 8.7mg/l defined to represent the ‘Worst Case’

These values are based on measured data presented in Cardno (2019) taken from an instrument deployed near the end of the marina channel through dry season months of 2019.

The mapping output from the model was made available on a 30-minute time interval from 5 vertical layers. The suspended sediment concentration (SSC) was analysed in all five model layers and the highest SSC through the water column at each location on the model output grid was adopted at each timestep.

Running mean values of modelled SSC were analysed against WAMSI thresholds provided by O2Marine applying the method presented in Fisher et al 2019 (WAMSI dredging node). This analysis has determined the zones of impact that will be used in the environmental monitoring and management program.

6.6 Zones of Impact

The EPA has developed a spatially based zonation scheme for proponents to use as a common basis to describe the predicted extent, severity and duration of impacts associated with their dredging proposals (EPA, 2016g). The scheme consists of three zones that represent different levels of impact:

1. Zone of High Impact (ZoHI) is the area where impacts on benthic communities or habitats are predicted to be irreversible. The term irreversible means ‘lacking a capacity to return or recover to a state resembling that prior to being impacted within a timeframe of five years or less’. Areas within and immediately adjacent to proposed dredge and disposal sites are typically within zones of high impact.
2. Zone of Moderate Impact (ZoMI) is the area within which predicted impacts on benthic organisms are recoverable within a period of five years following completion of the dredging activities. This zone abuts, and lies immediately outside of, the zone of high impact. The outer boundary of this zone is coincident with the inner boundary of the next zone, the Zone of Influence.
3. Zone of Influence (ZoI) is the area within which changes in environmental quality associated with dredge plumes are predicted and anticipated during the dredging operations, but where these changes would not result in a detectible impact on benthic biota. These areas can be large, but at any point in time the dredge plumes are likely to be restricted to a relatively small portion of the Zone of Influence.

6.6.1 Calculation Method for Zones of Impact

The calculation of the ZoMI and ZoHI areas from the dredge plume modelling has been completed based on analysis of the running mean of modelled SSC against possible and probable coral mortality thresholds, from the method presented in the recent work by Fisher et al 2019 and Jones et al 2019 in the Dredging Science Node of the Western Australian Marine Science Institution (WAMSI).

The time series dredge plume mapping output of suspended sediment is analysed spatially to calculate the running mean of SSC at 7-day, 14-day and 28-day periods across the grid over the dredge program. At each grid point location, the modelled SSC value is defined at half hour timestep through the dredging program. At each time step the SSC is calculated based on the combined total of all sediment fractions (clay, silt, sand). The results from the model are in 5 vertical layers through the water column and the level in the water column where the highest SSC occurs is adopted. The stratification of the plume is most pronounced adjacent the generation source with the SSC approaching uniform distribution through the water column at a distance away in the model.

The calculated running means were assessed against 7-day, 14-day and 28-day threshold limits for corals based on advice from O2Marine and work presented in Fisher (et al 2019) as shown in Table 6.10. The ZoHI and ZoMI regions were categorised as those locations where the modelled running mean crossed the respective 7-day, 14-day or 28-day threshold at any point in the dredging program.

Table 6.10: Threshold Limits for Modelled Suspended Sediment Concentration used to define ZoMI and ZoHI regions through the dredge program (from Fisher et al 2019)

Threshold Type	Running Mean Period	ZoMI Threshold (>SSC)	ZoHI Threshold (>SSC)
Running Mean (SSC)	7 day	14.7 mg/L	24.5 mg/L
	14 day	11.7 mg/L	18.0 mg/L
	28 day	9.3 mg/L	13.2 mg/L

The process for calculating the ZoMI and ZoHI regions has been analysed through a Matlab algorithm which applies the following steps:

1. The dredge model output is a spatial grid on a 30-minute timestep. The grid points store the SSC value through the water column for the combined sediment fractions (fine sand, silt, fine silt and clay). The model is in 3D with the mapping at 5 vertical layers from the surface to seabed (units mg/L);
2. Modelled outcomes represent excess above background. Background SSC is added to the results for running mean analysis against the 7-day, 14-day and 28-day thresholds for the 'Likely' ZoMI and ZoHI areas based on adopting a P50 value of 7.8mg/L. For analysis of the 'Worst Case' ZoMI and ZoHI a P95 background SSC value of 8.7mg/L is adopted.
3. The running mean vs threshold analysis (see thresholds in Table 6.10) is applied to analyse spatial results through the time series at every respective grid point on the gridded map output for SSC. The highest SSC through the water column in the model is adopted at each timestep as part of the analysis;
4. The calculated ZoMI and ZoHI region is defined as a polygon area bounding the point where any of the 7-day, 14-day or 28-day running mean thresholds is exceeded;
5. To assess ZoMI and ZoHI best and worst case extents, sensitivity cases examined the following:
   - 5.1 The background SSC was applied for a 'Likely' scenario adopting a P50 value of 7.8mg/L and 'Worst Case' scenarion with P95 value of 8.7mg/L;
   - 5.2 Rock flour was included in the dredge plume modelling as a 'Worst Case'. Where rock was encountered in the dredge program, an assumed production rate of 1% to 5% of rock flour by dredge volume was released at the cutter head. The additional SSC from the rock flour was included in the analysis to examine the final spatial areas for ZoMI and ZoHI;
   - 5.3 The sensitivity of the model outcomes to the sediment composition assumed at the seabed was analysed by increasing the relative sediment fractions (clay, silt, sand) in the model by 25% with comparison of the final spatial areas for ZoMI and ZoHI against the background SSC approach;

The sensitivity cases analysed in the model for cases 'Including Rock Flour' and 'Increased sediment composition by 25%' as a 'worst case' both indicated a spatial area smaller than adoption of the P95 background SSC definition. For this reason a background SSC at the P95 level was adopted as the 'Worst Case' ZoMI and ZoHI with the knowledge this covered additional uncertainties in the dredging process.

The calculated zones of impact (ZoMI and ZoHI) are presented in Figure 6.15

6.6.2 Time Series presentation of Suspended Sediment Concentration during channel dredging

Time series output from the model for SSC (mg/L) is shown for locations around the dredge footprint in Figure 6.9.

- The modelled SSC time series with and without rock flour for the locations shown in Figure 6.9 are presented in Figure 6.10 and Figure 6.11.
- Analysis of the time series data from the points shown in Figure 6.9 applying the WAMSI thresholds from Table 6.10 is presented in Figure 6.12 and Figure 6.13.

Figure 6.9: Locations for time series output around the dredge footprint

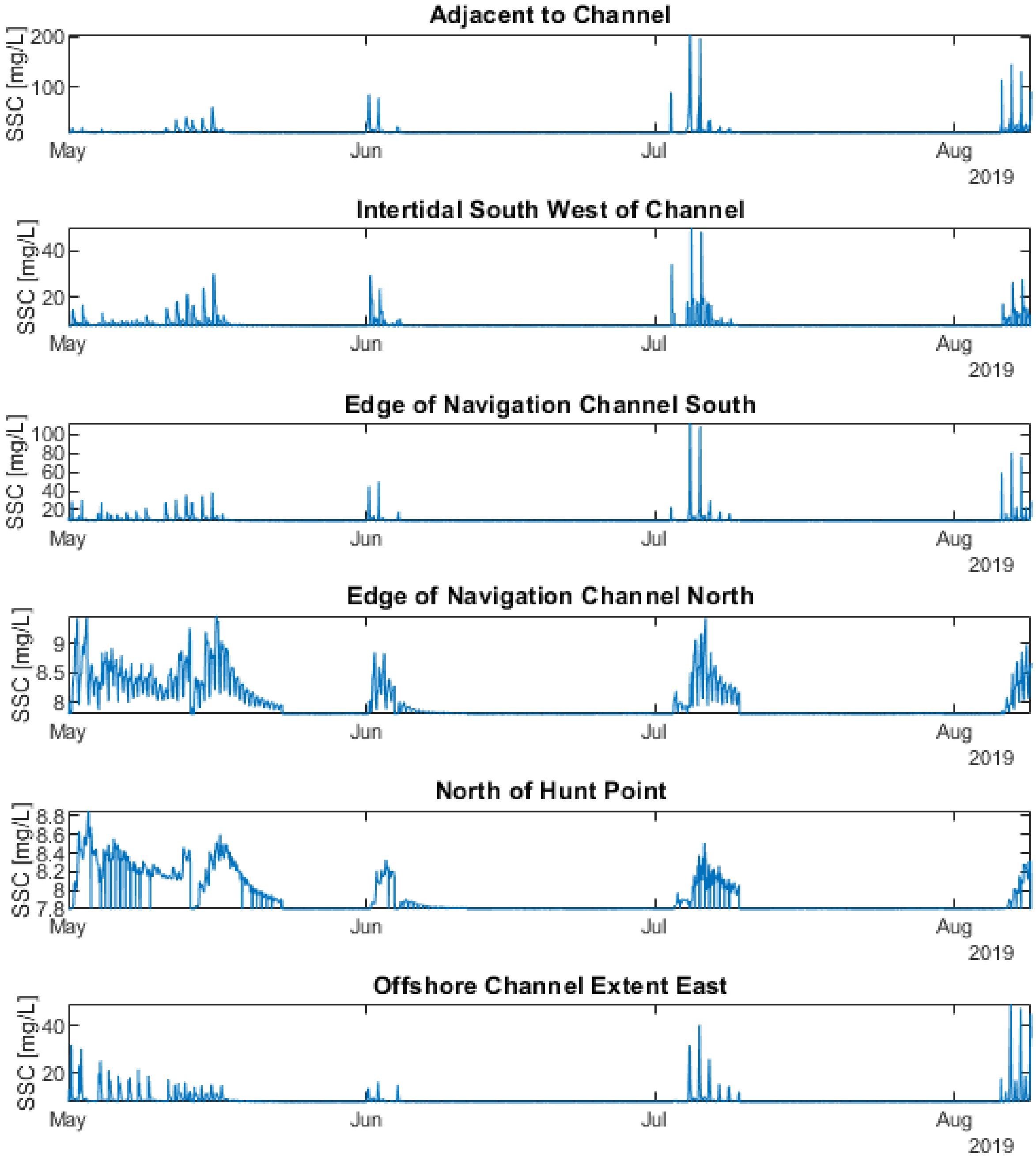


Figure 6.10: Time series modelled suspended sediment concentration (SSC) for points on the western side of the Spoilbank through the offshore dredging campaign. Cases show the modelled results without inclusion of rock flour

