Te Karaka Flood Resilience

Hydraulic Modelling

Report

13th April 2026

Prepared for Gisborne District Council

The expert in **WATER ENVIRONMENTS**

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Hydraulic Modelling

Report

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1 Introduction

In February 2023, Cyclone Gabrielle caused significant flooding in the Te Karaka township as a direct result of floodwaters overtopping the stopbanks of the Waipaoa River. This catastrophic flooding caused one person's life to be lost. Five hundred people were evacuated to higher ground from the small inland town, 31 kilometres from Gisborne. The call to evacuate by local Civil Defence volunteers was critical and undoubtedly saved many lives in Te Karaka.

In mid-2023, DHI was commissioned by Gisborne District Council (GDC) to carry out flood modelling for the Waipaoa River at the Te Karaka township. Stage One of this modelling investigation has focussed on Te Karaka, with Stage Two to considering overdesign events and determining what information would be helpful for a civil defence response. The aim of Stage One was to answer the following:

- Current Level of Service of Existing Scheme
- What does an Equal Level of Service (to what the Waipaoa Scheme is currently being upgraded to) look like for Te Karaka. How does that impact upstream/downstream properties, bridges, roads and other infrastructure?
- How would a partial upgrade for the top half of Te Karaka scheme protect houses in the township, but still allow spillover/losses into the southern basin protected by the scheme for storage function (where there's no housing)?
- Are there benefits of a secondary flowpath following the state highway on the western side?
- Are there benefits to protecting the State Highway low point (Nisbit Dip) just south of Te Karaka so that evacuation is possible?
- Understanding the residual risk of the solution.

This report summarises an investigation into providing the Te Karaka township with a more resilient flood protection scheme. Poverty Bay experienced a large flood in May 1948, that resulted in an (estimated) flow at Kanakanaia Bridge of 3,965 m^3/s (140,000 cusecs). This event caused extensive flooding in the Gisborne area and instigated the Waipaoa Flood Control Scheme (WFCS), which was built in the 1950's and 1960's. The scheme also included stopbanks in Te Karaka along the Waipaoa River. The Te Karaka Flood Control Scheme upgrade was only partly complete when cyclone Bola hit and, because of this, was outflanked and seriously damaged. After cyclone Bola, the design was modified to allow for a cyclone Bola maximum water level plus 300 millimetres. This stopbank design level did not account for climate change or bed aggradation. The Te Karaka Flood Control Scheme upgrade was completed in 2002.

It is noted that any changes to Te Karaka's current flood protection measures could impact the Waipaoa River's downstream reaches and/or the WFCS.

Section 2 of this report details previous modelling for the Waipaoa River, focusing on the modelling that was completed to enable the WFCS to be consented and designed/constructed. Section 3 briefly lists the data used in the model. Section 4 describes the model schematisation, which details why the model was updated in certain locations and by certain means. Section 5 details the model inflow boundaries and hydrological modelling that was undertaken, and Section 6, the hydraulic modelling. Section 7 covers the model calibration and validation, with Section 8 describing the scenarios modelled. Section 9 details the preferred option modelled with conclusions in Section 10.

Land River Sea Consulting Limited were engaged as peer reviewer for this project and have been involved at all key stages of the project.

2 Previous Modelling

The WFCS comprises approximately 64 kilometres of stopbanks along the Waipaoa River, together with other river control structures and protection works (pipes, floodgates etc). Construction started in 1953 and was completed in 1969, to provide flood protection to the Poverty Bay floodplains and Gisborne City.

Hawkes Bay Regional Council (HBRC) developed a MIKE FLOOD model of the Waipaoa River on behalf of GDC, in order to aid design of stopbank upgrades for the river. The aim of the current upgrade project (anticipated to be complete in 2028) is to increase the level of flood protection of the WFCS to a 100 year return period event accounting for climate change effects out to the year 2090. The upgraded stopbanks have an associated freeboard of 600 millimetres incorporated into the design.

The HBRC model (circa 2017) provided to DHI in 2018, for review purposes, was a 1D-2D coupled MIKE FLOOD model, with the central channel represented in 1D (MIKE 11) and the river berms represented in 2D (MIKE 21). Areas of floodplain beyond the stopbanks were also represented in the 2D component of the model but were, in effect, excluded by the stopbanks being set well above expected design levels, to ensure that all flow would be contained within the stopbanks. The model extent is from Kanakanaia Bridge to the coast. This model was the starting point for building an extended and updated model for this study.

A peer review carried out by DHI in 2018 was conducted in two stages, starting with a review of the model build and followed by review of the model calibration. This 2018 model was calibrated to the Cyclone Bola event, which had an estimated lower end maximum flow of 4,500 m^3/s, (NIWA, 2011). The model build was reviewed firstly and feedback was provided back to GDC. Changes to the model build by GDC followed the DHI review. Following this the model calibration was reviewed. This review, was one-directional: i.e. DHI were provided with the model and provided review comments back to GDC. Past this point, DHI were not party to any changes made to the model, in response to the review comments and suggestions.

3 Data

A variety of different types of data have been used for the model update including:

Table 1 – Data supplied for use in the model

Item	Description	Data Source
1	Various topographical/bathymetry surveys	GDC
2	2019 LiDAR	GDC
3	2023 LiDAR	LINZ
4	Surveyed Stopbank Levels	GDC
5	Surveyed Flood Levels & Debris Lines	GDC
6	Mapped Sediment Extent	GDC
7	Water Level & Flow Data @ Kanakanaia Bridge	GDC
8	TOPNET Discharges	ESNZ
9	New Zealand River Flood Statistics	ESNZ Online
10	Kanakanaia & Rangitara Bridge drawings	GDC
11	Caesar to Ngakaroa Crest Levels	Earthworks Solutions
12	Design Near Bridge, 1053 Levenham Rd to 1913 Matawai Rd Crest Levels	Civil Projects
13	Te Karaka Stopbank Shapefiles	Civil Projects
14	Te Karaka Options to be modelled	Tonkin Taylor
15	Te Karaka Accreation Surface	Tonkin Taylor
16	Western and Eastern Waipaoa Scheme stopbanks as built levels	GDC
17	Te Karaka Stopbank Design V4	GDC

4 Model Schematisation

Once the data was received, the initial focus of this project was the model schematisation. The objective of the model schematisation was to answer the following questions:

- What should be the extent of the 1D and 2D domain and how much should the 1D model be utilised?
- How much of the model to represent as hydrology vs fully hydrodynamic?
- What simplifications need to be made?
- Should a grid or mesh be used?
- What is an ideal mesh resolution?
- What model run times are we aiming for?

Several internal meetings were held during the early stages of the project, supported with test model simulations, to determine the best approach. In particular, the test simulations gave us an idea of the expected model run times. This internal process was followed by meetings with the peer reviewer before settling on a final model schematisation.

The final model schematisation consists of a 2D model covering the full extent of the Stage 1 area of interest, i.e. Te Karaka. The 2D model extent is shown in Figure 1. Upstream of the 2D extent, a short length of 1D model routes the hydrological inflows provided by Earth Sciences New Zealand (ESNZ), into the top of the 2D model. Downstream of the 2D extent, the Waipaoa River is modelled using a 1D/2D coupled model, with the lower section isolated to a 1D only model, based on the Hawkes Bay Regional Council's (HBRC) 2017/2018 model. The lower section of the model does not allow flood flows to spill onto the floodplain area; instead, it has "glass walls" to contain flows. This approach does not affect model results in the area of interest for Stage 1, Te Karaka.

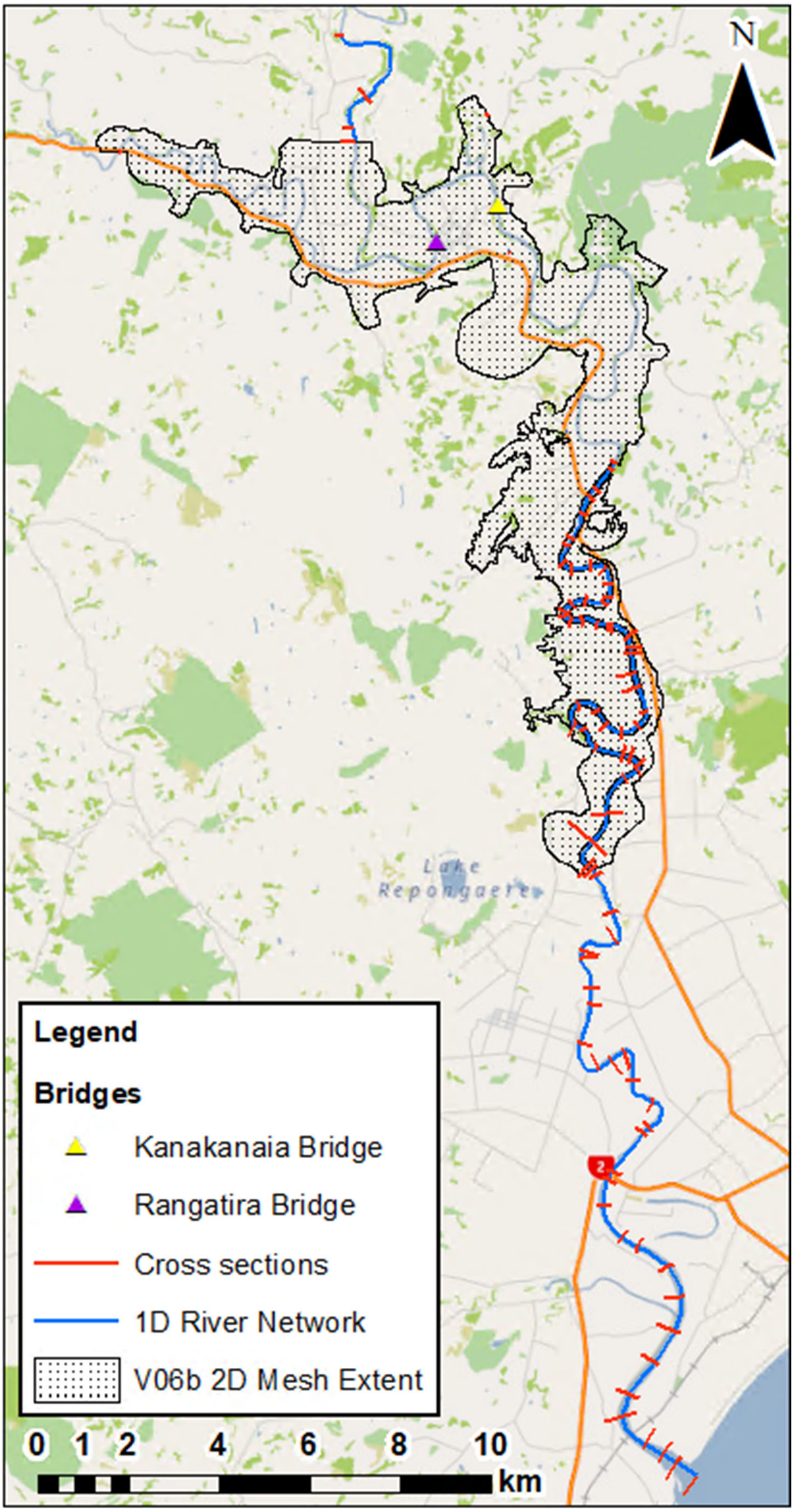

Figure 1 - Waipaoa MIKE+ model extent

Figure 2 and Figure 3 show the 2D extent of the model and the detail of the mesh resolution. A mesh was used rather than a grid to make use of being able to align the mesh elements to the river direction, thus helping improve model accuracy while maintaining a fast run time. The main river channels are represented as quadrilateral mesh elements, with two bridges and two key culverts included. Major and minor hydrograph inflow locations for the 1D and 2D are also shown. The major inflows were supplied directly by ESNZ based on their national TOPNET model. Minor inflows (green points) were derived from the New Zealand River Flood Statistics online portal, with more detail provided in Section 5.

