Oroua River - Almadale to Downstream of Aorangi Bridge and Adjacent Eastern Rural Area

Flood Model Build, Validation and Design Simulations

Project No 44801993

27 November 2023

Prepared for Horizons Regional Council

The expert in **WATER ENVIRONMENTS**

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Prepared for: Horizons Regional Council
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Project No.:	44801993
Approved by:	Greg Whyte
Approval date:	27 November 2023
Revision:	FINAL
Classification:	**Confidential:** This document is only accessible to the project team members and sharing it outside the project team is subject to the client's prior approval.
File name:	Oroua_Report_FINAL.docx

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1 Introduction

1.1 Study Purpose

The purpose of this study is to undertake floodplain hydraulic modelling and hazard mapping of the rural area lying between the town of Fielding and the settlement of Aorangi, in line with the DHI proposal dated 2 December 2022. The study was commissioned by Horizons Regional Council (HRC), with a signed contract being received on 19 December 2022.

The study has required the development of a comprehensive hydrologic-hydraulic flood model for the Oroua River and its eastern floodplain (Figure 1-1). The model has been used for assessment of hazards from design flood events of varying Annual Exceedance Probabilities (AEP's).

The outputs of the project are expected to allow for more informed decisions regarding flood management and the suitability of land for various development purposes in the study area.

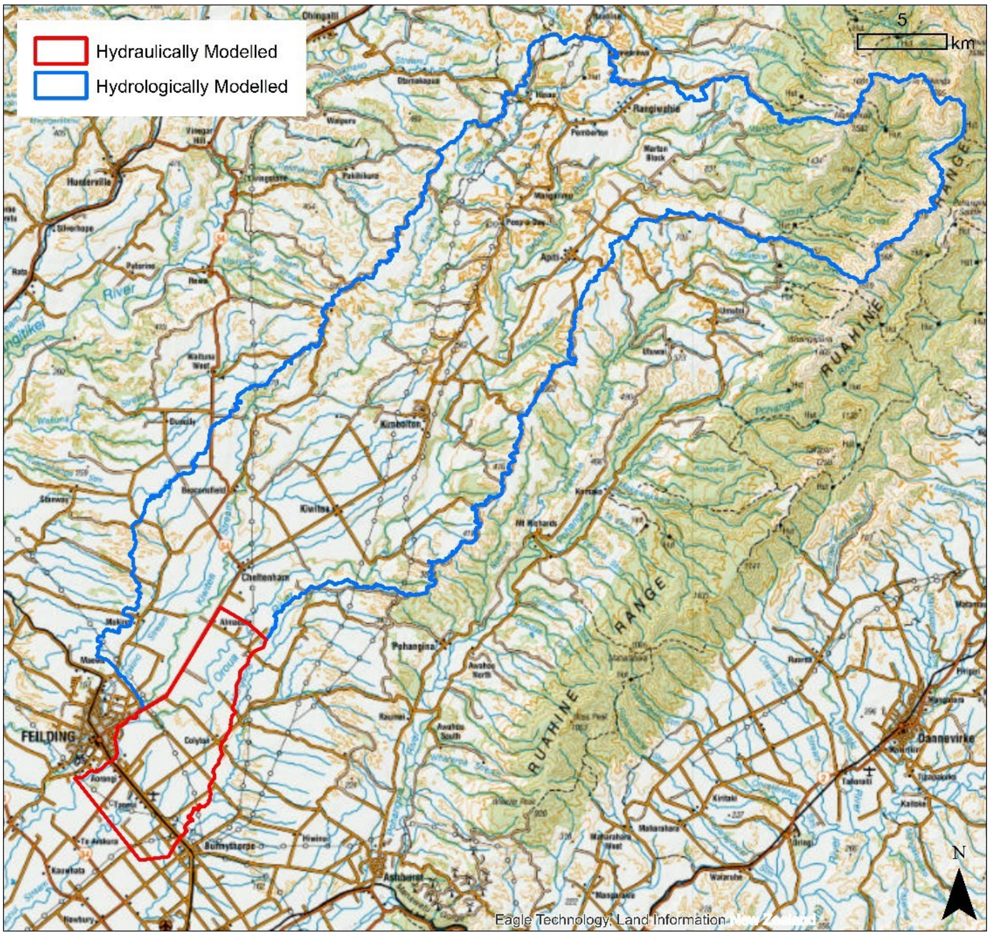

Figure 1-1: Study Location

1.2 Background

The Oroua River flows southwards between Feilding town and the settlement of Aorangi, with the two built up areas connected by the SH54 bridge (and the main trunk railway line crossing) and protected by a number of stopbanks. Feilding is a rural service town situated in the south-central portion of the Horizons District, located some 20 km north of Palmerston North, to which it is increasingly a desirable lower cost dormitory town. It is a prosperous agricultural area, with the Manawatu Plains on which the town is sited being very fertile land.

The town has a growing population of over 15,000 and is expected to see significant growth in the coming years, with associated significant pressure for new land to be made available for development. A key potential area for this growth has been identified as the eastern floodplain of the Oroua River north of SH54 (Waughs Road), resulting in the present study. The model and the findings of this study regarding the flood risk associated with land and structures within the project area will provide a basis for HRC and Manawatu District Council (MDC) to make more informed decisions regarding the suitability for development of land within the study area. It is known that there was extensive flooding here in a historic event in 1897, though it is possible that the riverbed has degraded since then.

For HRC to fulfil its responsibilities relating to land-based activities undertaken within its region, the Council commissioned a modelling and mapping project for Oroua River - Almadale and the adjacent eastern floodplain areas. This will allow HRC to better understand the capacity of the existing Oroua River and floodplain to convey runoff from storm events associated with floods of specified annual exceedance probabilities (AEPs), as well as the risk associated with further residential, commercial, and industrial development in areas within the floodplain between Waughs Road and Almadale Reserve.

1.3 Project Tasks

To generate the required outputs for the area of interest, a MIKE+ 2D hydraulic model has been built for the project and used as a tool to assess flood hazards. The process required has included:

- Extreme Value Analysis of historic gauged flows in the Oroua River and Kiwitea Stream.
- Deriving suitable precipitation for use in the hydrological and hydraulic models.
- Defining the 2D domain based on the area of interest and anticipated flow paths.
- Building and validating a hydrological model for the gauged flows.
- Building a hydrological model to generate boundary inflows for the defined 2D domain.
- Developing a computational mesh.
- Adding in 1D components to allow for the modelling of critical bridges.
- Incorporating surveyed culvert and stopbank data in the model.
- Estimating roughness and infiltration across the domain.
- Running design event model simulations for the required range of AEP historic and future climate events.
- Processing the required results for each design event.

2 Hydrological Modelling

2.1 Approach

Early attempts to calibrate catchment hydrology models to specific rainfall events highlighted significant spatial and temporal variations across such events, with no consistent pattern discernible in the runoff parameters required to reproduce gauged flows. A significant component of this issue is considered to be the difficulty in relating rainfall patterns and flow runoff in the Oroua headwaters running off the Ruahine ranges to the north-east of Pohangina with the downstream gauging station data. It was therefore determined (in consultation with HRC staff) that fitting a lumped catchment hydrology model using Extreme Value Analysis (EVA) derived flows and rainfall depths, represented the best basis for estimating flood event peak inflows from the Oroua and Kiwitea rivers for the AEPs and climate scenarios of interest.

NIWA's HIRDSv4 was used to derive precipitation depths. An EVA approach using peak discharge data was undertaken using HRC provided gauge data for the Oroua and Kiwitea rivers. An Extreme Value Analysis using flow data is often referred to as a Flood Frequency Analysis (FFA), and the terms can be used interchangeably. The gauge data indicates the relative timing of flood peaks between Oroua and Kiwitea rivers varies between events (in both directions) depending on the prevailing storm direction. Therefore the timing used for rainfall has been taken as consistent across both catchments (similar to the previous Entura report), providing if anything a conservative assumption. However, it is noted that the Oroua flood peak is the larger of the two and reaches the confluence slightly later. Any reduction in peak coincidence would be relatively arbitrary, certainly without significant further analysis.

2.2 Flood Frequency Analysis

2.2.1 Gauge Data

The Oroua catchment above Almadale has 63 years of flow gauge records from two closely located gauging sites (Almadale and Almadale Slackline (Oroua A/AS), Figure 2-1). Due to their proximity, these records were combined without adjustment for the purposes of FFA, and annual maximums (AM) extracted.

Table 2-1: Comparative Catchment Sizes of Kiwitea Gauges

Catchment	Record	Area (km^2)	Difference (km^2)	Scaling Factor
SRE	1976-1998	240.9	-	-
SF	2016-2022	235.0	5.9	+2%
CGC	1998-2004	165.5	75.4	+31%
HL	2005-2016	161.0	79.9	+33%

The Kiwitea Catchment has 46 years of flow gauging across four spatially distributed gauges; Spurs Road Extension (SRE), Strathspey Farm (SF), Cheltenham Gun Club (CGC) and Haynes Line (HL), Figure 2-1. In order to undertake the FFA, the three upstream gauge records were scaled based on comparative catchment area to the lowermost gauge (Table 2-1) and combined to form a pseudo record at the Spurs Road Extension gauge location (listed in shorthand as Oroua_pSRE). AM data were then extracted (Figure 2-2).

There are 63 years of data for Almadale (Oroua A/AS) gauge, though with a 13 year data gap (1979-1992). The potential use of the Kawa Wool flow gauge (1967-1992) downstream of the Oroua/Kiwitea confluence was considered for filling this 'gap', or for understanding flood peak timings. However, due to the difficulty of relating gauge data between these locations, and with only three years (1976-1979) where all three gauges were operating, any use of this would be highly uncertain. Comparing AM data for Oroua and Kiwitea (Figure 2-2) suggests that the FFA would be little changed by any gap filling.

Figure 2-1: Gauge Locations and Associated Catchments

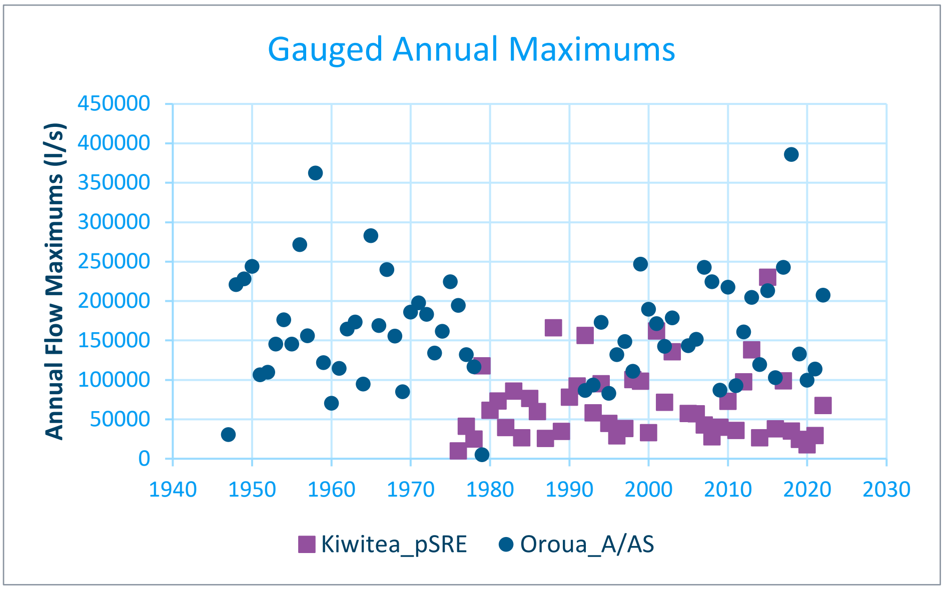

Figure 2-2: Combined Gauge Annual Maximum Flows

2.2.2 EVA Distribution Fitting of Annual Maxima Data

For the analysis of the extracted annual maxima data, a Bayesian estimation and fitting software, ‘RMC-BestFit’ (Version 1.0; USACE, 2020), was used to carry out EVA distribution fitting.

For the Oroua A/AS gauge data, two low outliers were identified and excluded using a Multiple Grubbs Beck Test (specifically, the annual maximums from the years 1947 and 1979, shown as red crosses), noting that these two years also had only partial data available and so could probably be omitted from the analysis anyway. The fitting procedure identified a Generalised Logistic distribution as a good choice for modelling the data (Figure 2-3).

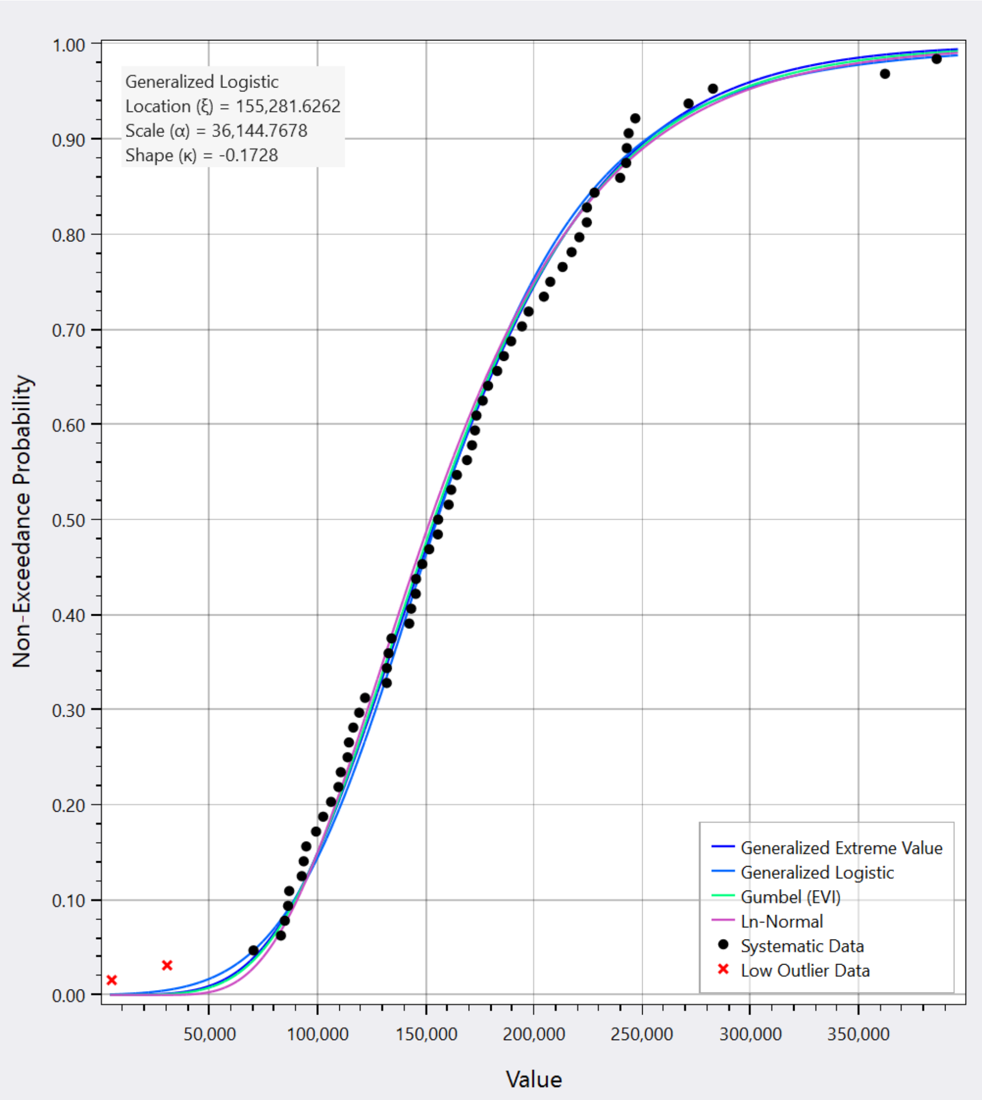

Figure 2-3: Oroua A/AS Gauge, Fitted Cumulative Distribution Functions

For the Kiwitea pSRE annual maxima data, no low outliers were detected using the Multiple Grubbs Beck Test. A Generalised Extreme Value (GEV) distribution was selected as a suitable model to represent the data series (Figure 2-4).

