

Design Modelling

Hakaru Catchment (M08)

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 km², 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, 9 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 calibration results and design modelling methodology for Hakaru Catchment (M08), noting that this catchment was calibrated to the December 2014 flood event.

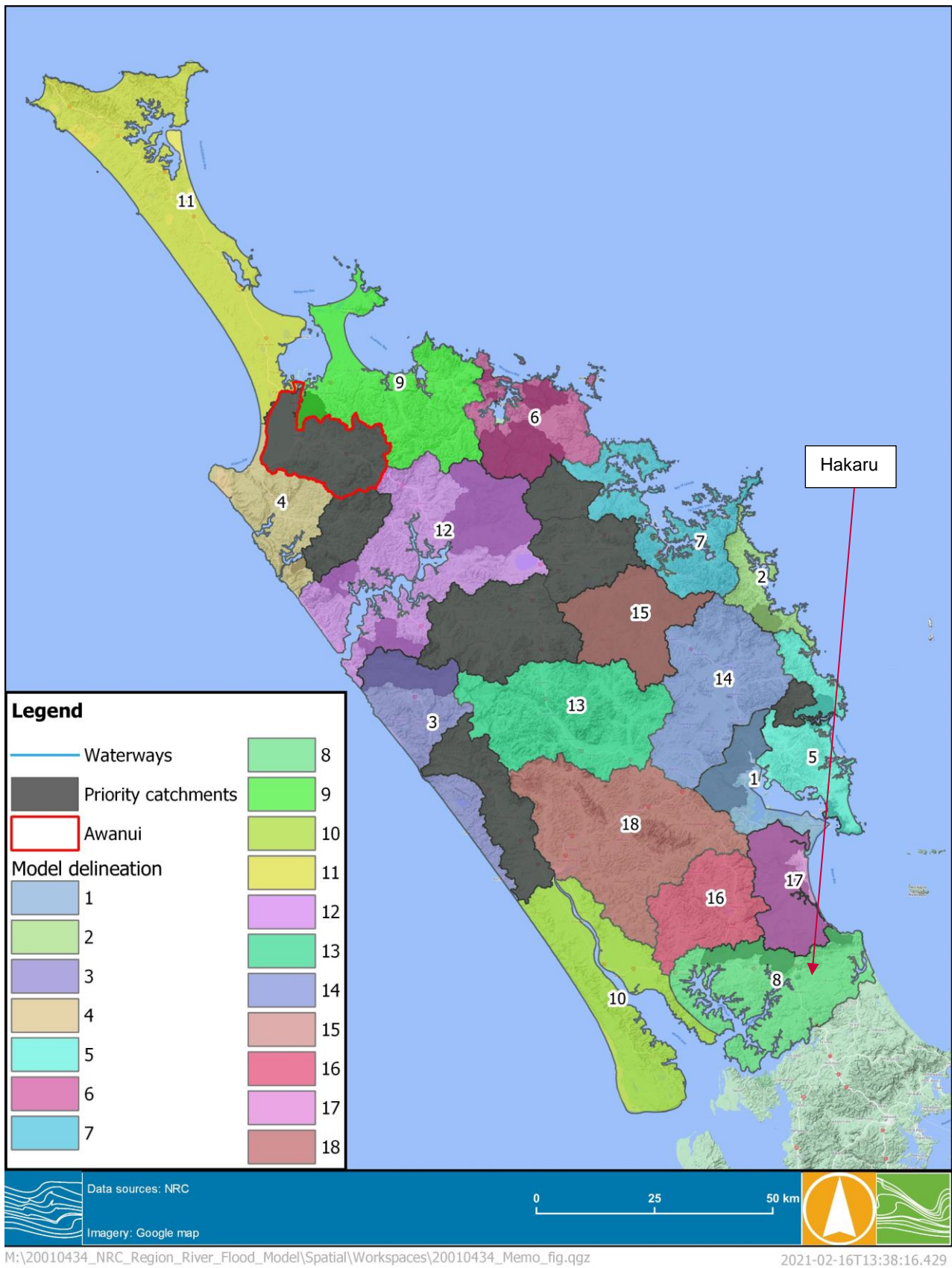


FIGURE 1-1 MODEL DELINEATION



2 STUDY AREA

The Model 08 catchment is coastal catchment, covering a total area of approximately 739 km² with Mangawhai its largest township. The Arapaoa River and Otamatea River are the two major waterways within the catchment with numerous tributaries that join them upstream before discharging into the sea to the west of the catchment. Several small waterways also merge at Mangawhai Harbour before leaving from the east coast of the catchment. Figure 2-1 displays the study area of the catchment Model 08.

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FIGURE 2-1 STUDY AREA



3 CALIBRATION RESULTS

The detail methodology of model calibration should refer to the *Calibration Report*. This section documents the final model calibration results and its performance.

Hakaru at Topuni Creek Farm gauge is the only streamflow gauge found available within the catchment. This gauge has both flow and water level records. There is no gauge zero and the model could not be calibrated against recorded flood levels. However, an arbitrary gauge zero was used to compare the shape of the water level plot. This model calibration therefore relied on matching the modelled flows to the gauged flows.

The calibration focused on calibrating the model to the rainfall event between 13th to 18th December in 2014 which is the largest event in the 9 years of available data in this gauge. Table 3-1 summarises the comparison between the observed and modelled values and Table 3-2 shows the quantitative assessment of the calibration performance. Figure 3-1 and Figure 3-2 show the modelled plots compared to the gauged records.

The modelled hydrograph has a good match to the gauged hydrograph in terms of its peak value, shape and timing. The modelled peak flow is close to the gauged record with around 8% difference and the time to peak is only 1 hours earlier than that observed. However, the modelled flood volume is much smaller than the total volume recorded during the event.

With the gauge zero not available, the modelled peak water level could not be compared to the gauged level. However, with using an arbitrary gauge zero, the modelled level plot shows a good match to the gauged one in terms of its shape as shown in Figure 3-2.

Based on the calibration result, the model calibration for the catchment appears suitable and fit for purpose.

