Design Modelling

Awanui Catchment (Awanui)

Northland Regional Council

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WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

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Te Kaunihera ā rohe o Te Taitokerau

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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, 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 design modelling methodology for Awanui Catchment (Awanui), noting that this catchment was calibrated to the July 2020 flood event.

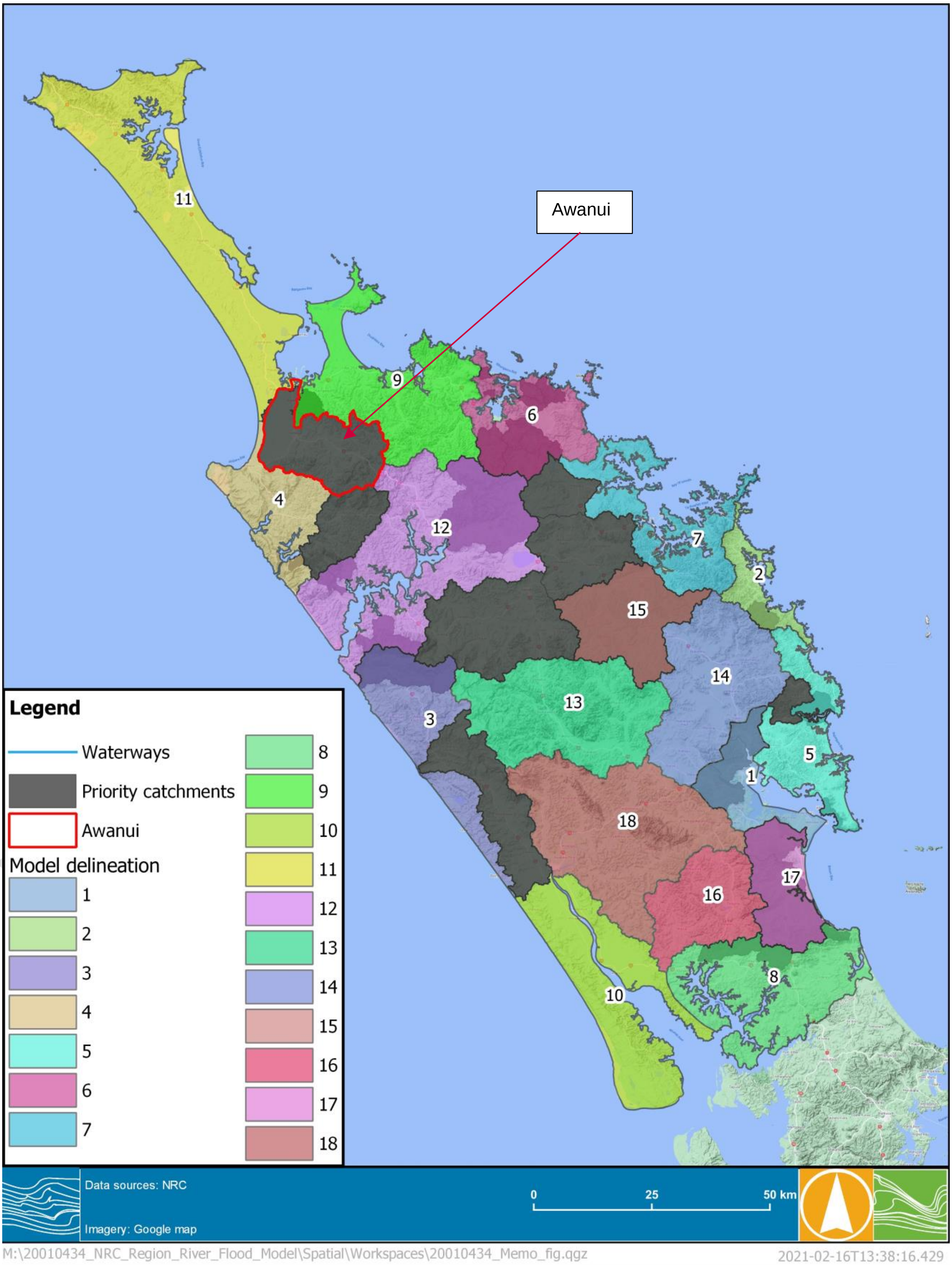

FIGURE 1-1 MODEL DELINEATION

2 STUDY AREA

The model Awanui catchment is a inland and mountainous catchment, covering a total area of approximately 368 km^2 with Kaitaia and Awanui its main townships. The largest waterway within the catchment is Awanui River which is fed by several upstream tributaries, including the Takahue River, Victoria River, Karemuhako River and Tarawhataroa Stream. Figure 2-1 displays the study area of the catchment model Awanui.

