Clive River Dredging: Numerical Modelling and Ecological Impact Assessment

Prepared for:

HAWKE'S BAY
REGIONAL COUNCIL

eCoast
eTakutai

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Executive Summary

This report addresses part 4 of the Section 92 Request for Further Information from the Hawke's Bay Regional Council with respect to the resource consent application to dredge the lower Clive River. The proposed dredging will remove 60,000 m^3 of material over an area of approximately 124,000 m^2, which is to be is transferred through a pipe onto the seaward side of the southern head of the Clive River. Sediment is to be discharged for 9 hours a day over approximately 67 days. The dredging will reduce the dredged area to a depth of approximately 1.6 m below Mean Sea Level (MSL).

Results from the sediment transport modelling shows that sand falls out of suspension rapidly. While the 99th percentile concentration of suspended sand is <0.05 kg/m^3 in the vicinity of the outfall, it rapidly falls to <0.0001 kg/m^3 within 100 m of the outfall in both Summer and Winter conditions. For fines, the suspended plume is considerably larger. Overall, in Summer conditions, the suspended plume of fines is dispersed less rapidly under the less energetic conditions than under Winter conditions creating a larger plume. Mean concentrations are generally low, and this is largely due to the 17 hour daily downtime in the dredging schedule. The 90th and 99th percentile plumes for fines cover a considerably larger area and show concentrations up to 1 kg/m^3 close to the outfall though the concentrations fall away rapidly with distance. The plume is most concentrated to the north of the outfall with concentrations of 0.3 kg/m^3 seen up to 500 m towards the estuary mouth.

Sediment deposition is greatest near to the outfall with maximum deposition levels of nearly 1 m within 150 m of the outfall. Beyond this point the maximum deposition thickness rapidly falls off to approximately 0.01 m. The 0.01 m deposition footprint is larger in Winter conditions than in Summer conditions extending some 800 m away in the former and 500 m in the latter. In both cases, the footprint extends northeast from the outfall location with a smaller area extending to the southeast. The maximum deposition pattern is very similar to the final deposition footprint in the model. This indicates that, while the deposited sediment is expected to be highly mobile under the influence of larger wave events, it may remain where it settles until then. Based on the long-term wave data, the occurrence of these larger wave events that will resuspend and disperse the material occur approximately 3% of the time, or~11 days per year.

Modelling is also presented showing the change to the flow regime in the lower Clive River due to the modified seabed resulting from the proposed dredge activity. The pre and post dredging results show that spring flood and ebb current speeds decrease by up to approximately 0.1 m/s during ebb tides following dredging. Neap ebb and flood tidal currents are low (<0.05 m/s) and not affected greatly by the dredging operation. These changes to the flow rates of the river are unlikely to result in any physical/morphological impacts to the lower river or river mouth (other than with respect to infilling rates, which are discussed below). This is because the changes are of the order of 0.1 m/s maximum, which is the threshold of sediment movement for fine unconsolidated material. The lower river/Waitangi Estuary area has a sandy bed, while the river entrance is comprised of shingle banks; i.e., the relatively small changes to flow cannot result in movement of these materials.

The results of the hydrodynamic modelling and recorded volumes of sedimentation suggest that the amount dredged will be infilled to a similar level within the next 10-12 years. It is likely that somewhat of an equilibrium is tended towards where, as the lower Clive River continues to fill with sediment, the current velocities increase, which has a result of decreasing sedimentation rates (i.e., infilling rates are determined by feedback due to the cross-sectional area of the river). That is, the lower Clive River is likely to infill faster following dredging, and then reduce through time as the cross-sectional area of the river is decreased and the flow rate is consequently increased.

Although the Waitangi Estuary and lower Clive River score poorly with respect to species diversity, richness and physical traits, it is part of the Waitangi Regional Park and is associated with areas that provide exceptional habitat for wetland bird species. Overall, the ecological impacts of dredging the 1.4 km stretch of the lower Clive River are considered minor to less than minor and temporary. This is because the operation is temporary (~67 days) and represents a ‘pulse’ impact, rather than a permanent ‘press’ impact, and due to the current ecological status of the lower river, estuary and nearshore coast.

Biosecurity risks associated with the invasive tubeworm (*Ficopomatus enigmaticus*) can be mitigated by undertaking removal in the winter months and disposing to land.

It is valid that there is the potential to have minor impacts on zinc-sensitive species at locations 1-3 (noting that no living fauna were identified in the low oxygen/anoxic sediment), and that through the dredging procedure the 4 to 1 ratio of water to sediment will mix and dilute the zinc contaminant to below the ISQG-low threshold level (meaning less than minor effects on organisms at and around the discharge point). It is also noted that these higher zinc levels are likely linked with stormwater run-off from the road/bridge where they were sampled (i.e., the majority of the material to be dredged will not have high levels of contaminants). However, consideration needs to be given to future dredging and disposal, and methods to mitigate environmental impacts. The material has not been removed from the environment, and cultural and longer-term cumulative impacts should be considered.

Impacts on fish species both in the estuary and on the open coast are considered to be mostly temporary behavioural impacts, which are considered less than minor. To avoid impacts on whitebait, dredging should not occur between August and November inclusive (the whitebaiting season is 15 August to 31 November), when whitebait runs occur, or during spawning in late summer/early autumn.

Given the localised nature of water quality changes (turbidity) derived from the dredge discharge in relation to the scale of the nearshore coastal area in the Hawke's Bay, effects on coastal bird species are anticipated to be less than minor. Similar to the attraction of fish by the infaunal organisms that are disposed of in the discharge plume, there is the potential that some species of birds will be attracted to the area. This behavioural change is considered short term and less than minor.

The river benthos will very likely recover to its currently impacted state. Once dredged, it will again infill with fine sediments, which together with low flow rates will result in low oxygen/anoxic content in the sediments, and low biodiversity. This is due to a combination of historical changes to the rivers hydrology including the 1931 earthquake, river diversion in 1969 and the continued terrestrial sediment inputs. The open coast where the temporary dredging discharge will occur is a very abrasive environment in the intertidal and shallow sub-tidal zone, and water quality is mostly poor due to the terrestrial run-off/river discharge and erosion of the Cape Kidnapper cliffs that result in nearshore waters that are almost always sediment laden in southern Hawke's Bay, especially around the Clive River entrance. As a result, there are low abundances and species numbers in the area. As a result, the accumulation of seabed sediment from the discharge will not cover important habitat and will also be dispersed during significant wave events.

Both reduction in terrestrial sediment and modifications to the hydrology of the Clive River could be considered for the future management of the site.

Contents

Figures

Tables

1 Introduction

This report addresses part 4 of the Section 92 Request for Further Information from the Hawke's Bay Regional Council with respect to the resource consent application to dredge the lower Clive River, namely:

4. In order to determine whether the advice and conclusions provided in the application are environmentally robust, could you please provide:

a. An assessment of coastal processes prepared by an appropriately qualified and experienced specialist to provided evidence of the coastal process of the area and the likely impact of the discharge of dredge material on the coastal environment. At a minimum, we would expect the following matters to be covered:

  i. downstream effects of sediment mobilisation, dispersal, and deposition during dredging; and,
  ii. the fate of deposited material, including a consideration of shorter-term environmental outcomes if deposition occurs during calm, dry weather,
  iii. infilling rates once dredging is complete; and,
  iv. whether altering river morphology (deepening) will have downstream physical effects on the lower river or river mouth.

b. An ecological effects assessment prepared by appropriately qualified and experienced, independent specialists and informed by the coastal processes assessment and sediment sampling already carried out, that assesses the ecological impact on the river environment from the proposed dredging operation and the estuarine and coastal environments from the proposed discharge of dredged material. The assessment(s) should include evidence which supports any statements made in the main report regarding:

  i. impacts on fish (including whitebait); and,
  ii. biosecurity risks associated with the invasive tubeworm,
  iii. ecological values and effects of dredging within the footprint, lower river/estuary and any nearshore areas potentially affected,
  iv. ecological values (including avian values) and effects of disposal at the proposed site (i.e. "the shore above mean high water springs, on or near the river mouth groyne, whereby the dredge sediments, in slurry form, will flow down the beach and into the sea") and nearshore areas potentially affected; and,
  v. likelihood and timeframes for the recovery of river benthos.

The first part of this report presents numerical modelling study investigating the effects of the proposed dredging activity; i.e., 4a above. The proposed dredging footprint is shown in Figure

1-2. The second part of this report addresses points i-v, that is, 4b of the request for further information.

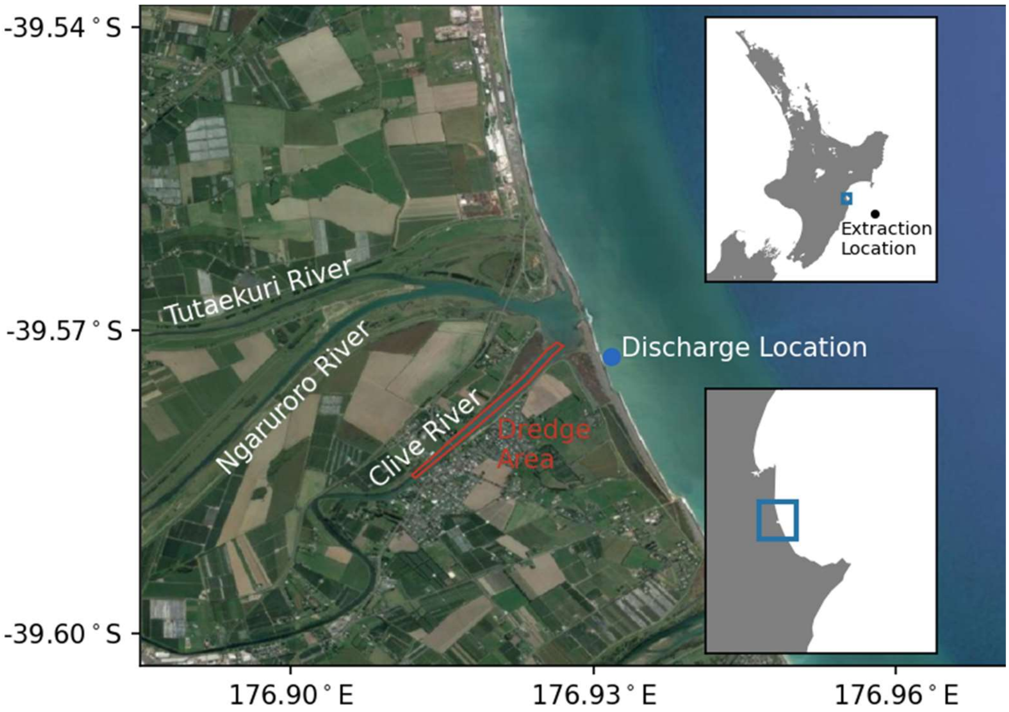

Figure 1-1: Location of the Clive River and relevant landmarks. The inset map also shows the extraction location for wave data from the NOAA WW3 model.

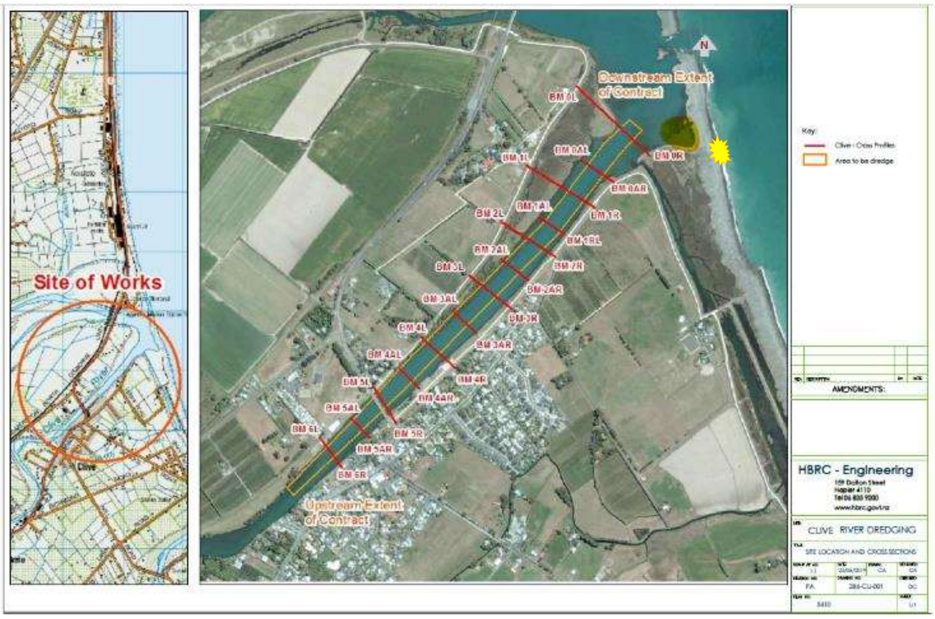

Figure 1-2. Location plan of area to be dredged (delineated by the elongated yellow box). The potential disposal site is shown in yellow on the southern side of the estuary entrance.

1.1 Proposed Dredging Operation

The footprint of the proposed dredging operation is shown in Figure 1-3. The dredging will remove 60,000 m^3 of material over an area of ~124,000 m^2, which is to be is transferred through a pipe onto the seaward side of the southern head of the Clive River (approximate location shown in Figure 1-3). The dredged material is to be output a rate of 500 m^3/hour (0.138 m^3/s), with a 20% sediment content of 100m^3/hour (0.028 m^3/s) discharged for 9 hours a day. At this rate, the dredging operation is expected to take approximately 67 days. The dredging will reduce the dredged area to a depth of approximately 1.6 m below Mean Sea Level (MSL), where the historic gravel riverbed is located. The pipeline will have a diameter of 14” (35cm) but can be widened (split) at the discharge point reducing the velocity.

Figure 1-3: Disposal location as advised by HBRC.

1.2 Site Overview

The Clive River is one of three rivers that form a confluence at the estuary, which is known as the Waitangi Estuary. The other two rivers are the Ngaruroro River and the Tutaekuri River to the north (see Figure 1-1). The rivers are received by the marine environment via a highly mobile estuary mouth as shown in Figure 1-4. River flows for the Ngaruroro and Tutaekuri Rivers are shown in Figure 1-5 (with 5-minute resolution) illustrating seasonal variability and flood events.

On the open coast, the wave climate is shown by month in Figure 1-6 for significant wave height (Hs), and Figure 1-7 for peak period (Tp). This record was extracted from the NOAA[1] WW3 global wave model at a resolution of 0.5 by 0.5 degree. The model extraction location was -40 latitude and 178 longitude (see Figure 1-1). Wave heights are generally less than 4 m and are dominated by high period (10 to 14 s Tp) swell from the south west at the offshore extraction location. Little of this south westerly wave energy is expected to reach the Clive estuary mouth, as it is blocked by Cape Kidnappers. An increase in wave activity from the north east is seen through the summer months (December through to April inclusive).

The wind record (Figure 1-8) shows wind directions predominantly from the south through to the west and north. During the summer months, the wind climate shows an increase in wind directions from the north east aligned with the short period waves which are seen at the same time of year.

Figure 1-4: The highly mobile estuary mouth of the Clive River illustrating the movement of the mouth over the space of 1 year.

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[1] http://polar.ncep.noaa.gov/waves/nopp-phase1/

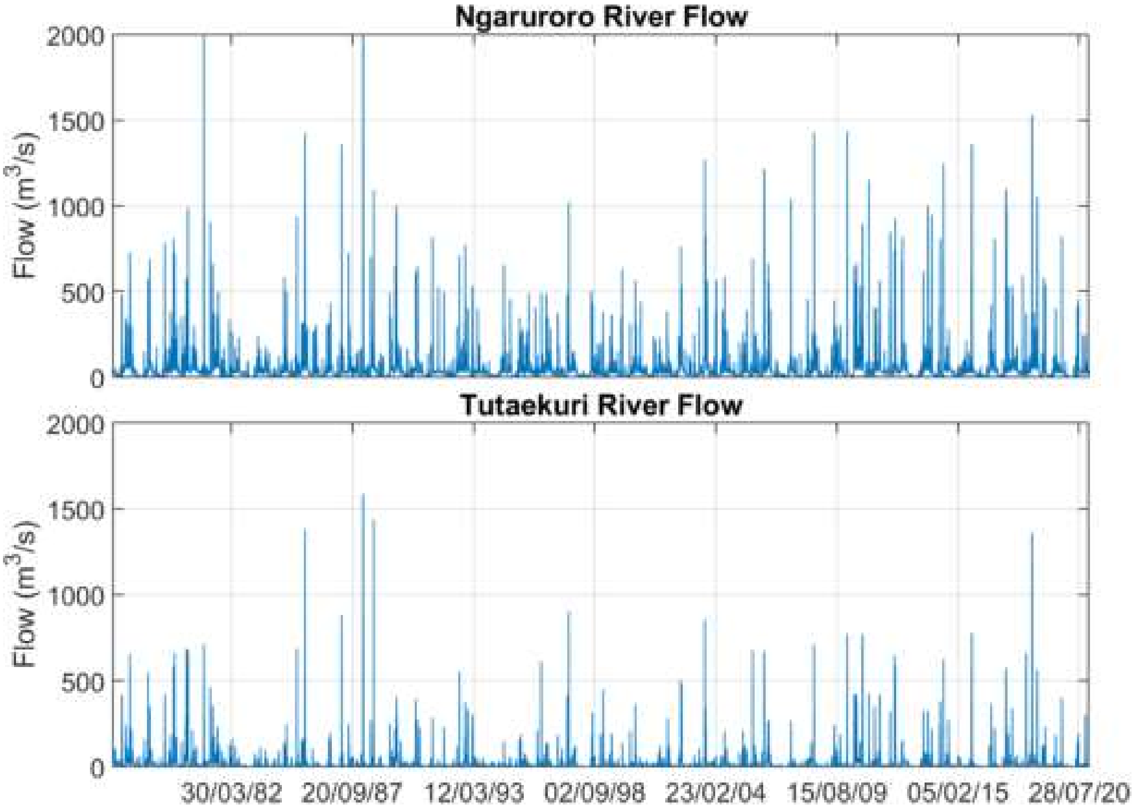


Figure 1-5: Long term river flow for the Ngaruroro and Tutaekuri Rivers showing periodic high flow events throughout.

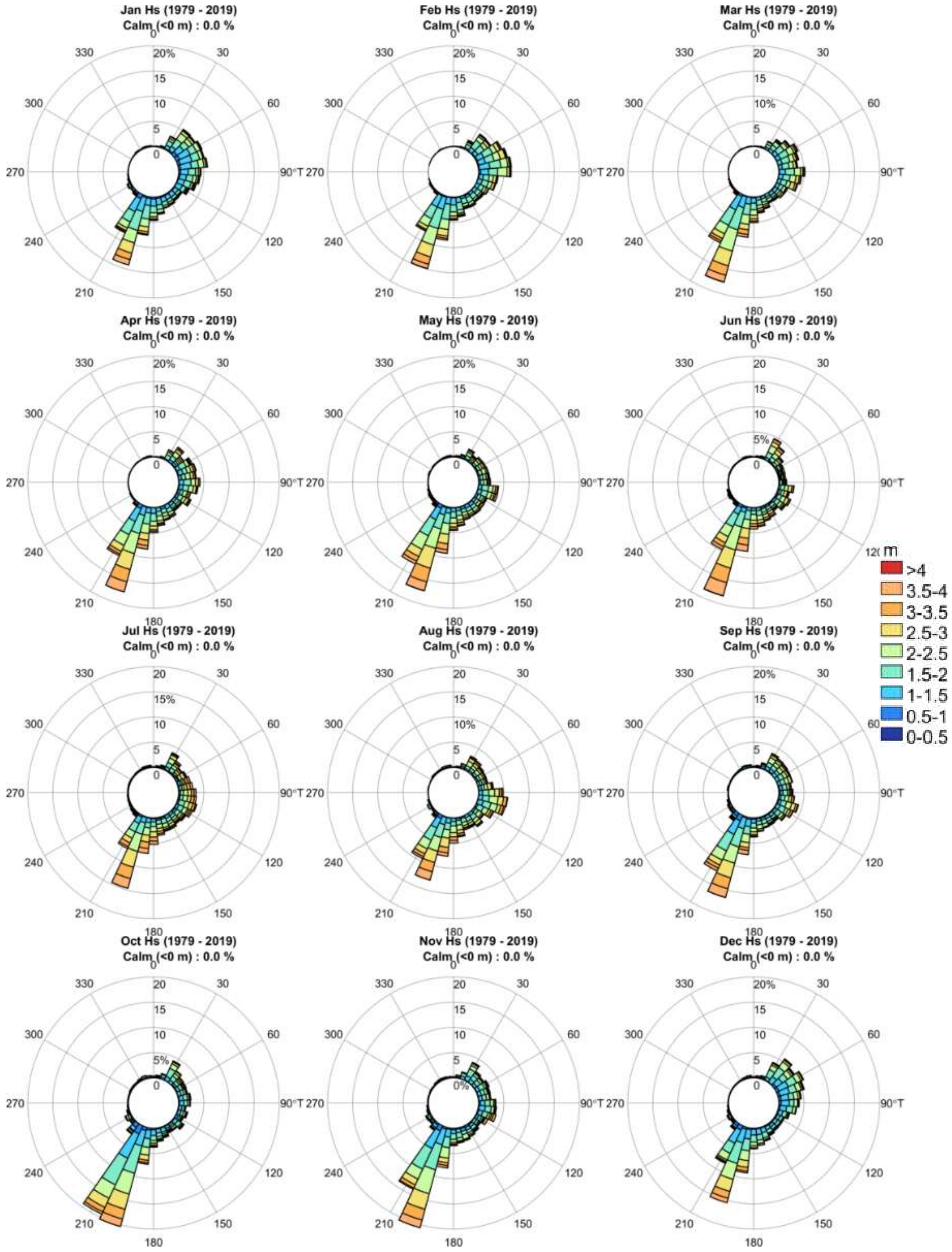


Figure 1-6. Rose plots of significant wave height (Hs) by month for a 41-year record (1979 - 2019) extracted from -39 latitude, 179 longitude.