TABLE 3-1 SUMMARY OF CALIBRATION RESULTS FOR CATCHMENT MODEL 03

Location	Peak flow (m ³ /s)			Time to peak diff. (hour)	Volume (ML)			Peak WSE (m OTP)		
	Modelled	Gauged	Diff.		Modelled	Gauged	Diff.	Modelled	Gauged	Diff. (mm)
Hakaru at Topuni Creek Farm gauge	132	122	8.22%	-1.0	4736	10055	-52.90%	5.21	N/A	N/A

TABLE 3-2 QUANTITATIVE ASSESSMENT OF JANUARY 2011 CALIBRATION FOR CATCHMENT MODEL 03

Location	Peak flow within 15% of recorded (Y/N)	Volume within 15% of recorded (Y/N)	Peak WSE within 300mm of recorded (Y/N)	Timing to peak within +/- 1 hour	Model flow within 10% of recorded flow at the same stage (Y/N)
Hakaru at Topuni Creek Farm gauge	Y	N	N/A	Y	N/A

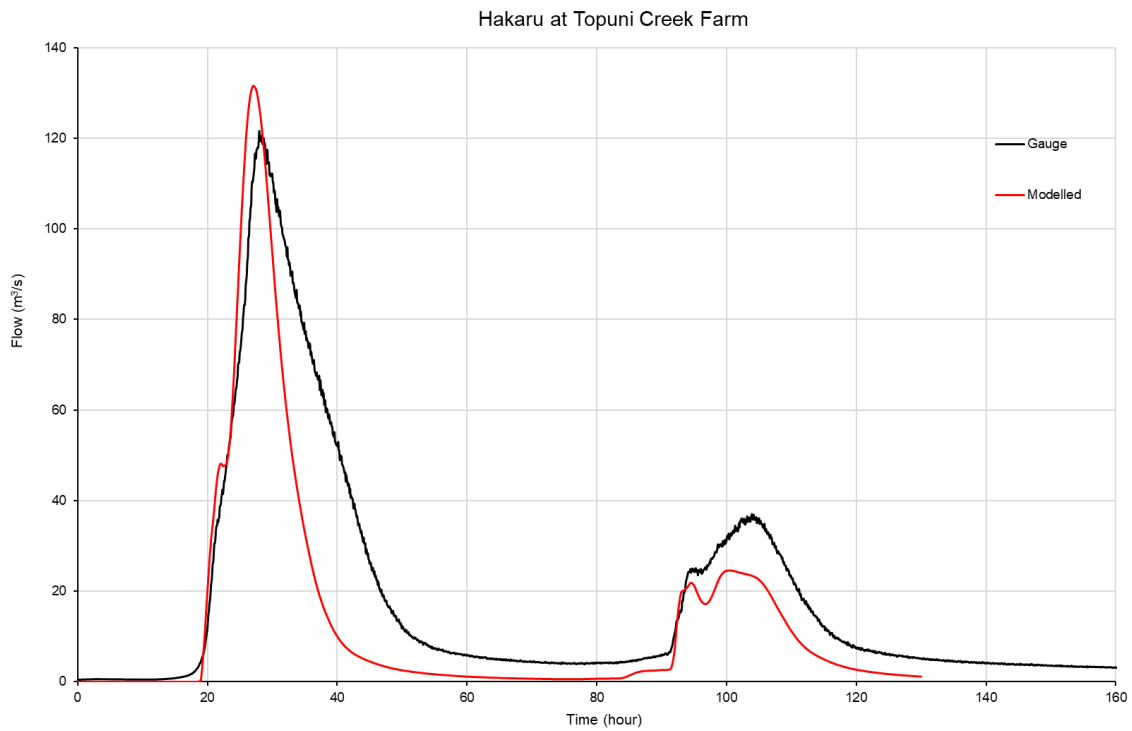


FIGURE 3-1 MODELLED AND GAUGED HYDROGRAPH AT HAKARU AT TOPUNI GAUGE

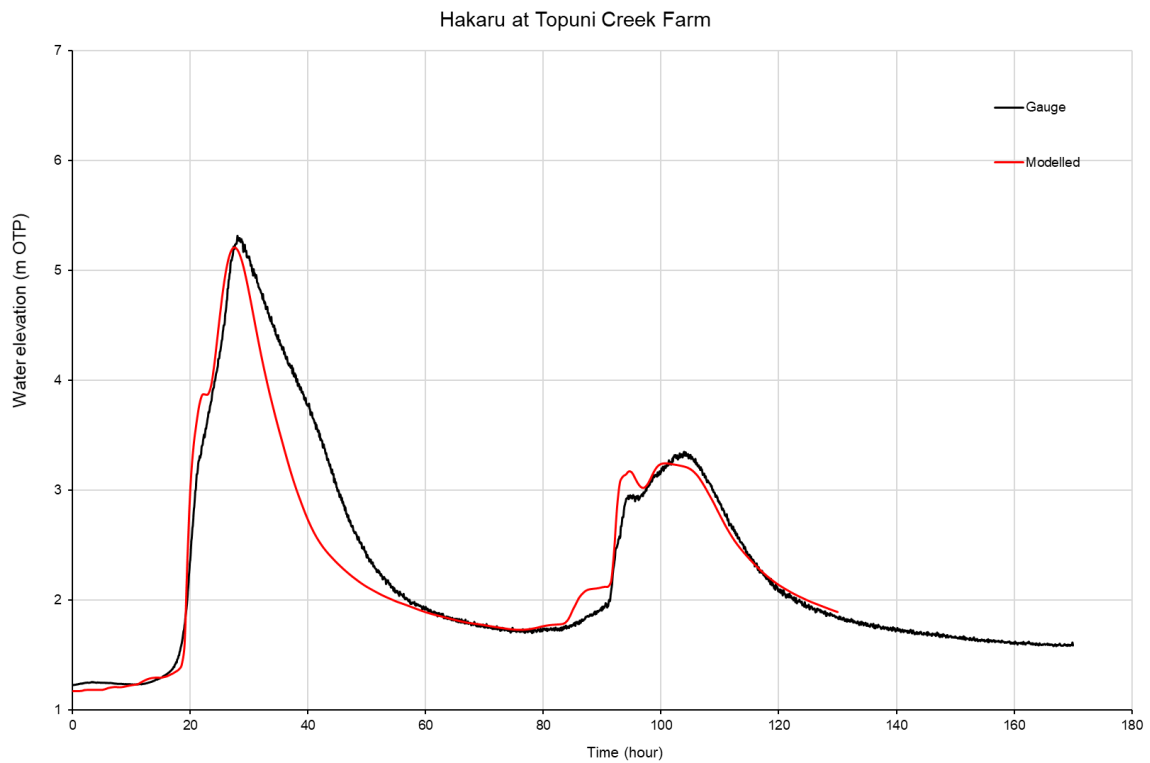


FIGURE 3-2 MODELLED AND GAUGED WATER LEVEL AT HAKARU AT TOPUNI GAUGE (*ARBITRARY GAUGE ZERO)



4 DESIGN MODELLING

4.1 Overview

A hydraulic model (TUFLOW) of the Hakaru catchment (M08) 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 4-1 and the following sections detail the key modelling information used in the development of the hydraulic model.

TABLE 4-1 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 4.2.1 and 4.2.4
Losses	See Section 4.2.3
Boundaries	See Section 4.2.4
Modelling solution scheme	TUFLOW HPC (adaptive timestep)
Modelling hardware	GPU
Modelling technique	Sub-grid-sampling (SGS)
Model grid size	10m with 1m SGS

4.2 Model Parameters

A range of model parameters were adopted based on the calibration of the December 2014 event for the Hakaru Catchment. Details of these are outlined below.

