Inundation Modelling of the Rangaunu Harbour

Prepared for:

Northland
REGIONAL COUNCIL

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eTakutai

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Executive Summary

eCoast Marine Consulting and Research was commissioned by Northland Regional Council to carry out a series of hydrodynamic flood simulations for the Rangaunu Harbour in Northland, New Zealand. This modelling was undertaken as an extension to a previous eCoast model, which only simulated the southern part of the Rangaunu Harbour (O'Neill *et al*., 2017). In addition, the modelling bathymetry utilised the updated NZVD2016 datum (OTP 1964 was previously used).

This assessment utilises Mean High Water Spring (MHWS) and Coastal Flood Hazard Zone (CFHZ) levels derived by Tonkin and Taylor (2020) to model extreme water level scenarios that correspond to:

- CFHZ0 - 1% Annual Exceedance Probability (AEP) for 2020 water levels
- CFHZ1 - 2% AEP for 2080 water levels
- CFHZ2 - 1% AEP for 2130 water levels
- CFHZ3 – 1% AEP for 2130 water levels under highest sea level rise scenario
- MHWS-10
- MHWS 2080
- MHWS 2130

These scenarios were used to derive boundary conditions for the model, which contained high resolution LiDAR topography data, overland roughness parameterisation due to land cover type and background river flow. All model simulations have been undertaken using the HEC-RAS version 5.0.7 modelling suite (Hydraulic Engineering Centre – River Analysis System) developed by the U.S. Army Corps of Engineers.

The model setup was validated using the MHWS-10 results and calculated extreme water levels at Rangiputa. Model results were processed into raster files of maximum water surface elevation, maximum water velocity and maximum depth, as well as flood extent shape files for the Council's databases.

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1 Introduction

eCoast Marine Consulting and Research was contracted by Northland Regional Council (NRC) to develop a hydrodynamic flood model for the Rangaunu Harbour, Northland, New Zealand (see Figure 1.1 for location). This study follows on from previous flood modelling undertaken by eCoast where only the southern section of the Rangaunu Harbour was simulated (O'Neill *et al*., 2017). The objective of this study was to extend the model domain to include the entire harbour and its surrounding land using new 1 m x 1 m resolution LiDAR and up to date flood inundation levels to NZVD2016 (New Zealand Vertical Datum 2016). Seven flood scenarios have been modelled:

- 1% Annual Exceedance Probability (AEP) 2020 static water level;
- the 2% AEP 2080 static water level,
- the 1% AEP 2130 static water level,
- the 1% AEP 2130 static water level under highest sea level rise scenario
- the 10% exceedance mean high water spring (MHWS) level,
- the 2080 MHWS level, and,
- the 2130 MHWS level.

It is expected that these results will help inform NRC of the areas that will require stopbank upgrades or other flood aversion procedures, as well as planning for the impacts of SLR (sea level rise)

Figure 1.1. Location map for the study site in New Zealand's Northland Region.

1.1 Project Scope and Methodology

The following methodology has been applied to this project:

a) Digitise Rangaunu Harbour bathymetry and merge with 2019 LiDAR.
b) Set up flood model domain. Transfer tidal boundary condition from ocean to Ben Gunn Wharf.
c) Extract stopbank elevation from Digital Terrain Model (DTM) or survey and modify model domain.
d) Use flexible mesh from 50 m x 50 m to 15 m x 15 m to 1 m x 1 m, with 1 m x 1 m resolution used where required to enable identification of features such as roads/stopbanks potentially blocking flow.
e) Where necessary fill unexpected gaps in stopbanks in DTM using dykes (e.g. if overtopping occurs at regular tides).
f) Define roughness based on assumed terrain and best-practice guidelines.
g) Derive boundary conditions based on recorded tidal series adjusted to MHWS10 (10% exceedance), MHWS 2080, MHWS 2130, CFHZ0, CFHZ1, CFHZ2 and CFHZ3 elevations.
h) Sensitivity-tests for model domain size and boundary conditions, repeating steps a - d until optimal size determined, model validation.
i) Sensitivity test for roughness.
j) Test model levels against any known coastal flood data (NRC to provide data, where available).
k) Validate against empirical levels for Rangiputa (Tonkin and Taylor, 2020). Domain includes locality of Rangiputa but will need to check that low lying areas to east of harbour are covered.
l) Run seven inundation scenarios and output shapefiles for flow elevation, depth, velocity for each and supply to Council for review.
m) Concise report summarising methodology, model set up, assumptions made, sensitivity testing details and results for Council review
n) Make any changes required based on Council review (provisional Item).

1.2 Datums and Coordinates

All elevations (levels) presented in this report are presented in terms of New Zealand Vertical Datum (NZVD) 2016. The coordinate reference system used for this project is New Zealand Transverse Mercator 2000 (NZTM2000).

2 Model Set Up

2.1 Model Description

For the hydrodynamic modelling, the HEC-RAS 5.0.7 modelling suite (Hydraulic Engineering Centre – River Analysis System, 2016) developed by the U.S. Army Corps of Engineers as part of the "Next Generation" of hydraulic engineering software was applied. In addition to the river analysis system, the model encompasses rainfall-runoff analysis (HEC-HMS), reservoir system simulation (HEC-ResSim), flood damage analysis (HEC-FDA and HEC-FIA) and real-time river forecasting for reservoir operations (CWMS).

HEC-RAS is capable of simulating two-dimensional unsteady flow through a full network of open channels, alluvial fans and floodplains and can perform subcritical, supercritical and mixed flow regime calculations. The basic computational procedure solves the full-dynamic two-dimensional Saint Venant equations (2D shallow water equations) using an implicit finite difference method. Further detail about the model can be found in the HEC-RAS 5.0 User's Manual.

2.2 Preparation of Digital Terrain Model and Model Grid

The Rangaunu Harbour Digital Terrain Model (DTM), shown in Figure 2.1, was created based on measured topographic and bathymetric data. High resolution 1 m x 1 m LiDAR topography data was supplied by the NRC, while additional bathymetric data was extracted from hydrographic charts provided by Land and Information New Zealand (LINZ).