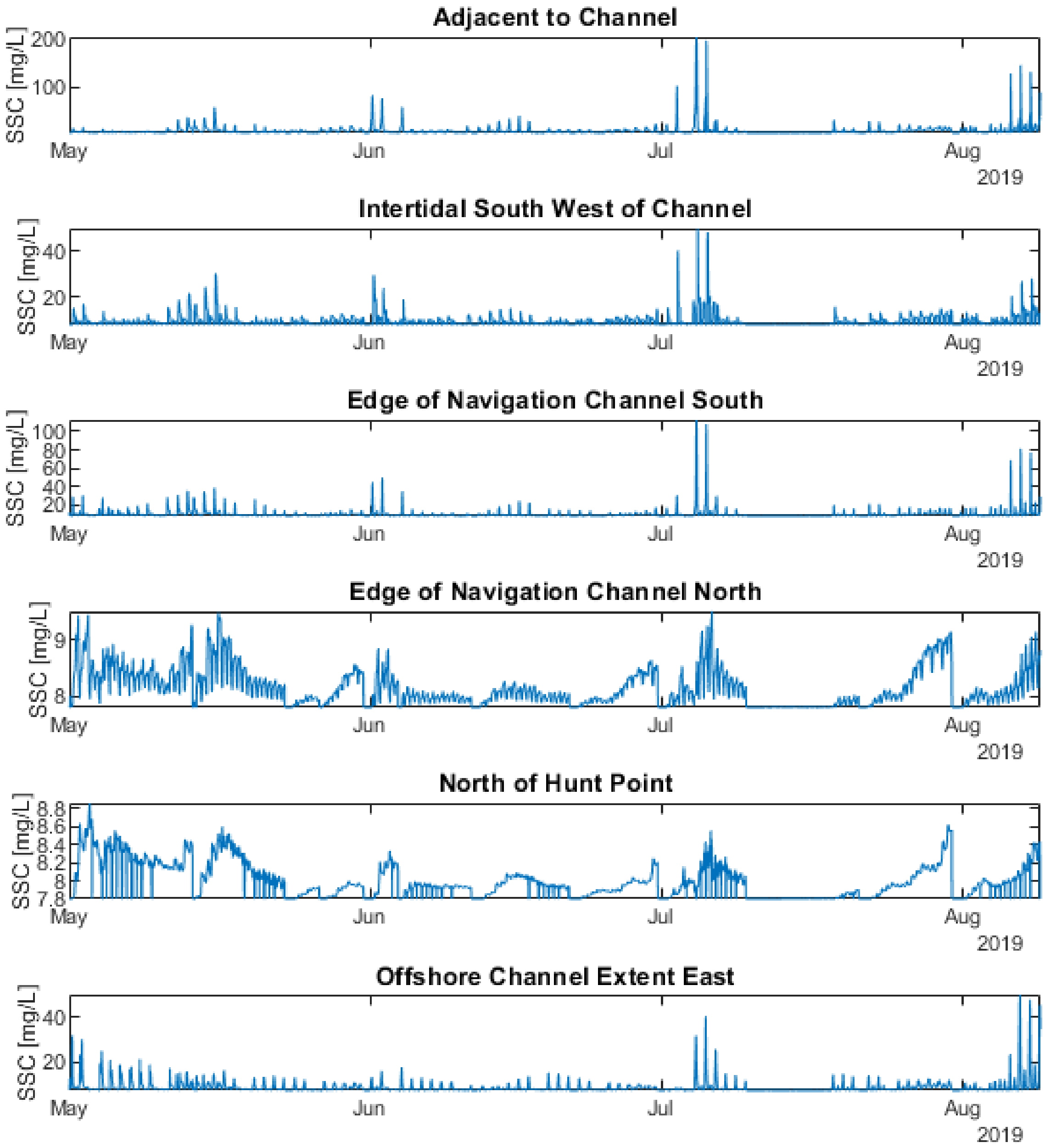


Figure 6.11: Time series modelled suspended sediment concentration (SSC) for points on the western side of the Spoilbank through the offshore dredging campaign. Cases show the modelled results with inclusion of rock flour

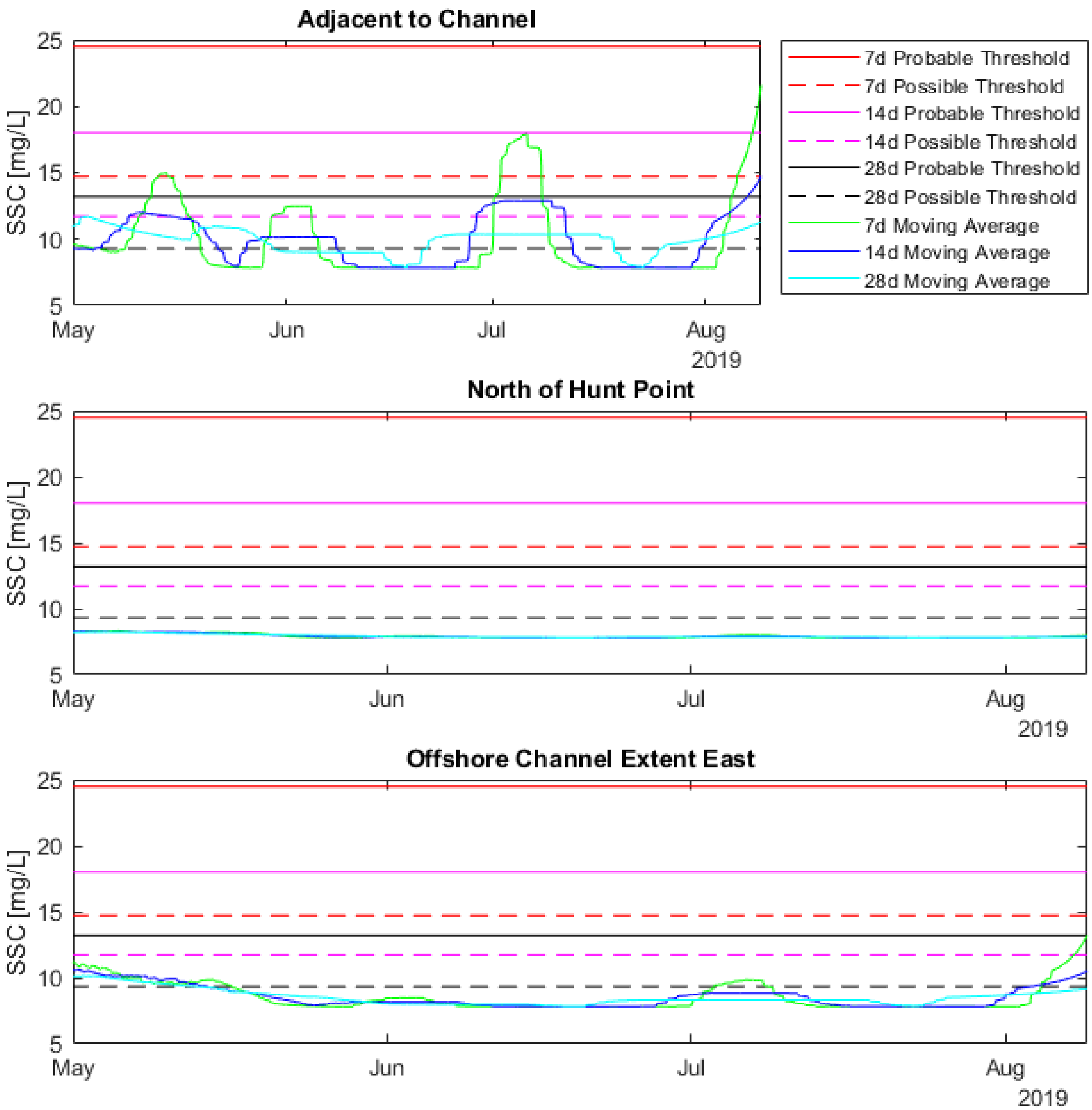


Figure 6.12: Running mean analysis of modelled time series data (without rock flour) against threshold limits for coral at 7 day, 14 day and 28 day (based on WAMSI).

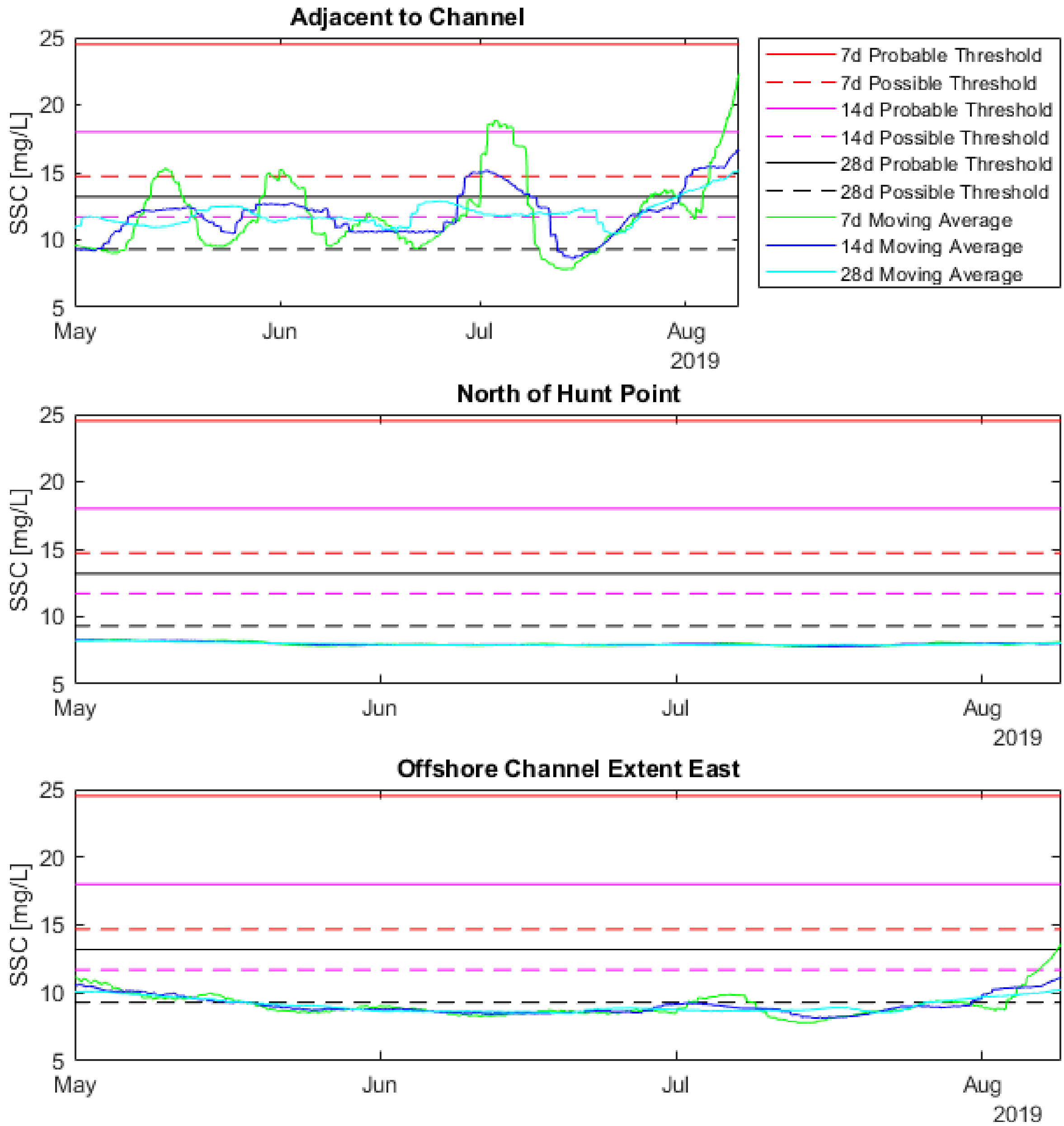


Figure 6.13: Running mean analysis of modelled time series data with rock flour against threshold limits for coral at 7 day, 14 day and 28 day (based on WAMSI).

The following is noted for the time series plots

- The SSC time series in Figure 6.10 are representative of the dredging timeline outlined in Table 6.2. In Figure 6.10, data point “Adjacent to Channel” exhibits spikes in SSC levels later in the dredging program when dredging of sand commences nearer to the points location. Similarly, points “Edge of Navigation Channel North” and Edge of Navigation Channel South” illustrate a rise in SSC levels early in the time series, when dredging commences adjacent to them.
- The SSC values of the “Edge of Navigation Channel North” and “North of Hunt Point” are reduced by almost two orders of magnitude when compared to data point “Adjacent to Channel” indicating that the majority of sediment plume constituents do not reach the associated locations. Comparatively, the

"Offshore Channel East" data point demonstrates that nearer the location of the entrance channel, SSC levels directly relate to the assumed dredging timeline.