4.2.1 Rainfall Intensity-Duration-Frequency

Intensity-Duration-Frequency (IDF) tables were developed by NIWA through the High Intensity Rainfall Design System (HIRDSV4)¹. Design rainfall totals for durations from 10 minute up to 120 hours were developed for design modelling and were developed at 179 rainfall gauge sites across the wider study area. The IDF tables cover a range of magnitude events from 1 in 1.58 ARI through to 1 in 250 ARI along with climate change predictions (Representative Concentration Pathway 4.6, 6 & 8.5) up to the year 2100. For this catchment, ten rainfall gauges were used with a spatially weighted grid of rainfall totals created for design modelling. Figure 4-1 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/>

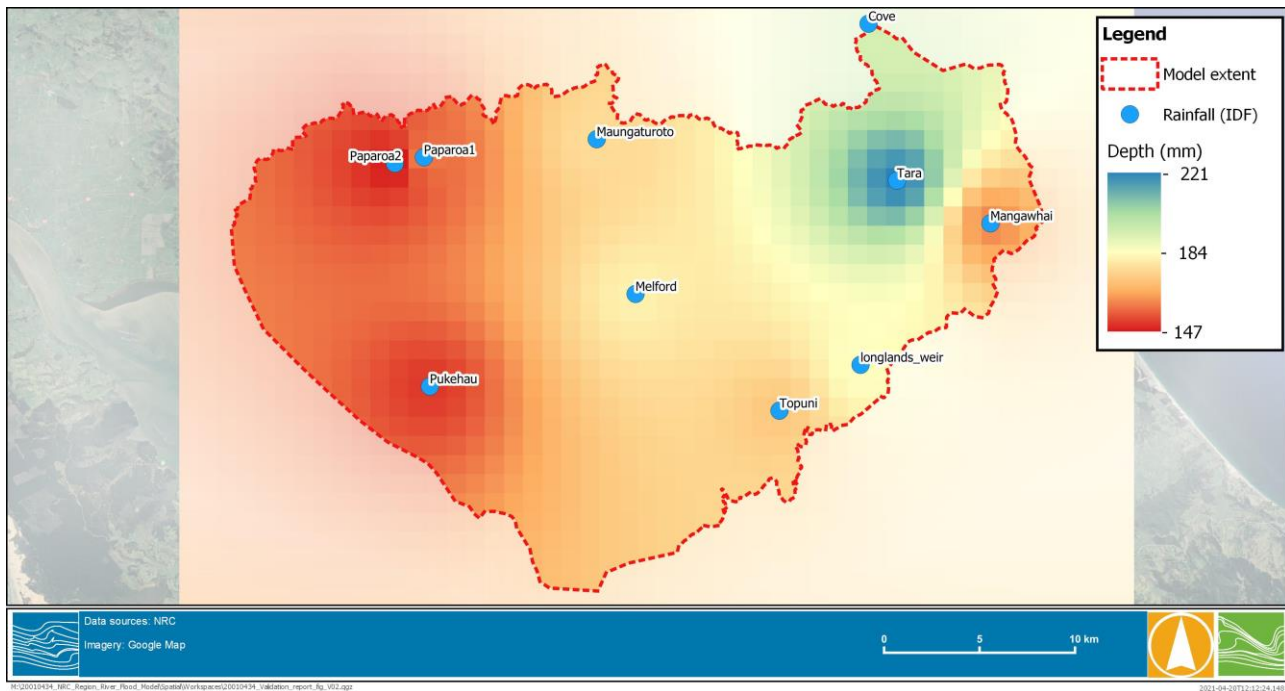


FIGURE 4-1 EXAMPLE OF DESIGN RAINFALL GRID (12-HOUR, 1% AEP RAINFALL) FOR M08

4.2.2 Design Rainfall Temporal Patterns

Design temporal patterns (rainfall hyetographs) were provided by NRC for design modelling. These were developed by HIRDS and subsequently reviewed as part of a 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 catchments². Hence, the design hyetographs for the rainfall gauges were developed using the rainfall IDF data at available rainfall gauges for the catchment. Although a 12-hour hyetograph is suitable for design modelling for most Northland catchments as suggested², a range of durations were selected; including 1-hour, 6-hour, 12-hour and 24-hour for each of the following AEPs: 10%, 2% and 1% AEP 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 are generally the predominant factor in generating peak flood levels.

Table 4-2 summarises the 1% AEP rainfall depth (based on IDF from HIRDSV4) for different event durations at each rainfall gauge and Figure 4-2 shows the design cumulative rainfall across the different gauges for the 12-hour duration event. Considering a single temporal pattern is assigned (i.e. HIRDS hyetograph), the proportional amount of rainfall applied through time for a given duration (e.g., 6-hour) is generally consistent (as shown in Figure 4-2) across the catchment area.

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



TABLE 4-2 1% AEP DESIGN RAINFALL DEPTH

Gauge location	1% AEP (mm)			
	1-hour	6-hour	12-hour	24-hour
Hakaru at Tara_641512	70	167	221	278
Mangawhai_A64151	63	128	161	199
Maungaturoto Melford_A64132	59	137	181	234
Paparoa 2_A64123	55	115	146	181
Paparoa 1_A64121	58	124	160	199
Paparoa at Maungaturoto_641213	61	138	176	218
Pukehau_A64221	54	118	151	189
Topuni_A64241	64	135	172	211
Waikoukou at Longlands Weir_647512	67	146	185	225
Waipu Cove_A64051	68	152	193	238

