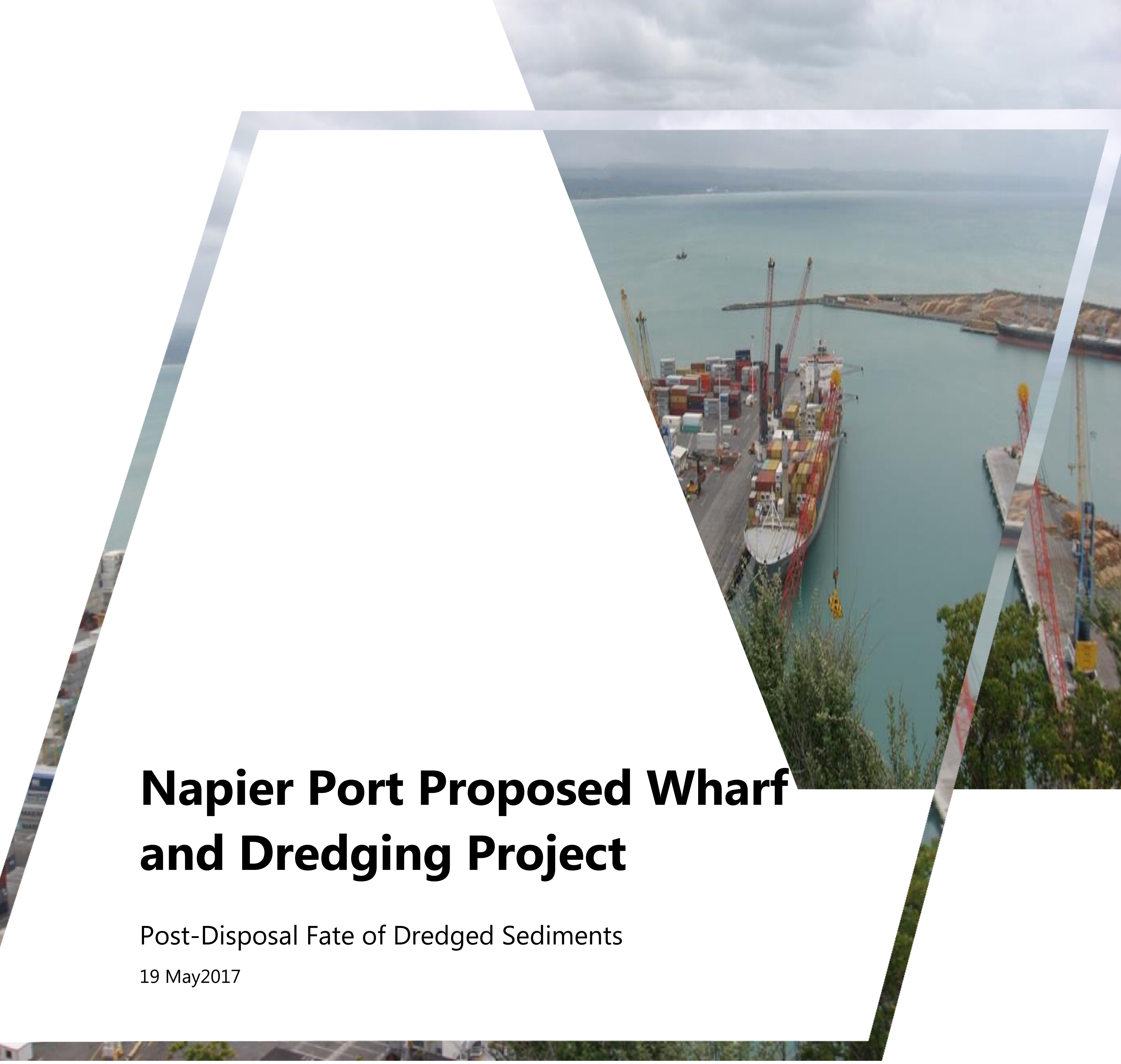
APPENDIX F

NAPIER PORT PROPOSED WHARF AND DREDGING PROJECT, POST DISPOSAL FATE OF DREDGED SEDIMENTS



Napier Port Proposed Wharf and Dredging Project

Post-Disposal Fate of Dredged Sediments

19 May2017

Level 17, 141 Walker St
North Sydney NSW 2060
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Synopsis

This report outlines the analysis of likely sediment transport pathways for dredge spoil sediments following deposition at spoil grounds located inshore and offshore of Napier Port.

Disclaimer

Project No: 301015-03651-301015-03651-CS-004 – Napier Port Proposed Wharf and Dredging Project: Post-Disposal Fate of Dredged Sediments

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Executive Summary

Advisian has been engaged by Napier Port Ltd to undertake sediment transport modelling to understand the likely fate of dredge spoil sediments after disposal ('post-disposal fate of sediments'). Sediment transport pathways involving two alternative spoil ground locations have been assessed:

- West of the Port navigation channel ('inshore disposal ground), in approximately 6 – 7 m water depth. This corresponds to the 'status quo' currently used by Napier Port for disposal of material from maintenance dredging
- East of the Port navigation channel ('offshore disposal ground'), in approximately 22 m depth. The thickness of sediment deposit at the offshore site has been assumed at 2m above ambient bed levels.

The locations of the disposal areas are shown in Figure *i*

In undertaking this work we have applied our comprehensively calibrated and validated numerical models of 3D hydrodynamics and wave processes, and state-of-the-art sediment transport algorithms by Van Rijn (2007, 2017).

The scope of work for this study has included:

- Assessing 'annual average' sediment transport (magnitude, direction) at discrete locations around the port where ADCP current meters have been deployed for periods of weeks to months by applying the wave climates in combination with measured time series of currents at the ADCP unit. A statistical description of the wave climate has been constructed at the location of the ADCP units.

- Assessing sediment transport patterns in the vicinity of Napier Port for different sediment diameters. Patterns are assessed under 'energetic' wind and wave conditions for the 6 main wind directions as measured at Napier Port.

- Assessing the potential for sediment resuspension and transport at the proposed offshore disposal ground for different sediment particle diameters. Patterns are assessed under 'energetic' wind and wave conditions for the 6 main wind directions as measured at Napier Port.

- Assessing potential impacts to wave refraction around the vicinity of Marine Parade Beach due to the location of the proposed offshore disposal ground, and associated repercussions for morphological change at the Beach.

The analysis inshore of Napier Port assesses sediment transport for 5 sand particle diameters ranging from 100 μm (very fine sand) to 500 μm (coarse sand), whereas the analysis for the offshore site considers two silt fractions (medium silt, coarse silt) as characterised by their settling velocities and three further sand fractions corresponding to very fine sand, fine sand and medium sand.

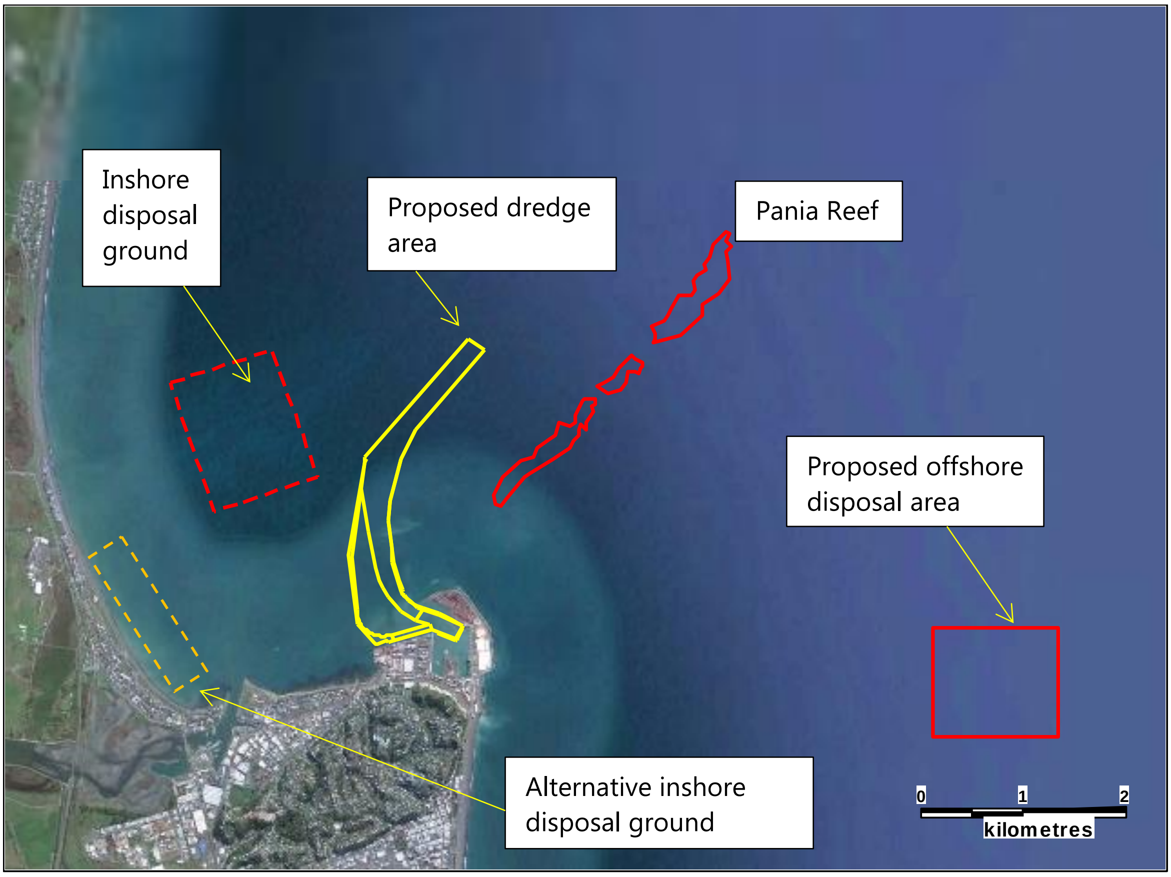

Figure *i* – Location of proposed disposal area

RESULTS

Sediment Mobility

Figure *ii* shows the percent of time per year each sediment diameter may be expected to be active as (a) bedload (including incipient motion), and as (b) suspended load. On the basis of currents measured at 'Channel Approaches'[1] and 'Beacons'[1], for water depths of 10 m and 6 m respectively.

For a sediment diameter of 125 μm (representative of approximately 70% of the particle size distribution obtained from vibrocore sediments), sediment would be expected to be mobile for approximately 11% of the year at 'Channel Approaches[1]' and 'Beacons'[1], and approximately 5% of the year at the offshore disposal site[1].

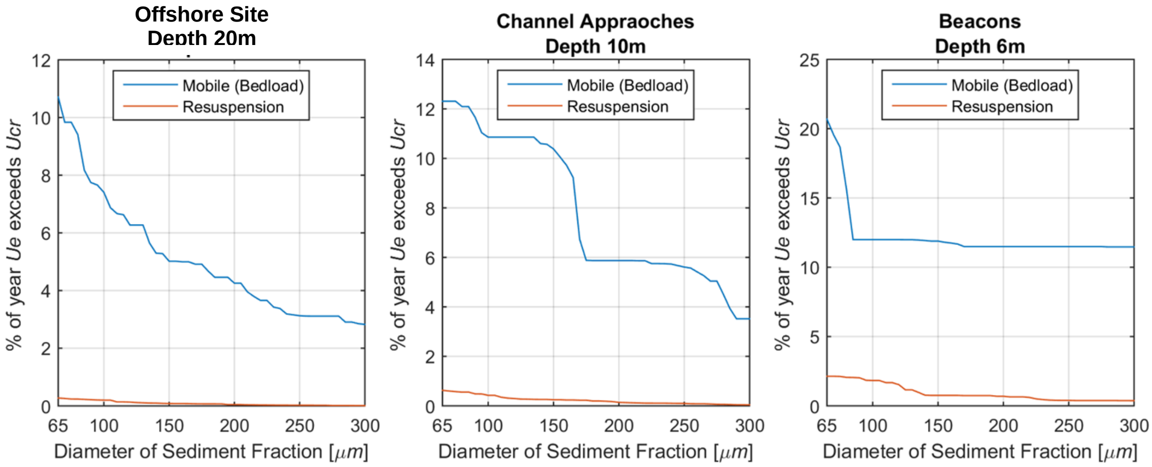

Figure *ii*: Percent of time sediment is mobile as (a) bedload (blue line) and (b) suspended load (orange line) at three instrument locations.

Sediment Transport Climates

Figure *iii* shows calculated sediment transport potential (magnitude and direction) for 125μm diameter sand (the fraction most representative of sandy spoil material). The upper two panels correspond the 'Beacons' and 'Channel Approaches' ADCP deployments, and are representative of processes occurring in the nearshore disposal areas. The lower panel is the sediment transport estimate from the proposed offshore disposal ground. A clear eastward transport is observed in the inshore areas, strongly suggesting that any spoil sediment disposed of west of Napier Port will move eastward back towards the navigation channel. At the offshore site, the transport is almost exclusively (>90% of time) southward, away from Pania Reef.

[1] *Refer Figure 2-4 in Section 2 for location of ADCP units used in sediment mobility analysis.*

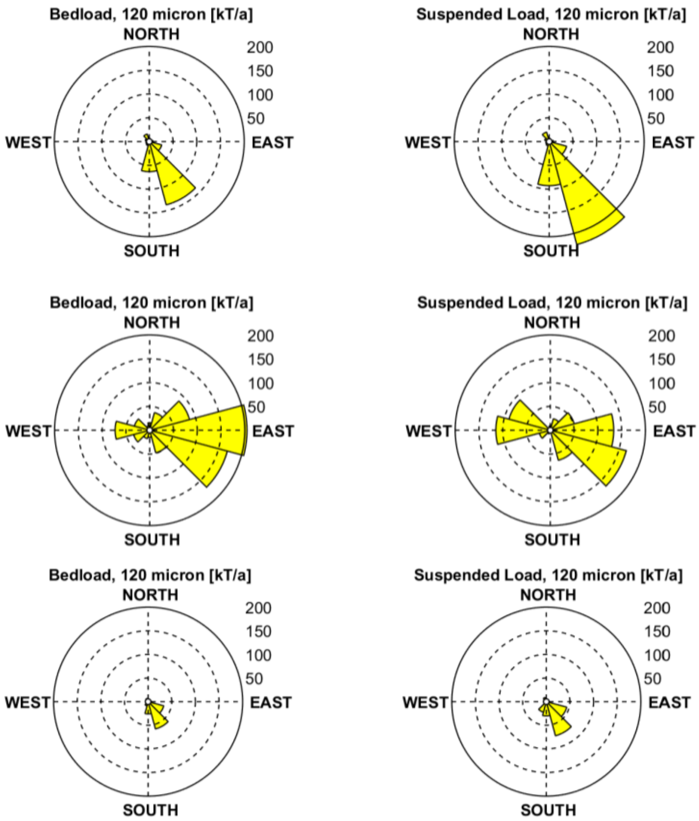

Figure *iii*:: Comparative analysis of direction and relative magnitude of fine sand transport, predicted from analysis of ADCP data at several sites around Napier Port. Upper Panel - 'Beacons', Middle Panel - 'Channel Approaches' . Lower Panel – Offshore disposal site.

Sediment Transport Patterns Around Nearshore Disposal Areas

Figure iv shows spatial patterns of sediment transport for sediment diameters found in dredge spoil material. The results corroborate the analysis of ADCP current meter data, showing a clear anti-cyclonic circulation adjacent to the navigation channel for sediment diameters finer than 200μm. Fine sediments are transported eastward by shore-parallel currents, and will deposit in either the Port navigation channel or the basin.

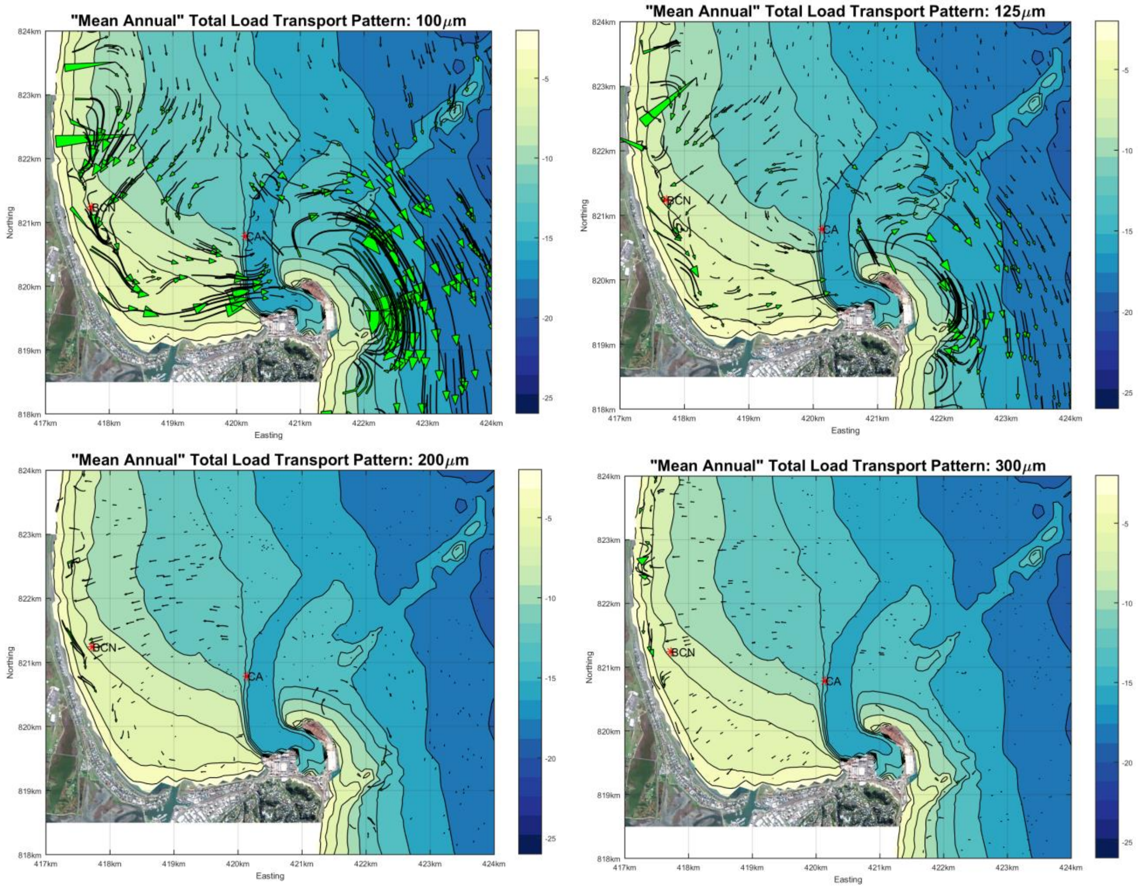

Figure iv: Sediment Transport patterns in vicinity of Napier Port for different grain sizes observed in the Particle Size Distribution of grab samples taken adjacent to the Port Navigation Channel.

Potential for Turbidity Plume Generation from the Proposed Offshore Disposal Ground During Storm Events

Although the majority of dredge spoil sediments are sandy material, there is a component of stiff clay with included silt fractions. Rather than being dispersed during spoil disposal operations this material will settle rapidly to the sea floor and consolidate over time. This therefore presents a potential source of turbidity during severe storm events. The potential for turbidity plume generation by silty material disposed of at the proposed offshore disposal site has been assessed in this study for a storm event expected to occur once every few years. The worst case results are shown in Figure *v*, and show that even for an exceptionally severe storm (recurrence interval greater than 15 years) the suspended sediment concentration over Pania Reef will not exceed 10mg/l above ambient levels.

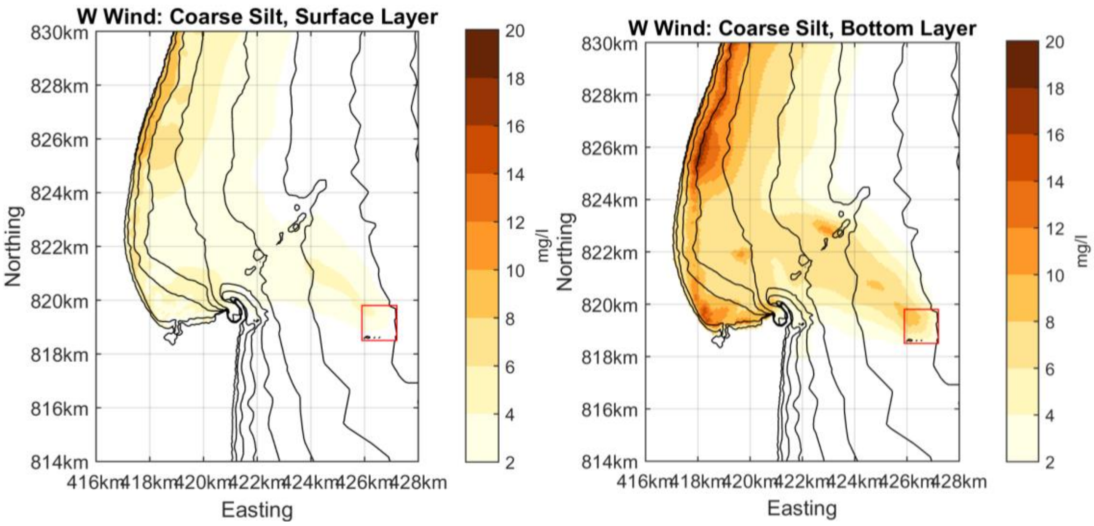

Figure *v*: Worst-case scenarios of plume generation from the proposed offshore disposal site during extremely severe storm conditions.

Impact on Marine Parade Beach

The expected change in wave refraction patterns from disposal of spoil material at the proposed offshore site is shown in Figure *vi*. The predicted change in wave height is less than 4%, and no change in wave direction is predicted in the nearshore area adjacent to Marine Parade.

As the wave direction is not modified adjacent to Marine Parade Beach, no changes are expected to its alignment. Any changes in wave height due to refraction by the proposed spoil ground are limited to 1km south of Town Reef.

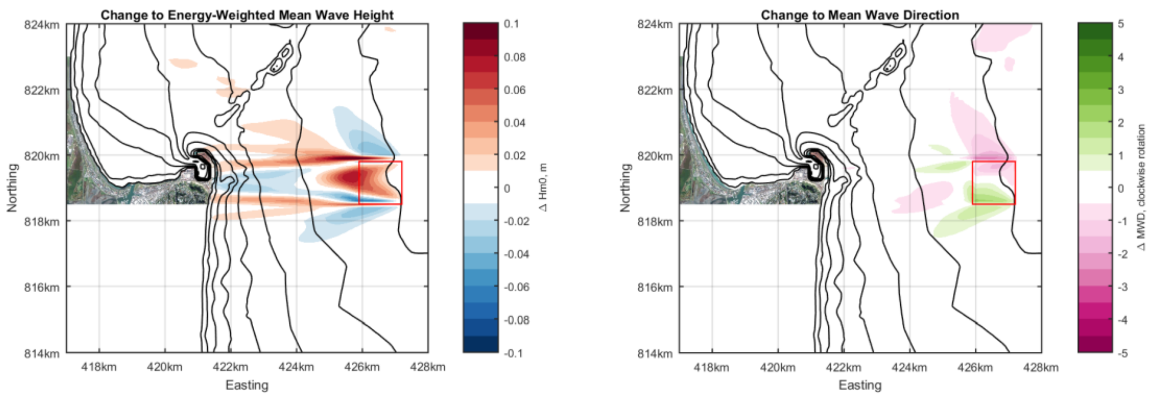

Figure *vi*: Changes to energy-weighted mean wave height and direction around Marine Parade Beach due to disposal of spoil sediments at the proposed offshore disposal ground.

1 Introduction

1.1 Background

Napier Port Ltd. proposes to undertake capital dredging to accommodate deeper draft vessels in the Port's 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 an 'inshore' and 'offshore' disposal ground. Reports outlining the results of these assessments were produced in October 2016 and January 2017 (Advisian 2016, 2017). Figure 1-1 shows the location of the disposal sites. The inshore site is located west of the Port navigation channel, in about 6 – 7 m water depth. The offshore site is located in about 20 m water depth.