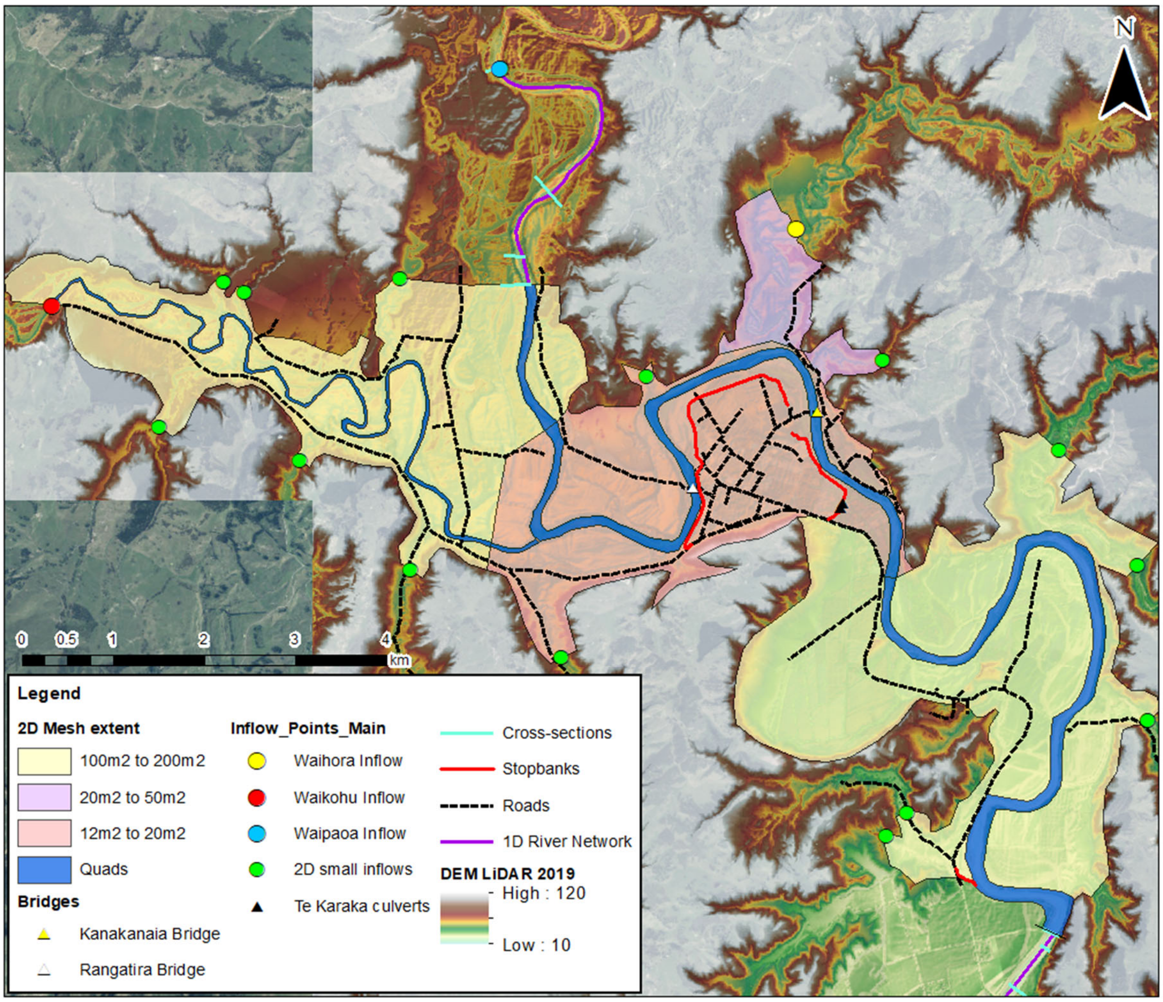

Figure 2 - Waipaoa MIKE+ 2D extent details Upper Area

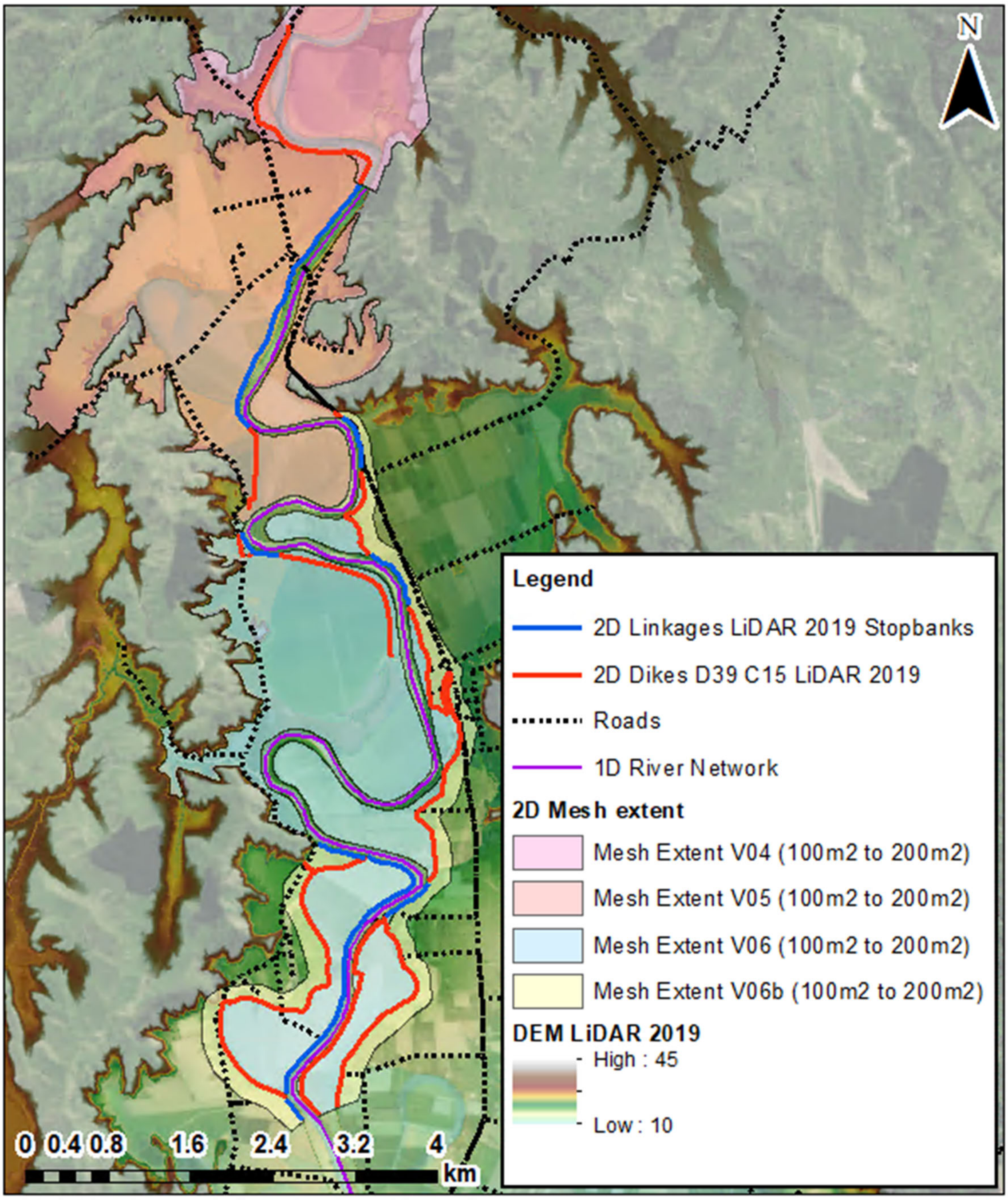

Figure 3 - Waipaoa MIKE+ 2D extent details Lower Area

The detail included in the mesh was defined by the physical drainage features, the land use type and the underling terrain. The key features modelled and the mesh sizes used are shown in Table 2.

Table 2 - Waipaoa mesh sizes based on land-use or land features

Land use type	Waipaoa Mesh	
	1,347,839 elements	
	Minimum element size, m^2	Maximum element size, m^2
Rural or underdeveloped	18	150
Urban areas and buildings	12	13
Roads	12	20
Small tributary rivers	12	20
Large buildings	12	10
Streams (Quads)	12	25
Stopbanks (Quads)	20	25

A graphical representation of the mesh is shown in Figure 4 and Figure 5. With the blue points showing where additional detail is included.

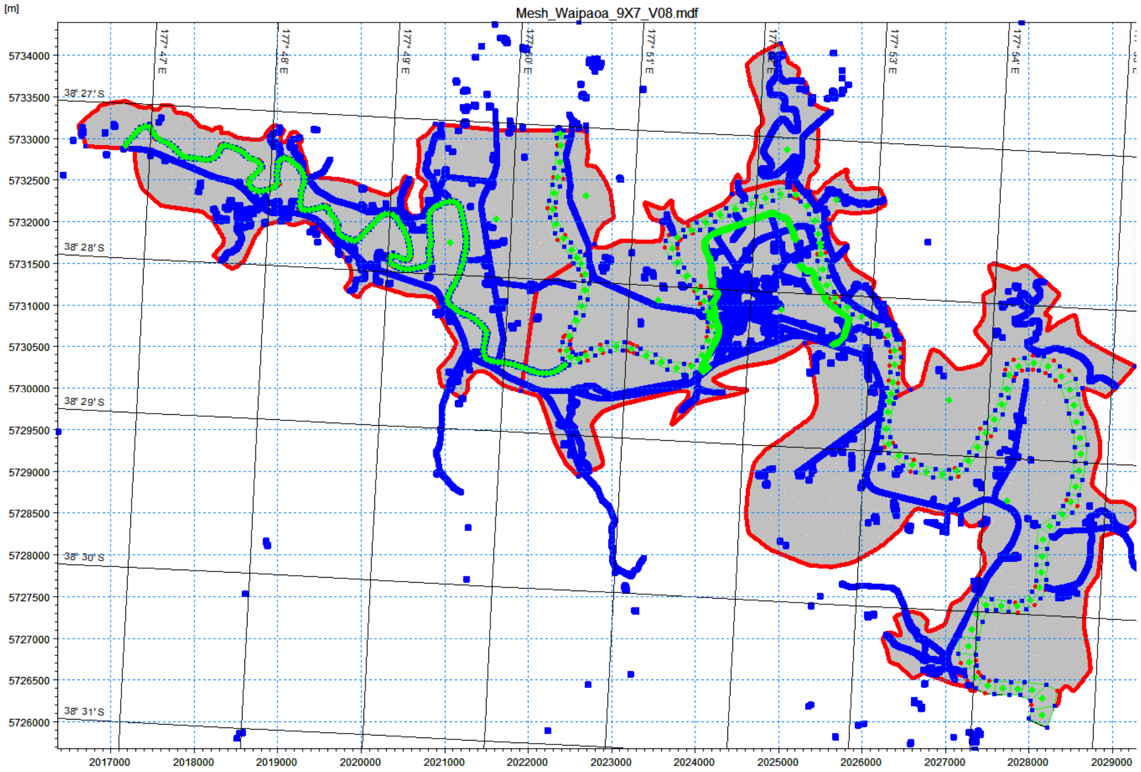

Figure 4 – Initial Mesh schematization in the Mesh Generator tool up to version V04

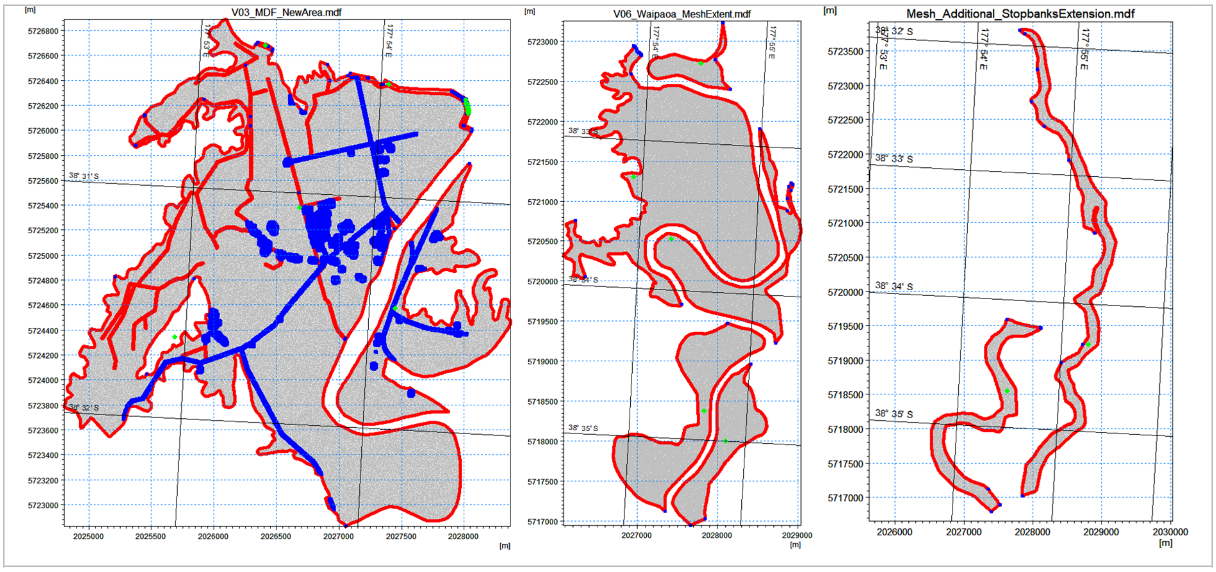

Figure 5 - Mesh schematization additions to create the mesh versions V06b to V09b

5 Model Inflow Boundaries & Hydrological Modelling

5.1 Cyclone Gabrielle Inflows

Cyclone Gabrielle was the calibration event used for the updated model of the Waipaoa River. As noted in Section 4, ESNZ provided hydrographs from its TOPNET model for the Cyclone Gabrielle event inflows. They provided inflows for the Waipaoa River at the top of the model extent and two tributaries of the Waipaoa River, the Waihora and Waikohu Rivers. ESNZ's estimated flow at the Kanakanaia gauge was 4,417 m^3/s, with GDC recording 3,968 m^3/s.

For twelve smaller tributaries, inflows were derived by DHI at the locations shown in Figure 2. This derivation assumed that the Cyclone Gabrielle event was approximately a 1-in-100-year event for inflow estimation for all other tributaries in the model. The Q100 peak flow values from ESNZ's New Zealand River Flood Statistics online tool for each tributary were used to produce an inflow hydrograph based on the ESNZ-supplied hydrograph for the Waihora catchment. The Waihora catchment was the smallest of the ESNZ-supplied hydrographs and, size-wise, more appropriate to use to derive scaled hydrographs based on catchment size. The timing of the hydrographs was also adjusted based on their size and length relative to the Waihora catchment hydrograph, so they coincided at Kanakanaia Bridge. Sub-catchment sizes ranged from 1-42 km^2 and derived peak flows from 8 – 830 L/s. Including the twelve tributaries is unlikely to significantly impact overall flood flows or water levels in Te Karaka, due to their small size relative to the rest of the catchment. These twelve tributary inflows were only included for the Cyclone Gabrielle event for completeness, and not for the 5,625 m^3/s design event described in Section 5.2 or the 1 in 500 year event described in Section 5.3.

5.2 Design Event, 5,625 m^3/s Inflows

The Waipaoa River Flood Control Scheme (WFCS), is an upgrade project that started investigation in 2012 and began construction in 2019. The scheme will be completed in 2028. The design discharge for the scheme was based on analysis that NIWA undertook in 2011. In the NIWA report (NIWA, 2011), the discharge estimate for Cyclone Bola was presented with a variation between 4,500 m^3/s and 6,100 m^3/s. A coupled 1-dimensional/2-dimensional river/floodplain model was created by HBRC and calibrated by HBRC to Cyclone Bola using the lower end of the discharge estimate (4,500 m^3/s) with no bed scour, (HBRC,2018). This model was then updated to include cross sections surveyed in 2017, and a design discharge with a peak of 4,500 m^3/s x 1.25 = 5,625 m^3/s was input to the model to represent the 1 in 100-year (±20%) return period discharge (assumed to be 4,500 m^3/s) plus a 25% increase for climate change to year 2090.

The same design event hydrograph has been used for this investigation, but has been scaled down to produce three inflow hydrographs, for the Waipaoa, Waihora and Waikohu Rivers that total to approximately 5,625 m^3/s at the Kanakanaia gauge site, Figure 6.

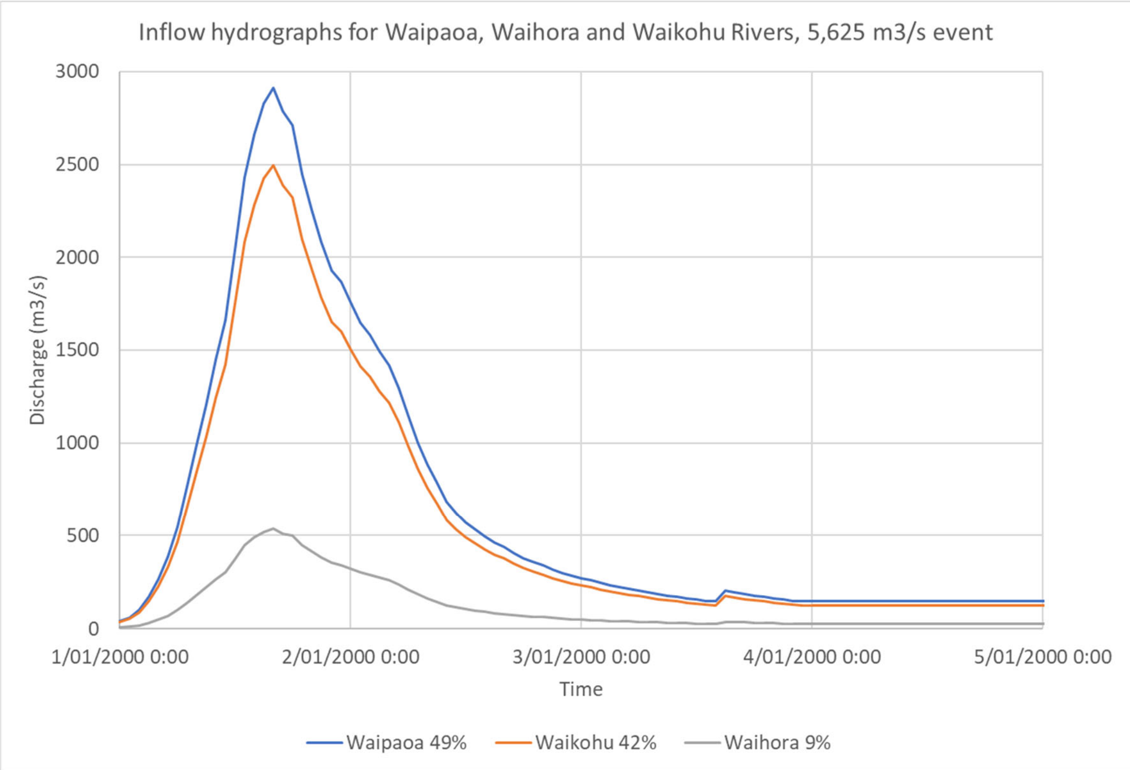

Figure 6 – Inflow hydrographs for Waipaoa, Waihora and Waikohu Rivers, 5,625 m^3/s event

5.3 1 in 500-year climate change-adjusted event

A flood frequency analysis of the flow record at the Kanakanaia Bridge gauge was completed as a starting point for developing a suitable 1-in-500-year climate-change-adjusted inflow for the flood model, to assess the impacts of an extreme event at Te Karaka and upstream and downstream of Te Karaka.

NIWA (2024) carried out a number of flood frequency analyses of the Cyclone Gabrielle event and assigned return periods to the various rivers in the Hawkes Bay/Gisborne region. They used a GEV distribution for the Waipaoa River at Kanakanaia, but suggested that anything above a 1 in 200-year event could be overestimated, due to the curving shape of the GEV distribution. With that understanding, and without any other suitable simplistic approach (that doesn't involve a standalone detailed study/analysis), we have also used a GEV analysis for the derivation of the 1 in 500-year event. This is on the understanding that this approach may produce a conservative answer.

We have also applied a climate change adjustment to the 1 in 500-year flood event discharge. This was done by creating a MIKE RDI (semi-distributed continuous hydrological model) model of a single catchment upstream of the Kanakanaia Bridge gauge. This model was then auto-calibrated to the flow record at the Kanakanaia Bridge gauge using actual recorded rainfall in the catchment. The calibrated model was then adjusted to allow for the antecedent conditions (by changing the initial conditions) and to achieve a match between rainfall and runoff, i.e. a 1 in 500 year rainfall produces a 1 in 500 year runoff. Following this 1 in 500 year rainfall with RCP 8.5 from HIRDS was run in the MIKE RDI model to get the resulting runoff peak flow of 14,869 m^3/s at the Kanakanaia River gauge. This peak flow value from applying the 1 in 500 year rainfall with RCP 8.5 was then used to scale the 5,625 m^3/s flow hydrograph for the same three river inflows as mentioned in Section 5.2, for the Waipaoa, Waihora and Waikohu Rivers, see Figure **7** below.

