Design Modelling

Lower Mangakahia Catchment (M13)

Northland Regional Council

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1 PROJECT OVERVIEW

Overview

Water Technology was commissioned by Northland Regional Council (NRC) to undertake a region-wide flood modelling study. The study area encompassed the entire Northland Regional Council area which covers an area of over 12,500 km^2, with the exclusion offshore islands. The aim of this project was to map riverine flood hazard zones across the entire Northland region and update existing flood intelligence.

Modelling approach

This project used a 2D Direct Rainfall (also known as Rain on Grid) approach for hydraulic modelling and has provided flood extents for a defined range of design storms. The hydraulic modelling software TUFLOW was used. TUFLOW is a widely used software package suitable for the analysis of flooding. TUFLOW routes overland flow across a topographic surface (2D domain) to create flood extent, depth, velocity and flood hazard outputs that can be used for planning, intelligence and emergency response. The latest release of TUFLOW offers several recent advanced modelling techniques to improve modelling accuracy which where practical, were tested and adopted in this project.

This study delineated and modelled 19 catchments, shown in Figure 1-1. To validate the adopted methodology and model parameters used in the design modelling, 10 catchments were calibrated against recent (and historic) flood events. The calibration/validation methodology is documented in a standalone report *NRC Riverine Flood Mapping - Calibration Report – R01* and is referred to throughout this document as the *Calibration Report*.

This report documents the design modelling methodology for Lower Mangakahia Catchment (M13), noting that this catchment was calibrated to the January 2011 flood event.

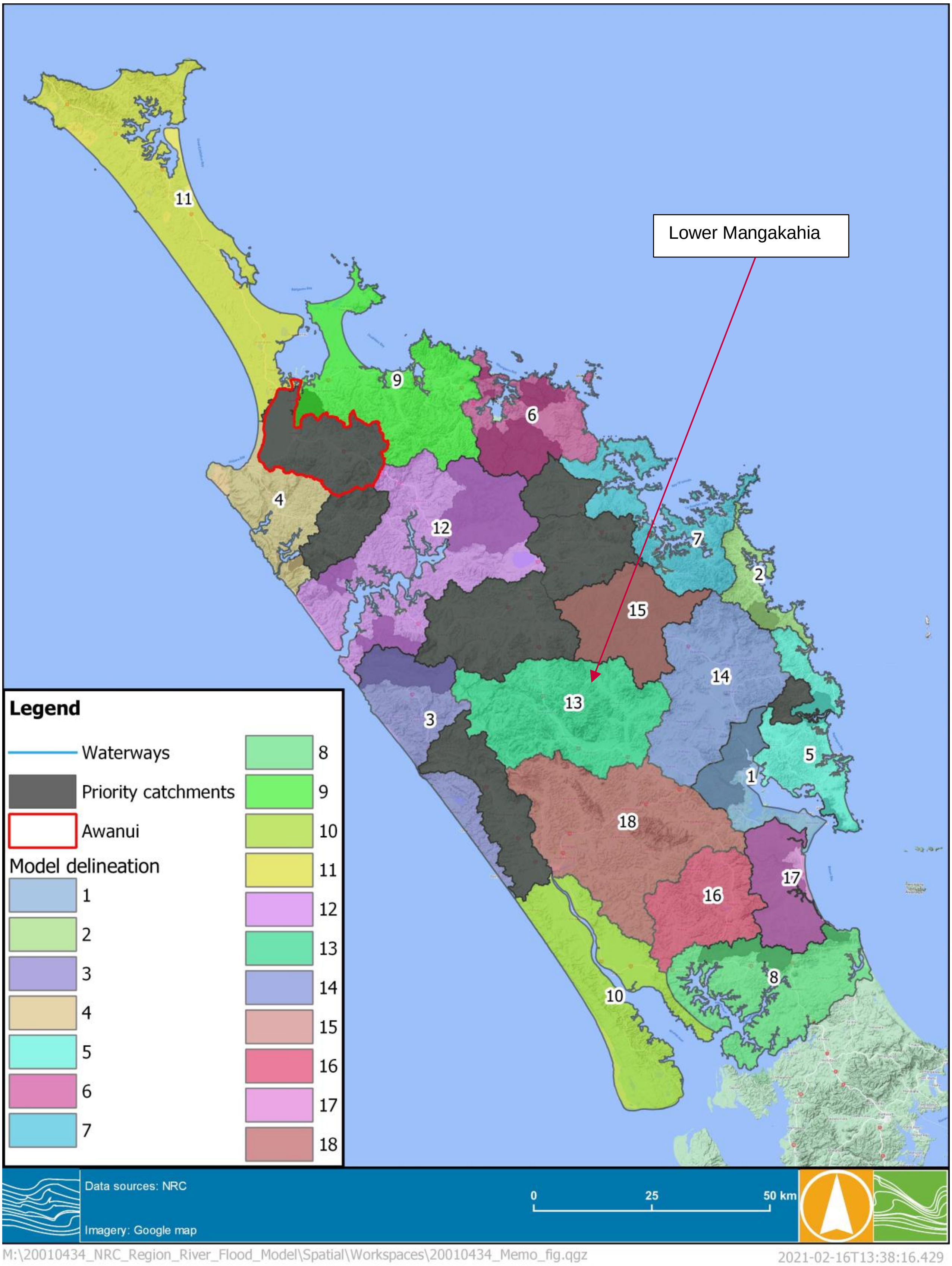

FIGURE 1-1 MODEL DELINEATION

2 STUDY AREA

The model 13 catchment is mountainous and consists of the Hikurangi and Lower Mangakahia River catchments, covering a total area of approximately 810 km^2 and several small towns, such as Pakotai, Parakao and Titoki. The Hikurangi River and Mangakahia River are two major waterways within the catchment. The Mangakahia River is fed by the Awarua River and other upstream tributaries. It runs from west to east while The Hikurangi River runs from north to south, joining the Mangakahia River just upstream of Titoki. Figure 2-1 displays the study area of the catchment model 13.

FIGURE 2-1 STUDY AREA

3 DESIGN MODELLING

3.1 Overview

A hydraulic model (TUFLOW) of the Lower Mangakahia catchment (M13) was constructed to model overland flooding. A range of storm durations were run and results for each Annual Exceedance Probability (AEP) event were enveloped to ensure the critical duration was well represented across each part of the study area. The merged results captured the maximum flood level and depth of the range of design event durations modelled.

Table 3-1 and the following sections detail the key modelling information used in the development of the hydraulic model.

TABLE 3-1 KEY MODELLING INFORMATION

Terrain data	NRC 1m LiDAR without filling of sinks but includes the "burning of creek alignments' through embankments
Model type	Direct rainfall model
Model build	Build: 2020-10-AA-iSP-w64
Rainfall	See Sections 3.2.1 and 3.2.2
Losses	See Section 0
Boundaries	See Section 3.2.4
Modelling solution scheme	TUFLOW HPC (adaptive timestep)
Modelling hardware	GPU
Modelling technique	Sub-grid-sampling (SGS)
Model grid size	10m with 1m SGS

3.2 Model Parameters

A range of model parameters were adopted, based on the calibration of Lower Mangakahia catchment. Details of these are outlined below.