This report presents detailed modelling and investigations of the expected behaviour of sediments at the inshore and offshore disposal sites after completion of dredge spoil disposal activities. That is, the potential for erosion, transport (advection[2]) and deposition of sediments after disposal. The analysis is focussed on 'annual average' sediment transport magnitudes and directions. This is considered representative of the medium to long-term fate of sediments at Napier.

The analysis is designed to answer to the following questions that will inform the consenting process currently being undertaken by Napier Port:

a) Is there potential for sandy sediments disposed of at the 'inshore' disposal ground to be reworked into the navigation channel by the action of waves and currents?
b) What is the potential for resuspension of silty and sandy sediments disposed of at the 'offshore' spoil disposal site? Is there potential for sediments resuspended at the offshore site to be transported towards Pania Reef?
c) Will placement of dredge spoil material at the offshore disposal site have morphological impact consequences to Marine Parade Beach by influencing wave refraction?

1.2 Scope of Work

Our analysis considers both 'data-driven' (empirical) and 'model driven' (numerical) approaches to answer the above questions:

Data driven (empirical) analysis of sediment transport magnitude and direction at three ADCP current meter deployments around Napier Port.

The currents measured at each location over a period of weeks to months have been used in combination with a statistical description of the wave climate to assess the magnitude and

[2] 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)..

direction of sediment transport. The analysis has assumed that current data measured at each site is representative of that expected to occur over the course of a year.

Numerical simulation of sediment transport patterns for a select number of sediment diameters, for energetic wind speeds occurring from each of the 6 main wind directions.

An energetic wave condition has been assumed with this to provide wave stirring. The sediment transport patterns have been used to provide a spatial context to the 'point' measurements and corroborate interpretation of the anticipated movements of dredge sediments in the marine environment.

Potential for disposal at the offshore site to impact morphodynamic behaviour at Marine Parade beach.

The potential for morphodynamic impact at Marine Parade Beach has been assessed through the consideration of changes to the energy-weighted mean wave height and direction.

In undertaking the numerical modelling studies we have applied calibrated and validated numerical models of 3D hydrodynamics and wave processes within Hawke Bay, and state-of-the-art sediment transport algorithms by Van Rijn (2007, 2017). The numerical models have been applied previously by Advisian for the study of spoil disposal plumes at the 'inshore' and 'offshore' disposal sites.

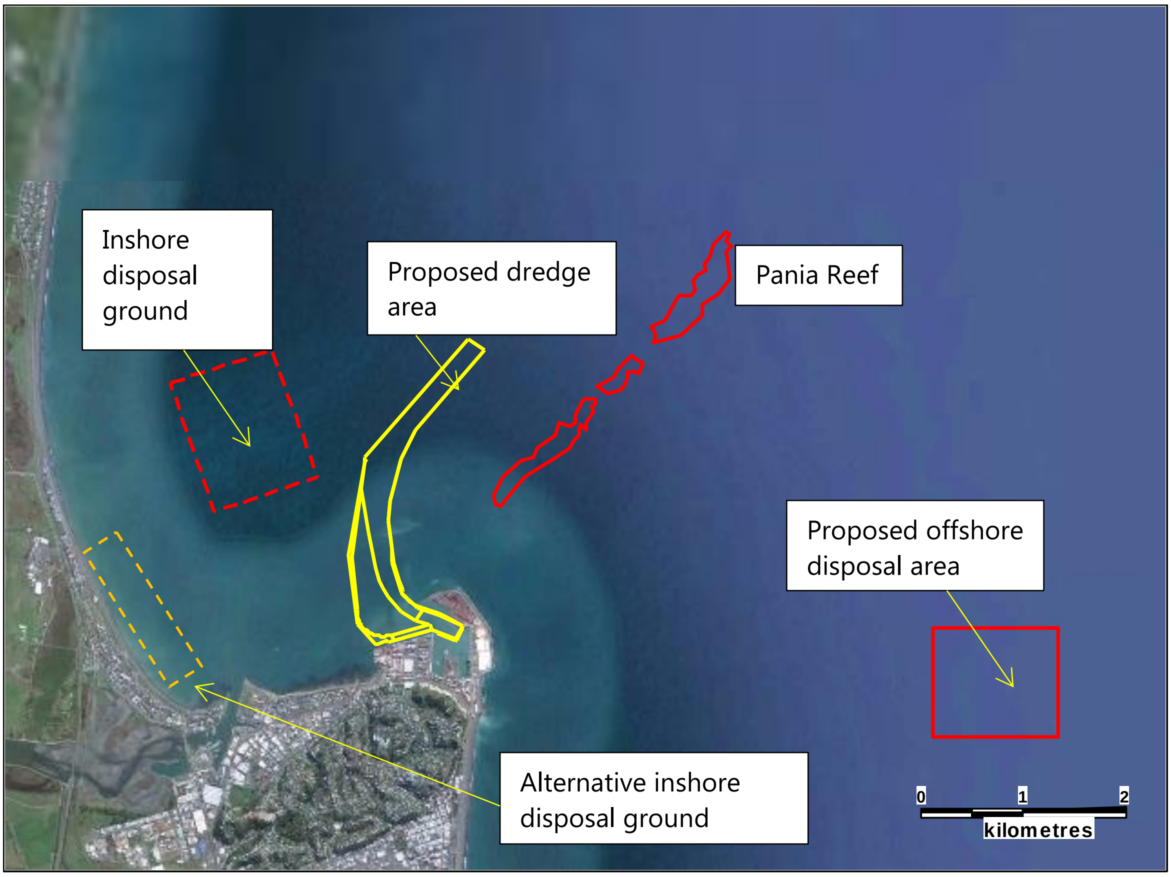

Figure 1-1 – Location of 'inshore' and offshore disposal grounds.

2 Available Data

2.1 Bathymetry

Bathymetry for the Hawkes Bay and Napier are provided from the following sources:

- Beach profile data has been obtained from Hawke's Bay Regional Council along Westshore and North Beach. The profiles were measured between December 2015 and January 2016.
- Topographic survey data was collected at Port Beach and along Hardinge Road in March 2016. The data extended seaward from the crest of the revetment to a level of 0 m Chart Datum[3].
- Detailed 'single beam survey' soundings in the vicinity of Napier Port and navigation channel approaches by Napier Port Ltd in 2011, 2013, 2014 and 2015.
- Detailed 'single beam survey' soundings in the vicinity for the sea floor fronting Hardinge Road and Ahuriri Inlet in February 2016. Single-beam survey data was obtained by Port of Napier in 2015 for the current inshore disposal area adjacent to Westshore beach.
- Bathymetric information for the wider area of Hawke Bay was taken from New Zealand hydrographic survey charts NZ 5512, NZ 561, and NZ 56.

Figure 2-1 illustrates the above data, which has been compiled and used to construct the model bathymetry as detailed in Section 3. The data have been reduced to depths relative to Chart Datum. Horizontal positions are given to NZGD2000, HawkesBay2000 circuit.

[3] Chart Datum is the plane below which all depths are published on a navigational chart. By international agreement, Chart Datum us defined as a level so low that the tide will not frequently fall below it. At most locations this level is normally approximately the Lowest Astronomical Tide. Chart Datum is shown on charts as the zero metre contour.

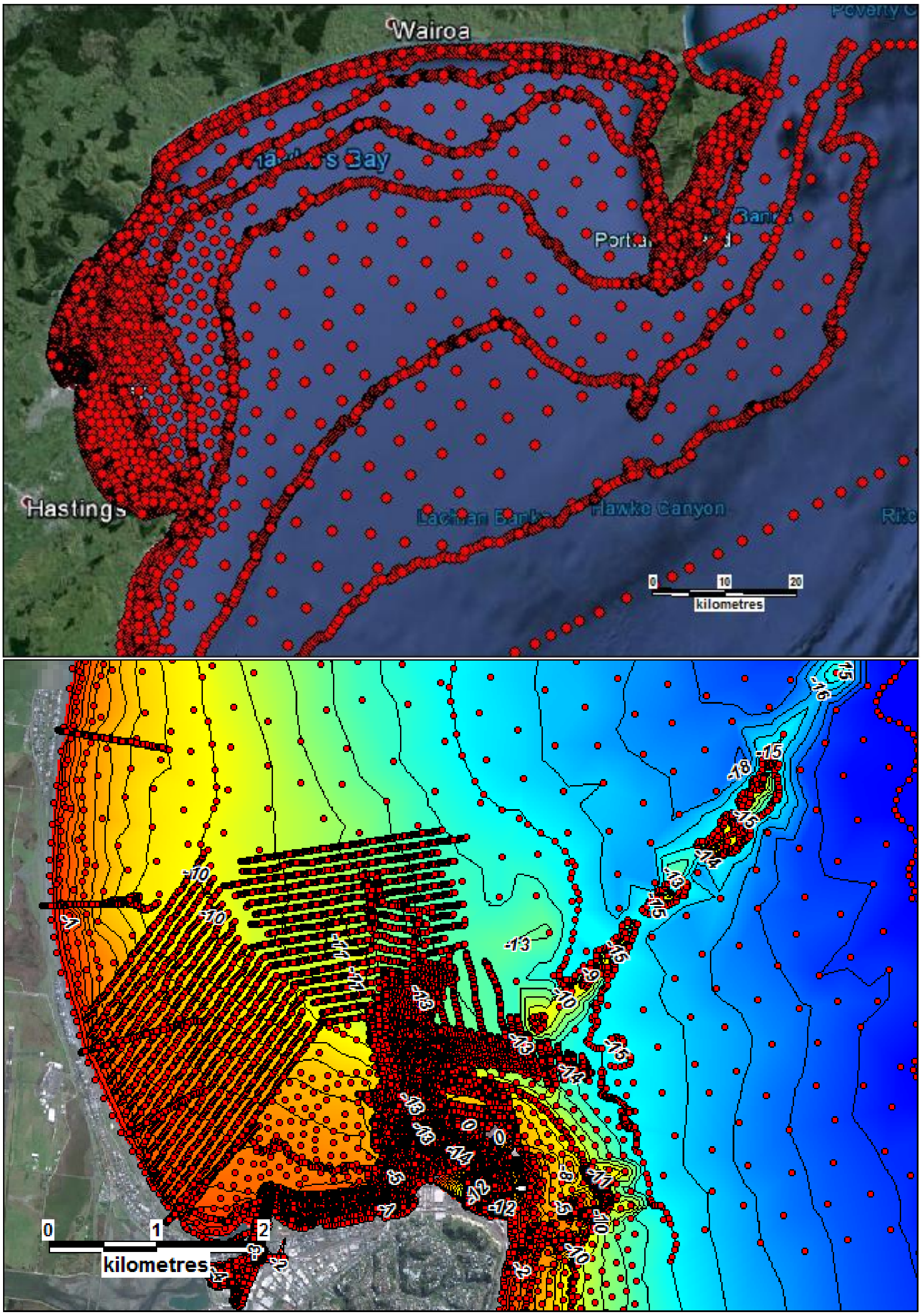

Figure 2-1 – Model bathymetry. Top: Bathymetric within Hawke Bay. Bottom: detail bathymetric data in the vicinity of the Port

2.2 Wind

Anemometer data has been collected by Napier Port Ltd since 2004 at a level of 10.3 m above Napier Mean High Water Springs. The anemometer is located on the harbour breakwater.

Analysis of 1-minute average wind speeds (Figure 2-2) shows wind most frequently occurs from the south-west and west. Analysis of seasonal data reveals a clear pattern in the wind directions and speeds. Between May and August winds most frequently occur from the south-west, but also commonly from the west, north-west and north-east. Between September and March the distribution of winds are more even, occurring reasonably equally from north-east to south-east, and from south-west to north-west.

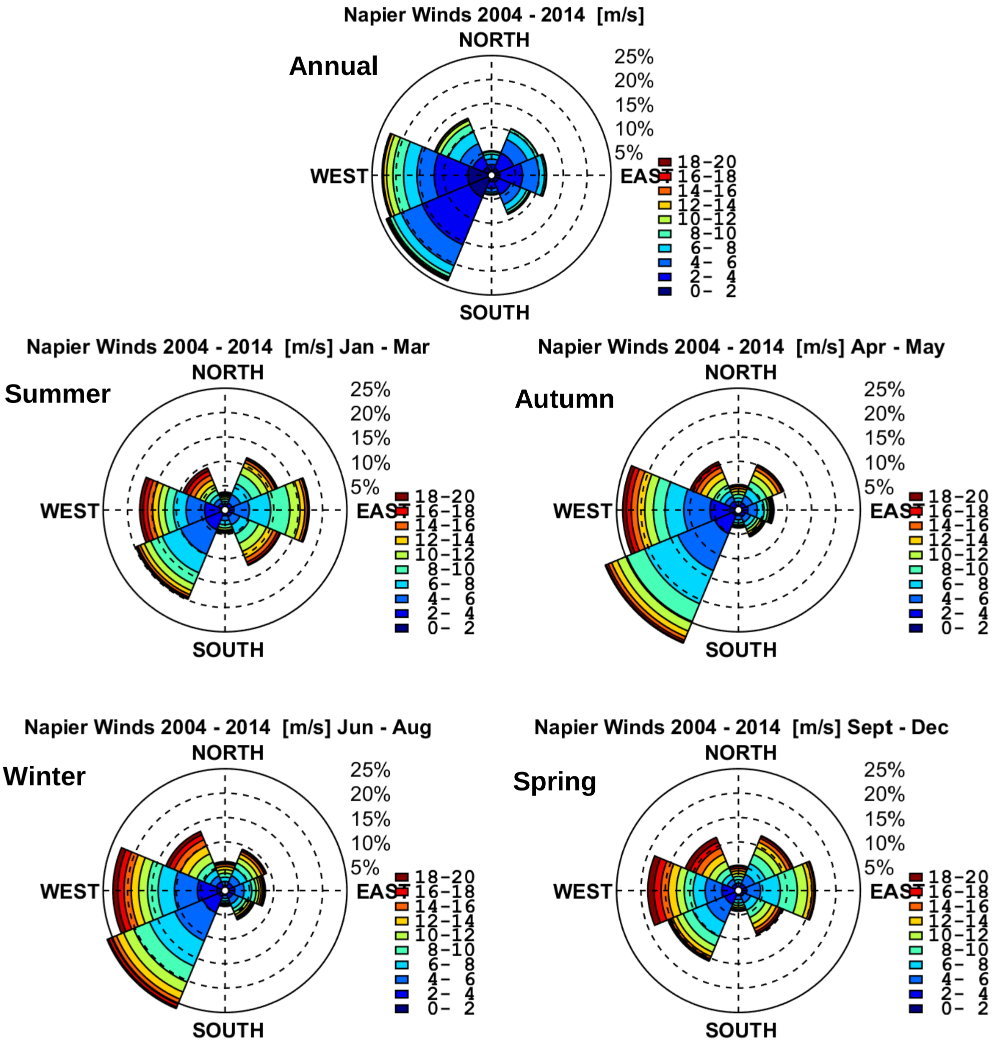

Figure 2-2: Rose plots of 1-minute average wind speed measured at Napier Port. Directions shown as 'coming from'.

2.3 Waves

Port of Napier Ltd has operated a series of Triaxis wave buoys measuring swell waves incident to the navigation channel adjacent to Pannier Reef since 2004. Additional wave data has been collected by Port of Napier since April 2016 for the purposes of verifying the performance of wave models. Figure 2-3 shows the location of each of the instruments. Table 2-1 summarises the instrument type, wave parameters measured and data coverage period.

Table 2-1: Locations of wave gauges

Location	Instrument type	Position	Parameters	Period
Offshore	Triaxis buoy	39.457690° S, 176.934442° E	Swell wave height, period, direction	2004 to Present
Channel Approaches	Triaxis buoy	39.463400° S, 176.907713° E	Swell wave height, period, direction	May – September 2016
Beacons	RBR Solo (pressure transducer)	39.459333° S, 176.879575° E	Swell wave height, period	April – September 2016
East Pier	RBR Solo (pressure transducer)	39.475750° S, 176.897098° E	Swell wave height, period	April – September 2016
Hardinge Road	RBR Solo (pressure transducer)	39.476017° S, 176.905400° E	Swell wave height, period	April – September 2016

Figure 2-3: Locations of wave gauges used in calibration and validation of wave model. 'Offshore' corresponds to Triaxis wave buoy used as boundary conditions for the wave model.

2.4 Tidal Elevations

The maximum tidal range at Napier is less than 2.0 m, which is generally classified as 'microtidal' (Davies, 1964). Spring and neap tidal ranges are 1.9 m and 1.2 m, respectively. Analysis of monthly-mean water levels from tide gauge data spanning 1999 – 2010 (Komar & Harris, 2014) shows that the highest water levels occur during the winter months of roughly March to June, with a marked decline in to summer, reaching a low in September. The maximum difference between the seasonal mean water levels is 0.1 m.

Tidal elevations at Napier have been described using astronomical constituents derived from high-resolution satellite altimeter data. Elevations are calculated from eight primary (M2, S2, N2, K2, K1, O1, P1, Q1), two long period (Mf, Mm) and three non-linear (M4, MS4, MN4) harmonic constituents. Further details are given in Section 3.2.2.

2.5 Currents

Currents have been measured via ADCP at three locations around Napier Port. The locations and deployment dates are given in Table 2-2. The instruments were configured to record burst-averaged currents at approximately 30 minute intervals. The vertical bin size was 1m. Wave roses of the ADCP measurements are shown in Figure 2-4 and Figure 2-5.

Table 2-2: Summary details of ADCP deployments

Location	Instrument type	Water depth	Deployment Dates	Analysis Dates
Proposed Offshore Disposal Site	ADCP	20m	9th December to present	9th December 2016 to 16th January 2017
Channel Approaches	ADCP	10m	April to December 2016	June to December 2016
Beacons	ADCP	6m	May to August 2016	May to August 2016

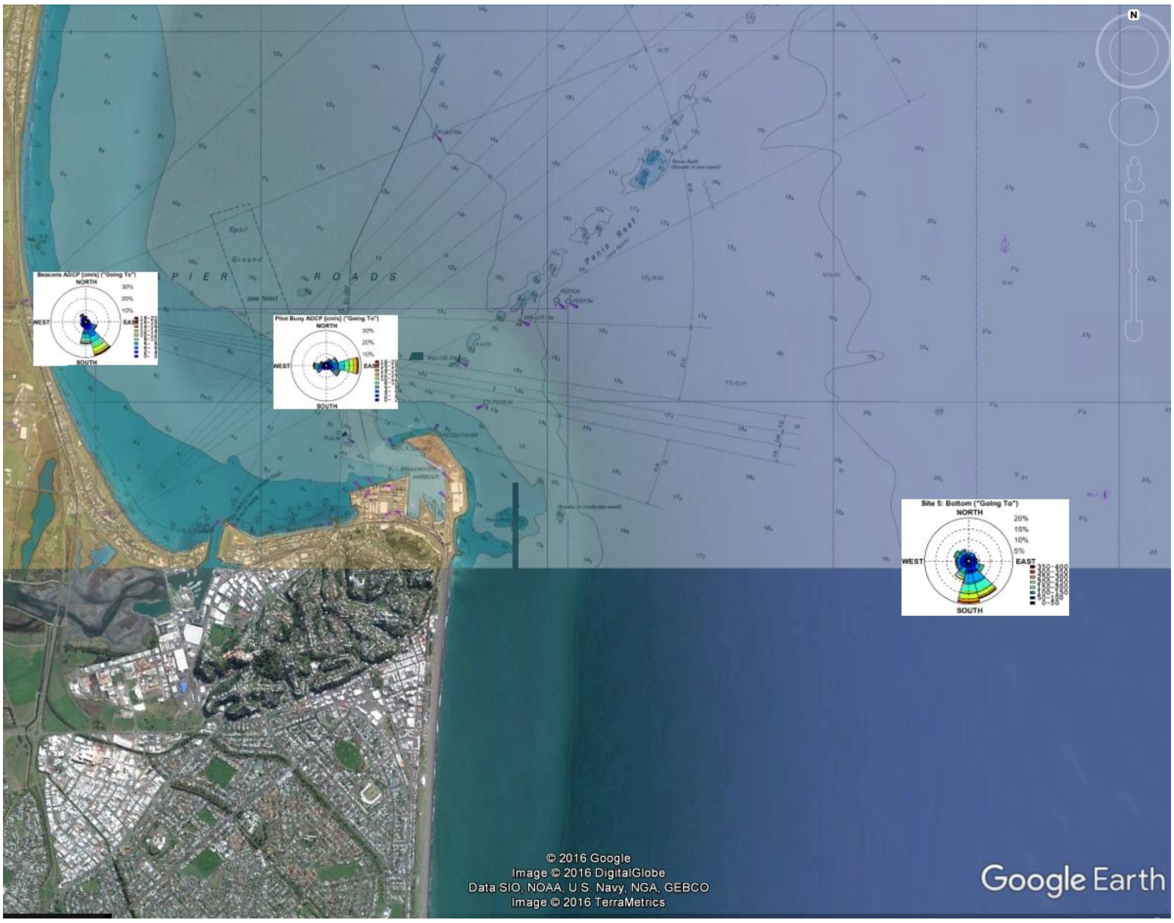

Figure 2-4: Measured current speed and direction at ADCP sites 'Beacons', 'Channel Approaches', and proposed offshore site. Directions given as 'going to'.

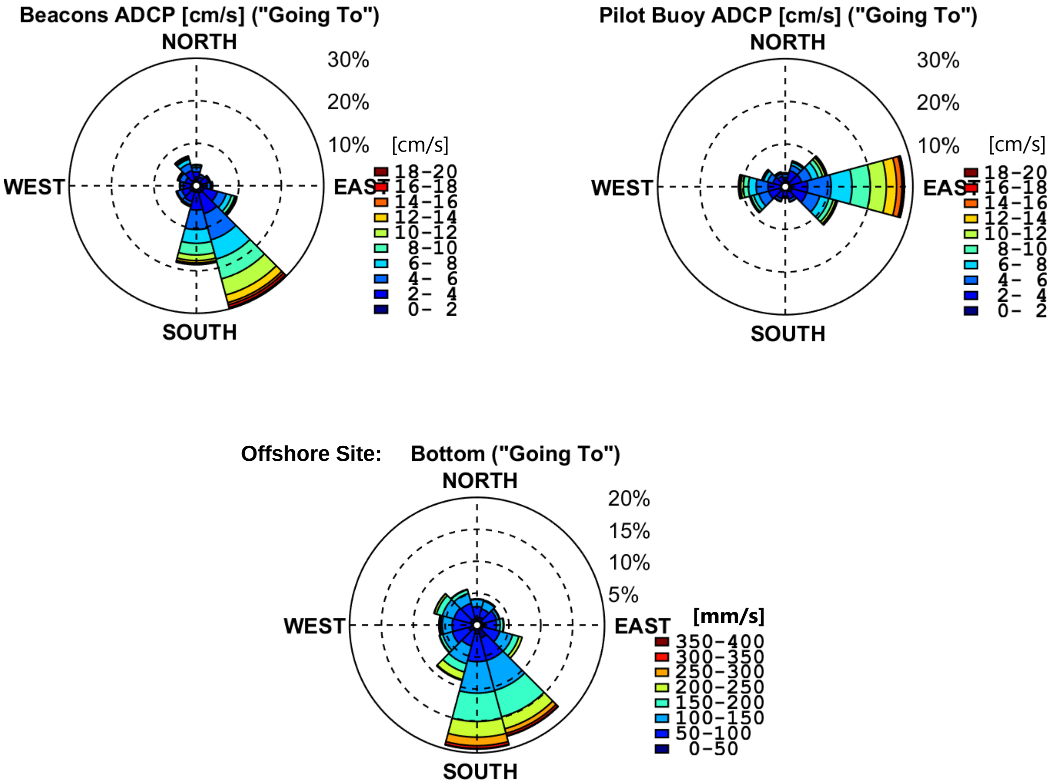

Figure 2-5: Detail of ADCP measurements taken inshore locations 'Beacons', 'Channel Approaches' and 'Proposed Offshore Site', respectively.

3 Delft3D Model Description

3.1 Introduction

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.

