

**Kaituna River to Maketu Estuary Re-diversion:
Model Calibration and Initial Hydrodynamic Impact Assessment**



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Model Calibration and Initial Hydrodynamic Impact
Assessment**

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A Fords Cut Tidal Gauging



1 INTRODUCTION

Environment Bay of Plenty (EBoP) has commissioned DHI NZ to build a hydrodynamic and advection/dispersion model of the lower Kaituna River and Maketu Estuary. The model will be used to assess the likely effects of re-diverting flow from the Kaituna River into the Maketu Estuary. The model has been developed so that it can be coupled with an ecological model at a later date if required. This report outlines the set up and calibration of the three dimensional hydrodynamic and advection/dispersion model of the Kaituna River and Maketu Estuary. The model was used to assess the impacts of re-diverting further flow from the Kaituna River to the Maketu Estuary, with emphasis on salinity changes and flooding effects.

1.1 Description of Study Area

The Kaituna River and Maketu Estuary are located in the central Bay of Plenty. The Kaituna River has its headwaters at the outlet of Lake Rotoiti at Okere Arm and enters the sea at Te Tumu near Maketu. The whole catchment area covers 1,250 square kilometres (125,000 ha). It passes through a steep, narrow gorge, before meandering through the alluvial terraces of the mid Kaituna River and the peat and sand deposits of the lower Kaituna basin. Lakes Rotorua and Rotoiti contribute a large proportion of the everyday flows. The Mangorewa River is a major tributary, which contributes greatly to flood flows in the Kaituna River. Other significant tributaries include the Waiari, Ohineangaanga, Raparapahoe and Kopuaroa Streams, which drain the hill country behind Te Puke. Figure 1-1 presents an overview of the study area.

Historically the Kaituna River entered the sea via the Maketu Estuary. The river entered the estuary through the Papahikahawai Channel in the north of the estuary. In 1958 the river was diverted directly to the sea, through the Te Tumu Cut. The estuary has deteriorated as a result of the diversion. A large amount of sedimentation has occurred and without the additional flushing, the estuary mouth has begun to close. Domijan (2000) calculated the reduction in net inter-tidal storage between 1985 and 1996 was $150,000\text{m}^3$ or $13,640\text{m}^3/\text{y}$. Ever since the diversion there has been support among locals and estuary users to re-divert the river back into the estuary. In 1996, the re-diversion of limited flows occurred via the construction of gated culverts at Ford Cut. It has been calculated that this has resulted in an additional volume of $100,000\text{m}^3$ per tidal cycle of flow into the estuary (Domijan, 2000).



Figure 1-1 Study area overview.



1.2 Further Re-diversion of Flow into the Estuary

The Kaituna River and Maketu Estuary Management Strategy was developed with the aims to:

- maintain the cultural values;
- achieve long term sustainable management; and
- improve environmental quality of the Kaituna River, its related waterways and catchment, and the Maketu Estuary.

As a part of the strategy, a number of options were developed to increase the amount of flow diverted to the estuary. EBoP commissioned a one dimensional modelling study to investigate the effects of each of the options on flood and drainage levels, and compare the effectiveness of each in diverting water to the estuary (Wallace, 2007). The costs and economic impacts of each option were also considered in another study (EBoP, 2008). From these investigations one option was chosen as the preferred option. The option is to re-divert flow back through Papahikahawai Channel via twin floodgated box culverts. The one dimensional modelling investigations suggest that this will increase the existing flow to the estuary fourfold (449,000 m³ per tidal cycle).

1.3 Study Objectives

The objectives of this study have been defined as the following:

- Assess the impacts of re-diverting flow from the Kaituna River through the Papahikahawai Channel in terms of the ratio of freshwater/seawater entering the estuary and the resulting changes to the overall salinity of the estuary.
- Assess the change in flood levels on the properties in close proximity to the study area for a combination of elevated tidal levels and/or river flows.

1.4 Scope of Work

To achieve the study objectives, the scope of work for the study has been defined and summarized as follows:

- Generate a model domain of the Kaituna River, Maketu Estuary and appropriate offshore region.
- Set up a MIKE3 model of the Kaituna River and Maketu Estuary, including culverts at Fords Cut.
- Calibrate the model using data provided by EBoP and other sources.
- Modify the model domain to represent reopening of Papahikahawai Channel and include proposed culverts in the model setup.
- Utilise the model to assess the impacts on salinity of re-diverting further flow from the Kaituna River to the Maketu Estuary via Papahikahawai Channel



- Run model for several flood scenarios to assess change in flood risks under existing and proposed conditions.
- Report on data review, model set up, model calibration and findings from impact assessment of flow re-diversion.



2 DATA REVIEW

This chapter focuses on the data made available for the study from both existing sources and that collected specifically for the study. Field surveys were carried out by EBoP, the University of Waikato and Discovery Marine Ltd.

2.1 Bathymetry Surveys

2.1.1 River

The area of interest for the Kaituna River extended from the Te Matai gauging station, downstream to the river mouth entrance at Te Tumu. Also included in the survey was section of river including the Fords Cut loop. Depth soundings were collected by the University of Waikato on the 8th and 20th June 2006. Locations were obtained using a Garmin Etrex GPS and an echo sounder was used to measure the depths. Depths were provided in electronic form in Moturiki datum. A section of the surveyed area is shown in Figure 2-1.

2.1.2 Maketu Estuary Entrance and Kaituna River Mouth

The entrances to Kaituna River and the Maketu Estuary were surveyed by Discovery Marine Ltd surveyed 18-19 February 2008, during a High Water period. The survey was undertaken using a boat fitted with a full digital hydro graphic survey outfit comprising RTG GPS, digital echo sounder. The data was provided in WGS84 datum, Bay of Plenty 2000 at Moturiki datum. Vertical accuracy of final soundings was assessed as better than 0.15m. The surveyed areas are shown in Figure 2-1.

2.1.3 Maketu Estuary

A Real Time Kinetic (RTK) survey was carried out of the main channel of the Maketu Estuary from the entrance to the Fords Cut channel by Goodhue (2007). The RTK survey was carried out using a boat and echo sounder at approximately 2 hours either side of high tide, when the water depth was sufficient to navigate the channel. The surveyed areas are shown in Figure 2-1.

2.1.4 Papahikahawai Channel

After the submission of the draft report for this study, EBOP requested that further simulations were required with a more accurate representation of the Papahikahawai Channel. Discovery Marine Ltd was commissioned to survey the channel. The survey was carried out over two periods, the 20th August and 27th-28th August 2008. This data was only utilised for two simulations in Section 4 investigating the salinity impacts for proposed layouts, Option B and Option C. The data was provided in New Zealand Transverse Mercator Projection 2000 at Moturiki datum. The surveyed area is shown in Figure 2-2.



Figure 2-1 Bathymetry surveys



Figure 2-2 Additional bathymetry survey for Papahikahawai Channel.

2.2 Offshore Bathymetry

Offshore bathymetry was obtained from MIKE C-MAP. C-MAP™ is an electronic chart database which covers the world. MIKE C-MAP is an interface to C-MAP™ which allows one to easily extract depth data and tidal information from almost any location in the world relative to chart datum.

2.3 Land Levels

LiDAR data points surveyed in 2008 were provided by EBoP. These were used to obtain levels for the intertidal parts of the estuary and beach. The LiDAR extent is shown in Figure 2-3.



Figure 2-3 Extent of LiDAR land level data supplied by EBoP.

2.4 Climate Data

The following set of climate data was obtained from EBoP:

- Hourly wind and atmospheric pressure observations from Tauranga Airport for the period 23rd April 2008 to 10th June 2008.
- Hourly wind observations from Te Puke for the period 23rd April 2008 to 22nd May 2008.

The wind data is presented in Figure 2-4 and atmospheric pressure data in Figure 2-5.

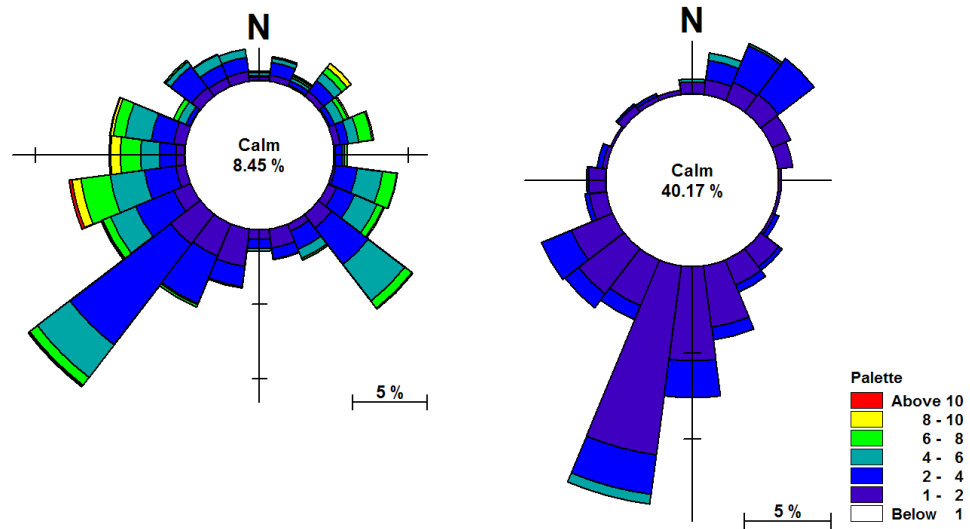


Figure 2-4 Wind data from Tauranga Airport (left) and Te Puke (right).

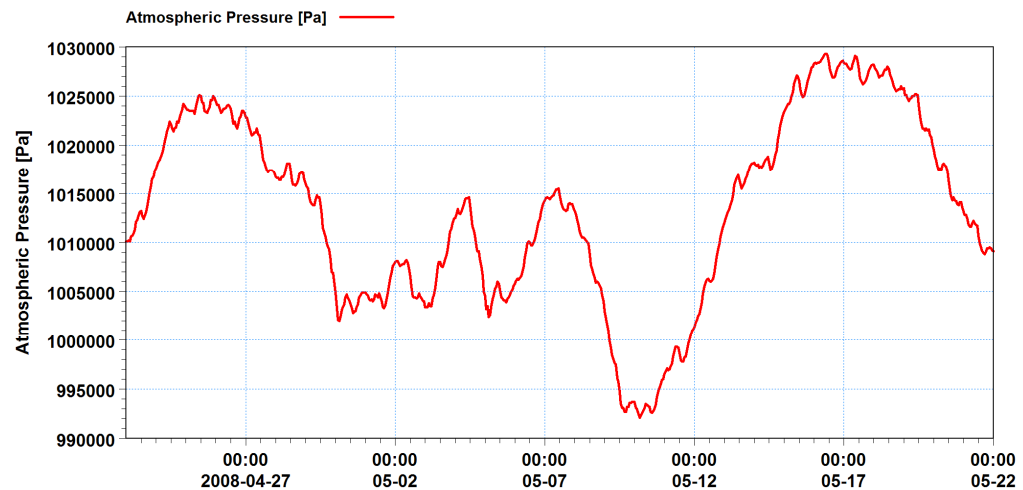


Figure 2-5 Atmospheric pressure at Tauranga Airport.

2.5 **Metocean and River Data**

Figure 2-6 presents an overview of the data collected in the proximity of the lower Kaituna River and the Maketu Estuary.

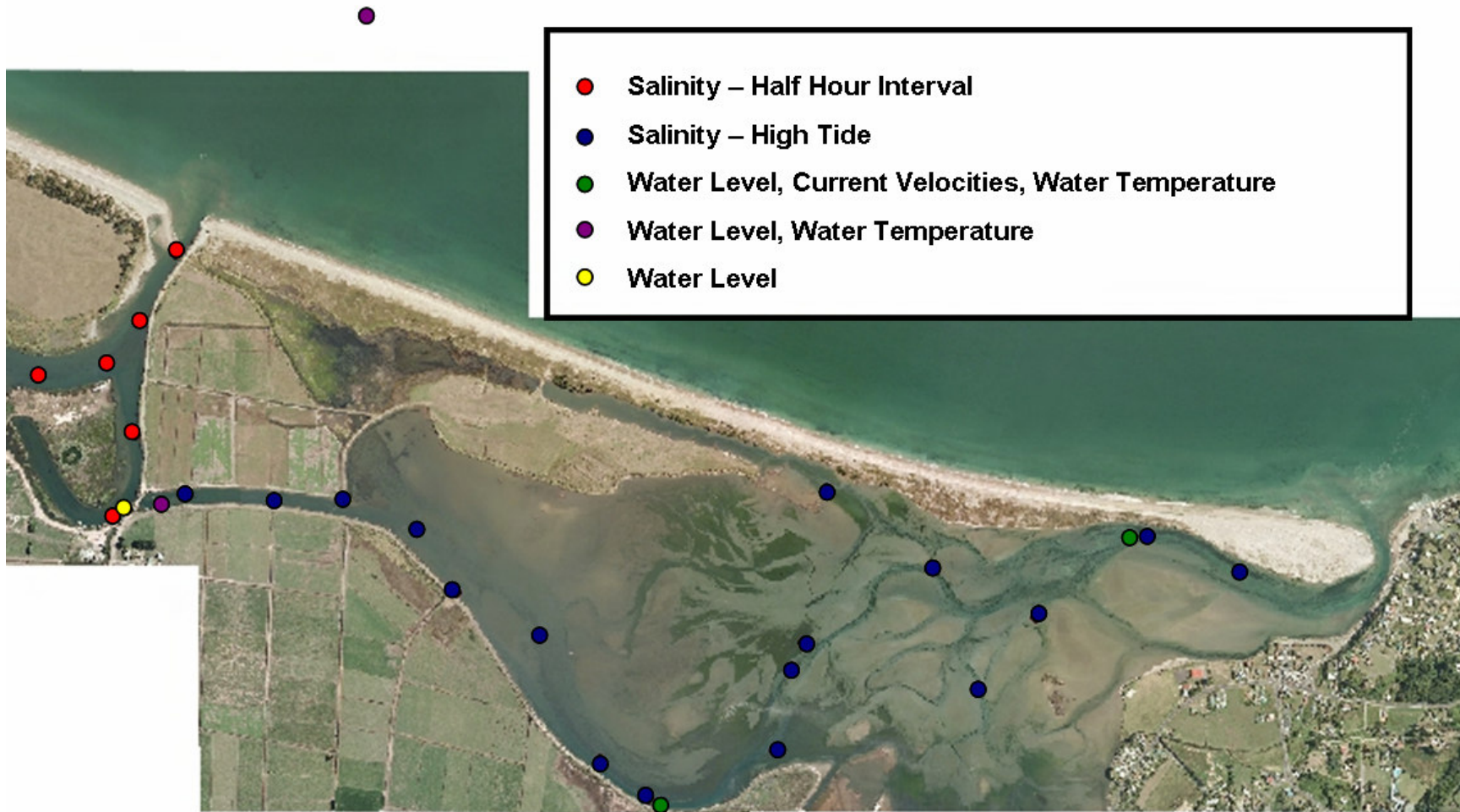


Figure 2-6 Data overview for Kaituna River and Maketu Estuary



2.5.1 River Discharges

Flow discharges from the Kaituna River gauge at Taaheke at outlet of Lake Rotoiti and the Mangorewa River have been provided by EBoP for the period 24th April 2008 to 10th June 2008, see Figure 2-7. There is a control structure above the Taaheke site at the top of the Kaituna River and outlet of Lake Rotoiti, which regulates the flow from the lake.

