EASTLAND PORT MAINTENANCE DREDGING AND DISPOSAL PROJECT

Morphological response of the offshore disposal ground to maintenance dredging

Report prepared for Eastland Port, Gisborne

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MetOcean SOLUTIONS

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Contents

List of Figures

List of Tables

1. Introduction

Eastland Port Ltd are seeking to renew their maintenance dredging and disposal consents at the Port of Gisborne.

Currently, dredged sediment is disposed at an offshore disposal site situated in approximately 18 – 20 m water depth (**Error! Reference source not found.**), with an average annual rate of approximately 73,000 m^3 based on estimates obtained between 2002 and 2019 by Eastland Port.

Maintenance dredging is expected to occur using the Trailing Suction Hopper Dredge (TSHD) “Pukunui” although, if there are significant inflows of sediment due to large storm events, a higher productivity Trailing Suction Hopper Dredge (TSHD) may be required to ensure the required port and channel depths can be maintained. It is likely that some maintenance dredging may also be undertaken using a Backhoe Dredger (BHD) or Cutter Suction Dredger (CSD).

MetOcean Solutions (MOS) has been contracted to provide coastal oceanographic expertise to investigate both physical and morphological effects and associated sediment transport patterns resulting from the dredging and disposal of maintenance dredging material at the current disposal site. For this purpose, the process-based model Delft3D has been used to hindcast the sediment dynamics over northern Poverty Bay and Eastland Port. This included the use of combined reduction techniques and morphological acceleration factors (MORFACs) as well as storm-induced morphological reconstructions. Qualitative and quantitative calibration has been achieved through the comparison of morphological model outputs against measurements.

In this study, the calibrated numerical model extents have been expanded to include the entire Poverty Bay and have been used to assess the likely morphological response of the proposed offshore disposal ground to ambient wave and hydrodynamic conditions. The present report is a technical reference document that investigates the physical process affecting the proposed disposal site as well as the likely effects of the disposal on the existing environment. Details of the morphological modelling approach, including calibration and validation can be found in MetOcean Solutions (2018b).

The report is structured as follows; the methodology applied in this study is presented in Section 2, including a description of the numerical modelling approach followed to assess the disposal ground dynamics. An assessment of the effect of dredge spoil disposal is provided in Section 3. A brief summary is presented in Section 4 while the references cited in this document are listed in Section 5.

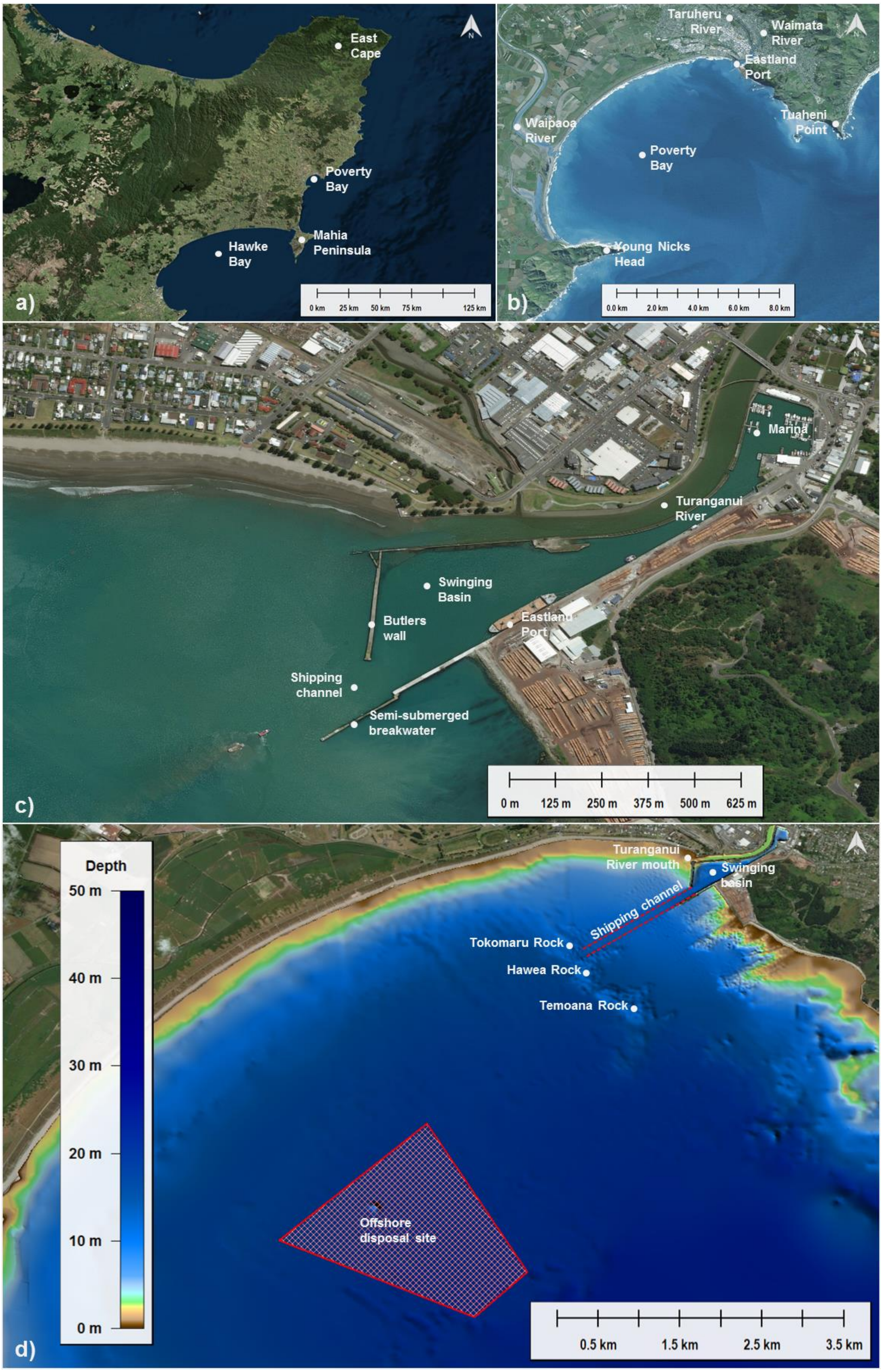


Figure 1.1 Maps showing the location of Poverty Bay (a, b), and Eastland Port (c) with the locations used in the present study. Both offshore disposal and shipping channel are indicated on top of the bathymetry in (d).

2. Methods

The primary objective of the study was to predict the likely morphological response of the proposed offshore disposal ground to the ambient wave and hydrodynamic conditions following disposal of maintenance dredged material. To meet this objective, the numerical modelling was carried out applying input reduction techniques combined with the use of morphological acceleration factors into the Delft3D system. The successful validation of the numerical model in MetOcean Solutions (MetOcean Solutions, 2018b) showed this approach was suitable for predicting medium-term sediment dynamics within Poverty Bay.

The present section details the methodology used to undertake both the impact and the disposal assessments of the proposed disposal program.

2.1 Numerical modelling strategy

2.1.1 Initial bathymetry

In MetOcean Solutions (2018b), the process-based model Delft3D was used to hindcast the sediment dynamics over the northern Poverty Bay and Eastland Port environs. Single and multi-beam survey data were used to determine morphological changes and used to calibrate and validate the Delft3D morphological model.

Within the morphological model framework (MetOcean Solutions, 2018b), the expected maintenance annual dredging volume were homogeneously spread throughout the offshore disposal ground (Figure 1.1). This approach is considered conservative, as the applied methodology does not consider the fraction of sediment dispersed from the disposal ground during disposal activities (MetOcean Solutions, 2018a) before settlement or the amount of sediments potentially eroded between the maintenance dredging operations. This "worst-case" scenario aims to bound the potential effects of the disposal ground on the existing environment.

To isolate the effect of dredged sediment discharged at the disposal ground, the initial model conditions assumed sediment available only within the disposal ground, which is then progressively dispersed throughout the sequence of representative events.

The annual maintenance dredging volume associated with the existing channels and swinging basin bathymetry is predicted to range between 75,000 $m^3.yr^{-1}$ and 120,000 $m^3.yr^{-1}$ for "La Nina" and "El Nino" simulated periods, respectively (MetOcean Solutions, 2018b). As such, two scenarios were simulated; the first one considered a total disposal volume of 75,000 m^3 and a disposal mound height of 0.028 m; the second considered a total volume of 120,000 m^3 and a disposal mound height of 0.044 m (~0.2% of the water column). Details of the dredging and disposal volumes and heights are given in Table 2.1.

Table 2.1 Details of the dredging and disposal volumes at Eastland Port from previous morphological modelling.