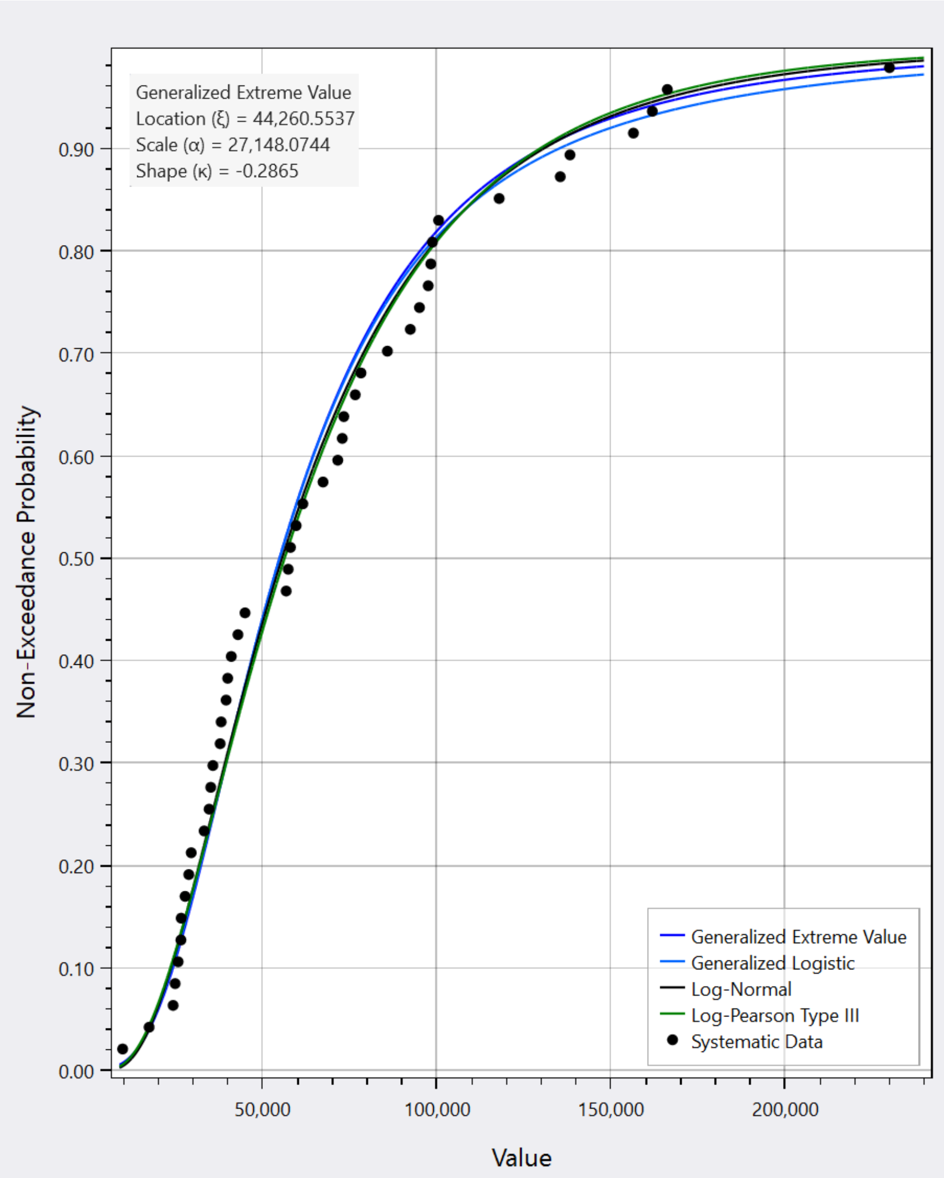

Figure 2-4: Kiwitea pSRE Gauge, Fitted Cumulative Distribution Functions

2.2.3 Bayesian peak flow estimates

Based on these two parameterised distributions, Bayesian peak flow estimates and associated confidence intervals were generated using a Markov Chain Monte Carlo (MCMC) algorithm. These envelopes are displayed graphically in Figure 2-5 and Figure 2-6, and estimates for the four AEPs of interest in this study are listed in Table 2-2. The event probability in one year (AEP) can also be quoted in terms of the average recurrence interval (ARI) in years. The Confidence Level (CL) values shown in the table define the confidence envelope at the specific ARIs. As described above, the two incomplete years of data (1947 and 1979) or low outliers have been removed from the analysis.

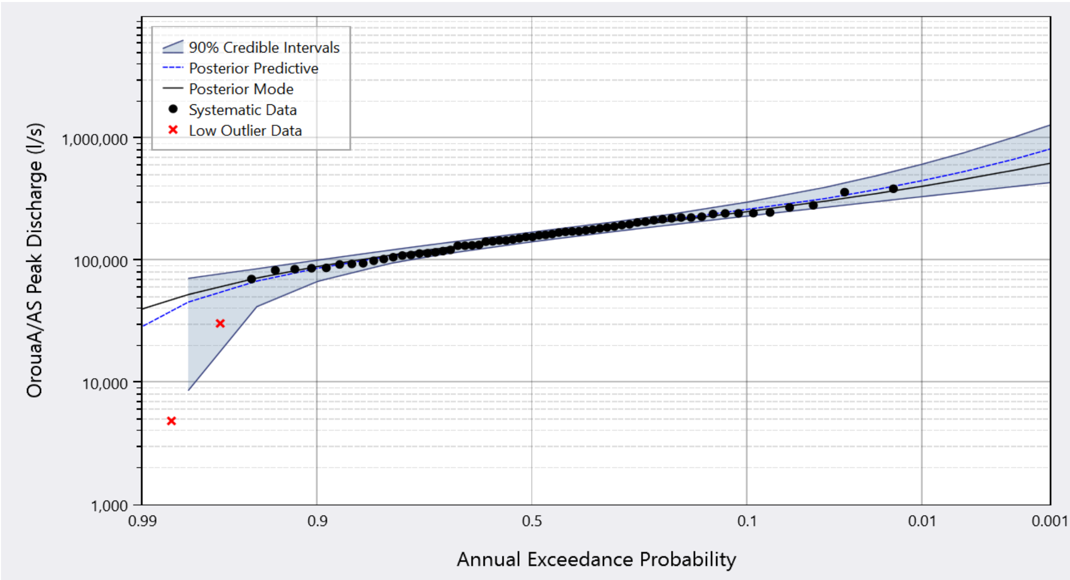

Figure 2-5: Oroua A/AS, Generalised Logistic Bayesian Peak Flow Estimates and Associated Confidence Envelope

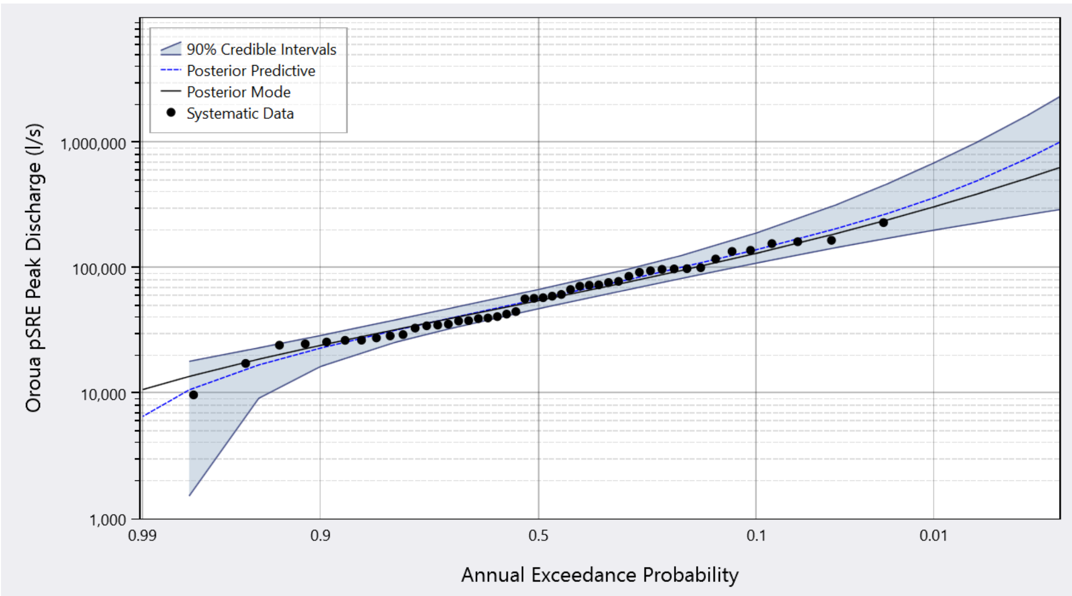

Figure 2-6: Kiwitea pSRE, Generalised Extreme Value Bayesian Peak Flow Estimates and Associated Confidence Envelope

Table 2-2: Bayesian Peak Discharge Estimates for the ARI/AEP Events

Gauge	ARI	AEP	Peak Discharge rate (m^3/s)		
			95% CL	5% CL	Estimate
Oroua A/AS gauge	200	0.5	761	363	462
	100	1	613	333	404
	50	2	493	303	353
	25	4	397	272	306
Kiwitea pSRE gauge	200	0.5	1003	228	387
	100	1	689	200	307
	50	2	470	173	242
	25	4	319	145	188

2.3 Precipitation

Rainfall depths and hyetographs were derived in the same way for the EVA hydrological validation and for subsequent design modelling. In both cases, the spatially varying HIRDSv4 rainfall data (published by grids) were used. These grids were sampled using catchment and 2D domain zonal statistics, and averages were captured (Table 2-3).

Time of concentration calculations for the inflow catchments suggested the use of a 6-hour storm duration, and this was also consistent with the conclusion drawn in an earlier HRC-commissioned study undertaken by Entura (Hydro Tasmania) in April 2013.

Rainfall depth grids were available for 5, 2, 1 and 0.4% AEP events (or 20, 50, 100 and 250 year ARIs), so for the required 25 and 200 year events an interpolation between the published data sets was required. Interpolations were conducted between the 20 and 50 year ARI grids for the 25 year ARI event, and between the 100yr and 250 year ARI grids for the 200 year ARI event. As suggested by the lead HIRDSv4 scientist (pers comm. Dr Carey-Smith, 2019), the interpolation was carried out in 'Gumball Space', as the HIRDSv4 model reduces to near linear using an *x* variable of $(-\ln(-\ln\left(1-\frac{1}{ARI}\right))$.

Table 2-3: Zone Averaged Rainfall Depths (Historic) for ARIs of Interest

Zone	Rainfall Depth (mm)			
	ARI 25	ARI 50	ARI 100	ARI 200
Oroua A/AS Gauge	79.5	90.7	102.4	114.6
Kiwitea SRE Gauge	60.5	69.1	78.2	87.8
Oroua Model Input	79.5	90.7	102.4	114.6
Kiwitea-Makino Combined Model Input	60.3	68.8	77.9	87.4
2D Domain	57.0	65.1	73.7	82.7

HIRDSv4 climate change factors depend on the ARI, the storm duration, time period and Relative Concentration Path (RCP) scenario. For these simulations, it was agreed with HRC to use an RCP of 6.0 and the time period 2081-2100, for which a 1.63 ̊C increase in temperature is anticipated for a 6-hour duration storm, Table 2-4. A natural log curve was fitted to the published factors, in order to derive the percentage change for the 25 and 200yr ARIs, which were not included in the HIRDSv4 projection table. These factors were applied uniformly to the total rainfall depths in our four design AEP (ARI) event rainfall grids for the model design runs, as shown in Table 2-5.

Table 2-4: Climate Change Projection Factors

6hr Duration Storm				
ARI	25	50	100	200
%Change/ ̊C	11.1	11.3	11.5	11.9
%Change for 1.63ºC	18.1	18.4	18.7	19.4

Table 2-5: Historic and Climate Change (cc) Rainfall depths used

Rainfall Depth, 6hr Duration Storm (mm)								
Zone	ARI25	ARI25cc	ARI50	ARI50cc	ARI100	ARI100cc	ARI200	ARI200cc
Oroua	79.5	93.9	90.7	107.4	102.4	121.6	114.6	136.9
Kiwitea-Makino	60.3	71.2	68.8	81.5	77.9	92.5	87.4	104.4
2D Domain	57.0	67.3	65.1	77.1	73.7	87.5	82.7	98.7

Temporal distribution of the total rainfall depths was undertaken using a non-dimensional asymmetric hyperbolic tangent function (Equation 1) and factors indicated in the HIRDSv4 technical report, derived from modelling historical data, as outlined below (see Table 2-6 and Figure 2-7). HRC consider that the typical representative rainfall trend for Ōroua River would be relatively front loaded. This study area lies in the 'East of North Island' climate zone as shown in Figure 2-8 (taken from Figure 33 from the NIWA 'HIRDSv4' document, August 2018). This zone was selected due to it having data points closer to Feilding, around the Manawatu Gorge, along the Ruahine and Tararua ranges and east of Dannevirke, whereas the 'West of North Island' climate zone only has data points west of Whanganui and SH4 including New Plymouth to the west and north towards Hamilton.

Equation 1: Cumulative Hyetograph

$$P\ (proportion\ of\ total\ depth) = m \tanh[(D-n)Wl] + m \qquad 0 \le D \le n$$

$$P\ (proportion\ of\ total\ depth) = (1-m) \tanh[(D-n)Wr] + m \qquad n \le D \le 1$$

Table 2-6: Cumulative Hyetograph Parameter Values

East of North Island, 6hr Duration Storm	
Wl (warp factor, representing curvature on left side of peak)	3.31
Wr (warp factor, representing curvature on right side of peak)	3.53
D (proportion of duration at given time of calculation)	-
m (proportion of rain fallen at the peak rainfall depth)	0.48
n (abscissa of the peak rainfall depth (i.e. proportion of time))	0.52

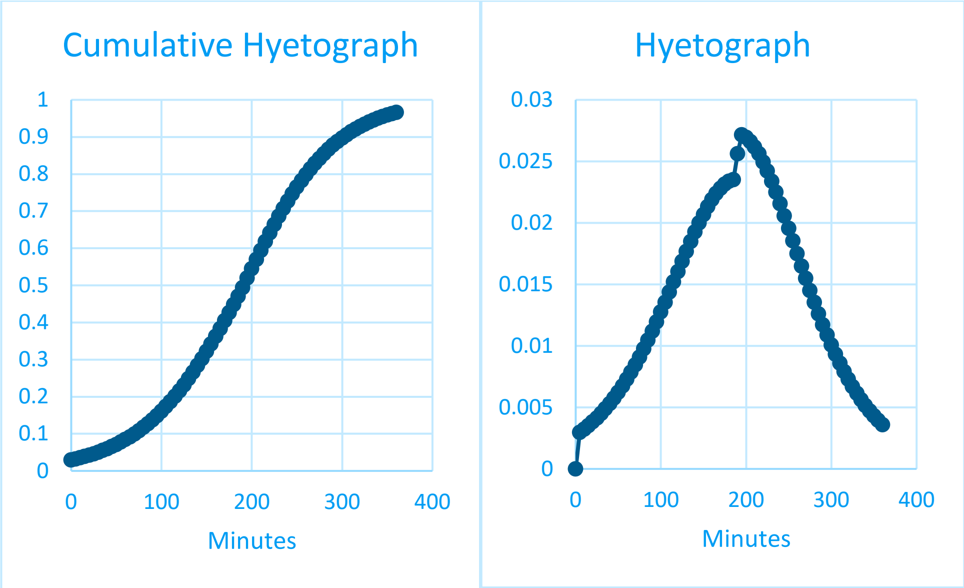

Figure 2-7: Normalised Hyetographs used to Distribute Design Rainfall

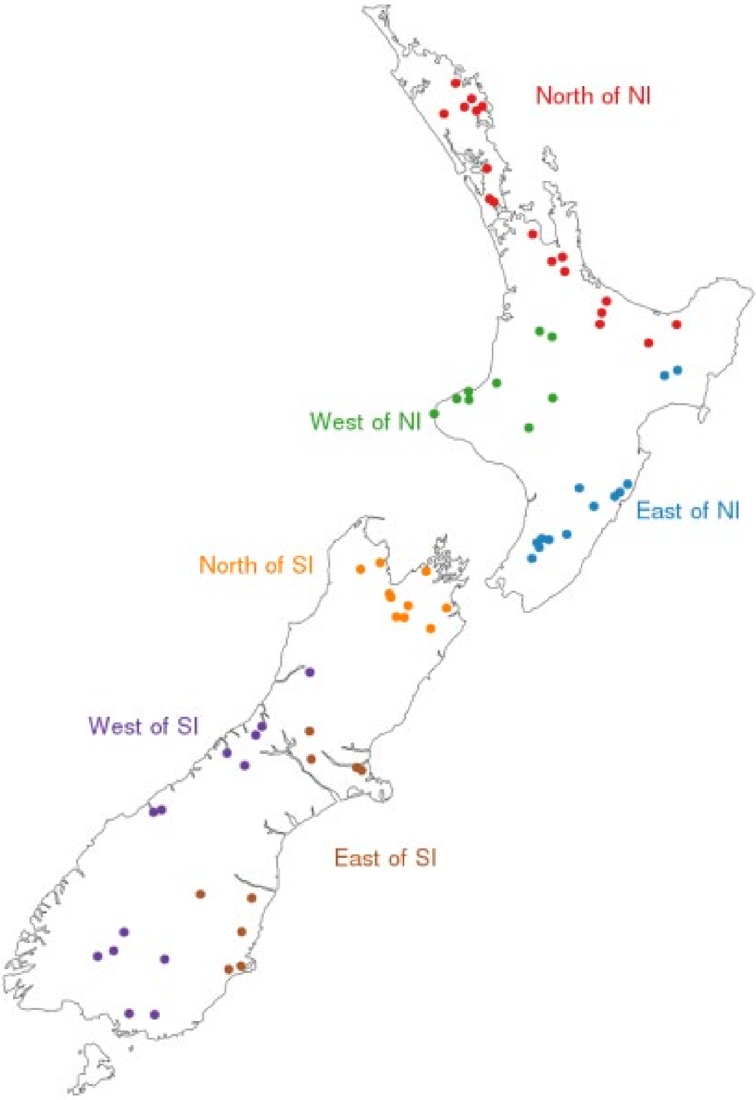

Figure 2-8: Location of Raingauges and Regions used for HIRDSv4 Analysis

2.4 Hydrological Modelling – Approach

Kinematic Wave (Model B) hydrological models were built and calibrated for the two FFA gauge locations, namely Oroua A/AS and Kiwitea pSRE. The resulting parameters were then ported across to the two hydrological catchment models used to generate the source inflows feeding into the 2D Domain.

