Design Modelling

Bay of Islands Coast Catchment (M07)

Northland Regional Council

16 October 2025

Document Status

Version	Doc type	Reviewed by	Approved by	Date issued
01	Draft	Bertrand Salmi	Ben Hughes	03/05/2021
02	Final	Bertrand Salmi	Ben Hughes	16/10/2025

Project Details

Project Name	Bay of Islands Coast Catchment (M07)
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Document Number	M07_20010434_R02V02_Validation_Report.docx

Cover Photo: Helen Beech (https://www.rnz.co.nz/news/national/350285/flooding-in-northland-forces-school-and-road-closures)

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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 calibration results and design modelling methodology for Bay of Islands Coast Catchment (M07), noting that this catchment was calibrated to the January 2011 flood event.

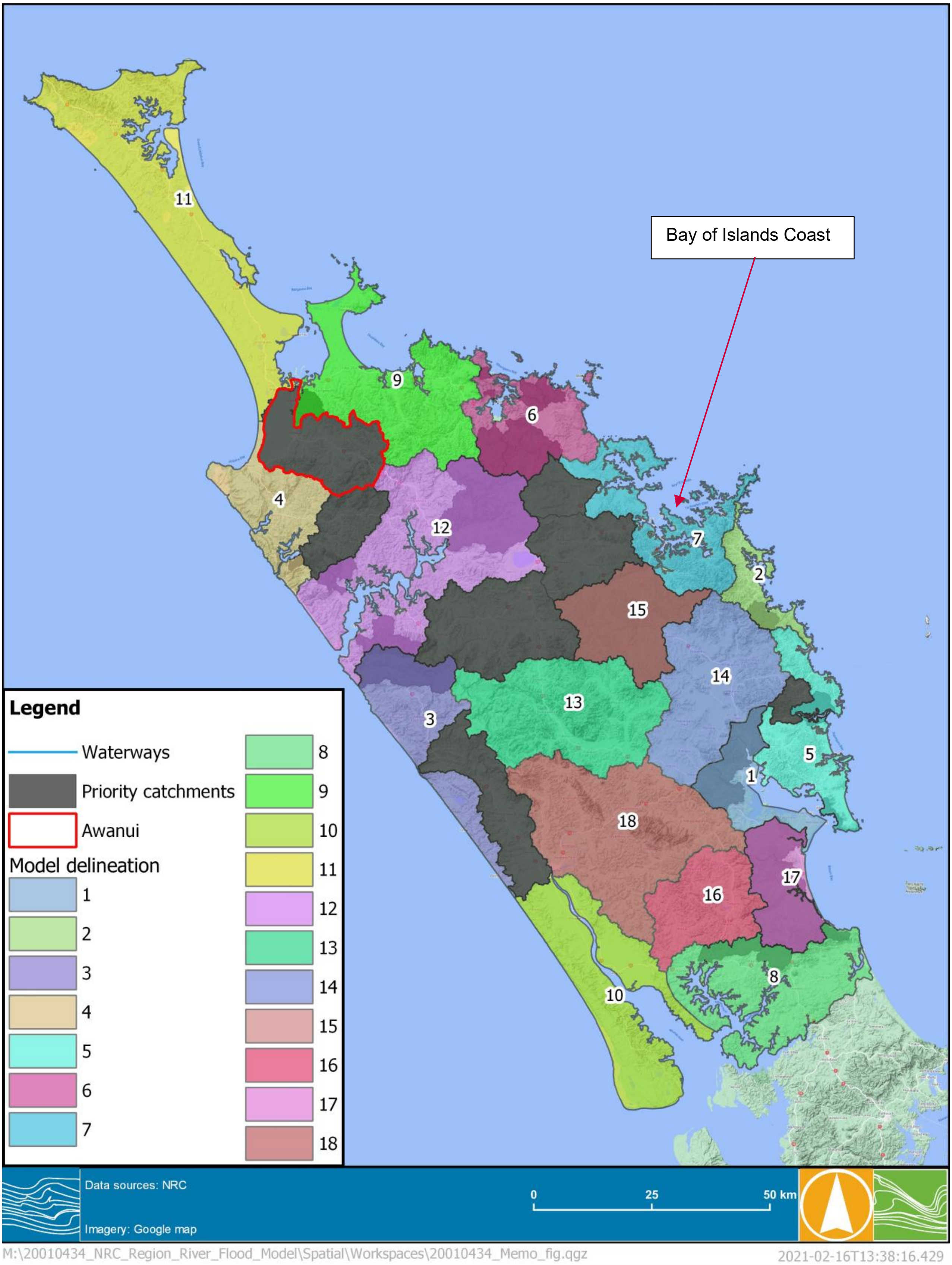

FIGURE 1-1 MODEL DELINEATION

2 STUDY AREA

The Model 07 catchment is coastal catchment, covering a total area of approximately 449 km^2 with several isolated islands but these small isolated islands were excluded in the modelling. The major waterways within the catchment include the Rangitane River and the Waikare River. There are several other small unnamed waterways and they all discharge into the bay. Figure 2-1 displays the study area of the catchment Model 07.

