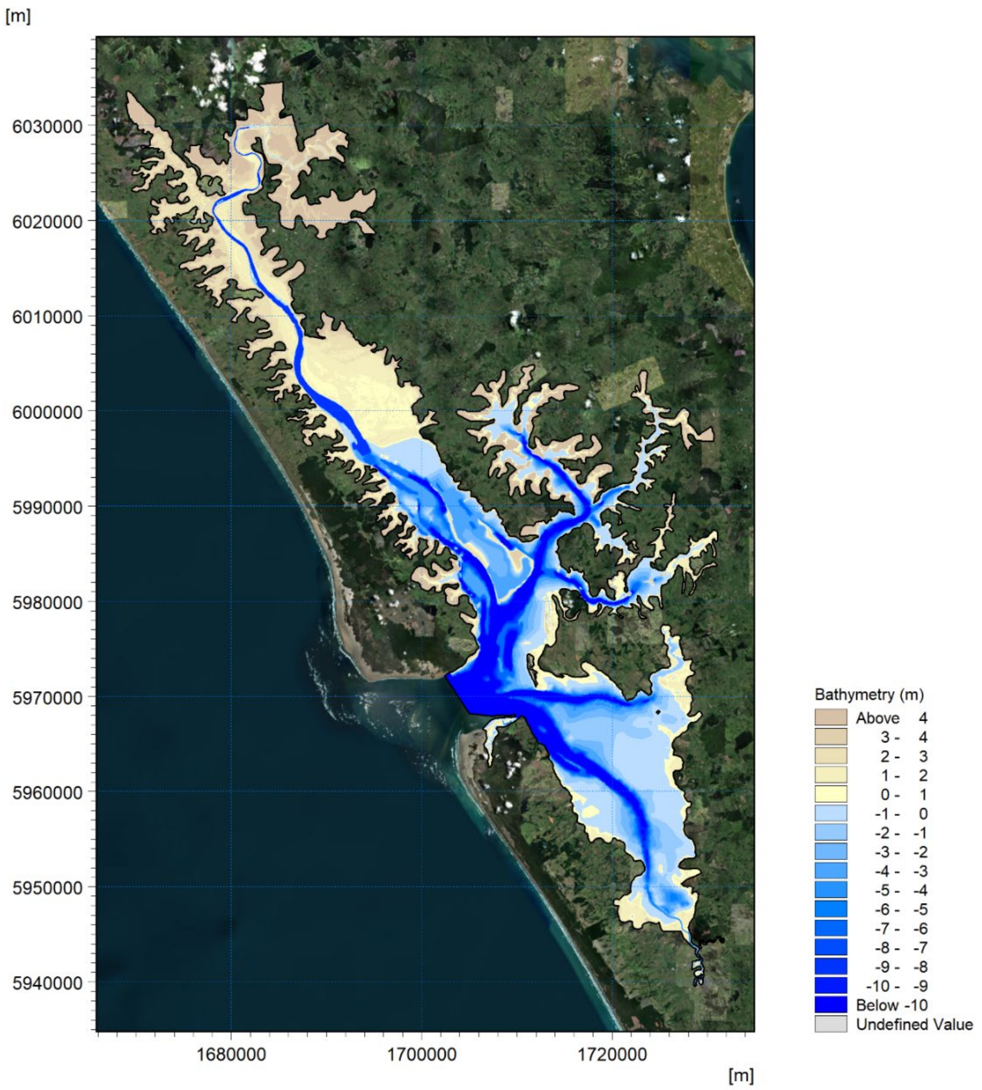
Technical Report: Coastal Inundation Modelling for Northern Kaipara Harbour

Numerical Modelling



Northland REGIONAL COUNCIL
Te Kaunihera ā rohe o Te Taitokerau

Report

March 2021

The expert in **WATER ENVIRONMENTS**

This report has been prepared under the DHI Business Management System
certified by Bureau Veritas to comply with ISO 9001 (Quality Management)

ISO 9001
Management System Certification
BUREAU VERITAS
Certification Denmark A/S

Technical Report: Coastal Inundation Modelling for Northern Kaipara Harbour

Numerical Modelling

Prepared for	Northland Regional Council
Represented by	Matthew de Boer

Project manager	Benjamin Tuckey

Project number	44801566
Approval date	26/03/21
Revision	Final 2.1
Classification	Open

DHI Water and Environment Ltd• ecentre, Gate 5, Oaklands Road• Albany 0752 Auckland• New Zealand•
Telephone: +64 9 912 9638 • Telefax: • info.nz@dhigroup.com• www.dhigroup.com

CONTENTS

1 Technical Summary 1

2 Introduction 2
2.1 Co-ordinate System, Vertical Datum and Time Zone 3

3 Model Set Up 4

4 Model Calibration and Validation 9
4.1 Model Calibration – Tidal Water Levels 9
4.2 Model Calibration - Significant Storm-Tide Event 10
4.3 Model Validation - Significant Storm-Tide Event 11

5 Design Scenarios 12
5.1 CFHZ Simulations Boundary Condition Generation 14
5.2 Elevated River Flow Input 18

6 Simulation Result 19
6.1 Sensitivity Tests 19

7 Simulations with High Resolution Model 23

8 Summary 25

9 References 26

1 Technical Summary

Simulations have been undertaken using a calibrated hydrodynamic model of the Kaipara Harbour, to assess peak flood inundation levels in the northern Kaipara Harbour, due to coastal storm surge and/or sea level rise for the following scenarios:

1. MHWS – Present day mean high water spring level.
2. CFHZ0 - Present day 1% AEP storm event with wave set up allowance.
3. CFHZ1 - 2% AEP storm event with wave set up allowance and 0.6 m sea level rise.
4. CFHZ2 - 1% AEP storm event with wave set up allowance and 1.2 m sea level rise.
5. CFHZ3 - 1% AEP storm event with wave set up allowance and 1.5 m sea level rise.
6. MHWS – Mean high water spring and 0.6 m sea level rise.
7. MHWS – Mean high water spring and 1.2 m sea level

2 Introduction

Northland Regional Council (NRC) commissioned DHI to develop a hydrodynamic model of the Kaipara Harbour for simulating coastal inundation of floodplains of the northern Kaipara Harbour, utilising a new LiDAR survey dataset.

A hydrodynamic model of the southern Kaipara Harbour developed for Auckland Council, to assess coastal inundation at Parakai/Helensville (DHI, 2019), has been extended to include the northern arm of the harbour and updated with the latest LiDAR data. The inundation assessment was only required for areas within the northern part of the Kaipara Harbour (as presented in Figure 2-1 below).

Figure 2-1 The extent of the inundation assessment required is the Northern part of the Kaipara Harbour.

NRC required simulations were undertaken for the following seven extreme sea levels design scenarios:

1. MHWS – Present day mean high water spring.
2. CFHZ0 - Present day 1% Annual Exceedance Probability (AEP) storm event with wave set up allowance.
3. CFHZ1 - 2% AEP storm event with wave set up allowance and 0.6 m sea level rise.
4. CFHZ2 - 1% AEP storm event with wave set up allowance and 1.2 m sea level rise.
5. CFHZ3 - 1% AEP storm event with wave set up allowance and 1.5 m sea level rise.
6. MHWS – Mean high water spring and 0.6 m sea level rise.
7. MHWS – Mean high water spring and 1.2 m sea level rise.

Sensitivity tests were undertaken to provide the following:

- Assessment of the impact on water levels within the floodplain for the assumed bed roughness for the floodplain;
- Evidence that the selected model resolution is appropriate; and
- Assessment of the impact on flood levels if a significant river flood events coincides with a coastal inundation event (a CFHZ0 event was simulated with a 50 year Annual Recurrence Interval (ARI) flood event for Wairoa River included).

2.1 Co-ordinate System, Vertical Datum and Time Zone

For this study, all data is presented using the New Zealand Transverse Mercator projection (NZTM) and the vertical datum is NZ Vertical Datum 2016 (NZVD2016). All time and dates are presented in Coordinated Universal Time (UTC).

For key locations within the study area, the following vertical datum conversions have been applied between either One Tree Point 1964 (OTP-64) or Auckland Vertical Datum 1946 (AVD-46) and NZVD2016:

Kaihu Estuary	$H_{NZVD2016} = H_{OTP64} – 0.126$ m
Dargaville-Wairoa	$H_{NZVD2016} = H_{OTP64} – 0.133$ m
Ruawai	$H_{NZVD2016} = H_{OTP64} – 0.118$ m
Pouto Point	$H_{NZVD2016} = H_{OTP64} – 0.290$ m
Helensville	$H_{NZVD2016} = H_{AVD46} - 0.2695$ m

3 Model Set Up

An existing MIKE 21 Flexible Mesh (FM) two dimensional hydrodynamic model of the southern Kaipara Harbour (DHI, 2019) has been extended to include the northern Kaipara Harbour and adjacent floodplain.

