APPENDIX H Hydraulic Memorandum

A0006 KiwiRail Br217 PNGL Hydraulic Modelling & Results

To	**TREC PMO** **KiwiRail**
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From	Bryce Warner, Braeden McInnes
Date	21 August 2025
Subject	A0006 KiwiRail Br217 PNGL Hydraulic Modelling & Results
Reference	A0006-PL-00-17000-SW-MM-TREC-000001
Revision	A

Background

Significant debris collection and subsequent scour occurred at KiwiRail Bridge 217 on the Palmerston North Gisborne Line during the events of Cyclone Gabrielle in February 2023. A temporary replacement bridge was constructed in the following months. As part of KiwiRail's endeavour to extend the life of this replacement bridge, a hydraulic assessment has been undertaken.

The location of KiwiRail Bridge 217 Palmerston North Gisborne Line (Br217) is shown in Figure 1.

Figure 1. Location of Bridge 217 PNGL.

Geography and Hydraulic Conditions

Bridge 217 is located downstream of the junction of the Tutaekuri and Ngaruroro Rivers. The Bridge crosses the Awatoto overflow channel which activates during high flows. The State Highway 51 (SH51) Awatoto bridge is located approximately 50m downstream.

River flow through the secondary overflow channel is governed by the mouth position and condition downstream which naturally closes during periods of lower flows and may breach during higher flows. An example of closed and open position is shown in Figure 2.

Historic photography shows that the channel under and around Bridge 217 has experienced aggradation, with the primary channel narrowing over time and rewidening to near (but still less than) 1969 widths during Cyclone Gabrielle.

Figure 2. Closed mouth condition example (left) and post-cyclone mouth breached condition (right)

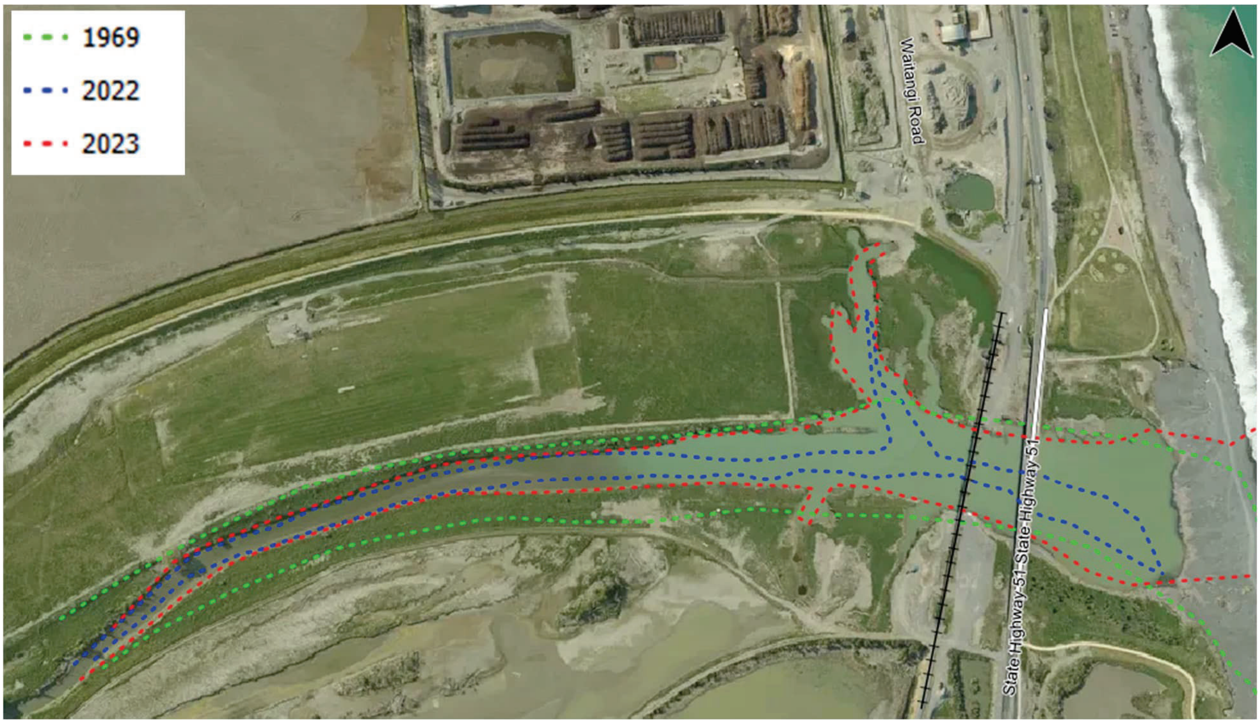


Figure 3. Channel extent examples (1969, 2022, and post-Cyclone Gabrielle)

Data & Resources

All levels stated in this memo are in NZVD2016.

Supplied Hydraulic Model

Hawkes Bay Regional Council provided a draft version of the Heretaunga Plains hydraulic model in September 2024. The hydraulic model included a draft version model build report (T+T, 2024).

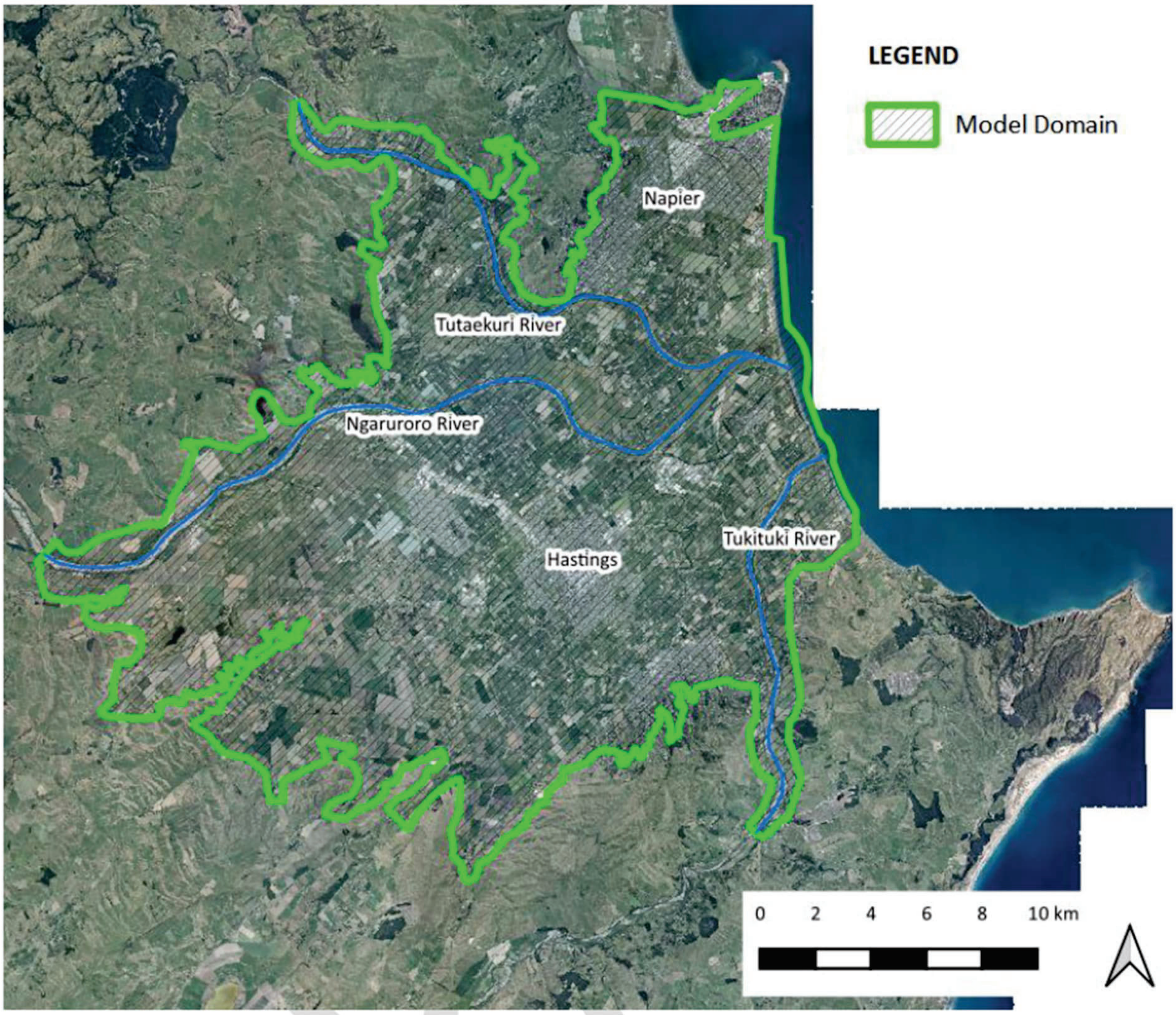


Figure 4. Heretaunga Plains model domain. Figure from T&T, 2024

The HBRC Heretaunga Plains draft hydraulic model (HBRC Model) is a 2D TUFLOW model utilising the TUFLOW's HPC, Quadtree, and GPU modules and was built in version 2023-03-AE. From discussions with T+T and HBRC, the model's primary purpose was to develop flood protection in the upper reaches of the Ngaruroro and Tutaekuri sub catchments. Consequently, detail in the lower reaches of the model was not prioritised.

Structures

Bridges were incorporated into the HBRC Model via TUFLOW's 2d_bg command with a form loss coefficient used to represent piers. See Table 3.3 of T+T, 2024 for further details (Refer Appendix A).

Stopbank crests were incorporated from various sources of LiDAR and construction drawings. See Table 3.1 of T+T, 2024 for further information.

Tidal Area Bathymetry

Coastally inundated areas were lowered to RL (-)2m NZVD within the Awatoto and Waitangi Bridge vicinity.

The T&T report states that:

> *More accurate instantaneous representation of the coastal and tidal area bathymetry could be achieved by undertaking a 2D bathymetric survey. However, given the dynamic nature of the river/tidal processes, such survey would likely become outdated after a short period of time.*

Hydrology

Hydrology for the HBRC Model is based on statistical analysis of river flow records performed by NIWA post-Cyclone Gabrielle. The model is river flow only, with input flows incorporated as boundary conditions at the model domain boundaries. The coastal boundary conditions are represented as a 10yr or 50yr ARI event as defined in 3.10.5 of T&T (2024).

Peak flows and an example hydrograph are shown in Table 1 and Figure 5.

Table 1.Peak flows modelled in Ngaruroro and Tutaekuri Rivers

ARI	Peak Flow (m^3/s)	
	Ngaruroro	Tutaekuri
2y	820	460
5y	1410	830
10y	1880	1160
50y	3210	2240
100y	3930	2910
200y	4750	3740
500y	6020	5160
1000y	7160	6560

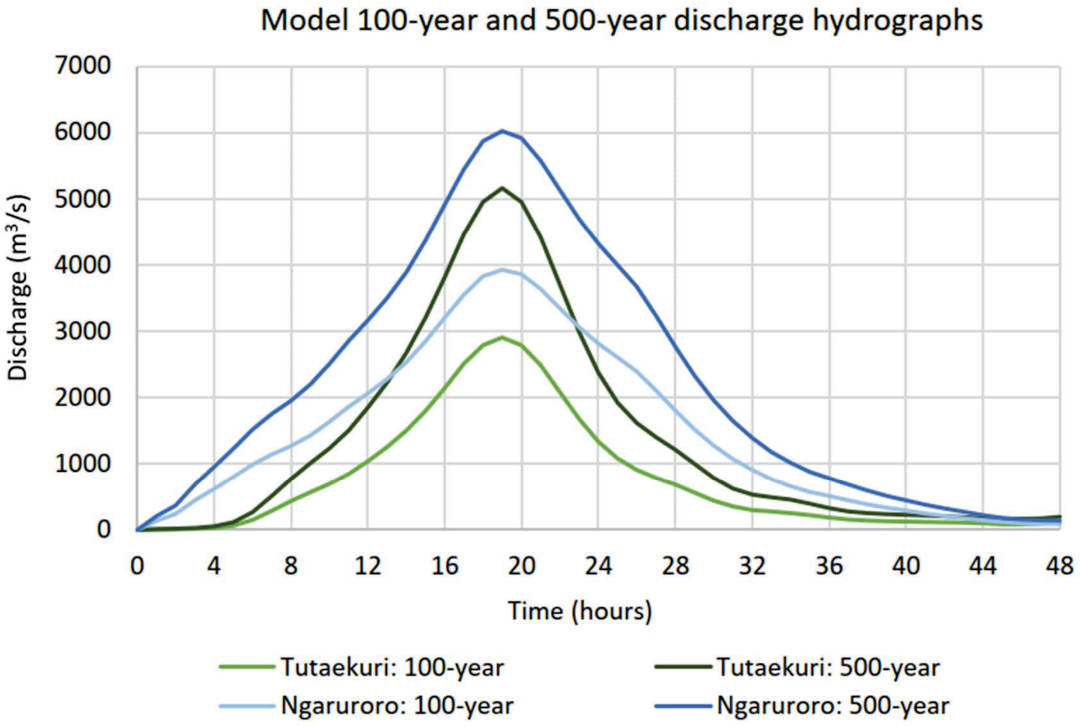


Figure 5. Example hydrograph for 100yr and 500yr ARIs in the HBRC Model.

2023/2024 DEM and Bathymetry

To ensure TREC was using the most recent information:

- A bathymetric survey from April 2024 near the Awatoto SH51 and KiwiRail bridges was utilised from another TREC project.
- The December 2023 Hawkes Bay Digital Elevation Model (DEM) was sourced from LINZ.

Bridges

Given the nature of the project, validation of the existing KiwiRail and state highway Awatoto bridge structures was performed using as-builts and recent surveys. Bridge details are shown in Table 2.

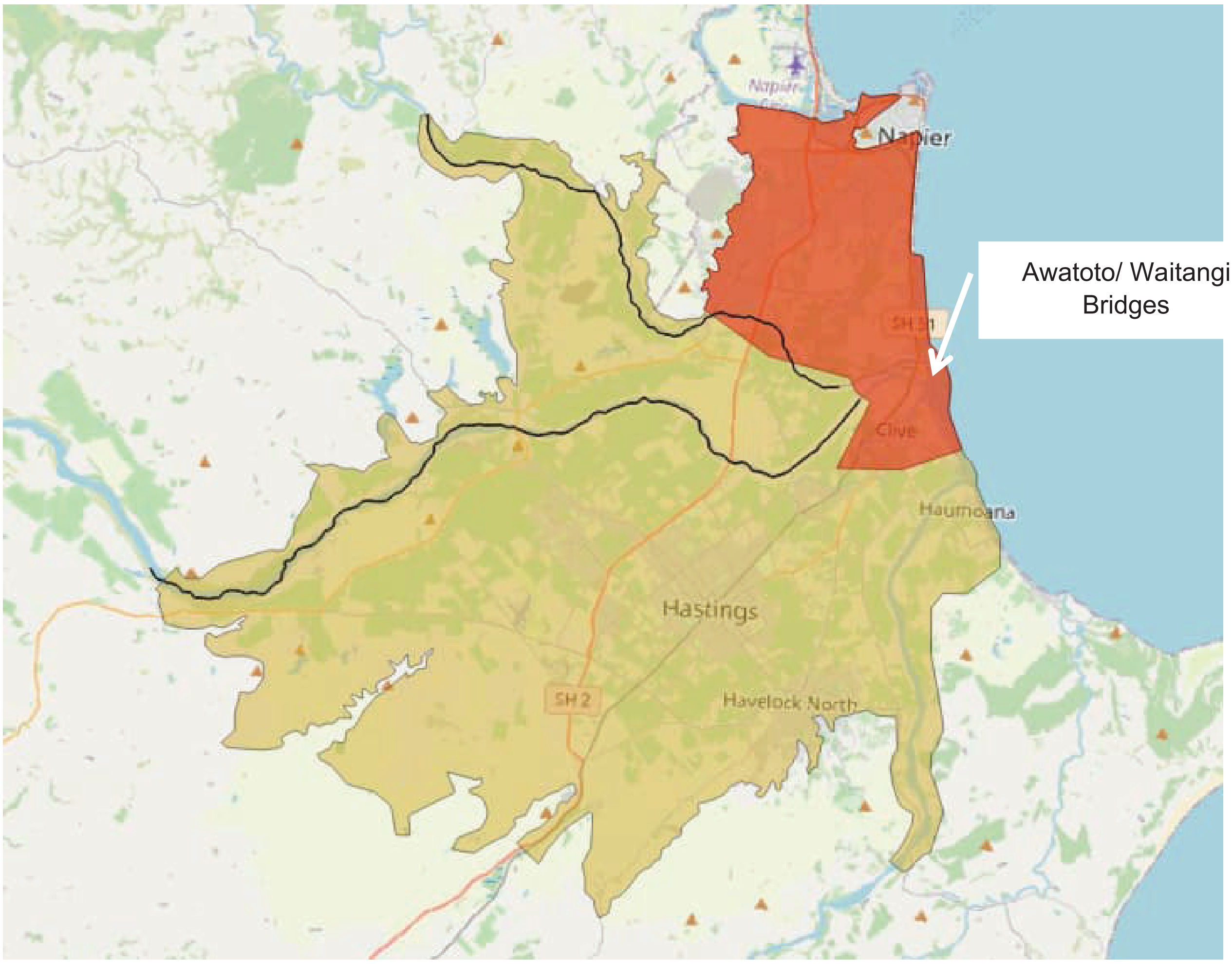
Table 2. Bridge structure details.

Parameter	KR Bridge 217 PNGL	NZTA SH51
Soffit Level (m NZVD)	3.7	2.96
Deck Thickness (m)	1.0	1.2
Rail (Ballustrade) Depth (m)	1.0	1.2
Form Loss (-)	0.1	0.2

Updates to Hydraulic Model

Multiple updates to the HBRC Heretaunga Hydraulic Model were performed for this assessment:

- The HBRC Heretaunga Plains hydraulic model domain was reduced to lessen simulation run times. Upstream boundaries were reduced to approximately 2.5km upstream of the Awatoto and Waitangi bridges (Figure 6).
- Bridge structures were updated as shown in Table 2, above.
- The underlying DEM was updated to the 2023 Hawkes Bay DEM sourced from LINZ.
- The TREC Awatoto river bathymetry was used in place of a generic -2m RL value.



Awatoto/ Waitangi Bridges

Figure 6. TREC Model domain (red) in comparison to HBRC Model domain (yellow). Imagery: OpenStreetMap, 2024

Designs & Events Modelled

Two designs (and one sensitivity test) were simulated. The extent for both designs is shown in Figure 7 and Figure 8:

- **Des1** – Terrain around Br217 and SH51 bridges lowered to +1.2m RL.
- **Des2** – Terrain around Br217 and SH51 bridges lowered to -1.65m RL. (This design was performed as a sensitivity test.)
- **Des 4** – Terrain around Br217 and SH51 bridges lowered to +1.2m RL for a smaller area following stakeholder and community consultation.

Each design run was performed with both a Fully Closed mouth, and a Fully Open mouth.

A 10% AEP tide was applied to each simulation.

A 2%, 1%, and 0.2% AEP river flow scenario was simulated for each design and mouth condition scenario.

All scenarios were performed without the inclusion of climate change.

Figure 7. Extent of terrain modification for both Des1 and Des2 (black hatch)

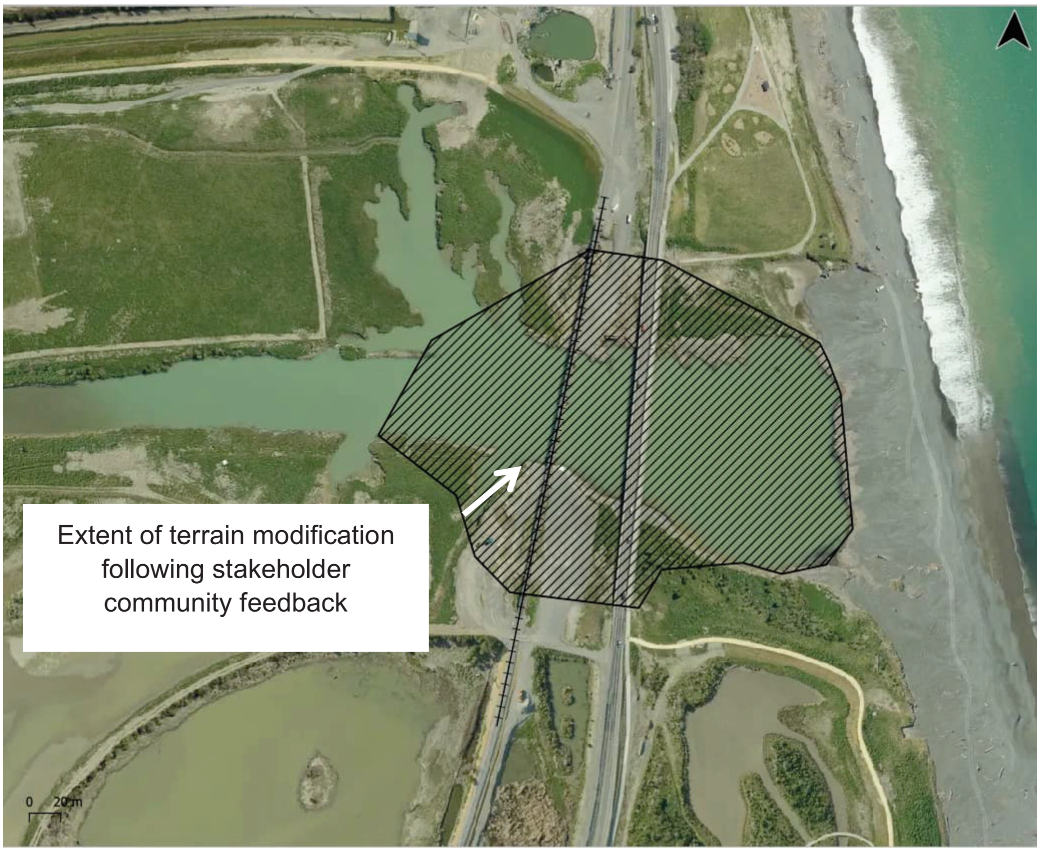


Figure 8. Extent of terrain modification for Des4 (black hatch) following community feedback

Model Assumptions and Limitations

There are several assumptions and limitations for the KR Br217 hydraulic model:

- The model terrain has been sourced from LiDAR. As LiDAR does not penetrate water, the water surface outside of the TREC bathymetric survey is represented with engineering judgement.
- As with any gravel river, the thalweg (the lowest, main flow path) will regularly change. Consequently, averaged cross-section results, incorporating the regular change of riverbed have been used. It is assumed that the LiDAR on which the model has been developed is representative of normal river conditions.
- There is a significant level of uncertainty in trying to predict flows for extreme events when given a limited amount of historical data.
- The Awatoto river bar, when included, has been modelled as a non-scourable solid bar: this is an extremely improbable scenario, but can be used to represent a worst case scenario. During high flows, should the bar overtop or breach, it would reduce the crest levels. In real-world scenarios, maximum water levels would reside somewhere between the blocked and fully open bar conditions.
- The bathymetric survey under Br217 and SH51 bridges includes some of the scour caused by Cyclone Gabrielle. Over time, if there are no additional significant events, the existing scour hole will fill.
- Hawke's Bay Regional Council are planning to upgrade the Brookfields Lower Stopbanks to build resilience for the region. This model doesn't include any future planned upgrades. This can be revisited at a later date if required.

Model Results

Raw Results

Long-sectional hydraulic model water level results for the 2%, 1% and 0.2% AEPs (current climate scenario) are shown in Figure 9 through Figure 17.

A cross section of the Terrain profile at the location of Bridge 217 under consideration can be seen in Figure 18.

Cross-sectional water levels and velocities in the channel approximately 10m upstream of Br217 are shown in Figure 19 through Figure 24.

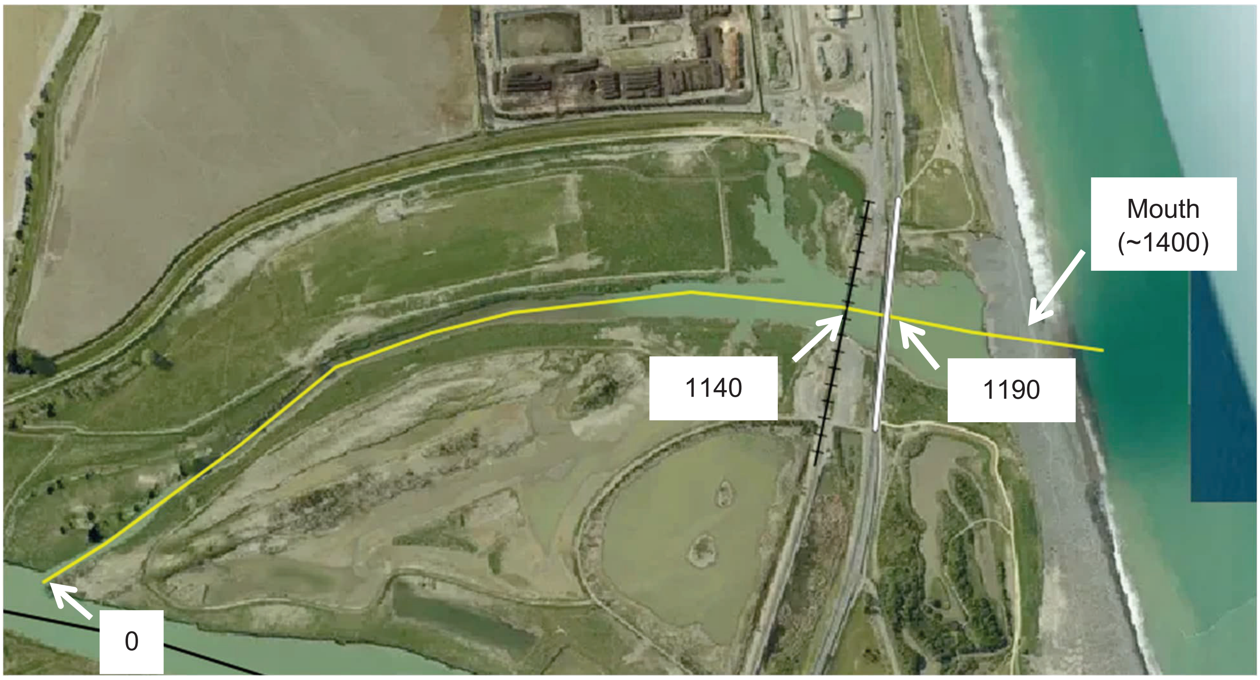


Figure 9. Long-section location and key points for Figure 10 -Figure 15.