3.2.1 Rainfall Intensity-Duration-Frequency

Design rainfall totals for durations from 10 minute up to 120 hours were developed for design modelling. This was undertaken at 179 rainfall gauge sites across the wider study area. These Intensity-Duration-Frequency (IDF) tables were developed by NIWA through the High Intensity Rainfall Design System (HIRDSV4)[1]. A range of magnitude events from 1 in 1.58 ARI through to 1 in 250 ARI along with climate change predictions (Regional Concentration Pathway 4.6, 6 & 8.5) up to 2100. For this catchment, 10 rainfall gauges were used with a spatially weighted grid of rainfall totals created for design modelling. Figure 3-1 shows the 12-hour cumulative rainfall grid for the 1% AEP event along with the rainfall gauge locations used to create the grid.

[1] Accessed via https://hirds.niwa.co.nz/

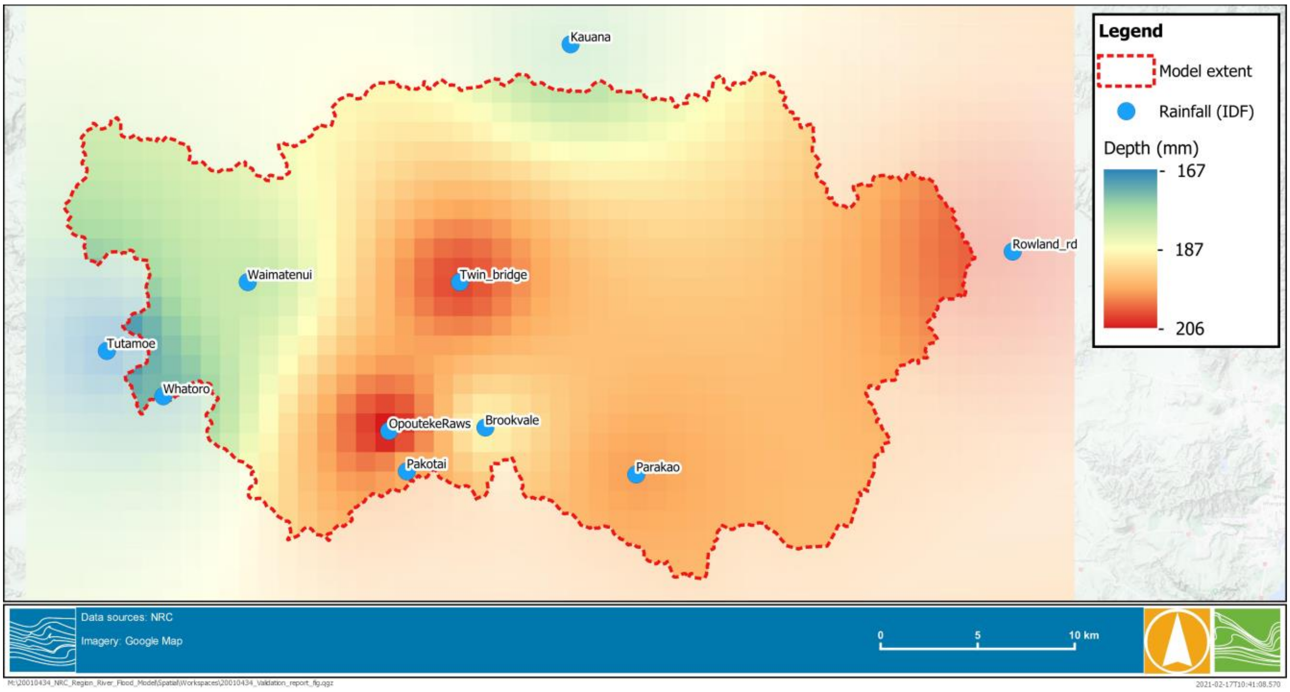

FIGURE 3-1 EXAMPLE OF DESIGN RAINFALL GRID (12-HOUR, 1% AEP RAINFALL) FOR M13

3.2.2 Design Rainfall Temporal Patterns

Design temporal patterns (rainfall hyetographs) were provided by NRC for design modelling. These were developed as part of a previous project undertaken by Macky & Shamseldin (2020)[2]. The project aimed to provide multiple design hyetographs and a better representation of rainfall variability across the Northland region, replacing the single set of design hyetographs previously developed.

The HIRDS design temporal pattern is recommended for design modelling of Northland catchments[2]. Hence, the design hyetographs for the rainfall gauges were developed using the rainfall IFD data at available rainfall gauges for the catchment. Although a 12-hour hyetograph is suitable for design modelling for most Northland catchments as suggested[2], a range of durations were selected; including 1-hour, 6-hour, 12-hour and 24-hour for each design event, including 10%, 2% and 1% AEP events to ensure that the event critical duration was identified across the catchment. The shorter durations were critical in the upper parts of the catchment, while the longer 24-hour durations were critical in the lower catchment, where flood volumes can be critical factor in generating peak flood levels.

Table 3-2 summarises the 1% AEP rainfall depth for different event durations at each rainfall gauge and Figure 3-2 shows the design rainfall temporal patterns across different gauges for the 12-hour duration event. Considering a single temporal pattern is assigned (i.e. HIRDS hyetograph), the amount of rainfall applied during a design event is generally consistent (varies by +/- 10%) across the catchment area.

[2] Macky & Shamseldin (2020) - Northland Region-wide Hyetograph review

TABLE 3-2 1% AEP DESIGN RAINFALL DEPTH

Gauge location	1% AEP (mm)			
	1-hour	6-hour	12-hour	24-hour
Glenmont_Pakotai_A53781	57	133	178	231
Kauana_Downs_A53591	66	152	197	247
Mangakahia at Twin Bridges_536816	55	129	170	218
Okarika at Rowland Road_546216	65	136	172	211
Opouteke at Brookvale_536812	60	141	186	238
Opouteke_Raws_O00854	53	124	167	216
Parakao_A53791	57	133	176	226
Waima at Tutamoe_536613	61	149	206	276
Waimatenui2_A53672	58	143	193	252
Whatoro_A53661	63	150	200	259