The Kinematic Wave model is a lumped surface runoff model with moderate data requirements. The runoff computation is based on a treatment of hydrological losses (including infiltration) and the runoff routing by the Kinematic Wave (Manning) formula. The surface runoff is computed as flow in an open channel, considering the gravitational and friction forces only.

The amount that runs off is controlled by the various hydrological losses and the size of the contributing area. The shape of the runoff hydrograph is controlled by the longest channel parameters of length, slope and roughness, Table 2-7.

To the west of the Kiwitea Catchment, lies the Makino Stream, which runs through the town of Fielding. This stream has historically provided a significant flood risk to the town. To manage that, flood gates are installed on the Makino to divert water along the Reid Line Floodway and into the Kiwitea Stream, a kilometre above its confluence with Oroua. For the purposes of this modelling, after discussion with HRC, we have assumed 100% diversion of the water from the Makino catchment upstream of the flood gates. This was done by generating and merging the relevant Makino catchment with the Kiwitea Catchment when generating the inflow hydrograph to be used in the hydraulic model (Figure 2-9).

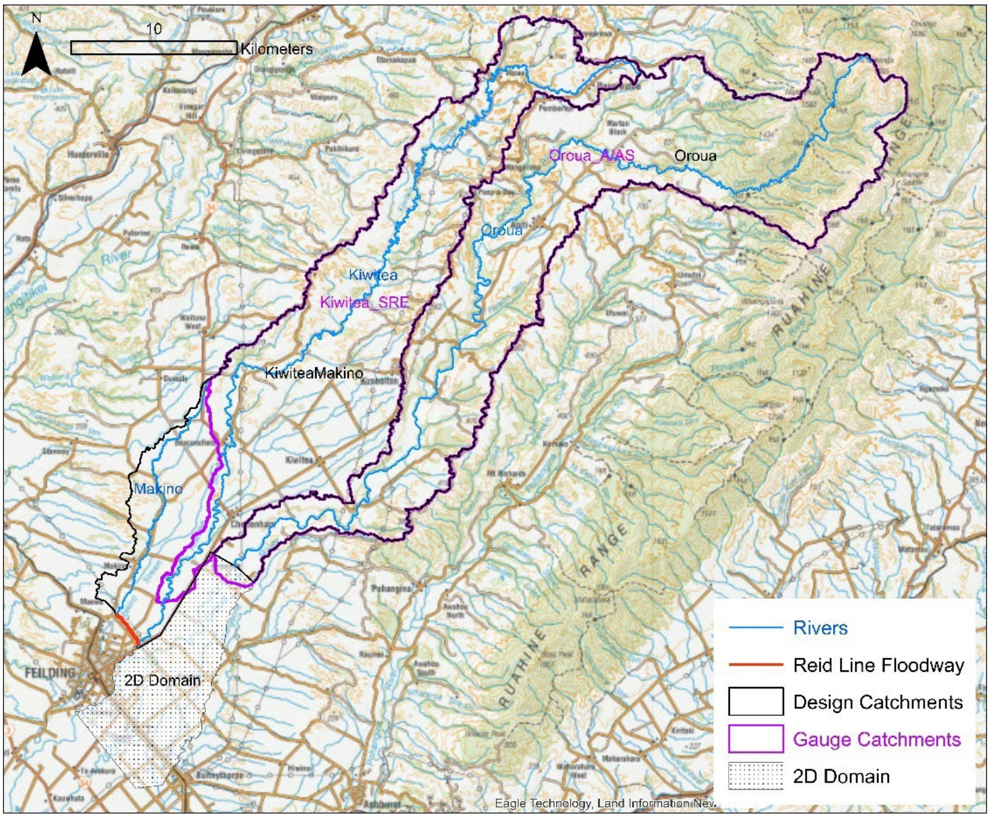

Figure 2-9: Modelled Hydrology Catchments

Table 2-7: Geometric Properties of Modelled Hydrology Catchments

Catchment	Area (hectares)	Flow Path Length (m)	Flow Path Slope[1] (degree)	Flow Path Slope[2] (‰)
Kiwitea_SRE	24,089	85,225	2.7	47
Oroua_AS	30,557	87,021	4.5	79
Kiwitea Makino	29,241	89,244	2.7	46
Oroua	30,347	85,522	4.5	79

2.5 Hydrological Modelling Parameter Calibration

Using the FFA (summarised in Table 2-2), the hydrological parameters of the Kinematic Wave rainfall runoff model were calibrated for each AEP design event until the peak discharge of the simulated hydrograph approximated the FFA results (Table 2-8 and Table 2-9). The final calibrated hydrological parameters for the Kinematic Wave model are presented in Table 2-10, with varying Manning M values for each modelled AEP event being as listed in Table 2-11. These hydrological roughness values are not necessarily those used in the hydraulic model, which use more typical values for the stream type. It is also noted that, while the calibrated infiltration rates (Table 2-10) are used within the design hydrology, the hydraulic (2D) design model applies more typical values based on land use and soils data.

Table 2-8: Peak Discharge Calibration Exercise, Oroua A/AS

AEP	Oroua Peak Flow (m^3/s)	
	FFA Estimate	Kinematic Wave Model
4% (1 in 25)	306	299
2% (1 in 50)	353	352
1% (1 in 100)	404	406
0.5% (1 in 200)	462	458

Table 2-9: Peak Discharge Calibration Exercise, Kiwitea pSRE

AEP	Kiwitea Peak Flow (m^3/s)	
	FFA Estimate	Kinematic Wave Model
4% (1 in 25)	188	200
2% (1 in 50)	242	250
1% (1 in 100)	307	304
0.5% (1 in 200)	387	375

[1] As an angle of inclination to the horizontal, in degrees.
[2] As a per mille figure (‰), the formula for which is either 1000×(rise/run) or 1000× the tangent of the angle of inclination.

Table 2-10: Calibrated Infiltration Parameters

Parameter	Kiwitea pSRE	Oroua A/AS
Wetting (mm)	0.05	0.05
Storage (mm)	0	1
Start inf. rate (mm/h)	1	3.5
End inf. rate (mm/h)	0.5	1
Wet exponent (s^{-1})	0.0015	0.0015
Dry exponent (s^{-1})	5E-06	5E-06

Table 2-11: Calibrated Manning M Values for each AEP

AEP	Manning (M) [m^(1/3)/s]	
	Kiwitea pSRE	Oroua A/AS
4% (1 in 25)	48	30
2% (1 in 50)	49	28
1% (1 in 100)	49	26
0.5% (1 in 200)	51	24

2.6 Hydrology Design Flows

The peak design flood flows for each event are summarised in Table 2-12, for present day and future climate change events as outlined above. There are two catchment model inflows, one from the Oroua catchment and one from the combined Kiwitea and Makino catchment. For design inflows the Makino catchment, with its confluence downstream of the Kiwitea SRE gauge, has been added to the Kiwitea catchment, using the calibrated parameters outlined above for Kiwitea across the combined catchment. These flows are added at the 2D domain model boundary (linearly distributed across ten mesh elements respectively) into the channels of the Oroua and Kiwitea.

Table 2-12: Peak Hydrograph Inflow for Design Events

AEP	Model Design Peak Flow (m^3/s)	
	Oroua Inflow	Kiwitea + Makino Inflow
4% (1 in 25)	301	229
2% (1 in 50)	355	288
1% (1 in 100)	409	351
0.5% (1 in 200)	461	434
4% (CC)	397	299
2% (CC)	469	377
1% (CC)	541	460
0.5% (CC)	615	571

Simulated design flood hydrographs for the Oroua and combined Kiwitea-Makino Catchments for the four climate change design events are shown in Figure 2-10 and Figure 2-11.

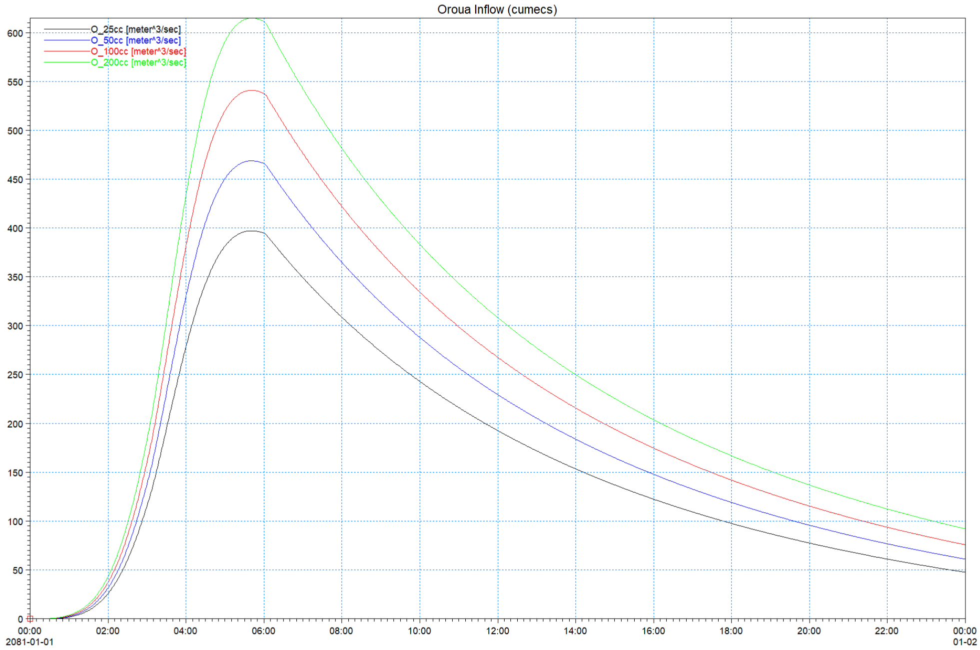

Figure 2-10: Modelled Oroua Inflows (cc)

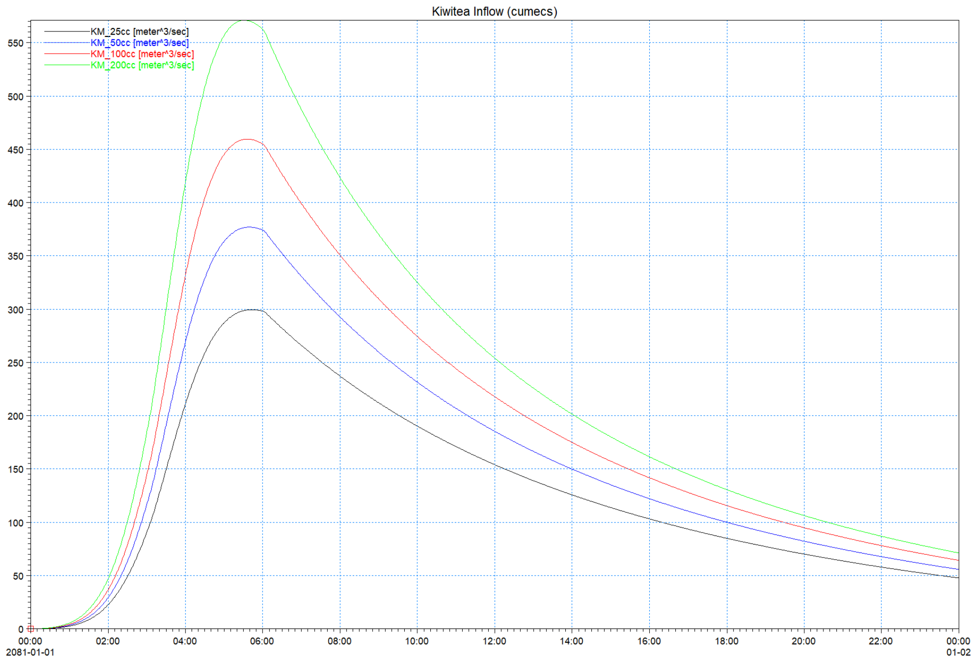

Figure 2-11: Modelled Kiwitea Inflows (cc)

3 Hydraulic Modelling

3.1 Hydraulic Domain

The area of interest for this model was specified by HRC in the original RFP documentation, as outlined in red in Figure 3-1. From discussions with the client, a decision was made to extend the north-west domain boundary from the Oroua flood plain change of slope outwards to Kimbolton Road (SH54) and into the Kiwitea Catchment. On the north-east side, the domain boundary was brought inwards from Mangaone Stream, as the excluded area to the east drains to the Mangaone Stream, which is not under consideration in this study. The downstream boundary was extended ~350m beyond Roberts Line, to minimise the chance of any boundary backwater effects impacting the area of interest.

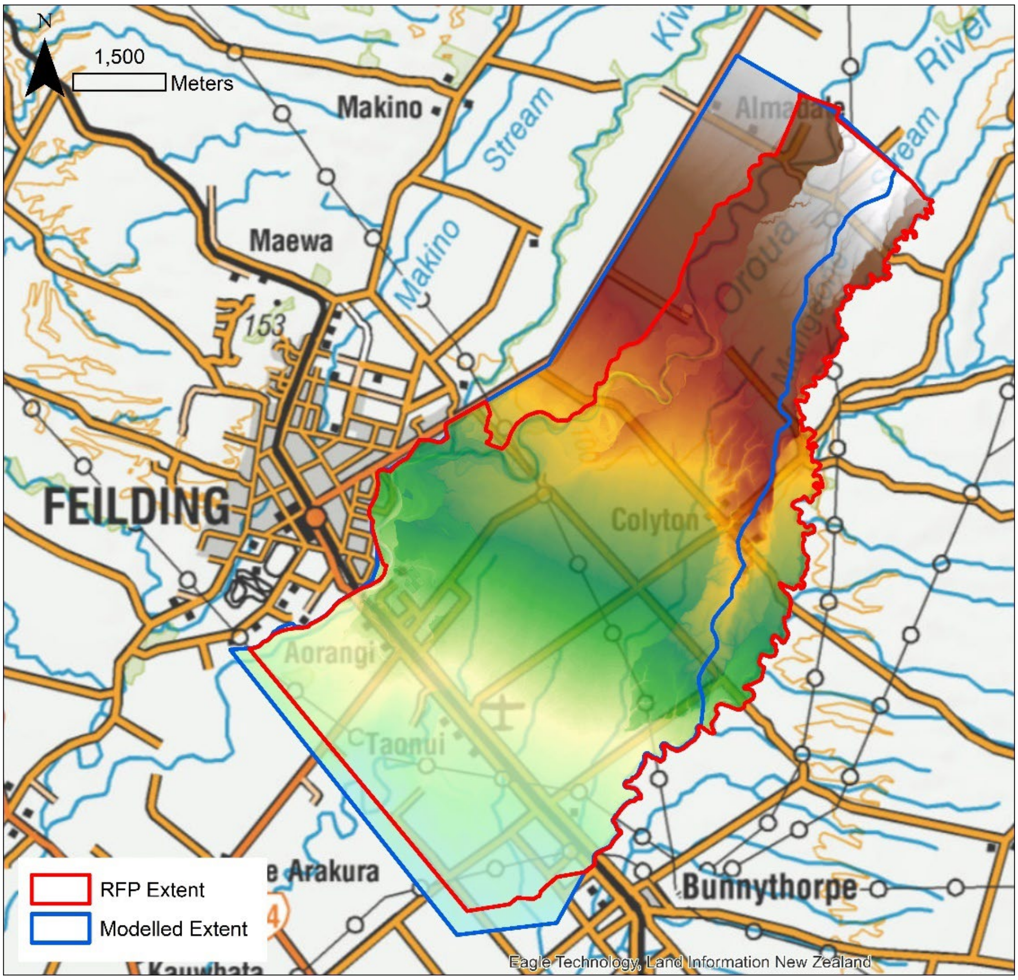

Figure 3-1: Modelled hydraulic domain alongside RFP extent

3.2 1D Components

The approach for this project was to model both the floodplain and riverbed using a 2D hydraulic model. However, in order to accommodate bridge structures within the model domain, two small sections of 1D channel were coupled within the wider model.

Although not included in the final model, a 1D lengthwise model of the Oroua River was built in order to generate a riverbed DEM using the provided cross section survey data, as this represented the channel bed better than was possible from the LiDAR. A hybrid DEM, combining the cross-section derived riverbed DEM with the LiDAR, was used to assign mesh element ground levels across the domain.

3.2.1 Bridges and associated 1D channels

Three bridges cross the Oroua River within the area of interest for this project. From upstream to downstream these are Colyton Road Bridge, Aorangi Rail Bridge, and Waughs Road (Aorangi) Bridge (Figure 3-2). Survey data was provided for all three structures (Figure 3-3 to Figure 3-5). The two Aorangi bridges are within 50m river length of each other, which is potentially problematic from a model stability standpoint. An interrogation of the survey data showed that the downstream Waugh's Road bridge provides the more significant impediment to flow, so the decision was made to exclude the rail bridge from the model and combine the effect into one structure.