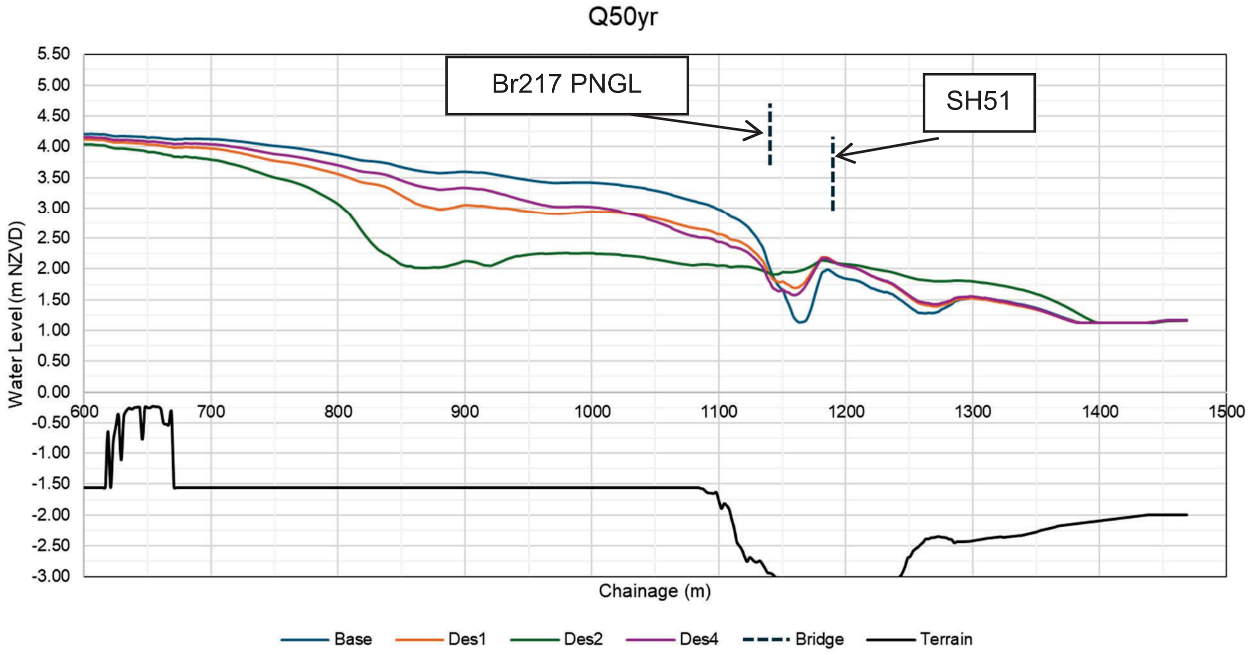


Figure 10. Baseline, Des1, Des2 and Des4, 2% AEP maximum water level with mouth open longsection.

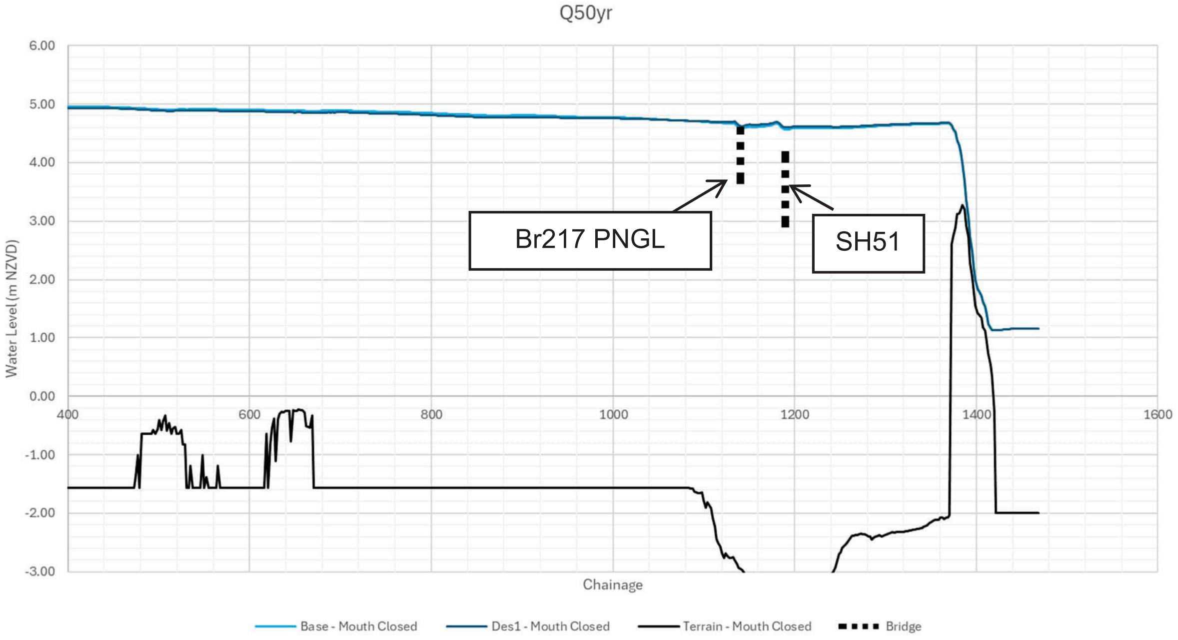


Figure 11 Baseline and Des1, 2% AEP maximum water level with mouth closed longsection.

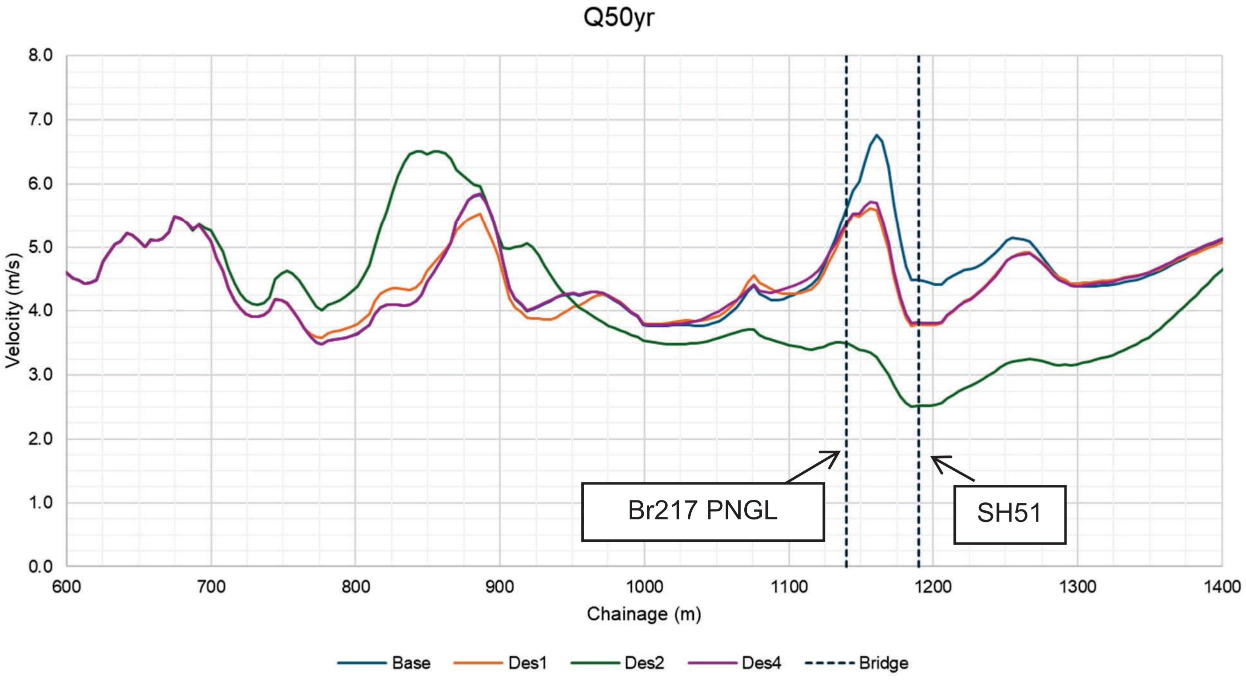


Figure 12. Baseline, Des1, Des2 and Des4, 2% maximum water velocity with mouth open longsection.

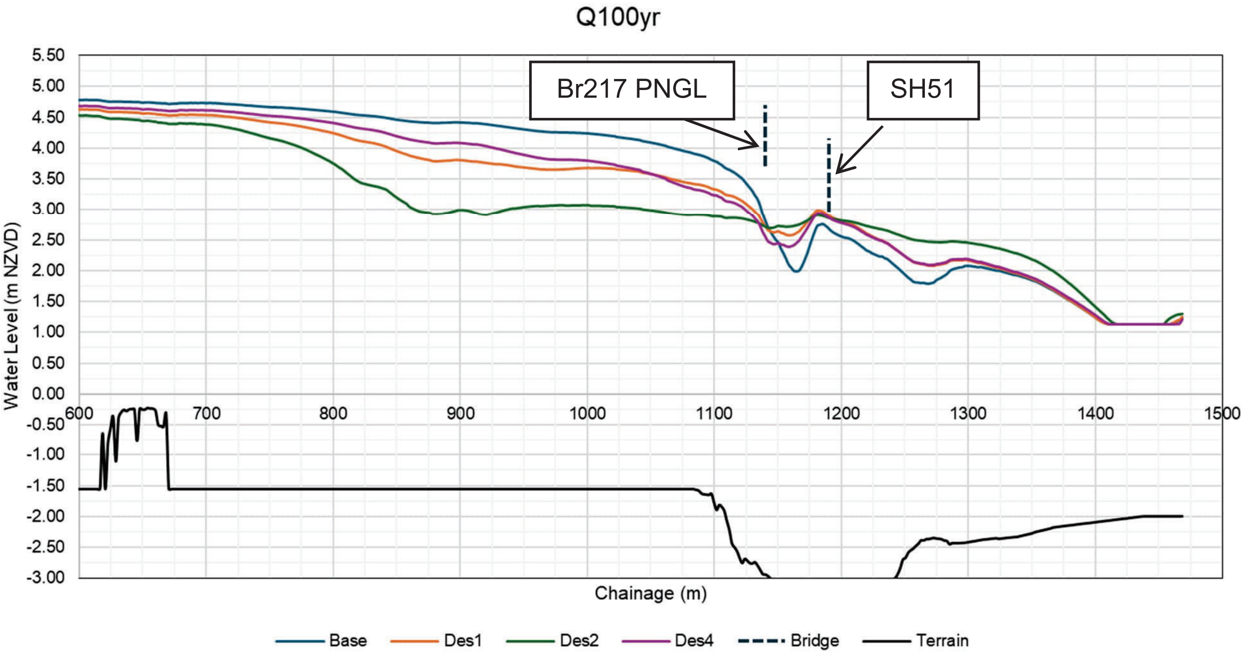


Figure 13. Baseline, Des1, Des2 and Des4, 1% AEP maximum water level with mouth open long section.

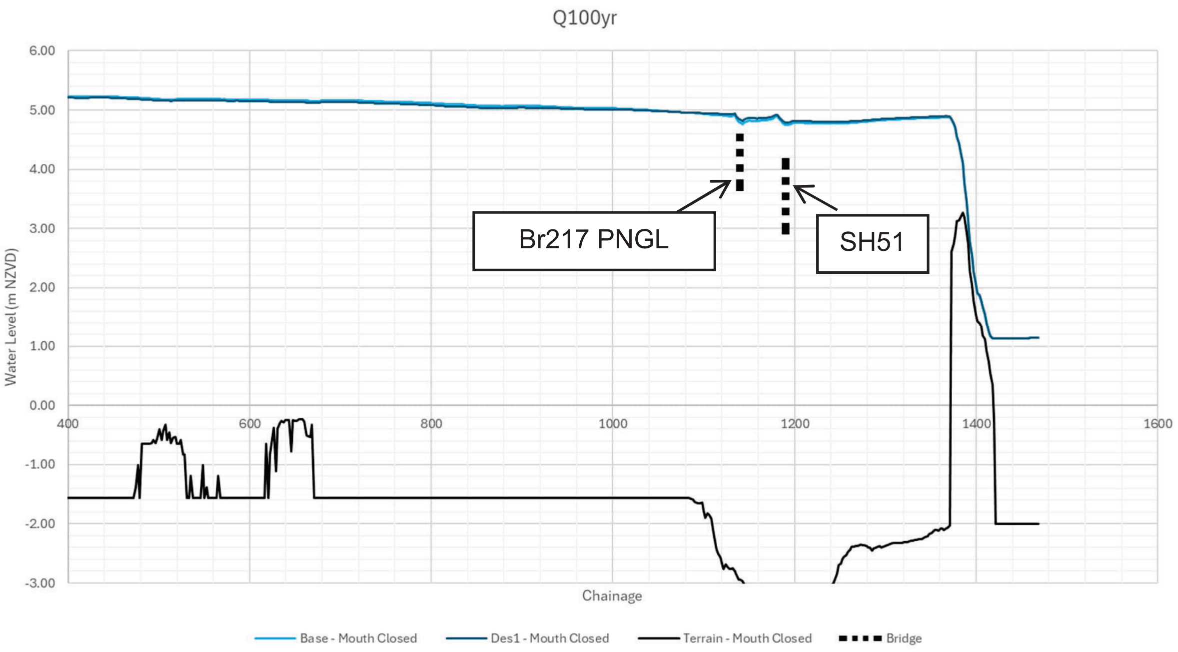


Figure 14. Baseline and Des1, 1% AEP maximum water level with mouth closed longsection.

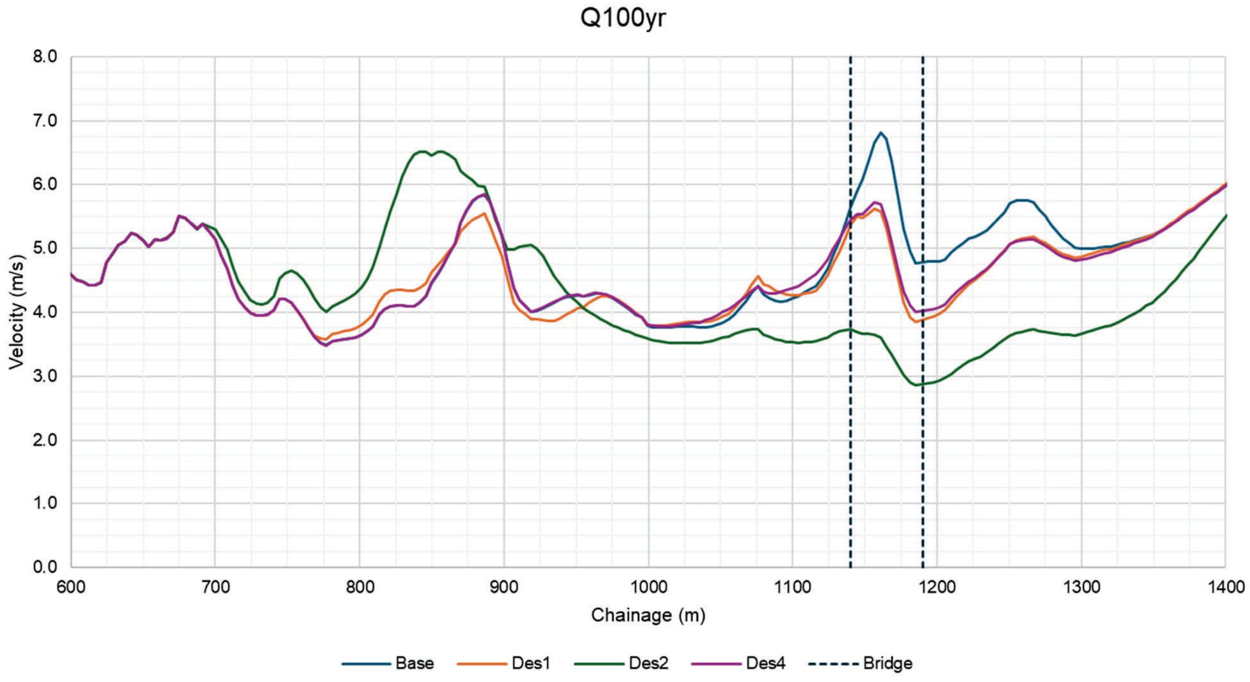


Figure 15. Baseline, Des1, Des2 and Des4, 1% AEP maximum water velocity with mouth open longsection.

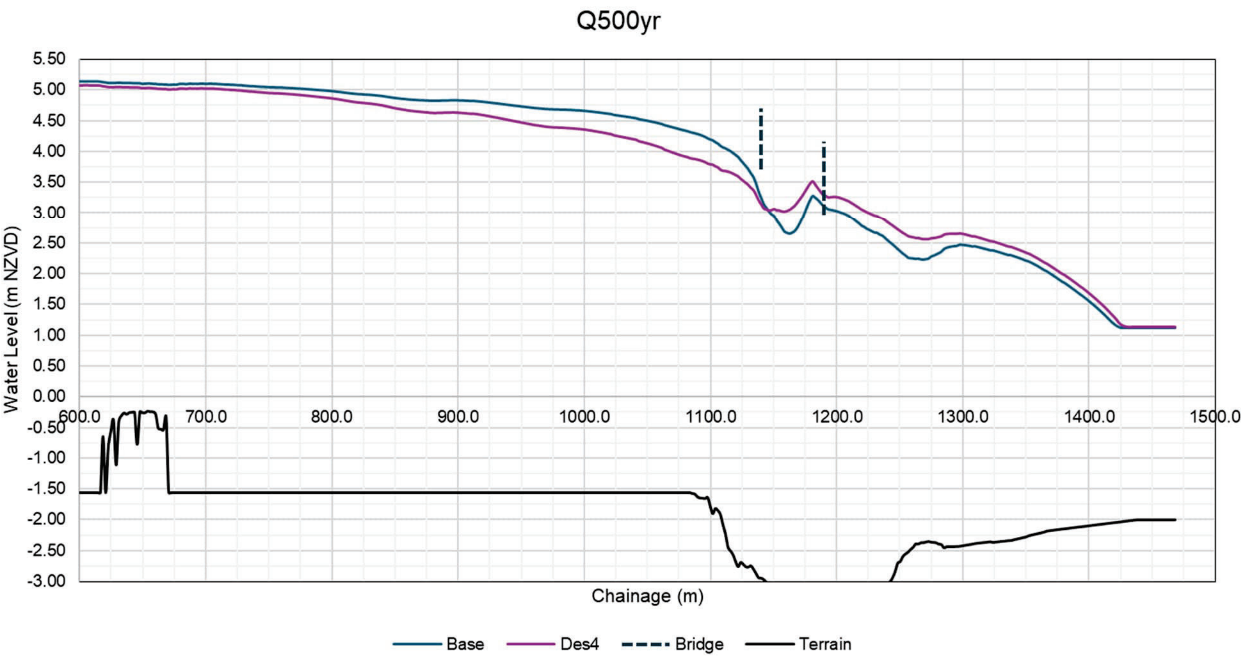


Figure 16. Baseline and Des4, 0.2% AEP maximum water level with mouth open long section.

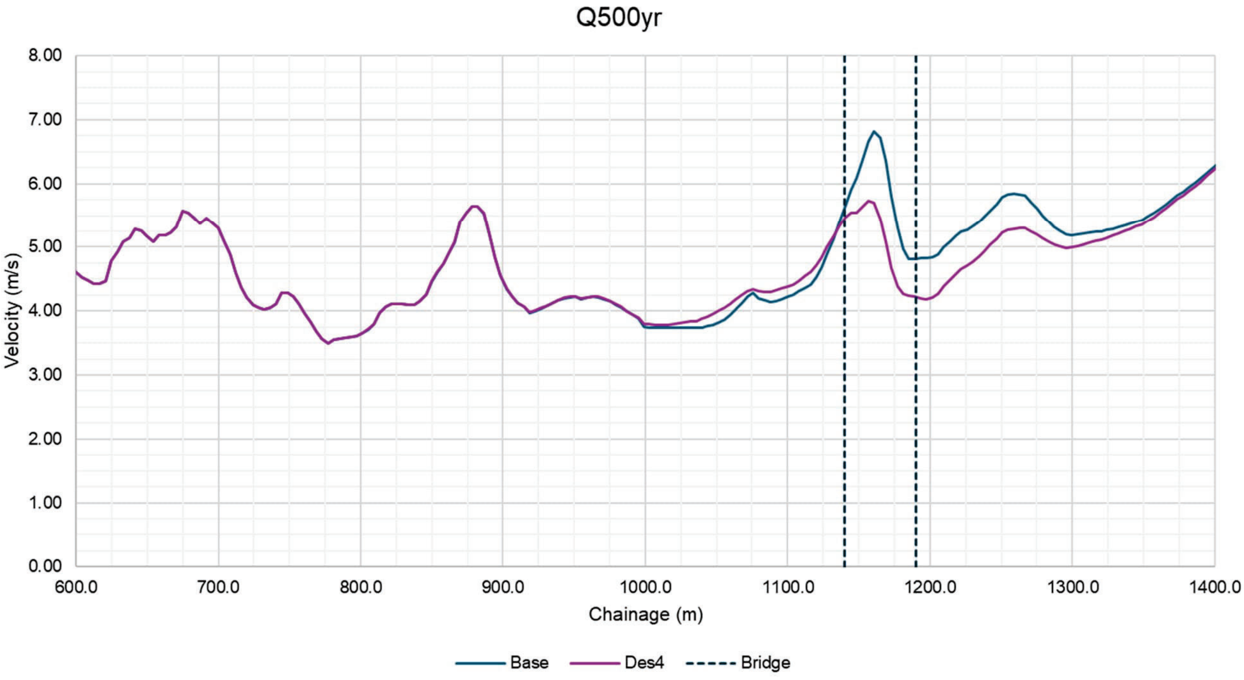


Figure 17. Baseline and Des4, 0.2% AEP maximum water velocity with mouth open longsection.

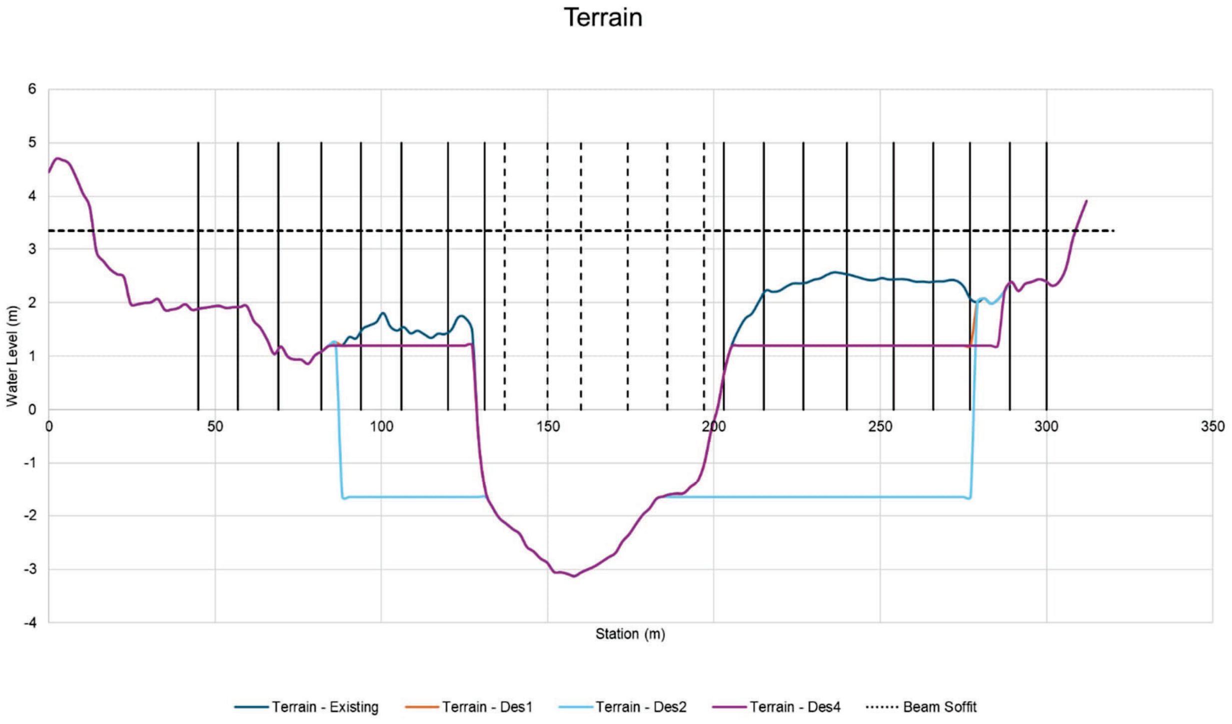


Figure 18. Cross section of terrain profile at Bridge 217

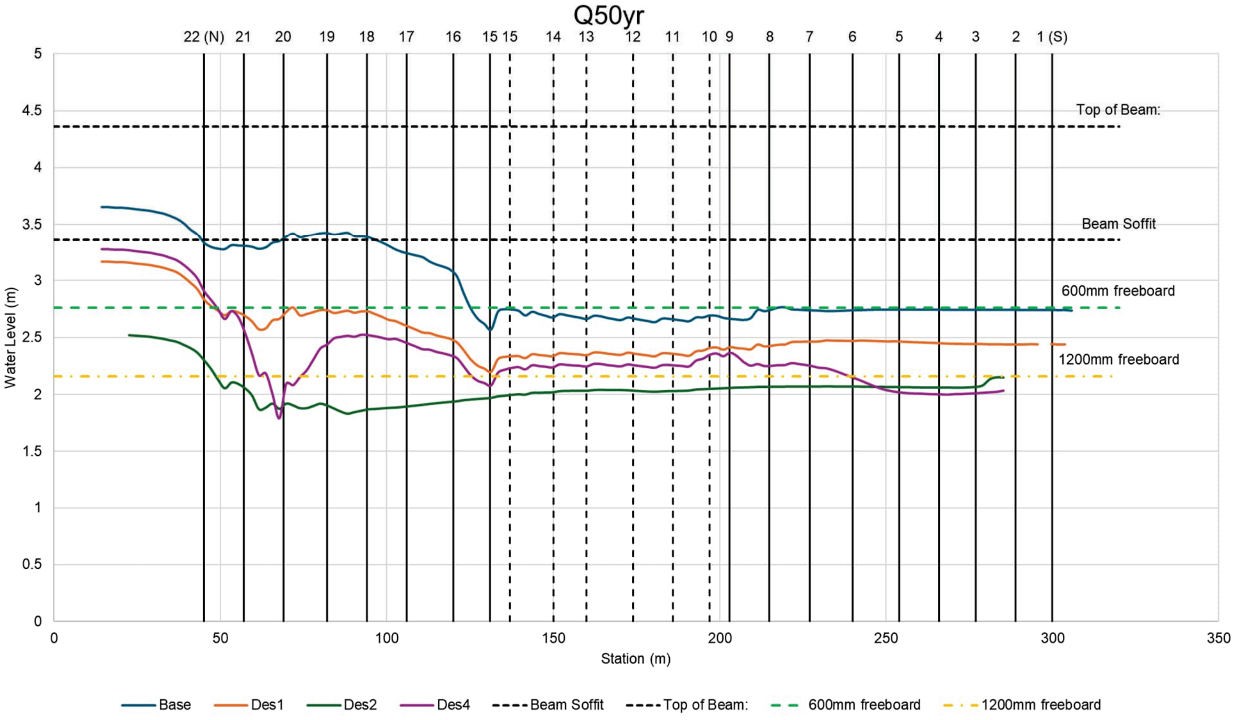


Figure 19. Baseline, Des1, Des2 and Des4 maximum cross-sectional water levels approximately 10m upstream of Br217 for a 2% AEP, mouth open scenario.