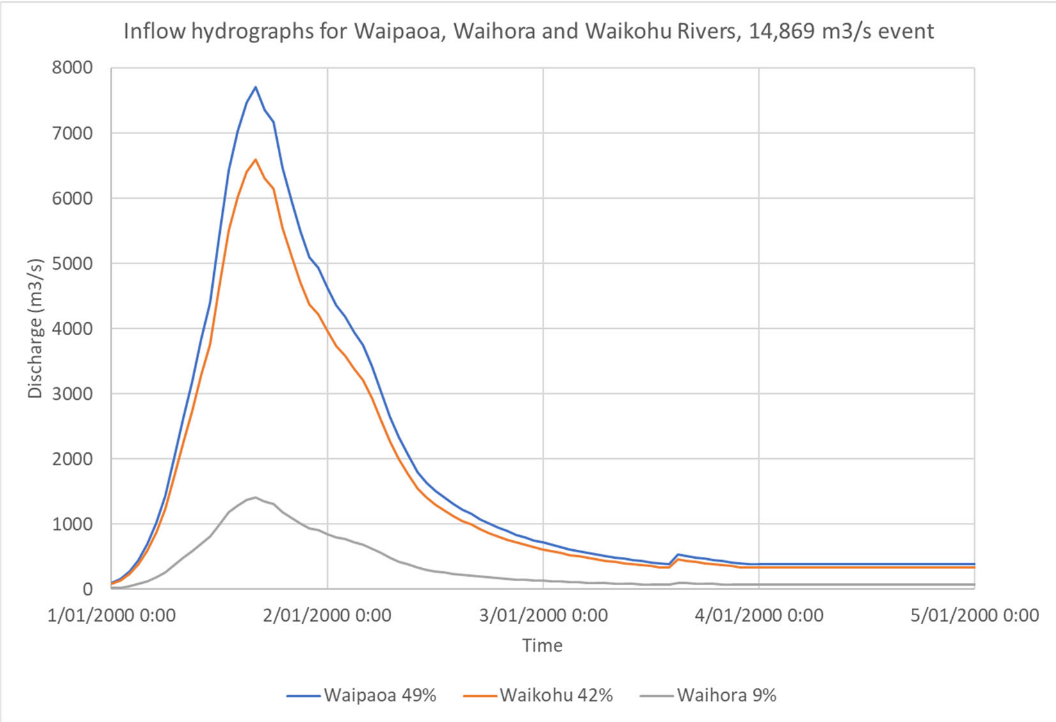

Figure 7 - Inflow hydrographs for Waipaoa, Waihora and Waikohu Rivers, 14,869 m^3/s event

6 Hydraulic Modelling

The model is built in the NZGD 2000 NZTM and NZVD2016 horizontal and vertical coordinate systems.

6.1 2D River Channels

The following methodology was used to generate the main river channels for the Waipaoa and Waikohu rivers:

- Create 1D cross-sections using MIKE+ cross-section generator from the XYZ points provided. For Waikohu, as survey data was provided, an intermediate step was carried out to extract cross-sections from the provided point cloud
- Run the MIKE+ model, an accurate representation of the cross-sections in 1D and define the output “2D Map” – “DEM” from the “Network” model type to obtain a raster interpolation of the cross-sections
- Replace the ground levels of the LiDAR bathymetry raster with the interpolated cross-section raster only for the areas that cover the main river channel using a polygon to clip areas that should not change.
- Interpolate the mesh elements using the new bathymetry raster.

Examples of the mesh structure and element sizes for the Kanakanaia and Rangatira bridges and surrounding areas are shown in Figure 8 and Figure 9.

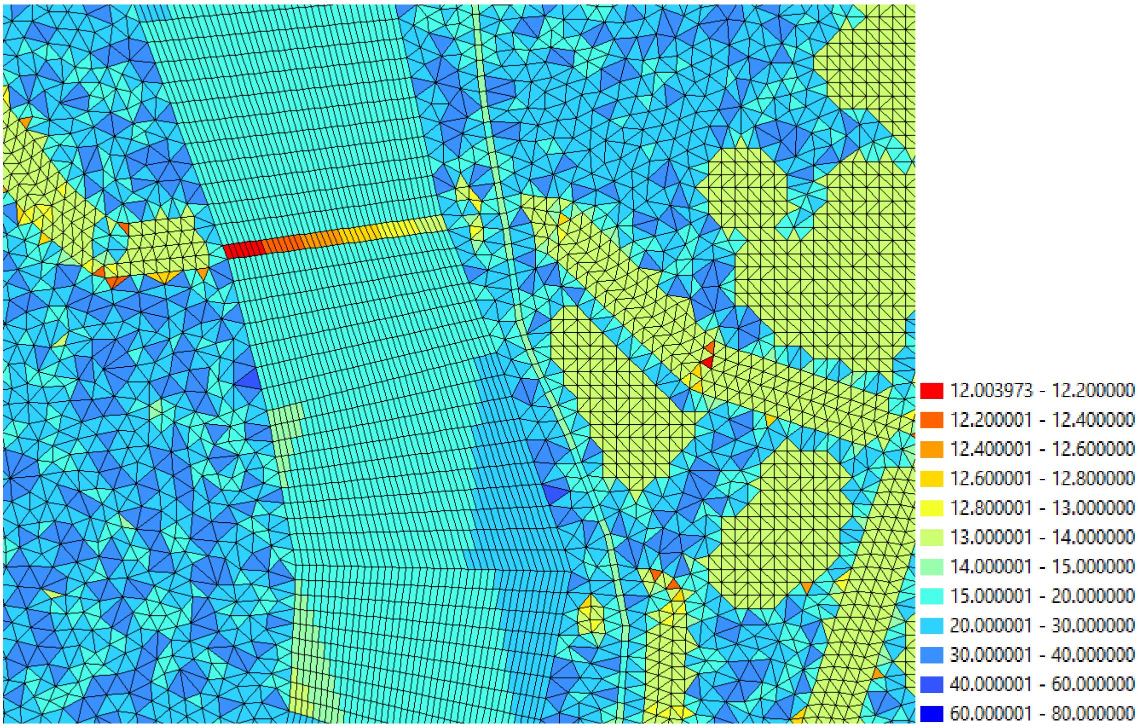

Figure 8 – Mesh structure sample at Rangatira Bridge, with the element size shown

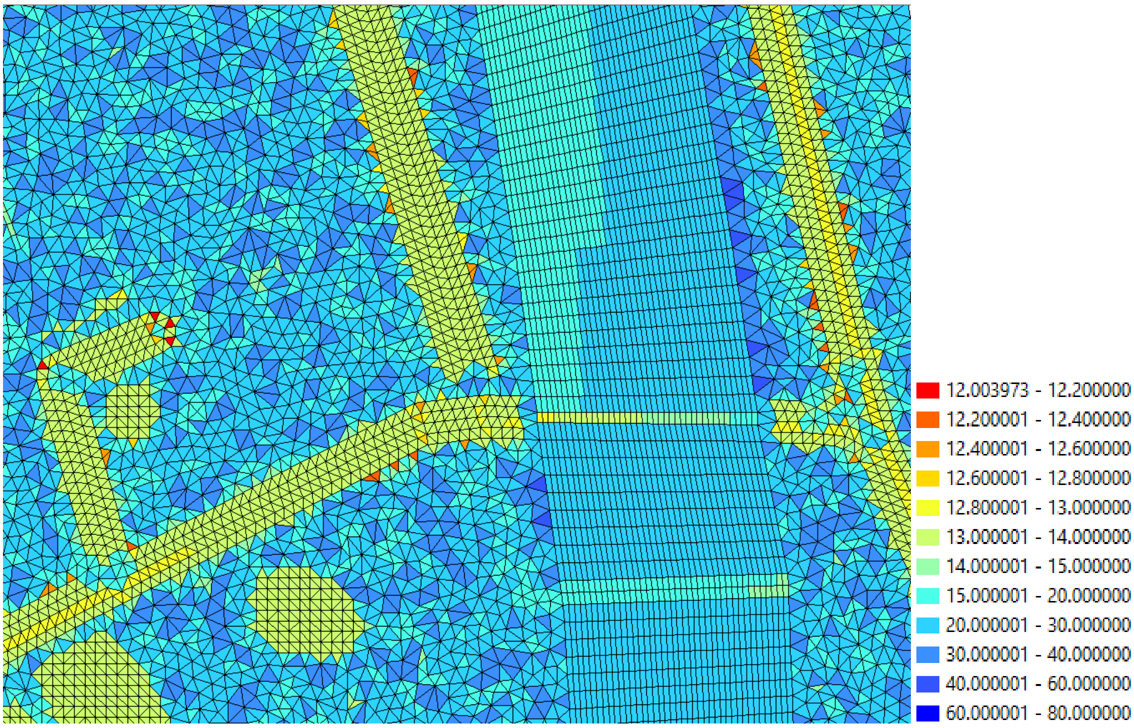

Figure 9 - Mesh structure sample at Kanakanaia Bridge with the element size shown

6.2 Structures

There are four structures represented in the model, as shown in Figure 10. Two of these are bridge structures and the remaining two are small culverts in the stopbank included to allow drainage before and after the peak.

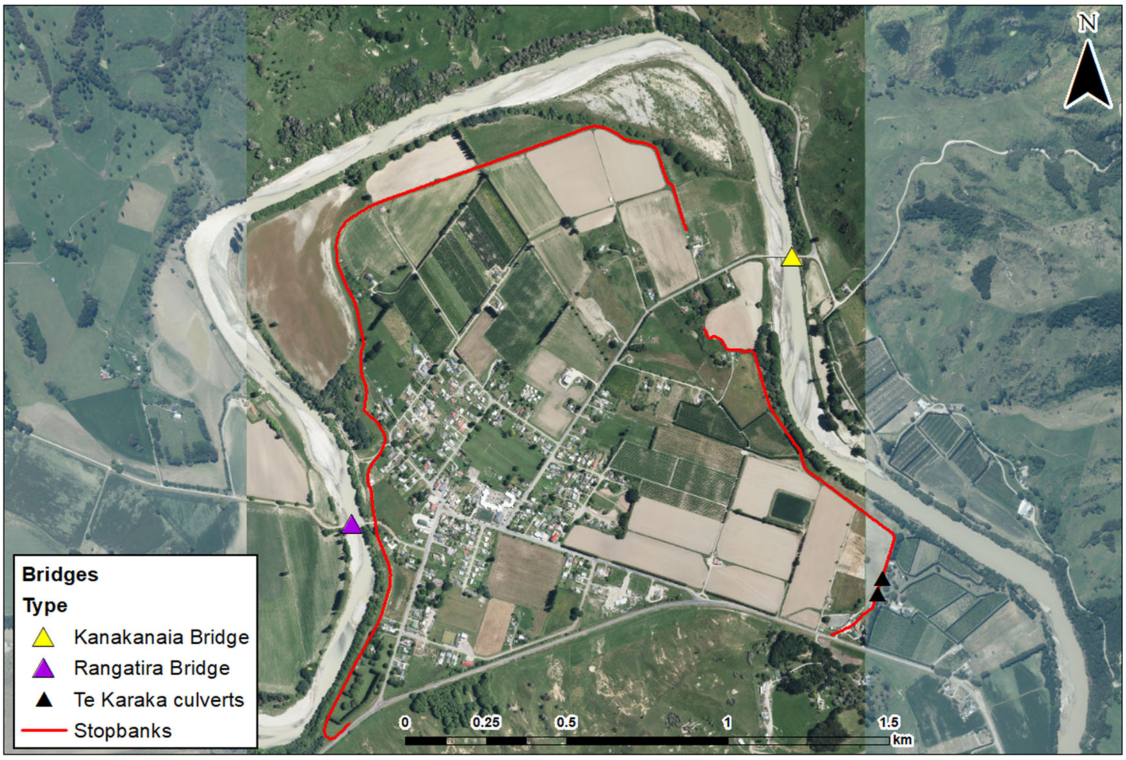

Figure 10 – Location of structures included in model for Te Karaka

The two bridges included in the model have pier losses represented, as well as the soffit and deck levels, as shown in Table 3. Bridge losses are defined as depth-dependent roughness, as shown in Figure 11.

Table 3 - Soffit and deck levels of bridges included in model

Bridge	Soffit (m)	Deck (m)	Bottom level (m)	Depth to soffit (m)
Rangatira Road Bridge	42.86	44.96	32.96	9.40
Kanakanaia Road Bridge	39.81	41.91	29.32	9.96

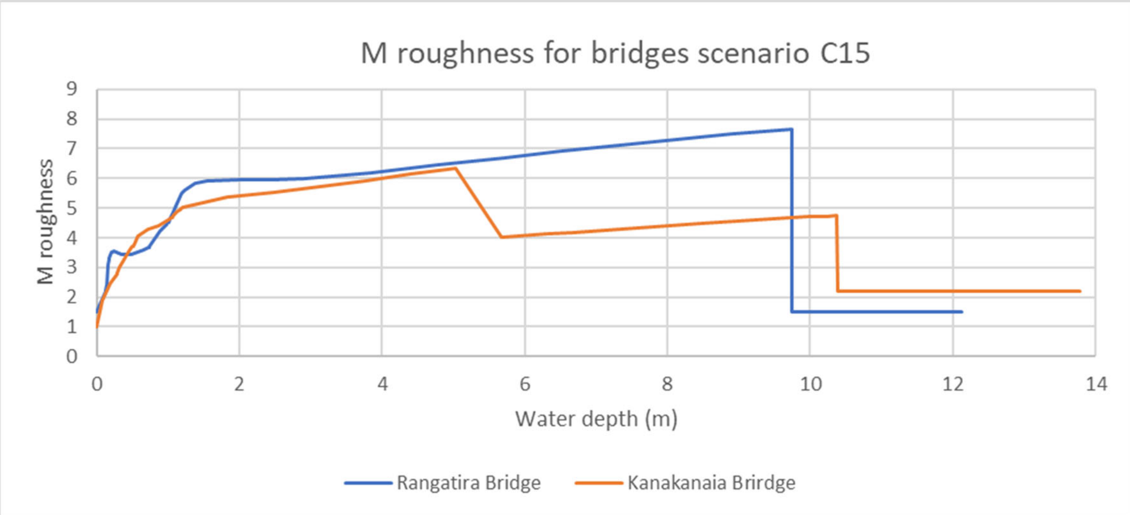

Figure 11 – Manning (M) roughness curve for the Waipaoa River bridges

The actual head losses across the two bridges were obtained from the 2D water level difference upstream and downstream at each bridge, as shown in Figure 12.

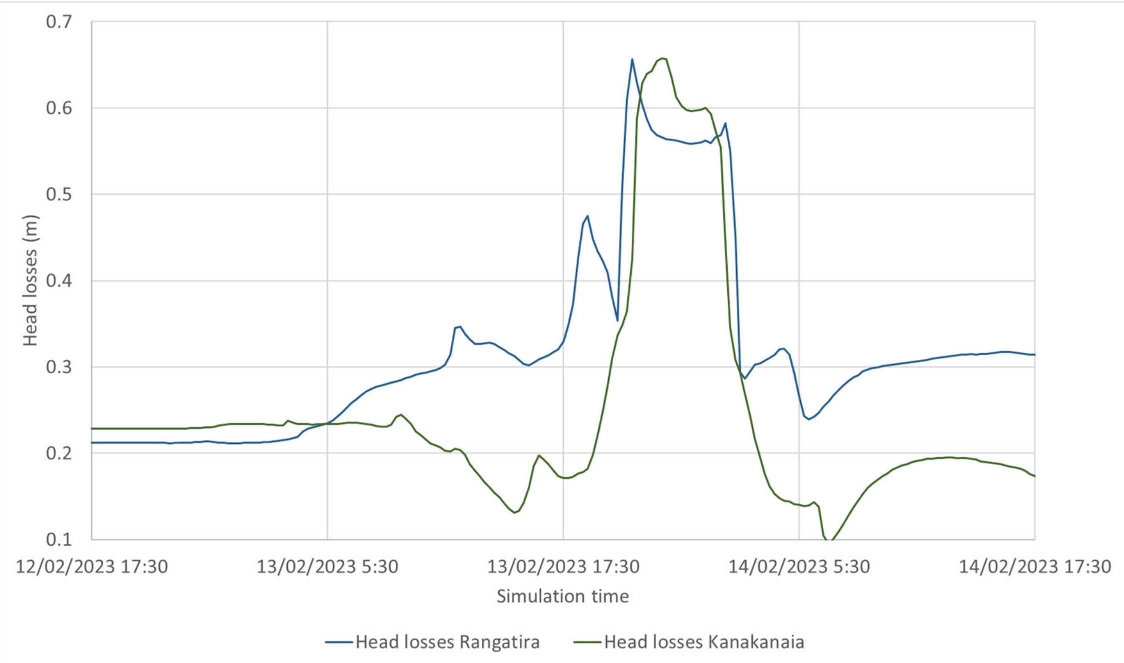

Figure 12 – Head losses across Rangatira and Kanakanaia Bridges for C13 simulation

An extracted hydrograph from the model for calibration simulation C15 is compared to the observed discharge hydrograph in Figure 13. The close match to the hydrograph indicates that the methodology used for representing the bridges is adequate for the purposes of this study.