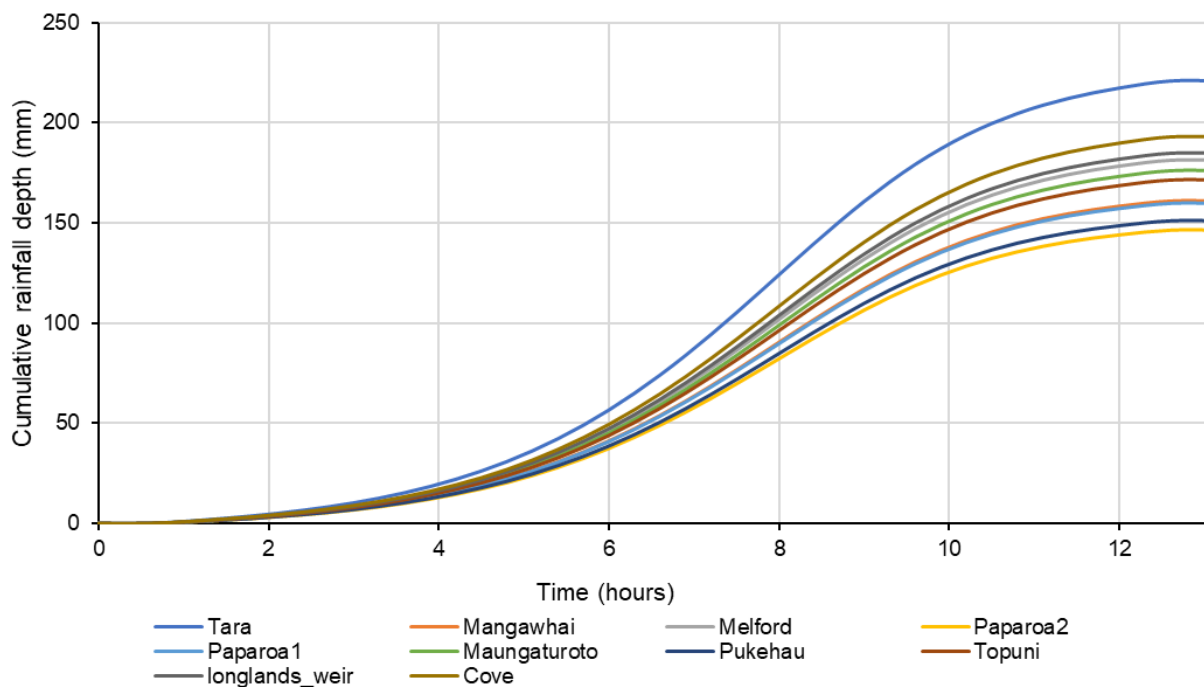


FIGURE 4-2 TEMPORAL PATTERN FOR DESIGN RAINFALL OF 12-HOUR, 1% AEP EVENT

A climate change scenario (for the 1% AEP events) was modelled for the 2081-2100 timeframe, for the RCP 8.5. This is based on the increases in rainfall intensity of 35%, 30%, 26% and 22% respectively for 1-hour, 6-hour, 12-hour and 24-hour duration events.



4.2.3 Losses

Each model cell was assigned a Manning's " n " (surface roughness), initial loss and a continuing loss based on the land use types and hydrologically important characteristics. Table 4-3 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 4-3 displays the roughness layer based on the land use type, showing most land use is forest and grassland.

TABLE 4-3 DESIGN MODEL PARAMETERS

Hydrological areas	Land use types	Manning's n	Initial loss (IL) – mm	Continuing loss (CL) – mm/hr
Entire M08 catchment	Forest	0.18	42	1.5
	Grassland	0.15	42	1.5
	Cropland – perennial	0.06	20	1
	Cropland – annual	0.06	20	1
	Wetland – open water	0.04	0	0
	Wetland – vegetated	0.05	10	1
	Urban areas	0.10	5	1.5
	Waterways	0.08	0	0
	Other	0.06	15	1.5

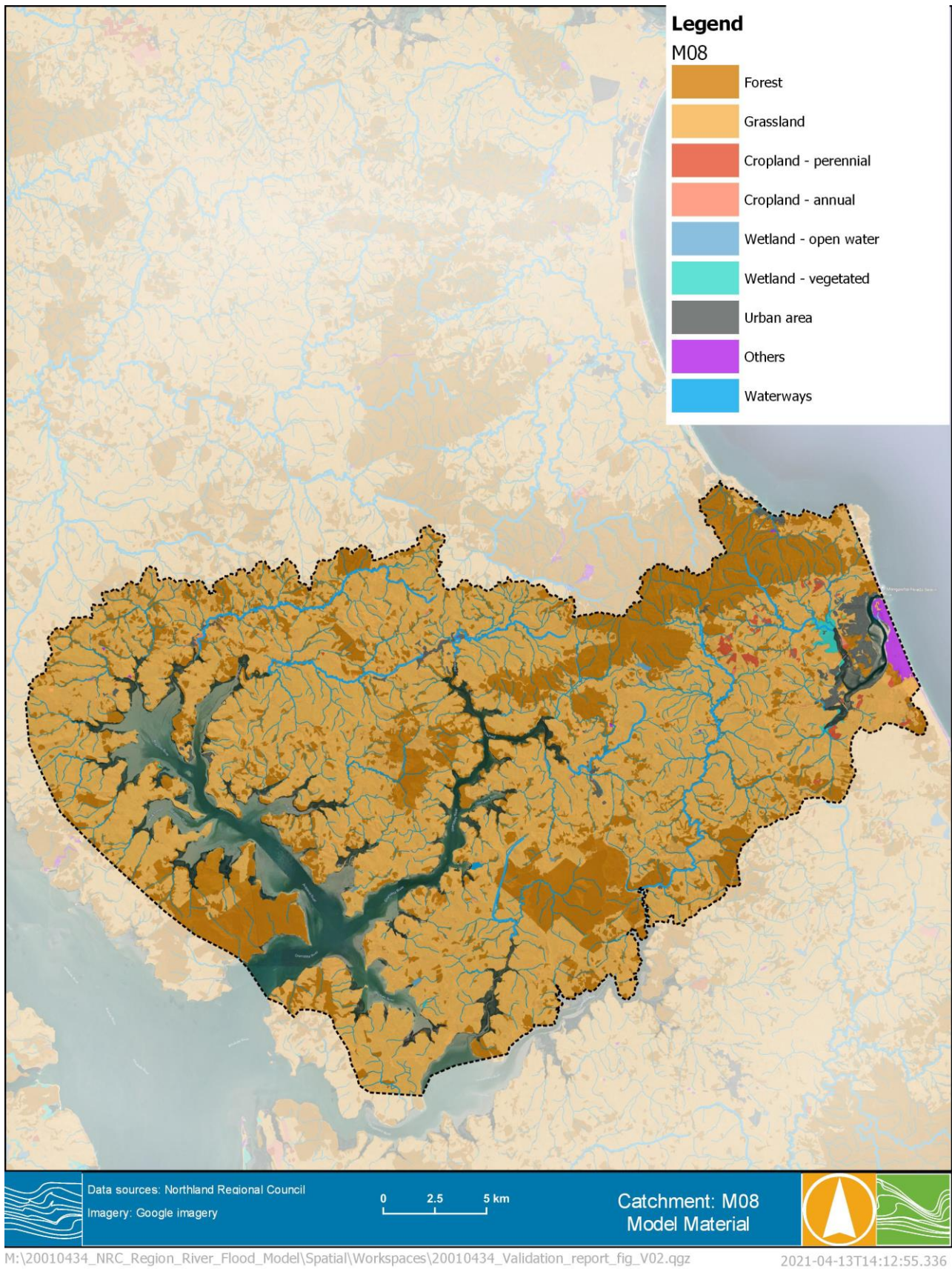


FIGURE 4-3 HYDRAULIC MODEL MATERIAL LAYER



4.2.4 Boundaries

As the Hakaru catchment is a coastal catchment, a static tail-water (i.e. 2161 mm OTP) outflow boundary based on the 2 year ARI tide level³ at Pouto Point was applied at the western downstream boundary and a static tail-water (i.e. 1396 mm OTP) outflow boundary based on the 2 year ARI tide level at Marsden Point was applied at the eastern downstream boundary for the design modelling. A 1.2 m sea level rise was adopted for climate change runs based on the project brief. In the calibration modelling, both of these boundaries were stage-discharge boundary (i.e. type HQ).