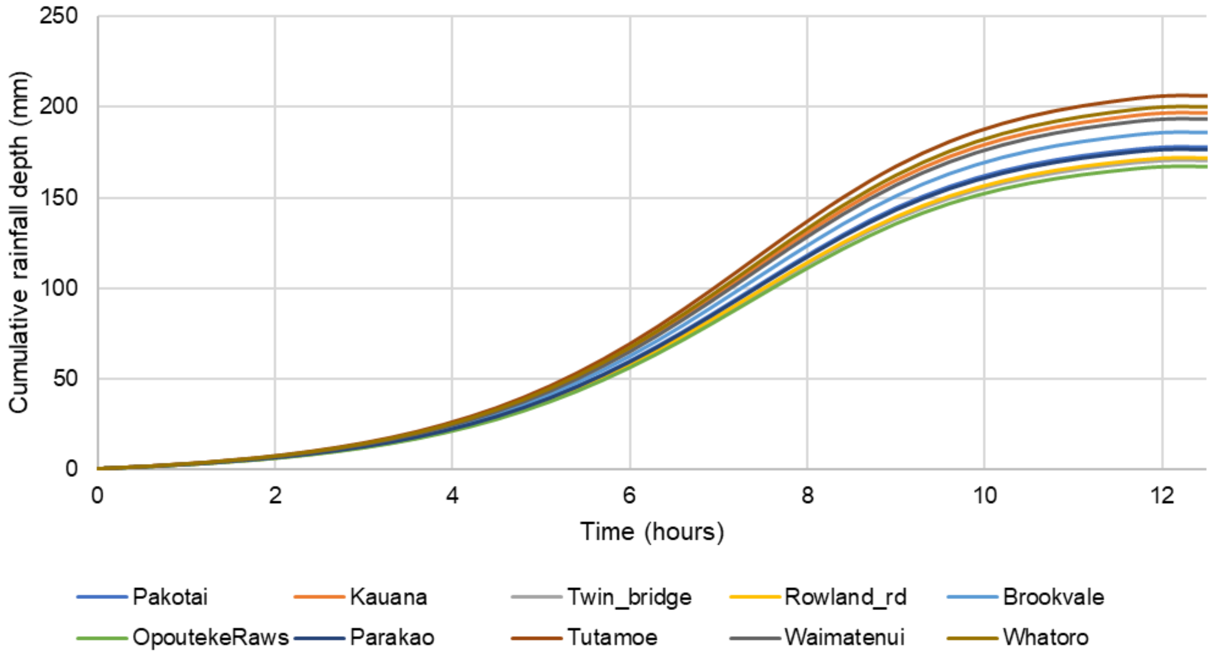

FIGURE 3-2 TEMPORAL PATTERN FOR DESIGN RAINFALL OF 12-HOUR, 1% AEP EVENT

A climate change scenario (for the 1% AEP events) was modelled for the 2081-2100 timeframe, for the RCP 8.5.

3.2.3 Losses

A series of land use types and importantly hydrological areas, were assigned a Manning's "*n*" (surface roughness), initial loss and a continuing loss. Table 3-3 summarises the adopted roughness and loss parameters. It should be noted these parameters were calibrated to a historic event where streamflow gauges were present within the catchment. Figure 3-3 displays the roughness layer based on the land use type, showing most land use is forest and grassland.

TABLE 3-3 DESIGN MODEL PARAMETERS

Hydrological areas	Land use types	Manning's n	Initial loss (IL) – mm	Continuing loss (CL) – mm/hr
Eastern catchment	Forest	0.12	50	6
	Grassland	0.10	50	6
Western catchment	Forest	0.10	55	7
	Grassland	0.08	55	7
Entire M13 catchment	Cropland – perennial	0.04	20	2
	Cropland – annual	0.04	20	2
	Wetland – open water	0.04	0	0
	Wetland – vegetated	0.05	10	1
	Urban areas	0.10	5	1.5
	Waterways	0.065	0	0
	Other	0.06	15	1.5

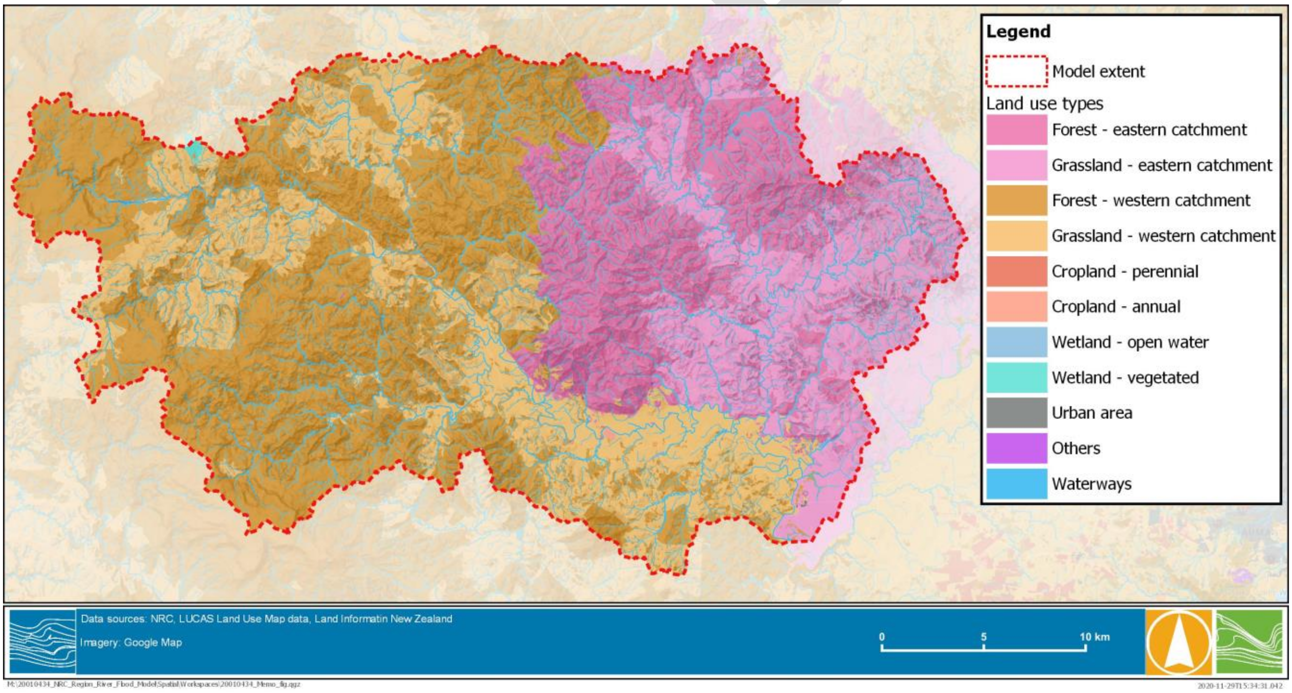

FIGURE 3-3 HYDRAULIC MODEL MATERIAL LAYER

3.2.4 Boundaries

As the Lower Mangakahia catchment is an inland catchment, a stage-discharge (i.e. type HQ) outflow boundary based on the catchment slope was applied at the downstream of the Titoki Bridge streamflow gauge (as per the Calibration Report). There is no upstream inflow coming from upstream catchments applied in this catchment model.

4 MODELLING RESULTS

4.1 Modelled Result Processing/Filtering

Design modelling consisted of running the model for four storm durations (1-hour, 6-hour, 12-hour and 24-hour) with the results enveloped for each design event (i.e. 1%, 2% and 10% AEP) to ensure the critical duration was well represented across each part of the catchment. Each model run produced gridded results, including depth, water surface elevation (WSE), hazard (Z0) and velocity. Several post-processing steps were required to produce the final design modelling outputs. These are described as follows:

Step 1:

- The modelling results are firstly merged to produce the maximum outputs of the range of storm durations modelled. For example, the maximum 1% AEP flood depth is produced by merging the results of 4 different duration runs.