- The clear spikes in SSC visible in both Figure 6.10 and Figure 6.11 are the result of the commencement of dredging operations offshore, followed by the dredging beneath the rock layer in zone 16 and 12, which comprises 20% clay content, causing a significant increase in SSC levels.
- Consideration of rock flour does not carry a significant effect on the SSC scale used in Figure 6.11, resulting in minor fluctuations above the background SSC level. Figure 6.12 and Figure 6.13 demonstrate that rock flour does impact the 7, 14 and 28 day SSC moving averages of locations near the channel entrance.
- Figure 6.10 to Figure 6.13 demonstrate the sensitivity of the dredge plume to the presence of rock flour.Rock flour results in the exceedance of the 7 day possible (May 30th) and 14 day probable (July 1st) thresholds for the "Adjacent to Channel" data point (Figure 6.13), that are otherwise not exceeded (Figure 6.12).
- Figure 6.12 and Figure 6.13 demonstrate that rock flour essentially raises the background SSC level for locations near the entrance channel. This increases the extent to which probable and possible thresholds are exceeded, particularly for dredge zones comprising sediment volumes with high clay percentages (Zone 19, 16 and 12). However, this does not drastically increase the size of the ZoMI or the ZoHI, as this increase in exceedance generally occurs within the impact zone bounds that are governed by dredging large quantities of sand with high concentrations of clay at a much greater production rate.
- The most significant rise in moving average SSC occurs in the final week of the modelled dredging period, during which sediment below the layer comprising a very high content of clay (20%) and silt (25%) for the "red beds" dredged in zone 12. This accounts for the large spike in SSC values shown at the end of the time series plots in Figure 6.10 and Figure 6.11.

6.7 Construction Tasks for the Inner and Outer Breakwater

6.7.1 Preparation of Seabed

The construction of the northern and southern breakwater structures will require removal of sediments to below the rock level prior to the breakwater construction. The excavation of the sediments, rock and red beds is required to get the breakwater protection down to the channel bed depth to incorporate the slots for the breakwater toes adjacent to the channel (MPRA2019a).

The dredge volume and sediment composition of dredge material has been analysed based on the nearshore bathymetry, available borehole data and sediment samples. The bathymetry, geotechnical sources and structure alignments are shown in Figure 6.14. Calculated volumes of sediment that would be released into the water column by longreach excavator are summarised in Table 6.11 for the above rock sediments and Table 6.12 for the below rock sediments. Rock flour is not considered a risk for longreach excavation (refer Section 6.4.4).

In summary the analysis of the excavation by longreach excavator shows:

- the volume of the fines released into the water column as the excavator removes the sand overlaying the rock layer for the northern breakwater is 131m^3 at a rate of between 2.4m^3 to 17m^3 / day;
- the volume of the fines released into the water column as the excavator removes the sediments below the rock layer for the northern breakwater is 212m^3 at a rate of 17m^3 / day;
- the volume of the fines released into the water column as the excavator removes the sand overlaying the rock layer for the southern breakwater is 36m^3 at a rate of between 2.3m^3 / day; and
- the volume of the fines released into the water column as the excavator removes the sediments below the rock layer for the southern breakwater is 95m^3 at a rate of 17m^3 / day.

The volume of fines (clay, silts) released through these processes is markedly lower than the volumes of fines released by the CSD over the 4-month program to dredge the channel.

- During dredging of the channel through Zone 16 adjacent the northern breakwater offshore, the CSD released approximately 1725m^3 of fine material from above and below the rock layer.
- During dredging of the channel through Zone 12 adjacent the southern breakwater and northern breakwater nearshore, the CSD released approximately 2,100m^3 of fine material from above and below the rock layer in the sediment plume.

Table 6.11: Preparation of seabed for breakwater structures – excavation of sand overlaying rock.

Element	Depth of Rock	Total Volume of Material Excavated to top of rock layer	Total Volume released by excavator bucket (4%)	Total Fines Released in Plume	Borehole and Sample Location References
Northern Breakwater Offshore Excavation of Sand Overlying the Rock using long reach excavator	0.2m to 0.4mLAT	10,500m^3	420m^3	Upper layer is 6% Fines. Total 12m^3 fines released over 5 days Lower layer is 45% Fines. Total 95m^3 fines released in 5.5 days Release fines 2.4m^3/day and 10m^3/day	BH15, BH16 (CMW2019) B11, B12-2
Northern Breakwater Nearshore Excavation of Sand Overlying the Rock using long reach excavator	1.3m LAT	14,900m^3	600m^3	Seabed is 6% Fines. Total 36m^3 fines released in 15 days. Release fines at 2.4m^3/day	BH12 (CMW2019) B15, B16
Southern Breakwater Nearshore Excavation of Sand Overlying the Rock using long reach excavator	1.3m LAT	15,400m^3	620m^3	Seabed is 6% Fines. Total 36m^3 fines released in 15.5 days. Release fines at 2.3m^3/day	BH12 (CMW2019) B15, B16

Table 6.12: Preparation of seabed for breakwater structures – excavation of sediment below rock.

Element	Depth below rock to -2.5mCD	Total Volume of Material Excavated below rock layer	Total Volume released by excavator bucket (4%)	Sediment Composition and Total Fines Released	Borehole and Sample Location References
Northern Breakwater Offshore Excavation of layer below rock by long reach excavator	1.1m	6,060m^3	240m^3	Seabed is 45% Fines. Total 108m^3 fines released in 6 days. Release fines at 17m^3/day	BH15, BH16 (CMW2019) Rock Layer is 1.5m to 1.6m thickness Worst of redbeds and B12-2
Northern Breakwater Nearshore Excavation of layer below rock by long reach excavator	1.4m	5,800m^3	230m^3	Seabed is 45% Fines. Total 104m^3 fines released in 6 days. Release fines at 17m^3/day	BH12 (CMW2019) Rock Layer is 2.0m thickness Worst of redbeds and B12-2
Southern Breakwater Excavation of layer below rock by long reach excavator	1.8m	5,200m^3	210m^3	Seabed is 45% Fines. Total 95m^3 fines released in 5 days. Release fines at 17m^3/day	BH12 (CMW2019) Rock Layer is 2.0m thickness Worst of redbeds and B12-2

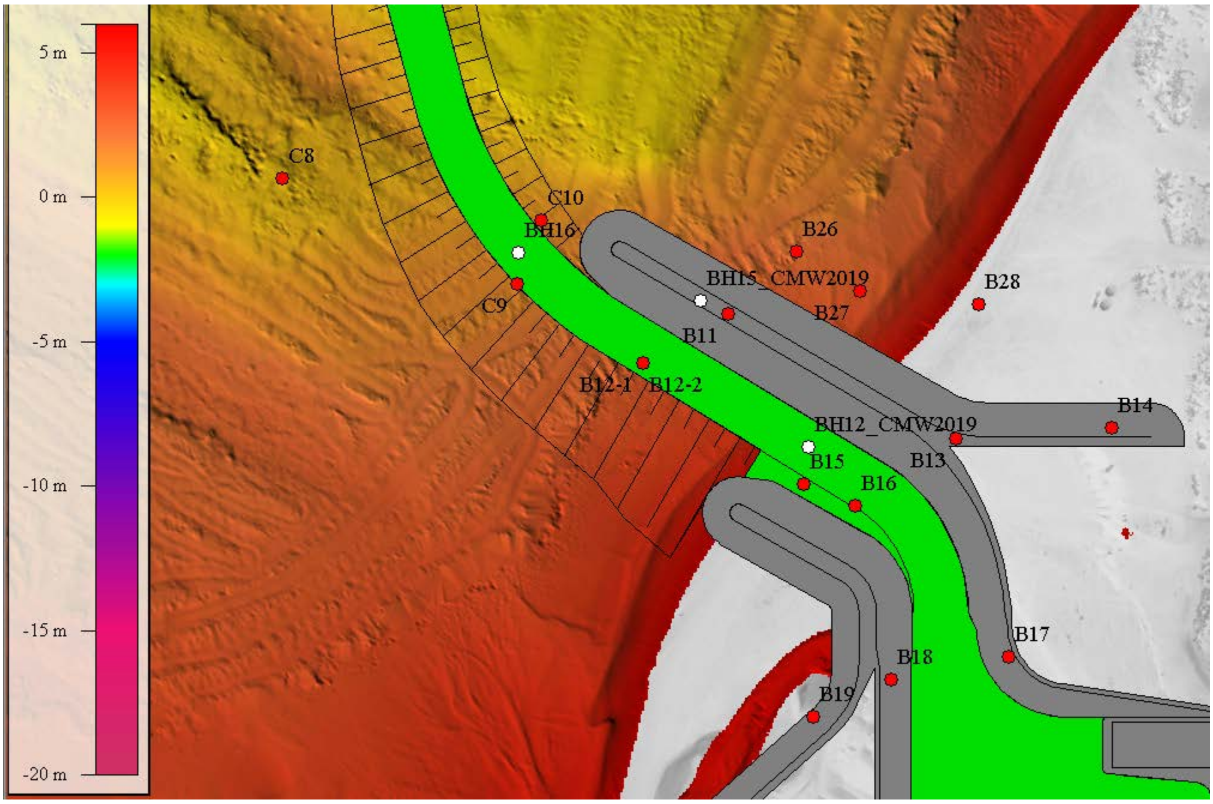


Figure 6.14: Borehole Locations and Sediment Sample locations around the entrance structures based on CMW 2019 and O2Marine 2019. Existing Seabed Bathymetry shown (to Datum mCD)

6.7.1.1 Dumping of Core Material in the Nearshore

The dumping of core material in the shoreline to construct the breakwaters will be done by trucks along the breakwater centreline. Dumping will commence from the landside and progressively move seaward with a tipping rate of 1,500m^3 a day assumed. As the core material is tipped into the nearshore areas, this will generate a sediment plume associated with the release of the fines in the core material. This plume source is assumed as 2% by volume of core (0.5% clay / fine silt / coarse silt / fine sand respectively).

The sediment plume is released at the seaward end of the core mound as it extends offshore, with the release of sediments distributed vertically through the water column. It is assumed that the plume is generated only from the breakwaters in the region offshore of the existing Spoilbank feature (ie the landside segments of the breakwater will be constructed in the dry).

Based on the extent of the breakwater length where core material will impact the nearshore and the assumed production rate of the trucks (1,500m^3/day), the total fine sediments released through the core placement is estimated in Table 6.13.

Table 6.13: Placement of Core and release volumes of fines

Location	Total Volume core material for areas seaward of HAT	Fines Released assumed at 2% of Total Volume	Construction Period (1500m^3/day, 6 day working week)
Core placed in Northern breakwater	41,500m^3	Total Fines = 830m^3	4.5 weeks
Core Placed for Southern Breakwater	52,000 m^3	Total Fines = 1,040m^3	6 weeks

By comparison the volume of fines (clay, silts) released into the water column during the core dumping is markedly lower than the volumes of fines released by the CSD when it is operating to dredge the channel. The rates from the CSD for comparison are as follows:

- During dredging of the channel through Zone 16 adjacent the northern breakwater offshore, the CSD released approximately 1725m^3 of fine material from above and below the rock layer.
- During dredging of the channel through Zone 12 adjacent the southern breakwater and northern breakwater nearshore, the CSD released approximately 2,100m^3 of fine material from above and below the rock layer in the sediment plume.

In conclusion the volume of fines released during the dredging of the nearshore channel section are comparatively higher than the calculated fines released during the dumping of core for the outer and inner breakwater. Under this assumption the sediment plumes generated will not increase the spatial impact areas for the ZoMI and ZoHI calculated over the offshore dredging phase.

It is noted that this assumes there is no overlap between the onshore and offshore scheduling of activities which should be confirmed with the appointment of a civil contractor.