For the northern arm of the harbour model, within the river and subtidal areas, navigational chart data (Chart NZ 4265) has been utilised. For intertidal areas and floodplains, 2019 LiDAR data provided by NRC (as a 1 m DEM with vertical accuracy = 0.15 m) has been utilised. For the southern arm, no changes were made to model mesh or bathymetry, except for converting the mesh from AVD-46 to NZVD2016. The full model extent is presented in Figure 3-1 with the model boundary and location of the Wairoa River inflow point indicated.

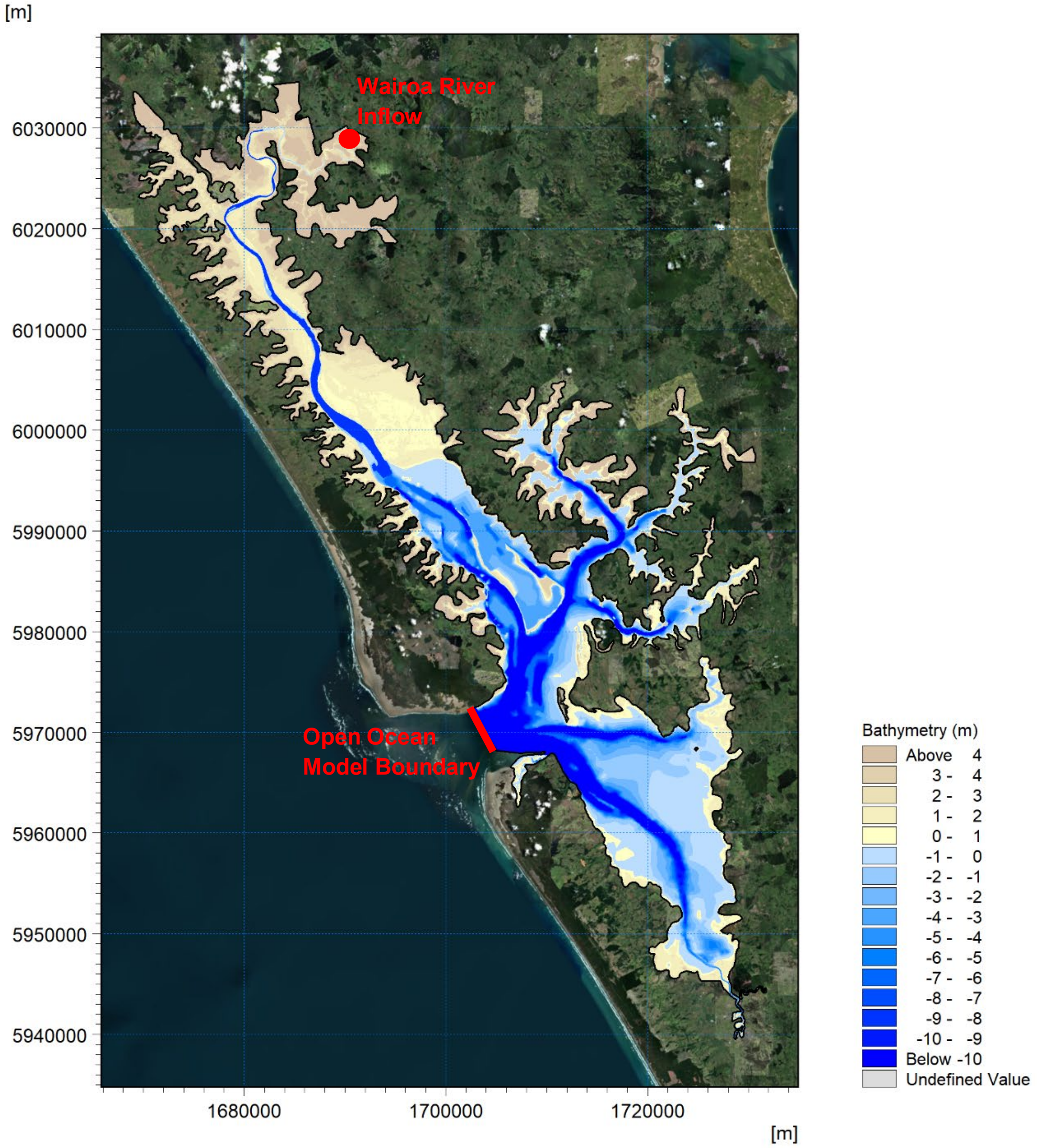


Figure 3-1 Kaipara Harbour model extent with model boundary and Wairoa River inflow point indicated.

The hydrodynamic model mesh was constructed with a horizontal resolution deemed (by DHI) to accurately simulate coastal-storm inundation over the northern Kaipara Harbour floodplain, while still maintaining efficient and realistic model run-times. Sections of the river have been deepened to -8m, as part of calibration process for tidal water levels. This deepening was carried out as it is likely that data from the navigation charts for the Wairoa River are not accurate.

The majority of the river and stopbanks upstream from Ruawai are represented by quadrangular elements (10 m x 10 m), while the floodplain beyond this, has been represented with triangular elements with an area of approximately 1,500 m^2. An example of the model mesh and bathymetry south of Dargaville is presented in Figure 3-2.

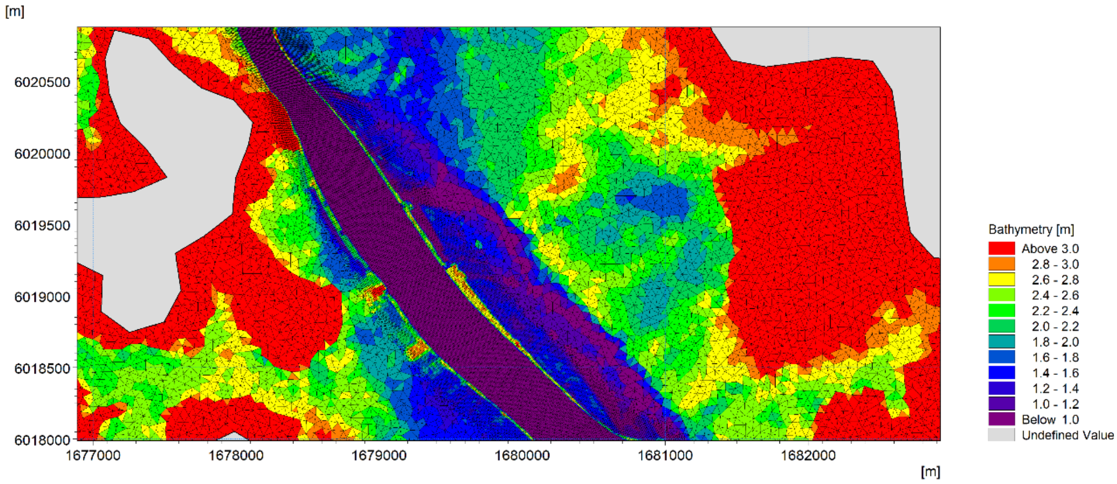


Figure 3-2 Wairoa river and floodplain representation in model mesh south of Dargaville. Depths are shown relative to NZVD2016.

The stopbanks have been represented in the model bathymetry, where feasible with a 10 m x 10 m resolution. However, to ensure the stopbank was sufficiently resolved, stopbanks were also typically included as a dike in the model set up, with the crest levels extracted from the LIDAR data. The main highways which are an obstruction to flood flow in the floodplain have only been represented with dikes in the model set up.

NRC provided survey data for a wooden stop bank south of Dargaville, not well resolved in the LIDAR. This has been included as a dike in the model set up.

During initial MHWS simulations, it became apparent that there are some small inaccuracies in the LIDAR, which allow the floodplain to be inundated for only a typical MHWS tide. Some examples of this issue from immediately south of Dargaville are presented in Figure 3-3. This presents the LIDAR data, along with cross sections taken from LIDAR, where it is apparent there is an erroneous gap in the stopbank.

NRC have deemed that this is due to LIDAR limitations in dense vegetation areas. NRC requested that DHI close the numerous gaps using dikes in the model set up, with crest levels selected at DHI's discretion, based on the surrounding stopbank crest levels.