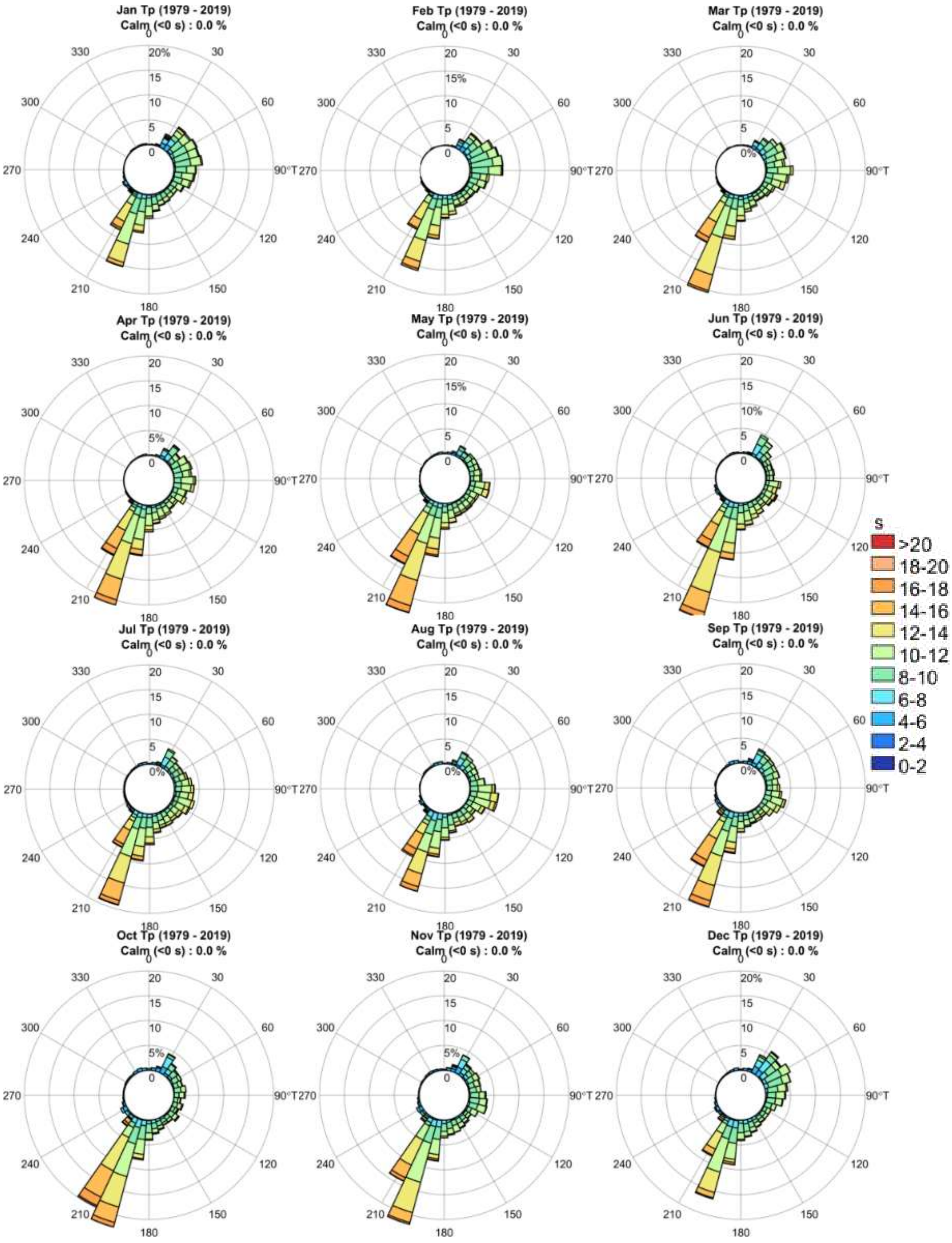
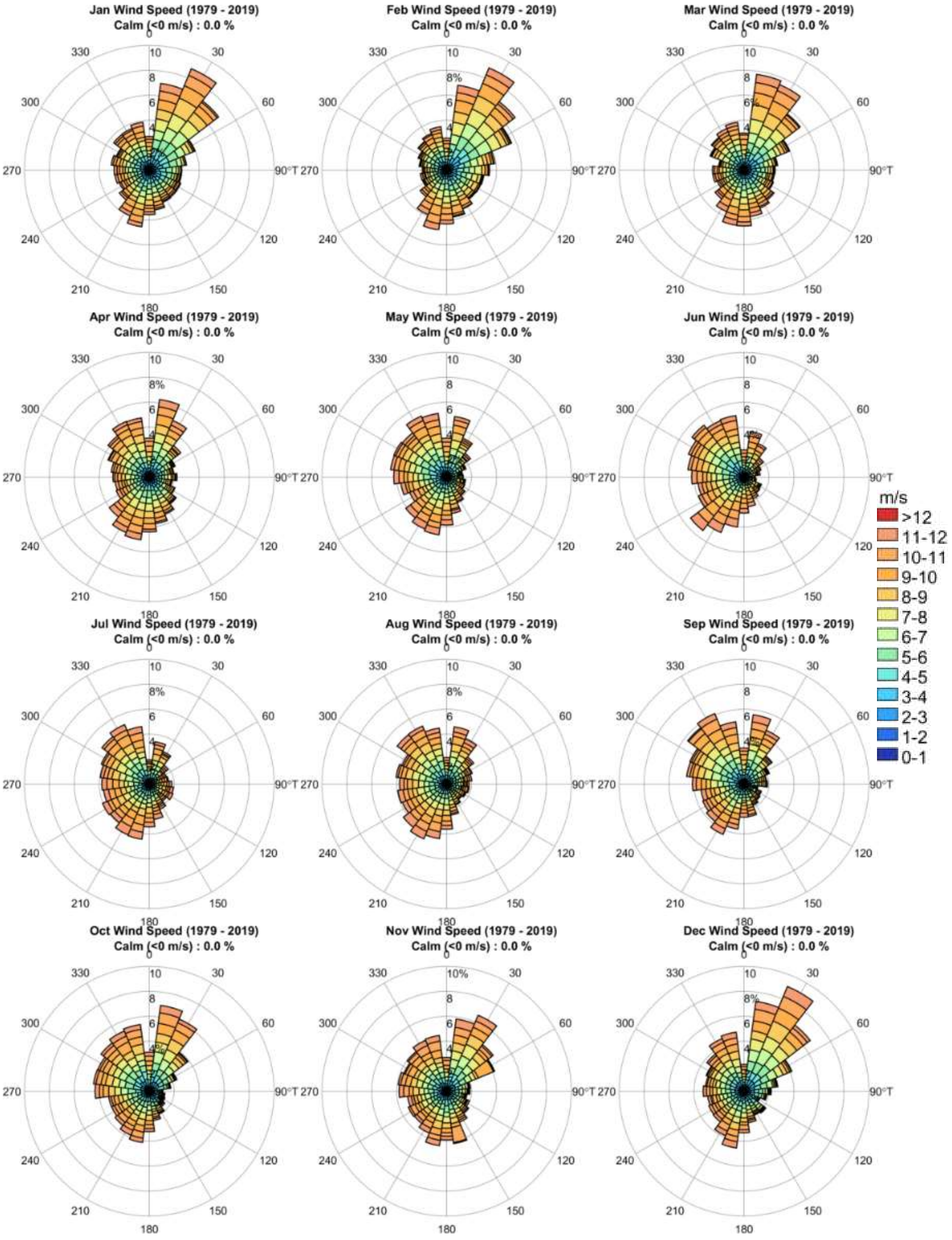


Figure 1-7. Rose plots of peak wave period (Tp) by month for a 41-year record (1979 - 2019) extracted from -39 latitude, 179 longitude.



Jan Wind Speed (1979 - 2019) Calm (<0 m/s) : 0.0 %

Feb Wind Speed (1979 - 2019) Calm (<0 m/s) : 0.0 %

Mar Wind Speed (1979 - 2019) Calm (<0 m/s) : 0.0 %

Apr Wind Speed (1979 - 2019) Calm (<0 m/s) : 0.0 %

May Wind Speed (1979 - 2019) Calm (<0 m/s) : 0.0 %

Jun Wind Speed (1979 - 2019) Calm (<0 m/s) : 0.0 %

Jul Wind Speed (1979 - 2019) Calm (<0 m/s) : 0.0 %

Aug Wind Speed (1979 - 2019) Calm (<0 m/s) : 0.0 %

Sep Wind Speed (1979 - 2019) Calm (<0 m/s) : 0.0 %

Oct Wind Speed (1979 - 2019) Calm (<0 m/s) : 0.0 %

Nov Wind Speed (1979 - 2019) Calm (<0 m/s) : 0.0 %

Dec Wind Speed (1979 - 2019) Calm (<0 m/s) : 0.0 %

Figure 1-8. Rose plots of wind speed by month for a 41-year record (1979 - 2019) extracted from -39 latitude, 179 longitude.

2 Numerical Modelling Methodology

Investigating the fate of disposed dredge material requires the use of a sediment transport model driven by currents and waves. Here we outline the details of the numerical modelling methodology including nearfield and far-field modelling of the dredged material accounting for both waves and currents. The approach used here uses a coupled wave and hydrodynamic modelling approach to ensure that the interaction between the two processes are simulated within the model.

Sediment transport is largely a product of the combined effects of broadscale hydrodynamics and orbital motion from passing waves. Broadly speaking, wave energy is usually responsible for suspending sediment (or maintaining it in suspension), while hydrodynamics driven by tides and wind are often responsible for transport of sediment. However, close to the shore, as in this case, waves can also be responsible for setting up current fields that can also transport sediment.

2.1 Hydrodynamic Modelling

The hydrodynamic model was developed using the Delft FM model suite. This Flexible Mesh (FM) model uses unstructured grids, with 3- to 6-sided cells and allows for irregular shapes. This grid format allows model cell shape and size to be manipulated based on the morphology in areas of interest, negating the need for multiple model domains and making simulations more accurate and efficient. Around features and areas of interest, the resolution is increased so the features are suitably resolved, whereas in featureless, flat and distal areas, such as in the deep water offshore, the cell size can be increased.

The bathymetry grid was developed to provide definition over the river, the estuary mouth and over the dredge disposal location. Bathymetry data was sourced from LINZ hydrographic charts[2] and river transects provided by HBRC (Figure 2-1) preferentially including data from a survey of the lower Clive River, the estuary mouth and the region directly offshore from the mouth from Mead *et al*. (2019b), as shown in Figure 2-2. The final model grid used in this study is shown in Figure 2-3 and provides a resolution of approximately 16 by 16 m near the sediment release location. A modified version of this bathymetry grid was created to reflect the changes that would occur due to the proposed dredging operations (Figure 2-4). This modified bathymetry grid was used to investigate changes in the flow regime as a result of the proposed dredging. For this purpose, the model was run for a 16 week period (1 to 17 January 2018) including 2 days of spin up time. During this time, the river flows were generally low

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[2] https://data.linz.govt.nz/

(Tutaekuri River 6.7 to 8.2 m^3/s, Ngaruroro River 18.1 to 33.3 m^3/s and Clive River 1.2 to 1.3 m^3/s), which is considered worse case with respect to dispersion.

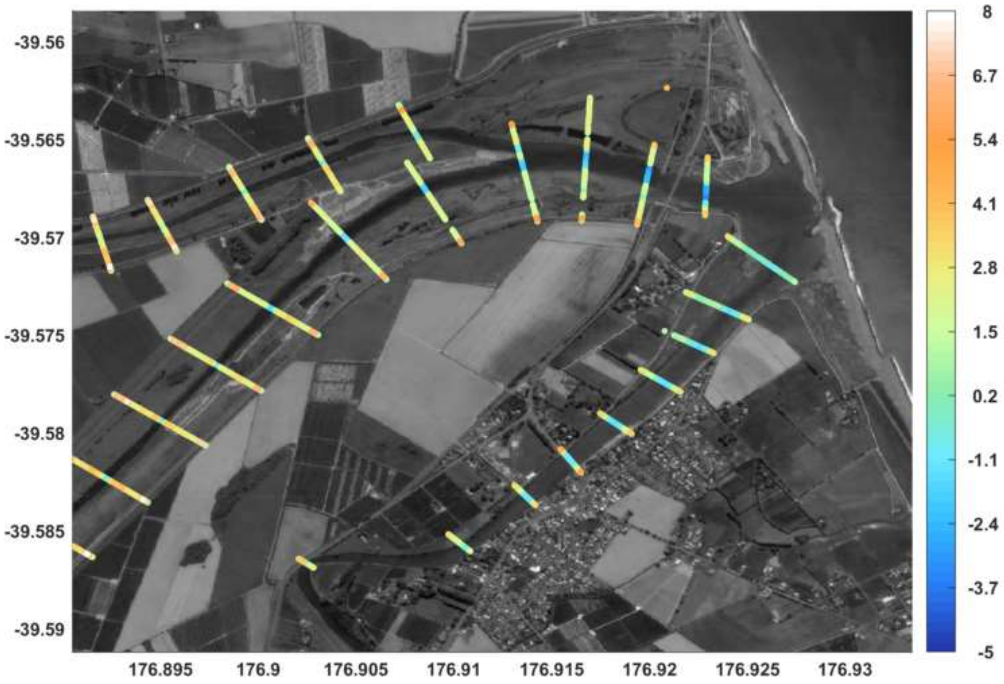

Figure 2-1: River transect data provided by HBRC.

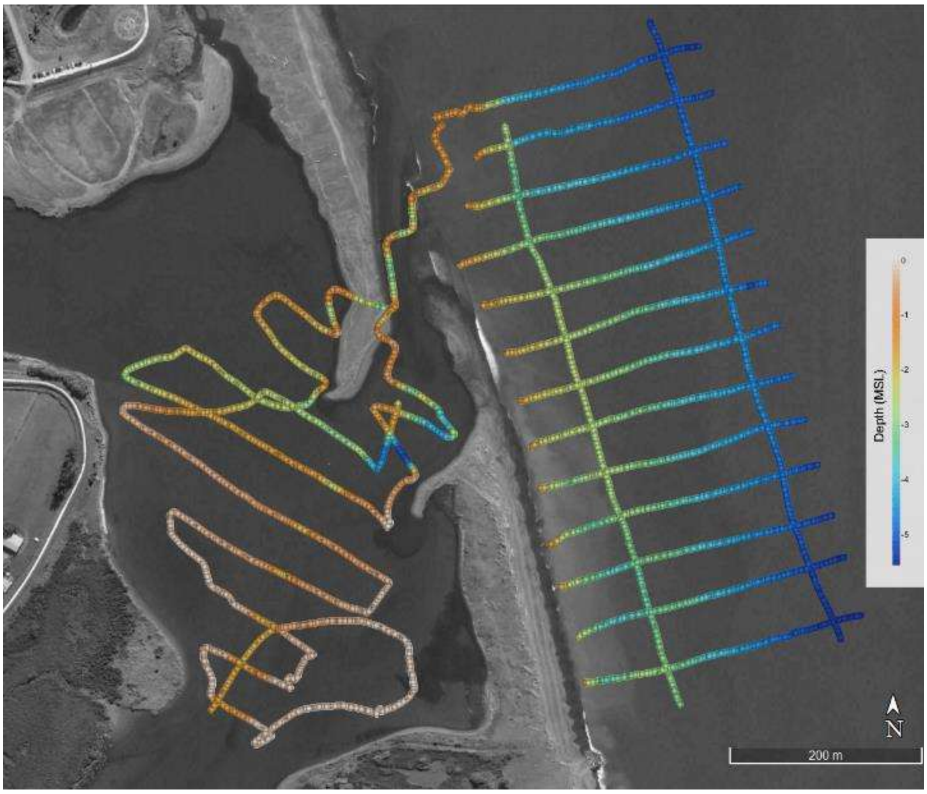

Figure 2-2: Bathymetry data collected as part of a survey of the Lower Clive River (Mead *et al*. 2019).

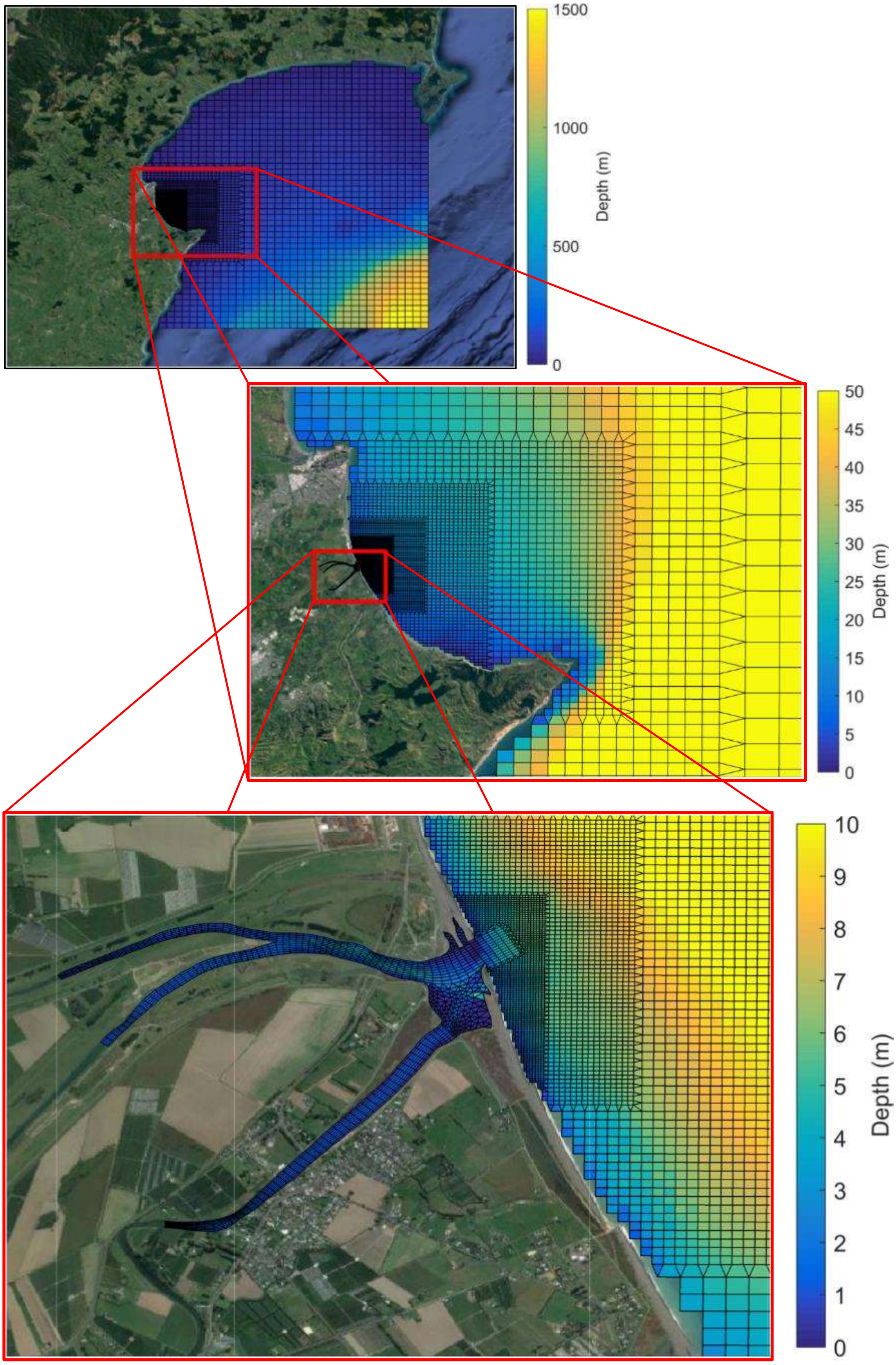

Figure 2-3: Bathymetry grid implemented in the hydrodynamic model used for subsequent sediment transport.

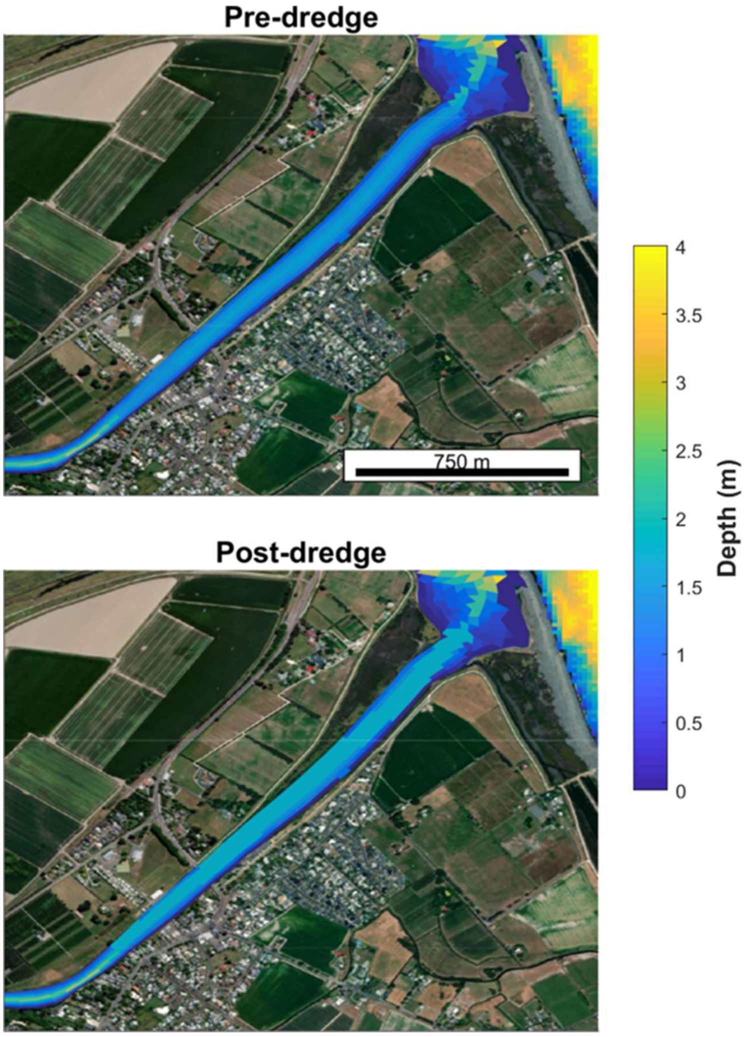

Figure 2-4: Bathymetry grid modification reflecting the depth changes due to the proposed dredging activities.

