APPENDIX E

# NAPIER PORT PROPOSED WHARF AND DREDGING PROJECT, DREDGE PLUME MODELLING

NAPIER PORT

# Napier Port Proposed Wharf and Dredging Project

Dredge Plume Modelling

1/6/17

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## Synopsis

This report outlines the methodology and results of dredge plume modelling for the proposed Wharf 6 Development at Napier Port.

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## Project No: 301015-03651-003 – Napier Port Proposed Wharf and Dredging Project: Dredge Plume Modelling

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# Executive Summary

Advisian was engaged by Napier Port Ltd to undertake dredge plume modelling to assess the impact of dredging at a proposed Berth 6 and port navigation channel, and disposal at the offshore spoil disposal ground. A report outlining the results of that assessment was produced in October 2016. The scope of work for the previous study included:

- Setting up a 3D hydrodynamic variable resolution model covering Hawke Bay to obtain wind and tide-generated currents in three dimensions over the entire Bay and with higher resolution in the vicinity of the Port;
- Calibrating and validating the 3D hydrodynamic model against measured current speed and direction data at two measurement locations;
- Setting up a particle tracking model coupled to the calibrated hydrodynamic model, to simulate the potential spread of the sediment plume generated at the dredging sites and disposal ground, for one month based on measured wind data. July 2016 was chosen for the analysis, which was a relatively stormy period and provides a conservative assessment for the sediment plume dispersion.

Following production of the previous report, Napier Port Ltd has engaged Advisian to undertake a re-assessment of potential impacts due to suspended sediments associated with the dredging and dredge material relocation using a combination of backhoe dredging (BHD) and trailer suction hopper dredging (TSHD). The re-assessment has considered the disposal of all dredge material at the proposed disposal location, approximately 5 km south-east of Pania Reef (Figure 1). The assessment has used the existing calibrated and validated DELFT3D coupled wave and hydrodynamic model that covers Hawke Bay and was used for the study of spoil disposal at the in-shore spoil ground.

This report assesses the potential impacts due to suspended sediments associated with the dredging using a combination of BHD and TSHD and the disposal of the dredged material. Five separate dredging campaigns are proposed, with various portions of the berth, swing basin and navigation channel proposed to be dredged in stages.

The scope of work for this study included re-running the existing water quality model coupled to the calibrated hydrodynamic model, to simulate the potential spread of the sediment plume generated at the dredging sites and disposal ground, for one month, taking into account measured wind data. As per the previous study, the approach was developed around investigations to quantify the potential impacts of dredging and dredge material relocation, through assessment of total suspended sediment (TSS) concentration above background levels and sedimentation.

The model results take into account important processes such as:

- wave-stirring;
- detailed sediment properties obtained through direct measurements;
- understanding of the sediment volumes, dredge campaigns, dredge methodology and dredge plant to be deployed;

- calibration and validation of the hydrodynamic model against measured current data over a range of depths;
- a range of weather conditions; and
- suspended sediment parameter values obtained based on literature, previous WorleyParsons dredge plume modelling experience and engineering judgement.

The modelling study found that:

- The plume generated at the proposed disposal spoil ground was more extensive than that generated at the dredge site, for all scenarios tested;
- Sediment concentrations are spread relatively evenly over the vertical distance of the water column in the vicinity of the spoil disposal ground but are higher near the bed in the vicinity of the dredge area;
- The model results do not show any potential for deposition of fine silts or clays over the footprint of Pania Reef during the timeframe of the dredging campaigns;
- The model results show that the suspended sediment concentrations over the Pania Reef footprint were less than 10 mg/L above background over the entire simulation period. The 98%ile Silt/clay fraction concentrations (exceeded for less than 1 day per month during the dredging campaigns) were less than 10 mg/L above background levels over the reef area throughout the simulation period;
- The sand fraction of the discharge settles quickly. Sand fraction deposition is limited to the immediate vicinity of the disposal and dredge areas;
- The highest suspended sediment concentrations above background levels are in the inner port area and at the spoil ground;
- The highest concentrations occur at the beginning of the campaigns due to TSHD dredging dominating. Lower concentrations result from backhoe dredging; and
- Prevailing currents at the disposal site are generally directed toward the south-east. However, under certain wind conditions, currents can be directed toward the north-west and this can result in suspended sediments being directed toward the Reef, albeit at concentrations below 5 mg/L over the footprint of the reef. This was found to occur less than 2% of the time over the simulation period.

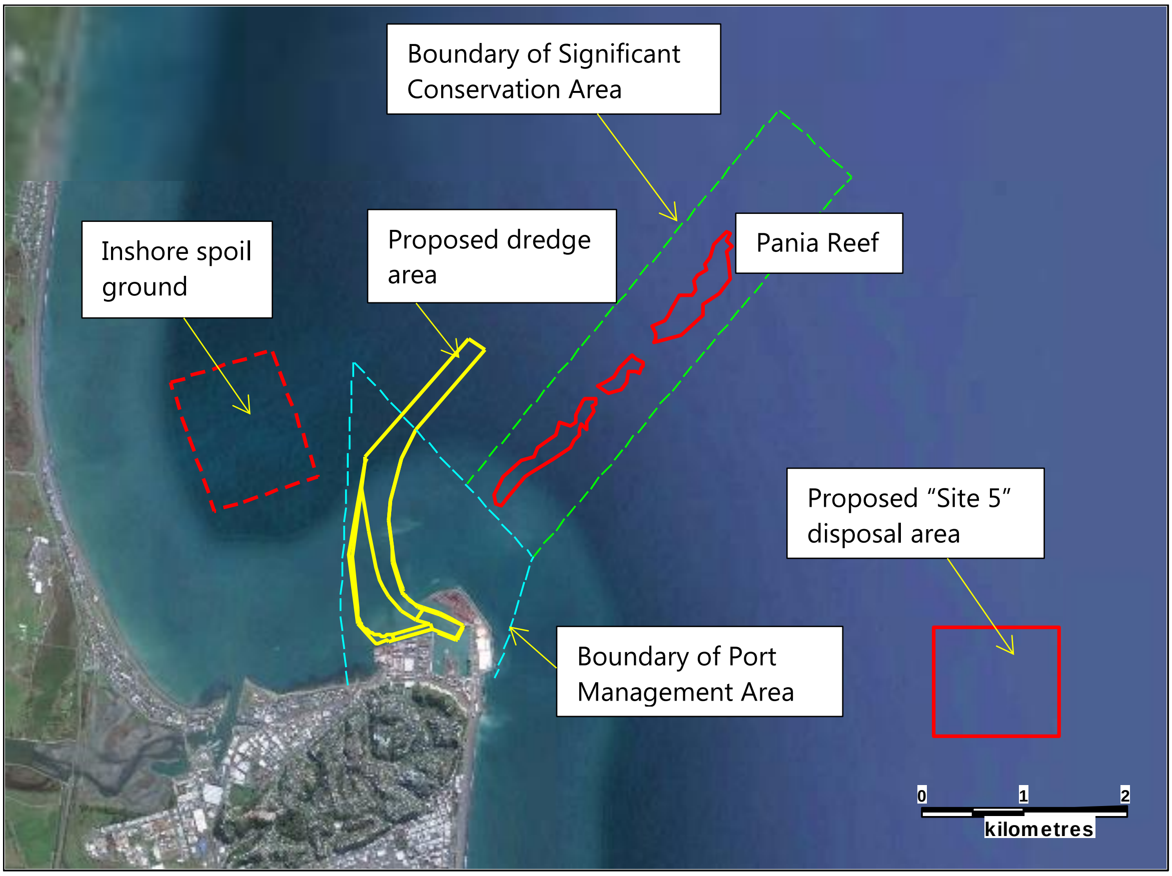



**Figure 1 – Location of disposal area (Site 5)**

# 1 Introduction

## 1.1 Background

Napier Port Ltd. proposes to undertake capital dredging to accommodate deeper draft vessels in the fairway and swing basin. Advisian was engaged by Napier Port Ltd to undertake dredge plume modelling to assess the impact of dredging at a proposed Berth 6 and port navigation channel, and disposal at the nearshore (or inshore) spoil disposal ground (Figure 2). A report outlining the results of that assessment was produced in October 2016.

To provide guidance on the potential spread of dredge plume material around Pania Reef, detailed hydrodynamic and suspended sediment modelling simulations were undertaken and documented in Report no. 301015-03651-CS-REP-002. Following production of that report, Napier Port Ltd engaged Advisian to undertake a re-assessment of potential suspended sediment impacts associated with the dredging on the basis of a different dredge disposal location. The re-assessment has considered the disposal of all dredge material at a site known as Site 5, approximately 5 km south-east of Pania Reef, in contrast to the previous assessment which considered disposal at the pre-existing in-shore spoil ground. The assessment has used the existing calibrated and validated DELFT3D coupled wave and hydrodynamic model that covers Hawke Bay and that was used for the study of spoil disposal at the in-shore spoil ground.

This report documents the results of the detailed dredge plume modelling, the associated suspended sediment plume and its spatial extent as a result of the *advection*[1] and dispersion associated with the tidal and wind generated currents and wave-stirring. A comparison of the suspended sediment impacts associated with dredging at the proposed Berth 6 and port navigation channel is presented, including an analysis of suspended sediment concentrations at the proposed spoil disposal ground and surrounds.

## 1.2 Scope of Works

This report assesses the potential impacts of suspended sediments associated with the dredging and dredge material relocation using a combination of backhoe dredging (BHD) and trailer suction hopper dredging (TSHD). Five separate dredging campaigns have been proposed, with various portions of the berth, swing basin and navigation channel proposed to be dredged in stages.

The scope of work for this study included:

- Setting up a 3D hydrodynamic variable resolution model covering Hawke Bay to obtain wind and tide-generated currents in three dimensions over the entire Bay and with higher resolution in the vicinity of the Port;

[1] *The term "advection"* refers to the horizontal transfer of matter (in this case, horizontal transport of suspended sediment) by the flow of a fluid (in this case, wind and tide-generated ocean currents).

- Coupling of a wave model to the 3D hydrodynamic model so that the effect of wave-stirring of sediments can be included in the analysis;
- Calibrating and validating the 3D hydrodynamic model against measured current speed and direction data at two measurement locations;
- Setting up a particle tracking model coupled to the calibrated hydrodynamic model, to simulate the potential spread of the sediment plume generated at the dredging sites and the Site 5 disposal ground (in lieu of the existing inshore disposal ground), based on measured wind data. The effect of wave forcing on sediment stirring and resuspension has been included in the analysis.

The study approach was developed around investigations to quantify the potential impacts of dredging and dredge material relocation in relation to suspended sediments, through assessment of total suspended sediment (TSS) concentration above background levels and sedimentation.

The Dredge Plume Dispersion simulations have not included effects such as spatially varying temperature or salinity but, based on previous studies at Napier, these factors are not expected to influence sediment dispersion.

## 1.3 Disposal site assessment

Previous dredge plume modelling (Report no. 301015-03651-CS-REP-002) considered spoil disposal at the inshore spoil disposal ground, located at Site 1 as indicated in Figure 2.

It was found that there was a potential for fine sediments to be transported to the south-east from the inshore spoil disposal ground. To address this risk, several alternative disposal sites were considered for analysis, with these sites 1 to 5 shown in Figure 2.

Of the sites considered for further analysis, Site 5, located in deeper water to the south-east of Pania Reef, was expected to reduce the risk of affecting Pania Reef compared with disposal at the "inshore" spoil ground and the other sites, for the following reasons:

- Prevailing currents are generally directed toward the east, resulting in the sediment plume moving from the disposal site offshore and away from Pania Reef;
- The longer distance of the spoil ground from Pania Reef when compared with the inshore spoil disposal ground results in less potential for sedimentation of fine silt fractions on the reef during instances when currents are directed toward the north-west;
- The location of the spoil ground at "Site 5" is in deeper water than the inshore spoil ground (approximately 20 m depth for Site 5 and 10 m depth for the inshore spoil ground). Due to the greater depth at Site 5, sediments on the bed at this disposal area would be less likely to be re-suspended in the water column by the action of currents acting near the bed, when compared with sediments at the inshore spoil ground. This is because near-bed tidal, wind and wave-induced currents will be much lower in the deeper water when compared with those at the inshore spoil ground. The lower currents would generally be below the threshold required for re-suspension and re-mobilisation of fine sediments that have already settled at the disposal ground. In comparison, near-bed

current velocities at the inshore spoil ground would be higher due to the shallower water and therefore more likely to result in fine sediment re-suspension.

While Site 5 is considerably further from the dredge area than the inshore spoil ground, it is still within an acceptable distance of the dredge area.

For these reasons, the Site 5 disposal area was chosen for further analysis and the impact of dredge spoil disposal at Site 5 has been modelled, with the findings described in this report.

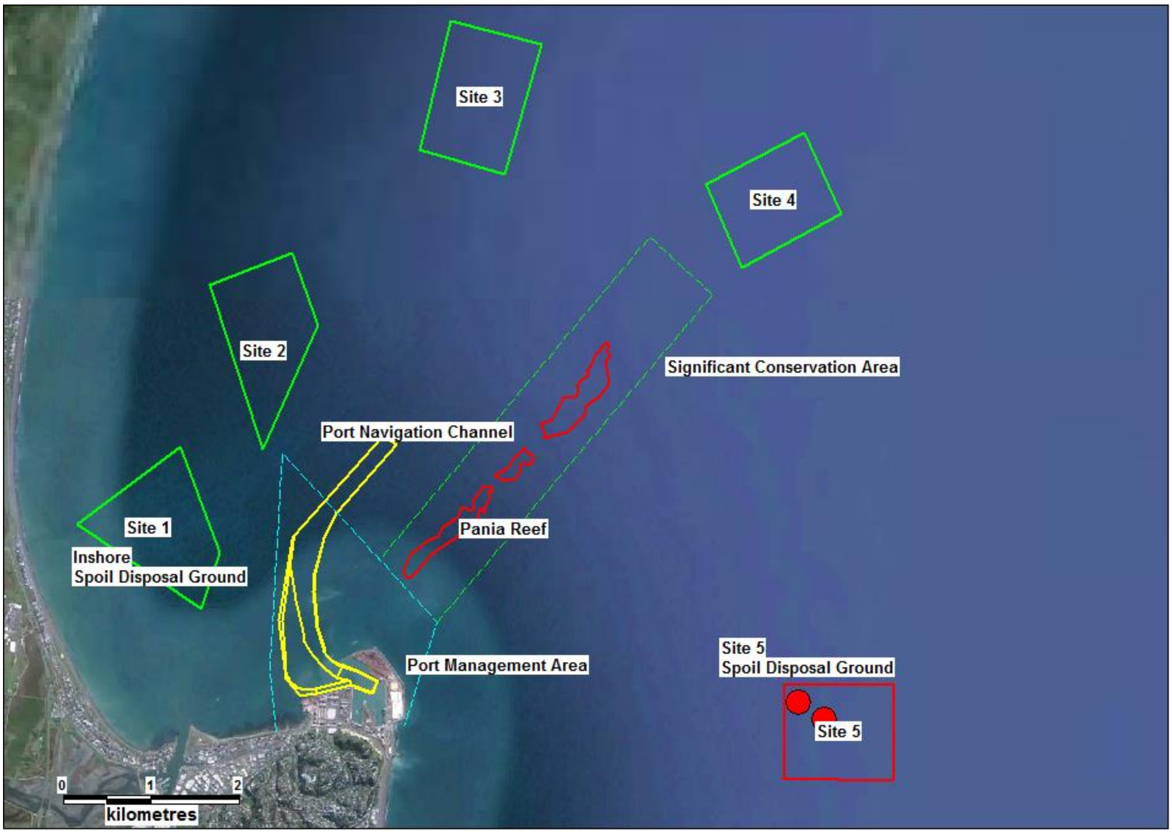



**Figure 2 – Disposal sites considered for assessment**

# 2 Model Setup

## 2.1 Introduction

For sediment plume modelling studies, it is important that the model domain is sufficient to encompass the total area affected by the sediment plumes arising from the proposed dredging. The total area affected not only includes the initial extent of the sediment plume and deposition, but also areas affected following the reworking of sediments, which occurs through re-suspension and subsequent transport. As such, it is necessary to ensure that accurate hydrodynamic inputs are used. For correct characterisation of the hydrodynamic climate, the domain of the study area must be large enough to capture wind energy transfer properly to the sea surface over long fetches, in the order of 50-100 km. For this reason, the entire Hawke Bay area has been included in the hydrodynamic simulations.

The sediment transport model must account for the particle-size settling velocity, sedimentation and re-suspension of sediments given the range of current conditions indicated for the area, as derived by the hydrodynamic model.

Other necessary inputs are specific to the project and relate to the dredging operation itself. Details of the dredge vessel to be utilised, transport and disposal plans for the removed material, indicative schedule and production rates are all necessary inputs for the model.

All of these requirements have been considered in setting up the modelling system used for this study.

## 2.2 Model Description

The DELFT3D-FLOW module, which is used to simulate tidal and wind-driven currents, is a multi-dimensional (2D or 3D) hydrodynamic (and transport) simulation program that calculates non-steady flow and transport phenomena that result from tidal and meteorological forcing on a curvilinear, boundary fitted grid. For the 3D simulations considered in this study, the vertical grid is defined following the σ−co-ordinate approach[2]. That is, the model is split in to a number of layers that are defined as a constant percentage of water depth. An illustration of this concept is provided in Figure 3. Five layers have been used in the hydrodynamic model, with a sixth "bed layer" describing sedimentation.

The 3D hydrodynamic model has been calibrated and validated against measured currents at a

[2] *The σ-coordinate system was first introduced by N Phillip in 1957 for atmospheric models. The σ-coordinate system is a variable layer-thickness modelling system meaning that over the entire computational domain, irrespective of the local water depth, the number of layers is constant. As a result, smooth representation of the bathymetry can be obtained.*

downward facing Acoustic Doppler Current Profiler (ADCP)[3] mounted on a buoy, at a location in approximately 10 m water depth west of the navigation channel.

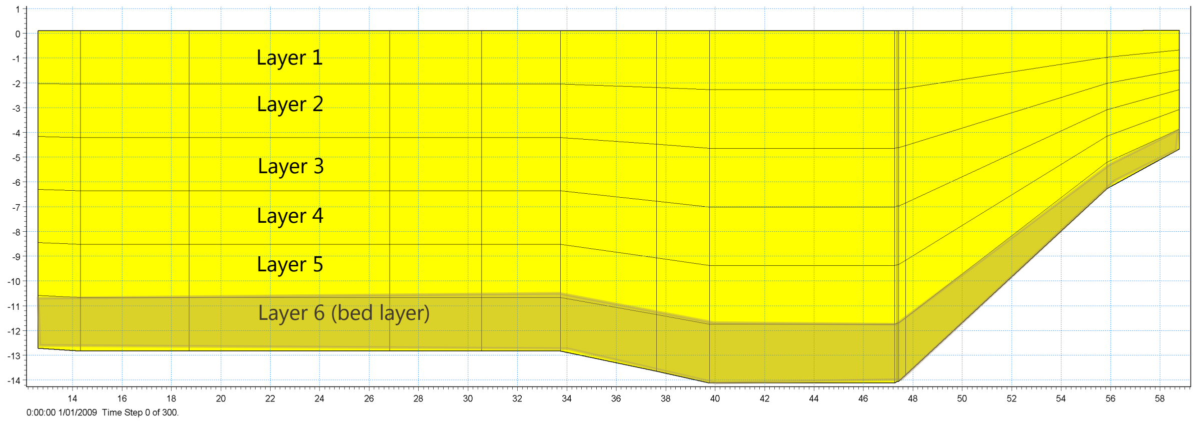



**Figure 3 – Illustration of vertical σ–layer approach with 6 vertical layers**

### 2.2.1 Simulation Time

For the dredge scenarios considered within this report a 29 day lunar cycle is considered long enough to allow a reasonable estimate of the dredge plume dispersal to the wider environment. The ultimate selection of simulation time is a compromise between accuracy (longer is better) and computational efficiency (shorter is better). The key criterion is that some form of quasi-equilibrium is achieved with the dispersal of fine suspended sediment at the site. Model tests were carried out with varying simulation times to ascertain that the quasi-equilibrium condition would be reached after a one-month simulation time.

For the detailed dredge dispersion studies, the dredging time for each campaign has been calculated based on the proposed plant (BHD and TSHD), volume of sediment to be dredged over each dredge campaign and properties of the sediment to be dredged.

## 2.3 Model Domain

The hydrodynamic model domain covers the entire area of Hawke Bay and has been constructed in Delft-3D using a curvilinear grid. The model is 3-dimensional with five equally spaced vertical layers. In the vicinity of the port and navigation channel, the grid resolution is approximately 50 m. The design of the proposed navigation channel has been included in the model bathymetric grid.

Included in the hydrodynamic model is wind and tidal forcing. An entire month based on the relatively stormy month of July 2016 has been used to estimate exceedances of total suspended

*[3] An Acoustic Doppler current profiler (ADCP) is a hydro-acoustic current meter similar to a sonar, attempting to measure water current velocities over a depth range using the Doppler effect of sound waves scattered back from particles within the water column.*

sediment concentrations and potential for sedimentation in the vicinity of the Port and Pania Reef over the course of the expected dredging campaigns.

The extent of the curvilinear grid used for the modelling is illustrated in Figure 4.

Figure 5 provides a detailed view of the computational grid in the vicinity of the Port and shows the outline of Pania Reef, the proposed spoil disposal ground (site 5), existing inshore spoil disposal area, the port navigation channel and proposed Berth 6.

The model bathymetry was derived from a combination of a multibeam survey of the approaches to Napier Port undertaken by Napier Port Ltd, the Admiralty Chart NZ5612 and the design of the port navigation channel and berth supplied by Napier Port Ltd.