Period	Annual Maintenance Dredging Volume [m^3]	Disposal Mound Area [m^2]	Disposal Mound Height [m]
La Niña	75,000	2,714,050	0.028

El Niño	120,000	2,714,050	0.044

2.1.2 Multi-grain size model

The morphological model was set up using mud, very fine-grained and fine-grained sand sediment classes. The spatial distribution of sediments was homogeneously initialised over the disposal area using the bed composition analysis from the sediment sampling within the navigation channel and the inner basin (i.e. the sediment expected to be dredged). Surficial sediment characteristics are defined as below:

- The disposal mound is composed of 66% cohesive particles (silt). These particles are characterised in the model with a dry bed density of 650 kg.m^{-3} and a settling velocity ranging from 0.05 to 0.65 mm.s^{-1} depending on the ratio of saline and fresh waters. By contrast with the channel modelling study, the critical shear stress is constant over the domain with a value of 0.018 N.m^{-2}. The operations of disposal make the material weakly consolidated. For this reason, the lowest value of critical shear stress provided in Van Rijn (2016) has been applied based on the ratio of mud/sand (Figure 2.1).
- Non-cohesive very fine-grained and fine-grained sand particles compose 19% and 15%, respectively, of the sediment within the model disposal ground. A dry bed density of 1350 kg.m^{-3} is used, with median sediment diameters (d50) of 110 µm and 180 µm respectively.

These sediment parameters are consistent with the disposal plume modelling study provided in MetOcean Solutions (2018a).

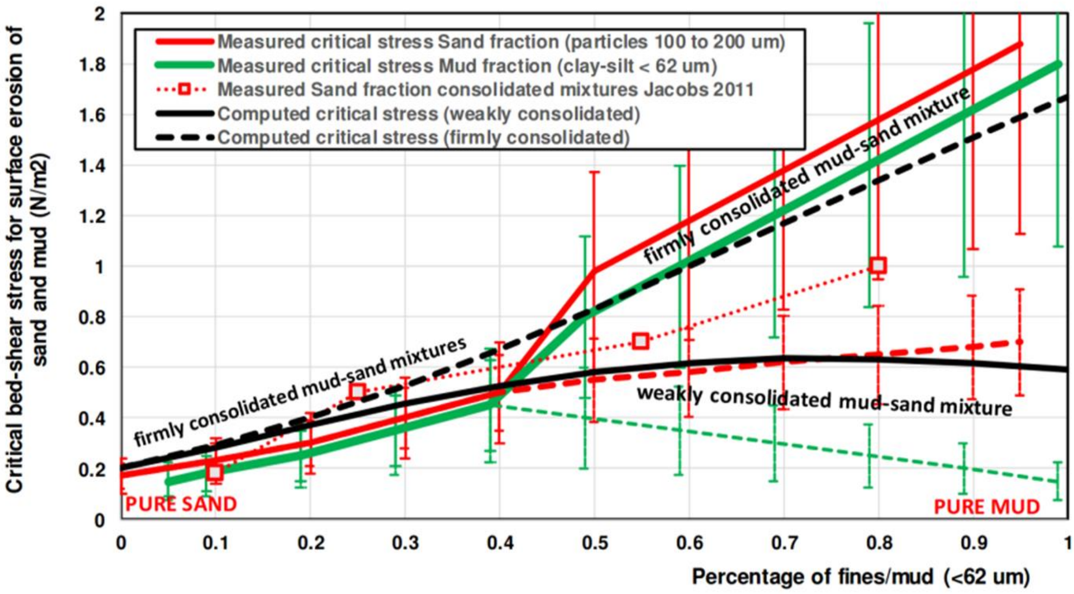


Figure 2.1 Empirical relationship between critical bed-shear stress for surface erosion and percentage of fine-grained sand/mud as described in Van Rijn (2016).

2.1.3 Scenarios and forcing

The medium-term disposal modelling included two simulations from June 1998 to May 1999 and from June 2002 to May 2003. These periods were characterised, respectively, by "La Niña" and "El Niño" phases of "El Nino – Southern Oscillation" (ENSO). Waves, currents and river discharges were defined as in MetOcean Solutions (2018b) to allow assessing the morphological response of the proposed disposal mound.

Additionally, the Delft3D – WAVE model ran standalone to assess the effect of the 0.044 m disposal mound on the nearshore wave climate, therefore, nohydrodynamic forcing or morphological update was applied. The wave model was used in stationary mode based on the 6 representative scenarios used in the morphological modelling (Table 2.2).

Table 2.2 Significant wave height (Hs), direction (Dp) and period (Tp) for the six representative wave classes used in the Delft3D – WAVE standalone simulations.

Classes	Hs (m)	Dp (deg)	Tp (s)
Class 1	2.16	100.42	10.02
Class 2	3.18	89.86	10.56
Class 3	4.75	73.67	10.44
Class 4	2.49	215.40	11.98
Class 5	3.53	219.84	12.01
Class 6	5.72	232.19	12.05

2.2 Model settings

The morphological model domain was extended to encompass the entire Poverty Bay with a grid resolution ranging from 25 m to 200 m (see Figure 2.2). The applied wave and hydrodynamic model settings were consistent with the settings applied in MetOcean Solutions (2018b). The critical shear stress, dry bulk densities and mean sediment diameters (d_{50}) of cohesive and non-cohesive particles were as described in Section 2.1.2.

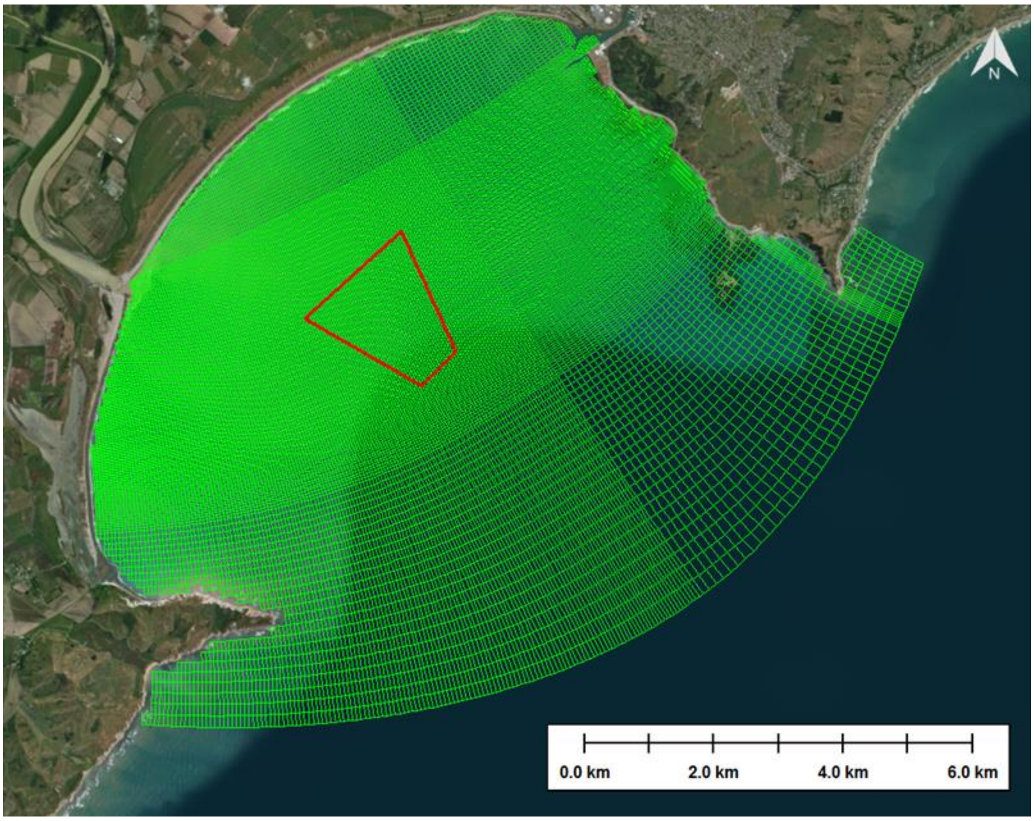


Figure 2.2 Map showing the Delft3D – FLOW and MOR grids used to replicate the hydro- and morpho-dynamics over northern Poverty Bay and the disposal ground (red polygon).The resolution of the grid ranged from 30 m to 200 m.

2.3 Measured disposal changes

Five hydrographic surveys of the offshore disposal ground are available for analysis, providing four periods over which the morphological response of the disposal ground can be examined, i.e.

- 01/2005 to 08/2007
- 08/2007 to 11/2009
- 11/2009 to 06/2012
- 06/2012 to 02/2017

During these periods, maintenance dredge material was disposed of at the site.