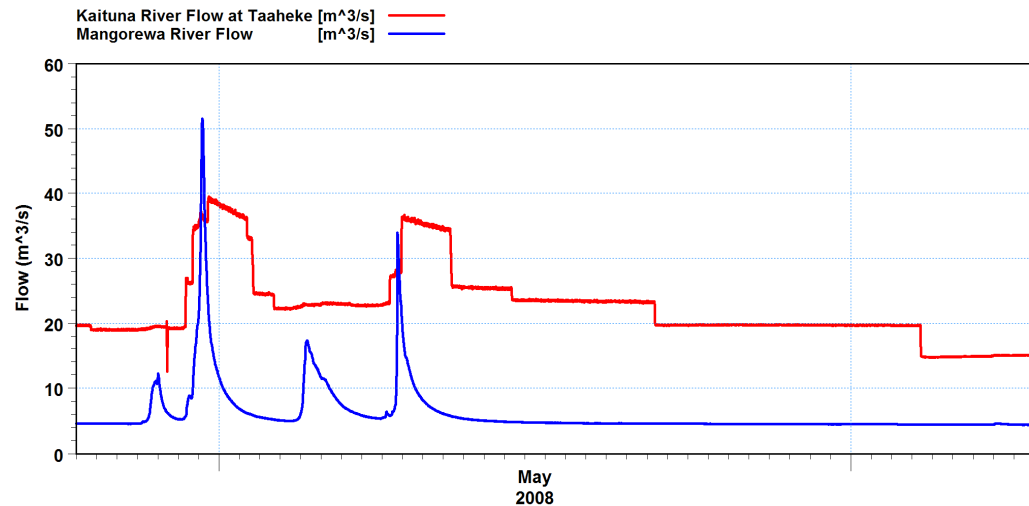


Figure 2-7 River flow for Kaituna River at Taaheke and Mangorewa River.

2.5.2 Water Level, Current and Temperature Data

EBoP have provided water level data from the gauges at Te Matai and at Fords Cut for the period 23rd April 2008 to 10th June 2008, see Figure 2-8. The visible sudden drop in levels is associated with the control structure operation at the top of the Kaituna River.

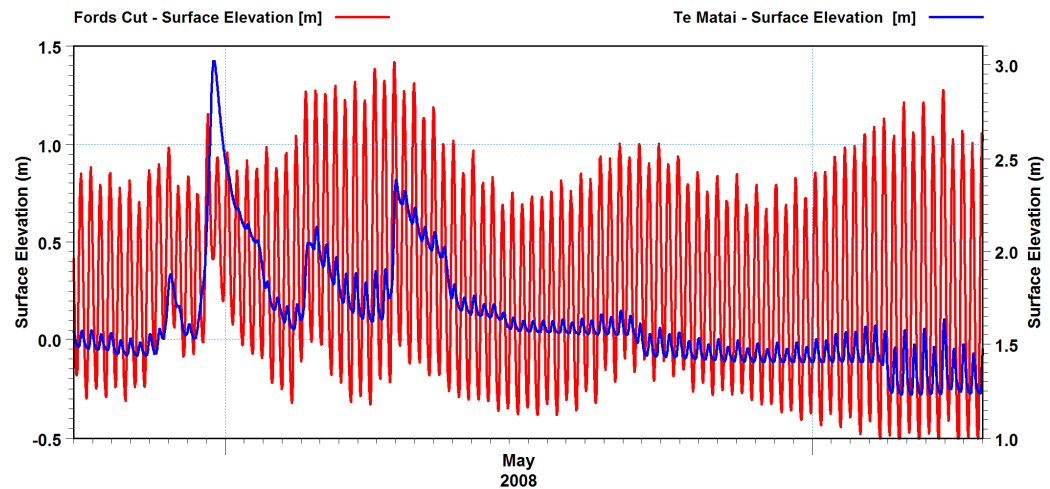


Figure 2-8 Surface elevation from gauges at Te Matai and Fords Cut (Moturiki datum).



Two Hobo pressure sensors were also deployed to obtain instantaneous water level measurements as shown in Figure 2-9. The first sensor was deployed in Fords Cut channel (NZTM 1900846, 5815854) over the period 2nd May 2008 to 20th May 2008. The second sensor was deployed 500m offshore of the Kaituna River entrance (NZTM 1901145, 5817280) in the open ocean for the period 6th May 2008 to 16th May 2008. The Hobo sensors also measured the water temperature as seen in Figure 2-10.

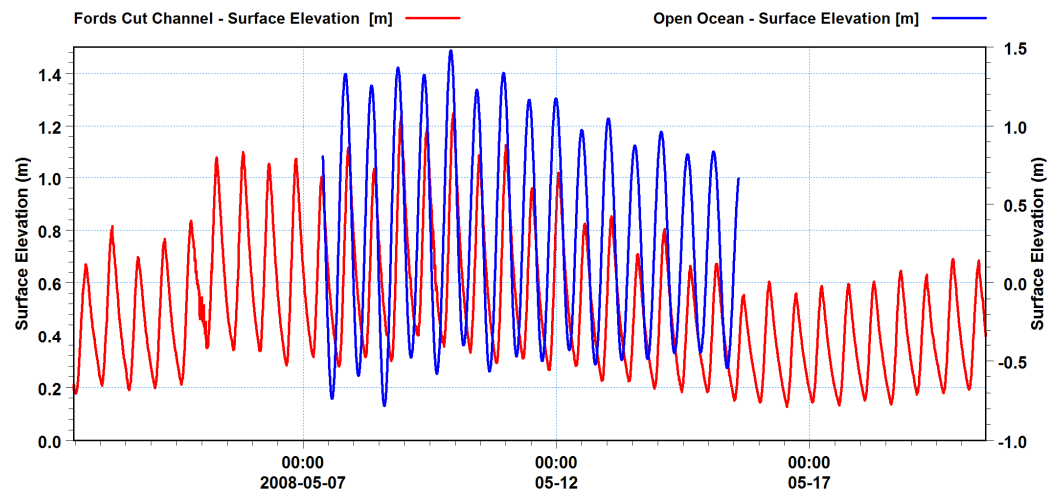


Figure 2-9 Surface elevations measurements from open ocean site and Fords Cut channel (Moturiki datum).

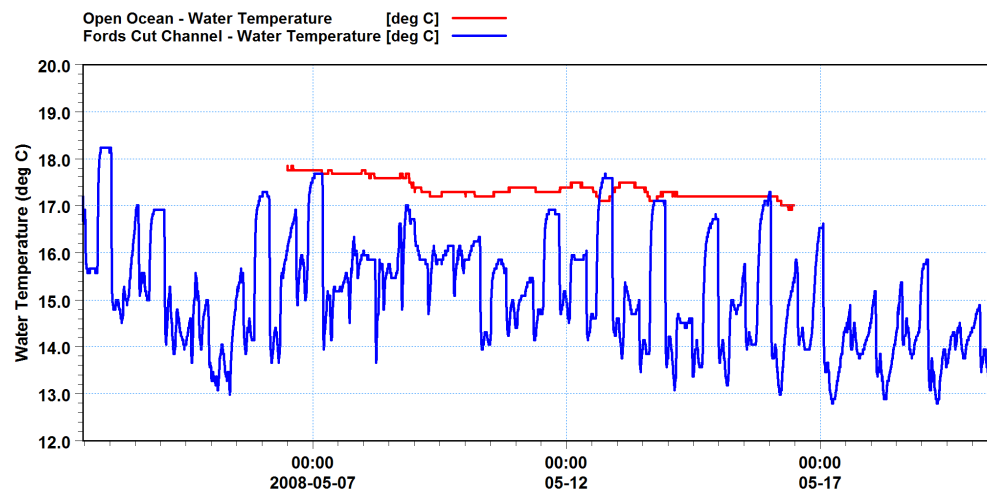


Figure 2-10 Water temperature measurements from open ocean site and Fords Cut channel.

Two triton instruments with pressure sensors were deployed within the estuary at the entrance (NZTM 1903668, 5815763, -0.51m Moturiki datum) and mid estuary (NZTM 1902299, 5814984, -0.67m Moturiki datum) for the period, 25th April 2008 to 8th May 2008, see Figure 2-11. The instruments measured current velocities, as shown in Figure 2-12, and also water temperature, presented in Figure 2-13.

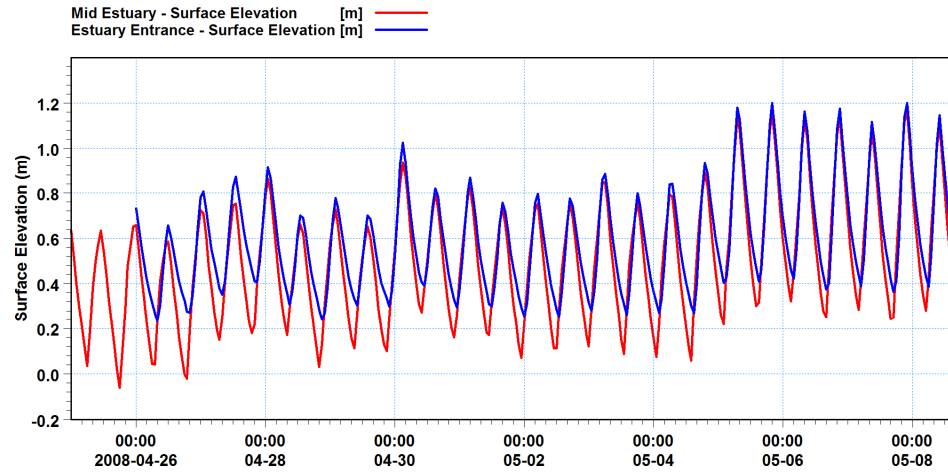


Figure 2-11 Surface elevations for mid estuary and estuary entrance (Moturiki datum).

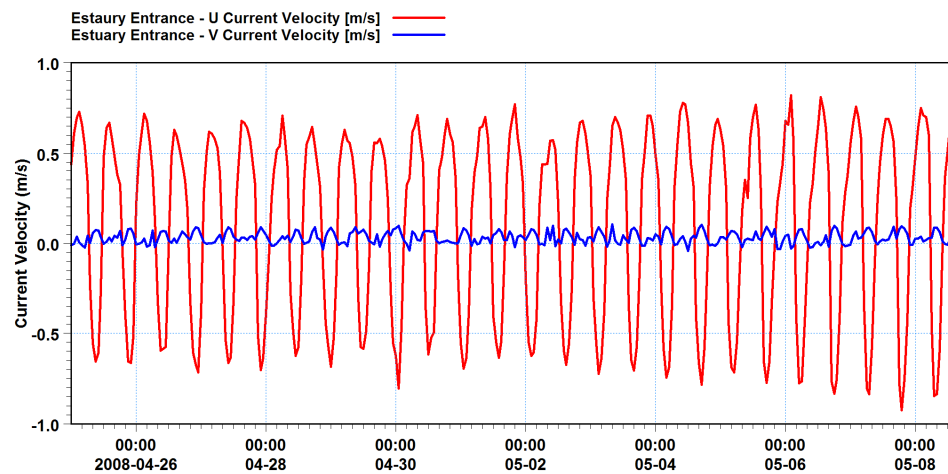
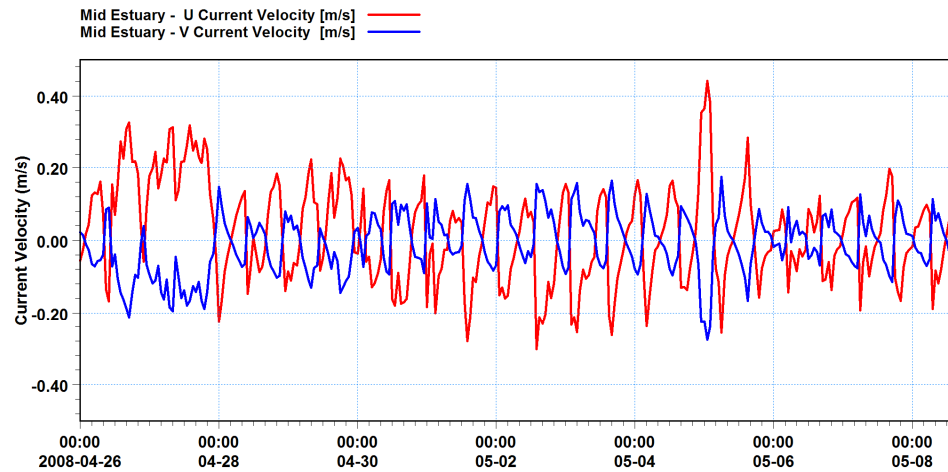


Figure 2-12 Current velocities for mid estuary (top) and estuary entrance (bottom).

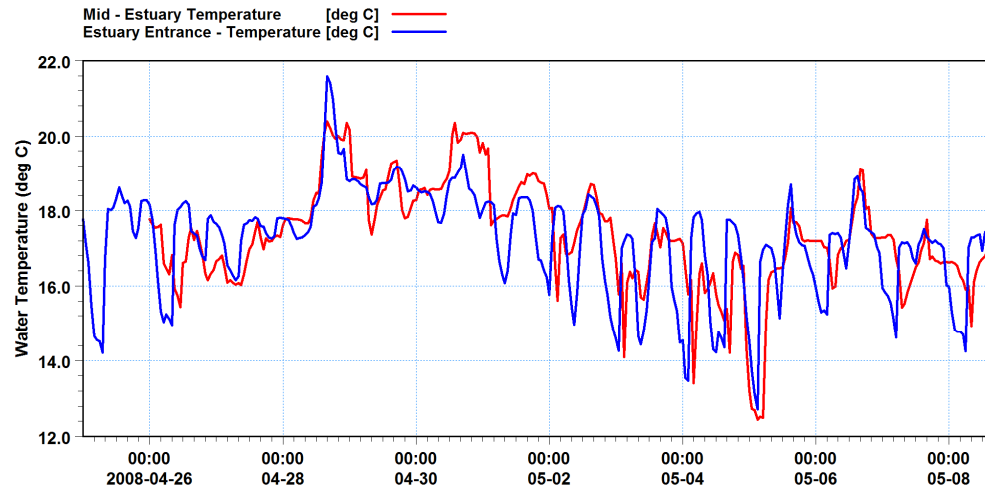


Figure 2-13 Water temperature measurements from within estuary.

