3 MODEL SET-UP AND CALIBRATION

This chapter outlines the details of the hydrodynamic and advection-dispersion model development and calibration. A model of the Maketu Estuary and lower Kaituna River extending out to an open sea boundary was developed using MIKE3. A three dimensional model was chosen as it is important to replicate the vertical salinity stratification. In a two dimensional model it would not be possible to reasonably predict the ratio of freshwater and saltwater that flows through from the river into the estuary.

3.1 Model

The hydrodynamic model used was the DHI MIKE3 FM, version 2008. The MIKE3 model is based on the numerical solution of the three-dimensional incompressible Reynolds averaged Navier-Stokes equations, invoking the assumptions of Boussinesq and of hydrostatic pressure. Thus the model consists of continuity, momentum, temperature, salinity and density equations and it is closed by a turbulent closure scheme. In this 3D model, the free surface is taken into account using a sigma-coordinate transformation approach.

The Flexible Mesh (FM) allows the computational domain to be disceteized into a mixture of tessellating triangular and quadrilateral elements of various sizes. This allows great flexibility in defining the model domain, and features within the domain such as river channels. Quadrilateral elements were employed in the Kaituna River channel, Fords Cut channel and main channel of the estuary, where flow is constrained along a streamwise direction. Triangular elements were employed in the more open areas of the domain, and along the coastline. This enabled hi-resolution definition where necessary, but reducing computational requirements in other areas

3.2 Co-ordinate System and Vertical Datum.

For this study, all data is presented using the New Zealand Transverse Mercator projection (NZTM) and the Moturiki vertical datum.

3.3 Bathymetry

The bathymetry for the model was constructed using:

- Electronic C-MAP data using level D, this is extracted as Chart datum.
- Bathymetric survey data from 2008 of the entrance of the Maketu Estuary and Kaituna River mouth in Moturiki datum.
- Bathymetric survey data of the Kaituna River, Fords Cut loop and main estuary channel in Moturiki datum.
- LiDAR land levels dating from 2008 in Moturiki datum.
- MIKE11 cross section data for the Fords Cut channel.

The model extent and bathymetry used in the model is shown in Figure 3-1. Figure 3-2 presents the bathymetry of the estuary and Fords loop and shows how the mesh is constructed. Note that the quadrangular elements are used for the main channels and triangular elements for the tidal areas. A number of different meshes were tested during the model calibration phase, with the final resolution a compromise between accurate results and realistic model run times.

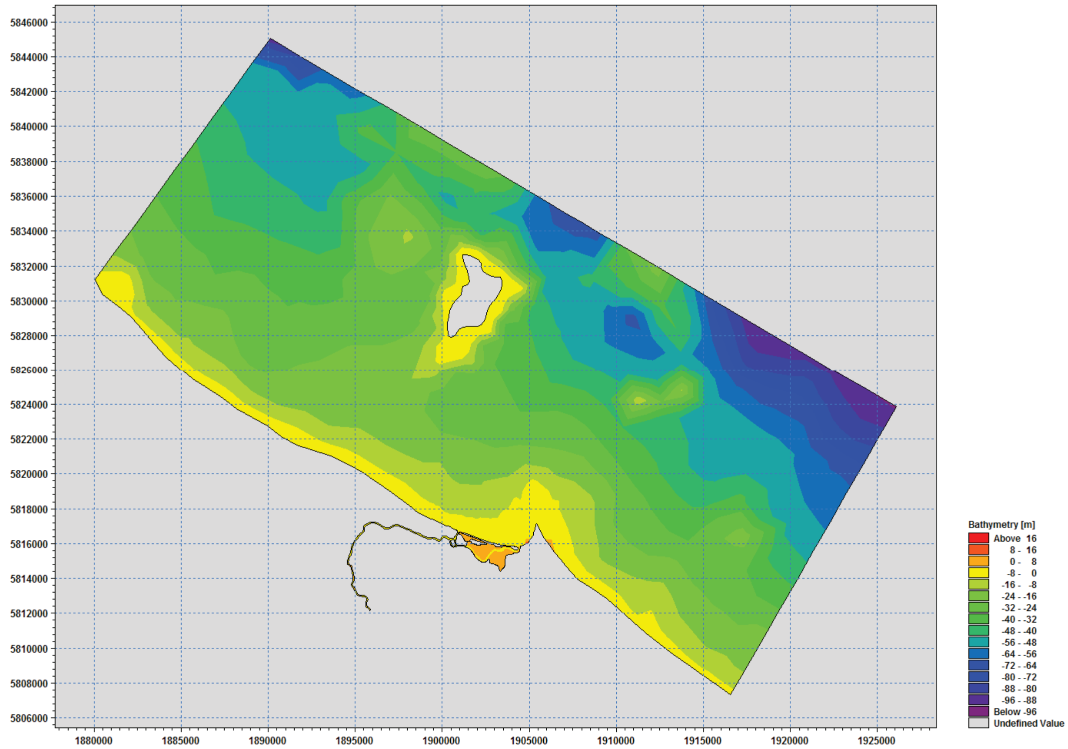

Figure 3-1 Model extent and bathymetry (Moturiki datum).

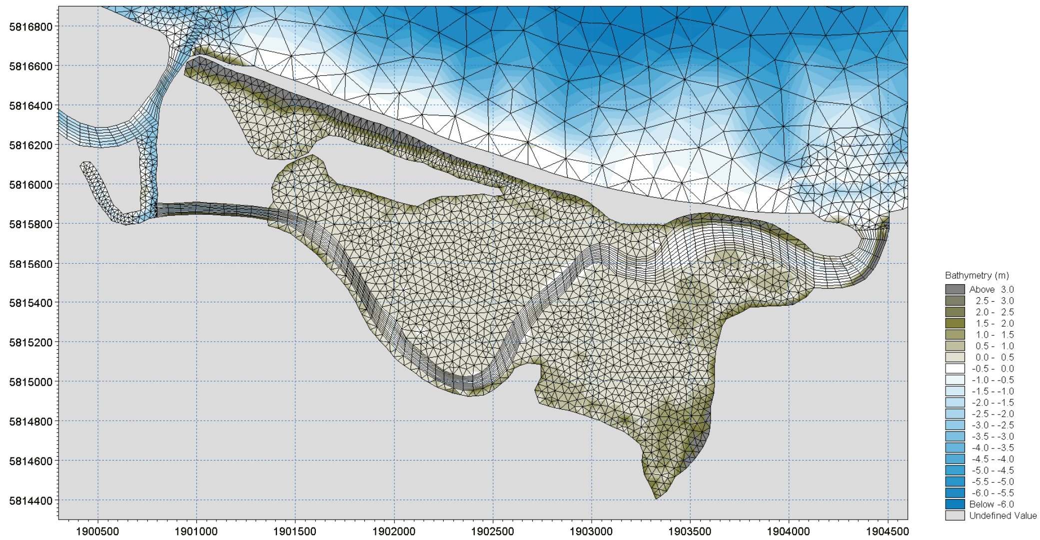

Figure 3-2 Estuary and Fords loop bathymetry and model element mesh (Moturiki datum).

3.4 Open Ocean Boundary Conditions

The data within the study area was collected during a period of significant wave energy and variable winds. These events have an effect on the mean level of the sea. As the surface elevation data from the Hobo sensor located offshore did not cover the whole data collection period, water levels from the Moturiki Island tide gauge were used as open ocean boundaries. The gauge is located on the open coast and is sensitive to changes in water level from significant metocean events. Figure 3-3 presents the comparison between the open ocean surface elevation data and the Moturiki Island gauge data. The Moturiki Island data has been smoothed and has had a phase shift of minus 20 minutes applied to account for phase difference, resulting from the distance between Moturiki Island and Maketu Estuary.

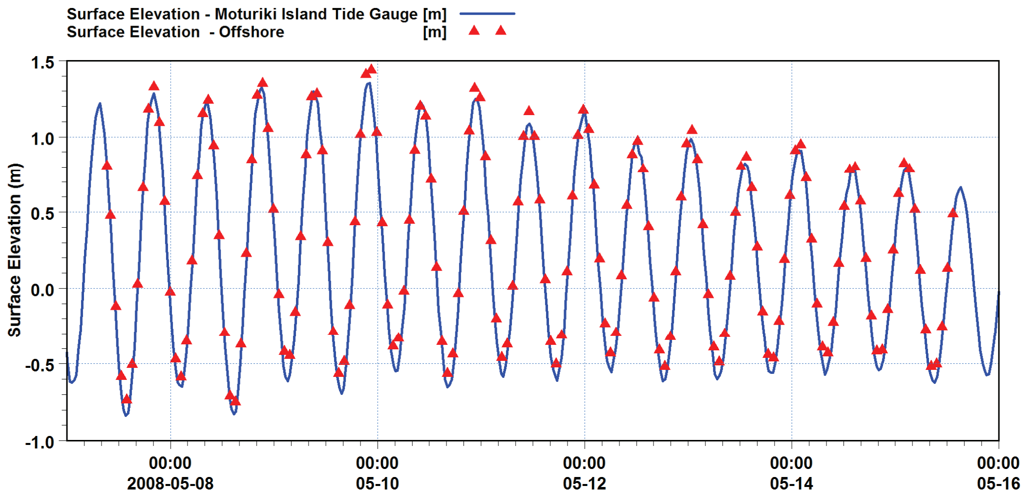

Figure 3-3 Comparison of observed and predicted surface elevations at open ocean location (Moturiki datum).

3.5 Freshwater Inflow

The gauge at Te Matai is tidally influenced, hence only stage data has been provided. This cannot be used directly as a boundary condition as the bathymetry at the MIKE3 boundary would need to be very accurate for the model to correctly calculate the corresponding river flow. An existing calibrated MIKE11 model was utilised with Te Matai stage and Moturiki Island tide gauge data as the boundary conditions. The model was run for period 22nd April 2008 to 10th June 2008 and the calculated flow was extracted close to the Te Matai boundary. The water level at Te Matai and corresponding calculated flow is shown in Figure 3-4. There are several drains that discharge to the estuary downstream of the gauge, however the amount of flow for normal conditions is considered negligible and is not included in the model. The flow from the Kaituna River is included as a point source in the MIKE3 model.