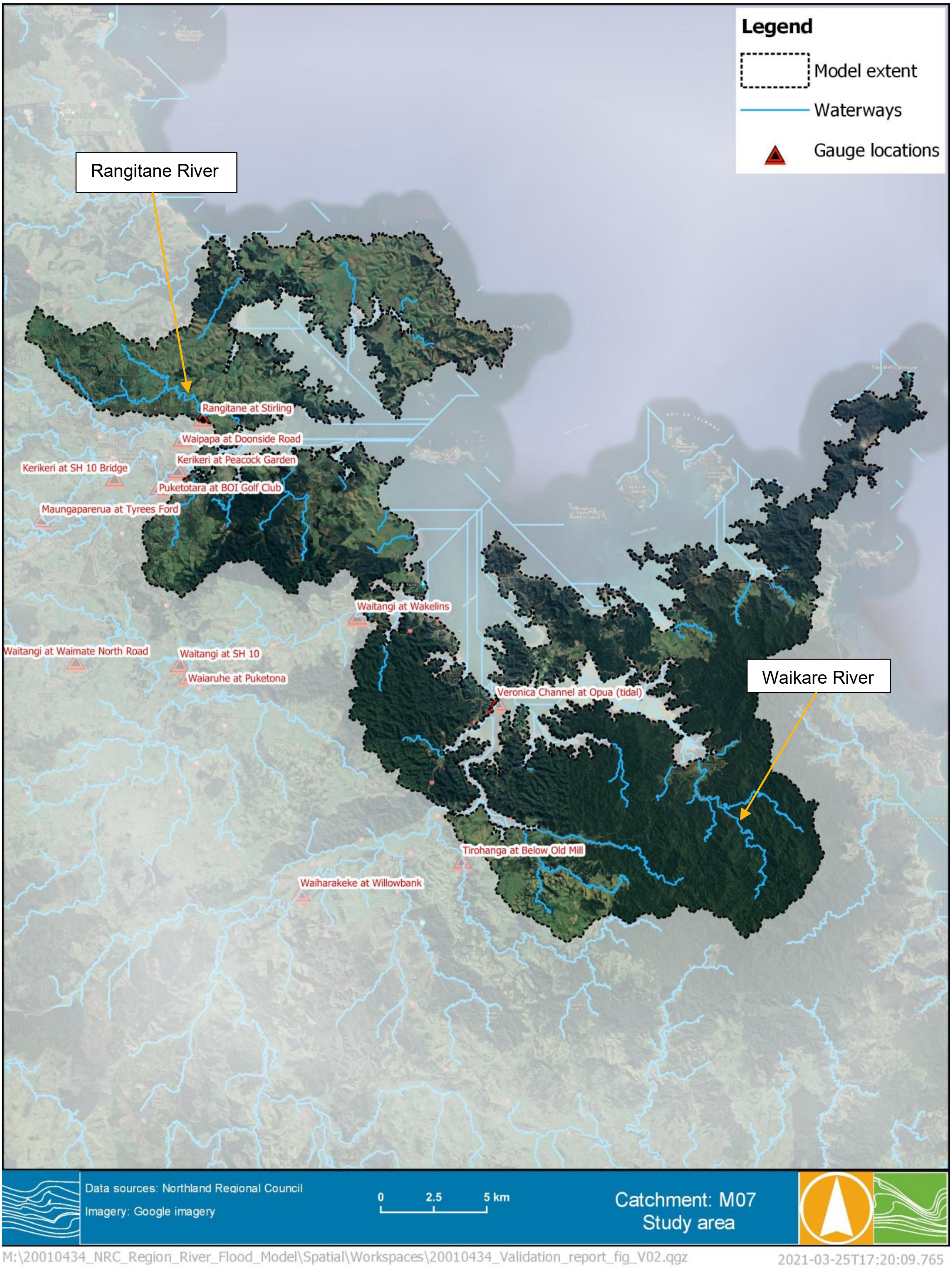

FIGURE 2-1 STUDY AREA

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.

Rangitane at Stirling is the only streamflow gauge found within the catchment. This gauge only has water level records. While there is no flow records and other flood information can be utilised, this model calibration strongly relied on matching the modelled levels to the gauged levels.

The calibration focused on calibrating the model to the larger rainfall event between 28th to 29th January. A relatively smaller event occurred 4 days before in 22nd to 24th January. The hydraulic model was also run for both events as a sensitivity test on how the preceding event impacts the model calibration. The sensitivity test shows the inclusion of the preceding event does not materially affect the calibration performance. Details can be referred to *Calibration Report*.

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 shows the modelled water levels compared to the gauged records.

The modelled levels at the Rangitane at Stirling gauge show a good match to the gauged records in terms of water level hydrograph shape, timing and peak level. The modelled peak was 1.5 hours later than that observed while the peak water level was slightly underestimated.

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 07

	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)
Rangitane@Stirling	114	N/A	N/A	1.5	3149	N/A	N/A	17.90	18.03	-127.60

TABLE 3-2 QUANTITATIVE ASSESSMENT OF JANURARY 2011 CALIBRATION FOR CATCHMENT MODEL 07

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)
Rangitane@Stirling	N/A	N/A	Y	N	N/A