Tidal boundary conditions were applied on the open ocean boundaries of the model and were extracted from the TPXO wave atlas (Egbert and Erofeeva, 2002). This model was developed by the Oregon State University, who created a global model of ocean tides which uses along-track averaged altimeter data from the TOPEX/Poseidon and Jason satellites. The methodology applied in the global tide models has been refined to create regional models at higher resolution modelling here. For this project, the Pacific Ocean model with a resolution of 1/12 degree was used. The model provided the 11 most influential constituents, as well as two long period (Mf, Mm) harmonic constituents. Each constituent is a sinusoid which represents the gravitational influence of a particular aspect of a planetary body or of several bodies. Each sinusoid was described in the model by a phase and amplitude of the sinusoid and these were extracted at regular intervals along the model boundary.

For wind driven currents, 10 m wind data were sourced from the NOAA's global NCEP reanalysis model (Kalnay et al. 1996). The wind model resolution is 0.312 by 0.312 degree resolution from 1979 until 2011 (Saha *et al*., 2010) and 0.205 by 0.204 from 2011 onwards (Saha *et al*., 2010).

While no calibration data were available for this model, a similar model was developed by eCoast in 2018 for the Wairoa River which was calibrated against measured water level, current and salinity data (Greer and Mead, 2018). Since the Wairoa River is of a similar scale to the river network in the current study, the parameters were considered appropriate for use in the models presented here. The parameters from this model were carried over into this model including friction of 80 $m^{0.5}/s$ (Chézy coefficient) and diffusion of 20 m^2/s. As the Wairoa River model was developed in Delft 3D it used a static Horizontal Eddy Viscosity (HEV) of 20 m^2/s units. Delft FM uses a variable Smagorinsky HEV and here a coefficient of 0.2 was used. The model was run in 2D. River flow data for the Tutaekuri and Ngaruroro Rivers were taken from the Puketapu and Chesterhope Bridge flow gauges respectively (Figure 1-5).

A reliable flow record does not exist for the Clive River so modelled flow was derived using a scaling factor on the Tutaekuri River flow. The scaling factor was obtained by comparing daily flow from the Karamu Stream in the Clive River against the daily flow from the Tutaekuri River at the Puketapu gage. The scaling factor was then applied to the 5-minute resolution Tutaekuri River flow to obtain Clive River flows. The model boundary conditions were setup to run for the year of 2018 providing the means to model the dredging process under a range of metocean conditions. As noted previously, the mouth where flow from the three rivers is received by the marine environment, is highly mobile and it is expected to change considerably under the influence of large wave and flow events. While the model was used to transport sediment, it did not include a full morphology model for the estuary mouth as this is beyond the scope of the project. Consequently, river flows in the model were capped at 100 m^3/s to maintain realistic flow speeds within the estuary system. All model runs included 2 days of spin up time prior to any sediment releases.

As well as providing input to the sediment transport model, the hydrodynamic model was run with the present day bathymetry and again using the modified bathymetry to investigate the effects of the dredging on the flow regime in the lower Clive River.

2.2 Wave Modelling

Wave modelling was undertaken using SWAN (Simulating WAves Nearshore) which is part of the Delft3D model suite and is an industry standard for wave modelling. SWAN is a third generation ocean wave propagation model, incorporating current knowledge regarding the generation, propagation and transformation of wave fields in both deep water and nearshore regions. SWAN solves the spectral action density balance equation for frequency-directional spectra. This means that the growth, refraction, and decay of each component of the complete sea state, each with a specific frequency and direction, is solved, giving a complete and realistic description of the wave field as it changes in time and space.

Physical processes that are simulated include the generation of waves by the surface wind stress, dissipation by white-capping, resonant nonlinear interaction between the wave components, bottom friction and depth limited breaking. The model is described fully in the user manual (Holthuijsen et al., 2004).

Wave boundary conditions were taken from a 0.5 degree by 0.5 degree global model of wave characteristics maintained by NOAA[3]. The wave boundary information was extracted from a model node at -40 latitude and 178 longitude (see Figure 1-1). The wind boundaries were the same as those used in the hydrodynamic model. The model was run with a timestep of 6 hours and was coupled to the hydrodynamic model described above in Section 2.1.

The wave modelling was undertaken using a series of 3 nested grids resulting in a resolution of approximately 27 by 27 m near the study site. The nested bathymetries are shown in Figure 2-5.

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[3] http://polar.ncep.noaa.gov/waves/nopp-phase1/

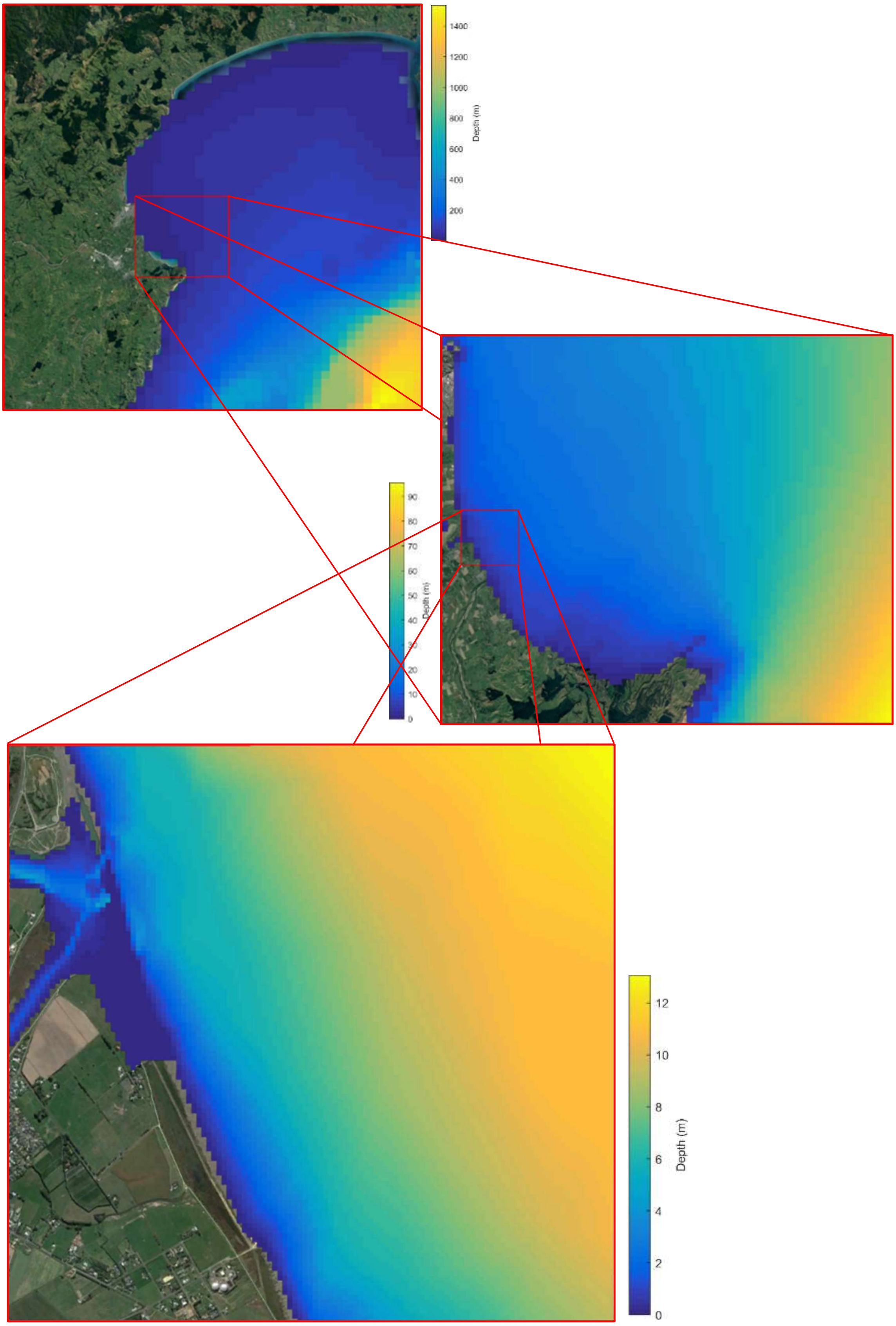

Figure 2-5: Bathymetry grids used in the SWAN wave modelling.

2.3 Sediment Transport Modelling

Sediment transport modelling was carried out in two phases: nearfield and far-field. The nearfield modelling considers the complex dynamics of the discharged material as it is released from the discharge pipe and how the initial plume behaves. This is used to parametrise a far-field model that simulates the dispersal of sediment over a larger area.

2.3.1 Sediment Characteristics

The composition and nature of the sediment being dredged was largely derived from the sediment sampling and analysis presented in Mead *et al.* (2019a). This study provides details of 10 samples collected throughout the proposed dredge area (shown in Figure 2-6 and Table 2-1). The samples were analysed and provided percentages of clay, silt and fine-medium sand at each location (Table 2-2). The average of these (14% clay, 61% silt, 25% sand) were used to parameterise the modelling of the dredge disposal.

Dry density (ρ_{dry}) of the combined sediment fractions was calculated using the method of Lara and Pemberton (1963) presented in Van Rijn (1993).

$$\rho_{dry} = 1{,}550p_{sand} + 1{,}120p_{silt} + 420p_{clay}$$

Where p_{sand} is the percentage of sand, p_{silt} is the percentage of silt and p_{clay} is the percentage of clay leading to ρ_{dry} = 1,128 m^3.

Bulk density (ρ_{bulk}) was calculated (Whitehouse *et al.* 2000) as

$$\rho_{bulk} = \rho + \rho_{dry}\left(\frac{\rho_s - \rho}{\rho_s}\right)$$

Where ρ is the density of sea water (1025 kg/m^3) and ρ_s is the specific density of the sediment (taken here to be 2,650 kg/m^3). This leads to ρ_{bulk} = 1,702 kg/m^3.

The dredged material is output with a 20:80 ratio so the density of the material as exits the disposal pipe is $0.8 * 1{,}025 + 0.2 * 1{,}702 = 1{,}160.4$ kg/m^3.

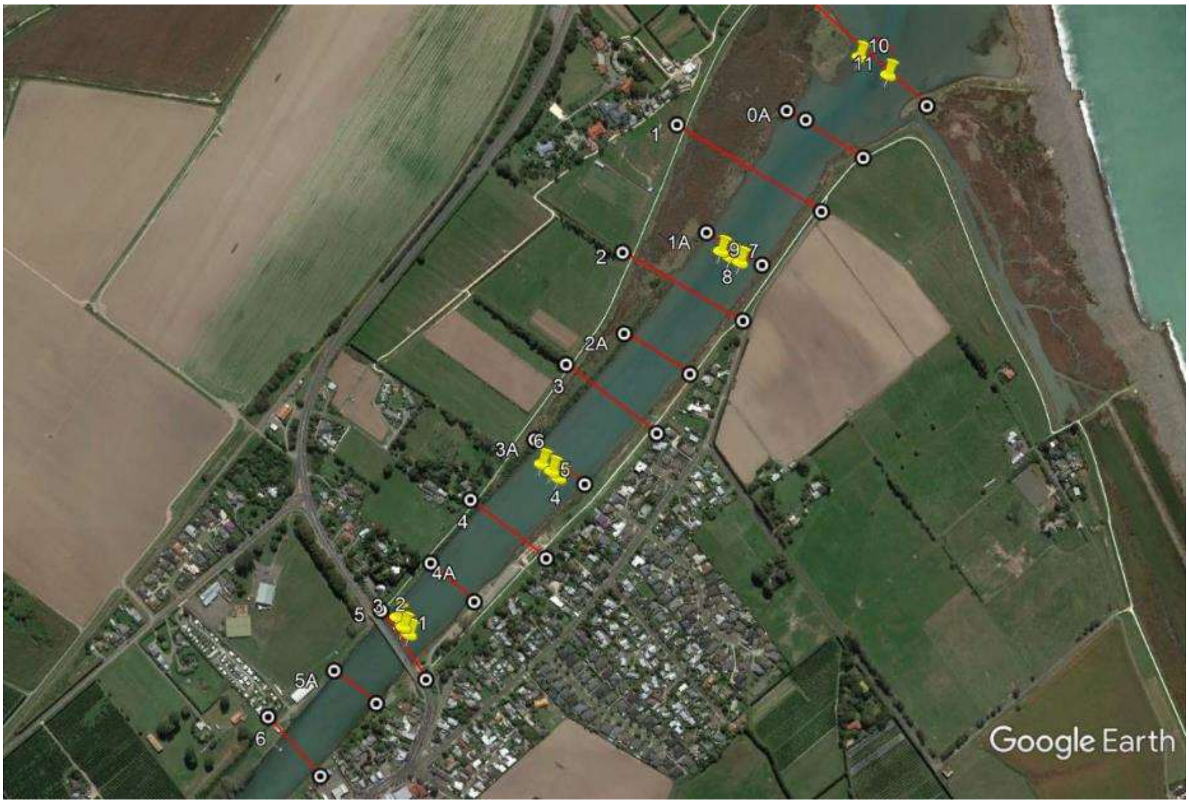

Figure 2-6: The 11 sediment and probe sampling sites are indicated by the yellow markers (the coordinates are presented in Table 2-1), and the digitised transects for dredging volume calculations are shown by the red lines.

Table 2-1: Sediment and probe sampling locations (WGS84) refer Figure 2-6.

Site	Latitude	Longitude
1	39°34'53.29"S	176°54'58.05"E
2	39°34'52.87"S	176°54'57.60"E
3	39°34'52.29"S	176°54'57.14"E
4	39°34'44.01"S	176°55'9.56"E
5	39°34'43.61"S	176°55'9.03"E
6	39°34'43.18"S	176°55'8.27"E
7	39°34'31.19"S	176°55'23.54"E
8	39°34'30.90"S	176°55'22.78"E
9	39°34'30.54"S	176°55'22.06"E
10	39°34'18.99"S	176°55'32.74"E
11	39°34'20.06"S	176°55'34.93"E

Table 2-2: Broad classification of sediment grainsize fractions in the samples.

Site	Clay	Silt	Fine-Med Sand
1	18%	72%	11%
2	12%	71%	18%
3	14%	69%	18%
4	19%	70%	11%
5	17%	73%	10%
6	15%	71%	14%
7	18%	72%	11%
8	16%	65%	20%
9	16%	69%	15%
10	6%	25%	69%
11	3%	13%	84%
Mean	**14%**	**61%**	**25%**

2.3.2 Nearfield Modelling

The dredge release was simulated in the nearfield using a two-stage approach as outlined in Fissel and Lin (2018), by firstly using a continuous discharge model to simulate the initial dilution zone and using the results in a dedicated dredge dispersal model.

The initial dilution of the discharged sediment was determined using the model Visual Plumes (Frick *et al.*, 2003) which is a mixing zone modelling system that can simulate the advection and mixing of jets with different densities in the receiving environment. The model was run under a moderate current speed of 0.1 m/s with a surface discharge as specified in Section 1.1. The results of this simulation are shown in Figure 2-7 and Figure 2-8. The plume travels horizontally approximately 1 m before sinking rapidly to the seabed in an ellipsoid with semi minor and major axes sizes of 1 m and 3 m, respectively.

An additional model Short Term FATE (STFATE) was used to determine how much of the sediment settled directly on the seabed due to nearfield processes. STFATE is a model for simulating sediment disposal, which can be used to simulate the short-term fate and near-field distribution of the disposal material released from marine barges immediately following each disposal operation (Environmental Protection Agency, 1998). The STFATE operates on the actual bathymetry using an identical or smaller model mesh to match the 3D hydrodynamic model grid. STFATE simulates the dilution and dispersion of released sediments due to the gravitational descent, horizontal transport due to the ocean currents and turbulent diffusion and the rapid deposition of most coarse sediments.

When released in the marine environment, dense sediment typically disperses in three distinct phases, namely:

- Convective descent –controlled by gravity and momentum.
- Dynamic collapse –bottom encounter, spreading dominates.
- Passive transport dispersion –currents and turbulence dominates.

These processes are shown graphically in Figure 2-9. While this is generally applied to dredged material released from a barge or hopper, the same principle applies to material released through a pipe. STFATE simulates these processes and provides estimates of how much material settles straight to the seabed and how much is released into the water column for passive transport. The model was run using results from the Visual Plumes model and parameterised with the sediment fraction data from Mead *et al.* (2019a)

The results of the STFATE modelling are shown in Table 2-3. The depositional footprint of the sediments was a 12 m circle and very similar dimensions applied to the suspended plume in the nearfield.

Table 2-3: Results of nearfield modelling for release of dredged material

	Sand	**Silt**	**Clay**
Suspended (%)	72.4	98.6	99.5
Settled (%)	27.6	1.4	0.5

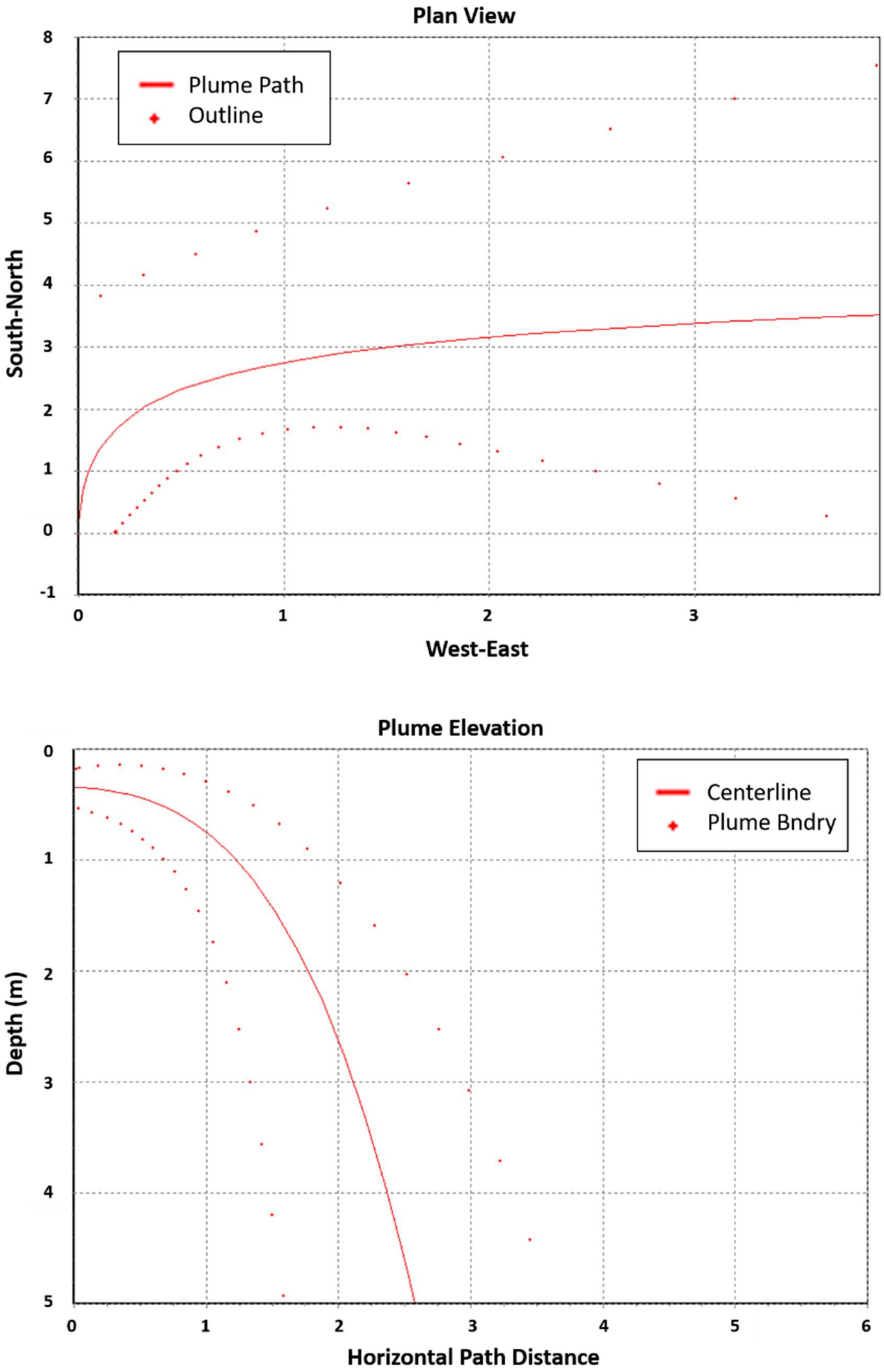

Figure 2-7: Plume dimensions as predicted by the Visual Plumes nearfield model.

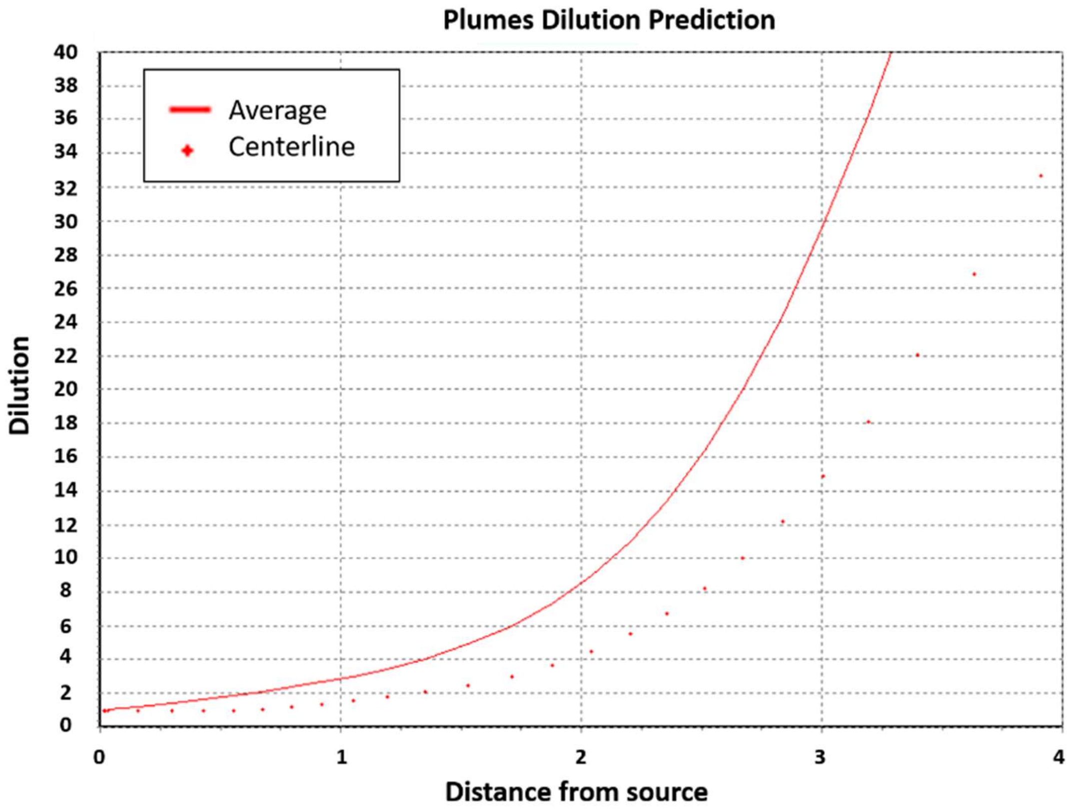

Figure 2-8: Plume dilution as predicted by the Visual Plumes nearfield model.