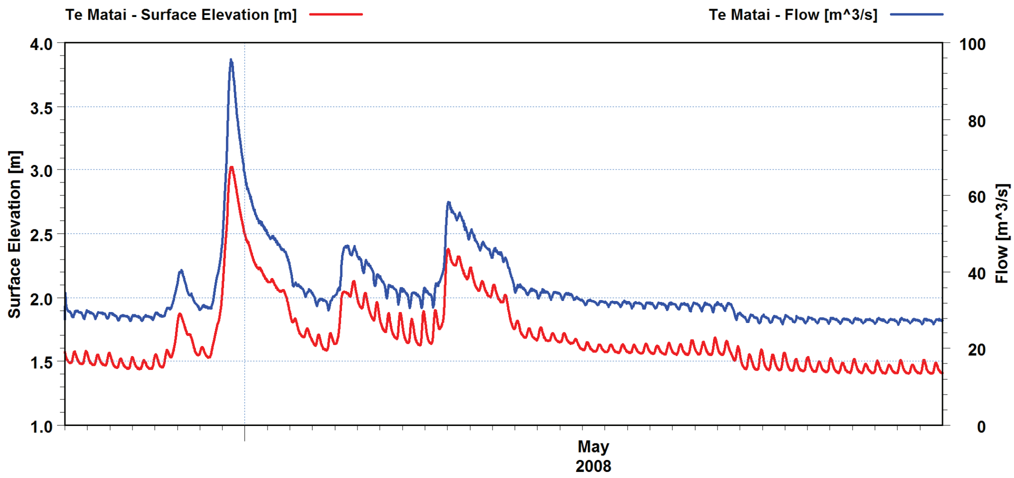

Figure 3-4 Observed surface elevation at Te Matai (Moturiki datum) and corresponding predicted flow from MIKE11.

3.6 Fords Cut Culvert

There are four gated culverts that allow flow to discharge from Kaituna River into the Maketu Estuary. MIKE3 FM can model the behaviour of culverts using a subgrid technique and calculate the resulting flow and head loss. The dimensions of the culverts were taken directly from survey drawings provided by EBoP. To ensure that the model was correctly predicting flow through the culverts, a comparison of calculated flows was made with the software, HY-8, a culvert discharge calculation programme developed by the Federal Highways Administration, US (www.fhwa.dot.gov). There was a good agreement between the calculated discharges.

3.7 Model Calibration

3.7.1 Objectives and Description

Model calibration involves refinement of bathymetry and hydraulic parameters to resolve tidal flows and elevations resulting from boundary conditions and driving forces such as wind. The main aims of the study are:

- To ensure that the tidal levels in Fords Cut are accurate and predict the volume and salinities through the culverts.
- To describe the behaviour of the salt wedge in the lower Kaituna River.
- To describe levels, flows and salinity in Maketu Estuary including tidal exchange.

Specifications for the calibration simulations are provided in Table 3-1. The hydrodynamic model was calibrated using surface elevations and currents measured within the river and estuary. The model bathymetry was adjusted within the main channel of the estuary due to the uncertainties created by the sparse coverage from the channel survey data. The period that the hydrodynamic model was calibrated for was 2nd May 2008 to 8th May 2008. The reason this period was chosen was that there was simultaneous water level and current velocity data available from within the estuary and water level data from Fords Cut. Although simultaneous data existed before this period, there was a significant flood event on 30th April 2008, during which the model under predicts river levels in Fords Cut. Accurately predicting levels during a flood event was not a main objective of the study, so emphasis was placed on obtaining a good calibration for "normal" conditions.

The advection/dispersion model was calibrated for the two days when salinity profiles were measured. The profiles were used to calibrate the eddy viscosity parameters, dispersion coefficients and bed resistance to obtain a reasonable agreement between observed and predicted salinities.. The following should be noted for the model parameters:

- Water levels can be affected by wind. In general they increase with wind set up (on-shore winds) and decrease with wind set down (off-shore winds). Wind data from Tauranga were used to drive the model as it appears there may be a sheltering effect at Te Puke airport.

- Water levels can be affected by barometric pressure, and can rise as the barometric pressure falls and vice versa. The effect on water level from changes in barometric pressure should be included in the Moturiki Island tide gauge data.

- For marine applications the Smagorinsky formulation is normally used for horizontal eddy viscosity with coefficients ranging from 0.25 - 1.0. The vertical eddy viscosity was specified using a constant eddy or log-law formulation.

- The vertical dispersion was set to zero to support the stratification of salinity, as observed from salinity profiles. The horizontal dispersion was formulated using a scaled eddy formulation. The dispersion coefficient is calculated as the eddy viscosity used in the solution of the flow equations multiplied by a scaling factor.

- For bed resistance a roughness height in meters was specified. For two dimensional models, Manning number (reciprocal of Manning's n) is normally specified for marine applications. The Manning number (M=1/n) and the Nikuradse roughness height (k) are related by the following formula:

  $$M = 25.4/k^{1/6}$$

- In the vertical domain an equidistant (uniform) distribution of fiver layers was applied. Increasing the vertical resolution results in a significant increase in run time.

- Density was assumed to be a function of salinity (baroclinic mode), as although some temperature data was collected, there was not sufficient data to be able to determine water temperatures for both the river and open ocean boundaries. The data (Figure 2-10) suggests that there was a maximum temperature gradient of approximately 4ºC between freshwater and saltwater. A temperature gradient can contribute to water column stability, but its effect is less than 10% of the contribution from the salinity gradient.

Table 3-1 Specifications for calibration simulations

Parameter	Value
Mesh and Bathymetry	Existing.mesh, 5 equidistant vertical layers
Time Step Interval	300s
Solution Technique	Low order, fast algorithm Minimum time step: 0.01sec Maximum time step: 10 sec Critical CFL number: 0.8
Enable Flood and Dry	Drying depth: 0.01m Flooding depth: 0.05m Wetting depth: 0.1m
Density	Function of Salinity
Wind	Varying in time, constant in domain (Tauranga Airport)
Wind Friction	Constant at 0.001255
Eddy Viscosity	Horizontal: Smagoringsky formulation, constant 0.28 Vertical: Log law formulation or constant varying over domain (0.05 m^2/s in river and 0.002 m^2/s elsewhere).
Resistance	Resistance length (m), varying over domain: 0.005m (M ≈ 60) in estuary 0.1m (M ≈ 40) in river and open ocean 1m (M ≈ 25) on open ocean boundaries
Dispersion	Horizontal: scaled eddy viscosity formulation, 1 Vertical: scaled eddy viscosity formulation, 0
Boundary Conditions	Open Ocean: Moturiki Tide Gauge, 35 PSU
Sources	Kaituna River, 0 PSU

3.7.2 *Water Levels – Normal River Conditions*

Figure 3-5 shows the comparison between observed and predicted surface elevations at the Kaituna River gauge, Fords Cut channel, mid estuary and at the estuary entrance. There is a good agreement for all locations, with the difference in levels usually less than +/-0.1m the possible error in observed data (per comms, Glenn Ellery). On the ebb tide there is a slight phase difference that is most pronounced at the mid estuary location, with the observed levels leading the predicted levels by up to 1 hour. Elsewhere the phases between the observed and predicted levels agree within approximately 30 min. An interesting feature that the model replicates well is the sudden rise in levels that occurs early on the 5th May 2008. It was not possible to determine the cause of this increase from the available data; however the rise is observed at the Moturiki Island tide gauge and consequently included in the boundary conditions.

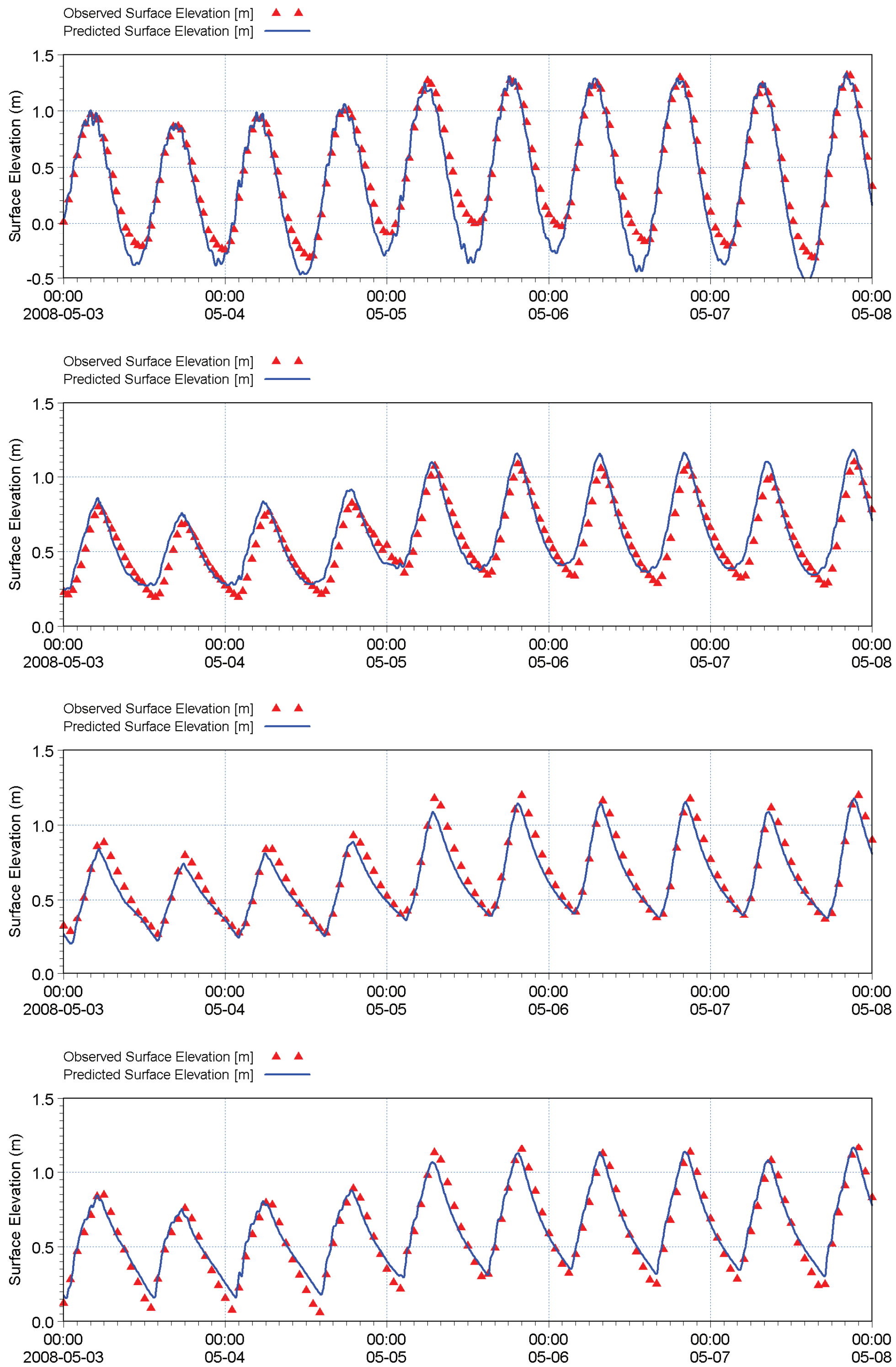

Figure 3-5 *Comparison between observed and predicted surface elevations (Moturiki datum) at Kaituna River level gauge (top), Fords Cut channel (middle-top), mid estuary(middle-bottom) and estuary entrance (bottom).*

3.7.3 Water Levels – Flood Event

Although accurately predicting levels during a flood event was not a main objective of the study, it was requested by EBoP that the model should be used for a flood impact assessment. Consequently the performance of the model was assessed for the 30th April 2008 flood event. Figure 3-6 shows the comparison between observed and predicted surface elevations at the Kaituna River gauge. During the flood event, the model under predicts levels by 0.2m at the peak of the tide and by 0.4m at the trough of the tide. There was significant wave energy over the period of the flood event (EBoP, per comms), and the resulting wave setup could elevate levels in the river. The flood event simulation may also highlight inaccuracies in the model river bathymetry that are not apparent for normal flow conditions.