Model grids, or 2D flow areas, were constructed for the Rangaunu Harbour model encompassing all open channels, alluvial fans, floodplains and other flood pathways. The initial cell size was set to 50 m x 50 m for the permanently submerged areas of the harbour and 15 m x 15 m for intertidal and land areas. This resulted in a mostly rectilinear mesh, with the exception of the cells adjacent to the grid boundaries that take an irregular shape in order to 'snap' to the shape of the 2D flow area. The grid extents are displayed in Figure 2.1, while an example of a high-resolution area is illustrated in Figure 2.2. A total of 874,417 cells were used in the model domain, which through sensitivity testing was found to be close to the limits of HEC-RAS' capabilities, although provided sufficient detail to include stopbanks, roads, etc.

Any feature acting as a barrier to flow identified in each of the model terrains such as stopbanks, raised roads, river and creek banks, canal banks, drainage ditch banks, etc., required break lines to be enforced into the grid. This means that such features received greater cell resolution on each of their sides as well as forcing cell faces along their crest lengths (Figure 2.2). The smallest grid cells created as a result of this procedure were 1 m x 1 m, matching the LiDAR resolution of the underlying terrain.

During the model validation process a number of gaps in the stopbanks were discovered. Some of the gaps were likely to be artefacts within the DTM, while others may be real gaps but have a nearby drainage structure such as a culvert to prevent flooding. The stopbank gaps caused unrealistic flooding of the model domain and therefore required that the DTM be manually edited to fill the gaps.

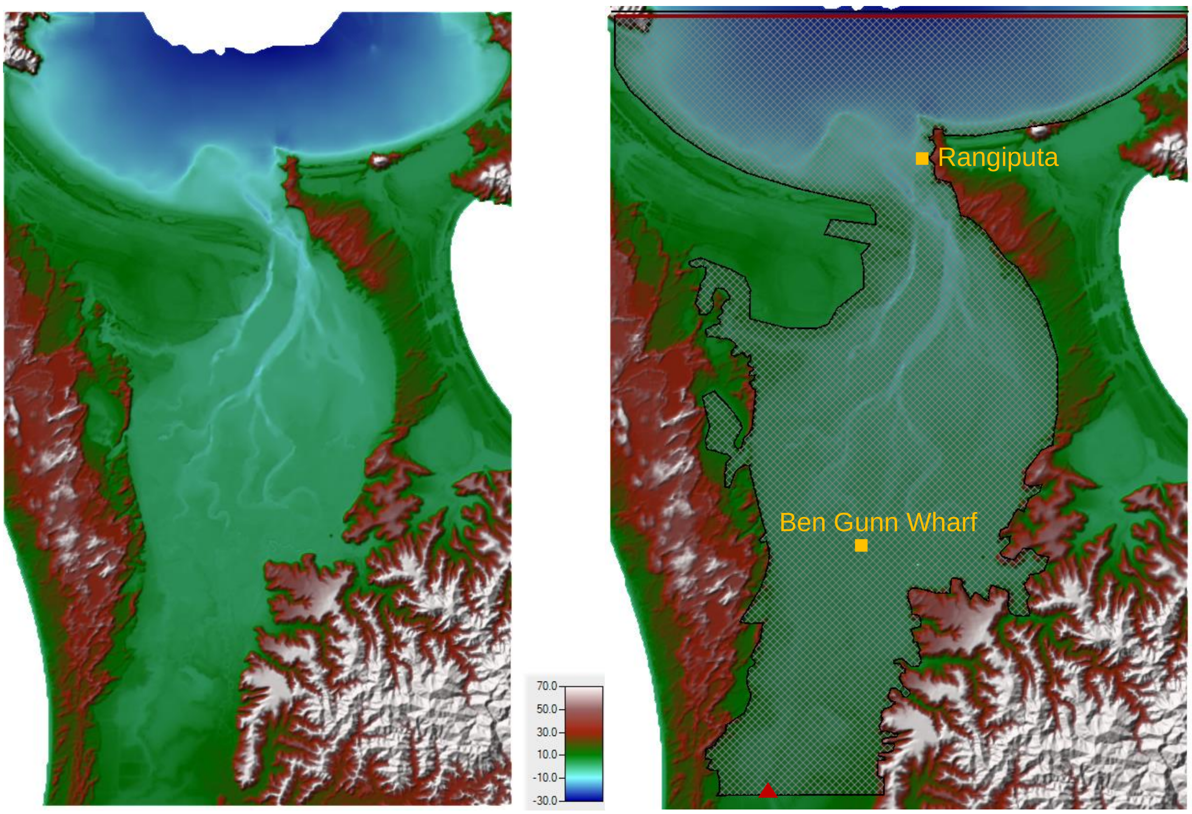


Figure 2.1. Rangaunu Harbour DTM, derived from 1 m x 1 m LiDAR and hydrographic chart data (left) and the DTM with the grid extents overlaid (right). The right image also shows the locations of the ocean boundary (red line), Awanui River boundary (red triangle), Ben Gunn Wharf and Rangiputa.