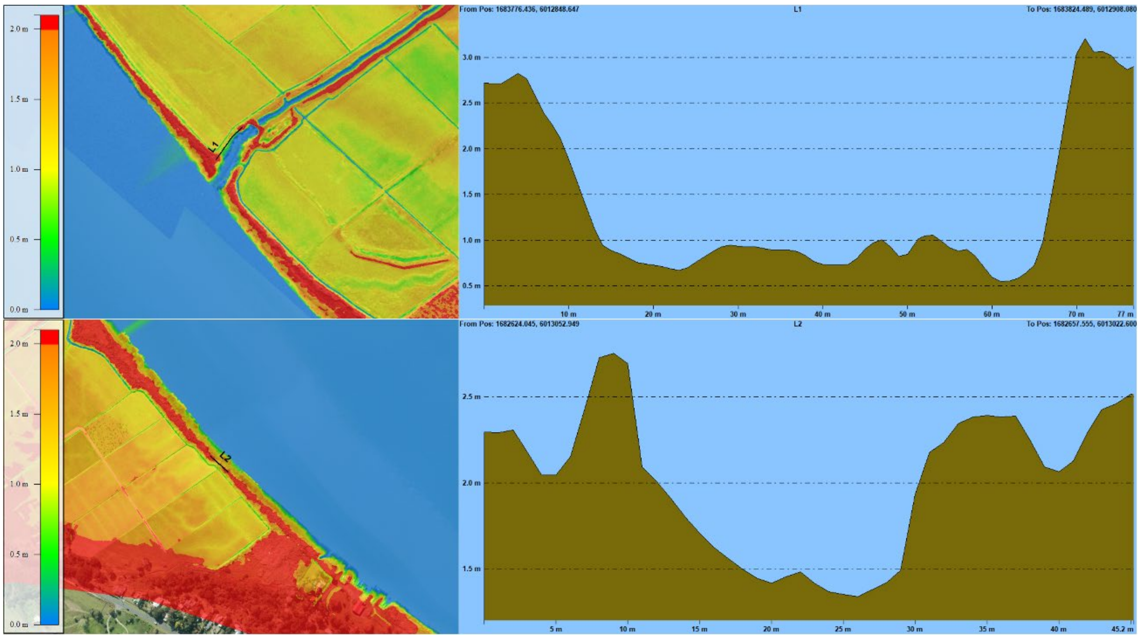


Figure 3-3 Wairoa river and floodplain representation in model mesh south of Dargaville. Depths are shown relative to NZVD2016. Cross section data (right panel) is extracted along the two transects (L1 and L2) shown in the left panel.

A constant Wairoa River flow of 80 m^3/s was applied at the northern upstream boundary of the Kaipara Harbour model for all simulations (calibration, validation and design). This has been calculated as the approximate mean flow of the Wairoa River at Ruawai (WRENZ, 2007). Applying an upstream flow was essential for achieving a reasonable calibration for water levels at Dargaville. This was applied for calibration, validation and design scenarios.

Observed water levels from Pouto Point for the period 2001 to 2013 were provided by NRC. This was utilised as the boundary condition with a shift of minus 55 mins to account for the time for the tide to propagate from the open ocean boundary to the Pouto Point tide gauge. The data was provided in OTP-64 and converted to NZVD2016. The model performed best if the tidal boundary condition was also shifted by +0.08 m. This was applied for calibration, validation and design scenarios.

A varying bed roughness map (Manning number M) was generated for the northern arm of the harbour (including flood plain) based on land use characteristics for the area (LCDB4), obtained from Land Resource Information Systems (LRIS) data portal. The land use GIS layer was used to derive a resistance map for the MIKE 21 model extent. A spatially varying resistance map was generated by mapping land uses types to various hydraulic resistances (Manning number M) based on experience and accepted use in the industry. The adopted mapping is shown in Table 3-1. For the southern part of the harbour, a constant Manning Number M of 43 is adopted, since this provided a good calibration for previous work (DHI, 2019).

An overview of parameters and inputs is provided in Table 3-2. There were no stability issues with the model, which would require adjustment of the default parameters.

Table 3-1 Land use codes with associated resistance Manning number. Note table is sorted from highest to lowest roughness (smallest to highest Manning Number).

Description (LCDB2)	Land Use Code	Manning Number (M)
Pine Forest - Closed Canopy	66	8
Manuka and or Kanuka	52	8
Pine Forest - Open Canopy	65	8
Indigenous Forest	69	8
Orchard and Other Perennial Crops	32	8
Vineyard	31	8
Broadleaved Indigenous Hardwoods	54	8
Other Exotic Forest	67	8
Gorse and or Broom	51	8
Afforestation (imaged, post LCDB 1)	63	8
Deciduous Hardwoods	68	8
Major Shelterbelts	61	8
Afforestation (not imaged)	62	8
Forest Harvested	64	8
Built-up Area	1	10
Transport Infrastructure	5	10
Fresh Water Vegetation	41	10
Saline Vegetation	45	10
Mangroves	70	10
High Producing Exotic Grassland	40	20
Short-rotation Cropland	30	20
Surface Mine	3	20
Low Producing Grassland	41	20
Mixed Exotic Shrubland	56	20
Flaxland	47	20
Urban Parkland / Open Space	2	30
River	21	50
River and Lakeshore Gravel and Rock	11	50
Lake and Pond	20	50

Table 3-2 Specifications for model parameters and inputs.

Parameter	Value
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: 0.005m Wetting depth: 0.1m
Eddy Viscosity Horizontal	Smagoringsky formulation, constant 0.28
Resistance	Manning number M (varying over domain)
Boundary Conditions	Pouto Point with a shift -0.1 m and a shift of minus 55 mins to account for the time for the tide to propagate from the open ocean boundary to Pouto Point tide gauge.
Sources	Wairoa River (constant flow = 80 m^3/s)

4 Model Calibration and Validation

The model has been calibrated against observed tidal water levels at the Helensville and Dargaville water level gauges. Water level data for Dargaville was provided by NRC (OTP-64), while water level data for Helensville was provided by NIWA (AVD-46). Both water level records were converted to NZVD2016.

The calibration and validation of storm surge events were carried out for events when river flows were not significantly elevated.

The model has then been calibrated at the Dargaville water level gauge for a significant storm-tide event that occurred in June 2012, and then validated for an event that occurred in September 2006.

There was an event in September 2005 which resulted in higher water levels at Dargaville than the June 2012 and September 2006 events (peaking at around 2.8 m on the 18th September 2005). However, river flow in the lower river is not gauged and for the September 2005 event it is know that there were elevated river flows (Tonkin & Taylor, 2017a).

4.1 Model Calibration – Tidal Water Levels

To illustrate the model is reasonably reproducing tidal level at Helensville and Dargaville, a five day simulation (including one day warm up) was undertaken for approximately MHWS at Pouto Pt for the period, 19th to 25th July 2005. Water levels at Helensville for this simulation are presented in Figure 4-1, while water levels at Dargaville are presented in Figure 4-2. The model is able to predict typical tidal water levels at these locations very well.

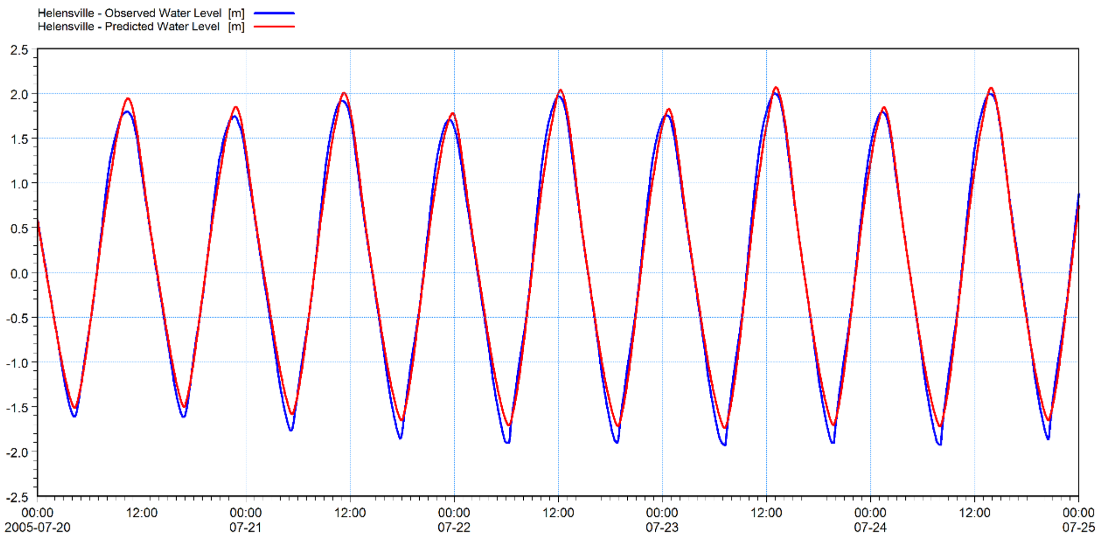


Figure 4-1 Comparison of observed and predicted tidal water levels at Helensville 20th to 25th July 2005.