The morphology at the disposal ground is controlled by the hydrodynamic processes at the site (waves, tidal and residual current velocities) and sediment inputs. The offshore disposal ground receives sediment inputs from maintenance dredge disposal and Waipaoa River plume discharges, as well as parabathic and diabathic sediment transport. The combination of processes and various sediment sources makes it difficult to isolate the effect of maintenance disposal activities on the overall morphological response of the offshore disposal ground, with morphological changes at the offshore disposal ground varying over the measurement periods available. As such, it is impossible to quantitatively distinguish the impact of maintenance dredging on the morphological response of the system. However, qualitatively these data can be used to examine morphological response of the disposal ground to the combined sediment inputs:

- Between 01/2005-08/2007 most of the disposal area experienced accretion of the order 0.1-0.2 m (average) and a maximum of approximately 0.5 m, while the south eastern corner experienced a net deficit of sediment, with depths increasing by ~0.2 m (Figure 2.3).
- Between 08/2007-11/2009 sediment accretion of the order 0.2 m is observed within the north-western corner of the disposal ground (inshore), while net erosion of a similar magnitude is expected within the S-SE section of the disposal ground (Figure 2.3).
- Between 11/2009-06/2012 most of the disposal area experienced accretion of the order 0.1-0.2 m (average) and a maximum of approximately 0.4 m (Figure 2.3).
- Between 06/2012-02/2017 the offshore disposal ground experienced a net negative sediment budget, with water depths increasing by ~0.1-0.2 m and a maximum of approximately 0.4 m. Minor areas of accretion were measured within the inner most sections of the disposal ground (Figure 2.3).

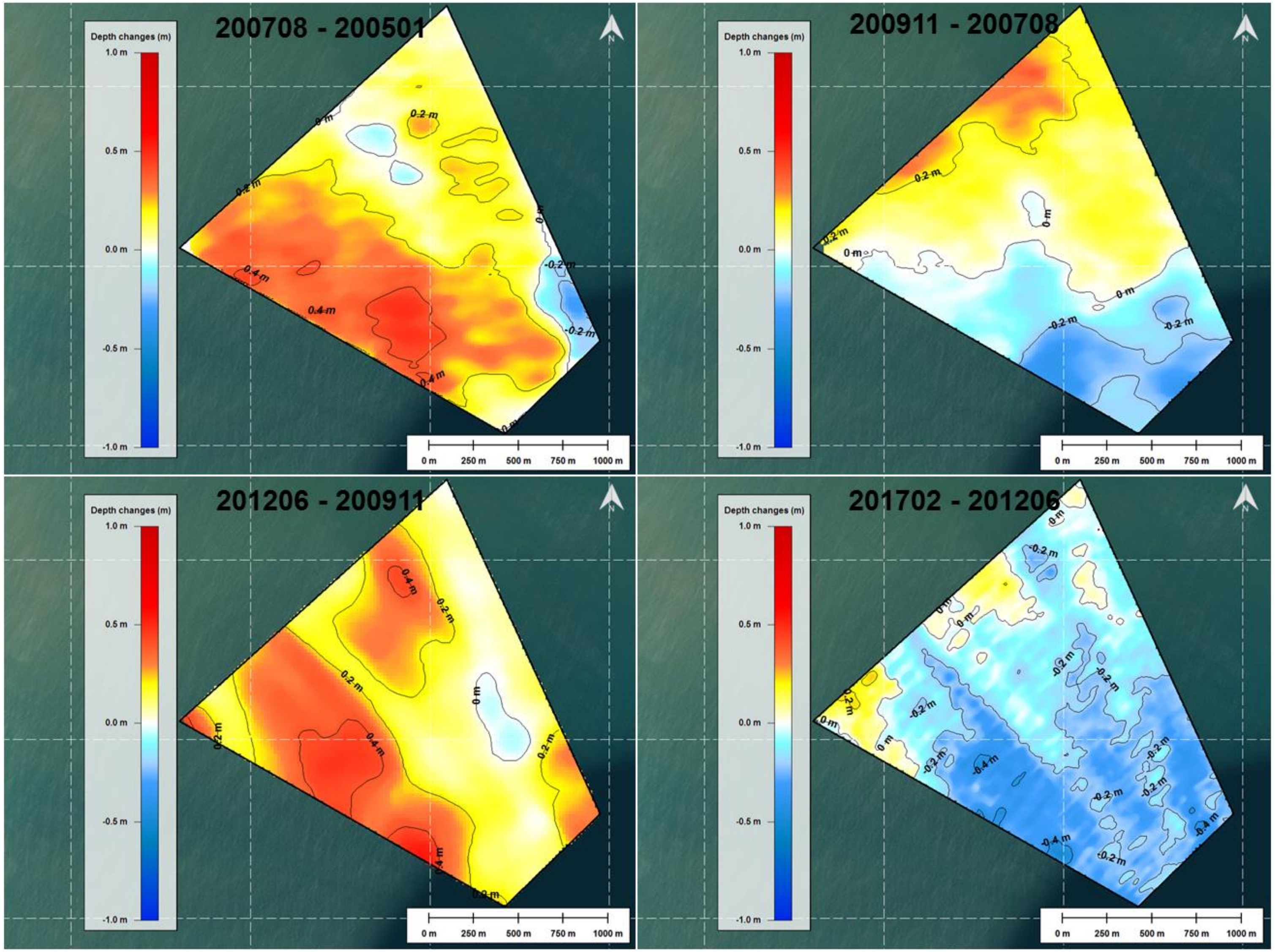


Figure 2.3 Measured depth changes over the disposal area for four different periods.

3.Results

3.1 Effect of disposal on the nearshore wave climate

The maximum disposal mound associated with the maintenance dredging requirements expected under El Niño climatic conditions (i.e. 0.044 m, see section 2.1.1) is expected to have minimal effect on the inshore significant wave height (Figure 3.1 to Figure 3.6).

Due to wave refraction over the disposal mound, areas of slightly increased wave height are expected inshore of the disposal ground, with the location of the wave height increase dependant on the incident wave direction. Conversely, areas of slightly reduced wave height are expected along each shore normal edge of the disposal ground and inshore, with the locations of reduced wave energy also dependent on the incident wave direction (Figure 3.1 to Figure 3.6).

The changes in wave height are of the order 0.005 m, with a maximum increase of ~0.01 m and maximum decrease of 0.006 m. This corresponds to an approximate 0.2% change in wave heights, which is consistent with the water depth modification (~0.2%) related to the disposal of 120,000 m^3 of sediment at the offshore disposal ground. In general, the mound had a negligible effect on the wave direction approaching the coast. Figure 3.7 shows the difference in wave direction at the 10-m isobath across the area where changes in wave height are expected. Only wave class 5 had detectable changes, at one location, which is unlikely to modify the overall sediment transport patterns and beach shoreline. Therefore, changes in both wave height and wave direction caused by the disposal mound are expected to have negligible effects on the inshore morphological processes and recreational surfing conditions.

Results presented assume no morphological changes to the disposal mound over the extended period maintenance dredging is expected to occur over. As such, presented results are considered to represent the worst-case outcome in terms of wave height modifications over the disposal mound and inshore. The response of the disposal mound in terms of sediment dynamics is examined in Section 3.2.