Water levels from the Moturiki Island tide gauge (NZTM 1881791, 5830304) were provided by NIWA for the period 22nd April 2008 to 10th June 2008. This data is presented in Figure 2-14. The gauge is located on the open coast and any local variations in MSL that occur for the western Bay Of Plenty are well represented.

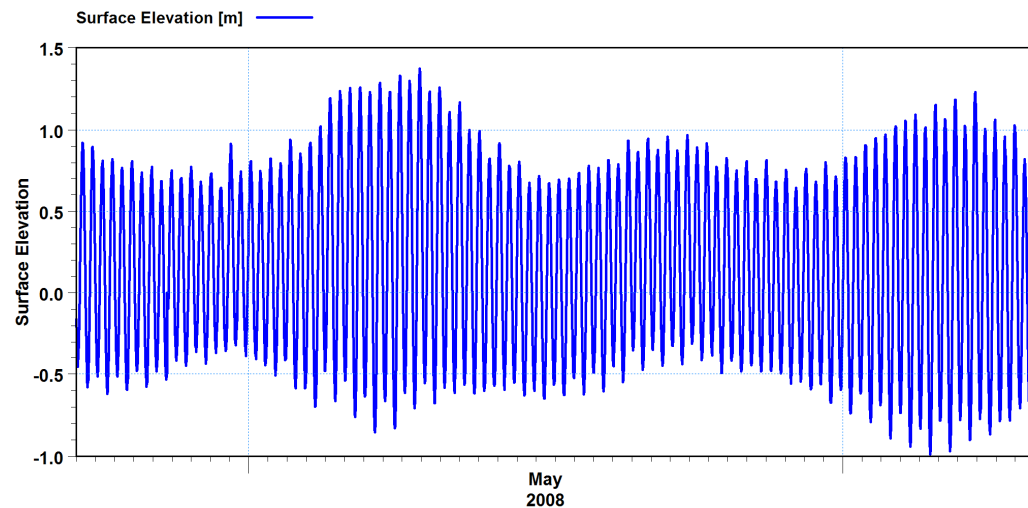


Figure 2-14 Surface elevation from Moturiki Island tide gauge (Moturiki datum).

2.5.3 Salinity Measurements

Salinity profiles were taken at six locations within the Kaituna River in the proximity of Fords Cut, and for seventeen locations within the Maketu Estuary as shown in Figure 2-15. The profiles were measured using a CTD on two days, 30th April 2008 and 29th May 2008. Within the Kaituna River the profiles were collected from Site 1 to Site 6 successively. This was repeated every half hour. Profiles were only measured once within Maketu Estuary at high tide when navigation over the intertidal areas was possible.



Figure 2-15 Salinity profile locations

2.5.4 Fords Cut Culvert Flow Measurements

On two occasions the flow through the Fords Cut culverts connecting the Kaituna River with the Maketu Estuary was measured by EBoP. The flow measurements were taken on the 12th December 2007 over a complete tidal cycle (see Appendix A) and 30th April 2008 over a partial tidal cycle. The measurements are presented in Figure 2-16.

The gates of the Fords Cut culverts are designed to stop flow back into the river from the estuary; however it was observed that a significant amount of water could flow from the estuary to the river as indicated by the negative flow in the December 2007 measurements. It was calculated that at low tide an estimated 9,000 m³ of water flowed back into the Kaituna River from Fords Cut on 12th December 2007. For the December 2007 measurements an estimated 150,000 m³ of water flowed through the culverts into the estuary. The tidal range during the measurement period was approximately 1.52m, close to a mean tide. Flow in the Kaituna River was close approximately 30 m³/s. Previous studies have suggested that the mean discharge rate is approximately 100,000 m³ per tidal cycle (Domijan, 2000). The flow measurements from April 2008 were taken during a flood event on the Kaituna River with flow varying between approximately 80 - 100 m³/s during the duration of the flow measurement.

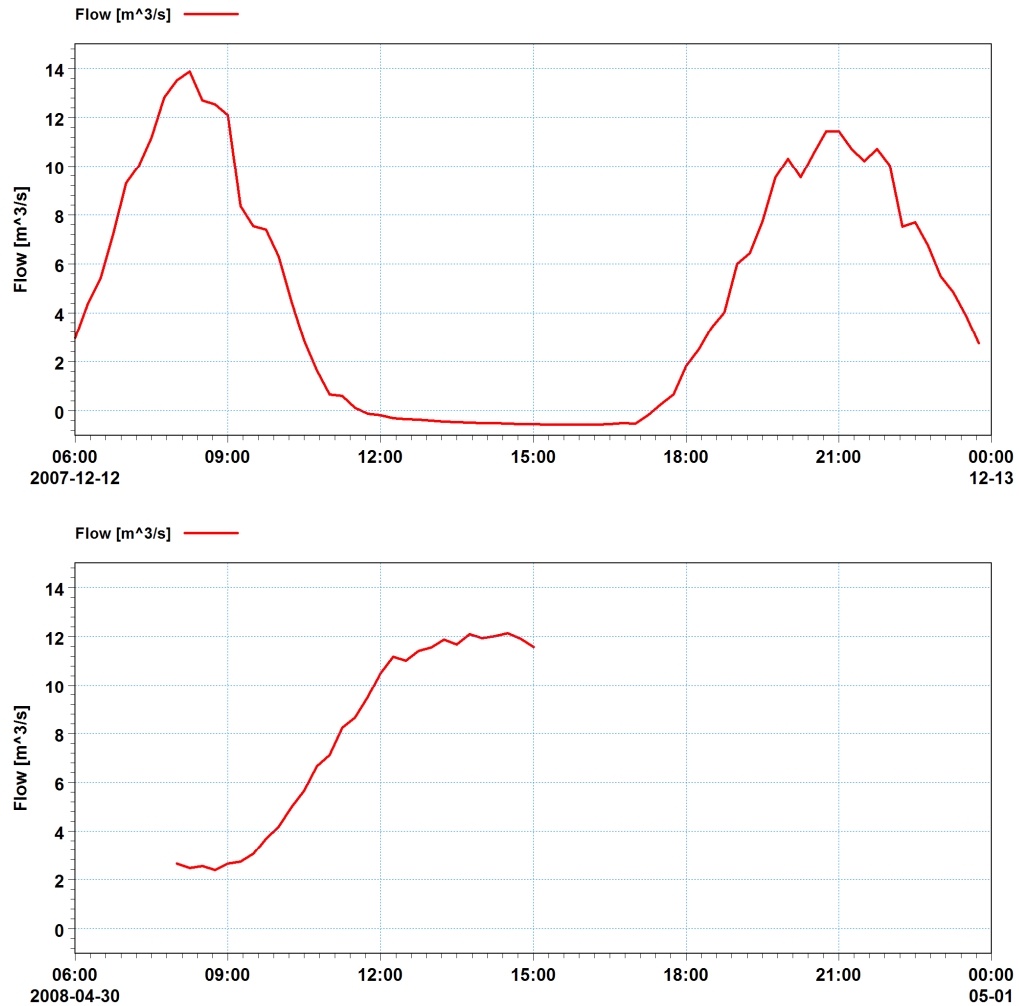


Figure 2-16 Flow through Fords Cut culverts 12th December 2007 (top) and 30th April 2008 (bottom).

A timeline that outlines the collection periods for metocean, river and meteorological data is presented in Figure 2-17.

2.6 MIKE11 Model

A 1D MIKE 11 model of the lower Kaituna River and floodplain was provided by EBoP. This model was built by Phil Wallace to assess the effects on flood and drainage levels from a number of options for re-diverting more Kaituna River flow through the Maketu Estuary (Wallace, 2007). The model extended from upstream of the Te Matai gauge down to estuary and river mouths. The model was used to calculate the resulting flow using Te Matai stage data as a boundary condition.

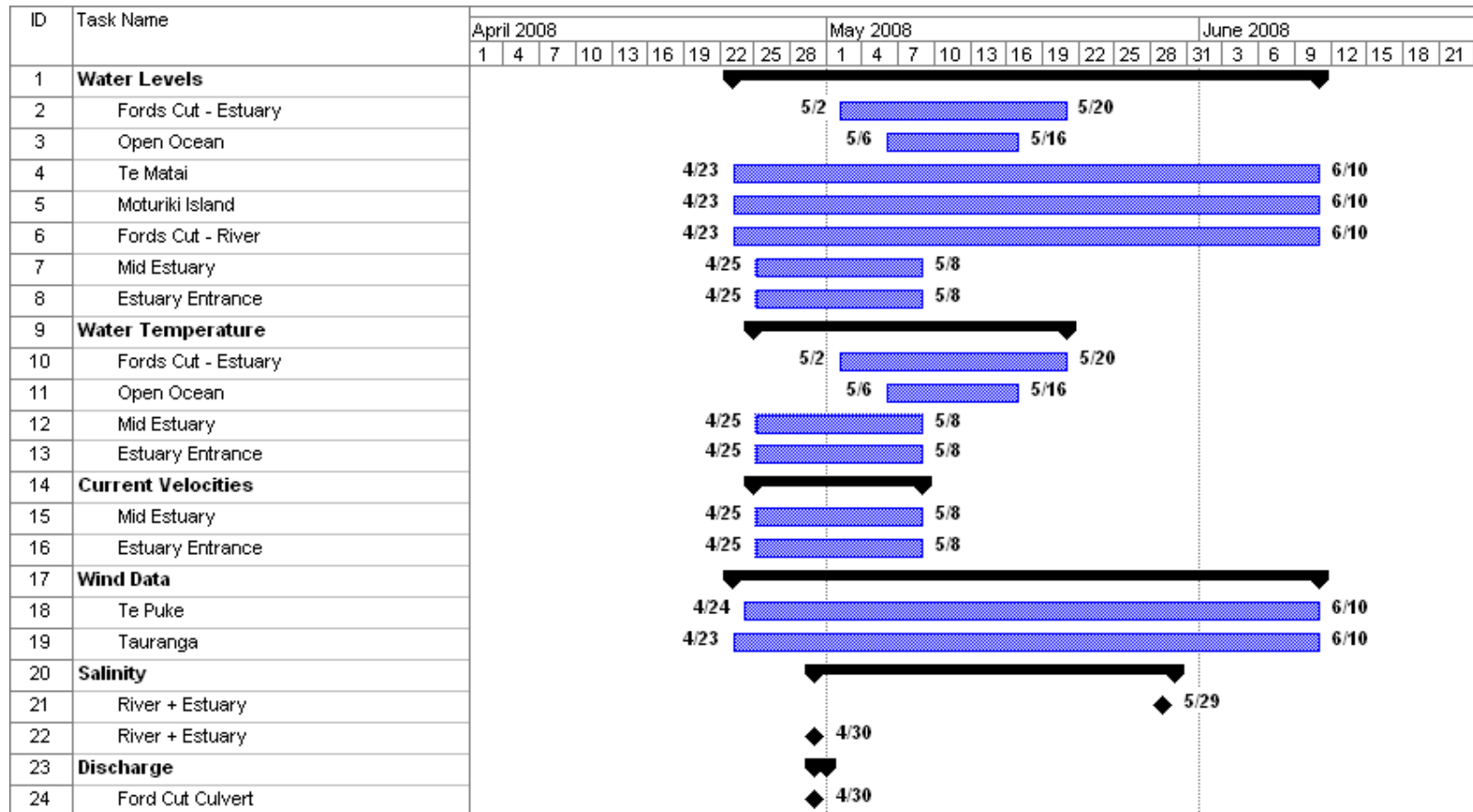


Figure 2-17 Data collection timeline



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 discretized 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.

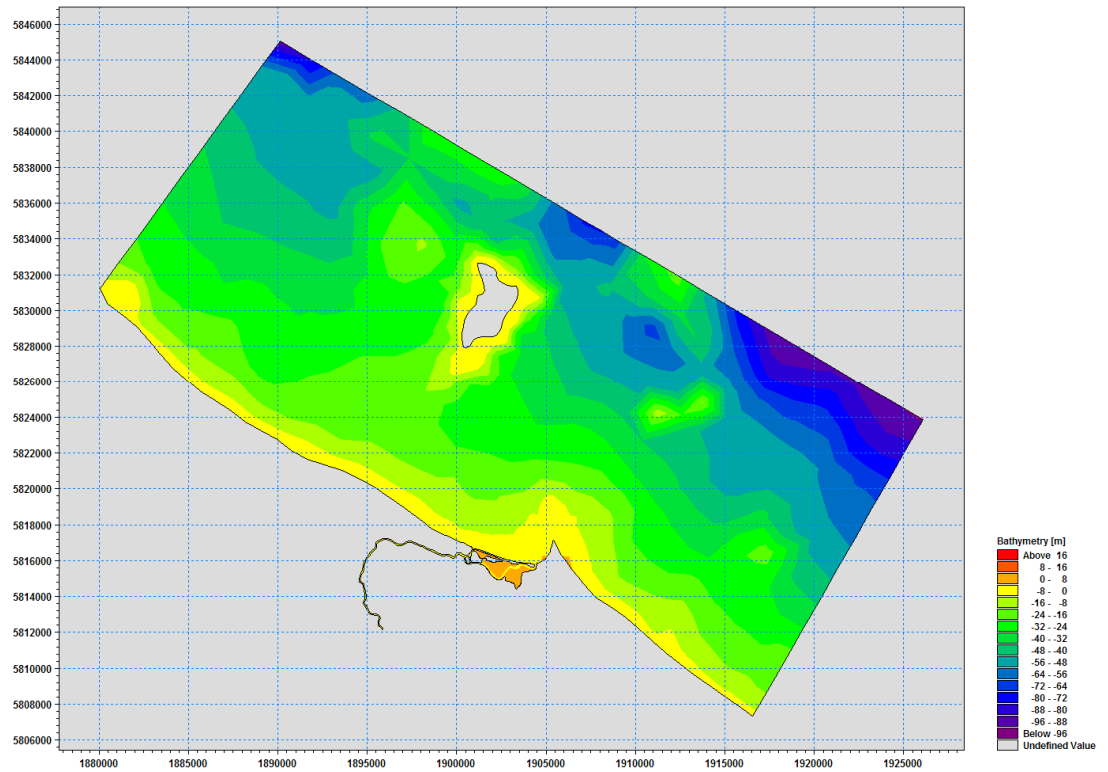


Figure 3-1 Model extent and bathymetry (Moturiki datum).