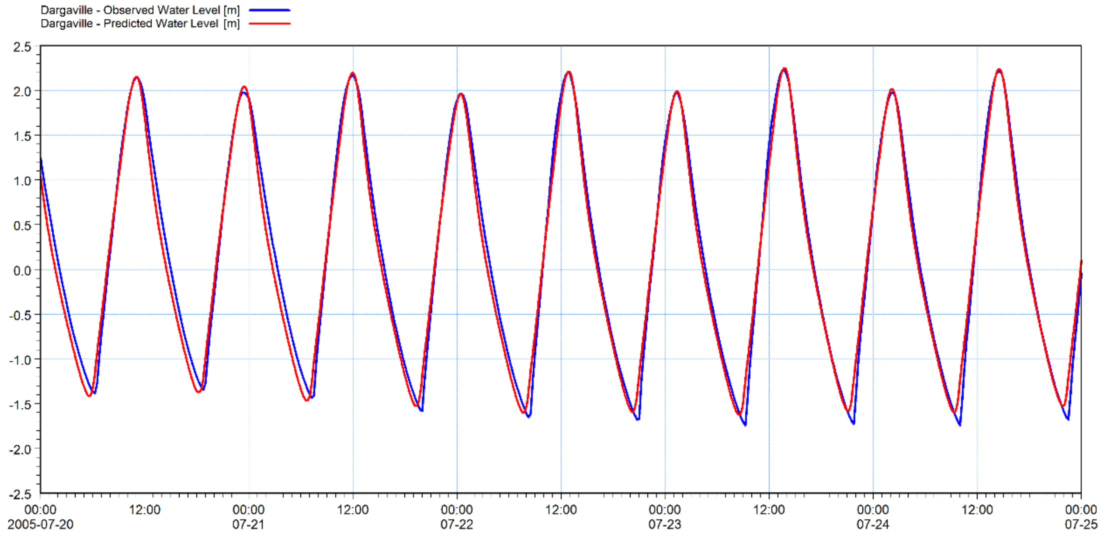


Figure 4-2 Comparison of observed and predicted tidal water levels at Dargaville 20th to 25th July 2005

4.2 Model Calibration - Significant Storm-Tide Event

On 6th June 2012 at approximately 1:30 pm, a peak water level of 2.59 m was observed at the Dargaville water level gauge. This event was selected for calibrating the hydrodynamic model.

The comparison of the observed and predicted water levels for the event at the Dargaville water level gauge is presented in Figure 4-3. The calibrated model was able to match the observed peak high water levels within 1 cm. As such, the model was deemed to be suitably calibrated for the purposes of this study.

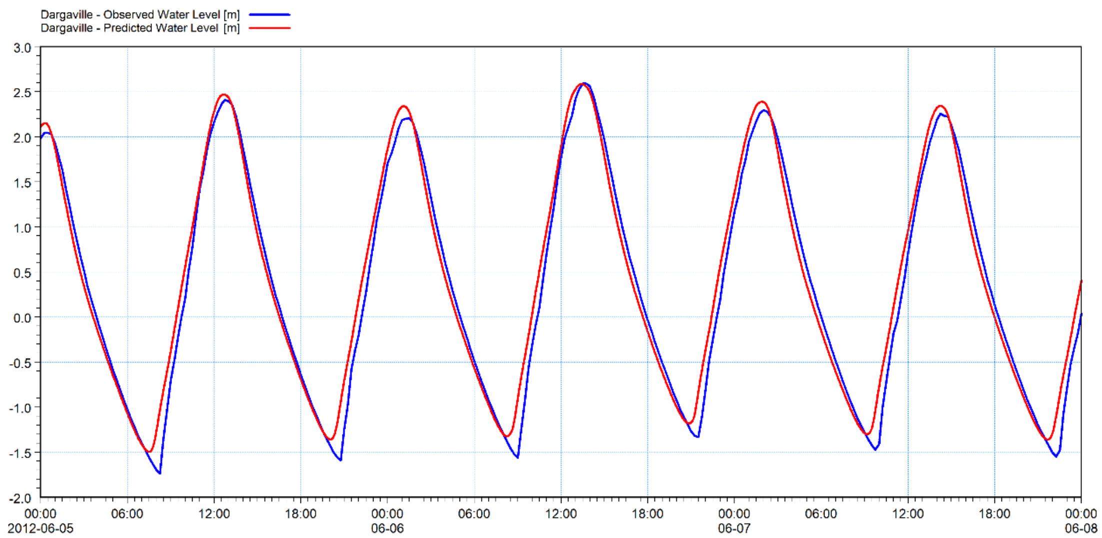


Figure 4-3 Comparison of observed and predicted water levels at Dargaville tide gauge for June 2012 calibration event.

4.3 Model Validation - Significant Storm-Tide Event

On 9th September 2006 at approximately 1:00 pm, a peak water level of 2.52 m was observed at the Dargaville water level gauge. This event was selected for validating the calibrated hydrodynamic model.

The comparison of the observed and predicted water levels for the event at the Dargaville water gauge is presented in Figure 4-4. The calibrated model was able to match the observed high water levels within 6 cm. The good agreement for the validation event further supported that the model was sufficiently calibrated and that the model is suitable for predicting coastal inundation of the northern Kaipara Harbour floodplains.

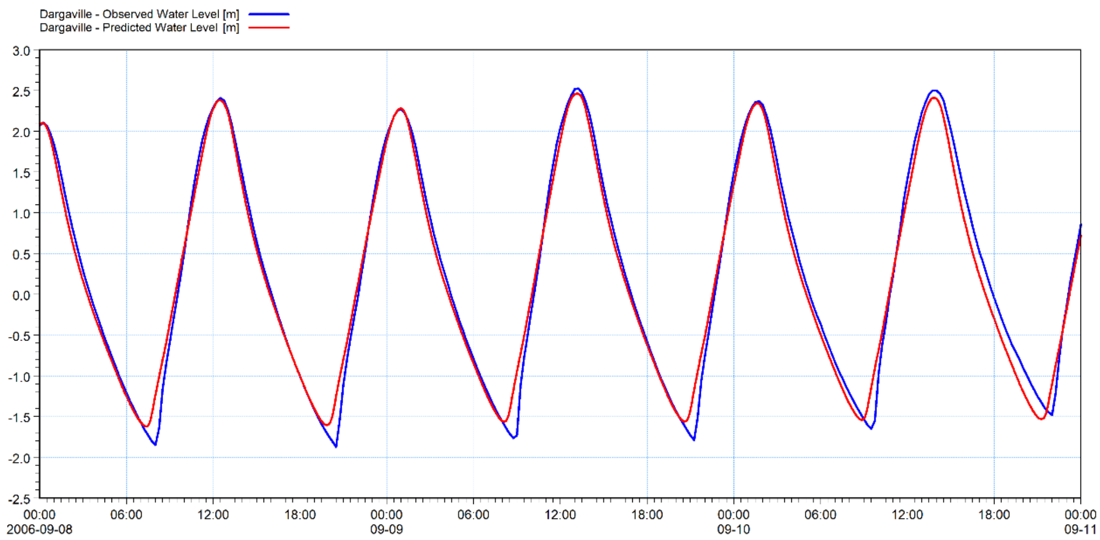


Figure 4-4 Comparison of observed and predicted water levels at Dargaville tide gauge for September 2006 calibration event.

5 Design Scenarios

This section outlines the simulations that were undertaken to assess peak coastal flood inundation levels for the northern Kaipara Harbour floodplain. The scenarios simulated were as follows:

1. MHWS – Present day mean high water spring level.
2. CFHZ0 - Present day 1% AEP storm event with wave set up.
3. CFHZ1 - 2% AEP storm event with wave setup and 0.6 m sea level rise.
4. CFHZ2 - 1% AEP storm event with wave set up and 1.2 m sea level rise.
5. CFHZ3 - 1% AEP storm event with wave set up and 1.5 m sea level rise.
6. MHWS – Mean high water spring and 0.6 m sea level rise.
7. MHWS – Mean high water spring and 1.2 m sea level rise.

Tonkin and Taylor (2017b) presented the MHWS, CFHZ0, CFHZ1 and CFHZ2 levels, at Kaihu Estuary, Dargaville and Ruawai. These are presented in Table 5-1 which includes both storm tide (assessed from site data) and calculated wave set up. It should be noted that DHI and NRC converted Tonkin and Taylor levels from OTP-64 to NZVD2016.

The approximate positions for these locations are presented in Figure 5-1. For this study, only Ruawai Cell B has been considered (as opposed to Ruawai Cell A), since it is not possible to create an open ocean boundary condition to match both Ruawai Cell A and Cell B water levels.