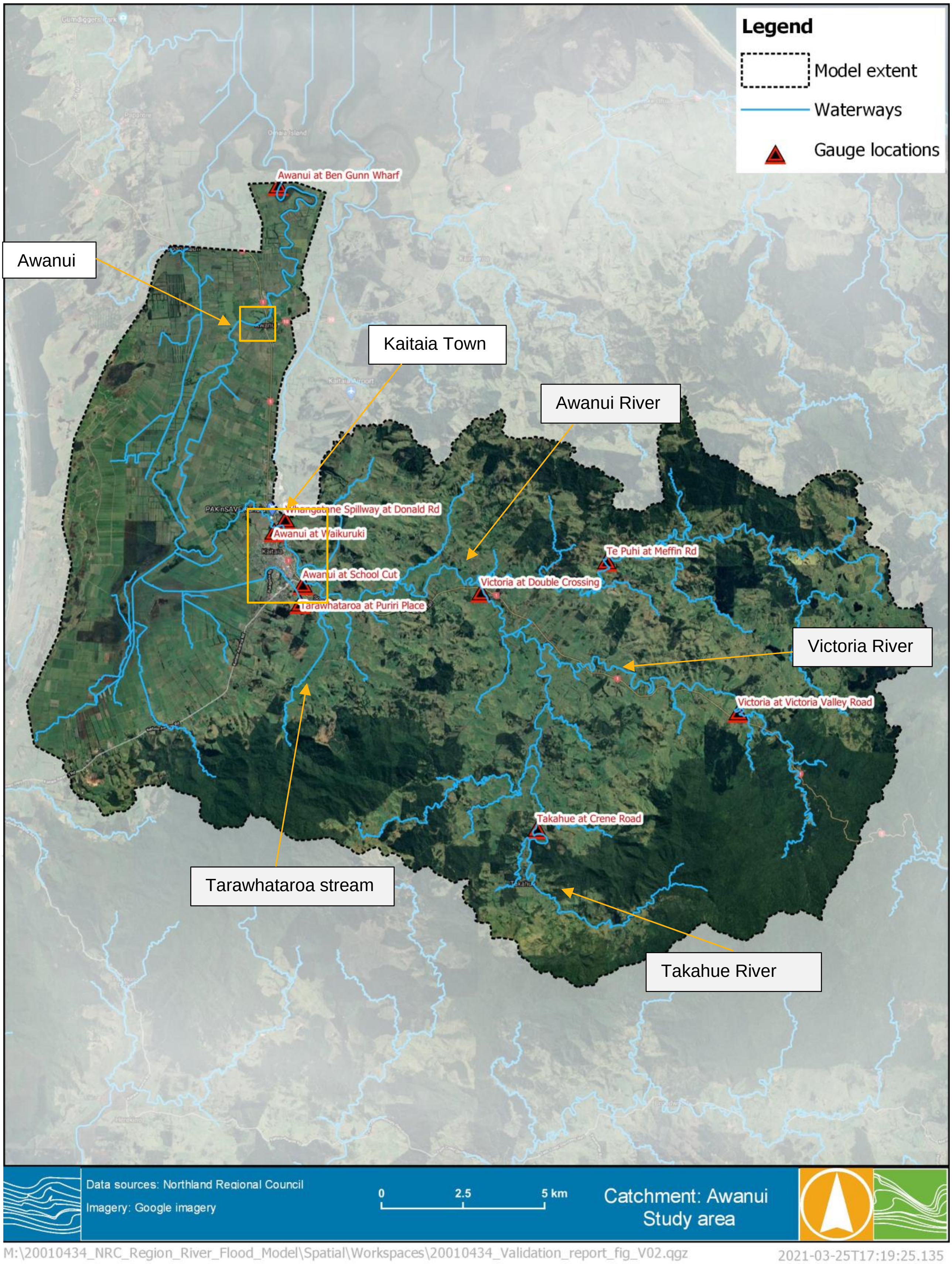

FIGURE 2-1 STUDY AREA

3 DESIGN MODELLING

3.1 Overview

A hydraulic model (TUFLOW) of the Awanui catchment (Awanui) 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 3.2.4
Losses	See Section 3.2.3
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 the July 2020 event for Awanui catchment. Details of these are outlined below.

3.2.1 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, 11 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/

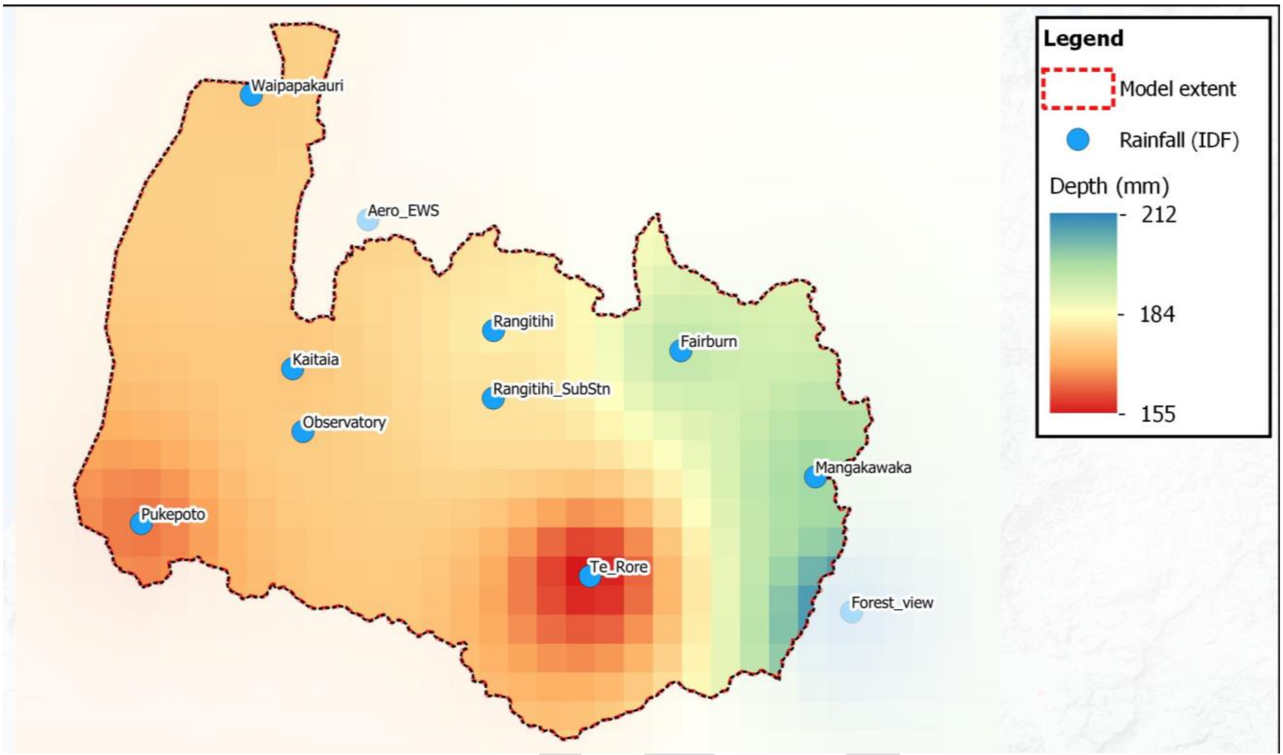

FIGURE 3-1 EXAMPLE OF DESIGN RAINFALL GRID (12-HOUR, 1% AEP RAINFALL) FOR AWANUI

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)[3]. 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[3]. 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 suggested[3], 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 (based on IDF from HIRDSV4) 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 proportional amount of rainfall applied through time in a design event is generally consistent (as shown in Figure 3-2) across the catchment area.