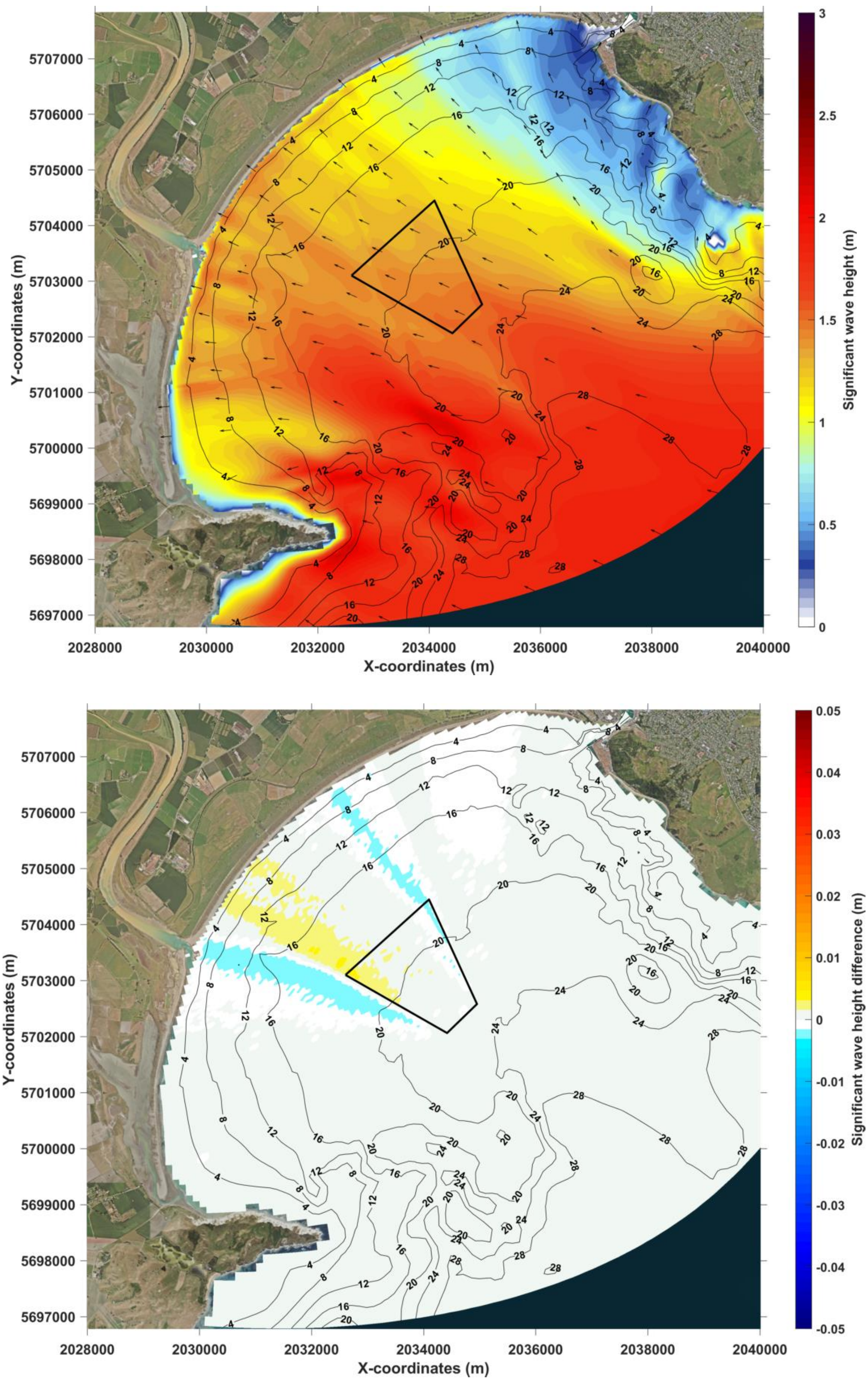


Figure 3.1 Post-disposal significant wave height (top) and difference in significant wave height (bottom) caused by the 4.4 cm disposal mound for the wave class 1 (Hs = 2.16 , Tp = 10.02 , Dir = 100.42).

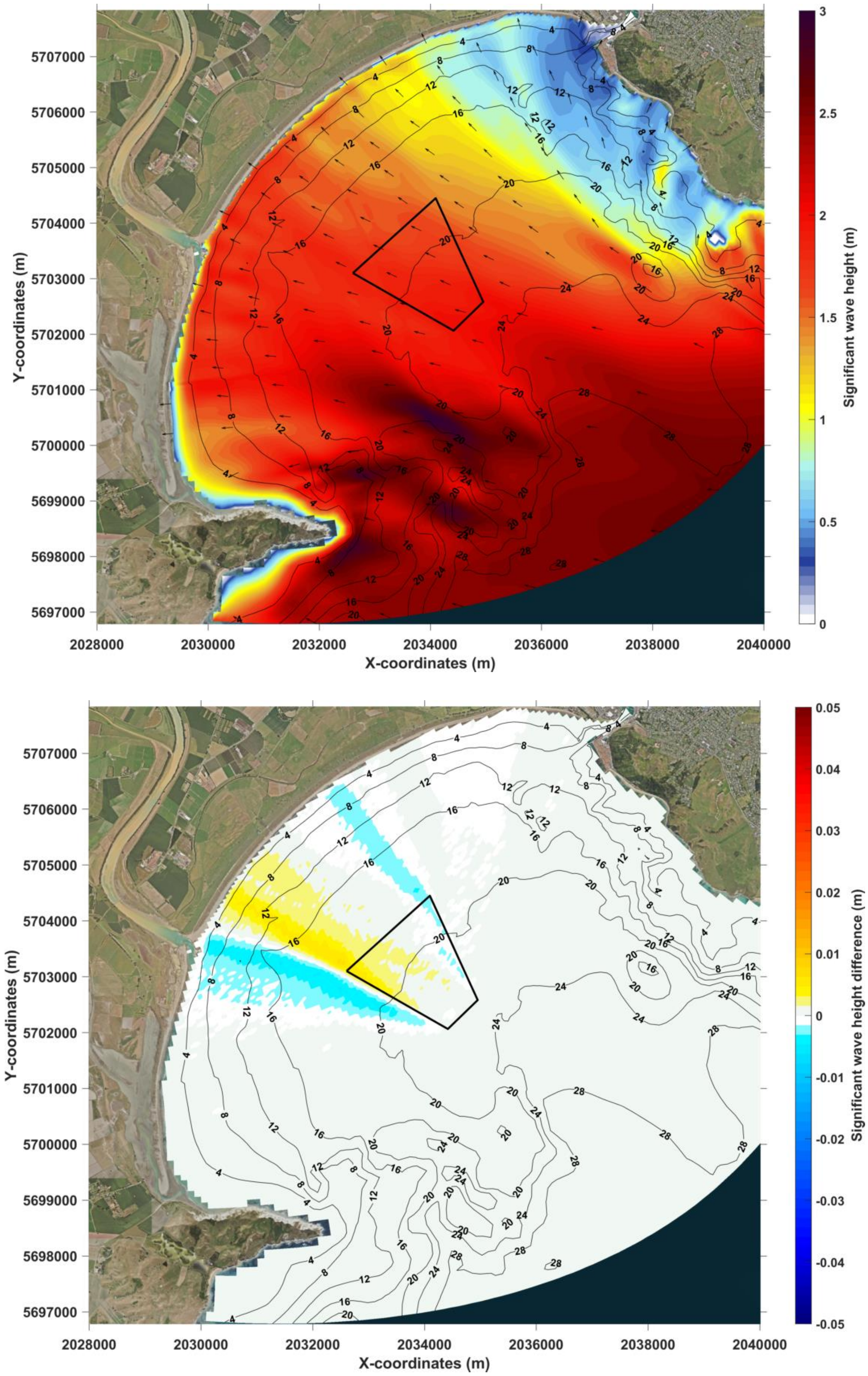


Figure 3.2 Post-disposal significant wave height (top) and difference in significant wave height (bottom) caused by the 4.4 cm disposal mound for the wave class 2 (Hs = 3.18 , Tp = 10.56 , Dir = 89.86).