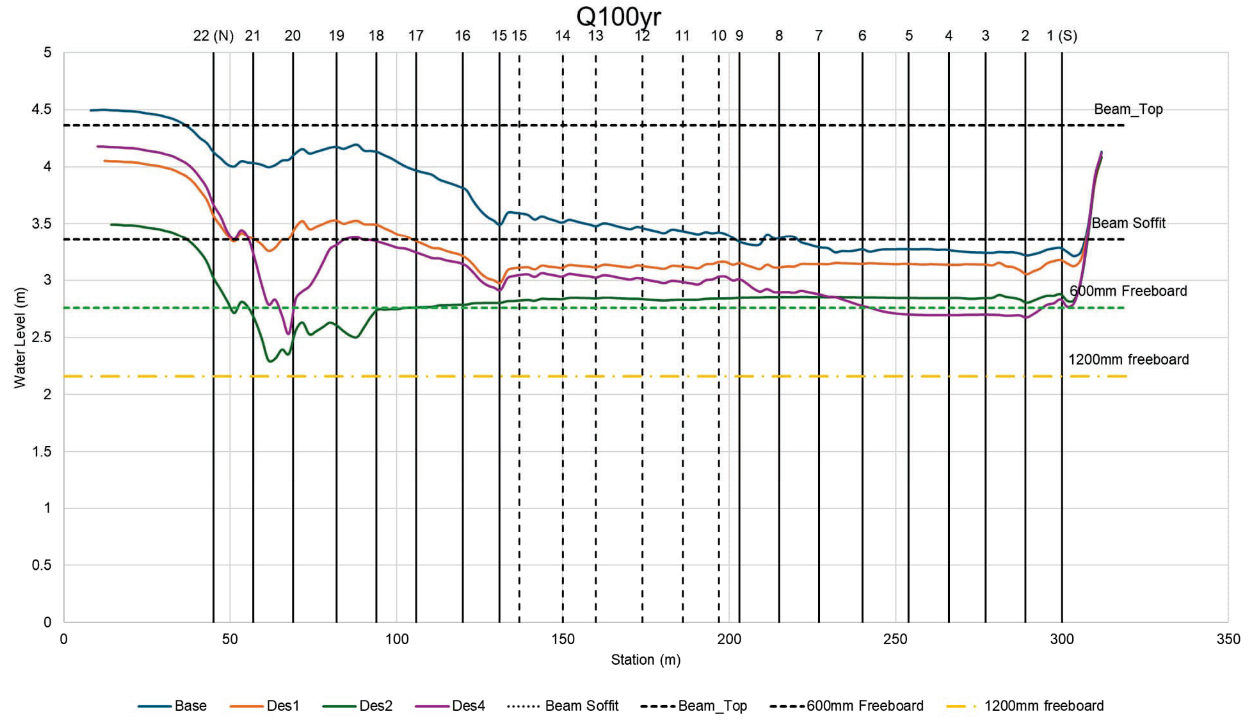


Figure 20. Baseline, Des1, Des2 and Des4 maximum cross-sectional water levels approximately 10m upstream of Br217 for a 1% AEP, mouth open scenario.

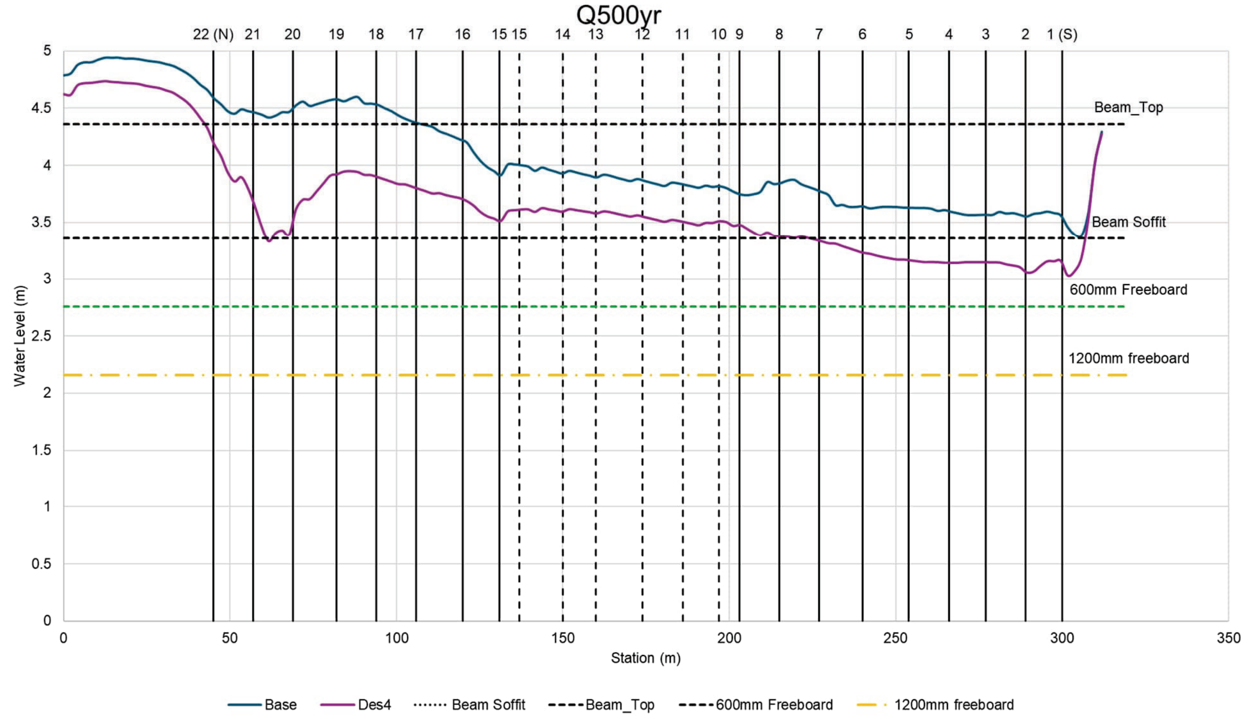


Figure 21. Baseline and Des4 maximum cross-sectional water levels approximately 10m upstream of Br217 for a 0.2% AEP, mouth open scenario.

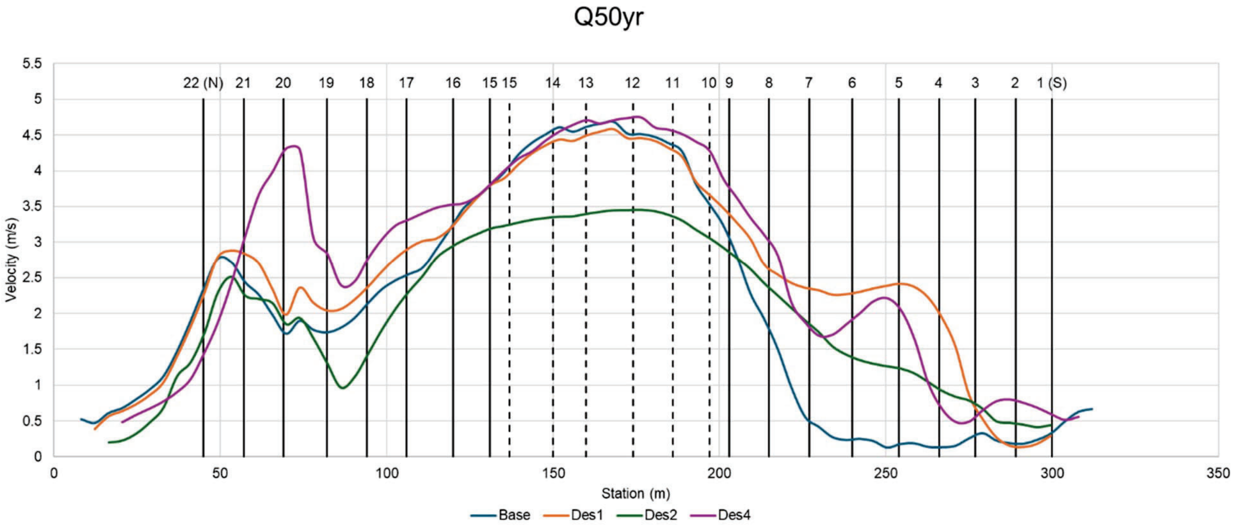


Figure 22. Baseline, Des1, Des2 and Des4 maximum cross-sectional water velocities approximately 10m upstream of Br217 for a 2% AEP, mouth open scenario.

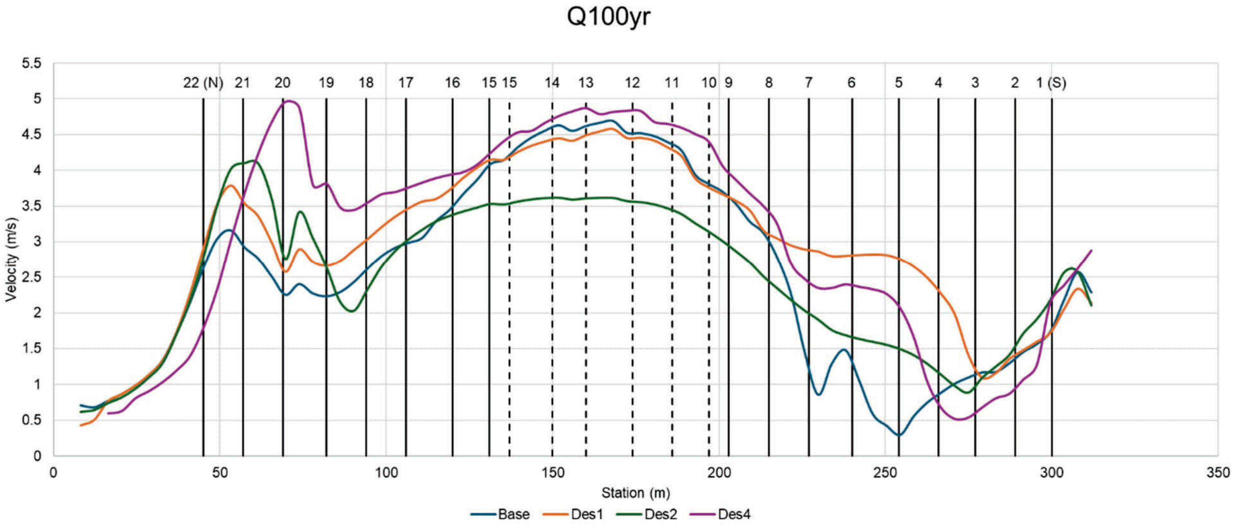


Figure 23. Baseline, Des1, Des2 and Des4 maximum cross-sectional water velocities approximately 10m upstream of Br217 for a 1% AEP, mouth open scenario.

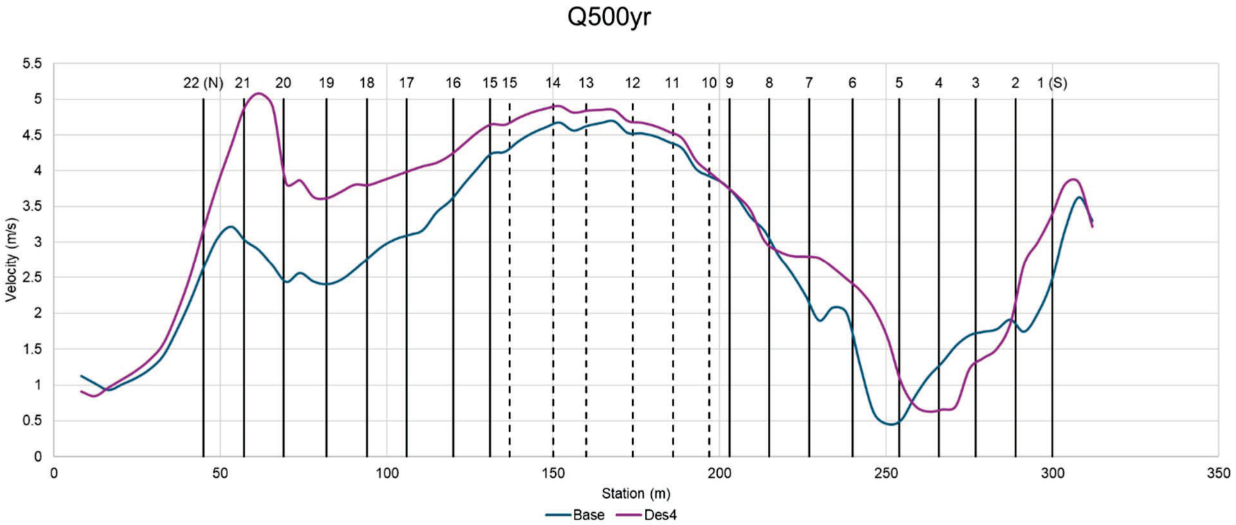


Figure 24. Baseline and Des4 maximum cross-sectional water velocities approximately 10m upstream of Br217 for a 0.2% AEP, mouth open scenario.

Analysis

The above figures show that there is no benefit to increasing cross-sectional area when the bar is closed, as the bar defines water levels and flows through the Awatoto channel. However, when floodwaters can freely flow through the bar, the improvement of cross-sectional area in Des1, Des2 and Des4 reduces water depth at both Br217 and SH51 and significantly reduces water velocities between Br217 and SH51, providing a reduced-scour benefit to Bridge 217 (and incidentally SH51 bridge).

Scour Assessment

Des4 has been further analysed in a scour assessment and compared to the Baseline condition.

The scour analysis has been performed using the FHWA Hydraulic Toolbox v5.4 with NZTA guidance for debris accumulation and has been sense checked using historic scour at this location and general/pier scour rules of thumb.

These calculations show that there is no real benefit to scour for lowering the channel, with estimates, pre- and post-design, consistent with depths that occurred during Cyclone Gabrielle.

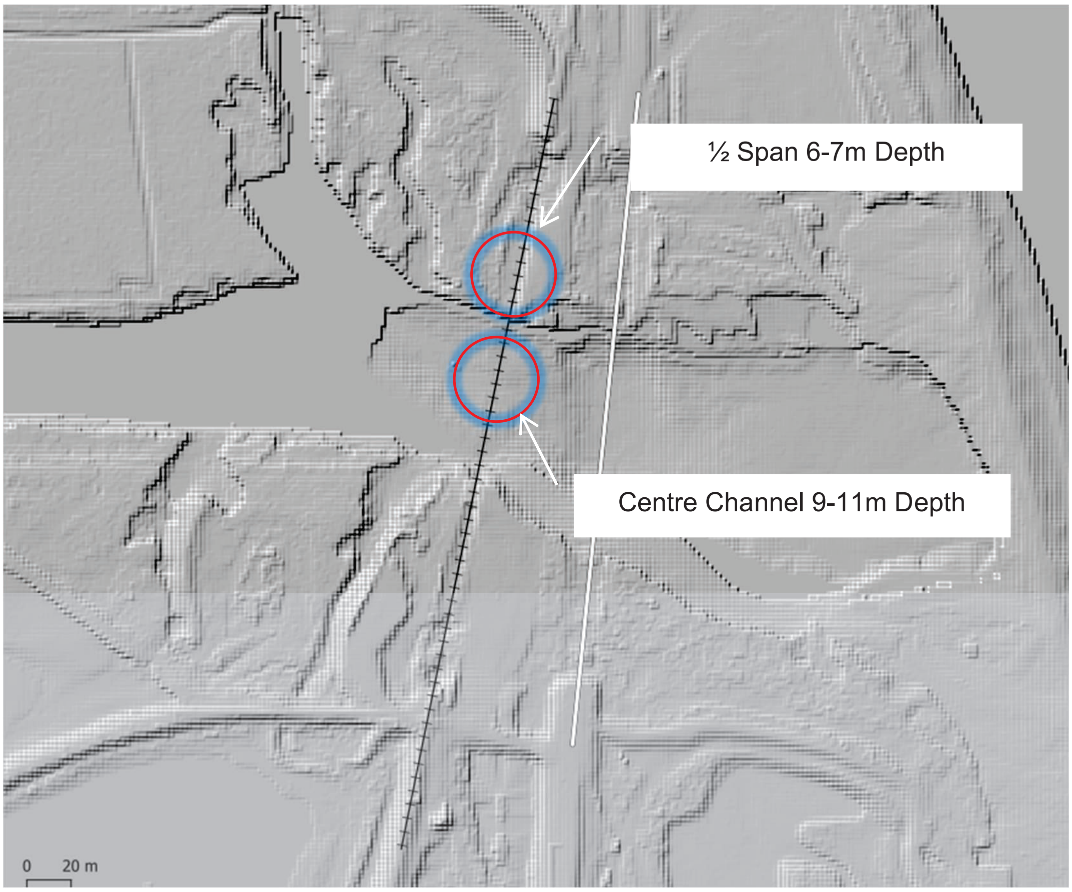


Figure 25. Baseline estimated pier debris scour for a full span blockage with 1% AEP, fully open mouth, and existing bed levels using FHWA Hydraulic Toolbox. Calculations include effects of debris blockage.

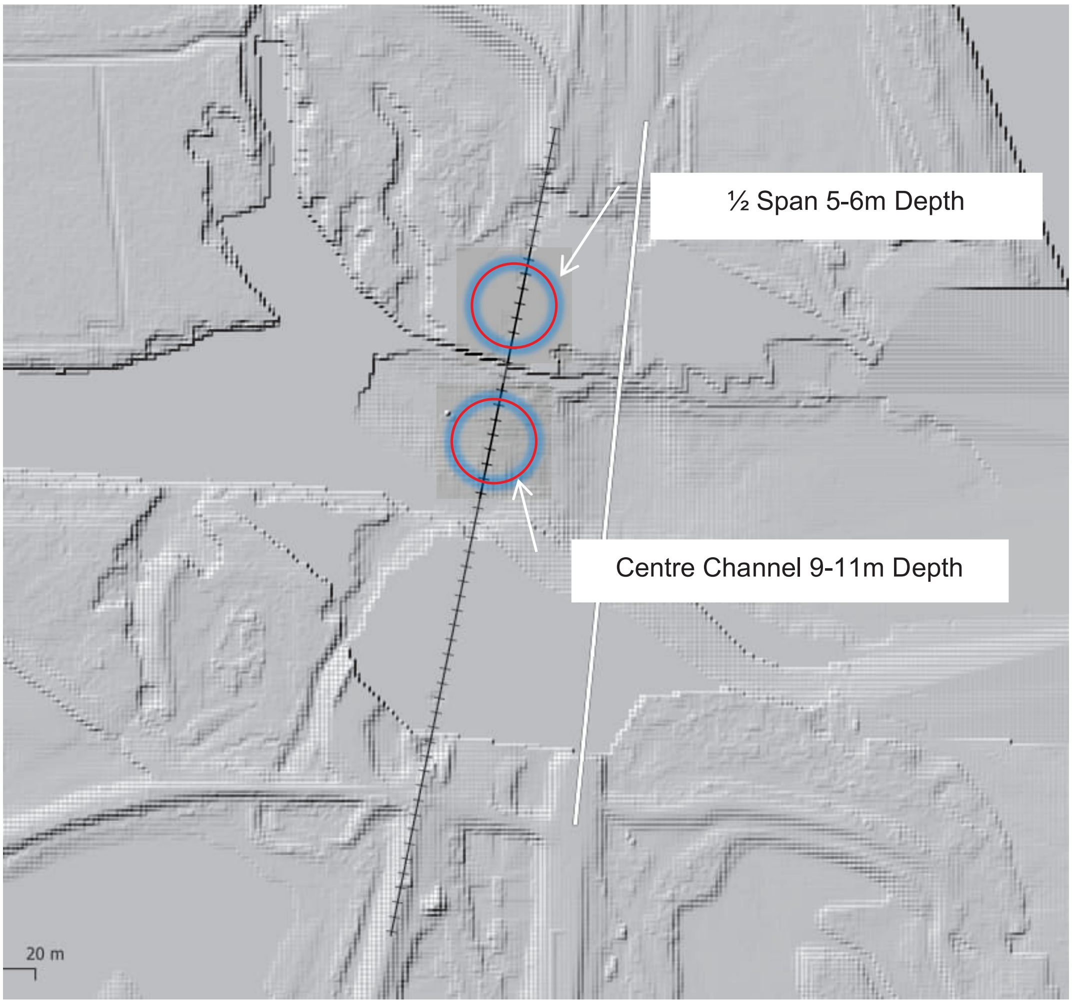


Figure 26. Estimated pier scour for a full span blockage with 1% AEP, fully open mouth, and Des1 bed levels using FHWA Hydraulic Toolbox. Calculations include effects of debris blockage.

Summary

A hydraulic assessment of KiwiRail Bridge 217 PNGL has been undertaken:

- A hydraulic model of the Heretaunga Plains supplied by Hawke's Bay Regional Council was adapted to provide a more accurate representation of conditions in the Awatoto area
- A baseline and design scenario, where the surrounding terrain was lowered to a maximum of 1.2m RL was simulated. Results from these scenarios were compared.
- Comparison of these results shows that the Des1 and Des4 (and sensitivity Des2) options succeed in reducing maximum water levels at the KiwiRail and NZTA SH51 bridges for both the 2% and 1% AEPs (current climate).
    - The reduced water level for Des 4 will likely provide required freeboard during a 2% AEP event (SLS, IL2 event in accordance with the NZTA Bridge Manual). Refer to the Flood Departure for more information.
- These results also show negligible change to water velocity upstream of KiwiRail but a notable change (~0.5m/s) reduction in velocity downstream in the 1% AEP.
    - Des4 shows a notable increase in velocity at the northern end of the bridge due to the removal of temporary staging pad between Bridge 217 and SH51.
- A scour assessment shows that increasing the cross-sectional area of flows has no notable effects on scour potential.

- There is minimal difference in flood velocities between 1% and 0.2% AEP flood events, however water levels do increase.

Appendix A T+T Heretaunga Plains Flood Protection Scheme Hydraulic Model Build Report

REPORT

Tonkin+Taylor

Heretaunga Plains Flood Protection Scheme

Hydraulic Model Build Report

Prepared for
Hawkes Bay Regional Council
Prepared by
Tonkin & Taylor Ltd
Date
August 2024
Job Number
1017353.2302 v1

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Document control

Title: **Heretaunga Plains Flood Protection Scheme**					
Date	**Version**	**Description**	**Prepared by:**	**Reviewed by:**	**Authorised by:**
14/08/2024	1	Draft Report	R. Brunton L. Klingen	M. Pennington	T. Morris

Distribution:

Hawkes Bay Regional Council	1 electronic copy
Tonkin & Taylor Ltd (FILE)	1 electronic copy

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Appendix D **Scheme improvement options maps**

Executive summary

The Heretaunga Plains Flood Control Scheme (HPFCS) encompasses the low-lying historic river plains of the Tutaekuri, Ngaruroro and lower Tukituki Rivers. It includes all of Hastings, Flaxmere and Havelock North urban areas, as well as most of the Napier urban area. The area directly benefiting from the scheme covers approximately 39,000 hectares.

Hawke's Bay Regional Council (HBRC) has engaged T+T to undertake a review of the HPFCS. As part of this review, a hydraulic model has been built to assist in the scheme review (for example, informing level of service and improvement options) and help understand the scheme performance during Cyclone Gabrielle.

This DRAFT report documents the hydraulic model build, providing details of model parameters used and how the model was validated against the Cyclone Gabrielle event. The focus of this report is the model build on the Ngaruroro and Tutaekuri rivers. A separate report will discuss the model build of the lower Tuki Tuki river.

1 Introduction

1.1 Project background

The Heretaunga Plains Flood Control Scheme (HPFCS) encompasses the low-lying historic river plains of the Tutaekuri, Ngaruroro and lower Tukituki Rivers. It includes all of Hastings, Flaxmere and Havelock North urban areas, as well as most of the Napier urban area. The area directly benefiting from the scheme covers approximately 39,000 hectares.

In February 2023, Cyclone Gabrielle caused widespread flooding throughout the HPFCS resulting in severe damage to property and infrastructure. Several of the scheme's stopbanks overtopped and failed in multiple locations.

A review of the HPFCS is being undertaken to identify improvements and address the emerging challenges of over design events, and ensure the scheme remains relevant and effective. To assist in this process, Hawke's Bay Regional Council (HBRC) has engaged Tonkin & Taylor Ltd (T+T) to build a 2-Dimensional (2D) hydraulic flood model of the HPFCS. This report documents the model build, providing details of the model inputs, assumptions and outputs.

This report forms part of a larger study report, Heretaunga Plains Flood Control Scheme review, T+T ref: 1017353.2302.

1.2 Model build philosophy

The hydraulic flood model has been built to:

- Assist in the HPFCS review (for example, informing level of service and improvement options); and
- Help understand the HPFCS performance during Cyclone Gabrielle.

The focus of the modelling is to assess floodplain flooding from the river system during a major flood event. Analysis of floodplain and urban flooding from inadequate local drainage and/or an inability for local drainage networks to discharge to the rivers during times of elevated river levels is not required at this time, and the model has not been developed with this use in mind

The inputs and assumptions made in the model represent a specific set of conditions based on supplied information and data from various parties. Different model results are expected if the inputs or assumptions are changed. Care should be taken when using the model for specific purposes.

On completion of this project, HBRC will be supplied with all model files and results. It is important to recognise the purpose for which the model was built and not use it for different uses for which the model may not be suitable.

2 Model schematisation

2.1 Purpose

The model was built specifically as a tool to assist in the review of the HPFCS which includes assessment of levels of service and improvement scenarios. As such, the model is focused on large river flood events only, namely:

- 100-year design event (Level of Service event, LoS); and
- 500-year over design event.

The model is not suitable for:

- Low flow modelling; and
- Analysing local flooding issues caused by local drainage issues (and/or an inability for local drainage networks to discharge during times of elevated river levels).

The model is to understand the overall floodplain and in its current form is not suitable to use to inform detailed design of particular infrastructure at particular locations.

2.2 Schematisation summary

Table 2.1 provides a summary of the model schematisation. Further details are provided in the subsequent report sections.

Table 2.1: Schematisation Summary

Model Element	Description
Software	The model has been built and run using 2D TUFLOW Heavily Parallelised Compute (HPC) Software. See Section 3.1 for further details. The model uses the HPC solver adaptive timestep to maintain stability. See Section 3.2 for further details.
Domain	The model domain includes the Ngaruroro, Tutaekuri and lower Tukituki Rivers plus the Heretaunga Plains area. The model domain area is approximately 450 km^2. See Section 3.4 for further details.
Elevation data	Model elevation data was based on the 2020/2021 Light Detection and Ranging (LiDAR) 1 m Digital Elevation Model (DEM), from Land Information New Zealand (LINZ). See Section 3.5 for further details.
Geometry modifications	Several modifications to the model geometry were made, including: • Low flow channel bed was “burnt” into the DEM to account for conveyance capacity not defined in the DEM. • Within the coastal and tidal areas of the Ngaruroro River mouth, the DEM was modified to better represent the bathymetry conditions could be expected in a large flood event. • Stopbanks were enforced into the model using estimated stopbank crest elevations along the stopbank centreline. See Section 3.6 for further details.
Structures	Bridges were represented in the model to account for surcharging, pressure flow of bridge decks and submerged bridge flow at higher water levels. As the purpose of this model is to consider large river floods only, drainage assets (such as culverts with flap gates and drainage channels) were not represented in the model.

Model Element	Description
Computational cell size	The model incorporates computational cell size adjustment through TUFLOW's quadtree nesting. Quadtree nesting enables users to specify smaller cell sizes in areas requiring detailed resolution, and larger cell sizes in areas where coarser resolution will not significantly affect conveyance. See Section 3.8 for further details.
Roughness	Hydraulic roughness is a parameter used in hydraulic modelling to describe the resistance to surface water flow across the terrain, within a channel, or through a pipe. Hydraulic roughness is represented in the model by Manning's 'n' roughness value.
Boundary conditions	Time varying discharge hydrographs for the Tutaekuri and Ngaruroro Rivers were input as inflows at the upstream end model domain. 100-year, 500-year and 1000-year events modelled. See Section 3.10 for further details. Climate change scenario allowance, based on an assumed nominal increase in the Tutaekuri and Ngaruroro Rivers discharge hydrographs by 25 %. A time varying water level stage boundary was applied to the model at the costal boundary of the model domain. See Section 3.10.5 for further details. No rainfall is applied to the model domain. The rivers are dry at the start of the simulation (baseflows are < 1 % of flood flows being modelled).