Table 5-2 presents the corresponding extreme sea-level estimates for Pouto Point derived by NIWA (2020). It should be noted that DHI and NRC converted NIWA derived levels from MSL to NZVD2016.

The MHWS calculations from Tonkin and Taylor (2017b), presented in Table 5-1, are difficult to interpret. Due to tidal amplification, it would be expected that MHWS would have a higher value at Kahui Estuary compared with Ruawai. In agreement with NRC, the MHWS value which Tonkin and Taylor reported at Ruawai and Dargaville-Wairoa (see Table 5-1), has been interpreted instead as MHWS level at Pouto Point.

For the MHWS simulation, an open ocean boundary has been applied where a peak tidal water level of 1.51 m was achieved at Pouto Pt, which is close to the NIWA, derived MHWS calculation (see Table 5-2). Using this approach the simulated MHWS level for Ruawai B = 1.89 m; Dargaville – Wairoa = 2.05 m; and Kahui Estuary = 2.19 m.

Table 5-1 Summary of CFHZ levels at Kaihu Estuary, Dargaville and Ruawai. (NZVD2016).

Location	Cell	MHWS	Current 1% AEP		2065 2% AEP		2115 1% AEP	
			Storm Tide	CFHZ0	Storm Tide	CFHZ1	Storm Tide	CFHZ2
Kaihu Estuary		1.55	2.68	2.77	3.07	3.17	3.67	3.77
Dargaville - Wairoa		1.59	2.71	2.77	3.07	3.17	3.67	3.77
Ruawai	A	1.59	2.80	3.18	3.18	3.58	3.78	4.18
	B	1.59	2.90	3.08	3.28	3.38	3.88	4.08

Table 5-2 Extreme sea-level estimates for Pouto Point derived by NIWA (NZVD2016).

Annual Exceedance Probability	Pouto Point
$MHWS_{10}$	1.45
20%	2.01
10%	2.05
5%	2.08
2%	2.13
1%	2.17

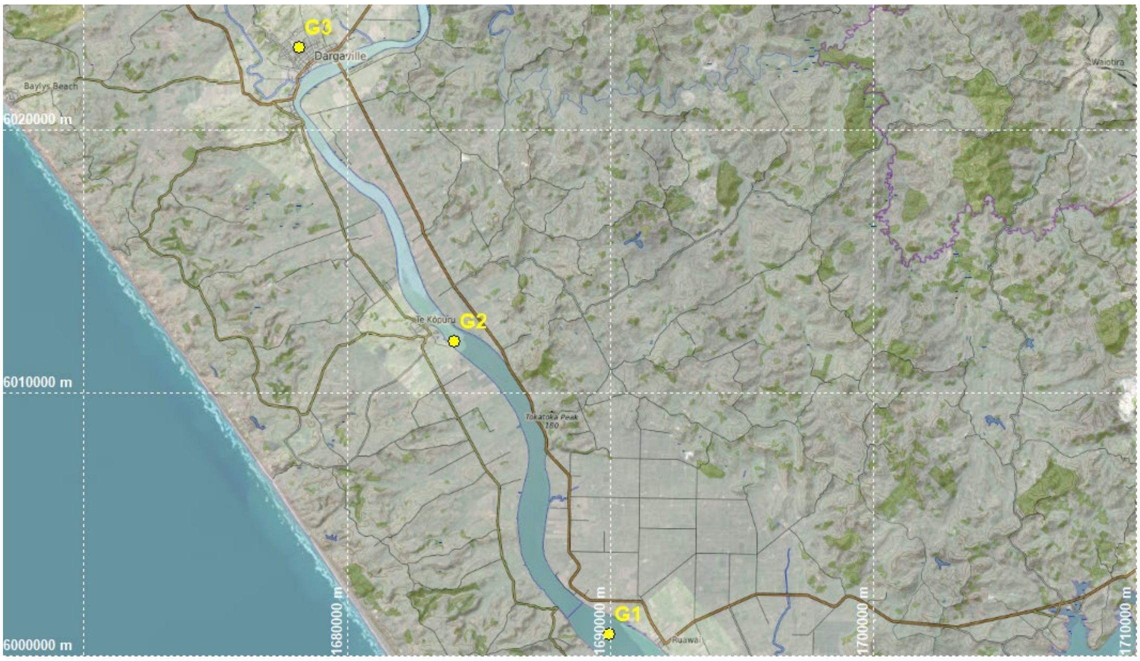


Figure 5-1 Approximate location of Ruawai B (G1), Dargaville – Wairoa (G2) and Kaihu Estuary (G3).

5.1 CFHZ Simulations Boundary Condition Generation

For the design scenarios, a 48 hour duration storm surge profile (based on a $sech^2$ relationship) was generated, with the peak of the surge coincident with the high water of a spring tide.

The storm surge profile (y_{ss}) was generated using the following $sech^2$ relationship:

$$y_{ss} = a_{ss} sech^2 k(t - t_0)$$

where a_{ss} = amplitude of the storm surge and wave set up profile;

t_0 = time of the peak;

k = frequency defined by:

$$k = \frac{3}{n_d}$$

where n_d = number of days either side of peak when y_{ss} falls to ass/100.

Originally it was anticipated that the amplitude of a storm surge and wave set up profile would be calculated such that at the Ruawai location, the required extreme water level (i.e. for CFHZ0, 3.08 m) was achieved. It was subsequently agreed after discussions with NRC that the model would then be required to match design water level at Dargaville (i.e. CFHZ0, 2.77 m) within 0.2 m. The agreed approach was to focus was on matching required water levels at Ruawai first (as close as possible) and then Dargaville second (within 0.2 m).

As an example, the boundary condition generated to obtain the peak water level for the CFHZ0 scenario, is presented in Figure 5-2. For this scenario, the peak water level for the boundary condition is 2.85 m. This achieved a peak water level of 3.09 m at Ruawai; 2.90m at Dargaville – Wairoa and; 2.82 m at Kaihu Estuary.

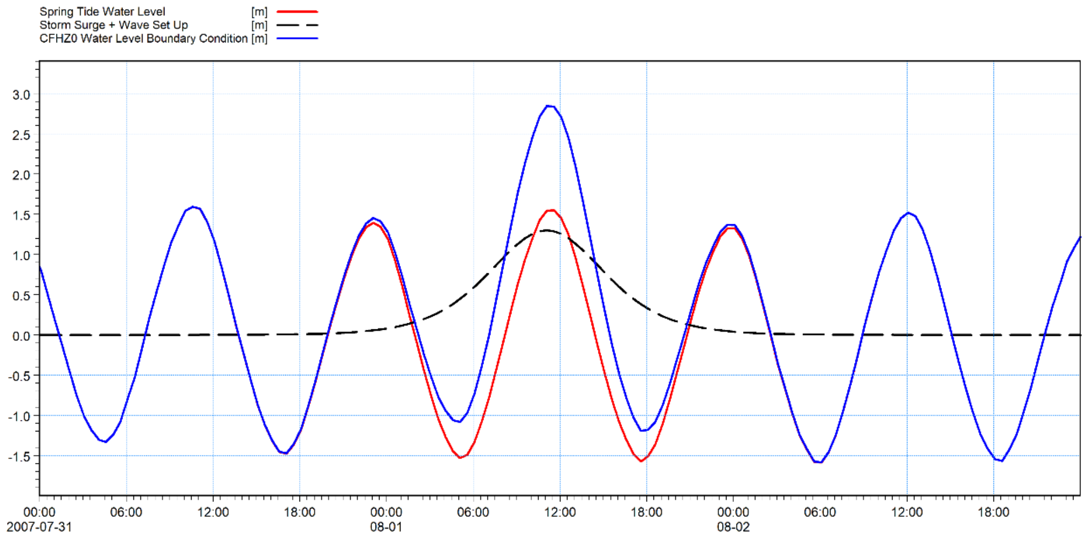


Figure 5-2 Preliminary CFZH0 water level open ocean boundary condition, including spring tide and storm surge and wave set up components (red line and black dashed line are added together to give the solid blue line).

For the sea level rise scenarios, the spring tide water level was to be shifted +0.6 m, +1.2 m or +1.5 m as required, before applying the storm surge and wave set up profile (scaled if required).

However, when this approach was used for CHFZ1, CFZ2 and CHFZ2, it became apparent that T&T calculated CFHZ levels for the northern Kaiprara sites, did not account for significant floodplain inundation that would occur and the impact this would have on the derived extreme flood levels.

Using the CFHZ2 simulation as an example. To match the required 4.08 m (NZVD2016) at Ruawai, after removing tide and sea level rise (+1.2), a surge and wave set-up profile that reached a peak of approximately 1.9 m water level (which is then applied on top of tide and sea level rise) was required. The highest storm surge measured at Pouto Pt, is more in the order of 1 m, hence it became apparent the approach was not sensible or robust.

