

# Coupled Flow-Wave Numerical Model in Assessing the Impact of Dredging on the Morphology of Matakana Banks

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## Abstract

The short- and long-term impacts of dredging on the Matakana Banks ebb-tidal delta was investigated by numerical modelling using Delft3D. The model covered dredging locations inside Tauranga Harbour and the offshore areas around the Matakana Banks ebb-tidal delta, and was calibrated by an extensive field programme to measure hydrodynamic processes and sediment characteristics, and high resolution bathymetric surveys. The impacts of dredging was then investigated by modelling three different conditions: (1) before dredging started in 1968, using 1967 bathymetry; (2) the present situation using 2013 bathymetry with existing dredging and dumping; and (3) future scenarios using 2013 bathymetry with alternative offshore disposal locations.

The field data and hydrodynamic model results showed that the ebb-tidal delta can be separated into two main regions that are dominated by tidal processes or wave processes. Overall, the wave influence becomes more dominant as the distance from the entrance channel (main ebb jet) increases, and vice versa for tidal processes. Sediment transport pathways were inferred using spatial patterns of erosion and accretion from bathymetric surveys and cross-sectional profiles along the shoreline. The pathways reflected the interactions between the identified wave and tide processes.

A month-long time series of wave conditions were used to force a wave model coupled with the hydrodynamic model for the 2013 bathymetry to simulate the present day situation. The results showed that the sediment volume of the ebb-tidal delta fluctuated with tidal range; accretion occurred during neap tides and erosion during spring tides. To assess the long term impact, the *morphological factor (morfac)* tool in Delft3D was used. *Morfac* of 60 was applied for 12 days simulation time and the results will be presented in this paper

*Keywords: ebb-tidal delta, Delft3D Flow-SWAN, dredging impacts, morphological changes.*

## 1. Introduction

Matakana Banks ebb-tidal delta has potentially been affected by dredging and spoil disposal over the past 47 years. The first dredging campaign was conducted by the Bay of Plenty Harbour Board in 1968 to develop the main shipping channels. Subsequently, biennial maintenance dredging is regularly conducted to maintain the channels at their design depth. This study focuses primarily on the morphological impacts on the Matakana Banks ebb-tidal delta of the biennial maintenance campaigns, specifically the 2013 dredging campaign.

## 2. Study area

Matakana Banks is the name given to the ebb-tidal delta located at the seaward part of the Tauranga Harbour entrance channel, North Island, New Zealand (Figure 1). The inlet throat, which acts as the entrance to the Port of Tauranga, is approximately 500 m wide with a maximum water depth of 34 m and a mean depth of 15 m [7]. The harbour is defined as a tide-dominated inlet, with a mean tidal range of 1.4 m and a mean annual significant wave height of 0.5 m [4].

The delta is classified as a constricted ebb-tidal delta [6], which occurs where the inlet is oriented at a broad shoreline angle and is offset between a rock headland (Mt. Maunganui) and a barrier island (Matakana Island), which restricts the lateral spread of the delta.

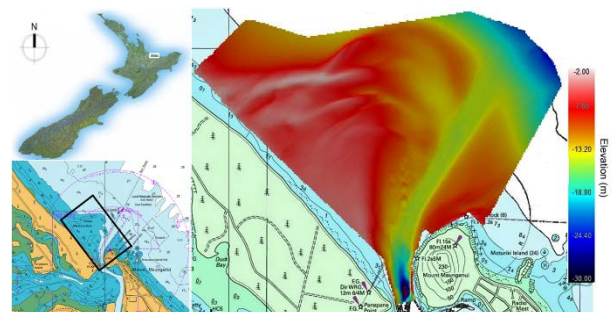


Figure 1 Map showing the location of the Matakana Banks ebb tidal delta, which is the focus of this study.

## 3. Dredge and dumping Data

Dredging and spoil disposal volumes for the 2013 campaign were provided by the Port of Tauranga Ltd. In order to maintain the average channel depth outside and inside the harbour at 14.1 m and 12.9 m respectively, about 193,757 m<sup>3</sup> of sediment was dredged and dumped at spoil disposal sites offshore from Tauranga Harbour (Figure 3). Sand-sized sediment from the Entrance Channel and No. 2 Reach went to sites B, C, and H1, while siltier sediment from Cutter Channel, Mt. Maunganui Roads and Stella Passage went to sites D, G, and H2 [13].