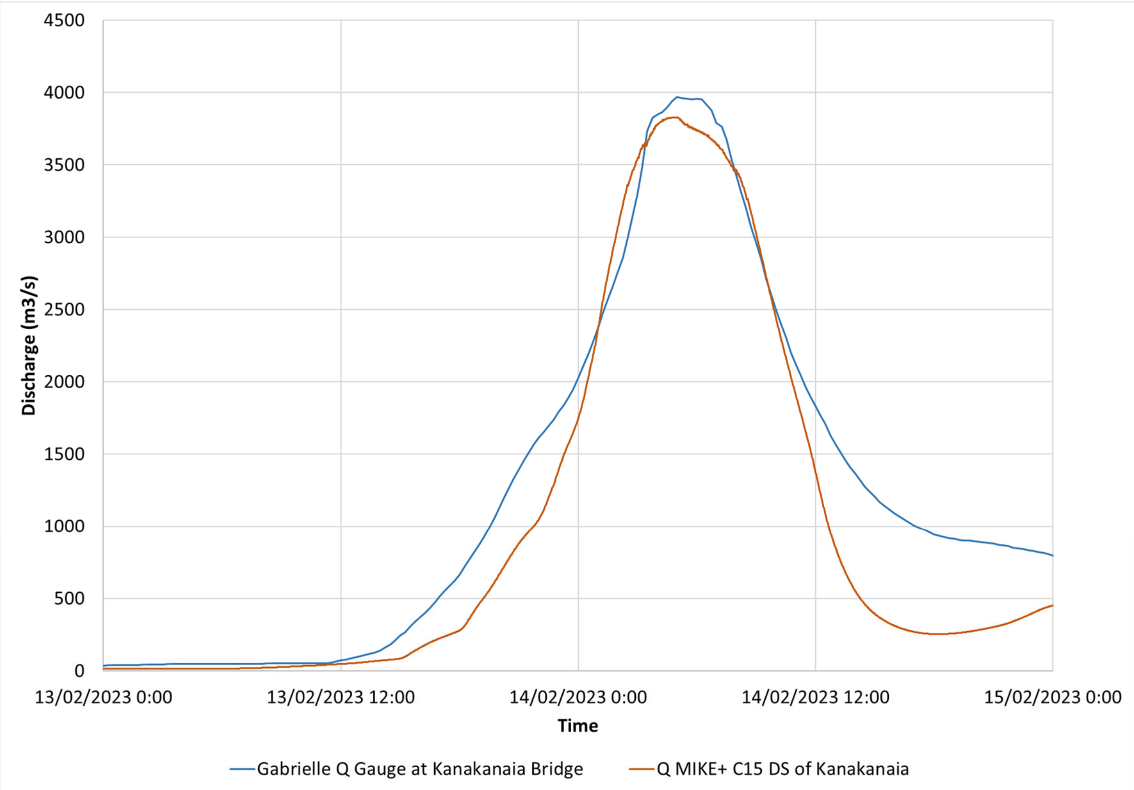

Figure 13 – Discharge Hydrograph at Kanakanaia Bridge for the D39 scenario calibration C15

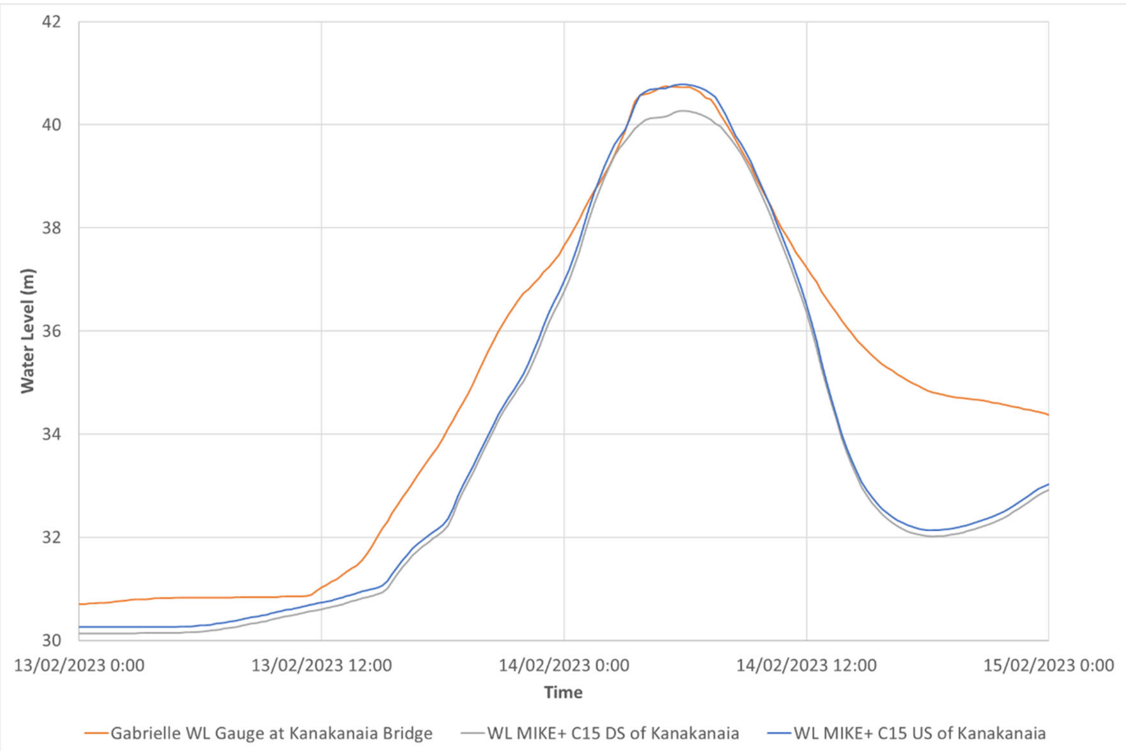

Figure 14 – Water Level Hydrograph at Kanakanaia Bridge for the D39 scenario calibration C15

6.3 Downstream Boundary

The downstream boundary condition, which is the outlet of the Waipaoa River to the sea, is set to a constant water level boundary of RL 1.67 m. It was taken from the 2017/18 HBRC Waipaoa MIKE FLOOD model. The appropriateness of this boundary should be considered if the focus of the modelling is broadened to include the lower reaches that are tidally influenced.

6.4 1D Roughness

The 1D roughness in the portion of the model that is a coupled 1D/2D MIKE+ models uses the same channel roughness as the HBRC model, (HBRC, 2018). The lower portion of the model is purely a 1D model, where the main river channel and berm have been combined. This uses the same main channel roughness as the HBRC model, (HBRC, 2018).

6.5 2D Roughness

The M roughness in the MIKE+ model uses a depth-dependent representation. The main land use areas use small values of M roughness for shallow depths below 100 mm, the minimum M roughness is 1, and it increases rapidly to reach the final values shown in Table 4. The depth dependant roughness is primarily for use in the bridge representation and the remainder of the roughness representation uses standard non-depth-varying values.

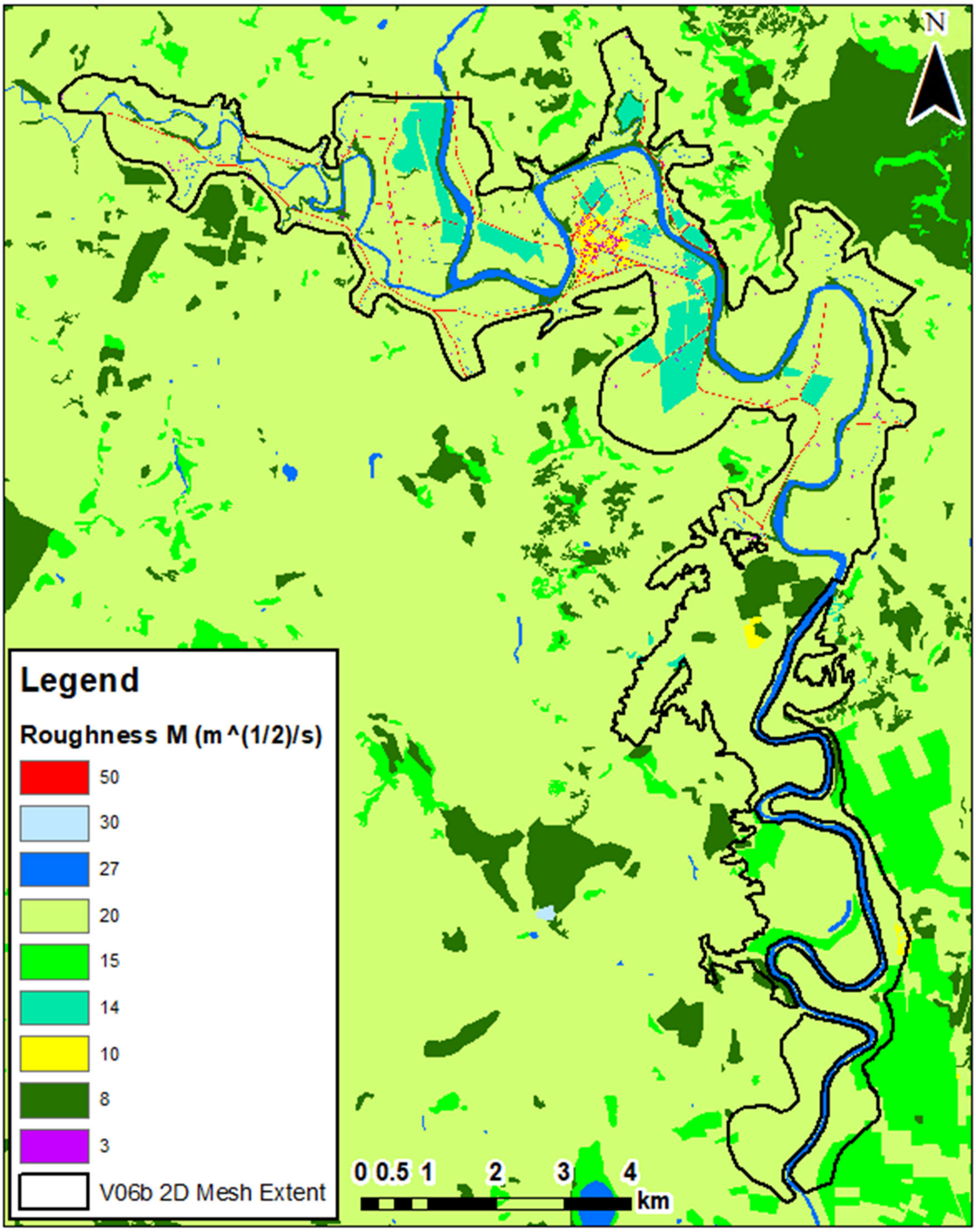

Figure 15 – Manning (M) roughness for the 2D model area

Table 4 - Roughness (M) values for the 2018 land use map

Land Use Map 2018	M Manning
Broadleaved Indigenous Hardwoods	8
Built-up Area (settlement) *Not including buildings outline	10
Deciduous Hardwoods	8
Exotic Forest	8
Forest - Harvested	8
Gravel or Rock	20
High Producing Exotic Grassland	20
Indigenous Forest	8
Lake or Pond	27
Low Producing Grassland	20
Manuka and/or Kanuka	15
Orchard, Vineyard, or Other Perennial Crop	15
River	27
Short-rotation Cropland	20
Surface Mine or Dump	30
Roads	50
Buildings from Outline	3
Rivers and small creeks generated by DHI	27
High level crops (Defined from Review)	14

6.6 1D-2D coupling

MIKE+ dynamically links the river and the overland flow model. Two types of linkages were used in the modelling:

- Standard links - linking the end of the 1D channels to the 2D surface,
- Lateral links – linking the bank of the 1D channels to the 2D surface

6.7 Hydraulic Computational Parameters

Table 5, shows the main computational parameters used in the C15 (calibration) version of the model and the design model.

Table 5 – Computational parameters for C15 model version

Parameter Type	Value C15 model	Value Design model
Model Timestep	Max 1s, Minimum 0.001	Max 1s, Minimum 0.001
1D model timestep	1s	1s
Critical CFL	0.8	0.8
Solution technique	Low order	Low order
Flooding and Drying	15mm and 10mm respectively	15mm and 10mm respectively
Eddy Viscosity	0.002	0.002
Initial Condition	Hot started with base flow at the start of Gabrielle event. Dry for 5625 & 1 in 500yr	Started dry for 5,625 m^3/s & 1 in 500yr events

7 Model Calibration/Validation

A total of fifteen calibration simulations were carried out, as detailed in Table 6. The base scenario was a best guess of key model parameters. Table 6 gives a brief description of each calibration scenario and the primary outcomes from the simulation.

Table 6 – Summary of calibration simulations description and outcomes

Scenario	Description	Outcomes
Base	Model representation in 2D with 3 main inflows and 17 additional inflows, bridges represented with depth-dependant roughness, M. Te Karaka stopbanks obtained from the maximum of the LiDAR. MIKE+ 2024 model running in <2.5hrs.	There was a lot of flooding with an average overestimation of 0.44m, meaning that the losses or inflows were too high.
C1	Base + NIWA inflows with 3 major flows and 17 small inflows reduced by 20%.	By reducing the flow by 20% the depths changed significantly to the point where the model was underestimating flooding overall and with some areas in Te Karaka dry that were flooded
C2	Base + reduced the roughness of the river channel from 27 to 35.	The average comparison between modelled water levels and observed was good, but there were many points inside the Te Karaka township area that were above the observed levels, which gave a false positive
C3	Base + reduced the roughness of the river channel from 27 to 35 and forest near the bank from 8 to 15.	The average comparison between modelled water levels and observed was good, but there were many points inside the Te Karaka township area that were above the observed levels, which gave a false positive
C4	Base + lowered the bed level of Waipaoa River by 0.5m.	The average comparison between modelled water levels and observed was good, but there were many points inside the Te Karaka township area that were above the observed levels, which gave a false positive

C5	Base + Blocked Rangatira Bridge by 20% Upstream (using manning based on the top of the bridge losses).	Higher losses created a significant increase in water level, which meant that the inflows should be lower or the losses through the bridge were too high.
C6	Base + Blocked Kanakanaia Bridge by 20% Downstream (using Manning based on the top of the bridge losses).	Higher losses created a significant increase in water level, which meant that the inflows should be lower or the losses through the bridge were too high.
C7	C1+C3+C4.	There was no overtopping of the stopbank into Te Karaka, it was not realistic.
C8	Base + NIWA inflows with 3 major flows and 17 small inflows reduced by 10% and shifted the hydrograph timing.	There were several areas where the losses did not match the observed water level well. Even though the average was good, the water level in some areas was too high, and in other areas too low.
C9	C8 + reduced bridge losses before the soffit + half a meter lower.	Reduction of the losses across the bridges combined with a lower ground level of the bed level caused less overtopping of the stopbank
C10	Base + redid stopbanks levels based on survey centrelines, 10% flow reduction, reduce losses of bridges to be half of what was being used (half of MIKE11 results).	There was an area in the south of Te Karaka that remained dry even though it was reported to be wet. There was also a negative average difference that implied that more water was required in the model.
C11	C10 + reduced losses at Kanakanaia bridge with roughness M, reduced flow to 9% from base instead of 10%, added two culverts at the end of Te Karaka development.	It was worse in terms of water level differences, indicating that more water was required
C12	C11 + instead of a 9% reduction of flows, these were reduced to 5% to 4,196 m^3/s from 4,417 m^3/s. Noting that this is the total flow applied upstream of Te Karaka, which resulted in a flow at Kanakanaia gauge of 3,968 m^3/s. This means there was an approximate flow of 200 m^3/s through the Te Karaka township for the Cyclone Gabrielle event.	The match to measured water levels was almost perfect in some areas except south Te Karaka, which went from a difference of -0.19 to 0.21, indicating that the increase of water level upstream of Rangatira bridge was too high.