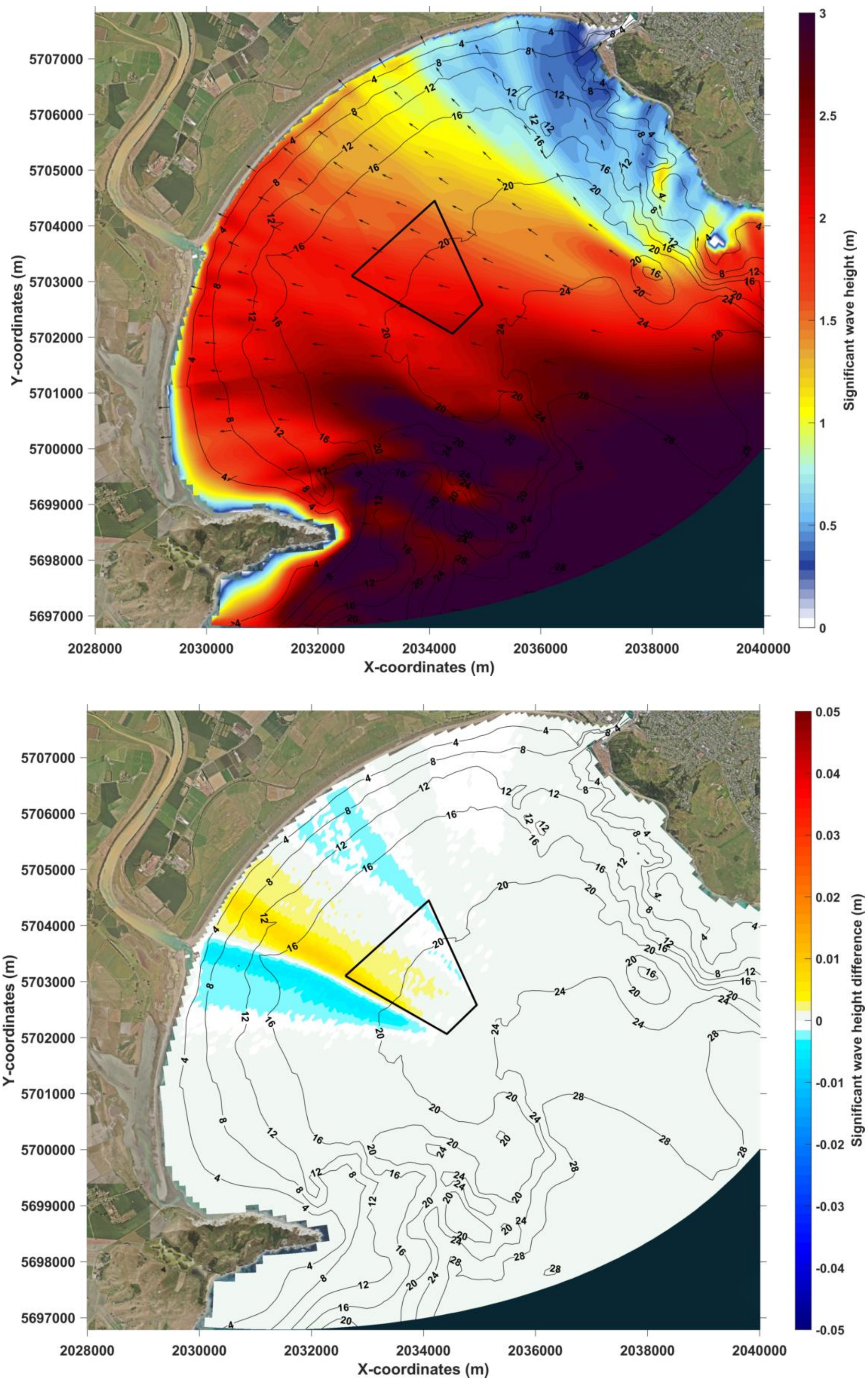


Figure 3.3 Post-disposal significant wave height (top) and difference in significant wave height (bottom) caused by the 4.4 cm disposal mound for the wave class 3 (Hs = 4.75 , Tp = 10.44 , Dir = 73.67).

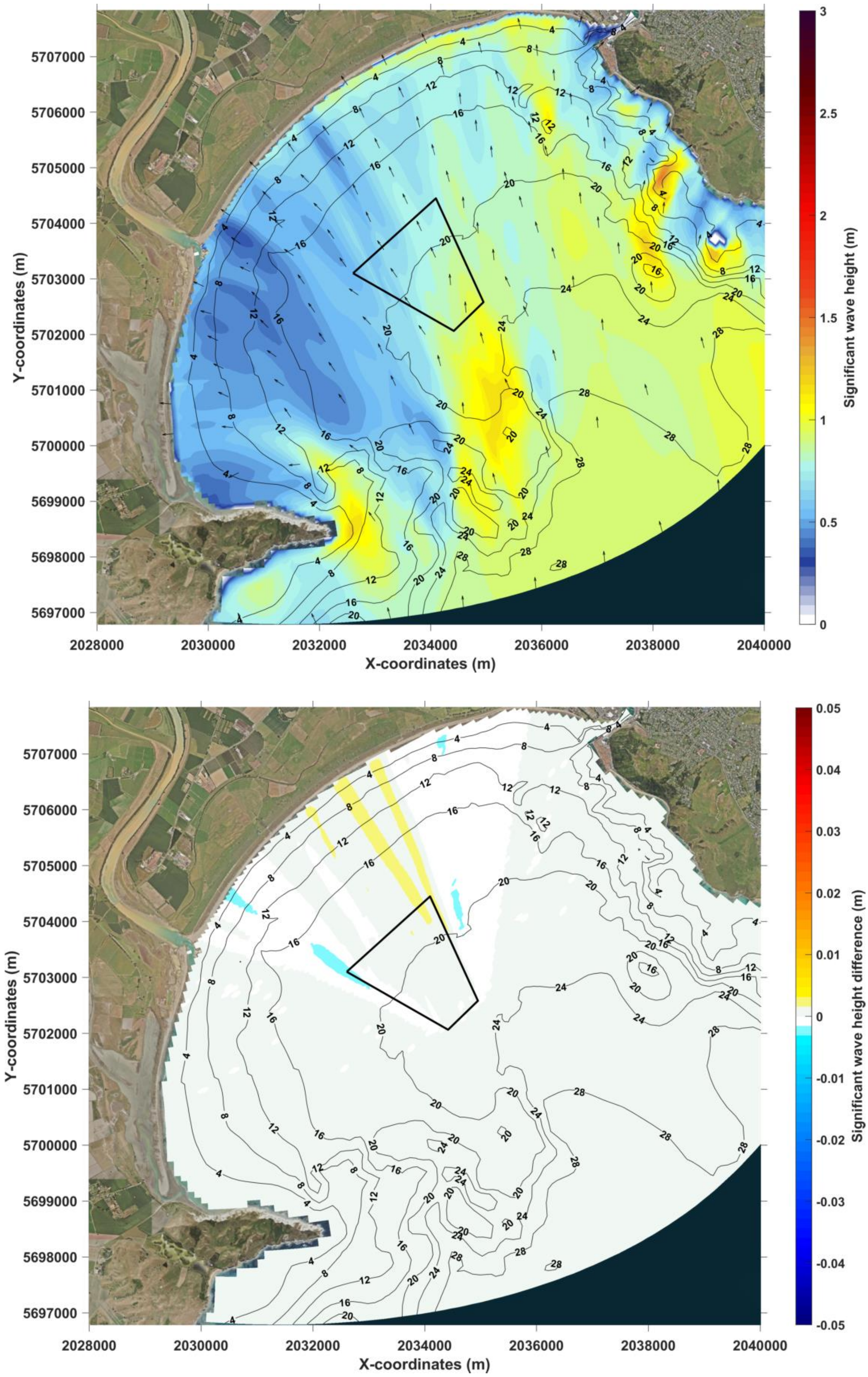


Figure 3.4 Post-disposal significant wave height (top) and difference in significant wave height (bottom) caused by the 4.4 cm disposal mound for the wave class 4 (Hs = 2.49 , Tp = 11.98, Dir = 215.40).