Step 2:

- The maximum gridded results are then remapped to a finer DEM grid using the 5-m LiDAR data. This allows the flood extent to be more accurately displayed on the map and the higher resolution gridded results (i.e. same resolution as the 5-m DEM) to be produced.

Step 3:

- Finally, the remapped results are post-processed by filtering depths below 200mm and puddle areas less than 2000m^2.

Figure 4-1, Figure 4-2 and Figure 4-3 respectively show the final post-processed flood depths, velocity and hazard of the 1% AEP design event modelled for M13. It is noted that the hazard classification is based on the following criteria:

TABLE 4-1 FLOOD HAZARD CLASSIFICATION

Hazard classification	Hazard – VxD (m^2/s)
Low	< 0.2
Low to Moderate	0.2 to 0.4
Moderate	0.4 to 0.6
Moderate to High	0.6 to 0.84
High	> 0.84

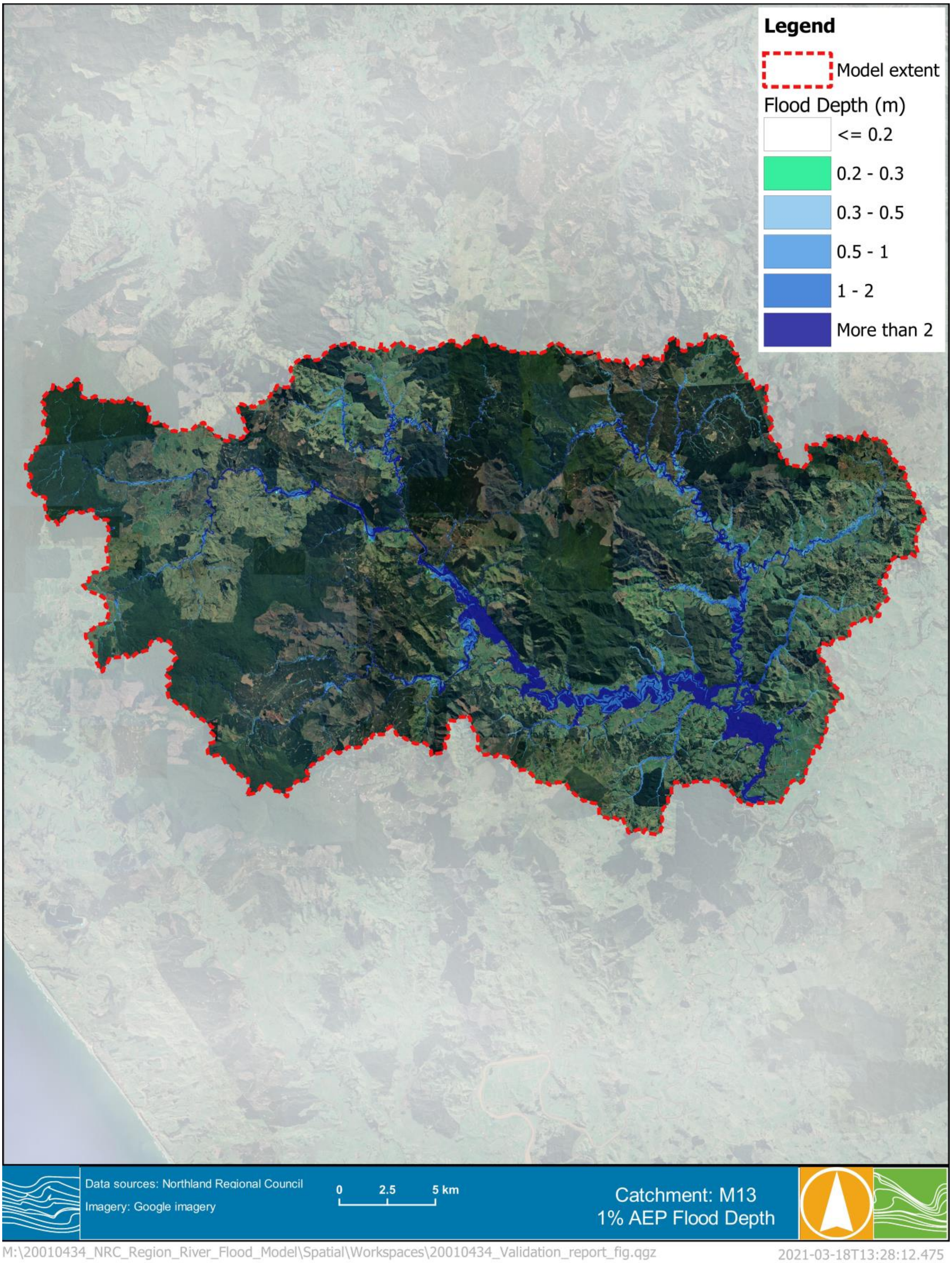

FIGURE 4-1 DESIGN MODELLING OF 1% AEP FLOOD DEPTH

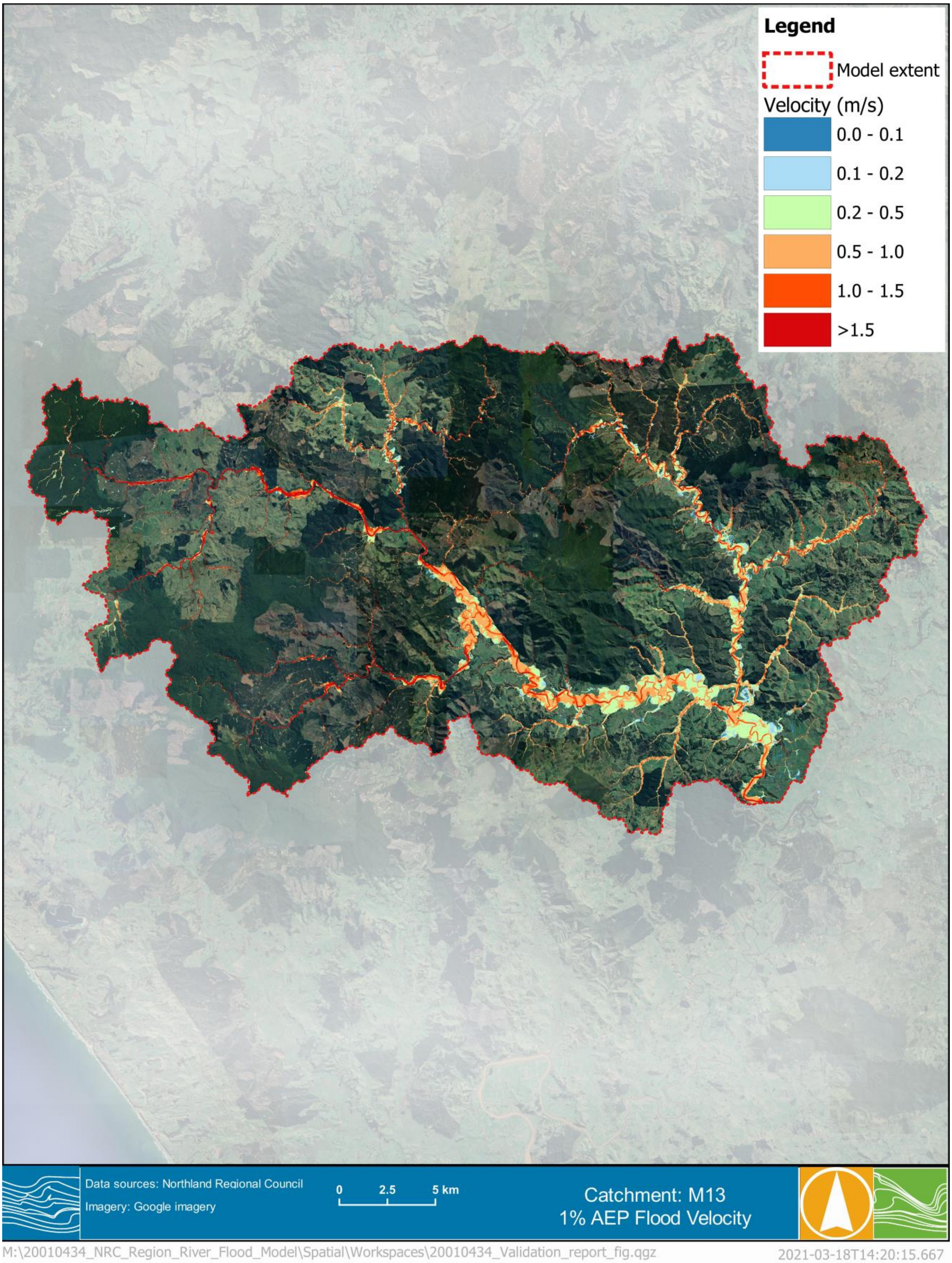

FIGURE 4-2 DESIGN MODELLING OF 1% AEP FLOOD VELOCITY

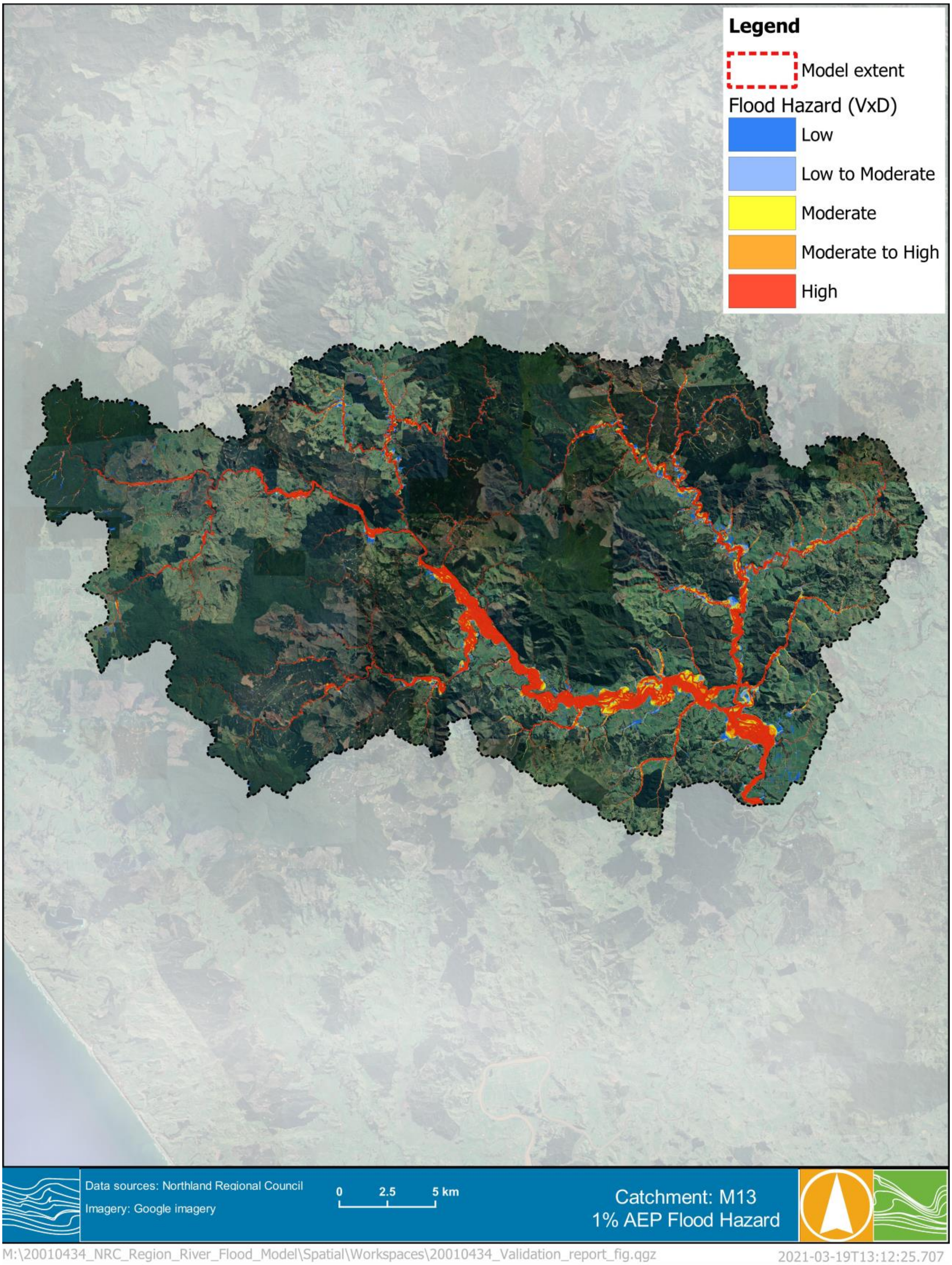

FIGURE 4-3 DESIGN MODELLING OF 1% AEP FLOOD HAZARD

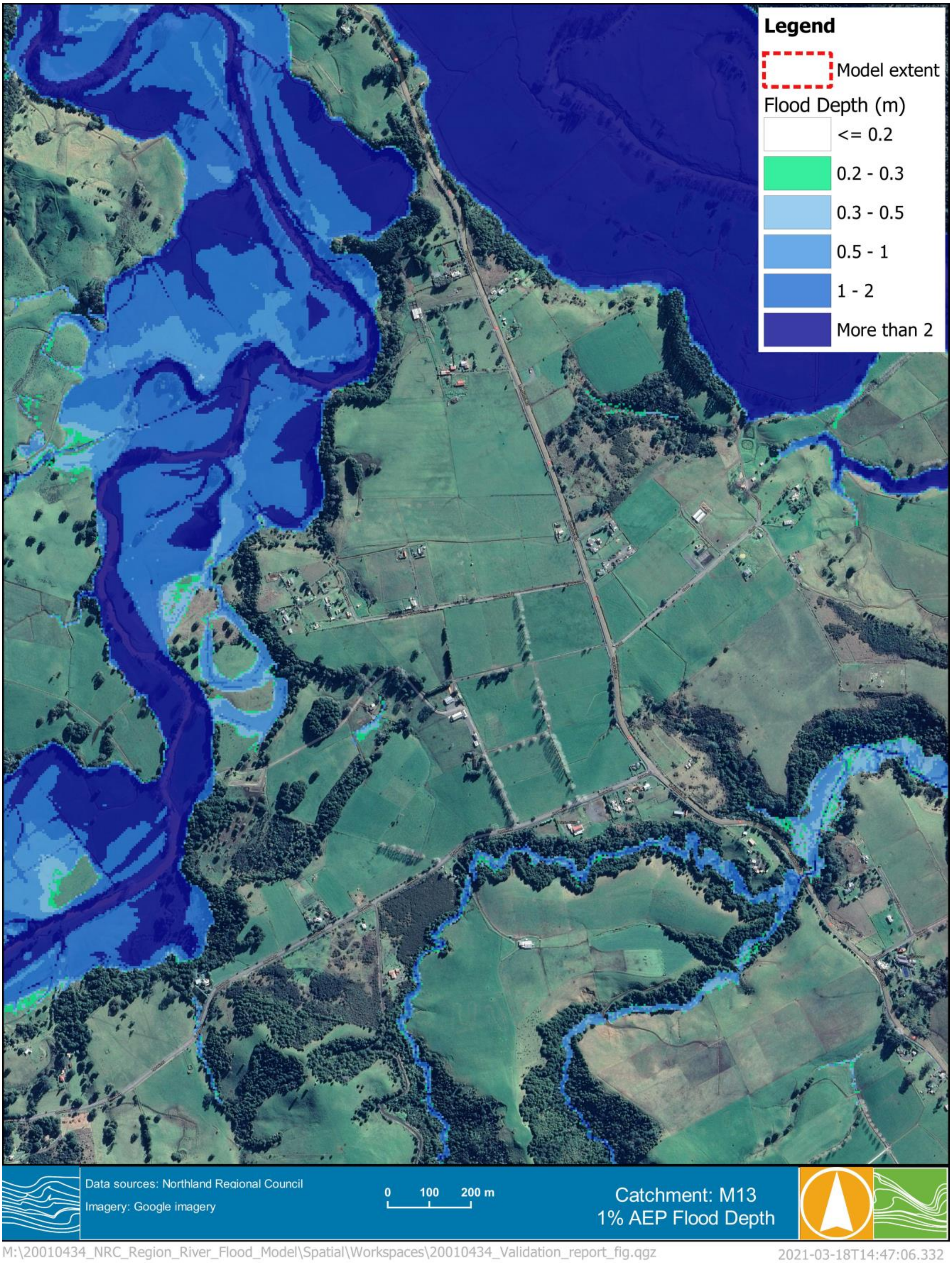

FIGURE 4-4 DESIGN MODELLING OF 1% AEP FLOOD DEPTH AT PAKOTAI

5 VERIFICATION OF DESIGN FLOWS