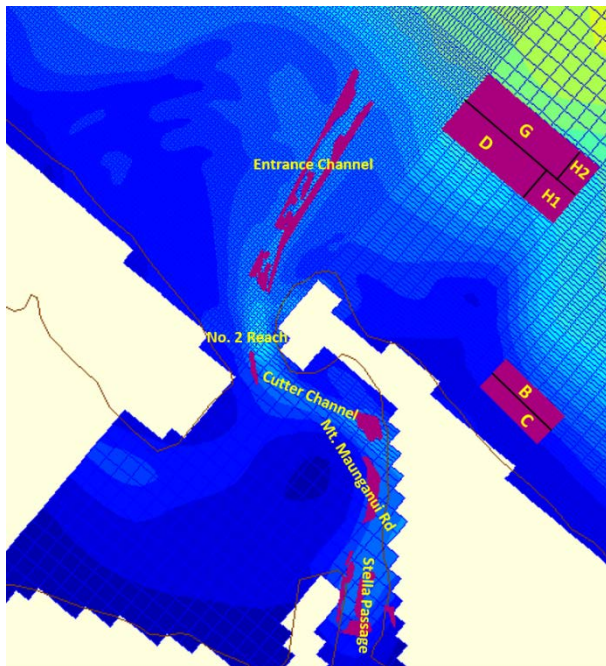


Figure 2. Numerical model grid used by Delft3d-Flow. Also shown are the areas dredged and spoil disposal sites used during the 2013 campaign.

#### 4. Model description and simulation setup

##### 4.1 Model description

In order to investigate the geomorphologic changes of the Matakana Banks ebb-tidal delta system due to physical processes and sediment exchange between Tauranga Harbour and the open coast, and the effects of dredging, a coupled Delft3D Flow and SWAN wave numerical model was created.

Delft3D-Flow forms the core of the model system; simulating water motion due to tidal and meteorological forcing by solving the unsteady shallow-water equations in two (depth-averaged) or three dimensions [9] and [5]. The model which was used is the depth-averaged (2DH) version of the Delft3D model which is extensively described in [9]. The spectral wave model SWAN was applied in stationary computational mode, to propagate waves from the offshore to the coastline, and also simulate wave-induced sediment resuspension. SWAN models the effects of wind-wave generation, refraction, shoaling, dissipation by bottom friction, white capping, non-linear wave-wave interactions, and ambient currents on the wave properties [17].

Morphological acceleration factor (morfac) is a modeling approach used to assist with managing the difference in time-scales between hydrodynamic processes and morphological responses. This technique allows long morphological simulations to be achieved with hydrodynamic simulations covering only a fraction of the required duration [9].

##### 4.2 Grids, forcing and bathymetry

Computational grids for both flow and wave models were set up. The grid mesh covers ~14 km offshore from the tidal inlet and the SE region within Tauranga Harbour. To examine the morphological response of Matakana Banks within a reasonable computation time, a nested model with a finer grid was applied to the area of Matakana Banks ebb-tidal delta. Here, the average spacing between grid lines is about 30 m, while for the offshore area it is about 150 m. Figure 2 shows the computational grid mesh with the closed boundaries of the mainland, Matakana Island, and an artificial closed boundary blocking off the upper Western Channel.

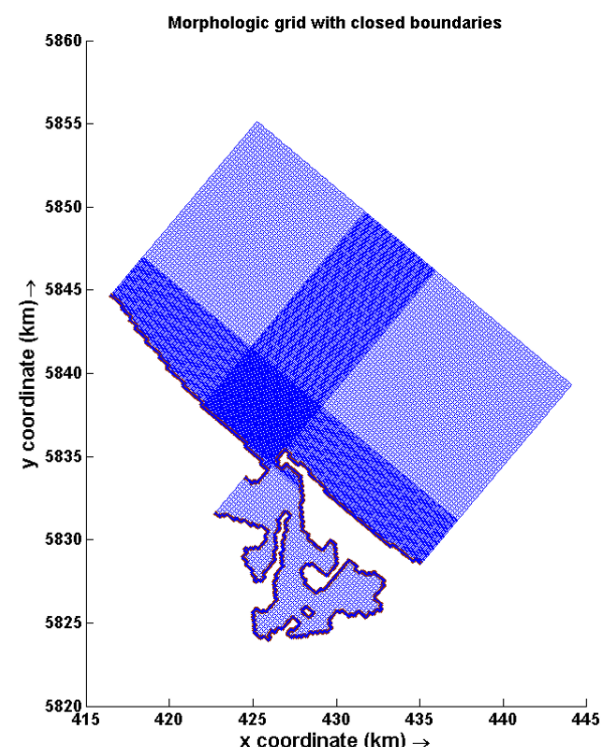


Figure 3. Computational grid mesh.