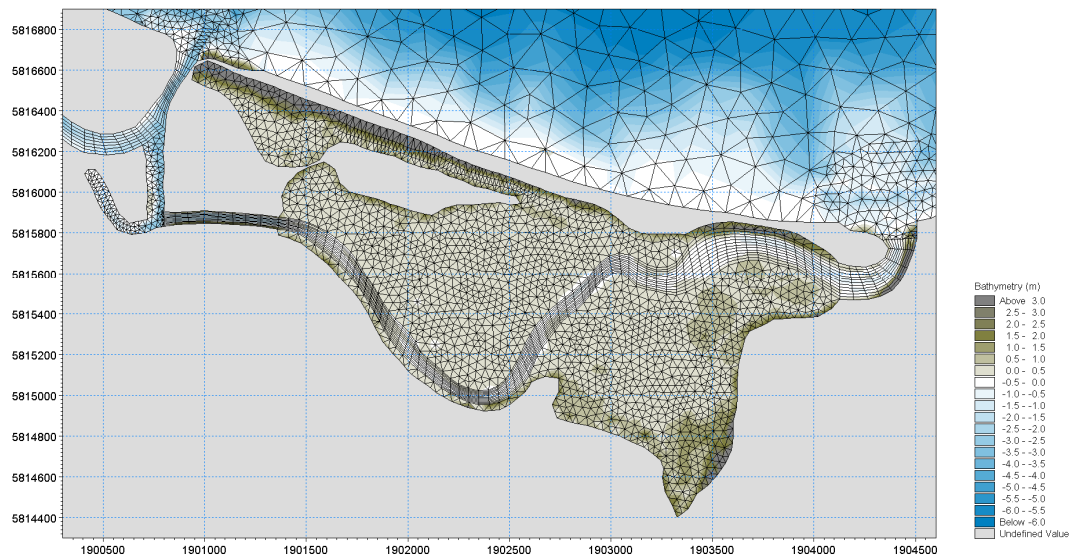


Figure 3-2 Estuary and Fords loop bathymetry and model element mesh (Moturiki datum).



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 meteocean 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.

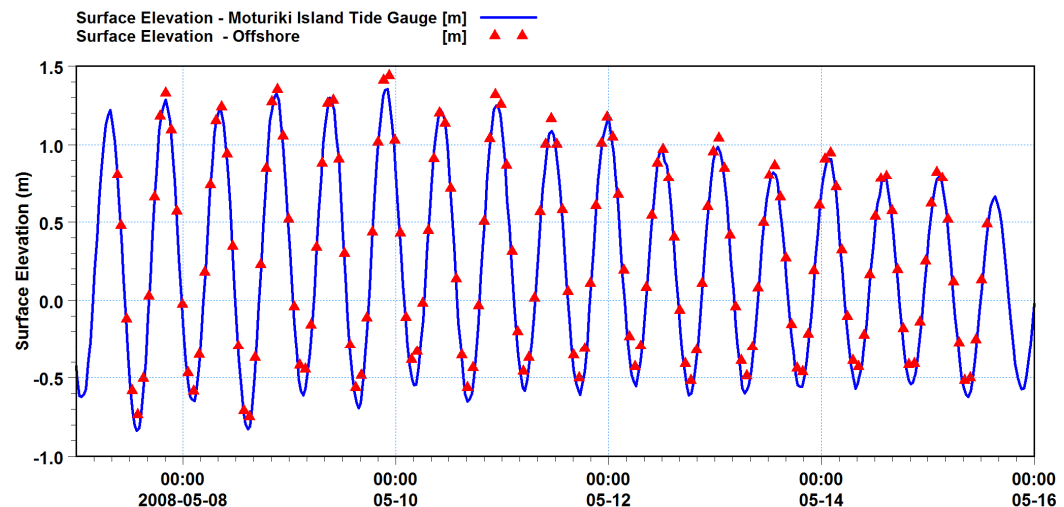


Figure 3-3 Comparison of observed and predicted surface elevations at open ocean location (Moturiki datum).

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.

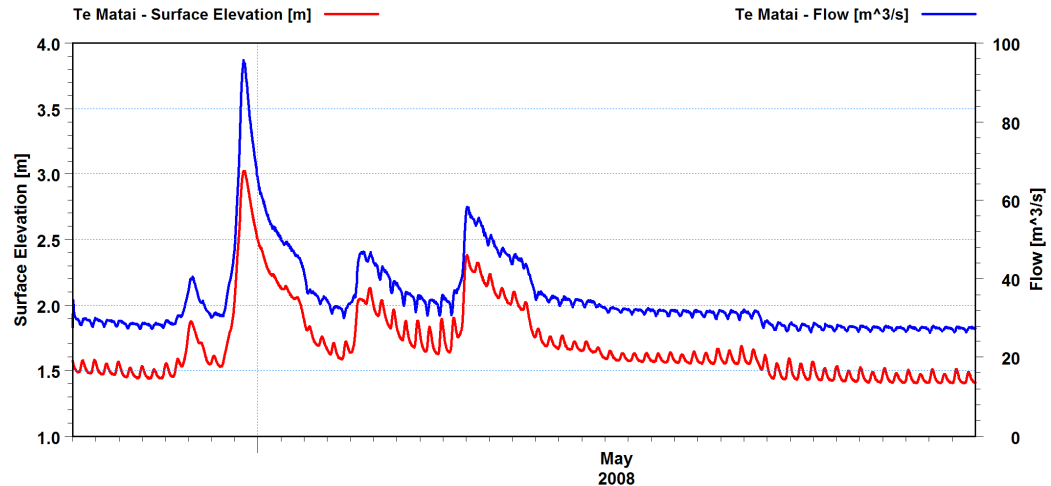


Figure 3-4 Observed surface elevation at Te Matai (Moturiki datum) and corresponding predicted flow from MIKE11.

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 five 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 4°C 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: Smagorinsky 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.

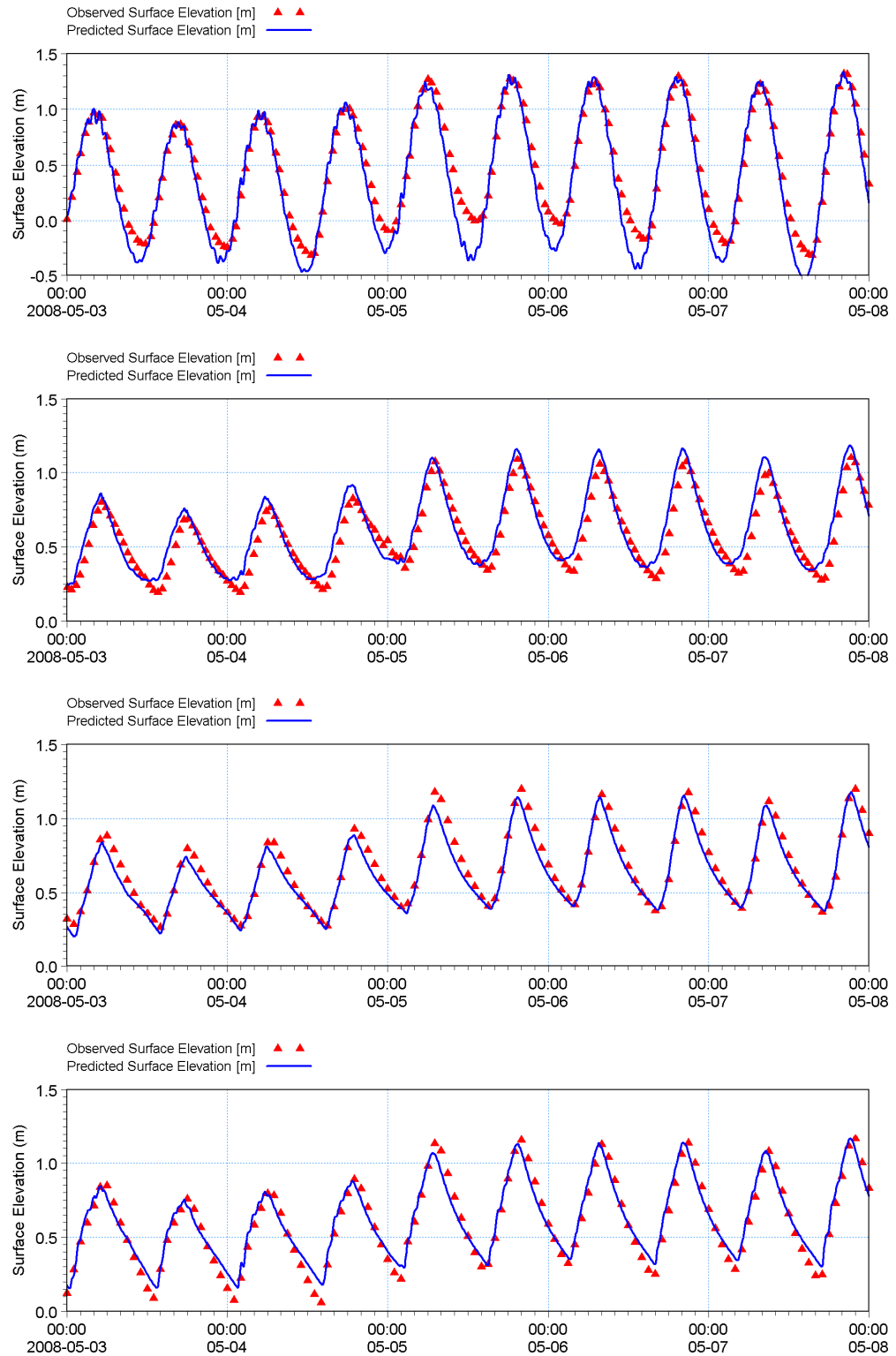


Figure 3-5 Comparison between observed and predicted surface elevations (Moturiki datum) at Kaituna River level gauge (top), Fords Cut channel (middle-top), mid estuary (middle-bottom) and estuary entrance (bottom).



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.

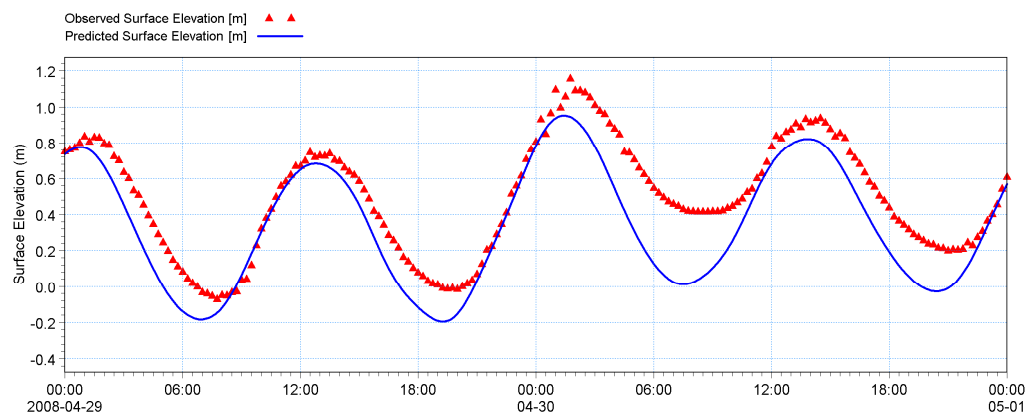


Figure 3-6 Comparison between observed and predicted surface elevations (Moturiki datum) at Kaituna River level gauge during 30th April 2008 flood event.

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 through 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 10th May 1996, the flood prism was measured as 449,000m³, 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 364,000m³. The difference in the flood prism is 85,000m³, 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 7,000m³/y. This is almost half of the estimate made by Domijan of 13,640m³/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.

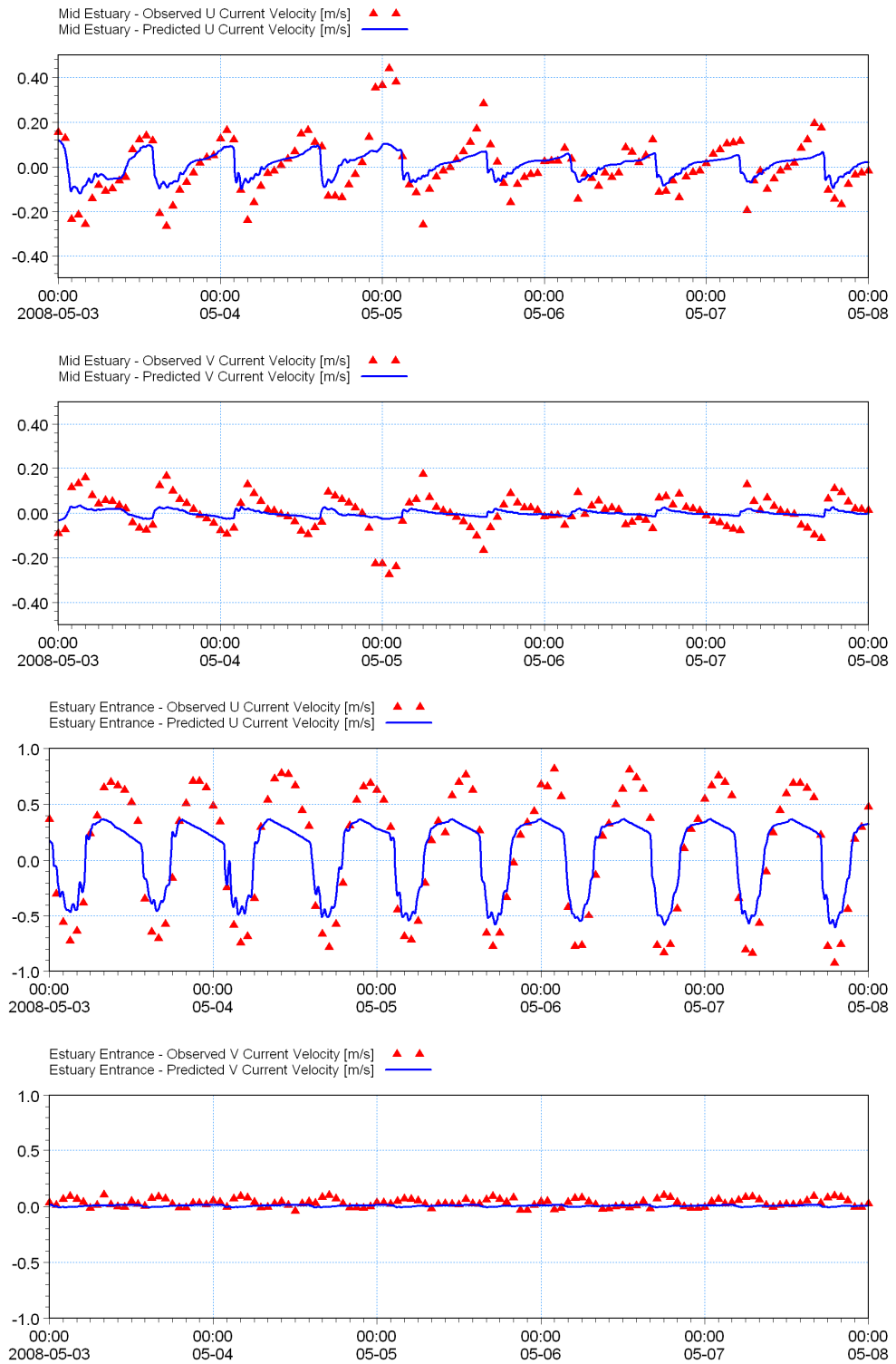


Figure 3-7 Comparison between observed and predicted current velocities at mid estuary (top) and estuary entrance (bottom).