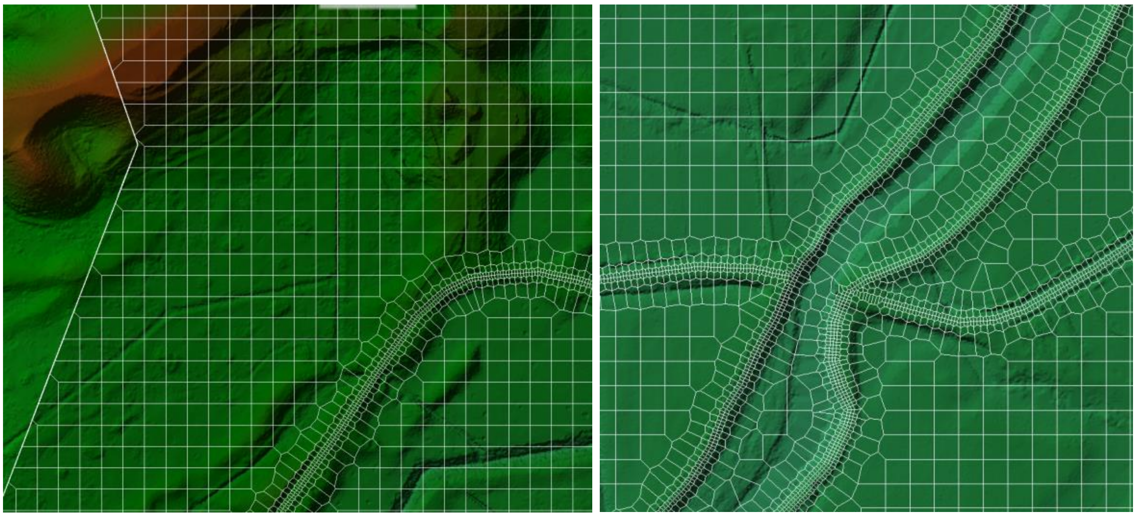
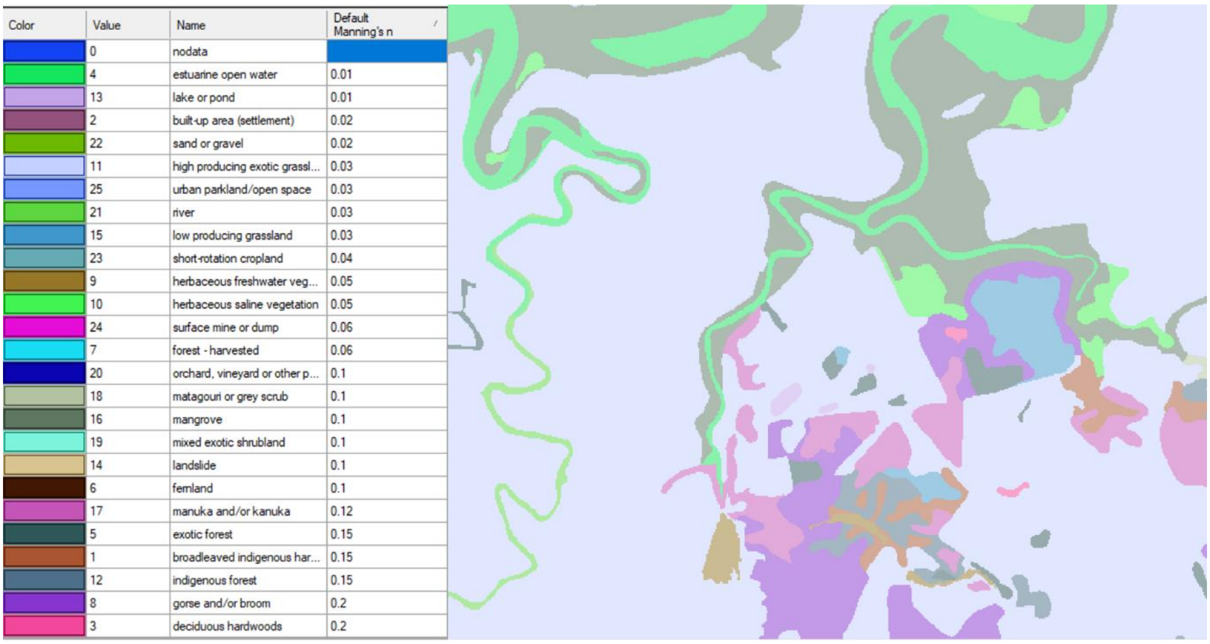


Figure 2.2. Typical grid cell shapes at the 2D flow area boundaries (left) and grid cell arrangement enforced by break lines (left and right).

2.3 Overland Roughness

HEC-RAS has the capability of defining spatially variable roughness within the model domain. This allows for realistic representation of the resistance to flood flows over rough land cover such as fernlands or mangroves. This was done by assigning Manning's roughness coefficients (Manning's n values) to each land use type recognised in the region. Land use shape files for each of the three model domains were acquired from the Land Resource Information Systems (LRIS) data portal and Manning's n values were assigned following U.S. Geological Survey Water Resources Division (1984) and Chow (1959). Figure 2.3 presents the Manning's n values used along with an example of the spatial distribution of the different land uses. It is also important to note that in regions where a land use was not specified, a default Manning's n value of 0.03 was applied to all model runs.

Manning's n values were adjusted to test for sensitivity and to calibrate the model (see Section 2.4.2 for more detail). The model was found to be relatively sensitive to changes in overland roughness, in the order of 50 cm differences in water level between extremes within reasonable ranges of Manning's n values.



Color	Value	Name	Default Manning's n
	0	nodata	
	4	estuarine open water	0.01
	13	lake or pond	0.01
	2	built-up area (settlement)	0.02
	22	sand or gravel	0.02
	11	high producing exotic grassl...	0.03
	25	urban parkland/open space	0.03
	21	river	0.03
	15	low producing grassland	0.03
	23	short-rotation cropland	0.04
	9	herbaceous freshwater veg...	0.05
	10	herbaceous saline vegetation	0.05
	24	surface mine or dump	0.06
	7	forest - harvested	0.06
	20	orchard, vineyard or other p...	0.1
	18	matagouri or grey scrub	0.1
	16	mangrove	0.1
	19	mixed exotic shrubland	0.1
	14	landslide	0.1
	6	fernland	0.1
	17	manuka and/or kanuka	0.12
	5	exotic forest	0.15
	1	broadleaved indigenous har...	0.15
	12	indigenous forest	0.15
	8	gorse and/or broom	0.2
	3	deciduous hardwoods	0.2

Figure 2.3. Example of land use types with associated Manning's n values for spatially varying roughness.

2.4 Model Forcing and Boundary Conditions

Coastal Flood Hazard Zone (CFHZ - consisting of storm tide, wave set up and sea-level rise) and Mean High Water Spring (MHWS) levels derived by Tonkin and Taylor (2020) have been assessed as follows: For each scenario, a tidal time series has been derived with maxima consistent with the maximum water level values in Table 2.1. The time series was then applied to the open ocean boundary model boundary and adjusted until the maximum water level values were correct at Ben Gunn Wharf to the south of the Rangaunu Harbour (Figure 2.1). The boundary condition creation process is discussed further in the following Section.