Flow lines were included at gauge locations in the hydraulic model as 2D Plot Output (2D PO) for calibration and design events. This allows flow hydrographs and peak flows to be extracted at these locations. Figure 5-1 displays the location of streamflow gauges in the Lower Mangakahia catchment.

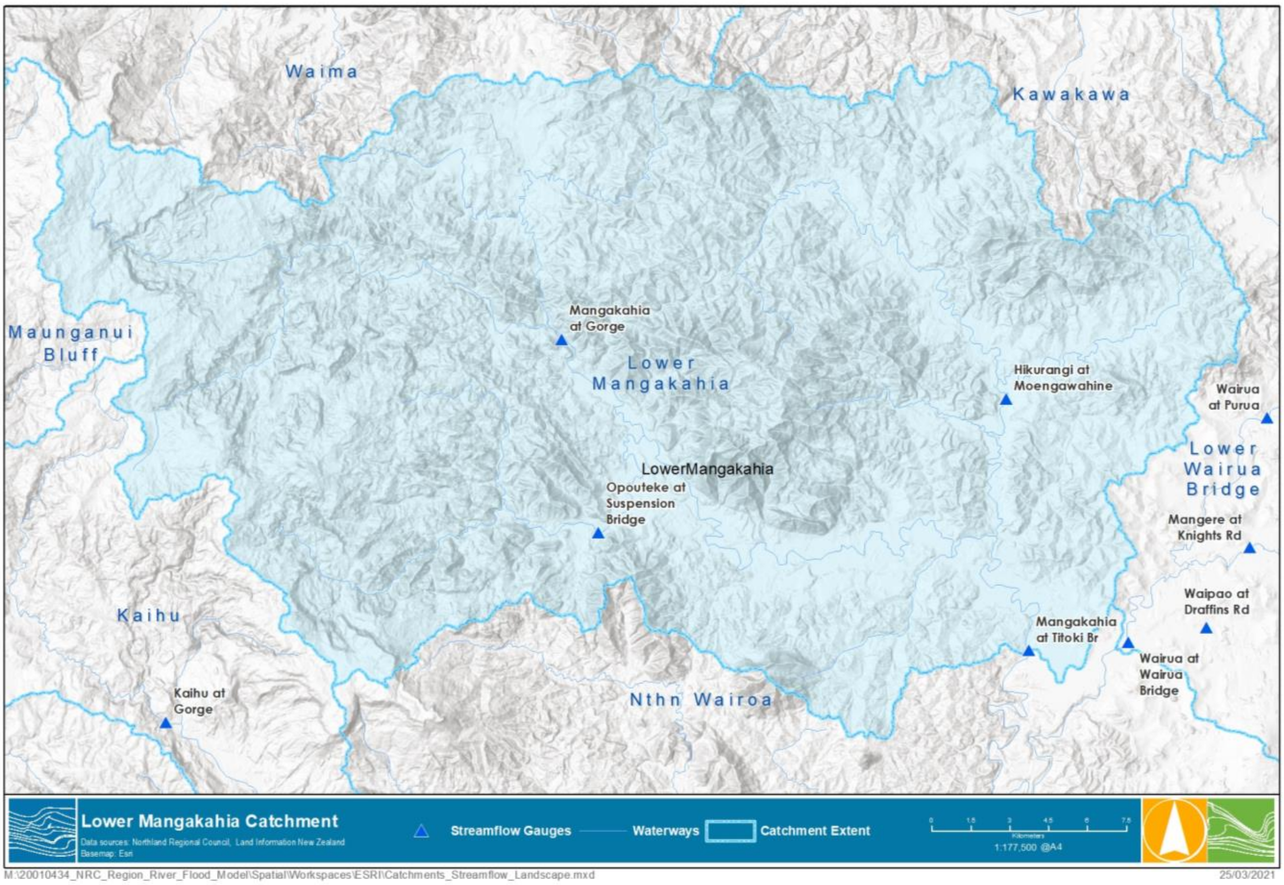

FIGURE 5-1 AVAILABLE STREAMFLOW GAUGES WITHIN LOWER MANGAKAHIA CATCHMENT

The modelled peak flow for the 1% AEP design flood was compared with hydrological estimates, including FFA, rational method, SCS method and the Mean Annual Flow method, as well as observations from 2011 and historic maxima from streamflow gauge records.