[3] 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
Fairburn A53133	60.9	147	194.4	244.8
Kaitaia Aero EWS A53026	62.5	139.8	176.4	213.36
Kaitaia Observatory A53125	62.3	136.8	175.2	215.04
Kaitaia A53121	61.4	135.6	174	213.84
Mangamuka Forest View 531412	64.8	155.4	213.6	288
Pukepoto A53129	58.9	128.4	164.4	204.96
Rangitihi Sub Stn A53132	60.7	138.6	178.8	218.88
Rangitihi A53131	61.9	140.4	181.2	225.12
Takahue at Te Rore_531313	58.9	121.2	154.8	192.72
Te Puhi at Mangakawaka Trig_531415	58.3	148.2	199.2	256.8
Waipapakauri A53022	62.7	139.2	175.2	211.2

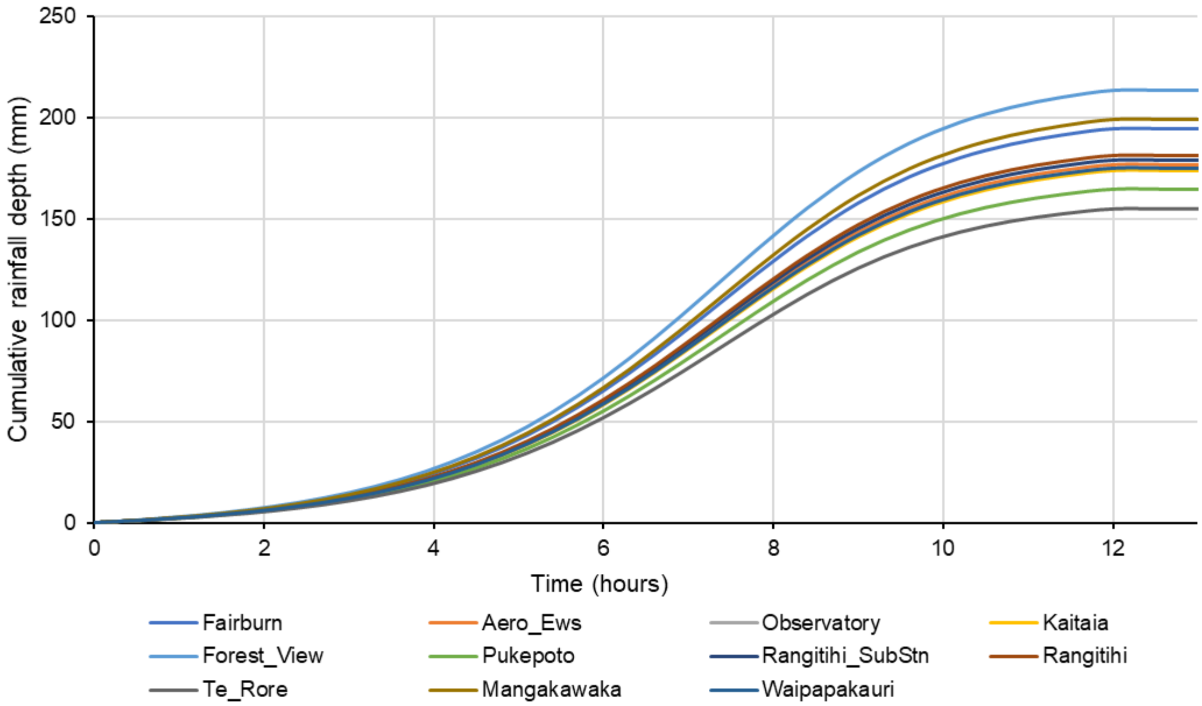

FIGURE 3-2 TEMPORAL PATTERN FOR DESIGN RAINFALL OF 12-HOUR, 1% AEP EVENT

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

3.2.3 Losses

Model cells were assigned a Manning's "*n*" (surface roughness), initial loss and a continuing loss based on land use types and hydrologically important characteristics. 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
Tarawhataroa	Forest	0.06	55	11.5
	Grassland	0.03	55	11.5
Te Puhi	Forest	0.10	15	4
	Grassland	0.06	15	4
Te Rore and other areas	Forest	0.10	30	4
	Grassland	0.06	30	4
Entire Awanui 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	0.055	0	0
	Other	0.06	15	1.5