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.

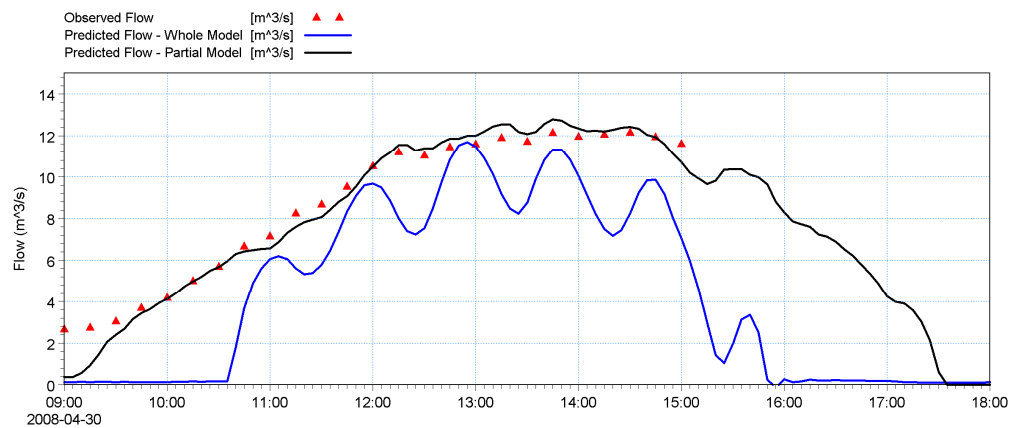


Figure 3-8 Comparison between observed and predicted flow through Fords Cut culverts.

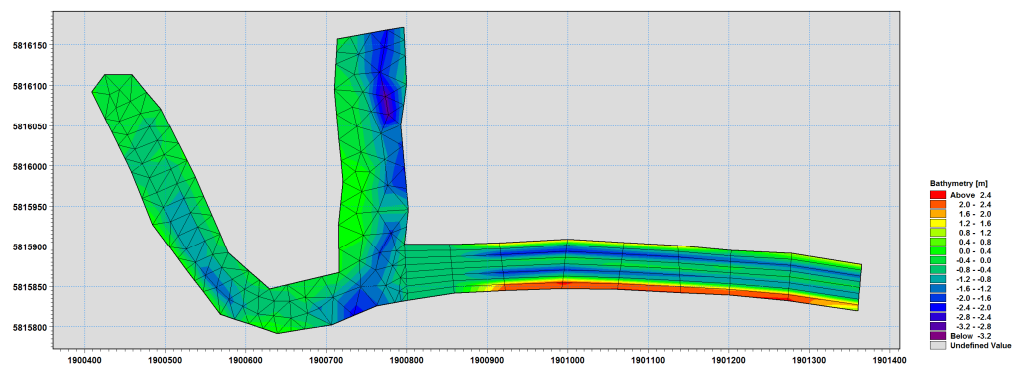


Figure 3-9 Partial model domain of Fords Cut (Moturiki datum).



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.

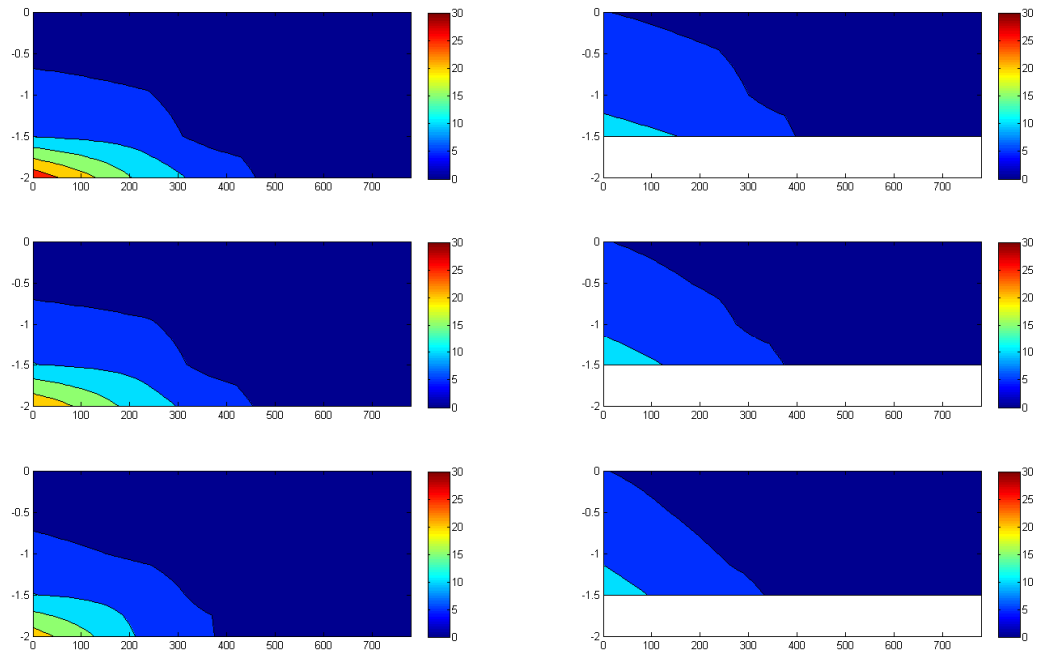


Figure 3-11 Observed (left) and predicted (right) vertical salinity profile at 7:45 am (top), 8:15am (middle) and 8:45 am (bottom), 29th May 2008.

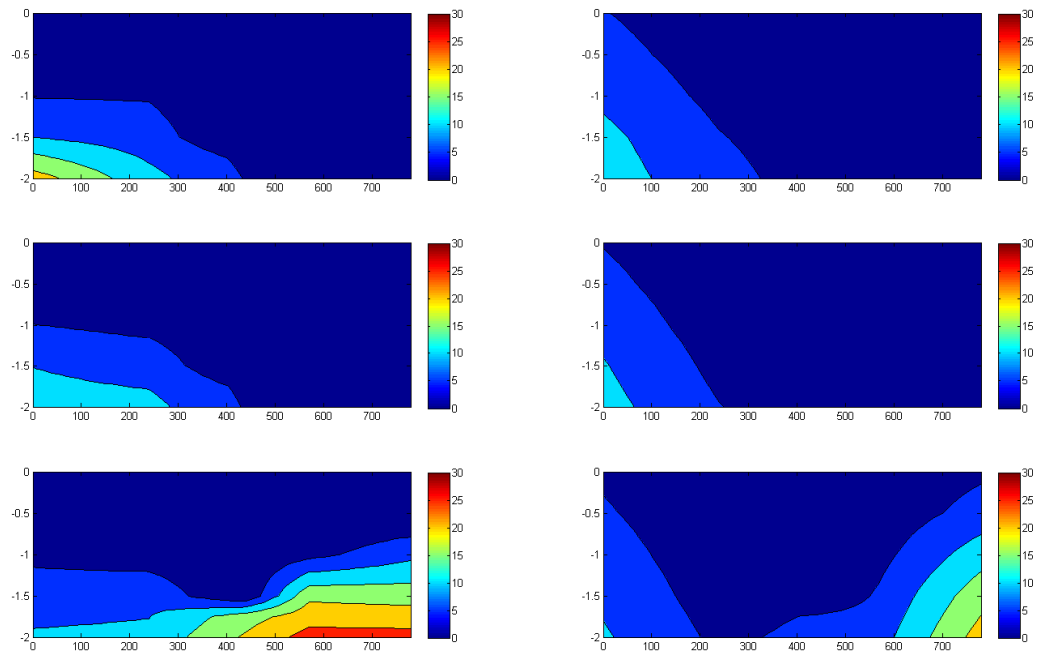


Figure 3-12 Observed (left) and predicted (right) vertical salinity profile at 9:15 am (top) 9:45am (middle) and 10:15 am (bottom), 29th May 2008

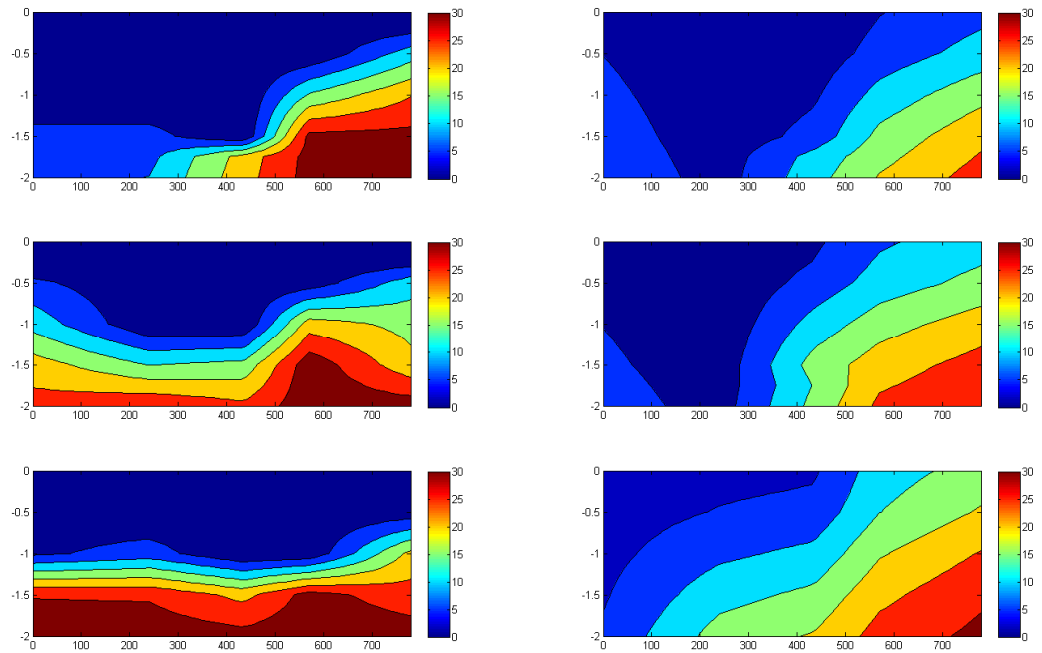


Figure 3-13 Observed (left) and predicted (right) vertical salinity profile at 11:15 am (top) 11:15am (middle) and 12:15 am (bottom), 29th May 2008.

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.

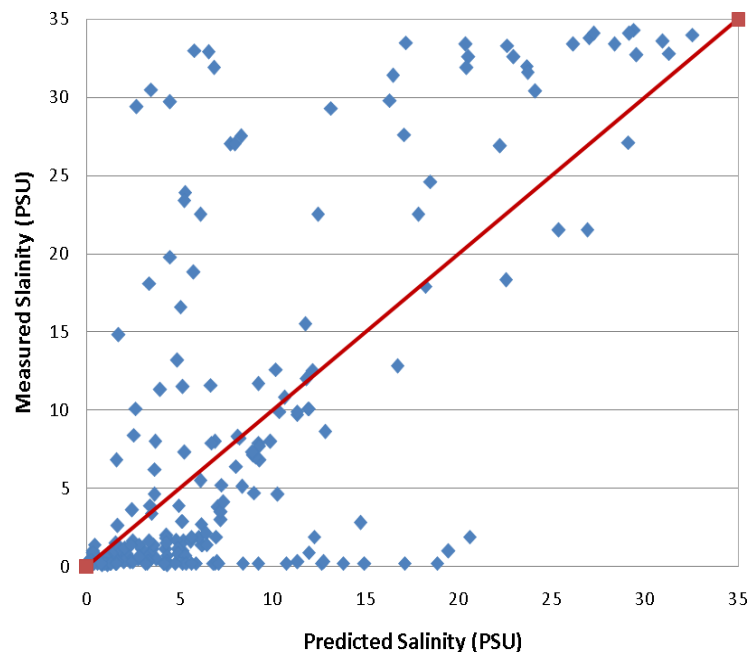


Figure 3-14 Comparison of observed and predicted salinities for Site1 to Site6, 29th May 2008.



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 long-shore 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.

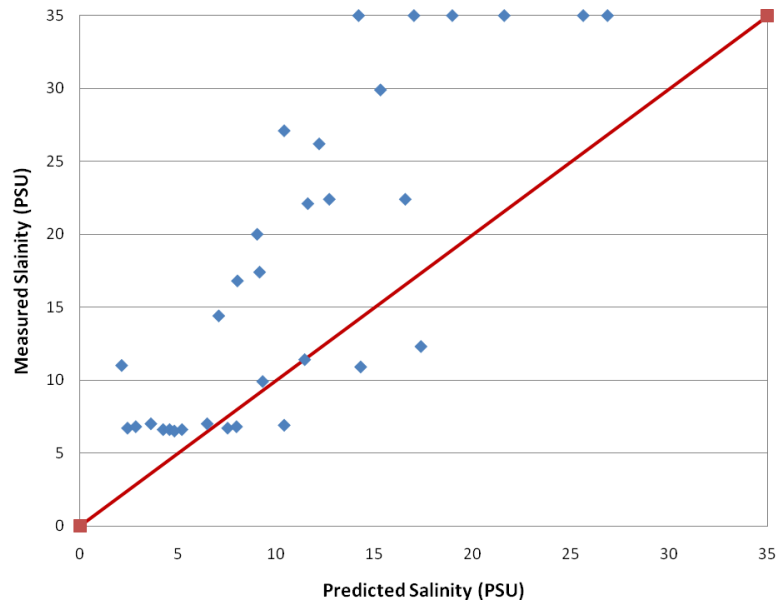


Figure 3-15 Comparison between observed and predicted salinities within the estuary, 29th May 2008, with constant vertical eddy viscosity formulation.