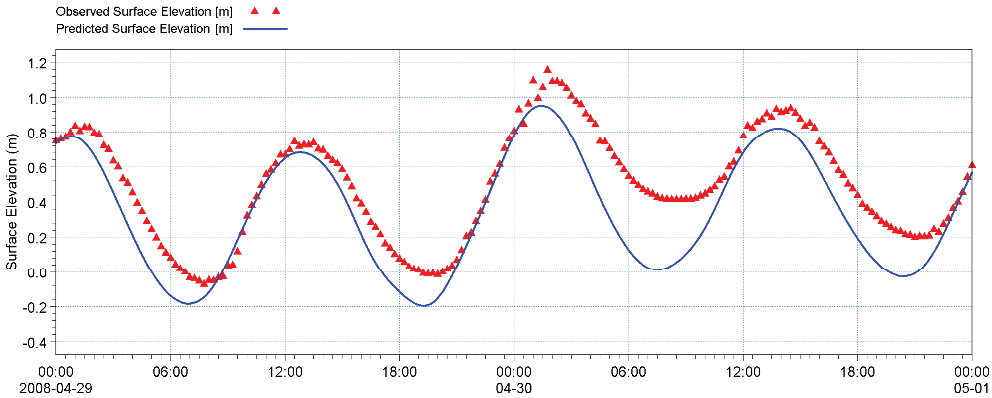

Figure 3-6 Comparison between observed and predicted surface elevations (Moturiki datum) at Kaituna River level gauge during 30th April 2008 flood event.

3.7.4 Current Velocities

Figure 3-7 shows the comparison between observed and predicted for U and V direction current velocities for the mid estuary and at the estuary entrance. For the mid estuary location there is a reasonable agreement between the phase of the observed and predicted current velocities, however the model is under predicting current speeds. For the location close to the mouth of the estuary, although there is a reasonable agreement between the phase of the observed and predicted current velocities, the current speeds are under predicted by a factor of approximately 2. Some possible reasons why the model is under predicting current speeds are:

- The bathymetry of the main estuary channel may have changed significantly since the channel was surveyed in 2006. It has been observed that the mid estuary channels can change over a relatively short time (per comms, Stephen Park).

- The geometry of the estuary mouth may have changed significantly since it was surveyed in early 2008. There are high rates of sediment transport along the Bay of Plenty coastline and the geometry of river and estuary mouths have been observed to change rapidly during significant wave or flood events.

- The location of the current velocity measurements may not be representative of the channel or vertical current profile. This is a problem that can commonly occur when taking continuous measurements from a single location. In hindsight it may have been more practical to have collected Acoustic Doppler Current Profiler (ADCP) measurements close to the mouth of the estuary. The ADCP could be moored to a boat and measurements collected comprising cross section transects, measuring water speed and direction (at regular intervals over the water depth) as well local water depth. If this is performed over the flood and ebb tides, an accurate assessment of the total flow going though the entrance on both an incoming and outgoing tide can be made. This type of measurement however is more expensive to undertake than single point current measurements.

To assess if the model was predicting the tidal exchange in the estuary correctly comparisons were made with the tidal exchange measured by Domijan (2000). On 10^{th} May 1996, the flood prism was measured as $449{,}000m^3$, when the tidal range was 1.79m at Moturiki Island tide gauge. The predicted flood prism from the model with a similar tidal range was $364{,}000m^3$. The difference in the flood prism is $85{,}000m^3$, however this is expected as even with the introduction of the Ford Cuts culverts there has been an observed net inter-tidal sedimentation since 1996 (per comms, Stephen Park). The results suggest that there has been a net inter-tidal sedimentation of $7{,}000m^3/y$. This is almost half of the estimate made by Domijan of $13{,}640m^3/y$ based on observations between 1985 and 1996 before re-diverting flow back to the estuary. It is expected that the rate of inter-tidal sedimentation would have decreased significantly since the introduction of the culverts at Fords Cut. This gives confidence that the model is adequately predicting the tidal exchange between estuary and the open ocean.

For this phase of the study it was most important to obtain a good agreement between the observed and predicted water levels in the river and estuary, as these are most critical in accurately predicting inflows into the estuary through Fords Cut. For this reason the hydrodynamic component of the model was considered sufficiently calibrated. To improve the current calibration for any further investigations with the model, DHI suggest that further work would be required modifying bathymetry of estuary channel and mouth. Although the bathymetry for estuary mouth was generated using surveyed bathymetry data, it would be justifiable to widen the estuary mouth as it appears quite active morphologically. This would require considerably altering the model mesh. A better representation of the main estuary channels could be achieved with a new bathymetric survey of the main channels.

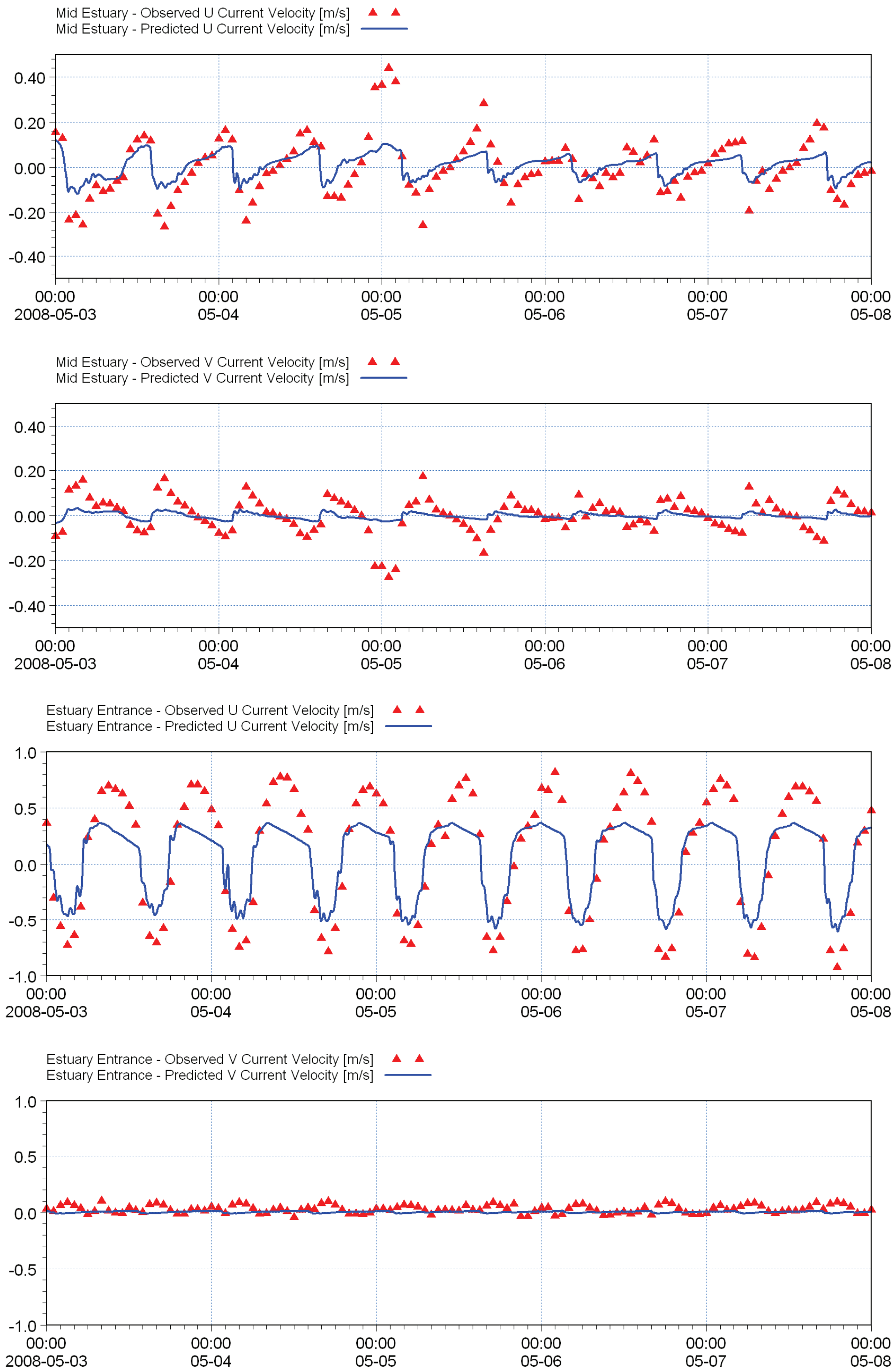

Figure 3-7 Comparison between observed and predicted current velocities at mid estuary (top) and estuary entrance (bottom).

3.7.5 Flow through Fords Cut Culverts

Figure 3-8 presents the comparison between the observed flow through the culverts at Ford Cut with the flow predicted by the model. The flow was measured during a flood event in the Kaituna River and during this time the predicted levels from the model in the lower Kaituna River upstream of Fords Cut are too low. This explains why the model under predicts the flow. As a validation that the model can accurately predict flows through the culverts if the levels are correct at Fords Cut loop, a model was set up using only a section of the whole model domain as shown in Figure 3-9. The boundary conditions used for the simulation were the Kaituna River level gauge at Fords Cut for the river boundary and levels extracted from the whole domain model for the estuary boundary. There is a very good agreement between the flow predicted from the partial model and the observed flow through the Fords Cut culverts.

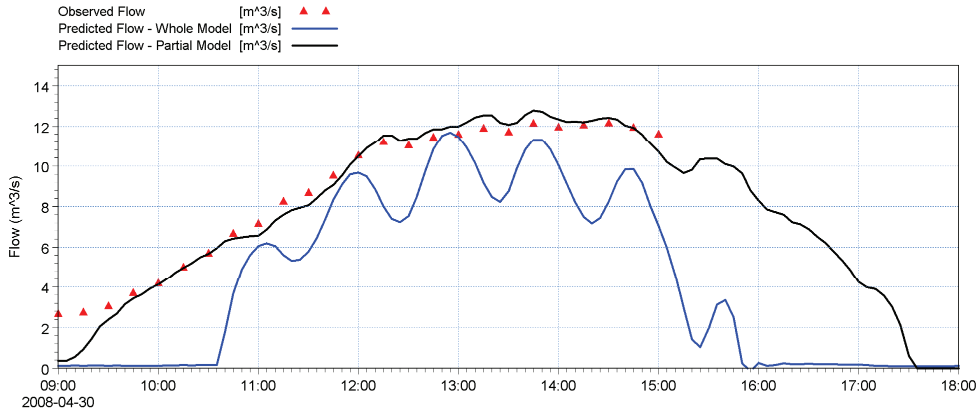

Figure 3-8 Comparison between observed and predicted flow through Fords Cut culverts.