There are four open boundaries with tidal forcing of water level, a boundary inside the harbour and three offshore boundaries. The initial estimates of water level at the boundaries were obtained from the NIWA online tide forecaster [10]. Then T\_Tide tidal harmonic analysis [12] was used to derive the amplitudes and phase of the 7 largest tidal constituents: O1, K1, M2, N2, S2, M4 and MS4. The physical parameters used in the model were: non-cohesive median bed diameter ( $D_{50}$ ) of 632  $\mu\text{m}$ ; sediment transport and wave conditions were based on the field measurements in April – May 2013 [14]; and  $\sim 0.118 \text{ kg/m}^3$  was allowed for the suspended sediment concentration alongshore [1]. A uniform wind was applied to Flow model, based on wind data for Tauranga Airport retrieved from the New Zealand National Climate Database (Cliflo) [11].

The distribution of Manning bottom roughness ( $M$ ) was estimated from the Nikuradse roughness length,  $k_s$  using

$$M = \frac{25.4}{k_s \cdot 6} \quad (1)$$

After considering several relationships recommended in [15] to estimate  $k_s$  over flat beds, it was estimated from the median grain size diameter ( $D_{50}$ ) as approximately

$$k_s = 2.5 D_{50} \quad (2)$$

The Delft3D-Wave model was forced by a uniform time-series offshore wave conditions, provided by MetOcean Solution Ltd.

The initial bathymetry before the dredging campaign was digitized from hydrographic chart NZ 5412 for 1967 in UTM 60S coordinates. This bathymetry was updated for 2013, particularly around Matakana Banks, using data obtained by a multi-beam echo sounder survey in March 2013. All the bathymetry data were gridded at 30 m resolution, being interpolated with triangular method, and saved as a depth file using DELFT QUICKIN to be used in the computational grid.

### 4.3 Model calibration and simulation scenarios

For hydrodynamic model calibration, the stand-alone depth averaged (2DH) Delft3D-Flow model simulated 29 days covering 2 spring and 2 neap tides, with a simulation time step of 0.05 minutes. The best calibration was achieved with the Manning bottom roughness formula based on the measured sediment grain size distribution, and the Delft3D-Flow default values for uniform horizontal eddy viscosity of  $1.2 \text{ m}^2/\text{s}$  and  $10 \text{ m}^2/\text{s}$  for the horizontal eddy diffusivity.

The sediment transport and morphological response model was then schematized as a single sediment fraction with  $D_{50}$  of  $632 \mu\text{m}$  and morfac of 1 for hydrodynamic calibration purposes. Subsequently morfac values of 10, 20, 30, 40 and 60 were used to better characterise the ebb-jet behaviour over time.

The SWAN model was separately calibrated using the field observations from April- May 2013 [14]. This included a range of wave conditions from calm fair-weather through to severe storm activity. Once the hydrodynamic and wave models were calibrated, the coupled Flow-Wave model was set up with time step of 0.1 minute and initial uniform sediment thickness of 15 m across the entire grid. Average wave conditions ( $H_s = 0.8 \text{ m}$  to  $1.2 \text{ m}$ ) were used for long-term simulations. Each of the simulations was run for 12 days that covered a spring-neap tidal cycle. Since maintenance dredging is conducted biennially, the maximum time each simulation was run was 2 years (morfac 60). The main groups of scenarios simulated were:

- Before dredging started in 1968, using the 1967 bathymetry.
- Present situation using 2013 bathymetry with existing dredging and disposal sites.
- Future scenarios using 2013 bathymetry with alternative offshore disposal locations.

### 5. Model validation

The predictive capability of the Delft3D-Flow model with regard to water levels, current velocities and directions was verified by comparing measured and modelled values. The flow parameters from the model were calibrated and validated against different subsets of the field data collected within the model domain during 11 April – 5 May 2013 [14]. The water level was nearly exactly reproduced by the model at all measured locations. However, the current velocity verification results were variable, with the best calibration being achieved just inside the harbour entrance (Figure 4).