An alternative methodology was then applied based on the 1% and 2% AEP extreme water levels derived by NIWA at Pouto Pt. For the CFHZ simulations the boundary conditions were derived in the following way.

1. CFHZ0 - Storm surge profile scaled, so that 1% AEP extreme level at Pouto Pt was achieved. A constant 0.18 m added to boundary condition to account for wave set up at Ruawai Cell B.
2. CFHZ1 - Storm surge profile scaled, so that 2% AEP extreme level at Pouto Pt was achieved. A constant 0.10 m added to boundary condition to account for wave set up at Ruawai Cell B. A constant +0.6 m added to boundary condition to account for sea level rise.
3. CFHZ2 - Storm surge profile scaled, so that 1% AEP extreme level at Pouto Pt was achieved. A constant 0.20 m added to boundary condition to account for wave set up at Ruawai Cell B. A constant +1.2 m added to boundary condition to account for sea level rise.
4. CFHZ3 - Storm surge profile scaled, so that 1% AEP extreme level at Pouto Pt was achieved. A constant 0.20 m added to boundary condition to account for wave set up at Ruawai Cell B. A constant +1.5 m added to boundary condition to account for sea level rise.

Examples of the open ocean boundary condition generated for CFHZ0 and CFHZ2 are presented in Figure 5-3 and Figure 5-4 respectively.

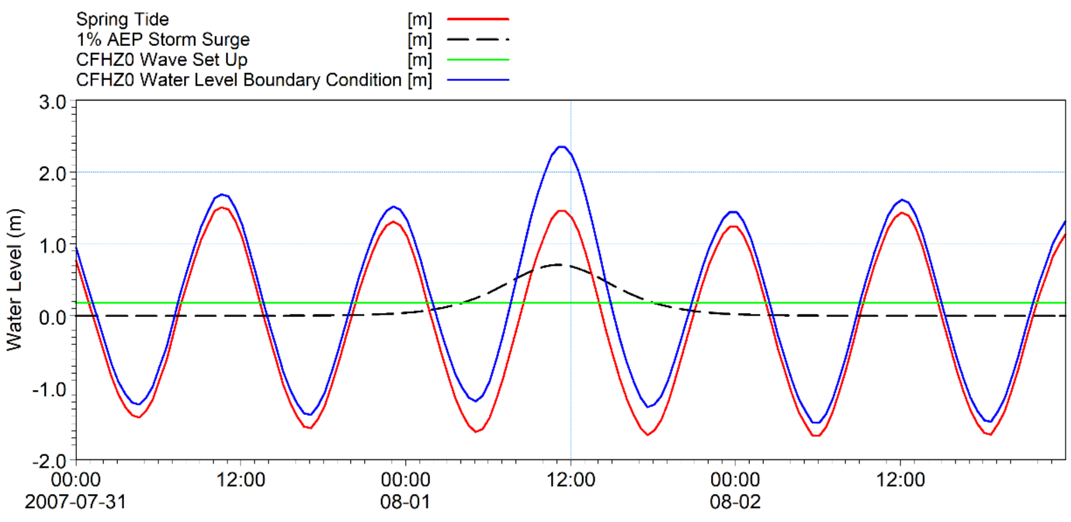


Figure 5-3 CFZH0 water level open ocean boundary condition, including spring tide, storm surge and wave set up components (red, green and black dashed line are added together to give the solid blue line).

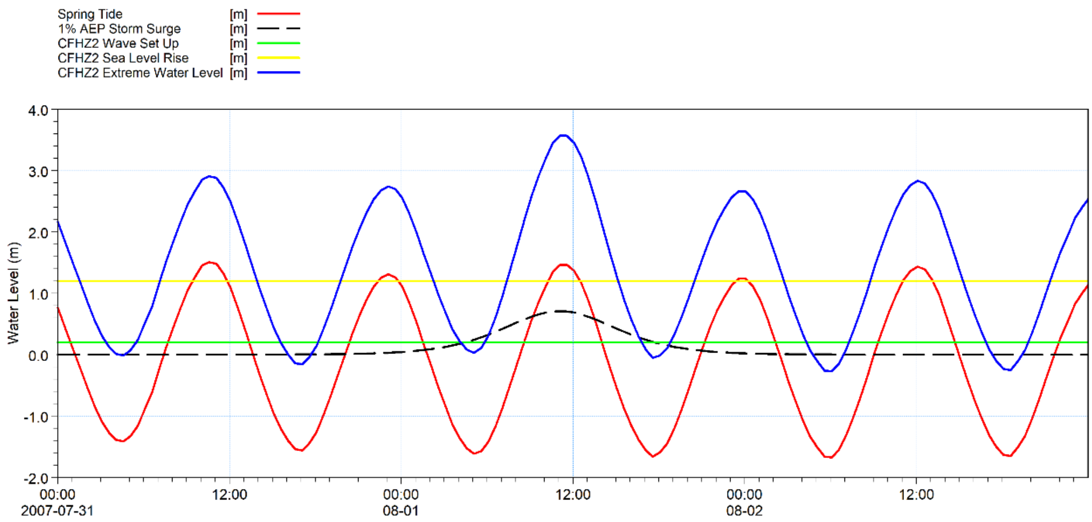


Figure 5-4 CFZH2 water level open ocean boundary condition, including spring tide and storm surge and wave set up components (red, green, yellow and black dashed line are added together to give the solid blue line).

The original Tonkin and Taylor derived levels and final achieved simulated peak water levels for each scenario is presented in Table 5-3. It should be noted that DHI and NRC converted Tonkin and Taylor levels from OTP-64 to NZVD2016.

Table 5-3 Comparison between simulated CFHZ peak water levels for each scenario, at Kaihu Estuary, Dargaville and Ruawai and Tonkin and Taylor derived levels. (NZVD2016).

Location	CFHZ0		CFHZ1		CFHZ2	
	Simulated	T&T Level	Simulated	T&T Level	Simulated	T&T Level
Kaihu Estuary	2.71	2.77	2.96	3.17	3.48	3.77
Dargaville - Wairoa	2.70	2.77	2.96	3.17	3.44	3.77
Ruawai	2.73	3.08	3.09	3.38	3.57	4.08

For the MHWS with sea level rise scenarios, the MHWS simulation boundary condition was shifted +0.6 m or +1.2 m as required.

5.2 Elevated River Flow Input

To assess the impact on flood levels if a significant river flood events coincides with a coastal inundation event, NRC provided the flow hydrograph for a 50 year ARI event for Wairoa River. The flow time series for this event is presented in Figure 5-5 and has a peak flow of 1,700 m^3/s. The peak of the flood was shifted to coincide with the peak of the coastal inundation at Dargaville.

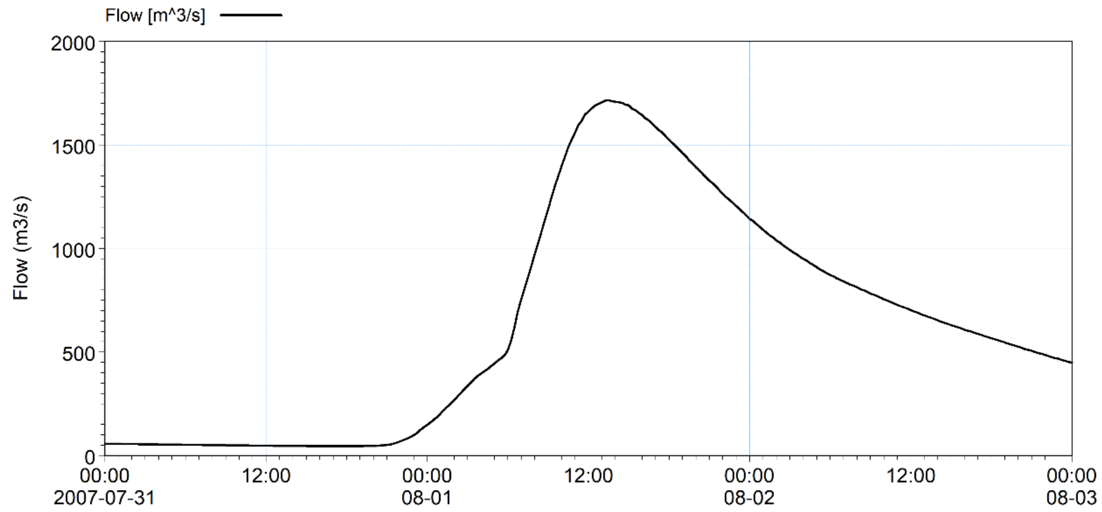


Figure 5-5 NRC provided hydrograph for 50 Year ARI flood event for Wairoa River.