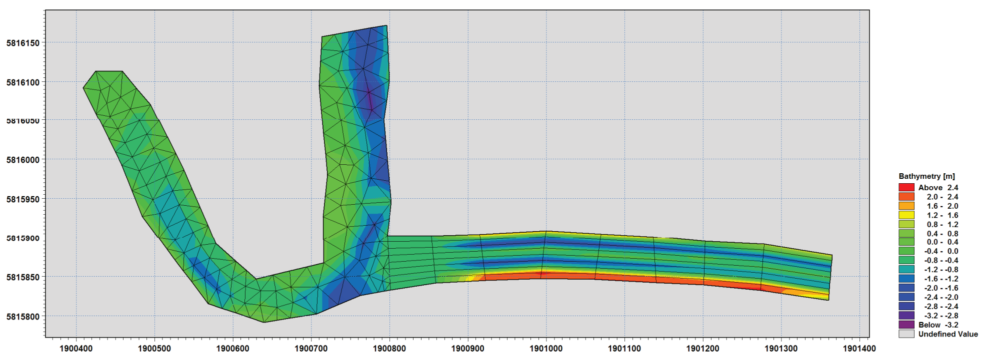

Figure 3-9 Partial model domain of Fords Cut (Moturiki datum).

3.7.6 *Salinity Distribution – Lower Kaituna River*

It was critical to obtain a reasonable calibration of the salinity distribution, especially the propagation of the salt wedge up the Kaituna River, as this will have an influence on the inflow through the Fords Cut and proposed culverts. To assess the performance of the model in predicting the salinities within the Kaituna River and Fords Loop, a comparison was made of the observed and predicted salinities along the vertical profile connecting Sites 1, 2, 4, 5 and 6 as shown in Figure 3-10.

Figure 3-10 Vertical profile for salinity profile comparison.

Figure 3-11 to Figure 3-13 shows the comparison between the observed and predicted salinities along the profile over the period 7:45 am – 12:15 pm 29th May 2008. One feature of the observed salinity profile that is not very well represented in the predicted salinity profile is the higher salinities at the bottom of the water column at Site 1. This higher salinity is probably a result of the observed backflow from the estuary to the river during low tide (see Appendix A). It was not feasible to accurately simulate this kind of culvert behaviour.

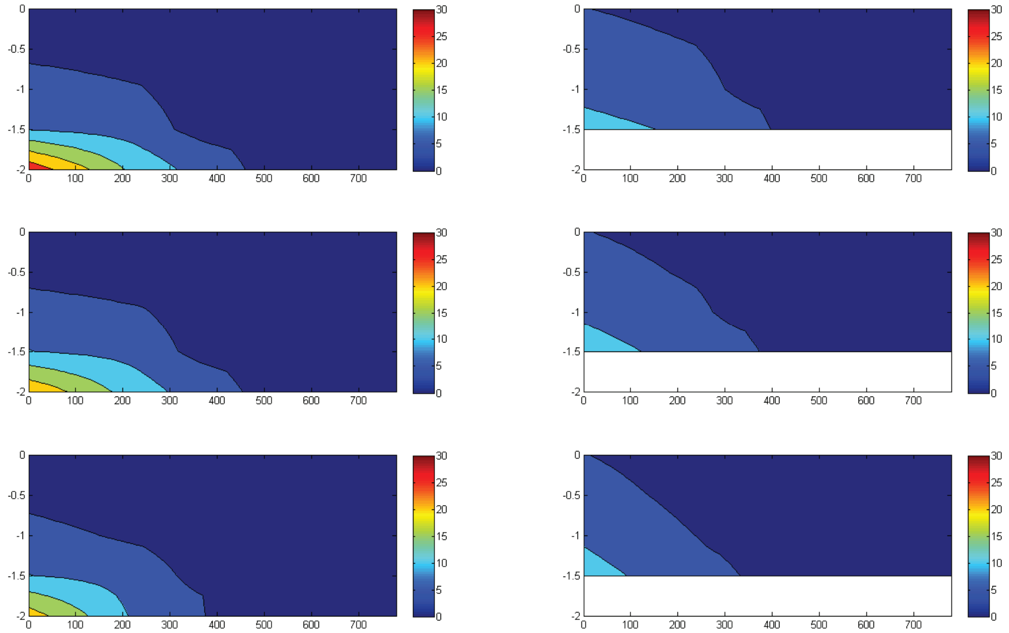

Figure 3-11 Observed (left) and predicted (right) vertical salinity profile at 7:45 am (top), 8:15am (middle) and 8:45 am (bottom), 29th May 2008.

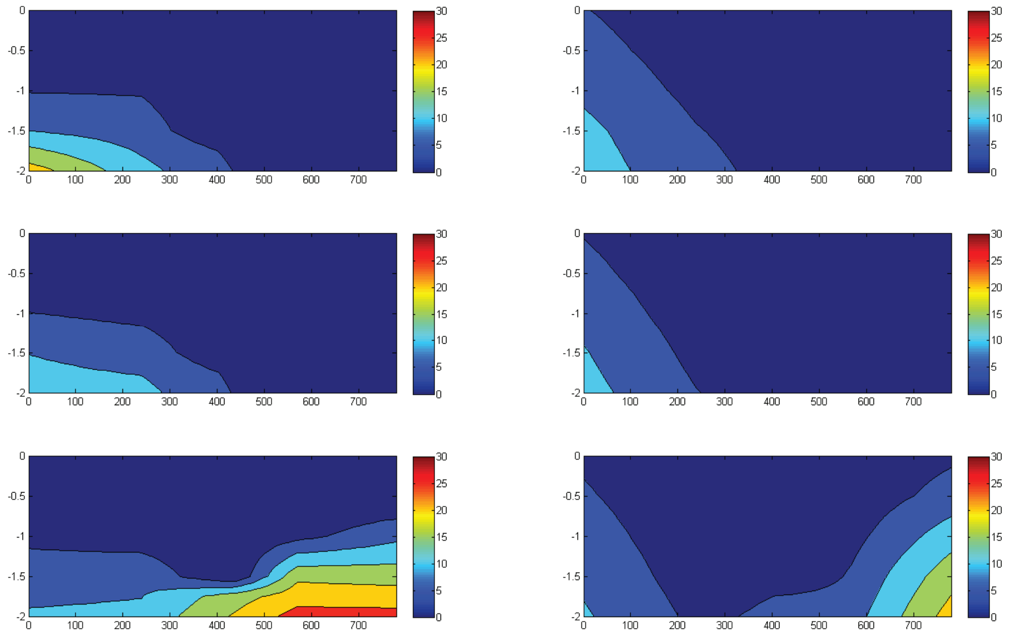

Figure 3-12 Observed (left) and predicted (right) vertical salinity profile at 9:15 am (top) 9:45am (middle) and 10:15 am (bottom), 29th May 2008

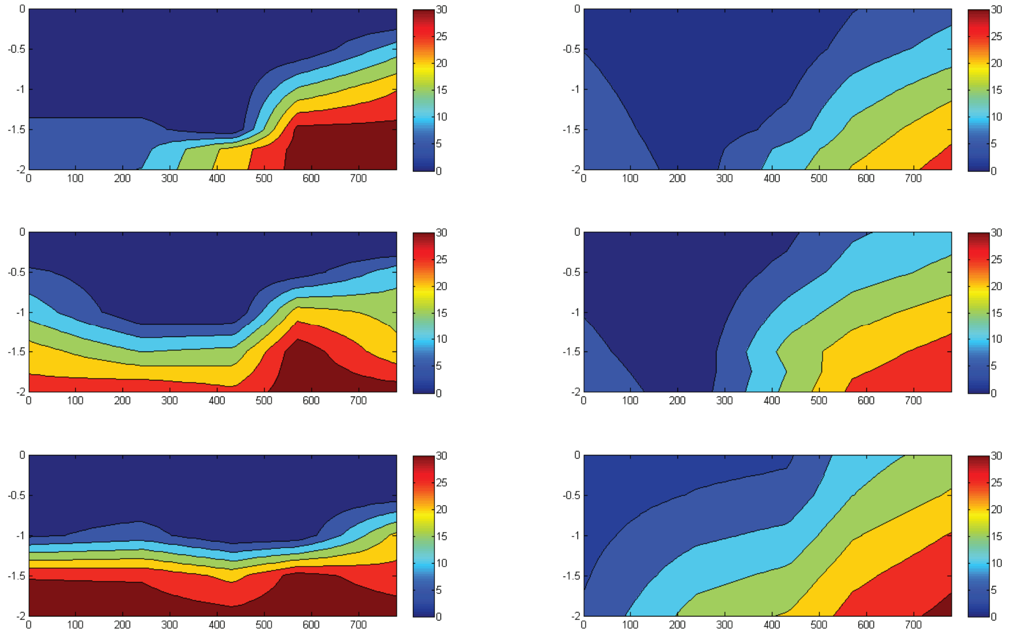

Figure 3-13 Observed (left) and predicted (right) vertical salinity profile at 11:15 am (top) 11:15am (middle) and 12:15 am (bottom), 29th May 2008.

Figure 3-14 shows the comparison between observed and predicted salinities in the Kaituna River on 29th May 2008 for Site 1 to Site 6. 78% of the predicted salinities agree within 5 PSU of the measured salinities. This is considered a sufficient calibration to provide initial guidance.

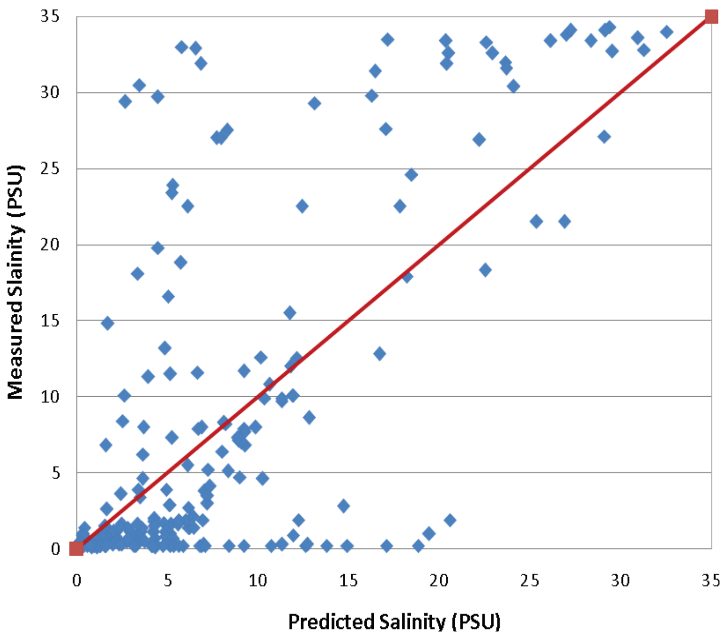

Figure 3-14 Comparison of observed and predicted salinities for Site1 to Site6, 29th May 2008.