There is no upstream inflow coming from upstream catchments applied in this catchment model.

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³ MWH, 2010 *Priority Rivers – Flow Assessment, Sea Level Rise and Storm Surge*, prepared for Northland Regional Council



5 MODELLING RESULTS

5.1 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), flood 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 a single data set for each AEP from the storm durations modelled. For example, the flood depth output is produced by merging the depth results of the four different durations within each AEP. This allows for the critical storm duration across each part of the catchment to be represented (i.e. the short intense storms in upper reaches and longer duration storms in the lower parts of the catchment).

Step 2:

- The maximum gridded results are then remapped to a finer DEM grid using LiDAR data resampled to a 5-m grid resolution. 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 out depths below 100mm and puddle areas less than 2000m² as agreed with NRC.

Figure 5-1, Figure 5-2 and Figure 5-3 respectively show the final post-processed flood depths, velocity and hazard of the 1% AEP design event modelled for M08. Figure 5-4 shows the flood depth map zoomed in at a township (Kaiwaka) as an example. It is noted that the hazard classification is based on the following criteria:

TABLE 5-1 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

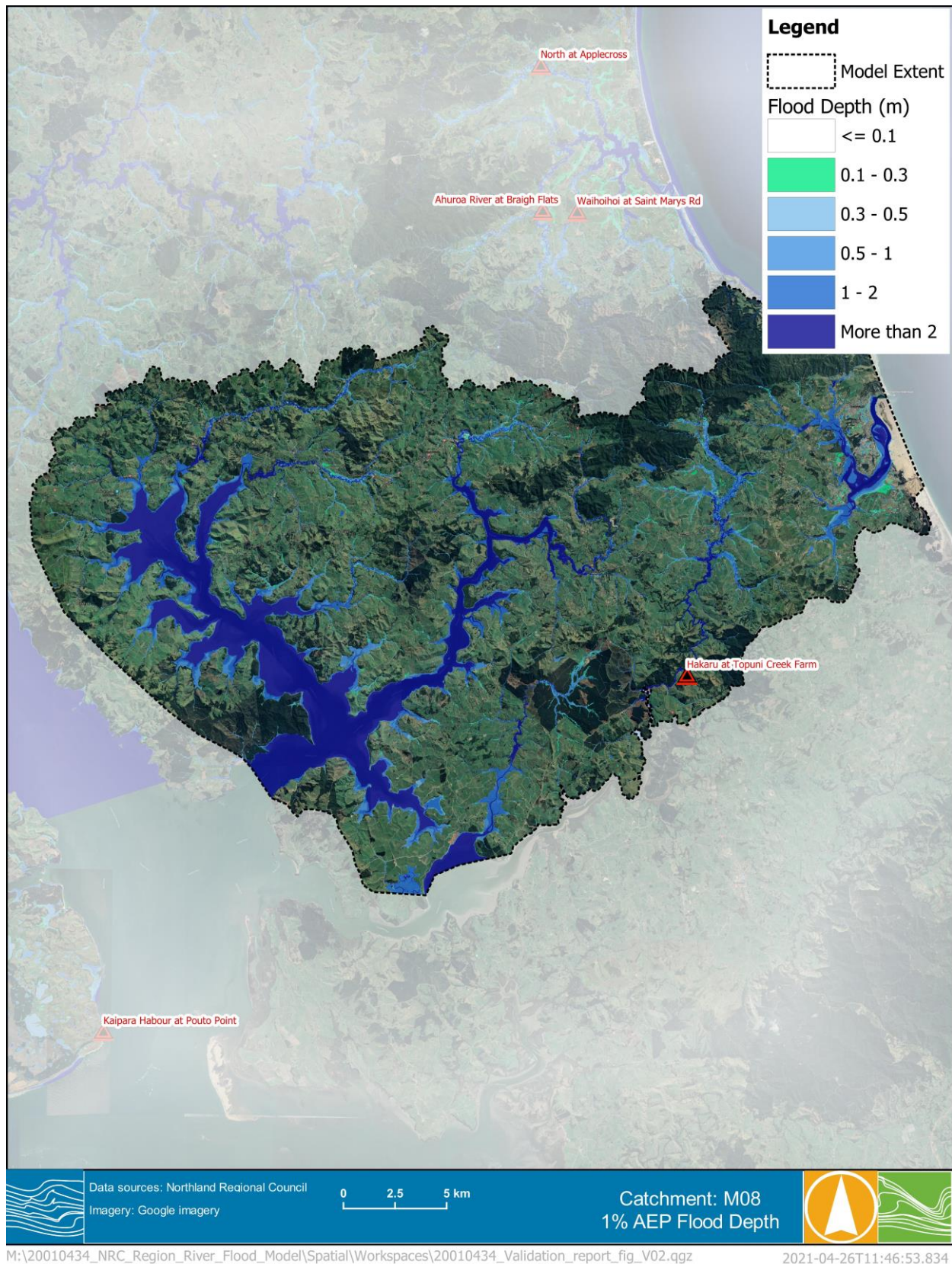


FIGURE 5-1 DESIGN MODELLING OF 1% FLOOD DEPTH

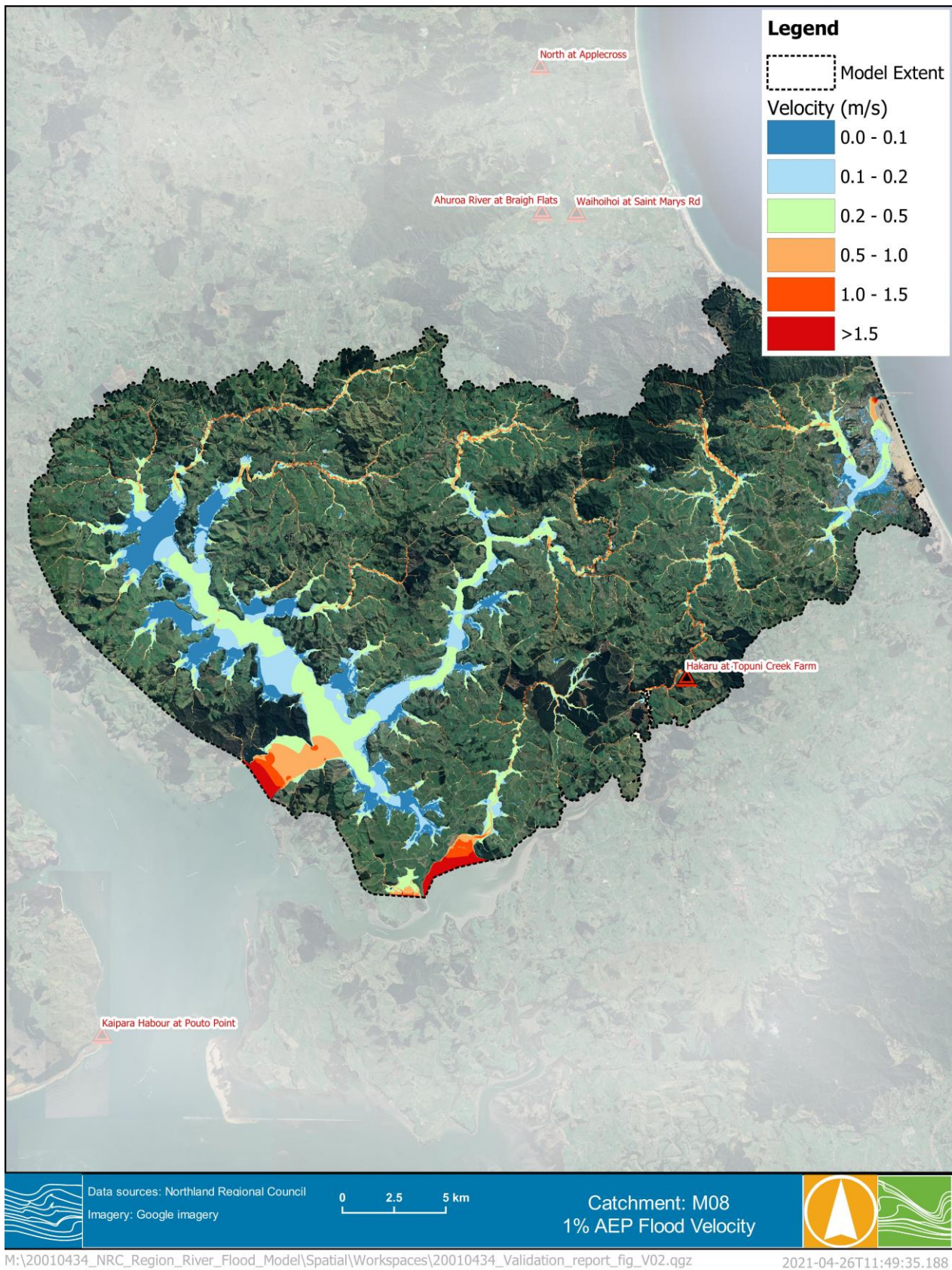


FIGURE 5-2 DESIGN MODELLING OF 1% AEP FLOOD VELOCITY

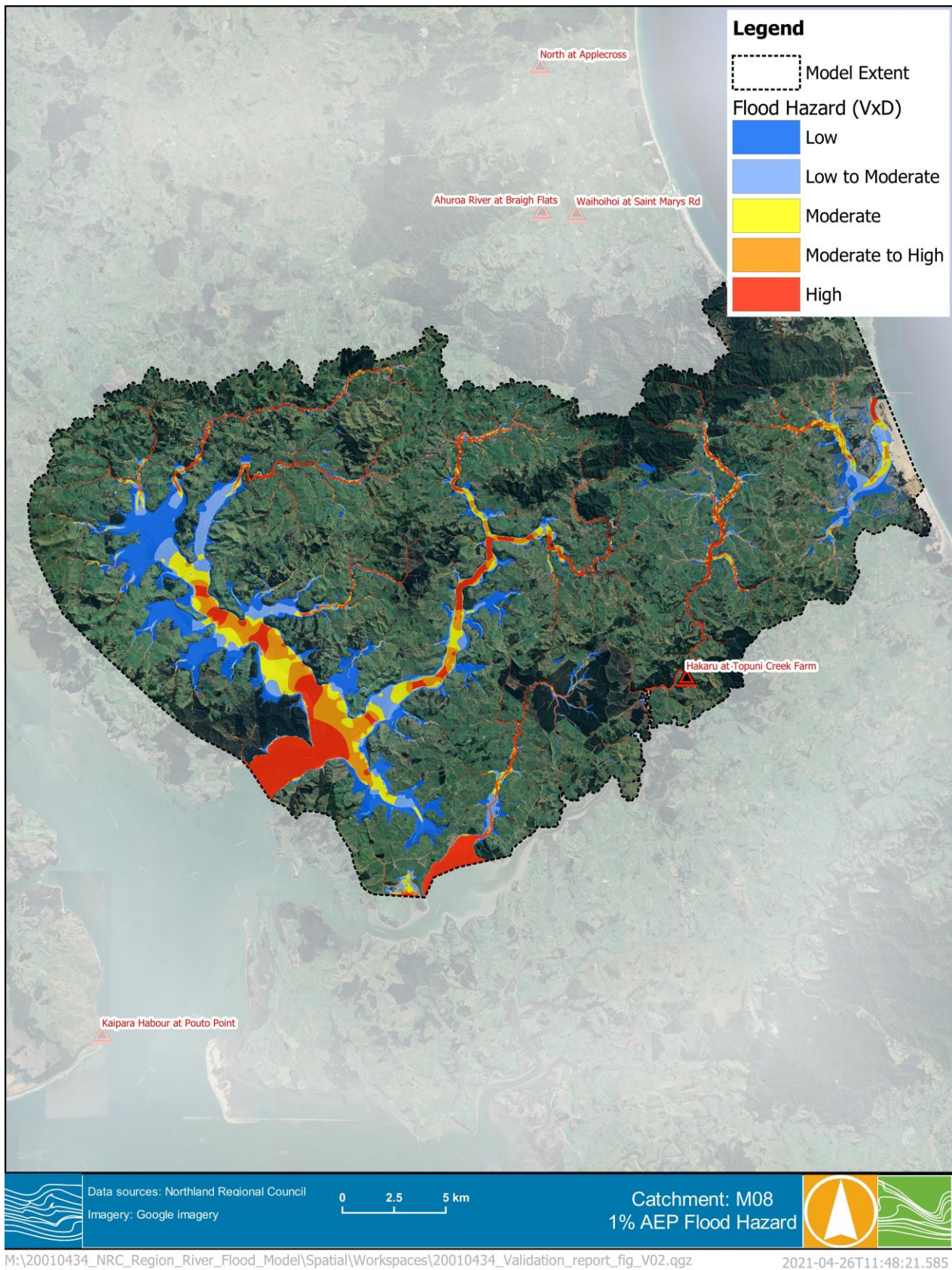