Wave processes are simulated by running the Delft-3D Wave model, SWAN. SWAN is a 3rd Generation phase-averaged spectral wave model incorporating most of the key physical processes occurring in the coastal zone including generation by wind; refraction and shoaling over a bottom of variable depth and/or a spatially varying ambient current; dissipation by whitecapping, bottom friction and depth-induced breaking, and (to some extent) nonlinear wave-wave interactions.

Wave-induced currents are calculated by coupling Delft3D WAVE with Delft3D FLOW to calculate wave setup and set-down, undertow, near bed current velocities, and near bed shear-stresses induced by the combination of wave dissipation and wave-induced currents. These quantities in turn are used by the sediment transport module and hence the potential for dredge spoil sediments within the potential disposal areas to be re-mobilised or re-suspended under wave and current action.

Transport of non-cohesive sediments are simulated in the model using the TRANSPOOR2004 sediment transport algorithm (Van Rijn, 2007[a,b,c]), which represents the state-of-the-art in sediment transport algorithms and knowledge of sediment transport processes.

3.2 Model Setup

3.2.1 FLOW model Grid and Bathymetry

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 (Section 3.2.1.1). In the vicinity of the port and navigation channel, the grid resolution is approximately 50 m. The extent of the curvilinear grid used for the modelling is illustrated in Figure 3-1. A detailed view of the computational grid in the vicinity of the Port is shown in Figure 3-2, which also sketches the outlines of Pania Reef, the proposed offshore spoil disposal ground, existing inshore spoil disposal area, the port navigation channel and proposed Wharf 6

The model bathymetry was derived from a combination of detailed bathymetric sounding data in the vicinity of Napier Port, Hardinge Road, Ahuriri Inlet and Westshore beach, and Admiralty Chart NZ5612. The bathymetric and topographic survey data used to construct the model bathymetry is discussed in Section 2.1.

Figure 3-1 – Extent of Delft3D FLOW curvilinear computational model mesh, and illustrating location of study area

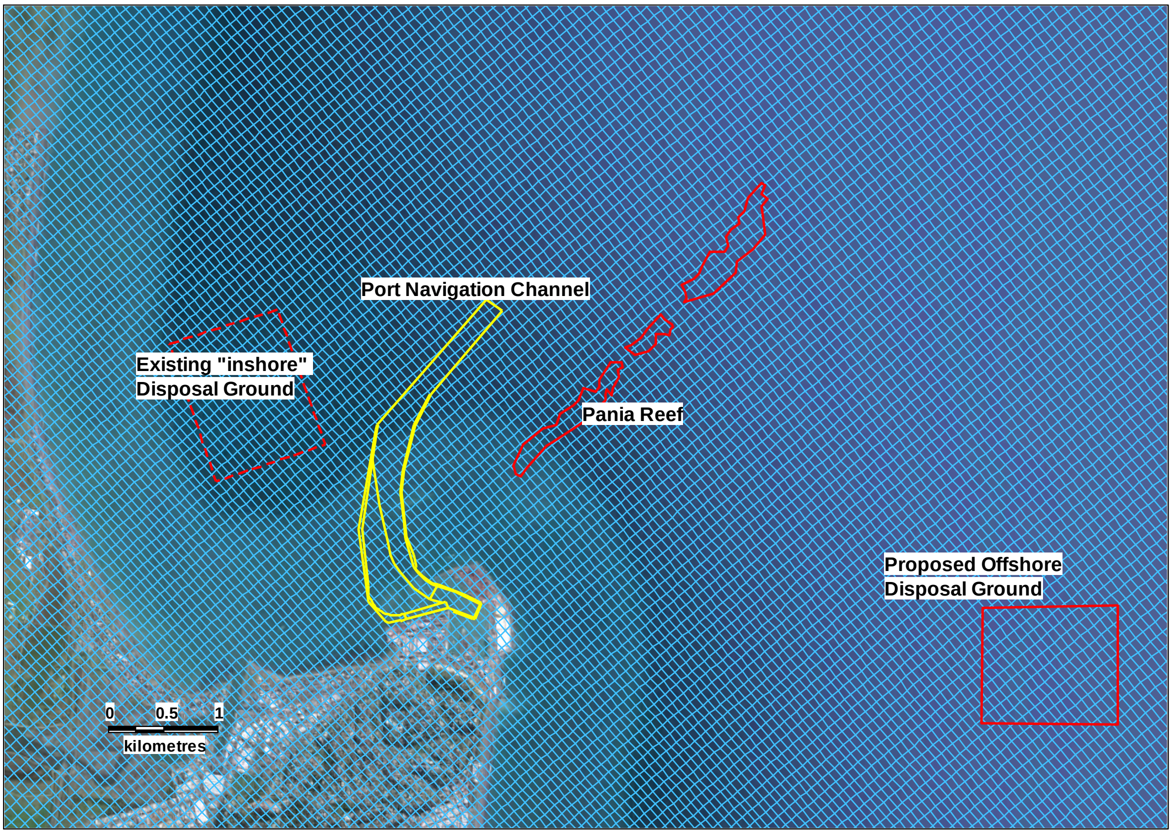

Figure 3-2 – Detail view of FLOW model computational mesh, port navigation channel, proposed dredge areas, proposed offshore spoil disposal ground, and Pania Reef

3.2.1.1 3D (sigma) layers

For the 3D simulations considered in this study, the vertical grid is defined following the σ−co-ordinate approach[4]. That is, the model is split into a number of layers that are defined as a constant percentage of water depth. An illustration of this concept is provided in Figure 3-3. For this study, five layers have been used in the hydrodynamic model, prescribed at a uniform 20% of ambient depth, with a sixth "bed layer" describing sedimentation and resuspension.

[4] *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.*

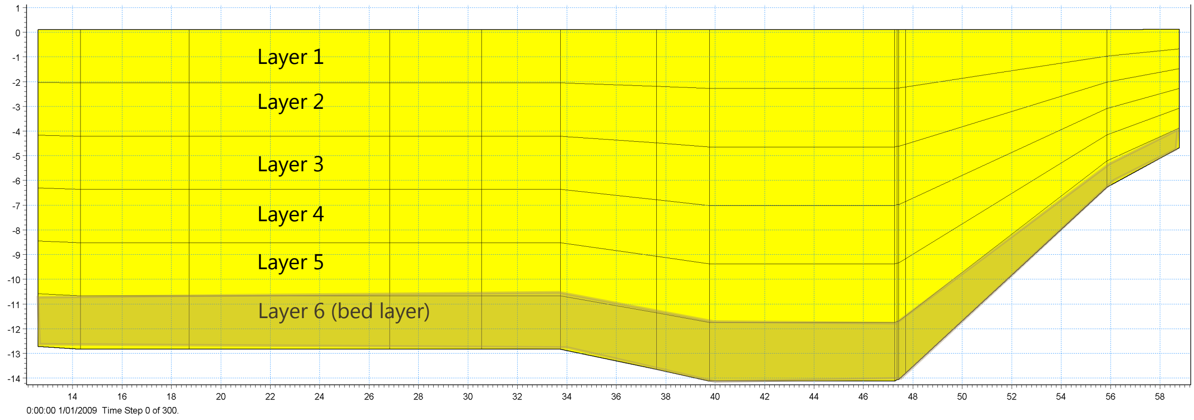

Figure 3-3 – Illustration of vertical σ–layer approach with 6 vertical layers

3.2.2 Tidal Forcing

Tidal boundary conditions were forced by tidal elevations derived from a Global Inverse Tide re-analysis 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.

3.2.3 Wind Forcing

Ten years of wind data at Napier Port was analysed to determine storm wind speeds and variation with incident direction. For the purpose of this analysis, the hourly-averaged wind speed not exceeded for more than 24 hours per year was selected to drive the 3D hydrodynamic model. The application of this wind speed is justified on the basis that:

(a) It provides sufficient energy to 'spin up' the water column in a practical amount of time for numerical computation.

(b) Once suspended, sediments are transported in the direction of currents in the overlying water column. As the carrying-capacity of a current typically is proportional to the cube of its speed (u^3), patterns of net and gross transport are typically dictated by current patterns under energetic conditions rather than quiescent conditions.

Table 3-1 shows the number of days per year the 24-hour storm wind speed is exceed for a total of 12 hours or more. Although it is rare that such wind speeds would blow continuously for 24 hours, the 'spin-up' time of the water column typically is less than this. Sensitivity analysis with the calibrated FLOW model suggests that, for the wind speeds considered, the water column around

Napier Port will achieve equilibrium current speed in approximately 12 hours. Therefore Table 3-1 gives an indication of how often the simulated conditions might be expected to occur.

The storm wind speeds applied in Delft3D are shown in Table 3-2. Note that the highest wind speeds occur from the west, north-west, east and south-east. This compares with relatively low storm wind speeds occurring from the south-west, even though this is the most frequently occurring direction (Figure 2-2).

Table 3-1: Analysis of 1-minute wind speeds, averaged to hourly intervals.

Sector	N	NE	E	SE	S	SW	W	NW
Hourly-averaged Speed (m/s)	12.5	10.4	12.3	12.6	11.1	11.4	15.8	15.2
Year	Number of days per year wind speed is exceeded for 12 hours or more							
2004	0	6	0	0	0	5	11	4
2005	0	3	2	3	0	2	3	2
2006	0	2	1	1	0	5	11	7
2007	0	2	2	2	0	0	16	5
2008	0	6	2	1	0	1	5	6
2009	0	4	0	1	0	1	7	1
2010	0	5	0	1	1	3	3	3
2011	2	10	0	1	1	15	2	0
2012	4	2	4	4	0	11	12	3
2013	4	3	2	1	0	7	3	4
2014	2	5	6	1	0	18	10	5

Table 3-2 – Storm wind speeds at Napier applied in the 3D hydrodynamic model

Wind direction	Wind speed (m/s)
North-East	10.4
East	12.3
South-East	12.6
South-West	11.4
West	15.8
North-West	15.2

3.2.4 Wave Forcing

The WAVE model grid is illustrated in Figure 3-4 with a detail view in Figure 3-5. Wave height, period and direction measured at the 'offshore' Triaxis buoy maintained by Napier Port (Figure 2-3) 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 sediments to be moved as bedload or re-suspended.

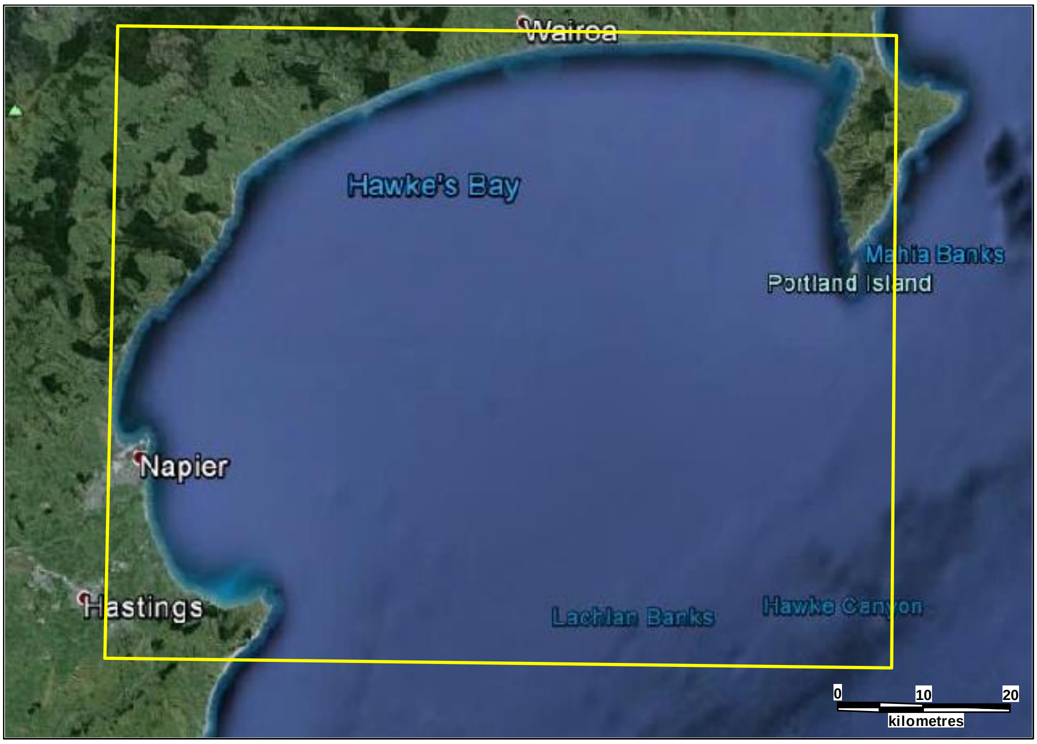

Figure 3-4 – Extent of rectilinear WAVE model grid

A description of the calibrated wave model is given in Section 3.3.2.

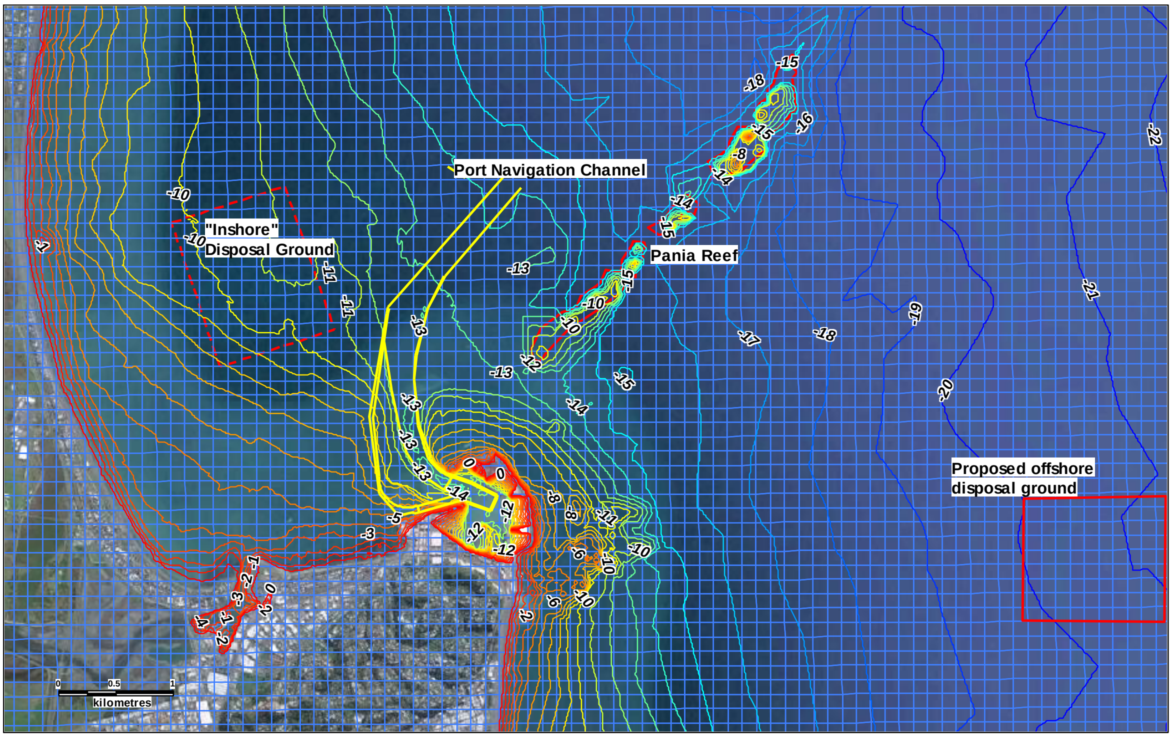

Figure 3-5 – Detail view of WAVE model grid, superimposed with existing bathymetry contours. Outline of proposed navigation channel and Wharf 6 berth, and the 'inshore' and 'offshore' disposal area shown for context.

3.3 Calibration and Validation

3.3.1 Flow Model

The 3D hydrodynamic model has been calibrated and validated against currents measured by Acoustic Doppler Current Profiler (ADCP)[5] at two locations (Figure 3-6): 'Channel Approaches' (also referred to as 'pilot buoy') corresponds to the real-time Triaxis buoy operated by Napier Port at the western boundary of the navigation channel approaches to the Port entrance. The water depth is approximately 10m. 'Beacons' corresponds to a bottom-mounted upward-facing ADCP unit deployed in approximately 6 m water depth.

[5] *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.*

Figure 3-6: Locations of ADCP current meter data used for Calibration and validation of flow model.

Model calibration occurred against data current speeds measured over a 10 day period (16th to 26th May 2016) at the 'Channel Approaches' ADCP. The wind drag coefficient (Cd) and bottom roughness (Chezy coefficient) were used as free parameters. The Root Mean Square (RMS) error of the calibration process is shown in Figure 3-7. RMS values are given in mm/s. A time series comparison of the calibrated 3D model compared to measured currents is shown in Figure 3-8.

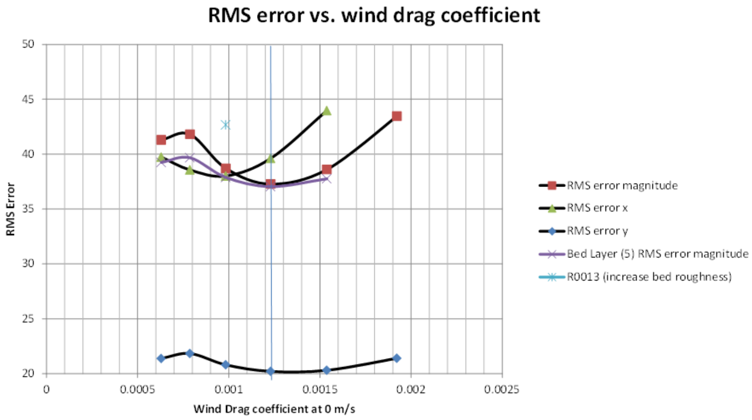

Figure 3-7: Error statistics during the calibration process of the 3D flow model. RMS Error in mm/s.

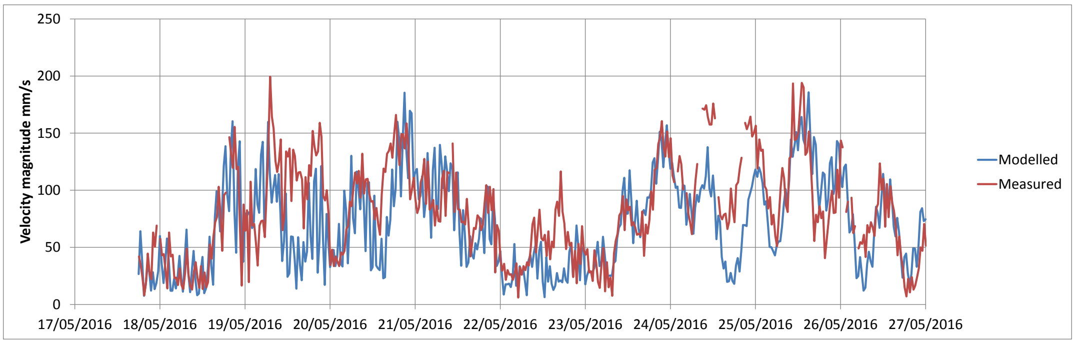

Figure 3-8: Time series comparison of current velocity at 'Channel Approaches'

The performance of the calibrated 3D flow model was verified against ADCP data measured over a longer period between 24th June and 3rd August (Figure 3-9). The wind record over the validation period was relatively stormy compared with seasonal mean values over period 2004 to 2014. The model predicts both the magnitude and direction of the measured current velocities at both ADCP validation sites very well. At both locations the current was correlated closely to the wind speed, which is consistent with previous observations of currents around Napier Port (WorleyParsons, 2005). Finally, the validation showed also that the model is able to reproduce high current velocities during major storm events as well as the overall trend in magnitude over the duration of the storm event.

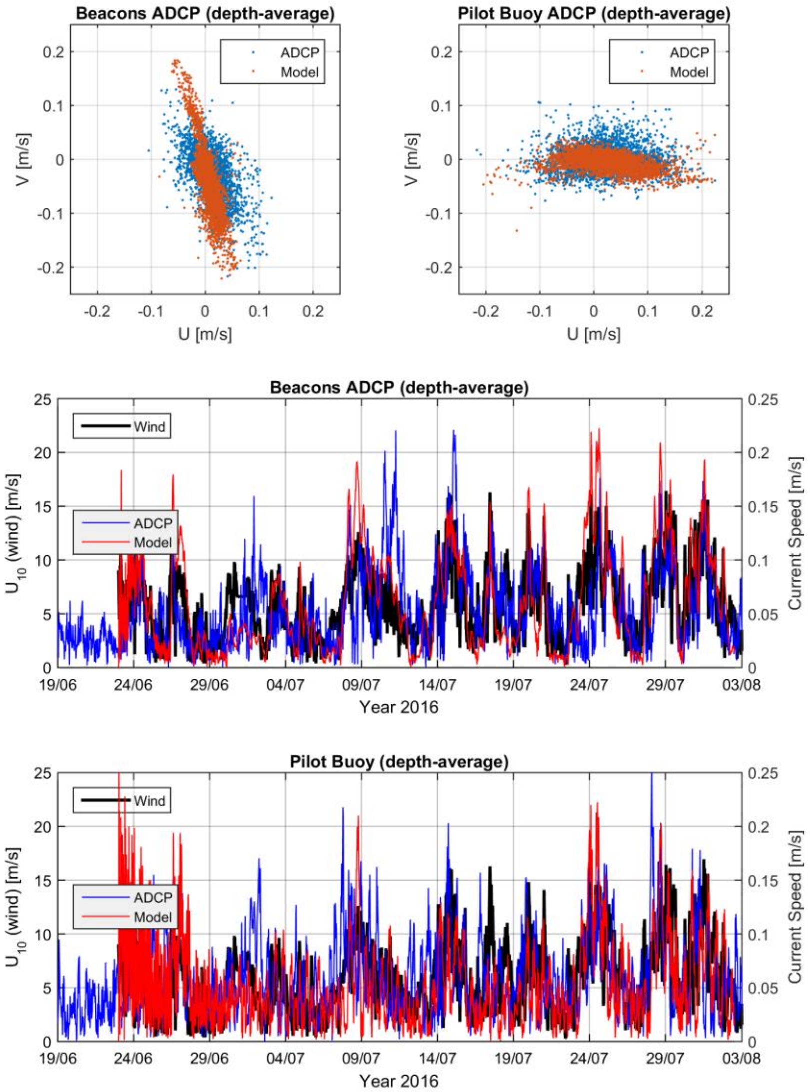

Figure 3-9 – Model validation results at the Pilot Buoy and Beacons ADCPs for July 2016

3.3.2 Wave Model

The wave model has been calibrated using observations of wave height and period measured by RBS Solo pressure transducers at three inshore locations (‘Beacons’, ‘East Pier’, ‘Hardinge Road’). Calibration used wave data measured hourly over two separate storm events, with bottom friction and directional spreading varied as free parameters within the model. Water level was used as an additional sensitivity check of the model results. Figure 3-10 shows the locations of the wave gauges used in the calibration and validation process.

Figure 3-10: Locations of wave gauges used in calibration and validation of wave model. 'Offshore' corresponds to the Triaxis wave buoy used as boundary conditions for the wave model.

Bulk error statistics (Mean Absolute Error, Bias, Scatter Index, Skill Score) were calculated for each location by amalgamating model results across both storms to give approximately 150 comparisons between simulated and observed data at each location (Table 3-3). Generally accepted qualifications of different skill scores for numerical models are shown in Table 3-4.

Model calibration was achieved with JONSWAP bottom friction of 0.06 and directional spreading parameter (n) of 10. Comparison of model error for water level in the range of Lowest Astronomical Tide (LAT) to Highest Astronomical Tide (HAT) found little sensitivity to water depth at the calibration locations.

The model reproduces wave heights at the calibration location to an accuracy (MAE) of better than ±0.1m, with a bias of less than or equal to 0.05m. The skill score of the model is close to or greater than 0.8, corresponding to 'excellent' accuracy. Time series plots comparing the calibrated model against observed H_{m0} and T_p for the storm events at each of the three locations are shown in Figure 3-11 to Figure 3-13.