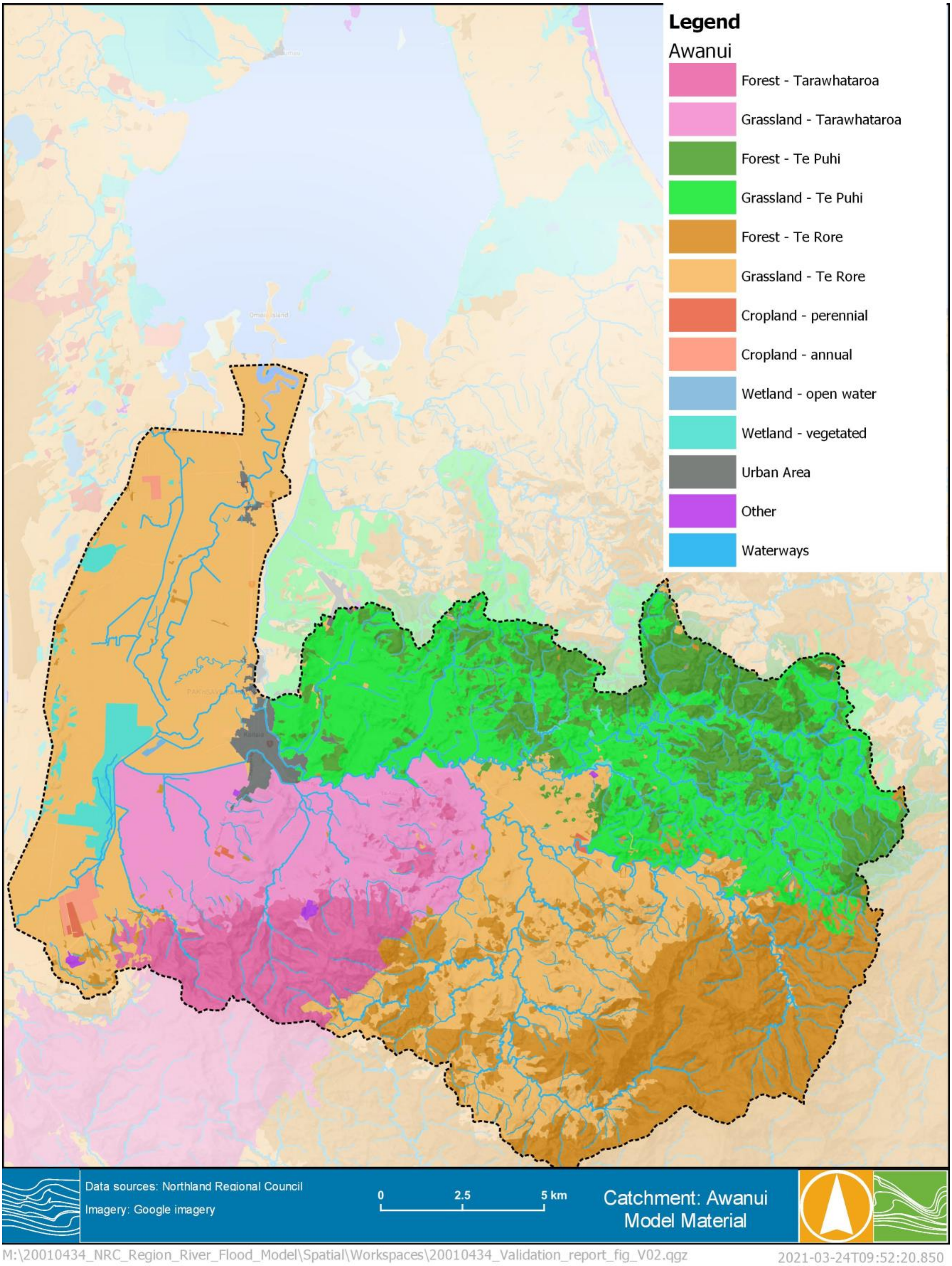

FIGURE 3-3 HYDRAULIC MODEL MATERIAL LAYER

3.2.4 Boundaries

Although the Awanui catchment is an inland catchment, a static tail-water (i.e. 1396 mm OTP) outflow boundary based on the 2 year ARI tide level[4] at Marsden Point gauge was used at the Awanui River at Ben Gun Wharf and a stage-discharge boundary (i.e. HQ) at Donald Road gauge was used for the design modelling. And a 1.2 m sea level rise was adopted for climate change runs based on the project brief. In the calibration modelling, the boundary at Ben Gun Wharf was a tidal boundary (i.e. type HT), using the tidal records during the event at this gauge. Similar HT boundary was applied at downstream of Donald Road bridge using the water level records at the gauge.

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

[4] MWH, 2010 *Priority Rivers – Flow Assessment, Sea Level Rise and Storm Surge*, prepared for Norhland Regional Council

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 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 2000m^2 as agreed with NRC.

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 the Awanui Catchment. Figure 4-4 shows the flood depth map zoomed in at Kaitaia as an example. 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