FIGURE 5-3 DESIGN MODELLING OF 1% AEP FLOOD HAZARD

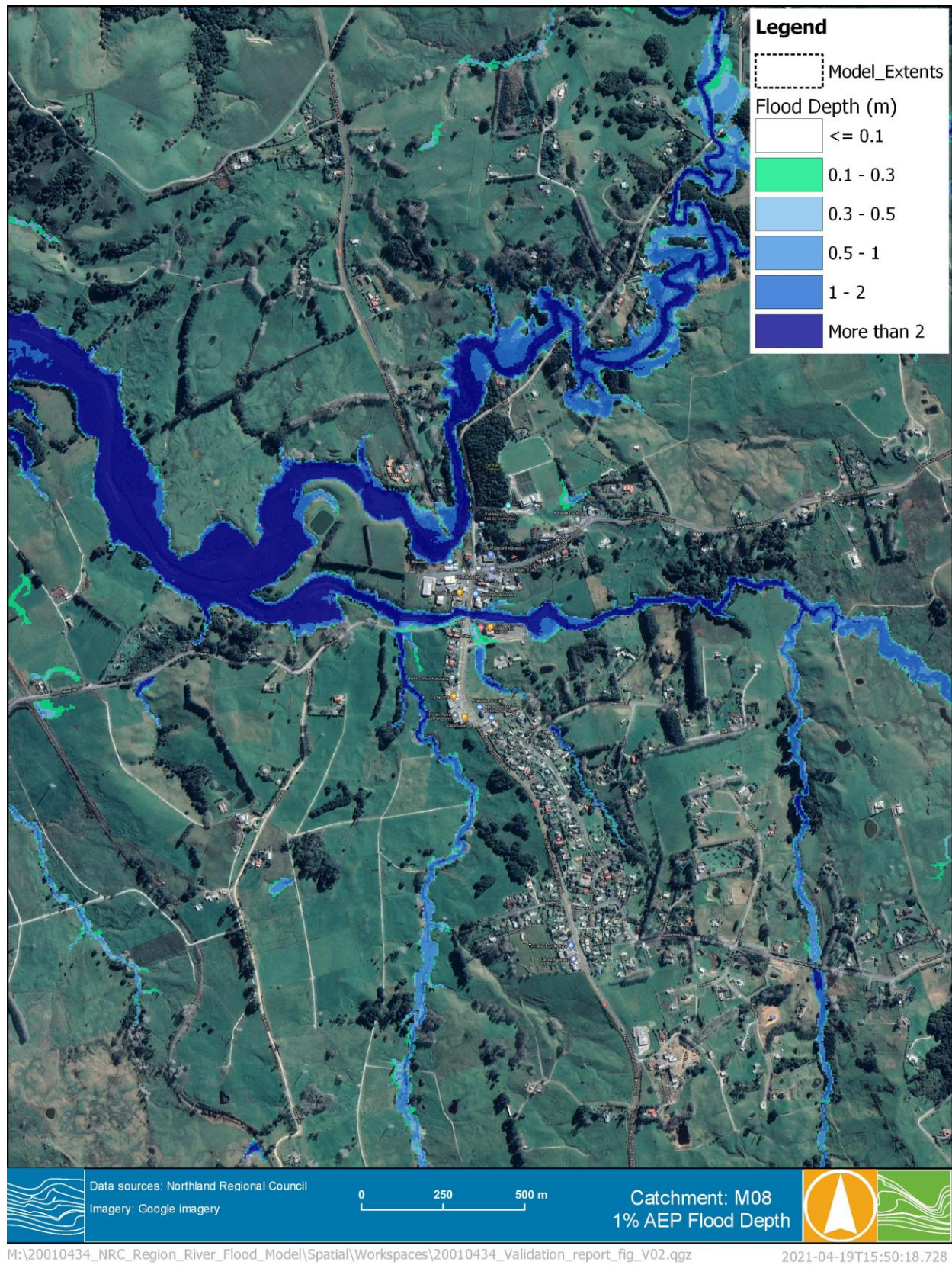


FIGURE 5-4 DESIGN MODELLING OF 1% AEP FLOOD DEPTH ZOOMED AT KAIWAKA

6 VERIFICATION OF DESIGN FLOWS

Flow lines were included at gauge locations in the hydraulic model as 2D Plot Outputs (2D PO) for calibration and design events. This allows flow hydrographs and peak flows to be extracted at these locations. Figure 6-1 displays the location of the Hakaru at Topuni Creek Farm gauge which is the only gauge found in the Hakaru catchment.

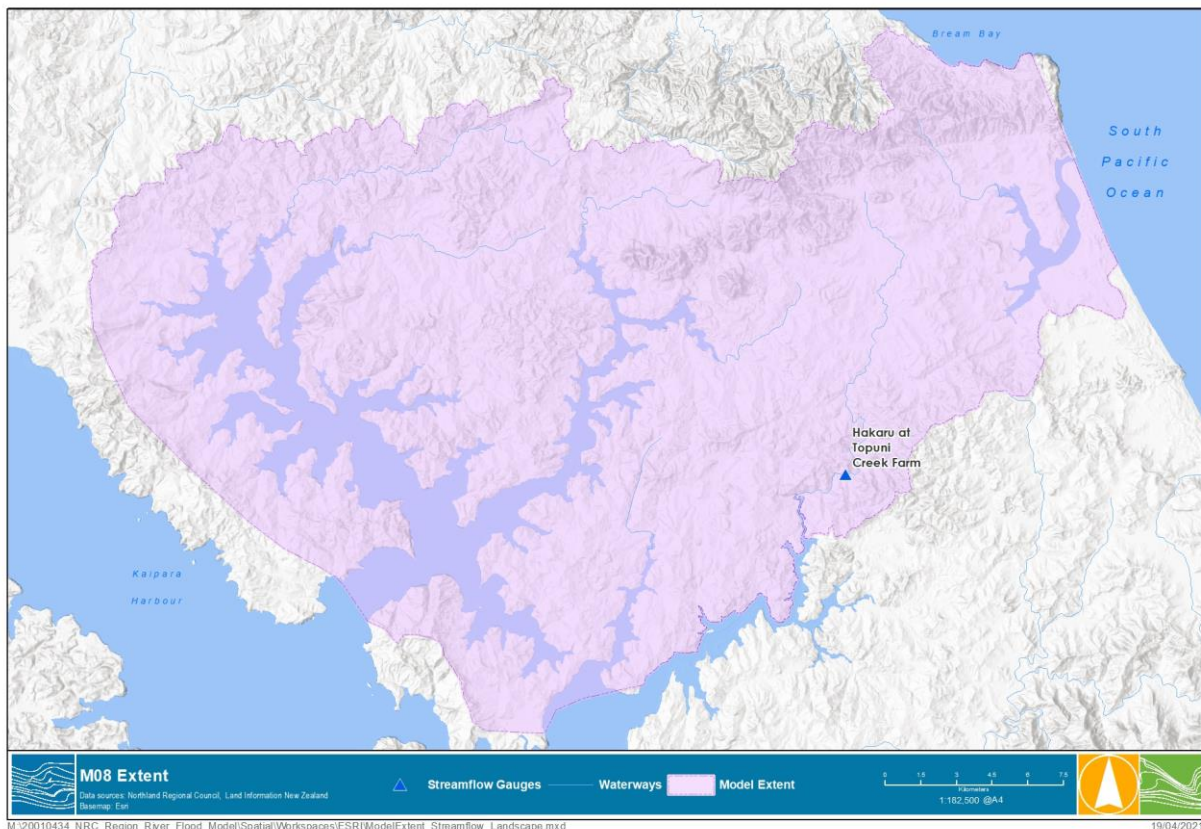


FIGURE 6-1 AVAILABLE STREAMFLOW GAUGES WITHIN HAKARU CATCHMENT

The modelled peak flow for the 1% AEP design flood was compared with hydrological estimates, including the Rational Method and SCS Method, as well as the historic maxima from streamflow gauge records.