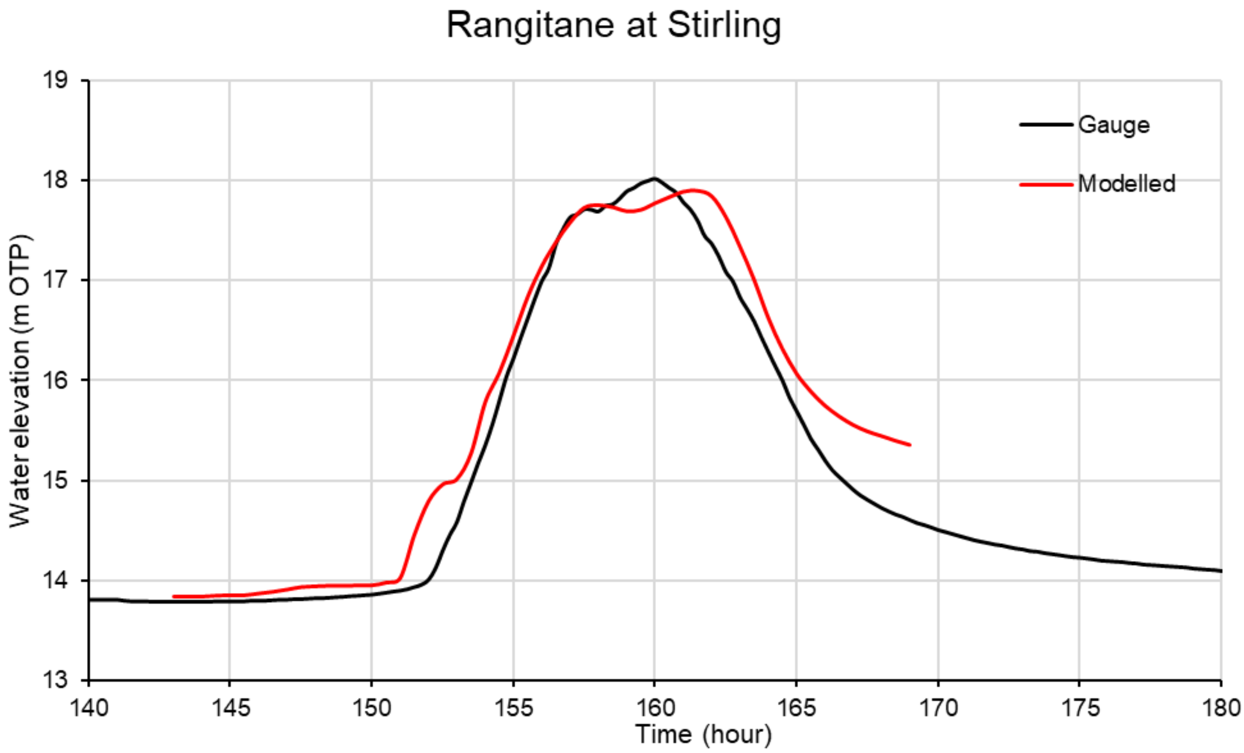

FIGURE 3-1 MODELLED AND GAUGED LEVELS AT KAEO AT WAIARE ROAD GAUGE

4 DESIGN MODELLING

4.1 Overview

A hydraulic model (TUFLOW) of the Bay of Islands Coast catchment (M07) 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 January 2011 event. 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 minutes 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, eight 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/

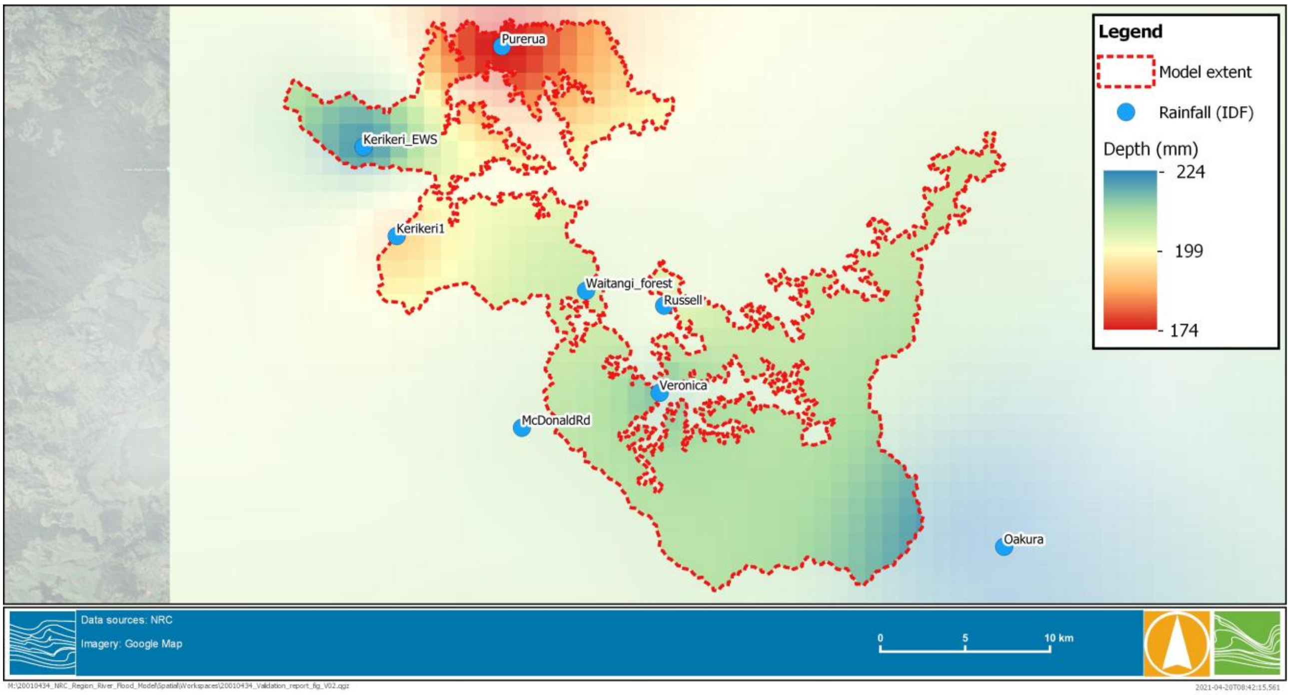

FIGURE 4-1 EXAMPLE OF DESIGN RAINFALL GRID (12-HOUR, 1% AEP RAINFALL) FOR M07

4.2.2 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**Error! Bookmark not defined.**. 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**Error! Bookmark not defined.**, 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
Kerikeri1_A53291	61	144	193	247
Kerikeri EWS_A53191	61	162	221	283
Oakura Bay at Te Kapua Street	79	175	224	281
Purerua AWS_ A54101	63	137	174	213
Russell_A54211	73	160	203	250
Veronica Channel at Opua_543111	73	167	215	266
Waitangi Forest_A54201	68	157	206	259
Waitangi at McDonaldsRd_543010	68	159	209	264