As wave direction data were not collected at the calibration sites, the model was not calibrated for direction. However the model does validate very well to wave direction as shown in the next section.

Table 3-3: Summary of calibration error statistics for calibrated wave model

Location	MAE (m)[6]	Bias (m)[7]	Scatter Index[8]	Skill Score[9]
Beacons	0.08	0.05	0.17	0.85
East Pier	0.06	0.03	0.20	0.78
Hardinge Road	0.04	-0.01	0.13	0.89

The performance of the calibrated wave model was also verified for three further storm events occurring between May and July 2016. This is considered as an independent check of the model performance using the calibration settings.

Figure 3-14 validates the performance of the wave model at 'Beacons', 'East Pier' and 'Hardinge Road' for three large storm events occurring between May and July 2016. The model MAE for wave height remains at better than ±0.1m. At the Pilot Buoy the MAE for wave period is better than ±1 second, and MAE for wave direction better than ±5 degrees.

Table 3-4: Skill Score qualifications

Range	Qualification
0.8 to 1.0	Excellent
0.6 to 0.8	Good
0.3 to 0.6	Reasonable
0 to 0.3	Poor
Less than 0	Unacceptable

[6] *Mean Absolute Error (MAE) is a quantity used to measure how close the model results are to the measured data. A MAE of 0.1m means that the model is considered accurate to ±0.1m.*

[7] *The Bias is a measure of whether the model tends, on average, to over-or under-predict the observed wave heights at a particular location. A positive bias means that the model tends to over-predict. A negative bias means that the model tends to under-predict.*

[8] *The Scatter Index is a non-dimensional measure of whether the natural scatter in the comparison between model and data is comparable to the natural variation in the observations themselves. The Scatter Index is defined as the standard deviation of the difference between model and observations, normalised by the mean of the observations, and ideally should as small as possible.*

[9] *The Skill of the model is another non-dimensional performance statistic. A Skill score of 1 indicates a perfect agreement between measured and simulated values. Scores equal to or less than 0.*

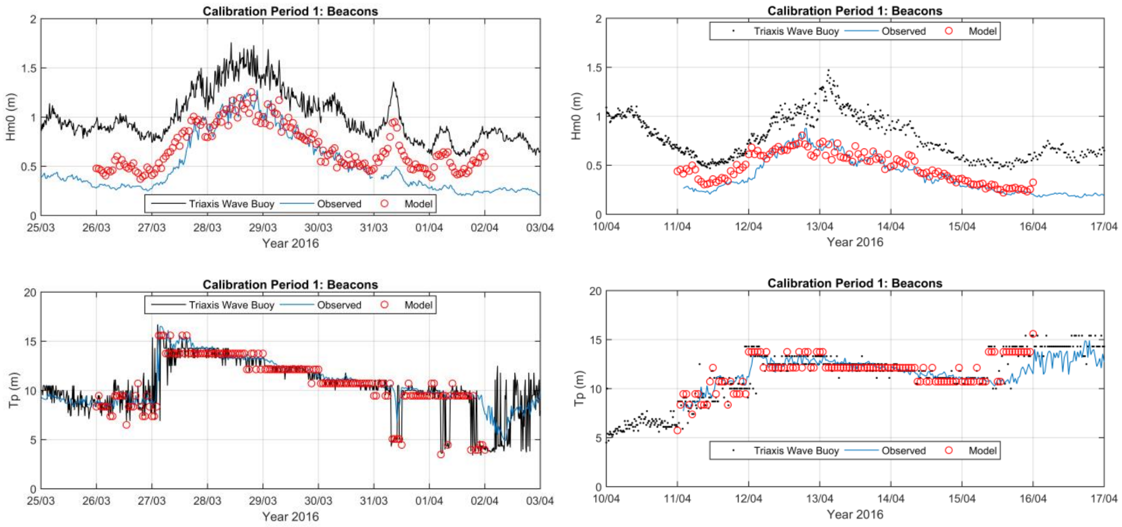

Figure 3-11: Time series of calibrated wave results for two storm events used in wave model calibration. Calibration site 'Beacons'.

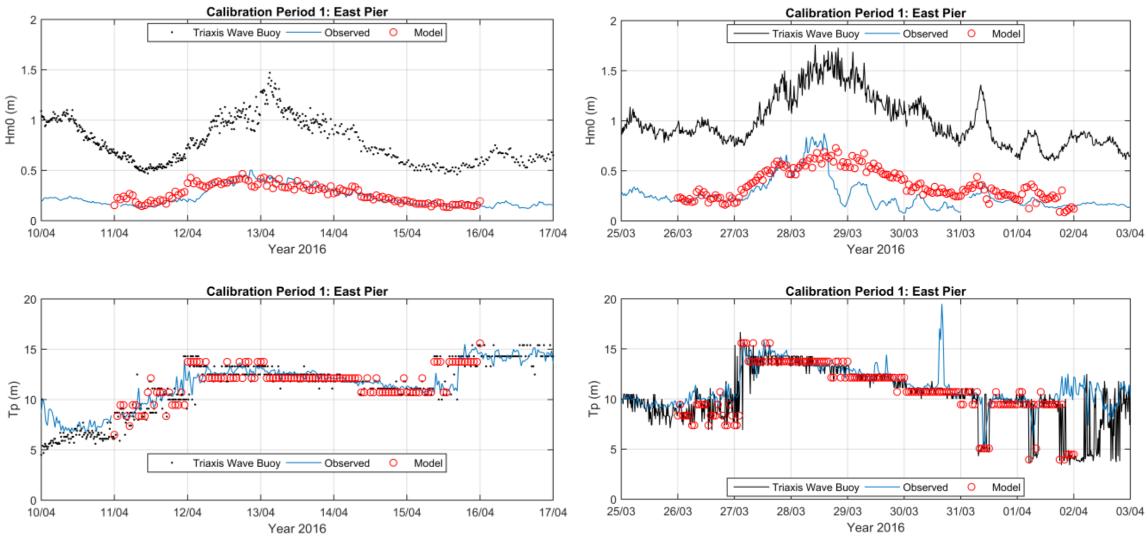

Figure 3-12 Time series of calibrated wave results for two storm events used in wave model calibration. Calibration site 'East Pier'.

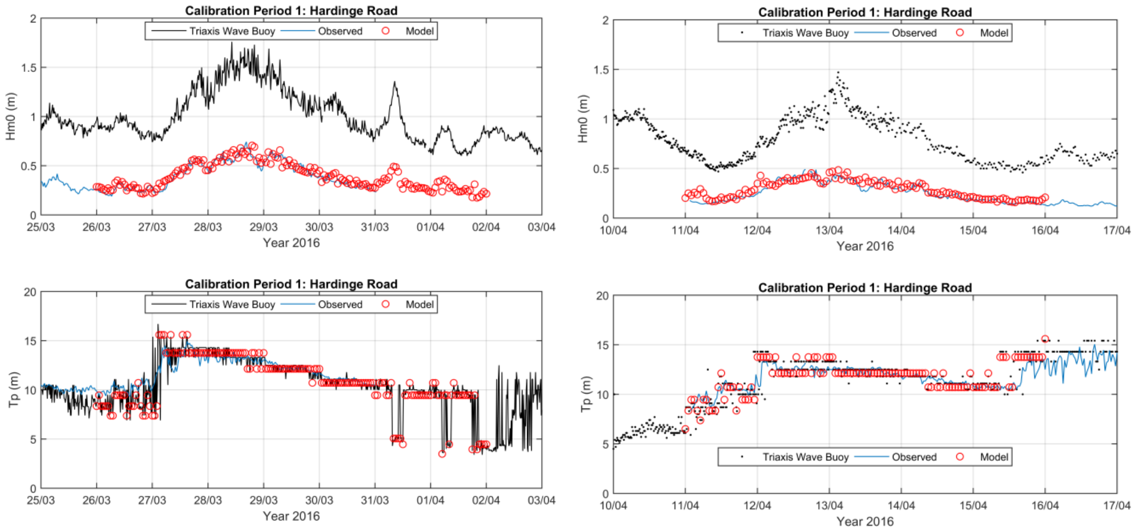

Figure 3-13 Time series of calibrated wave results for two storm events used in wave model calibration. Calibration site 'Hardinge Road'.

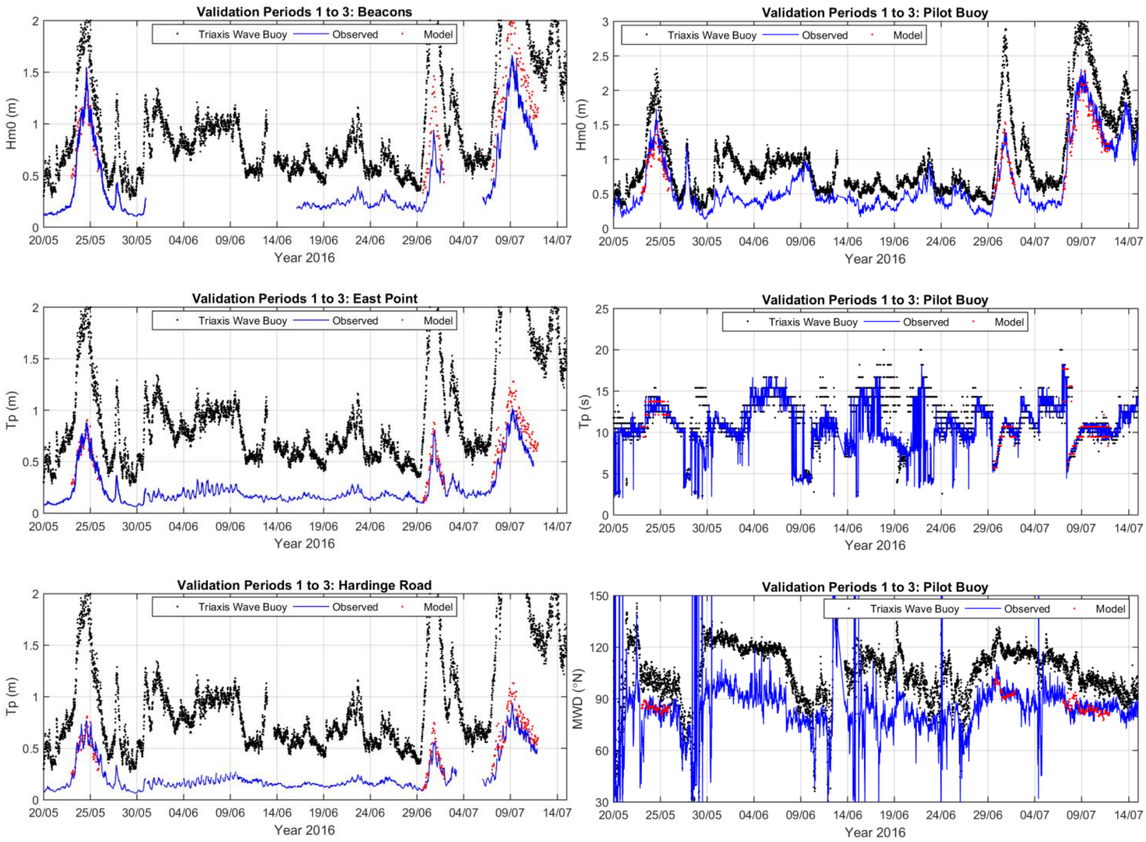

Figure 3-14: Validation of wave model at inshore locations. Left panel: Validation for Hm0 and Tp at 'Beacons', 'East Pier' and 'Hardinge Road'. Right panel: Validation for Hm0, Tp and MWD at 'Channel Approaches' real-time buoy.

4 Sediment Transport Methodology

4.1 Introduction

Two approaches were used to understand sediment transport processes occurring around Napier Port and the potential disposal sites:

1. A *data-driven* approach to understand, in a statistical sense, what the expected magnitude and direction of transport may be for various sand-sized sediments. This approach used detailed observations of current speeds and direction measured by ADCP current meters at specific locations around Napier Port and the disposal sites, and applied sediment transport algorithms for waves and currents
2. A *model driven* approach using Delft3D to assess sediment transport patterns over the wider coastal environment at Napier. These calculations were undertaken using a limited number of 'representative' wind and wave conditions, and a limited number of sediment diameters. The patterns were combined to make an estimate of the 'annual mean' sediment transport pathways.

Both approaches, which use the Van Rijn (2007, 2017) formulae for sediment transport, were designed to be corroborative. The patterns produced by the numerical models cannot give *absolute* magnitude, but do give a clear idea of *relative* magnitude between different areas of the coastal zone, and different environmental forcing conditions. These patterns can then be interpreted in the context of the sediment transport magnitudes and directions calculated at the locations of the ADCP current meters

It should be noted that any assessment of sediment transport is subject to inherent uncertainties. Therefore such estimates refer to sediment transport *potential* as the estimates assume rather idealised conditions (such as an inexhaustible supply of sediment, no interaction between sediment fractions and assumption of static current and wave fields), whereas processes in nature tend to be rather variable.

A recent study by Advisian (Nielsen and Williams, 2017) found even with a perfect supply of sediment, the precision of suspended sediment estimates using the Van Rijn algorithms was no better than a factor 5 (0.2 to 5.0), while that for bedload transport was no better than a factor of 3 (0.3 to 3.0). While these were site-specific values, they are in the general range reported by others. This illustrates why net and gross estimates of sediment transport are often considered accurate only to an order-of-magnitude.

Nevertheless, the study presented in this report describes the relative transport magnitudes between different sediment fractions and for each direction. Such information can then be checked against data such as annual maintenance dredging volumes.

4.2 Particle Size Characteristics

Detailed sedimentological data throughout the study area were obtained from several boreholes and vibrocores (Beca 2016), as was information on the volume of sediment to be dredged and the breakdown of the various dredging campaigns.

The available data included:

- *Sediment fall velocity*[10] 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 the geological unit from which the sediment derives for each proposed campaign.

Locations of available sediment data are provided in Figure 4-3 and the distribution of settling velocity by mass at the measured locations within the study area is shown in Figure 4-1.

4.2.1 Sediment Classes: Sand Particle Diameters

Figure 4-1 shows the Particle Size Distribution (PSD) of various vibrocore samples (positions shown in Figure 4-3). The samples correspond to burial depths of 0 to 1 m below ambient bed levels.

- Approximately 20% of sediments are finer than 100 μm (0.1 mm).
- Approximately 70% of sediments are sized between 100 μm and 200 μm (0.1 mm and 0.2 mm)
- Approximately 10% of sediments are coarser than 200 μm, 5% coarser than 300 μm, and 1% coarser than 500 μm.
- The median ('50% passing') particle diameter is approximately 125 μm

These particle diameters were used as the basis for non-cohesive sediment transport calculations presented in Section 5 and Section 6.

[10] *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, sphericity, and the surface texture of the particle.

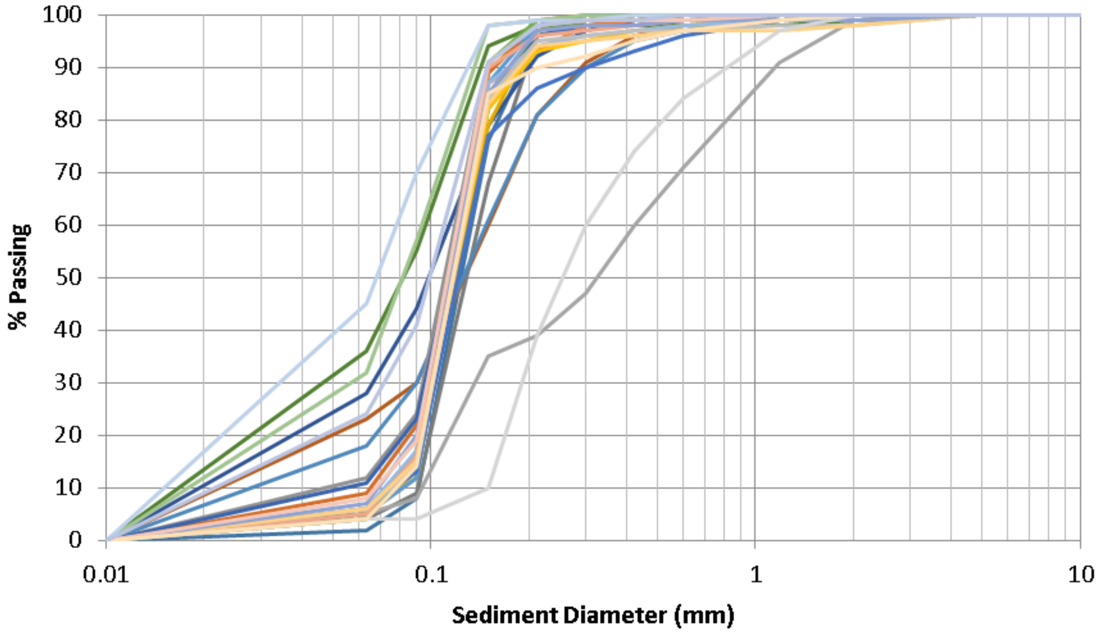

Figure 4-1: Particle Size Distribution of near-surface vibrocore samples taken within the proposed dredge footprint of Napier Port navigation channel. (Different colours indicate different boreholes)

4.2.2 Sediment Classes: Silt Settling Velocity

Two silt fractions (as characterised by their settling velocity characteristics) have been used in the analysis for fine sediments. Clay particles and fine silt are considered to have dispersed on initial deposition of dredge spoil and, therefore, would not be present within sediments after deposition to the sea floor. Therefore, the analysis concentrated on dispersion of medium and coarse silt. The defined settling velocity classes are presented in Table 4-1 together with the corresponding particle fraction.

Table 4-1 Particle size classes and settling velocities used for the modelling assessment (silt fractions)

Particle Size Fraction [micron]	Settling Velocity [mm/sec]
16 (silt)	0.23
62 (silt)	3.29

The sediment velocity classifications listed above are based on an unflocculated sediment sample. The assumption is that once suspended in to the water column, concentrations will be insufficient to initiate flocculation. Van Rijn (1989) considers flocculation in salt water to be relevant only once suspended sediment concentrations exceed 100 mg/l. Given that the majority of fine sediments will have already dispersed during disposal, this concentration is not expected to occur at the offshore disposal ground.

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.

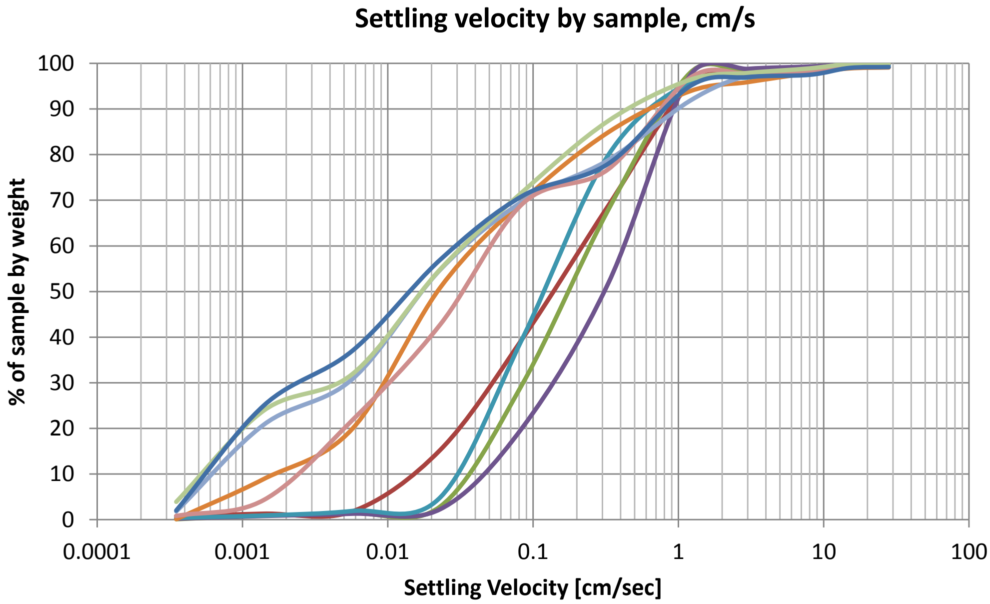

Figure 4-2 – Range of sediment settling velocity distributions at various sampling locations within the study area. (Different colours represent different boreholes)

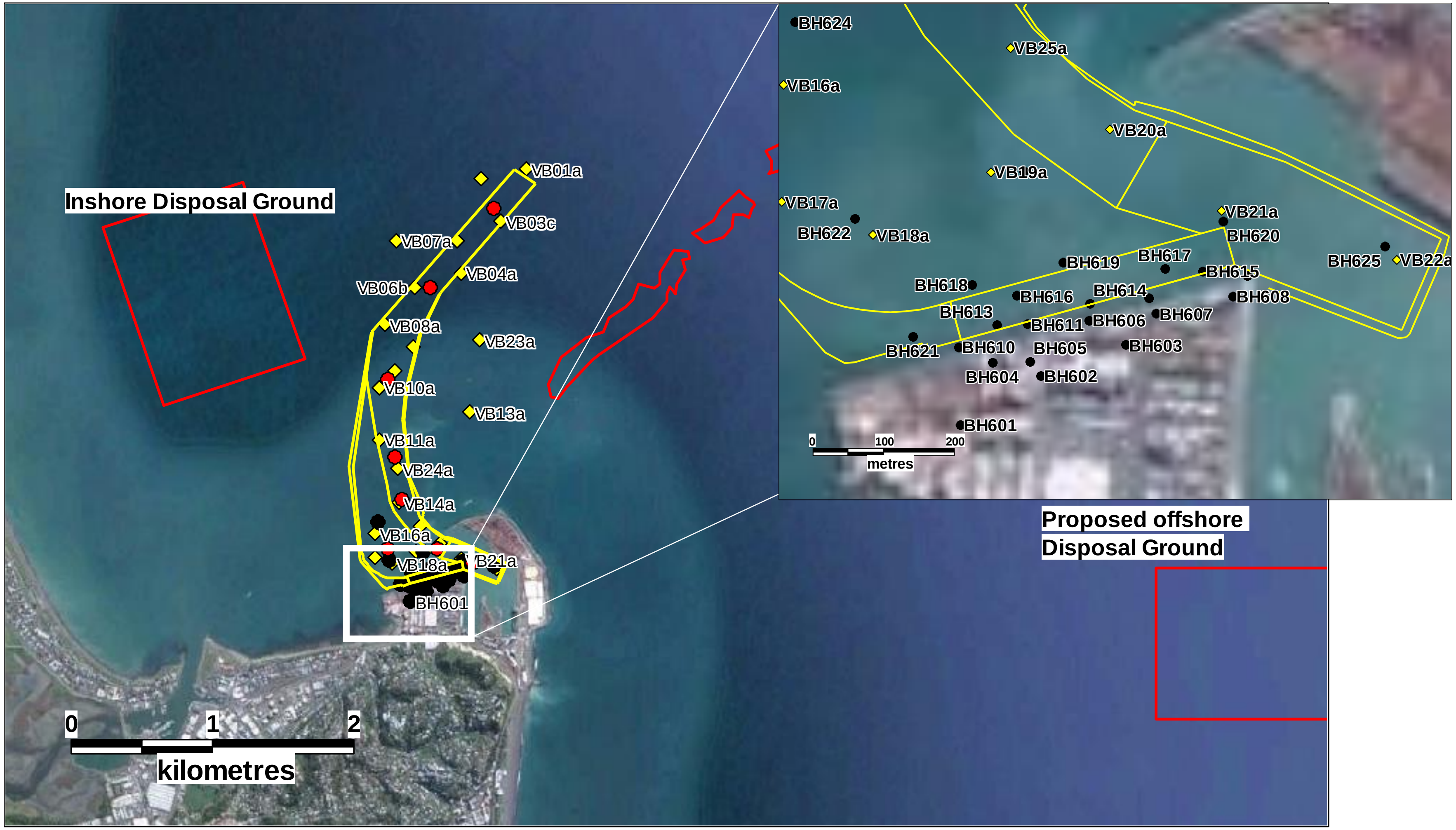

Figure 4-3 – Locations of available sediment data – boreholes (BH) and vibrocores (VB)

4.3 Van Rijn Analytical Expressions for Non-Cohesive Sediments

Van Rijn has published comprehensive research of analytical, laboratory and field studies of sediment transport under currents and waves that is applied widely in both academic and engineering studies. In this assessment we apply formula for bedload and suspended load transport under combined wave and current conditions (Van Rijn, 2007[a,b], 2017).