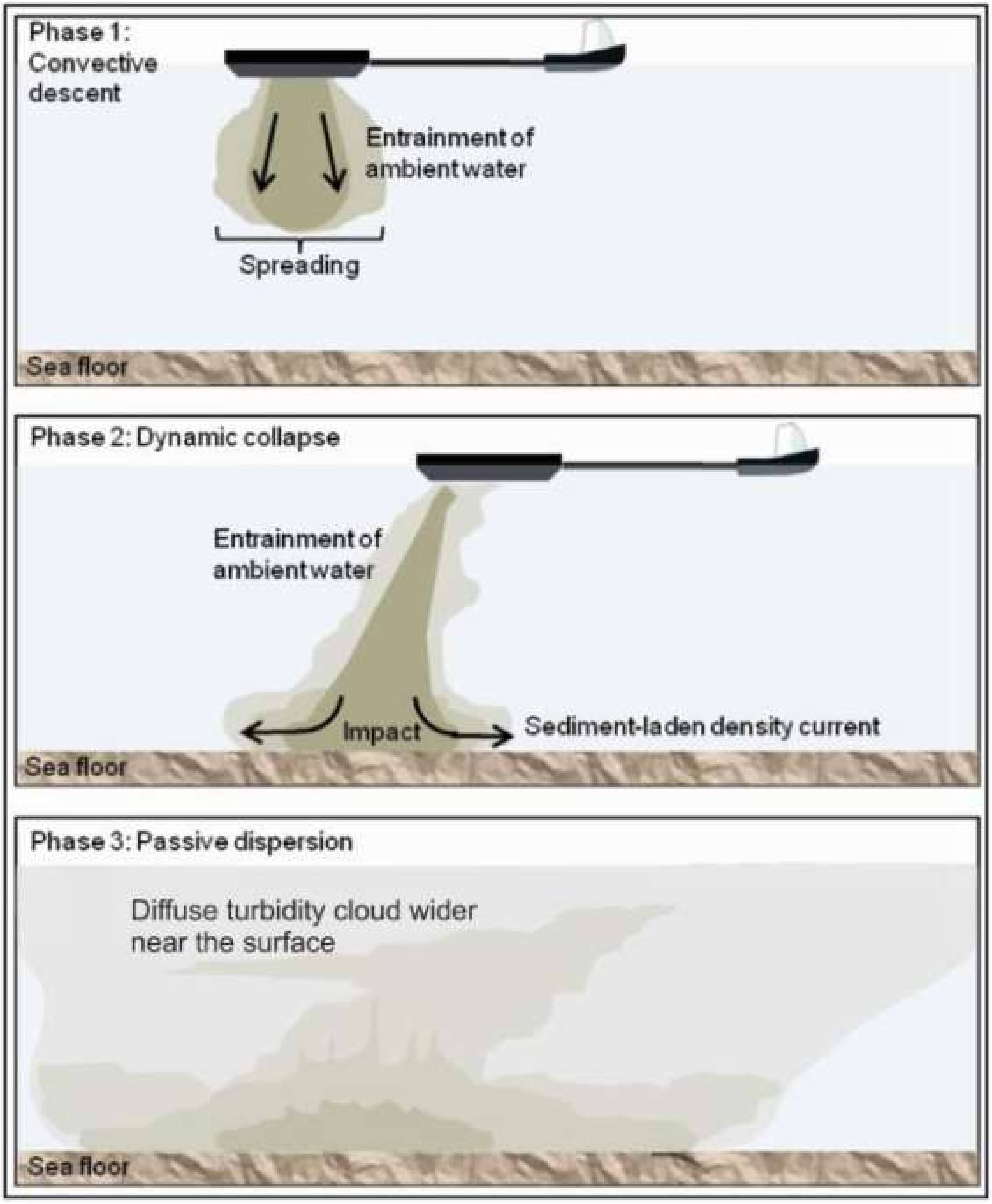

Figure 2-9:The three phases of surface released dredge spoil (source: Beca, 2018).

2.3.3 Far-field modelling

Far-field sediment transport modelling was undertaken using the DelftFM D-Morphology module. This uses the coupled wave/hydrodynamic model together with sediment release boundary conditions to simulate advection, settling and resuspension of released material. The sediment model was run in an ‘online’ mode meaning that the wave and hydrodynamic models are affected by changes to the bathymetry from the sediment transport modelling and vice-versa. This is particularly relevant in this situation where sediment in being deposited into a shallow water. The sediment transport model is run on the same grid used for the hydrodynamic modelling.

The sediment release location applied was -39.572614° latitude and 176.931702° longitude and sediment was released for 9 hours continuously out of each 24 hours. The release location was approximately 3 m deep (MSL). Disposal was simulated for 67 days to model the release for the duration of the dredging operation. Two sediment fractions were simulated in this model: one for non-cohesive sediment (sand) and one for cohesive sediment (clay and silt combined and referred to hereafter as 'fines'). As per the results from the nearfield modelling, all of the clay and silt was released into the water column and 27.6% of the sand was released straight to the seabed beneath the discharge pipe.

Two scenarios were run to explore the sediment transport under different metocean conditions: one in summer months (1 January 2018 through to 10 March 2018 precise dates) and one during winter months (1 June 2018 to 8 August 2018 precise dates).

Sediment properties within the sediment transport model are largely based on literature review. For sand, the Soulsby formulation (Soulsby, 1997) was used which requires a value for resistance length (Z_0) and median grain size (D_{50}). A typical value for Z_0 for this environment is 0.00125 (Soulsby, 1997) and the grain size of fine-medium grain sand is 0.25 mm. The specific density of sand was taken to be 2,650 kg/m^3 with a dry bed density of 1,600 kg/m^3.

For fines the Partheniades-Krone scheme was used. The settling velocity ($w_s = 0.0005$ m/s), erosion parameter (0.0001 kg/m^2s), critical shear stress for sedimentation ($\tau_d = 0.08$ N/m^2) and critical shear stress for erosion ($\tau_e = 0.18$ N/m^2) were all taken from Whitehouse et al. (2000).

3 Numerical Modelling Results

This section presents the results of the modelling described in Section 2 including the pre- and post-dredging hydrodynamics and the fate of the discharged dredge material.

3.1 Effects on Hydrodynamics and Infilling Rates

As described in Section 2.1, the hydrodynamic model was run for with both the pre- and post-dredge bathymetry to investigate the changes in the flow regime resulting from the deeper channel following dredging. Increasing the cross-sectional area of the river bed by dredging results in a slight reduction of current speeds. Summary results are shown in Figure 3-1 and Figure 3-2. During spring flood and ebb flows current speeds decrease by up to approximately 0.1 m/s during ebb tides following dredging. Neap ebb and flood tidal currents are low (<0.05 m/s) and not affected greatly by the dredging operation. The effect of reduced current flows means that sedimentation of the dredged area will occur at a greater rate than prior to dredging.

These changes to the flow rates of the river are unlikely result in any physical/morphological impacts to the lower river or river mouth (other than with respect to infilling rates, which are discussed below). This is because the changes are of the order of 0.1 m/s maximum, which is the threshold of sediment movement for fine unconsolidated material. The lower river/Waitangi Estuary area has a sandy bed, while the river entrance is comprised of shingle banks; i.e., the relatively small changes to flow cannot result in movement of these materials.

Infilling rates following dredging are a function of sediment inputs (which are mainly from terrestrial sources) and river flow rates (which are associated with rainfall), and so varies year to year. Infilling of the lower Clive River is due to a combination of events including the 1931 earthquake uplifting the riverbed and reducing the grade of the lower reaches, which consequently prevented any new gravel from reaching the lower Clive, changes to the river systems in 1969 and changes to land-use. As described on the HBRC website[4], originally the lower Clive River was part of the Ngaruroro River until 1969 when the Ngaruroro was diverted entirely down the overflow channel, providing relief from frequent flooding in Clive and Hastings. This resulted in a drastic change of flow regime of the lower Clive River by reducing flow rates to a quarter of their pre-diversion volumes. A consequence of this was a build-up of silt (inputs from land run-off due to land-use changes) over the river-bed which had previously been gravel, as the lower river velocities meant that the sediment was no longer transported to the coast. Clode (2018) details these changes to the Clive River, as well as

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[4] https://www.hbrc.govt.nz/services/flood-control/clive-river-dredging/

assesses potential options to prevent the sedimentation (i.e., revert the lower Clive to its pre-1969 state). However, there are a number of complexities that may make the reversion of the lower Clive difficult if not impossible, with Clode (2018) concluding that limiting the sediment input through land management controls would provide the most benefit, although the management regime of the future for this section of river may be to value the muddy bottom ecology for what it is.

A 1993 survey indicated that since the diversion of the Ngaruroro River, 66,000 m^3 of silt was deposited over a length of 2,000 metres of the lower Clive River, reducing the depth by an average of 0.35m. Dredging was first carried out in 1997 after obtaining a resource consent and again in 2009, with another resource consent and renewed community liaison. The dredging volume in 2009 was less than the 1997 volume and did not extend as far upstream.

The current proposed dredging is to remove 60,000 m^3 from ~1.4 km stretch along the lower Clive River. The results of the hydrodynamic modelling and recorded volumes of sedimentation suggest that the amount dredged will be infilled to a similar level within the next 10-12 years. While beyond the scope of this present study, it is likely that somewhat of an equilibrium is tended towards where, as the lower Clive River continues to fill with sediment, the current velocities increase, which has a result of decreasing sedimentation rates (i.e. infilling rates are determined by feedback due to the cross-sectional area of the river).

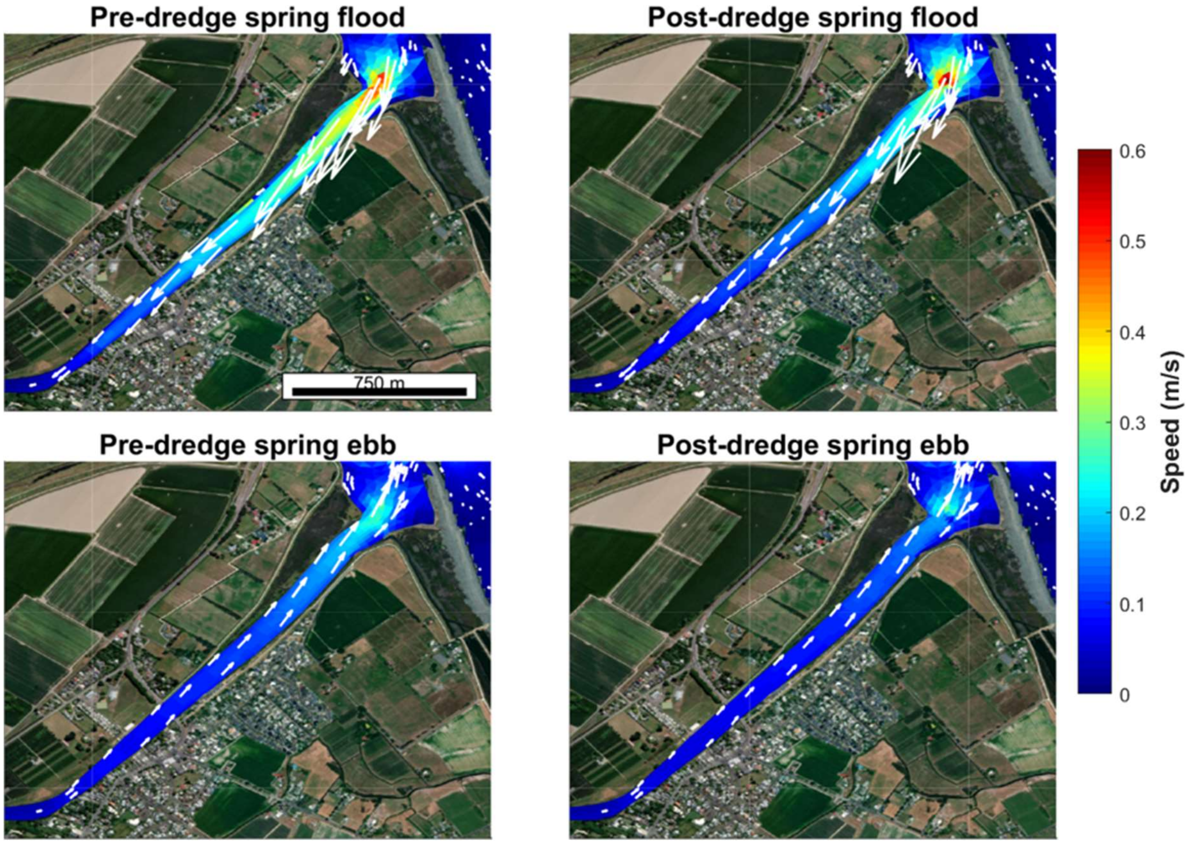

Figure 3-1: Peak flood and ebb current speeds for pre and post dredging river conditions during spring tides.

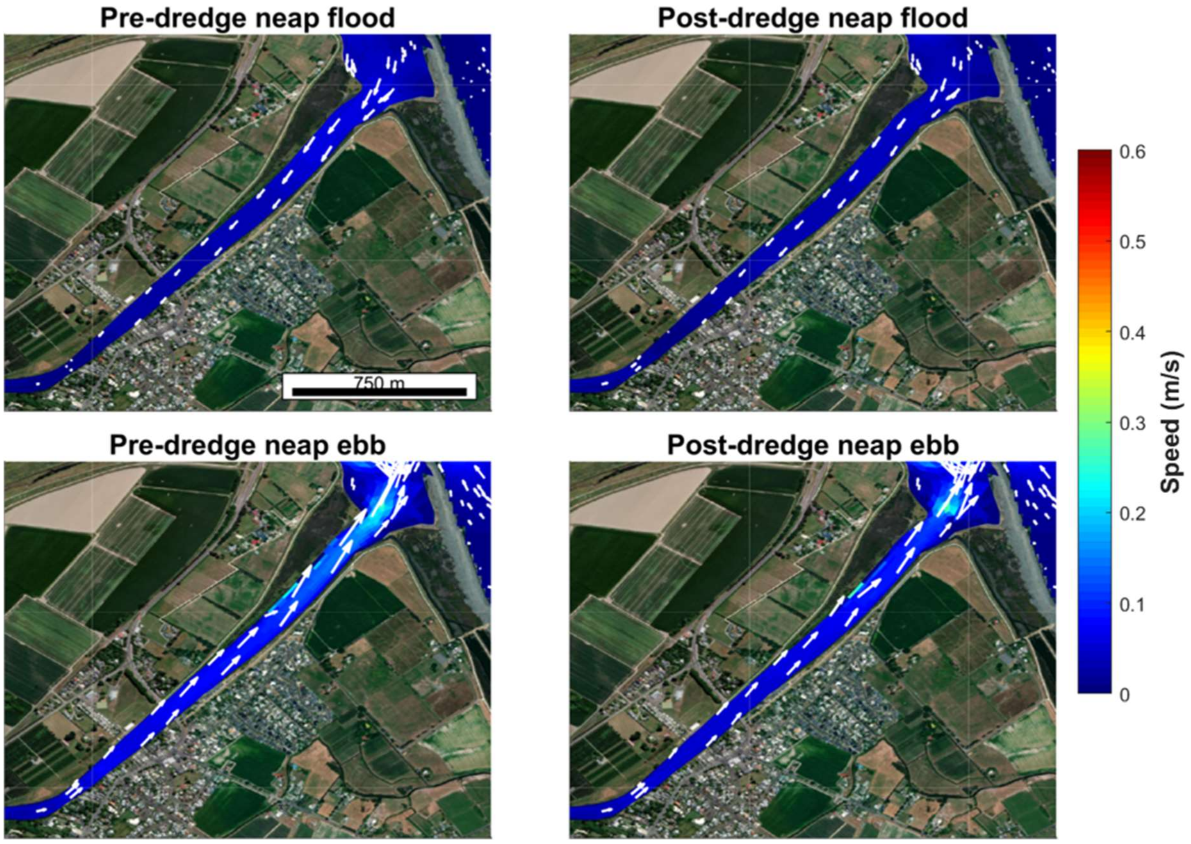

Figure 3-2: Peak flood and ebb current speeds for pre and post dredging river conditions during neap tides.

3.2 Dredge Discharge Fate

The sediment transport modelling provides the means of predicting both the dispersion of the sediment plume and the thickness of sediment layer resultant from the plume falling out of suspension. Suspended sediment can be examined as sand and fines separately, which is useful as for a given concentration, suspended fines have a considerably higher effect on light attenuation than sand. Fines are also expected to stay in suspension for much longer and disperse much farther from the point of release in the short term.

The suspended sediment results are shown in Figure 3-3 to Figure 3-5 for fines Figure 3-6 to Figure 3-8[5] for sand and present mean, 90th percentile and 99th percentile concentrations. As expected, the sand falls out of suspension rapidly. While the 99th percentile concentration of suspended sand is > 0.05 kg/m^3 in the vicinity of the outfall, it rapidly falls to <0.0001 kg/m^3 within 100 m of the outfall in both Summer and Winter conditions. For fines, the suspended plume is considerably larger. Overall, in Summer conditions, the suspended plume of fines is dispersed less rapidly under the less energetic conditions than under Winter conditions creating a larger plume. Mean concentrations are generally low, and this is largely due to the 17 hour daily downtime in the dredging schedule. The 90th and 99th percentile plumes for fines cover a considerably larger area and show concentrations up to 1 kg/m^3 close to the outfall, although the concentrations fall away rapidly with distance. The plume is most concentrated to the north of the outfall due to the predominance of wind-driven currents from the southern quarter, with concentrations of 0.3 kg/m^3 seen up to 500 m towards the estuary mouth.

Sediment deposition for combined fines and sand is shown in Figure 3-9 to Figure 3-10 showing the maximum sediment thickness at each cell through the runs and the deposition at the end of the model runs. Sediment deposition is greatest near to the outfall with maximum deposition levels of nearly 1 m within 150 m of the outfall. Beyond this point the maximum deposition thickness rapidly falls off to approximately 0.01 m. The 0.01 m deposition footprint is larger in Winter conditions than in Summer conditions extending some 800 m away in the former and 500 m in the latter. In both cases, the footprint extends north east from the outfall location with a smaller area extending to the south east. The maximum deposition pattern is very similar to the final deposition footprint in the model. This indicates that, while the deposited sediment is expected to be highly mobile under the influence of larger wave events, it may remain where it settles until then. Based on the long-term wave data, the occurrence

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[5] Note, modelled discharge is at the water's edge, however, the material runs down the steep nearshore subtidal slope and the main accumulation is at the bottom of this slope some 50-60 m offshore (see Figure 4.2 in the Lower Clive River Sediment Sampling and Depth Probing, and Entrance Bathymetry and Ecological Assessment), which is where the densest concentrations occur

of these larger wave events that will resuspend and disperse the material occur approximately 3% of the time, or~11 days per year.

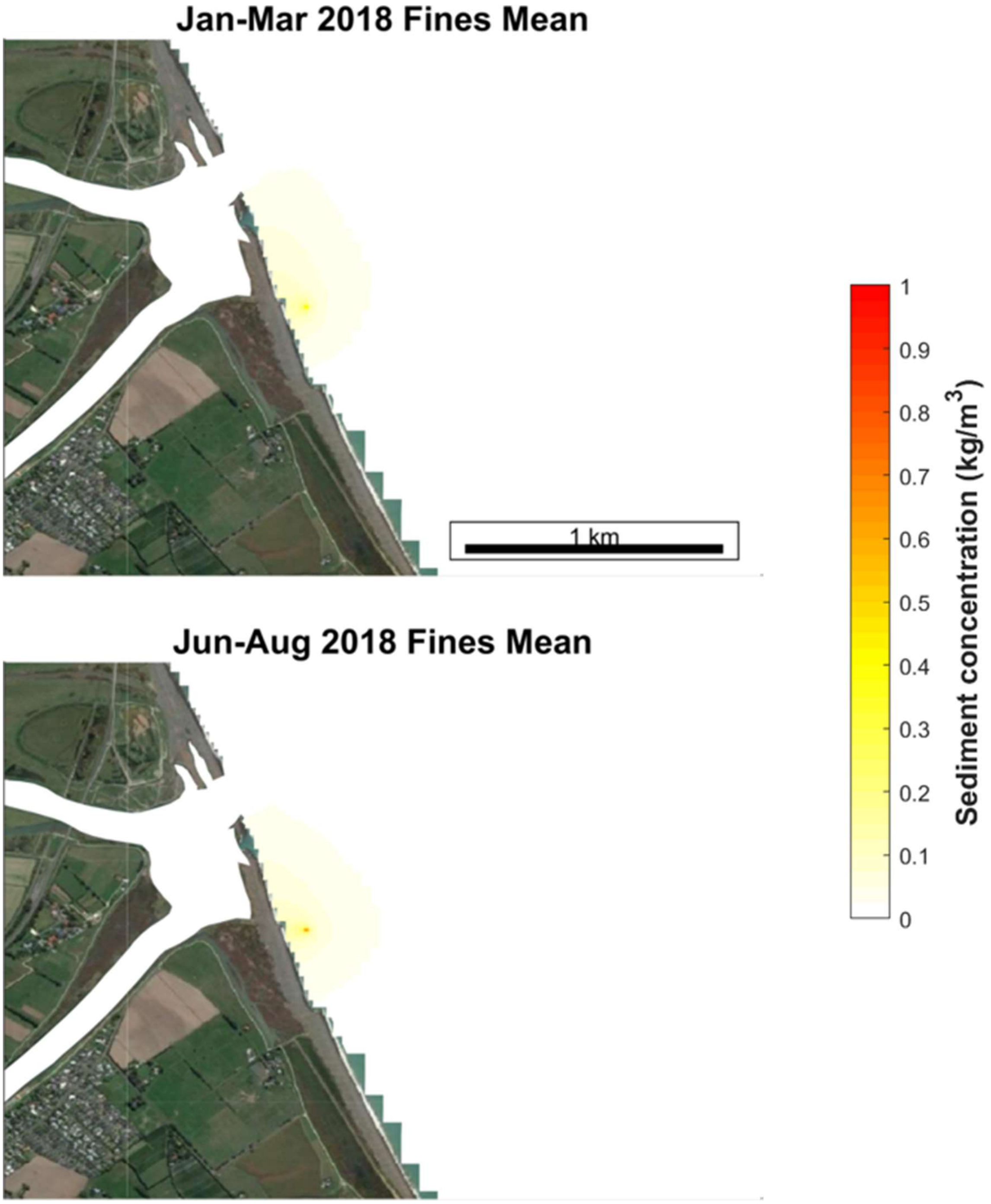


Figure 3-3: Mean sediment concentration for fines for Summer (top panel) and Winter (lower panel) conditions.