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.

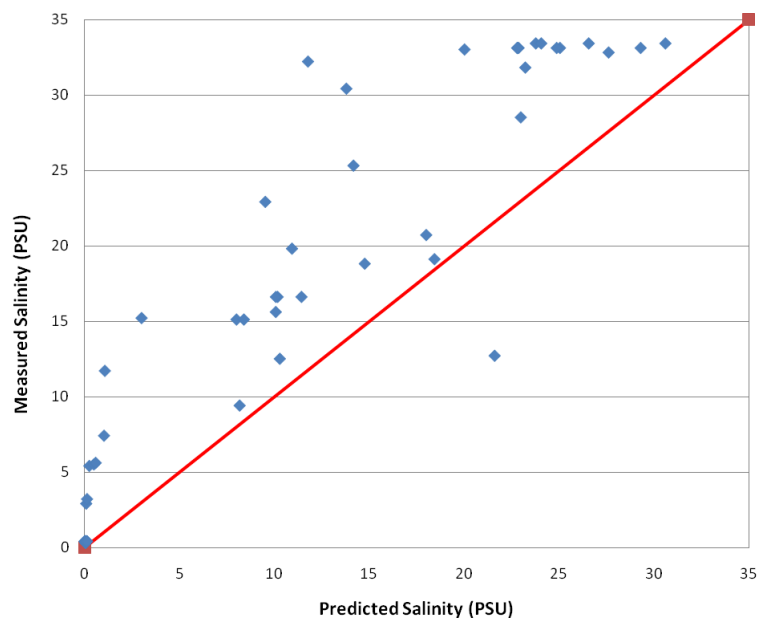


Figure 3-16 Comparison of observed and predicted salinities within estuary, 30th April 2008, with constant vertical eddy viscosity formulation.



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.



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.

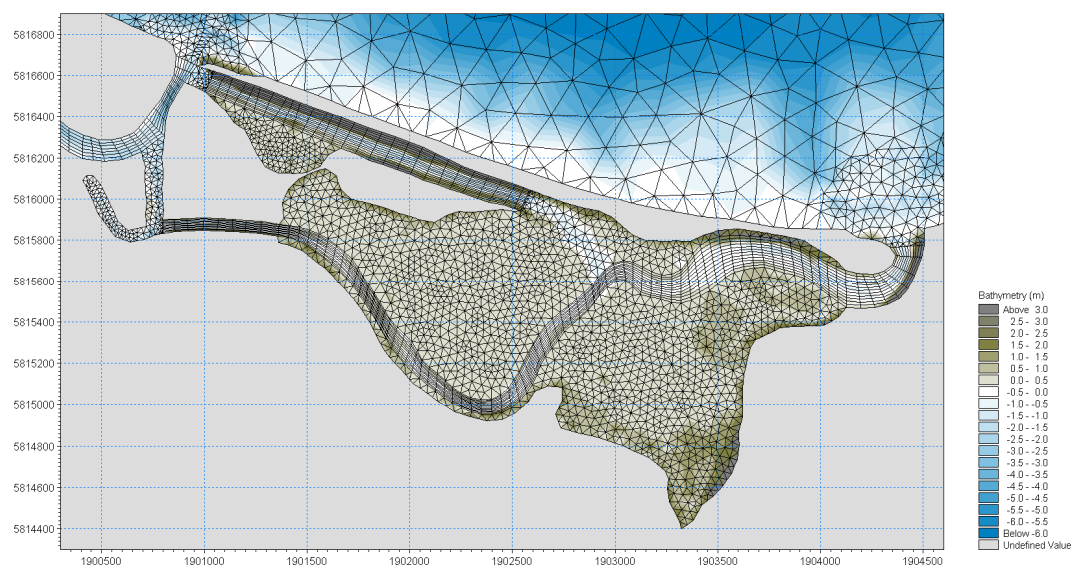


Figure 4-1 Bathymetry and model element mesh for Option A.



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.

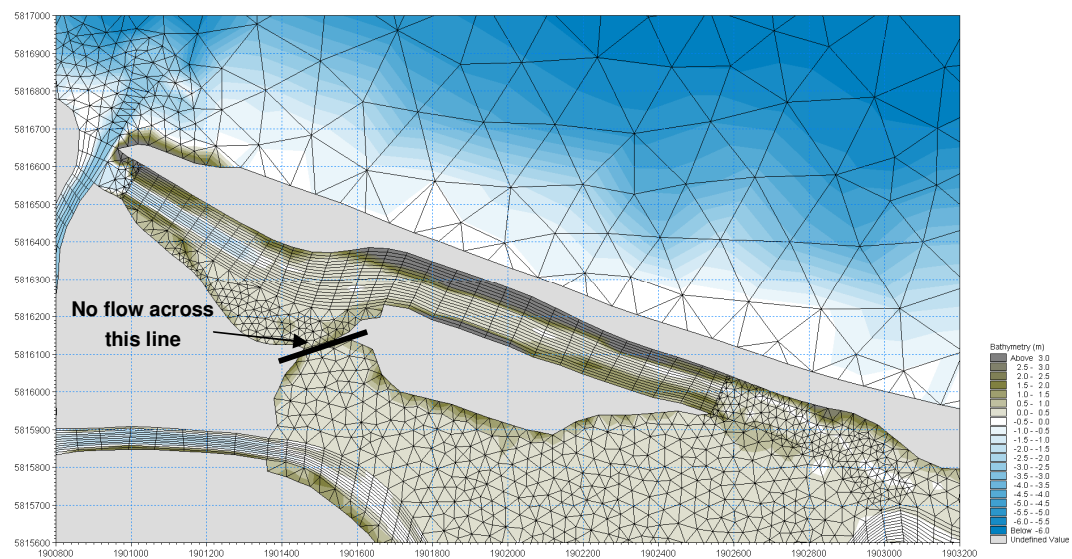


Figure 4-2 Papahikahawai Channel bathymetry and model element mesh for Option B.

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 $0.25^\circ \times 0.25^\circ$ 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.

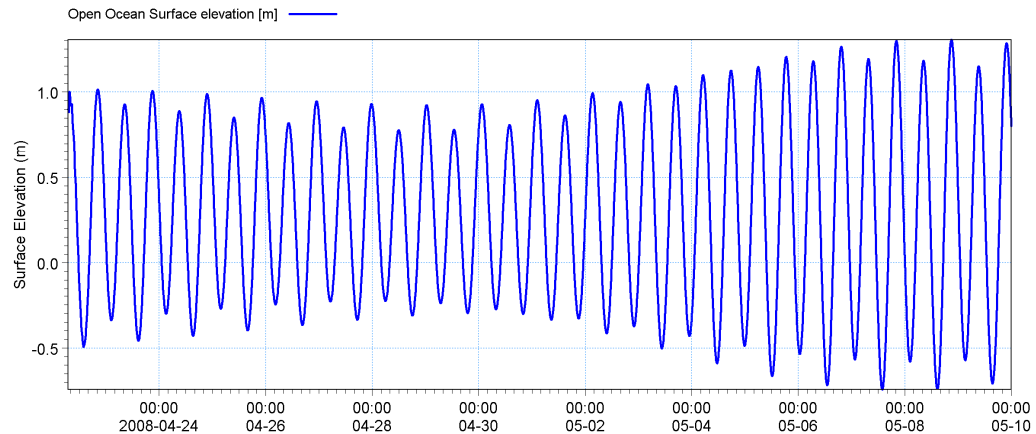


Figure 4-3 Open ocean surface elevations for 15 day neap-spring tide cycle (Moturiki datum).

EBoP have specified a freshwater inflow for the simulated period corresponding to mean river flow of the Kaituna River at Te Matai, $40 \text{ m}^3/\text{s}$. 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 $449,000\text{m}^3$ per tidal cycle, with $105,000\text{m}^3$ passing through Fords Cut and $344,000\text{m}^3$ through the proposed culverts. The DHI MIKE 3 model predicts that the mean inflow per tidal cycle through Fords Cut culverts is approximately $133,500\text{m}^3$ and the predicted mean inflow per tidal cycle through Papahikahawai Channel culverts is $302,000\text{m}^3$. 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 in-



flow 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 m³ (67%) in a spring and 48,000 m³ (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 48,000m³ to 71,000 m³. 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 483,000m³ enters the estuary, of which approximately 309,000m³ is saltwater and 176,000m³ 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 $40\text{m}^3/\text{s}$.
- 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 predict 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 $170\text{m}^3/\text{s}$ 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.

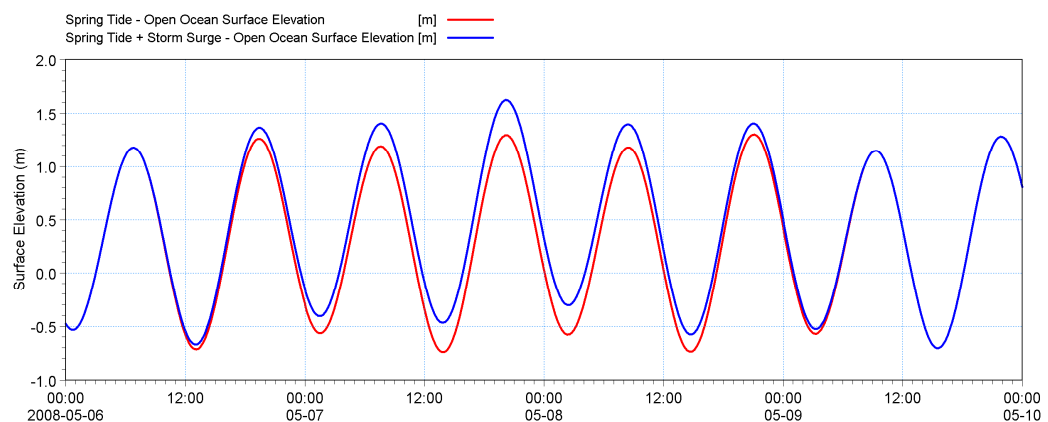


Figure 4-4 Open ocean surface elevations for a spring tide, and a spring tide with storm surge.

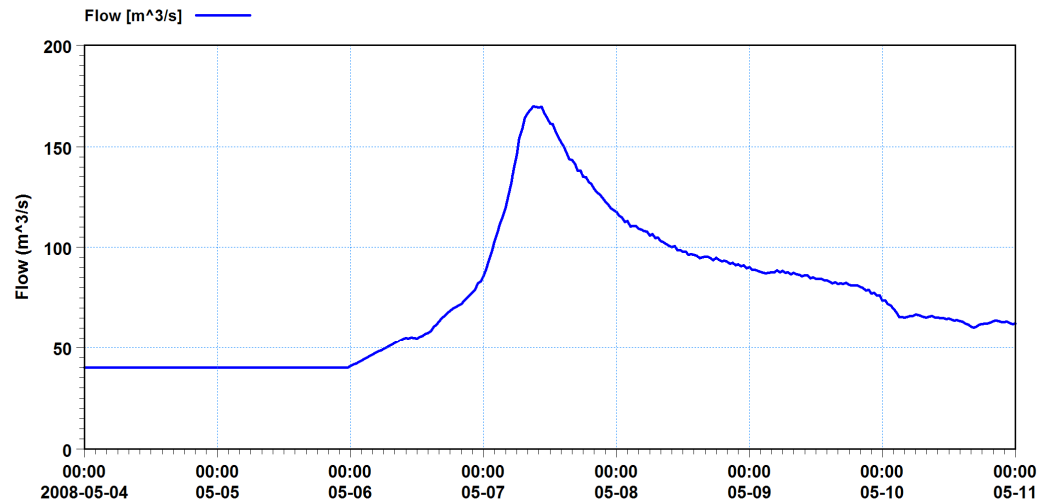


Figure 4-5 20% AEP flood hydrograph.

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.

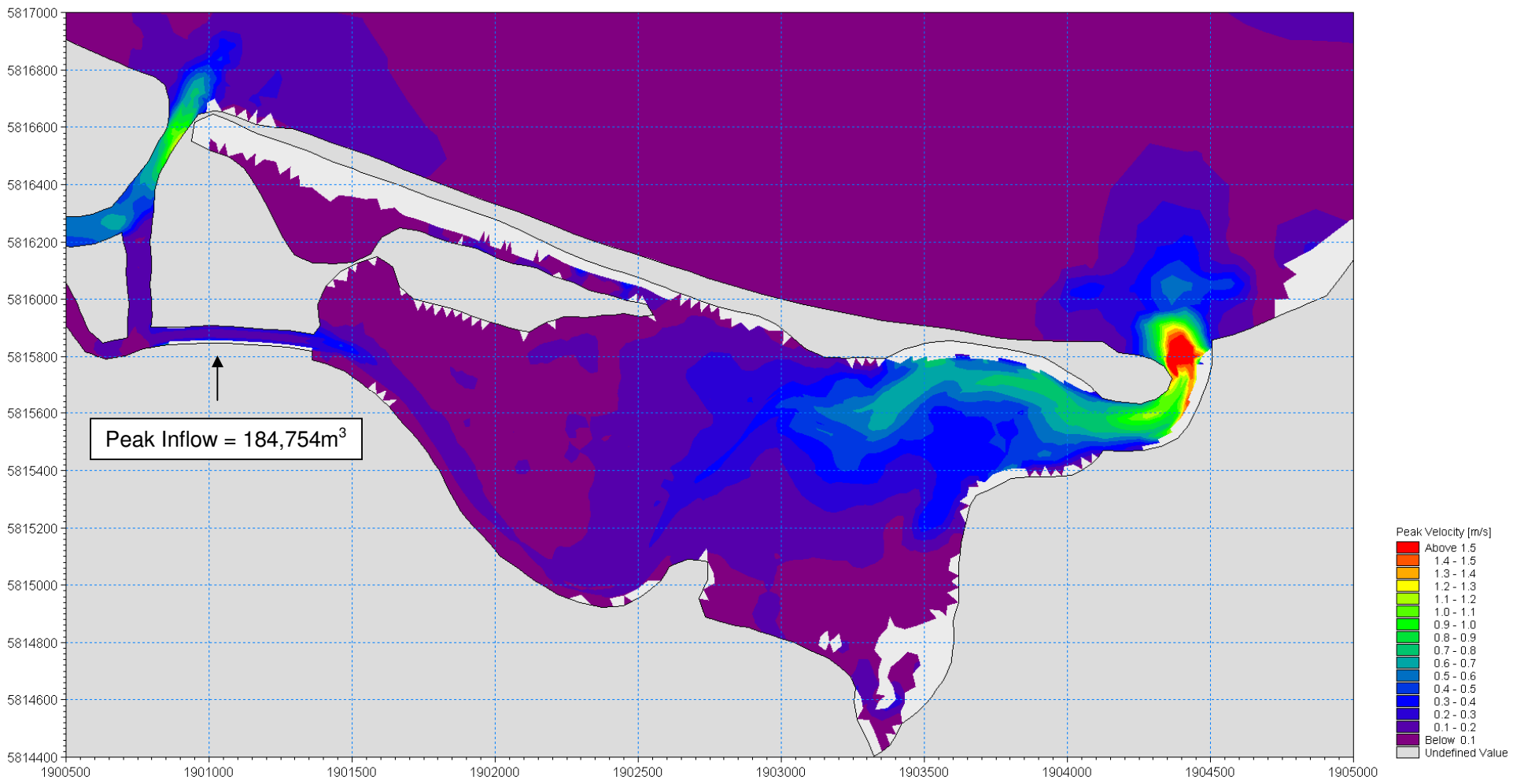


Figure 4-8 Scenario 1 - Peak velocities for existing situation.