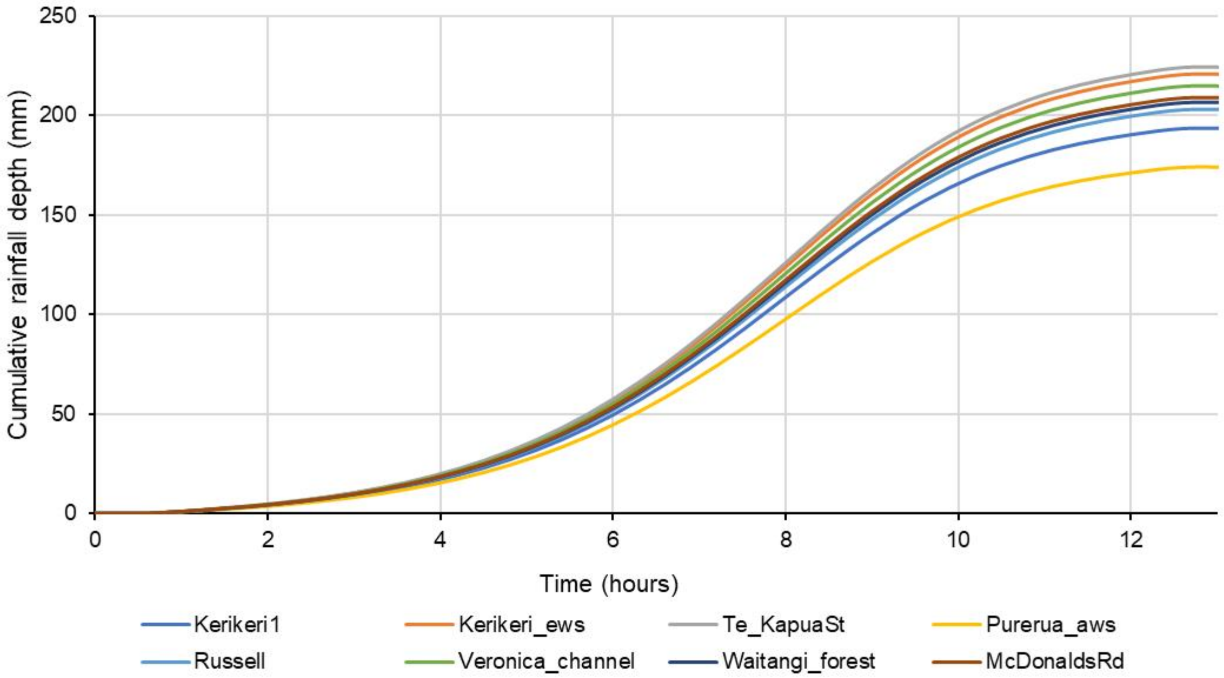

FIGURE 4-2 TEMPORAL PATTERN FOR DESIGN RAINFALL OF 12-HOUR, 1% AEP EVENT

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

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 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 M07 catchment	Forest	0.08	8	13
	Grassland	0.05	5	10
	Cropland – perennial	0.04	12	2
	Cropland – annual	0.04	12	2
	Wetland – open water	0.04	0	0
	Wetland – vegetated	0.05	10	1
	Urban areas	0.10	5	1.5
	Waterways	0.035	0	0.2
	Other	0.06	15	1.5