6 Simulation Result

For each of the simulated scenarios, 10 m x 10 m resolution rasters of maximum water depth, maximum water level and maximum current speed were provided to Northland Regional Council.

GIS polygon shapefiles for each event assessed, mapped to 1m DEM, based on maximum flood elevation raster file have also been provided using the following process. The 10 x 10 m maximum water level raster was converted to a 1 m x 1 m raster. The 1 m x 1 m LIDAR DEM was then subtracted from this with resulting water depths greater than 0 m, converted to polygons.

6.1 Sensitivity Tests

Bed Roughness

Along with topography, the roughness of the land is also an important influence on the dynamics of overland flow and the predicted depth of overland flow. A method was used that we believe is appropriate for approximating the bed roughness, by mapping land use to expected bed roughness (Section 3). To determine any impact of the selected bed roughness values for the floodplain on peak inundation levels, simulations were undertaken for the CFZH0 simulation, with - 25% for the varying bed roughness map (only for the floodplain). The maximum water depth difference for the floodplain adjacent to Ruawai, for this simulation compared with the CFZH0 simulation with the standard bed roughness values are presented in Figure 6-1.

For higher roughness (i.e. the bed roughness map minus 25%), water depths for the majority of the floodplain decrease by -1 cm to -10 cm, however there are some isolated areas where water depths decrease by up to approximately -30 cm.

Therefore, the bed roughness sensitivity analysis suggests that the inundation modelling is probably accurate to ± 10 cm over most of the floodplain.

Mesh Resolution

To illustrate that an appropriate mesh resolution was selected to represent the flood plains (i.e. triangular elements with an area of approximately 1,500 m^2), a model mesh was generated with an increased resolution (approximately 500 m^2) for the floodplain adjacent to Ruawai.

Maximum water depth extents greater than 5 cm, for CFZH0 event, for the flood plain adjacent to Ruawai, for the higher resolution simulation compared with the selected model resolution is presented in Figure 6-2. The model extents match very closely, apart from one additional area of flooding with the higher resolution model. Despite this, the selected model resolution was deemed appropriate based on this sensitivity test.

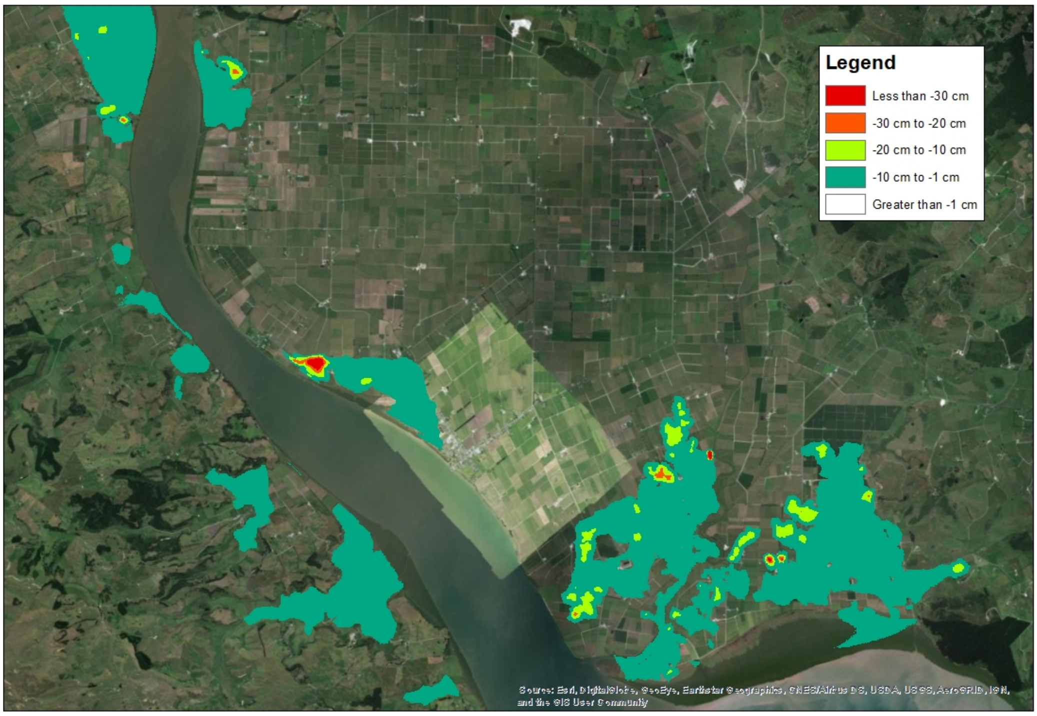


Figure 6-1 Maximum water depth difference for CFZH0 event, for floodplain adjacent to Ruawai, with bed roughness reduced by 25%.

Figure 6-2 Spatial extent of area where water depth of greater than 5 cm occur for CFZH0 event, for floodplain adjacent to Ruawai. Blue extent is for the selected model resolution, while red extent is for an increased model resolution.

River Flow

To assess the impact on inundation levels of significant river flood events the CFHZ0 event was simulated with a 50 year Annual Recurrence Interval (ARI) flood event for the Wairoa River included.

The maximum water depth difference for the floodplains north of Ruawai floodplain, for this simulation compared with the CFZH0 simulation without the Wairoa River flood event is presented in Figure 6-3. Associated maximum water depth extents greater than 5 cm are presented in Figure 6-4.

Greater than 15 km upstream of Dargaville, there is significant inundation of the floodplain due to the elevated river flow, which is not inundated from coastal inundation. This indicates flooding for this area is dominated by river flows.

For the Ruawai floodplain, there is less than 5 cm increase in maximum flood depths. South of Dargaville, there is predominantly up to a 10 cm increase in maximum water depths. The floodplain across the river from Dargaville has up to a 20 cm increase in maximum water depths. North of Dargaville, there is significant areas of the floodplain with greater than a 30 cm increase in maximum water depths.

The sensitivity test indicates that the role of river floods coinciding with coastal storm surge needs to be considered further for floodplain areas upstream of the Ruawai floodplain in future work.

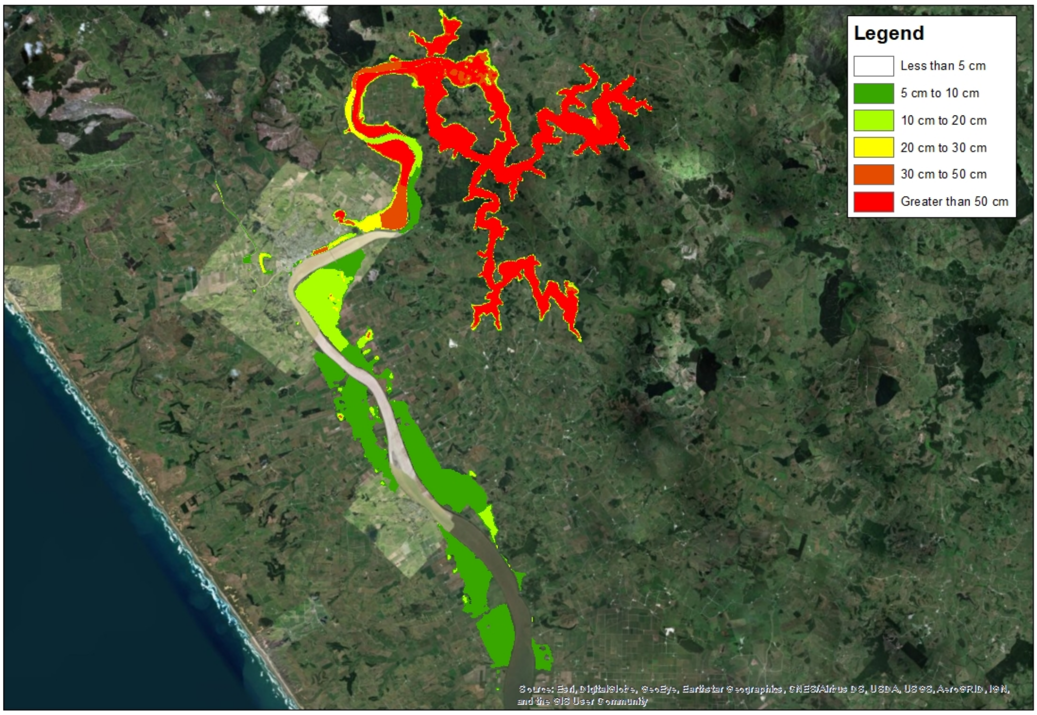


Figure 6-3 Maximum water level difference for CFZH0 event with and without 50 year flood event for Wairoa River.