Although the analytical expressions are simpler than those employed within the Delft3D model, they have been calibrated against the more detailed TRANSPOOR2004 sediment transport algorithm (Van Rijn, 2017) to provide consistent answers.

The analytical expressions are valid only outside of the surf zone. That is, the model considers current-related transport, enhanced by wave stirring. This assumption is valid for the water depths encountered.

Note that the TRANSPOOR2004 algorithm employed by Delft3D, and described in Section 4.4 is valid both inside and outside the surf zone.

4.3.1 Summary of Method

The methodology applied to each ADCP current meter location may be summarized as follows:

1. Derive a statistical description of current speed and direction ('current rose') from current observation at the ADCP current meter.
2. Apply the calibrated wave model to produce a statistical description of the wave climate at the site of current observations; that is, the joint occurrence probability of a number of combinations of wave height and period at the site.
3. For a given data point of current speed and direction in the ADCP time series, calculate the expected sediment transport for that current speed with all combinations of the wave height and period calculated in step (2). Weight each of these transport calculations by the probably of occurrence of each (Hm0, Tp) class to derive a single 'representative' value of sediment transport.
4. Repeat step (3) for each entry in the ADCP current meter record.
5. Scale the results so that the ADCP record is assumed to occur over a year.

The sediment transport results are then plotted as roses, showing the expected magnitude and direction of transport over the course of a year, for each of the sediment fractions. The roses show both the amount expected to be transported as bedload, and as suspended load.

It is an inherent assumption of the above approach that the current data measured at each site over a period of weeks to months is representative of that expected to occur over the course of a year.

4.4 Numerical Simulation of Sediment Transport

4.4.1 Model Assumptions: Particle Sizes and Settling Characteristics

Sediment diameters present in dredge spoil material are described in Section 4.2. Specific size fractions considered in the model are given in Table 4-3.

4.4.2 Model Assumptions: 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 by wave and current action. 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 4-2. 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 4-2. This corresponds to silty material that has remained on the sea floor to partially consolidate.

Table 4-2 - 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

The erosion, transport and deposition of each sediment fraction have been treated independently in the Delft3D model. That is, there is no interaction between the different sediment fractions.

A further parameter used in the Delft3D model is the ‘erosion parameter’. This user-controlled parameter defines the rate at which sediment mass is injected in to the water column once the critical threshold of erosion is exceeded. This has been retained at a default value of 0.0001 kg/m^2/s to give a conservative estimate of fine sediment (silt) entrained in to the water column.

4.4.3 Model Assumptions: 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.

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).

The critical shear stress for sand particles is calculated internally within the Van Rijn sediment transport algorithm.

4.4.4 Parameters Summary

Table 4-3 summarises the key parameters used in the 3D hydrodynamic and sediment transport model.

Table 4-3 - Key parameters and formulations used in the Delft3D sediment transport model

Key Parameters for 3D Hydrodynamic Model	
Number of vertical sigma layers	5 (equal layers each spanning 20% of the depth) plus bed layer
Horizontal dispersion	HLES, time and space varying
Vertical dispersion	k-E, time and space varying
Bottom Shear Stress	Waves + Currents, time and space varying
Key Parameters for Sediment Transport Model (Sand)	
Algorithm	Van Rijn
Dry Bed Density	1600kg/m3
D50 (sand fraction 1)	100 micron
D50 (sand fraction 2)	125 micron
D50 (sand fraction 3)	200 micron
D50 (sand fraction 4)	300 micron
D50 (sand fraction 5)	500 micron
Key Parameters for Sediment Transport Model (Silt, Mud)	
Algorithm	Van Rijn (2007)
Critical shear stress for erosion	0.2 N/m^2
Critical shear stress for deposition	0.05 N/m^2
Ws (Silt Fraction 1)	0.26 mm/s
Ws (Silt Fraction 2)	3.3 mm/s
Dry Bed Density	450kg/m3
Erosion Parameter	0.0001 kg/m^2/s

4.4.5 Selection of Morphological Wave

Analysis of the hourly wave record shows little correlation between incident swell wave conditions and hourly averaged wind conditions. Therefore, It was considered that the incident wind and wave conditions were independent statistically. While it is equally valid to simulate any particular combination of wave and wind conditions, sediment transport patterns are most often determined by energetic (i.e. storm) conditions.

In this assessment the incident wave was used to drive sediment transport by the following processes:

- Bedload, via wave asymmetry. Typically this is directed on-shore.
- Suspended load, by stirring sediments into suspension whereupon they can be either transported offshore by wave processes or are carried by ambient currents driven by associated wind fields.

The 'total load' is the summation of the two above processes. Coarser sediments or more quiescent environments tend to promote bedload. Whereas finer sediments or more energetic environments tend to promote suspended load.

In the simulations considered in this study, the wave conditions are used to provide wave stirring to promote transport under 'energetic' conditions. For the offshore disposal ground, the aim is to maximise wave stirring by assuming a severe storm event. This provides a very conservative estimate of sediment resuspension and, hence potential to transport sand and silt from the spoil ground.

For simulations of sediment transport around the inshore disposal sites west of the navigation channel, the aim is to provide energetic storm conditions that occur relatively frequently. As exposure to wave energy in this region is strongly related to the incident wave direction (due to sheltering provided by Napier Port), a more easterly wave direction is used than is typically experienced during 'mean' wave conditions.

The selected wave conditions are shown in Table 4-4. These have been back-refracted to deeper water and applied to the wave model boundary. Figure 4-4 shows the selected wave conditions in context of the overall wave climate experienced at the Triaxis wave buoy operated by Napier Port.

Table 4-4: Morphological waves used in simulations, as measured at location of Triaxis waverider buoy operated by Napier Port

	ISDG simulations	OSDG simulations
Hm0	2.3 m	3.3
Tp	12.0	13.3
MWD (coming from)	96°	98°

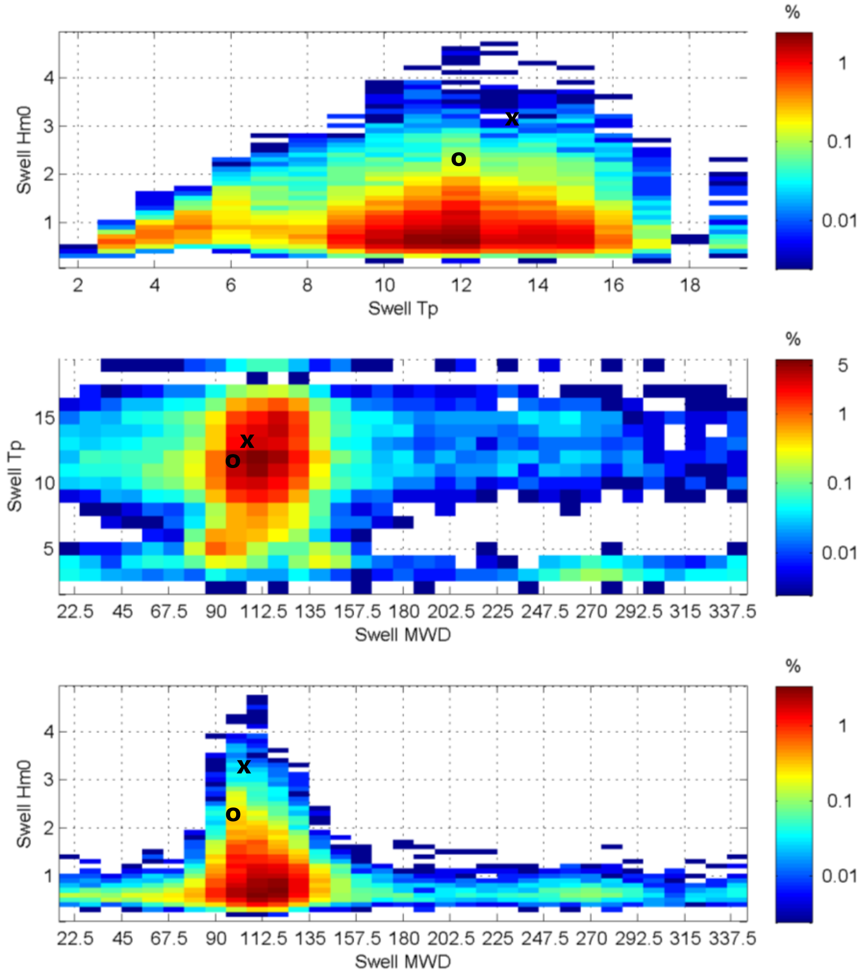

Figure 4-4: Statistical description of wave climate at Triaxis Buoy, based on wave data 2004 – 2104. 'o'= Wave condition for inshore disposal ground. 'x' = wave condition for offshore disposal ground.

5 Post-Disposal Fate of Sediments at Inshore Disposal Ground

5.1 Sediment Mobility

Figure 5-1 shows the percent of time per year each sediment diameter may be expected to be active as (a) bedload (including incipient motion), and (b) as suspended load, on the basis of currents measured at 'Channel Approaches' and 'Beacons', for water depths of 10 m and 6 m respectively. The locations of the current meters and a statistical description of the observed current speed and direction are given in Figure 5-2.

For a sediment diameter of 125 μm (representative of approximately 70% of the particle size distribution obtained from vibrocore sediments), sediment would be expected to be mobile for approximately 11% of the year at 'Channel Approaches' and 'Beacons'.

Figure 5-1 suggests that at the 'Beacons' ADCP site, all fine and medium sands are in motion equally. This contrasts with 'Channel Approaches', where sediment mobility drops dramatically for particle diameters larger than 160 μm. This suggests that, close to the navigation channel in about 10 m water depth, a degree of sediment sorting occurs with sediments <160 μm available to be transported more frequently than sediments >160 μm.

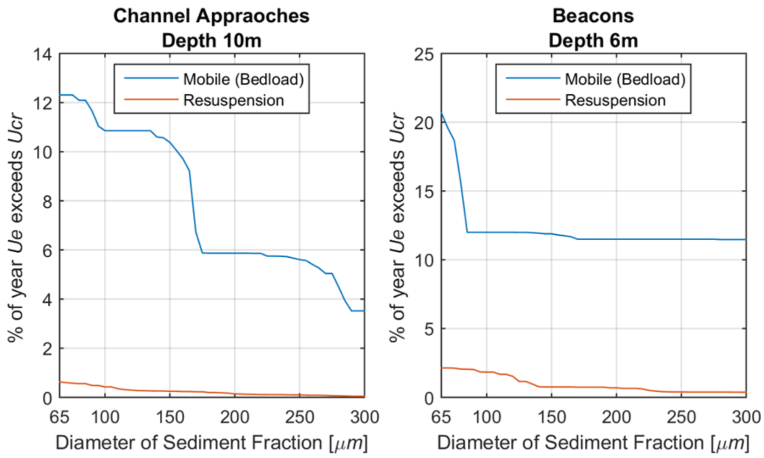

Figure 5-1: Percent of time each year shear stress exceeds (a) threshold for sediment mobility (incipient motion or bedload), (b) threshold for sediment resuspension, for different sediment fractions.

5.2 Analytical Assessment of Sediment Transport Potential

Figure 5-2 shows the measured current speed and magnitude at 'Beacons' and 'Channel Approaches' ADCP units for the deployment periods given in Table 2-2.

The resultant estimates of net and gross sediment transport potential (both bedload and suspended load) are given for sand diameters corresponding to very fine, fine, and medium sand. The sediment transport estimates are valid for assessing the relative magnitude of sediment transported in the different directions and the relative sediment transport potential between sediment fractions. Based on previous experience the transport estimates are considered precise to a factor of about 5 (0.2 to 5.0).

A reasonable estimate of total sediment transport can be estimated by multiplying the results for each sediment rose by the mass each sediment fraction represents from the particle size distribution measured from the vibrocores.

- Results for 100 µm are representative of 10% of the particle size distribution measured from vibrocores; scale magnitudes to 10% of values given in rose plots.
- Results for 120 µm are representative of 40% of the particle size distribution measured from vibrocores; scale magnitudes to 40% of values given in rose plots.
- Results for 160 µm are representative of 40% of the particle size distribution measured from vibrocores; scale magnitudes to 40% of values given in rose plots.
- Results for 200 µm are representative of 5% of the particle size distribution measured from vibrocores; scale magnitudes to 5% of values given in rose plots.
- Results for 300 µm are representative of 5% of the particle size distribution measured from vibrocores; scale magnitudes to 5% of value quoted in rose plots.
- Combine the results to give the total magnitude transported in each direction.

The key point to observe is that at both the 'Beacons' and 'Channel Approaches' ADCP site, overwhelmingly the transport is towards the navigation channel. This suggests strongly that any dredge spoil material deposited here will be removed from the disposal site and moved eastward, filling in the navigation channel , or if remaining in suspension, moving towards Pania Reef.

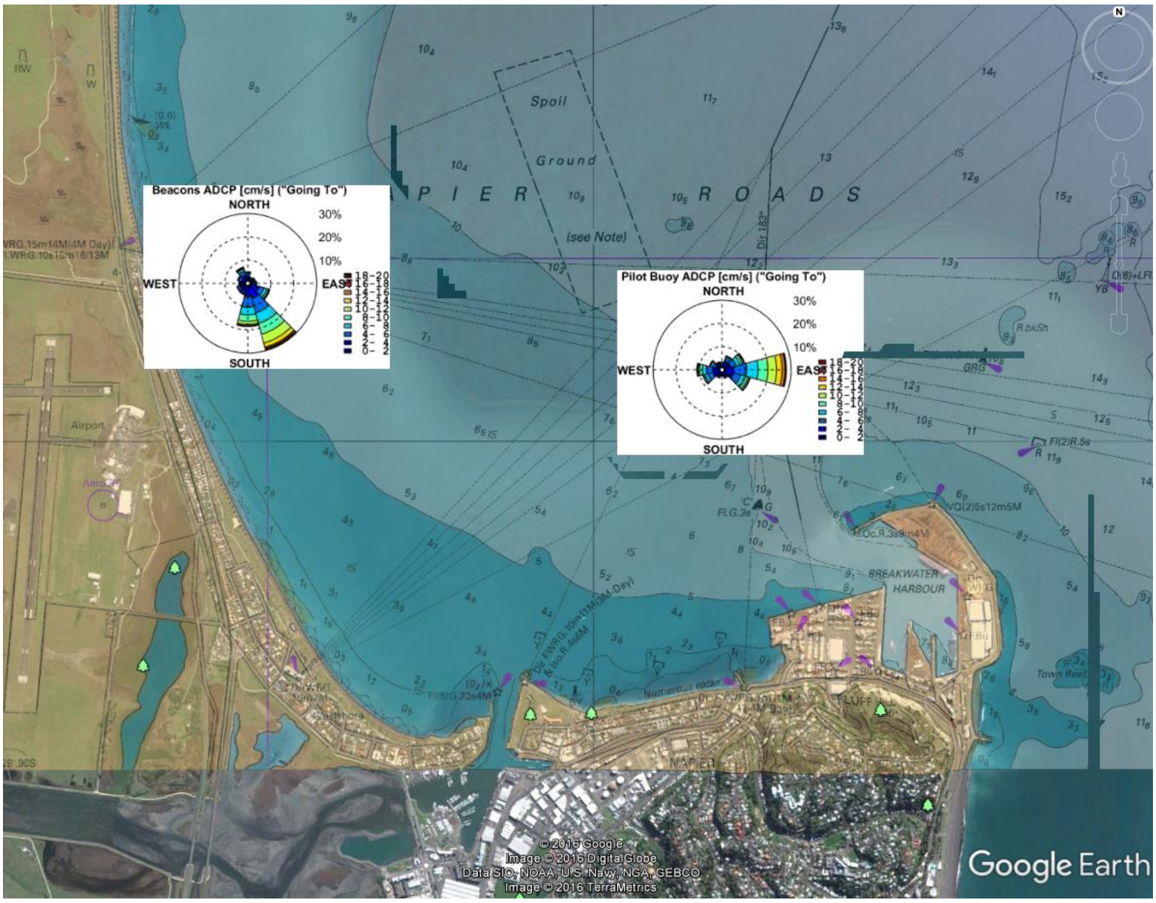

Figure 5-2: Statistical description of depth-averaged current speeds at 'Beacons' and 'Pilot Buoy' (Channel Approaches) ADCP units. Directions given 'going to'. Magnitudes given to cm/s.

5.2.1 Beacons

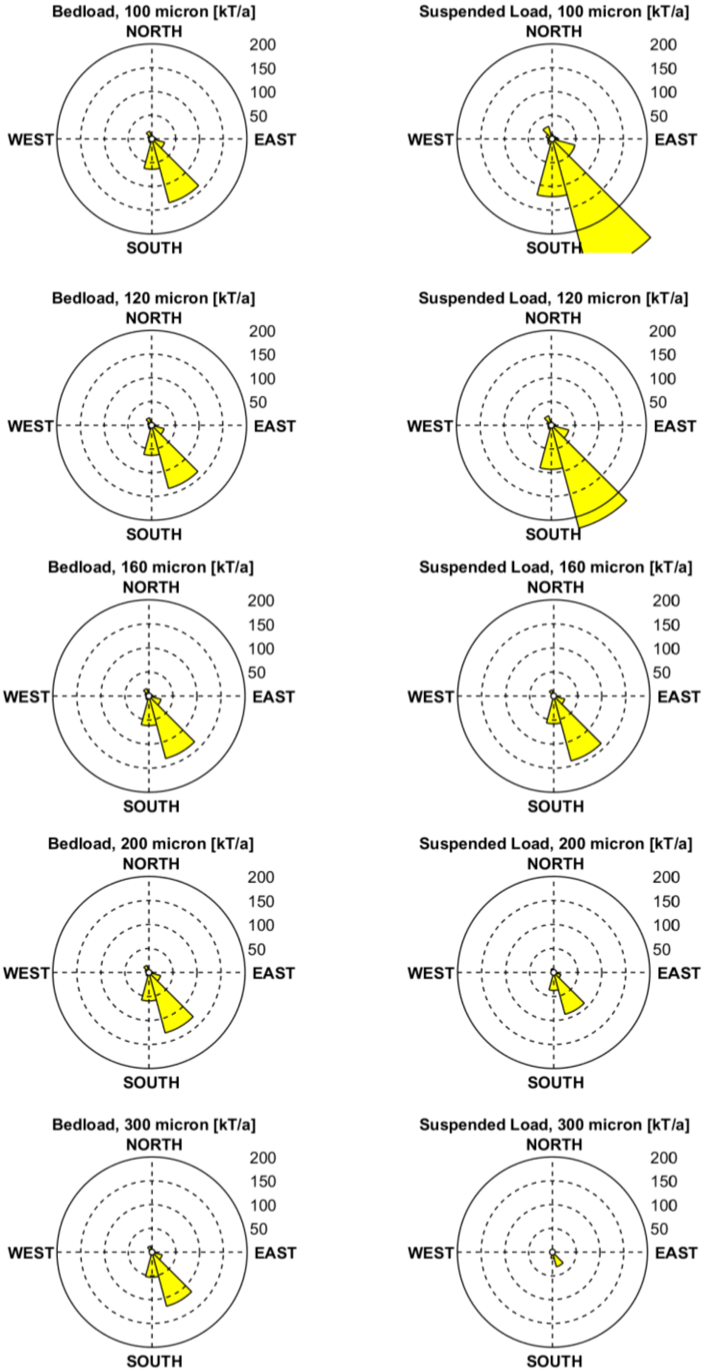

Figure 5-3: Estimates of current-related bedload and suspended load *potential* at 'Beacons' ADCP unit, for grain sizes corresponding to very fine to medium sand.

5.2.2 Channel Approaches

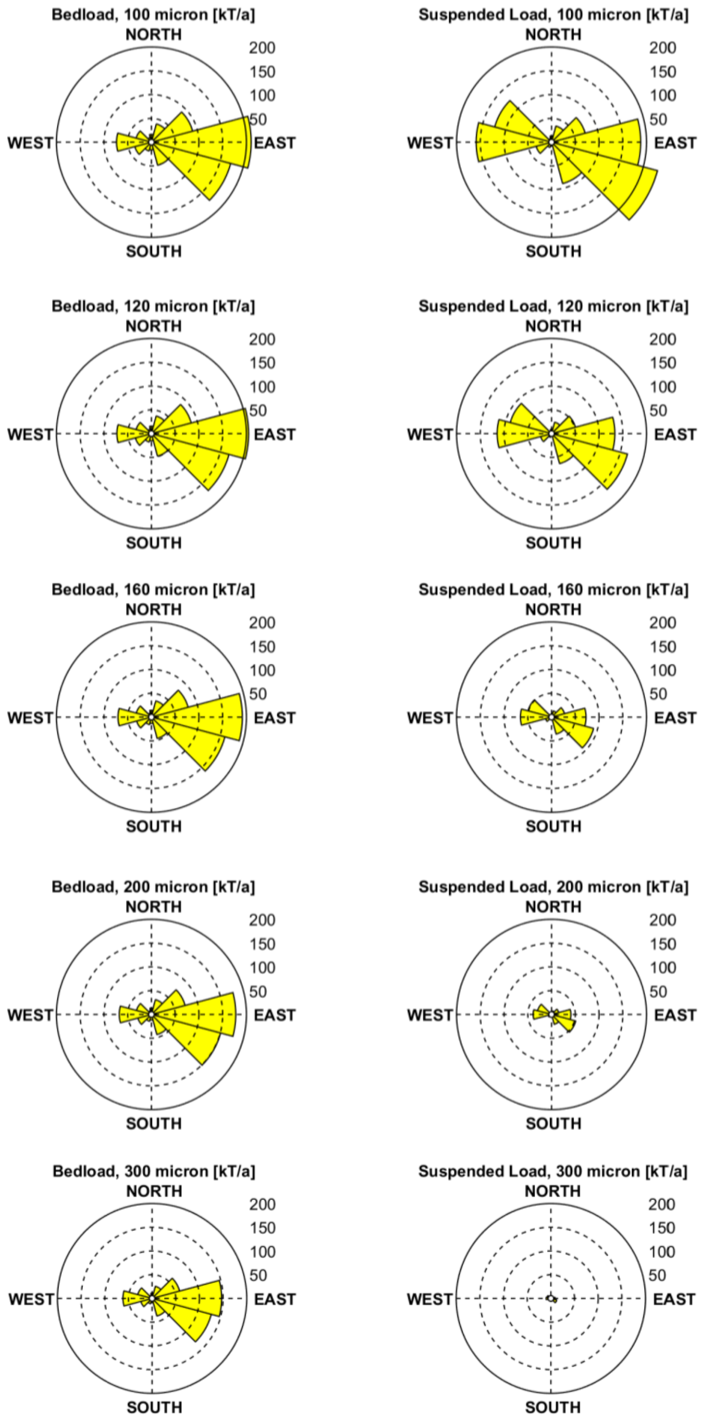

Figure 5-4: Estimates of current-related bedload and suspended load *potential* at 'Beacons' ADCP unit, for grain sizes corresponding to very fine to medium sand.

5.3 Spatial Patterns of Sediment Transport

Spatial patterns of sediment transport obtained for energetic wind speeds from each of the six wind directions are shown in Figure 5-5 to Figure 5-7. The percentage of time each wind direction occurs in the wind record is given for each sediment transport pattern. This is roughly analogous to the percent of time the pattern could be expected to occur during the course of each year. The absolute magnitudes transported will be dependent on the specific combination of wave energy and wind speed, but the pattern will remain approximately consistent.

The results in Figure 5-5 to Figure 5-7 are shown as vectors showing the relative magnitude and direction of total transport (suspended load plus bedload), for 100 µm, 125 µm and 200 µm. Together these sediment fractions represent roughly 90% of the particle size distribution of sandy sediments measured in the vibrocore particle size distribution (Figure 4-1). Bathymetric contours are also shown.