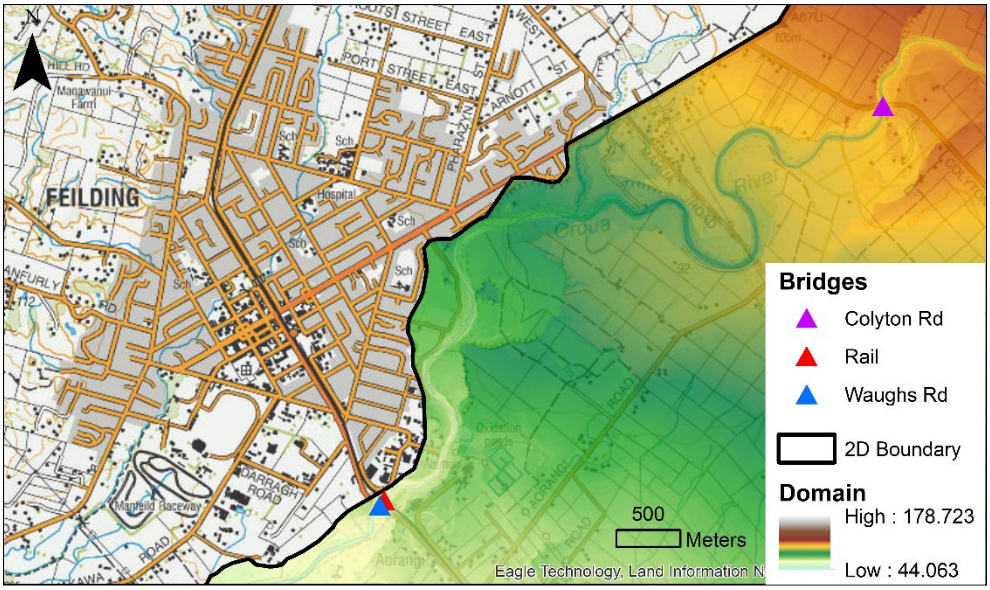

Figure 3-2: Location of Oroua River Bridges within the 2D Domain

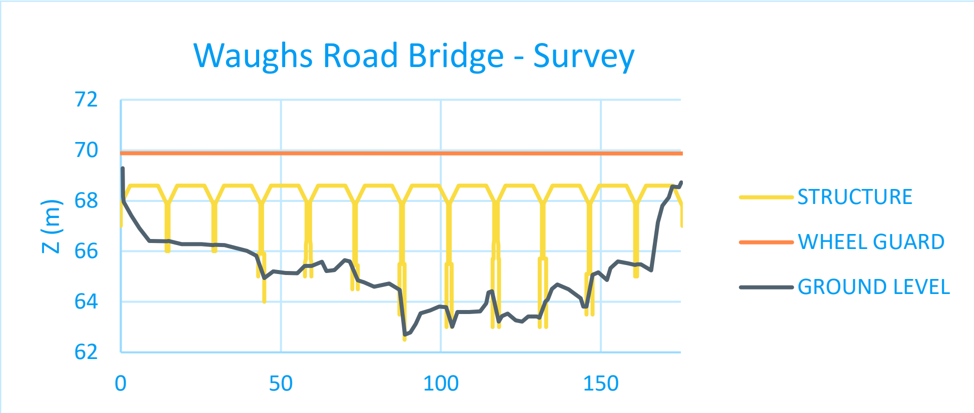

Figure 3-3: Waughs Road Bridge Survey

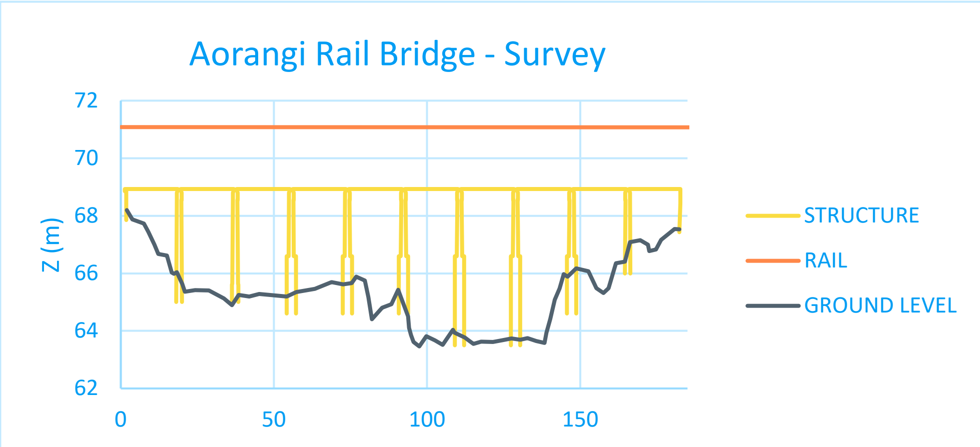

Figure 3-4: Aorangi Rail Bridge Survey

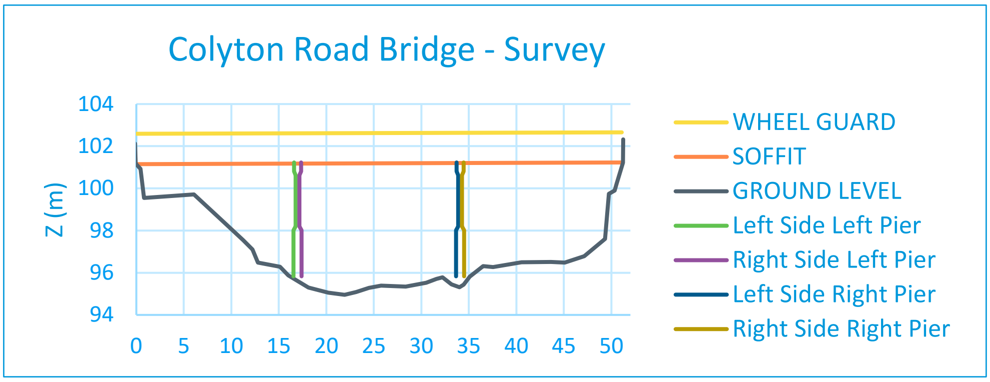

Figure 3-5: Colyton Road Bridge Survey

Two short sections (<= 20m) of 1D channel were generated to contain the two bridges selected for inclusion, and these were coupled to the overland model using standard upstream and downstream river end links, adjusting local mesh values to the relevant surveyed bed levels. For flow through the bridges, a simple Energy Equation method was selected, with contraction and expansion loss coefficients of 0.3 and 0.5 respectively. A percentage blockage factor was used to account for the bridge piers; 3% for Colyton and 11% for the Aorangi Road Bridge. Potential submergence and overflow effects were assigned to the FHWA WSPRO methodology, with a discharge coefficient 0.8.

3.2.2 Oroua Cross Section Data and Riverbed DEM

Cross section survey data was provided for the Oroua River (35km-60km), at the locations shown in Figure 3-6. These 47 cross sections were processed and imported into a 1D model, along with a river centre line. Additional cross sections were interpolated such that the model contained a cross section approximately every 10m along the considered length.

This process allowed a synthetic DEM to be generated along the length of the Oroua River (Figure 3-7) that represents the bed of the flow channel well, better than would be the case from a LiDAR generated DEM which would be impacted by water depth and vegetation. This synthetic DEM has been used to improve the model DEM in regard to bed levels, but is not meant for use on its own as it would not follow the bank contours (between cross-section locations) as well as the LiDAR generated DEM. The process used took the minimum ground levels from the two sources, such that there is no discontinuity with the combined DEM.

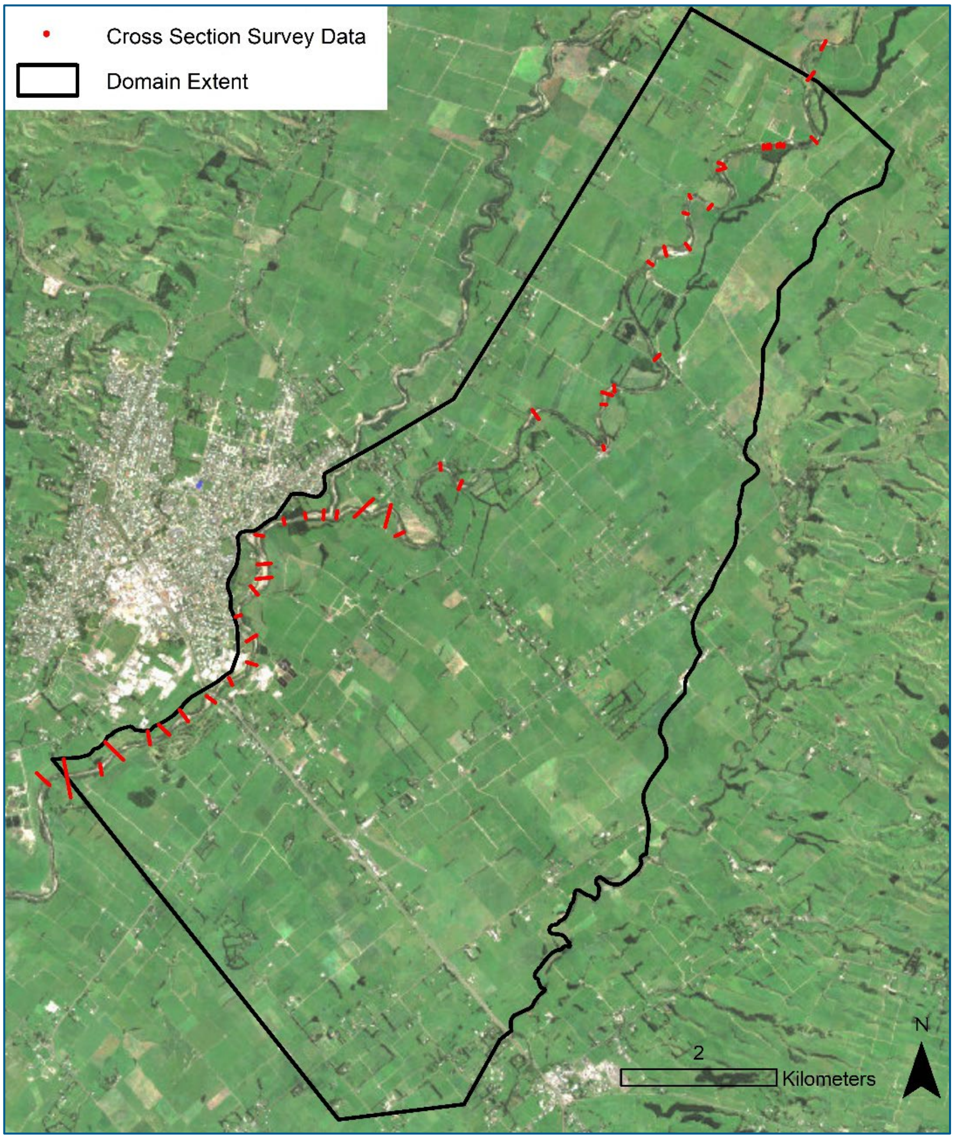

Figure 3-6: Locations of the Provided Cross Section Survey for the Oroua

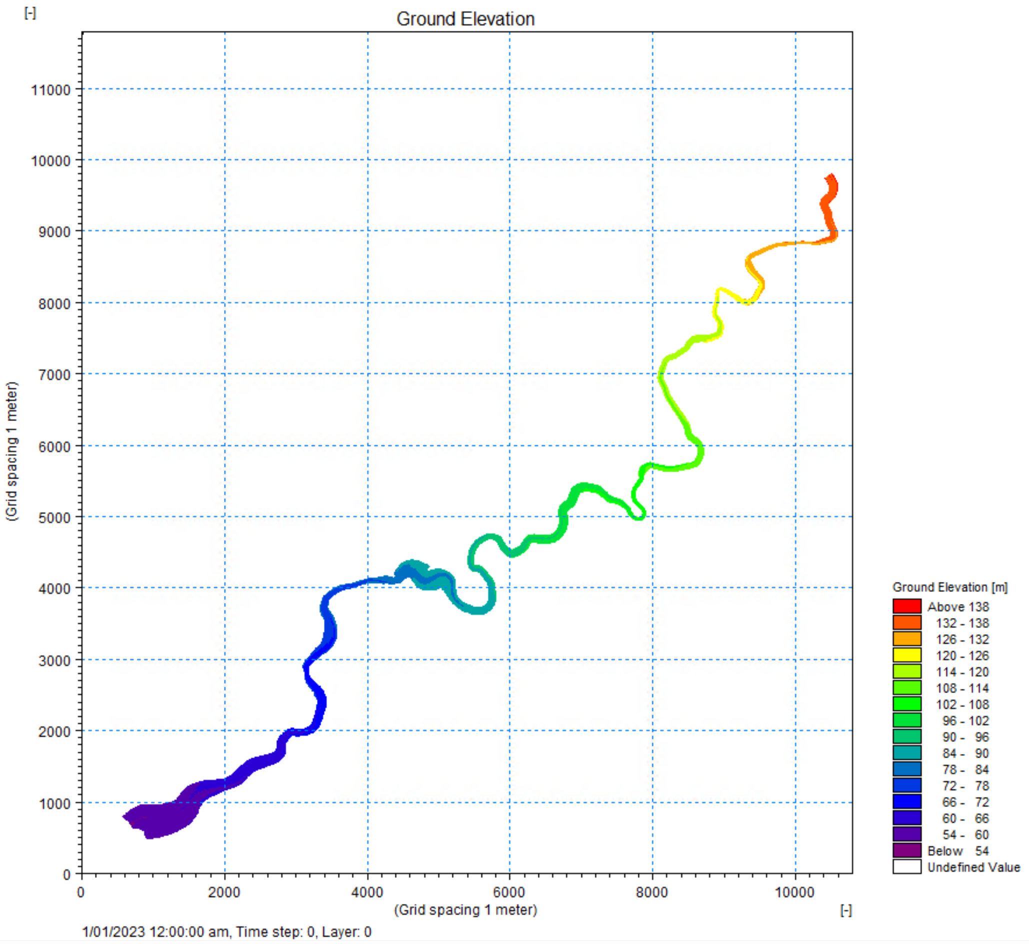

Figure 3-7: Cross Section Derived 1m DEM of the Oroua Riverbed

3.3 Computational Mesh

The computational mesh and corresponding ground levels are key components of a 2D overland flow model. The mesh transports the water which has accumulated via direct rainfall or entered the model from source point inflows.

A flexible mesh was constructed across the chosen model domain, using quadrilateral elements for the Oroua River, and triangular elements elsewhere. For the triangular elements, point clouds were generated to force element size and alignment along roads, streams and stopbanks.

The mesh contains 1,794,524 elements, with a mean area of 35.7 m^2. Minimum element size was 9 m^2, and the maximum was 65.9 m^2. The distribution of element size can be seen in the Figure 3-8 histogram.

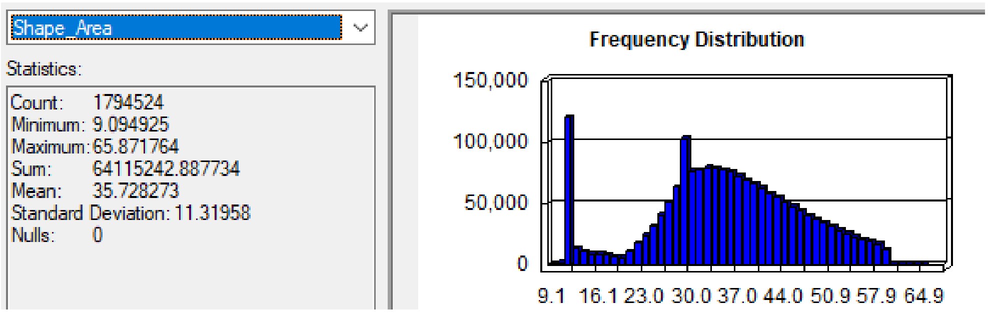

Figure 3-8: Mesh Element Area Statistics and Frequency Distribution

A ground surface DEM was created using a mosaic of the provided LiDAR with the cross section-derived DEM, with minimum values from the two sources being taken. Assigning values for individual mesh elements was undertaken by calculating the mean Z value for each mesh element polygon using ArcGIS zonal statistics. After completing this interpolation, manual adjustments were made to the ground surface at the free outflow boundaries, in elements linked to the 2D culvert features, and at the four standard links coupling the two 1D bridge containing channels to the hydraulic domain.

Some examples of the way the 2D mesh has been set up in different areas are shown from Figure 3-9 to Figure 3-12.