**Figure 4 – Extent of curvilinear computational model mesh and illustrating location of study area**

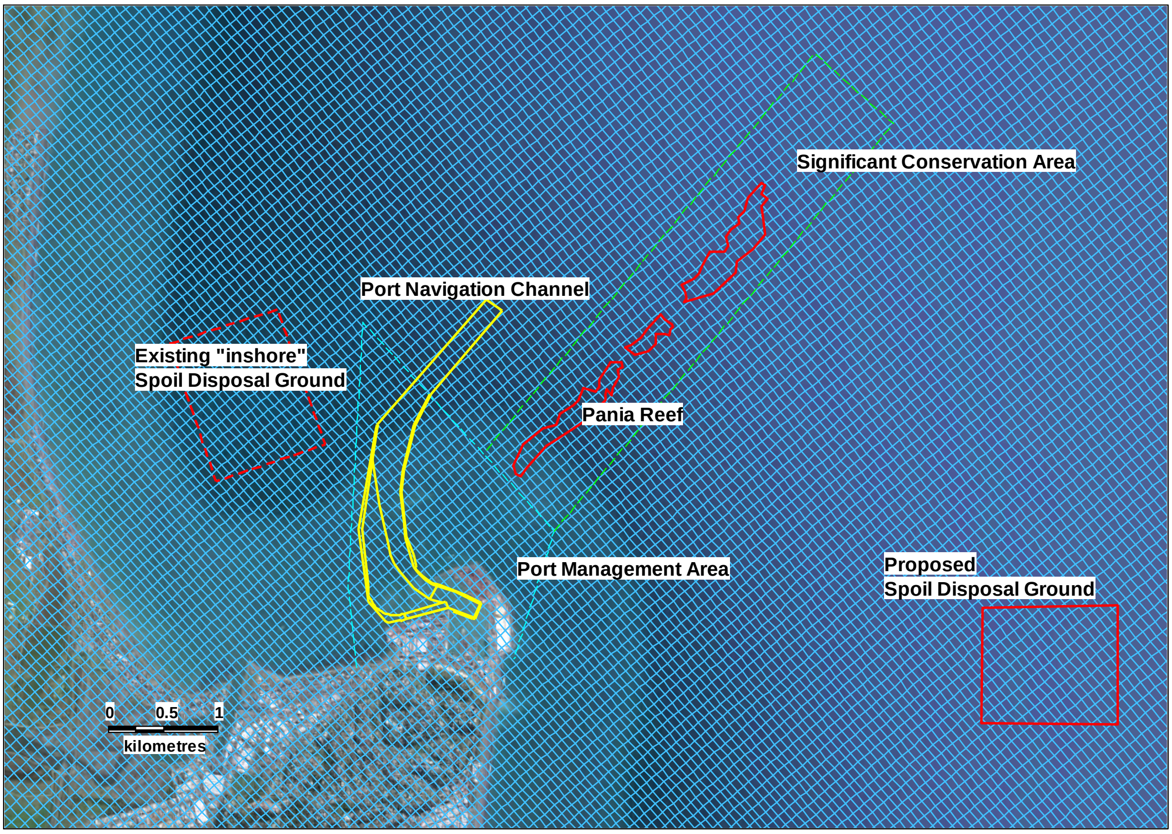



**Figure 5 – Detail view of computational mesh, Port navigation channel, proposed dredge areas, proposed spoil disposal ground and Pania Reef**

# 3 Hydrodynamic Modelling

## 3.1 Wind Forcing

Wind data at the Napier breakwater were provided by Napier Port Limited, with continuous one-minute averaged wind speeds and directions. Speeds were taken at 10 m above Napier Mean High Water Springs.

These data were applied across the entire model domain over the period of current data collection, for model calibration and verification purposes.

A time-series of the measured wind speeds and a wind rose illustrating the wind direction vs. percentage of the wind record is provided in Figure 6.

It can be seen that winds are generally from the west over the period of record, with significant wind energy coming from a narrow band in the north-west. It can also be seen that there were two high wind events over the period of record, with high wind events (wind speeds greater than 12 m/s) occurring around 20 May, and again over several days from mid-late July. These two distinct periods of high winds were compared with the measured currents, with the May wind event deemed to be suitable for model calibration, and the July event suitable for model validation.

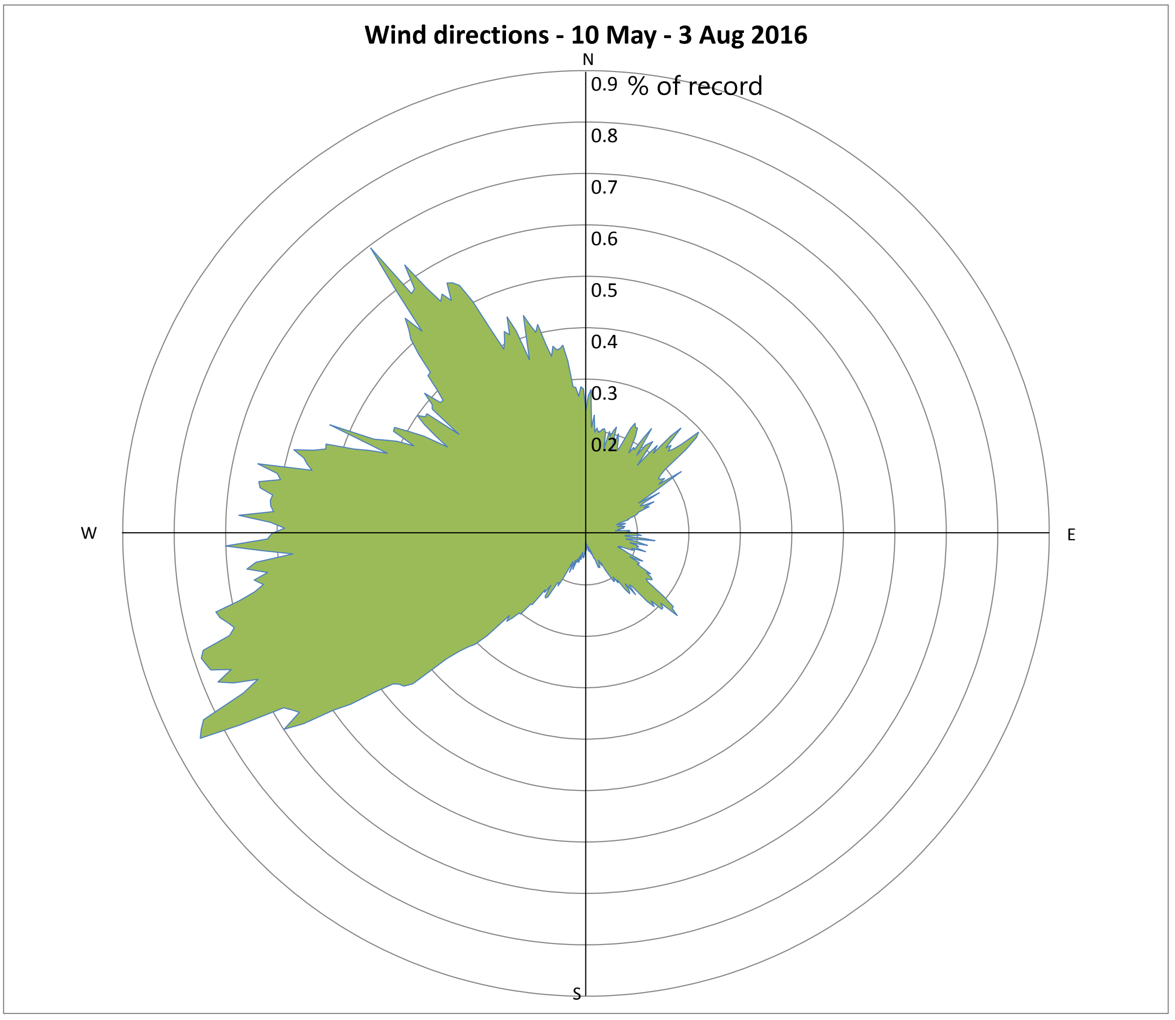
Ten years of wind data at Napier Port were analysed to determine:

- Maximum 24-hour averaged wind speed and variation with incident wind direction over the summer months (December through March) and winter months (April through November);
- Median monthly wind speeds for each of the summer and winter months over the historical record, to compare with the most recent measured wind data for May to August 2016. It was found that the period from May to August 2016 included individual wind events that were higher than the maximum 24-hour wind speeds measured over the ten-year record (14.8 m/s), thus representing a relatively stormy period with greater potential for re-suspension and transport of dredged sediments.

The results of the wind analysis are outlined in Table 1, below. Note that the highest wind speeds generally correspond to winds from the west or north-west.

**Table 1 – 24 hour wind speeds at Napier**

| Wind direction | Summer Wind speed (m/s) | Winter wind speed (m/s) |
|---|---|---|
| North | 12.5 | 13.8 |
| North-East | 10.8 | 13.6 |
| East | 10.8 | 13.8 |
| South-East | 10.8 | 13.3 |
| South | 11.1 | 13.8 |
| South-West | 12.1 | 13.3 |
| West | 12.3 | 14.8 |



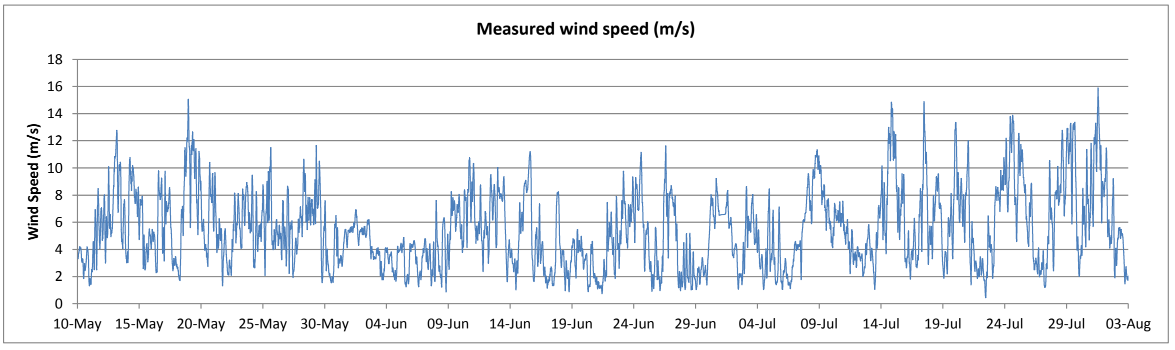




**Figure 6 – Measured wind record, 10 May to 3 August 2016. Top: Wind directions (coming from); Bottom: Wind speed**

## 3.2 Tidal Forcing

Tide conditions for the Napier area are derived from a Global Inverse Tide reanalysis model derived from satellite altimeter data. The TPXO 8.0 global model of ocean tides best-fits, in a least-squares sense, the Laplace Tidal Equations and along-track averaged data from TOPEX/Poseidon and Jason satellite constellations (Egber, Bennet & Foreman, 1994; Egbert and Erofeeva, 2002). The tides are provided as complex amplitudes of earth-relative sea-surface elevation for eight primary (M2, S2, N2, K2, K1, O1, P1, Q1), two long period (Mf, Mm) and three non-linear (M4, MS4, MN4) harmonic constituents. These constituents are used to provide boundary conditions for the tidal hydrodynamic model.

## 3.3 Wave Forcing

Waves over the model domain were simulated by running the Delft-3D Wave model, SWAN, coupled with the hydrodynamic FLOW model.

The SWAN model accounts for the following:

- 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
- diffraction.

The WAVE model grid is illustrated in Figure 7 with a detail view in Figure 8. Wave height, period and direction time-series measured at the Triaxis buoy maintained by Napier Port was back-refracted to deep water and then applied as boundary conditions to the southern and eastern boundaries of the model. The resultant wave heights and periods simulated by the WAVE model are then used by the FLOW model to calculate near bed current velocities, near bed shear-stresses induced by the waves and, hence, the potential for dredged sediments to be re-suspended or remain in suspension. Wave transformation coefficients and wave vectors in the vicinity of the study area from the WAVE model are illustrated in Figure 9.

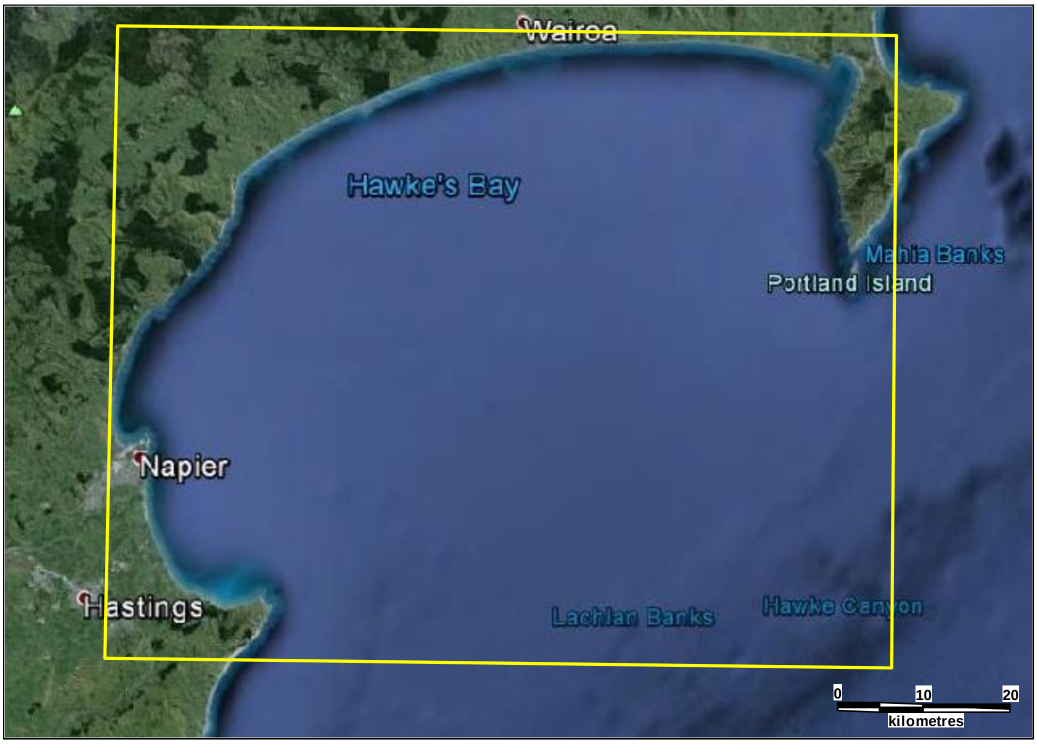



**Figure 7 – Extent of rectilinear WAVE model grid**

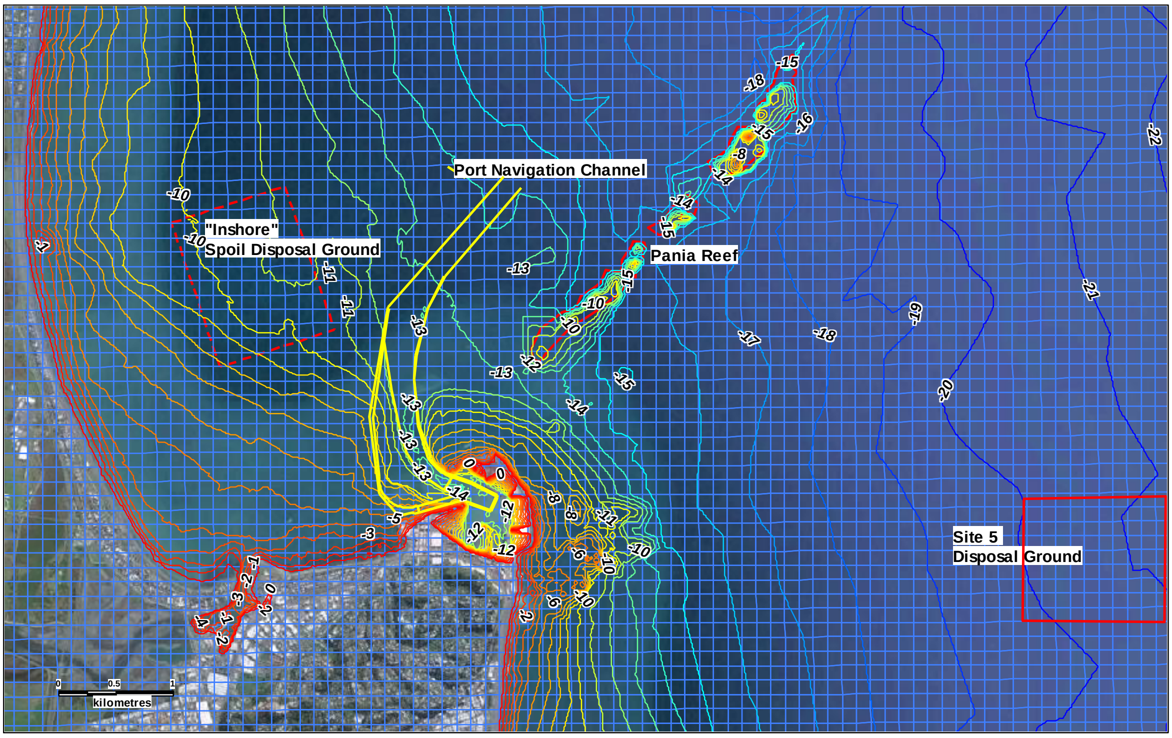



**Figure 8 – Detail view of WAVE model grid, superimposed with existing bathymetry contours**

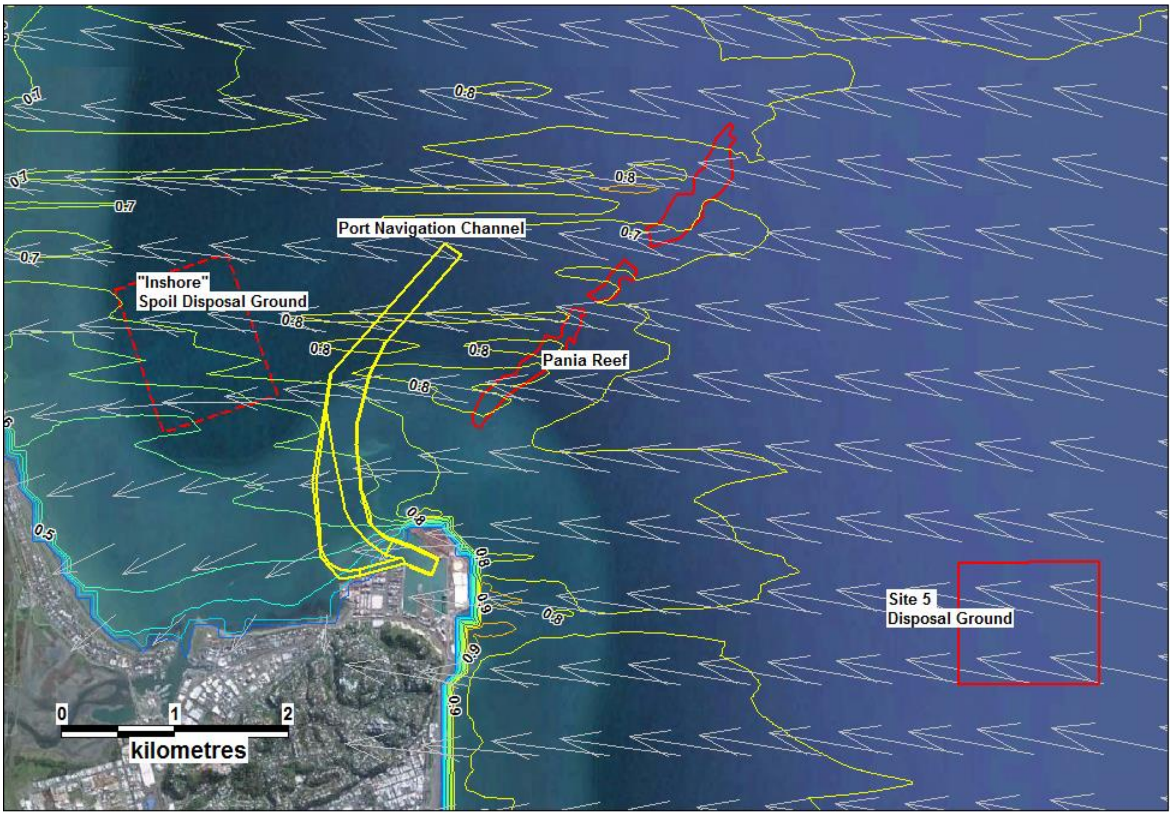



**Figure 9 – Example of wave approach vectors and wave transformation coefficients in the vicinity of the study area, SWAN model**

## 3.4 Model Bathymetry

Model bathymetry was schematised based on a combination of data from the following sources:

- High-resolution bathymetric charts covering Hawke Bay;
- Detailed soundings carried out in the vicinity of Napier Port by Napier Port Ltd. in 2011 and 2014;
- Recent beach profiles and soundings obtained from Hawkes Bay Regional Council and Napier Port Ltd. undertaken to the north and west of the Port derived from both land and nearshore surveys.

The data used to compile the model bathymetry are illustrated in Figure 10.

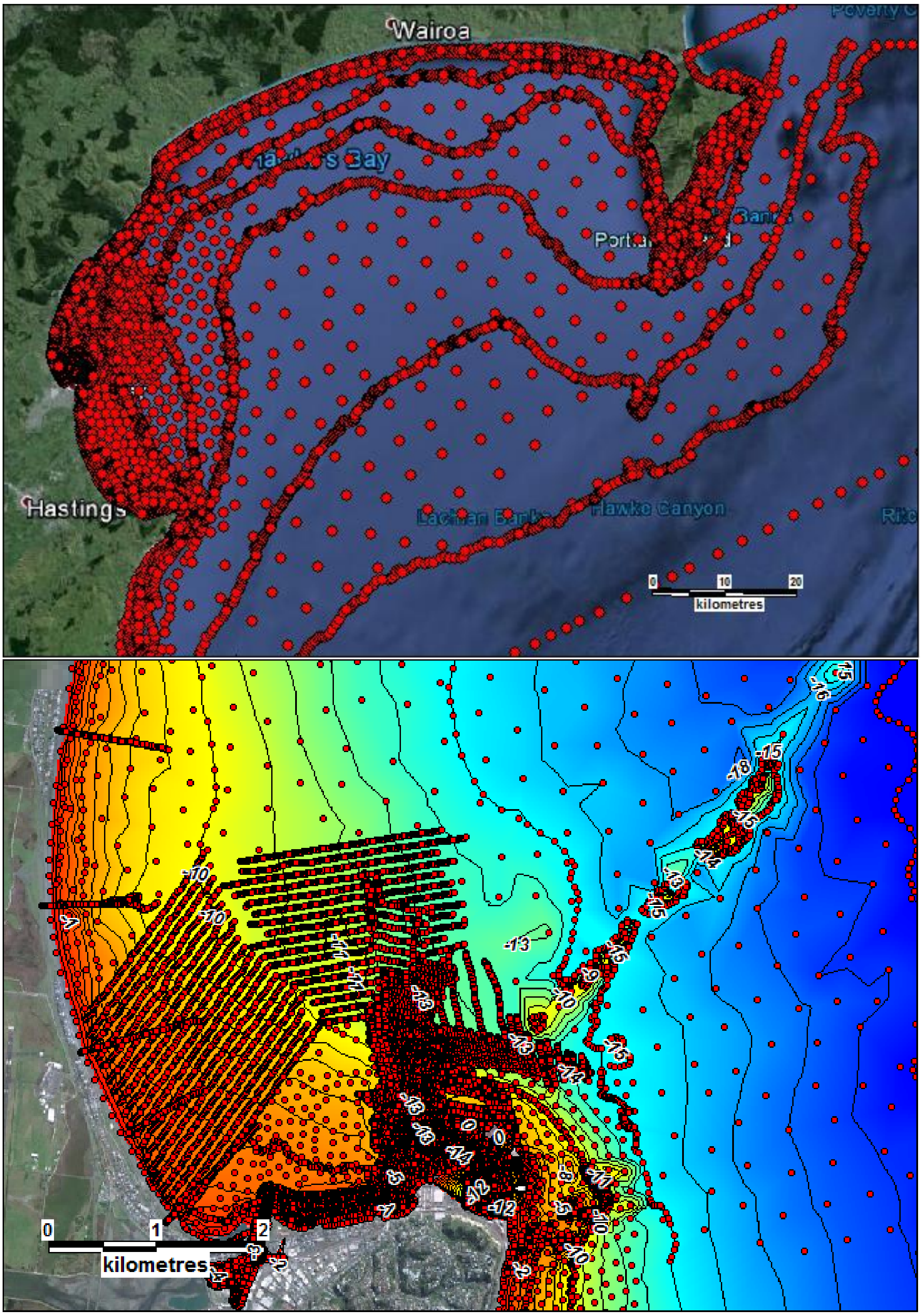



**Figure 10 – Model bathymetry. Top: Bathymetric points over entire model grid; Bottom: detail model bathymetry in the vicinity of the Port**

## 3.5 Hydrodynamic Model Calibration

The hydrodynamic model was calibrated and validated against measured currents at a downward facing ADCP mounted on a buoy, at a location in approximately 10 m water depth west of the navigation channel indicated in Figure 11. Data were collected at the buoy from 17 May to 3 August 2016, with usable data provided at 1 m intervals between 3 m and 10 m below local chart datum. This enabled a direct comparison between the output from the ADCP and the modelled current velocities and directions within the vertical layers of the hydrodynamic model.