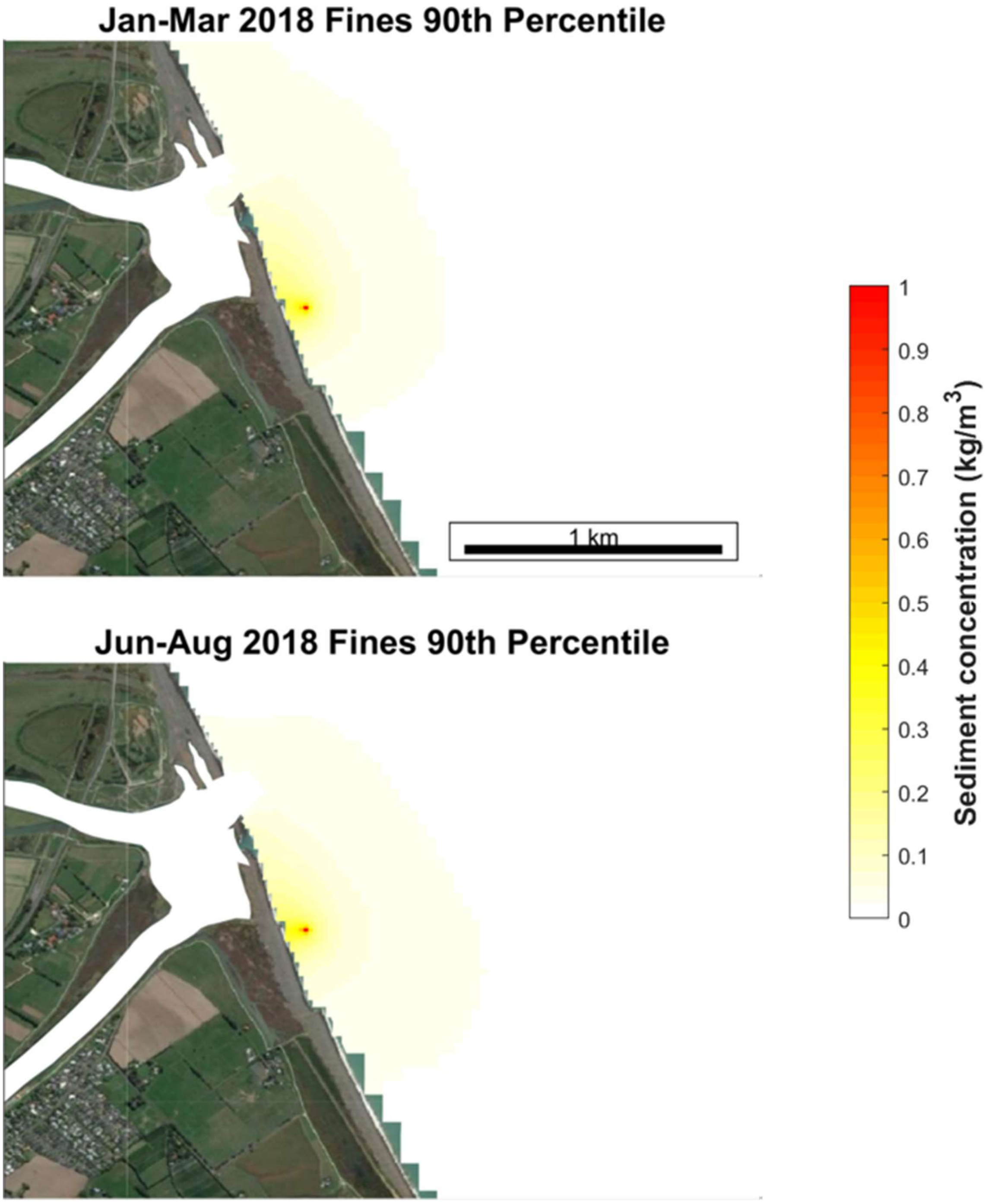


Figure 3-4: 90th percentile sediment concentration for fines for Summer (top panel) and Winter (lower panel) conditions.

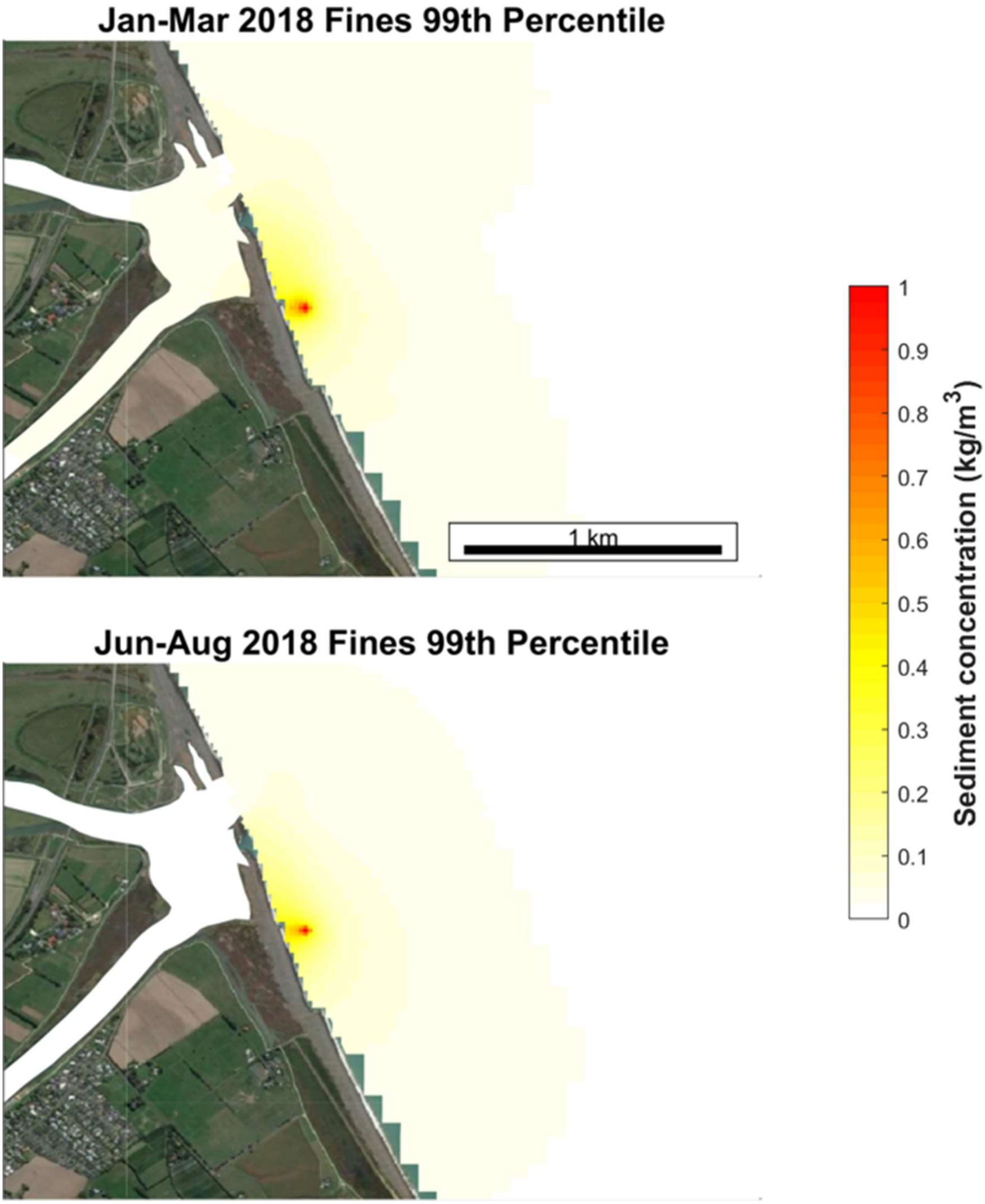


Figure 3-5: 99th percentile sediment concentration for fines for Summer (top panel) and Winter (lower panel) conditions.

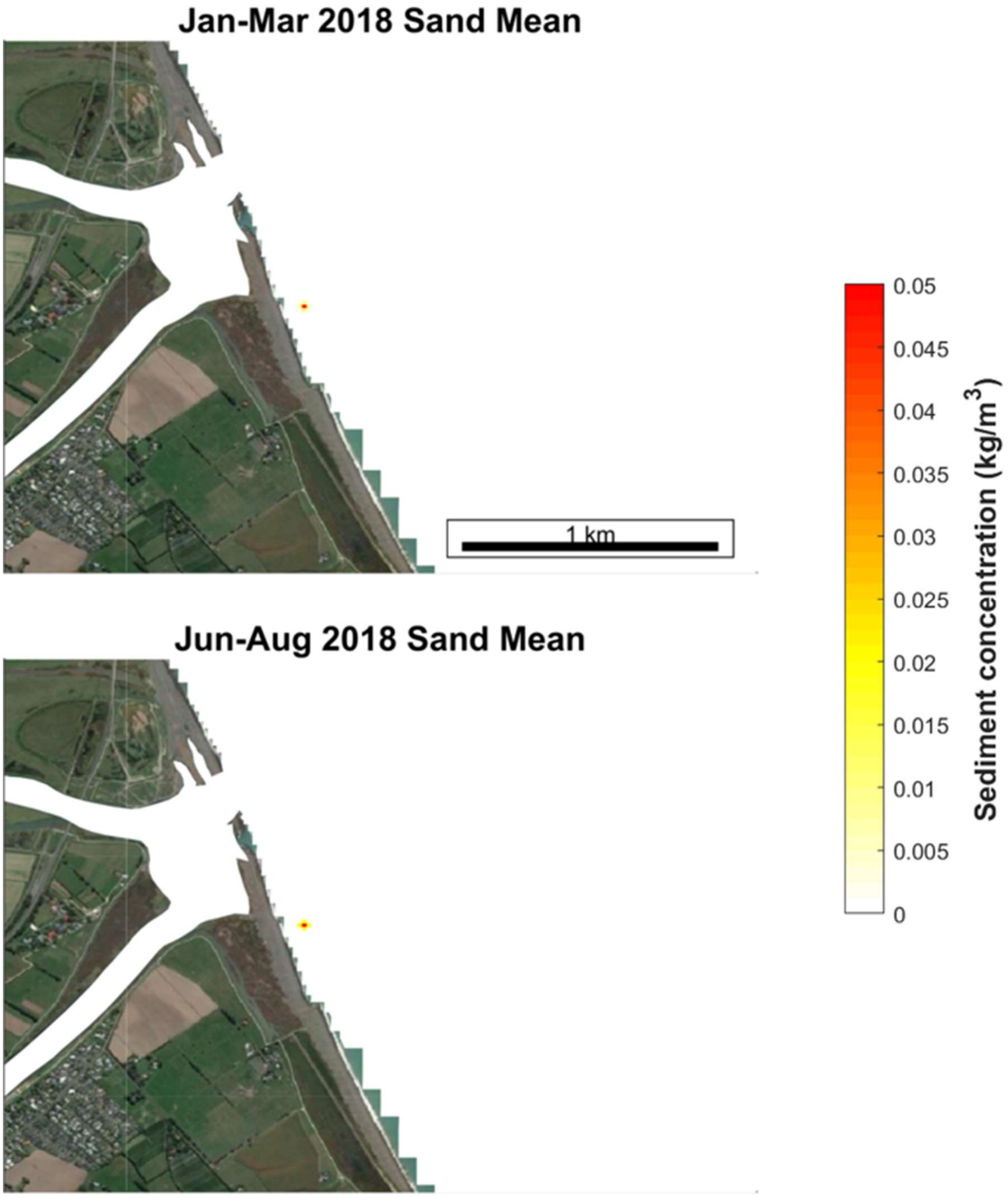
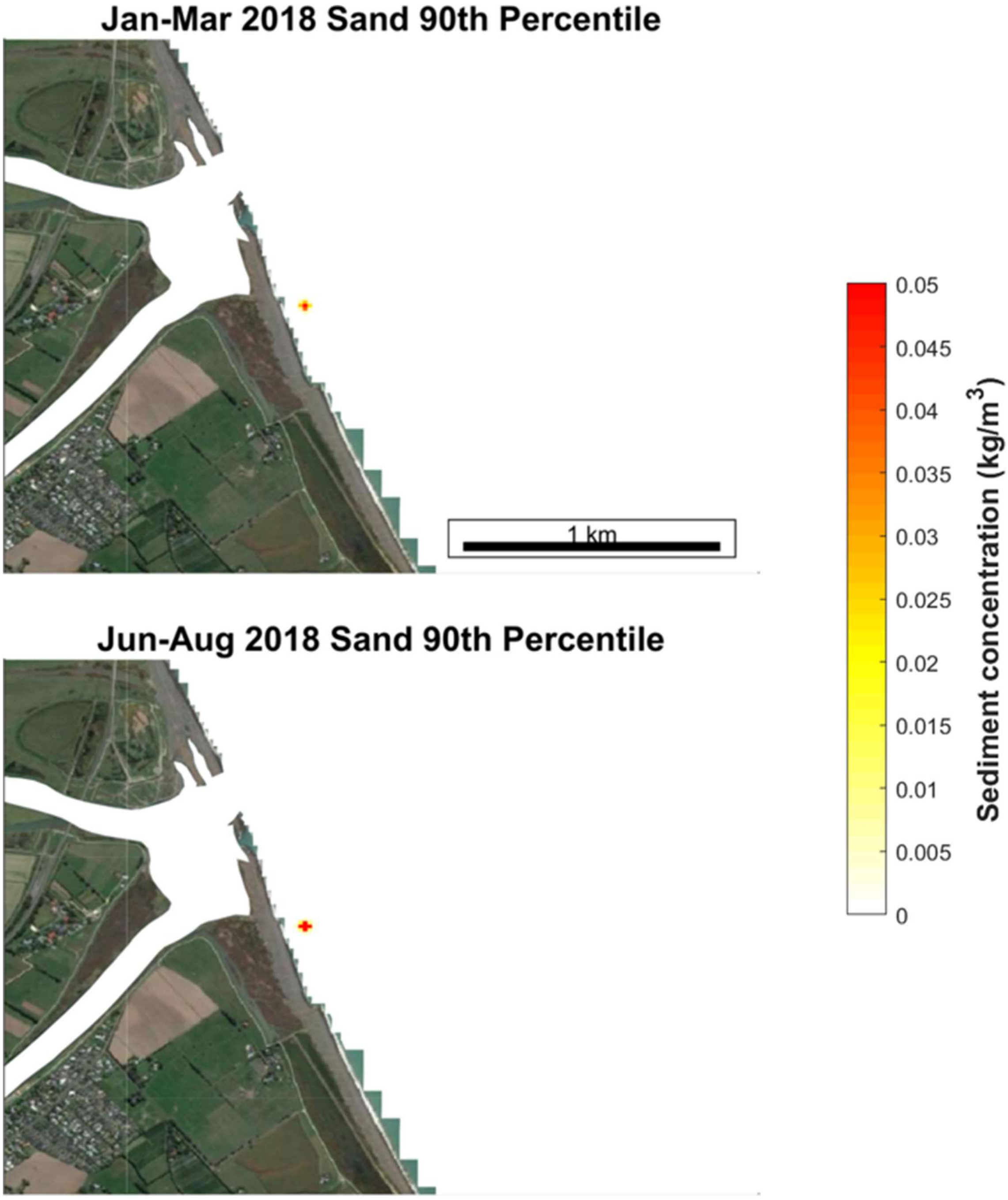


Figure 3-6: Mean sediment concentration for sand for Summer (top panel) and Winter (lower panel) conditions.



Jan-Mar 2018 Sand 90th Percentile

Jun-Aug 2018 Sand 90th Percentile

Figure 3-7: 90th percentile sediment concentration for sand for Summer (top panel) and Winter (lower panel) conditions.

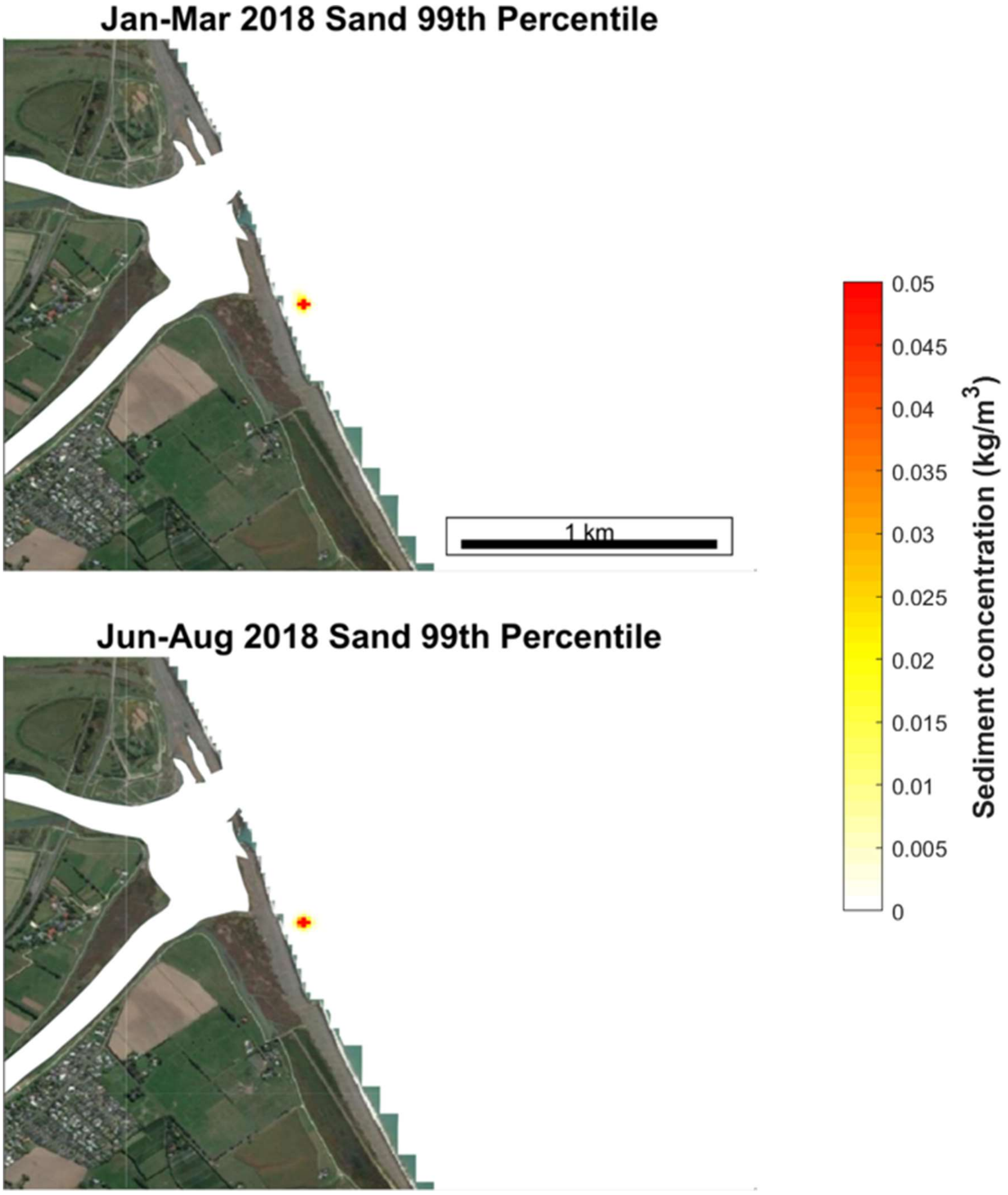


Figure 3-8: 99th percentile sediment concentration for sand for Summer (top panel) and Winter (lower panel) conditions.