3 Hydraulic model details

3.1 Model Solver

The model has been built and run using 2D TUFLOW HPC 2023-03-AE release version. TUFLOW HPC is an explicit solver for the full 2D Shallow Water Equations (SWE), including a sub-grid scale eddy viscosity model. The scheme is both volume and momentum conserving, is 2nd order in space and 4th order in time.

3.2 Timestep

The model uses the HPC solver adaptive timestep to maintain stability. The timestep is adjusted so that it complies with the mathematical stability criteria of a 2D SWE explicit solution. There are three primary processes that determine the maximum timestep that an explicit solution to the SWE uses, including the Courant Number (Nu), Wave Celerity Number (Nc) and Diffusion Number (Nd). The model uses the highest timestep possible without exceeding the following processes limits:

Courant number: <1.0.
Celerity Control: < 1.0.
Diffusion control: < 0.3.

3.3 Coordinate system and datum

The model uses New Zealand Transverse Mercator (NZTM) horizontal coordinate system and the New Zealand Vertical Datum (NZVD) 2016 vertical datum.

3.4 Domain

The model domain encompasses the area as shown in Figure 3.1.

The domain includes the Ngaruroro River from Maraekakaho, the Tutaekuri River from Dartmoor and the lower Tukituki River from Red Bridge. The domain includes all areas discussed and agreed with HBRC.

The Tukituki River from Red Bridge was included in the model domain for efficiency but all modelling for this river is being undertaken under separate engagement with HBRC. All inputs and assumptions for the Tukituki River are presented in a separate report.

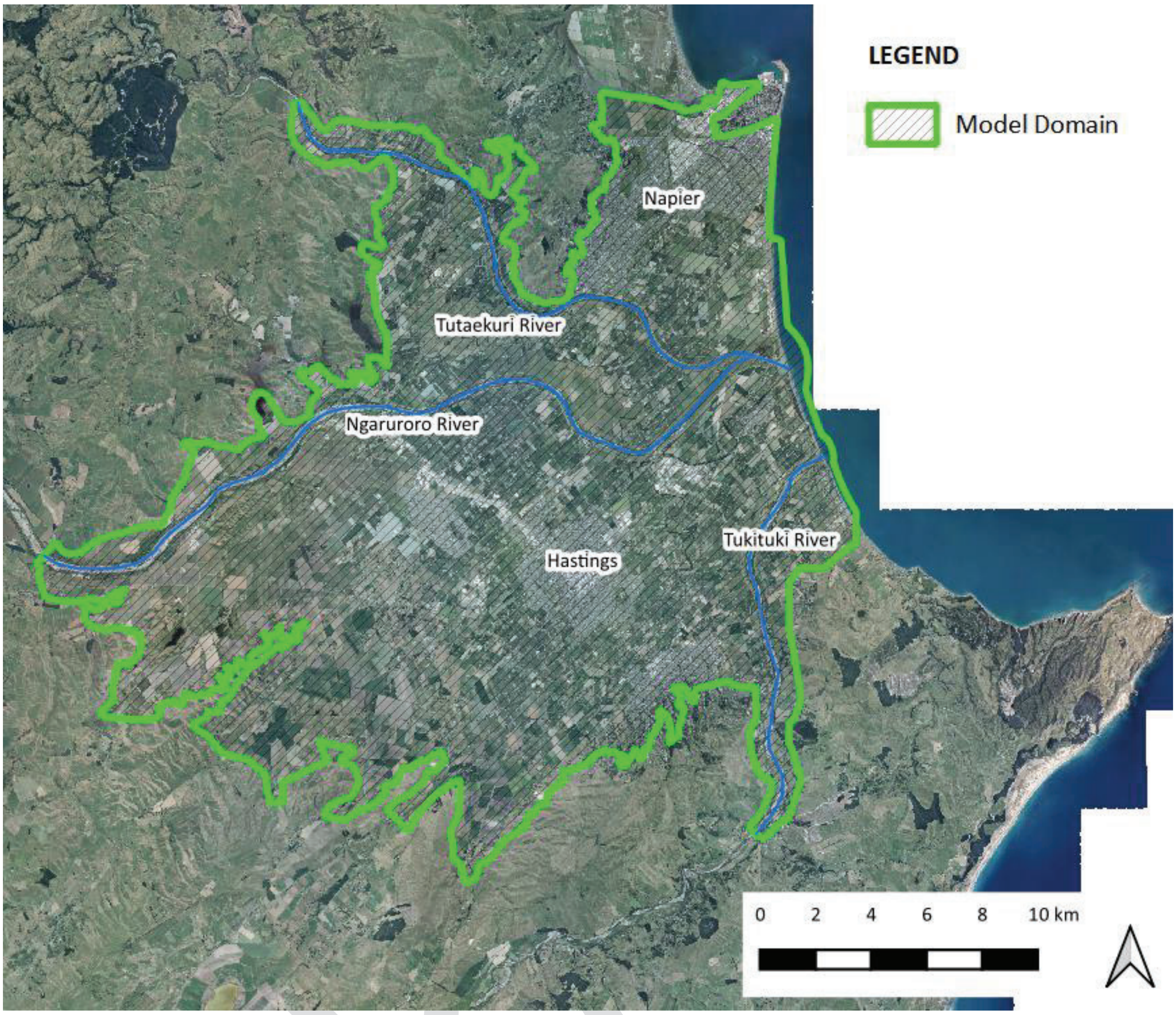

Figure 3.1: Model domain.

3.5 Elevation data

Ground elevation data for the model was based on the 2020/2021 Light Detection and Ranging (LiDAR) 1 m DEM which has stated specification accuracies of Vertical +/- 0.2 m (95 %) and Horizontal +/- 1.0m (95 %). The link to this data is at: https://data.linz.govt.nz/layer/112889-hawkes-bay-lidar-1m-dem-2020 2021/metadata/iso/

The LiDAR is available from Land Information New Zealand (LINZ) as a Digital Elevation Model (DEM), which is used in the model as supplied. The DEM is a gridded bare earth dataset which is supposed to exclude trees, buildings and other above ground surface objects. Verification of the DEM accuracy was not part of this study.

Cyclone Gabrielle caused significant transport and deposition of sediment throughout the scheme which resulted in a change of ground elevations in some areas of the active river channel and overbanks. Post-Cyclone Gabrielle LiDAR DEM elevation captured from 26 February to 15 March 2023 is available for most of the model domain and is publicly available from LINZ. No documentation regarding the accuracy of the DEM is available on LINZ. The Post-Cyclone DEM was only used for model sensitivity simulations (refer Section 6). This assumption was discussed and agreed with HBRC. This means that changes in sediment deposition have not been captured in the base model, as this adopts the older 2020 LiDAR DEM.

3.6 Geometry modifications

Several modifications were made to the DEM to better represent river channels, coastal bed levels and stopbanks within the model domain.

3.6.1 River channel

The supplied DEM does not represent bathymetry elevations below wetted surfaces of water bodies such as river channels. As a result, the cross-sectional area of the channel can be underrepresented in the DEM resulting in a loss of hydraulic conveyance and an increase in modelled peak water levels.

HBRC supplied 2018 river channel cross section survey of the Ngaruroro and Tutaekuri Rivers at several locations within the model domain. The cross-section survey elevations were compared to the supplied DEM as shown in Figure 3.2.

The cross-section survey confirms that the supplied DEM omits a portion of the river channel cross-sectional area below the wetted surface. On average, the supplied DEM is estimated to omit in the order of 5 % to 10 % of the total cross-sectional area between the stopbanks.

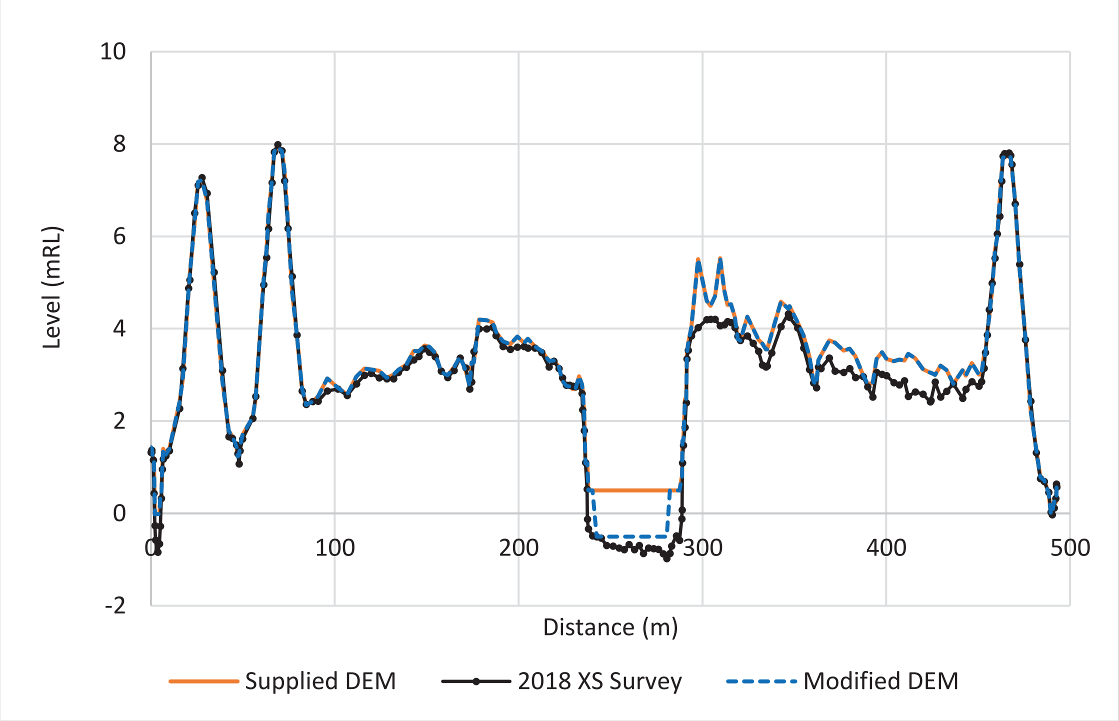

Figure 3.2: Modified DEM and cross section survey.

To recover some of the estimated loss of cross-sectional area within the supplied DEM, a channel was "burnt" into the DEM as shown on Figure 3.3. A 40 m wide channel was burnt into the Ngaruroro River and a 25 m wide channel into the Tutaekuri River, to a depth of 1 m along the entire channel length. These dimensions were estimated from the cross-section survey and represent a typical width and depth along the channel. The alignment of the burnt channel approximately follows the centreline of the wetted surface captured by the supplied DEM. An example of the channel burn extent being applied to the model is shown on Figure 3.4. Using this approach, the estimated cross-sectional area difference between the modified DEM and the cross-section survey was reduced to well below 5 %.

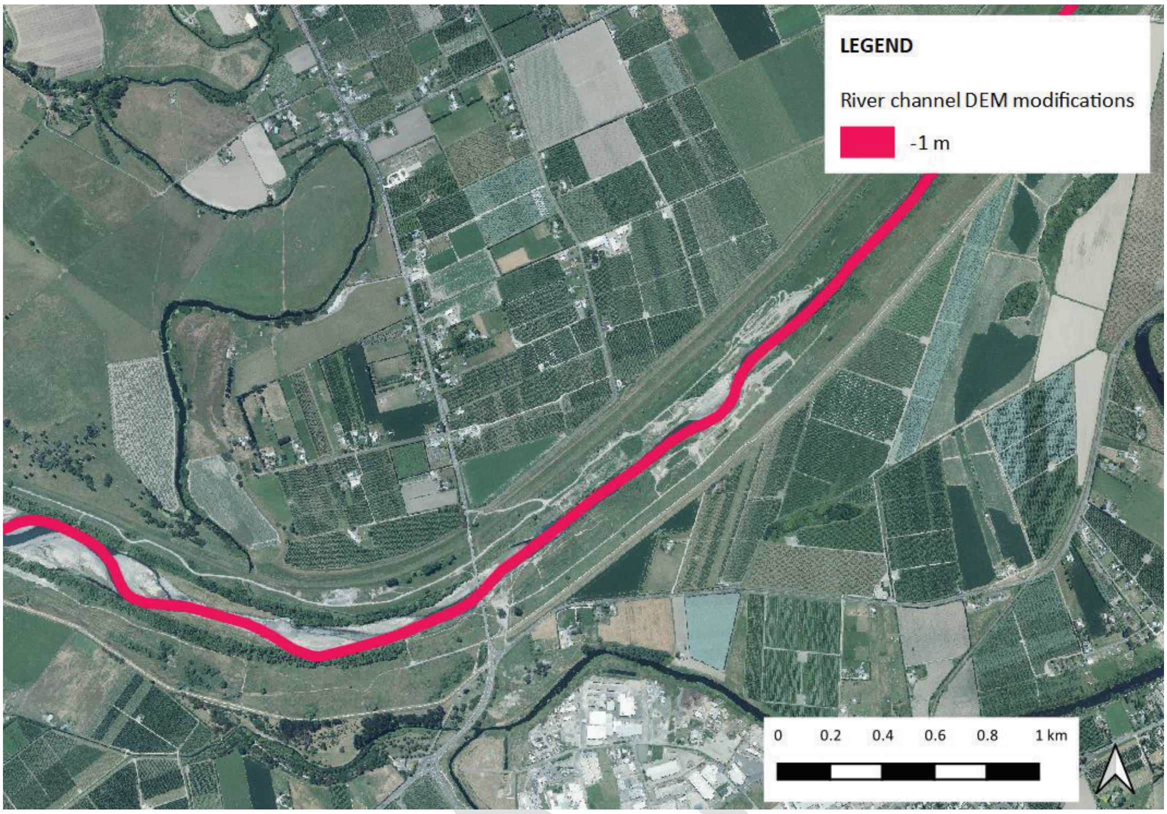

Figure 3.3: DEM modification – river channel.

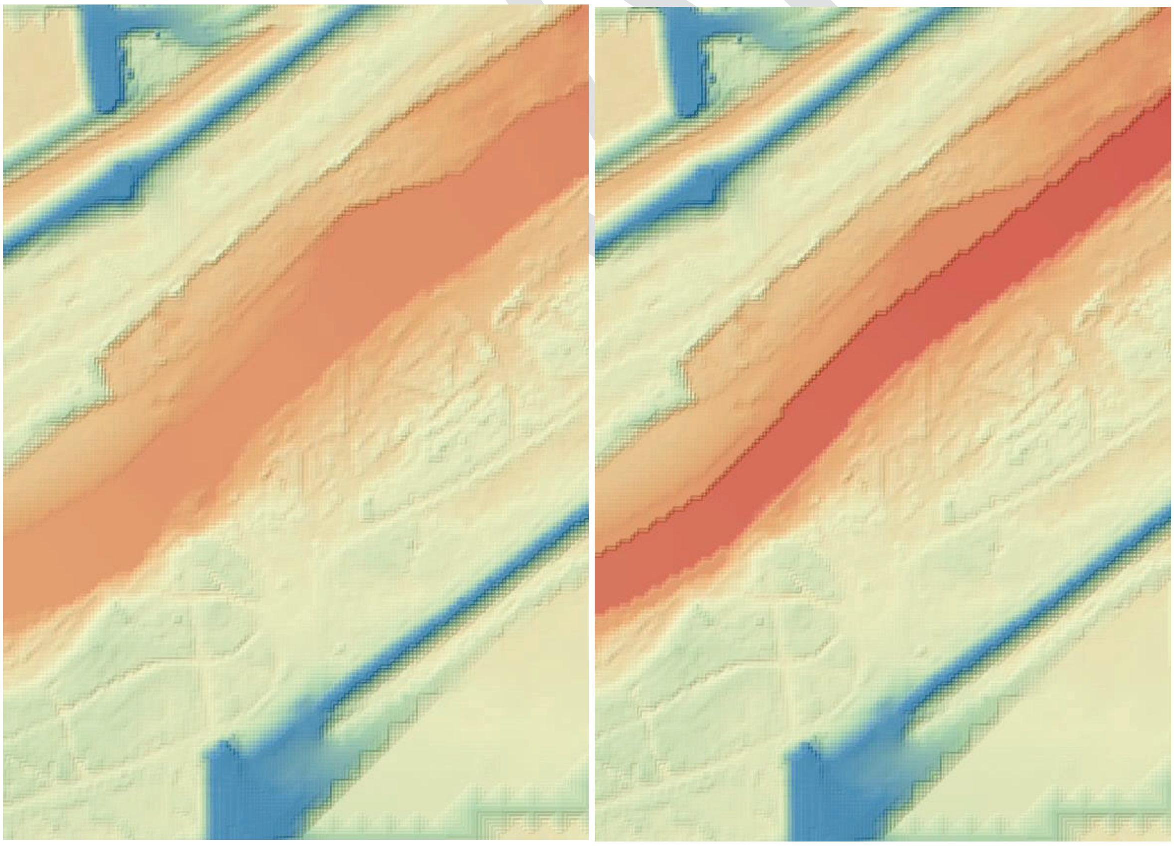

Figure 3.4: DEM modification example – river channel (left supplied DEM, right: Modified DEM).

More accurate representation of the river bathymetry could be achieved by undertaking a 2D bathymetric survey of the river. However, given the dynamic nature of the rivers, this would likely become outdated after a short period of time and would be unlikely to provide significant accuracy improvements. The approach used for this model provides a closer approximation of the cross-sectional area of the channels compared to using only the supplied DEM. It does not provide an exact match to the cross-section survey, which also has several limitations.

3.6.2 Coastal area

Within the coastal and tidal areas of the Ngaruroro River mouth, the DEM was modified to better represent the bathymetry conditions that could be expected in a large flood event. Several factors were considered to warrant this approach, including:

- The supplied DEM does not represent bathymetry elevations below the wetted surface of the coastal and tidal areas.
- Historical fluvial flood events show clear evidence of mouth avulsion both at the primary river mouth to the south and the backwash area to the north. Evidence of mouth avulsion is apparent from Cyclone Gabrielle observations as shown in Figure 3.5.

Figure 3.5: River mouth imagery – Coastal area (normal conditions 2022, right: post Cyclone Gabrille).

The DEM was lowered to a level of -2.0 mRL in the areas shown in Figure 3.6. The area selected to lower the DEM includes the approximate extent of the mouth avulsion observed during Cyclone Gabrielle. The area and elevation was discussed and agreed with HBRC.

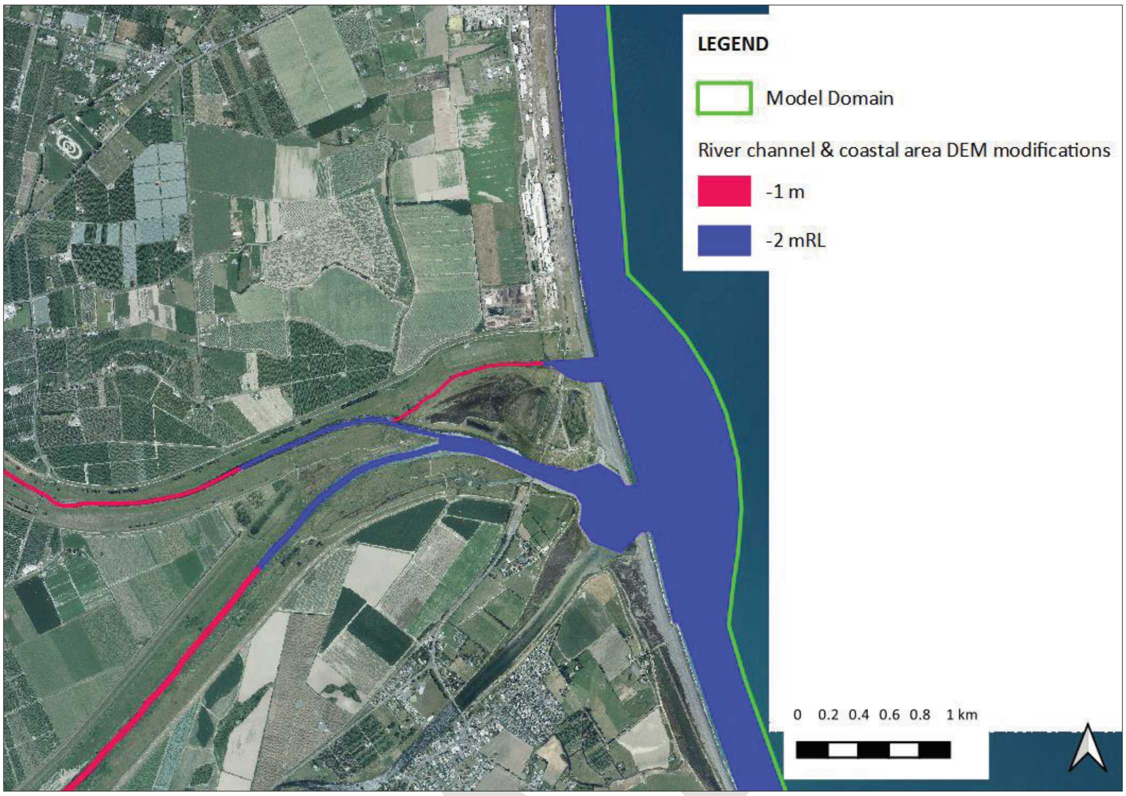

Figure 3.6: DEM modifications.

More accurate instaneous representation of the coastal and tidal area bathymetry could be achieved by undertaking a 2D bathymetric survey. However, given the dynamic nature of the river/tidal processes, such survey would likely become outdated after a short period of time.

The approach used for the model is one potential condition that could occur during a large flood event. Different flood events combined with tidal conditions (e.g., storm surge) could result in different bathymetry and model results. The model indicates that water levels in the costal and tidal area are sensitive to the assumed depth and width of the bathymetry within the vicinity of the rail and road bridges. Care should be taken when using the model results for the design of infrastructure within this area.

3.6.3 Stopbanks

Stopbanks were represented in the model using TUFLOW's 2d_zsh feature which enforces the estimated stopbank crest elevation along the stopbank centreline into the model computations using the following approach:

- Stopbank alignment lines supplied by HBRC.
- Intermediate points created at 5 m intervals along the stopbank alignment lines.
- 10 m long transect lines created at intermediate points perpendicular to the stopbank alignment lines.
- Maximum elevation of the DEM sampled along each transect and joined to the intermediate points along the stopbank centreline to create the 2d_zsh Point feature.

Table 3.1 provides the data sources used to estimate stopbank crest elevations for the model. The stopbank alignments applied to the model are shown on Figure 3.8.

Table 3.1: Stopbank crest elevation data source

Stopbank	Description
Heretaunga	2020/2021 LiDAR DEM https://data.linz.govt.nz/layer/112889-hawkes-bay-lidar-1m-dem-2020 2021/metadata/iso/
Taradale	2023 LiDAR DEM https://data.linz.govt.nz/layer/118755-hawkes-bay-lidar-1m-dem-2023/metadata/dc/
Ngatarawa	For Construction Drawings: NGARURORO RIVER, X-SECTION 51 TO 49, RIGHT BANK NGATARAWA (NG5149R) STOPBANK UPGRADE (project 2-T4384.00)

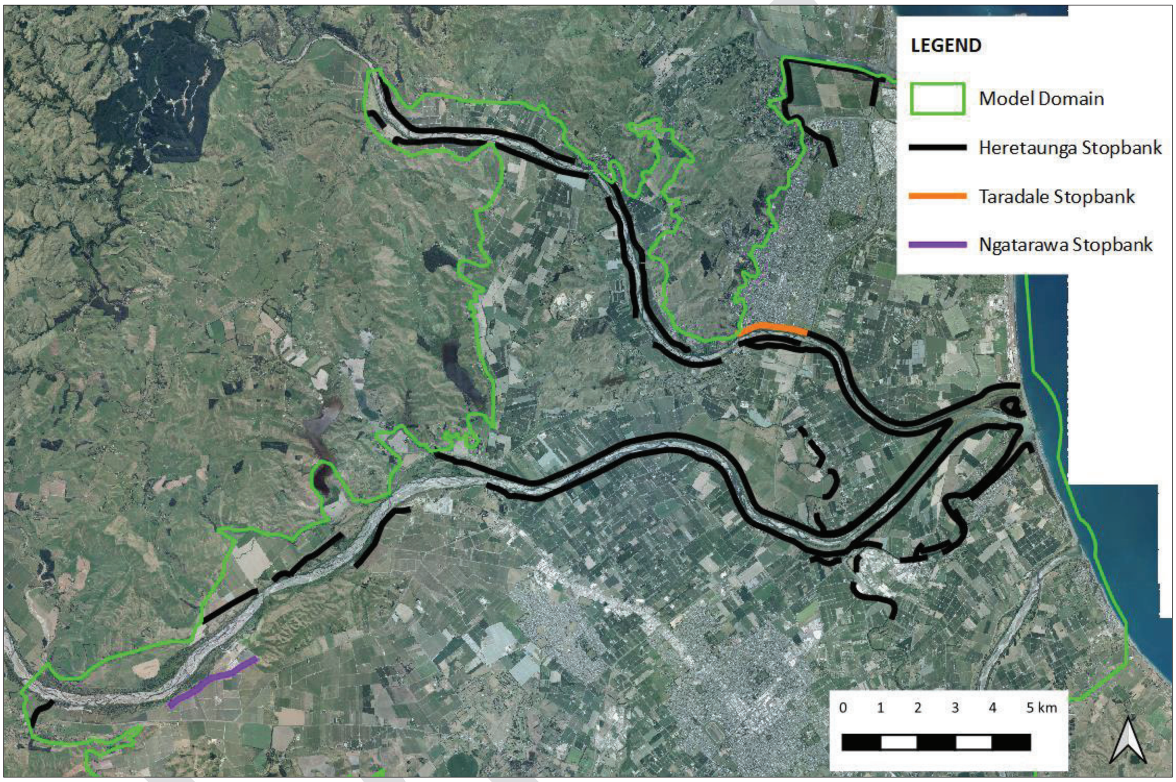

Figure 3.7: Stopbank locations.

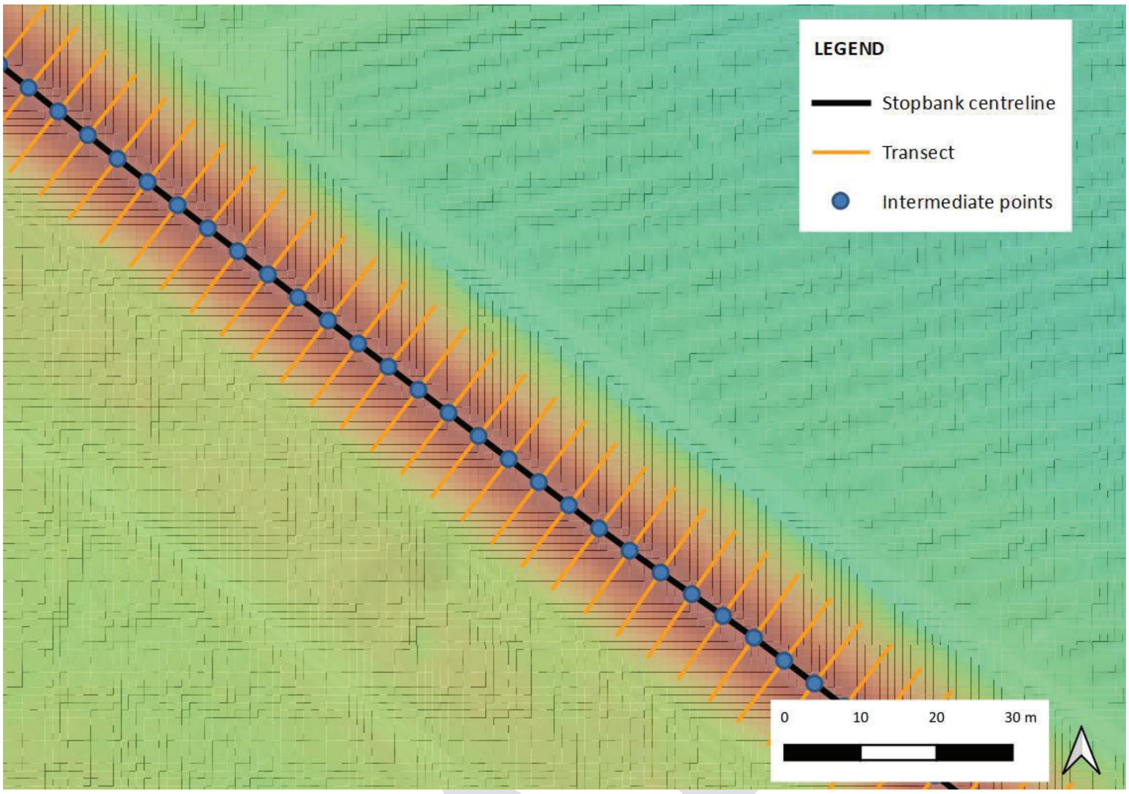

Figure 3.8: Stopbank crest elevation approach.