5.1 Flood Frequency Analysis

A Flood Frequency Analysis (FFA) was undertaken for streamflow gauging stations with at least 25 years of record. The length of record for can affect the reliability of the FFA especially for the estimation of major flood events (e.g. 1% AEP). The design flow estimates provided additional verification against the design hydraulic modelling results. The streamflow gauging stations that were selected for FFA and the corresponding 1% AEP flow estimates can be found in the Calibration Report (R01).

The annual series (maximum streamflow values for each year of gauge record) were calculated and input into FLIKE. FLIKE is a software package used for FFA and provides five different probability distributions for fitting the historical records. Log Pearson III distribution is commonly used across New Zealand and south east Australia to fit streamflow records and was used for all gauges within the study area. The FFA results showed that the probability distribution had a relatively good fit at all stations.

An example flood frequency curve fitting the annual maximum streamflow values with the Log Pearson III distribution is shown in Figure 5-2. The design curve generated by the probability distribution shows a good fit with the historic records in more frequent events (i.e. 1 in 10 year or more frequent) but may slightly overestimate the design flows for rare events (e.g. 1% AEP flow). The flattening of the historic points may also suggest limitations with the current rating curves. Overall, the design curve shows a good fit with the tight confidence intervals indicating low uncertainty within these estimates.

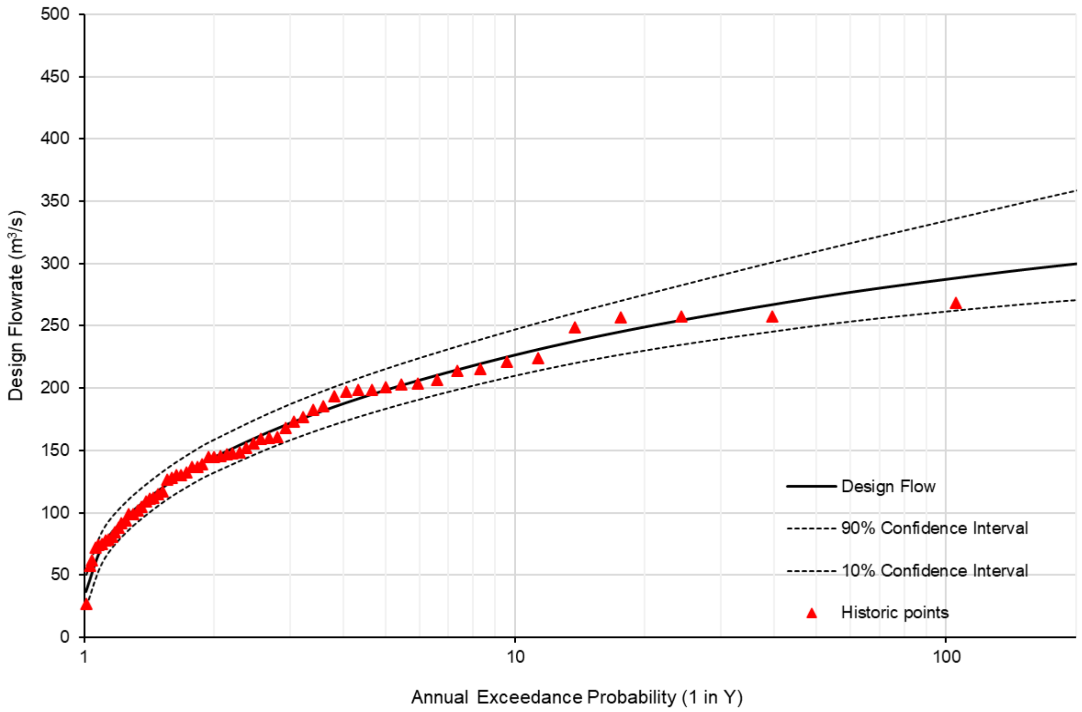

FIGURE 5-2 EXAMPLE OF FLOOD FREQUENCY CURVE OF LOG PEARSON III DISTRIBUTION FIT

5.2 Regional Estimation Methods

For catchments where a suitable streamflow gauge record was not available, additional estimation methods based were used to provide design flow verification. These methods are based on empirical estimations using catchment area and design rainfall totals to verify design flows. These methods were checked for each streamflow gauge location within the study area and are described below.

5.2.1 NIWA New Zealand River Flood Statistics Portal

The New Zealand River Flood Statistics portal[3] provides peak flood estimation at streamflow gauging stations and the entire river system in New Zealand completed in 2018. The design estimates can be extracted from the portal are:

- Flood Frequency estimates (at flow gauge).
- Flood Frequency estimates, noted as Henderson & Collins 2018 (at river reach).
- Rational Method HIRDS V3 (at river reach).

[3] NIWA Flood Frequency tool, accessed via: https://niwa.co.nz/natural-hazards/hazards/floods

The flood frequency estimates given by the portal are determined using the Mean Annual Flow method developed by Henderson & Collins (2018)[4].

5.2.2 SCS method

The Soil Conservation Service (SCS) method, first developed by the U.S. Department of Agriculture's Soil Conservation Service, calculates peak flood flow based on rainfall and land-cover-related parameters. It is the recommended method for stormwater design in the Auckland region, providing a useful comparison. The peak flow equation is:

$$Q = (P - Ia)^2 / (P - Ia + S)$$

where:

- Q is run-off depth (millimetres)..
- P is rainfall depth (millimetres)
- S is the potential maximum retention after run-off begins (millimetres).
- Ia is initial abstraction (millimetres), which is 5 millimetres for permeable areas and zero otherwise.

The retention parameter S (measured in millimetres) is related to catchment characteristics through:

$$S = (1000/CN - 10)\ 25.4.$$

The value of the curve number (CN) represents the run-off from 0 (no run-off) to 100 (full run-off) and it is influenced by soil group and land use. A CN value of 50 was used for the SCS estimation of this catchment.

The run-off depth (Q) is then converted to a peak flow rate using the SCS unit hydrograph.

5.2.3 Rational Method

The Rational Method is widely used across both New Zealand and Australia. The equation is based on catchment area and design rainfall. The equation is:

$$Q = C\ i\ A\ /3.6$$

where:

- Q is the estimate of the peak design discharge in cubic meters per second
- C is the run-off coefficient
- i is rainfall intensity in mm/hr hour, for the time of concentration
- A is the catchment area in km^2.

[4]Henderson, R.D., Collins, D.B.G., Doyle, M., Watson, J. (2018) *Regional Flood Estimation Tool for New Zealand Final Report Part 2*. NIWA Client Report

5.3 Verification Results

Table 5-1 summarises the comparison of 1% AEP peak flow estimates with the modelled values at streamflow gauging stations in the Lower Mangakahia catchment and the differences between the estimation methods and modelled results can be visualised in Figure 5-3.