6.8 Marina basin excavation

The modelled dredging sequences for the marina basin construction are scheduled to occur in the second year of the dredge program. There is 359,300m^3 of dredging that is required to be undertaken by a medium sized CSD over an eight-month period outside of the turtle season (refer Table 6.6). In total there is 158,700m^3 of sand above the rock layer, 122,500m^3 of rock layer and 78,100m^3 of high fines content red-beds under the rock layer. It is noted that under the assumed production rates for a medium CSD this volume of material would not be possible to remove within the 8 months of available operations in the year (ie outside turtle season) should there be no land based excavation.

For the dredge sequences completed through Zone 11A, Zone 11B, Zone 13A and Zone 13B a 2D model was used for the dredge plume modelling. Due to the confined nature of the basin dredging which requires the CSD to be working inside the narrow channel and basin areas, where the dredge plume impacts outside of the entrance are due to the tidal exchange, the 2D results are considered representative for examining the plume through the channel and western Spoilbank regions.

The dredge plumes associated with the excavation of sand, rock and red-beds layers were examined using the one-month dry season simulation applied previously. Analysis of the plume impacts against threshold limits under 7-day, 14-day and 28-day running mean values outlined in Section 6.5.6 was completed to examine the spatial areas of the ZoHI and ZoMI.

Outcomes from the analysis of the basin excavation dredge plume modelling indicate:

1. For the sections where sediment is overlaying the rock, the dredge plumes are generated within the confines of the dredged Marina channel and basin and directed through the Marina entrance on the ebb tides to disperse over the western side of the Spoilbank. The impacts are very high in the confined

basin and channel. The plume disperses through the entrance and is directed west along the dredged channel towards the Goldsworthy Channel. Outside the entrance on the western side of the Spooilbank the spatial extent of the ZoMI and ZoHI are within the spatial regions calculated during the 4-month dredging of the offshore channel sections in Year 1 (ie Zone 12 and Zone 16 to Zone 19);

2. For the sections within the basin identified as rock in the borehole analysis, the modelled outcomes for rock flour and generation of dredge plumes was examined. The plume from the dredged Marina channel and basin is directed through the Marina entrance on the ebb tides to disperse over the western side of the Spoilbank. The impacts are very high in the confined basin and channel. The plume disperses through the entrance and is directed west along the dredged channel towards the larger Goldsworthy Channel. Outside the entrance on the western side of the Spooilbank the spatial extent of the ZoMI and ZoHI are within the spatial regions calculated during the 4-month dredging of the offshore channel sections in Year 1 (ie Zone 12 and Zone 16 to Zone 19);
3. For the 'red-beds' layer below the rock the modelling showed that the very high fines content (32%) and the persistence of the operations which require continuous dredging over long durations led to high SSC directed out of the basin and through to the western shoreline of the Spoilbank due to the levels of fines being released over a prolonged period. This release of fine suspended sediment through the entrance if left unmanaged would create a larger spatial extent for the ZoHI and ZoMI areas calculated during the 4-month dredging of the offshore channel sections. The risk could be reasonably managed onsite through management techniques that restrict the fines from leaving the marina basin either through use of a silt curtain at the time of dredging red-beds or constructing a temporary barrier at the entrance to restrict flows completely from the site. Other management considerations from an operational perspective that could restrict the release of the fines during dredging of red-beds layer for the basin could include changing dredging modes (ie from CSD to long-reach excavator) or slowing the production rates. These options have not been further assessed at this stage, without clear understanding of the intended dredging methodology that the civil contractor will adopt over the Spoilbank area.

6.8.1 Final Calculation of Zones of Impact from Model Results

The final calculation of the final ZoMI and ZoHI boundaries for the 'best' case and 'worst' case scenarios is summarised in the areas presented in Figure 6.15.

The spatial regions have been calculated based on the methodology presented in Section 6.6.1:

- a median background (50th percentile, P50) SSC value of 7.8mg/l has been adopted in calculation of the 'Best Case' areas for the ZoHI and ZoMI
- a higher background (95th percentile, P95) SSC value of 8.7mg/l has been adopted in calculation of the 'Worst Case' areas for the ZoHI and ZoMI

These areas have been provided to O2Marine for application in the dredge management plan.

Figure 6.15: Calculated spatial regions for Zone of Moderate Impact (ZoMI) and Zone of High Impact (ZoHI) over the duration of the construction program for the Port Hedland Spoilbank Marina. The calculations for 'Best Case' and 'Worst Case' incorporate different assumptions for background suspended sediment concentration as P50 (Best) and P95 (Worst) based on measured data from the location. Image Google Earth.

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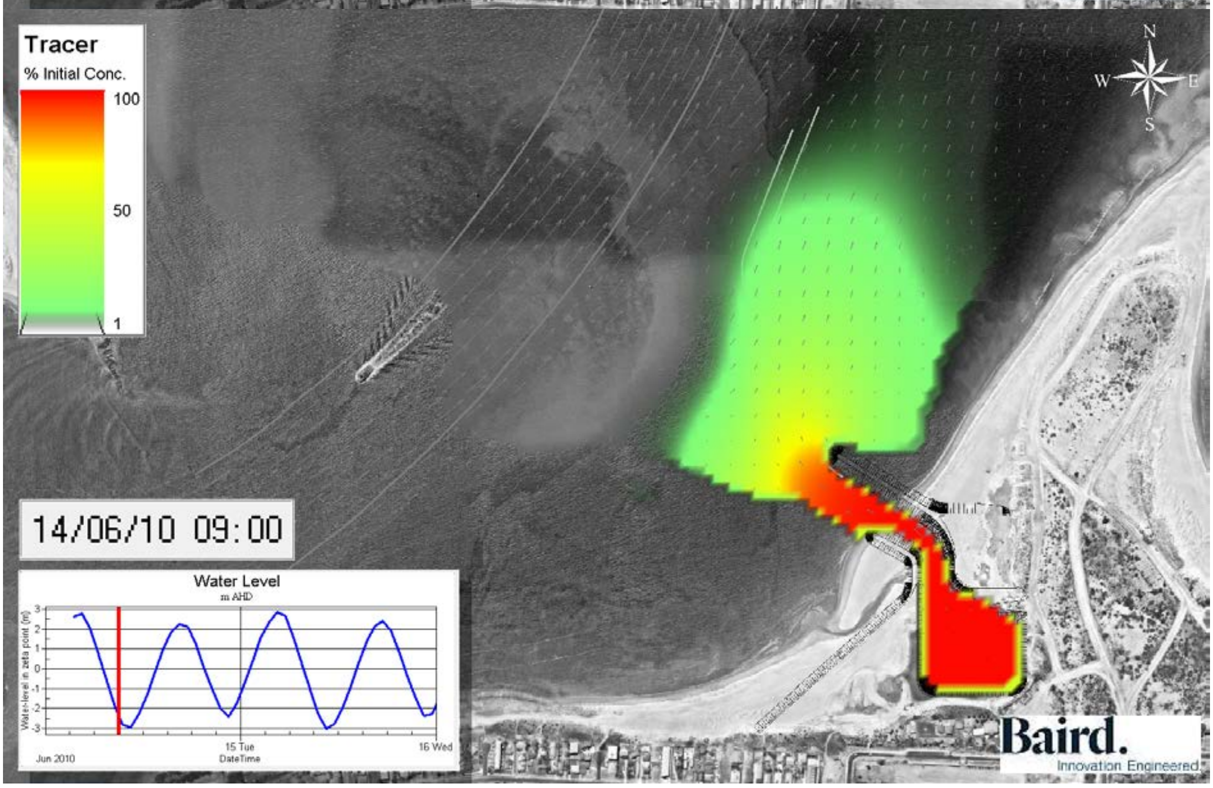
Appendix A

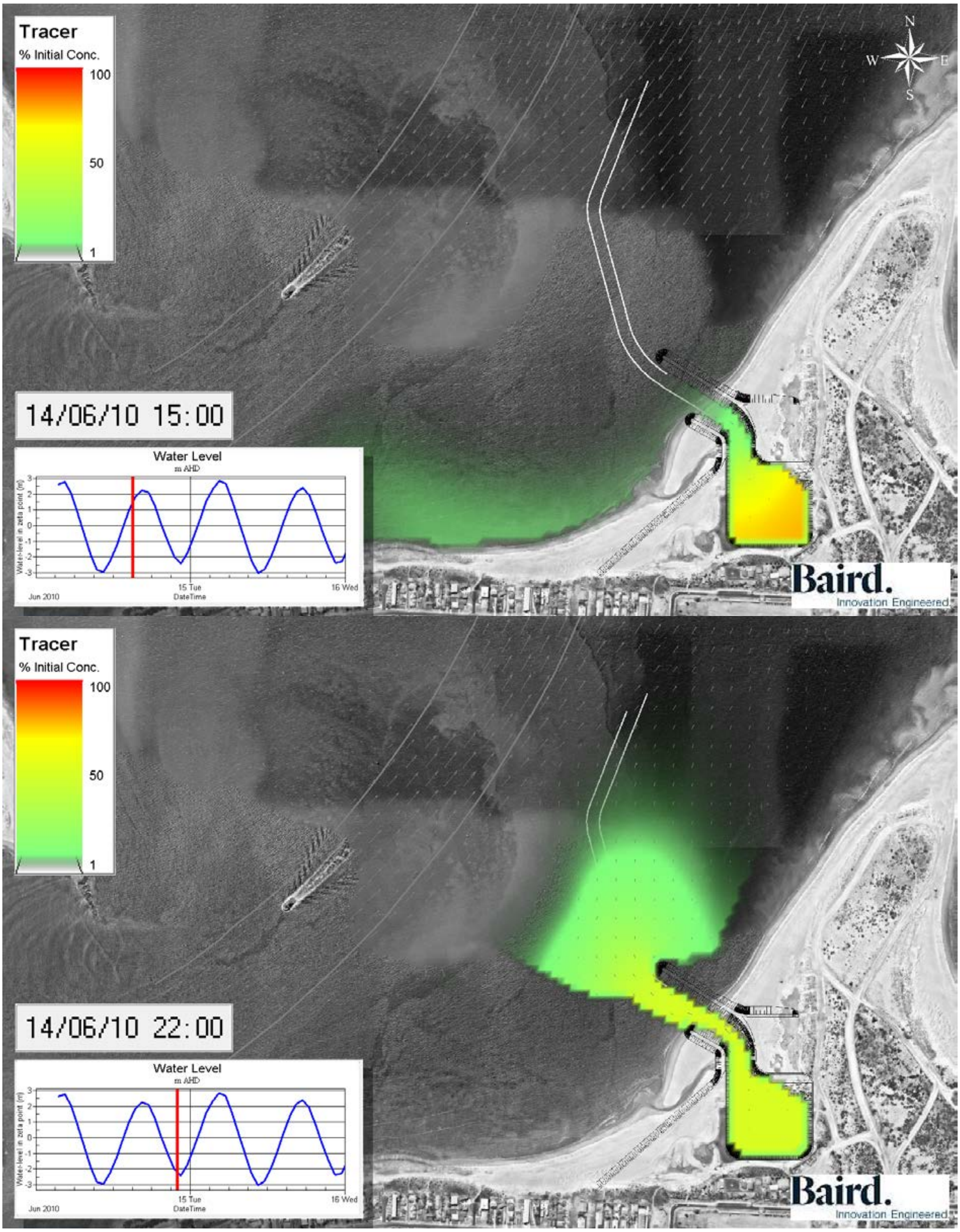
2D and 3D Model Hydrodynamic and Wave Model Validation