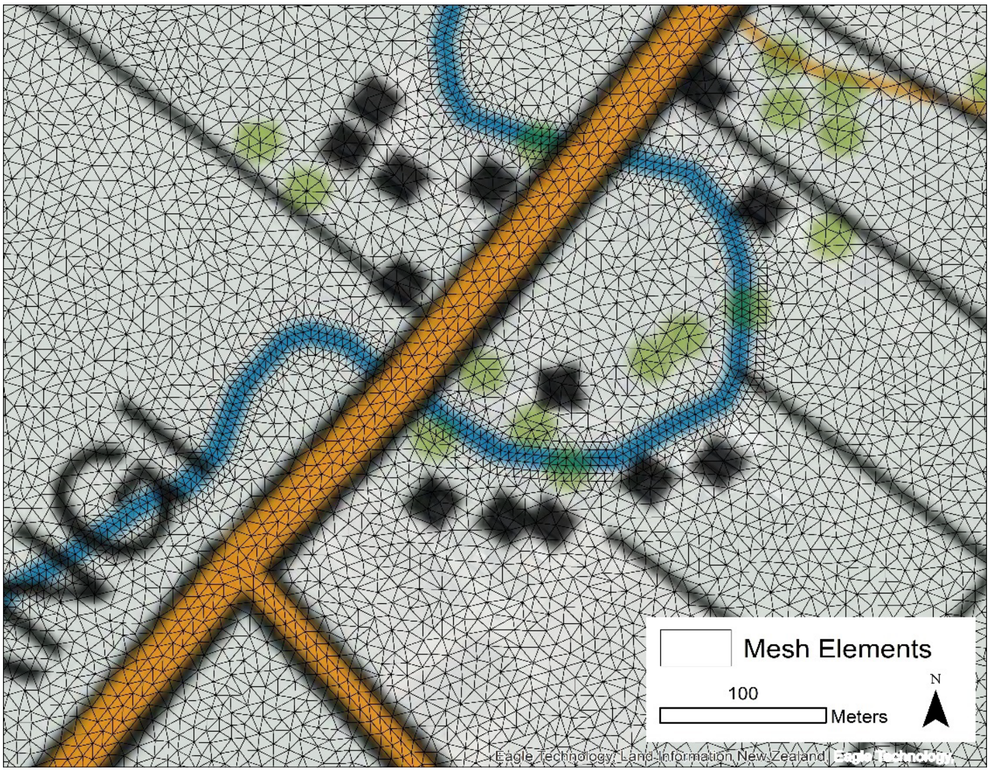

Figure 3-9: Mesh example; the intersection of Aorangi Road with Durie Road and an unnamed stream

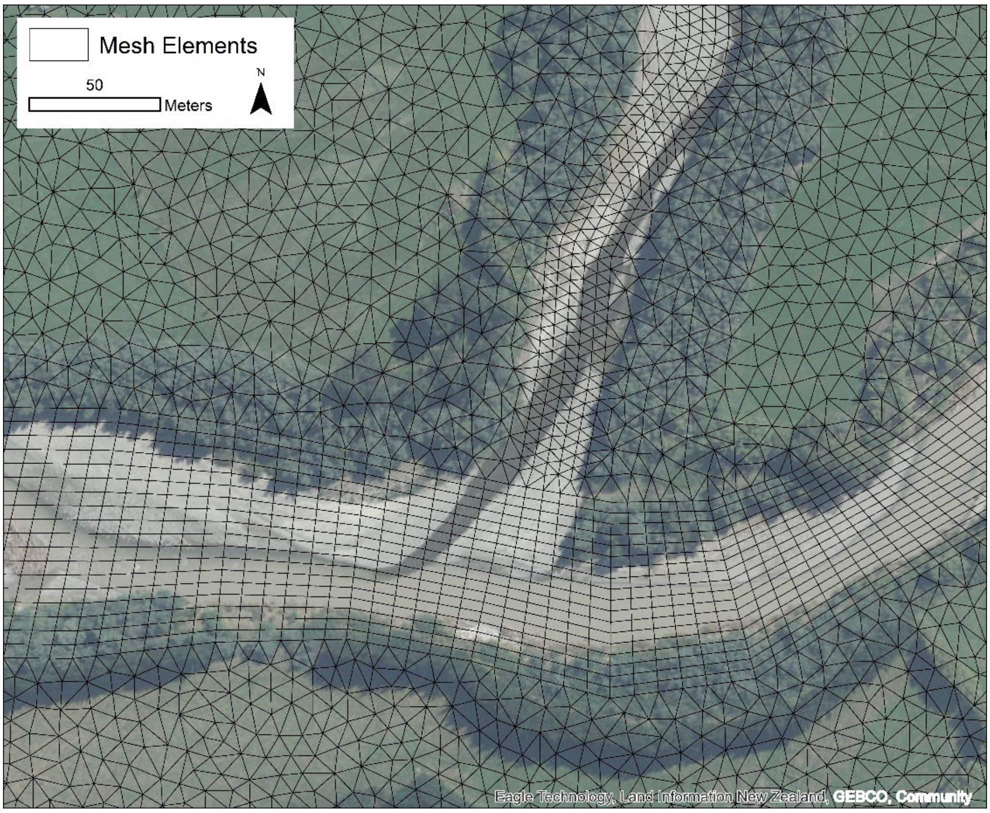

Figure 3-10: Mesh example; where Kiwitea Stream joins the Oroua River, which has been represented using a quadrilateral mesh

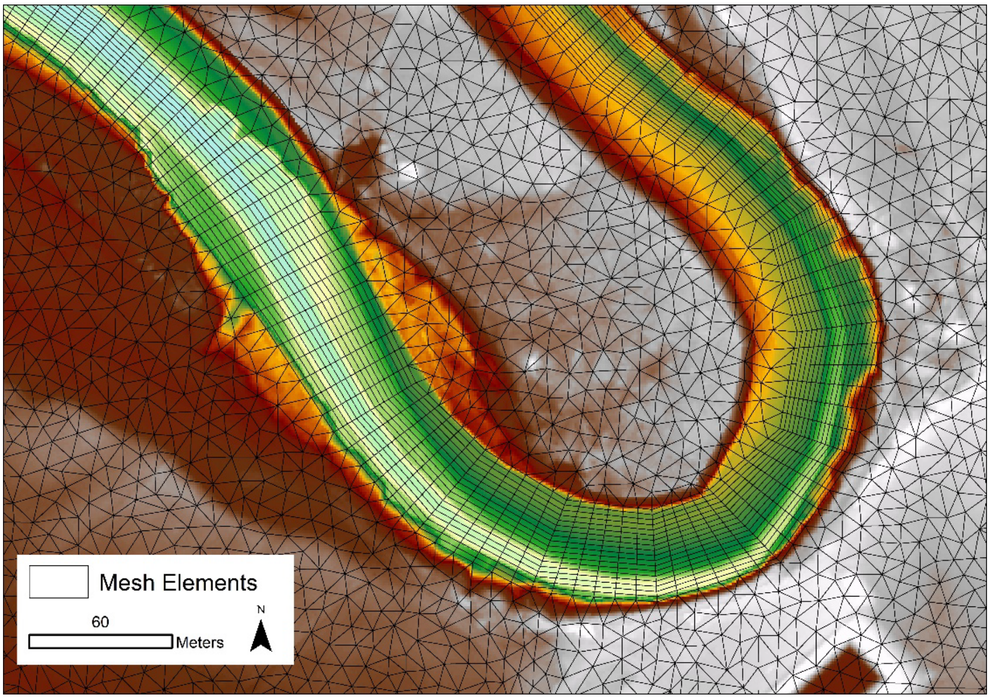

Figure 3-11: Mesh example; quadrilateral elements defining a horseshoe bend in the Oroua River, adjacent to the residence at 201 Colyton Road, Colyton

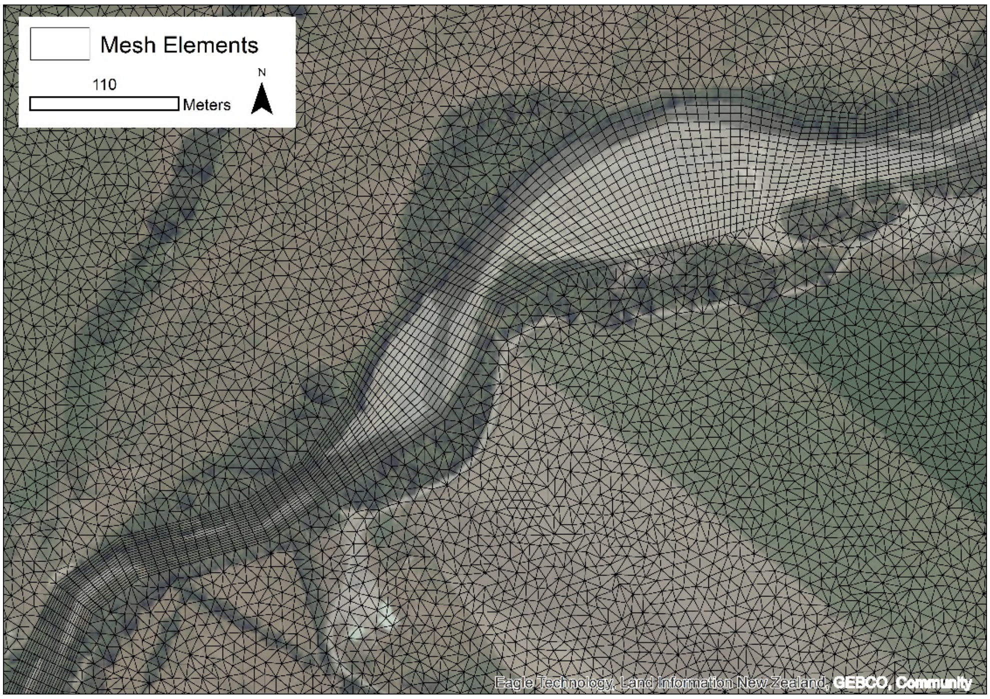

Figure 3-12: Mesh example; how quadrilateral elements adapt to width changes. Oroua River, approximately a kilometre upstream of the Fielding Gun Club, Ridds Road

3.4 2D Structures

MIKE+ allows for a variety of structures to be placed within a hydraulic overland model. For this project we used both the 'Dike' and 'Culvert' features.

3.4.1 Dikes

To the south of Fielding, the Oroua River has three notable stopbanks, two on the Right Bank (DS-RB and US-RB), and one on the Left Bank (DS-LB), Figure 3-13. Surveyed 3D point data was provided by HRC for all three stopbanks, and these were included in the model using the MIKE+ 2D dike feature. The underlying mesh elements were aligned to minimise potential distortions and more accurately represent the topography, as in Figure 3-14, which shows a zoomed in portion of mesh elements around a section of the DS-LB stopbank.

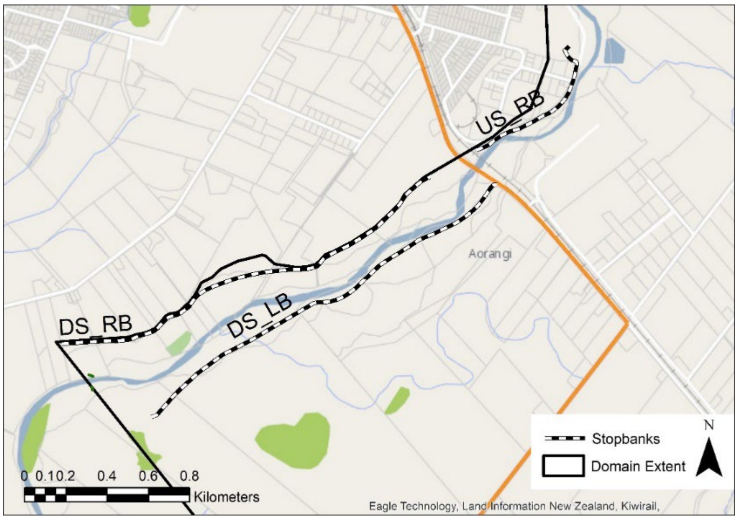

Figure 3-13: Modelled stopbank locations in the western corner of the hydraulic domain

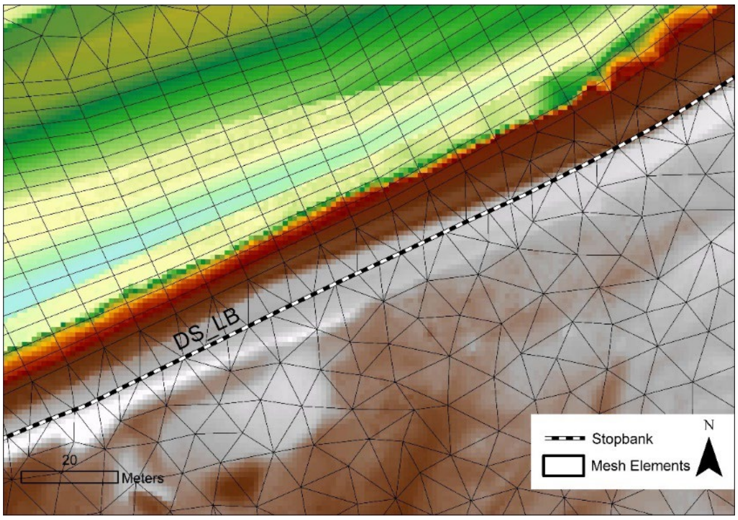

Figure 3-14: An example of triangular mesh element alignment along a modelled stopbank, in this case DS-LB

3.4.2 Culverts

Culvert and Stock Underpass data provided by HRC was augmented by publicly available Kiwirail culvert data and incorporated into the model using the MIKE+ 2D Long Culvert feature (locations identified in Figure 3-15). Ground levels of the linked mesh elements were altered to align with the documented upstream and downstream invert levels.

Trending NW-SE across the lower portion of the 2D domain is a transport corridor where Waughs Rd, the Railway, and Campbell Rd run parallel in close proximity. Along this corridor, there were several instances of two or three culverts in series allowing water flow in a SW direction. For model stability and simplicity, these culverts were merged for the purpose of model inclusion, taking the cumulative length but minimum diameter as a conservative approach in estimating potential flow conveyance.

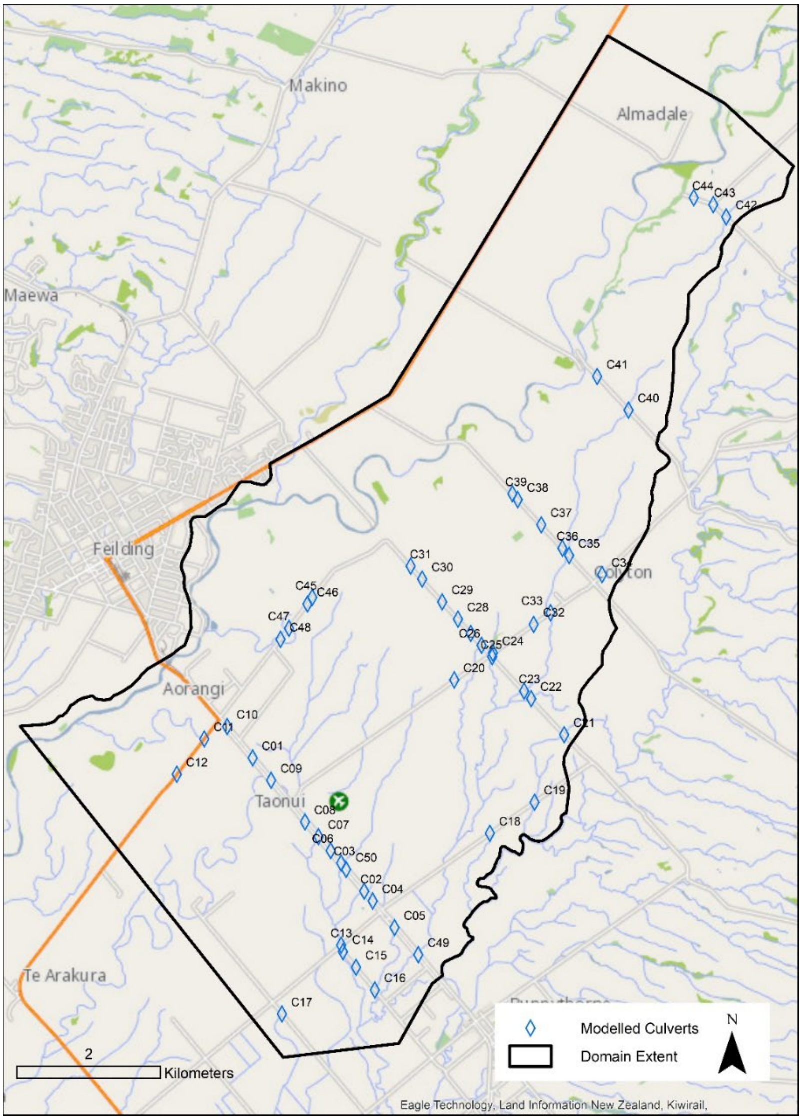

Figure 3-15: Locations and IDs of Modelled Culverts within the Hydraulic Domain

3.5 Surface Roughness

The surface resistance to overland flow is made up of many forms of friction loss. In this model, surface resistance is represented by a Manning's M friction loss. The spatial variation is derived from the 2018 land cover database, overlain with road outlines (Figure 3-16). Each category was designated a corresponding Manning's roughness, based on experience, and generally accepted values (Table 3-1).