To accurately predict the ratio of freshwater/saltwater that will enter Fords Cut and the reopened Papahikahawai Channel it is important that there is a good agreement between the observed and predicted salinities in the upper layers of the water column at Site 1 and Site 6. At Site 1 only water above -0.4m Moturiki datum will flow through the Fords Cut culverts. On 29th May 2008, the high tide level at Fords Cut was 0.66m Moturiki datum. Hence at high tide it is possible that the top 1m of the water column may flow through the Fords Cut culverts. For Site 1, only comparing salinities for data taken from 0 – 1m depth, 92% of the predicted salinities agree within 5 PSU of the measured salinities.

At Site 6, water above -1m Moturiki datum will flow through the proposed culverts. The model predicts that the highest level that occurs at Site 6 during data collection period is 0.7m. Hence at high tide it is possible that the top 1.7m of the water column may flow through the proposed culverts. For Site 6, only comparing salinities for data taken from 0 – 1.5m depth, 73% of the predicted salinities agree within 5 PSU of the measured salinities. The advection/dispersion model is sufficiently calibrated to predict ratio of freshwater/saltwater that will enter estuary.

Flows in the Kaituna River were elevated on 30th April 2008, and the majority of the salinity measurements in the river indicated fresh or nearly freshwater conditions. The predicted salinities in the river from the model over this period were also mostly fresh.

3.7.7 *Salinity Distribution – Maketu Estuary*

Figure 3-15 presents the comparison between observed and predicted salinities within the estuary. Within the estuary, 45% of the predicted salinities agree within 5 PSU of the measured salinities. For the western part of the estuary, where the salinity is dominated by inflows through Fords Cut, the agreement is very good. However for the eastern part of the estuary there is not a good agreement. This is a result of having to use a constant vertical eddy viscosity formulation to simulate the propagation of the salt wedge up the river. The freshwater plume that flows out of the estuary mouth on the ebb tide does not disperse sufficiently and is drawn back into the estuary on the flood tide, so that the predicted salinities that should be purely saltwater, contain a mixture of freshwater and seawater.

DHI suspect that since the model does not have a high resolution outside of the estuary and river, and waves are not included in model set up, bay wide phenomena like longshore currents or wave driven currents are not present to transport the freshwater plume offshore and prevent re-circulation of the freshwater plume into the estuary.

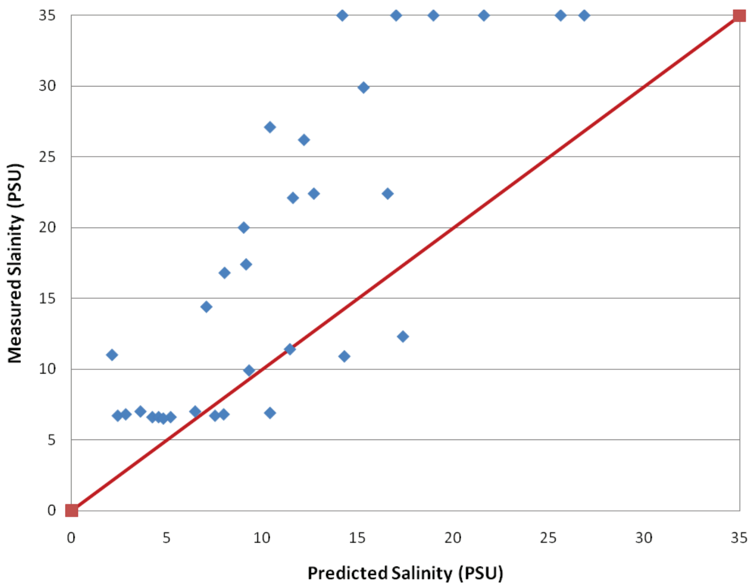

Figure 3-15 Comparison between observed and predicted salinities within the estuary, 29th May 2008, with constant vertical eddy viscosity formulation.

Figure 3-16 presents the comparison between observed and predicted salinities within the estuary at high tide on 30th April 2008 using a constant vertical eddy formulation. 44% of the predicted salinities agree within 5 PSU of the measured salinities.

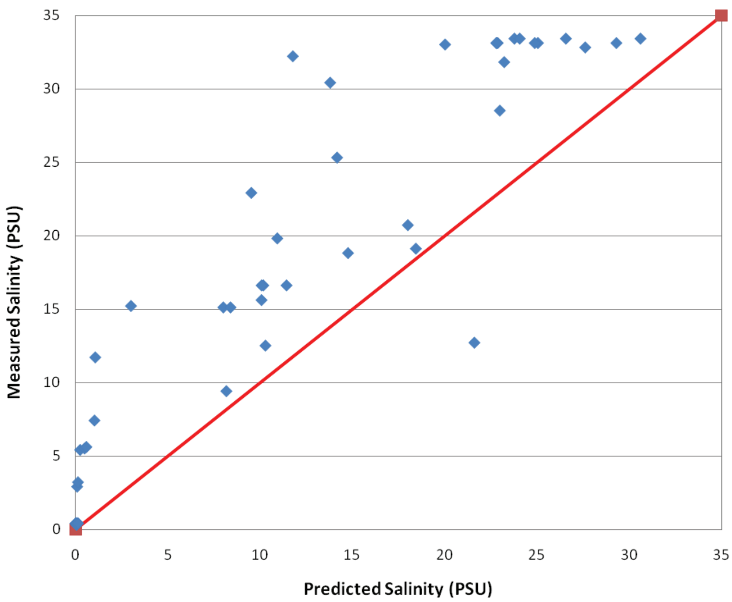

Figure 3-16 Comparison of observed and predicted salinities within estuary, 30th April 2008, with constant vertical eddy viscosity formulation.

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The main purpose of the study is to predict the ratio of freshwater/saltwater into the estuary; for this reason the advection/dispersion model was deemed sufficiently calibrated. For any further investigations using the model such as the proposed water quality modelling, DHI suggest the following ways that the advection/dispersion calibration could be improved:

- Apply an artificial tilt to the open ocean boundaries. If the levels of either the east or west boundaries were increased by a few centimetres, the model may generate a longshore current.

- DHI have used a constant vertical eddy viscosity formulation to correctly simulate the upstream propagation of the salt wedge in the Kaituna River. Further investigations could be carried out to determine whether a satisfactory calibration can be obtained using the k-epsilon formulation, which uses a different turbulence model. It should be noted that all formulations were tested during advection / dispersion model calibration; however due to time restraints DHI was unable to explore all possible k-epsilon formulation configurations. Increasing the number of vertical layers in the model from five to ten may also improve the calibration.

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4 IMPACTS OF RE-DIVERTING FURTHER FLOW INTO ESTUARY

The calibrated model was utilised to assess the impacts of re-diverting flow through Papahikahawai Channel via twin floodgated box culverts. The model was used to:

- Quantify the amount of freshwater/saltwater flow through the culverts and the impacts on the overall salinity of the estuary.

- Determine the effect on water levels on property near the proposed new channel during three flood scenarios.

The diversion option initially considered comprised a fully engineered Papahikahawai Channel (Option A), connecting the Kaituna River just upstream of the mouth with the estuary. However after discussions on the Option A results with EBoP, an alternative proposal (Option B) was included in the impact assessments. These options are described in detail below.

4.1 Model Domain

For all proposed layouts the model domain was regenerated with the Papahikahawai Channel connected to the Kaituna River via twin floodgated box culverts. The dimensions of the culverts were taken from the EBoP MIKE 11 modelling study, and have a width of 10m, height of 3m, a length of 4m and an invert level of -1m (Moturiki datum). The specifics of each proposed layout is outlined below.

4.1.1 Option A

Option A comprises a fully engineered channel connecting the Kaituna River to the main channel within the estuary via the Papahikahawai Channel. The channel is approximately 30m wide and has a depth of -1m (Moturiki datum). Figure 4-1 shows the model domain for Option A.

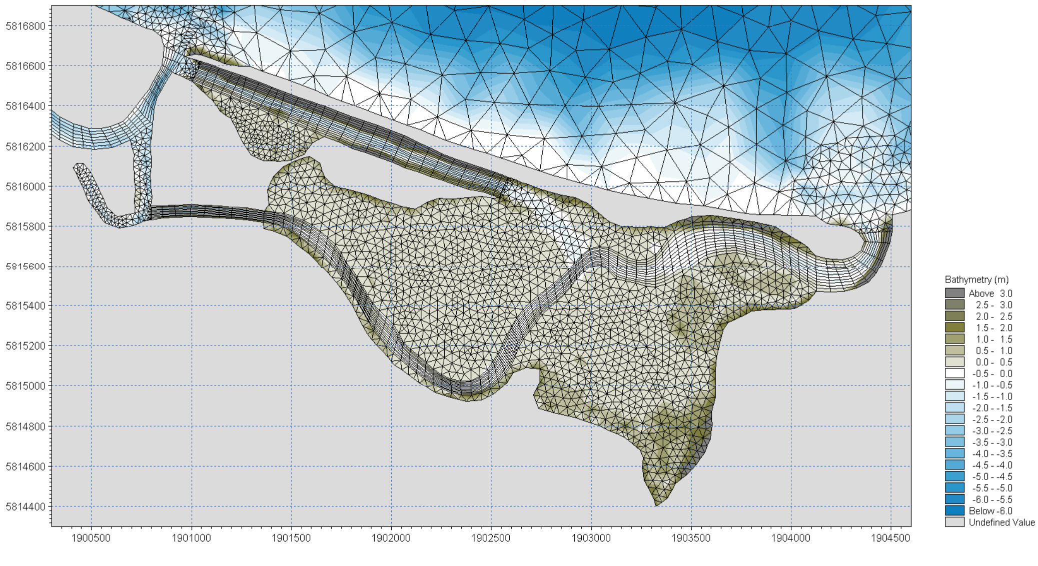

Figure 4-1 Bathymetry and model element mesh for Option A.

4.1.2 Option B

In this option only the upper 400m of the Papahikahawai Channel is assumed to be of an engineered design, with the remaining length of the channel left in its natural (existing) state. The engineered channel is the same width as Option A but is slightly deeper, at -1.2m (Moturiki datum). Data from additional bathymetry survey acquired by EBoP has been used to define the geometry of the natural channel. Figure 4-2 shows the model domain of Option B for the Papahikahawai Channel.