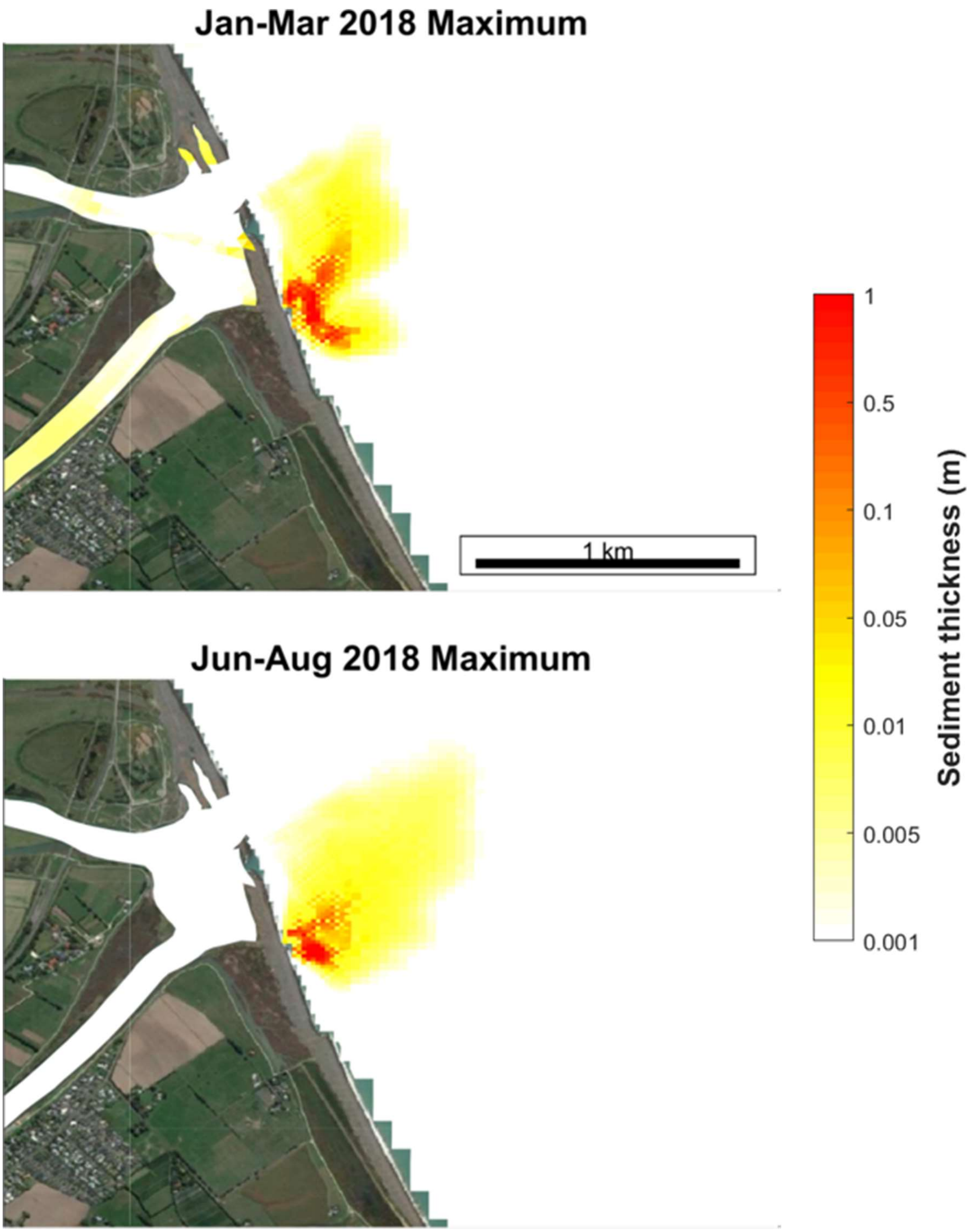


Figure 3-9: Maximum change in bed level for Summer (top panel) and Winter (lower panel) conditions. Note sediment thickness is shown on a log scale.

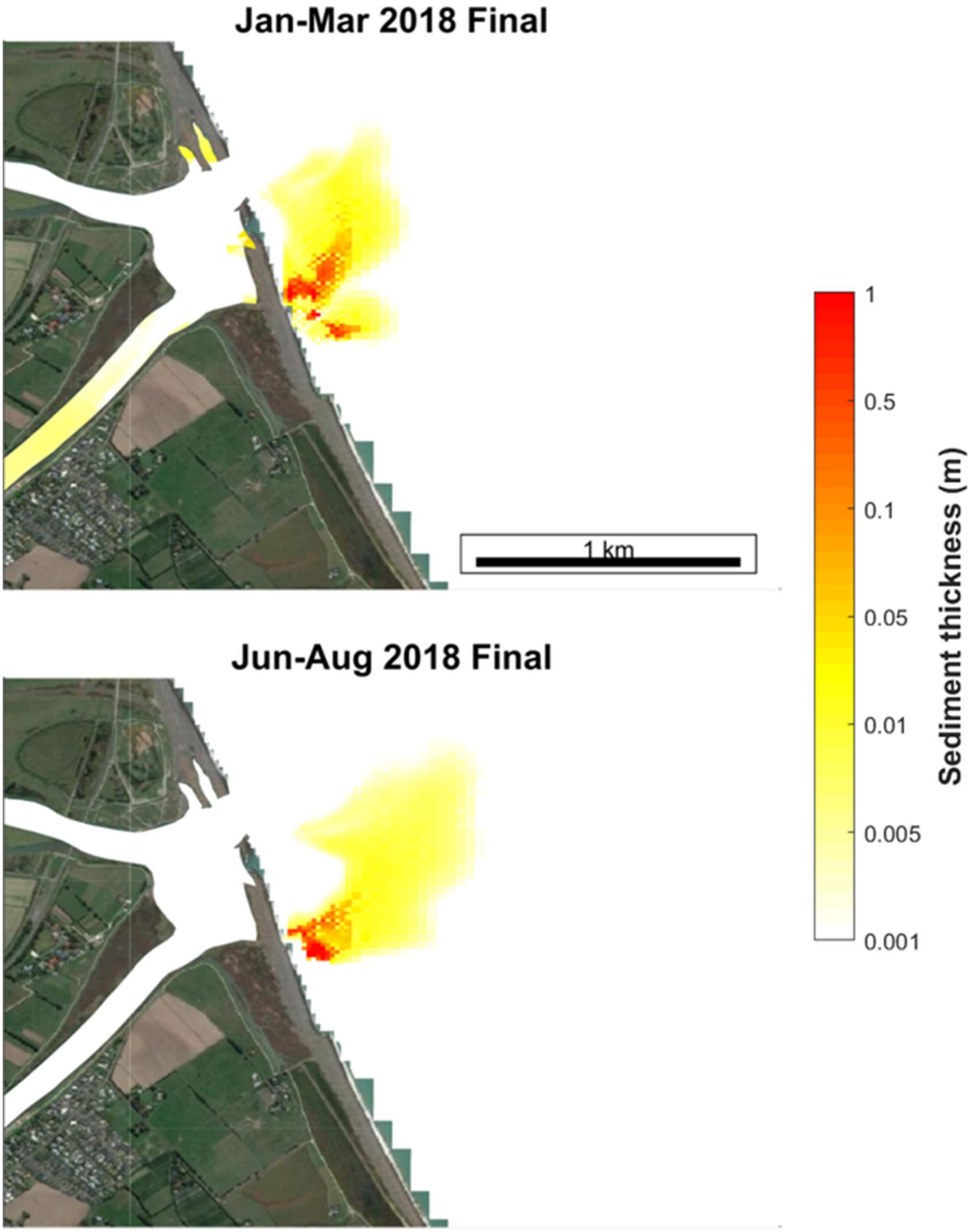


Figure 3-10: Final change in bed level for Summer (top panel) and Winter (lower panel) conditions. Note sediment thickness is shown on a log scale.

4 Numerical Modelling Limitations

As with all modelling studies, there are limitations in the representation of physical processes by mathematical representations. Here we present some of the limitations in the present study.

- There was no calibration data (current, wave, sea level) which to compare model output. While these would have been useful, a previous pollutant dispersion modelling study undertaken by eCoast in the Wairoa River was useful in providing guidance for model parameterisation.
- There was no high temporal resolution river flow records for the Clive River so a high resolution flow record had to be synthesised using nearby river flow records. The sediment transport modelling study was largely driven by processes external to the estuary mouth (principally waves and tides), so for this part of the study, this is unlikely to affect the results of the modelling.
- Sediment properties used in the sediment transport modelling were derived from literature search rather than through laboratory experiments on sediment samples from the study site.

5 Numerical Modelling Conclusions

A coupled hydrodynamic and wave model and subsequent sediment transport model were successfully developed to investigate the effects of dredging in the lower Clive River.

The sediment transport modelling was used to investigate the fate of sand and fines (silt and clay) following release through a pipe on the open coast outside the estuary. The release was simulated for the duration of the dredge operation under both Summer and Winter conditions.

As expected, the sand falls out of suspension rapidly. While the 99th percentile concentration of suspended sand is > 0.05 kg/m^3 in the vicinity of the outfall, it rapidly falls to <0.0001 kg/m^3 within 100 m of the outfall in both Summer and Winter conditions. For fines, the suspended plume is considerably larger. Overall, in Summer conditions, the suspended plume of fines is dispersed less rapidly under the less energetic conditions than under Winter conditions creating a larger plume. Mean concentrations are generally low, and this is largely due to the 17 hour daily downtime in the dredging schedule. The 90th and 99th percentile plumes for fines cover a considerably larger area and show concentrations up to 1 kg/m^3 close to the outfall though the concentrations fall away rapidly with distance. The plume is most concentrated to the north of the outfall with concentrations of 0.3 kg/m^3 seen up to 500 m towards the estuary mouth.

Sediment deposition is greatest near to the outfall with maximum deposition levels of nearly 1 m within 150 m of the outfall. Beyond this point the maximum deposition thickness rapidly falls off to approximately 0.01 m. The 0.01 m deposition footprint is larger in Winter conditions than in Summer conditions extending some 800 m away in the former and 500 m in the latter. In both cases, the footprint extends north east from the outfall location with a smaller area extending to the south east. The maximum deposition pattern is very similar to the final deposition footprint in the model. This indicates that, while the deposited sediment is expected to be highly mobile under the influence of larger wave events, it may remain where it settles until then.

The model hydrodynamic model was used to investigate changes in current speed in the lower Clive River following dredging. This showed that spring flood and ebb current speeds decrease by up to approximately 0.1 m/s during ebb tides following dredging. Neap ebb and flood tidal currents are low (<0.05 m/s) and not affected greatly by the dredging operation.

6 Ecological Impact Assessment

6.1 Ecological Impact Assessment of Lower Clive Estuary and Coast

Ecological assessment of the lower Clive Estuary and the open coast adjacent to the coast was undertaken to consider the ecological value of the sites and the potential impacts of disposing of material dredged from the lower Clive River (Mead *et al*., 2019b). Core sampling and observations were also undertaken throughout the area to be dredged, which included sediment size and contaminant analysis (Mead *et al*., 2019a). These investigations form the basis on the assessment of ecological effects, which are supported by previous ecological studies of the site.

6.2 General Setting and Literature Review (Mead *et al*., 2019b)

The Clive/Karamu River mouth forms part of the Waitangi Estuary, the area of which is ~30 ha. The catchment mainly comprises sheep and beef pasture (42%), indigenous forest (16.5%) and manuka/kanuka scrub (13%) (HBRC, unpublished data 2016; cited in Haggitt and Wade, 2016). The Waitangi Estuary is regarded as providing exceptional habitat for wetland bird species, which include several rare and iconic species, such as the godwit, golden plover, black-billed gull, gannet and kotuku. The brackish swamps near the mouth provide habitat for the spotless crake and bitten. Haggitt and Wade (2016) describes the gravel beach ridge and bar system at the entrance as providing important nesting and roosting habitat for birds, such as dotterels, stilts, and terns. Walls (2005) reports that the estuary is also home to a significant number of native flora species including shore ribbonwood, marsh clubrush, and the threatened turf plant *Mimulus repens* (cited in Haggitt and Wade, 2016). The Karamu riverbanks provide important Inanga spawning habitat. Fish that frequent the Waitangi Estuary include Inanga, kahawai, eels, mullet, warehou (rarely) and flatfish.

Section 5.3 of the “State of the Hawke’s Bay Coastal Environment report (2004 – 2013)” (Wade *et al.,* 2016) describes the infaunal assemblages within Waitangi for a 5-year period between 2009 and 2013. Various community metric and indices were used to interpret the state and health of the Waitangi Estuary, among others within the region. In general, the Waitangi Estuary had the highest number of individuals per core (333 individuals), which was dominated by the amphipod *Paracorophium excavatum* (average of 227 individuals in each core) and the estuarine snail *Potamopurgus estuarinus* (average of 97 individuals per core). With respect to the various indices indicating species diversity and richness (Shannon’s diversity, Simpson's diversity, Margalef's richness, and Peilou's eveness) Waitangi Estuary scored lowest amongst all the sampled estuaries.

The SOE concluded that the infauna associated with individual estuary sites is responding to mud concentrations. As such, species reported as intolerant of higher mud fractions *(*e.g. *Aonides trifida and Macomona Liliana)* are largely absent from sites where concentrations are >25% (as found at site 5C with approximately 60% silt and clay). Further, a Traits Based Index (TBI) applied to the estuaries sampled corresponded closely to concentrations of mud (silt/clay), which indicates a reduction in the resilience of sites as mud concentrations increases. Waitangi Estuary scored 'poorly' in the TBI.

The Hawke's Bay Regional Council does not monitor the shingle beaches within its region (HBRC website), in turn there is a paucity of data pertaining to the local ecology of these beaches. In general, shingle beaches provide habitat for an array of invertebrates, particularly macro invertebrates and associated predators. Species richness typically increases on shingle beaches where wrack accumulates, which provides additional opportunistic invertebrate habitat and source of energy flow to higher order trophic levels (Menge, 1992, Dugan *et al.*, 2003). However, down the beach and into the surf zone, very few species are present due to the continual abrasive movement of the shingle (which becomes a sand/shingle mix moving into the subtidal zone) driven by almost constant wave action (Figure 6-1).

Figure 6-1. Even during very low wave conditions, wave action drives the continual abrasive movement of the shingle resulting in an inhospitable habitat.

The lower estuary site is very shallow and mostly intertidal in the small embayment on the southern side of the estuary entrance (Figure 2-2). This area is also very dynamic due to the migration of the entrance channel through the shingle barrier spit (Figure 6-2) and the interactions between the spit and the lower Clive River. For example, in October 2003, the small embayment in the southern part of the Waitangi Estuary had a distinctly different morphology in comparison to today (Figure 6-3 – it appears to have been stable since ~2013); even the location of the river entrance through the barrier spit had migrated significantly northward between 22 May 2019 and the date of the survey (23 August 2019). An additional feature of the southern estuary is the mobile shingle banks (Figure 6-3), which can be seen as dark patches at locations V and VI in 2003, and between VII and X in 2019 (Figure 6-4).

Figure 6-2. The shingle spit between the lower estuary and the open coast, which is an important habitat for birds and native plants.

Figure 6-3. The southern part of the Waitangi Estuary has changed since 2003 (top) to 2019 (bottom), which is due to the dynamic nature of both the entrance channel and the shingle barrier spit. It has been relatively stable since around 2013. The dark patches at sample locations V and VI in 2003 (top), and between VII and X in 2019 (bottom) are mobile shingle banks (Figure 6-4).

Figure 6-4. The mobile shingle of the current banks in the southern part of the estuary.

6.3 Suspended Sediment

As described above, with respect to the various indices indicating species diversity and richness (Shannon's diversity, Simpson's diversity, Margalef's richness, and Peilou's eveness) Waitangi Estuary scored lowest amongst all the sampled estuaries. This is mainly attributed to the high terrestrial silt load delivered to the estuary from the catchment. In addition to the negative environmental impacts of fine silts in the estuary, the nearshore coast adjacent to the river entrance is also highly impacted by suspended sediments, which is due to the sediment-laden river discharges to the coast, as well as the eroding cliffs of Cape Kidnappers.

Figure 6-5 presents satellite imagery from 2019 of the southern Hawke's Bay and the Clive River entrance showing the high concentrations of suspended sediment along the coast. Aerial images between 2004 and 2019 indicate that high concentrations of suspended sediment are an almost permanent feature of southern Hawke's Bay, and that suspended sediment concentrations are usually visibly higher at the Clive River entrance than anywhere else along the southern Hawke's Bay coast.

In Appendix A, the 10 available satellite images of the southern part of Hawke's Bay from Google Earth and 12 available satellite images of the Clive River entrance between 2004 and 2019 are presented, along with a series of 6/2/2017 Copernicus Satellite images from Cape Kidnappers to over 60 km up the coast. These images demonstrate:

a) Southern Hawke’s Bay is highly impacted by nearshore suspended sediment due to the sediment-laden river discharges and the eroding cliffs of Cape Kidnappers;
b) The concentration of suspended sediment is highest at the Clive River entrance, and;
c) The concentration of nearshore suspended sediment reduces moving north from Cape Kidnappers/the Clive River entrance.

Along with the mobile beach gravels and coarse grain sands of the nearshore, as a result of this ‘press’ impact of high suspended sediment concentrations at the Entrance to the Clive River, the benthic ecology is in a similarly poor state as the Waitangi Estuary.

Figure 6-5. Aerial images between 2004 and 2019 (Appendix A) indicate that (Top) high concentrations of suspended sediment are an almost permanent feature of southern Hawke’s Bay, and that (Bottom) suspended sediment concentrations are usually visibly higher at the Clive River entrance than anywhere else along the southern Hawke’s Bay coast. Images are of 2019 from Google Earth Pro.

6.4 Sediment Sampling and Ecological Data Collection

Samples were collected in the area of proposed dredging (Figure 6-6), at 4 locations above the lower Clive River (Figure 6-7), in the lower estuary below the proposed dredging area (Figure 6-7), and on the open coast adjacent to the proposed dredge discharge site (Figure 6-7).

Sediment samples were collected at 11 sites in the lower Clive River where the proposed dredging is to occur (Figure 6-6) using a 100 mm diameter PVC corer (Mead *et al*., 2019a). A YSI multi-meter was also used to measure the dissolved oxygen level in the upper layer of sediment, and the depth of soft sediment above the original gravel riverbed was also probed.

A ponar grab sampler was used to collect sediment samples at 10 locations on the open coast, and a 100 mm diameter core sampler was used to collect 10 in the shallow lower estuary (Figure 6-8) (Mead *et al*., 2019b). Samples were sieved through 500 µm mesh and 70% isopropyl alcohol and with rose Bengal was on hand to preserve species that could not be identified in the field for later identification at Leigh Marine Laboratory. However, in all the samples only 4 species were found, which could be identified on site.

In addition to grab sampling, a drop-camera was used to record the state of the seabed and any epifauna present. However, visibility was basically zero, which meant this method (or SCUBA diving) could not collect any useful data.

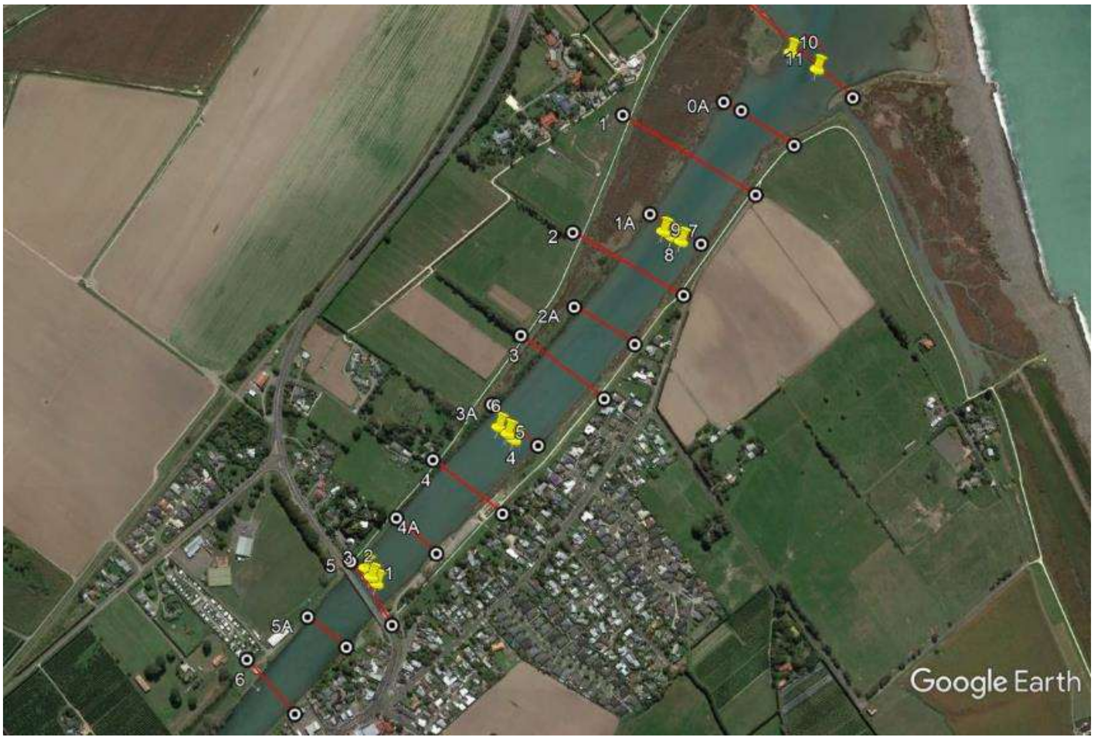


Figure 6-6. The 11 sediment and probe sampling sites are indicated by the yellow markers, and the digitised transects for dredging volume calculations are shown by the red lines.

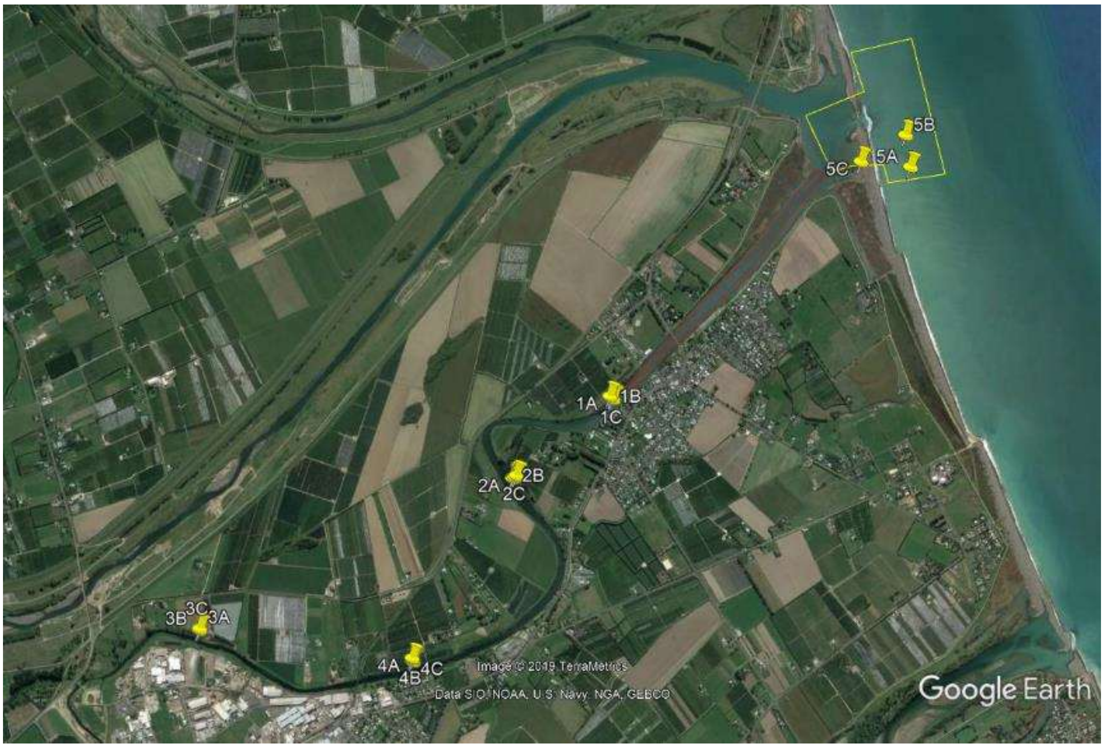


Figure 6-7. Location plan of the survey sites. Sediment sampling was undertaken at sites 1A through to 5C. Depth probing was undertaken at sites 1A to 4C. The bathymetry survey covered the area in the yellow box (the area delineated by the elongated red box is the area to be dredged (eCoast, 2019a)). The ecological assessment was undertaken in the area of the 5C marker near the entrance.