Appendix B

Flushing Simulation Tracer Concentration Plots

B.1 Spring Tide – SE Wind

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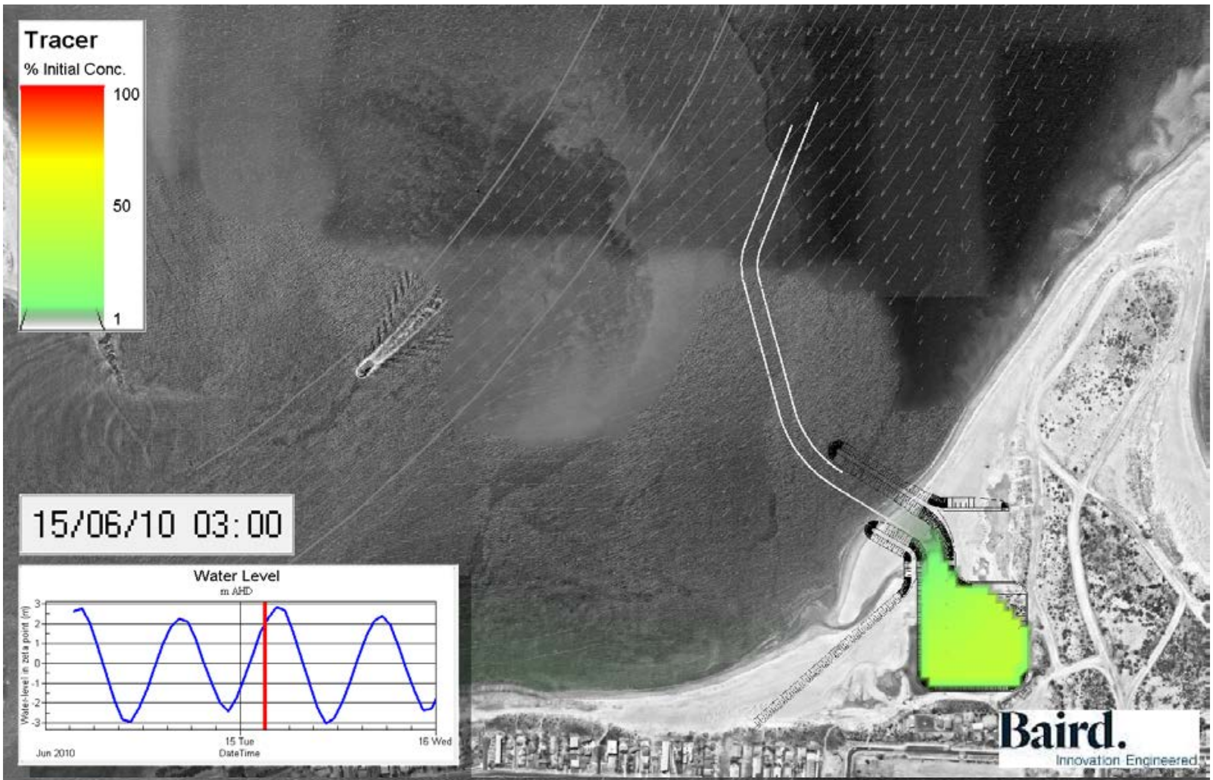
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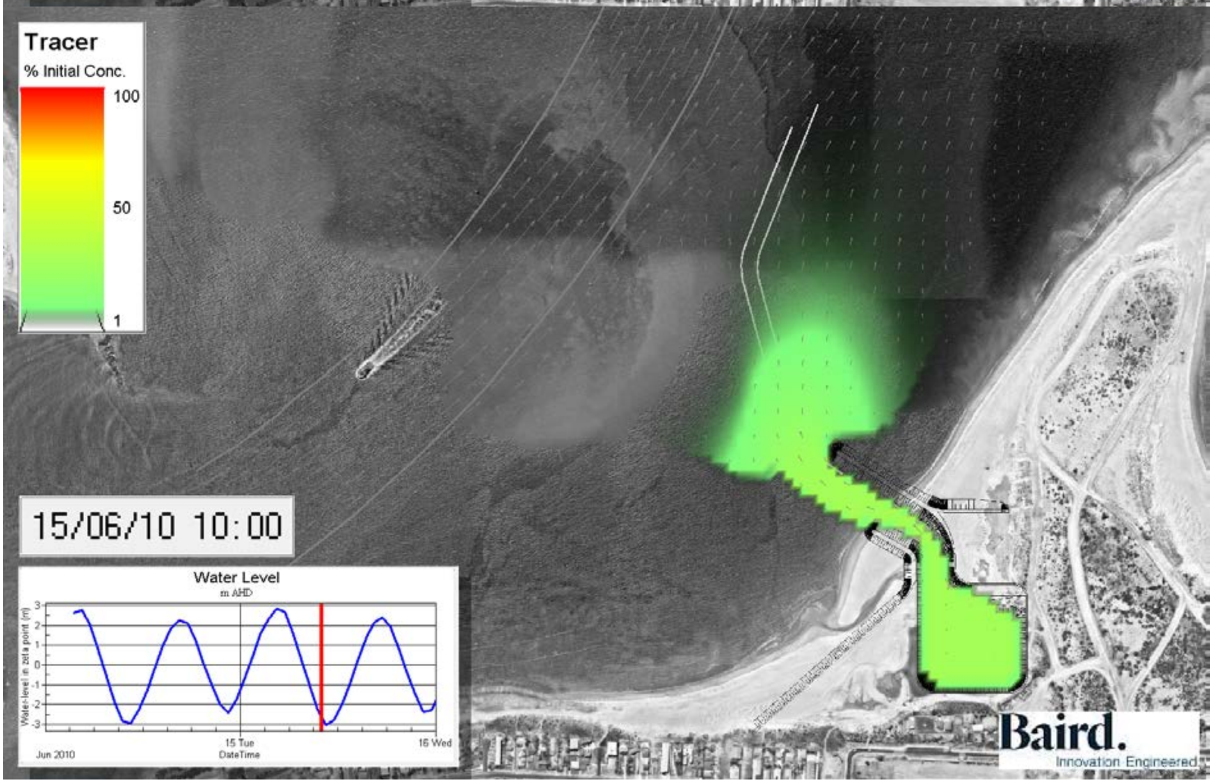
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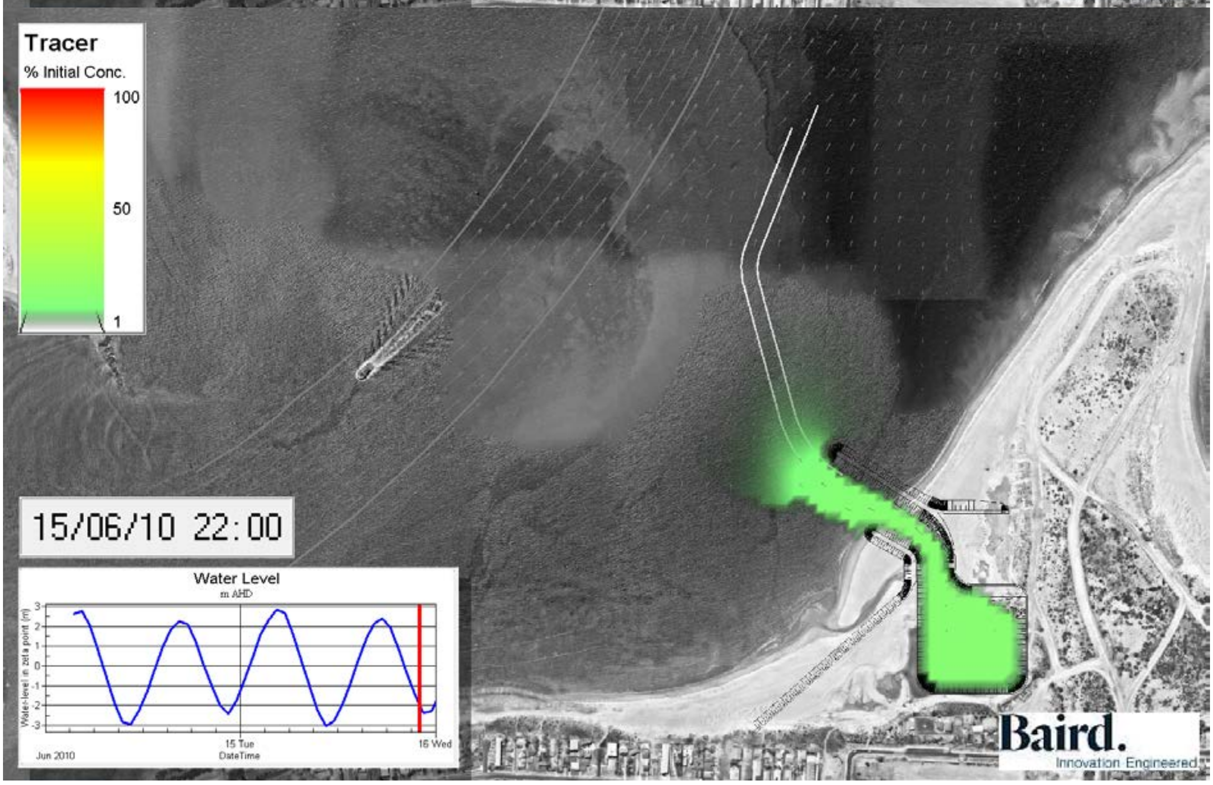
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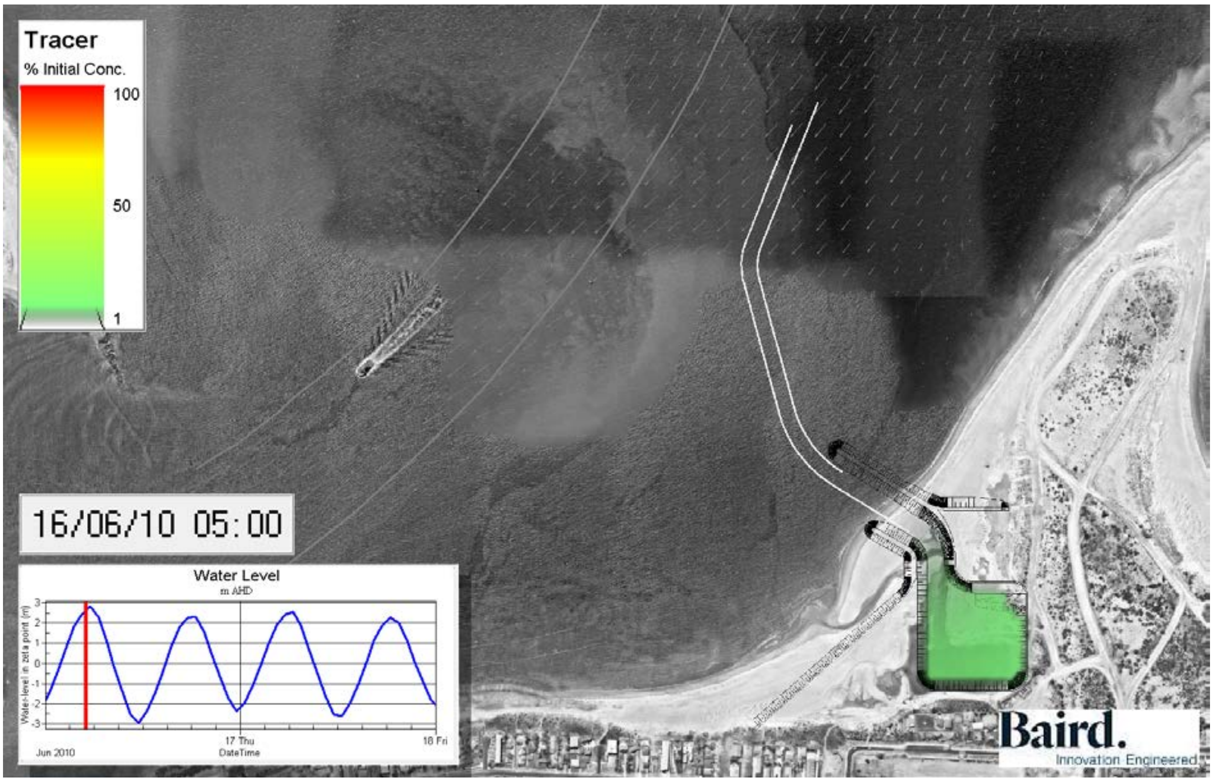
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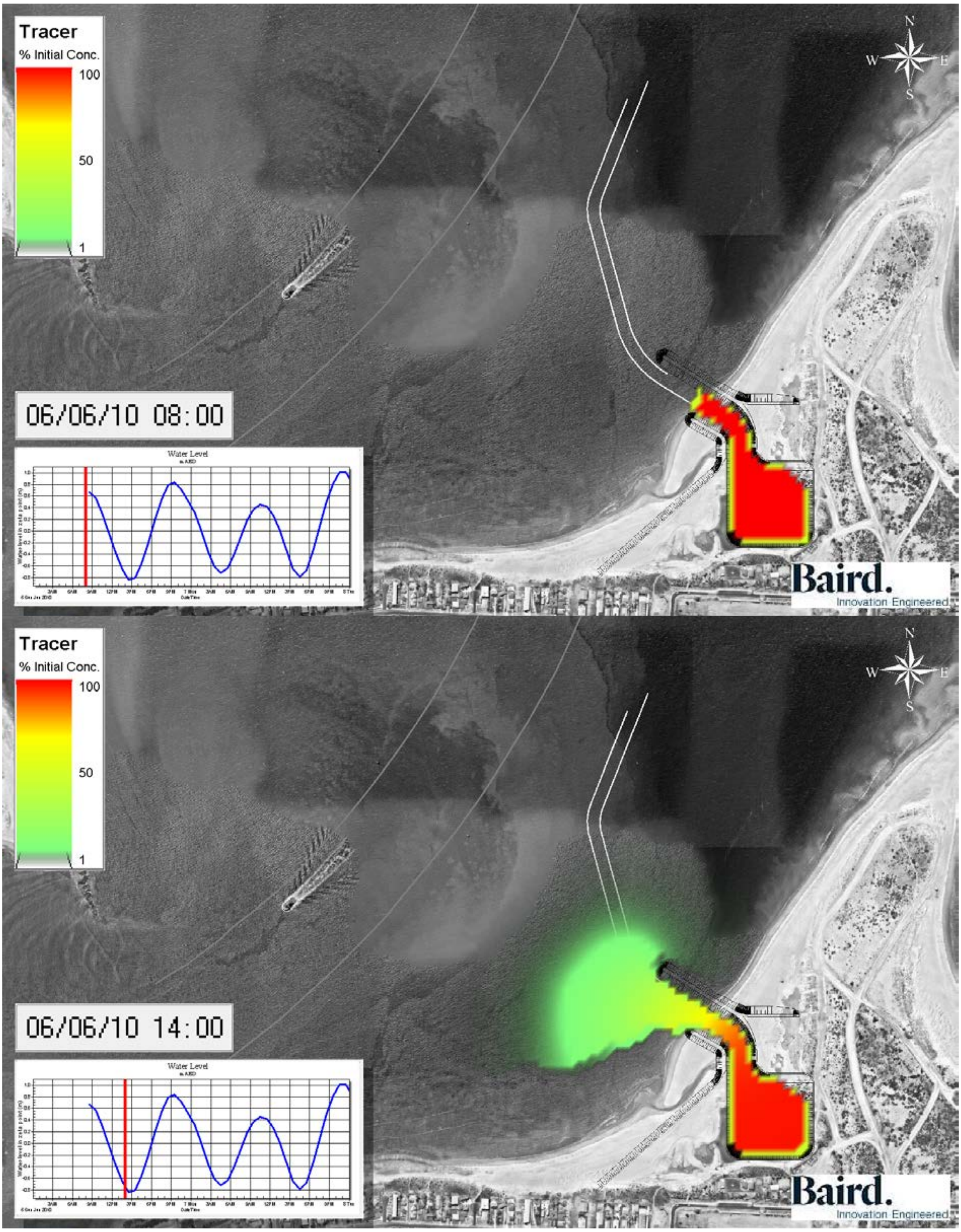