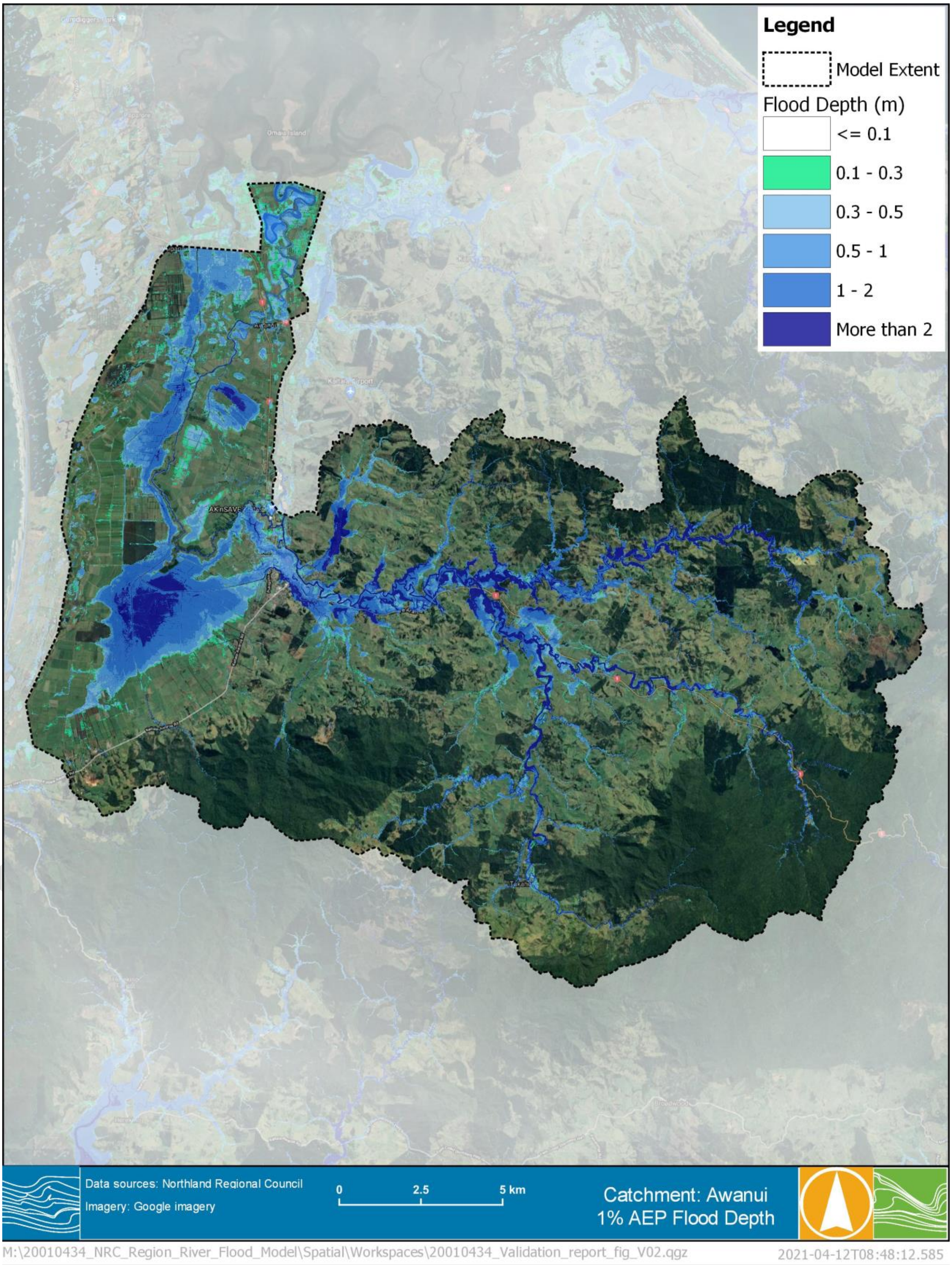

FIGURE 4-1 DESIGN MODELLING OF 1% FLOOD DEPTH

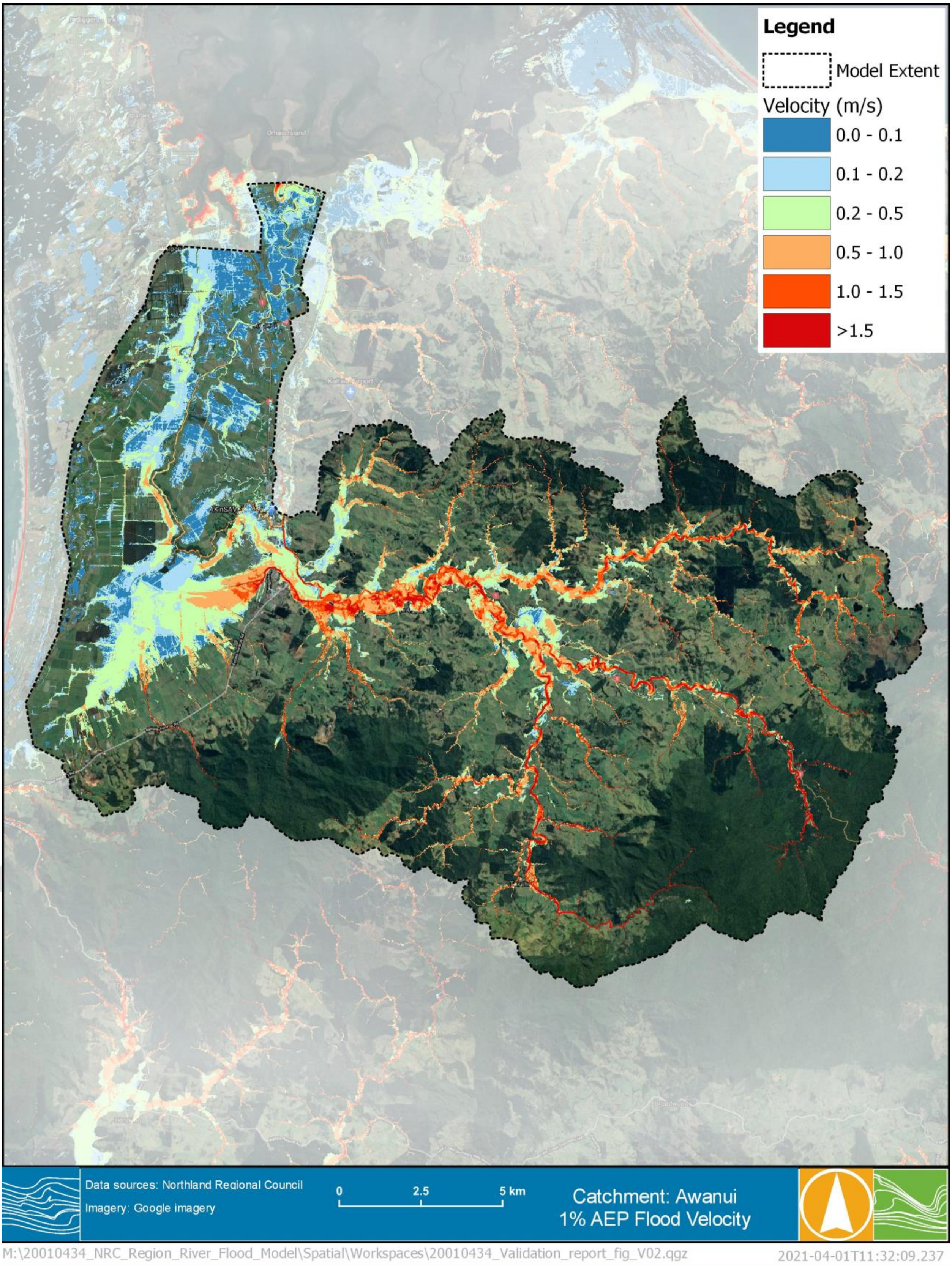

FIGURE 4-2 DESIGN MODELLING OF 1% AEP FLOOD VELOCITY

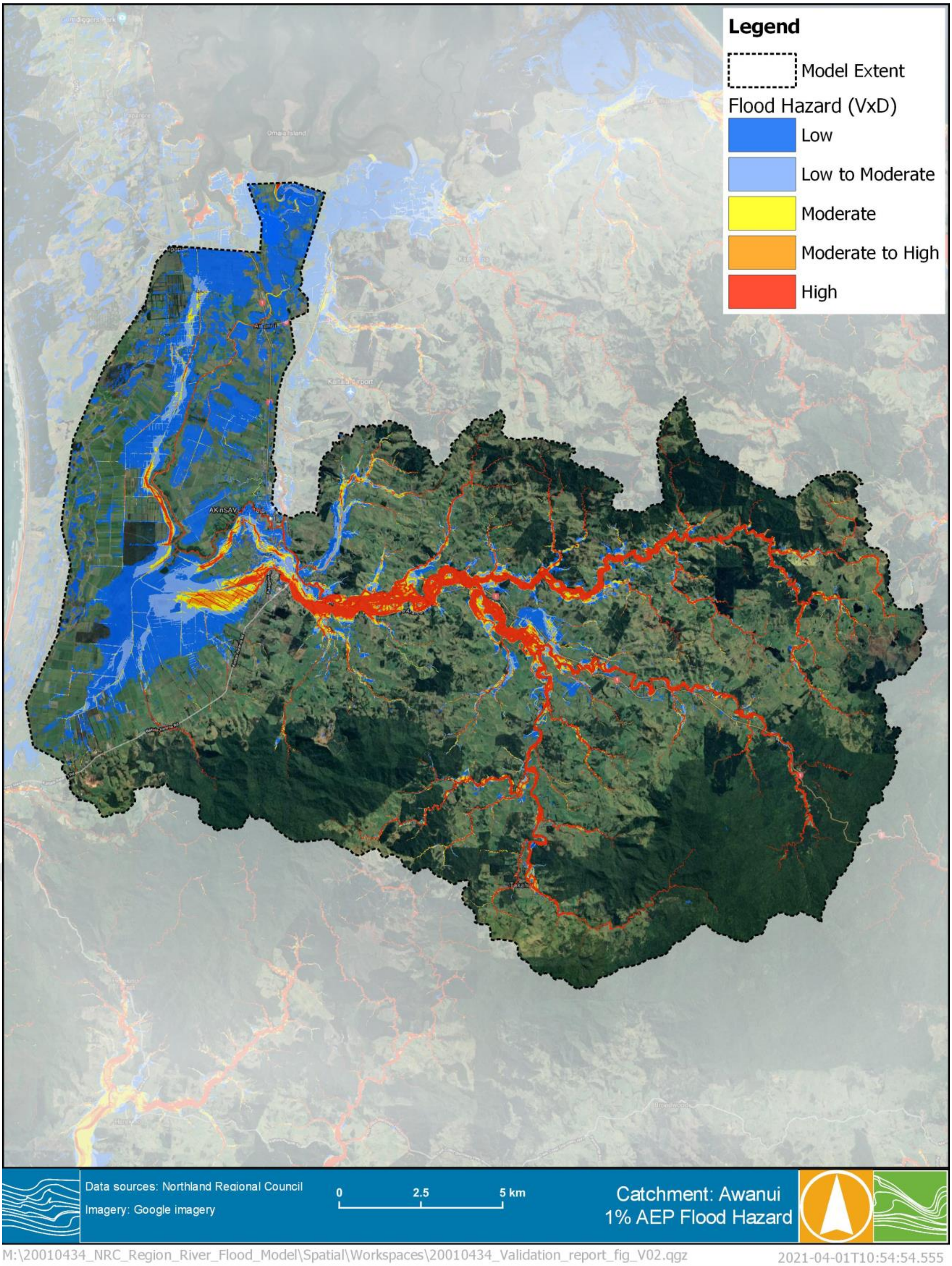