In the simulation of the Cyclone Gabreille event (refer Section 4.1), stopbank failure was represented in the model using TUFLOW's 2d_vzsh feature which lowers the DEM across the stopbank over a specified area and time. The locations of the breaches were identified from aerial imagery after the Cyclone on the 19th to 20th Feb 2023. Equations from '*Empirical equations for levee breach parameters based on reliable international data*' (Zomorodi, 2020) were used to estimate breach development time based on stopbank height and width. Some breach times were reduced to 1-hour based on observations which indicated rapid failure (for example, at Dartmoor). The model triggers a breach when the water level at the upstream side of the breach reaches 100 mm of overtopping at the stopbank crest. The stopbank breaches applied in the model are provided in Table 3.2 and shown spatially in Figure 3.9.

Table 3.2: Model stopbank breach failure inputs

Breach ID	Breach invert level[1] (m)	Breach trigger level[2] (m)	Breach development time[3] (hours)
NG_BreFH	24.2	26.7	1.0
NG_BreA	21.6	25.0	3.3
NG_BreB	16.0	20.2	0.6
NG_BreC	21.7	25.1	2.0
NG_BreD	20.1	23.9	2.5
NG_BreAwa	1.5	4.5	2.2
NG_BreE	18.2	21.6	2.5
NG_BreF	17.2	21.0	2.0
TK_BreMoteoA	28.5	33.2	1.4

Breach ID	Breach invert level[1] (m)	Breach trigger level[2] (m)	Breach development time[3] (hours)
TK_BreMoteoB	28.1	32.3	0.7
TK_BreDartL	34.0	36.5	1.0
TK_BreDartRc	34.5	37.5	1.0
TK_BreDartRa	39.5	42.1	1.0
TK_BreDartRb	38.8	41.6	1.0
TK_BreDartRd	41.8	43.6	1.0
TK_BreDartLB	35.2	37.8	1.6
TK_BreA	23.8	26.5	3.7
TK_BreC	26.0	27.9	1.0
TK_BreB	21.2	22.9	6.0
TK_BreD	25.3	27.6	1.0
TK_BreE	22.4	25.8	1.3
Pako_Bre	1.6	6.3	1.3

Notes:

1. Estimated from the DEM – landward side toe of stopbank.
2. Estimated from DEM – 100mm above stopbank crest.
3. Estimated from (Zomorodi, 2020).

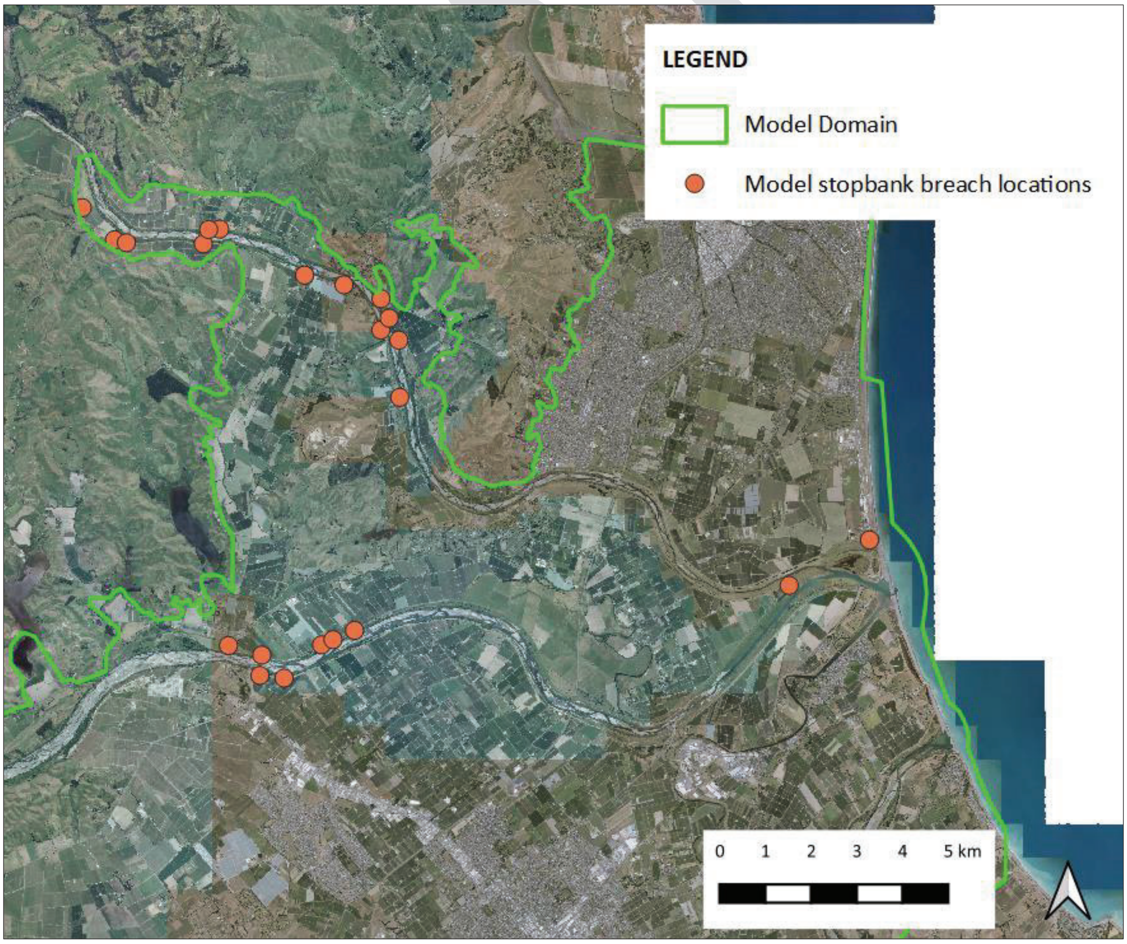

Figure 3.9: Stopbank breach locations applied to the model – Cyclone Gabrielle.

Where stopbank breaches have not been applied using the 2d_vzsh feature, the model allows for overtopping if the water level exceeds the elevation of the 2d_zsh features points applied along the stopbank crest (refer Section 3.6.3). In these cases, the DEM is not adjusted over the simulation (i.e., model assumes overtopping discharge but not failure).

In the 100-year, 500-year and 1000-year events, the model allows for overtopping discharge of the stopbank only (i.e., no failure). It is important to acknowledge that stopbanks are unlikely to withstand sustained overtopping.

The stopbank breach assumptions used for the Cyclone Gabreille model simulation are based on aerial imagery, the DEM, equations for estimating breach development time and observations and judgements made by T+T modellers. Stopbank breach discharge is complex and there were many factors which affected the discharge and development time during Cyclone Gabrielle. For example, several breaches observed in Cyclone Gabrielle formed a deep scour hole through the stopbank which may have affected the discharge. Furthermore, there were several stopbank locations where the crest was overtopped but failure did not occur. Different assumptions may result in different model results. There are likely to be other observations made by other parties during Cyclone Gabrielle which may not be captured by the model.

3.7 Structures

3.7.1 Bridges

Bridges were represented in the model using TUFLOW's 2d_bg feature which allows for surcharging, pressure flow of bridge decks and submerged bridge flow at higher water levels. Figure 3.10 shows TUFLOW's 2d_bg feature approach.

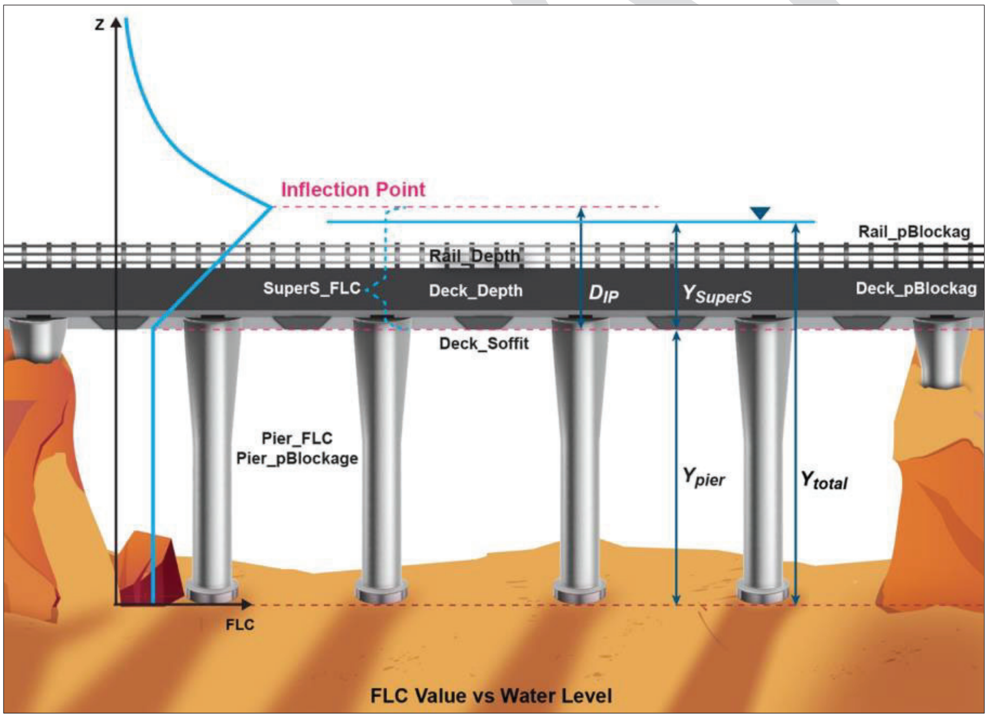

Figure 3.10: TUFLOW bridge modelling approach. (source – TUFLOW Manual).

Figure 3.11 shows an example of the 2d_bg region feature layer applied for the Ngaruroro River at Fernhill bridge.

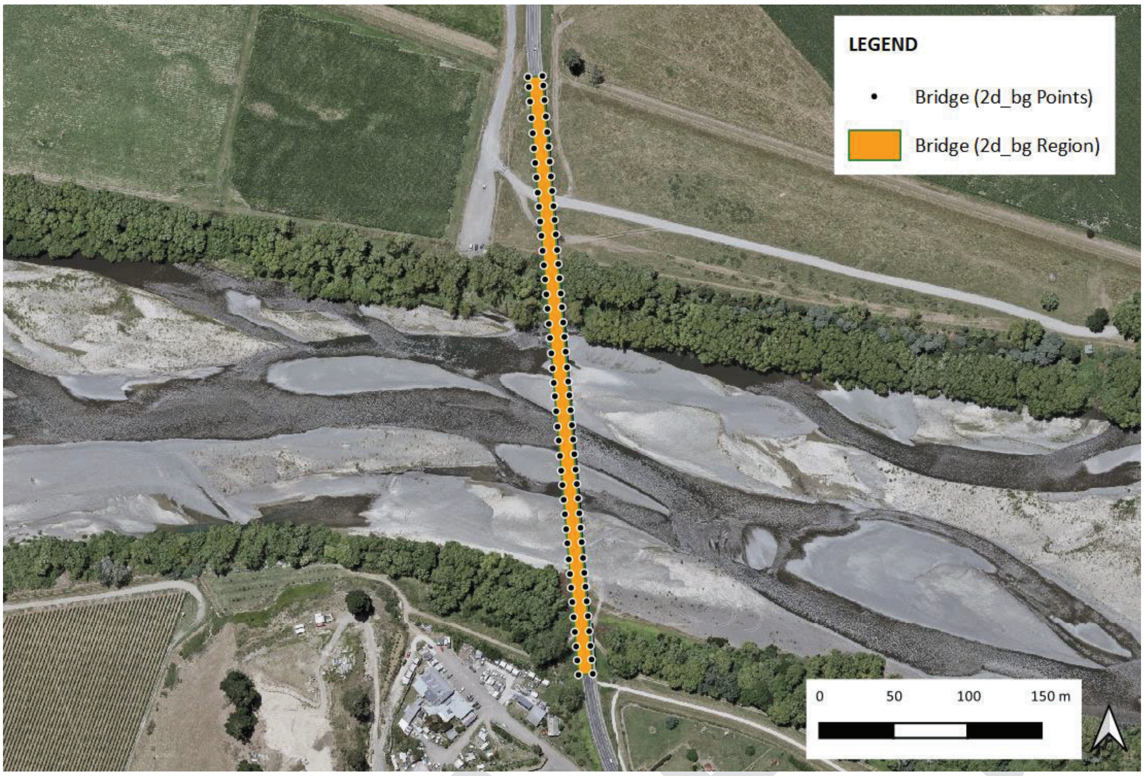

Figure 3.11: Ngaruroro at Fernhill bridge.

Bridge structure information was supplied by NZ Transport Agency Waka Kotahi (NZTA), KiwiRail and Hastings District Council (HDC). Information provided by these parties included:

- Bridge deck level survey provided by HBRC.
- Structural engineering plans from HDC, NZTA and KiwiRail.
- Bridge photographs taken by T+T.

Several of the structural engineering plans provided were hand drawn and stated historical vertical datum and imperial measurement units. Conversion was undertaken to NZVD2016 vertical datum and SI units to obtain inputs compatible with the model. In some cases, the hand drawn plans were unclear, and approximations were required. Bridge railing blockage was approximated from photos of bridge rail structure.

The model excludes the Tutaekuri at Brookfields and Tutaekuri at Puketapu bridges as these were destroyed during Cyclone Gabrielle and it is unclear at this time how they will be reconstructed. For the Cyclone Gabrielle simulation, the exclusion of these bridges may present some uncertainty.

Table 3.3 provides the 2d_bg feature input parameters for the modelled bridges.

Table 3.3: 2d_bg region inputs (no debris blockage)

Bridge ID	Pier FLC	Deck Soffi	Deck Depth	Deck width	Deck pBloc	Rail Depth	Rail pBloc
Ngaruroro at SH50/Fernhill	0.13	Varies	1.50	11.0	100	1.0	60
Ngaruroro at SH2	0.09		2.00	10.0	100	0.7	50
Ngaruroro at Chesterhope	0.07		1.75	12.5	100	1.0	30
5311 – SH51/Waitangi	0.11		1.65	9.0	100	1.2	30
361 - SH51/Waitangi (NZTA)	0.20		1.65	9.0	100	1.2	30

Bridge ID	Pier FLC	Deck Soffi	Deck Depth	Deck width	Deck pBloc	Rail Depth	Rail pBloc
Tutaekuri at SH50	0.07		1.80	10.0	100	0.9	30
Tutaekuri at Redclyffe	0.08		1.20	9.0	100	0.8	70
217 - SH51/Waitangi (KiwiRail)	0.10	3.7	1.00	3.5	100	1.0	30
216 - SH51/Waitangi (KiwiRail)	0.10	3.2	2.00	3.5	100	0.5	30

The inputs provided in Table 3.3 exclude any blockage from debris. A model sensitivity simulation considering one theoretical debris blockage scenario is provided in Section 6.

Peir form loss coefficients (Pier_FLC) for each bridge were estimated from figure 7 of Federal Highway Administration '*Hydraulics of Bridge Waterways*' (FHA, 1978) which is shown below in Figure 3.12.

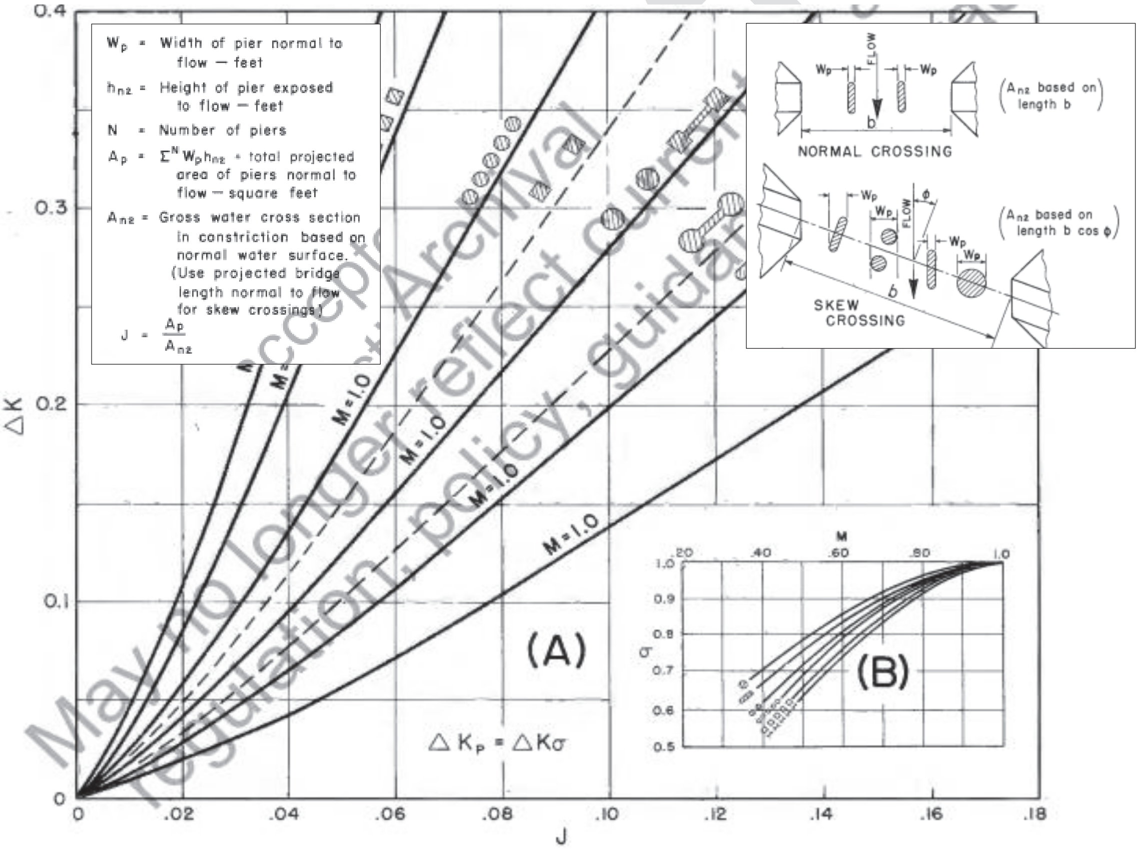

Figure 3.12: Figure 7 from 'Hydraulics of Bridge Waterways'.

As per TUFLOW software guidance, the pier form loss coefficient from FHA (1978) is derived based on the background velocity in the absence of piers. Therefore, input of a pier blockage (Pier_pBloc) is not required and has been left as NULL in the 2d_bg feature input.

Other 2d_bg feature inputs include:

- Variable deck soffit elevations (Deck_Soffi) are defined in the 2d_bg feature points layer as per structure information for each bridge.

- BG FLC Default Approach == LINEAR. The depth averaged FLC value is linearly increased from the bottom of the bridge deck to the inflection point. After the inflection point it gradually reduces.
- Blank BG FLC Approach == METHOD A. The blank superstructure FLC values will be calculated based on the ratio of the depth of the pier layer and the thickness of the super structure layer.

Modelled water level profile plots for the 100-year and 500-year events with and without bridges are provided in Section 5.2.

3.7.2 Drainage assets

As the purpose of this model is to consider large flood discharges only, drainage assets (such as culverts with flap gates and drainage channels) were not represented in the model.

3.8 Computational cell size

The model incorporates computational cell size adjustment through TUFLOW's quadtree nesting. Quadtree nesting enables users to specify smaller cell sizes in areas requiring detailed resolution, and larger cell sizes in areas where coarser resolution will not significantly affect conveyance. By varying the cell sizes, the model runtime can be optimized whilst maintaining detailed resolution where required.

The Quadtree nesting levels applied to the model domain are provided in Table 3.4 and shown spatially in Figure 3.13. The finest computation cell size applied to the model is 2.5 m and the coarsest cell size is 20 m. The 5 m cell size was used within active channel and overbank areas. The coastal boundary area was modelled at 10 m cell size. All other areas of the model were allocated a 20 m cell size.

Table 3.4: Quadtree nesting levels

Type	Quadtree nest	Cell size (m)
Tutaekuri-Waimate outlet channel	4	2.5
Active river channel and overbanks	3	5
Coastal boundary	2	10
Remaining areas	1	20

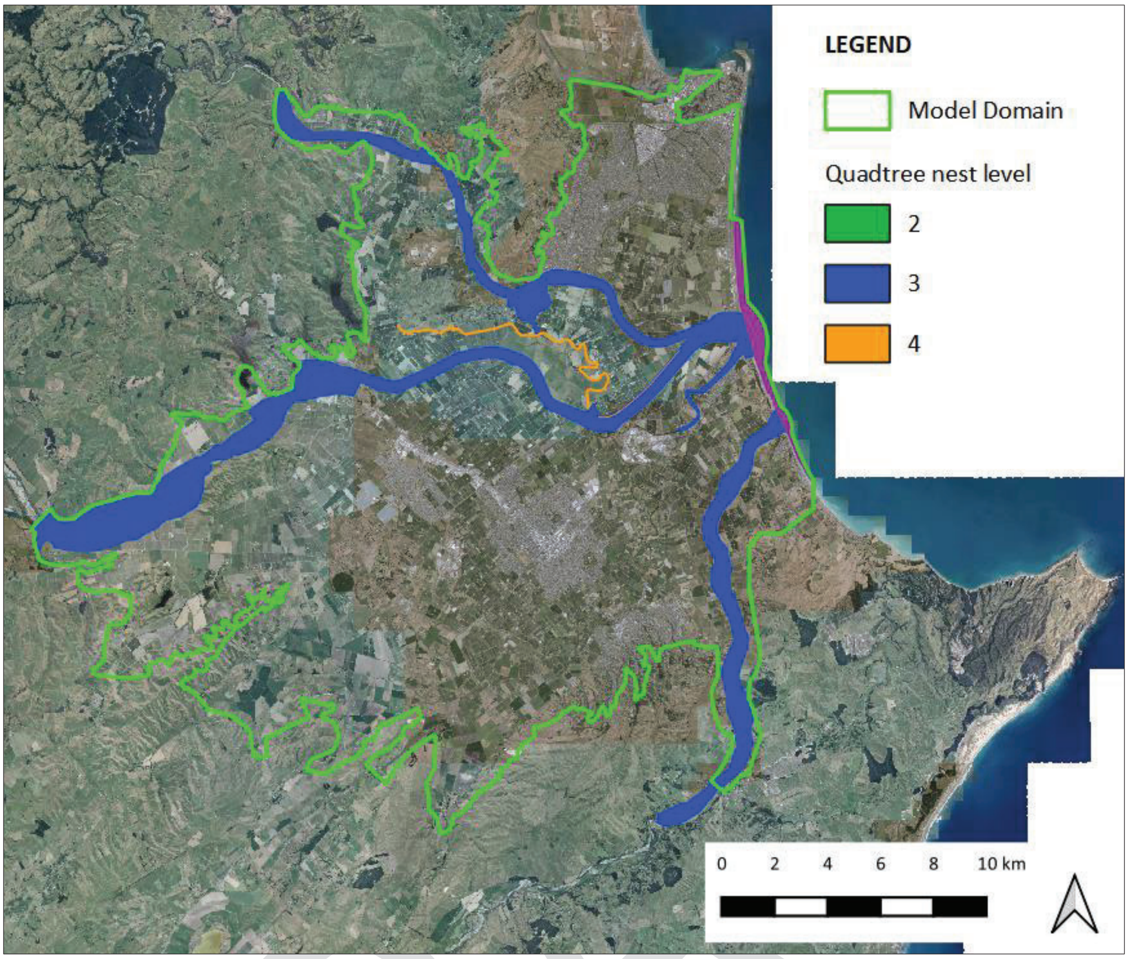

Figure 3.13: Quadtree nesting of hydraulic model. Coarsest cell size (2.5 m) in orange, active channel and overbank areas (5 m) in blue, coastal areas (10 m) in purple and largest cell size (20 m) elsewhere.

Convergence testing was undertaken to assess the sensitivity of the model run time to the computational cell size. Five simulations were run as provided in Table 3.5 for the 100-year event. All simulations included TUFLOW's Quadtree function.

Table 3.5: Convergence testing cell size

Cell size (m)				Model run time (hours)
Tutaekuri-Waimate outlet channel	**Active river channel and overbanks**	**Coastal boundary**	**Remaining areas (base cell size)**	
6.3	12.5	25	50	0.5
5	10	20	40	0.8
3.8	7.5	15	30	1.5
2.5	5	10	20	4.0
1.5	3	6	12	27

The estimated maximum water level outputs from each model simulation were compared to the smallest base cell size (12 m) to assess the variation in water levels along the active river channel centreline as shown in Figure 3.14. Water level was selected for comparison as this is the primary parameter of interest when assessing the level of service of stopbanks.