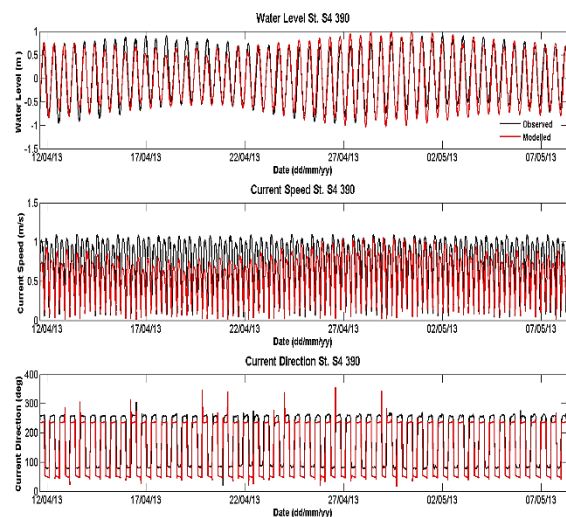


Figure 4. Measured and modelled water level, current speed and direction near Cutter Channel (St. S4 390) for the verification period,

A range of standard statistical parameters were used to assess the quality of the Delft3D-Flow model results and are summarised in Table 1. The performance rating, according to the RMAE of velocity values, for the modelled currents in this study are in the range Good to Reasonable/Fair [19][18].

Table 1 Flow model calibration and validation results

Parameter	Water Level		Current Speed		Current Dir	
	Sp 1	Np 1	Sp 1	Np 1	Sp 1	Np 1
ME	0.008	-0.1	-0.2	-.02	-28	-20
MAE	0.1	0.1	0.2	0.3	31	33
RMAE	0.3	0.7	0.3	0.6	0.2	0.2
R	0.97	0.96	0.94	0.7	0.96	0.9

Sp = Spring tide, Np = Neap tide

Validation of the SWAN wave model focussed on wave observation datasets obtained within the nearshore area over Matakana Banks and along Matakana Island, where wave-induced sediment transport was considered likely to be significant. Comparison between predicted and observed significant wave height ( $H_s$ ) gave correlations ( $R^2$ ) between 0.73 and 0.75.

Validation for the coupled flow-wave model with morphology updating was done by comparing the volumetric changes over 5 months duration between the simulation/model and the observed changes between 2 successive multi-beam echo sounder surveys over the same period. Volume changes were calculated by using the method of [7] assuming a constant lower surface depth ( $z$  value) of -15 m. The volumetric change validation gave a correlation ( $R^2$ ) of 0.95.

## 6. Results and Discussion

### 6.1 Sediment transport patterns

The Delft3D-Flow model results show that the tidal contribution to sediment transport is mostly concentrated in the area around the tidal inlet and SE portion of the ebb-tidal delta. However, the net tidal sediment transport during both spring and neap is low  $1.6 \times 10^{-16} \text{ m}^3/\text{s}/\text{m}$  as shown in Figure 5 (upper panel). It is evident that during flood tide, the sediment along the shore face adjacent to the tidal inlet and both sides of the entrance channel are transported into the harbour. However, less sediment is available on the eastern side limiting sediment transport there. The pattern reverses

during the ebb tide. However, less sediment is transported back to the shore face and more transport occurs along the eastern side of the inlet. Both spring and neap ebb tides, indicate that the sediment is deposited in the SE region of the ebb tidal data, but the sediment is distributed over a larger area during the neap ebb tide. These results are consistent with the results of [16], who attributed the pattern to the formation of eddies flanking the ebb jet.

Including the effects of wave-induced transport significantly alters the sediment transport pattern over the ebb-tidal delta. In Figure 5 (lower panel), once offshore waves are incorporated, sediment transport by the tides is no longer controlling the overall pattern. The tidal currents still produce the same underlying sediment transport pattern, but it is much smaller than the magnitude of wave-induced transport. Decreased water depth over the shallow shoal areas of the delta allows even small to moderate waves to cause an increase in the bottom orbital velocity and in increased potential for sediment resuspension [2]. The influence of waves appears to be stronger during ebb tide.

### 6.2 Ebb tidal delta volume

Calculation of ebb-tidal delta daily volume for 29 days using the coupled model showed volumetric fluctuations being related to the tidal conditions. Sediment volume increases over the ebb tide delta during the neap tide and vice versa for spring tide. The sediment gain and loss volume are around  $8.9 \times 10^6 \text{ m}^3$  and  $-8.9 \times 10^6 \text{ m}^3$  respectively.