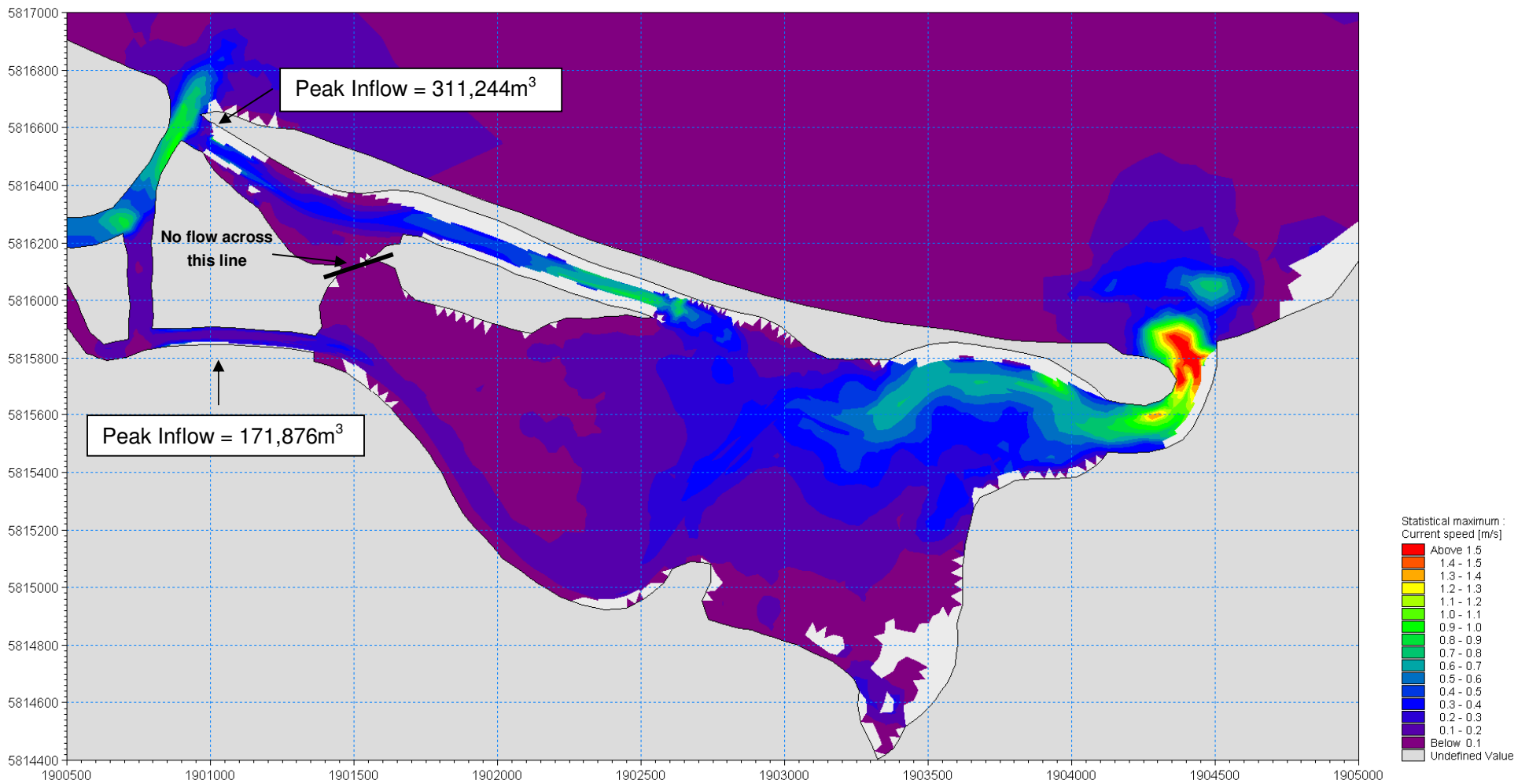


Figure 4-9 Scenario 1 - Peak velocities for proposed layout Option B.

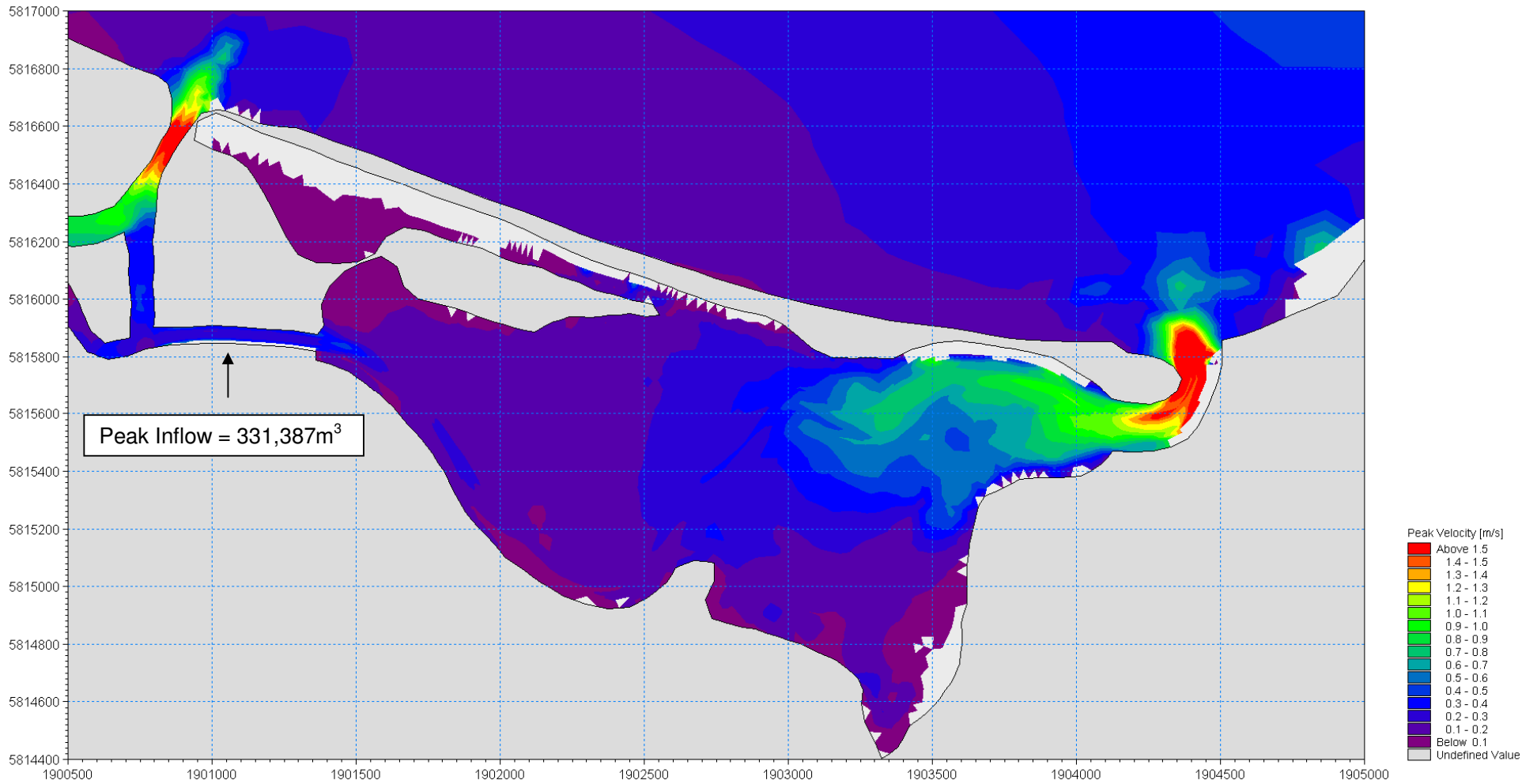


Figure 4-10 Scenario 2 - Peak velocities for existing situation.

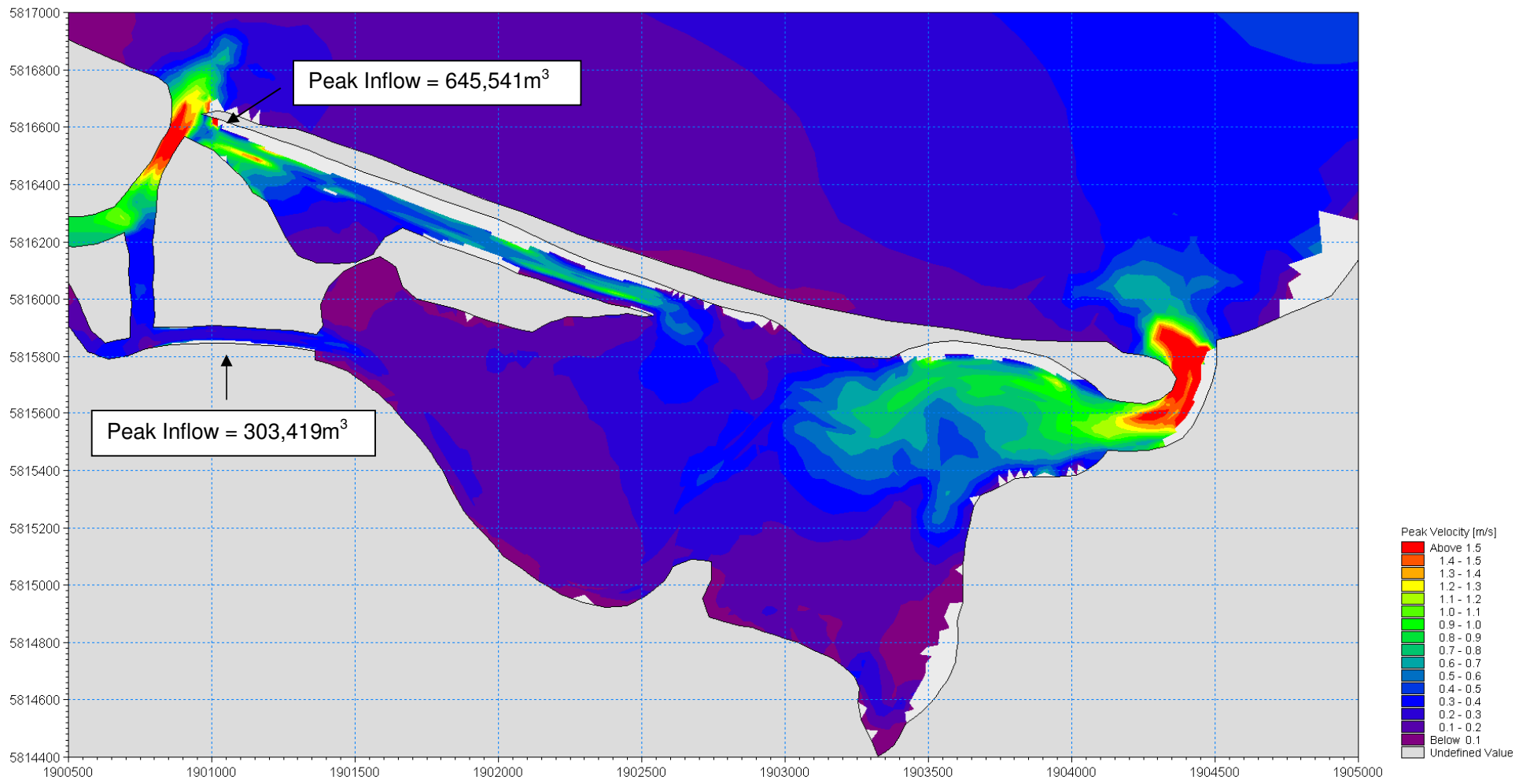


Figure 4-11 Scenario 2 - Peak velocities for proposed layout Option A.



5 **FUTURE MODEL APPLICATIONS**

A possible further phase to this study is to develop a water quality model for the Kaituna River and Maketu Estuary system. EBoP have highlighted the following water quality parameters as of importance for the river and estuary:

- Bathing suitability;
- Bacteria;
- Metals;
- Nutrients;
- Algal growth – both blue and green blooms;
- Sediment load;
- Water temperature;
- Clarity; and
- Pesticide / herbicide residues.

Now that a calibrated model of the Kaituna River and Maketu Estuary has been set up, the model can be extended with water quality functionality using ECOLAB. The water quality model, ECOLAB, is an established add-on module to MIKE 3 FM and links dynamically to the core hydrodynamic model. ECOLAB can be developed to model the water quality processes you require using standard templates as a basis. These templates can be modified meaning no ecological problem is too small or too complicated to accurately predict its behaviour. Essentially, any advection/dispersal, growth/decay process can be simulated, but typical process groups are:

- Water Quality (BOD-DO relationship, nutrient transport and bacterial fate);
- Eutrophication (nutrient cycling and relationship with primary production); and
- Heavy Metals (fate of dissolved and suspended metal in water and sediment).

The key to developing a robust water quality model will be a comprehensive data set. EBoP currently have a monitoring programme and collect measurements at several locations within the river and estuary. This may need to be complimented with further data collection. The type of shellfish and their extent within the estuary will need to be quantified as the filtration process of the shellfish will have a large impact on the concentrations of water quality parameters. DHI also suggest undertaking a literature review to identify any other possible studies or data collection that has occurred for the area.

If EBoP decide to proceed with this phase, additional work will be required to resolve that with the current model the freshwater plume from the river and estuary does not



disperse adequately and is drawn back into the estuary on the flood tide. Consequently water quality parameters will build up in the estuary, instead of dispersing out into the Bay of Plenty. It is possible to artificially induce a longshore current into the model to achieve the required behaviour. Such a current is likely to exist but is not currently represented in the model boundary definition.