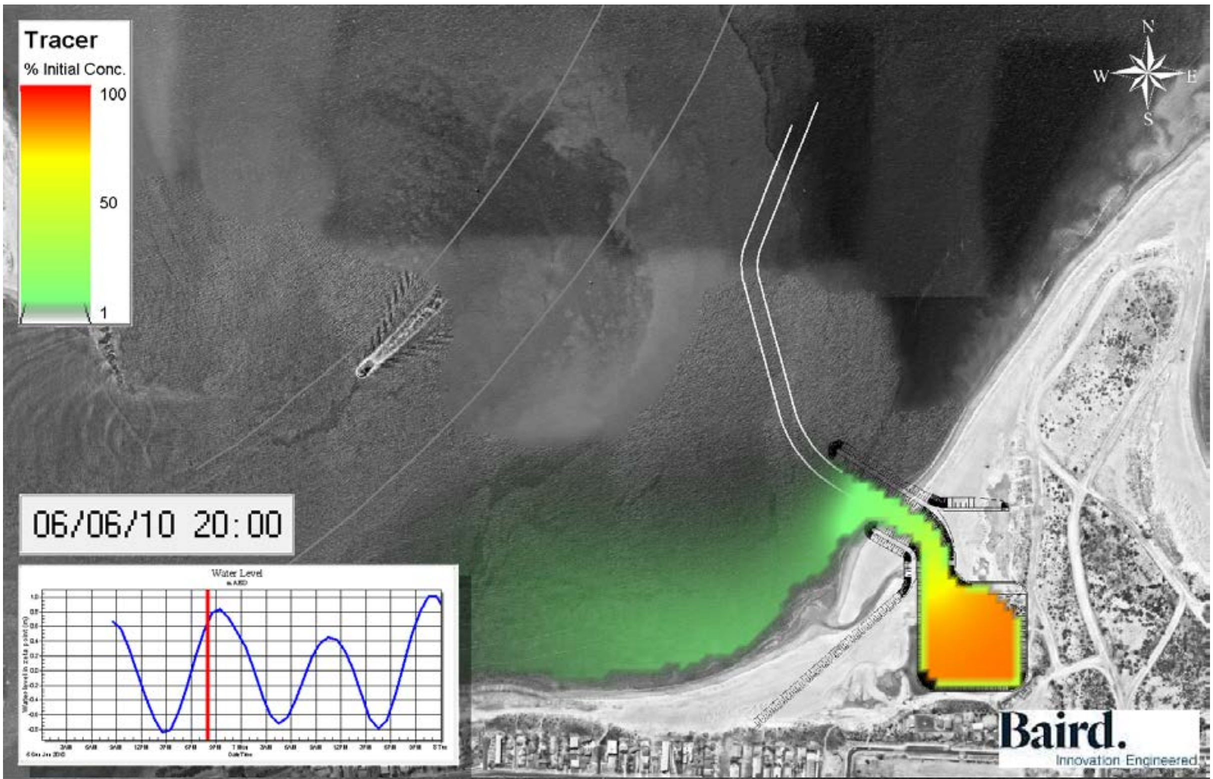
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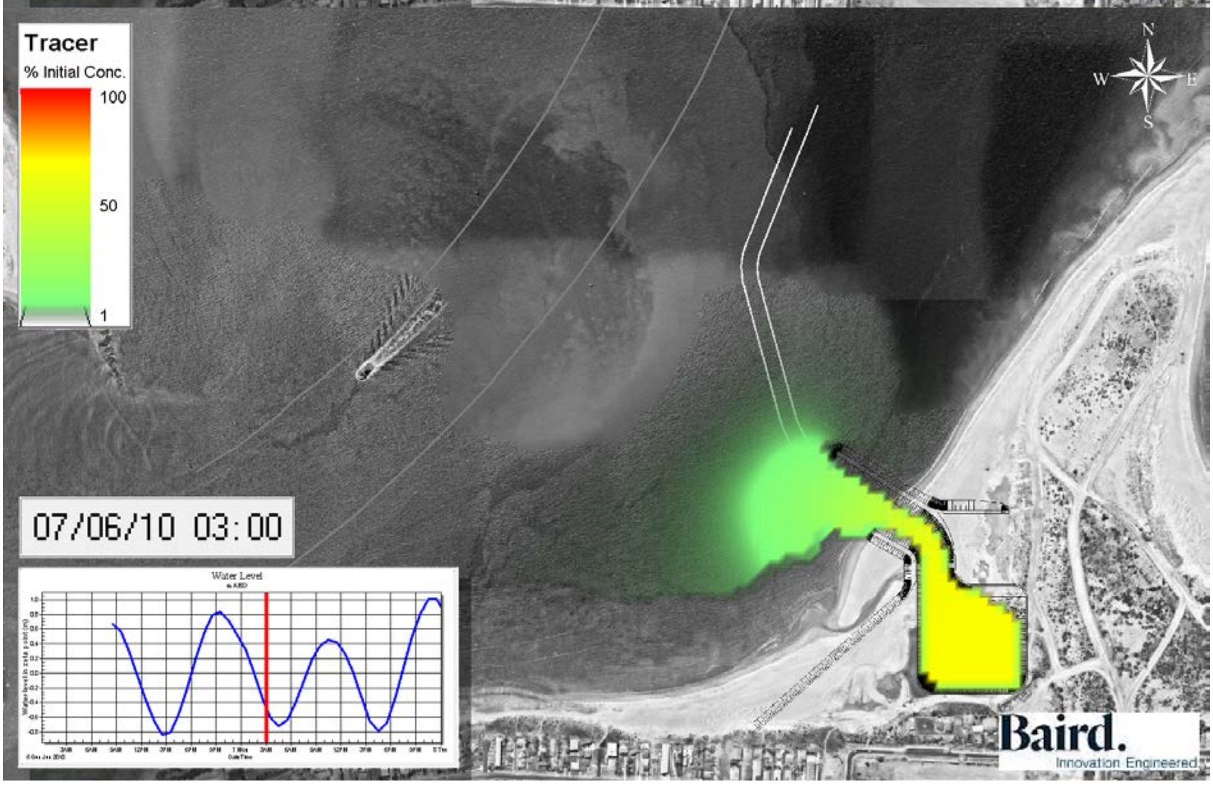
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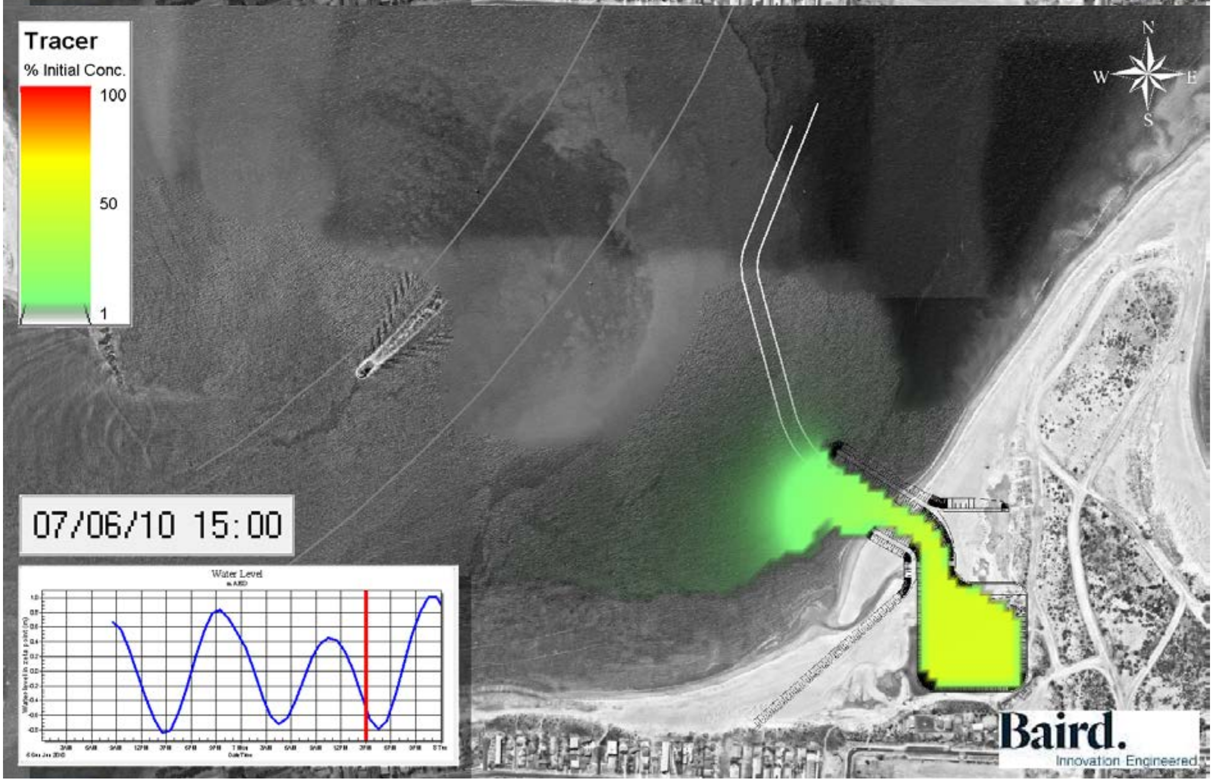
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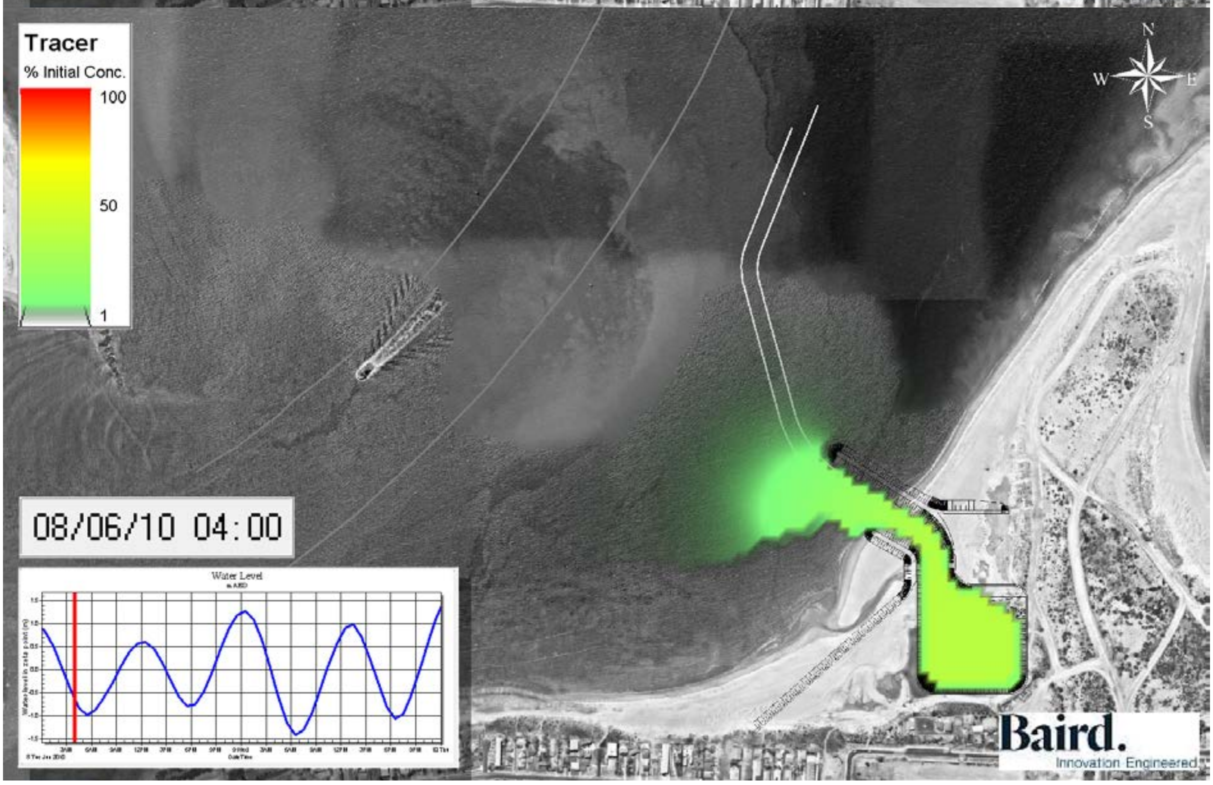
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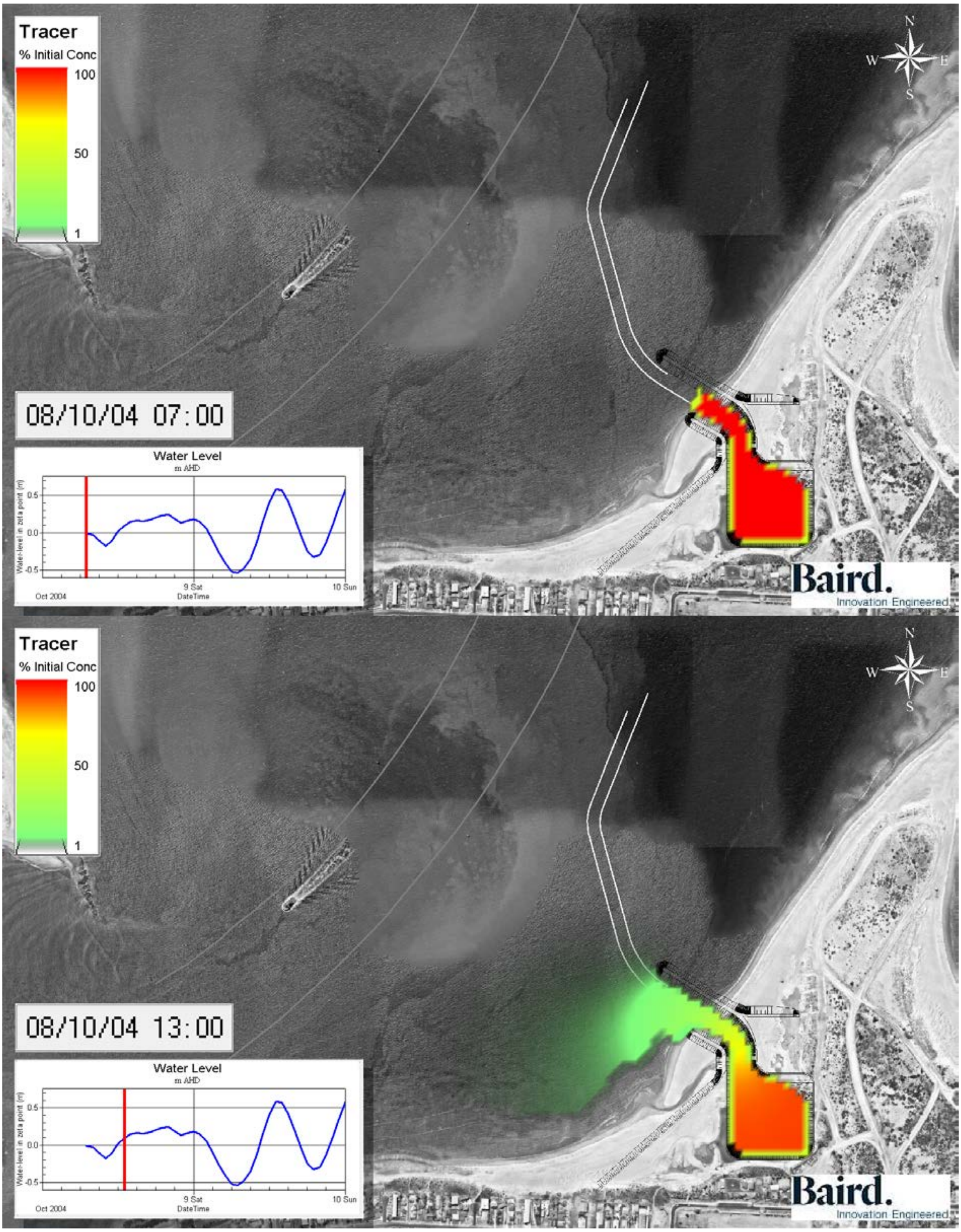
B.3 Extreme Neap Tide – SE Wind