CFHZ0, CFHZ1, CFHZ2 and CFHZ3 represent storm surge levels corresponding to the current (2020) 1% Annual Exceedance Probability (AEP), 2% AEP with 2080 sea-level rise (SLR), 1% AEP with 2130 sea-level rise and 1% AEP with highest sea level rise scenario for 2130 respectively. MHWS-10 is the elevation exceeded by the highest 10% of all high tides.

Table 2.1. Water levels at Ben Gunn Wharf for each modelled scenario in m (NZVD), derived from Tonkin and Taylor (2020). The maximum water level is the sum of the storm surge/MHWS level and sea level rise (SLR).

Scenario Name	Storm Surge	MHWS-10 Amplitude	SLR	Max. Water Level
CFHZ0 (1% AEP)	1.58	-	0	1.58
CFHZ1 (2% AEP)	1.54	-	0.6	2.14
CFHZ2 (1% AEP)	1.58	-	1.2	2.78
CFHZ3 (1% AEP)	1.58	-	1.5	3.08
MHWS-10	-	0.93	0	0.93
MHWS 2080	-	0.93	0.6	1.53
MHWS 2130	-	0.93	1.2	2.13

2.4.1 Boundary Conditions

Tidal boundary conditions for the model runs were created using a simple approach: generating a 24-hour MHWS-10 tidal curve based on data from the Ben Gunn Wharf tide gauge (see Figure 2.1 for location), as well as data from Tonkin and Taylor (2020) and iteratively adjusting the input curve based on model results. A 24-hour model duration was chosen since drainage structures such as culverts and other small underpasses are not represented in the HEC-RAS model domains. Inevitably, storm surge flood models that do not represent drainage structures accurately show increased flood extent error with increased model durations, as water is unrealistically unable to drain away after each high tide during the storm surge event.

A mean tidal period of 6.2 hours was extracted from long term Ben Gunn Wharf data and a tidal amplitude of 0.93 m was used based on Tonkin and Taylor's (2020) MHWS-10 value of 2.4 m chart datum (CD), shifted to NZVD2016. The entire curve was shifted to account for sea level rise where applicable (Table 2.1). For the storm surge scenarios (CFHZ0, CFHZ1, CFHZ2 and CFHZ3), the second high-tide peak was adjusted to match the maximum water level values in Table 2.1.

As the model boundary condition was applied approximately 18 km from Ben Gunn Wharf (Figure 2.1), the input tidal curve needed adjustments for some model runs to ensure that the maximum water levels were accurate at the wharf (Table 2.1). This was an iterative process which produced an input tidal curve multiplier of 1.1 for the CFHZ model runs and no multiplier for the MHWS model runs.

There was also a river flow boundary at the south of the domain, at the Awanui River near Kaitaia (Figure 2.1). A constant flow of 3 m^3/s was chosen as a representative value for the Awanui River and was applied to all scenarios.

All boundary condition time series are presented in Appendix B.

2.4.2 Model Validation

In order to validate the model, the MHWS-10 scenario (Table 2.1) was used to make sure there were no stopbank breaches in the model domain, which would not be expected under mean high water spring conditions. As mentioned in Section 2.2, stopbanks were breached in various locations due to gaps in the DTM, which were then filled manually in an iterative process. In the end a satisfactory MHWS-10 validation was achieved and is shown in Appendix A.

Another way to validate the model was to check the maximum water level reached at Rangiputa, to the east of the Rangaunu Harbour mouth (Figure 2.1), for all model runs. Rangiputa is another location that was assessed by Tonkin and Taylor (2020) for MHWS-10 and CFHZ conditions. The overland roughness of the model was adjusted until the appropriate maximum water level was achieved at Ben Gunn Wharf and the best possible levels were achieved at Rangiputa.

After adjusting overland roughness, modelled maximum water levels at Rangiputa were found to match the Tonkin and Taylor (2020) values for their Rangiputa output cell (Table 2.2).

Table 2.2. Differences between maximum modelled water levels at Rangiputa and those reported by Tonkin and Taylor (T + T, 2020) in m NZVD.

Scenario Name	T + T (2020)	Modelled
CFHZ0 (1% AEP)	1.7	1.7
CFHZ1 (2% AEP)	2.2	2.2
CFHZ2 (1% AEP)	2.9	2.9
CFHZ3 (1% AEP)	3.2	3.2
MHWS-10	0.9	0.9
MHWS 2080	1.5	1.5
MHWS 2130	2.1	2.1

3 Results

Model results from the seven inundation scenarios presented in Table 2.1 were processed into raster files of maximum water surface elevation, maximum water velocity and maximum depth, as well as flood extent shape files. All model results are displayed in Appendix A.

4 Study Limitations and Assumptions

1) Storm rainfall was not considered in this study and can have a significant influence on storm surge flood extents.
2) Drainage structures were not represented in the HEC-RAS model domains. These features can alter the flow of floodwaters both onto and away from low-lying regions.
3) With no up to date stopbank survey data, only the DTM could be used as a reference, which in some locations may not be fully accurate.

5 Summary and Conclusions

1) A hydrodynamic model (HEC-RAS version 5.0.7) of Rangaunu Harbour was created to simulate inland flooding under seven extreme scenarios:
   - 1% Annual Exceedance Probability (AEP) 2020 static water level;
   - the 2% AEP 2080 static water level,
   - the 1% AEP 2130 static water level,
   - the 1% AEP 2130 static water level under highest sea level rise scenario,
   - the 10% exceedance mean high water spring (MHWS) level,
   - the 2080 MHWS level, and,
   - the 2130 MHWS level.
2) The model was sensitivity tested for domain size, cell size and overland roughness.
3) The model was validated using MHWS-10 conditions for a period of 24-hours, ensuring that no flooding was occurring and typical water levels were observed.
4) An additional validation was undertaken by comparing modelled water levels at Rangiputa to those reported by Tonkin and Taylor (2020).
5) Maximum water surface elevation, maximum water velocity and maximum depth shape files of coastal flood extents have been supplied to NRC.