FIGURE 4-3 DESIGN MODELLING OF 1% AEP FLOOD HAZARD

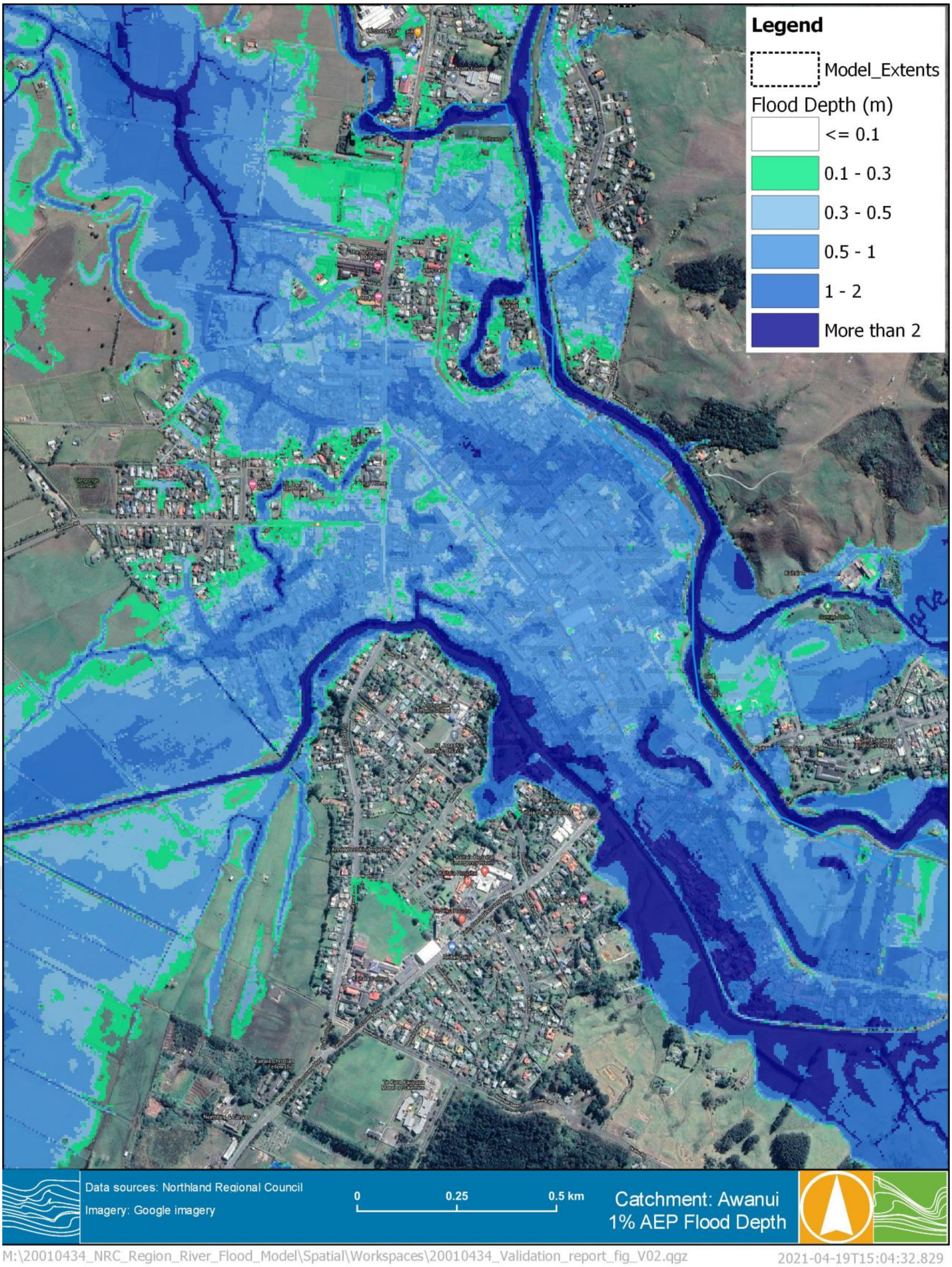

FIGURE 4-4 DESIGN MODELLING OF 1% AEP FLOOD DEPTH ZOOMED AT KAITAIA

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 Awanui catchment.