Interrogation of the measured ADCP and wind data illustrated the following:

- Current velocities are generally less than 250 mm/s at the measurement location, both near the surface and near the bed;
- There was a direct association between the higher wind speeds and higher current velocities, particularly near the surface;
- Current velocities corresponding to tidal variations were observed in the ADCP current data and this was most evident when wind speeds were low;
- The current velocities and directions near the surface generally correlated with those near the bed and over the entire water column when current speeds were low over the period of the record, generally indicating well-mixed conditions. However, when surface currents were higher, generally the bed current was lower, indicating that under higher wind speeds, the water column is generally not well-mixed.

The measured time-series of ADCP data and corresponding wind record are provided in Figure 12.

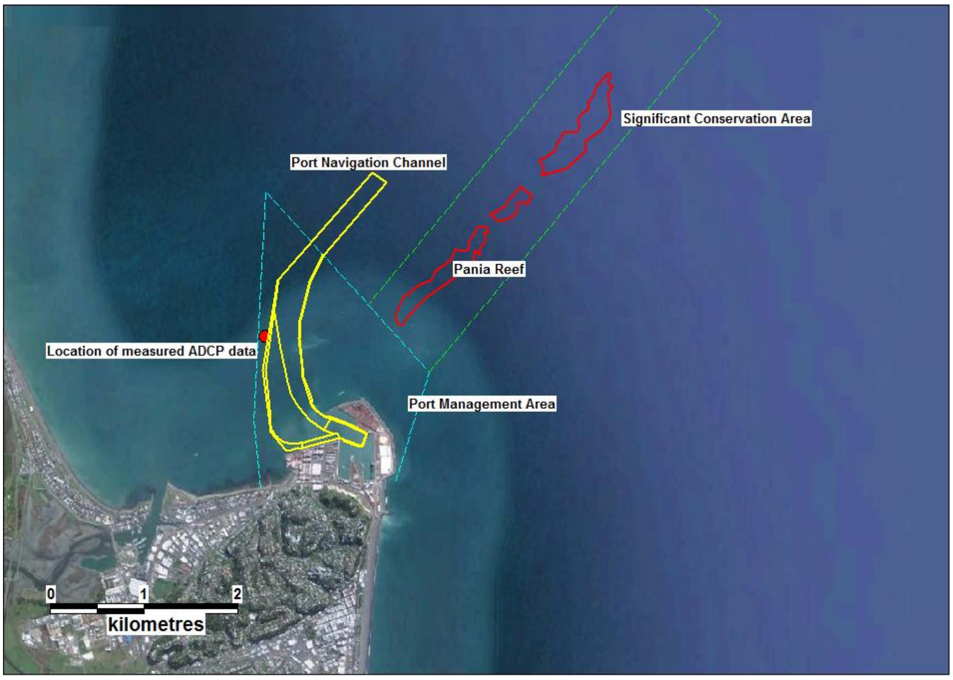



**Figure 11 – Location of measured ADCP data, 17 May – 3 August 2016**

From the measured wind and current data, the following periods were identified for model calibration and validation purposes:

- Model calibration from 18 May to 26 May 2016;
- Model validation measured data in the second half of July 2016.

These periods were chosen for calibration and validation purposes because they encompassed clearly identifiable storm events and relatively high current velocities, each with different wind and current directions.

### 3.5.1 Model Parameters

The following model parameters were used, based on Advisian's experience with projects at locations with similar characteristics:

- Model computational timestep 12 seconds;
- Uniform Chezy bed roughness coefficient of 65 $m^{1/2}/s$, representing a relatively smooth seabed;
- k–ε turbulence closure model used for vertical eddy viscosity.
- Wind drag coefficient $C_D$ linearly varying with windspeed.

### 3.5.2 Model Calibration

The following parameters were varied in the FLOW model to obtain an acceptable fit to the measured current data, both near the surface and near the bed:

- Wind drag coefficient, $C_D$
- Bottom roughness, or Chezy coefficient.

Several calibration simulations of the hydrodynamic model were undertaken with varying wind drag coefficients and bed roughnesses, with the root-mean square error in the current velocity magnitiudes, x-direction and y-direction evaluated for each model simulation. The results of this analysis are illustrated in Figure 13.

Figure 14 illustrates the comparison between measured and modelled current velocities over the calibration period, for varying values of wind drag coefficient. Through the calibration process, the optimum wind-drag coefficients for use in the hydrodynamic model were selected which minimised the model error and ensured that there was no bias toward under-predicting or over-predicting current velocities.

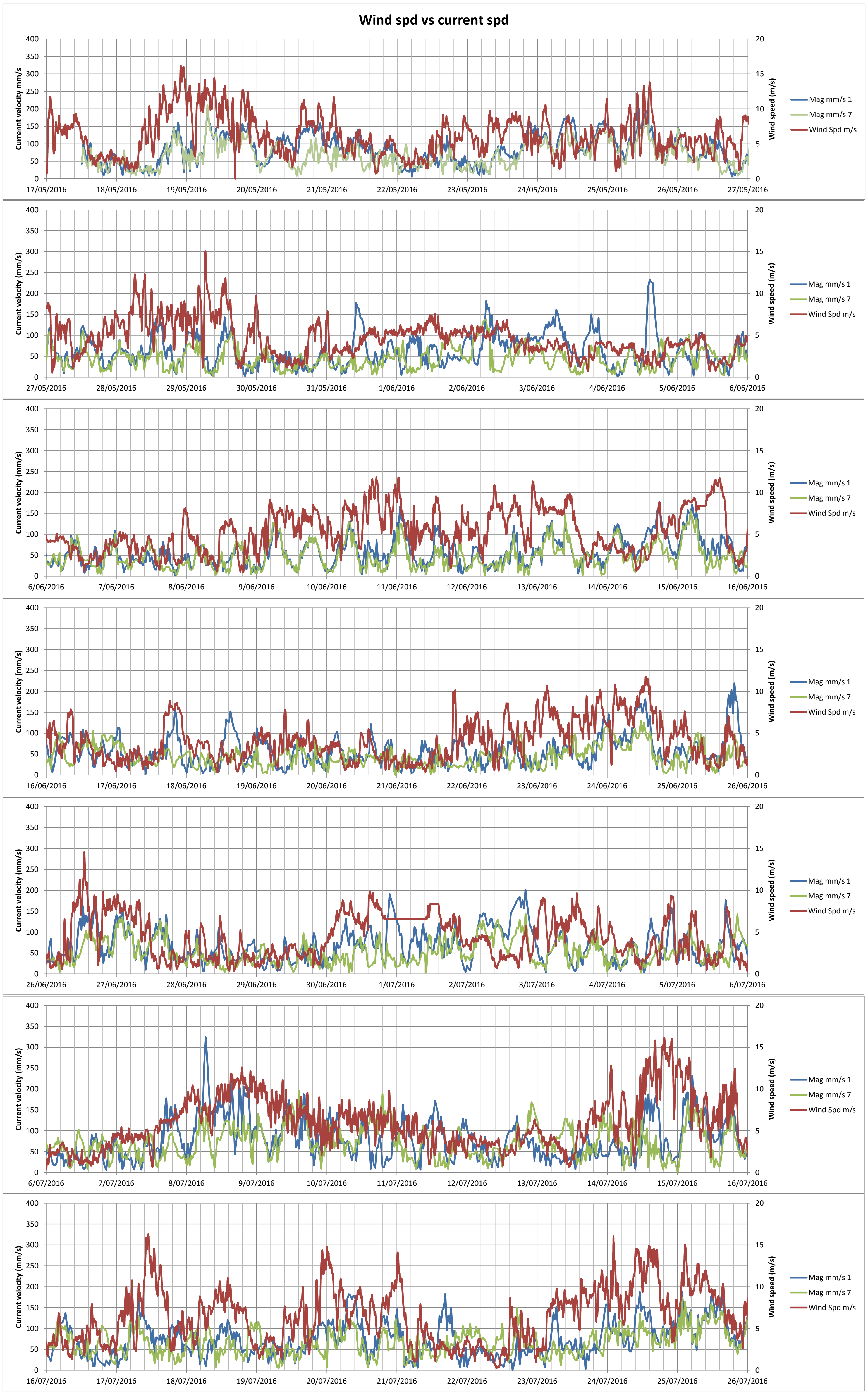



**Figure 12 – Measured ADCP currents and wind velocities, May to July 2016. Blue = near-surface velocity, Green = near-bed velocity, Red = wind velocity**

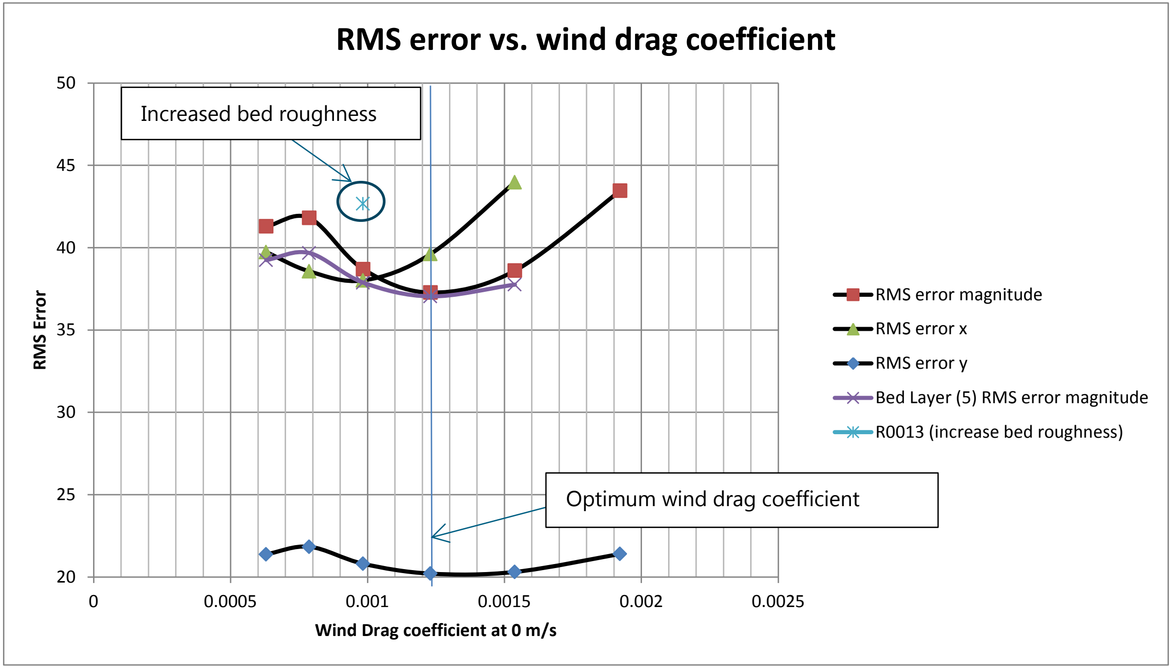



**Figure 13 – Effect of varying wind drag coefficient on root-mean square model error, for total velocity magnitude, x-velocity, y-velocity, near-bed velocity and near-surface velocity.**

### 3.5.3 Model Calibration Results

The results of the model calibration are illustrated in Figure 15, below. It can be seen that the model provides a good representation of the magnitude, phase and direction of the measured currents over the calibration period.

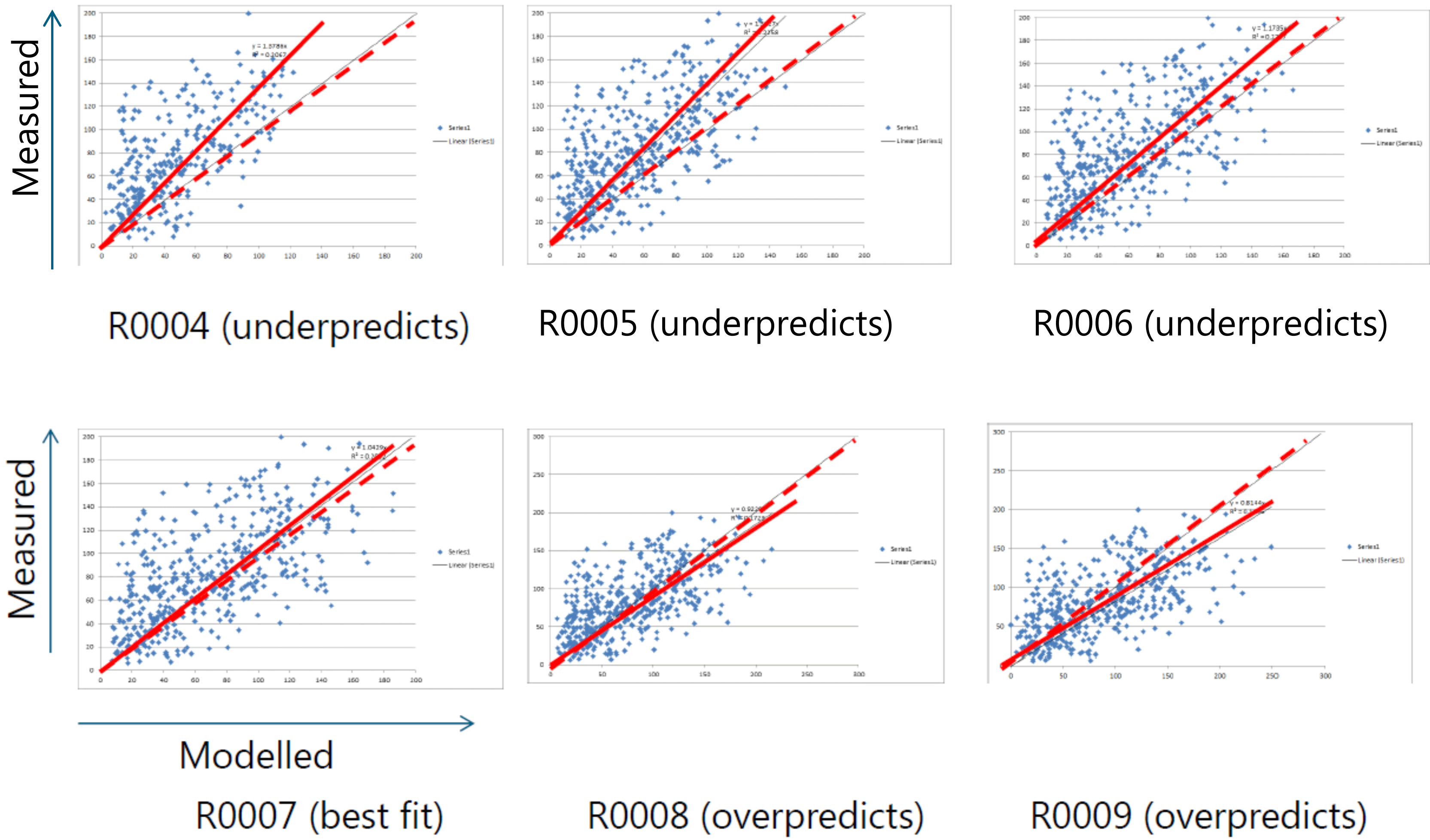
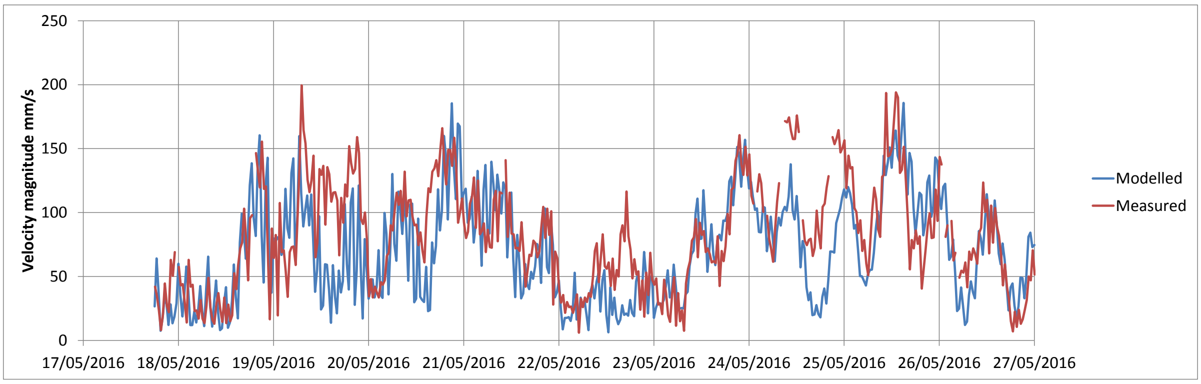



**Figure 14 – Variation in modelled vs. measured velocities over the calibration period, for varying wind drag coefficients**



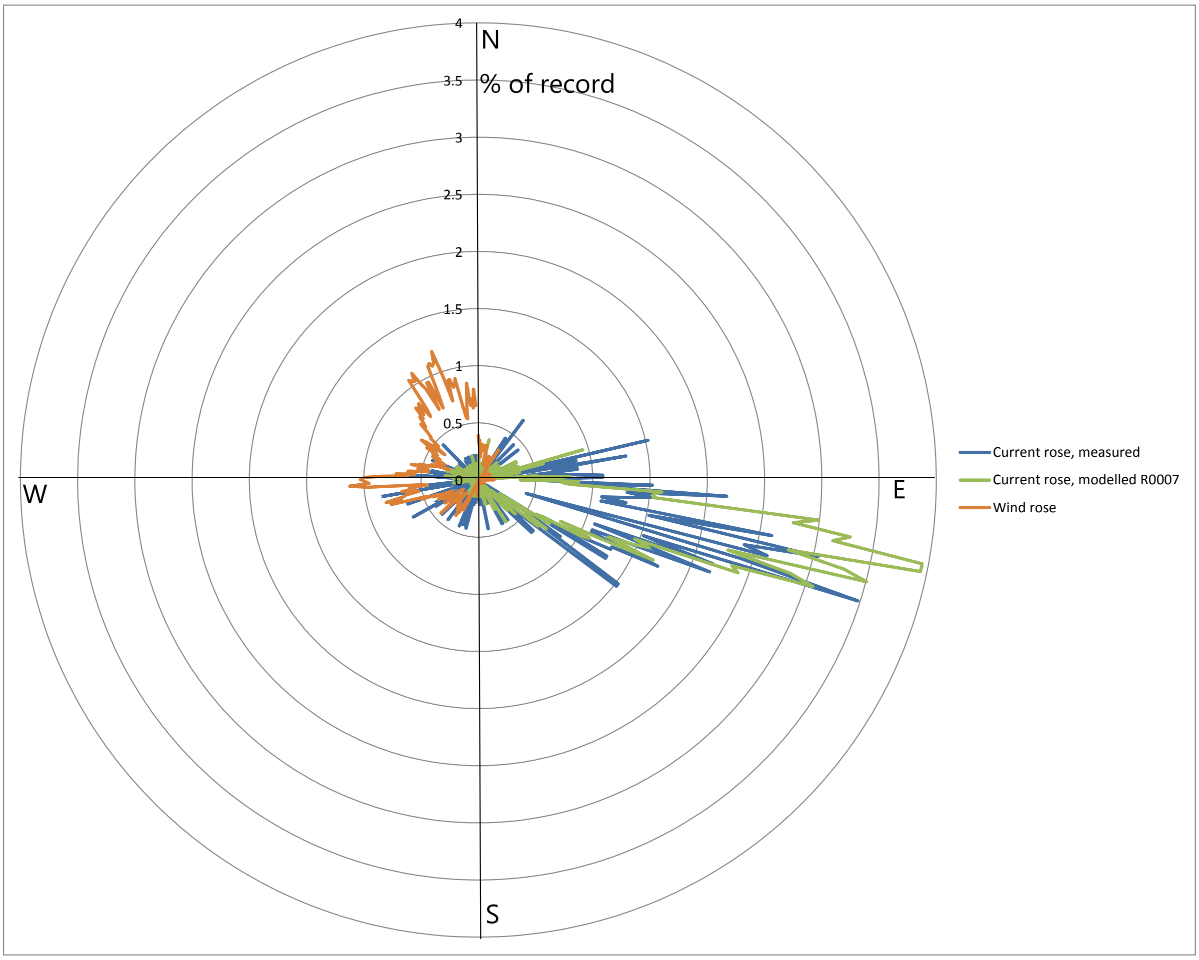




**Figure 15 – Modelled vs. measured current directions and magnitude time series for calibration period (note – wind direction shown is direction from which the wind is coming; current direction is the direction to which the current is travelling)**

## 3.6 Hydrodynamic Model Validation

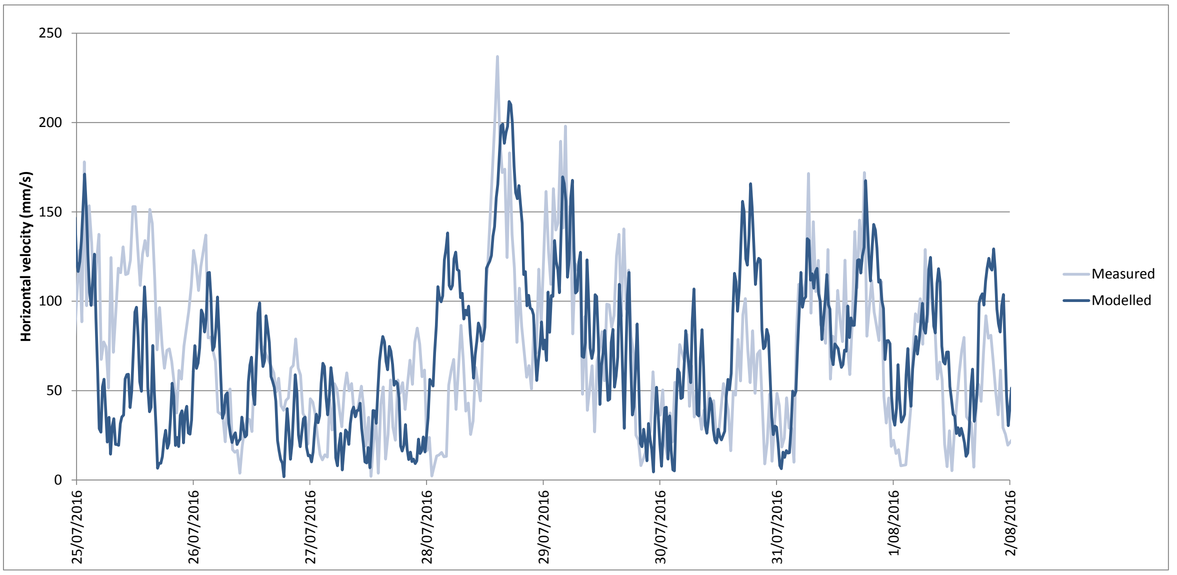
Following calibration, the model was validated against measured current data for the second half of July 2016, which was a relatively stormy period with high winds and current speeds.