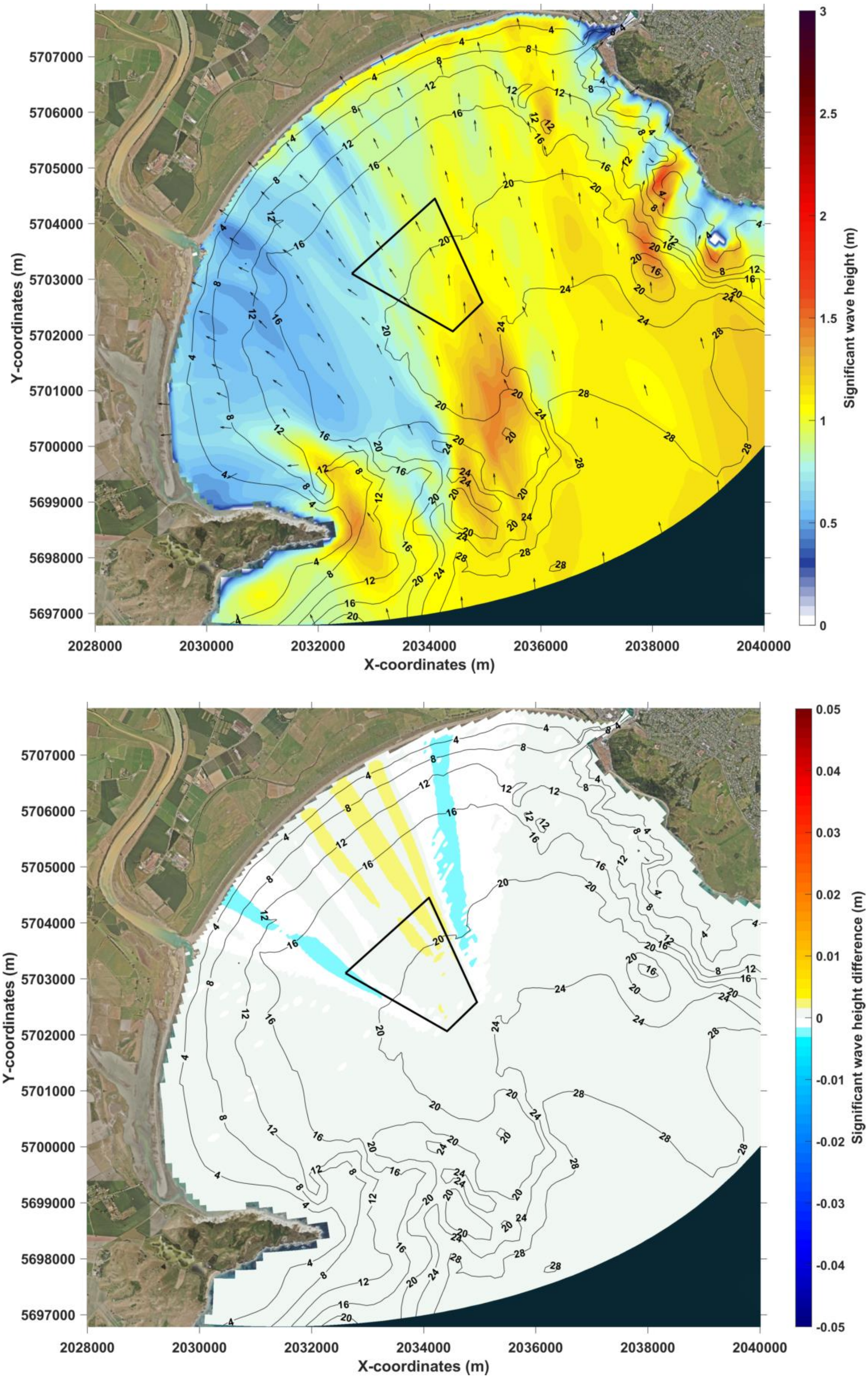
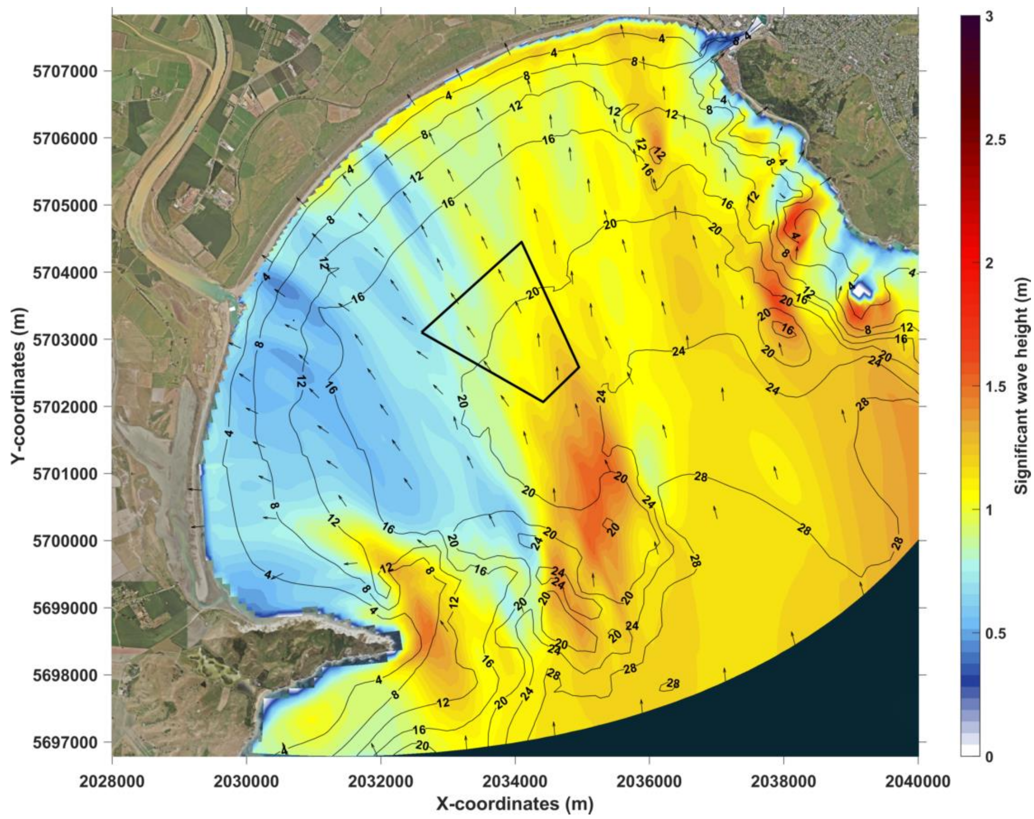


Figure 3.5 Post-disposal significant wave height (top) and difference in significant wave height (bottom) caused by the 4.4 cm disposal mound for the wave class 5 (Hs = 3.53 , Tp = 12.01 , Dir = 219.84).



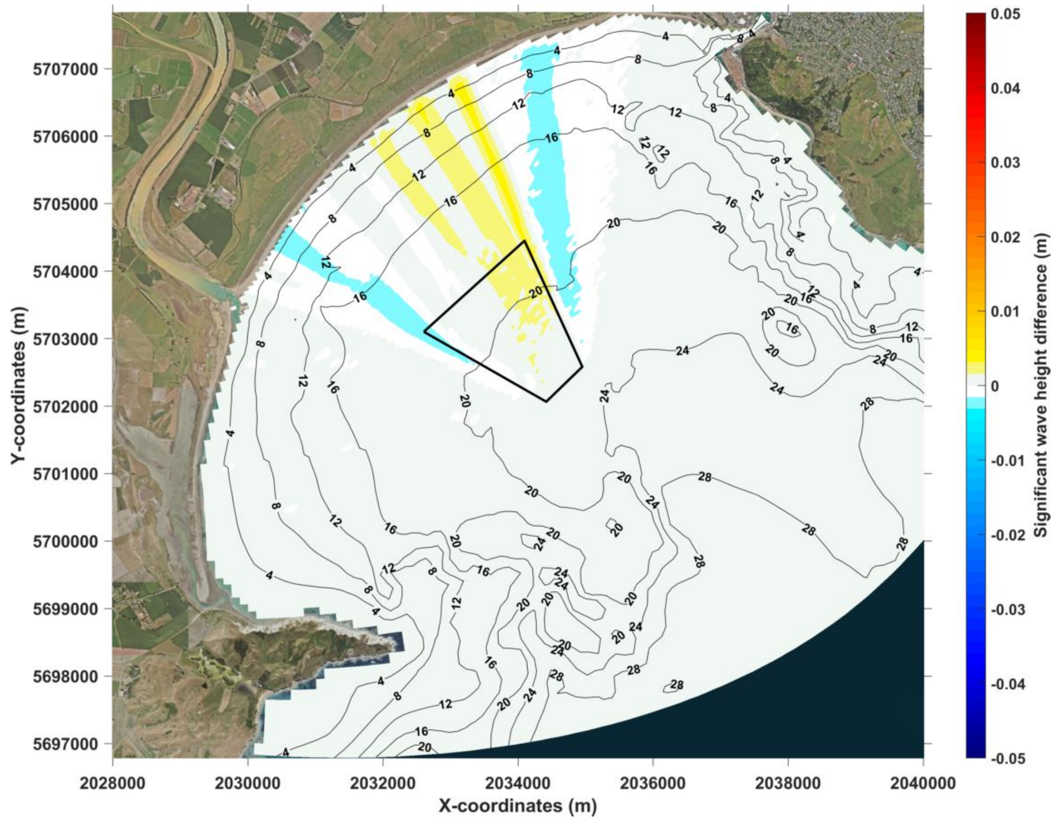


Figure 3.6 Post-disposal significant wave height (top) and difference in significant wave height (bottom) caused by the 4.4 cm disposal mound for the wave class 6 (Hs = 5.72 , Tp = 12.05 , Dir = 232.19).

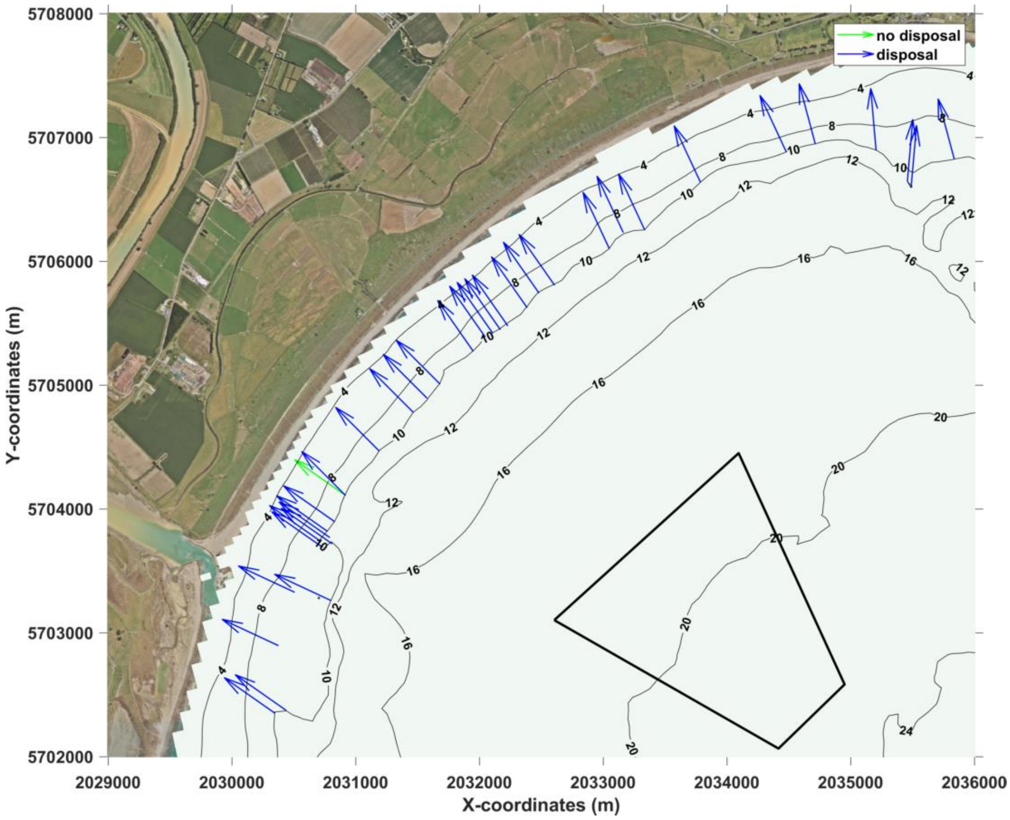


Figure 3.7 Change in wave direction at the 10-m isobath caused by the 4.4 cm disposal mound for the wave class 5 (Hs = 3.53 , Tp = 12.01 , Dir = 219.84).