References

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HEC-RAS (2016). U.S. Army Corps of Engineers Institute for Water Resources Hydraulic Engineering Centre River Analysis System – User's Manual Version 5.0.

O'Neill, S., McIntosh, R., Borrero, J. & Mead, S., (2017). Coastal Flood Modelling of Ruawai, Kaihu-Dargaville and Awanui. Technical Report prepared for Northland Regional Council, November 2017.

Tonkin and Taylor Ltd. (2020). Coastal Flood Hazard Assessment for Northland Region 2019-2020. Technical Report prepared for Northland Regional Council, October 2020.

U.S. Geological Survey Water Resources Division (1984). Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Floodplains. Technical Report number FHWA-TS-84-204.

Appendix A. Model Result Maps

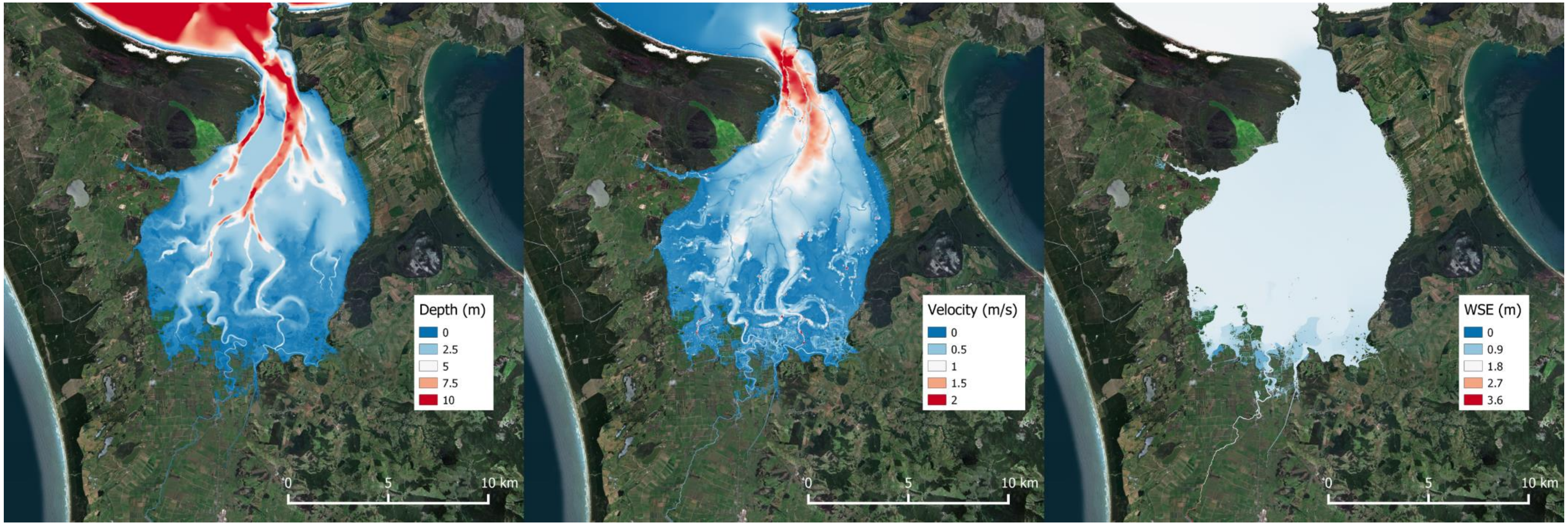

Figure A.1. Rangaunu Harbour CFHZ0 model run maximum depth, velocity and water surface elevation.

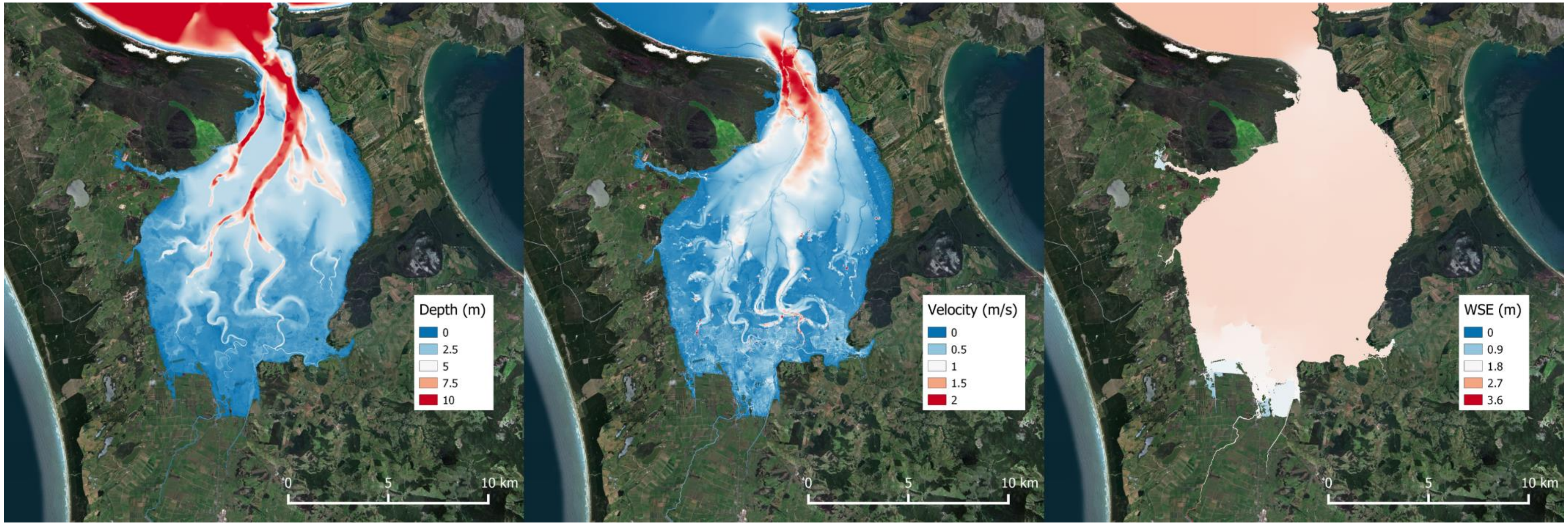

Figure A.2. Rangaunu Harbour CFHZ1 model run maximum depth, velocity and water surface elevation.