The model validation is illustrated in Figure 16 for the pilot buoy location. A second ADCP at Beacons, west of the navigation channel and adjacent to the beach area was installed in late June 2016 – the model validation at this location against east-west and north-south velocity magnitude and direction are illustrated in Figure 17.

From these plots it can be seen that:

- The model predicts both the magnitude and direction of the measured current velocities at both ADCP measurement locations very well;
- The current velocity is closely correlated to the wind speed at both locations; and
- The model is able to simulate the peak velocities during the major storm events, as well as the overall trend in current magnitude over the duration of the storm event.

Based on the above calibration and validation, the hydrodynamic model was considered suitable for use as the basis for developing a particle tracking model for dredge plume dispersion.



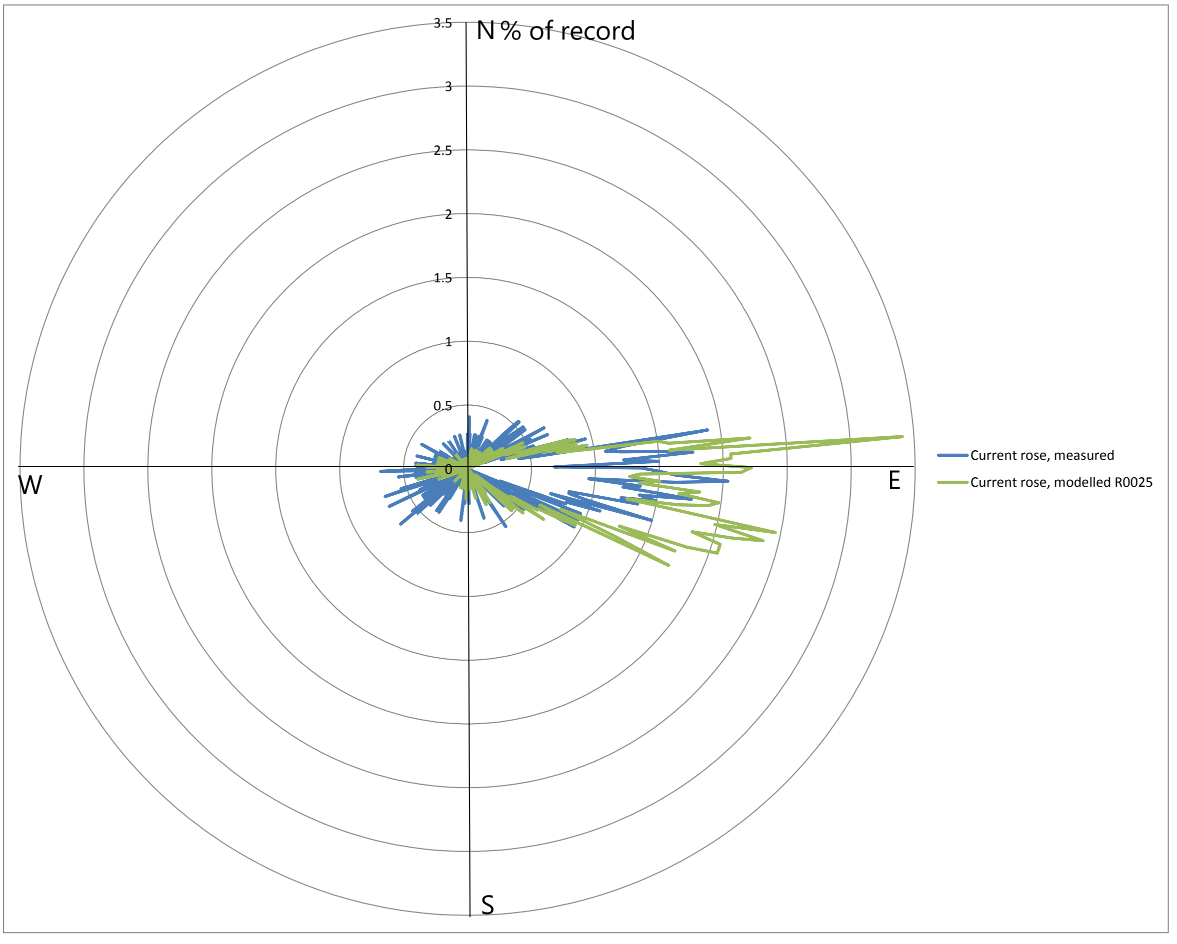




**Figure 16 - Validation of modelled vs. measured near surface current velocity and direction at the pilot buoy (note – current direction is the direction to which the current is travelling)**

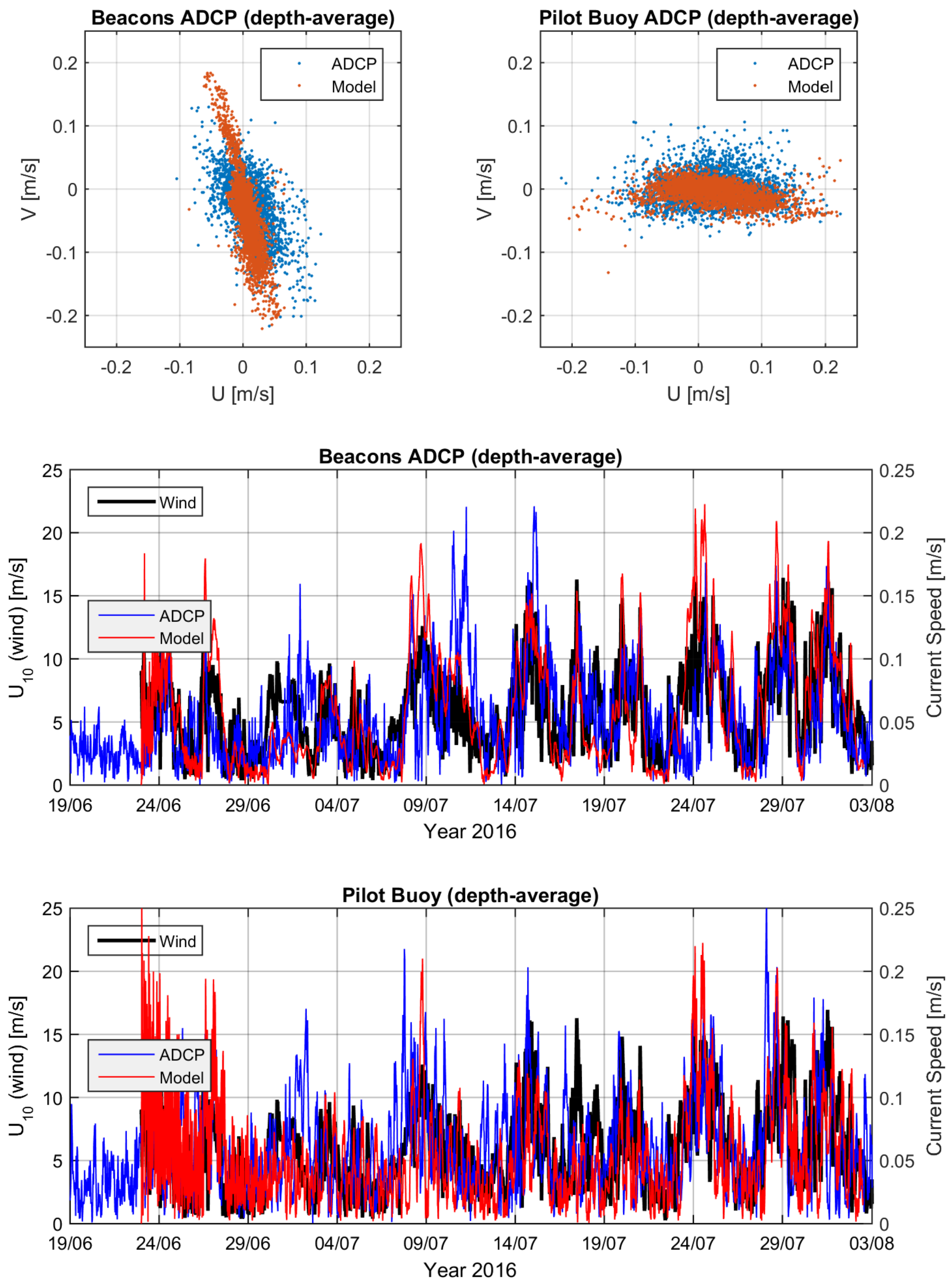



**Figure 17 – Model validation results at the Pilot Buoy and Beacons ADCPs for July 2016**

# 4 Sediment Transport Modelling

## 4.1 Introduction

The model used to describe the dredge plume behaviour was D-WAQ PART, a 3D random walk particle tracking model which is part of the Delft 3D suite and is coupled to the hydrodynamic model. Re-suspension of material is included within the model predictions, with all fines released from the dredging and suspended during the dredge disposal settling through the water column and being available for later re-suspension,based on a critical shear-stress formulation.

## 4.2 Model Assumptions

### 4.2.1 Sediment characteristics

Detailed sedimentological data throughout the study area from a variety of boreholes and vibrocores (Beca 2016), as well as information on the volume of sediment to be dredged and the breakdown of the various dredging campaigns, has been made available since the preliminary dredge plume modelling that was carried out by Advisian (2015).

The available data included the following:

- *Sediment fall velocity*[4] distribution by mass from vibrocores at nine locations near the navigation channel, with three samples at varying depths at the location of the proposed dredging;
- Vibrocore and machine borehole data near Berth 6, the navigation channel and the proposed swing basin (Beca 2016);
- Estimates of volumes of material to be dredged and geological unit from which the sediment derives for each proposed campaign.

It has been assumed that the sediments are homogenously mixed during the dredge and the disposal process.

Locations of available sediment data are provided in Figure 18 and the distribution of settling velocity by mass at the measured locations within the study area is shown in Figure 19.

[4] *Sediment fall velocity* is downward velocity of a sediment particle in water in which the sum of the gravity force, buoyancy force and fluid drag force is equal to zero. Fall velocity of a particle, depends on the density and viscosity of the fluid, and the density, size, shape, spherically, and the surface texture of the particle.

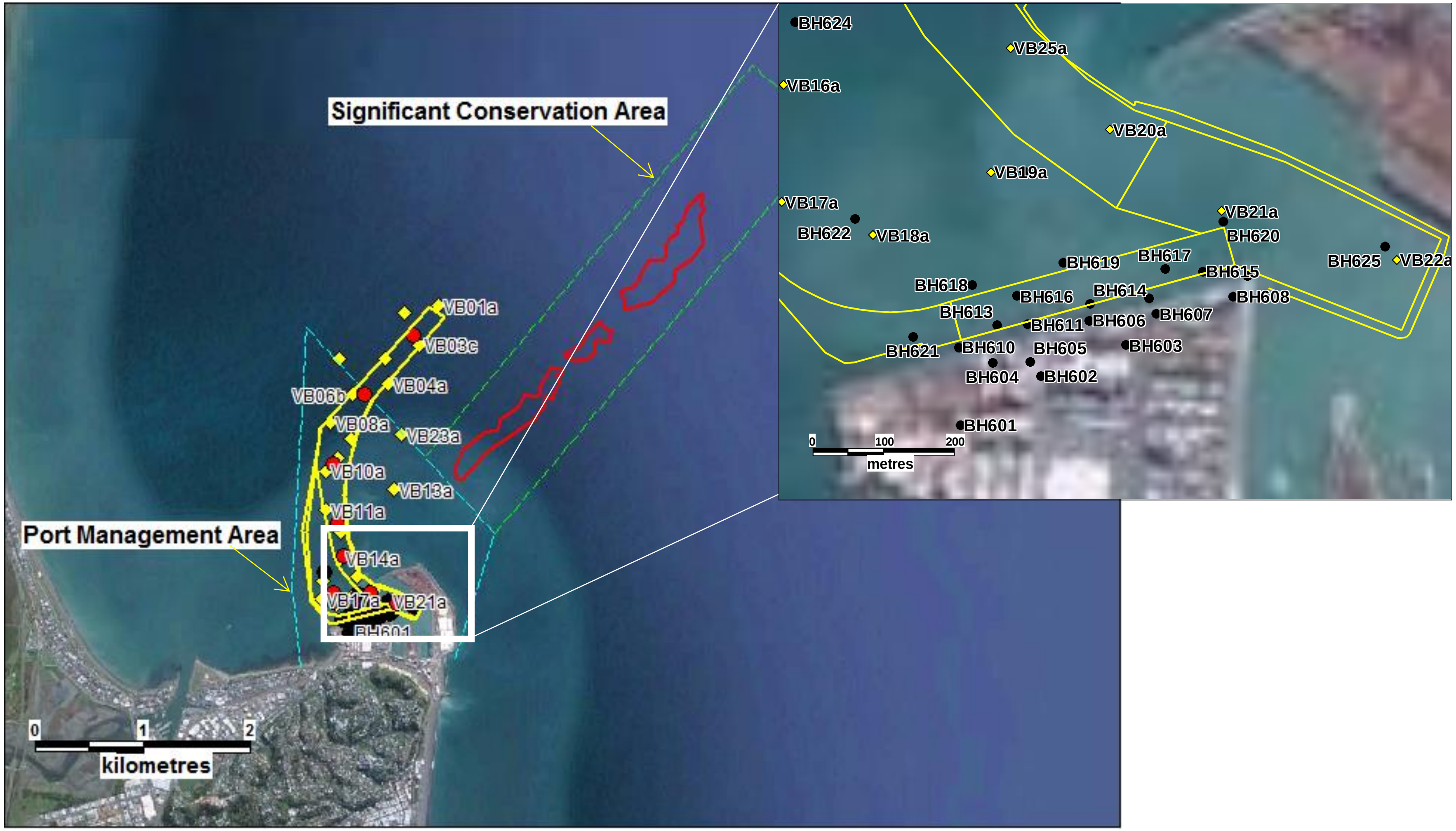



Figure 18 – Locations of available sediment data – boreholes (BH) and vibrocores (VB)

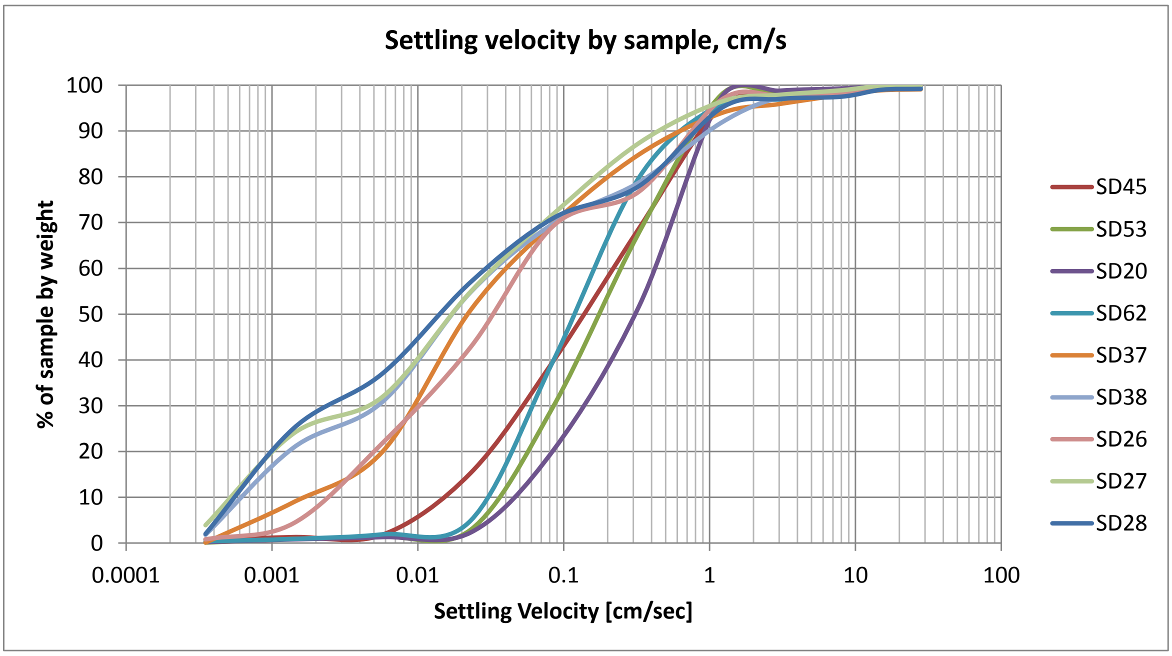



**Figure 19 – Range of sediment settling velocity distributions at various sampling locations within the study area**

## 4.2.2 Sediment Classes and Settling Velocity

Sediment plume dispersion studies typically require three to five particle size classes to be defined, based on their distinct settling patterns and potential for re-suspension as a result of current and/or wave action. As the plume dispersion model is used to simulate the dispersion of material suspended into the water column, typically only the fine particles, including silts and clays, are included in the model as coarser materials, including sands and gravels, settle out almost immediately.

Eleven particle settling velocity classes were used for the assessment, which was considered sufficient to characterise the material fractions at the various locations where dredging is to take place. These settling velocity classes are presented in Table 2 together with the corresponding particle fraction.

**Table 2 Particle size classes and settling velocities used for the modelling assessment**

| Particle Size Fraction [micron] | Settling Velocity [cm/sec] |
|---|---|
| 2 (clay) | 0.00035 |
| 4 (clay) | 0.0014 |
| 8 (silt) | 0.0057 |
| 16 (silt) | 0.023 |
| 31 (silt) | 0.085 |
| 62 (silt) | 0.329 |
| 125 (sand) | 1.2 |
| 250 (sand) | 3 |
| 500 (sand) | 8 |
| 1,000 (sand) | 15 |
| 2,000 (sand) | 28 |

The sediment velocity classifications listed above are based on an unflocculated sediment sample, that is, all the particles were separated in the analysis. In reality at high suspended sediment concentrations (>300 mg/l) the finer clay and silt particles are likely to floc together in the plume upon entering salt water, resulting in larger particles (or flocs) that have much higher settling velocities. Below this level of concentration flocculation appears to be of minor importance (van Rijn, 1989). The modelling presented in this report has assumed that the particles will not flocculate and have a constant settling velocity. This assumption is expected to give conservative estimates of the plume dimensions and concentrations as particles with lower settling velocities will remain in suspension for longer periods, allowing the plume to travel further.

### 4.2.3 Deposition

In the model, the deposition rate is formulated as a function of the settling velocity, the near-bed concentration and the actual critical bed shear stress for deposition.

For the current study, a critical bed shear stress for deposition of 0.05 $N/m^2$ was employed for the finer size classes (clays and fine silts), consistent with recommendations for dredge dispersion studies in areas of similar seabed characteristics (Doorn-Groen & Foster 2007; Van Rijn, L.C. 1989).

### 4.2.4 Erosion

The erosion rate depends on the seabed properties, whether the seabed is dense and consolidated or soft and only partly consolidated. In the present model, the bed is described as one layer with the material deposited and resuspended solely that which results from the dredging works at the project site. This enables the impact of the proposed dredging works to be isolated in the analysis. The layer contains the material which is re-suspended and subsequently settled during each tidal cycle. A threshold shear stress determines whether the deposition material is re-suspended or not. Erosion occurs when the driving forces moving the sediment exceed the sediment stabilising forces.

Partheniades (1965) and Parchure & Mehta (1985) investigated the critical shear stress for erosion of cohesive sediments as listed in Table 3. For the present modelling study the critical shear stress parameter in the model was set to the value of 0.2 N/m$^2$, corresponding to the lower bound value of shear stress required to mobilise partly consolidated mud from Table 3. This is because the particle tracking analysis is primarily concerned with the transport and fate of unconsolidated silt and soft mud suspended by the dredging processes, rather than the rapidly settling sand component which does not remain in the water column and therefore does not contribute to turbidity.

**Table 3 - Critical Shear Stress for Sedimentation and Erosion. (Partheniades (1965) and Parchure & Mehta (1985))**

| Mud Type | Density (kg/m$^3$) | Typical critical shear stress (N/m$^2$) |
|---|---|---|
| Mobile fluid mud | 180 | 0.05 – 0.1 |
| Partly consolidated mud | 450 | 0.2 – 0.4 |
| Hard mud | 600+ | 0.6 – 2.0 |

## 4.3 Parameters Summary

The dispersion coefficient is a critical parameter with respect to the spatial excursion of the sediment plume. This and other sediment parameters used in the model set-up, based upon Advisian’s experience in other sediment dispersion studies, have been summarised in Table 4. The dispersion coefficient models the effects of turbulence that are not included in the hydrodynamics, including random small-scale deviations from the mean hydrodynamic velocity field.

**Table 4 - Key parameters and formulations used in the MIKE3 MT and HD models**

| Model Parameter | |
|---|---|
| Critical shear stress for deposition | 0.05 N/m$^2$ |
| Critical shear stress for erosion | 0.2 N/m$^2$ |
| Horizontal dispersion coefficient | 1.0 m$^2$/s |
| Vertical dispersion coefficient | 0.01 m$^2$/s |
| Number of vertical sigma layers | 5 (equal layers each spanning 20% of the depth) plus bed layer |

## 4.4 Dredging Campaigns

It is understood that there are to be five dredging campaigns in all, to achieve the design depth for Berth 6 and the port navigation channel of -14.5 CD.

The following dredging campaigns have been used in the model as they were considered to represent the most conservative cases for sediment plume generation:

- **Dredge Campaign 1**
  - Dredging of Berth 6 (Area D in Figure 20) to the design depth of -14.5 CD using a BHD;
  - Dredging of Area C (swing basin) and Area B (within the Port) to -12.5 CD using a BHD;
  - Dredging of Area A1 (inner navigation channel) and Area A (outer navigation channel) to -12.5 CD using a TSHD.
- **Dredge Campaigns 2 - 4**
  - Dredging of Area C and Area B in 0.5 m increments of depth per campaign using a backhoe dredger;
  - Dredging of Area A and Area A1 in 0.5 m increments of depth per campaign using a TSHD.
- **Dredge Campaign 5**
  - Final capital dredging campaign to ultimate design depth using a TSHD for Areas A and A1 and a backhoe dredge for the remaining areas.

The locations and durations of the proposed dredging works are illustrated in Figure 20.