C13	C12 + head losses of Rangatira bridge were increased to let less flow through the bridge.	The south Te Karaka area had the opposite issues to C12. Still, with a good representation, the water level of some outliers near Rangatira Bridge became worse, and the match at Kanakanaia Bridge was better than C12
C14	Not used	Not used
C15 (D39)	Model set up used the depth dependant roughness as shown in Figure 15 and an extension of the mesh, to the south, to cover a larger area of the Waipaoa River scheme stopbanks. The scheme is represented using the 2019 LiDAR levels for the stopbanks to better represent what took place during the Gabrielle event flooding.	The calibration at Te Karaka was achieved an equivalent match to the original C13 agreed/peer-reviewed calibration. Calibration of the extended area downstream of Te Karaka matched within similar ranges as previously.

Table 7, details specific water level differences for different areas within the 2D model extent for calibration simulation C15, while also showing absolute water level differences.

Table 7 – Summary of calibration simulation C15 water level differences against the Gabrielle observed flood levels

Water Level difference (D39_C15 vs FL Gabrielle) in meters					
Difference Water Level (m)			Absolute Difference Water Level (m)		
Min	Mean	Max	Min	Mean	Max
Excluding outliers and Matawai			Excluding outliers and Matawai		
-0.464	0.040	0.470	0.002	0.179	0.470
Excluding outliers, Matawai and South Te Karaka			Excluding outliers, Matawai and South Te Karaka		
-0.464	0.077	0.470	0.004	0.153	0.470
Excluding outliers and Matawai with -9999			Excluding outliers and Matawai with -9999		
-0.464	0.024	0.470	0.002	0.186	0.470
Only Te Karaka			Only Te Karaka		
-0.116	0.131	0.470	0.004	0.157	0.470

Figure 16 to Figure 19 show the maximum water level and depth results for both the 2D model extent and a zoomed view of Te Karaka. Figure 20 and Figure 21 are plots of water level difference between the C15 calibration scenario and the observed flood levels from Cyclone Gabrielle.