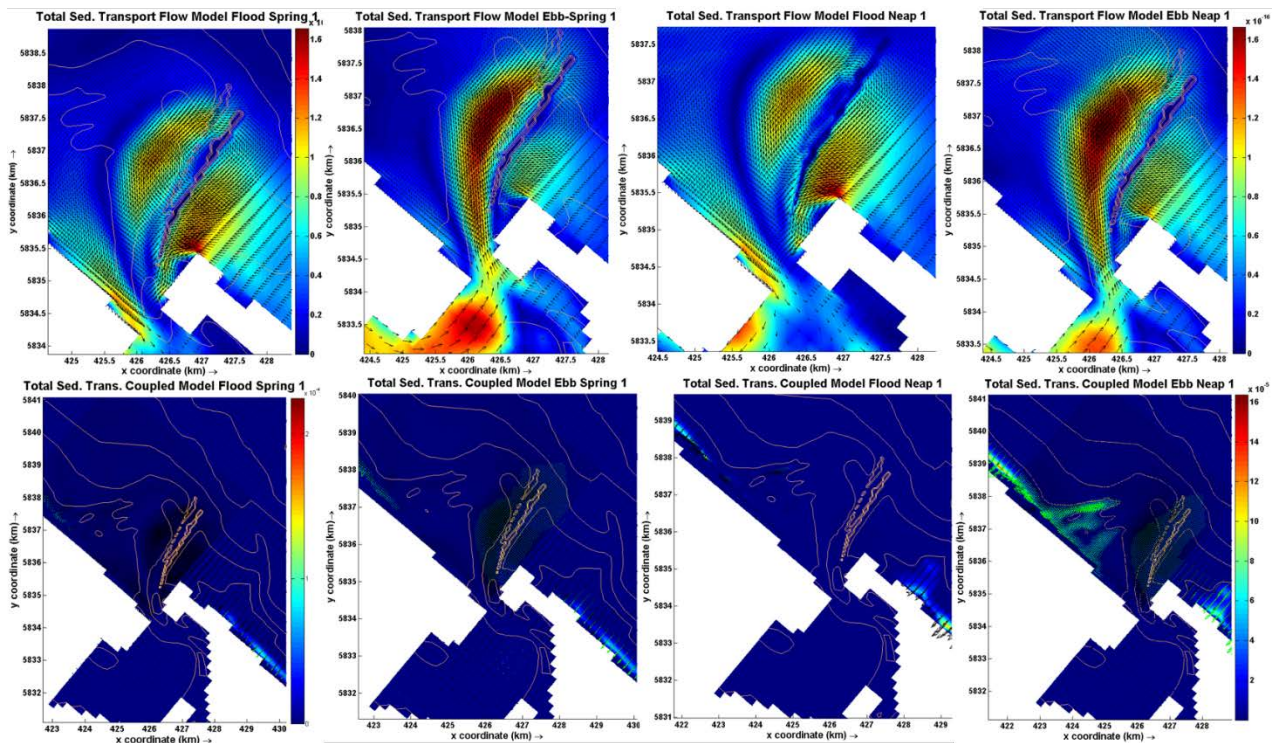


Figure 5. Total sediment transport ( $\text{m}^3/\text{s}/\text{m}$ ) during ebb and flood tides predicted by the coupled model with *morfac* 1 and measured dredging activity.

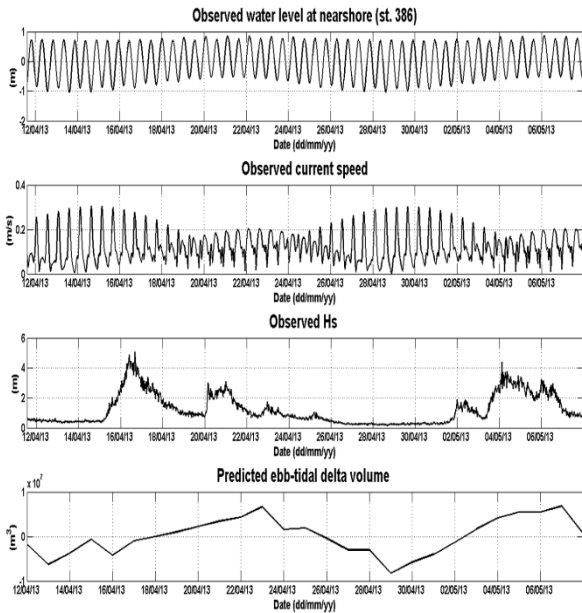


Figure 6. Coupled model predicted daily volumetric changes of the Matakana Banks ebb-tidal delta, and the corresponding observations of tide, current speed, and significant wave height ( $H_s$ ).