The Rational Method and the SCS method across all the locations tend to underestimate the design flows when comparing with the others. It is noted that both these methods are only applicable for relatively small catchments, with the SCS method limited to 12 km². The catchment sizes for the four gauge locations within this study area range from 100 -800 km^2. These equations are also subject to great uncertainty in summarising catchment characteristics.

At the Mangakahia at Gorge gauge, the modelled design flow has a good match to the two flood frequency estimates. This gauge has around 60 years of records available, making the FFA estimate of relatively high reliability. The modelled flows at the Opouteke Suspension Bridge gauge and Hikurangi at Moengawahine gauge tend to overestimate the estimated design flows. In contrast, the modelled peak flow at the Mangakahia at Titoki Bridge gauge is lower than the FFA estimate slightly lower than the January 2011 flood. Overall, the modelled peak flows at the four gauge locations tend to sit within a reasonable range of design flow estimates.

The use of empirical method estimations provideed an additional degree of verification for streamflow gauges with less than 25 years of record. It is also noted that the calibration process identified uncertainty with the streamflow records for high flows. The uncertainty of high flow extrapolation at these gauges could result in further uncertainty of flow estimate methods that rely solely on streamflow gauge data.

TABLE 5-1 SUMMARY OF 1% AEP PEAK FLOW COMPARISON

Gauge location	Hydraulic model (m^3/s)		Records at gauge (m^3/s)		Empirical estimates (m^3/s)			NIWA Flood Frequency Tool 2018 (m^3/s)		
	Critical duration	Modelled peak	Jan 2011 peak	Highest on record	FFA	SCS	Rational method	NIWA – FF at gauge	NIWA – Rational method	NIWA – H&C 2018
Mangakahia at Gorge	12hr	1225	953	1174	1125	418	291	1298	N/A	846
Opouteke at Suspension Bridge	6hr	764	313	507	595	259	206	572		512
Hikurangi at Moengawahine	12hr	644	349	349	372	338	230	418		447
Mangakahia at Titoki Bridge	24hr	1281	1369	1369	1585	1069	626	1498		1778

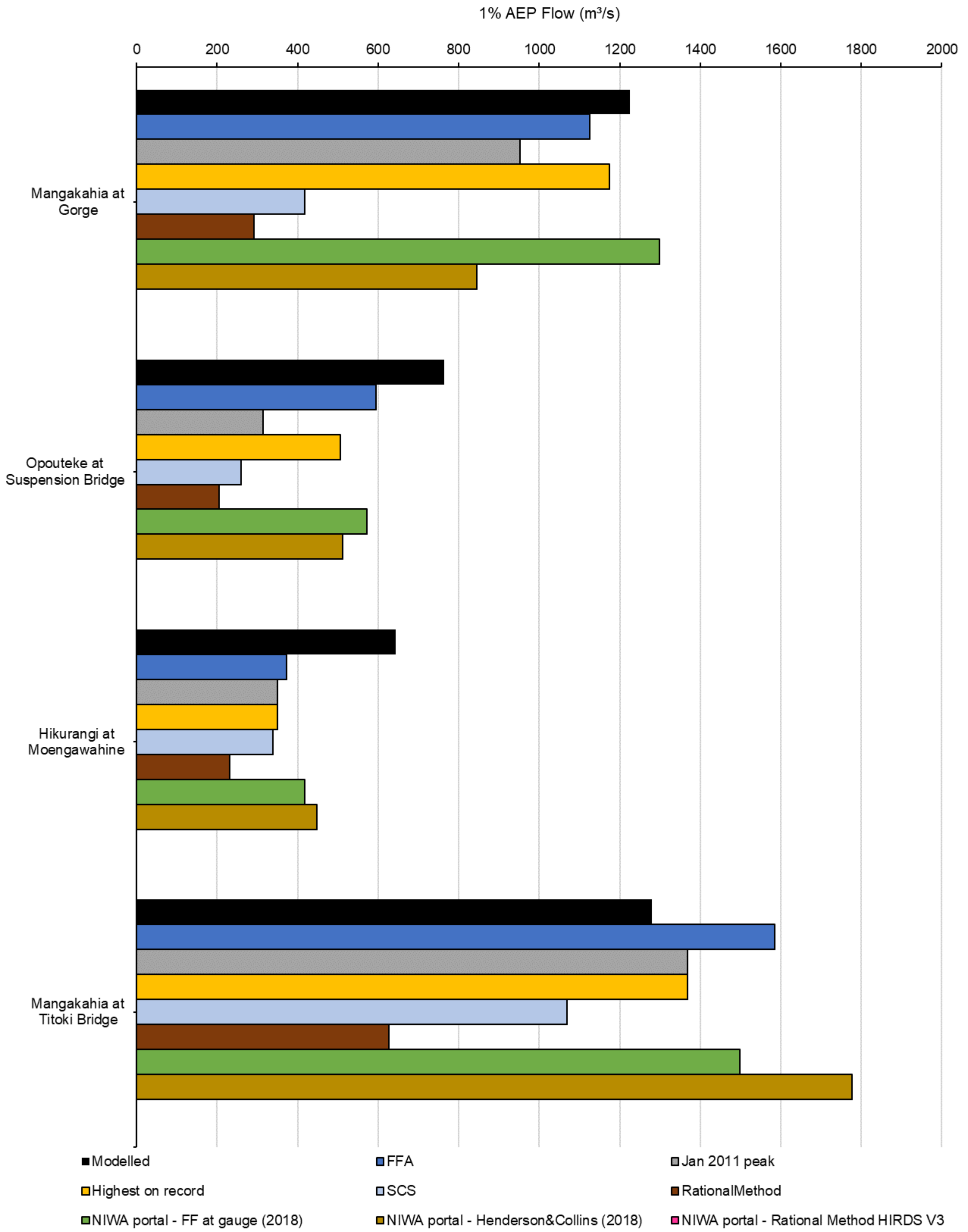

FIGURE 5-3 VERIFICATION OF DESING MODELLING RESULTS AGAINST HYDROLOGICAL ESTIMATES

6 SUMMARY

The Lower Mangakahia catchment model (M13) was previously calibrated and documented in the Calibration Report for the January 2011 flood event. The design modelling of this catchment consisted of four storm durations (1-hour, 6-hour, 12-hour and 24-hour) for each design AEP (i.e. 1%, 2% and 10% AEP). Design flood extents and gridded results, including depth, water surface elevation, velocity and hazard were produced and delivered to NRC.

The modelled 1% AEP design flows were verified against several design flood estimation methods at streamflow gauging stations. The comparison of design flows provides a general validation check of the modelled results given the accuracy of these estimation methods can be constrained by the reliability of gauged flow records (where used) and general limitations with empirical design estimates. Overall, the modelled design flows at the four streamflow gauge locations assessed within the study area provided a reasonable fit to design flow estimates.

When considering the scope and the scale of this project, the current modelling results are considered fit for use. Modelling outputs can be used to identify flood hazard and potential flood risk. It can also inform planning decisions, infill flood mapping between detailed flood studies and provide a basis for broad emergency management exercises.