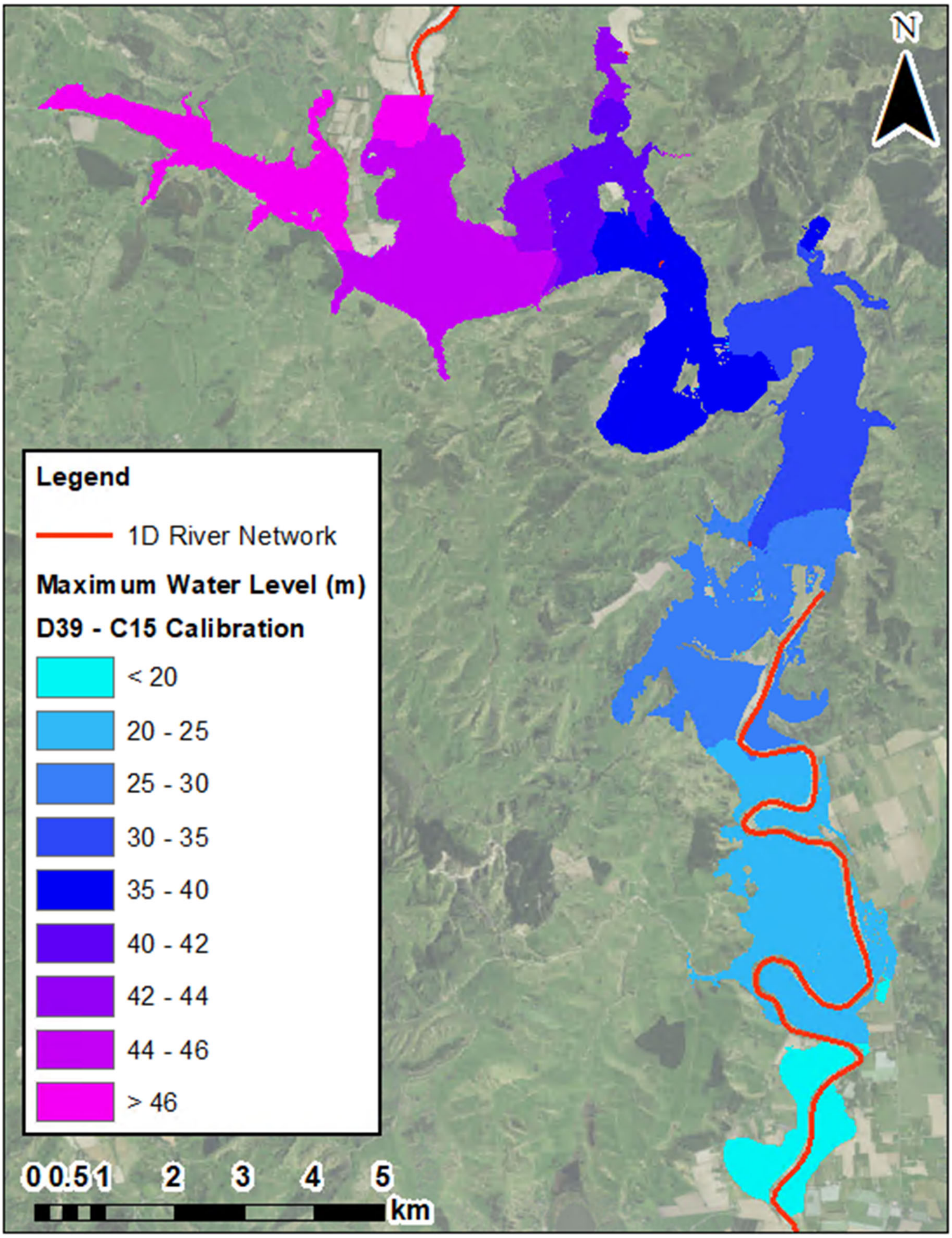

Figure 16 – Maximum Water Level for the C15 calibration simulation

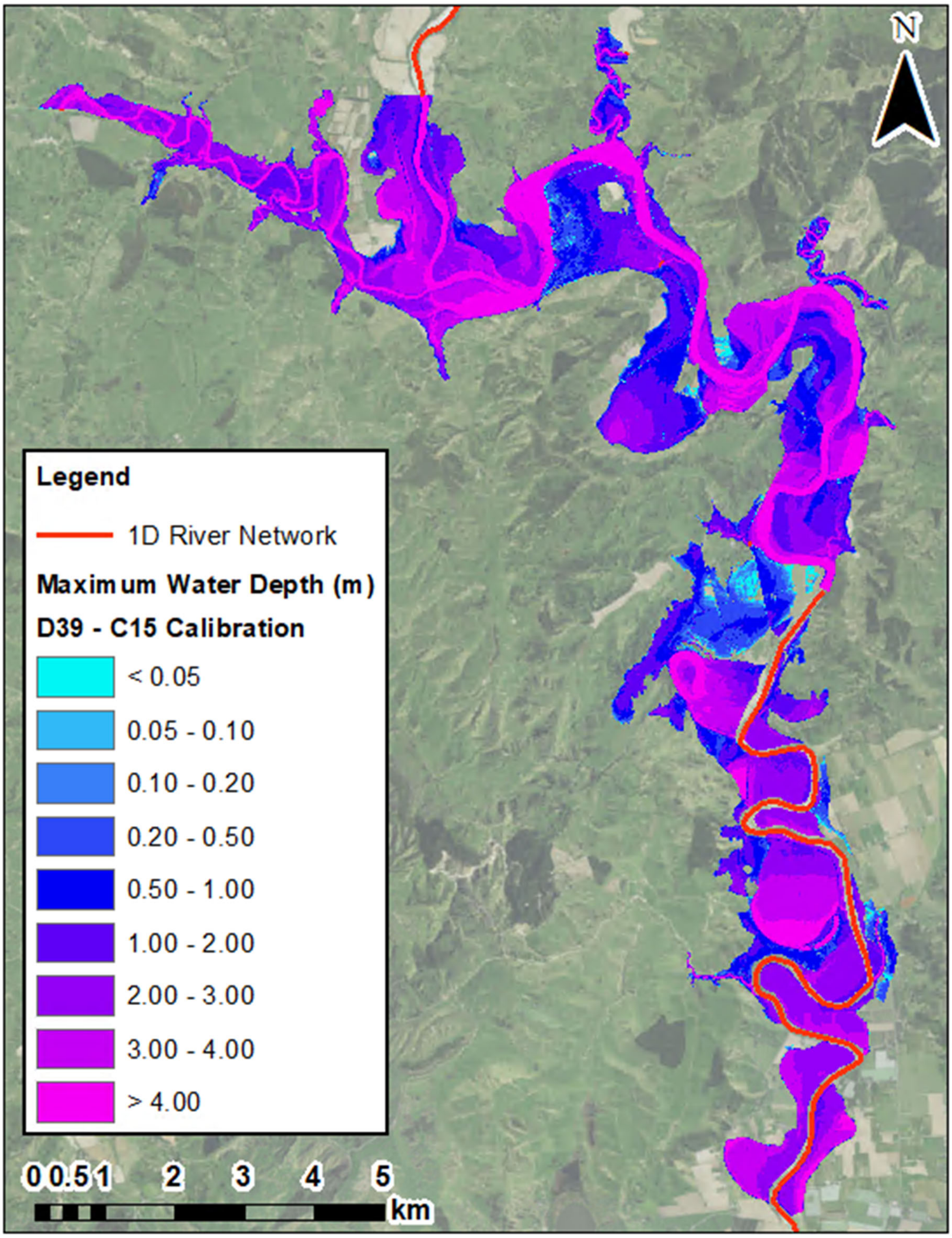

Figure 17 - Maximum Water Depth for the C15 calibration simulation

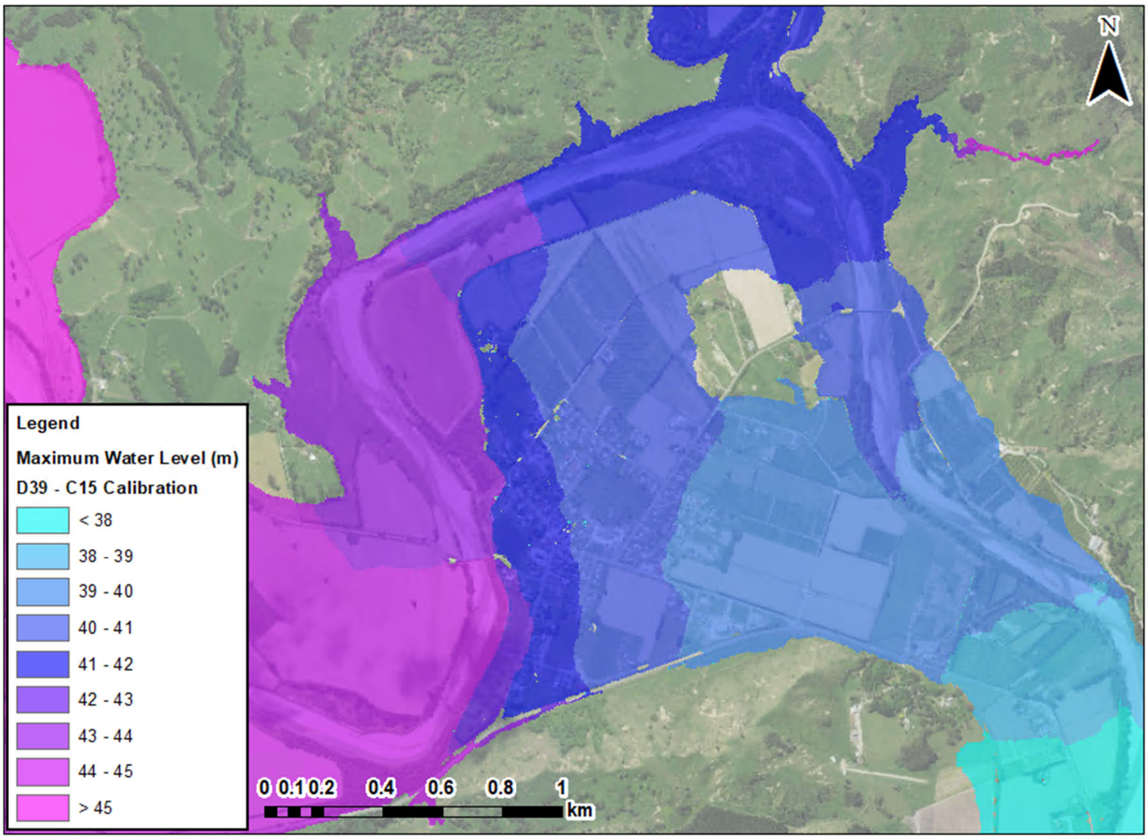

Figure 18 - Maximum Water Level for the C15 calibration simulation at Te Karaka

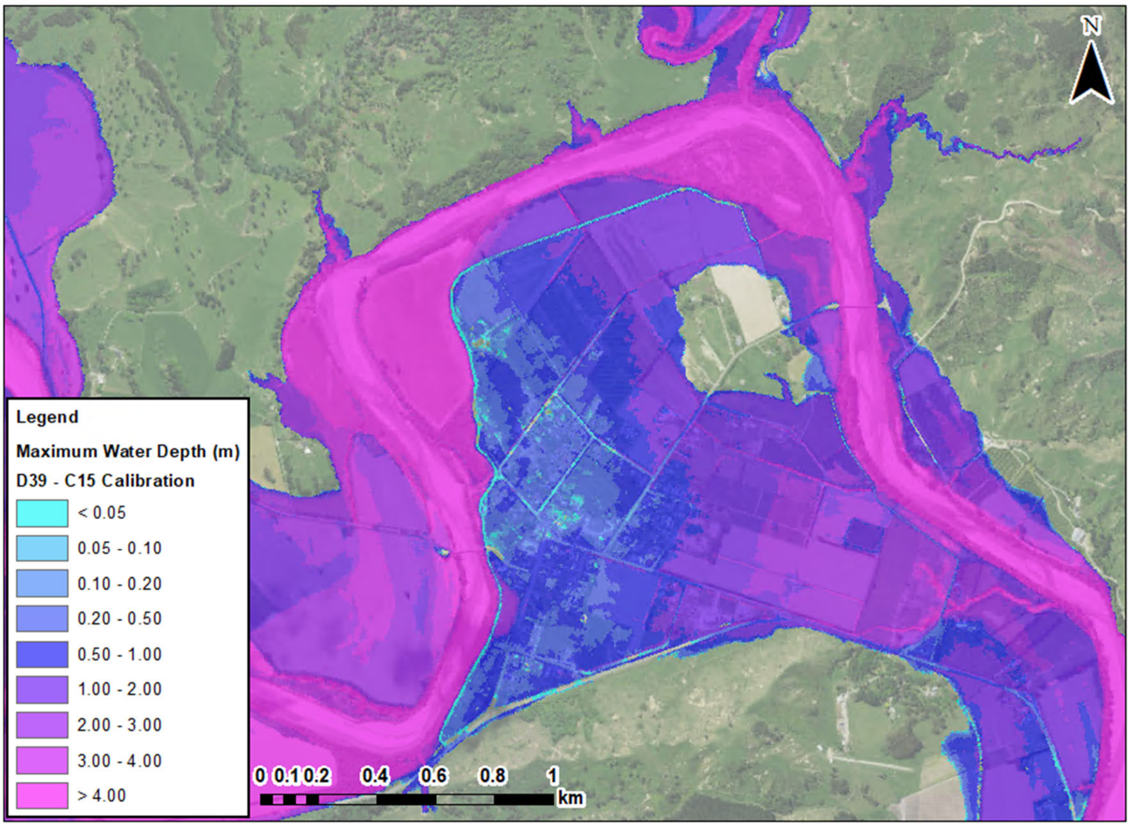

Figure 19 - Maximum Water Depth for the C15 calibration simulation at Te Karaka

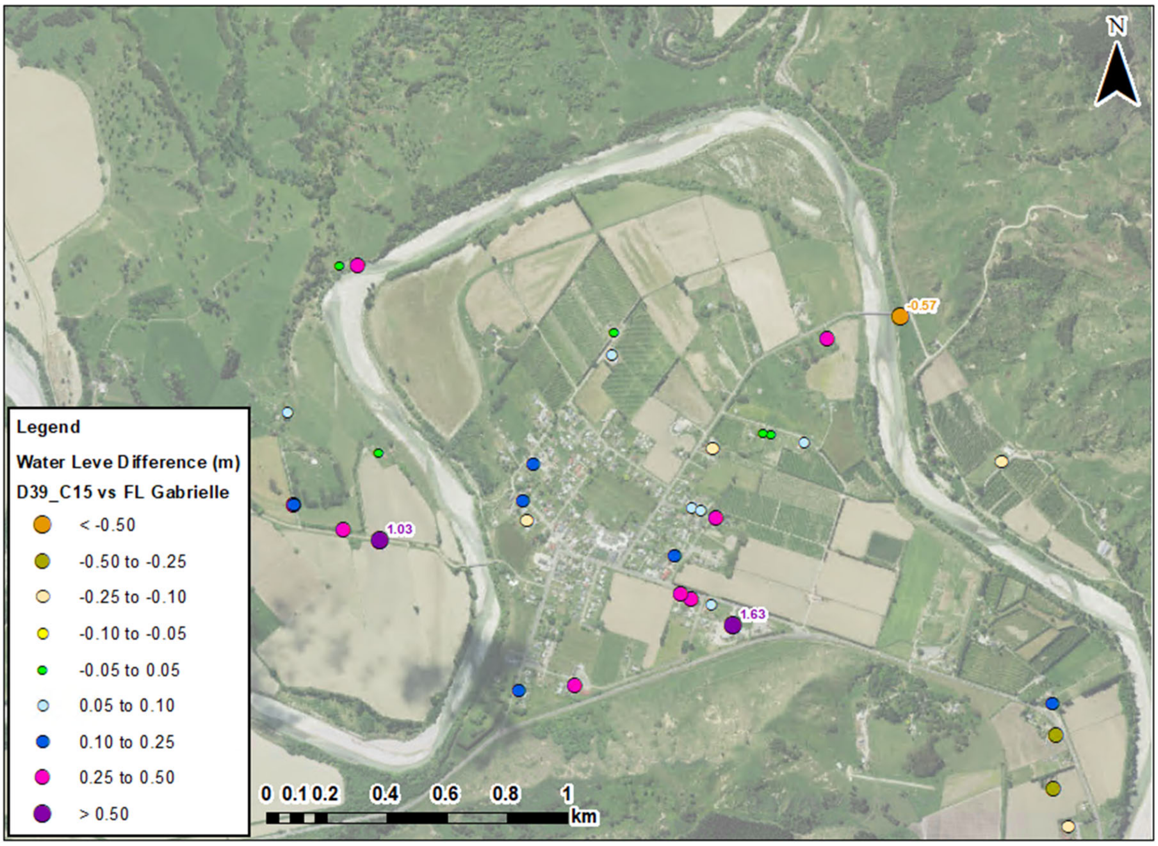

Figure 20 – Difference of Water Level between the C15 calibration simulation and the Gabrielle observed flood levels at Te Karaka

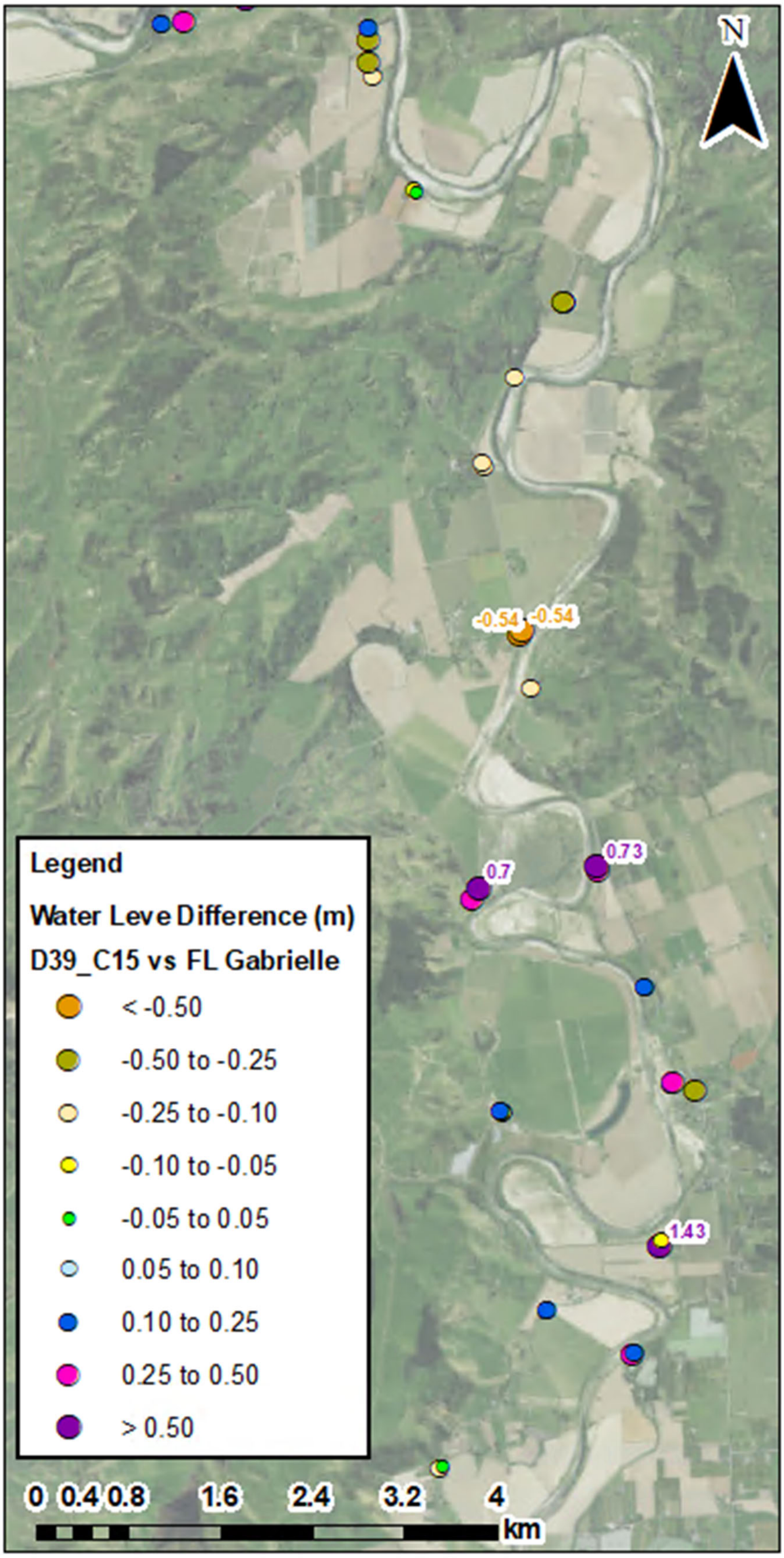

Figure 21 – Difference of Water Level between the C15 calibration simulation and the Gabrielle observed flood levels downstream of Te Karaka

We see differences between observed water levels and modelled water levels in Figure 20 and Figure 21, but because of the associated uncertainty in observed levels, we believe we have a suitable match for model calibration without overfitting the model parameters.

8 Scenario Modelling

Between mid-2023 and January 2025, DHI developed and calibrated a model of the Waipaoa River, and tested concept design options for enhancing flood resilience at Te Karaka. We also attended a public meeting presenting the preliminary model calibration and a second meeting with a smaller community group on the concept design option modelling.

In February 2025, Tonkin and Taylor Consultants (T&T) were commissioned to provide GDC with design assistance for the Te Karaka Flood Resilience Scheme.

8.1 Data Supplied

Between 10th-26th March 2025, we supplied model results to T&T for the concept design options modelled. The following was supplied to T&T:

- DEMs_scenarios_DFSU (m): DFSU used for each of the scenarios. These are not TIFFS, but we can provide them if needed. There is one DFSU for each scenario because each scenario had unique stopbanks alignments. Where the stopbanks had to be removed in some areas and they were removed from the original alignment, they were not added back because they were represented as 2D dikes
- Difference_WaterLevel_TIFF (m): The difference water level with the names based on the Te Karaka GDC presentation, including the layer symbology, -99 means "new dry" and 99 means "new wet"
- Max_Velocity_TIFF (m/s): Maximum current speed raster converted to TIFF filtered by 50 mm with the names based on the Te Karaka GDC presentation
- Max_WaterDepth_TIFF (m): Maximum water depth raster converted to TIFF filtered by 50 mm with the names based on the Te Karaka GDC presentation
- Roughness_scenarios_TIFF (m(1/3)/s): There are 2 roughness files, one for all the DXX scenarios and one for D16 Opt9, values 3 to 50 are in manning's M (m(1/3)/s), values higher than 100 are used to represent the bridges at Kanakanaia and Rangatira
- Stopbanks_SHP: The stopbanks were extracted directly from the model, so they are the ones used in MIKE+, they are all glass walls.

8.2 T&T Modelling Request

On 16th April 2025, T&T requested further scenario modelling to be carried out via a memo "20250416_Hydraulic Modelling Memo.pdf" and also included some shape files (Short List Modelling Options.zip) of the eight options to be modelled, listed in Table 8.

Table 8 - T&T Short List options modelled

Shortlist Option #	Modelling Run #	Description
1	1	Upgrade existing stopbanks.
	1A	Upgrade existing stopbanks with an increased bed levels by 1m XS 33 to 38.
3	2	Retreat northern stopbank 160 m plus State Highway Spillway.
	2A	Retreat northern stopbank 160 m plus State Highway Spillway with an increased bed levels by 1m XS 33 to 38.
5	3	Retreat northern stopbank by 300 – 315 m, with retreat of the eastern stopbank to within 10 of the edge of wastewater treatment pond.
	3A	Retreat northern stopbank by 300 – 315 m, with retreat of the eastern stopbank to within 10 of the edge of wastewater treatment pond with an increased bed levels by 1m XS 33 to 38.
6	4	Complete stopbank retreat to the smallest area of risk reduction.
	4A	Complete stopbank retreat to the smallest area of risk reduction with an increased bed levels by 1m XS 33 to 38.

8.3 T&T Scenarios modelled methodology

The eight scenarios were all stopbank scenarios with varying extents and alignments. There are four different extents/alignments, with each being modelled for an existing Waipaoa River bed level and an elevated Waipaoa River bed level of + 1 metre, that represented aggradation. Key features revised or added include:

- Stopbanks are represented as dikes in the 2D model, which have a glass wall. The dikes do not have a width as such, but are just a vertical glass wall between the model mesh elements along the provided alignment
- The berm in front of the current stopbank area has been lowered by approximately 1.5 metres, consisting of approximately 150,000 m^3, for all scenarios
- The bed level of the Waipaoa River between GDC chainage Cross Section 33 and Cross Section 38, has been raised in the 2D model by 1 metre.

8.4 Results provided

Results produced for the eight scenarios, a design event of 5,625 m^3/s, included Maximum Water Level (WL), Water Depth (WD), Shear Stress (SS) and Velocity (CS) TIF's. For velocity, depth and water level we filtered the results, removing depths less than 50mm. Water Level Difference TIF's and maps were also provided for each scenario compared to the baseline scenario. The baseline scenario is the existing stopbank height and alignment. We also provided a layer file (Difference WL.lyr) for the difference map symbology.

9 Preferred Option

From the options 1 to 4A modelled for T&T, based on the results obtained, the recommended option was Option 3 as described in Table 8.

The final version of stopbank was version 4 (V4), supplied by GDC to DHI on 19 January 2026. Using the preferred stopbank option V4, six model simulations were completed, that compare the existing stopbank protection at Te Karaka with the proposed upgraded stopbank protection. Three flow scenarios were modelled, Cyclone Gabrielle, a 5,625 m^3/s discharge at Kanakanaia Bridge and a 1 in 500 year discharge of 14,869 m^3/s at Kanakanaia Bridge.

Table 9 - Preferred Option Scenarios

Model Scenario Name	Te Karaka Stopbank	LiDAR Used	Flow	Waipaoa Scheme
D40	Existing	2023	Cyclone Gabrielle	As-builts & design
D41	Design V04 Jan 2026	2023	Cyclone Gabrielle	As-builts & design
D42	Existing	2023	5,625 m^3/s	As-builts & design
D43	Design V04 Jan 2026	2023	5,625 m^3/s	As-builts & design
D44	Existing	2023	1 in 500 year (14,869 m^3/s)	As-builts & design
D45	Design V04 Jan 2026	2023	1 in 500 year (14,869 m^3/s)	As-builts & design

The same model results that were produced for the Scenario Modelling were produced for the Preferred Option, Maximum Water Level (WL), Water Depth (WD), Shear Stress (SS) and Velocity (CS) TIF’s. For velocity, depth and water level we filtered the results, removing depths less than 50mm. Water Level Difference TIF’s were also provided for each scenario compared to the existing scenario, Figure 22 - Figure 24. Also Flood Hazard (HZ) (depth x velocity) was produced for each scenario.

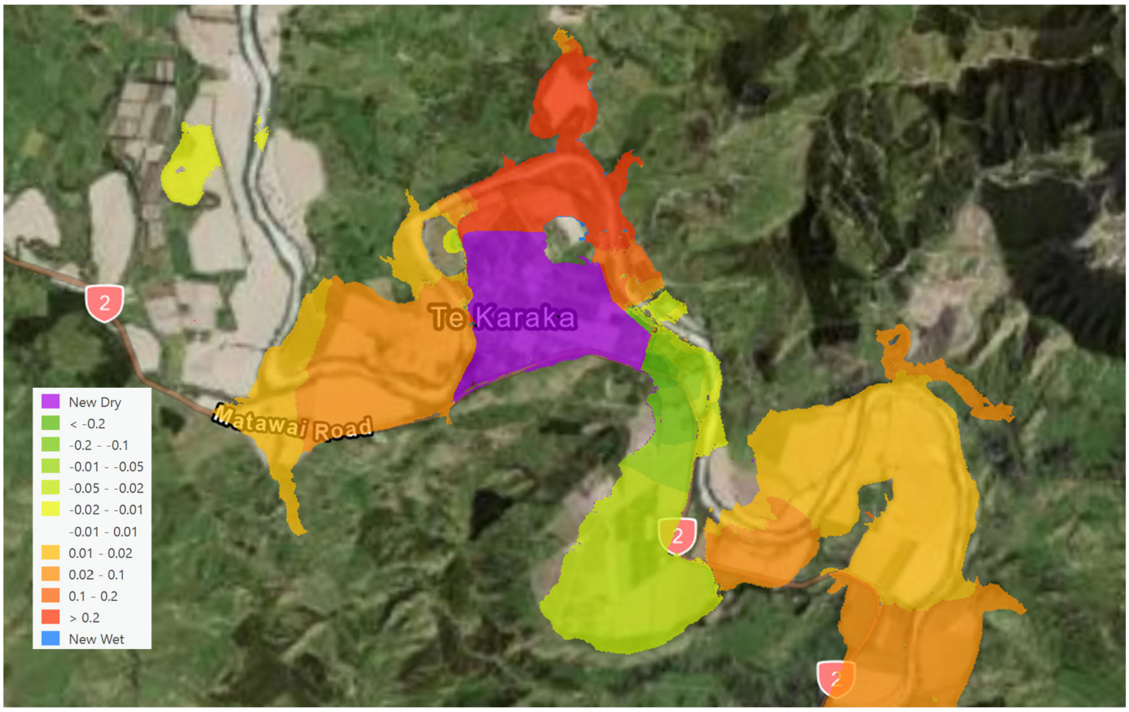

Figure 22 – Cyclone Gabrielle Event Water Level Difference Map, comparing the Current Te Karaka stopbank and the Proposed Te Karaka stopbank