Table 3-1: Surface Roughness Values per Land Cover Type

Surface	Manning M ($m^{1/3}/s$)
Orchard, Vineyard or Other Perennial Crop	8
Broadleaved Indigenous Hardwoods	8
Exotic Forest	8
Deciduous Hardwoods	8
Indigenous Forest	8
Built-up Area (settlement)	10
High Producing Exotic Grassland	20
Short-rotation Cropland	20
Gravel or Rock	29
Lake or Pond	25
River	28
Urban Parkland/Open Space	30
Roads	50

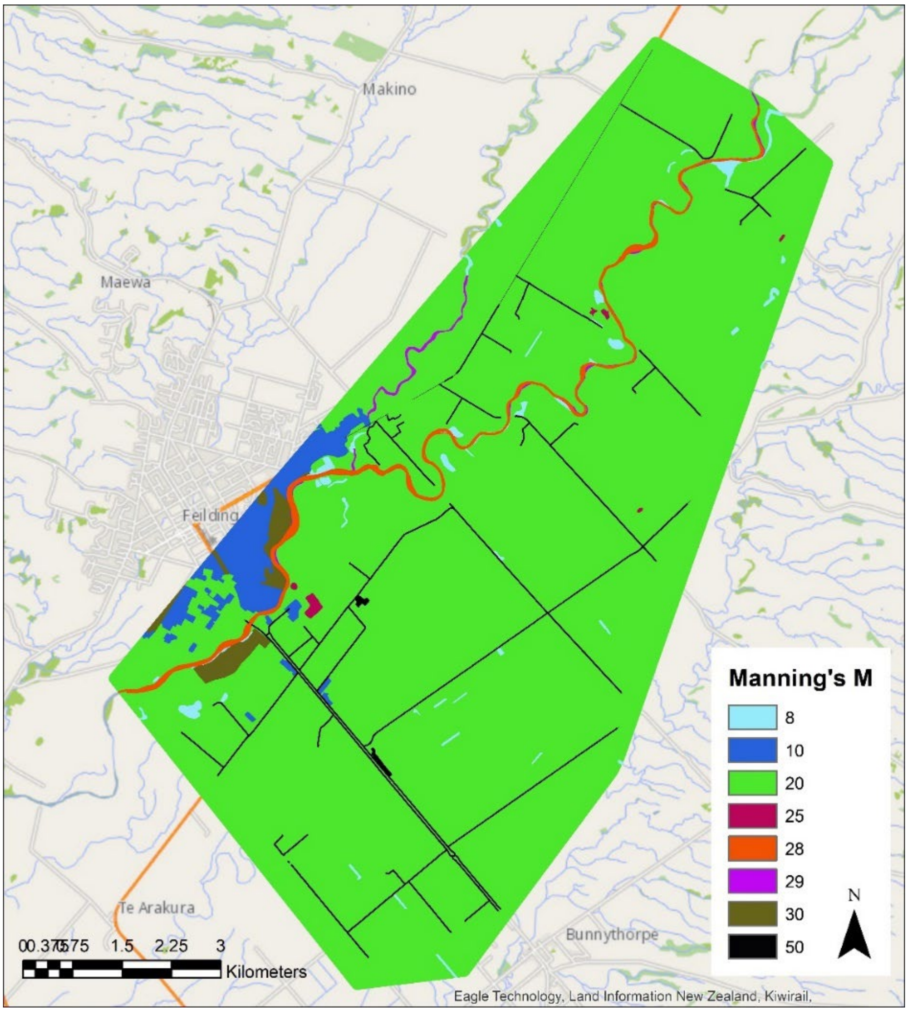

Figure 3-16: Modelled Surface Roughness Across the Hydraulic Domain

3.6 Infiltration

Spatially varying infiltration rates were defined over the model domain based on drainage class from the Fundamental Soil Layer (FSL) and land cover data (Table 3-2 and Figure 3-17).

Table 3-2: Infiltration Parameters per Soil or Land Cover Type

Drainage class	Leakage rate (mm/h)	Source
5 (Well)	2.0	FSL layer
4 (Moderate)	1.5	FSL layer
3 (Imperfect)	1.0	FSL layer
2 (Poor)	0.5	FSL layer
8 (River)	0.1	Land cover
7 (Built-up area)	1.0	Land cover
6 (Roads)	0.0	Land cover

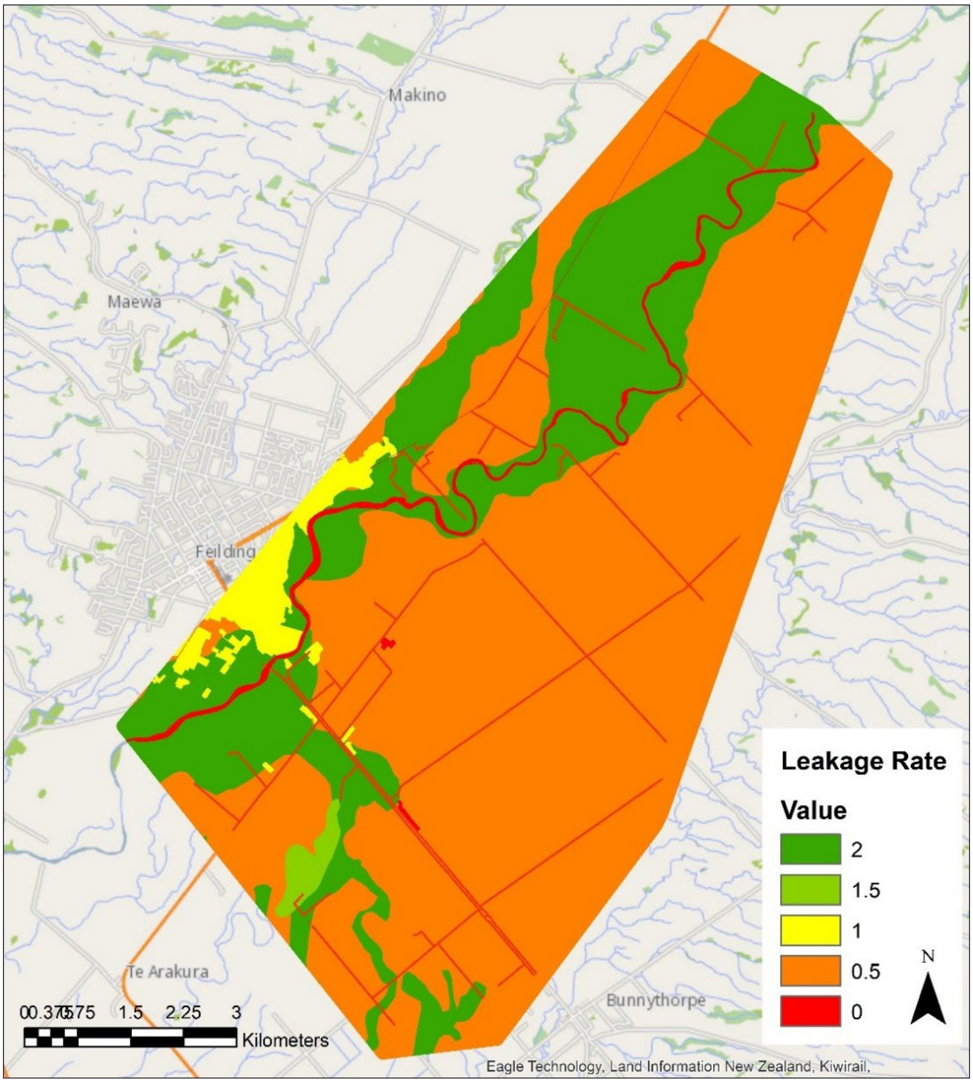

Figure 3-17: Infiltration 'Leakage Rate' (mm/hr) Across the 2D domain

3.7 Boundaries

Boundary data inputs to the flood model comprise the following:

- Rainfall: A precipitation rate hyetograph in mm/day (see Chapter 2.3).
- Inflow hydrographs: Catchment rainfall-runoff model generated hydrographs distributed between 10 adjacent point sources within the riverbed at each of the two inflow locations (Figure 3-18).
- Free Outflow Boundary, with adjacent mesh element elevations lowered by 0.5-1.5m to allow for smooth water egress.
- Closed Boundary.

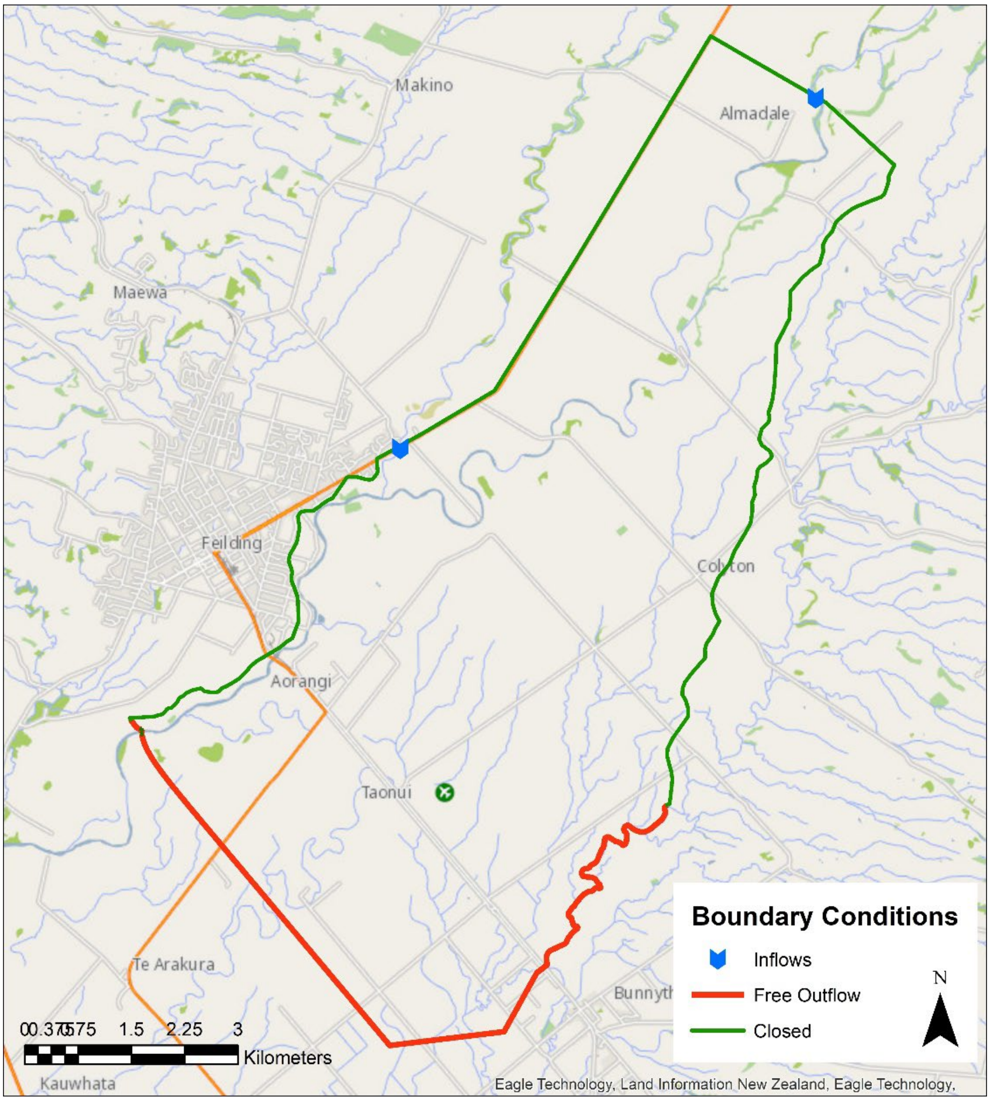

Figure 3-18: Model boundaries

3.8 Computational Parameters

The computational parameters used in the model are summarised in Table 3-3 below. These are typical values, which could be adjusted during model calibration/validation or for improving model stability, as and where required.

Table 3-3: Computational parameters used in the model

Parameter Type	Value
2D model timestep	Max 0.5s, Minimum 0.0001s
1D model and coupling timestep	0.5s
Critical CFL	0.8
Solution technique	Lower Order
Flooding and Drying	5mm and 3mm respectively
Eddy Viscosity	Uniform 0.1m^2/s

4 Calibration/Validation

The hydrological model was calibrated to the two FFA gauge locations (Oroua A/AS and Kiwitea pSRE) for each AEP design event as described in Section 2, adjusting parameters at each modelled AEP event until the peak discharge of the simulated hydrographs approximated the FFA results.

No formal calibration of the hydraulic model was possible due to the lack of appropriate data for such an exercise. Instead, the model has been validated against a set of aerial photographs and satellite imagery taken several days[3] after the February 2004 flood event. This event has been approximated to a 0.5% AEP event in the Oroua River based on peak flows and this design event has been used for the validation process. It should however be noted that the validation therefore does not allow for any blockage of the openings at the Aorangi bridges, there being some evidence of debris blockage occurring, though it is not clear what the condition was at the flood peak. The effects of such additional blockage at these structures would likely be relatively local but it could have a detrimental impact on overtopping of the nearby stopbanks.

For the satellite imagery, a false colour combination of Shortwave Infrared (SWIR), Near infrared (NIR) and Green bands was used to highlight areas of moisture laden sediment debris[4]. Despite the satellite image being taken after most of the ponding had drained away, it was possible to pick out areas of likely former inundation, and these matched reasonably well to modelled inundation along the banks of the Oroua River. An example of such a comparison is provided in Figure 4-1, which focuses on a portion of the Oroua floodplain downstream from Almadale Reserve.

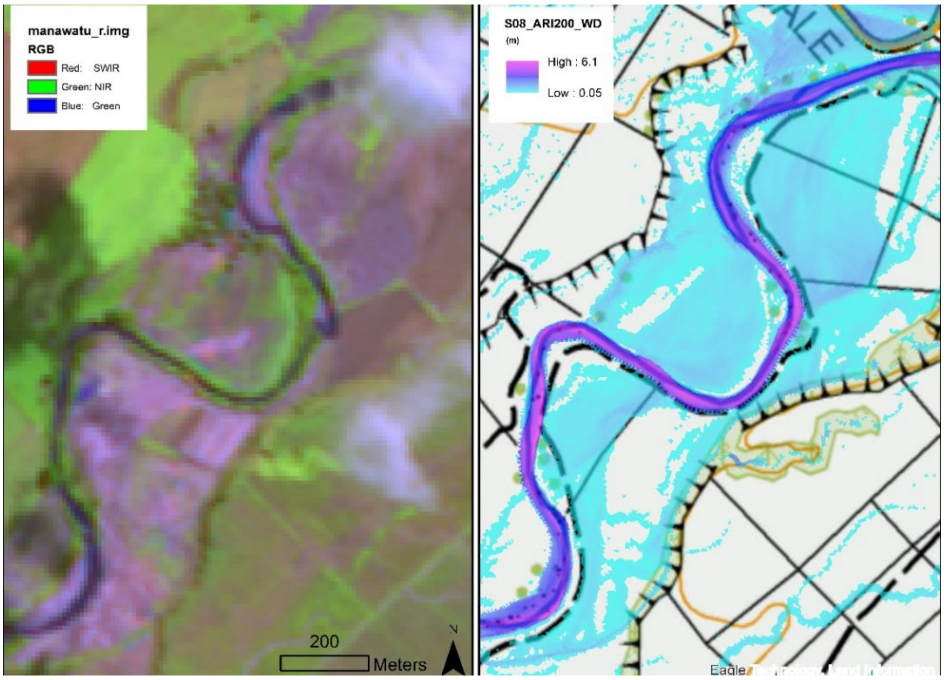

Figure 4-1: Comparison of satellite imagery and modelled water depth downstream of Almadale Reserve

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[3] These images were not provided with timestamps, but are understood to have been captured at least several days after the February 14-19th 2004 flood event (possibly as late as early March), once the majority of ponding had dissipated.
[4] Water absorbs all three of these wavelengths, so appears black. Vegetated areas appear bright green, while moisture laden, muddy ground shows up as purple.

Although the provided aerial images were taken after flood waters had receded, what is apparent in these images are areas of flood scour and mud debris, and it was these that were compared with model results. In Figure 4-2 it is possible to identify debris and scour from overflows from the Oroua River downstream of the Colyton Road Bridge. In Figure 4-3, similar scour can be seen from breakout flows through the southern portion of Timona Park, to the east of Fielding. In Figure 4-4, there are flood traces both adjacent to the main channel, and on overland flow paths cutting across paddocks to the west of the river between Ridds Road and Colyton Road, upstream of Colyton Bridge. In all cases, these residual traces match reasonably closely to the modelled flows in the S08_V07_ORO_HD_ARI200_2D design scenario.