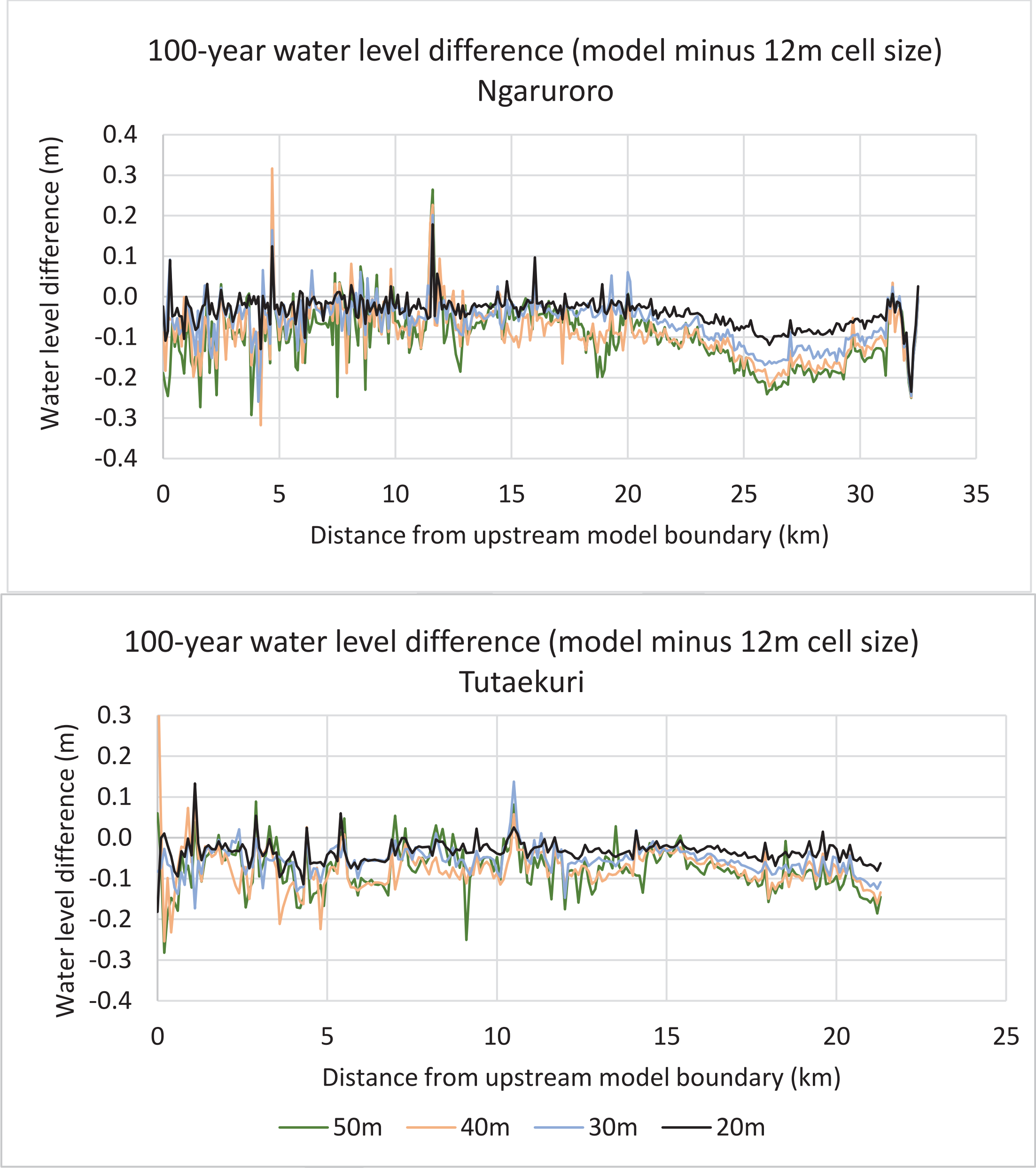

Figure 3.14: Convergence testing 100-year water level profile comparison.

The 20 m base cell size simulation was adopted for the model as this provided an acceptable balance between model runtime and produced flood levels generally within 100mm of the 12 m cell size scenario. The 20 m base cell size is within the vertical accuracy of the DEM reported as +/- 0.2 m.

The model applies TUFLOW's sub-grid sampling to the computational grid. Sub-grid sampling facilitates improved conveyance and storage within large grid cells by sampling the underlying DEM at its original resolution, which is a resolution of 1 m. TUFLOW's default SGS settings have been used ("Method C"). The SGS sample frequency is automatically calculated by TUFLOW from the cell size and the smallest underlying sample distance (which is 1 m).

3.9 Roughness

Hydraulic roughness is a parameter used in hydraulic modeling to describe the resistance to surface water flow across the terrain, within a channel, or through a pipe. Hydraulic roughness is represented in the model by Manning's 'n' roughness value.

HBRC supplied a 2D gridded layer of Mannings 'n' coefficients as an initial indication of roughness within the HPFCS. The supplied roughness layer was developed by HBRC from a previous model calibration of the Tutaekuri and Ngaruroro Rivers during Cyclone Bola (March 1988), which was a significant flood event in the region. Whilst the layer supplied by HBRC covered most of the model domain, several data gaps were filled using the Land Cover Database (LCDB)[1] version 5, supplied by Landcare Research New Zealand. The database, released in January 2020, considers land use classification up until the end of 2018. Land use types and Mannings 'n' coefficients from the LCDB layer were aligned for consistency with the HBRC layer.

The Manning's 'n' coefficients supplied by HBRC and applied in the model are provided in Table 3.6 and shown spatially in Figure 3.15.

Table 3.6: Manning's 'n' roughness coefficients

Description	Manning's 'n' coefficient	Description	Manning's 'n' coefficient
Coastal Sand and Gravel	0.025	Deciduous Hardwoods (Young Plants)	0.055
Estuarine Open Water	0.02	Exotic Forest (Medium Density)	0.15
Forest - Harvested	0.16	Grassland	0.035
Gorse and/or Broom	0.11	Gravel or Rock	0.025
Herbaceous Saline Vegetation	0.1	Herbaceous Freshwater Vegetation	0.1
Indigenous Forest	0.143	High Producing Exotic Grassland	0.025
Lake or Pond	0.015	Low Producing Grassland	0.025
Mixed Exotic Shrubland	0.1	Manuka and/or Kanuka	0.11
Surface Mine or Dump	0.025	Orchard, Vineyard or Other Perennial Crop	0.035
Transport Infrastructure	0.02	Sand or Gravel	0.025
Active River Channel	0.024	Short-rotation Cropland	0.038
Broadleaved Indigenous Hardwoods	0.1	Small Stream	0.04
Built-up Area (Settlement)	0.5	Transport Infrastructure	0.02
Deciduous Hardwoods (Low Density)	0.11	Urban Parkland/Open Space	0.033
Deciduous Hardwoods (Medium Density)	0.15	Wetland/Lake or Pond	0.04

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[1] https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/, Downloaded 30 May 2023.

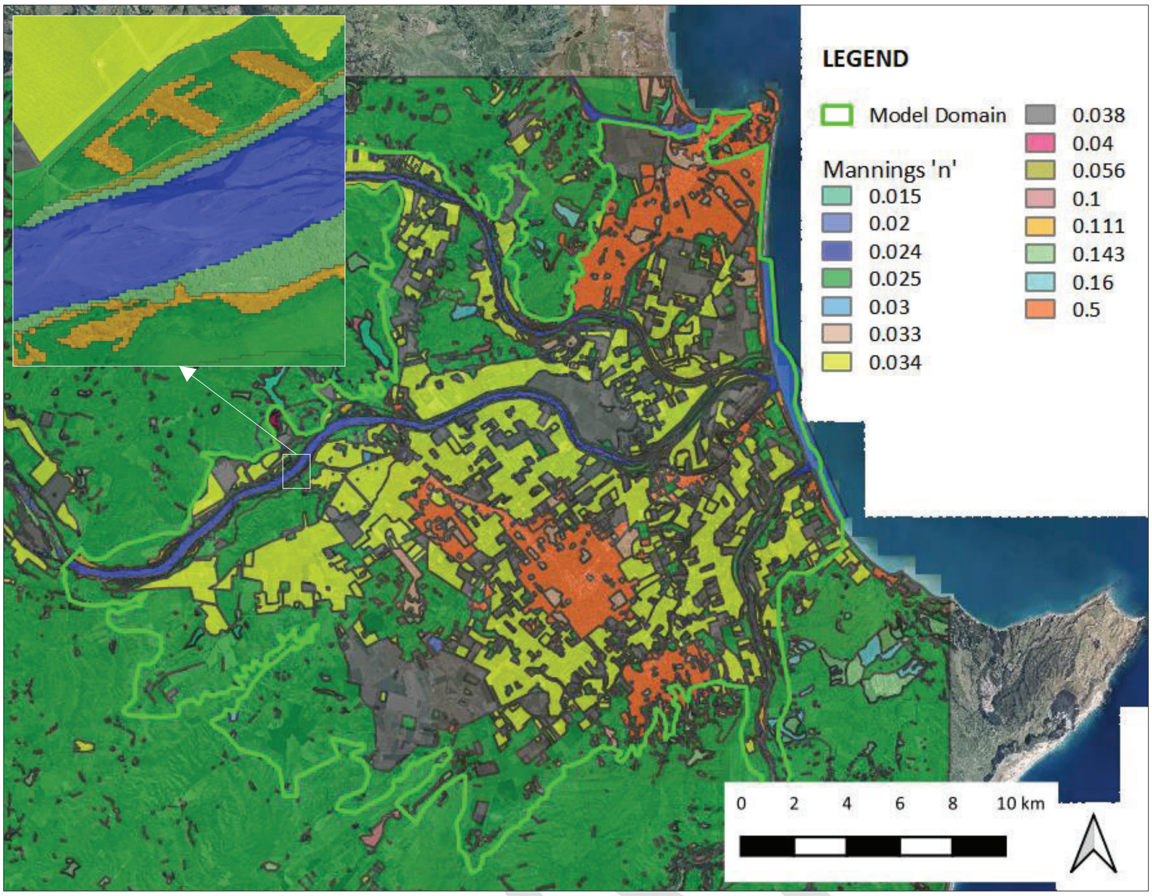

Figure 3.15: Spatial Mannings ‘n’ Roughness coefficients.

The Manning’s ‘n’ coefficients supplied by HBRC were compared to other technical reference information to assess their suitability for input into the model. The comparison focussed on the Tutaekuri and Ngaruroro River active channel and overbank areas, as these areas have the greatest influence on flood conveyance and level of service within the scheme.

‘*Open-Channel Hydraulics*’, (Chow, 1959) estimated Manning’s ‘n’ coefficients for various types of natural streams, floodplains and channels. In reality, each channel has unique roughness characteristics determined by factors such as channel variations, cross-section irregularity, obstructions, vegetation, and degree of meandering. The Tutaekuri and Ngaruroro River channels are generally comprised of a semi-confined braided active channel with gravel and cobble bed material bounded by vegetated overbanks. While this composition does not exactly align with the coefficients estimated by Chow, approximations can be made by comparing similar channel types. Manning’s ‘n’ coefficients from Chow (1959) that are similar to the Tutaekuri and Ngaruroro River active channel and overbank areas are provided in Table 3.7. The assumed model values are also provided for comparison.

Table 3.7: Manning’s ‘n’ coefficients from Chow (1959) and model for active channel and overbank areas

Description (from Chow, 1959)		Manning's ‘n’ coefficient	
		Chow	Model
Active channel	Natural streams: Main channels: clean, straight, full stage, no rifts or deep pools.	0.025 to 0.033	0.024
	Excavated channels: gravel, uniform section, clean.	0.022 to 0.030	
Overbank	Floodplains: dense willows, summer, straight.	0.110 to 0.200	0.143
	Floodplains: heavy stand of timber, a few down trees, little undergrowth with flood stage reaching branches.	0.100 to 0.160	0.111
	Floodplains: short grass.	0.025 to 0.035	0.025

Manning’s ‘n’ coefficients estimated by Chow (1959) are derived from empirical observations and measurements of various channel types. These values are primarily applicable to 1-Dimensional (1D), open-channel models, which implicitly capture energy losses due to lateral discharge and complex flow paths. In contrast, 2D models represent the energy losses due to lateral discharge and more complex flow paths explicitly. Therefore, it is reasonable to assume that 1D Manning’s ‘n’ coefficients should be adjusted downwards when applying them to a 2D model. The amount at which values should be decreased is not well studied but current practice suggests in the order of up to 15 % for simple flow paths.

‘Roughness Characteristics of New Zealand Rivers’, (Mason, 1991) estimated Mannings ‘n’ coefficients for the Ngaruroro River at the Chesterhope Bridge. Hicks and Mason estimated Mannings ‘n’ between 0.015 and 0.019 depending on the discharge. The higher Mannings ‘n’ was associated with a higher discharge, possibly because of the rougher overbanks resisting conveyance. The highest discharge assessed by Hicks and Mason was 563 m^3/s which around 14 % of the estimated 100-year discharge. At the discharges being modelled (i.e., 100-year event and larger), it could be expected that Mannings ‘n’ would be higher than estimated by Hicks and Mason because the rougher overbanks would have more influence on conveyance capacity.

Overall, the model assumes a Mannings ‘n’ coefficient of 0.024 within the active channel and 0.025 to 0.143 for the vegetated overbank areas. These values are generally in line with the range estimated by Chow (1959) and Hicks and Mason (1991).

Roughness coefficients applied to a hydraulic model are generally verified by simulating historical flood events in the model. Calibration and validation of hydraulic models requires accurate flood observations to adequately characterise flood levels. Two validation events including Cyclone Gabrielle and the June 2018 were simulated in the model to review the roughness values assumed. Additional details on the validation simulations are provided in Section 4.

The roughness coefficients applied to the model reflect the specific land use conditions at a given time. Changes in land use, such as vegetation clearance or growth, are anticipated to lead to varying roughness values. While the roughness of the active channel may remain relatively consistent, significant changes could occur in overbank areas due to human activities or natural processes.

3.10 Boundary conditions

3.10.1 Discharge hydrographs – design events

Discharge hydrograph boundaries were applied into the model domain at the upstream end of the Tutaekuri and Ngaruroro Rivers as shown on Figure 3.16.

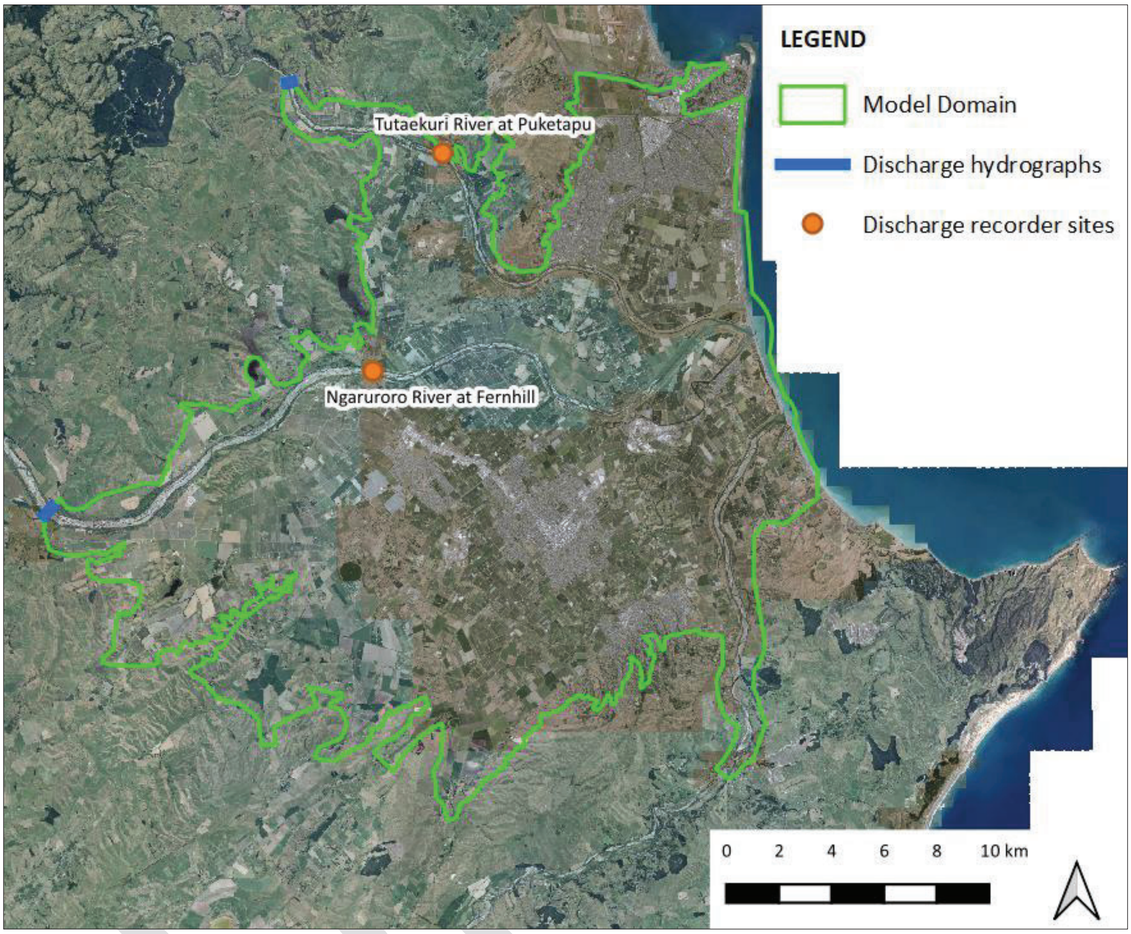

Figure 3.16: Inflow hydrograph and discharge recorder sites.

The hydrographs rely on peak discharges estimated by NIWA for the Tutaekuri at Puketapu and Ngaruroro at Fernhill discharge recorder sites as shown on Figure 3.16. The use of the estimated peak discharge by NIWA were discussed and agreed with HBRC[2]. For the purposes of this model, the flows estimated by NIWA have been assumed to represent a present-day climate scenario.

Discharge hydrographs for a future climate change scenario were estimated by applying a 25 % increase to the present-day climate hydrographs, as instructed by HBRC. A 25 % increase was applied to the entire hydrograph, resulting a 25 % increase in both peak flow and volume.

Table 3.8 provides the estimated peak discharge for the present day and future climate change scenarios.

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[2] Flows provided by HBRC via email, March 2024, Spreadsheet: 'EVA_ARI_Flows' column T (Post Gabrielle including Historic data)

Table 3.8: Peak discharge estimates based on the NIWA assessment

Recorder site	ARI	Peak discharge (m³/s)	
		Present day climate	**Future climate (+25 %)**
Tutaekuri at Puketapu	100-year	2,906	3,633
	500-year	5,162	6,453
	1000-year	6,563	Not modelled
Ngaruroro at Fernhill	100-year	3,925	4,906
	500-year	6,022	7,528
	1000-year	7,160	Not modelled

The hydrographs were applied to the model domain upstream of the discharge recorder sites, approximately 7 km for the Tutaekuri River and 15 km for the Ngaruroro River as shown on Figure 3.16. This approach means that the discharge within the reach between where the hydrograph is applied, and recorder site is conservative due to the contributing catchment area between the two locations. Further refinement of the catchment hydrology could be undertaken to refine the discharge, particularly when assessing scheme performance within the reaches upstream of the recorder sites.

Hydrograph temporal profiles were estimated from an assessment of previous large flood events at the discharge recorder sites. The hydrographs from the previous 5 largest flood events from the discharge recorder site were overlaid and normalised to make them independent of discharge. The normalised discharge hydrographs are shown in Figure 3.17 and Figure 3.18.

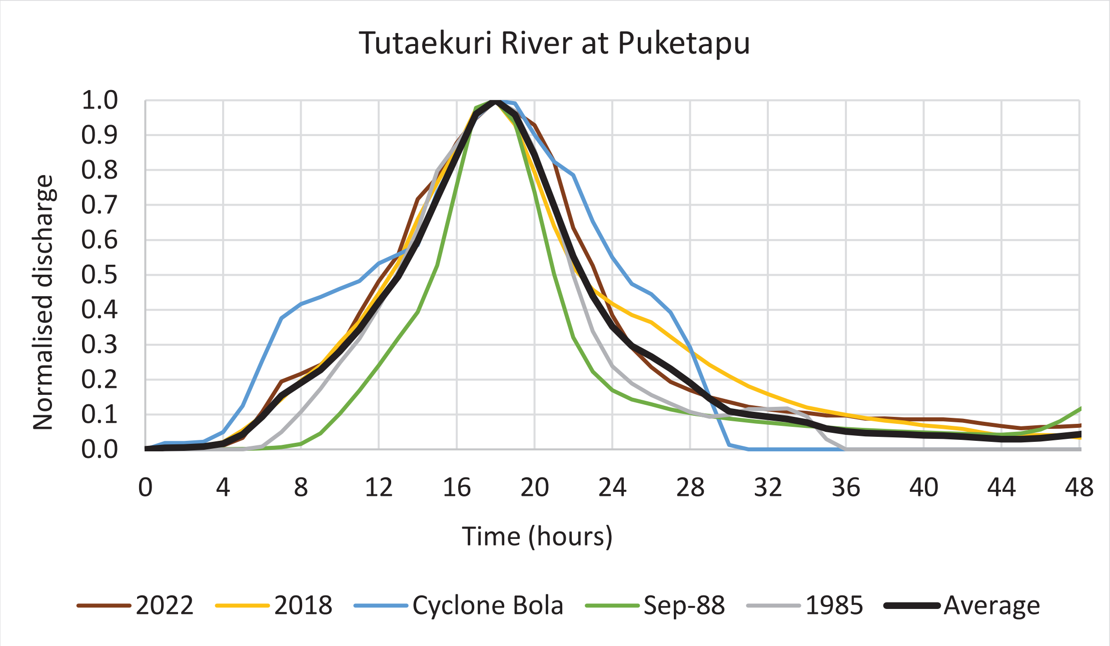

Figure 3.17: Normalised discharge hydrographs – Tutaekuri River.

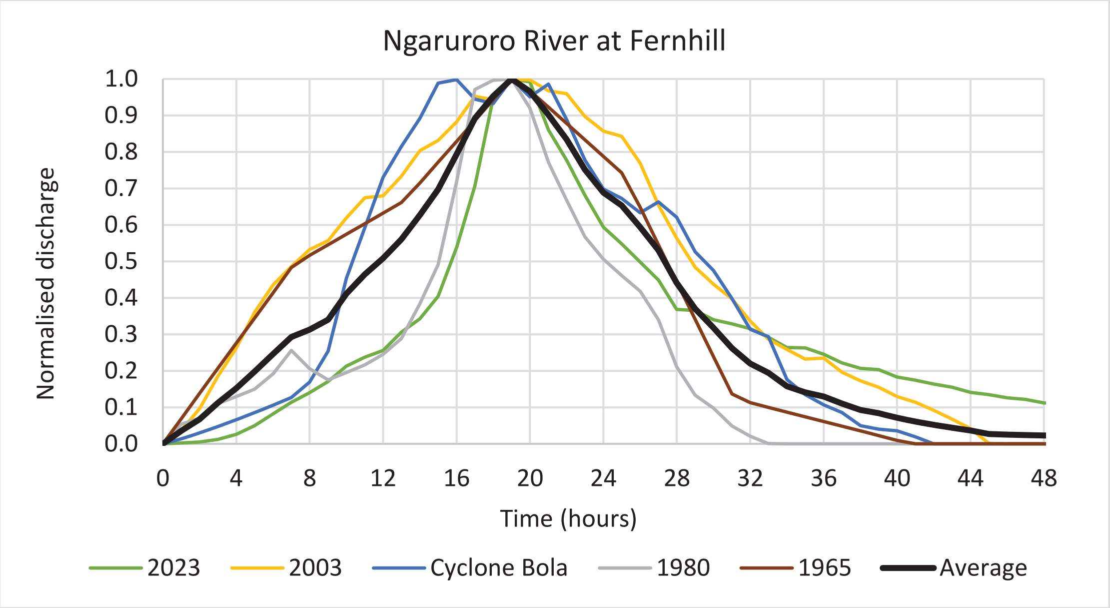

Figure 3.18: Normalised discharge hydrographs – Ngaruroro River.

The discharge hydrographs were developed by scaling the average (five largest events where HBRC hold flow records information) normalised hydrograph shape to the peak flows in Table 3.8.

The Tutaekuri and Ngaruroro River hydrographs were aligned so that the peak discharge at the Tutaekuri-Ngaruroro confluence was coincident.

Discharge hydrographs for the 100-year and 500-year present day climate events are shown in Figure 3.19.

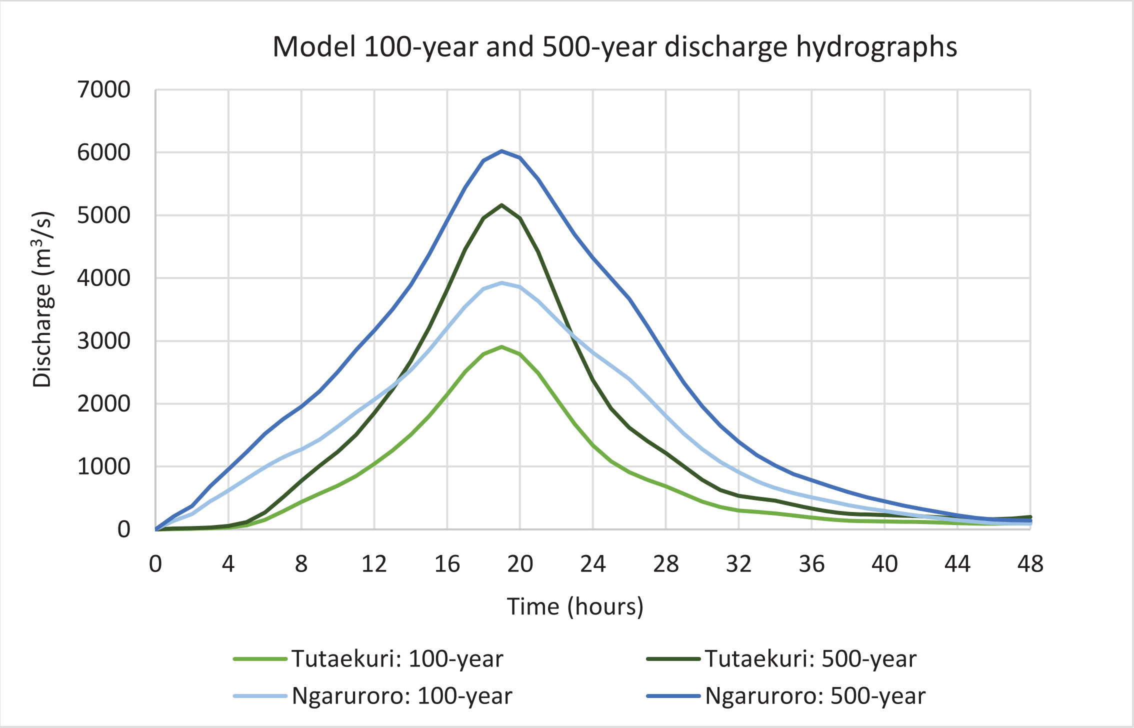

Figure 3.19: Model 100-year and 500-year discharge hydrographs – present day climate.

To account for attenuation caused by floodplain storage between the inflow boundary and discharge recorder sites, the hydrographs were increased by a factor of 1.02 using TUFLOW's 'f' multiplier. This minor increase ensured that the peak discharge and volume passing the discharge recorder was within 2 % of the intended peak discharge and volume.

The model assumes the rivers are dry at the start of the simulation. For the modelled flood events, the contribution of baseflow is minimal compared to the peak flood flows (average baseflow less than 1 % of flood flows).

Inflows for the Clive River, Tutaekuri-Waimate Stream and other small tributaries were not included in the model. For the purposes of this model, the contribution of these tributaries to the main rivers is minimal. However, inclusions of these inflows should be considered if adapting the model for other purposes.

Discharge hydrographs will vary from event to event and no two events will be the same, with each event having a different peak discharge and volume. Different hydrograph temporal profiles with the same peak discharge may result in different flood levels due to storage volume within the floodplain and other timing effects. The timing of hydrographs will particularly effect flood levels neat the confluence.

3.10.2 Discharge hydrographs - 2018 and Cyclone Gabrielle

Discharge hydrographs for two historical events including Cyclone Gabrielle and the 2018 event were applied to the model for validation as discussed in Section 4.

Discharge hydrographs for Cyclone Gabrielle were estimated based on scaling the recorded discharge at the Ngaruroro at Fernhill recorder to peak discharge estimates from an analysis by NIWA[3]. Because the Tutaekuri at Puketapu recorder a was destroyed during the event, the model uses a scaled hydrograph from the Ngaruroro at Fernhill recorder for the Tutaekuri hydrograph. The estimated discharge hydrographs for the Cyclone Gabrielle event are shown in Figure 3.20. Further review is ongoing at the time of writing, to review and confirm peak discharge estimates at the Puketapu recorder site.

Discharge hydrographs for the 2018 event were sourced from HBRC Environmental Monitoring data portal[4] and are shown in Figure 3.21.