3.2 Disposal ground dynamics

The annual morphological changes of the disposal mound under both “La Niña” and “El Niño” climatic conditions, with disposal mounds of 0.028 to 0.044 m, are given in Figure 3.8. To isolate the effect of dredged sediment discharged at the disposal ground, the initial model conditions assumed sediment available only within the disposal ground, which is then progressively dispersed throughout the sequence of representative events. Simulations of “La Niña” conditions suggest an overall erosion of the sediment mound and dominant north and northwest inshore deposition of sediment, with maximum sediment accretion of 0.05 m. Sediment transport for “El Niño” simulations are predominantly south and southwest with peak sediment accretion of 0.15 m expected within confined region.

Between 68% – 83% of the disposed material associated with maintenance dredging is expected to be eroded and transported. This corresponds to between 50,000 m^3 and 100,000 m^3 of sediment being advected from the disposal ground over a 1-year period (for “La Niña” and “El Niño” respectively). Most of the eroded material consists of the weakly-consolidated silt in the disposed sediment which is predicted to be winnowed from the disposal ground, diffused through the lower water column, and transported towards the shore or continental shelf by suspended-load transport.

The individual particle size (fine sand, very fine sand and silt) dispersion patterns under both La Niña” and “El Niño” climatic conditions are presented in Figure 3.9 and Figure 3.10. The cohesive component represents 66% of the expected dredge material, while very fine and fine sand represent 19% and 15%, respectively.

A relatively small fraction of silt sized particles may deposit along the western margin of Poverty Bay within 6 – 18 m deep water areas during “El Niño” conditions. These sediments are deposited during conditions characterised by southerly waves, during which the incident wave energy is dissipated by the reef structure in western Poverty Bay and wave shadowing in the lee of Young Nick's Head to allow settlement of the finer particles. Significant river discharges and clockwise flows are expected to largely mitigate the deposition of silt in this region of the bay. Over eastern Poverty Bay, the model predicts the deposition of disposed silt during events of “La Niña” climatic conditions, enhanced by low wave energy and a clockwise circulation (Figure 3.9). According to the findings in Bever (2010), silt particles deposited inshore at Poverty Bay are likely to be resuspended and transported to the continental shelf whereas relatively coarse material tend to move onshore, based on the wave climate of the region.

A significant fraction of the disposed very fine-grained sand particles is predicted to be eroded by wave action. The erosive patterns vary between the “La Nina” and “El Nino” climatic simulated periods. During “La Nina” conditions the very fine-grained sediment is expected to be transported offshore to the southwest and inshore. However, after the one-year simulation, most of the mass of sediment is kept into the limits of the disposal area. During “El Nino”, the disposed very fine sand is expected to be largely dispersed from the disposal ground to both the southwest and southeast (Figure 3.9 and Figure 3.10). Deposition of very fine sand occurs in 16 – 24 m depth and in area of moderate wave energy patterns.

The fine-grained sand fraction, which accounts for approximately 15% of the dredged material, is predicted to be weakly affected by bed-load transport processes. The combination of high wave energy and strong near-bottom current conditions can be expected to initiate the transport of a low volume of fine-grained sand over the disposal area and along its margins. No suspended-load transport is expected for this sediment class (Figure 3.9 and Figure 3.10).

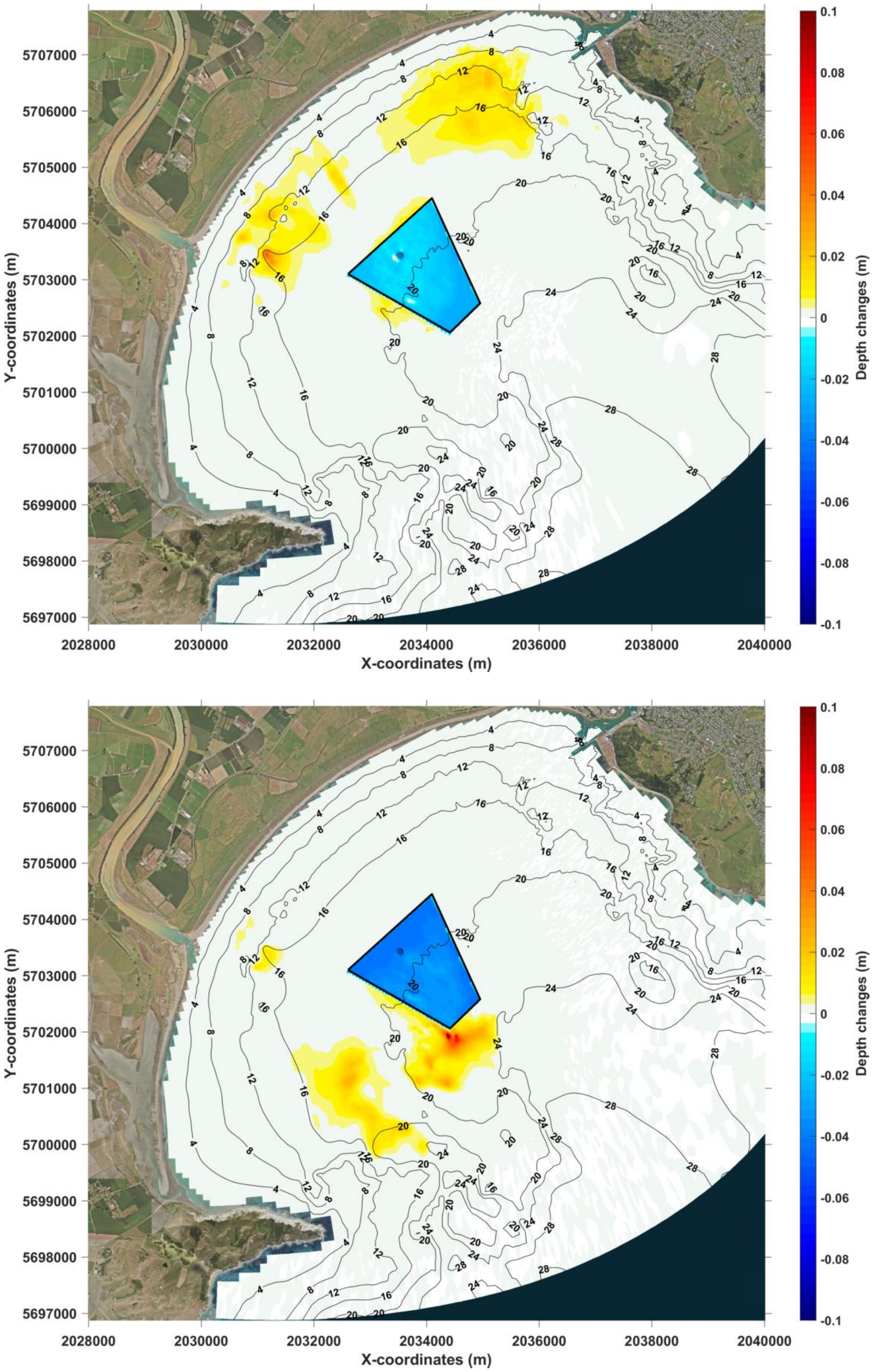


Figure 3.8 Disposal ground change predicted at the end of the 1-year "La Niña" (top) and "El Niño" (bottom) simulated periods considering disposal volumes of 75,000 m^3 and 120,000 m^3, respectively.