Other issues that may require investigation include morphological changes to channels and likely erosion risks, i.e. to understand the required flows to maintain estuary depths or produce net sedimentation out of the estuary. The existing MIKE3 model could be used for these investigations or DHI could develop a fully morphological model which can dynamically update the bed bathymetry in response to local currents. A restriction in using this model is that can be computationally expensive.



6 CONCLUSIONS AND RECOMMENDATIONS

EBoP commissioned DHI to develop a three dimensional model of the lower Kaituna River and Maketu Estuary to investigate the effects of re-opening Papahikahawai Channel. A model was developed using MIKE3 FM, consisting of both hydrodynamic and advection/dispersion components.

The hydrodynamic model was calibrated for a six day period, with a good agreement achieved between observed and predicted levels within the river and estuary, achieved. The model appears to under predict current velocities in the estuary when compared with the data; however the model seems to sufficiently simulate the tidal exchange between the estuary and open ocean. It was also shown that during normal flow conditions the model will accurately predict the inflow through the Fords Cut culverts.

The advection/dispersion model was calibrated for two separate days when salinity measurements were taken within both the river and estuary. One of the periods was during a significant flood event in the Kaituna River. A good agreement was found between the observed and predicted salinities within the river when using a constant vertical eddy viscosity formulation. It was concluded that for this study the model was sufficiently calibrated to predict freshwater / saltwater inflows through Fords Cut and the re-opened Papahikahawai Channel.

The model was modified to include re-opening of the Papahikahawai Channel. The model was validated with a previous modelling study, with a good agreement found between the predicted inflows through the proposed culverts. Impacts for the proposed re-opening of the Papahikahawai Channel were investigated by assessing the ratio of freshwater inflows to the estuary with the existing layout and with the channel re-opened. The model indicates that the volume and freshwater/saltwater composition of water that is introduced into the estuary by the opening is strongly affected by the tidal conditions. Higher total volumes are introduced through the Papahikahawai Channel during spring tides (an additional 311,000 m³) which are also more saline (75%) compared to neap tide conditions (93,000 m³ additional inflow, 48% saline). Volumes and compositions of flows through Ford's Cut are largely unchanged compared to existing conditions.

A flood impact assessment was carried out for two different Papahikahawai Channel geometries. Based on a channel geometry including minimal enlargement of the existing cross section, the peak levels within the river and estuary were found to increase by a small amount. The maximum water levels during a spring tide with a normal river flow are predicted to increase by up to 15 cm within the main estuary. The simulations suggest that peak levels will increase more in the eastern part of Papahikahawai Channel. During a spring tide with a storm surge (peak tidal level of 1.62 m, Moturiki datum) and a 20% AEP river flow, the maximum water levels are predicted to increase by 10 cm.

With the Papahikahawai Channel re-opened new areas of land will be exposed to elevated flood levels. Peak velocities in the channel during the a 20% flood event reach a maximum of 1.5 m/s locally near the Kaituna river end of Papahikahawai Channel and 0.2 to 1.8 m/s elsewhere in the channel. Higher velocities will assist to scour and main-



tain a larger channel cross section. Additional investigations are required to refine the final channel design and assess the flood impacts.

The developed model can be expanded in future with water quality functionality using ECOLAB, which is an add-on module that links dynamically to the hydrodynamic model. For this phase, additional work will be required to determine how to adequately disperse the freshwater plume from the study area to ensure that there is not a build up of the water quality parameters within the estuary.



7 REFERENCES

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A P P E N D I C E S



A P P E N D I X A

Fords Cut Tidal Gauging



MEMORANDUM



To: Glenn Ellery
Manager Data Services

From: Mark Lumsden
Environmental Data Officer

Date: 9 January 2008

File Ref:

Subject: Fords Cut Tidal Gauging 12th December 2007

INTRODUCTION

Late 2007, Environmental Data Services (EDS) were asked to provide an accurate estimate of the flow over a rise/fall tidal cycle through a man made channel connecting the Kaituna River with the Maketu estuary. This channel is commonly known as Fords Cut but is sometimes referred to as Brains Cut or Brains Drain.

Several site inspections were carried out in the following months to ascertain the most practical, replicable and accurate method of completing the task. There is a series of 4 large culverts under the road with self closing tidal gates operating on the Maketu side of the culverts. These gates stop almost all of the reverse flow down the drain back into the Kaituna (Figure1).



Figure 0-1 Fords Cut Tidal Gates



On the river side, there is a short abutment coupled with a concrete platform, approximately 11 meters wide, over which the water flowed, before it entered the culverts (Figure 2). At high tide the water level was approximately 2 metres deep. A gauging slack line was installed on the abutment 2 metres up from the culverts to allow safe measurement of flows.



Figure 0-2 Fords Cut Culverts

It was decided to conduct the gauging in a continuous series of gaugings with as small a gap as possible between each, over a complete tidal cycle (approximately 13 hours). Two teams of two staff from EDS were used in two shifts to break the time spent gauging to a more manageable length to reduce error and fatigue. These teams were Mark Lumsden and Adam Vankempen, Craig Putt and Krystie Knowles.

The day chosen to complete the gauging was the 12th of December, due to the tide compatibility as well as getting the task completed before summer break.

METHODOLOGY

On the morning of the 12th of December at approx. 0545 (ST) the gauging run started. This coincided with the turn of the incoming tide, and continued over the high tide, through the low tide and back to the turn of the incoming tide again. In all, 16 individual gaugings took place over 13 hours, with the teams swapping over at around 12:00 midday.

During the gauging run, when the flow reversed (water flowed from the drain out into the river), the gaugings were recorded as negative, to differentiate between inward and outward flow.

The start and finish times from the gaugings were then used to ascertain the corresponding stage heights from the EDS monitoring site, Kaituna at Fords Cut, situated upstream approximately 100m from the gates.

The gaugings undertaken appear as the squares on the stage hydrograph (Figure 3). The flows measured were then used to derive a rating for both the rising and falling limbs of the tidal cycle (Figure 4).

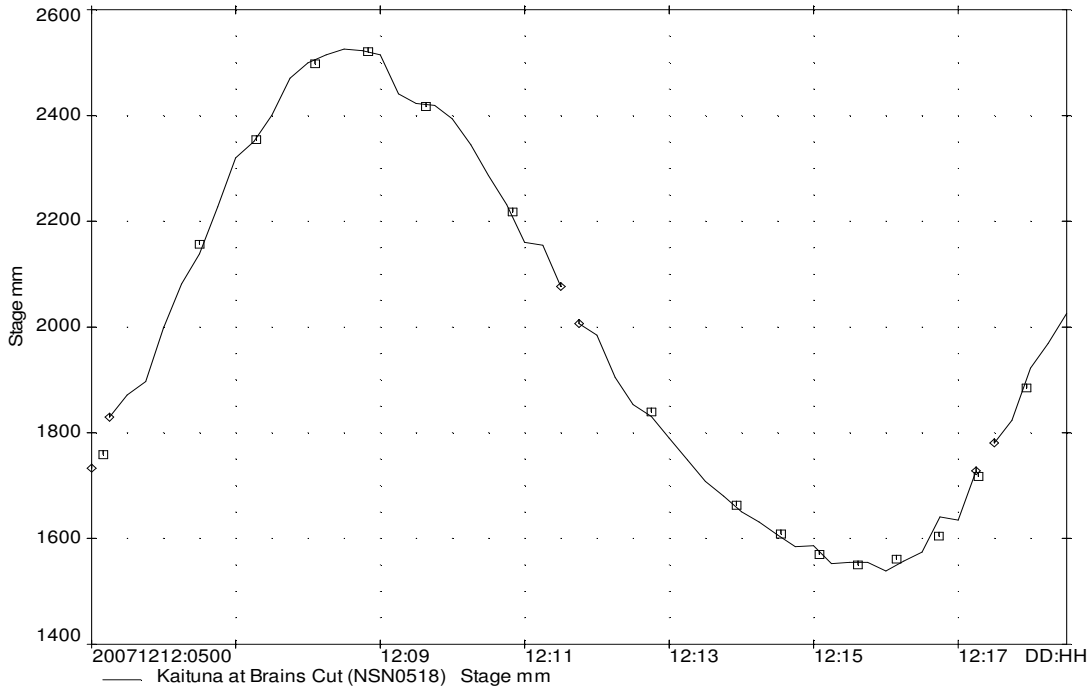
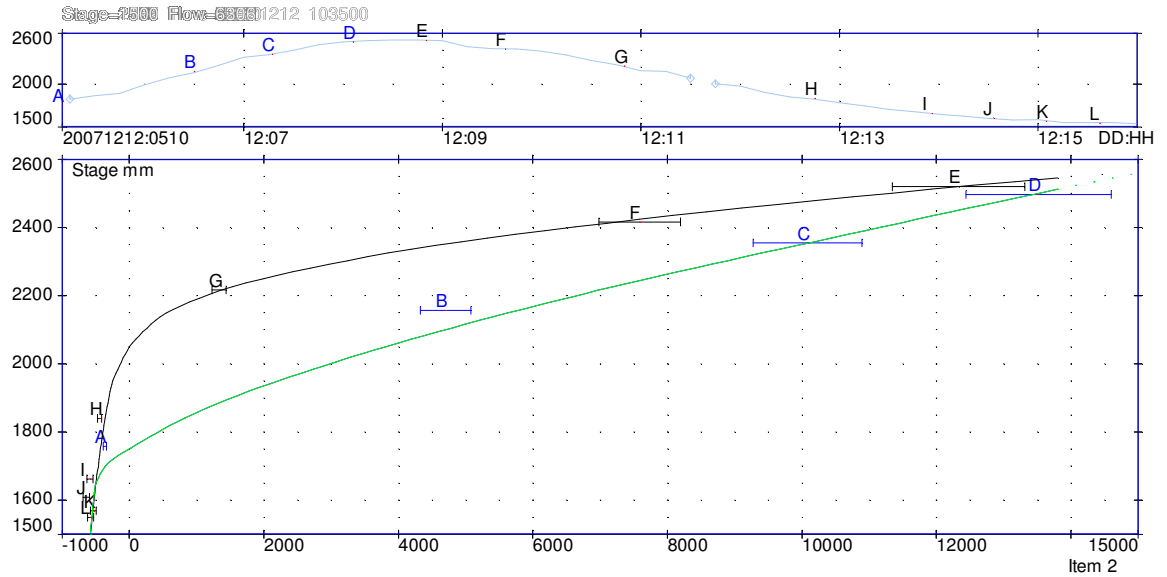


Figure 2 Stage Graph and Plotted Gaugings



Site: 518 Start Time: 20071212 051000 Finish Time: 20071212 160000

Figure 3 Rating Curves of Rising and Falling Tide

Using these ratings, a flow hydrograph was derived (Figure 5).

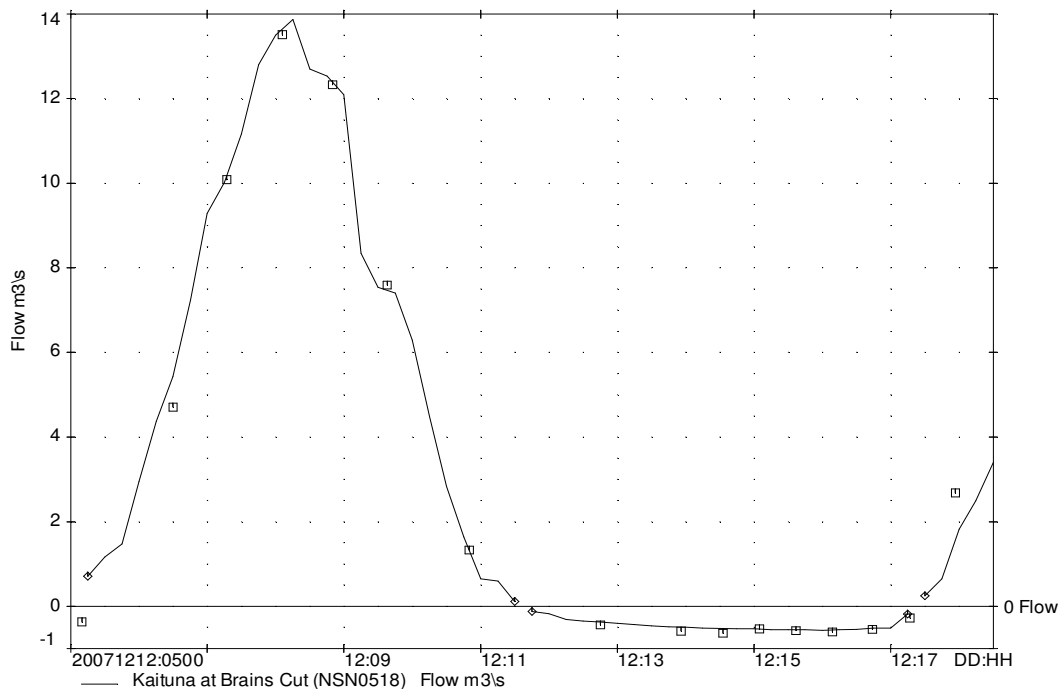


Figure 4 Flow Hydrograph and Plotted Gaugings

Once again using a program with in Tideda, the area under this curve was calculated, giving the total flow of water in cubic meters that passed through the culverts over the full tidal cycle. This curve was broken into two parts, positive and negative flow and their respective discharges calculated separately.

RESULTS

Of the 16 gaugings that were completed, half were negative flow, i.e. flow was moving from the Maketu Estuary into the Kaituna River. These gaugings all occurred during the low tide period when water was flowing back past the tidal gates. Although the gates look to be designed to stop the flow back into the river there was still considerable water getting past them and into the river. In total, over the time between no flow recorded through negative and back to no flow recorded, an estimated **9,053 cubic metres** of water flowed back into the Kaituna River from Fords Cut.

The rest of the gaugings that were completed were positive flow, i.e. that is the water was flowing from the Kaituna River through the culverts and into Fords Cut. There was a rapid transition from no flow through to positive flow, with the water level rising quickly. In total, from no flow through positive flow back to no flow, an estimated **153,555 cubic metres** of water flowed into Fords Cut.

It is also worth mentioning that it was noticed that at times during gauging, more so at lower flows, there was considerable surge, where the water level rose and fell approx. 50 – 75 centimetres, and the water increased in velocity. The surge seemed to be due to the large sea swell that was occurring at the time.

Mark Lumsden
Environmental Data Officer