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[3] https://www.hbrc.govt.nz/assets/Document-Library/Reports/External-Reports/NIWA-letterreport-230224.pdf

[4] https://www.hbrc.govt.nz/environment/river-levels/

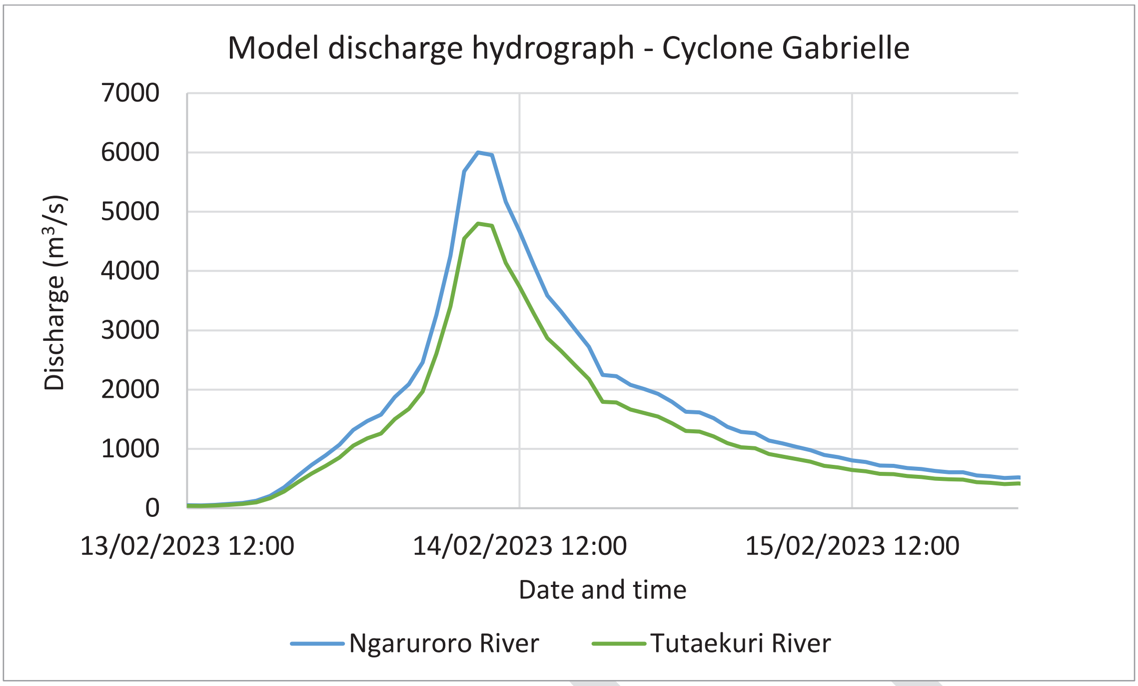

Figure 3.20: Estimated Cyclone Gabrille discharge hydrographs.

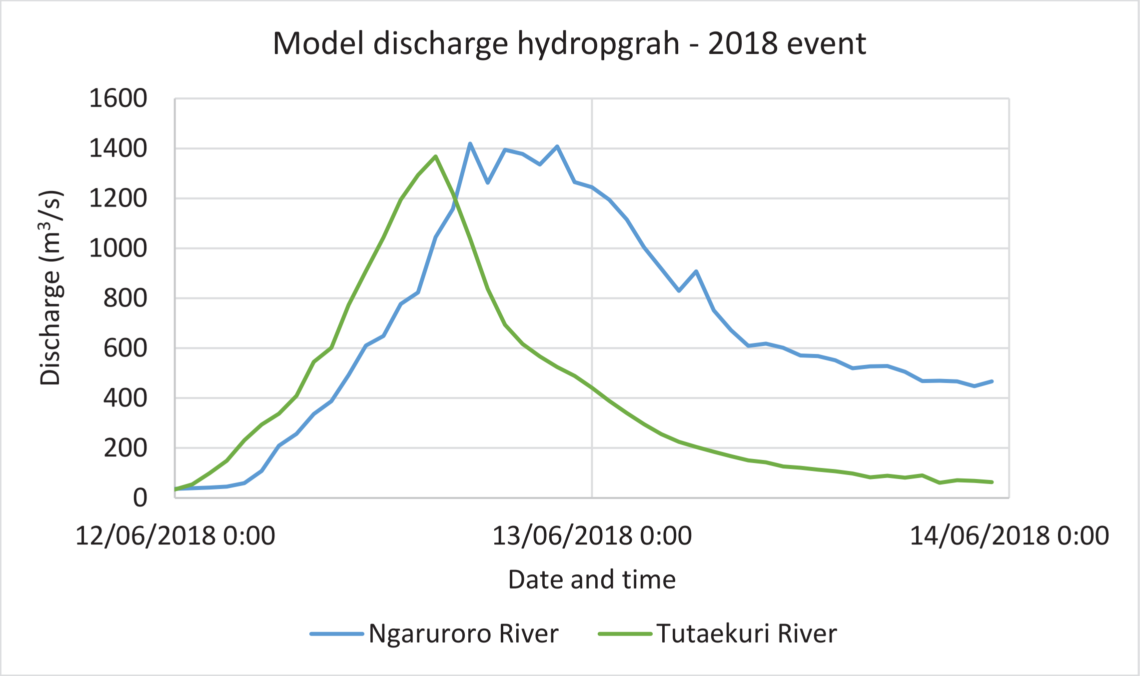

Figure 3.21: 2018 event discharge hydrographs.

The Cyclone Gabrielle event was an extreme event which destroyed the Tutaekuri at Puketapu discharger recorder site and resulted several stopbank breaches within the system including upstream of the Ngaruroro at Fernhill recorder site. As a result, the recorded discharges during the event have uncertainty and the discharge hydrographs for the event are approximate.

3.10.3 Direct rainfall

No direct rainfall was applied within the model domain. The runoff expected from within the model domain from rainfall is not expected to be significant compared in the events being modelled (i.e., 100-year event and larger). Furthermore, as noted in the model purpose, the model is not intended for analysis of local flooding issues caused by local drainage issues (and/or an inability for local drainage networks to discharge to the rivers during times of elevated river levels).

3.10.4 Soil infiltration

No soil infiltration was applied within the model domain for reasons similar to that provide in Section 3.10.3.

3.10.5 Coastal water level

A time varying stage boundary was applied at the costal boundary of the model domain as shown on Figure 3.22.

Figure 3.22: Coastal boundary.

The applied stage boundary comprised of astronomical tide plus storm surge which were sourced from the T+T report, '*Coastal Inundation: Tangoio to Clifton*', (Tonkin & Taylor Ltd, 2023). This report presented a range storm tide estimates (based on different analysis) for several ARI between Tangoio and Clifton. The range of levels stated in the report is provided in Table 3.9 (levels is in Chart Datum).

Table 3.9: Comparison of current and previous extreme storm tide values.

ARI	Current values (m, CD m)	T+T 2016 (m, CD m)	Beya and Asmat (2021)[1]	Beya and Asmat +5 % (2021)[2]
10yr	2.27	2.27	2.28	2.30
50yr	2.31	2.38	2.34	2.36

[1]Storm surge + MHWS.

[2]Storm surge+5 % + MHWS.

Tonkin & Taylor Ltd (2023) coastal assessments recommends adopting a peak 50-year storm tide level of 2.35 mCD (1.22 m NZVD2016[5]) and this level was adopted for the model. No recommendation was provided in the report for the 10-year storm tide event, however the model assumes a peak of 2.28 mCD (1.16 m NZVD2016), noting the minimal difference between the upper and lower range values presented in the report.

The joint probability of storm tide and river discharge is complex and was outside the scope of this study. The model assumes a 10-year storm tide level for the 100-year river discharge and a 50-year storm tide for the 500-year river discharge. The latter was selected based on observations made during Cyclone Gabrielle which indicated that the observed storm tide was in the order of a 50-year event. LINZ maintain a tide stage recorder at Port of Napier which recorded the stage shown in Figure 3.23 during Cyclone Gabreille (levels is in Chart Datum). The stage recorded a 60-second raw sample of approximately 2.7 mCD (1.6 m NZVD2016) and a 30-minute smoothed sample of approximately 2.35 mCD (1.23 m NZVD2016). The 30-minute sample aligns with the 50-year storm tide estimated by Tonkin & Taylor Ltd (2023).

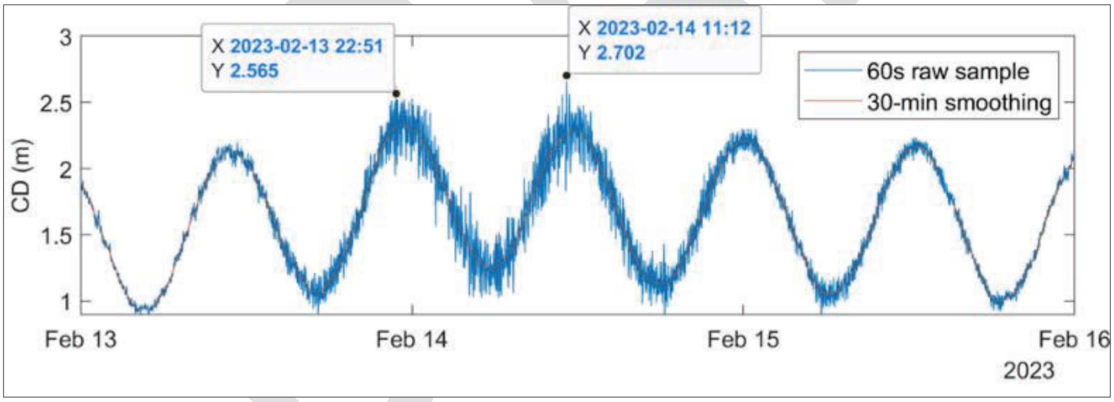

Figure 3.23: Port of Napier water level stage recording during Cyclone Gabrielle.

The peak storm tide levels were fitted to a Spring tide cycle shape generated from NIWA's Tide Forecaster tool (https://tides.niwa.co.nz/). The peak of the tide was aligned to coincide with the peak of the river discharge at the Ngaruroro-Tutaekuri confluence. Figure 3.24 shows the 10-year and 50-year stage boundary applied to the model.

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[5] Definition of chart datum: 4.837 m (https://www.linz.govt.nz/guidance/geodetic-system/coordinate-systems-used-new-zealand/vertical-datums/tidal-level-information-surveyors). Local datum: 3.713 m (https://www.linz.govt.nz/guidance/geodetic-system/coordinate-systems-used-new-zealand/vertical-datums/local-mean-sea-level-datums)

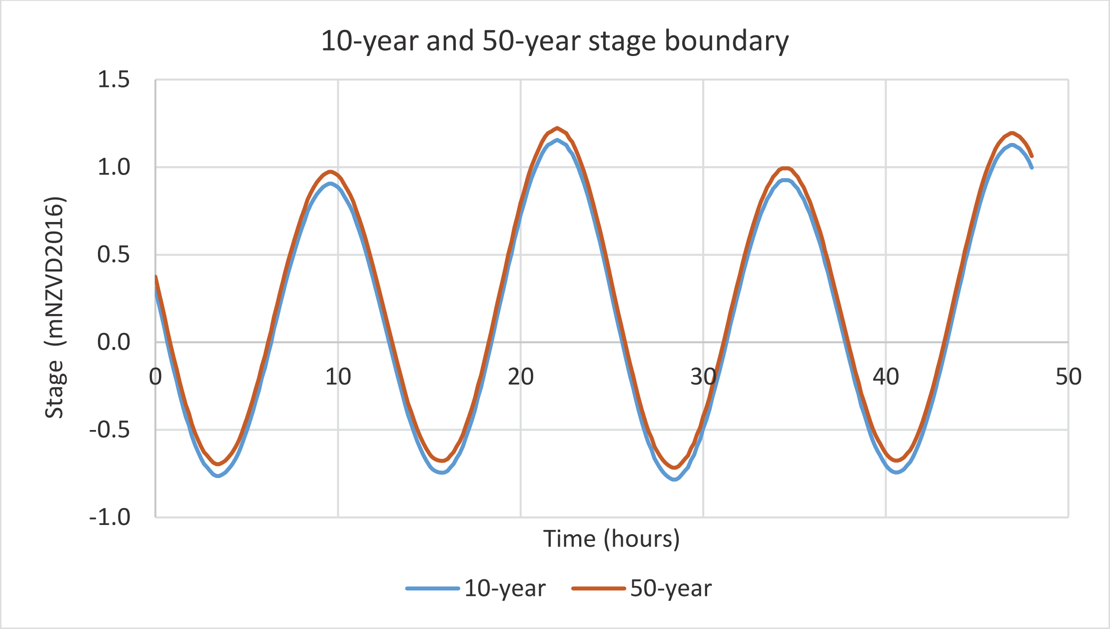

Figure 3.24: 10-year and 50-years stage boundary.

Model sensitivity simulations considering different stage boundary conditions is provided in Section 6.

The stage boundary applied to the model represents one potential theoretical astronomical tide and storm surge condition. Different tide and storm surge conditions could result in different flood levels, particularly within the lower reaches of the model. Model sensitivity analysis suggests that water levels are not particularly sensitive to the stage condition. However, care should still be taken when using the results of the model to assess potential water levels near coastal and tidal areas.

4 Model validation

Two historical events including the 2018 event and Cyclone Gabrielle were simulated in the model to validate the input parameters and assumptions. Model inputs for the two events are provided in previous report sections.

4.1 Cyclone Gabrielle

Estimates maximum water depth maps for the modelled Cyclone Gabrielle event are provided in Appendix A.

4.1.1 River stage and discharge

Figure 4.1 shows the recorded and modelled discharge at the Ngaruroro at Fernhill/SH50 discharge recorder site for the Cyclone Gabrielle event. The map below the graph shows the modelled maximum water depth at the bridge.

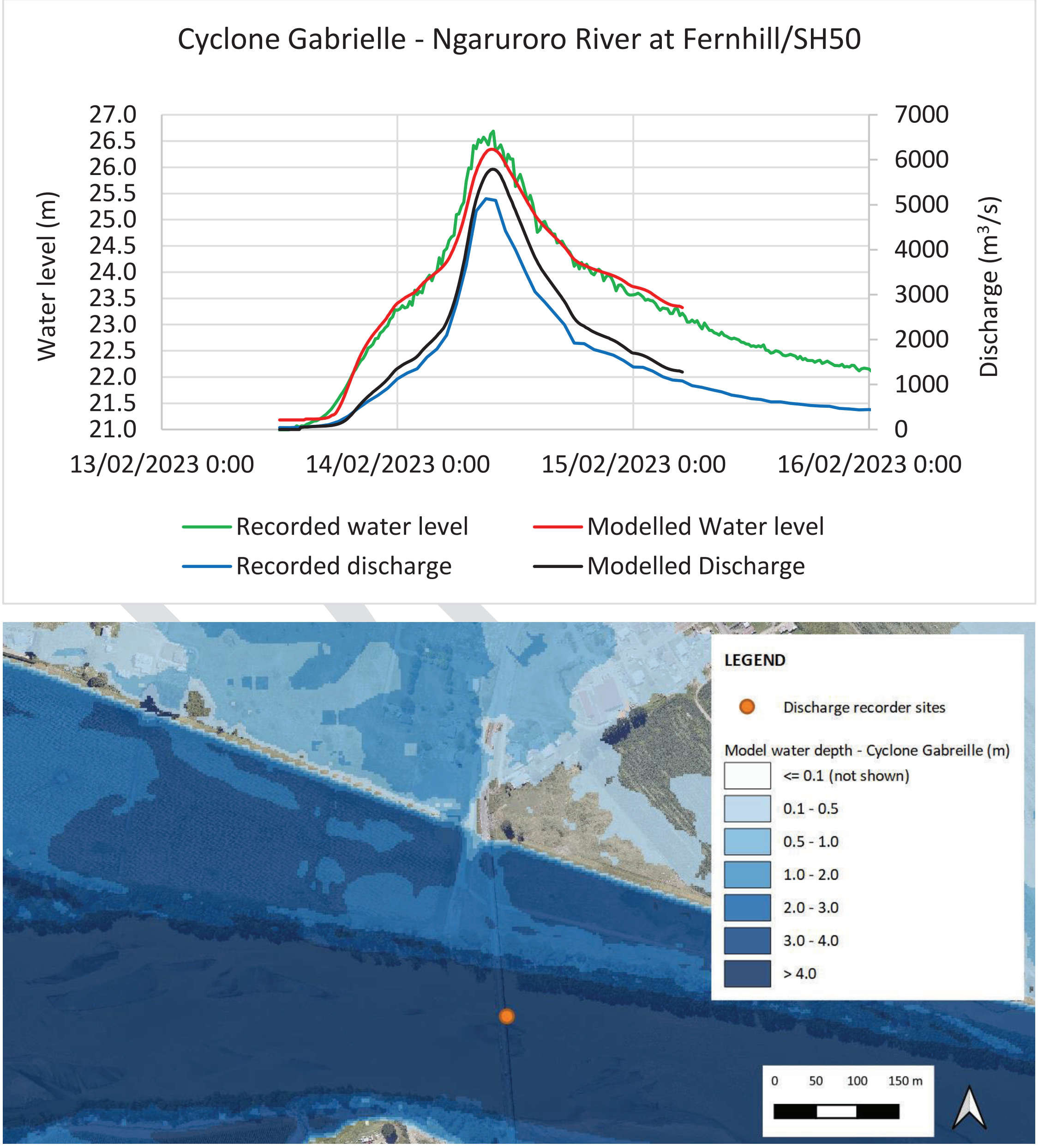

Figure 4.1: Recorded and modelled water level and discharge – Cyclone Gabreille - Ngaruroro at Fernhill/SH50.

Figure 4.1 indicates that the peak modelled water level is around 400 mm below the recorded peak water level and the modelled peak discharge is around 600 m^3/s (or about 10 %) higher than the recorded water discharge.

There is uncertainty in the recorded discharge and water level during Cyclone Gabreille due to several factors, including:

- The discharge was well beyond what the recorder site had previously measured which could lead to uncertainty in the recorders stage-discharge relationship.
- A breach occurred immediately upstream of the recorder which influenced water levels and discharge.
- The discharge recorder site was subject to complex hydraulic conditions, such as pressure waves which are clearly visible on videos taken at the site.

Overall, considering the uncertainties of the model and the recorder data mentioned above, there is reasonable agreement between the modelled and recorded water levels and discharge.

A similar analysis for the Tutaekuri River at Puketapu discharge recorder site is not possible as the recorder was destroyed before the peak of the flood occurred.

4.1.2 Event observations

Many observations were made of the HPFCS elements during Cyclone Gabrielle. Appendix A provides some caparisons of the modelled peak water levels against photo observations. The comparisons provided are a small sample of the observations made during the event by various parties. The timing of the photos is mostly unknown, but attempts were made to present photos taken near the peak of the event.

Following Cyclone Gabrielle, HBRC digitised sediment deposition and submerged areas within the scheme using aerial capture between 19th and 21st February. The digitised polygons were categorised based on a confidence rating, which includes high, medium, low, or submerged. The areas classified as submerged were only partially mapped, as comprehensive mapping of these areas was not a requirement of the study. Areas where flooding occurred but no sediment was deposited, or where the water subsided before the aerials were flown, may not have been captured. For further information on this data see https://hub.arcgis.com/documents/hbrc::cyclone-gabrielle-sediment-deposition-2023-report/about. Figure 4.2 shows the mapped sediment deposition and submerged areas and the modelled maximum flood extent. A large A3 sized map is provided in Appendix A.

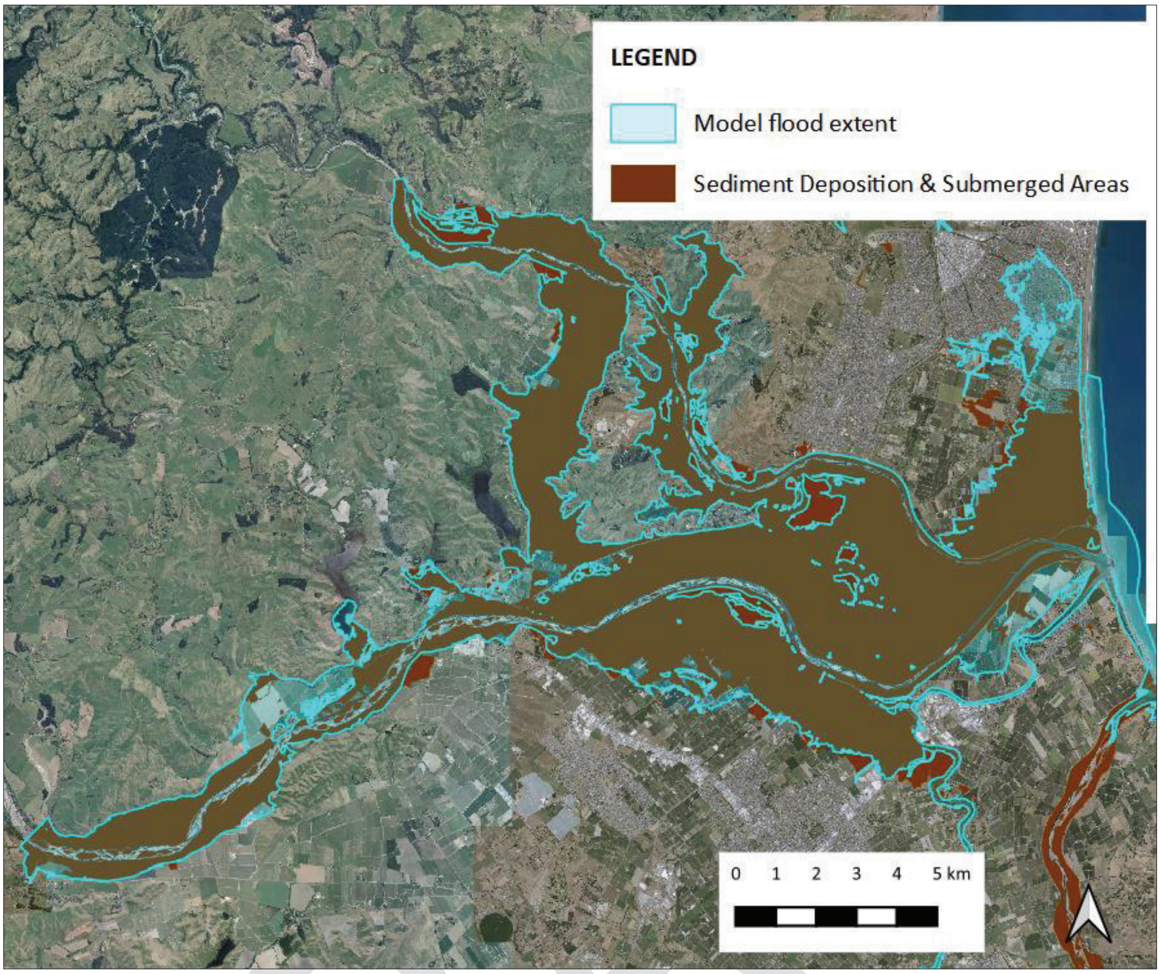

Figure 4.2: Model flood extent and mapped sediment disposition and submerged areas – Cyclone Gabrielle.

Figure 4.2 shows that the modelled flood extent aligns reasonably with the mapped sediment deposition and submerged areas. The total mapped sediment deposition and submerged area is approximately 110 km^2 versus 118 km^2 for the modelled flood extent.

The model makes provision for stopbank breaches as outlined at 3.6.3 above. Bridge blockage has been reviewed as a sensitivity case and is discussed in Section 6 below.

Overall, considering the highly complex hydraulic conditions that occurred during the event and the uncertainty in the model and recorded data, the model provides a reasonable estimate of the flooding that occurred during Cyclone Gabrielle. Other factors which are difficult to represent in a model due to insufficient observations (e.g., exact timing of when breaches occurred, timing of bridge debris build up etc) may result in different model results.

4.2 2018 event

Maximum water depth maps for the modelled 2018 event are provided in Appendix A.

4.2.1 River stage and discharge

Figure 4.3 shows the recorded and modelled discharge over time at the Ngaruroro Fernhill/SH50 discharge recorder site during the 2018 event. The map shows the corresponding modelled maximum water depth at the bridge.

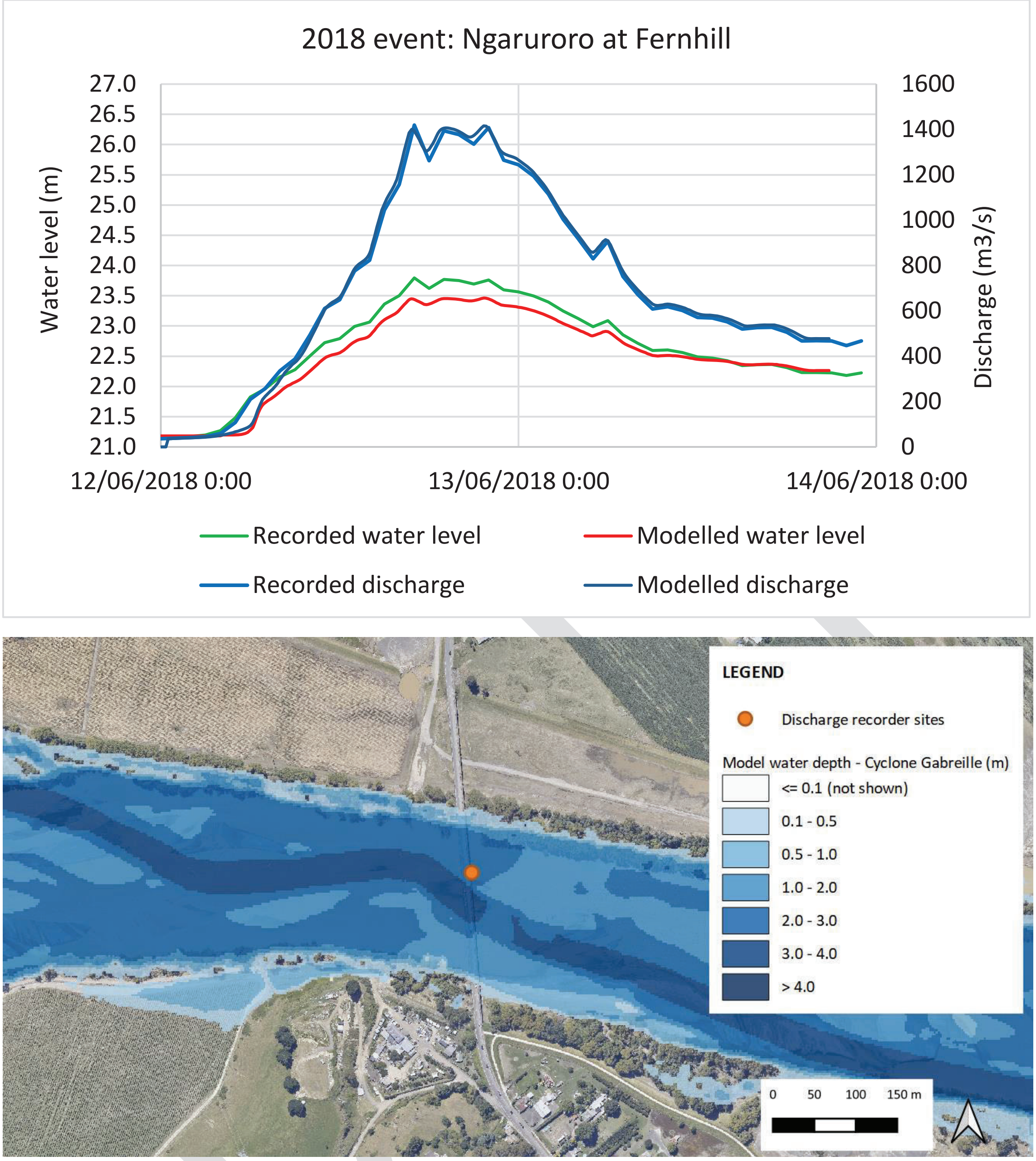

Figure 4.3: Recorded and modelled water level and discharge – 2018 event - Ngaruroro at Fernhill.