Figure 6-8. Sample locations for ecological assessment (Mead *et al*., 2019b).

6.5 Results of Field Data Collection

Sediment samples collected in the area of the proposed dredging were found to be anoxic (i.e., black with an odour of hydrogen sulphide) with a small layer (~5 mm) of aerated surficial sediment, except for samples 10 and 11 located in the lower/northern part of the river closest to the entrance to the sea (Figure 6-6). At sample sites 10 and 11, a thick surficial layer of living pipi (*Paphies australis*) and cockles (*Astrovenus stutchburyi*), many with barnacles and small anemones attached, and a mix of small gravel and dead bivalve shells was present (Figure 6-9).

Figure 6-9. The surface layer at sites 10 and 11 (Figure 6-6) included living pipis and cockles, and a mix of small gravel and dead bivalve shells.

Dissolved oxygen was found to be relatively high in the water column (>12 mg/l). However, dissolved oxygen in the surficial sediment was found to be <2 mg/l at sites 1 to 6 (i.e. hypoxic), and ~3-4 mg/l at sites 7 to 9; there was no surficial sediment layer at sites 10 and 11 (Figure 6-9). That is, oxygen levels in the surficial sediment increase towards the mouth of the river, which was supported by the presence of small gastropods (*Potamopurgus estuarinus*) at sample sites 7 to 9 (e.g. Figure 6-10) and bivalves at sites 10 and 11 (Figure 6-9).

No living organisms were found in any of the 10 ponar grab samples on the open coast; sampling at sites 1, 4 and 8 (Figure 6-8) resulted in acquiring no sediment for sieving, which was due to the extension of the shingle layer offshore into the intertidal zone.

Three species were found in the core samples in the southern embayment area of the lower estuary – a common amphipod *Paracorophium excavatum*, the estuarine snail *Potamopurgus estuarinus* (Figure 6-10), which was also found in core samples of the lower Clive River in the previous study (Mead *et al*., 2019a), and tiny red polychaetes (*Opheliid* sp.). Sea lettuce (*Ulva lactuca*) was also present on the occasional boulder (Figure 6-11).

The numbers of individuals in each sample was very varied and ranged between 0 and 44, with the latter being dominated by amphipods (Figure 6-12). Given the low number of species present and with 4 sites having zero individuals (Figure 6-12), the Shannon-Wiener biodiversity index and species evenness were both found to be very low (0.60 and 0.55, respectively), as would be expected.

Figure 6-10. The estuarine snail *Potamopurgus estuarinus* in low density in the intertidal zone at the southern estuary (top) and in a core sample some 500 m further up the Clive River (Mead *et al*., 2019a) (bottom).

Figure 6-11. Sea lettuce (*Ulva lactuca*) was observed on the occasional boulder.

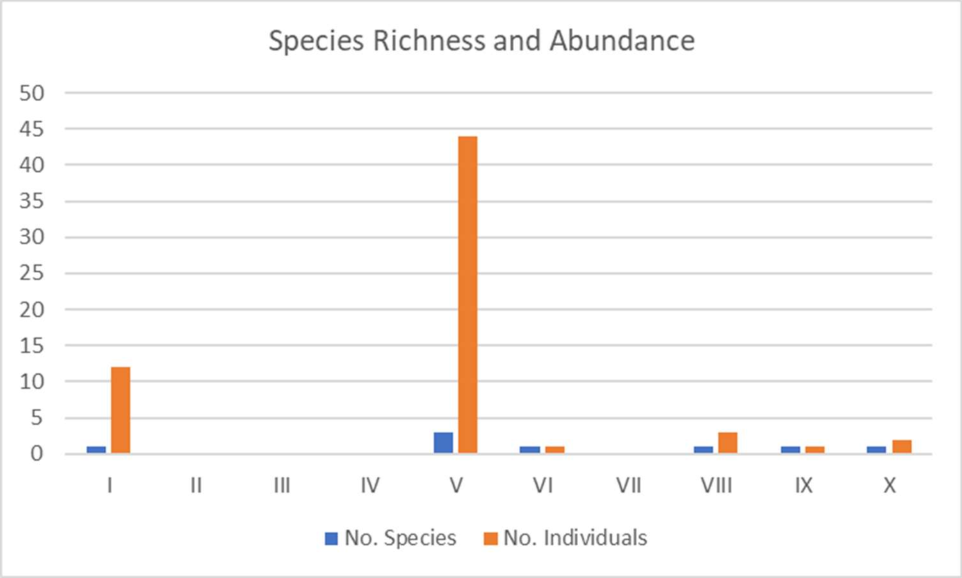


Figure 6-12. Species richness and abundance at the sample location

These results are in agreement with Wade *et al.* (2016), that is, only a few species present (estuarine snails, amphipods, bivalves) at relatively high densities resulting in the Waitangi Estuary and lower Clive River scoring lowest amongst all the sampled estuaries in the Hawke's Bay Region. This is likely to a large degree associated with the high mud fractions in the sediment (>25%), reducing the resilience of infauna (Wade *et al.* (2016)).

6.6 Request for Further Information Responses

6.6.1 Biosecurity Risks Associated with the Invasive Tubeworm (*Ficopomatus enigmaticus*)

Mead *et al*. (2019a) found the tubeworms on every pile on the Clive River Bridge (SH2) from the low water mark to close to the riverbed, and in some places >30 cm thick (Figure 6-13). Tubeworms were also present in clumps beside the bridge piles, presumably attached to pieces of rock or concrete.

Figure 6-13. Australian tubeworms (*Ficopomatus enigmaticus*) are present from the low water mark to near the riverbed on every pile of the bridge that is in the water.

Australian tube worms (*Ficopomatus enigmaticus*) live within a calcareous tube they have secreted. These are usually white and with age turn a brown colour. The tubeworm has many plumes or gills which vary in colour from brown, green or grey and the worm itself grows up to 4 cm although the tube they live in can be up to 10 cm long (HBRC, 2020).

Widespread around estuaries and harbours, this tubeworm can tolerate habitat ranging from brackish, polluted and low oxygen, to environments with high salinities and a preference to slow moving and protected areas of water (HBRC, 2020).

This aggressive invader is fast growing, forms colonies on shells, rocks, marine vegetation also jetties, marinas, boats and moorings. With the ability to grow on vessels and pipes, this can lead to heavy bio fouling and the clogging of underwater entry ports and pipes. Tubeworms, when established on vessels hulls are then easily transported to new areas, where new colonies can become dominant. These colonies of filter feeders compete with native marine life for essential nutrients and eventually displace previously established species (HBRC, 2020). Potential dispersion of this invasive species is related to its life-history and disposal methodology.

F. enigmaticus has separate sexes but there is evidence of protandric hermaphrodism. True gonads are absent, and the germ cells are produced by a germinal epithelium associated with genital blood vessels in the intersegmental septa. This species has external fertilization and spawning occurs through the specialized ducts in abdominal setigers of both males and females (Obenat *et al*., 2006b; cited in CABI, 2020).

Temperature is one of the most important factors affecting the reproduction and fecundity in *F. enigmaticus*. Gibson et al. (2001; cited in CABI, 2020) observed that, in general, development time increases with decreasing temperature. The minimum water temperature required for (or associated with) successful reproduction of *F. enigmaticus* differs among populations. In the Thames estuary (UK) it is about 18ºC (Dixon, 1981), whereas in the Emsworth lagoon (UK) and Tunis lagoon (Tunisia) it is 10ºC (Vuillemin, 1965; Thorp, 1995; cited in CABI, 2020).

This species has two periods of spawning and recruitment in most regions where it was studied, one in spring-summer and the other one during the autumn. Obenat and Pezzani (1994; cited in CABI, 2020) observed recruitment in November-December and in April-May in Mar Chiquita coastal lagoon. Dixon (1981) observed recruitment in south-eastern England starting in June and continuing through October. Settlement peaks in North Adriatic (Italy) occur in June-July and in September (Bianchi and Morri, 1996; cited in CABI, 2020) and in Japan occurs in May and October (CABI, 2020).

In New Zealand, few studies have been carried out on *F. enigmaticus,* and their reproductive biology is not well known. Based on the literature reviewed, however, it is thought that *F. enigmaticus* reproduces in the warmer months with spawning and recruitment occurring in spring-summer and possibly also in early autumn. Given the HBRC's objectives to prevent them being disposed of in the marine environment and leading to colonization and associated implications (HBRC, 2020), and to uncertainty in the with respect to the life history of the species in New Zealand, a precautionary approach is recommended.

At present, the removal of the population of tube worms from the bridge piles in the lower Clive River is not proposed, and so in order to avoid further spread and colonization of this invasive species, it is recommended that all efforts are made during the proposed dredging to avoid physical contact with the tubeworm colonies. As these tube worms are a marine biosecurity risk, if/when they are removed from the bridge piles, they should ideally be disposed of to landfill (MPI, 2019), as disposing of them in other areas of the marine environment may lead to colonization and associated implications (HBRC, 2020). In addition, due to uncertainty in their life history, a precaution to ensure that physical interference does not instigate a spawning response, removal should be undertaken in the winter months when it is known they do not spawn in other parts of the world.

6.6.2 Sediment Contaminant Levels

Mead *et al*. (2019a) noted that sediment contaminants were found to be mostly below guideline thresholds, and in some cases undetectable. However, zinc levels were found to be elevated above the ISQG-Low threshold level at sites 1, 2 and 3 (i.e. adjacent to the Clive River Bridge – Figure 6-6)[6]. The AEE for the proposed dredging (pg 15) states:

> *The results for zinc concentration indicate that sediments in the vicinity of the bridge, on their own, would potentially have a minor effect on zinc-sensitive species, based on the ANZECC default guideline values for 'Low' environmental effect. These particular samples are not, however, representative of the entire volume of dredged material and the mixing and dilution with other lower-concentration sediments from across the remainder of the dredge area needs to be taken into account. Allowing for this, the average zinc concentration falls below the default 200 mg/kg 'Low' effects threshold to approximately 150 mg/kg. At this concentration, and allowing also for dispersal in the receiving environment, there will be a less than minor effect.*

This statement in the AEE is valid, in that there is the potential to have minor impacts on zinc-sensitive species at locations 1-3 (noting that no living fauna were identified in the low oxygen/anoxic sediment), and that through the dredging procedure the 4 to 1 ratio of water to sediment will mix and dilute the zinc contaminant to below the ISQG-low threshold level (meaning less than minor effects on organisms at and around the discharge point). It is also noted that these higher zinc levels are likely linked with stormwater run-off from the road/bridge where they were sampled (i.e., the majority of the material to be dredged will not have high levels of contaminants). However, consideration needs to be given to future dredging and disposal, and methods to mitigate environmental impacts. The material has not been removed from the environment, and cultural and longer term cumulative impacts should be considered.

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[6] Based on the sampling results, it is thought to be highly likely that samples 3 and 6 were swapped, either during sampling or during analysis.

6.6.3 Impacts on Fish (including whitebait)

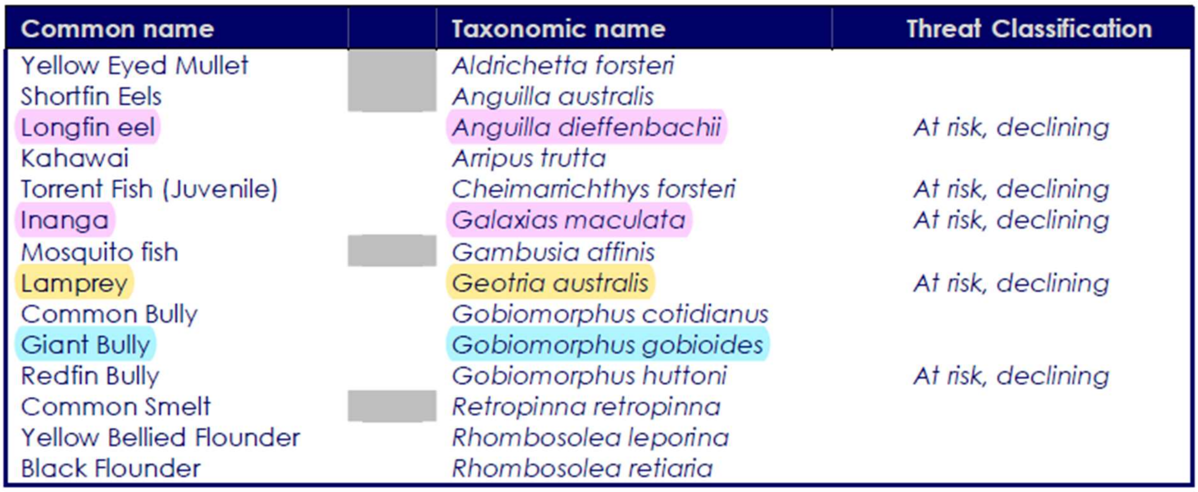
6.6.3.1 Fish Assemblage in the Waitangi Estuary

Fish that frequent the Waitangi Estuary include Inanga, kahawai, eels, mullet, warehou (rarely) and flatfish. Smith (2013) states that the Clive River is a nationally significant fisheries habitat and that the estuarine area is an important link for diadromous native freshwater fish. Rook (1993) Identified the Clive River as the largest inanga (*Galaxias maculatus*) spawning site in Hawke's Bay. This forms the basis of one of the more critical aspects to manage in terms of preservation of habitat. Smith (2013) notes that whitebait spawning has been recorded just upstream of the railway bridge on both the left and right banks associated with the inflows of the Awatoto Drain and the outflow from the 'horeshoe wetland' (i.e., around site CABA and on the opposite bank of the Tutaekuri blind arm).

Smith (2013) reported that there is a very large population of the introduced mosquito fish *(Gambusia affinis),* which is considered a threat to indigenous fish populations (especially in enclosed environments). The author further notes, however, that there is a considerable body of anecdotal evidence to suggest that mosquito fish is providing a beneficial service in terms of food source for the Nationally Critical Australasian bittern, and as such the mosquito fish presence is providing a benefit to the overall ecology of this endangered species.

Smith (2013) also provides a list of fish species in the Waitangi Estuary that is based upon a literature search, the New Zealand Freshwater Database, from previous experience of the author in fish surveys at the site and from observations during the Smith (2013) survey (Table 6-1). The varied species reflects the diverse habitat available to fish within the estuarine/riverine environment, and although many of these fish may be absent from the Tutaekuri Blind arm for much of the time, it is likely that some if not all have a transitory presence at some stage of their life cycles (Smith, 2013).

Table 6-1. Fish species identified during the Smith (2013) survey and from other cited literature. Shaded cells indicate observation of that particular species during the Smith (2013) survey. The colours denote threat classes according to the New Zealand Threat Classification Series 19 (DoC, 2016). Red = Threatened/Nationally critical, Yellow = Threatened/Nationally vulnerable, Green = At Risk/Naturally Uncommon, Light blue = At Risk/Declining, and Lavender = At Risk/Recovering. All non-coloured species are not classed as Threatened nor at At Risk. (Threat classifications based on Allibone (2010).)



Common name		Taxonomic name	Threat Classification
Yellow Eyed Mullet		*Aldrichetta forsteri*	
Shortfin Eels		*Anguilla australis*	
Longfin eel		*Anguilla dieffenbachii*	*At risk, declining*
Kahawai		*Arripus trutta*	
Torrent Fish (Juvenile)		*Cheimarrichthys forsteri*	*At risk, declining*
Inanga		*Galaxias maculata*	*At risk, declining*
Mosquito fish		*Gambusia affinis*	
Lamprey		*Geotria australis*	*At risk, declining*
Common Bully		*Gobiomorphus cotidianus*	
Giant Bully		*Gobiomorphus gobioides*	
Redfin Bully		*Gobiomorphus huttoni*	*At risk, declining*
Common Smelt		*Retropinna retropinna*	
Yellow Bellied Flounder		*Rhombosolea leporina*	
Black Flounder		*Rhombosolea retiaria*	

6.6.3.2 Dredging and Disposal Impacts on Fish

During dredging in the lower Clive River, the impacts on fish species are considered less than minor and temporary due to the relatively small area of impact caused by the dredged-head; fish will avoid this area. The plume from the cutter-suction dredge-head is expected to be mostly in close proximity to the area being dredged, since sediment and water are sucked into the dredge pipeline (at a ratio of approximately 4 parts water to 1 part sediment). It is noted that turbidity can be very high in the Clive River during/following rainfall events, and the impacts of the localise plume from the dredge-head is likely to have a less than minor and temporary impact on fish in the area.

The discharge plume on the open coast is expected to have little impact on fish in the area, as the species in the area are unlikely to rely on visual capacity for feeding, with the Hawke's Bay nearshore having very low visibility much of the time due to sediment run-off, and zero visibility on the seabed much of the time. There is the potential to impact on benthic feeders, although no living organisms were found in the nearshore grab sampling (which indicates that the area is depauperate of species, although does not confirm that it is absent of species). Of note, during prior dredging disposal of the lower Clive River, it has been reported that fish catches increased in abundance due to fish being attracted to the infaunal species being disposed of in the dredge material. This would likely result in temporary behavioural impacts, which are considered less than minor.

In New Zealand, whitebait is used to describe the juvenile forms (around 4–5 centimetres long) of five species of the fish family Galaxiidae. There are five species of whitebait in New Zealand, which comprise īnanga (Galaxias maculatus), kōaro (Galaxias brevipinnis), banded kōkopu (Galaxias fasciatus), giant kōkopu (Galaxias argenteus), and shortjaw kōkopu (Galaxias postvectis). As adults these five species differ in size, markings and habitat (Te Ara, 2020). These species mature in freshwater and then migrate downstream to spawn in areas of tidal estuary.

Īnanga and giant kōkopu prefer lowland marshes and sluggish waters. Kōaro, banded kōkopu and shortjaw kōkopu are found in forest streams at higher altitudes. Īnanga adults are barely twice the size of juveniles. The other species grow much larger – the giant kōkopu can reach half a meter (Te Ara, 2020).

In many rivers īnanga, kōaro, and banded kōkopu make up most of the whitebait catch, with īnanga being the most common species (50 -90% (Rowe *et al*., 1992)). In spring, whitebait make their way upstream from the sea, swimming near the river's edge. Large shoals are referred to as runs. Big runs often follow floods, a few days after the water clears – usually in the daytime on a rising tide (Te Ara, 2020).

To avoid impacts on whitebait, dredging should not occur between August and November inclusive (the whitebaiting season is 15 August to 31 November), when whitebait runs occur. Spawning occurs in late summer/early autumn where the adult galaxids migrate down-river and lay eggs on the vegetation during high spring tide. When the eggs hatch on the following spring tide (2 weeks later), they are carried downstream as larvae and spend the next six months at sea. In the spring they migrate upstream as whitebait (whitebait runs) and grow into adult fish.

The Karamu Streams banks provide important Inanga spawning habitat (Haggitt, 2016), with the end of the Karamu stream being some 6 km up-river from the SH2 Clive River bridge where there is a confluence with the Ngaruroro River. It is expected that dredging the lower Clive River what have only a very minor impact on larvae being carried downstream and out to sea after hatching. However, avoiding works during the late summer/early spring will ensure impacts do not occur.

6.6.4 Ecological Values and Effects of Dredging within the Footprint, Lower River/Estuary and any Nearshore Areas Potentially Affected

As noted above in Sections 6.1 and 6.4, the lower Clive River is ranked low in terms of biodiversity in the Hawkes Bay Region. However, the Waitangi Estuary area is regarded as providing exceptional habitat for wetland bird species.

The effects of dredging within the footprint will include the displacement and loss of infaunal species in the lower parts of the area, which are dominated by the amphipod *Paracorophium excavatum* and the estuarine snail *Potamopurgus estuarinus,* and a thick surficial layer of living pipi (*Paphies australis*) and cockles (*Astrovenus stutchburyi*), often with barnacles and small anemones attached where the lower end of the dredged area meets the estuary. The impacts on fish species and coastal/wetland bird species are discussed above and below, respectively.

As has been found previously, the area dredged will infill over the next 10-12 years, with recolonization of the lower areas of the dredged area expected to occur within 12 months; the river will not become gravel-bottomed again, fine sediments will continue to accumulate). The area to be dredged is considered of low value. It is not expected that the ecological values will be markedly changed by the dredging exercise, it will continue to fill with fine sediments and therefore continue to have low biodiversity.

Effects on the Waitangi Estuary and considered to be less than minor and temporary, with likely some increased turbidity from the dredge-head during operations, which will occur for 9 hours each day for ~67 days.

The discharged material will create a plume of fine suspended sediments, as well as a large area of deposited coarser sediment (Section 3.2), the impacts on fish species and coastal/wetland bird species are discussed above and below, respectively.