The key observations are:

- Transport is greatest for winds approaching from the NW as wind speeds from this sector tend to be higher.
- The magnitude of sediment transported is very sensitive to sediment diameter. Sands corresponding to 100 µm and 125 µm tend to be transported as suspended load, while those for 200 µm and 300 µm tend to be transported as bedload. This corroborates the relative contribution of suspended load and bedload for the sediment roses of each sediment diameter shown in Section 5.2.

An estimate of the 'annual average' sediment transport pattern may be obtained by combining the transport results for each wind speed and weighting by contribution to the wind record. This is shown in Figure 5-8 for various sediment diameters observed in the vibrocore particle size distribution.

The key results of the 'annual average sediment transport pathways for each sediment diameter are:

- The model shows the presence of a persistent anticyclonic circulation of sediments finer than 125 µm west of the Port and navigation channel. This existence of this feature is corroborated by the directionality of currents and sediment transport derived from analysis of ADCP data.
- Sediments finer than 125 µm are swept eastward from the areas corresponding to potential inshore disposal grounds, and transported directly towards the Port and Navigation channel

The hydrodynamic model predicts a northerly and westerly transport for winds occurring from the West. This is because, for the wind speed and duration considered in the simulations, an easterly circulation is initiated in Hawke Bay, drawing water northward along the Napier coast.

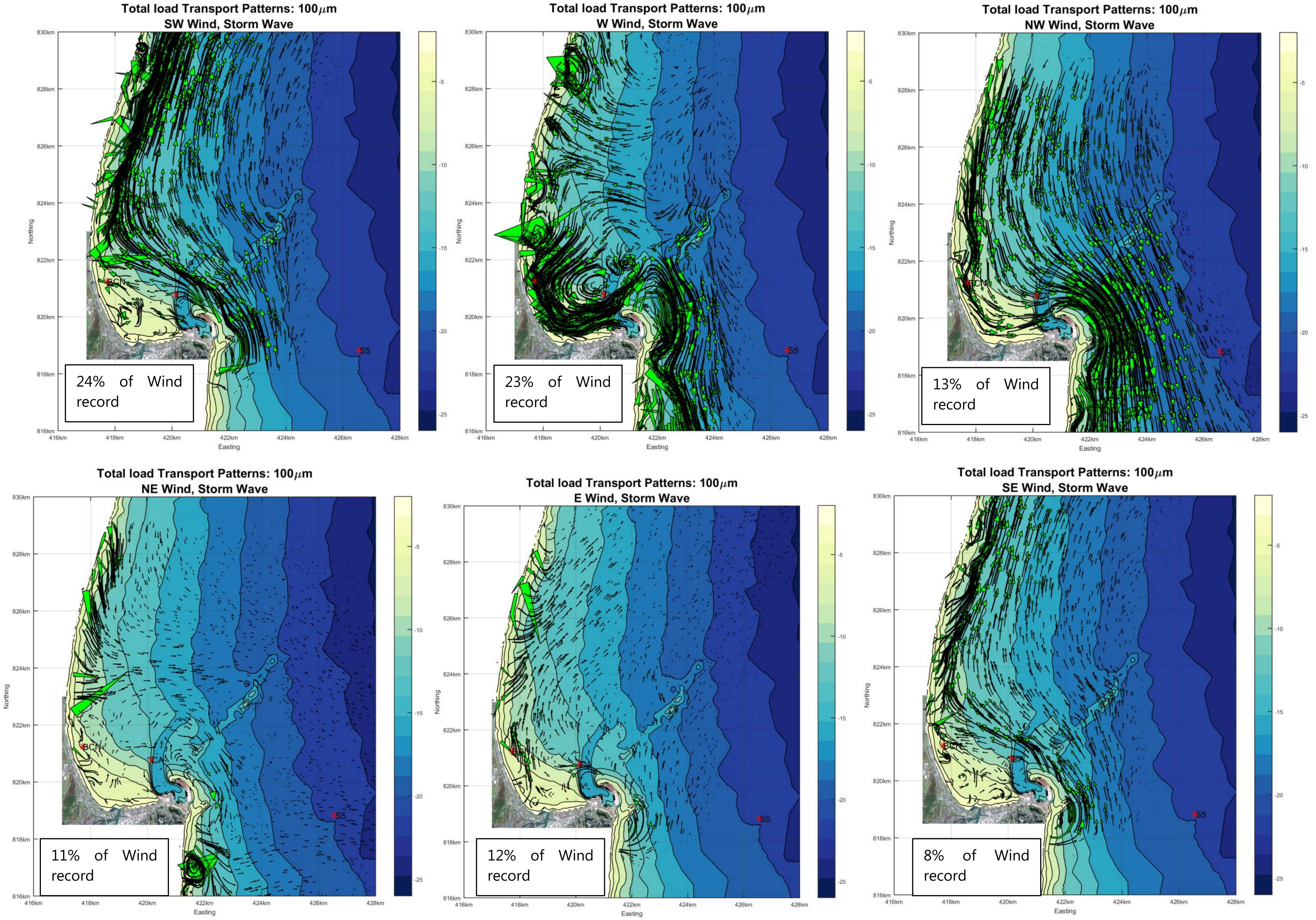

Figure 5-5: Sediment Transport patterns for most commonly occurring sediment diameter around Napier Port. Location of ADCP units at 'Proposed Offshore Disposal Ground', 'Channel Approaches' ('CA') and 'Beacons' (BCN') also shown.

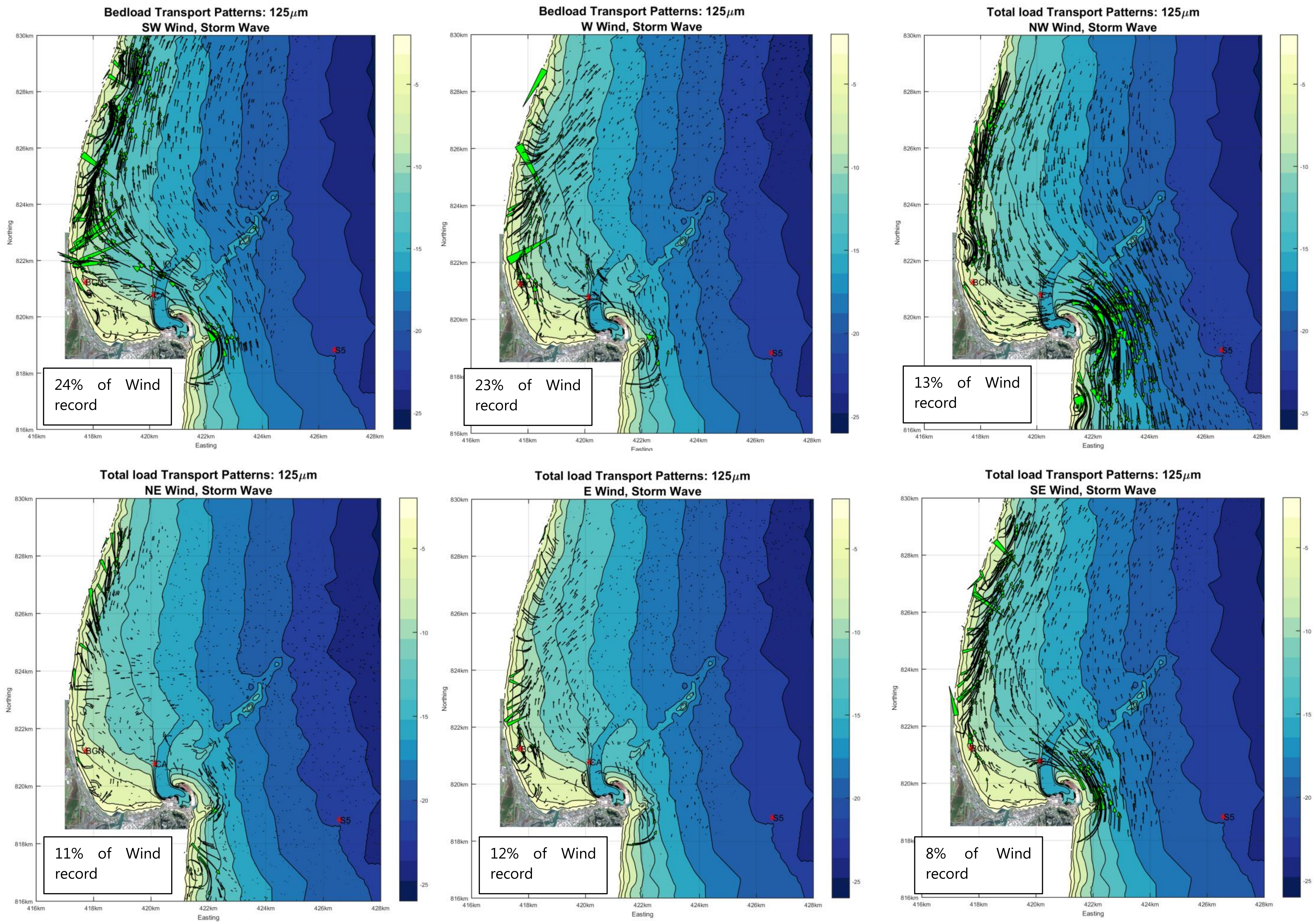

Figure 5-6: Sediment Transport patterns for most commonly occurring sediment diameter around Napier Port. Location of ADCP units at 'Proposed Offshore Disposal Ground', 'Channel Approaches' ('CA') and 'Beacons' (BCN') also shown.

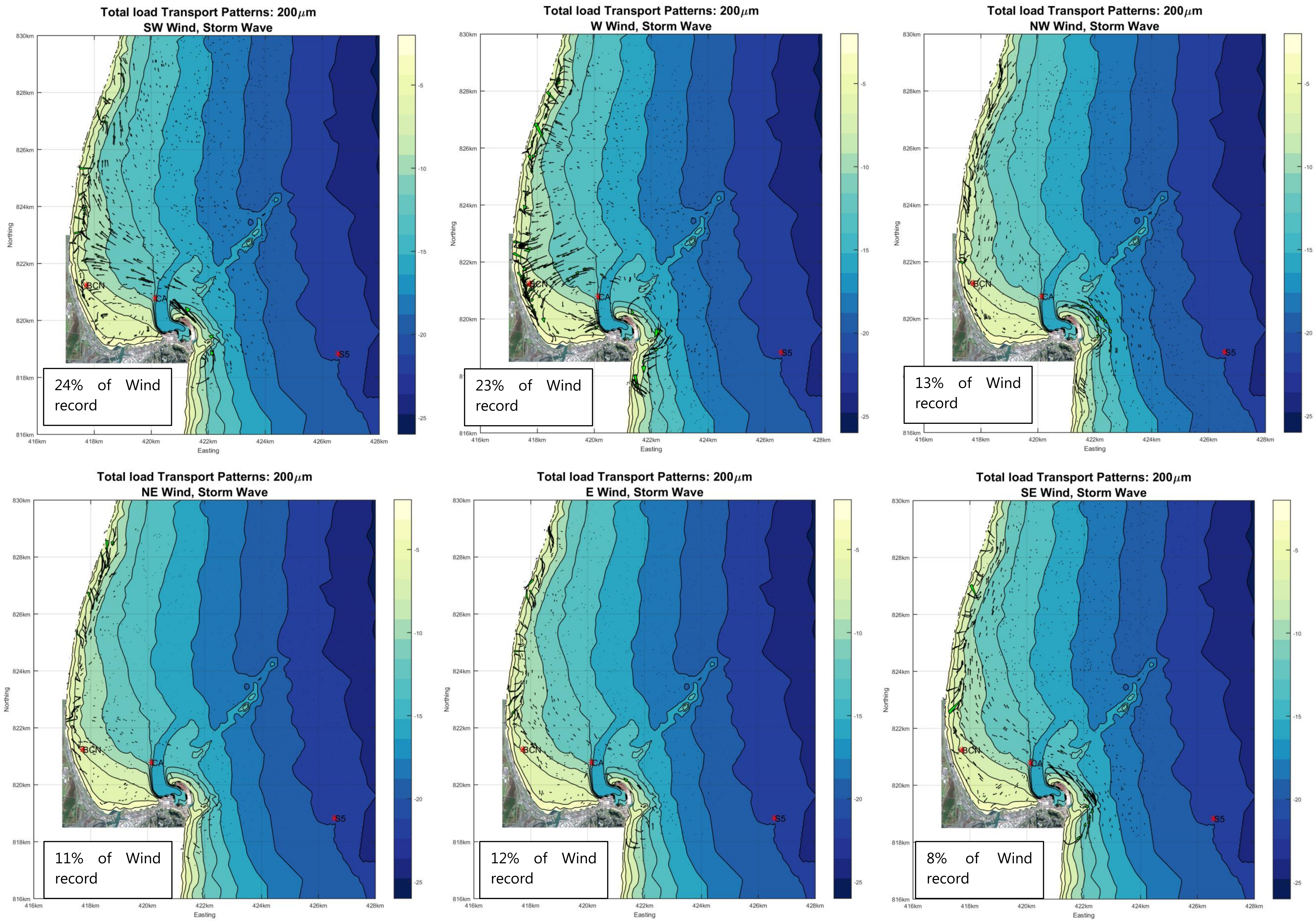

Figure 5-7: Sediment Transport patterns for most commonly occurring sediment diameter around Napier Port. Location of ADCP units at 'Proposed Offshore Disposal Ground', 'Channel Approaches' ('CA') and 'Beacons' (BCN') also shown.

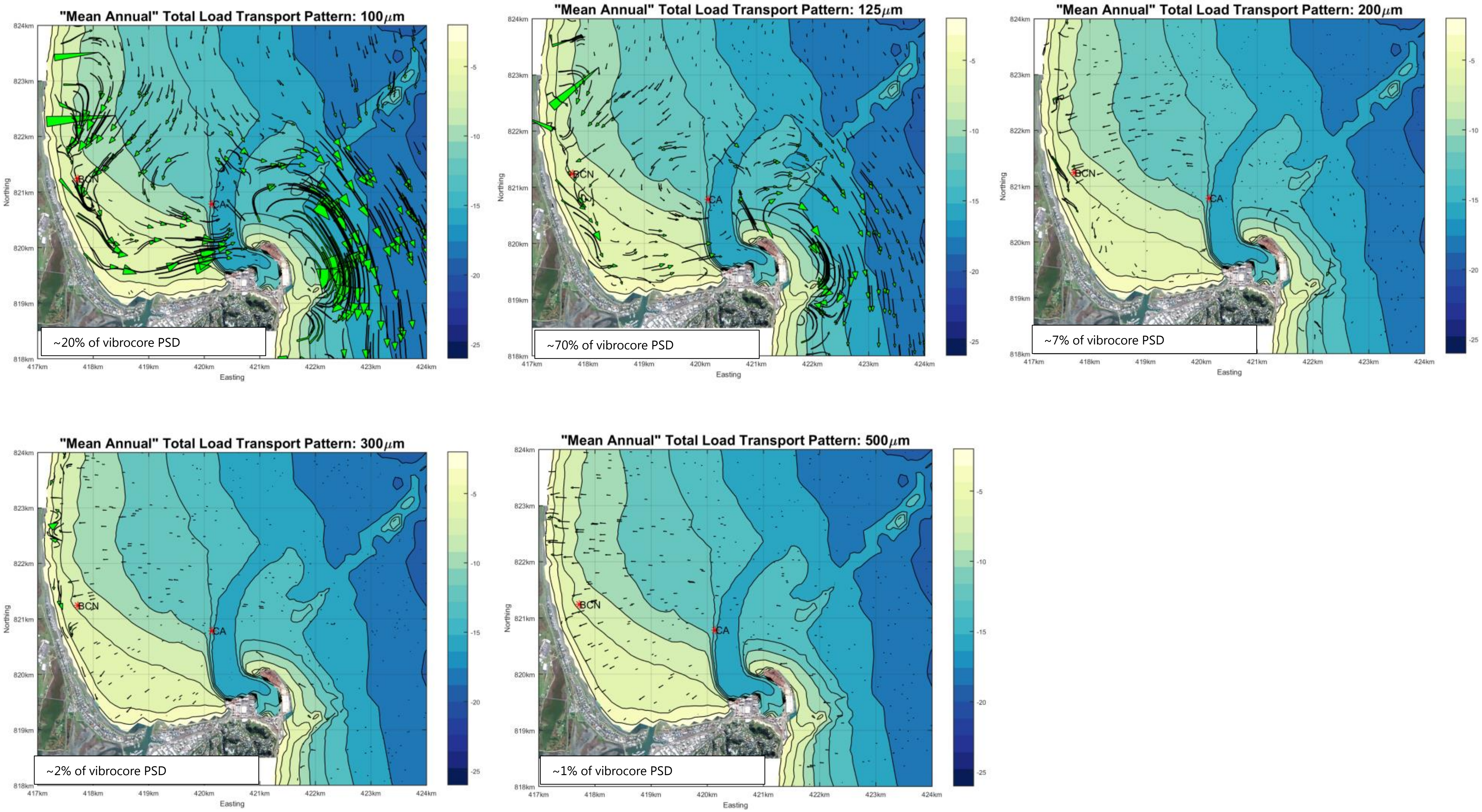

Figure 5-8: 'Annual Average' sediment transport patterns for discrete sediment diameters around Napier Port. Bathymetric contours given to Chart Datum.

6 Post-Disposal Fate of Sediments at Offshore Disposal Ground

6.1 Sediment Mobility

Figure 6-1 shows the percentage of time per year each sediment diameter may be expected to be active as (a) bedload (including incipient motion), and (b) suspended load. On the basis of currents measured at the proposed offshore disposal site, and a water depth of 20 meters.

As might be expected, potential for suspension is low (<<1%), even for silt fractions. This implies that only relatively severe waves which occur infrequently, are capable of suspending the sediments for transport by ambient currents. The threshold for sediment mobility as bedload is exceeded rather more often. Based on a sediment diameter of 125 μm (representative of approximately 70% of the dredge spoil sediments), sediment would be expected to be mobile *via* either incipient motion or as bedload for approximately 6% (3 weeks) of the year.

Overall, the results suggest that the proposed offshore disposal ground is mildly dispersive for silt, and weakly dispersive for fine and medium sand.

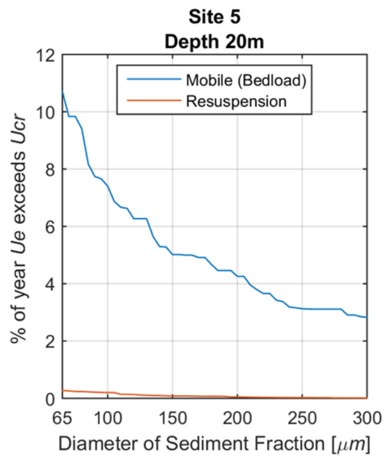

Figure 6-1: Percent of time each year shear stress exceeds (a) threshold for sediment mobility (incipient motion or bedload), (b) threshold for sediment resuspension, for different sediment fractions.

6.2 Sand Transport

The directionality and magnitude of currents experienced at the proposed offshore disposal ground is shown in Figure 6-2. Magnitudes are given to mm/s. The key observations are:

- Currents at the offshore disposal ground are almost exclusively southerly. Currents are directed SSW to SSE (away from Pania Reef) approximately 70% of the time, and WNW to N (towards Pania Reef) approximately 10% of the time.

- Maximum current speeds are approximately twice as fast as those measured at the 'Beacons' and 'Channel approaches' ADCP locations (40 cm/s *vs* 20 cm/s)

The observations of current speed and direction are based on ADCP measurements obtained between 9th December 2016 and 16th January 2017. Although the data are sufficient to show that the location is relatively energetic for current speed, it is possible that the relative contribution of northerly *vs* southerly currents may change as more data is collected.

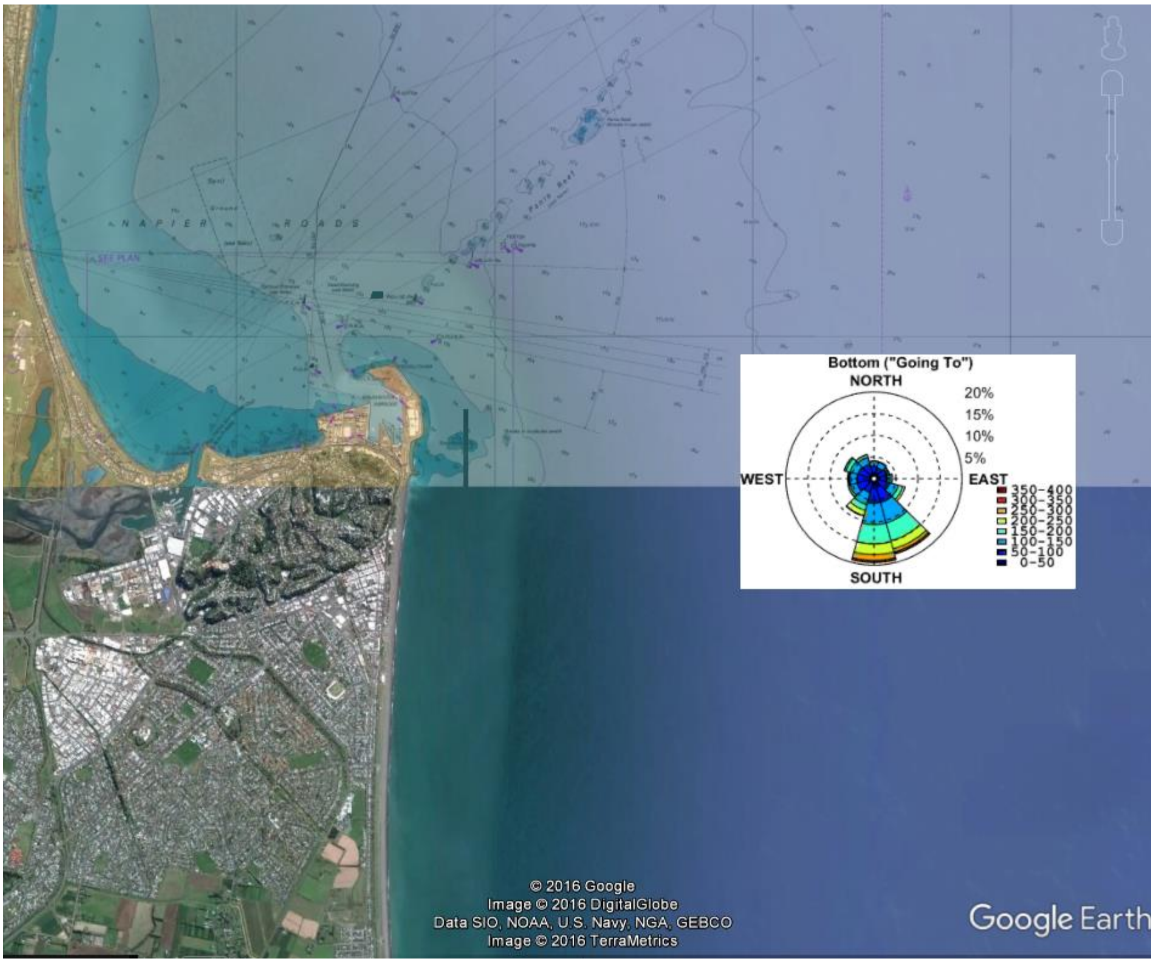

Figure 6-2: Statistical description of measured current speed and direction in the bottom 5 metres of the water column, Proposed Offshore Disposal Ground. 9th Dec 2016 to 16th January 2017.

6.2.1 Analytical estimates of sand transport

Estimates of net and gross sediment transport *potential* for sand diameters corresponding to very fine, fine, and medium sand are shown in Figure 6-3. The sediment transport estimates are valid for assessing the *relative magnitude* of sediment transported in the different directions and the relative sediment transport potential between sediment fractions. Based on previous experience, the transport estimates are considered precise to a factor of about 5 (0.2 to 5.0).

A reasonable estimate of total sediment transport can be estimated by multiplying the results for each sediment rose by the mass each sediment fraction represents from the particle size distribution measured from the vibrocores.