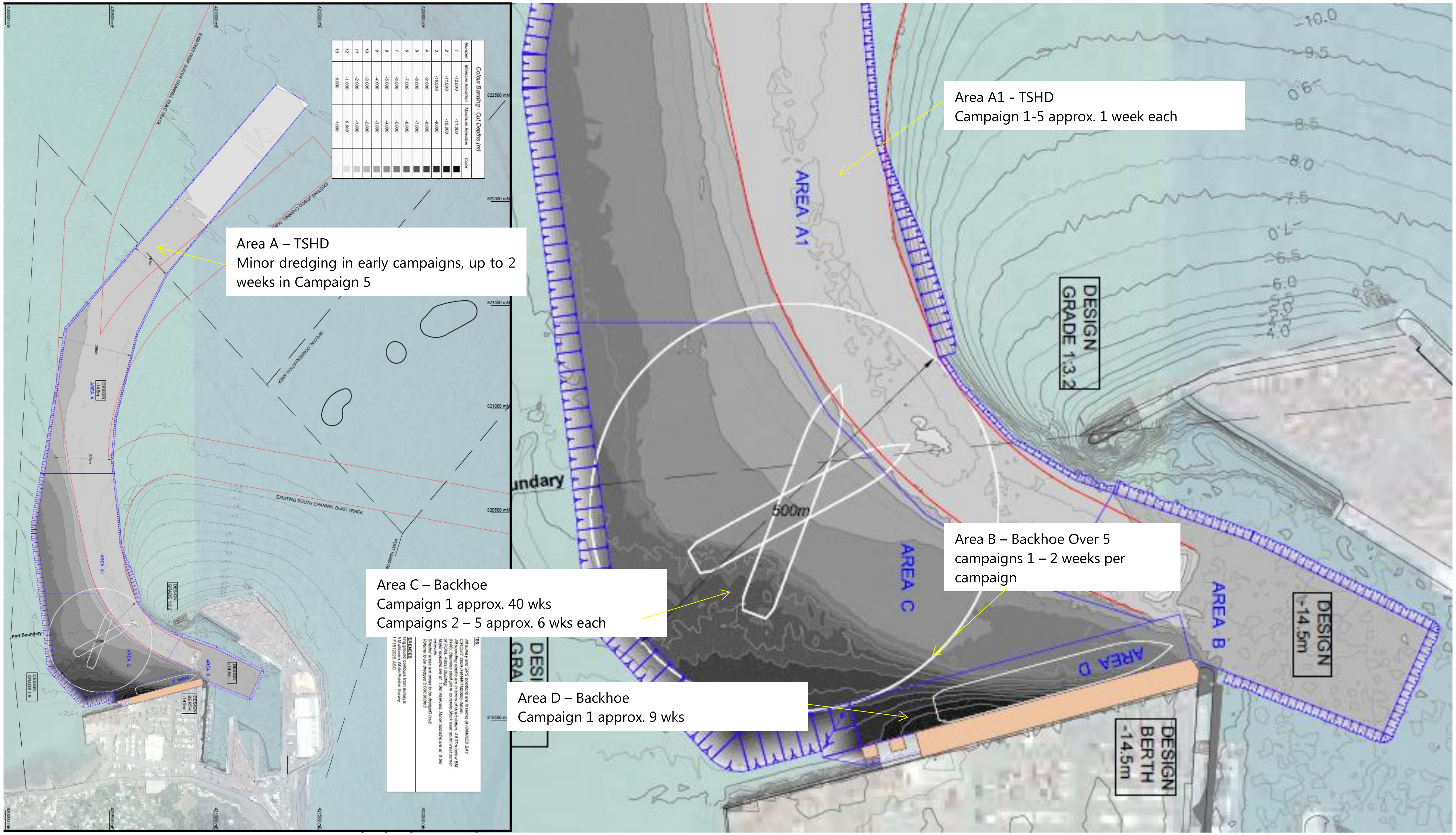



**Figure 20 – Proposed dredge areas and dredging campaigns and approximate timeframes**

## 4.5 Dredge Plant and Dredge Rates

Since the preliminary dredge plume study, further work and analysis has been carried out on the proposed dredge plant and methodology to be used, dredge rates and volumes to be dredged. A TSHD is to be used for dredging the outer and inner navigation channel areas, while the proposed Berth 6, swing basin and areas closer to the port are to be dredged using a BHD.

### 4.5.1 Trailer Suction Hopper Dredging

It is proposed to use a TSHD to dredge the inner and outer navigation channels, with the likely dredge being the MAHURY or similar (Figure 21). The Mahury is 75 m long, has a hopper capacity of 1,840 $m^3$, a vessel draught of up to 3.8 m, a sailing speed of up to 9 knots and is capable of dredging to a depth of 30 metres.

The TSHD dredges by pulling a drag head across the seafloor, mobilising the seabed material into the water column, while sucking the subsequent water and suspended material up through the drag head. This mixture of water and dredged material is then pumped through external pipes into a hopper. Heavier particles settle to the bottom of the hopper and lighter particles remain in suspension within the hopper. Once the hopper is full of water, the hopper is typically allowed to overflow with the low-density mixture overflowing back into the sea, while continuing to capture the denser material within the hopper. This reduces the number of trips required from the dredge area to the offshore disposal area and therefore reduces the overall duration of the dredging campaign. During dredging, fine sediment will be generated from bottom disturbance and from overflow from the hopper barges as well as potentially from propeller wash. The majority of the near-surface turbidity that would be visible to a casual observer at the dredging sites is likely to be attributed to the overflow water from the barges rather than effects from bottom disturbance. This is because the overflow discharge is closer to the surface than the effects from bottom disturbance and is more likely to produce a plume that is visible to a casual observer from above the surface.

The sediment characteristics, discharge depth of overflow and rate of overflow is dependent on the type of dredge and varies with make and model. WorleyParsons (2005) undertook a detailed analysis of the various options of dredge available to PONL to assess filling times and the length of time the barge will overflow.

Economic loading times and length of overflow discharge were assed in WorleyParsons (2005), considering the following factors:

- Type of dredge
- Hopper capacity
- Type of material dredged
- Behaviour of sediment during dredging
- Fully laden sailing speed
- Length of the dredging area
- Distance to disposal site

- Time to turn dredger
- Time to dispose (dump) sediment

The results of the analysis indicated that the most economic loading time for TSD is 20 and 30 minutes for silt and sandy material respectively.


**Figure 21 – Mahury TSHD (https://www.royalihc.com/-/media/royalihc/about-us/news/2015/royal_ihc_names_1_840m3_tshd_mahury_02.jpg)**

Concentrations of suspended sediment released during the dredging operation (excluding overflow) were estimated by the S factor method that provides estimates of sediment that passes out of the immediate dredging area, typically 50 m from the dredger. The S factor is defined as the following:

$$S = \frac{Amount\ resuspended\ (kg)}{Amount\ of\ Soil\ Dredged\ (m^3)}$$

Typical expected "S factors" assuming that overflow and degassing discharge is prohibited for TSD are in the order of 5 kg/m$^3$. Calculated S Factor for silt based on the material behaviour during extraction has previously been estimated at approximately 180 kg/m$^3$, and has been assumed for this analysis.

Suspended sediment concentration of the overflow discharge will be based on the WorleyParsons in-house database of recorded overflow concentrations for dredging in Western Australia, as reported in WorleyParsons (2005). Typical mean overflow concentrations are generally in the order of 6,000 to 8,000 mg/l. For this dredge plume study 8,000 mg/l is considered appropriate for the Hawke Bay sediments.

The sediment during dredging is likely to behave as non-cohesive sediment. It is expected that during dredging via TSHD the material will largely break down from the cohesive state and behave similar to a non-cohesive material. This is a conservative assumption, as in reality, at high suspended sediment concentrations (>300 mg/l) the finer clay and silt particles are likely to floc together in the plume upon entering salt water, resulting in larger particles (or flocs) that have much higher settling velocities.

Table 5 summarises the production rate characteristics that have been assumed for the purposes of the modelling.

**Table 5 - Summary of dredging characteristics (adapted from WorleyParsons 2005)**

| | Backhoe | | TSD 1000 | | TSD 5000 | | TSD 1840 (Mahury) | |
|---|---|---|---|---|---|---|---|---|
| | Sand | Silt + smaller | Sand | Silt + smaller | Sand | Silt + smaller | Sand | Silt + smaller |
| Time to fill (min) | 179 | 195 | 30 | 20 | 30 | 20 | 30 | 20 |
| Time of overflow (min) | - | - | 10 | 5 | 10 | 5 | 10 | 5 |
| In-situ sediment volume to fill barge incl. bulking ($m^3$) | 625 | 600 | 715 | 400 | 3,570 | 2,000 | 1,290 | 720 |
| Mean filling sediment discharge (kg/s) | 1.2 | 9 | 2.0 | 1.8 | 9.9 | 8.7 | 3.6 | 3.24 |
| Mean overflow discharge (kg/s) | | | 6.6 | 6.6 | 34.7 | 34.7 | 11.9 | 11.9 |
| Amount suspended per barge load (kg) | 12,900 | 105,300 | 8,350 | 4,000 | 42,900 | 20,400 | 15,030 | 7,200 |

### 4.5.2 Backhoe Dredging

A backhoe dredger is proposed to be used for dredging of Berth 6, the swing basin and the inner port areas.

The likely backhoe dredge to be used for the capital dredging is the Machiavelli or similar size vessel (Figure 22), which comprises a long-reach excavator mounted on a floating pontoon. The dredger excavates the seabed and fills two non-propelled split-hopper barges with a hopper capacity of 765 $m^3$ each. Once filled, the barges are propelled to the spoil disposal ground by a tug (Kurutai or similar) and would typically sail at around 5 knots, for a sailing time from the dredge site to the Site 5 spoil ground of around 40 minutes. The two non-propelled barges are assumed to work in series, with the dredger filling one barge while the other is being towed by the tug to the spoil disposal area.

Napier Port have advised that the following production rates for backhoe dredging can be expected (this is based on previous production rates achieved in similar material at the Port):

- 14,000 $m^3$ per week in "hard" material (assumed to comprise Mangahei Group and Residual Mangahei group sediments);
- 24,000 $m^3$ to 28,000 $m^3$ per week in "soft" material (assumed to comprise recent and quaternary marine sediments).

Dredging cycle times have been estimated from Table 5 and assuming both split hopper barges being used, for an overall dredge cycle time of 220 minutes.

Estimated volumes of material to be dredged per campaign and approximate timeframes (not including allowance for unforeseen delays, etc.) are presented in Table 6.

## Machiavelli

## Backhoe Dredger

| | |
|---|---|
| Name: | Machiavelli |
| Type: | De Donge 'D' Type Backhoe Dredge |
| Operators: | Heron Construction Company Ltd |
| Port of registry: | Auckland, New Zealand |
| Class: | Bureau Veritas |
| MNZ #: | 131883 |
| Official Number: | 876411 |
| Year built: | 2005 |
| Gross tonnage: | 648 |
| Displacement: | 1,200 tonne |
| Length overall: | 53.0m |
| Breadth: | 15.0m |
| Excavator: | Liebherr P994 |
| Monobloc (boom) length: | 16.0m, 19.0m |
| Stick (dipper) lengths: | 4.0m, 5.6m, 8.0m and 9.5m |
| Bucket sizes: | 4.0m$^3$, 5.0m$^3$ and 5.7m$^3$,6.0 m$^3$ |
| Clamshell sizes: | 3.5 m$^3$ Heavy duty and 6.0m$^3$ Environmental |
| Dredging control: | DipMate v3 by Seatools |
| Position and height control: | Twin 5700 Trimble RTK GPS |
| Aft spuds: | Two @ 30m long x 60 tonne each |
| Forward spuds: | One @ 30m long x 60 tonne in carrier |
| Spud carrier stroke: | 7.5m |
| Jackup capacity: | 780 tonnes |

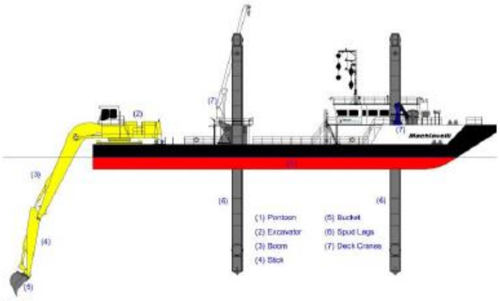



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**Figure 22 – Proposed backhoe dredge**

**Table 6 – Sediment volumes and length (in weeks) of dredging for various plant used and for each dredging campaign**

| | Recent marine sediment | Quaternary marine sediment | Residual Mangahei group | Mangahei group | No. weeks soft | No. weeks hard | Total weeks | |
|---|---|---|---|---|---|---|---|---|
| **Area D (Backhoe)** | | | | | | | | |
| -12.5 | 88205 | 6451.2 | 26539 | 3219.9 | 3.944 | 2.126 | | |
| -13 | 3418 | 923 | 5561 | 1626.8 | 0.181 | 0.513 | | |
| -13.5 | 2329 | 948.6 | 6153 | 2150.7 | 0.137 | 0.593 | | |
| -14 | 1695 | 1052 | 6054 | 2781.8 | 0.114 | 0.631 | | |
| -14.5 | 1353 | 1195.2 | 5572 | 3461.8 | 0.106 | 0.645 | | |
| **TOTAL** | 97000 | 10570 | 49879 | 13241 | 4.48 | 4.51 | 8.991 | (Campaign 1) |
| **Area B (Backhoe)** | | | | | | | | |
| -12.5 | 19932 | | 4445.4 | 0 | 0.831 | 0.318 | 1.148 | (Campaign 1) |
| -13 | 14991 | | 12365.6 | 0 | 0.625 | 0.883 | 1.508 | (Campaign 2) |
| -13.5 | 12419 | | 18774 | 289.05 | 0.517 | 1.362 | 1.879 | (Campaign 3) |
| -14 | 7871 | | 21543 | 2929.65 | 0.328 | 1.748 | 2.076 | (Campaign 4) |
| -14.5 | 3927 | | 20574 | 8257.3 | 0.164 | 2.059 | 2.223 | (Campaign 5) |
| **TOTAL** | 59140 | | 77702 | 11476 | 2.464 | 6.370 | | |
| **Area C (Backhoe)** | | | | | | | | |
| -12.5 | 967370 | | 2918.5 | | 40.307 | 0.208 | 40.516 | (Campaign 1) |
| -13 | 154930 | | 2942.2 | | 6.455 | 0.210 | 6.666 | (Campaign 2) |
| -13.5 | 153300 | | 4541.3 | | 6.388 | 0.324 | 6.712 | (Campaign 3) |
| -14 | 151800 | | 6033 | | 6.325 | 0.431 | 6.756 | (Campaign 4) |
| -14.5 | 150900 | | 7037 | | 6.288 | 0.503 | 6.790 | (Campaign 5) |
| **TOTAL** | 1578300 | | 23472 | | 65.763 | 1.677 | | |

| | Recent marine sediment | Quaternary marine sediment | Residual Mangahei group | Mangahei group | No. weeks soft | No. weeks hard | Total weeks |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| **Area A1 (TSHD)** | | | | | | | |
| -12.5 | 5953.6 | | | | 0.057 | 0.000 | 0.057 (Campaign 1) |
| -13 | 33895.4 | | | | 0.326 | 0.000 | 0.326 (Campaign 2) |
| -13.5 | 85571 | | | | 0.823 | 0.000 | 0.823 (Campaign 3) |
| -14 | 89770 | | | | 0.863 | 0.000 | 0.863 (Campaign 4) |
| -14.5 | 89850 | | | | 0.864 | 0.000 | 0.864 (Campaign 5) |
| **TOTAL** | 305040 | | | | 2.933 | 0.000 | |
| **Area A (TSHD)** | | | | | | | |
| -12.5 | 27069 | | | | 0.201 | 0.000 | 0.201 (Campaign 1) |
| -13 | 92131 | | | | 0.682 | 0.000 | 0.682 (Campaign 2) |
| -13.5 | 176170 | | | | 1.305 | 0.000 | 1.305 (Campaign 3) |
| -14 | 220300 | | | | 1.632 | 0.000 | 1.632 (Campaign 4) |
| -14.5 | 252820 | | | | 1.873 | 0.000 | 1.873 (Campaign 5) |
| **TOTAL** | 768490 | | | | 5.693 | 0.000 | |

## 4.6 Plume Dispersion Methodology

The release and settlement of sediments during dredging has been simulated using a particle tracking model. The particle tracking extension to Delft3D incorporates variable settling rates and allows the particles to be grounded and resuspended, to best represent conditions in the natural environment.

The model itself relies on the input of the Delft3D 3D hydrodynamic and wave model simulations, including allowing for wetting and drying effects and a number of diffusion models.

For the TSHD, sediment releases would occur from the drag head (i.e. distributed in layers 2, 3 and 4 of the model, i.e. at 25%, 50% and 75% of the water depth), and overflow releases near the surface (Layer 2 of the model at 25% of the water depth). Very little contribution from propeller wash would be expected, as the draft of the vessel is 3.8 m over an overall water depth of 12 – 15 m. At the spoil disposal ground, sediment suspended during disposal was added to model at 25%, 50% and 75% of the model depth (Layer 2, Layer 3 and Layer 4). The discharge depths are based on physical measurements presented in US Army Engineer Waterways Experiment Station (1992).

For the backhoe dredging, it is assumed that at the dredge site, sediment is released near the bed – i.e. in the bottom two layers of the model domain (Layer 4 and Layer 5). At the spoil ground, 600 $m^3$ of sediment is assumed to be released at 25%, 50% and 75% of the model depth (Layer 2, Layer 3 and Layer 4) over 20 minutes.

The following assumptions were used in modelling the production rate of sediment at the spoil ground and at the dredging site:

- For the TSHD, the overall cycle time used in the model is 90 minutes, which includes 30 minutes dredge time (to fill the hopper), 10 minutes overflow time at the dredge site, 20 minutes sailing time, 20 minutes dumping at the spoil ground and 20 minutes return sailing time.
- For the backhoe dredging, the cycle times used in the model includes 195 min filling, 40 minutes sailing (@ 5 knots), 20 minutes dumping at the spoil ground, 40 minutes return sailing time and two hopper barges working in series, 24 hours per day, 7 days per week.
- Based on previous experience with capital dredging works it is assumed that 80% of the reworked dredged material will settle immediately to the seabed with the dumped mass.
- The location that each barge load is dumped within the disposal area will be managed so that the dredged material will be evenly spread over the disposal area.

## 4.7 Model Scenarios

The following campaigns were investigated:

- Modelling of Dredge Campaign 1
- Modelling of Dredge Campaign 5

These are considered to present a conservative representation of the potential impacts of the dredging on suspended sediment concentrations and sedimentation at Pania Reef for the reasons set out below.

Campaign 1 was chosen for analysis due to the high overall volume of dredging occurring in that campaign, and also to assess the difference in impact between existing (pre-dredge) bathymetry and post-dredged bathymetry on the sediment dispersion. Campaign 5 was chosen also, due to the higher volume of TSHD occurring in the outer navigation channel, and therefore closer to Pania Reef. The other campaigns (2 – 4) involve lower volumes and durations of dredging.

For the hydrodynamic modelling, the relatively stormy period of July 2016 was used as the basis of the water quality modelling, which provides a conservative assessment. It was selected for the following reasons:

- July 2016 included major wind events when compared to measured wind data between 2005 and 2015, including strong westerly winds;
- However, a range of representative wind directions occurred over the month, including south-easterly winds
- Stormy periods have been shown by the preliminary dredge plume modelling to result in larger sediment plumes;
- A full month of simulation time encompasses a full neap and spring tidal cycle; and
- TSHD durations for all campaigns are not likely to exceed 2 weeks, with backhoe dredging occurring over an entire month. This allows the higher relative impact of TSHD carried out in conjunction with the backhoe dredging to be fully captured in the model simulations, with the impact of backhoe dredging carried out in isolation in the second half of the month being lower.

Multiple sediment sources were introduced into the model to indicate the likely sequence of dredging in the different areas, as well as two main sediment disposal locations at the proposed spoil ground, as indicated in Figure 23.

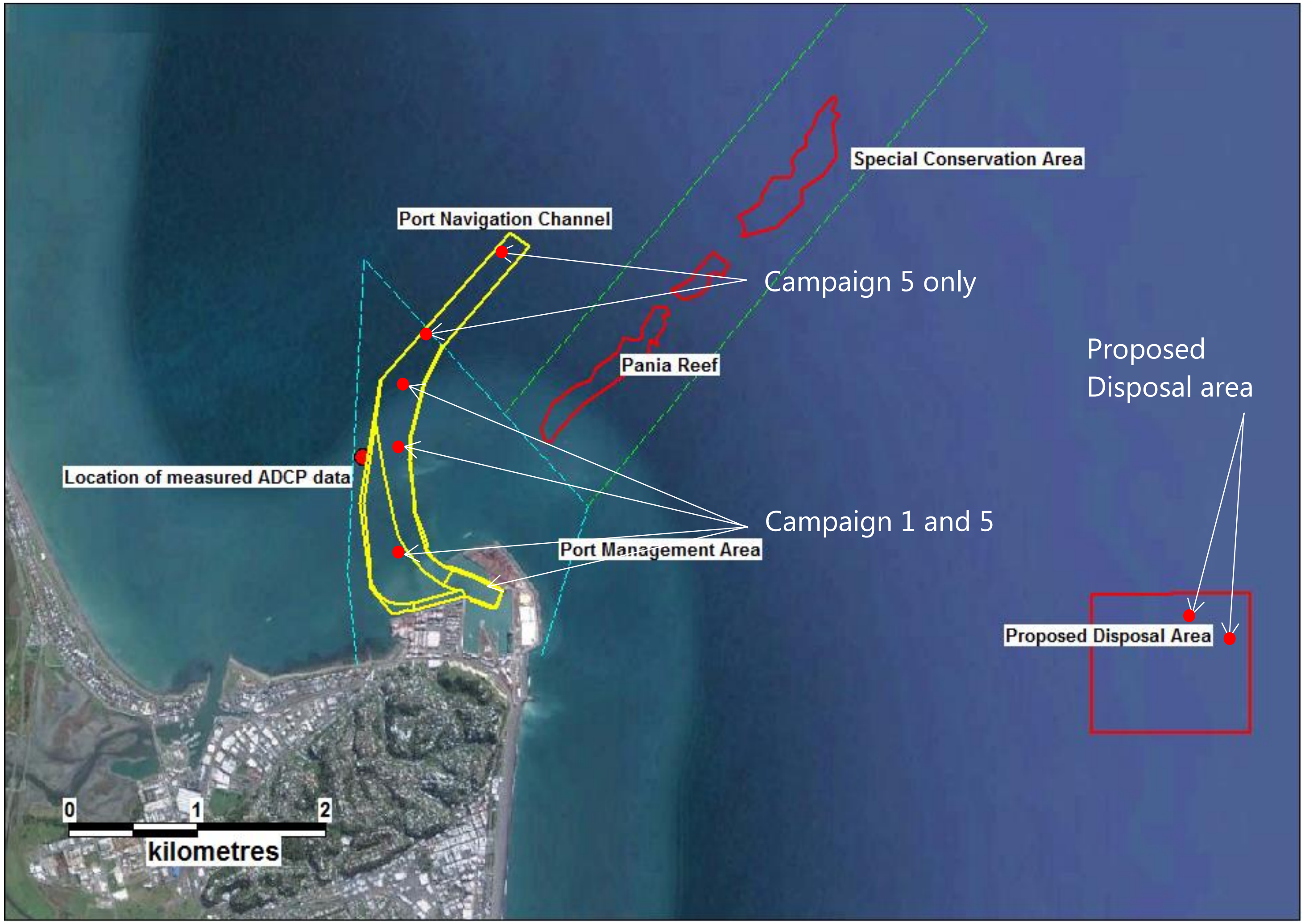



**Figure 23 – Schematic representing source areas (red) for sediment in the model for Campaign 1 and Campaign 5**

### 4.7.1 Campaign 1

For dredge Campaign 1, the pre-dredge (existing) bathymetry was modelled. Approximately 10 days of TSHD was simulated for Area A1, assumed to occur at the start of the month. Backhoe dredging was assumed to occur throughout the month, variously at Areas D, C and B. Eleven unique sediment fractions with unique settling velocities were modelled, ranging from clay-sized particles to coarse sand, based on the mass of each sediment fraction obtained from vibrocore data at the nearest location to the dredge sites. 23 unique sediment sources were included in the model for Campaign 1.