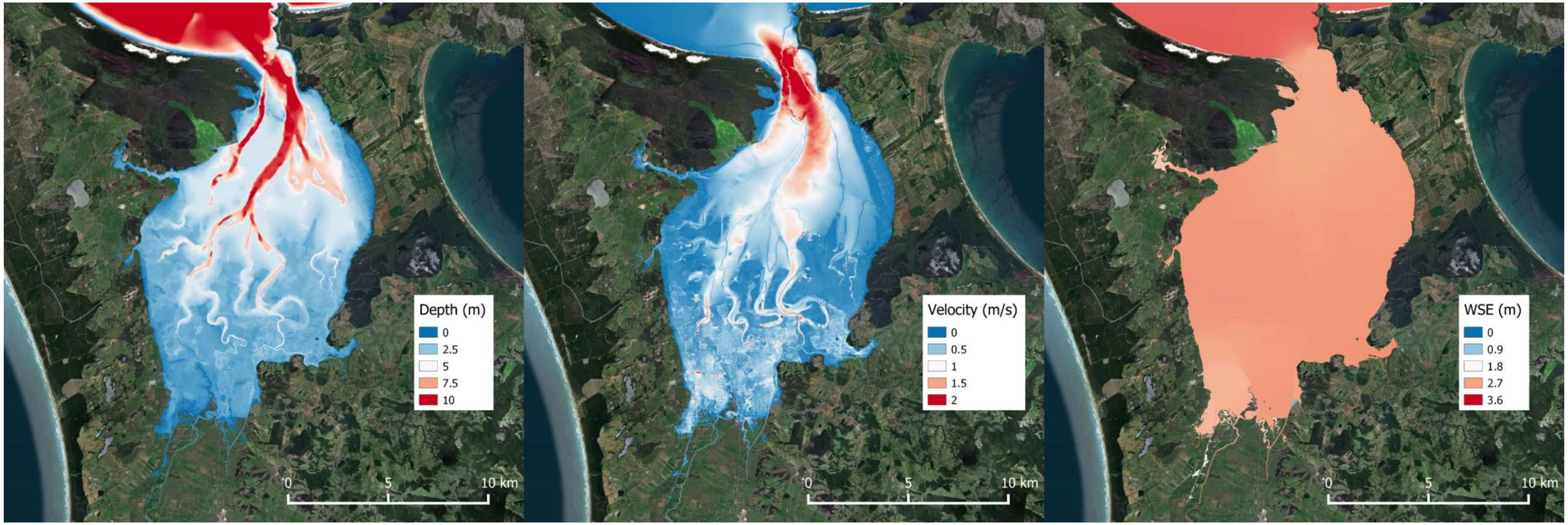

Figure A.3. Rangaunu Harbour CFHZ2 model run maximum depth, velocity and water surface elevation.

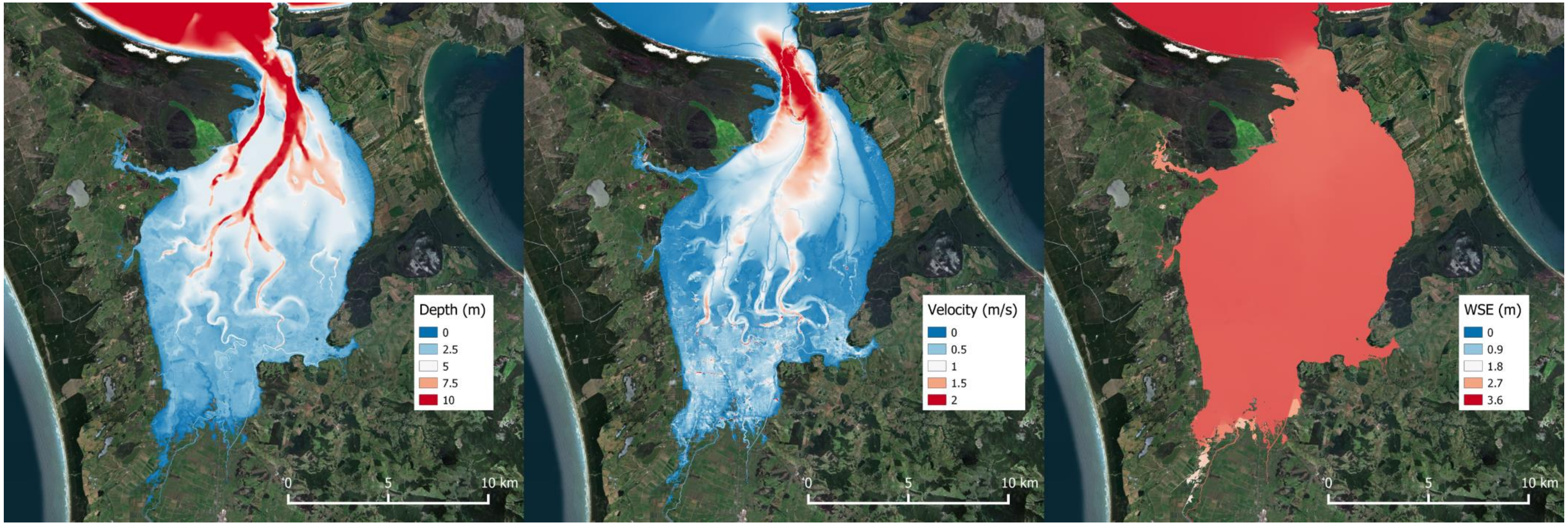

Figure A.4. Rangaunu Harbour CFHZ3 model run maximum depth, velocity and water surface elevation.