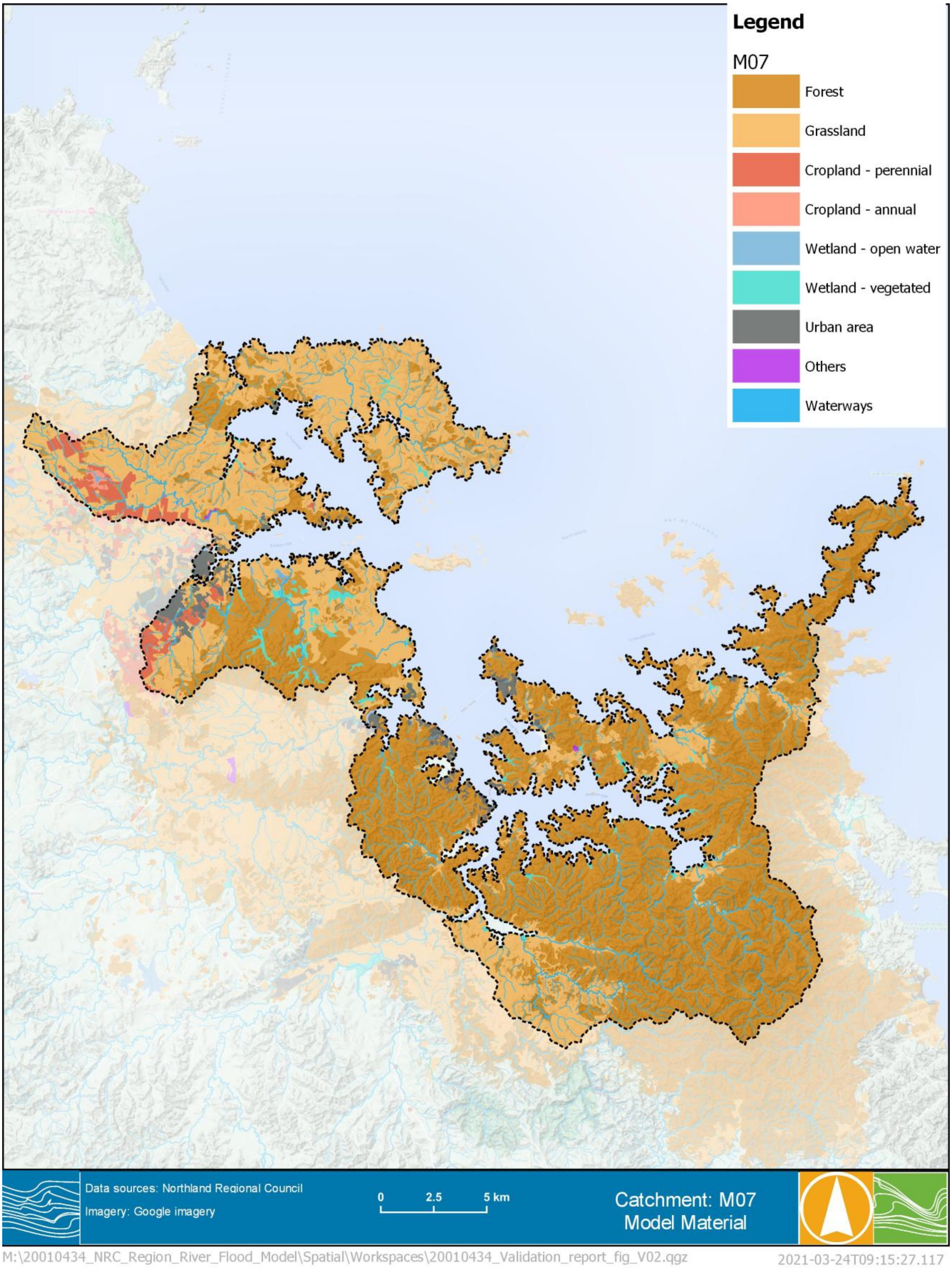

FIGURE 4-3 HYDRAULIC MODEL MATERIAL LAYER

4.2.4 Boundaries

As the Bay of Islands Coast catchment is a coastal catchment, a static tail-water (i.e. 1295 mm OTP) outflow boundary based on the 2 year ARI tide level[3] at Veronica Channel gauge was used 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, this boundary was a tidal boundary (i.e. type HT), using the tidal records during the event at Veronica Channel gauge.

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

[3] MWH, 2010 *Priority Rivers – Flow Assessment, Sea Level Rise and Storm Surge*, prepared for Norhland 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 2000m^2 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 M07. Figure 5-4 shows the flood depth map zoomed in at Waikare township 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