6.1 Regional Estimation Methods

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



6.1.1 NIWA New Zealand River Flood Statistics Portal

The New Zealand River Flood Statistics portal⁴ 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).

The flood frequency estimates given by the portal are determined using the Mean Annual Flow method developed by Henderson & Collins (2018)⁵.

6.1.2 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:

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

where:

- Q is run-off depth (millimetres).
- P is rainfall depth (millimetres)
- S is the potential maximum retention after run-off begins (millimetres).
- I_a 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.

⁴ NIWA Flood Frequency tool, accessed via: <https://niwa.co.nz/natural-hazards/hazards/floods>

⁵Henderson, 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



6.1.3 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 metres 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 km².

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6.2 Verification Results

Table 6-1 summarises the comparison of 1% AEP peak flow estimates with the modelled values at Hakaru at Topuni Creek Farm gauge in the Hakaru catchment and the differences between the estimation methods and modelled results can be visualised in Figure 6-2.

The Rational Method and the SCS method are only applicable for relatively small catchments, with the SCS method limited to 12 km². The catchment size for Hakaru at Topuni Creek Farm gauge is 82 km². These equations are therefore subject to great uncertainty in summarising the catchment characteristics.

At the Hakaru at Topuni Creek Farm gauge, the modelled design flow has a good match to the Henderson&Collins estimate from NIWA. Overall, the modelled peak flow at this gauge tends to sit within a reasonable range of the design flow estimates.

The use of empirical method estimations provides 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 6-1 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	Dec 2014 peak	Highest on record	SCS	Rational method	NIWA – H&C 2018
Hakaru at Topuni Creek Farm	24 hr	210.3	121.5	121.5	109.6	64.3	178

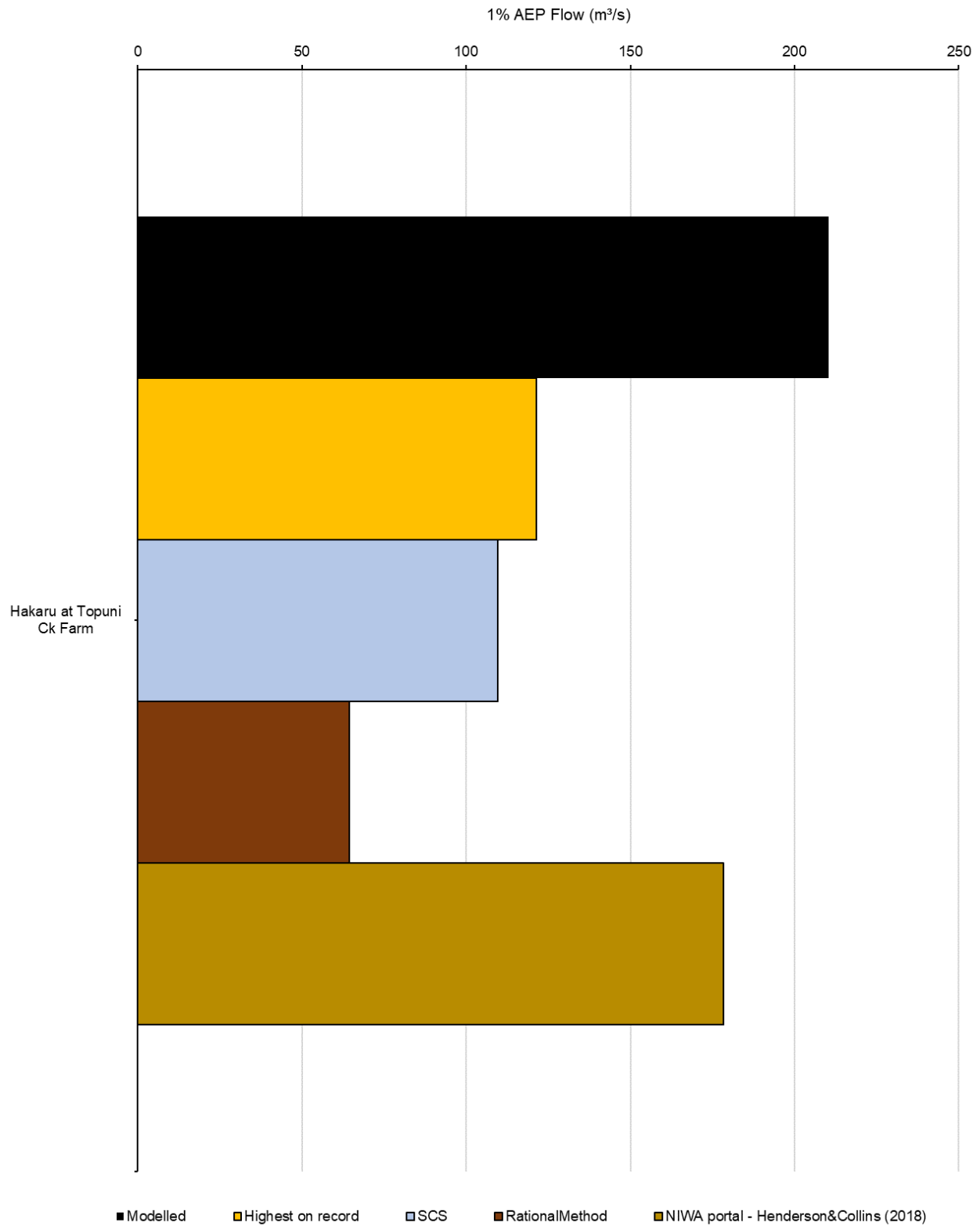


FIGURE 6-2 VERIFICATION OF DESIGN MODELLING RESULTS AGAINST HYDROLOGICAL ESTIMATES



7 SUMMARY

The Hakaru catchment model (M08) was calibrated to the December 2014 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 flow at Hakaru at Topuni Creek Farm gauge was verified against several design flood estimation methods. The comparison of design flow 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 flow at this streamflow gauge 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.

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