Figure 4-2: Comparison between post-flood aerial photo and model results downstream of Colyton Bridge

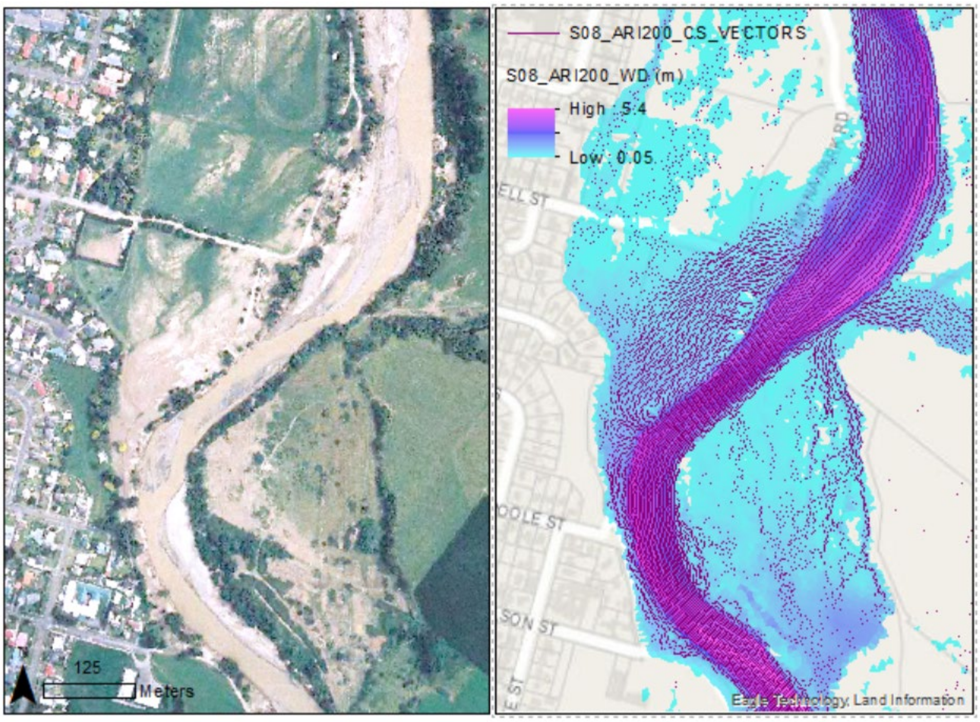

Figure 4-3: Comparison between post-flood aerial photo and model results at Timona Park

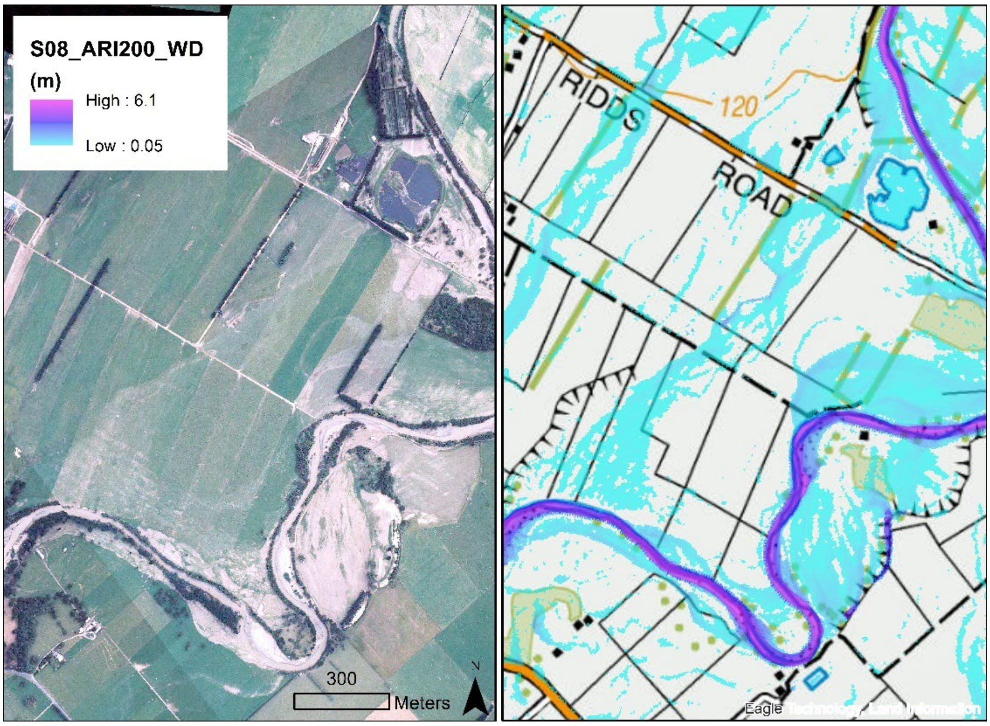

Figure 4-4: Comparison between post-flood aerial photo and model results, looking at breakout flows from the Oroua between Ridds and Colyton Road

5 Design Simulations

The hydrological and hydraulic models described in Chapters 2 and 3 were used to run eight design scenarios; four historic and four with a climate change (cc) factor applied to the design rainfall. Historic design scenarios are run with a 2016 timestamp, which is the final year of rainfall data to be included in the HIRDSv4 model. For the climate change scenarios, HRC selected a time horizon of 2081-2100 and a Relative Concentration Path (RCP) of 6.0 for which to apply the HIRDSv4 rainfall scaling factors. Climate change design scenarios are run with a 2081 timestamp. A list of the scenarios can be found below in Table 5-1.

As described earlier in Section 2, the timing of the rainfall has been taken as consistent across both catchments due the variability within the data sets, these indicating no clear dominant storm direction. If anything this is likely to provide a conservative approach downstream of the confluence of the Oroua and Kiwitea rivers.

Table 5-1: Design Scenarios

Scenario	Title	ARI (yr)	AEP (%)	Type
S01	S01_V07_ORO_HD_ARI25cc_2D	25	4	CC, RCP 6.0
S02	S02_V07_ORO_HD_ARI50cc_2D	50	2	CC, RCP 6.0
S03	S03_V07_ORO_HD_ARI100cc_2D	100	1	CC, RCP 6.0
S04	S04_V07_ORO_HD_ARI200cc_2D	200	0.5	CC, RCP 6.0
S05	S05_V07_ORO_HD_ARI25_2D	25	4	Historic
S06	S06_V07_ORO_HD_ARI50_2D	50	2	Historic
S07	S07_V07_ORO_HD_ARI100_2D	100	1	Historic
S08	S08_V07_ORO_HD_ARI200_2D	200	0.5	Historic

6 Results

6.1 Overview

Results are provided as feature and raster datasets, saved in an individual ESRI geodatabases (*.GDB) for each of the eight scenarios. Each geodatabase has 13 basic items relating to the scenario (Figure 6-1,Table 6-1), and up to two difference maps, comparing results (where relevant) with a one-step smaller ARI event or an associated non-cc scenario.

Name	Type
Dif_V07_ORO_HD_S04_ARI200cc_Vs_S03_ARI100cc_2D_WL	File Geodatabase Raster Dataset
Dif_V07_ORO_HD_S04_ARI200cc_Vs_S08_ARI200_2D_WL	File Geodatabase Raster Dataset
S04_V07_ORO_HD_ARI200cc_2D_CS	File Geodatabase Raster Dataset
S04_V07_ORO_HD_ARI200cc_2D_CS_h0p05	File Geodatabase Raster Dataset
S04_V07_ORO_HD_ARI200cc_2D_Haz	File Geodatabase Raster Dataset
S04_V07_ORO_HD_ARI200cc_2D_Haz_h0p05	File Geodatabase Raster Dataset
S04_V07_ORO_HD_ARI200cc_2D_HAZARD	File Geodatabase Feature Class
S04_V07_ORO_HD_ARI200cc_2D_STS	File Geodatabase Feature Class
S04_V07_ORO_HD_ARI200cc_2D_VECTORS_0440am	File Geodatabase Feature Class
S04_V07_ORO_HD_ARI200cc_2D_WD	File Geodatabase Raster Dataset
S04_V07_ORO_HD_ARI200cc_2D_WD_C100mm	File Geodatabase Feature Class
S04_V07_ORO_HD_ARI200cc_2D_WD_h0p05	File Geodatabase Raster Dataset
S04_V07_ORO_HD_ARI200cc_2D_WL	File Geodatabase Raster Dataset
S04_V07_ORO_HD_ARI200cc_2D_WL_C100mm	File Geodatabase Feature Class
S04_V07_ORO_HD_ARI200cc_2D_WL_h0p05	File Geodatabase Raster Dataset

Figure 6-1: Screenshot of the contents of the S04 geodatabase

Table 6-1: Result Files

File Ending	Data Type	Description
CS	Raster	Maximum Current Speed
CS_h0p05	Raster	Maximum Current Speed, filtered for water depths over 50mm
Haz	Raster	Hazard classification
Haz_h0p05	Raster	Hazard classification, filtered for water depths over 50mm
HAZARD	Polygon	Hazard classification by element
STS	Polygon	Flood statistics by element
VECTORS_0440am	Line	Current direction vectors at a timestamp of four hours and forty minutes into the event
WD	Raster	Maximum Water Depth
WD_C100mm	Line	Water Depth Contours with a 100mm vertical spacing
WD_h0p05	Raster	Maximum Water Depth, filtered for water depths over 50mm
WL	Raster	Maximum Water Level
WL_C100mm	Line	Water Level Contours with a 100mm vertical spacing
WL_h0p05	Raster	Maximum Water Level, filtered for water depths over 50mm

6.2 Current Speed Results

Current Speed results are provided in raster format. Figure 6-2 shows an example (100 year ARI CC event) of what this result looks like for a portion of the domain downstream of Almadale Reserve. The higher velocities, turning yellow/orange above about 2m^3/s, can be seen to generally lie within the centre of the Oroua River channel.

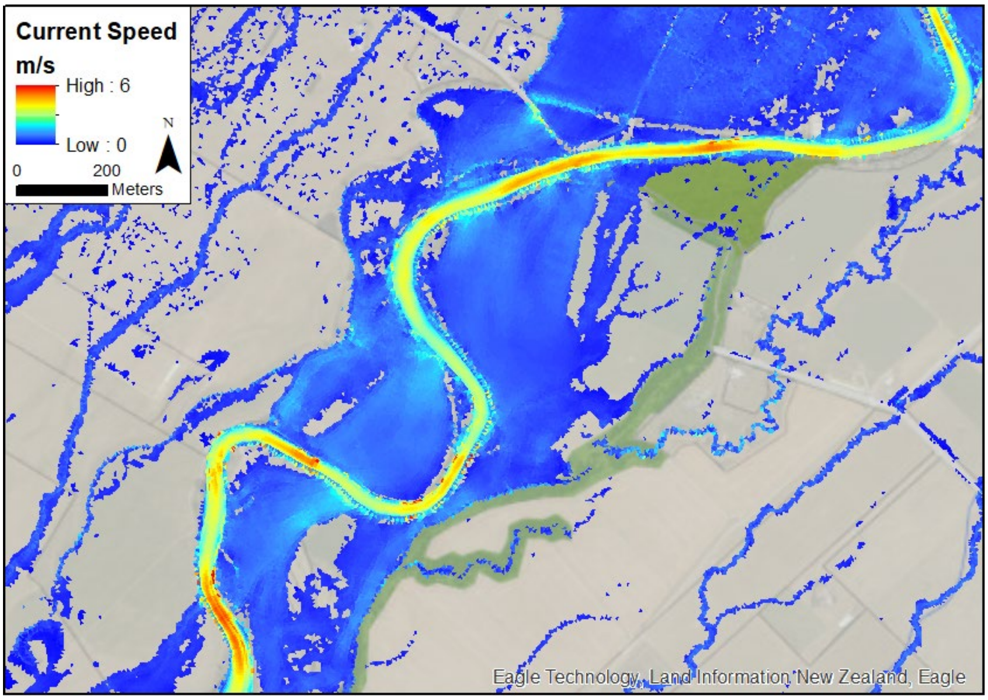

Figure 6-2: Portion of the S03_V07_ORO_HD_ARI100cc_2D_CS_h0p05, SW of Almadale Reserve

6.3 Hazard Results

Hazard across the domain was characterised using the NSW Flood Hazard method (Figure 6-3) and provided by mesh element, and as a raster file. Figure 6-4 shows an example of what this result looks like for a portion of the domain downstream of Almadale Reserve.

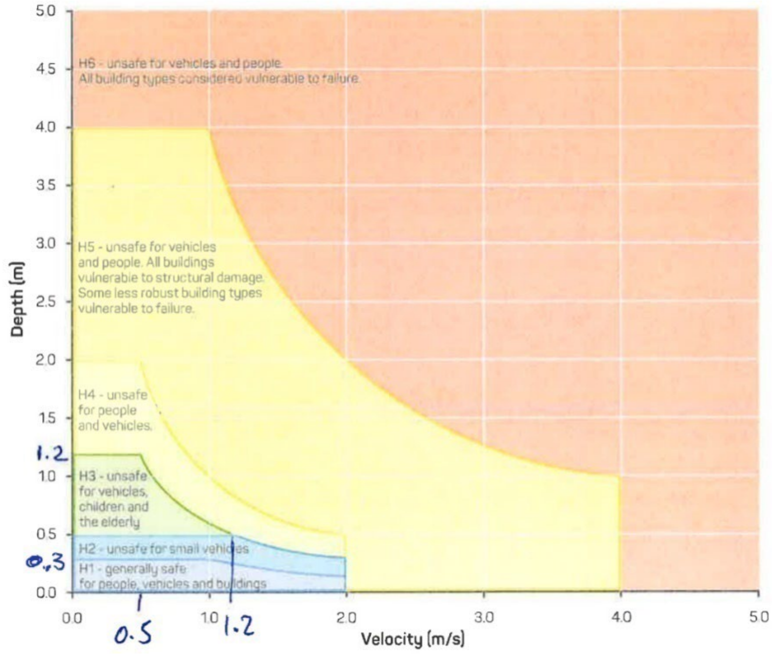

Figure 6-3: NSW Flood Hazard Code delineation

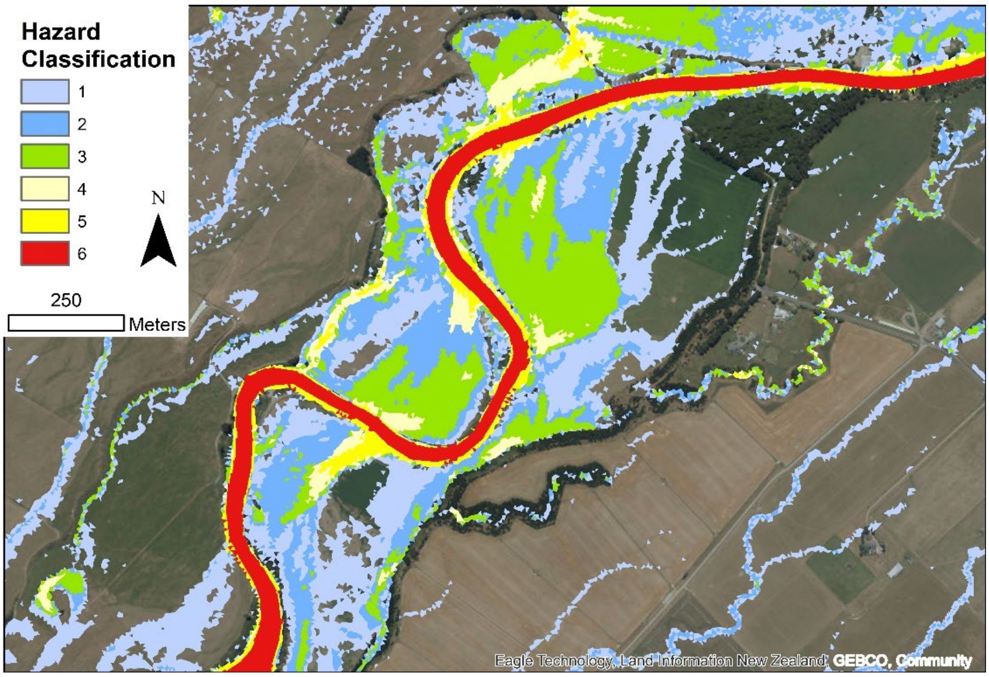

Figure 6-4: Portion of the S03_V07_ORO_HD_ARI100cc_2D_Haz_h0p05 result, SW of Almadale Reserve

6.4 Current Direction Vector Results

Current direction vector results are provided as feature line data, with lengths scaled with magnitude up to a limit of 0.5m/s. An example of how these might be plotted is included in Figure 6-5, which shows flow vectors at, in and around Taonui Stream as it intersects the Campbell Road/Railway/Waughs Road transport corridor. As might be expected, the fastest flows are confined to the stream bed, slower ones to the breakout overland flow paths.

Figure 6-5: Portion of the S03_V07_ORO_HD_ARI100cc_2D_VECTORS _0440am result

6.5 Water Depth Results

Water depth results are provided as both raster and contour datasets. In Figure 6-6, raster data has been plotted used a stretched colour scale in order to demonstrate ponding above the Campbell Road/Railway/Waughs Road transport corridor above the Waughs/Eggletons intersection. Figure 6-7 shows another instance of ponding, this time above the Campbell/Aorangi intersection, making use of both raster and contour data.