- Results for 100 μm are representative of 10% of the particle size distribution measured from vibrocores; scale magnitudes to 10% of values given in rose plots.
- Results for 120 μm are representative of 40% of the particle size distribution measured from vibrocores; scale magnitudes to 40% of values given in rose plots.
- Results for 160 μm are representative of 40% of the particle size distribution measured from vibrocores; scale magnitudes to 40% of values given in rose plots.
- Results for 200 μm are representative of 5% of the particle size distribution measured from vibrocores; scale magnitudes to 5% of values given in rose plots.
- Results for 300 μm are representative of 5% of the particle size distribution measured from vibrocores; scale magnitudes to 5% of value given in rose plots
- Combine the results to give the total magnitude transported in each direction.

The rose plots may be interpreted in conjunction with the spatial patterns of sediment transport presented in Figure 5-5 to Figure 5-7. The key points to observe are:

- The magnitude of sediment transport at the offshore disposal ground is roughly a factor of 3 lower than those estimated for the inshore ADCP sites. This corroborates with the spatial sediment transport patterns around Napier Port and the Inshore and Offshore disposal areas shown in Figure 5-5 and Figure 5-6. According to these results, appreciable sand transport at the offshore disposal ground occurs only during strong NW winds, and is directed southerly.
- Although current speeds generally are higher at the offshore site, the greater water depth reduces substantially the contribution of wave stirring and, thus, the ability of waves to resuspend sediment for transport by ambient currents.
- The sediment roses reflect the measured current speed and magnitude. The analysis predicts that, for the data available, sediment will be transported away from Pania Reef for over 90% of the time.

- Sediments coarser than about 120 µm are transported almost exclusively as bedload.

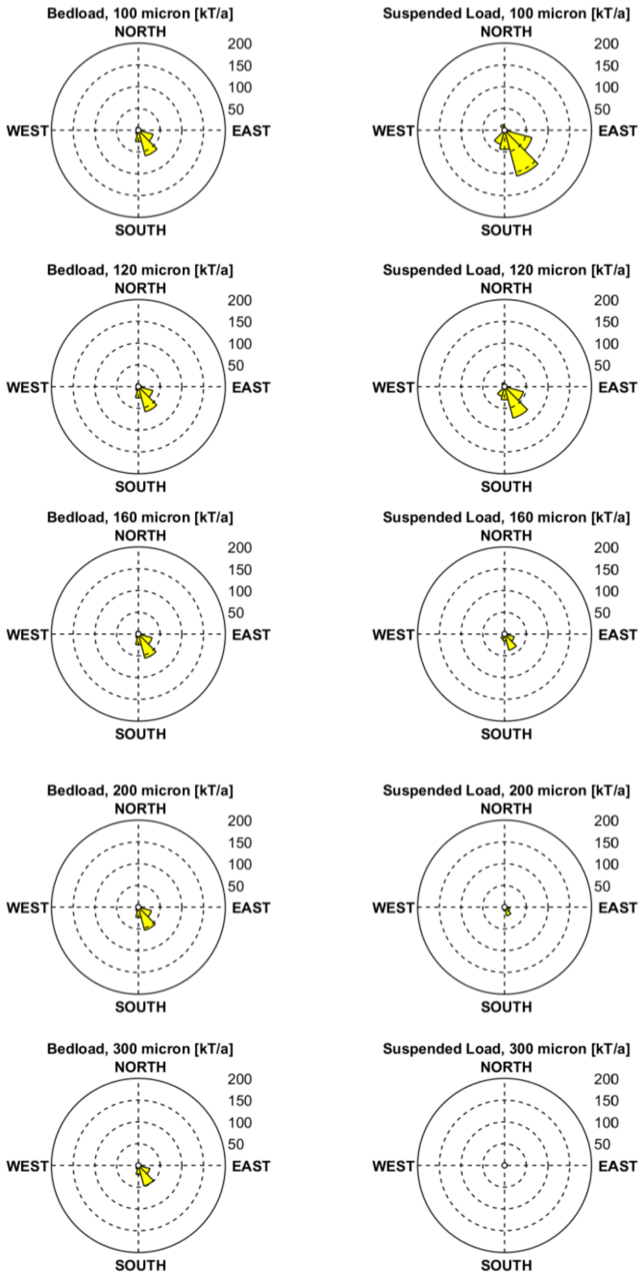

Figure 6-3: Estimates of current-related bedload and suspended load *potential* at ADCP unit deployed within proposed offshore disposal ground, for grain sizes corresponding to very fine to medium sand.

6.3 Potential for Turbidity Plume Generation

Although silt sized sediments are expected to largely disperse during spoil disposal operations, it is likely that material existing as stiff silty sandy clay deposits within the dredge footprint of the navigation channel will be deposited rapidly onto the sea floor. There remains potential for this type of material to act as a source of turbidity during storm events as the material is slowly eroded.

To investigate this, the 3D hydrodynamic and sediment transport model has been applied to assess the potential for erosion and transport of medium and coarse silt during storm events occurring from the six main wind directions. The setup of the cohesive sediment transport model is described in Section 4.4.

The wind speeds applied for each storm event are the 24 hour maximum wind speeds. These were applied to the model for a 24 hour spin-up period, followed by simulation of constant wind speed for a further 72 hours, during which time the storm wave condition was also applied to provide wave stirring. The mass and spatial extent of the silt material were extracted from the model results at the end of the simulation period.

The above approach provides a simple but extremely conservative analysis of the potential for turbidity plumes generated at the proposed offshore site to impact Pania Reef:

- A very severe wave height and period have been assumed to maximise wave stirring
- The wind speed not exceeded for more than 24 hours per year has been assumed to blow constantly for 72 hours. This significantly over-estimates the likely spatial extent of any plume generated by the offshore disposal ground during storm conditions. A storm of this wind speed and duration was not observed in wind data from 2004 to 2015. Events of this wind speed were observed in the wind record, but only with a maximum duration of 24 hours.

The results are shown in Figure 6-4 to Figure 6-7. The results are additive between the 'medium' and 'coarse' silt fractions. That is, the total predicted suspended sediment concentration in the water column is a product of both the medium and coarse silt fractions.

The results show:

- Only one wind direction (westerly wind) can result in a turbidity plumes advecting over Pania Reef. For the rest of wind directions, dispersion is away from Pania Reef, even when the wind-driven currents are moving northerly.
- Under extremely conservative assumptions, the maximum suspended sediment concentration expected over parts of Pania Reef are 2 mg/l above ambient in the surface of the water column, and 4 – 6 mg/l above ambient at the bottom of the water column.

Although the results show it is possible for sediments to be suspended and transported over the reef, deposition will not occur. This is because the shear stress at Pania Reef will be higher than that experienced at the proposed offshore disposal ground, which already exceeds that required to inhibit deposition.

6.3.1 Surface Turbidity, Medium Silt

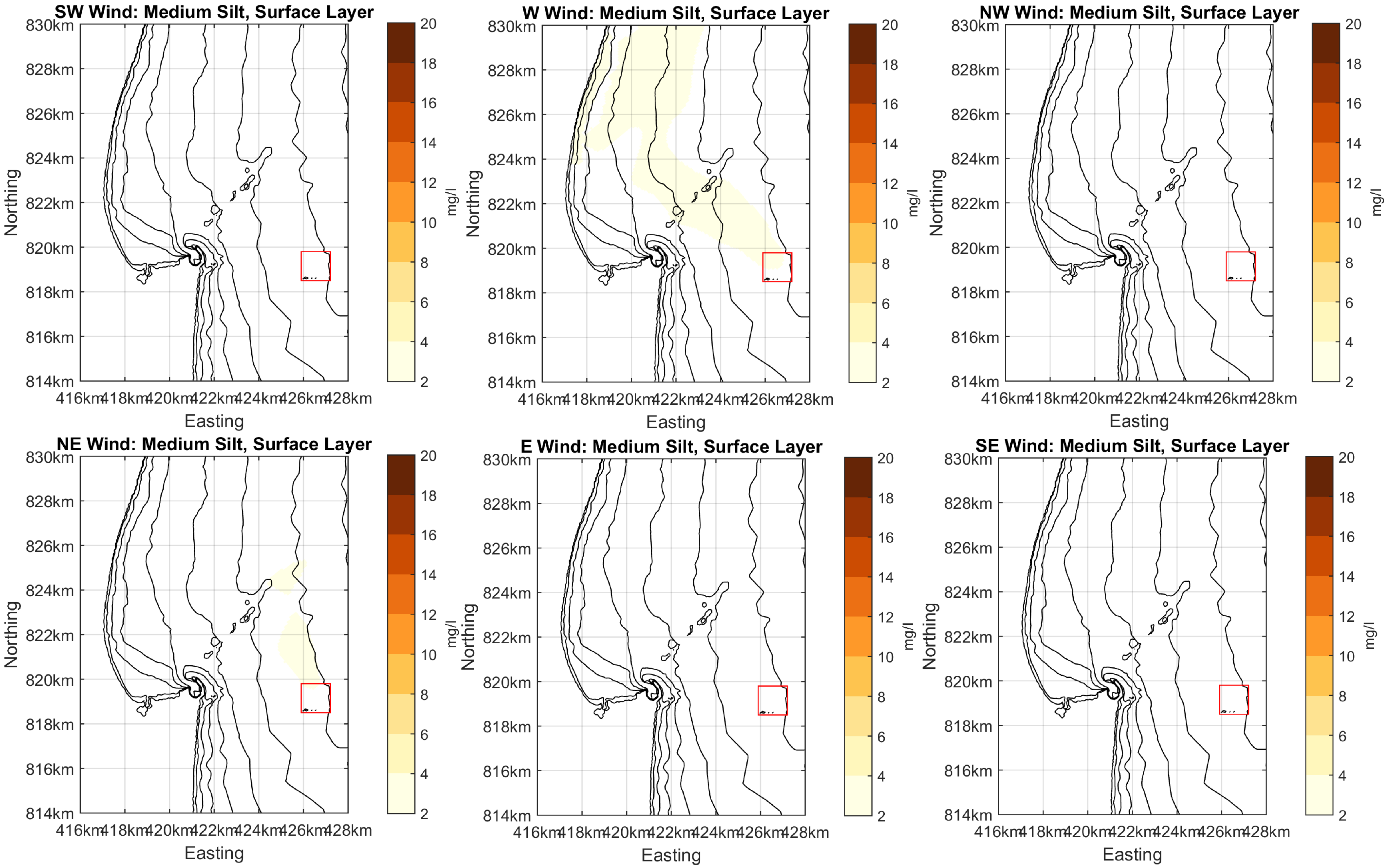

Figure 6-4: Turbidity plumes generated from resuspension of medium silt from the proposed offshore disposal site. Surface layer.

6.3.2 Bottom Turbidity, Medium Silt

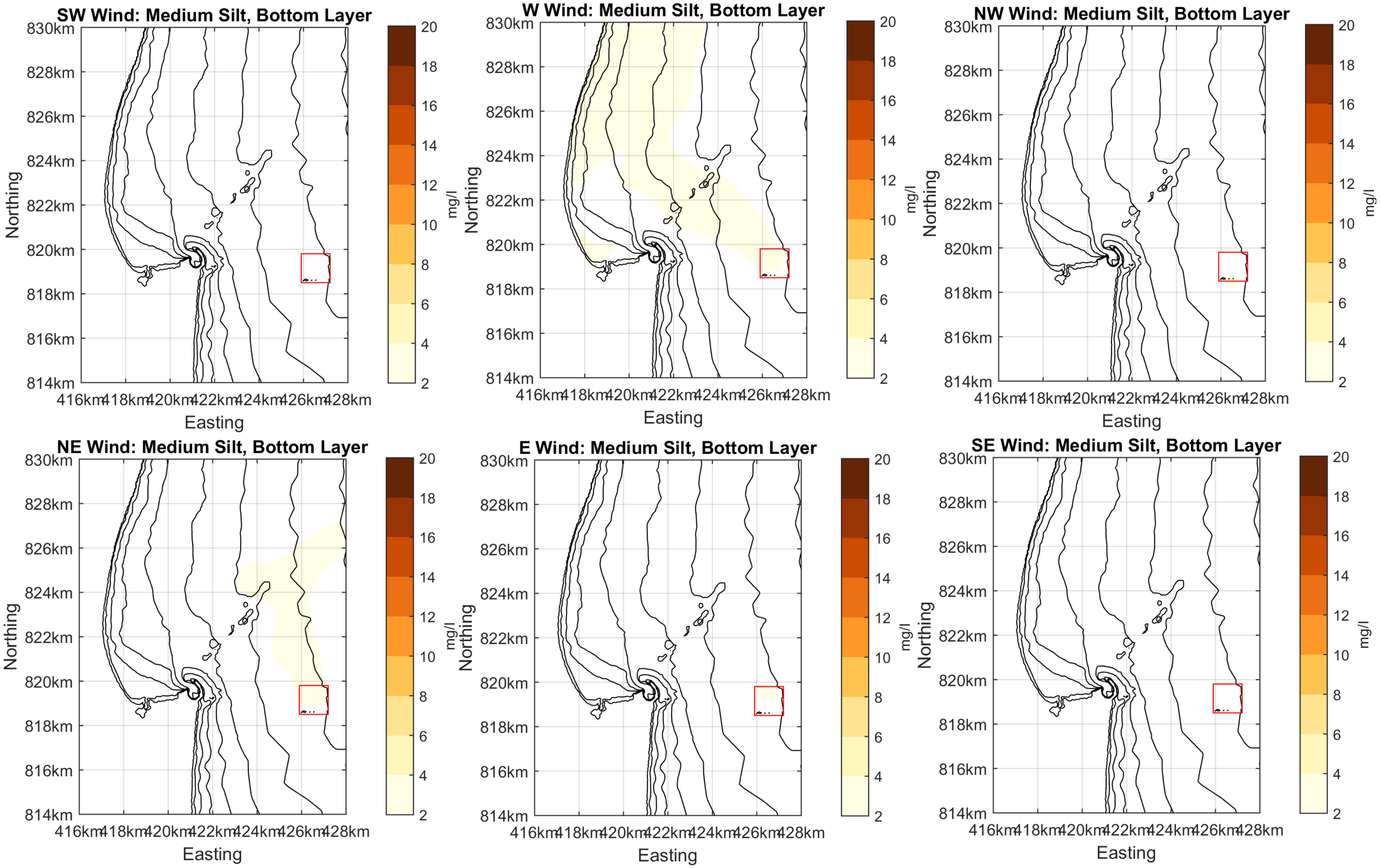

Figure 6-5: Turbidity plumes generated from resuspension of medium silt from the proposed offshore disposal site. Bottom layer.

6.3.3 Surface Turbidity, Coarse Silt

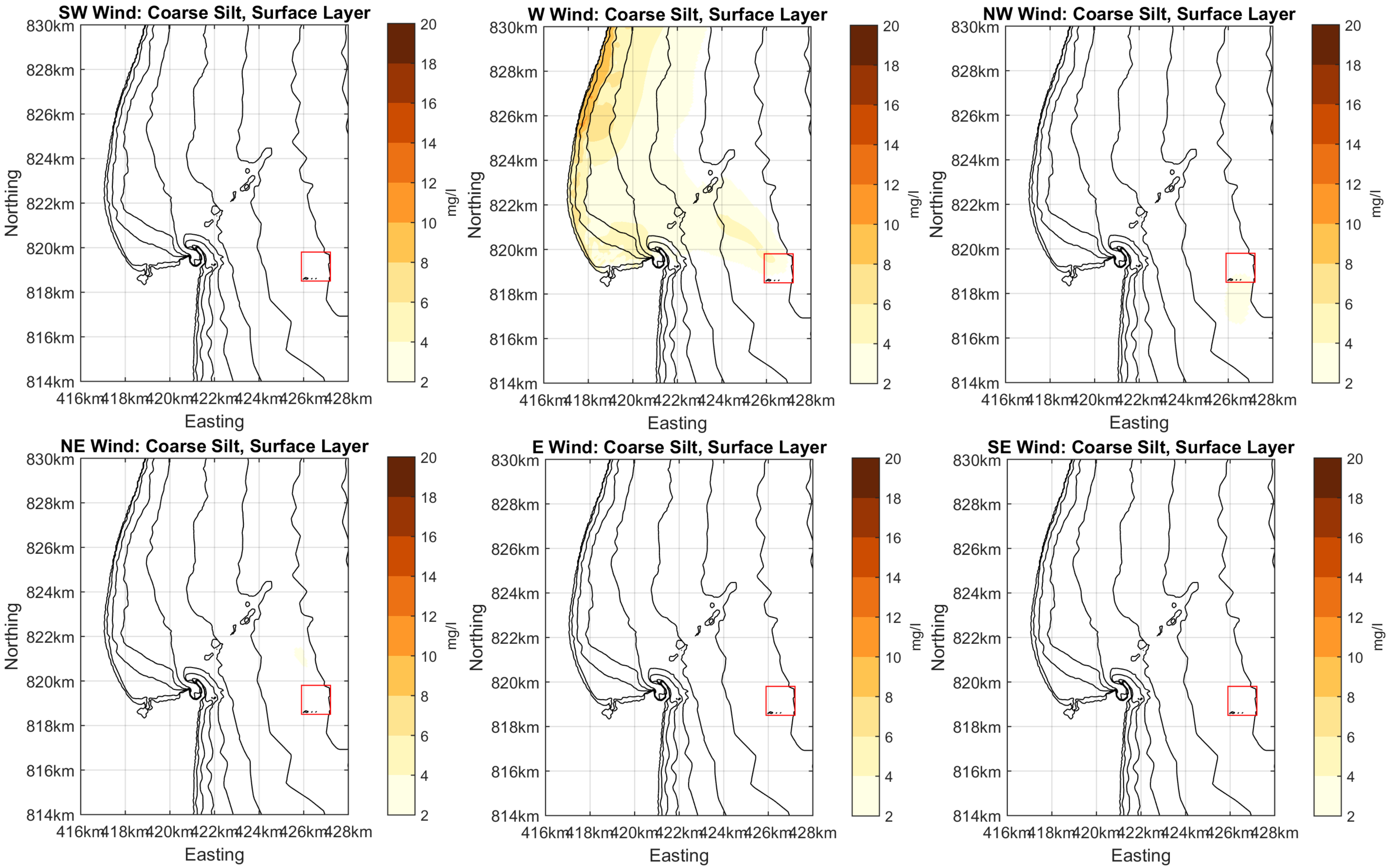

Figure 6-6: Turbidity plumes generated from resuspension of coarse silt from proposed offshore disposal site. Surface layer.

6.3.4 Bottom Turbidity, Coarse Silt

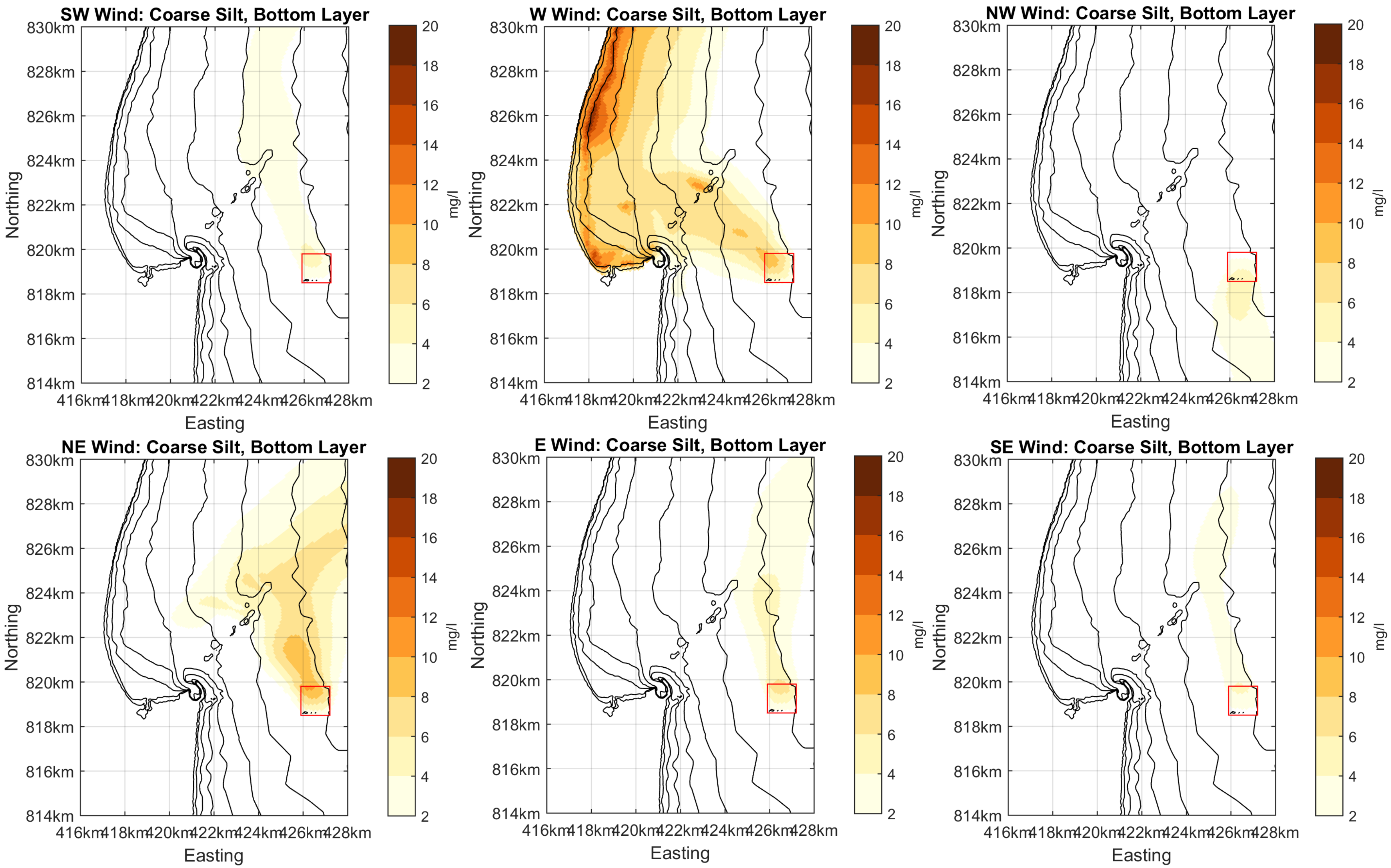

Figure 6-7: Turbidity plumes generated from resuspension of coarse silt from proposed offshore disposal site. Bottom layer.

7 Impact of Offshore Disposal Ground on Marine Parade

7.1 Introduction

In general, beaches tend to be aligned in the direction of incident waves and any changes to wave direction will affect coastal morphology. Changes to wave height govern the speed at which this adjustment to beach morphology will happen.

The degree to which waves are refracted, focussed or scattered depends on the wave incidence angle and wave period. A convenient method of visualising changes to the wave climate is therefore to assess the 'energy-weighted mean wave condition'.

7.2 Method of Assessment

The method is summarised as follows:

1. Classify the incident wave climate to discrete combinations of intervals of mean wave direction, period and wave height.

2. Calculate the occurrence probability of each combination of [MWD, T_p, H_{m0}]. Weight the occurrence probability in accordance to the energy of each bin. That is, weight in accordance to the square of the wave height.

3. Apply each combination of [MWD,Tp,Hm0] as a boundary condition to the wave model. For this analysis, some 200 combinations of wave direction, period and height were simulated.

4. Obtain values of simulated wave parameters at each grid point over all wave classes, and multiply by the energy-weighted occurrence probability. Summing over all weighted wave conditions results in the mean 'energy weighted' wave height, period and direction.

The advantage of this method is that by weighting the importance of each wave condition by its contribution to the total wave energy, relatively rare waves (e.g. large storms) that occur infrequently but are of importance to sediment transport are not neglected. Similarly, the contribution from frequently occurring but small waves is not exaggerated.

7.3 Results

7.3.1 Geometry of proposed offshore spoil disposal ground

The footprint of the proposed disposal ground considered in this analysis is shown by the area bounded by the red box in Figure 7-1 and Figure 7-2. The height differential due to spoil material was considered as +2 m above ambient levels. This level was edited into the model bathymetry.

Napier Port intends to deposit sediment in the spoil ground to a mean thickness of approximately 1 metre, so the modelling is conservative and the impacts likely to be less than those presented in this report.