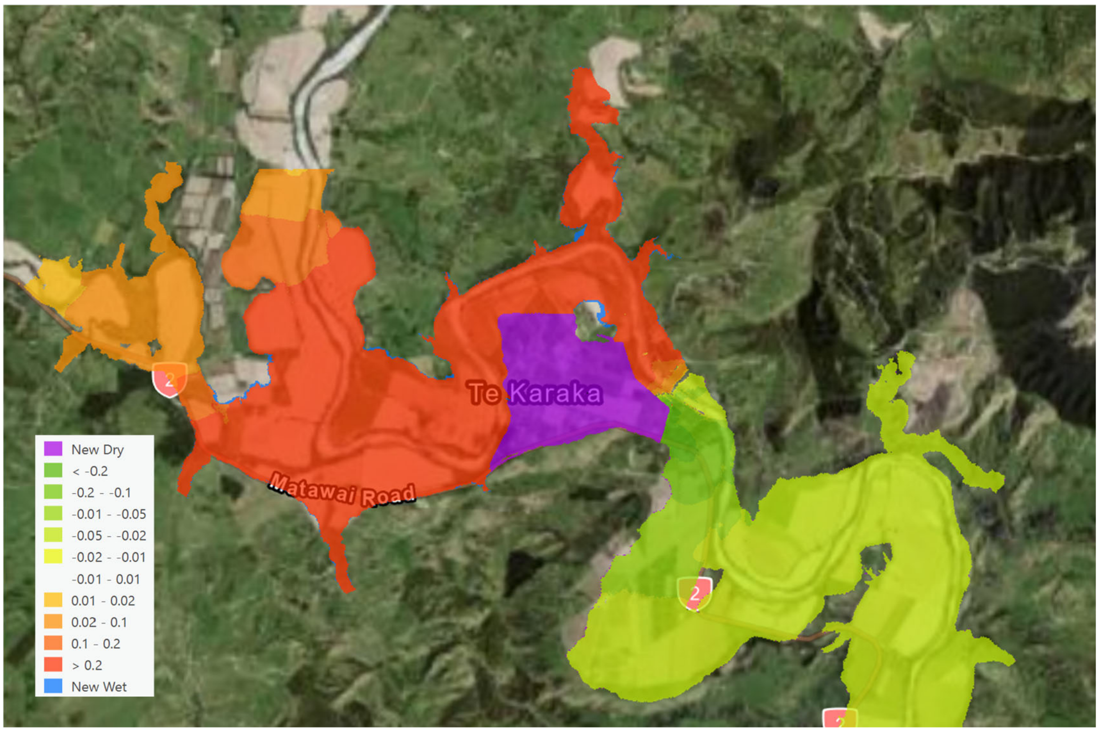

Figure 23 – 5,625 m^3/s Design Event Water Level Difference Map, comparing the Current Te Karaka stopbank and the Proposed Te Karaka stopbank

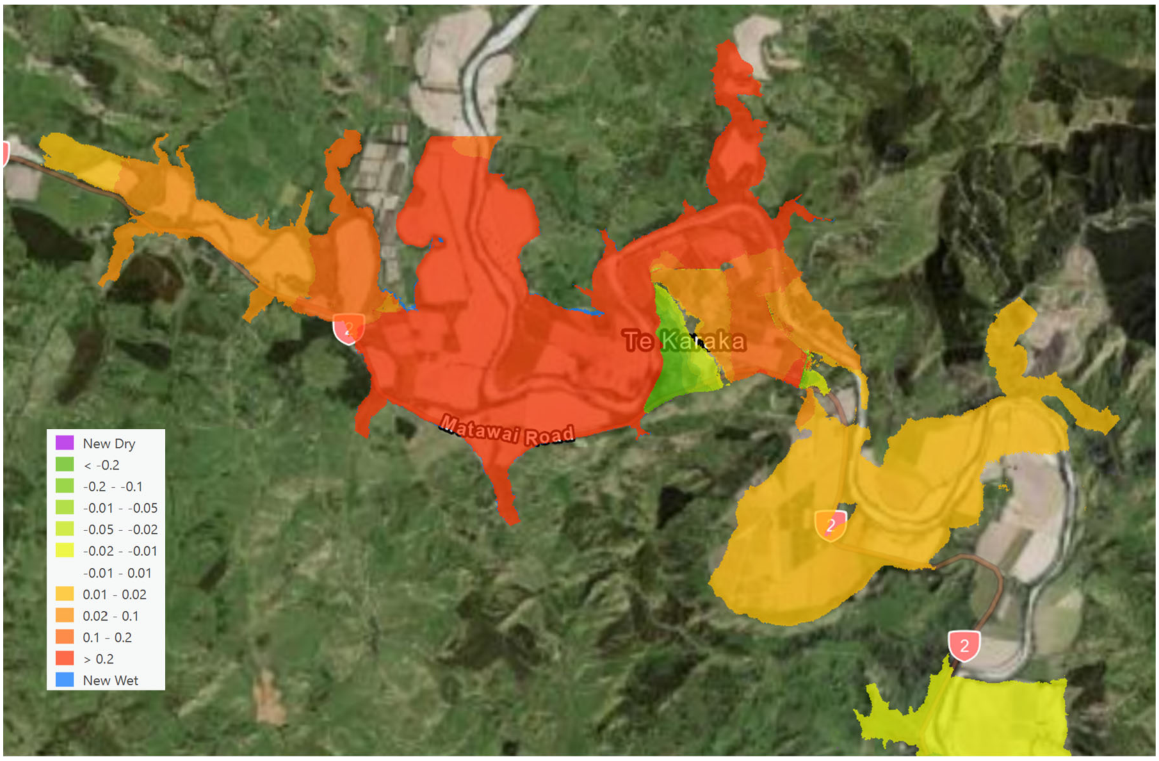

Figure 24 – 14,869 m³/s 1 in 500 Year Event Water Level Difference Map, comparing the Current Te Karaka stopbank and the Proposed Te Karaka stopbank

9.1 Comparison of D42 and D43 Discharges

When comparing the design case, a 5,626 m³/s flow, for the existing stopbanks at Te Karaka with the proposed stopbanks at Te Karaka, the modelling results show a slight reduction in flow upstream and downstream of Te Karaka. The reduction of flow is between 1-2% at the three locations shown in Figure 25. The proposed works eliminate floodwater overtopping into Te Karaka, thereby retaining more floodwater in the Waipaoa River. A slight attenuation effect on the flow is observed for the proposed stopbank design. Discharges have been extracted from the 2D model results for Scenarios D42 & D43 at the locations shown in Figure 25.

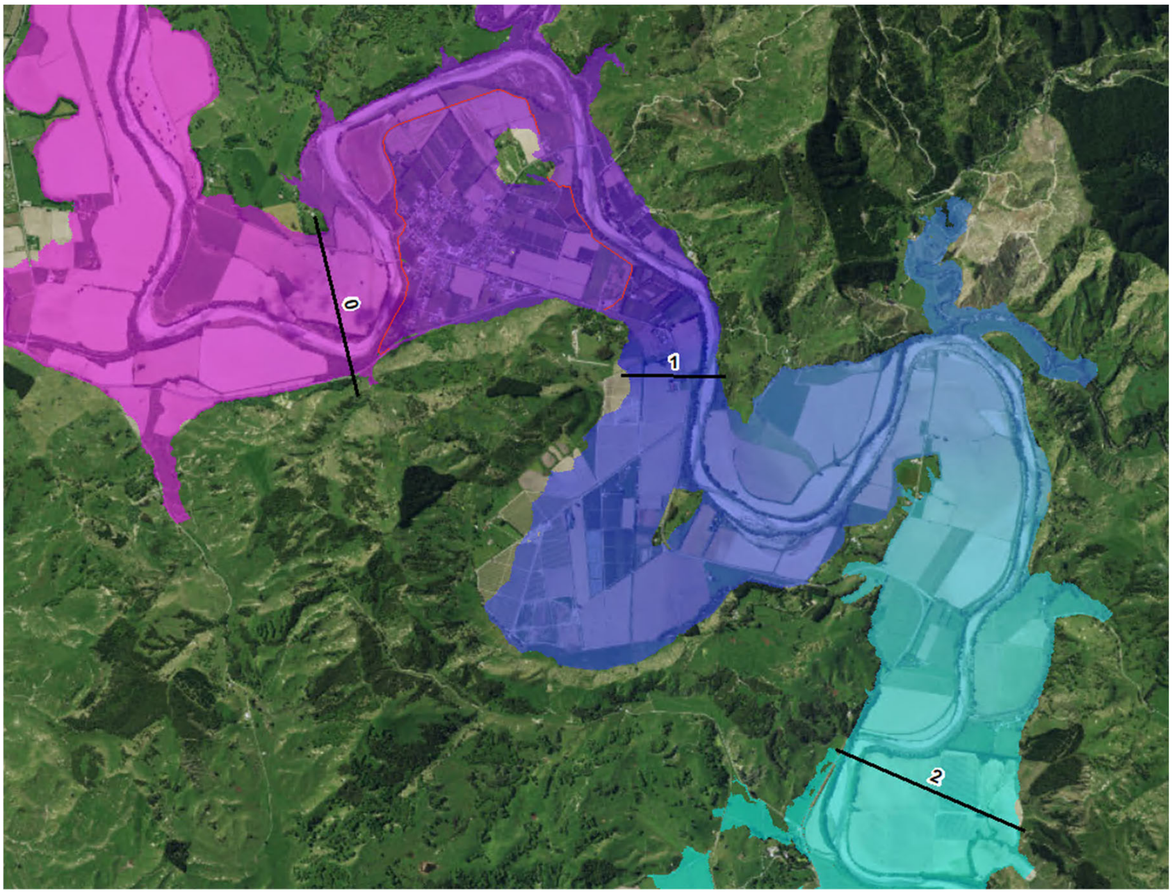

Figure 25 – Discharge Extraction Locations 0,1 & 2 for D42 & D43

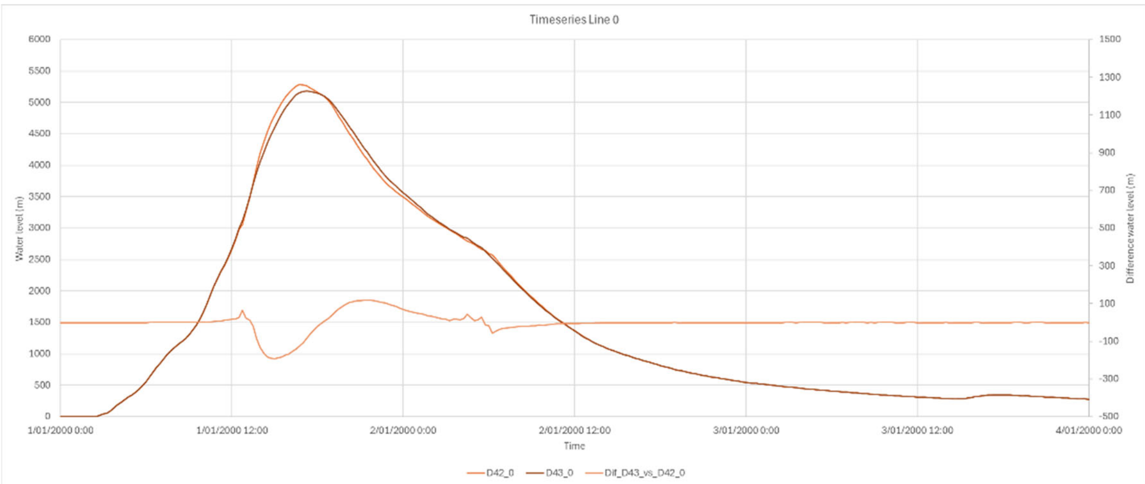

Figure 26 – Discharge Hydrographs for D42 & D43 and a Difference hydrograph at Location 0

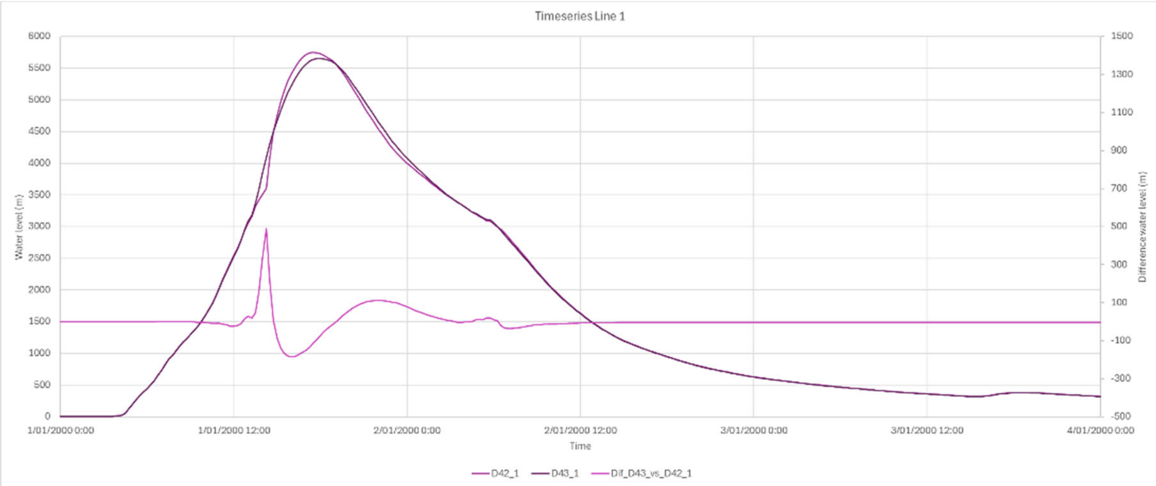

Figure 27 - Discharge Hydrographs for D42 & D43 and a Difference hydrograph at Location 1

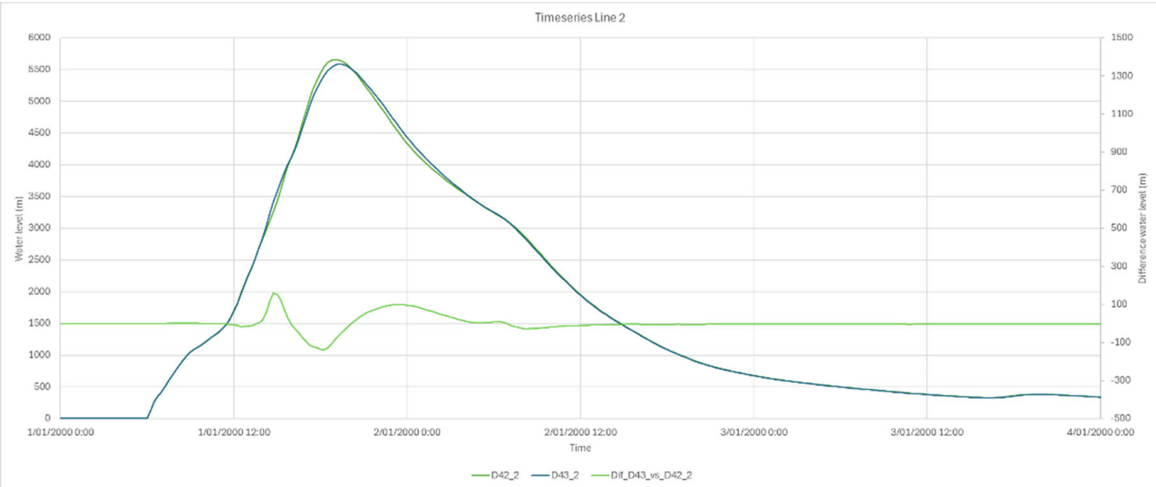

Figure 28 - Discharge Hydrographs for D42 & D43 and a Difference hydrograph at Location 2

9.2 Impacts on Waipaoa Scheme from proposed Te Karaka Stopbank upgrade

Stage 1 of this study focused on the Te Karaka upgrade, while Stage 2 will focus more on the Waipaoa Scheme and an overdesign event. The current model extent and configuration, i.e. 2D in the Te Karaka area with 1D/2D and 1D downstream, is suitable to make assessments of flooding in and around Te Karaka but not of the Waipaoa scheme. Ideally, the 2D model would extend along the entire protected reach of the Waipaoa, to allow for consistent and accurate representation of the river and stopbanks.

Considering that flows are being reduced for the proposed stopbank design for the 5,625 m^3/s event, as discussed in Section 9.1, we don't expect a significant effect on the Waipaoa scheme level of service. The actual impact can be determined as part of the Stage 2 modelling.

10 Conclusions

This report documents the update, calibration, and application of the Waipaoa River MIKE+ hydraulic model for Stage 1 of the Te Karaka Flood Resilience Investigation. The model was calibrated to the February 2023 Cyclone Gabrielle event and then used to test the performance of the existing Te Karaka stopbanks, short-listed concept options, and the final preferred stopbank alignment (Design V4, January 2026).

Based on the short-list modelling undertaken for Tonkin & Taylor (T&T), Option 3 was selected as the preferred concept and subsequently progressed through detailed design and iterative modelling to achieve a minimum freeboard of 600 mm (Design V4). Six comparative simulations were run to compare the existing and proposed stopbanks for: (i) Cyclone Gabrielle, (ii) the 5,625 m^3/s design event (1-in-100-year plus climate change allowance to 2090), and (iii) the 1-in-500-year, climate change-adjusted event (14,869 m^3/s).