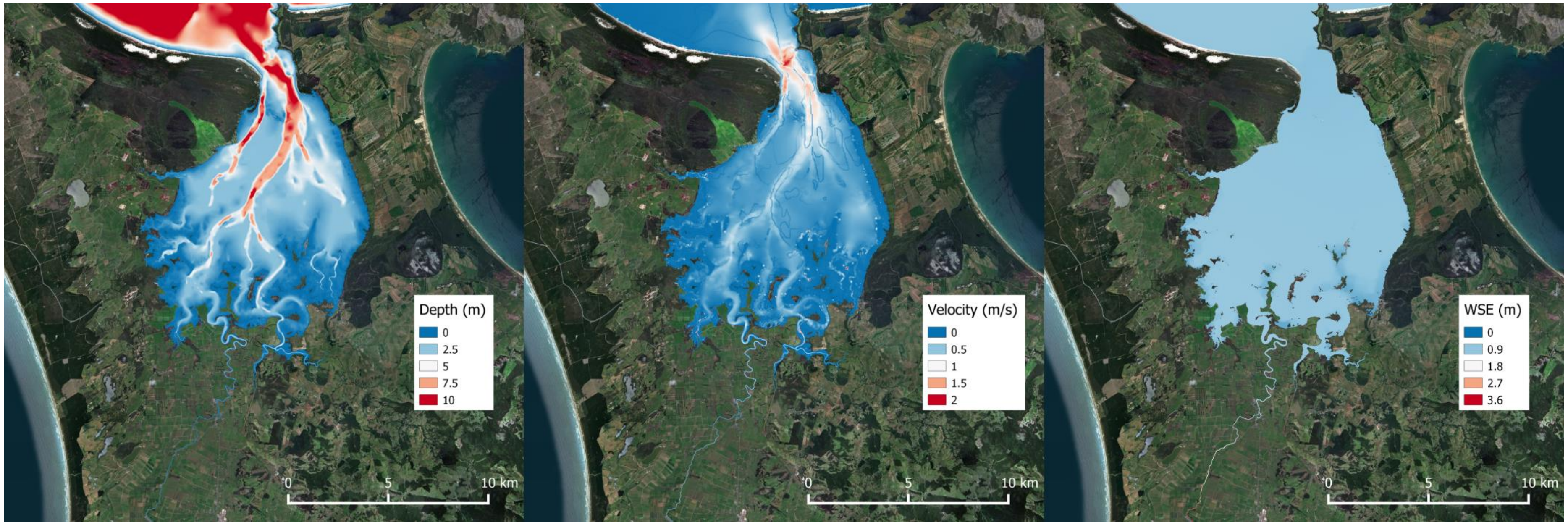

Figure A.5. Rangaunu Harbour MHWS-10 model run maximum depth, velocity and water surface elevation.

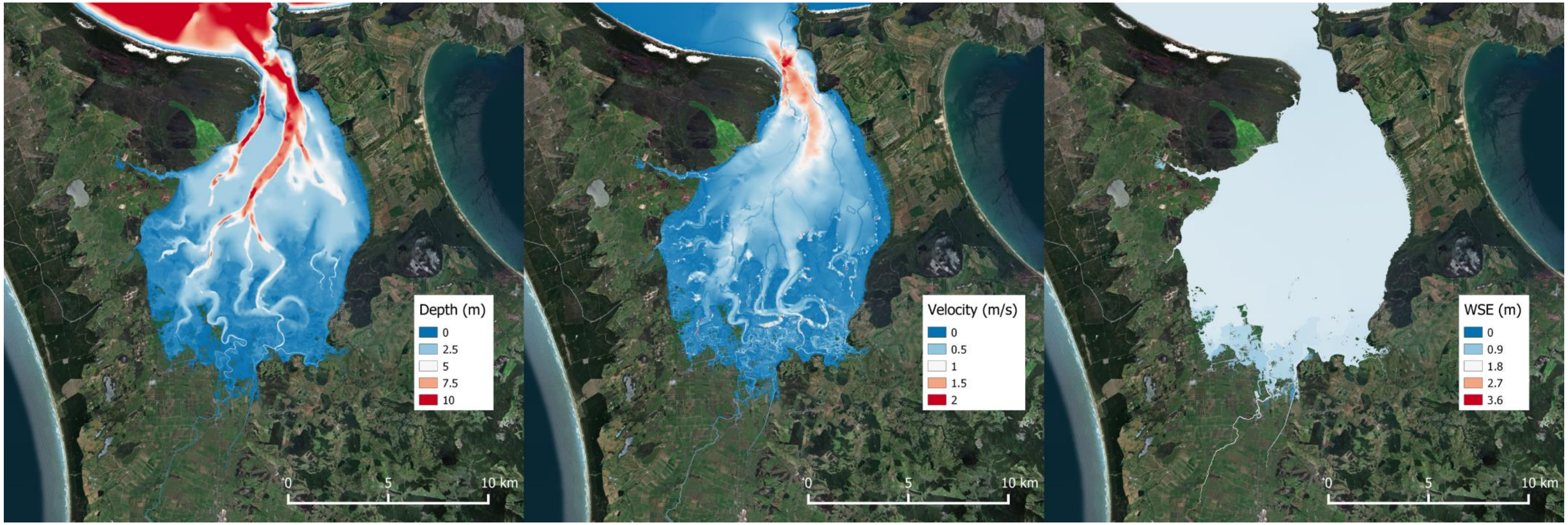

Figure A.6. Rangaunu Harbour MHWS 2080 model run maximum depth, velocity and water surface elevation.