Figure 6 shows the predicted ebb-tidal delta volume during the field programme in April-May 2013, and the corresponding tide water level, tidal current speed, and significant wave height. High current velocities during spring tides seem to contribute to volume loss of delta, but the sediment is replaced during neap tides. The occurrence of high wave events (storm/swell) did not appear to directly relate to ebb-tidal delta volume fluctuations

### 6.3 Short-term response to dredging

The potential cumulative effect on the ebb-tidal delta or dredging, and associated spoil disposal, was analysed by several model scenarios. Sediment accretion along the shoreface of Matakana Island is seen in each 2 year (morfac 60) model simulation (Figure 7). In 1967, before the first capital dredging, accretion predominantly occurs on the southwest sector of the ebb-tidal delta, with up to 4 m of sediment accumulation after 2 years. This accumulation results from offshore sediment transport by the ebb jet onto the

terminal lobe, with wave-induced transport pushing the sediment shoreward as shoal bars. A component of sediment is also provided by longshore transport from the west.

The dredging of an entrance channel in 1968 altered the trajectory of ebb flows, displacing a portion of the ebb jet eastwards. This resulted in a change in the sedimentation patterns over the ebb-tidal delta (Left hand two panels in Figure 7). Less sediment is transported to the margins of the terminal lobe, and sedimentation occurs closer to the shore. This may have contributed to the observed accretion of Panepane Pt and narrowing of the tidal inlet, although this trend had been occurring since the first survey in 1852.

Dredging since 1968, particularly the maintenance dredging, does not have any discernable effect. Locating a dredge spoil disposal ground in relatively shallow water to the NW of the delta (right-hand panel of Figure 7) would contribute sediment to feed the NW terminal lobe and swash bars.

## 7. Summary

Numerical simulations indicate the 1968 capital dredging significantly changes sedimentation patterns over the Matakana Banks ebb-tidal delta, concentrating accumulation on the Matakana Island shoreface, and reducing sedimentation on the swash platform. Subsequent dredging has had no discernable effect. Daily volumetric changes over a 1 month simulation show that the ebb-tidal delta gains and loses sediment in response to neap and spring tides.

## 8. Acknowledgement

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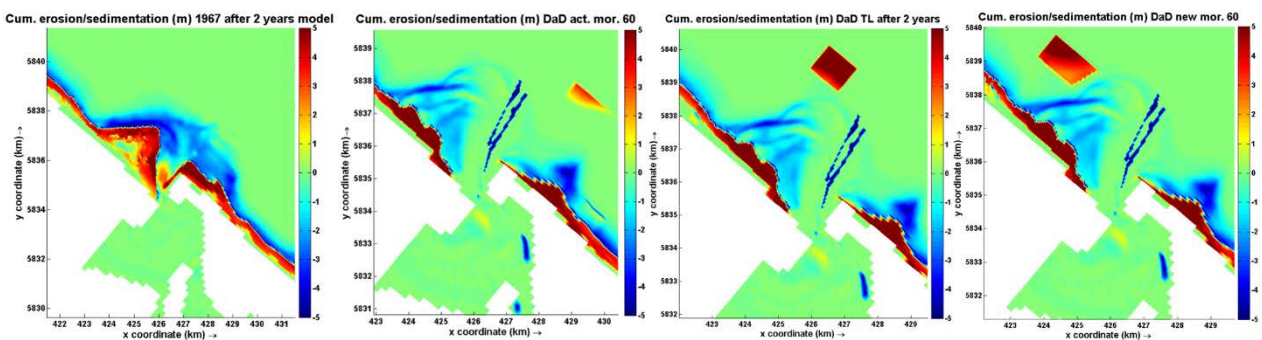


Figure 7. Cumulative effect of erosion and accretion over the ebb-tidal delta after 2 years (morfac 60) of dredging and spoil disposal (DaD). The first panel is based on 1968 bathymetry, and the remainder use 2013 bathymetry.