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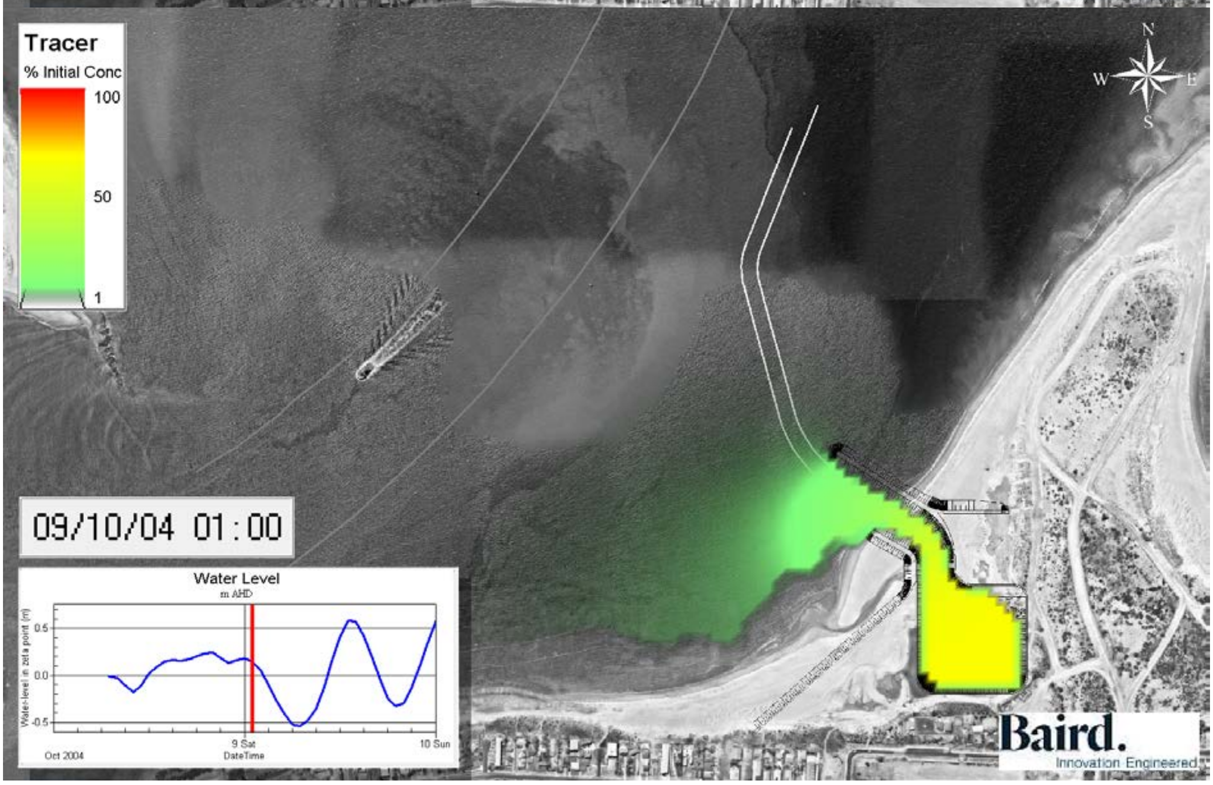
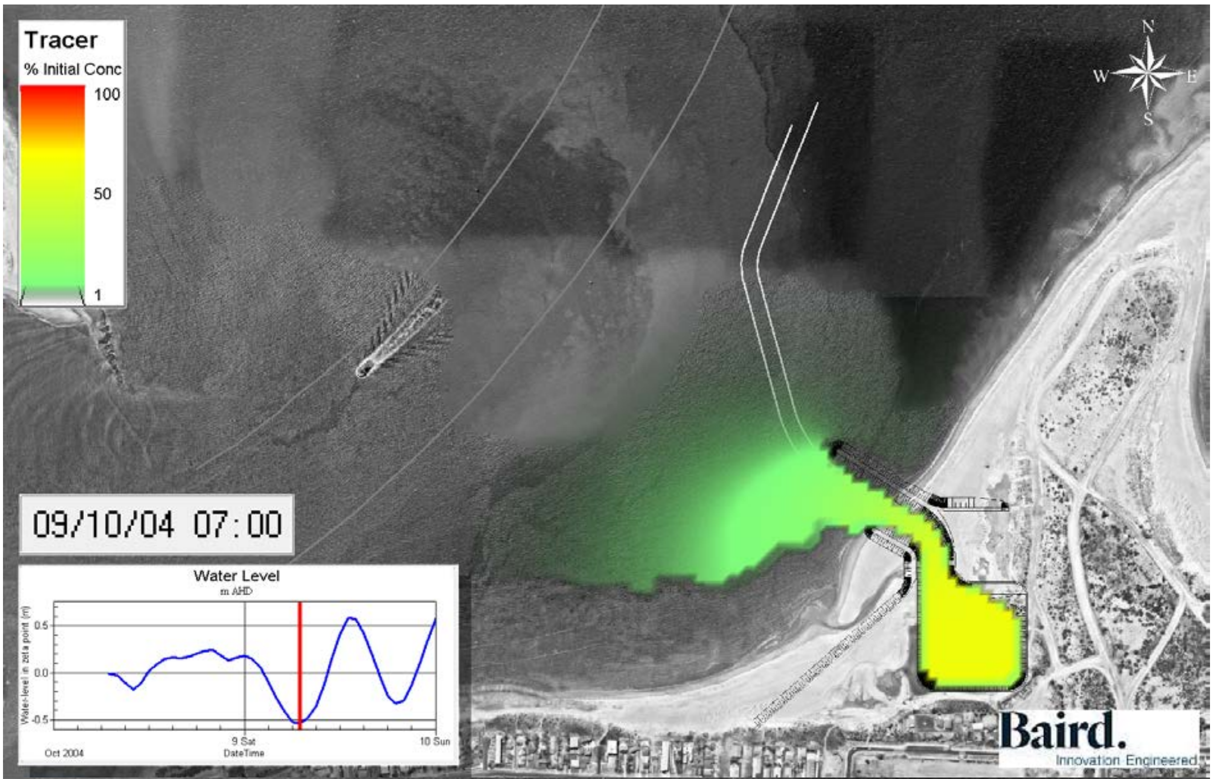
Baird.
Innovation Engineered