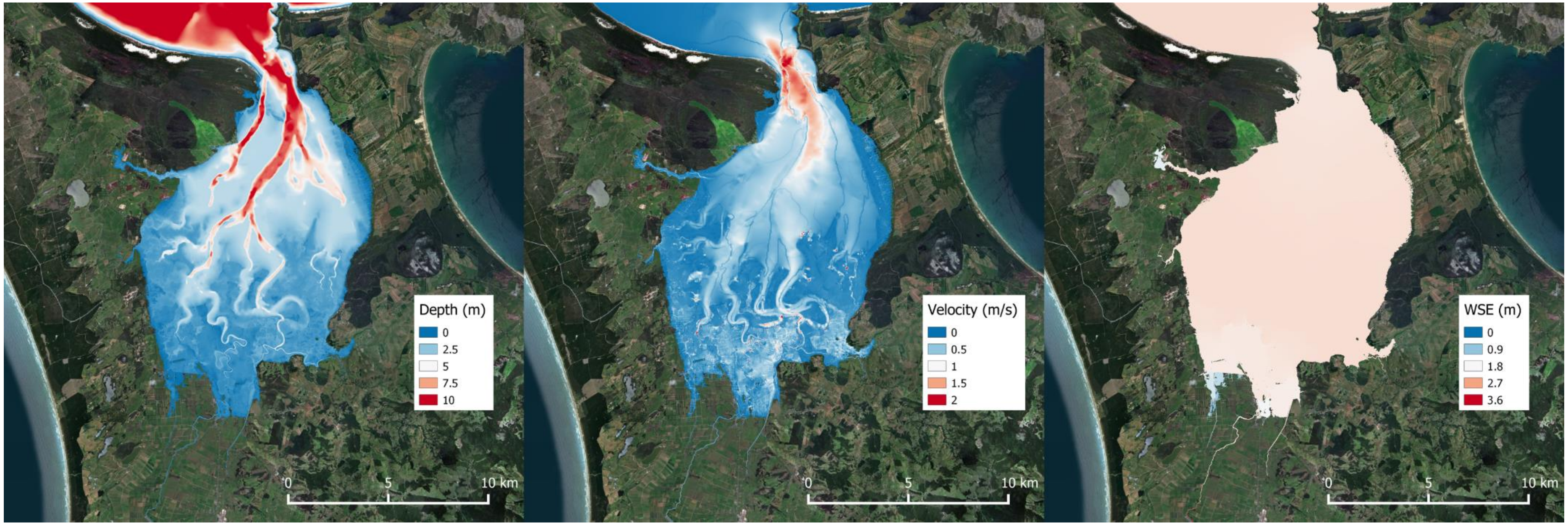

Figure A.7. Rangaunu Harbour MHWS 2130 model run maximum depth, velocity and water surface elevation.

Appendix B. Model Boundary Conditions

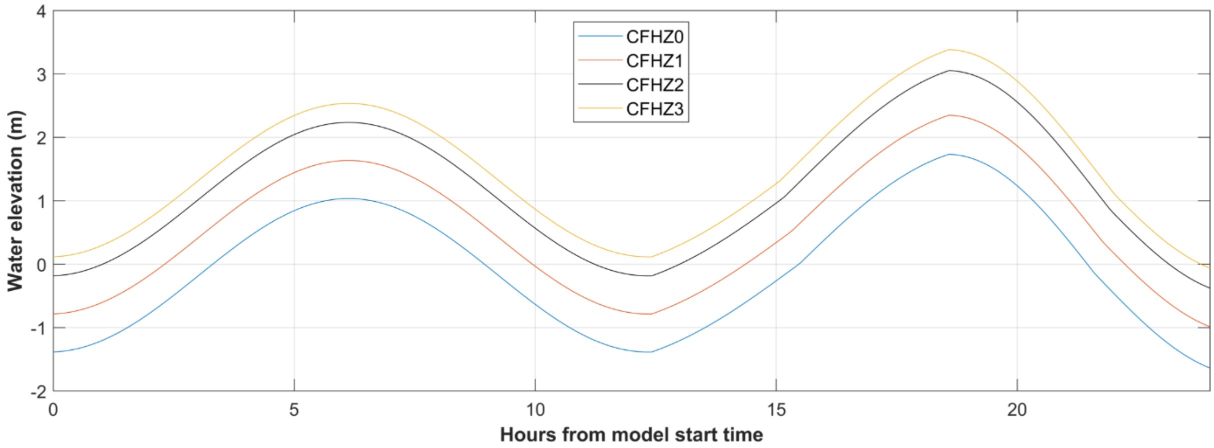

Figure B.1. Ocean boundary condition for Coastal Flood Hazard Zone (CFHZ) model runs. Note that the maximum water elevations are higher than those presented in Table 2.1 due to a multiplier of 1.1 being applied to them (see Section 2.4.1).

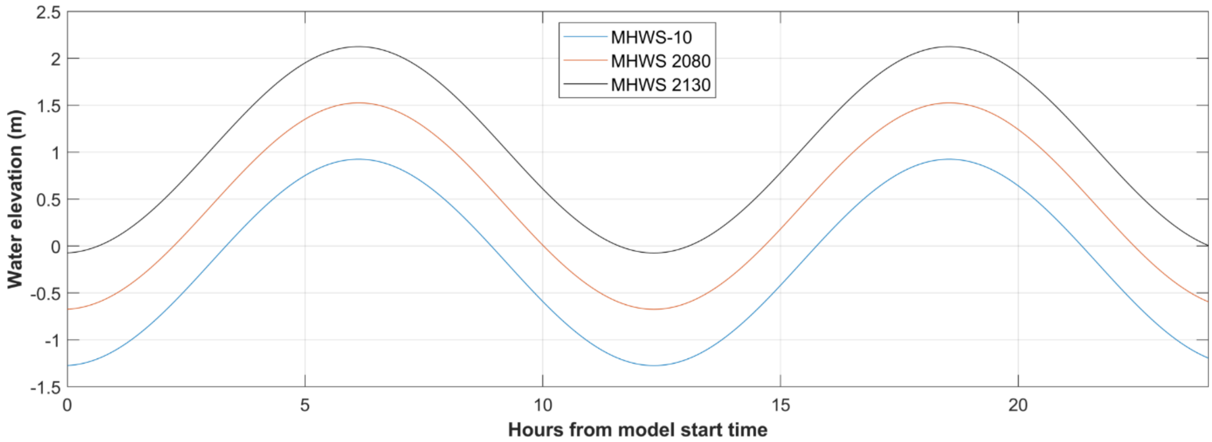

Figure B.2. Ocean boundary condition for Mean High Water Spring (MHWS) model runs.