### 4.7.2 Campaign 5

For dredge Campaign 5, post-dredge bathymetry was modelled. TSHD was assumed to occur at Area A1 and Area A over the first 3 weeks of the month. Backhoe dredging was occurring at the swing basin and within the inner port area, in parallel with the TSHD, for the entire month. For this model scenario, eleven sediment fractions were modelled with 43 unique sources of sediment introduced into the model.

# 5 Model Results

## 5.1 Presentation of Model Results

The model presents total suspended sediment concentrations (in mg/L which is equivalent to parts per million ppm), above background levels – i.e. the effect of suspended sediments from other sources such as input from local rivers or current-induced stirring of in-situ sediment from sources other than the dredging and dredge disposal are not included in the model.

The model results have been presented in the following ways:

- Maps showing the spatial extent of the 50th, 80th, 95th and 98th percentile exceedance near-surface total suspended sediment concentrations (in mg/L above background) for the silt fractions of the plume for the one-month scenarios, for dredging at all areas for Campaign 1 and Campaign 5;
- Maps showing the spatial extent of the 50th, 80th, 95th and 98th percentile exceedance bed sedimentation in $kg/m^2$ for the one-month scenarios, for dredging at all areas for Campaign 1 and Campaign 5, for both the sand and silt fractions of the discharge; and
- Time-series plots of suspended sediment concentrations above background at key locations around the study area, averaged over a 500 m grid area as indicated in Figure 24.

The median concentration plots provide a good representation of the likely concentrations at any time during the dredging cycle, whereas the 98th percentile plots provide a reasonable indication of where short term spikes may occur and reasonably expected suspended solids concentrations during these events. It should be noted that the 80th, 95th and 98th percentile plots represent concentrations that would be likely to occur only at the start of the dredging campaign, when TSHD is being undertaken in conjunction with backhoe dredging. It should be noted also that:

- The 95th percentile maps represent sediment concentrations above background likely to be exceeded for a total of 2 days during any one month of a dredging campaign; and
- The 98th percentile maps represent sediment concentrations above background likely to be exceeded for a total of less than 1 day during any one month of a dredging campaign.

## 5.2 Interpretation of Model Results

### 5.2.1 Background Suspended Sediment Concentrations

The modelling presents suspended sediment concentrations above background levels.

Limited background suspended sediment and turbidity data is available for the Hawke Bay region. However, some data is presented in WorleyParsons (2005), with suspended sediment concentrations induced by wave and current re-suspension near the seabed of between 2 –

3.1 mg/L. However, it is noted that sediment concentrations in flood discharge from rivers such as the Esk can exceed 10,000 mg/L (WorleyParsons 2005).

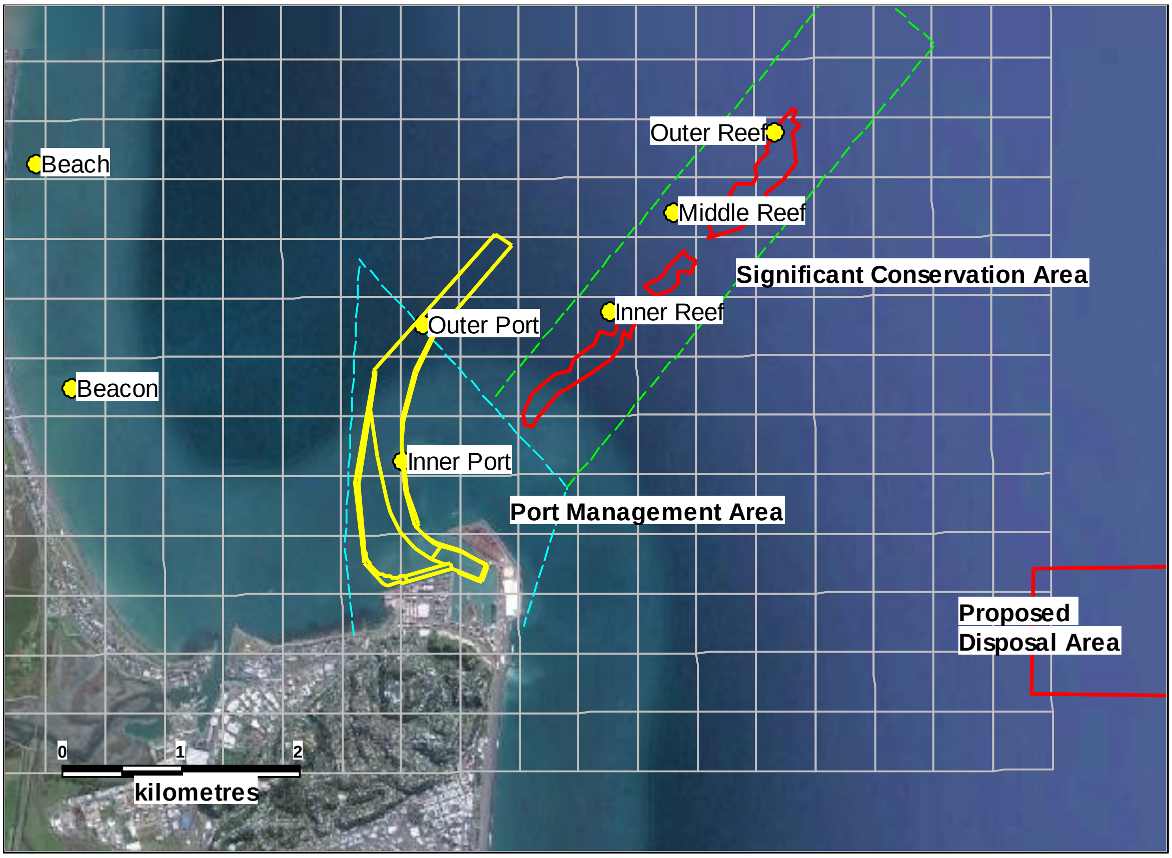



**Figure 24 – Locations for time-series output of sediment concentrations, with overlay of 500 m grid area**

## 5.2.2 Visibility of TSS

The appearance of turbid water with varying concentrations of TSS is illustrated Figure 25. For this study we have assumed that a plume would become visible to a casual observer above the water at a suspended sediment concentration above 10 mg/L.

Table 4.4.2 of the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000) outline physico-chemical stressor guidelines for the protection of aquaculture species. Issues controlled by turbidity affecting saltwater aquatic ecosystems that can affect biodiversity or ecological health include excess suspended particulate matter (resulting in smothering of benthic organisms, and inhibition of primary production), as well as poor optical properties (resulting in reduced photosynthesis, changes in predator-prey relationships), (ANZECC, 2000). For saltwater aquaculture production, the recommended guideline for suspended solids is

<10 mg/L. For turbidity, the ANZECC (2000) guidelines for default trigger values for physical and chemical stressors for slightly disturbed ecosystems for New Zealand marine waters recommend application of the default values for south-east Australia, which recommend a default trigger value for turbidity of 0.5 – 10 NTU.  Based on the visual impact of the sediment plume and ANZECC (2000) water quality guidelines for saltwater aquaculture production, this report has presented locations where increases in suspended sediment concentrations are >10 mg/L above background levels.

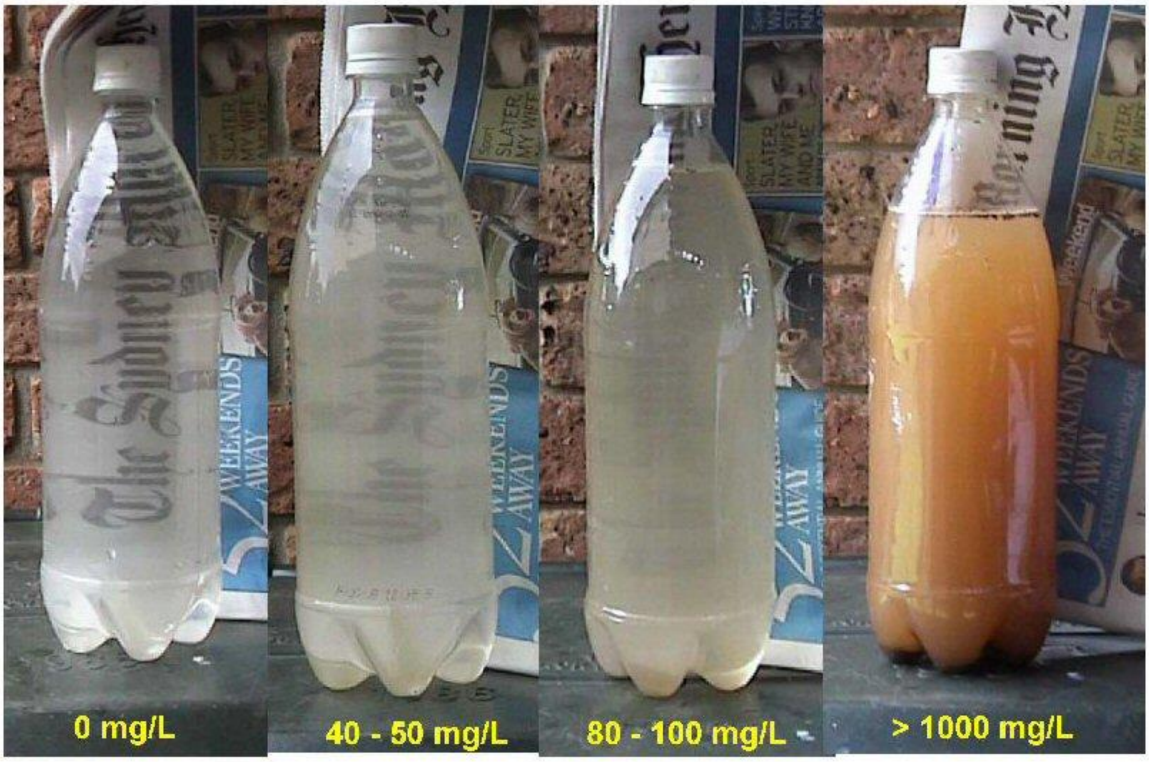



**Figure 25 – Visual representation of suspended sediment concentration**

## 5.3 Campaign 1

Percentile exceedance plots of near-surface total suspended sediment concentrations in mg/L above background (taken from 25% of the depth in the model) for the one-month simulation for the Campaign 1 scenario are shown in Figure 26 below. It can be seen that there is no potential for Pania Reef to be affected by increases in total suspended sediment concentrations above 10 mg/L at any time during Campaign 1, and that most of the suspended sediment emanates from the offshore spoil ground.

It should be noted that the suspended sediment is represented by the clay and fine silt fractions of the discharge only, as the sand fractions quickly settle out of the water column and onto the bed in the immediate vicinity of the disposal ground and dredging location.

To examine variation in total suspended sediment concentration with depth through the plume, two cross-sections were taken through the plume at the dredge area and disposal site. The locations for these cross-sections are shown in Figure 27, and the 98% exceedance variation in total suspended sediment concentration with depth is shown in Figure 28. This figure shows the concentrations within the plume against depth, exceeded for 2% of the time during the model simulation. It can be seen that at the dredge location (cross-section AA), the suspended sediment concentrations are highest near the bed, while at the disposal location, the suspended sediment concentrations are more evenly distributed with depth.

Figure 29 shows the 50%, 80%, 95% and 98% exceedances of bed deposition of the clay and silt fractions calculated by the model, assuming that the density of the bed layer is 400 kg/m$^3$ (i.e. corresponding to partly consolidated mud from Table 3). These figures show the modelled extent that bed deposition of the clay and silt sediment fractions of a given thickness will reach for 50%, 20%, 5% and 2% of the time during the model simulation. It can be seen that the greatest deposition of silt would be limited to the spoil ground and immediate dredge areas. While longer durations of dredging may result in further sediment deposition in deeper areas not affected by wave stirring, no deposition on the reef is predicted by the model for Campaign 1, due to the distance of the proposed spoil ground from the reef and sediment stirring by wave-generated currents, which would result in re-suspension of any sediments that may be deposited on the reef.

Figure 30 shows the 50%, 80%, 95% and 98% exceedances of bed deposition of the sand fractions calculated by the model, assuming that the density of the bed layer is 400 kg/m$^3$. These figures show the modelled extent that bed deposition of the sand sediment fractions of a given thickness will reach for 50%, 20%, 5% and 2% of the time during the model simulation. It can be seen that deposition of the sand fraction is restricted completely to the spoil ground and immediate vicinity of the dredging.

Figure 31 shows the time-series plot over the month of near-surface sediment concentrations, averaged over a 500 m grid area at the various key locations shown in Figure 24. It can be seen that at the sensitive receptor sites of Pania Reef, suspended sediment concentrations remain less than 5 mg/L above background values. The maximum value of suspended sediment concentrations at Pania Reef of 5 mg/L occurred over a 24 hour period on July 8, during which time ocean currents in the vicinity of the Site 5 spoil ground were directed toward the north-west.

Suspended sediment concentrations are highest in the inner port area, peaking at approximately 5 mg/L above background values, at the beginning of the dredge campaign when TSHD is being undertaken.