Overall, the model provides a reasonable estimate of the peak water level and discharge at the recorder site.

5 Model results

5.1 Output maps

Model outputs, represented as maximum modelled water depth for the 100-year, 500-year and 1000-year events, are provided in Appendix B. Water depths less than 0.1 m have been removed from flood maps as this is the threshold depth above which flooding has been considered with confidence as "real" and not potentially an artefact of inaccuracies in the DEM.

5.2 Bridge water level profiles

Estimates of the maximum water level profiles through the modelled bridges during the 100-year and 500-year events are shown in Figure 5.1.

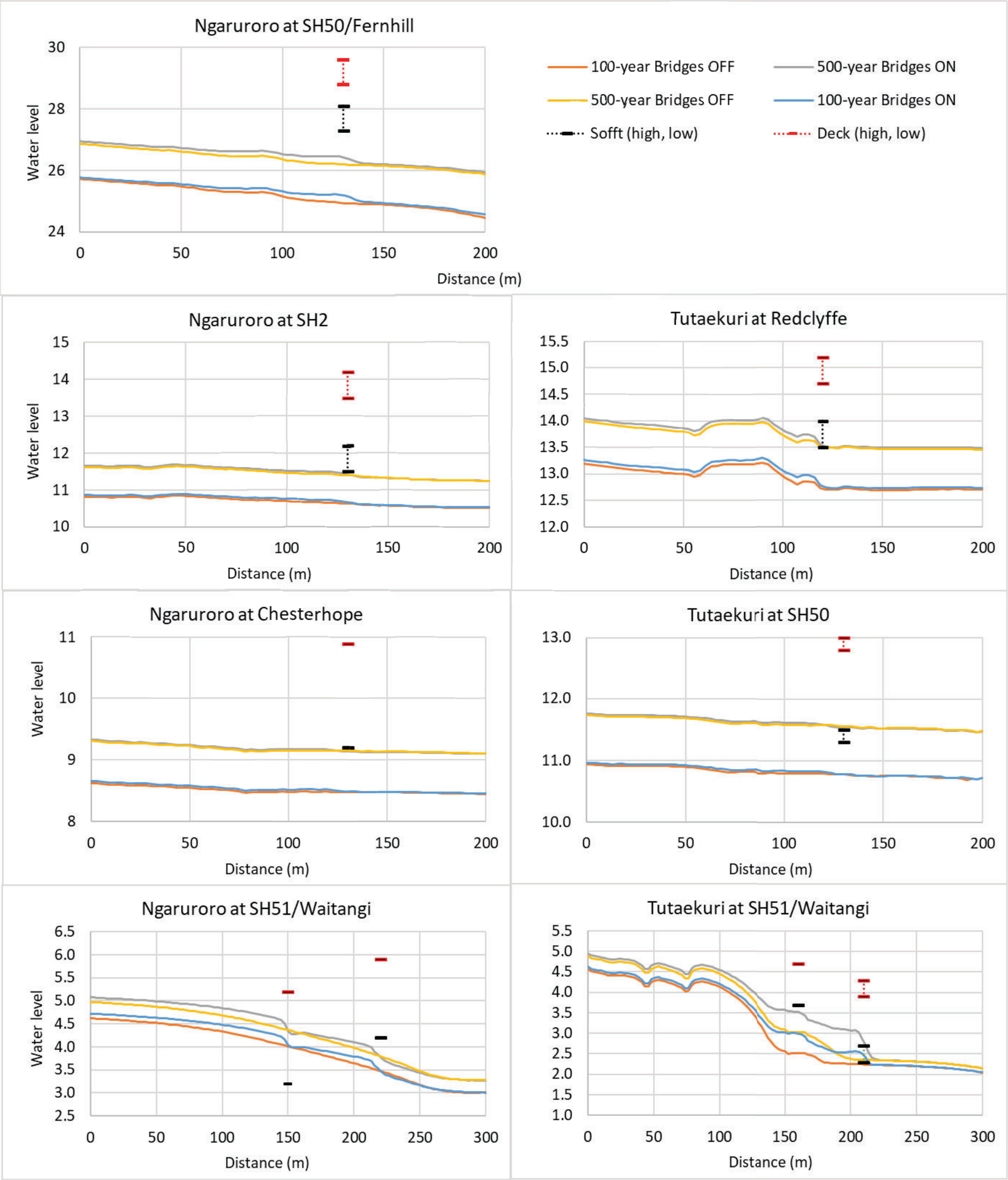

Figure 5.1: Modelled maximum water level profiles through bridges: 100-year and 500-year events.

6 Model sensitivity

Several sensitivity simulations were undertaken where model parameters were varied to determine the confidence in baseline flood outputs for the 100-year and 500-year events. The sensitivity simulations are provided in Table 6.1.

Table 6.1: Sensitivity scenarios

Sensitivity ID	Description	Additional information
Post-Cyclone Gabrielle DEM	Post-Cyclone Gabrielle DEM.	Post-Cyclone Gabrielle LiDAR DEM elevation captured from 26 February to 15 March 2023. The DEM does not have any stated accuracy verification. https://data.linz.govt.nz/layer/114544-gisborne-and-hawkes-bay-cyclone-gabrielle-river-flood-lidar-1m-dem-2023/ Stopbanks are assumed to be repaired to pre-cyclone levels.
Low tide	Low tide coincident with peak river discharge at Tutaekuri-Ngaruroro River confluence.	
Bridge debris blockage	Increased blockage at bridges.	2d_bg feature assumptions: • Peir blockage: 30 % • Deck and rail blockage: 100 %
Increased eddy viscosity	Increase the limit on the maximum eddy viscosity.	TUFLOW's Wu eddy viscosity term is limited to 0.1 in release 2023-03-AA and later. Some roughness elements in the model are > 0.1. Set Wu to unlimited for this sensitivity run.
Increased roughness	Increase Manning's 'n' coefficient within channel and overbanks.	Active channel: 0.033 Overbank: • Dense willows, summer, straight: 0.20 • Heavy stand of timber, a few down trees, little undergrowth with flood stage reaching branches: 0.160 • Short grass: 0.035.
Decreased roughness	Decrease Manning's 'n' coefficient within channel and overbanks.	Active channel: 0.022 Overbank: • Dense willows, summer, straight: 0.11 • Heavy stand of timber, a few down trees, little undergrowth with flood stage reaching branches: 0.10 • Short grass: 0.025.
No channel burn	Do not burn river channel.	River channel is not burned out as described in Section 3.6.1.

The sensitivity scenarios modelled represent a range of possible conditions, but it is not exhaustive. Within each sensitivity scenario, there are also a range of possible conditions that could occur, e.g., more or less blockage at bridges.

Appendix C provides difference maps from each option simulation compared to the base case simulation. Both the 100-year and 500-year events are provided.

Table 6.2 provides a summary of the sensitivity scenario results and effects on water depths/levels.

Table 6.2: Sensitivity scenario results

Sensitivity ID	Results compared to base case
Post-Cyclone Gabrielle DEM	Increase in water depths throughout much of the scheme area outside of the stopbanks. Decrease in water depths within the active river channel and overbanks. Caused by the post-cyclone DEM levels being higher (likely due to sediment deposition), resulting in higher water levels but lower water depths. The higher DEM levels within the river cause more water to overtop the stopbanks.
Low tide	Small decrease in water depths near the coast.
Bridge debris blockage	Increased water depths at bridges in the order of 200 mm. Increase in water depths at Awatoto due to more overtopping of the stopbank. This is caused by approx. 200 mm increase in water depth at the rail and road bridges.
Increased Wu eddy viscosity formulation	Minimal changes to water depths.
Increased Manning's 'n' roughness	Increase in water depths throughout most of the scheme.
Decreased Manning's 'n' roughness	Decrease in water depths throughout most of the scheme upstream of Tutaekuri – Ngaruroro confluence. Increase in water depths near the Tutaekuri – Ngaruroro confluence and Awatoto. Caused by the smoother active river channel and overbanks conveying more water to the confluence (i.e. less attenuation in upper areas). The river mouth is a hydraulic constraint, which causes in more water to overtop the stopbank into Awatoto.
No channel burn	Increase in water depths throughout most of the scheme in the order of 200 to 500 mm. Small decrease in water depth at Awatoto. Caused by more water overtopping stopbanks and being attenuated in the upstream area.

Appendix C provides a "fuzzy" maps for the 100-year and 500-year events. The fuzzy map overlays the maximum water depth from the sensitivity scenarios considered plus the base case (total of eight scenarios). A colour of blue indicates the cell was wet in all simulations, a colour of red indicates the cell was wet in only one simulation.

7 Scheme improvement options

Improvement options were simulated using the model to assess their effectiveness. Table 7.1 provides a summary of the modelled options. Further details on the options are provided in the separate report Heretaunga Flood Control Scheme Review report.

Table 7.1: Modelled improvement options

Option	Description	Model I.D
1A	Awatoto Raised Stopbank	Option1A
1B	Awatoto Secondary Stopbank	Option1B
1C	Mouth Improvement	Option1C
3A	Moteo Raised Stopbank	Option3A
3B	Moteo Stopbank Retreat	Option3B
3D	Moteo Lowered Stopbank	Option3D
4A	Omahu Raised Stopbank	Option4A
4B	Omahu Stopbank Retreat	Option4B
6A	Golf Course Spillway	Option6A

Appendix D provides difference maps from each option simulation compared to the base case simulation. Both the 100-year and 500-year events are provided.

8 Model limitations

Limitations of the hydraulic model include:

- The model has been developed for a specific purpose as stated in the report. It is important to recognise the purpose for which the model was built and not use it for different uses for which the model may not be suitable.
- The modelling undertaken has been based on Light Detection and Ranging (LiDAR survey) which has accuracy limitations stated in the report.
- Several modifications were made to the model DEM. The modifications made represent one potential set of conditions that could occur during a large flood event. Different flood events could result in different ground conditions are model results.
- The model estimates the flooding that occurred during Cyclone Gabrielle based on data, observations and modelling judgement provided to T+T. The event was complex, and the model does not represent all of the conditions which lead to flooding. Other factors which are difficult to represent in a model due to insufficient observations or data (e.g., exact timing of when breaches occurred, timing of bridge debris build up etc) may result in different model results.
- The model uses land use data sourced from LINZ and Landcare research. Detailed verification of this data has not been undertaken as part of this study. Actual land use and soil type may be different and/or may have changed since this data was generated.
- The model uses and relies on peak discharges estimated by NIWA for the 100-year, 500-year and 1000-year events. Verification of these estimates was outside the scope of this study. Inaccuracies in these data may lead to inaccuracies in model results.
- Culverts and other drainage pipes have not been included in the model. As stated previously, the effect of these on the hydraulic model results is likely to be minimal.
- The model indicates that water levels in the costal and tidal area are sensitivity to the assumed depth and width of the bathymetry within the vicinity of the rail and road bridges. Care should be taken when using the model results for the design of infrastructure within this area.
- Further refinement of the catchment hydrology could be undertaken to refine the discharge between the recorder sites (Tutaekuri at Puketapu and Ngaruroro at Fernhill) and the model boundary, particularly when assessing scheme performance within these reaches.

9 Conclusions

This DRAFT report documents the hydraulic model build, providing details of model parameters used and how the model was validated against the Cyclone Gabrielle event. The focus of this report is the model build on the Ngaruroro and Tutaekuri rivers within the Herataunga Plains.

A separate report will discuss the model build of the lower Tuki Tuki river.

10 References

Chow, V. T. (1959). *Open-channel hydraulics.*

FHA. (1978). *Hydraulics of Bridge Waterways.*

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Zomorodi, K. (2020). *Emperical equations for levee breach parameters based on reliable international data.*

11 Applicability

This report has been prepared for the exclusive use of our client Hawkes Bay Regional Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Ltd

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
....	....
Richard Brunton Water Resources Engineer	Tim Morris Project Director

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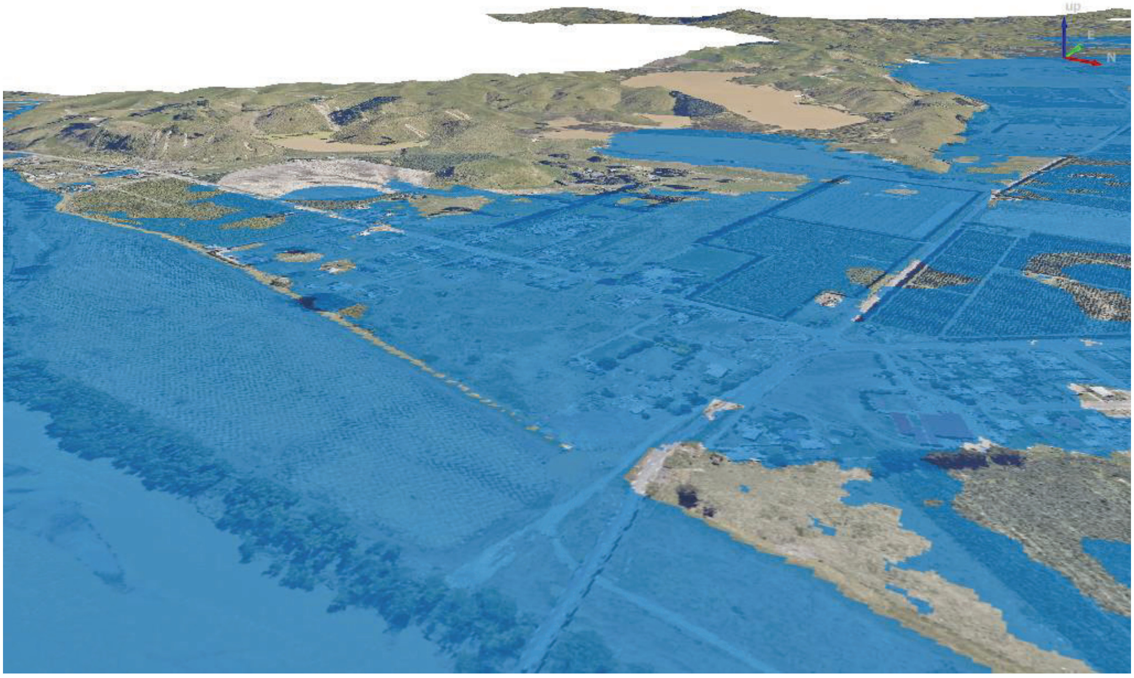
Appendix A Model validation

- **Figure A1. Modelled maximum water depth – Cyclone Gabrielle**
- **Figure A2. Model flood extent and mapped sediment disposition and submerged areas – Cyclone Gabreille**
- **Figure A3. Modelled maximum water depth – 2018 event**

- **Observation-model results comparison**

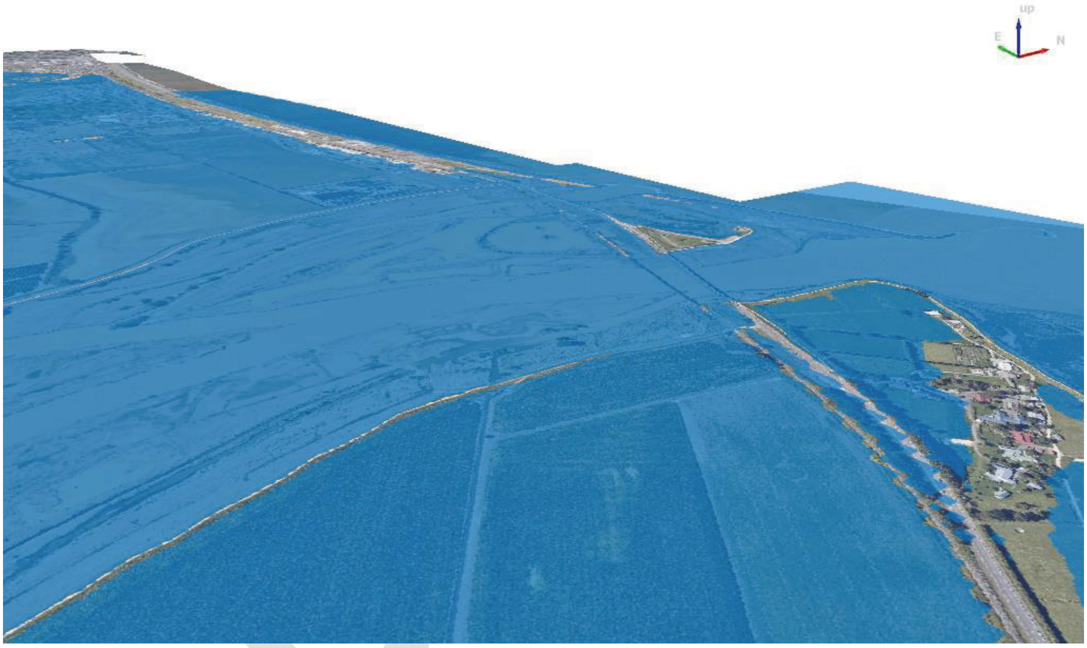
Ngaruroro at Fernhill (looking northwest)

Modelled maximum water depth



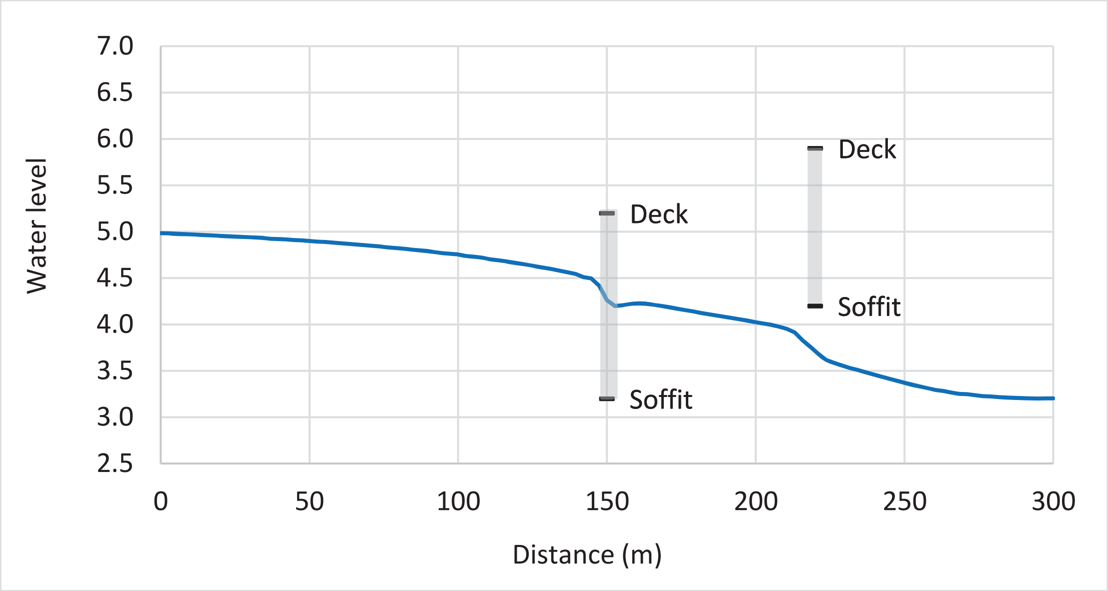
Ngaruroro-Tutaekuri confluence/Waitangi rail and SH bridges (looking north)

Modelled water depth



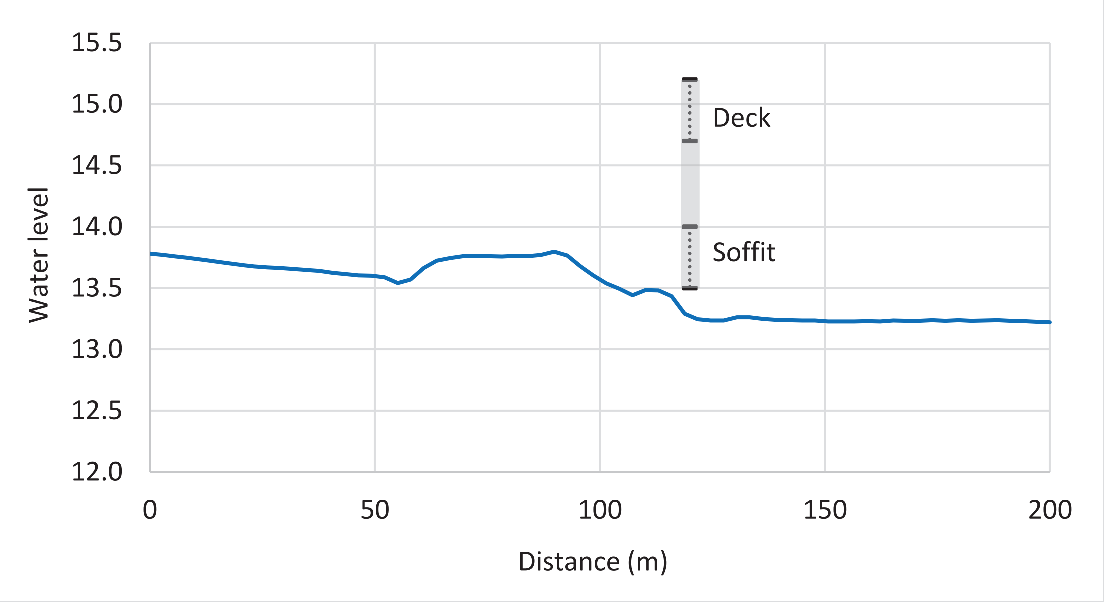
Ngaruroro-Tutaekuri confluence/Waitangi rail and SH bridges (looking north)

Modelled water level profile



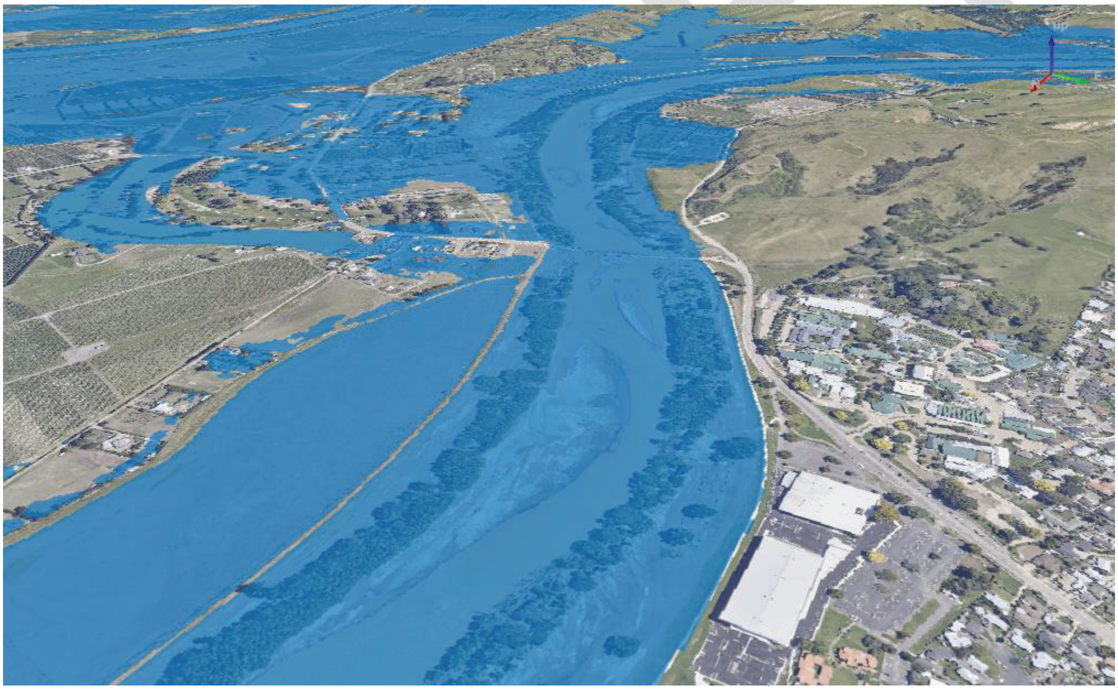
Tutaekuri at Waiohiki/Redclyffe bridge

Modelled water level profile



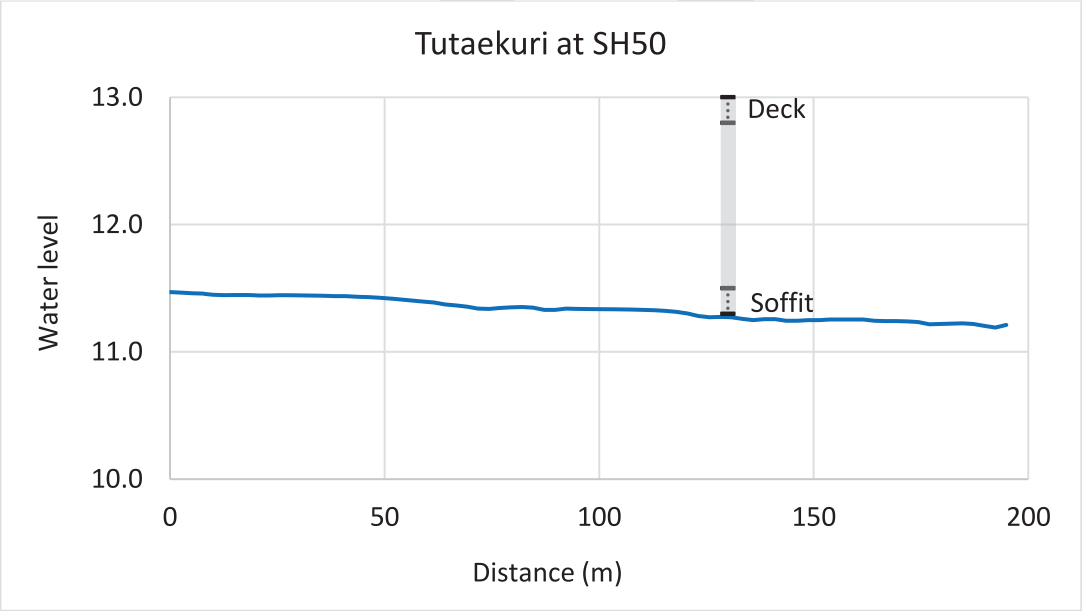
Tutaekuri looking upstream at Waiohiki/Redclyffe bridge

Modelled water depth



Tutaekuri at SH50

Modelled water level profile



Appendix B Model output maps

- **Figure B1. 100-year present-day climate maximum depth.**
- **Figure B2. 500-year present-day climate maximum depth.**
- **Figure B3. 1000-year present-day climate maximum depth.**

- **Figure B4. 100-year future climate change maximum depth.**
- **Figure B5. 500-year future climate change maximum depth.**

Appendix C Model sensitivity

Maps show difference between maximum water depth compared to base case

- **Figure C1. Post-Cyclone Gabrielle DEM**
- **Figure C2. Low tide coincident with peak discharge**
- **Figure C3. Debris blockage**
- **Figure C4. Increased eddy viscosity**
- **Figure C5. Increased roughness**
- **Figure C6. Decreased roughness**
- **Figure C7. No channel burn**
- **Figure C8. 100-year fuzzy map**

Appendix D Scheme improvement options maps

- **Figure D1.**

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