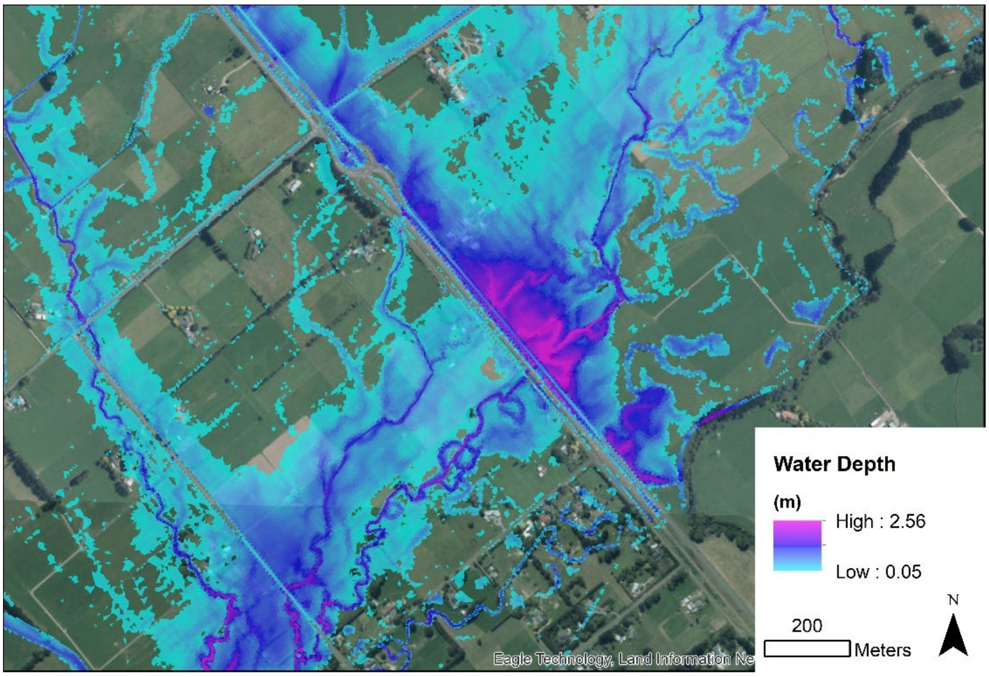

Figure 6-6: Portion of the S03_V07_ORO_HD_ARI100cc_2D_WD_h0p05 result

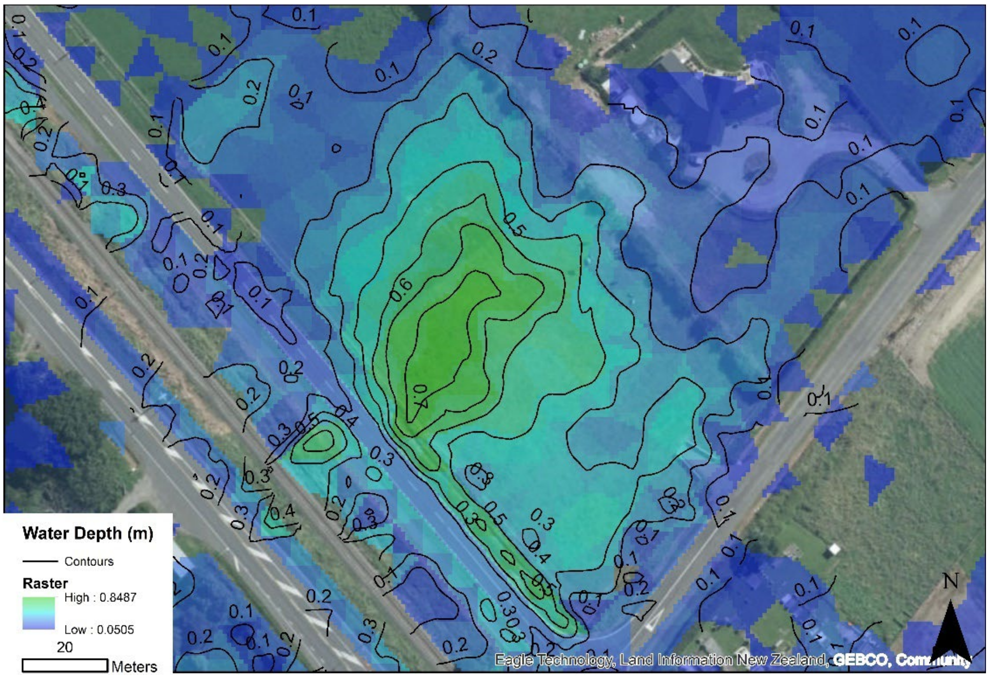

Figure 6-7: Portion of the S03_V07_ORO_HD_ARI100cc_2D_WD_h0p05 and S03_V07_ORO_HD_ARI100cc_2D_WD_C100mm results

6.6 Water Level Results

Water level results are provided as raster results and as a contour dataset. Figure 6-8 gives an example of these data plotted at a domain wide scale.

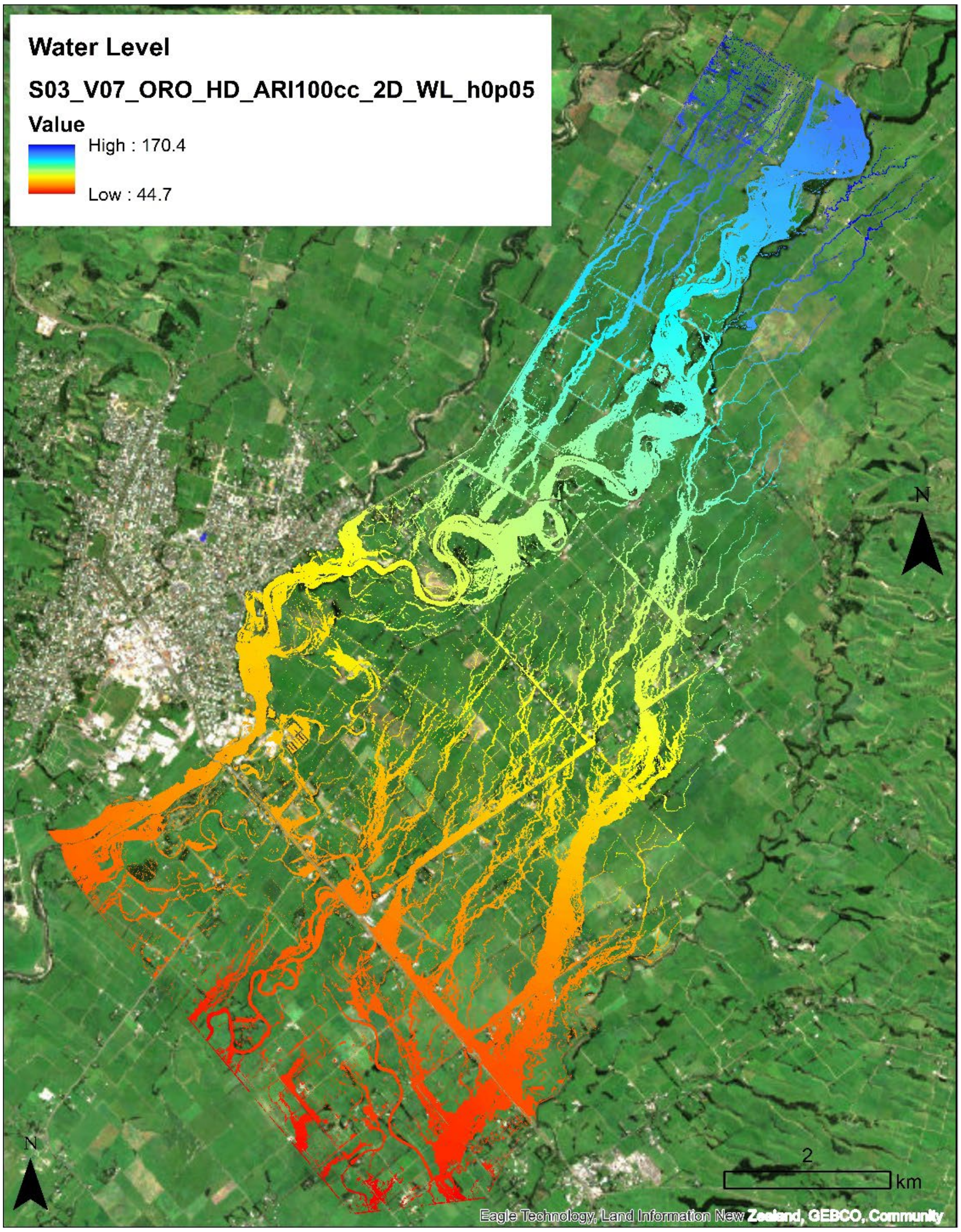

Figure 6-8: Flood mapping for S03_V07_ORO_HD_ARI100cc_2D_WL_h0p05

6.7 Difference Mapping

Difference mapping was conducted for varying ARI and climate conditions as part of our internal QA procedures, and the resultant ten raster's (Figure 6-9) have been included in the accompanying results. Figure 6-10 gives an example of how this might be plotted, in this case showing a section of the Oroua River downstream from Colyton Bridge (visible in the upper right quadrant).

- ☑ Difference_Climate
  - ☐ Dif_V07_ORO_HD_S01_ARI25cc_Vs_S05_ARI25_2D_WL
  - ☐ Dif_V07_ORO_HD_S02_ARI50cc_Vs_S06_ARI50_2D_WL
  - ☐ Dif_V07_ORO_HD_S03_ARI100cc_Vs_S07_ARI100_2D_WL
  - ☐ Dif_V07_ORO_HD_S04_ARI200cc_Vs_S08_ARI200_2D_WL
- ☑ Difference_ARI_FutureClimate
  - ☐ Dif_V07_ORO_HD_S02_ARI50cc_Vs_S01_ARI25cc_2D_WL
  - ☐ Dif_V07_ORO_HD_S03_ARI100cc_Vs_S02_ARI50cc_2D_WL
  - ☐ Dif_V07_ORO_HD_S04_ARI200cc_Vs_S03_ARI100cc_2D_WL
- ☑ Difference_ARI_PresentClimate
  - ☐ Dif_V07_ORO_HD_S06_ARI50_Vs_S05_ARI25_2D_WL
  - ☐ Dif_V07_ORO_HD_S07_ARI100_Vs_S06_ARI50_2D_WL
  - ☐ Dif_V07_ORO_HD_S08_ARI200_Vs_S07_ARI100_2D_WL

Figure 6-9: List of difference results generated

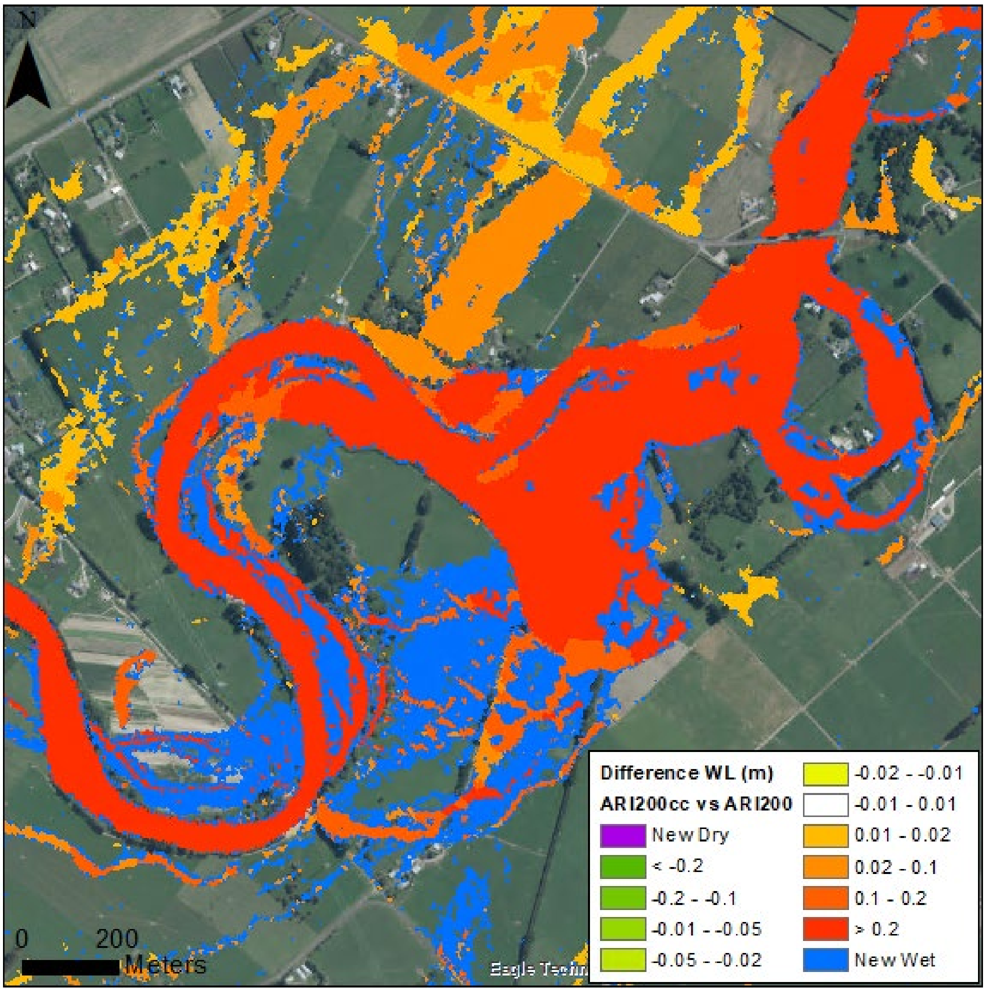

Figure 6-10: Portion of the mapping results for Dif_V07_ORO_HD_S04_ARI200cc_Vs_S08_ARI200_2D_WL

7 Limitations and Assumptions

The following assumptions and limitations were identified during the modelling:

- The hydraulic model was validated against only one flood event (February 2004), for which only photographic and satellite imagery were available. However, peak flood flows for the AEP design events are calibrated to the FFA results at the key gauge locations on the Oroua and Kiwitea rivers. Further calibration of the model would be advisable as and when an appropriate event occurs and if good data and records (e.g. photographic) are available for the process.

- The Aorangi Railway bridge between the town of Fielding and the settlement of Aorangi was not explicitly modelled, due to its proximity to the SH54 road bridge.

- Roughness values have been assigned based on typically accepted values for different land use areas. Some sensitivity testing could be carried out if required.

- Infiltration values have been assigned based on typically accepted values for different soil drainage classes and presence of impervious surfaces. Some sensitivity testing could be carried out if required.

- The downstream boundary at the Manawatu River confluence is considered sufficiently far downstream to not significantly affect the flood flows and levels along the Oroua River. However, some sensitivity testing could be carried out if required.

- No allowances for blockage of structures (e.g. bridges on the main river, culverts on the SH54/rail/road corridor) have been considered. These could potentially worsen conditions during large flood events, particularly along the major road and rail corridor. Sensitivity testing could be carried out if required.

- On the SH54/rail/road corridor, sequential culverts were merged into single structures, conservatively assuming the minimum size/diameter.

- Published streamline vector data (polylines), for example from LINZ, were used to guide the alignment and detail in the mesh, with higher level of detail along streams (25m wide buffer) and roads. When compared to the LiDAR data, some of these streamlines did not line up precisely with the currently observable stream alignments, and so for a few local stream lengths (such as at significant meander bends) the stream bed sat outside the area of increased detail. There is no noticeable effect in the mapping outputs, with the road culverts having by far the most significant impact in terms of holding flow up. The streams are still represented well in the mesh, as intended, just not at the same level of definition in a few areas. This is not expected to have any significant effect for Oroua due to the wide area of floodplain inundated and the culvert effects dominating.

8 Conclusions and Recommendations

The following conclusions can be drawn from the modelling process and results for the Oroua River, Almadale to Downstream of Aorangi Bridge and Adjacent Eastern Rural Area:

- The model has been built and validated as a robust tool for flood predictions of present day and future climate change events. However model calibration would be advisable, should an event with better data become available.

- The potential impact of blockage, both at the main bridge structures across the Oroua River, and at the SH54/rail/road corridor culverts, could be significant and can be explored further using this model should be this be considered useful.

- The Oroua River, the main drainage artery in the study area, is quite an active river channel due to erosion and deposition of the mobile gravel bed, which can result in the riverbed area changing course and/or depth. It will be important to monitor changes within the river system and update the model as and when required.

- The 2D model mesh comprises a total of 1.8M elements, these ranging in size from a minimum of 9 m^2 to a maximum of 65 m^2, averaging an area of 36 m^2. This has been found satisfactory for representing the channel networks and floodplain, and results in reasonable model run times.

- Some sensitivity testing on the model results could be beneficial, for example for:

  - the influence of the downstream boundary assumptions;

  - the impacts of a degree of blockage at bridges/culverts (as noted above);

  - the channel and/or floodplain roughness; and

  - infiltration parameter assumptions.

- Future work could also explore further:

  - the timing of flood peaks from the Oroua and Kiwitea rivers for different flood events;

  - the difficulty of matching the rainfall runoff from the upper Oroua catchment within the Ruahine ranges with the downstream gauged flows, and the potential to improve the understanding of the relationship by installing further gauges there; and

  - infiltration parameter assumptions.

9 References

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