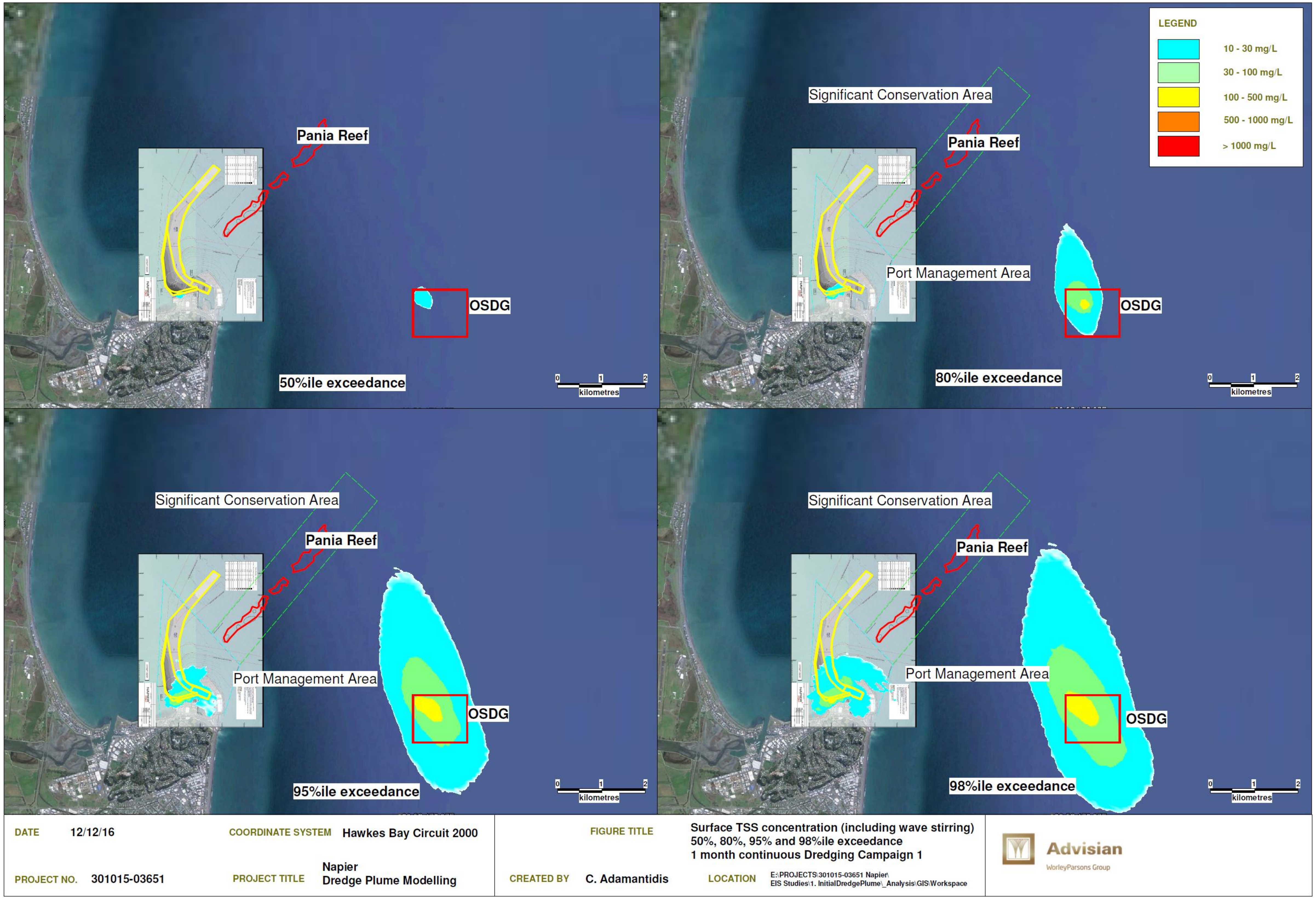



**Figure 26 – Surface TSS concentrations percentile exceedances, Campaign 1**

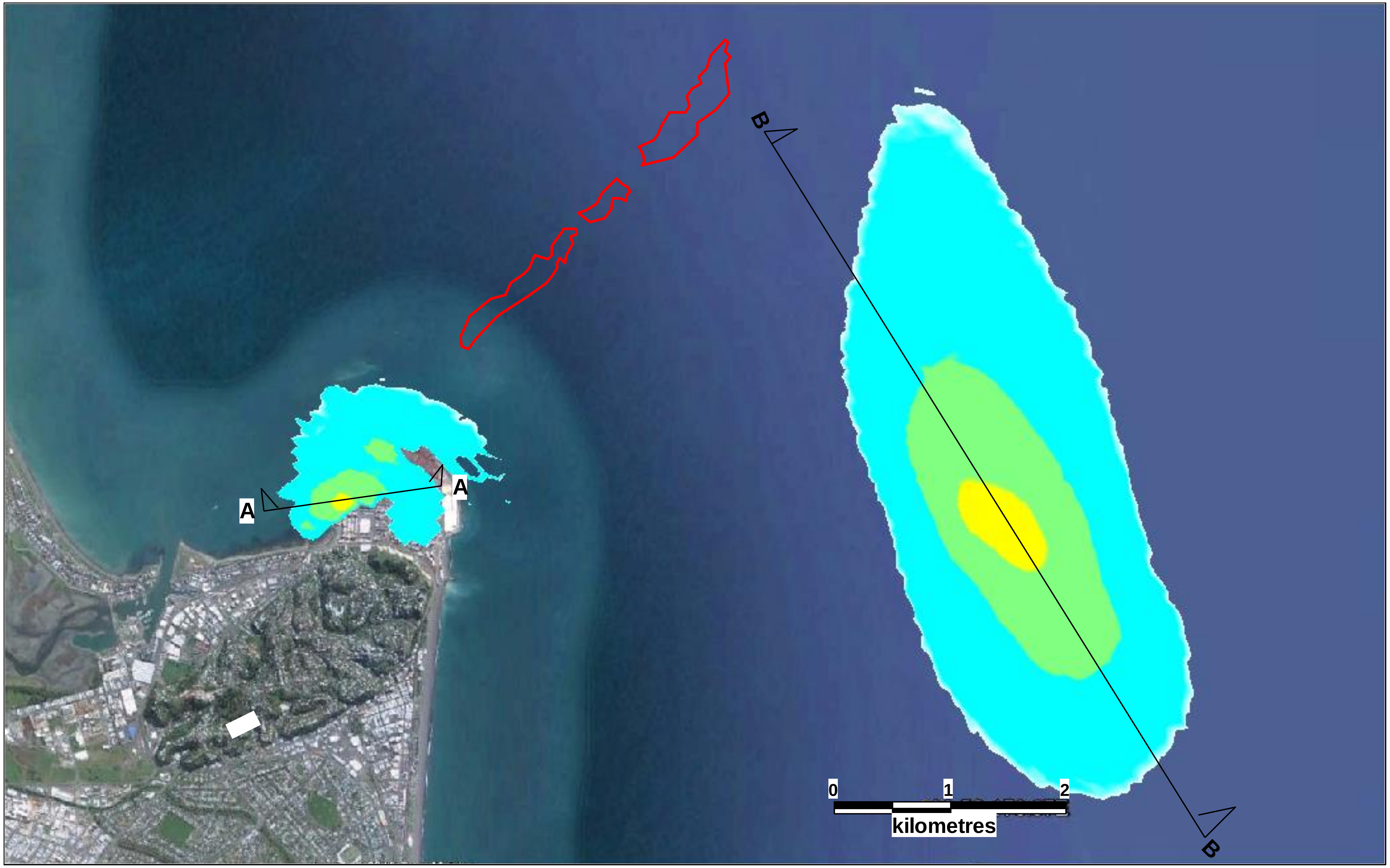



**Figure 27 – Locations for cross-sections A-A and B-B through plume, 98%ile TSS concentration exceedances, Campaign 1**

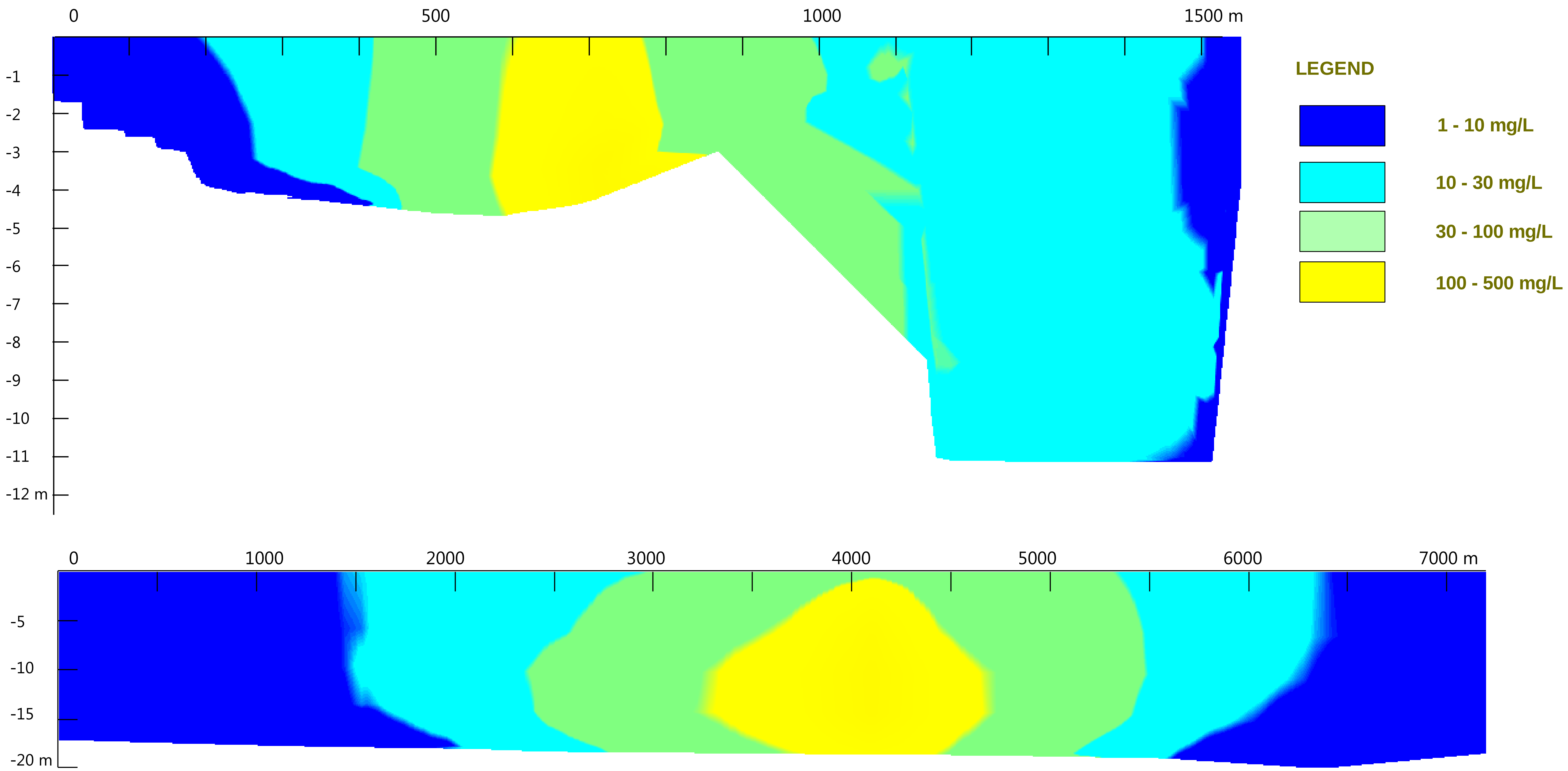
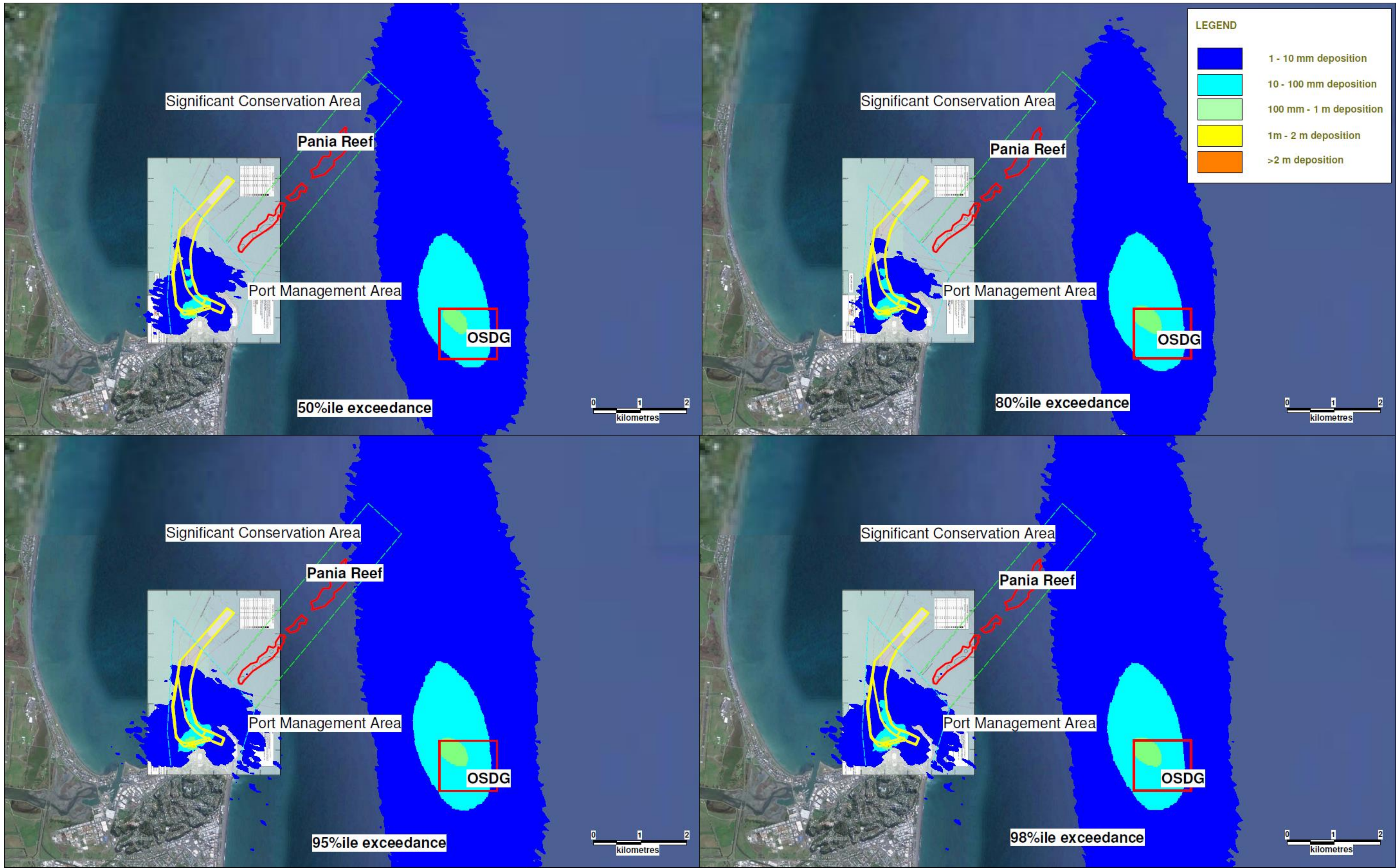



**Figure 28 – Top- Cross-section AA, Bottom: Cross section BB, 98%ile TSS concentration exceedances through plume with depth, Campaign 1 (vertical exaggeration = 1:50)**

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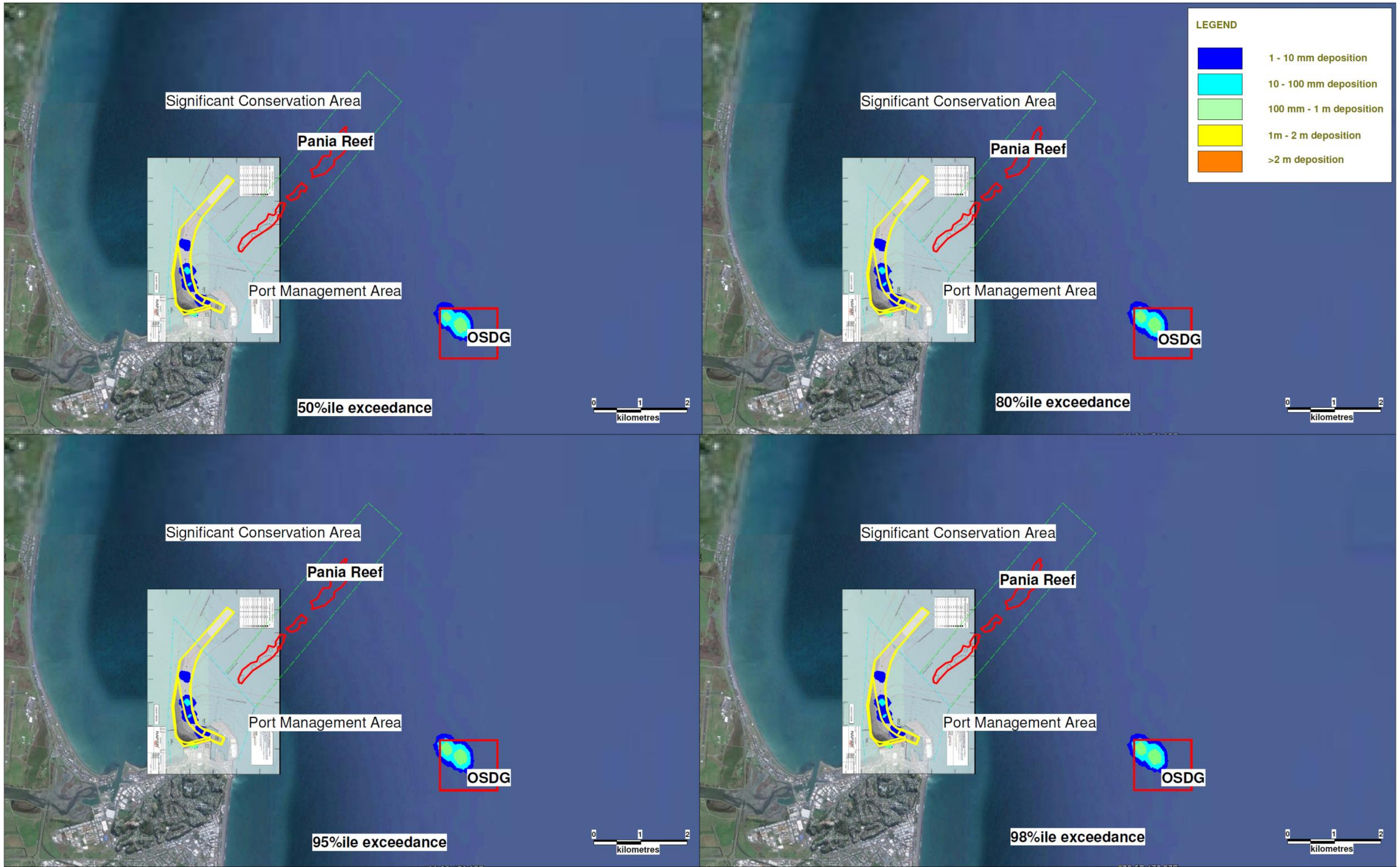
|---|---|---|---|---|---|---|---|
| DATE | 12/12/16 | COORDINATE SYSTEM | Hawkes Bay Circuit 2000 | FIGURE TITLE | Bed deposition, silt fraction (full wave stirring)<br>50%, 80%, 95% and 98%ile exceedance<br>1 month continuous Dredging Campaign 1 | | Advisian<br>WorleyParsons Group |
| PROJECT NO. | 301015-03651 | PROJECT TITLE | Napier<br>Dredge Plume Modelling | CREATED BY | C. Adamantidis | LOCATION | E:\PROJECTS\301015-03651 Napier\ EIS Studies\1. InitialDredgePlume_Analysis\GIS\Workspace |

**Figure 29 – Silt deposition percentile exceedances, Campaign 1**

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| DATE | 18/12/16 | COORDINATE SYSTEM | Hawkes Bay Circuit 2000 | | FIGURE TITLE | Bed deposition, sand fraction (full wave stirring)<br>50%, 80%, 95% and 98%ile exceedance<br>1 month continuous Dredging Campaign 1 | Advisian<br>WorleyParsons Group |
| PROJECT NO. | 301015-03651 | PROJECT TITLE | Napier<br>Dredge Plume Modelling | CREATED BY | C. Adamantidis | LOCATION | E:\PROJECTS\301015-03651 Napier\<br>EIS Studies\1. InitialDredgePlume_Analysis\GIS\Workspace |

Figure 30 – Sand deposition percentile exceedances, Campaign 1

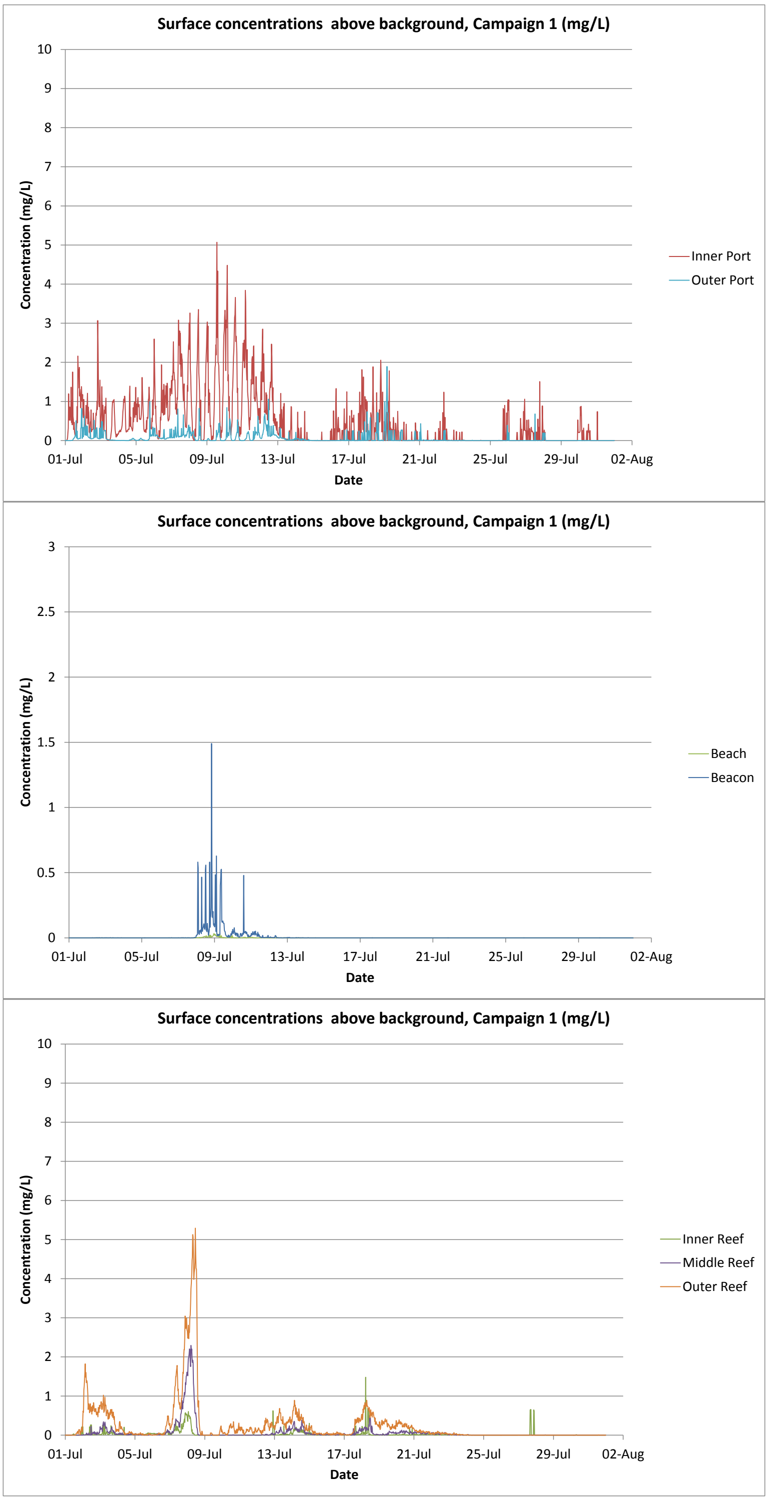



**Figure 31 – Time series of surface silt concentrations above background, Campaign 1 (Top: Inner and Outer Port, Middle: Beach and Beacon, Bottom: Inner, Middle and Outer reef). Refer to Figure 24 for spatial locations of time-series.**

## 5.4 Campaign 5

Percentile exceedance plots of near-surface total suspended sediment concentrations in mg/L above background (taken from 25% of the depth in the model) for the one-month simulation for the Campaign 5 scenario are shown in Figure 32 below. As per Campaign 1, it can be seen that there is no potential for Pania Reef to be affected by increases in total suspended sediment concentrations above 10 mg/L at any time during Campaign 5, and that most of the suspended sediment emanates from the offshore spoil ground. It should be noted that the suspended sediment is represented by the clay and fine silt fractions of the discharge only, as the sand fractions quickly settle out of the water column and onto the bed in the immediate vicinity of the disposal ground and dredging location.

To examine variation in total suspended sediment concentration with depth through the plume, two cross-sections were taken through the plume at the dredge area and disposal site. The locations for these cross-sections are shown in Figure 27, and the 98% exceedance variation in total suspended sediment concentration with depth is shown in Figure 28. This figure shows the concentrations within the plume against depth, exceeded for 2% of the time during the model simulation. It can be seen that at the dredge location (cross-section AA), the suspended sediment concentrations are highest near the bed, while at the disposal location, the suspended sediment concentrations are more evenly distributed with depth.

Figure 35 shows the 50%, 80%, 95% and 98% exceedances of bed deposition of the clay and silt fractions calculated by the model, assuming that the density of the bed layer is 400 kg/m$^3$ (i.e. corresponding to partly consolidated mud from Table 3). These figures show the modelled extent that bed deposition of the clay and silt sediment fractions of a given thickness will reach for 50%, 20%, 5% and 2% of the time during the model simulation. As per Campaign 1, it can be seen that the greatest deposition of silt would be limited to the spoil ground and immediate dredge areas. No deposition on the reef is predicted by the model for Campaign 5, due to the distance of the proposed spoil ground from the reef and sediment stirring by wave-generated currents, which would result in re-suspension of any sediments that may be deposited on the reef.

Figure 36 shows the 50%, 80%, 95% and 98% exceedances of bed deposition of the sand fractions calculated by the model, assuming that the density of the bed layer is 400 kg/m$^3$. These figures show the modelled extent that bed deposition of the sand sediment fractions of a given thickness will reach for 50%, 20%, 5% and 2% of the time during the model simulation. It can be seen that deposition of the sand fraction is restricted completely to the spoil ground and immediate vicinity of the dredging for Campaign 5, as per Campaign 1.

Figure 37 shows the time-series plot over the month of near-surface sediment concentrations, averaged over a 500 m grid area at the various key locations shown in Figure 24. It can be seen that at the sensitive receptor sites of Pania Reef, suspended sediment concentrations remain less than 7 mg/L above background values. The maximum value of suspended sediment concentrations at Pania Reef occurred over a 24 hour period on July 8, during which time ocean currents in the vicinity of the Site 5 spoil ground were directed toward the north-west. Suspended sediment concentrations in the inner port area peaked at approximately 6 mg/L above background values, at the beginning of the dredge campaign when TSHD is being undertaken. Suspended sediment concentrations were slightly higher for Campaign 5 than for Campaign 1, particularly at the inner port area, reflecting the greater proportion of TSHD for this campaign than for Campaign 1.

## 5.5 Discussion

The following general observations are made with respect to the model results:

- The plume generated at the "Site 5" spoil ground was more extensive than that generated at the dredge site, for all scenarios tested;
- Sediment concentrations are spread relatively evenly over the vertical distance of the water column in the vicinity of the spoil disposal ground but are higher near the bed in the vicinity of the dredge area;
- The model results do not show any potential for deposition of fine silts or clays over the footprint of Pania Reef during the timeframe of the dredging campaigns based on the scenarios modelled. Sediment deposition at the reef would be limited also due to the effects of sediment re-suspension due to wave stirring, as the water depth at the reef is relatively shallow, allowing sediments to be re-suspended by wave-induced near-bed currents;
- The model results show that the suspended sediment concentrations over the Pania Reef footprint were less than 10 mg/L above background over the entire simulation period. The 98%ile Silt/clay fraction concentrations (exceeded for less than 1 day per month during the dredging campaigns) were less than 10 mg/L above background levels over the reef area throughout the simulation period;
- The sand fraction of the discharge settles quickly. Sand fraction deposition is limited to the immediate vicinity of the disposal and dredge areas;
- The highest suspended sediment concentrations above background levels are in the inner port area and at the spoil ground;
- The highest concentrations occur at the beginning of the campaigns due to TSHD dredging dominating. Lower concentrations result from backhoe dredging; and
- Prevailing currents at Site 5 are generally directed toward the south-east. However, under certain wind conditions, currents at Site 5 can be directed toward the north-west and this can result in suspended sediments from Site 5 being directed toward the Reef, albeit at concentrations below 5 mg/L over the footprint of the reef. These concentrations would be below those that would be visible to a casual observer above the surface. This was found to occur less than 2% of the time over the simulation period.