7.3.2 Changes to Energy Weighted Wave Height and Direction

The predicted change to energy-weighted wave height is shown in Figure 7-1. That for energy-weighted wave direction is shown in Figure 7-2. The results show:

- The impact of the proposed disposal ground on wave refraction is rather localised, being constrained mainly to due west of the spoil ground.
- There is no change to the energy-weighted mean wave direction at the shoreline.
- There is modification of wave height due to wave refraction by the spoil ground. The maximum change to the energy-weighted wave height at the shore is limited to ±4 cm. This is less than 4% of the incident energy-weighted wave height at the Triaxis wave buoy operated by the Port.
- Any impacts on wave height at Marine Parade Beach due to the proposed offshore disposal site are limited to a distance of 1 km south of Town Reef.

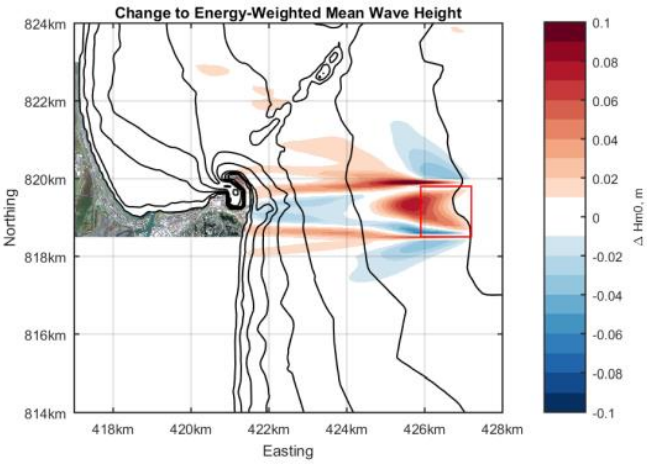

Figure 7-1: Change to energy-weighted mean wave height due to 2m accumulation of sediment within the proposed disposal area boundaries.

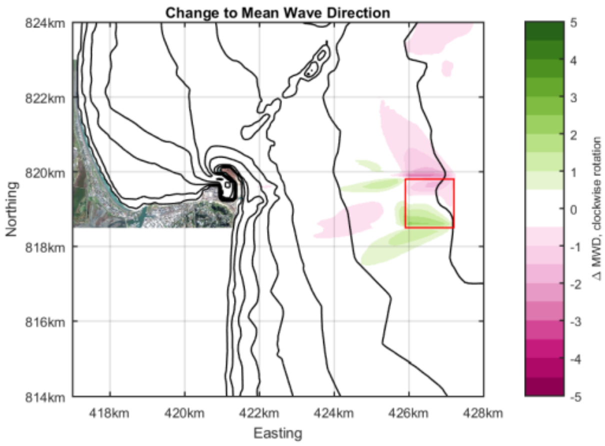

Figure 7-2: Change to energy-weighted mean wave direction due to 2m accumulation of sediment within the proposed disposal area boundaries.

7.3.3 Potential for Impact to Shoreline Orientation

The transport of gravel on the beach in the along-shore direction is a function of incident wave direction and wave height. The wave height affects the rate of sediment transport, whereas the equilibrium shoreline orientation is determined by the incident wave direction. For the predicted change in wave energy suggested by the simulations, no change to longshore sediment transport or shoreline orientation is expected to occur.

8 Summary and Conclusions

8.1 Introduction

This report has presented analysis and detailed modelling of the expected behaviour of sediments after disposal at (a) an inshore and (b) an offshore disposal site. The inshore site is located west of the Port navigation channel, in about 6 – 7 m water depth. The offshore site is located in about 20 m water depth.

The analysis in this report has been designed to answer to the following questions to inform the consenting process application:

a) Is there potential for sandy sediments disposed of at the 'inshore' disposal ground to be reworked to the navigation channel by the action of waves and currents?
b) What is the potential for resuspension of silty and sandy sediments disposed of at the 'offshore' spoil disposal site? Is there potential for sediments resuspended at the offshore site to be transported towards Pania Reef?
c) Will placement of dredge spoil material at the offshore disposal site have consequential impacts at Marine Parade Beach via influencing wave refraction?

Our analysis has considered both 'data-driven' (empirical) and 'model driven' (numerical) approaches to answer the above questions as described as follows:

- Data driven (empirical) analysis of sediment transport magnitude and direction was undertaken at three ADCP current meter deployments around Napier Port. The currents measured at each location over a period of weeks to months have been used in combination with a statistical description of the wave climate to assess the magnitude and direction of sediment transport. The analysis has assumed that current data measured at each site is representative of that expected to occur over the course of a year.

- Numerical simulation of sediment transport patterns for a select number of sediment diameters, for energetic wind speeds occurring from each of the 6 main wind directions. An energetic wave condition has been assumed with this to provide wave stirring. The sediment transport patterns have been used to provide spatial context to the 'point' measurements and corroborate interpretation of the anticipated movements of dredge sediments in the marine environment.

- Potential for disposal at the offshore site to impact morpodynamic behaviour at Marine Parade beach has also been assessed through consideration of changes to the energy-weighted mean wave height and direction.

8.2 Fate of Sediment disposed of at Inshore Disposal Areas

Analysis of ADCP current meter and numerical model results show clearly the potential for sediments to be transported from any disposal site west of the Port, towards the navigation channel.

The majority of spoil sediments correspond to a particle diameter between 100 µm and 200 µm, with the median being around 125 µm. Examining the ‘annual average’ transport patterns for these three sediment diameters shows clearly the presence of an anticyclonic circulation of sediment adjacent to the Port navigation channel and the eastward transport of fine sediments in the nearshore area.

8.3 Fate of Sediment disposed of at Proposed Offshore Disposal Area

Assessment of ADCP current meter data suggests that, for the analysis period considered, currents are directed away from Pania Reef approximately 70% of the time. Assessing non-cohesive sediment transport for the current data available suggests that transport is directed between SSW and SSE over 90% of the time.

Analysis of the potential for turbid plume generation at the proposed offshore disposal area during consolidation of fine sediments disposed of in deep water found that under extremely conservative assumptions on storm wind speed and storm longevity, the maximum turbidity that could be expected to occur on Pania Reef during a severe storm condition is roughly 6 mg/l above ambient. Analysis of the wind record suggests that the recurrence interval of this storm intensity and duration is greater than 15 years. Although sediments can be suspended over Pania Reef, deposition during such storm events cannot occur as the shear stress at Pania Reef will be much higher than the critical shear stress for deposition.

8.4 Potential for impacts to Marine Parade Beach

Assessment of the energy-weighted mean wave condition shows that no change is expected to the mean wave direction. The mean wave height is expected to vary slightly, with a predicted maximum change on the order of ±5 cm. This corresponds to a change in the incident wave height of less than 4%.

The transport of gravel on the beach in the along-shore direction is a function of incident wave direction and wave height. The wave height affects the rate of sediment transport, whereas the equilibrium shoreline orientation is determined by the incident wave direction. For the predicted change in wave energy suggested by the simulations, no change to longshore sediment transport or shoreline orientation is expected to occur.

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Appendix A: [Glossary]

Glossary

The following meanings are attached to terms that may be used within this report:

Accretion	The accumulation of (beach) sediment, deposited by natural fluid flow processes.
Algorithm(s)	Formula or combination of formulae used for calculations.
Alongshore	Parallel to and near the shoreline; same as longshore.
Amphibolis	A type of seagrass that forms meadows on calcareous sands. The interweaving roots and leaves consolidate the substrate of the ocean floor, protecting it from erosion by currents and wave action.
Astronomical tide	The tidal levels and character which would result from gravitational effects, e.g. of the Earth, Sun and Moon, without any atmospheric influences.
Backshore	(1) The upper part of the active beach above the normal reach of the tides (high water), but affected by large waves occurring during a high tide. (2) The accretion or erosion zone, located landward of ordinary high tide, which is wetted normally only by storm tides.
Bank	See Shoal
Bar	An offshore ridge or mound of sand, gravel, or other unconsolidated material which is submerged (at least at high tide), especially at the mouth of a river or estuary, or lying parallel to and a short distance from, the beach.
Bathymetry	The measurement of depths of water in oceans, seas and lakes; also the information derived from such measurements.
Bay	A recess or inlet in the shore of a sea or lake between two capes or headlands, not as large as a gulf but larger than a cove. See also *bight*, *embayment*.
Beach	The zone of unconsolidated material that extends landward from the low water line to the place where there is marked change in material or physiographic form, or to the line of permanent vegetation. The seaward limit of a beach – unless otherwise specified – is the mean low water line. A beach includes foreshore and backshore.
Beach erosion	The carrying away of beach materials by wave action, tidal currents, littoral currents or wind.
Beach face	The section of the beach normally exposed to the action of wave uprush. The foreshore of the beach.
Beach profile	A cross-section taken perpendicular to a given beach contour; the profile may include the face of a dune or sea wall, extend over the backshore, across the foreshore and seaward underwater into the nearshore zone.
Beach width	The horizontal dimension of the beach measured normal to the shoreline.

Beach nourishment	The process of placing sand from elsewhere onto an eroding shoreline to create a new beach or to widen an existing beach. Beach nourishment manages erosion by replacing sand lost and providing new sand to continue to feed the sand losing process.
Bed	The bottom of a watercourse, or any body of water.
Berm	On a beach: a nearly horizontal plateau on the beach face or backshore, formed by the deposition of beach material by wave action or by means of a mechanical plant as part of a beach recharge scheme.
Boussinesq	Boussinesq, J was a French mathematician and physicist who made significant contributions to the theory of hydrodynamics, specifically wave action. Boussinesq-type equations are used in computer models for the simulation of water waves in shallow seas and harbours. This type of modelling is considered to give the best representation of wave transformation that is possible at present.
Breaker zone	The zone within which waves approaching the coastline commence breaking, typically in water depths of between 5 m and 10 m on the open coast but in shallower waters within bays.
Breaking depth	The still-water depth at the point where the wave breaks.
Breakwater	Offshore structure aligned parallel to the shore, sometimes shore-connected, that provides protection to the shore from waves.
Calcarenite	A type of limestone that is composed predominantly of sand-size carbonate grains of, typically, corals, shells, fragments of older limestones and dolomites, other carbonate grains, or some combination of these. Calcarenite is the carbonate equivalent of sandstone.
CD	Chart Datum – usually the lowest tide level and a reference level for nautical charts used for navigation.
Chart datum	The plane or level to which soundings, tidal levels or water depths are referenced, usually low water datum.
Climate change	Refers to any long-term trend in changes to mean sea level, wave height, wind speed, etc.
Coastal currents	Currents that flow usually parallel to the shore and constituting a relatively uniform drift in the deeper water adjacent to the surf zone. These currents may be tidal, transient, wind-driven or associated with oceanic currents.
Coastal processes	Collective term covering the action of natural forces, such as winds, waves and tides, on the shoreline and the nearshore seabed.
Coastal zone	The land-sea-air interface zone around continents and islands extending from the landward edge of a barrier beach or shoreline of coastal bay to the Continental Shelf.
Coastline	The line where terrestrial processes give way to marine processes, tidal currents, wind waves, etc.

Common Distributables	Project costs that are not associated with any specific direct account. These may include such things as the field office, office supplies, temporary construction, utilities, etc., which, usually, are borne by the owner
Continental Shelf	The underwater landmass that extends seaward from a continent, resulting in an area of relatively shallow water, generally less than 200 m deep, lying between the shoreline and the deep ocean. Much of the Continental Shelf was exposed during the ice ages.
Contingency	In estimating cost, an allowance for uncertainty as to the precise content of all items in the estimate, how work will be performed, what work conditions will be like when the project is executed and so on (the known-unknowns).
Current	Ocean currents can be classified in a number of different ways. Some important types include the following: - Periodic - due to the effect of the tides; such currents may be rotating rather than having a simple back and forth motion. The currents accompanying tides are known as tidal currents - Temporary - due to seasonal winds - Permanent or ocean - constitute a part of the general ocean circulation. The term drift current is often applied to a slow broad movement of the oceanic water - Nearshore - caused principally by waves breaking along a shore. Also, coastal currents that run parallel to the coast.
Datum	Any position or element in relation to which others are determined, as datum point, datum line, datum plane.
Deep water	In regard to waves, where depth is greater than one-half the wave length. Deep-water conditions are said to exist when the surf waves are not affected by conditions on the bottom.
Depth of closure (DoC)	For a given or characteristic time interval, the depth on a beach profile seaward of which there is no significant change in bottom elevation and no significant net sediment transport between the nearshore and the offshore during storms and ensuing calm weather.
Design Allowance	An allowance in a cost estimate for the growth of costs as more detail of the project evolves through design
Design storm	Coastal protection structures will often be designed to withstand wave attack by an extreme design storm. The severity of the storm (i.e., return period) is chosen in view of the acceptable level of risk of damage or failure. A design storm consists of a design wave condition, a design water level and a duration.
Direct Construction Cost	The estimate of the cost of construction (i.e., the construction contractor’s fee) based on the application of unit rates to quantities or a detailed assessment of the cost of labour and materials that would be required for specific tasks
Down-drift	The direction of predominant movement of littoral drift.

Dredging	Excavation or displacement of the bottom or shoreline of a water body. Dredging can be accomplished with mechanical or hydraulic machines. Most is done to maintain channel depths or berths for navigational purposes; other dredging is for shellfish harvesting or for cleanup of polluted sediments. It can be used also to win sand to nourish beaches.
Dunes	Accumulations of windblown sand on the backshore, usually in the form of small hills or ridges, stabilised by vegetation or control structures.
Ebb tide	A falling tide or that portion of the tidal cycle between high water and the following low water.
Ebb tide (current)	The tidal current generated by a falling tide and associated with the waters within an estuary or bay being directed seaward.
Elevation	The distance of a point above a specified surface of constant potential; the distance is measured along the direction of gravity between the point and the surface.
Embayed	Formed into a bay or bays; as an embayed shore.
Embayment	(1) An indentation in a shoreline forming an open bay. (2) The formation of a bay.
EPCM	Engineering, Procurement and Construction Management - a contracting arrangement in which the owner selects a contractor to provide "management services" for the whole project on behalf of the owner. The EPCM contractor coordinates all design, procurement and construction work and ensures that the whole project is completed as required and in time. The EPCM contractor may or may not undertake actual site work.
Erosion	(1) Wearing away of the land by natural forces. On a beach, the carrying away of beach material by wave action, tidal currents or by deflation. (2) The wearing away of land by the action of natural forces.
Escarpment	A more or less continuous line of cliffs or steep slopes facing in one general direction which are caused by erosion or faulting, also called scarp.
Event	An occurrence meeting specified conditions, e.g. damage, a threshold wave height or a threshold water level.
Fetch	The length of unobstructed open sea surface across which the wind can generate waves (generating area).
Flood tide	A rising tide or that portion of the tidal cycle between low water and the following high water.
Flood tide (current)	The tidal current generated by a rising tide and associated with the flow of waters directed towards an estuary or bay from the ocean.
Foreshore	In general terms, the beach between mean higher high water and mean lower low water.
Geology	The science which treats of the origin, history and structure of the Earth, as recorded in rocks; together with the forces and processes now operating to modify rocks.

Geomorphology	That branch of physical geography which deals with the form of the Earth, the general configuration of its surface, the distribution of the land, water, etc.
Groyne (groin in the United States)	A rigid hydraulic structure built from the shore that interrupts the movement of littoral drift.
Hardpan	Firm sub-soil of clay, etc., hard unbroken ground.
High water (HW)	Maximum height reached by a rising tide. The height may be solely due to the periodic tidal forces or it may have superimposed upon it the effects of prevailing meteorological conditions. Also called the high tide.
Inshore	(1) The region where waves are transformed by their interaction with the sea bed. (2) In beach terminology, the zone of variable width extending from the low water line through the breaker zone.
Inshore current	Any current inside the surf zone.
Intertidal	The zone between the high and low water marks.
Isobath	A line on a plan that defines points of equal depth.
LADS	Laser Airborne Depth Sounder used for bathymetric survey.
Lee shore	A nautical term applied usually to wind effects where a lee shore is downwind of a vessel; that is, the wind is blowing towards it over the vessel. In this context it refers to the shore on the side of a breakwater that is sheltered from wave effects.
Leeward	The direction toward which the prevailing wind is blowing; the direction toward which waves are travelling.
Littoral	(1) Of, or pertaining to, a shore, especially a seashore. (2) Living on, or occurring on, the shore.
Littoral currents	A current running parallel to the beach and generally caused by waves striking the shore at an angle.
Littoral drift	The mud, sand, or gravel material moved parallel to the shoreline in the nearshore zone by waves and currents.
Longshore	Parallel and close to the coastline.
Longshore transport rate	Rate of transport of sedimentary material parallel to the shore. Usually expressed in cubic meters per year.
Low water (LW)	The minimum height reached by each falling tide. Also called low tide.
Mean high water (MHW)	The average elevation of all high waters recorded at a particular point or station over a considerable period of time, usually 19 years.
Mean high water springs (MHWS)	The average height of the high water occurring at the time of spring tides.
Mean low water (MLW)	The average height of the low waters over a 19-year period. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the result to the equivalent of a mean 19-year value.
Mean low water springs (MLWS)	The average height of the low waters occurring at the time of the spring tides.

Mean sea level	The average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings (see *sea level datums*).
Morphology	River/estuary/lake/seabed form and its change with time.
Neap tide	A tide around the first or third quarters of the moon when there is least difference between high and low waters.
Nearshore	In beach terminology an indefinite zone extending seaward from the shoreline well beyond the breaker zone.
Nearshore circulation	The ocean circulation pattern composed of the nearshore currents and the coastal currents.
Nearshore current	The current system caused by wave action in and near the breaker zone and which consists of four parts: the shoreward mass transport of water; longshore currents; rip currents; and the longshore movement of the expanding heads of rip currents.
Nourishment	See Beach nourishment.
Offshore	In beach terminology, the comparatively flat zone of variable width, extending from the shoreface to the edge of the Continental Shelf.
Offshore breakwater	A breakwater built towards the seaward limit of the littoral zone, parallel (or nearly parallel) to the shore.
Offshore currents	(1) Currents outside the surf zone.
	(2) Any current flowing away from the shore.
Offshore wind	A wind blowing seaward from the land in the coastal area.
Onshore wind	A wind blowing landward from the sea.
Outflanking	erosion behind or around the inner end of a Groyne or bulkhead, usually causing failure of the structure.
Photogrammetry	The science of deducing the physical dimensions of objects from measurements on images (usually photographs) of the objects.
Progradation	The seaward movement of a coastline when sediment input exceeds the rate of erosion.
Prograde	Coastline advance towards the sea as a result of the accumulation of waterborne sediment.
Recession	A net landward movement of the shoreline over a specified time.
Reflected wave	That part of an incident wave that is returned (reflected) seaward when a wave impinges on a beach, seawall or other reflecting surface. Waves may be reflected off deep channels by the process of wave refraction.
Reflection	The process by which the energy of the wave is returned seaward or in a partially opposing direction to which it is travelling. Waves may be reflected off deep channels by the process of wave refraction.
Refraction	The process by which the direction of a wave moving in shallow water at an angle to the bottom contours is changed. The part of the wave moving shoreward in shallower water travels more slowly than that portion in deeper water, causing the wave to turn or bend to become parallel to the isobaths. Refraction also can cause waves to "reflect" off a deeper channel.

Return period	Average period of time between occurrences of a given event.
RSA	Rapid Sediment Analysis – settling tube analysis equilibrating the fall velocities of the sands to their grain diameters as carried out at the University of Auckland.
Salient	A bulge of sand projecting from the shore in the lee of an offshore breakwater.
Sand	An unconsolidated (geologically) mixture of inorganic soil (that may include disintegrated shells and coral) consisting of small but easily distinguishable grains, usually and mainly quartz, ranging in size from about 0.062 mm to 2.000 mm.
Sand dune	A mound formed of sand that extends usually along the shore at the back of a beach.
Sand wave	A seabed feature in sand comprising a long undulating form generated by strong currents and reflecting sand transport.
Schema	Outline diagram or proposed arrangement.
Sea	Refers to short-crested waves generated locally by the wind. Within Port Phillip Bay their periods range from 1 s to 5 s.
Sea level rise	The long-term trend in mean sea level.
Seawall	A structure separating land and water areas primarily to prevent erosion and other damage by wave action.
Sediment	Loose, fragments of rocks, minerals or organic material which are transported from their source for varying distances and deposited by air, wind, ice and water. Other sediments are precipitated from the overlying water or form chemically, in place. Sediment includes all the unconsolidated materials on the sea floor.
Shoal	(1) (noun) A detached relatively shallow area of sand or mud the depths over which may be a danger to surface navigation. Can also be termed a bank. (2) (verb) As pertaining to waves becoming shallow gradually.
Shore	That strip of ground bordering any body of water which is alternately exposed, or covered by tides and/or waves. A shore of unconsolidated material is usually called a beach.
Shoreface	The narrow zone seaward from the low tide shoreline permanently covered by water, over which the beach sands and GRAVELS actively oscillate with changing wave conditions.
Shoreline	The intersection of a specified plane of water with the shore.
Shoreline protection structure	A structure on the shore or nearshore, such as a groyne, revetment or seawall, constructed typically of rock, concrete or sandbags, and designed to protect the shore from recession.
Significant wave	A statistical term relating to the average of the one-third highest waves of a given wave group and defined by the average of their heights and periods.
Significant wave height	Average height of the highest one-third of the waves for a stated interval of time.

Silt	Sediment particles with a grain size between 0.004 mm and 0.062 mm, i.e., coarser than clay particles but finer than sand.
Spectral wave model	A computer program that schematises wind wave spectra in all directions and frequencies and computes their evolution and transformation in coastal regions with shallow water and ambient current.
Spring tide	A tide that occurs at or near the time of new or full moon and which rises highest and falls lowest from the mean sea level (MSL).
Storm surge	A rise or piling-up of water against shore, produced by strong winds blowing onshore. A storm surge is most severe when it occurs in conjunction with a high tide.
Subaerial beach	That part of the beach which is not covered by water (i.e., where users sit and sunbake, etc.).
Surf zone	The nearshore zone along which the waves become breakers as they approach the shore.
Survey, hydrographic	A survey that has as its principal purpose the determination of geometric and dynamic characteristics of bodies of water.
Survey, photogrammetric	A survey in which monuments are placed at points that have been determined photogrammetrically.
Survey, topographic	A survey which has, for its major purpose, the determination of the configuration (relief) of the surface of the land and the location of natural and artificial objects thereon.
Swell	Waves that have travelled a long distance from their generating area and have been sorted out by travel into long waves of the same approximate period. Swell wave periods range from 6 s to 25 s.
Tide	The periodic rising and falling of the water that results from gravitational attraction of the moon and sun acting upon the rotating earth. Although the accompanying horizontal movement of the water resulting from the same cause is also sometimes called the tide, it is preferable to designate the latter as tidal current, reserving the name tide for the vertical movement.
Tidal Current	The flow of water induced by the rise and fall of the tide.
Tombolo	A deposition landform in which an island is attached to the mainland by a narrow sand spit or bar.
Topographic map	A map on which elevations are shown by means of contour lines.
Topography	The form of the features of the actual surface of the Earth in a particular region considered collectively.
Vector	In this context, an arrow on a plan delineating the speed and direction of tidal flow or the transport of sediment as derived from modelling.
Vibrocoring	A technique for collecting core samples of underwater sediments. The core tube is driven into sediment by the force of gravity, enhanced by vibration energy.

Wave	(1) An oscillatory movement in a body of water manifested by an alternate rise and fall of the surface. (2) A disturbance of the surface of a liquid body, as the ocean, in the form of a ridge, swell or hump.
Wave climate	The range of wave conditions and their occurrence, as shown by height, period, direction, etc., at a place as measured over periods of years.
Wave direction	The direction from which waves are travelling.
Wave generation	Growth of wave height and period by wind action.
Wave height coefficient	The ratio between the height of a wave in a nearshore area to its height in deep water
Wave propagation	The development of water waves from wind action.
Wave transformation	The process of wave transmission through shallow waters and tidal currents.
Wind current	A current created by the action of the wind.