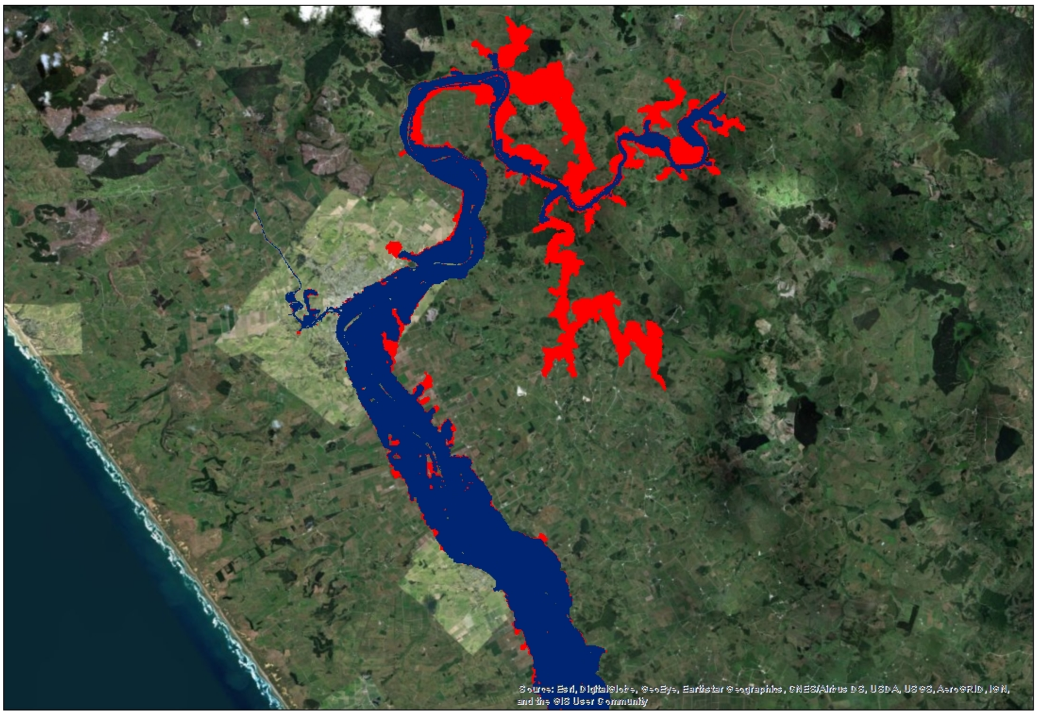


Figure 6-4 Water depth extents greater than 5 cm for CFZH0 event with and without 50 year flood event for Wairoa River. Blue extent is without river flood event, while red extent is with river flood event.

7 Simulations with High Resolution Model

In consultation with NRC, it was ultimately decided that the model resolution of 2,500 m^2, was not producing GIS polygons that were suitable for publication. To resolve this issue, a higher resolution model was developed with a 100 m^2 resolution (equivalent to 10 m x 10 m grid) for the Northern Kaipara Harbour.

GIS polygon shapefiles for each event assessed, mapped to the 1 m DEM, based on maximum flood elevation results file, were provided using the following process. The high resolution model maximum water level results were converted to a 1 m x 1 m raster. The 1 m x 1 m LIDAR DEM was then subtracted from this, with water depths greater than 0.1 m then converted to polygons. Ponding areas < 2,000 m^2, were then removed from these polygon shapefiles.

Interpolated 10 x 10 m rasters of the maximum water level, water depth and current speed for the Northern Kaipara Harbour have been provided for these scenarios.

Since the higher resolution model was essentially a different model than the original model, it can be expected it will produce slightly different results.

Table 7-1 provides for the storm tide calibration and validation events (see Section 4.2 and 4.3), a comparison of observed and predicted (original and high resolution model) peak water level at Dargaville tide gauge. With the high resolution model, the calibration event now agrees within 4 cm (previously 1 cm), while the validation event now agrees within 3 cm (previously 6 cm).

The original Tonkin and Taylor derived levels and final achieved simulated peak water levels for each scenario and model resolution is presented in Table 7-2. Note Tonkin and Taylor did not provide levels for CFHZ3, MHWS, MHWS with 0.6 m sea level rise and MHWS with 1.2 m sea level rise. There is a small difference in peak water levels between the two models, upto 3 cm, for Ruawai and Dargaville – Wairoa, but as large as 7 cm at Kaihu Estuary for CFHZ0 scenario upto 5 cm for rest of scenarios.

Table 7-1 For storm tide calibration and validation events, comparison of observed and predicted (coarser and high resolution model) peak water level at Dargaville tide gauge. (NZVD2016).

Event	Observed	Original Model	Higher Resolution Model
Storm Tide Calibration Event	2.59	2.58	2.63
Storm Tide Validation Event	2.52	2.46	2.49

Table 7-2 Comparison between high resolution and original resolution model simulated peak water levels for each scenario, at Kaihu Estuary, Dargaville and Ruawai and Tonkin and Taylor derived levels (where applicable). (NZVD2016).

Event		**Location**		
		Kaihu Estuary	**Dargaville - Wairoa**	**Ruawai**
CFHZ0	T&T	2.77	2.77	3.08
	Original Model	2.71	2.70	2.73
	Higher Resolution Model	2.78	2.73	2.74
CFHZ1	T&T	3.17	3.17	3.38
	Original Model	2.96	2.96	3.09
	Higher Resolution Model	2.95	2.98	3.09
CFHZ2	T&T	3.77	3.77	4.08
	Original Model	3.48	3.44	3.57
	Higher Resolution Model	3.49	3.45	3.57
CFHZ3	T&T	N/A	N/A	N/A
	Original Model	3.64	3.62	3.72
	Higher Resolution Model	3.66	3.63	3.73
MHWS	T&T	N/A	N/A	N/A
	Original Model	2.19	2.05	1.89
	Higher Resolution Model	2.21	2.07	1.90
MHWS + 0.6 m	T&T	N/A	N/A	N/A
	Original Model	2.63	2.58	2.52
	Higher Resolution Model	2.68	2.60	2.53
MHWS + 1.2 m	T&T	N/A	N/A	N/A
	Original Model	2.96	2.93	3.01
	Higher Resolution Model	2.99	2.96	3.01

8 Summary

DHI were commissioned by NRC to develop a hydrodynamic model of the Kaipara Harbour for simulating coastal inundation of floodplains of the northern Kaipara Harbour, utilising a new LiDAR survey. A hydrodynamic model of the southern Kaipara Harbour developed for Auckland Council, to assess coastal inundation at Parakai/Helensville was extended to include the northern arm of the harbour.

The hydrodynamic model has been calibrated against observed tidal water levels at the Helensville and Dargaville water level gauges. The model has then been calibrated at the Dargaville water level gauge for a significant storm-tide event that occurred in June 2012, and then validated for an event that occurred in September 2006.

Simulations were undertaken with the calibrated model to assess peak flood inundation levels due to coastal storm surge and/or sea level rise for the following scenarios:

1. MHWS – Present day
2. CFHZ0 - Present day 1% AEP storm event with wave set up allowance.
3. CFHZ1 - 2% AEP storm event with wave set up allowance and 0.6 m sea level rise.
4. CFHZ2 - 1% AEP storm event with wave set up allowance and 1.2 m sea level rise.
5. CFHZ3 - 1% AEP storm event with wave set up allowance and 1.5 m sea level rise.
6. MHWS – Mean high water spring and 0.6 m sea level rise.
7. MHWS – Mean high water spring and 1.2 m sea level rise.

A river flood sensitivity test, indicates that the role of river floods coinciding with coastal storm surge needs to be considered further in future work, for areas north of Ruawai floodplain.

Rasters of the maximum water level, water depth and current speed for the Northern Kaipara Harbour have been provided for these scenarios. GIS polygon shapefiles for each event assessed, mapped to 1 m DEM, based on the maximum flood elevation file have also been provided. Water depths greater than 0.1 m and ponding areas < 2,000 m^2, were removed from these polygon shapefiles.

9 References

DHI (2019). *Parakai/Helensville Coastal Flood Inundation – Numerical Modelling.* Report prepared for Auckland Council.

NIWA (2020). *Northland sea-level analysis*. Memo prepared for Tonkin and Taylor.

Tonkin and Taylor (2017a). *Free Range Broiler Farm, Arapohue: Flooding* assessment . Report prepared for Tegel Foods Ltd.

Tonkin and Taylor (2017b). *Coastal Flood Hazard Zones for Select Northland Sites 2017 Update.* Report prepared for Northland Regional Council.

WRENZ (2007). *National Institute of Water &Atmospheric Research – Water Resources Explorer NZ*. http://wrenz.niwa.co.nz/webmodel.