6.6.5 Ecological Values (including Avian Values) and Effects of Disposal at the Proposed Site (i.e. “the shore above mean high water springs, on or near the river mouth groyne, whereby the dredge sediments, in slurry form, will flow down the beach and into the sea”) and Nearshore Areas Potentially Affected

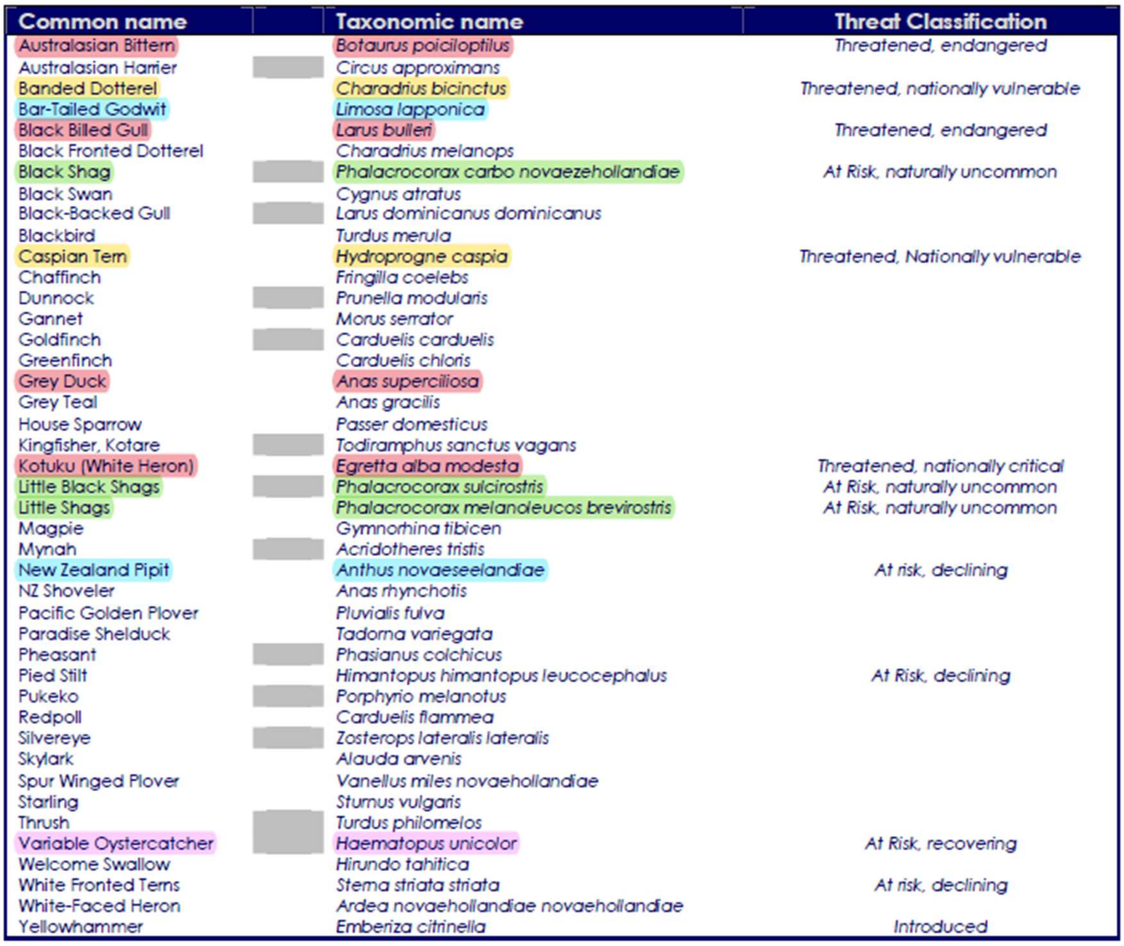
6.6.5.1 Avian Assemblage in the Waitangi Estuary

Smith (2013) carried out an avifaunal survey during an assessment looking into effects of stormwater discharge and process water from the Awatoto fertiliser works into Awatoto Drain, which feeds into the blind arm of the Tutaekuri River, and subsequently into the Waitangi Estuary. Table 6-2 presents a list of the avifaunal species that were observed during the Smith (2013) survey, as well as species that have been observed by the author and others during previous visits. Smith (2013) notes that the threat classifications are based on Miskelly (2008) and further notes that one of the species, the Australian Bittern, while not observed during the authors survey, has been recorded in the area around site CABA previously (~1.8 km north-east of the Clive River Bridge (furthest downstream)). Furthermore, Smith (2013) noted that Black Shags were transient through the site. This suggests that the neither the Australian Bittern nor Black Shags are permanently roosting or occupying the area that is the Waitangi Estuary and thus do not solely rely on this area of for resources.

Kelly (2021) notes that Smith' (2013) lists 23 species[7] that the author identified or from other literature and Kelly (2021) goes onto say that 10 of those species were classified as threatened, with: two endangered; two nationally vulnerable, and one nationally critical. Smith (2013) however lists a total of 43 species, not 23.

When comparing the Smith (2013) avifaunal species list (Table 6-2) with New Zealand Threat Classification Scheme (DoC, 2016) there are six 'Threatened' species: two Nationally Vulnerable species and four Nationally Critical species, and six 'At Risk' species: three Naturally Uncommon species, two Declining species, and one Recovering species. Again, Kelly (2021) has drawn incorrect conclusions regarding the threat classification of species from the Smith (2013) report.

Table 6-2. Bird species identified by the Smith (2013) survey and as well as from other reports. Shaded cells indicate observation of that particular species during the Smith (2013) survey (Modified from Smith, 2013). The colours denote threat classes according to the New Zealand Threat Classification Series 19 (DoC, 2016). Red = Threatened/Nationally critical, Yellow = Threatened/Nationally vulnerable, Green = At Risk/Naturally Uncommon, Light blue = At Risk/Declining, and Lavender = At Risk/Recovering. All non-coloured species are not classed as Threatened nor at At Risk.



Common name		Taxonomic name	Threat Classification
Australasian Bittern		*Botaurus poiciloptilus*	*Threatened, endangered*
Australasian Harrier	▨	*Circus approximans*	
Banded Dotterel		*Charadrius bicinctus*	*Threatened, nationally vulnerable*
Bar-Tailed Godwit		*Limosa lapponica*	
Black Billed Gull		*Larus bulleri*	*Threatened, endangered*
Black Fronted Dotterel		*Charadrius melanops*	
Black Shag	▨	*Phalacrocorax carbo novaezehollandiae*	*At Risk, naturally uncommon*
Black Swan		*Cygnus atratus*	
Black-Backed Gull	▨	*Larus dominicanus dominicanus*	
Blackbird		*Turdus merula*	
Caspian Tern		*Hydroprogne caspia*	*Threatened, Nationally vulnerable*
Chaffinch		*Fringilla coelebs*	
Dunnock	▨	*Prunella modularis*	
Gannet		*Morus serrator*	
Goldfinch	▨	*Carduelis carduelis*	
Greenfinch		*Carduelis chloris*	
Grey Duck		*Anas superciliosa*	
Grey Teal		*Anas gracilis*	
House Sparrow		*Passer domesticus*	
Kingfisher, Kotare	▨	*Todiramphus sanctus vagans*	
Kotuku (White Heron)		*Egretta alba modesta*	*Threatened, nationally critical*
Little Black Shags	▨	*Phalacrocorax sulcirostris*	*At Risk, naturally uncommon*
Little Shags		*Phalacrocorax melanoleucos brevirostris*	*At Risk, naturally uncommon*
Magpie		*Gymnorhina tibicen*	
Mynah	▨	*Acridotheres tristis*	
New Zealand Pipit		*Anthus novaeseelandiae*	*At risk, declining*
NZ Shoveler		*Anas rhynchotis*	
Pacific Golden Plover		*Pluvialis fulva*	
Paradise Shelduck		*Tadorna variegata*	
Pheasant	▨	*Phasianus colchicus*	
Pied Stilt		*Himantopus himantopus leucocephalus*	*At Risk, declining*
Pukeko	▨	*Porphyrio melanotus*	
Redpoll		*Carduelis flammea*	
Silvereye	▨	*Zosterops lateralis lateralis*	
Skylark		*Alauda arvenis*	
Spur Winged Plover		*Vanellus miles novaehollandiae*	
Starling		*Sturnus vulgaris*	
Thrush	▨	*Turdus philomelos*	
Variable Oystercatcher		*Haematopus unicolor*	*At Risk, recovering*
Welcome Swallow		*Hirundo tahitica*	
White Fronted Terns		*Sterna striata striata*	*At risk, declining*
White-Faced Heron		*Ardea novaehollandiae novaehollandiae*	
Yellowhammer		*Emberiza citrinella*	*Introduced*

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[7] Smith (2013) lists a total of 43 species, therefore Kelly's (2021) mention of 23 species is thought to be an error.

6.6.5.2 Dredging and Disposal Impacts on Avifauna

There are likely to be very short-term impacts on avifauna when placing and removing the pipeline over the shingle bank, which are also considered less than minor. For example, the shingle bar closest to the sea often has wintering Black-fronted Terns that will be displaced temporarily. However, the timing of the dredging should take seabird breeding into account and avoid times of year that they are breeding in the area in order to avoid any impacts.

Similar to impacts on fish by the dredging, since the plume from the cutter-suction dredge-head is expected to be mostly in close proximity to the area being dredged, and since sediment and water are sucked into the dredge pipeline (at a ratio of approximately 4 parts water to 1 part sediment), impacts are considered less than minor and temporary.

The pipeline discharge into a very abrasive environment where there is little life present. Therefore, the immediate local impacts are considered less than minor and temporary.

Nearshore, the plume of fine suspended sediments will be present during the operations; i.e., for approximately 67 days, mostly during daylight hours. The potential effects to coastal and wetland birds due to the dredge discharge plume include:

- Will any species likely be adversely affected by in water visual changes arising from sediment in the water column?
- Will any species likely be affected by changes in food availability?
- Will any species likely be affected in relation to their ability to roost and nest?

Taking the physical impacts of the dredging into account it is considered that impacts will have a less than minor effect on any species that are intertidal feeders, roosting or nesting species (e.g., black backed gull), since only a small area of the inter-tidal zone will be affected by the slurry running into the sea from the discharge point.

Species such as little Australian gannets, shags, terns and red-billed gull are likely to feed on small fish such as pilchard and mackerel species and some diving species will feed on large planktonic organisms (Pinkerton *et al.*, 2015). Those birds feeding in the nearshore will likely be feeding on smaller upper water column organisms. Although some species such as red-billed gull can be generalist feeders, increasing the distance for feeding is a negative effect for any coastal bird species in situations where the dredge disposal occurs close to a nesting site. In is noted that many species may travel significant distances to feed, well beyond the immediate disposal area. However, the nature of any changes in foraging distance are considered to be minor in the context of the scales of turbidity plumes generated by dredge discharge. Any increased distances any species may have to fly would likely only be in the order of a few hundred metres. However, similar to the attraction of fish by the infaunal organisms that are disposed of in the discharge plume, there is the potential that some species of birds will be attracted to the area. This behavioural change is considered short term and less than minor.

Given the localised nature of water quality changes (turbidity) derived from the dredge discharge in relation to the scale of the nearshore coastal area in the Hawke's Bay, effects on coastal bird species are anticipated to be less than minor and temporary.

6.6.6 Likelihood and Timeframes for the Recovery of River Benthos

The river benthos will very likely recover to its currently impacted state, with low oxygen/anoxic fine sediments and low biodiversity due to the combination of changes to the rivers hydrology (e.g., earthquake uplift, diversion, etc.) and the continued terrestrial sediment inputs. Recovery is expected to occur within 12 months following dredging given the species present at the site and the presence of adult populations of the same species in the surrounding riverine and estuarine environment; i.e., local recolonisation and local larvae are available.

6.6.7 Conclusions

Although the Waitangi Estuary and lower Clive River score poorly with respect to species diversity, richness and physical traits, it is part of the Waitangi Regional Park and is associated with areas that provide exceptional habitat for wetland bird species. Overall, the ecological impacts of dredging the 1.4 km stretch of the lower Clive River are considered minor to less than minor and temporary. This is because the operation is temporary (~67 days) and represents a 'pulse' impact, rather than a permanent 'press' impact, and due to the current ecological status of the lower river, estuary and nearshore coast (as noted in Mead *et al*., 2019b).

Once dredged, it will again infill with fine sediments, which together with low flow rates will result in low oxygen/anoxic content in the sediments, and low biodiversity. This is due to the historical changes to the rivers hydrology in 1969 and the continued terrestrial sediment inputs. The open coast where the temporary dredging discharge will occur is a very abrasive environment in the intertidal and shallow sub-tidal zone, and water quality is mostly poor due to the terrestrial run-off that occurs throughout the Hawke's Bay. As a result, there are low abundances and species number in the area. As a result, the accumulation of seabed sediment from the discharge will not cover important habitat, and will also be dispersed during significant wave events. Anecdotal evidence from previous similar dredging of the lower Clive

River indicates that some species will be attracted to the disposal site to feed on discharged organisms within the dredge material.

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Appendix A. Historical Satellite Images of South Hawke’s Bay and the Clive River Entrance

Southern Hawke's Bay:

2004

2009


Clifton
Te Awanga
Haumoana
NAPIER SOUTH
AHURIRI
Clive
Whakatu
Mangateretere
Napier
Google Earth

2013


Clifton
Haumoana
NAPIER SOUTH
Whakatu
Mangateretere
Napier
Google Earth

2014


Google Earth
NAPIER SOUTH
Napier
Clive
Haumoana
Te Awanga
Clifton
Whakatu
Mangateretere

2015


Google Earth
NAPIER SOUTH
Napier
Clive
Haumoana
Te Awanga
Clifton
Whakatu
Mangateretere

2016

2016b

2017


Clifton
Te Awanga
Haumoana
NAPIER SOUTH
Clive
Napier
Google Earth

2018

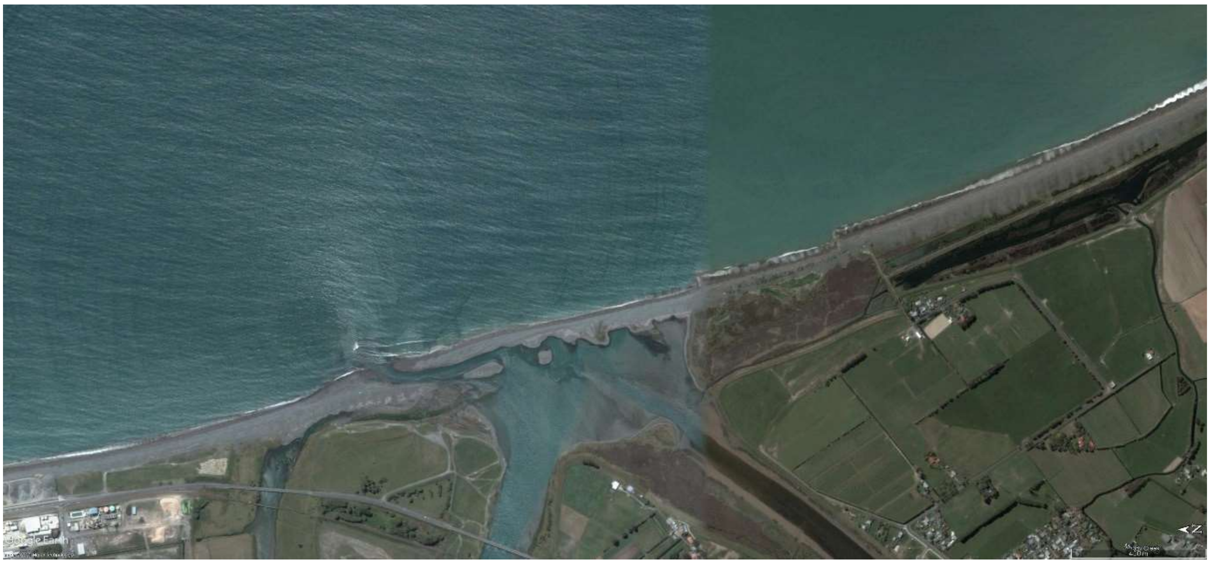

Clifton
Te Awanga
Haumoana
NAPIER SOUTH
Clive
Napier
Google Earth

2018b

2019

Clive River Entrance:

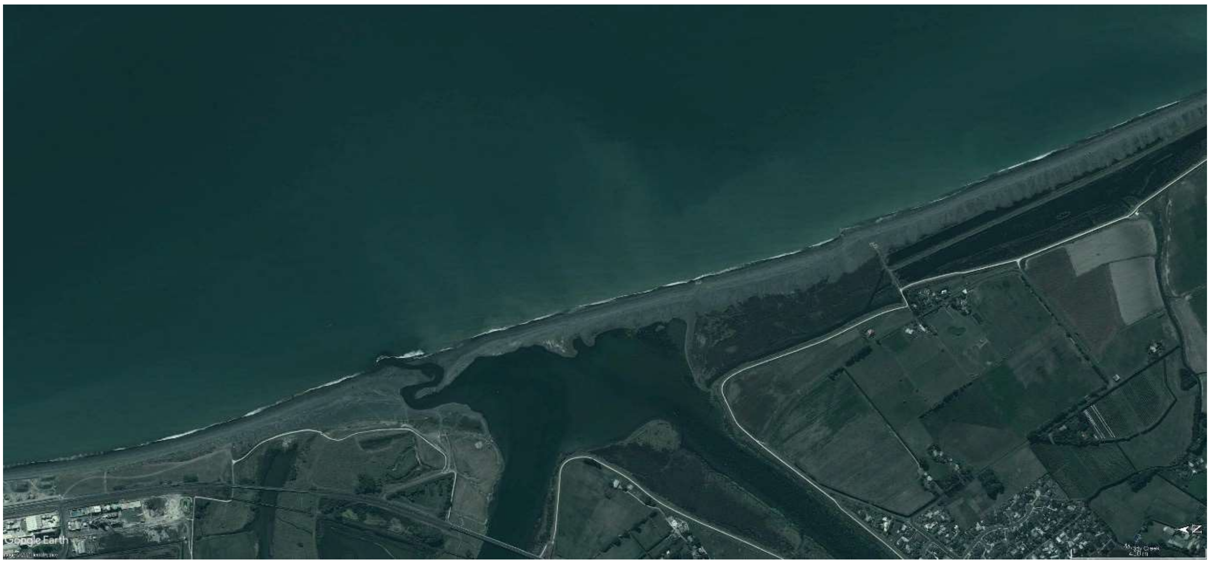
2004



2009

2012

2012b

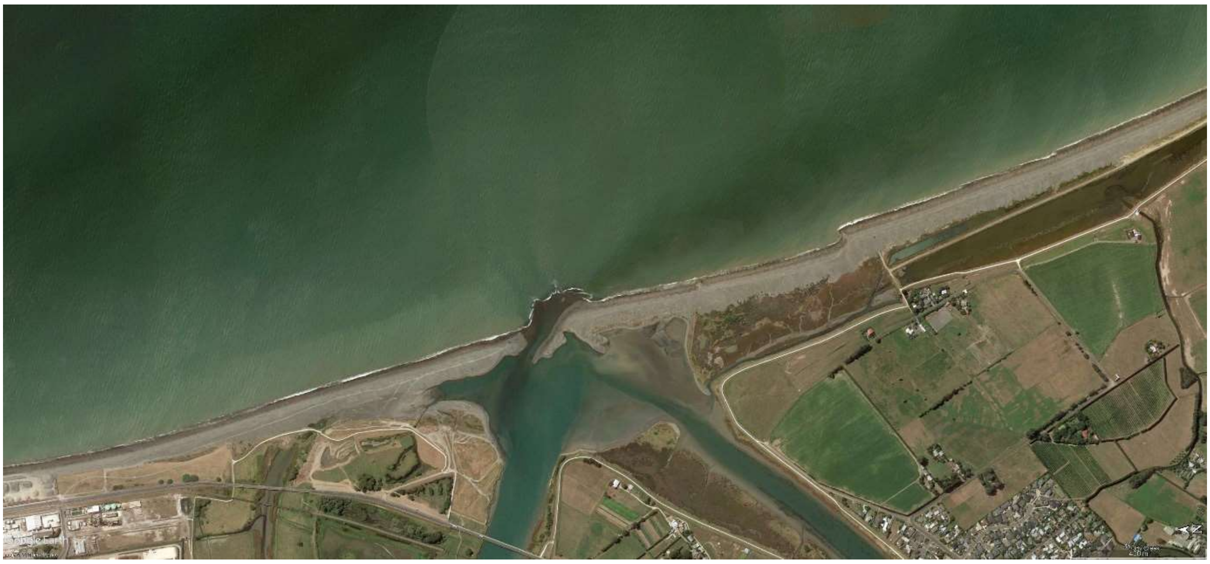


2013

2014

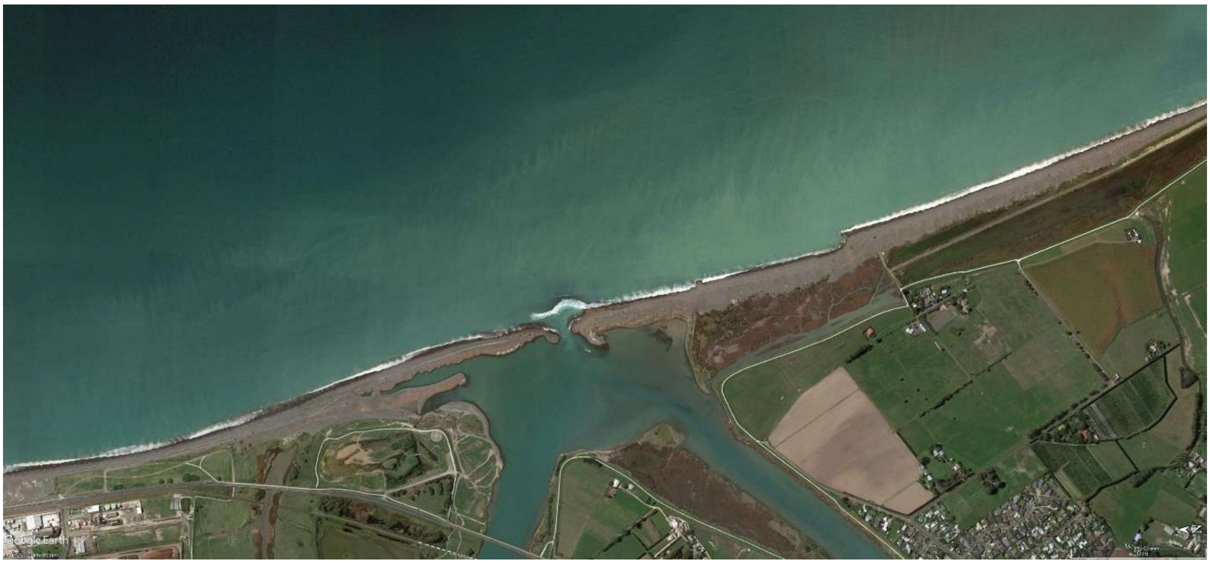
2015

2015b



2016

2017



2018

2018b

2019

6/2/2017 Copernicus Satellite images (darker blue areas on the inshore part of the images; lighter areas offshore are different satellite runs). Images are arranged clockwise from north to south