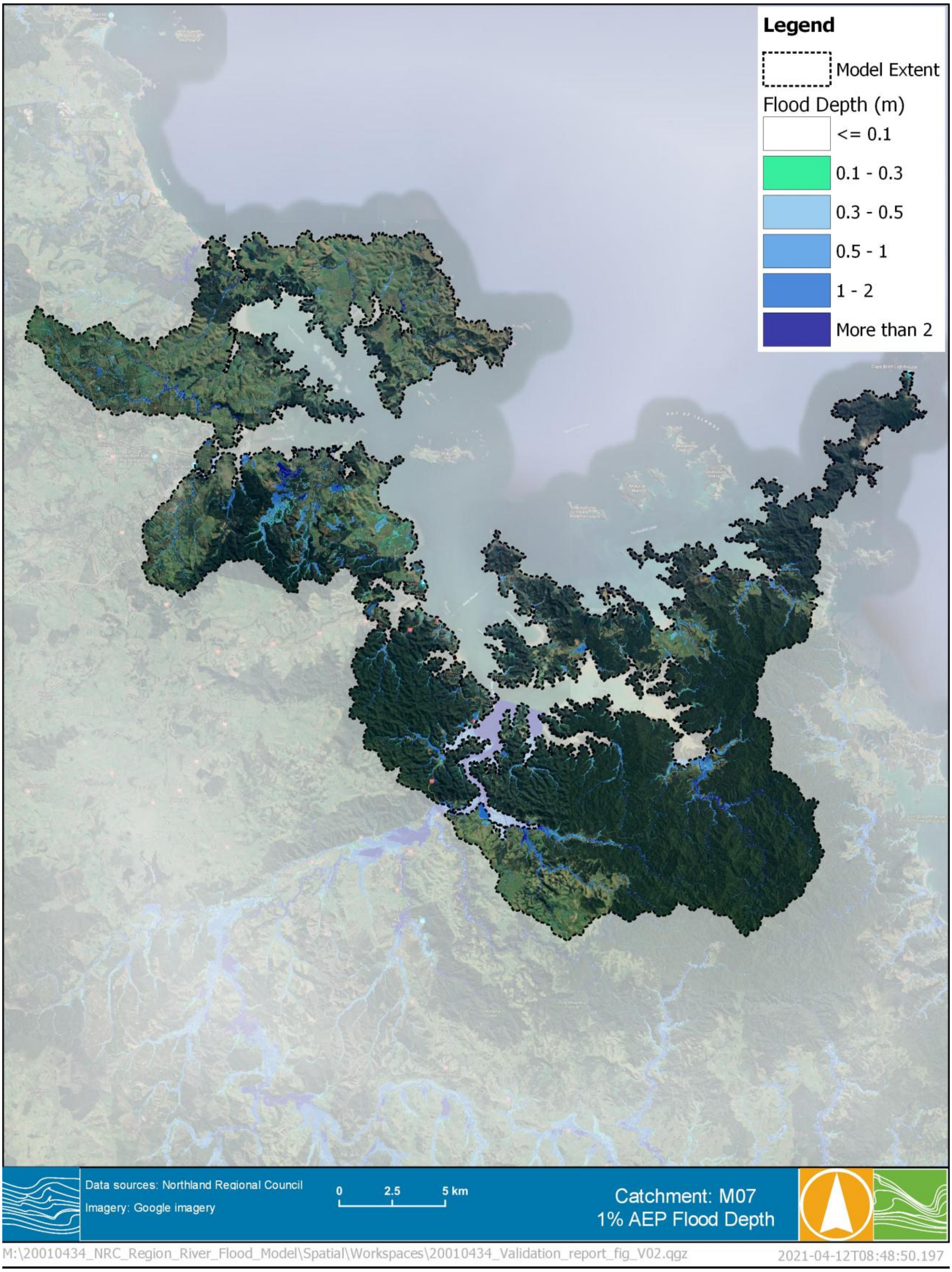

FIGURE 5-1 DESIGN MODELLING OF 1% FLOOD DEPTH

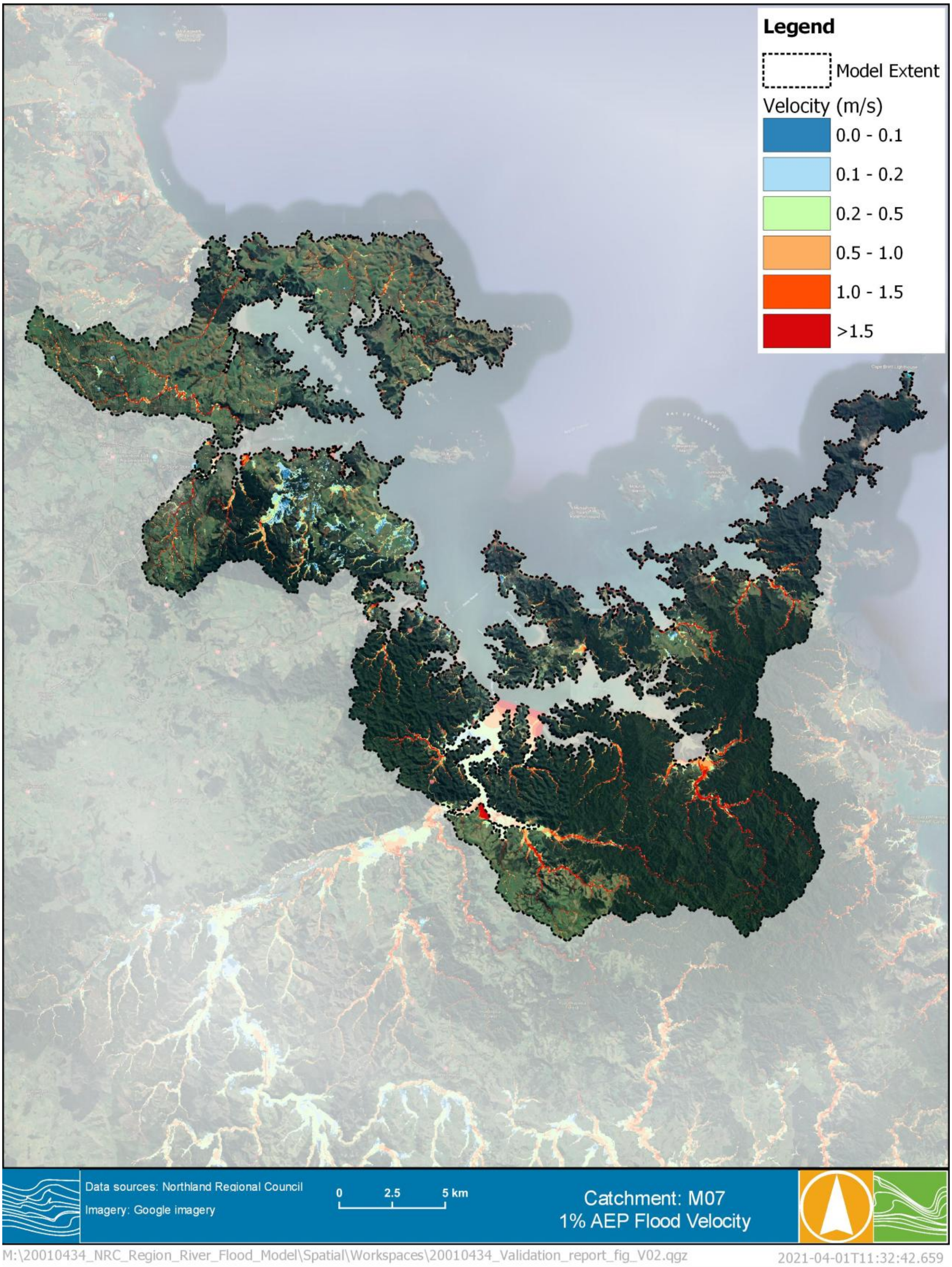

FIGURE 5-2 DESIGN MODELLING OF 1% AEP FLOOD VELOCITY

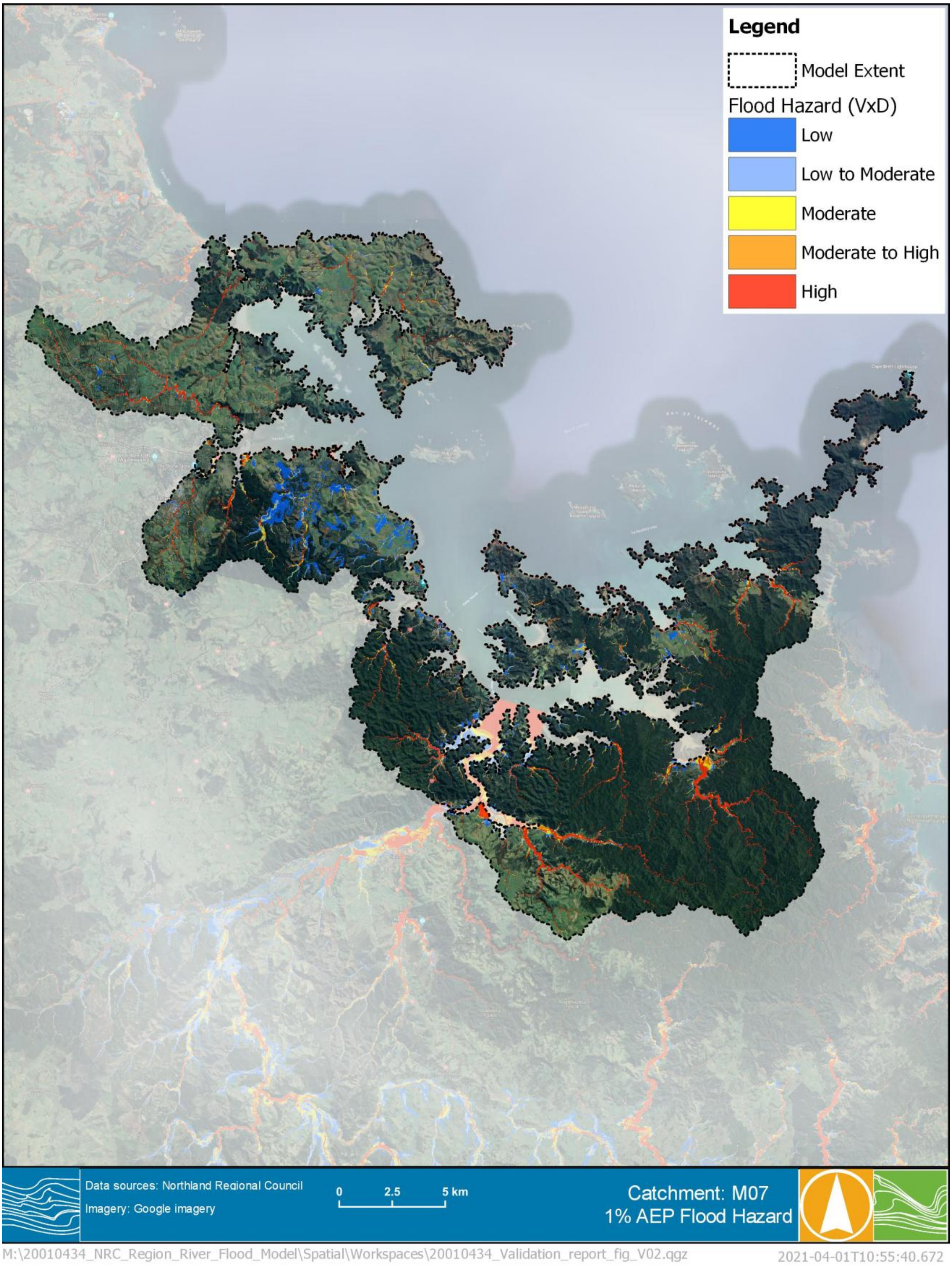

FIGURE 5-3 DESIGN MODELLING OF 1% AEP FLOOD HAZARD

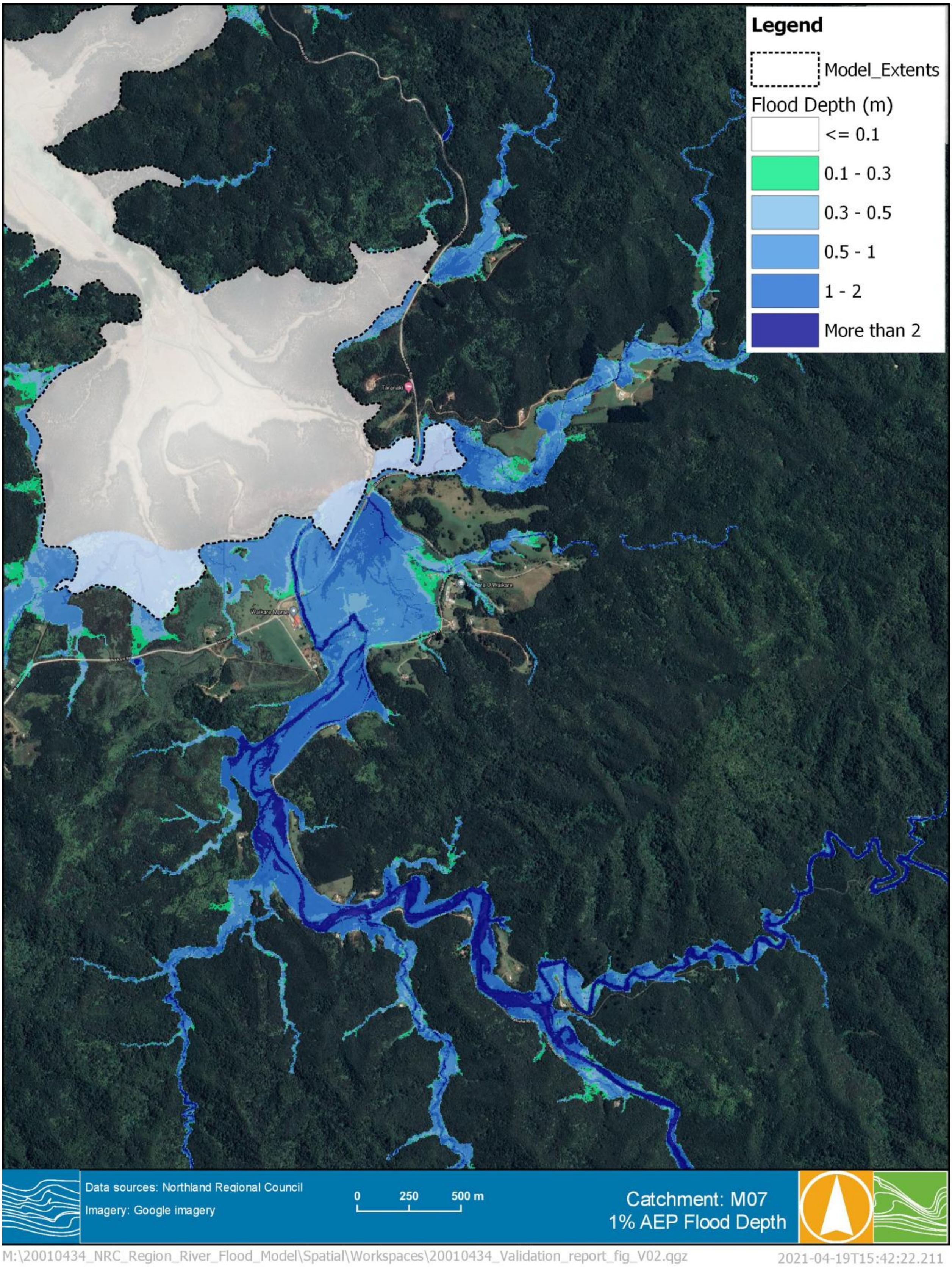

FIGURE 5-4 DESIGN MODELLING OF 1% AEP FLOOD DEPTH ZOOMED AT WAIKARE