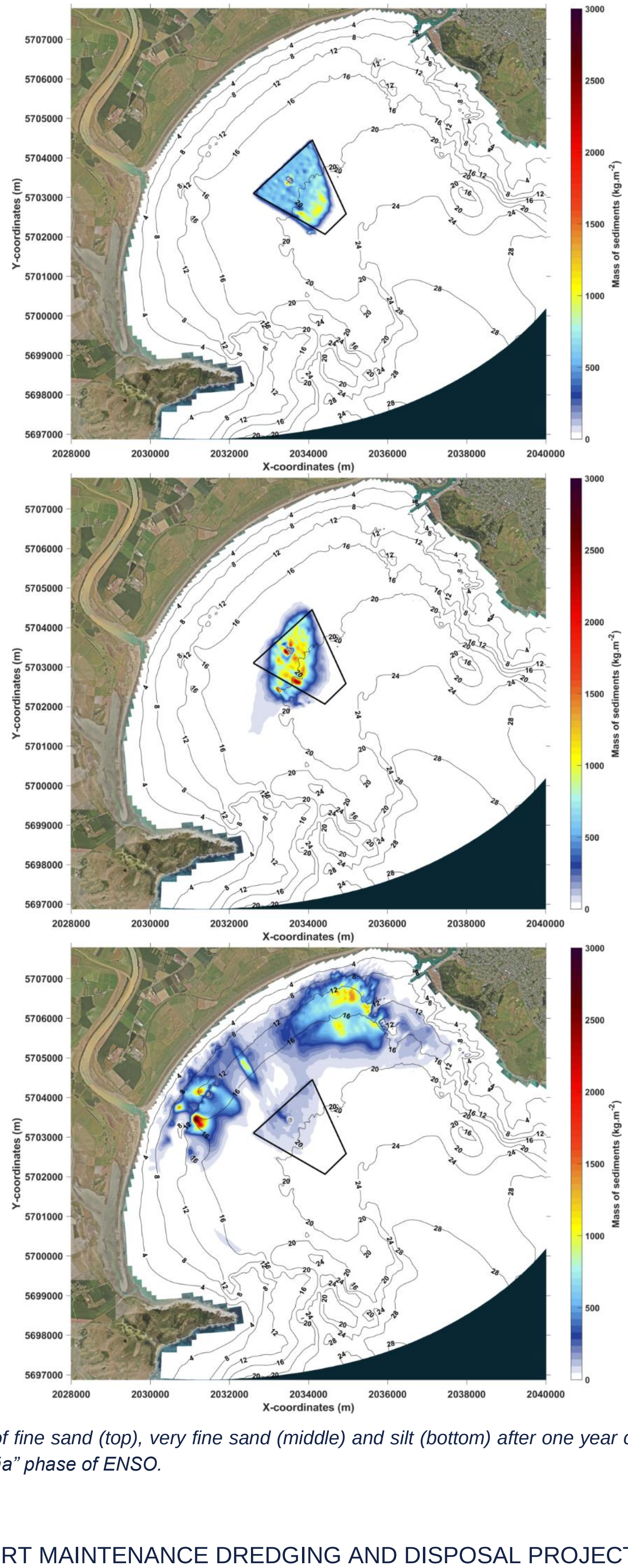


Figure 3.9 Mass of fine sand (top), very fine sand (middle) and silt (bottom) after one year characterised by the "La Niña" phase of ENSO.

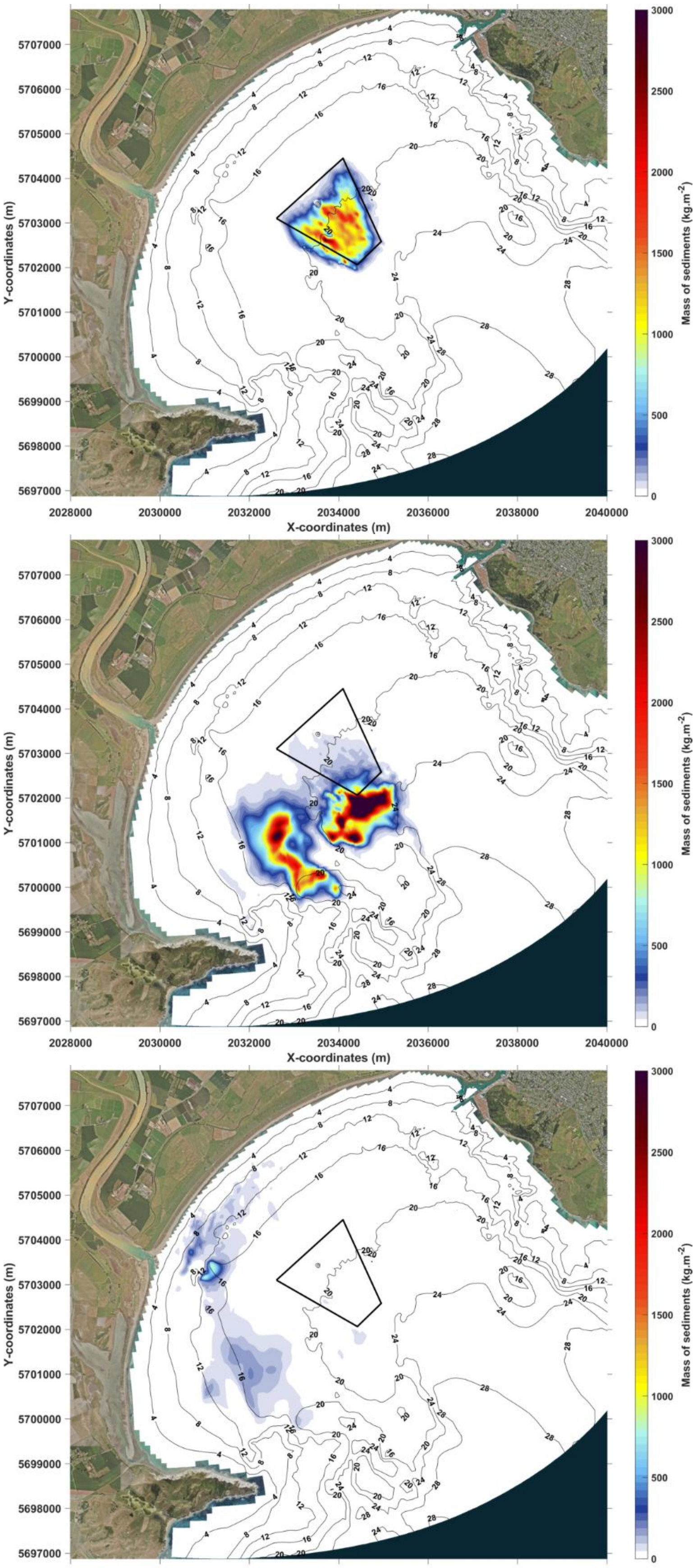


Figure 3.10 Mass of fine sand (top), very fine sand (middle) and silt (bottom) after one year characterised by the "El Niño" phase of ENSO.

4. Summary

The open-source Delft3D numerical modelling system has been used to run high-resolution process-based morphodynamic simulations over Poverty Bay. The numerical modelling involved fully-coupled wave, current and seabed interactions.

The modelling approach consisted of simulating the disposal ground dynamics over two complete, but climatically different (i.e. La Niña" and "El Niño" climatic conditions), one-year periods by applying an input reduction technique and morphological acceleration factors. To isolate the effect of dredged sediment discharged at the disposal ground, the initial model conditions assumed sediment available only within the disposal ground, which is then progressively dispersed throughout the sequence of representative events.

Additionally, the effect of the disposal mound on the wave climate has been examined by comparing the model wave heights between the pre- and post-disposal environments. A summary of the main conclusions is as follows:

- The effect of the disposal mound on the nearshore wave climate is predicted to be negligible. The wave energy is expected to be redistributed along the beach areas adjacent to the Waipaoa River mouth. The resultant increase in significant wave height during energetic storm event is, however, not expected to exceed ~1 cm, or 0.2% of the incident wave height. Some very localised changes in wave direction occur which are not expected to modify the overall longshore sediment transport patterns along the beach. The relative scale of effects is not expected to alter either the nearshore morphodynamic or inshore surfing conditions.
- Within the year period simulated, between 68% and 83% of the disposal mound associated with maintenance dredging activities is expected to be eroded due to the weakly-consolidated silt composition of the disposal. This corresponds to between 50,000 m^3 and 100,000 m^3 of sediment being advected from the disposal ground over a one-year period (for "La Niña" and "El Niño" respectively).
- A notable segregation of silt, very fine sand and fine sand is anticipated.
- The silt component of the disposal material (i.e. ~66%) is predicted to be transported northwest and northeast of the disposal ground. Small deposition of silt may occur to the west of the bay during relatively calm wave conditions.
- The very fine sand particles of the disposal (i.e. ~19%) are expected to migrate south-south-westward by near-bed suspended transport, with sediment expected to move to depths of 16 – 24 m within the one-year period simulated.
- The fine sand fraction of the disposal (i.e. ~15%) is expected to be weakly transported over the disposal area and its margins by bed-load transport.
- No dispersion of disposed-sediments is expected over the adjacent beach areas.

5. References

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