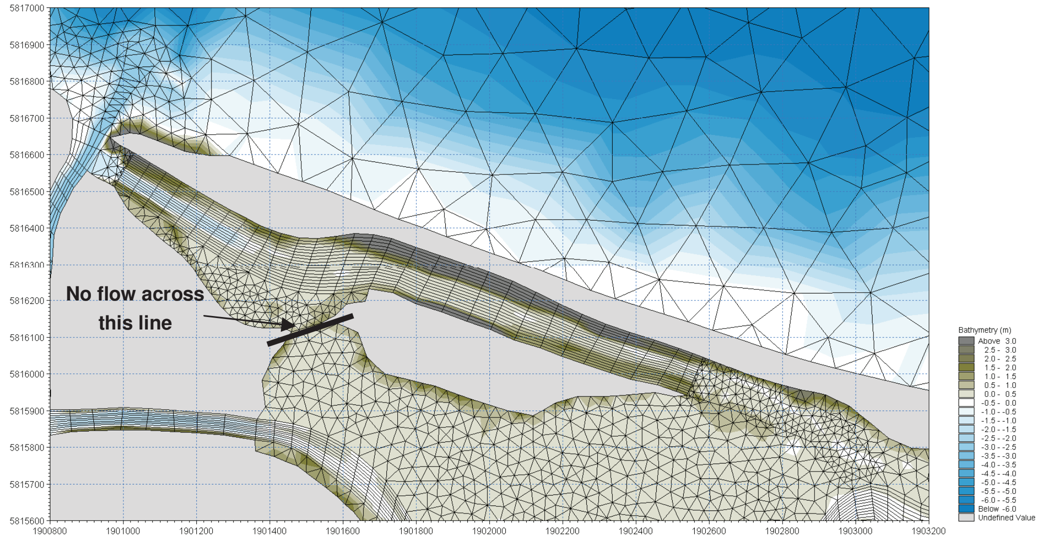

Figure 4-2 Papahikahawai Channel bathymetry and model element mesh for Option B.

It should be noted that only the results from the simulations with **Option B** layout have been presented in the salinity and flood impact assessments, with the only exception being Scenario 2 of the flood impact assessment where the results are derived from a simulation with the Option A layout. (EBoP did not wish to re-run this scenario with the Option B layout).

4.2 Model Setup for Salinity Impact Assessment

For the salinity impact assessment, the model was run for a 15 day neap - spring tide cycle, with an additional 3 days for the model to warm up. The boundary conditions for this period were taken from the DHI global tide model. The global tide model has a spatial resolution of 0.25° × 0.25° based on TOPEX/POSEIDON altimetry data and represents the major diurnal (K1, O1, P1 and Q1) and semidiurnal tidal constituents (M2, S2, N2 and K2). An offset of 0.28m was added to the generated surface elevation time series, derived from Domijan's (2000) analysis of mean sea level relative to Moturiki datum. The predicted offshore surface elevations for the simulated period are presented in Figure 4-3.

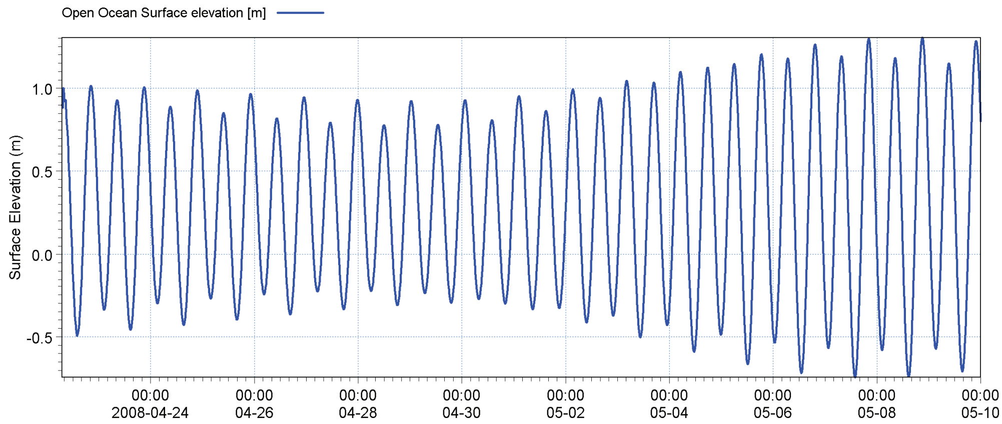

Figure 4-3 Open ocean surface elevations for 15 day neap-spring tide cycle (Moturiki datum).

EBoP have specified a freshwater inflow for the simulated period corresponding to mean river flow of the Kaituna River at Te Matai, 40 m^3/s. No wind forcing was applied.

4.3 Model Validation

To validate the DHI MIKE 3 model with the Papahikahawai Channel included, a comparison was made between the predicted average net inflow through Fords Cut and the new channel from Option A with results predicted from the EBoP MIKE 11 investigations (Wallace 2007). The comparison was made based on net average inflow per tidal cycle, calculated over two neap cycles, two spring cycles and an intermediate cycle.

Option B has not yet been modelled with the EBoP MIKE 11 model. The EBoP MIKE 11 model is not exactly the same as the MIKE 3 model Option A layout. The MIKE 11 model does not have a fully engineered Papahikahawai Channel and also allows flow to the estuary through the access causeway to Papahikahawai Island. However the layouts are similar enough for a comparison of the net average inflow per tidal cycle to be appropriate for a basic validation of the MIKE 3 model.

The EBoP MIKE 11 model calculated a net inflow of 449,000m^3 per tidal cycle, with 105,000m^3 passing through Fords Cut and 344,000m^3 through the proposed culverts. The DHI MIKE 3 model predicts that the mean inflow per tidal cycle through Fords Cut culverts is approximately 133,500m^3 and the predicted mean inflow per tidal cycle through Papahikahawai Channel culverts is 302,000m^3. The mean inflows per tidal cycle are comparable for the MIKE 11 and MIKE 3 models for the conditions modelled.

4.4 Salinity Impacts

In order to determine the ratio of freshwater/saltwater flow into the estuary, the total volume of water and total mass of salt entering Fords Cut and Papahikahawai Channel (while the flap gates in each channel remain open) was calculated for a spring tide, neap tide and mean tide, from the neap – spring simulation. Assuming that freshwater is 0 PSU and seawater is 35 PSU, the total volume of seawater can be calculated from the mass of salt transported into the system. This volume can be compared to the total inflow volume of water to obtain the freshwater/seawater ratio. The tidal range for the spring tide was 2.04m, for the neap tide 0.99m, and for the mean tide 1.51m.

The predicted freshwater inflows for existing and proposed layouts (Option B) are presented in Table 4-1. Also included in the table is the increase in the amount of freshwater for the proposed layout compared to the existing layout and the percentage of freshwater in relation to the estuary capacity. An approximate tidal capacity has been calculated for the existing and proposed layouts for spring, neap and mean tides. The following should be noted from the Table 4-1:

- By re-opening the Papahikahawai Channel total freshwater inflows to the estuary will increase by 71,000 m^3 (67%) in a spring and 48,000 m^3 (46%) in a neap tide.

- When the Papahikahawai Channel is re-opened there is a small decrease in the flow through Fords Cut, however there is little impact on the ratio of freshwater of the inflow.

- During a neap tide, the salt wedge does not propagate far up the Kaituna River; as a result the inflow through Fords Cut is predominantly freshwater and the inflow through the Papahikahawai Channel is approximately 50% saltwater and freshwater combined.

- During a spring tide when the salt wedge propagates further up the river, there is a significant increase in saltwater inflow to the estuary. For the proposed layout 45% of the flow through Fords Cut and 75% of the flow through the Papahikahawai Channel will be saltwater.

- The proposed layout will increase freshwater inflows to the estuary by between 48,000m^3 to 71,000 m^3. The percentage of freshwater inflow compared to the estuary capacity is between 8.7% to 16.7%.

- The fraction of the freshwater inflow through the Papahikahawai Channel varies greatly from spring to neap tides, between 25% and 52%.

- The largest inflow to the estuary occurs during a spring tide when 483,000m^3 enters the estuary, of which approximately 309,000m^3 is saltwater and 176,000m^3 is freshwater.

Table 4-1 Freshwater/saltwater inflow ratios for existing and proposed (Option B) layouts.

			Total Volume of Water (m^3)	Freshwater Fraction	Volume of Freshwater (m^3)	Freshwater Inflow Increase (m^3)	Tidal Capacity (m^3)	Percentage Freshwater of Estuary Capacity (%)
Spring Tide	**Existing**	**Fords Cut**	184,754	0.57	105,310		1,659,000	6.3
	Proposed	**Fords Cut**	171,876	0.55	95,293			
		Papahikahawai	311,244	0.25	80,849			
		Total	483,120	0.36	176,141	70,831	2,026,000	8.7
Neap Tide	**Existing**	**Fords Cut**	108,827	0.96	104,474		710,000	14.7
	Proposed	**Fords Cut**	109,465	0.95	104,263			
		Papahikahawai	92,820	0.52	48,175			
		Total	202,285	0.75	152,438	47,964	911,000	16.7
Mean Tide	**Existing**	**Fords Cut**	149,674	0.77	115,249		1,154,000	10.0
	Proposed	**Fords Cut**	142,987	0.74	106,505			
		Papahikahawai	187,404	0.26	61,461			
		Total	330,391	0.51	167,966	52,717	1,428,000	11.8

4.5 Model Setup for Flood Impact Assessment

For the flood impact assessment, EBoP requested that the following scenarios be simulated:

- Scenario 1: A spring tide with normal river flow at Te Matai of $40m^3/s$.
- Scenario 2: A peak tidal level of 1.62m and a 20% AEP river flow.

As discussed in Section 3.7, the model tends to under predicts water levels during flood events (high water stages) in the Kaituna River. As a result the model will also under predict flood inflows through the Fords Cuts and proposed Papahikahawai Channel culverts. Although there maybe some uncertainty in the resulting maximum water levels that occur in the river and estuary, the model can still be used to assess the likely relative increases in water levels resulting from re-opening proposed Papahikahawai Channel. However absolute flood level values should be used with caution.

The peak tidal level includes the likelihood of combinations of wave set-up, storm surge and barometric pressure effects. The rise in tidal level was assumed to peak and subside over a 72 hour period, with the maximum surge coinciding with the peak spring tidal level, 36 hours after the start of the surge. The peak tidal level for the flood event is 1.62m (Moturiki datum). The associated probability of this event is uncertain (EBoP, pers comm). The tidal boundary conditions are presented in Figure 4-4. The peak 20% AEP event river flow is $170m^3/s$ at Te Matai. The 20% AEP flood hydrograph at Te Matai was generated by scaling the flood event that occurred on 30th April 2008. The flood hydrograph is shown in Figure 4-5.

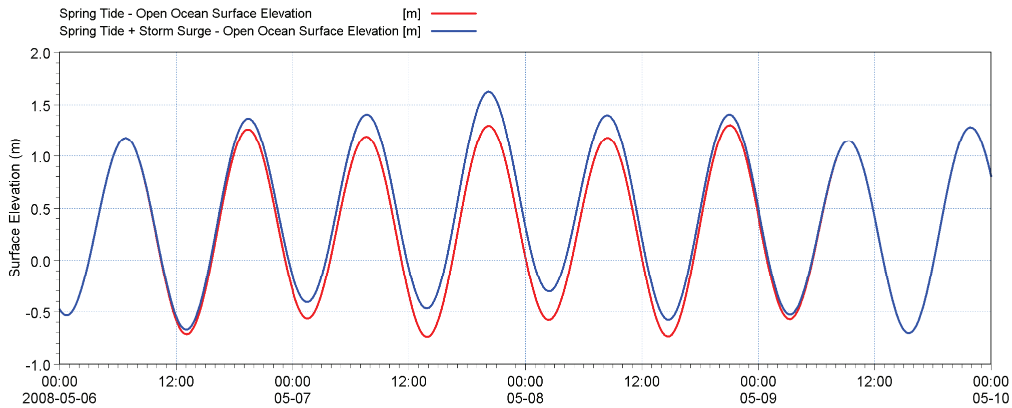

Figure 4-4 Open ocean surface elevations for a spring tide, and a spring tide with storm surge.