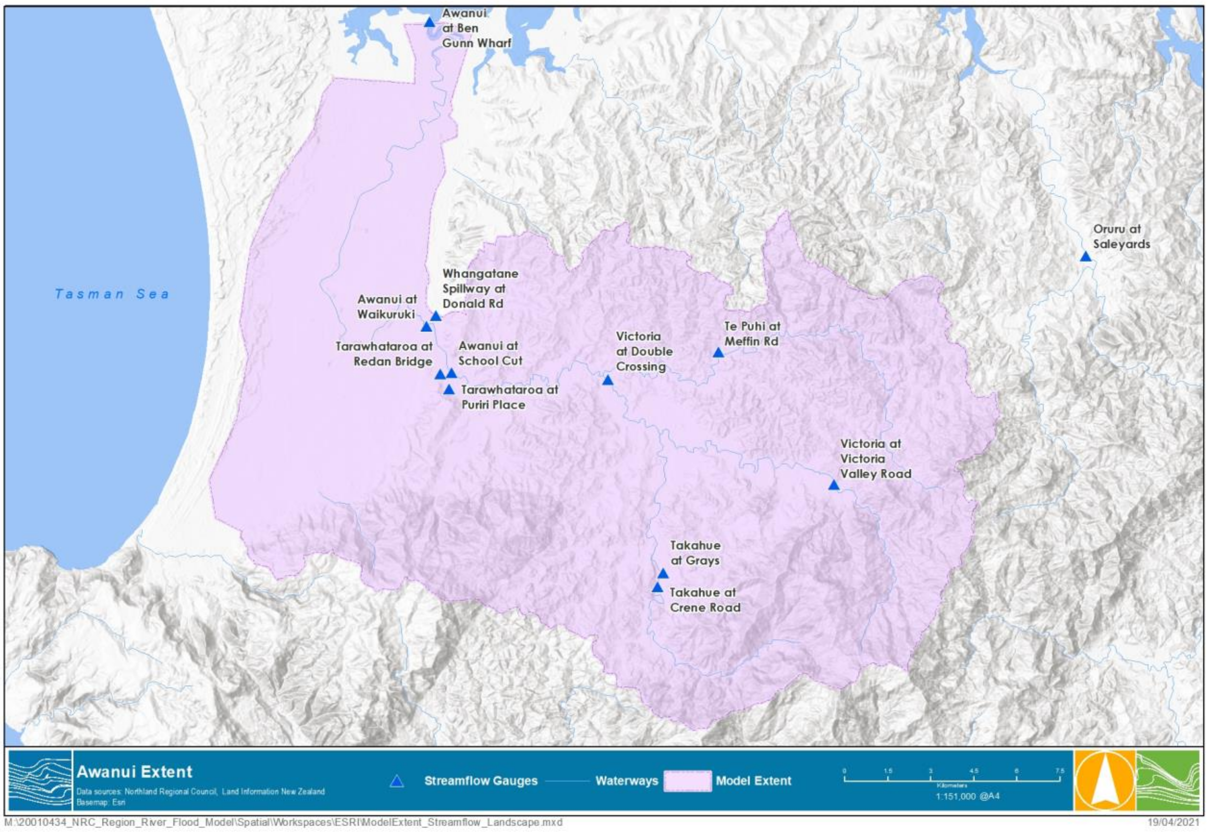

FIGURE 5-1 AVAILABLE STREAMFLOW GAUGES WITHIN AWANUI CATCHMENT

The modelled peak flow for the 1% AEP design flood was compared with hydrological estimates, including FFA, Rational Method and SCS 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.

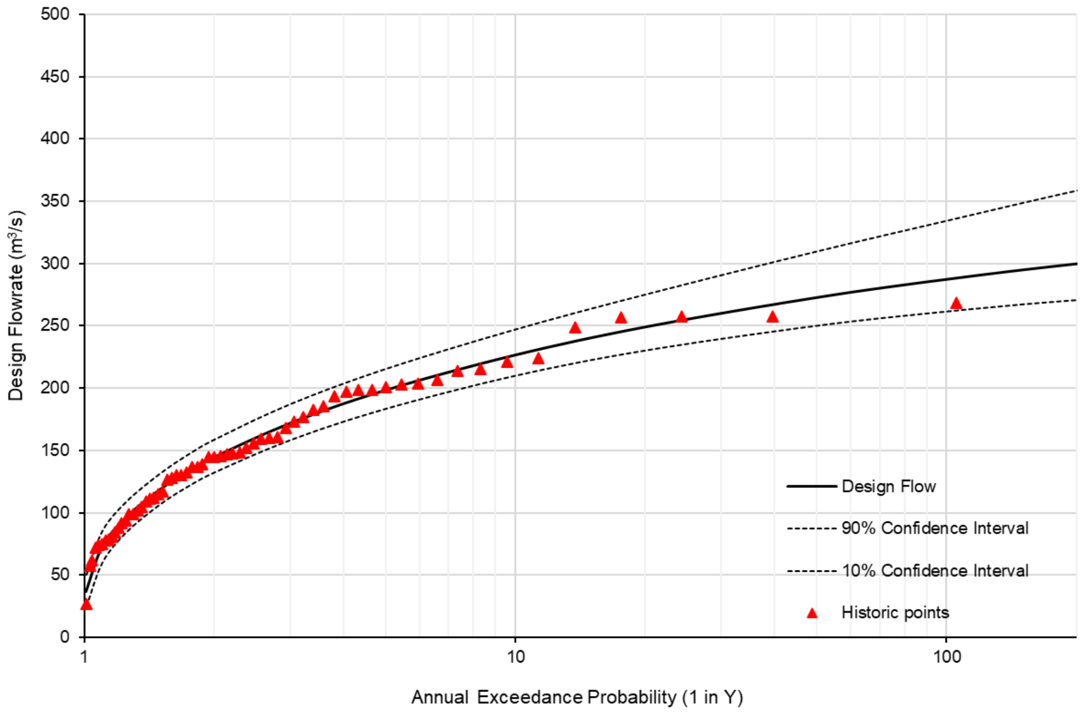

FIGURE 5-2 EXAMPLE OF FLOOD FREQUENCY CURVE OF LOG PEARSON III DISTRIBUTION FIT

5.2 Regional Estimation Methods

For catchments where a suitable streamflow gauge record was not available, additional estimation methods 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 and key flow line locations 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[5] 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).