## References

- [1] Badesab, F., von Dobeneck, T., Bryan, K.R., Muller, H., Briggs, R.M., Frederichs, T., and Kwoil, E. (2012). Formation of magnetite-enriched zones in and offshore of a mesotidal estuarine lagoon: An environmental magnetic study of Tauranga Harbour and Bay of Plenty, New Zealand. *Geochemistry, Geophysics and Geosystems*, 13(6).
- [2] Bever, A.J., and MacWilliams, M.L. (2013). Simulating sediment transport processes in San Pablo Bay using coupled hydrodynamic, wave, and sediment transport models. *Marine Geology vol. 345*, 235-253.
- [3] Bruun, P. (1978). *Stability of Tidal Inlets*. Amsterdam: Elsevier, 510p.
- [4] de Lange, W. P. (1993). *Wave Climate for No. 1 Reach, Port of Tauranga Ltd*. Hamilton, New Zealand: Department of Earth Sciences.
- [5] Elias, E.P.L., and Hansen, J.E. (2013). Understanding processes controlling sediment transport at the mouth of a highly energetic inlet system (San Francisco Bay, CA). *Marine Geology*, 345, 207-220.
- [6] Hicks, D.M. and Hume, T.M. (1997). Determining sand volumes and Bathymetric Change on an Ebb-Tidal Inlets and Tidal Delta. *Journal of Coastal Research*, 407-416.
- [7] Hicks, D.M., and Hume, T.M. (1996). Morphology and size of ebb tidal deltas at natural inlets on open-sea and Pocket-bay coast, north island, New Zealand. *Journal of Coastal Research*, 12 (1), 47-63.
- [8] Krueger, J.C., and Healy, T.R. (2006). Mapping the morphology of a dredged ebb-tidal delta, Tauranga Harbour, New Zealand. *Journal of Coastal Research*, 22(3), 720-727.
- [9] Lesser, G. (2009). *An approach to medium-term coastal morphological modelling*. Leiden, The Netherlands: CRC Press/Balkema.
- [10] NIWA. (2013). *Tide Forcaster*. Retrieved 2013, from <http://www.niwa.co.nz/services/online-services/tide-forecaster>
- [11] NIWA. (2014, March 30). *NIWA Taihoro Nukurangi. The National Climate Database*. Retrieved 2014, from [http://cliflo.niwa.co.nz/pls/niwp/wgenf.genform1\\_pr oc](http://cliflo.niwa.co.nz/pls/niwp/wgenf.genform1_pr oc)
- [12] Pawlowicz, R., Beardsley, B., and Lentz, S. (2002). Classical tidal harmonic analysis including error estimates in MATLAB using T\_TIDE. *Computers & Geosciences*, 28(8), 929 - 937.
- [13] Port of Tauranga Ltd. (2013). *Maintenance Dredging-Spoil Disposal Sites*. Tauranga, New Zealand: Port of Tauranga Ltd.
- [14] Ramli, A. Y., and de Lange, W.P. (2013a). Dredging impacts on the stability of an ebb tidal delta system. *Coasts and Ports 2013*. Sydney, Australia.
- [15] Soulsby, R. (1997). *Dynamics of marine sands, a manual for practical applications*. Thomas Telford Publications, 249p.
- [16] Spiers, K.C., Healy, T.R., and Winter, C. (2009). Ebb-Jet Dynamics and Transient Eddy Formation at Tauranga Harbour: Implications for Entrance Channel Shoaling. *Journal of Coastal Research*, 234-247.
- [17] SWAN Team. (2009b). *SWAN Scientific and Technical Documentation 40, 72*. Delft: Delft University of Technology.
- [18] van Rijn, L.C., Walstra, D.J.R., Grasmeijer, B., Sutherland, J., Pan, S., and Sierra, J.P. (2002). Simulation of Nearshore Hydrodynamics and Morphodynamics on the Time Scale of Storms and Seasons using Process-Based Profile Models. In *The behaviour of a straight sandy coast on the time scale of storms and seasons: Process Knowledge and Guidelines for Coastal Management: End Document March 2002. EC. MAST Project, MAS3-CT97-0086. COAST3D-EGMOND*.
- [19] Walstra, D.J.R., van Rijn, L., Blogg, H., and van Ormondt, M. (2001). *Evaluation of a hydrodynamic area model based on the COAST3D data at Teignmouth 1999. Paper D4 of COAST3D Final Volume of Summary Papers. Report TR121*. UK: HR Wallingford.