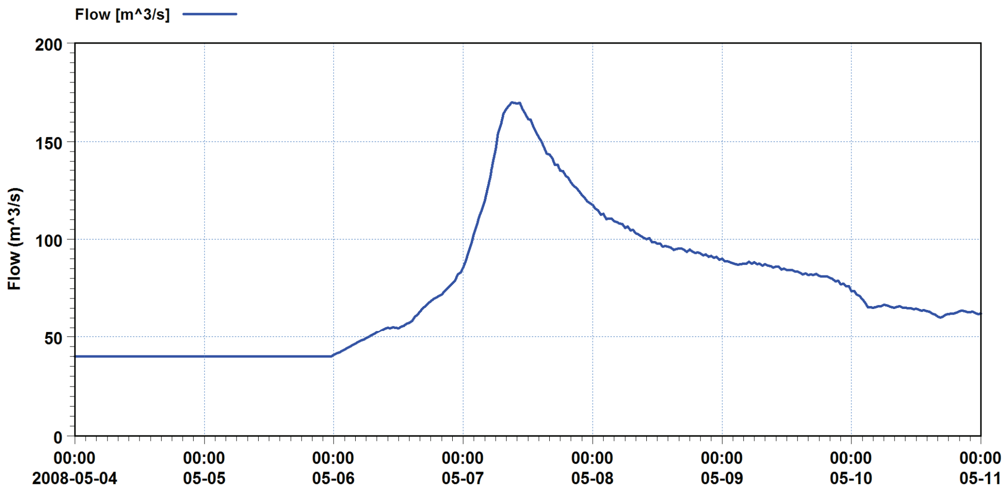

Figure 4-5 20% AEP flood hydrograph.

4.6 Flood Impacts

Model simulations were undertaken for Scenario 1 for the existing situation and proposed layout Option B. For Scenario 2 simulations were undertaken for the existing situation and proposed layout Option A, as it was decided a re-run for the Scenario 2 simulation with Option B layout was not required. Maximum water levels from locations shown in Figure 4-6 were extracted for each simulation. Table 4-2 lists the results from the flood impact simulations.

Figure 4-6 Location of water level comparison points.

Table 4-2 Peak water levels from flood impact scenario runs

		Comparison Point											
Scenario	**Layout**	**Pt 1**	**Pt 2**	**Pt 3**	**Pt 4**	**Pt 5**	**Pt 6**	**Pt 7**	**Pt 8**	**Pt 9**	**Pt 10**	**Pt 11**	**Pt 12**
		Peak Water Level (m, Moturiki Datum)											
1	**Existing**	1.31	1.18	1.18	1.17	1.10	1.07	1.17	0.89	0.96	N/A	N/A	N/A
	Proposed (Option B)	1.31	1.22	1.22	1.21	1.22	1.22	1.22	1.21	1.21	1.24	1.25	1.25
	Difference	*0.00*	*0.04*	*0.04*	*0.04*	*0.12*	*0.15*	*0.05*	*0.32*	*0.25*	N/A	N/A	N/A
2	**Existing**	1.80	1.55	1.53	1.53	1.54	1.54	1.53	1.53	1.53	N/A	N/A	N/A
	Proposed (Option A)	1.82	1.63	1.61	1.61	1.62	1.62	1.62	1.63	1.63	1.64	1.65	1.65
	Difference	*0.02*	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*	*0.09*	*0.10*	*0.10*	N/A	N/A	N/A

The following conclusions can be drawn from the flood impact simulations:

- For a spring tide with a normal river flow (Scenario 1), the re-opening of the Papahikahawai Channel will increase the peak levels for the majority of the estuary by up to 15cm. Peak levels in Papahikahawai Channel are the same as the rest of the estuary. There is a significant increase in levels in the Papahikahawai Channel (Point 8 and Point 9) due to the fact that the channel is now engaged to convey flood flows.

- For a spring tide with a storm surge (Scenario 2) and a 20% AEP river flow, the effect of re-opening the Papahikahawai Channel gives rise to an increase in peak water levels of up to 10cm in the estuary and 2cm in the river.

The flood impact assessment indicates that during a significant flood event, the re-opening the Papahikahawai Channel will lead to a small increase in the peak water levels in the river and main estuary. The increased risk of flooding to properties in the proximity of the river and the main estuary is negligible.

There are areas of land surrounding the section of the channel currently cut off from the estuary by causeways (Point 10, Point 11 and Point 12 in Figure 4-6) which will have an increased risk of flooding if Papahikahawai Channel is re-opened. There is the potential for flood inundation of the lower lying land of the western part of Papahikahawai Island (Polygon A in Figure 4-7) where no stop banks are present.

A second area where the risk of flooding will increase is the low lying land in Polygon B of Figure 4-7. The peak levels for both Scenario 1 and Scenario 2 are high enough to overtop sections of the stop banks and inundate the land.

Figure 4-7 Areas at risk from flood inundation as a result of re-opening Papahikahawai Channel.

4.7 Peak Velocities during Flood Events

Peak velocities within the estuary and Papahikahawai Channel for both flood events have been extracted from the model results to give an indication of potential for erosion and morphological changes.

Depth averaged peak velocities are presented in Figure 4-8 to Figure 4-11. In Scenario 1, which comprises only moderate flows in the Kaituna River, the highest velocities in Papahikahawai channel occur in the shallower eastern part of the channel. Velocities range from 0.1 to 1.0 m/s along the channel. In Scenario 2, representing a 20% flood event, flow velocities are higher, particularly near the Kaituna river end of Papahikahawai Channel, where speeds of more than 1.5m/s are evident in localised areas. Along the remainder of the channel the velocities range from 0.2 to 1.8 m/s.

It is difficult to draw conclusions from the two scenarios as they represent both different channel geometries and boundary conditions. However based on the two scenarios described above it would suggest that the channel may naturally scour under flood conditions. Additional simulations are recommended to further refine the channel design and assess its impacts.

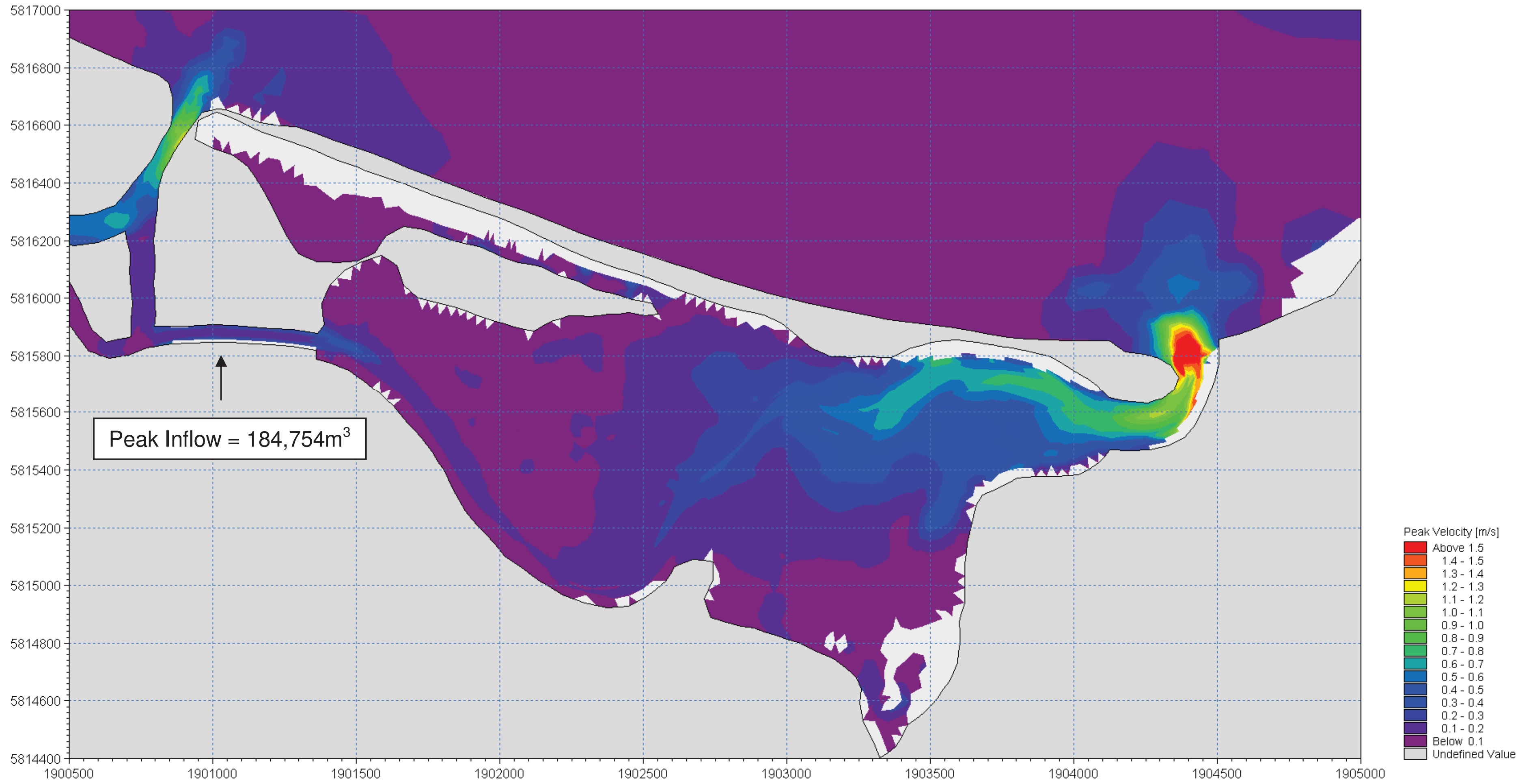

Figure 4-8 Scenario 1 - Peak velocities for existing situation.