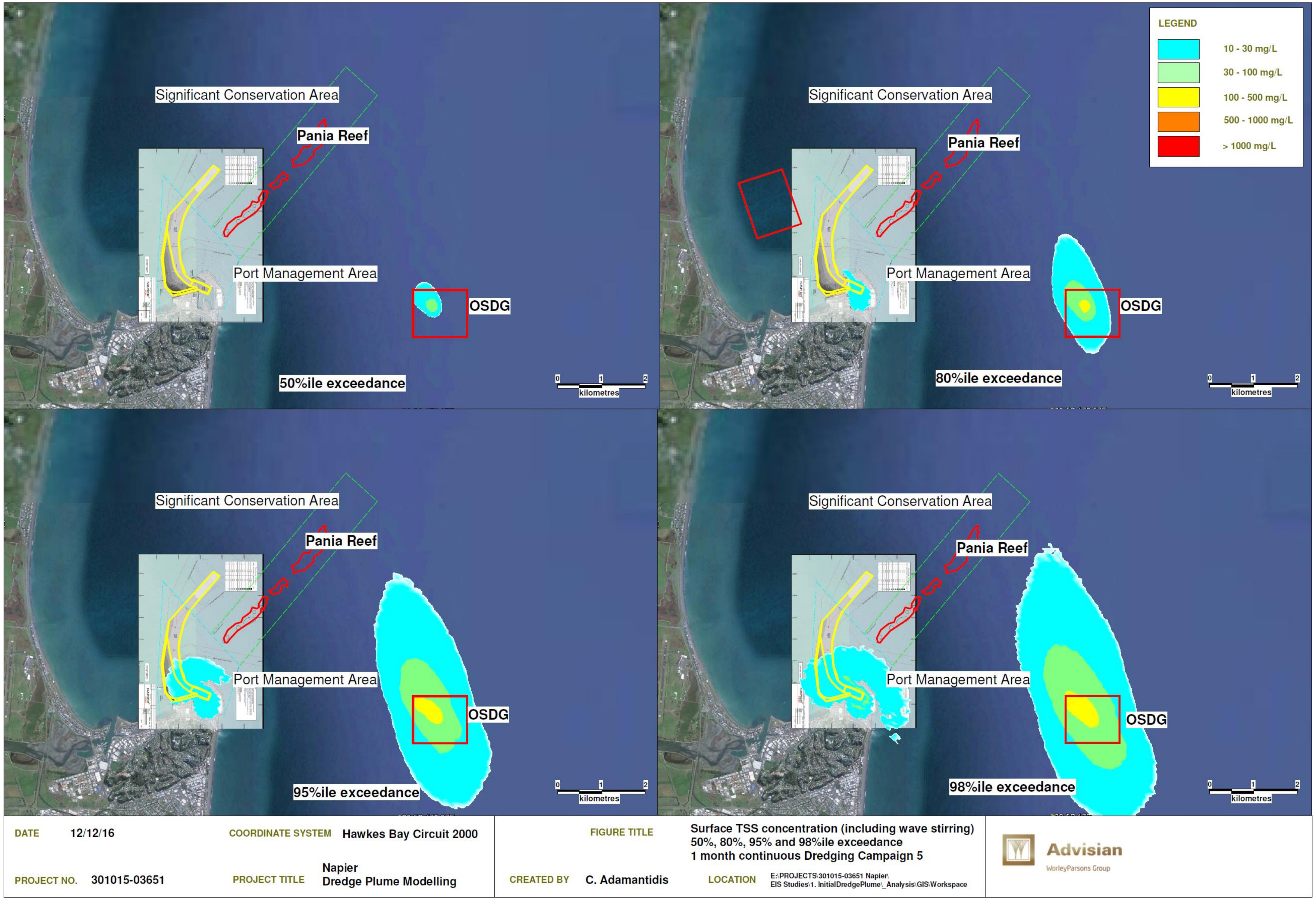



**Figure 32 – Surface TSS concentrations percentile exceedances, Campaign 5**

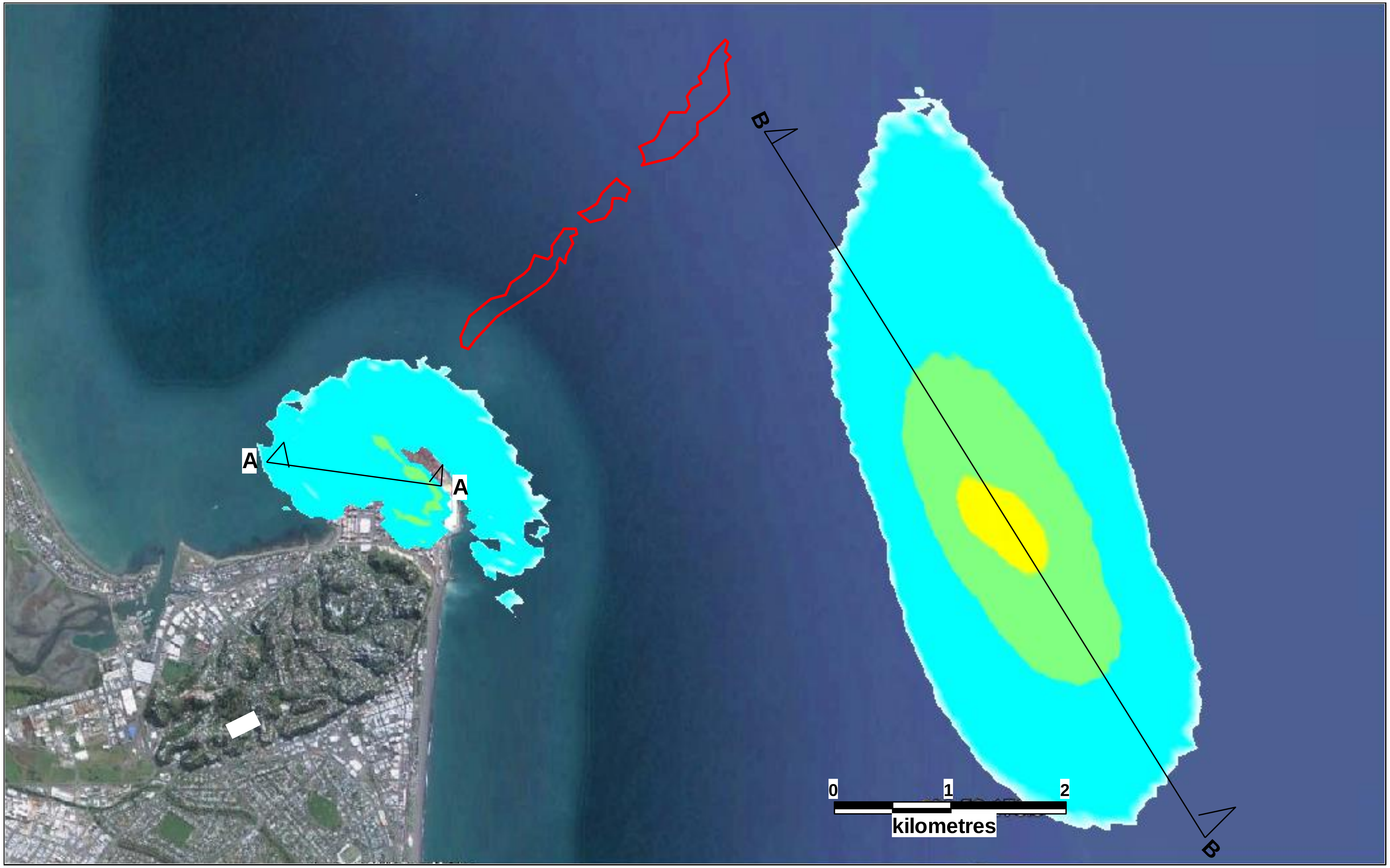



**Figure 33 – Locations for cross-sections A-A and B-B through plume, 98%ile TSS concentration exceedances, Campaign 5**

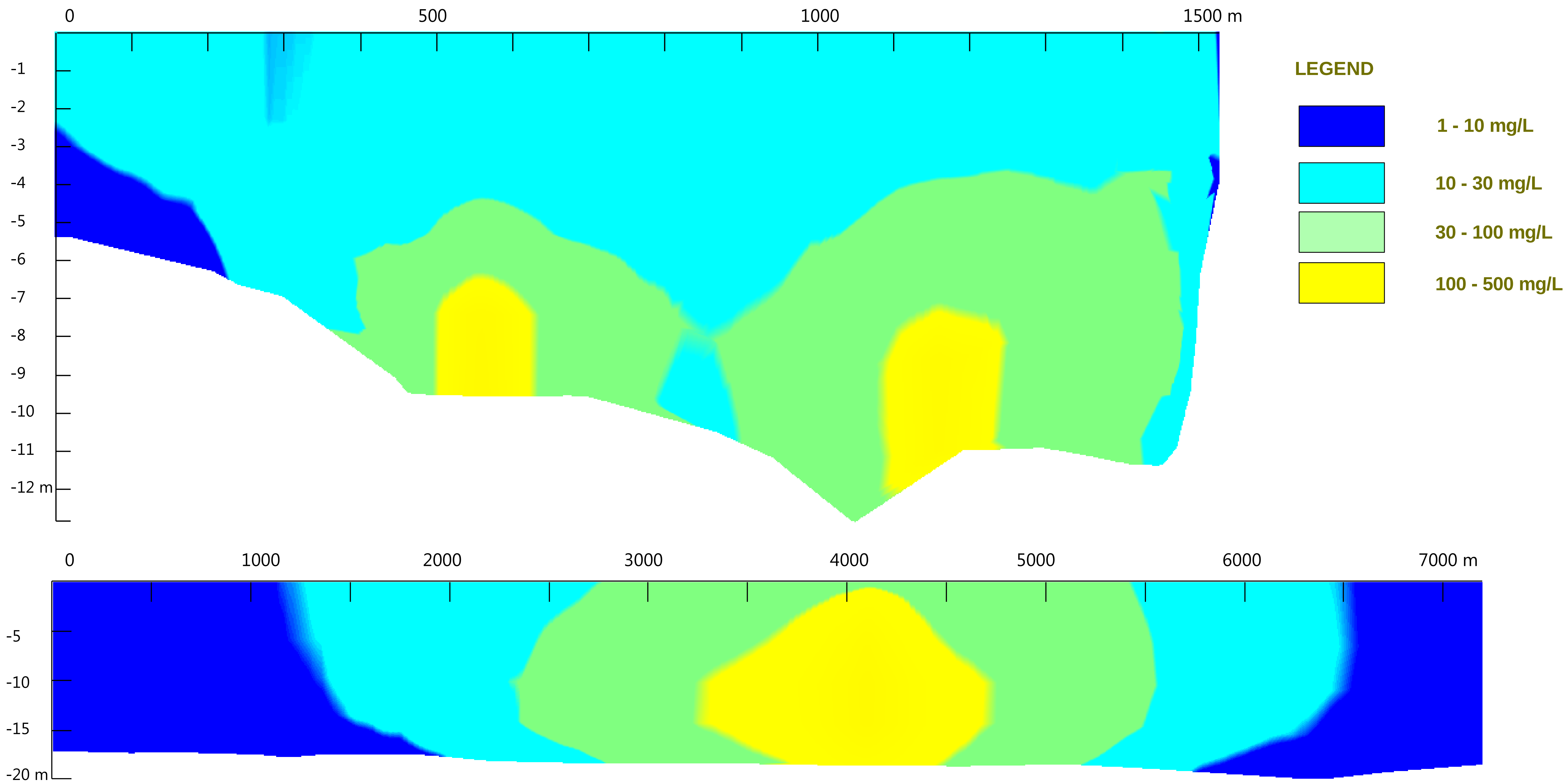
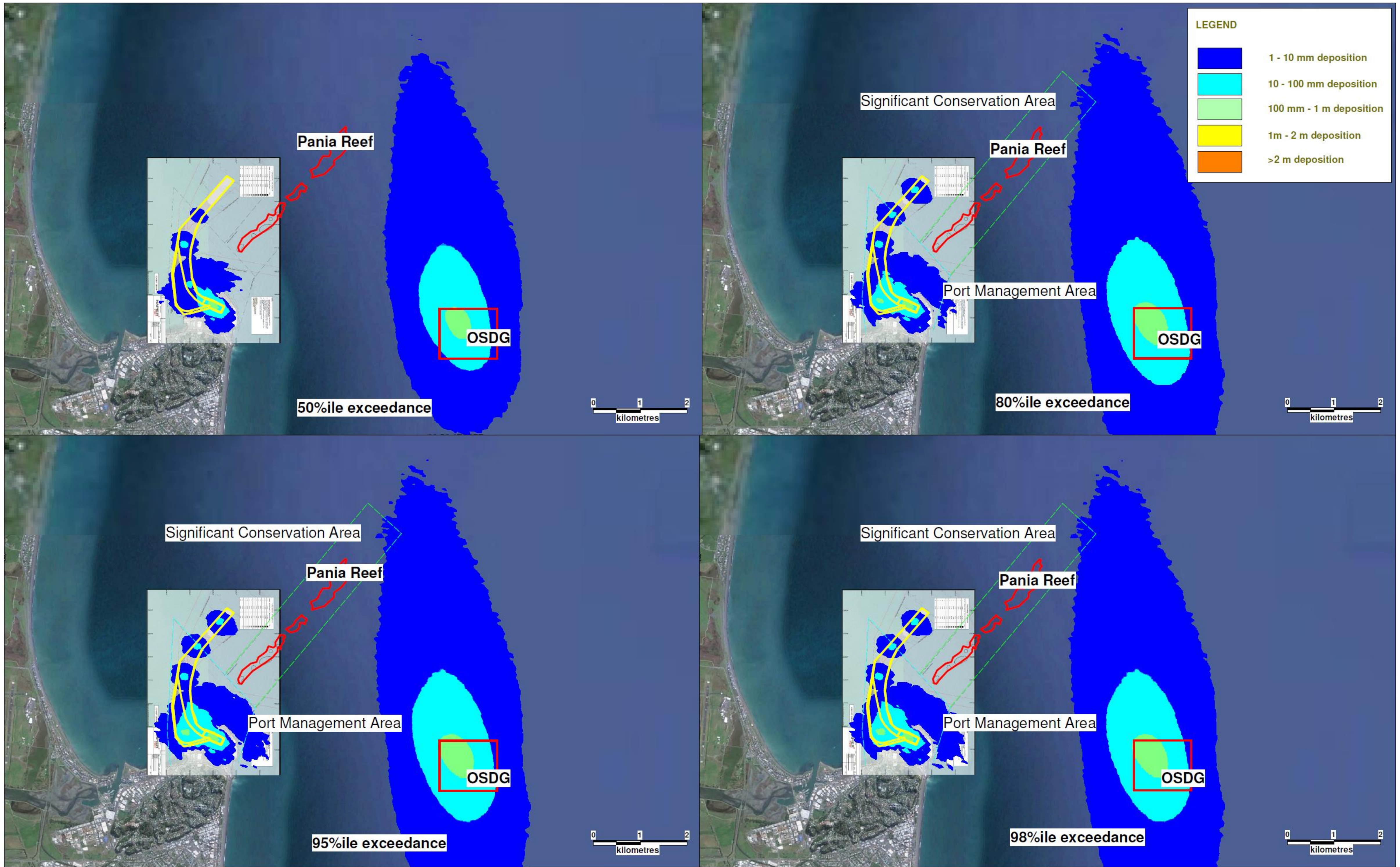



**Figure 34 – Top- Cross-section AA, Bottom: Cross section BB, 98%ile TSS concentration exceedances through plume with depth, Campaign 5 (vertical exaggeration = 1:50)**

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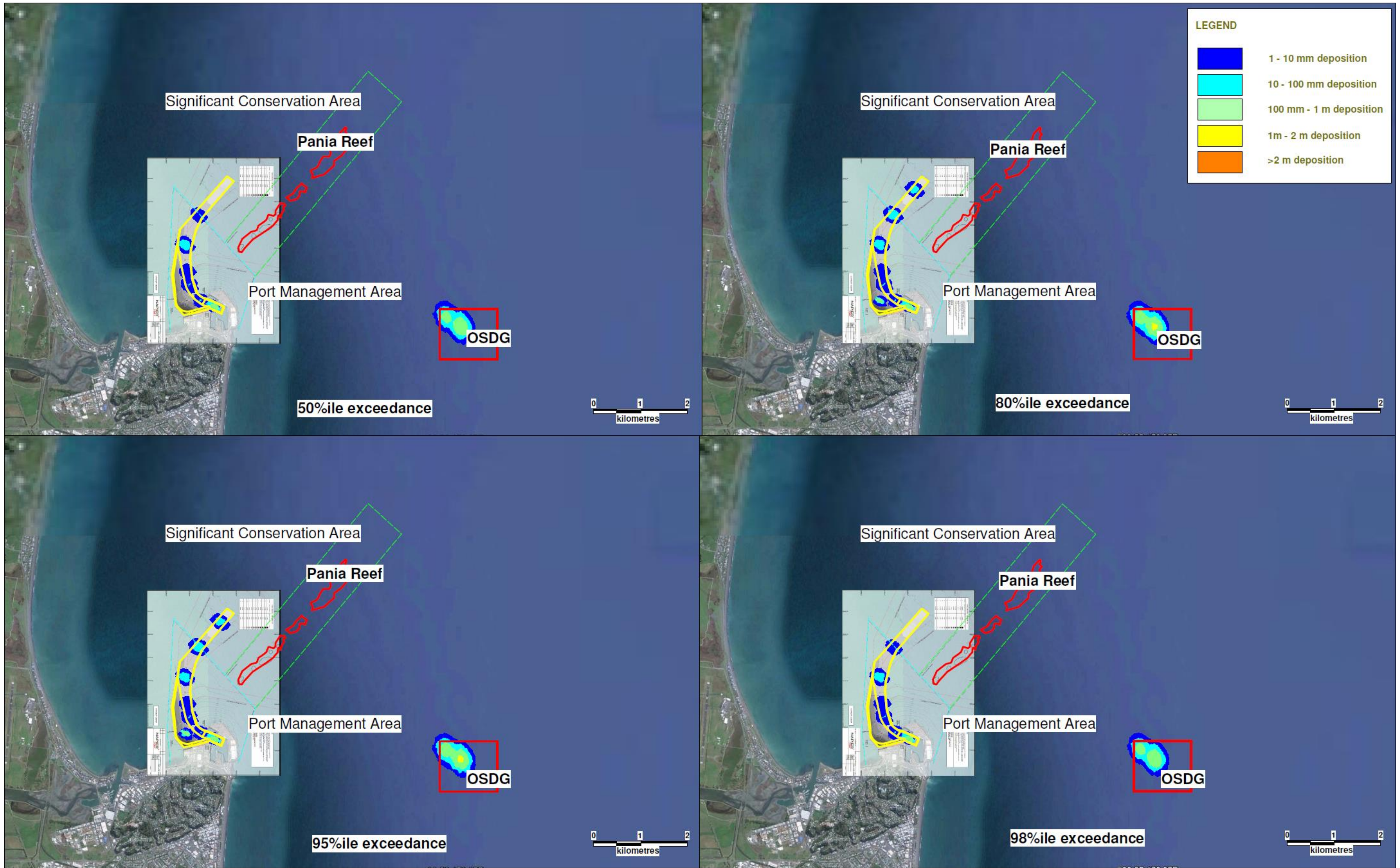
|---|---|---|---|---|---|---|
| DATE | 12/12/16 | COORDINATE SYSTEM | Hawkes Bay Circuit 2000 | FIGURE TITLE | Bed deposition, silt fraction (full wave stirring)<br>50%, 80%, 95% and 98%ile exceedance<br>1 month continuous Dredging Campaign 5 | Advisian<br>WorleyParsons Group |
| PROJECT NO. | 301015-03651 | PROJECT TITLE | Napier<br>Dredge Plume Modelling | CREATED BY | C. Adamantidis | LOCATION E:\PROJECTS\301015-03651 Napier\EIS Studies\1. InitialDredgePlume_Analysis\GIS\Workspace |

**Figure 35 – Silt deposition percentile exceedances, Campaign 5**

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| DATE | 18/12/16 | COORDINATE SYSTEM | Hawkes Bay Circuit 2000 | FIGURE TITLE | Bed deposition, sand fraction (full wave stirring)<br>50%, 80%, 95% and 98%ile exceedance<br>1 month continuous Dredging Campaign 5 | Advisian<br>WorleyParsons Group |
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**Figure 36 – Sand deposition percentile exceedances, Campaign 5**

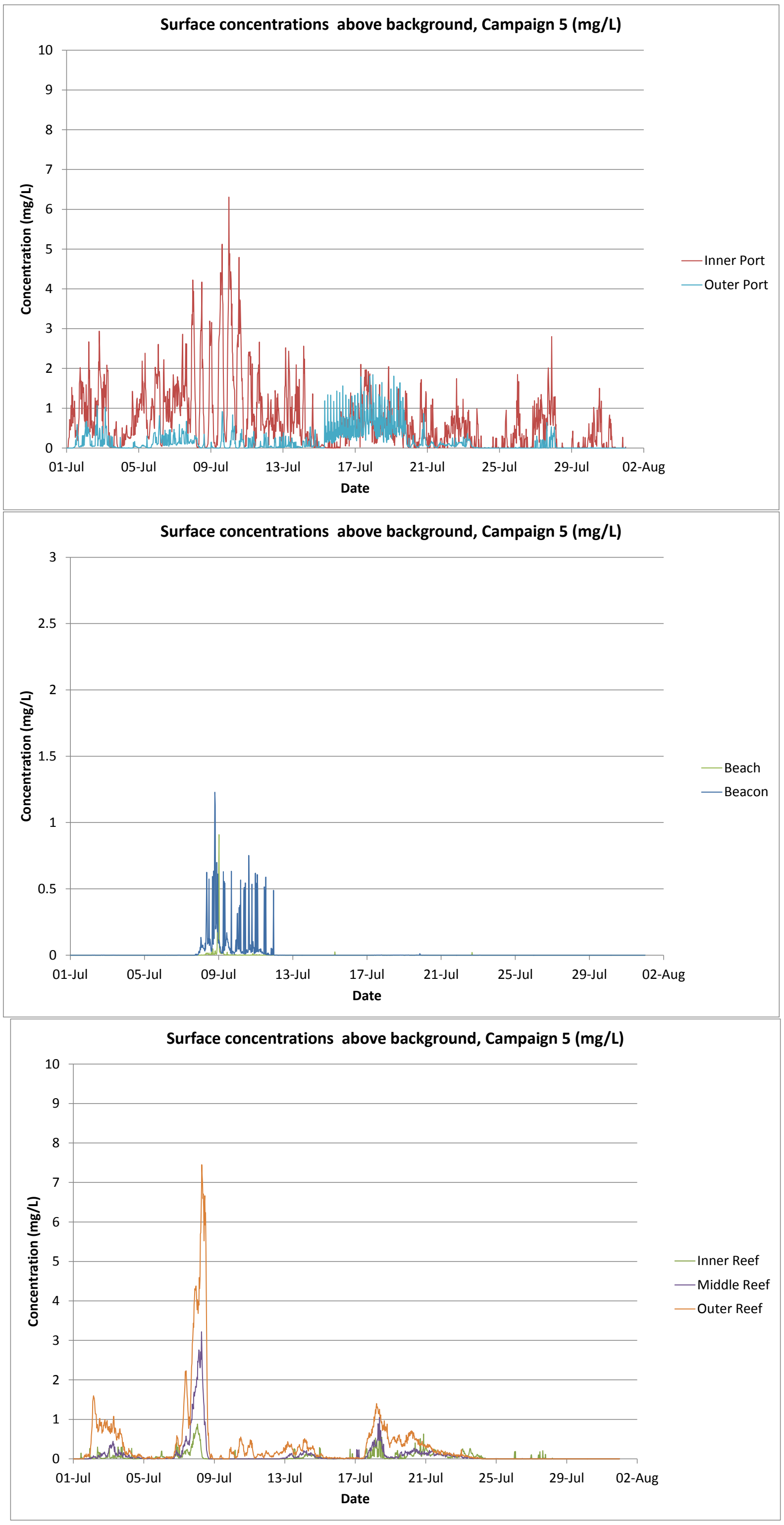


**Figure 37 – Time series of surface suspended sediment concentrations above background, Campaign 5 (Top: Inner and Outer Port, Middle: Beach and Beacon, Bottom: Inner, Middle and Outer reef). Refer to Figure 24 for spatial locations of time-series.**

# 6 Conclusion

This report has presented detailed dredge plume modelling based on a validated 3D hydrodynamic model of wind and tidal currents, coupled with a wave model and a particle tracking model to investigate the fate of suspended sediment generated from TSHD and backhoe dredging activities at the proposed Berth 6, swing basin and port navigation channel at the Napier Port.

Previous modelling carried out for dredge disposal at the "inshore" spoil ground to the west of the navigation channel found that there was a potential for dredge plumes to impact the southern tip of Pania reef, with fine sediment deposition possible, albeit limited due to the effects of sediment re-suspension due to wave stirring.

An alternative deposition site, known as "Site 5", located in deeper water to the south-east of Pania Reef, has been considered in this report. Deposition at this location was expected to result in a lower impact on Pania Reef than deposition at the "inshore" spoil ground, for the following reasons:

- Prevailing currents are generally directed toward the east, resulting in sediment plume movements from the disposal site directed offshore and away from Pania Reef;
- There is less potential for sedimentation of fine silt and clay fractions to occur at Pania Reef, due to the direction of prevailing currents at the Site 5 spoil disposal ground directing suspended sediments away from the reef;
- The location of the proposed spoil ground is in deeper water than the inshore spoil ground (approximately 20 m depth for Site 5 and 10 m depth for the inshore spoil ground). The deeper water at the proposed disposal area results in less potential for resuspension of fine sediments due to wave-induced stirring than at the inshore spoil ground, as wave-induced near bed currents would be typically very low in 20 m depth when compared to those in 10 m depth.

Near-surface suspended sediment concentrations over the footprint of Pania Reef exceeded for less than 2% of the time during the dredging campaigns were predicted to be less than 10 mg/L above background levels. Total suspended sediment concentrations above background over the footprint of Pania Reef have been shown by the model to be very low when compared with the concentrations near the centre of the plume, being less than 5 mg/L.

The model results do not show any potential for deposition of fine silts or clays over the footprint of Pania Reef during the timeframe of the dredging campaigns. Sedimentation of fine silt fractions on Pania Reef is not predicted to occur, due to the direction of prevailing currents generally directed toward the east, resulting in sediment plume movements from the disposal site directed offshore and away from Pania Reef. Sediment deposition at the reef would be limited also due to the effects of sediment re-suspension due to wave stirring, as the water depth at the reef is relatively shallow, allowing sediments to be re-suspended by wave-induced near-bed currents.

These model results have built upon and refined the previous preliminary model results, taking into account important processes such as:

- wave-stirring;
- detailed sediment properties obtained through direct measurements;
- detailed understanding of the sediment volumes, dredge campaigns, dredge methodology and dredge plant to be deployed;
- calibration and validation of the hydrodynamic model against measured current data over a range of depths;
- a range of weather conditions; and
- water quality parameter values obtained based on literature, previous WorleyParsons dredge plume modelling experience and engineering judgement.

The results are considered to be conservative, as they are based on a relatively stormy period. However, it is considered that the plume behaviour depicted in the model is representative of the full range of conditions that could be expected during the various capital dredging campaigns when compared with the results of previous investigations.

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