[5] 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)[6].

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.

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 km^2.

[6]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 Awanui 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 are only applicable for relatively small catchments, with the SCS method limited to 12 km^2.The catchment sizes for these gauge locations range 30 to 220 km^2. These equations are therefore subject to great uncertainty in summarising catchment characteristics.

At the Tarawhataroa at Puriri Place gauge, the modelled design flow is significantly greater than all empirical estimates. In contrast, the modelled peak flow at Awanui at School Cut gauge tend 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. The use of gauge levels and empirical estimation methods provides further validation that the results produced in the study are fit for purpose of mapping riverine flood hazard zones across the entire Northland region and to update existing flood intelligence.

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	July 2020 peak	Highest on record	FFA	SCS	Rational method	NIWA – FF at gauge	NIWA – Rational method	NIWA – H&C 2018
Tarawhataroa at Puriri Place	12 hr	531.3	27.3	172.8	N/A*	41.6	28.5	230	192.5	72
Awanui at School Cut	12 hr	397.9	224.1	268.3	287.6	392.1	269.0	317	N/A	606

*14 years of records, FFA not applicable.

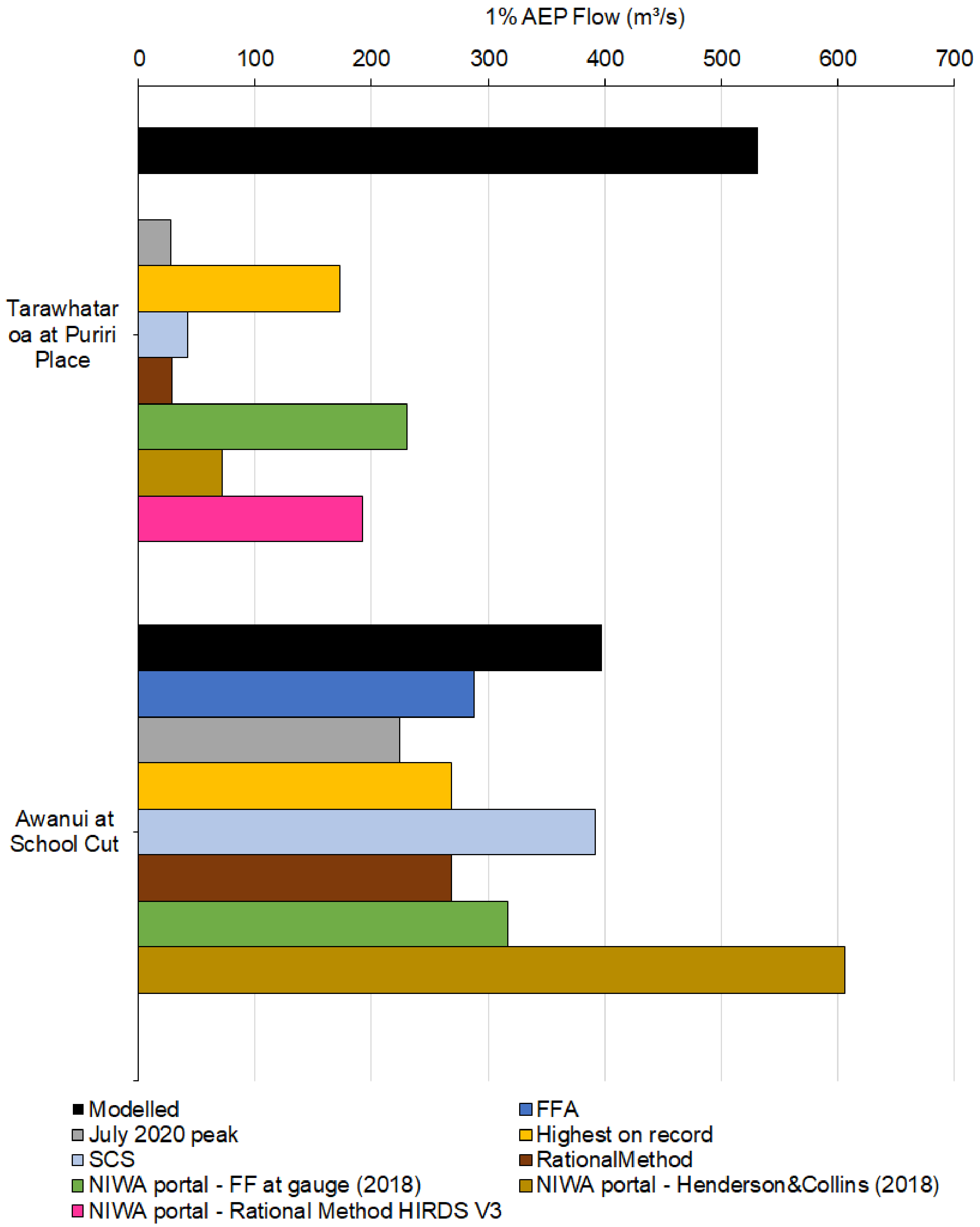

FIGURE 5-3 VERIFICATION OF DESIGN MODELLING RESULTS AGAINST HYDROLOGICAL ESTIMATES

6 SUMMARY

The Awanui catchment model (Awanui) was calibrated to the July 2020 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 was verified against several design flood estimation methods at Tarawhataroa at Puriri Place gauge and Awanui at School Cut gauge. The modelled design flows at Puriri Place gauge tends to overestimate the design flows while modelled design flows at School Cut gauge show a good match to the empirical design flow estimates. 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 availability of gauged flow records (where used) and general limitations with empirical design 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.