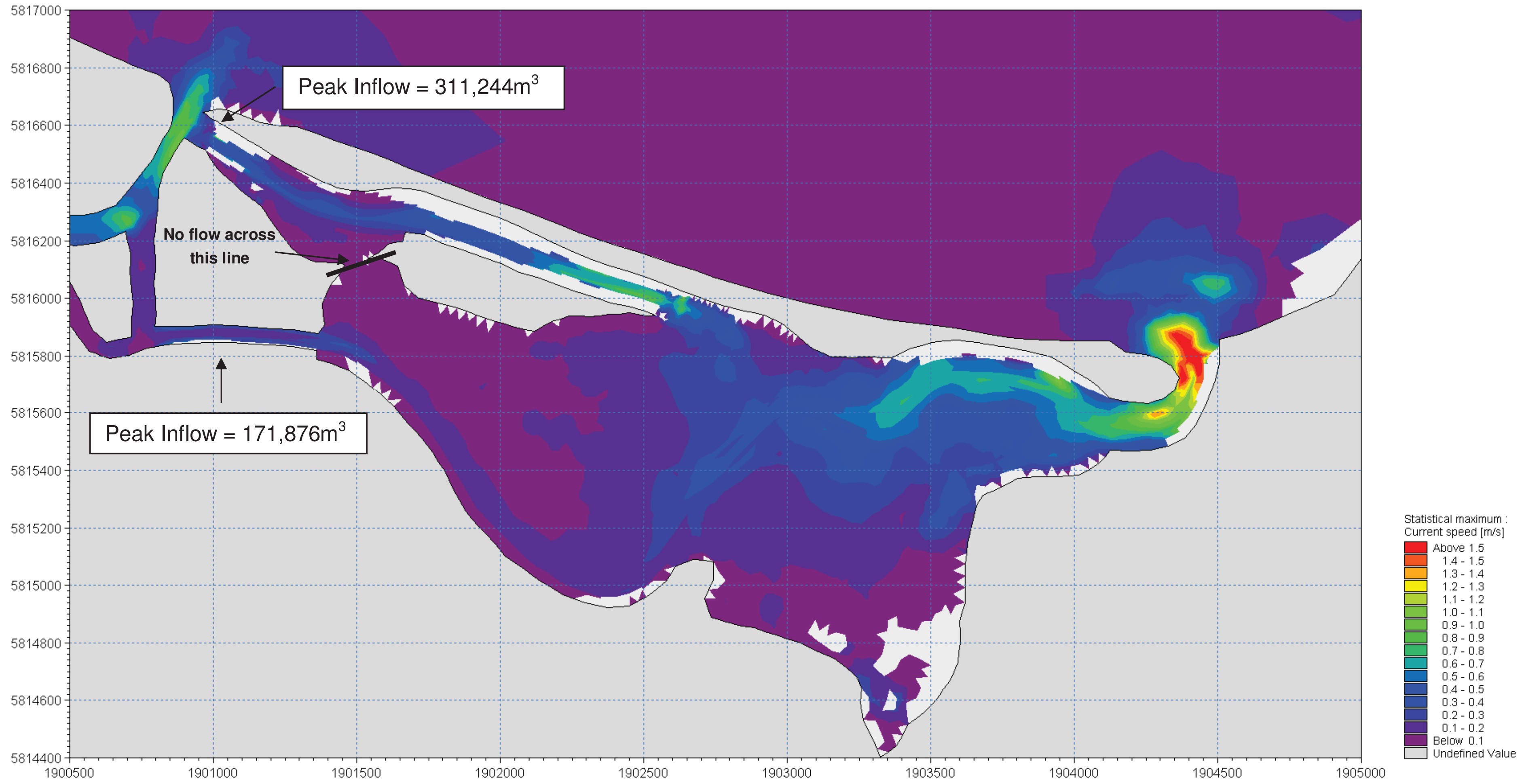

Figure 4-9 Scenario 1 - Peak velocities for proposed layout Option B.

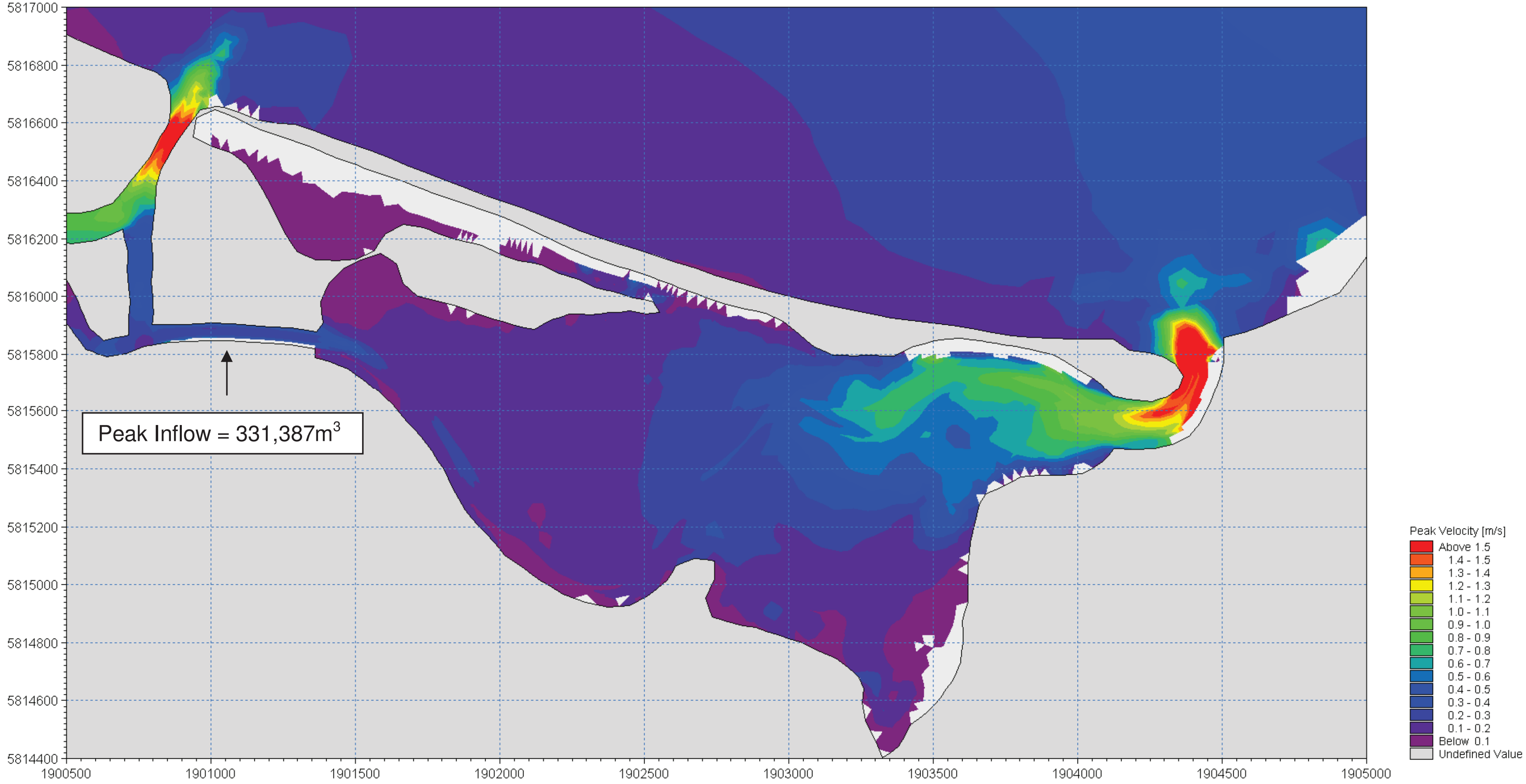

Figure 4-10 Scenario 2 - Peak velocities for existing situation.

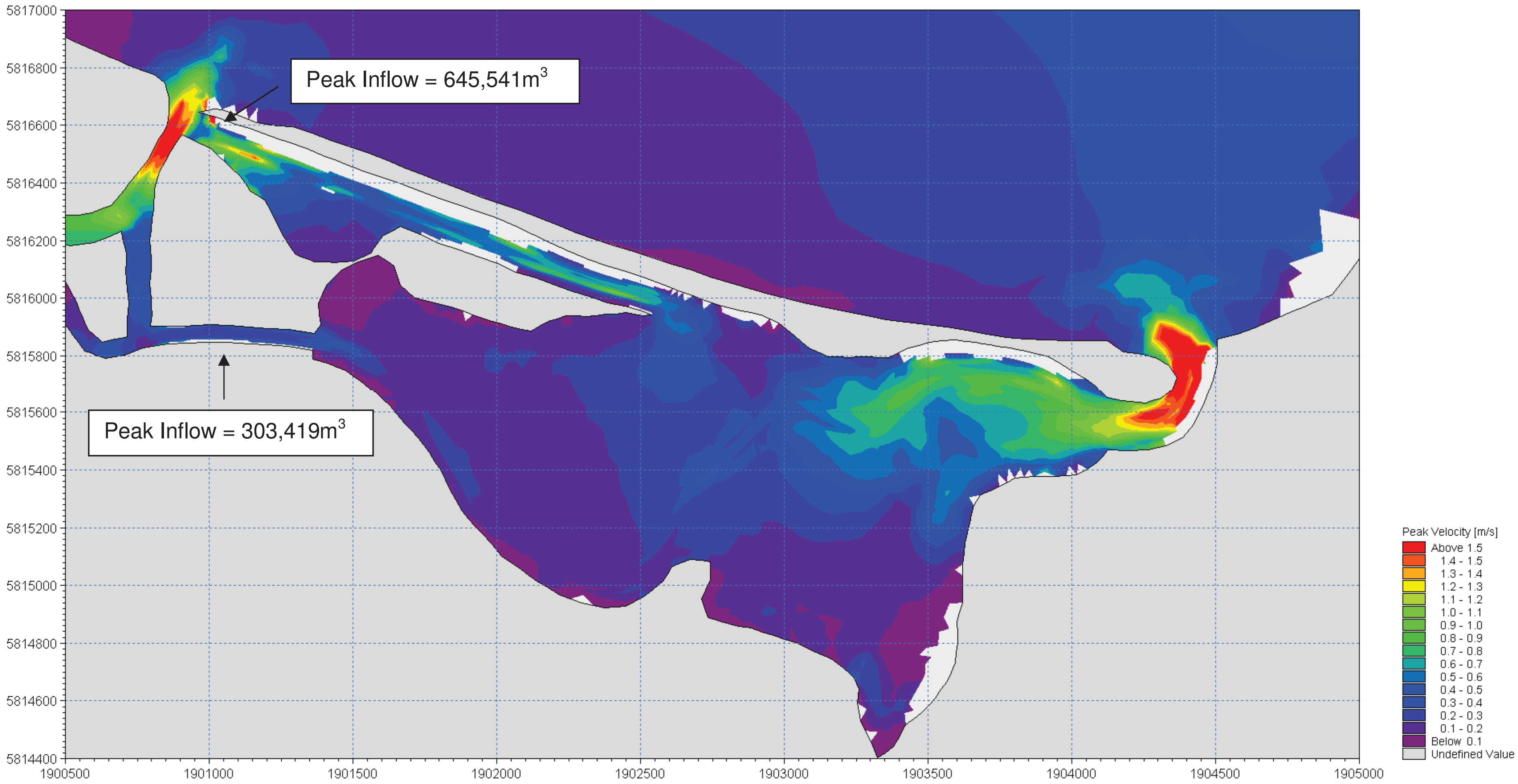

Figure 4-11 Scenario 2 - Peak velocities for proposed layout Option A.