For the 5,625 m^3/s design event, the proposed stopbank prevents overtopping into Te Karaka and indicates a small reduction in discharges (approximately 1–2%) upstream and downstream of Te Karaka relative to the existing stopbank protection. For larger events, including the 1-in-500-year scenario, the modelling indicates that significant flooding can still occur outside the design intent and that residual risk remains for events exceeding the design basis.

Model results are subject to uncertainty associated with hydrological inputs and boundary conditions, representation of structures (notably bridge losses), roughness assumptions, and future changes such as bed aggradation and climate change. The modelling is therefore best used to compare relative option performance and to support decision-making and communication of flood risk, rather than as a guarantee of no flooding. Assessment of broader impacts on the Waipaoa Scheme and overdesign/extreme events is intended to be progressed as part of Stage 2.

Recommended next steps are:

- Confirm final Design V4 crest levels, tie-ins, and local low points (including around bridges) and verify that the 600 mm freeboard target is achieved where required and remains constructible and maintainable.
- Undertake targeted sensitivity testing for key uncertainties that influence decisions (e.g., inflow assumptions, bridge representation/head losses, roughness, and plausible aggradation scenarios) and document implications for level of service and residual risk.
- Progress consenting and stakeholder engagement using clear communication of design intent, event basis (Gabrielle, 5,625 m^3/s, 1-in-500-year), and the remaining residual risk for events beyond the design basis.
- In Stage 2, extend the 2D assessment to the Waipaoa Scheme (including downstream reaches as needed) and overdesign/extreme events, and produce outputs tailored to emergency management (e.g., timing of overtopping, depth/velocity hazard corridors, and evacuation route performance such as the Nisbit Dip low point).

11 References

/1/, NIWA, R. Henderson, G. Smart (2011) *Waipaoa Flood Review,* Report Number CHC2011-099

/2/, NIWA, S. Singh, G Griffiths, E. Lane, (2024) *Flood frequency in Tairāwhiti following Cyclone Gabrielle*

/3/ Hawkes Bay Regional Council, C. Goodier, (2018), *Waipaoa River Flood Control Scheme - Design Flood Hydrodynamic Analysis*

Appendix A Bridge Representation & Analysis

As part of the Te Karaka model build DHI has been investigating the most effective way of modelling the two main bridges, the Rangatira and Kanakanaia bridges. It was found that using the standard approach of modelling the bridges in 1D and coupling them via standard links resulted in excessive head loss, and all attempts to reduce this loss by adjusting the 1D structure parameters and even the channel cross-section did not bring the head loss down to a reasonable level. A 1D model was developed to assess appropriate head loss across the bridges, and it has been used as an iterative target.

The final method we have tested is to use depth-varying roughness to implicitly model the bridge structures, using the headloss information from the 1D model to “calibrate” the roughness values across the bridge. It is this method that we suggest using for the final modelling, with the depth-varying roughness values outlined in Section 6.5, as it produced the best match to the 1D model head losses.

Details

Descriptions of the scenarios tested to model the bridges are listed below:

- Base: the first scenario represents the bridges in 1D as bridge structures with standard links upstream and downstream of each bridge and a 2D mesh representing the Waipaoa River.
- Bridges1D: The second scenario represents the bridges in 1D as bridge structures with a fully 1D setup representing the flow interactions near each bridge with bypass flows to represent flows via the floodplain.
- NoBridges: The third scenario removes the bridges completely to represent them as open river spaces; it removes the 1D representation of the bridges and reverts any changes made to the ground level of the 2D mesh.
- Bridges_M2: The fourth scenario represents the bridge losses as an increase in roughness. The model was set to depth-dependent roughness, with the lowest roughness set to 2 $m^{1/3}/s$ for the Rangatira Bridge and 1 $m^{1/3}/s$ for the Kanakanaia Bridge.
- Bridges_M1: The fifth scenario represents the bridge losses as an increase in roughness. The model was set to depth-dependent roughness, with the lowest roughness being 0.5 $m^{1/3}/s$ for both the Rangatira Bridge and the Kanakanaia Bridge.

The scenarios were defined to answer the following questions:

- Does the Base scenario correctly represent the bridge's losses?
- What would happen if the bridges were removed?
- Could the bridges be represented differently?
- How should the bridge's losses be considered?

The representation in this area is composed of a (2D overland + 1D Rivers) MIKE+ setup with an unstructured mesh that combines quads at the riverbed and triangles to represent other areas. The setup of each of the bridges is shown in Table 10 and Figure 29.

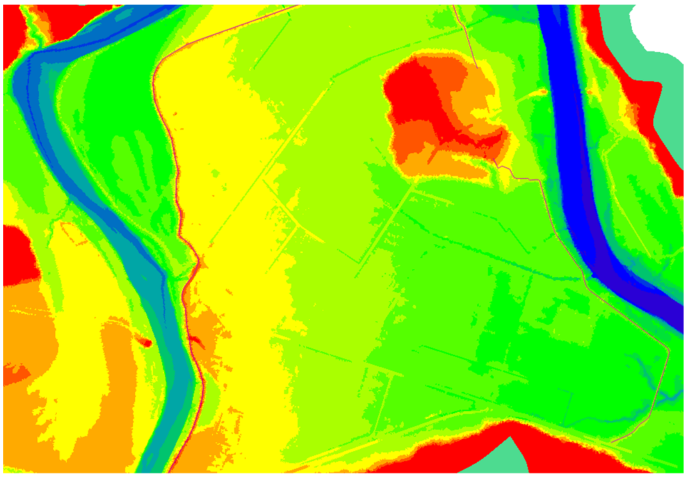

Figure 29 - Roughness representation of the final calibration scenario C15 representing the bridges as depth-dependent roughness M.

The bridges have pier losses represented and are defined by their repsective soffit and deck levels:

Table 10 - Soffit and deck levels of bridges along Waipaoa River

Bridge	Soffit (m)	Deck (m)	Bottom level (m)	Depth to soffit (m)
Rangatira Road Bridge	42.86	44.96	32.96	9.40
Kanakanaia Road Bridge	39.81	41.91	29.32	9.96

C15 Calibration scenario

This scenario represents the bridges in 1D; it uses the surveyed cross-section and the provided bridge details. Several simulations were run to assess the effects of changes to the cross-sections and bridge parameters, but no impact was observed.

Figure 30 shows how the bridges behave, combining both 2D overland and 1D bridge configuration. It is evident that the head losses of the bridges begin to increase as water levels rise, resulting in unrealistically high head losses before the soffit is overwhelmed. This is not representative of how the bridge should behave, so an alternative method to represent the bridges was necessary.

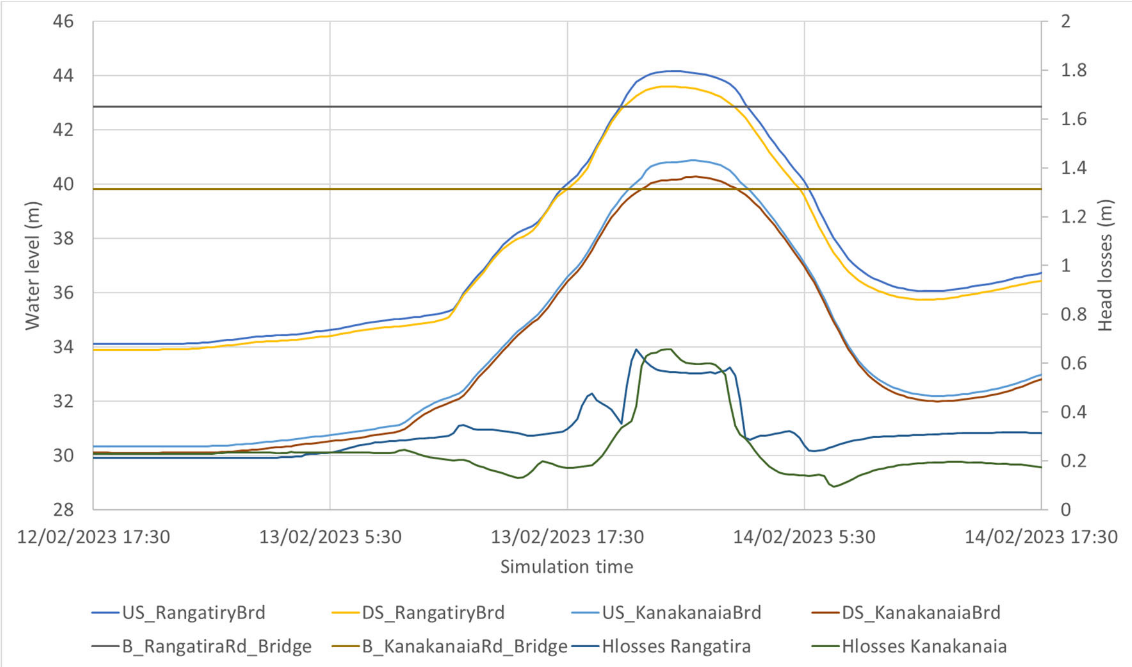

Figure 30 Hydrograph of Rangatira and Kanakanaia bridges with head-losses, soffit, and deck levels for the final calibration C15 scenario

Level vs Level plots

Upstream Level vs Downstream Level plots were produced to more closely compare head losses across the different scenarios. Figure 31 and Figure 32 show the comparison between the head losses for 3 of the simulations, the Base scenario (2D_Simulation_1Deng – light blue), the Bridge1D scenario (1D_Simulation_1p3_V04 - purple), and the Bridge_M1 scenario (2D_Simulation_1Deng_CAL_M1 - red). It can be seen that the bridges in the Base scenario have double the losses before the soffit is overwhelmed, while the model underestimates the head losses after it is overwhelmed for both bridges. The red lines represent the scenario we used in the model (Bridges_M1), and they compare very closely with the 1D model's relative upstream/downstream levels (purple lines).

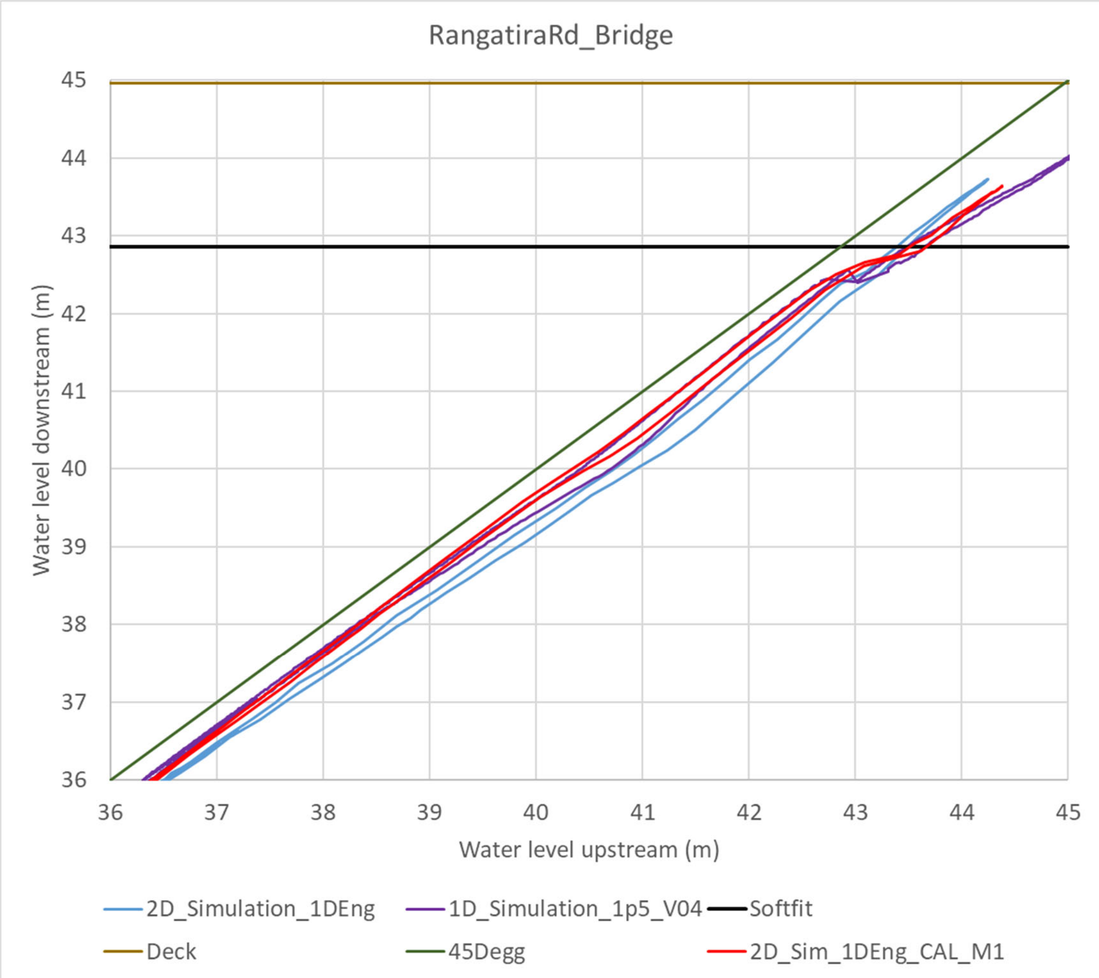

Figure 31 Upstream vs Downstream water level comparison for Rangatira Bridge.

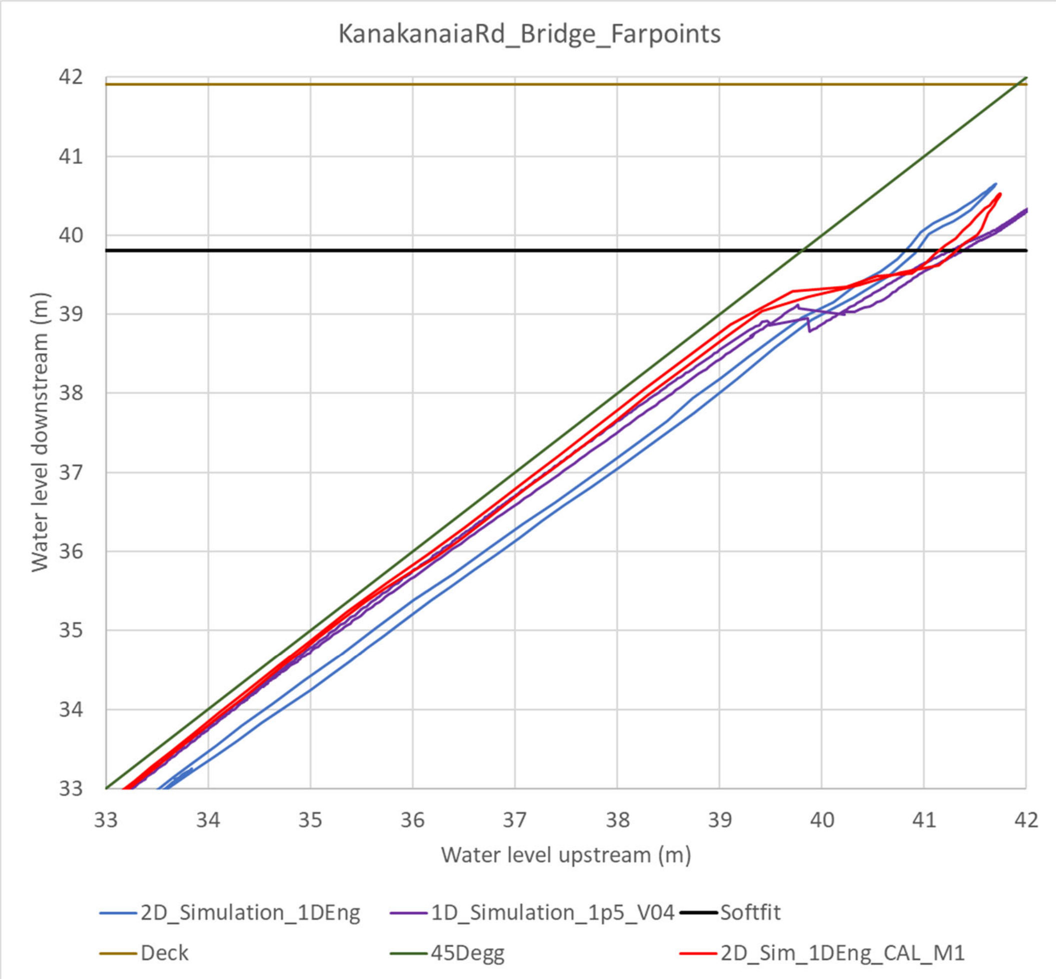

Figure 32 Upstream vs Downstream water level comparison for Kanakanaia Bridge.