Tracer
% Initial Conc
100
50
1
09/10/04 01:00
Water Level
m AHD
0.5
0.0
-0.5
Oct 2004
9 Sat
DateTime
10 Sun
N
W
E
S
Baird.
Innovation Engineered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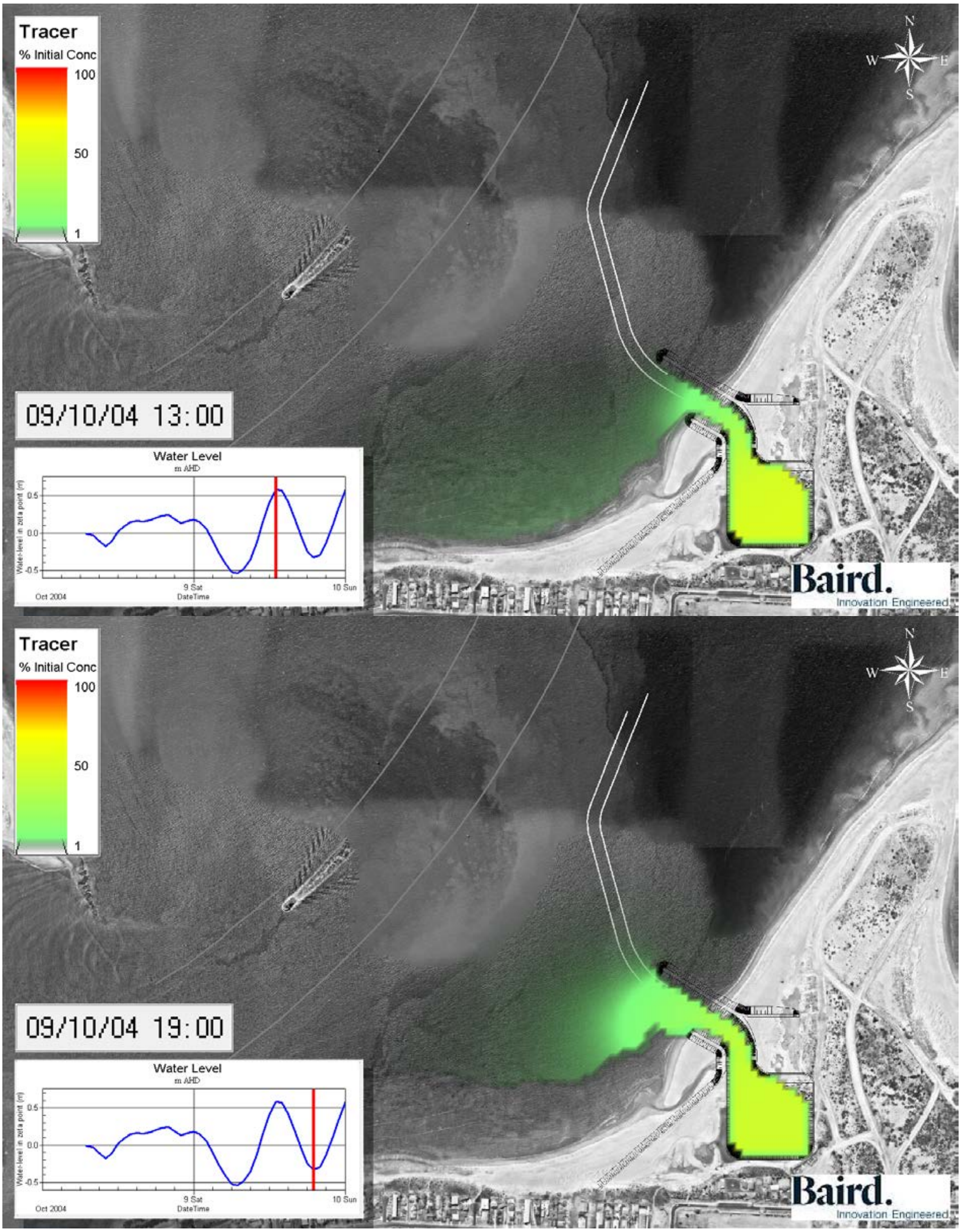
% Initial Conc
100
50
1
09/10/04 07:00
Water Level
m AHD
Water-level in zeta point (m)
0.5
0.0
-0.5
Oct 2004
9 Sat
DateTime
10 Sun
N
W
E
S
Baird.
Innovation Engineered


Tracer
% Initial Conc
100
50
1
09/10/04 13:00
Water Level
m AHD
Water-level in zeta point (m)
0.5
0.0
-0.5
Oct 2004
9 Sat
DateTime
10 Sun
N
W
E
S
Baird.
Innovation Engineered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50
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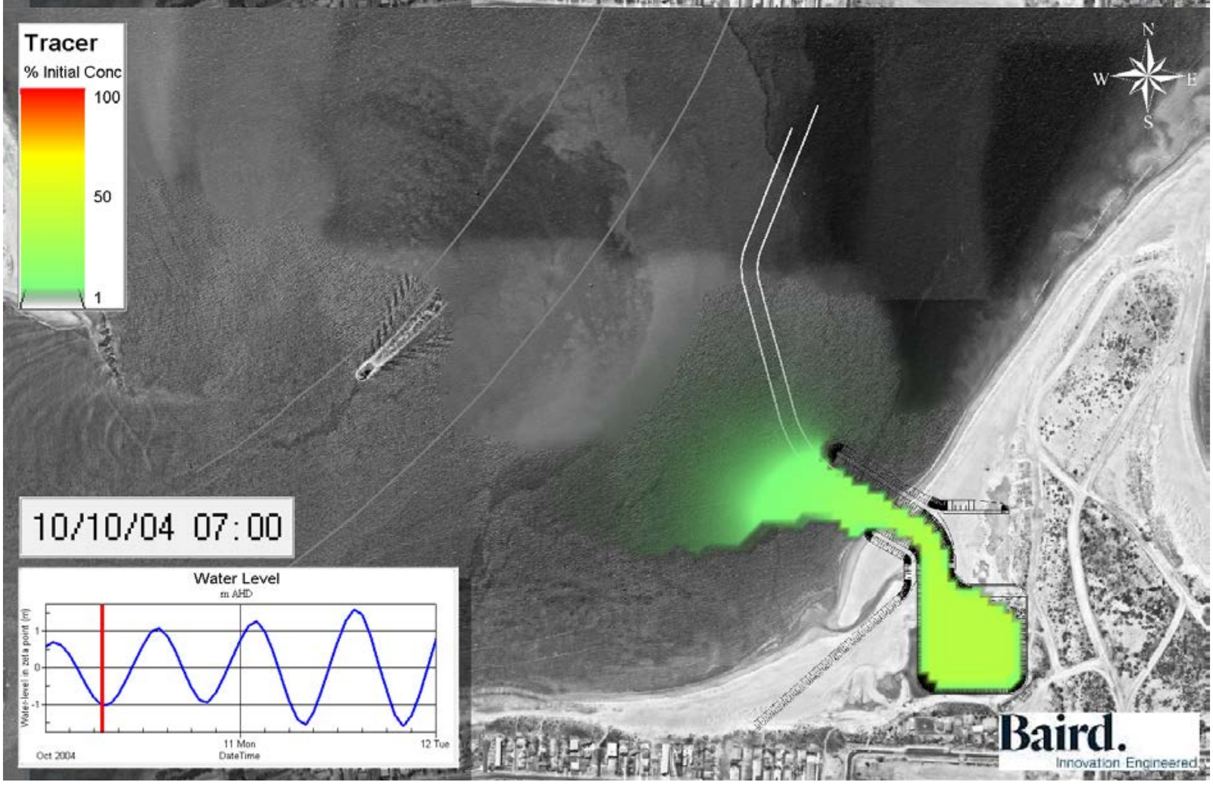
09/10/04 13:00
Water Level
m AHD
Oct 2004
9 Sat
10 Sun
DateTime
Baird.
Innovation Engineered
Tracer
% Initial Conc
100
50
1
09/10/04 19:00
Water Level
m AHD
Oct 2004
9 Sat
10 Sun
DateTime
Baird.
Innovation Engineered


Tracer
% Initial Conc
100
50
1
10/10/04 01:00
Water Level
m AHD
Oct 2004
11 Mon
DateTime
12 Tue
Baird.
Innovation Engineered


Tracer
% Initial Conc
100
50
1
10/10/04 07:00
Water Level
m AHD
Oct 2004
11 Mon
DateTime
12 Tue
Baird.
Innovation Engineered