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 streamflow gauges in the Bay of Islands Coast catchment. It should be noted that the Veronica Channel at Opua gauge is a tidal levels gauge and hence, it was not included in the verification.

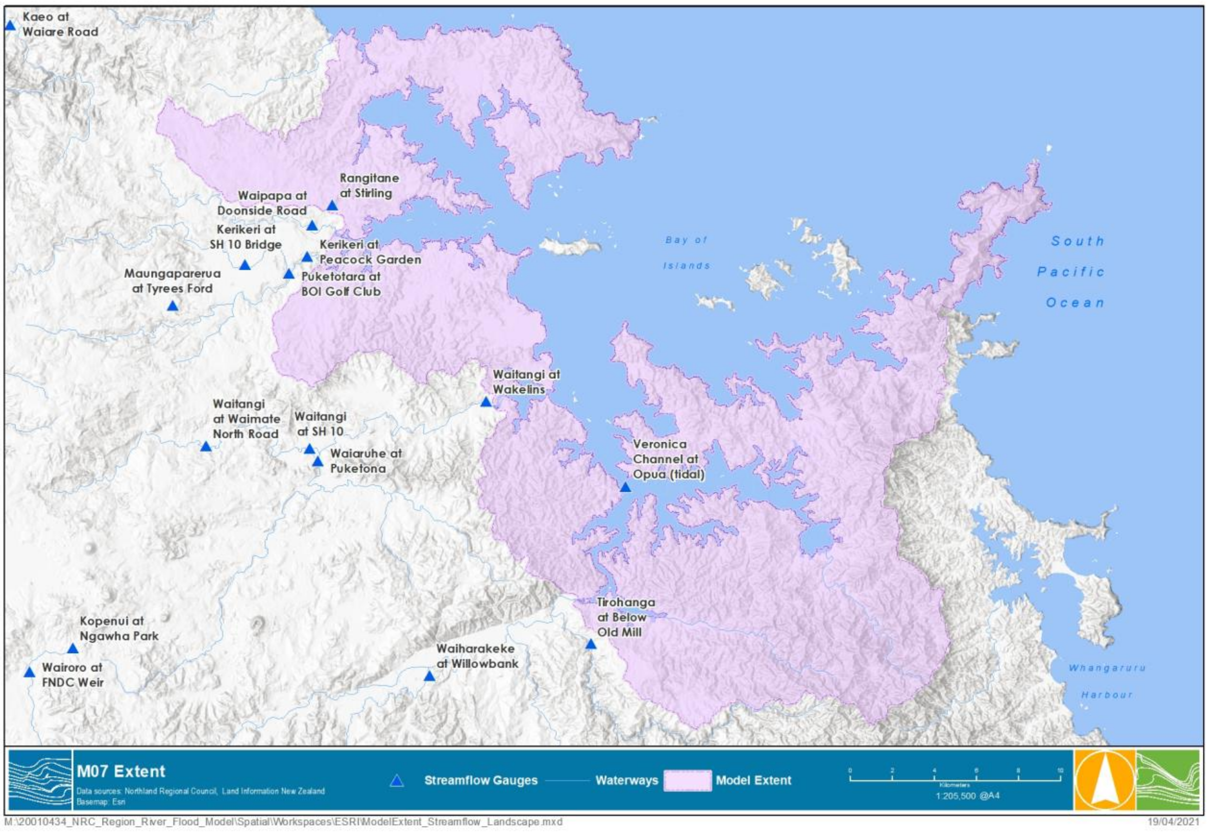

FIGURE 6-1 AVAILABLE STREAMFLOW GAUGES WITHIN BAY OF ISLANDS COAST CATCHMENT

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

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 portal[4] 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 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.

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

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[4] NIWA Flood Frequency tool, accessed via: https://niwa.co.nz/natural-hazards/hazards/floods
[5] 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

- A is the catchment area in km^2.

6.2 Verification Results

Table 6-1 summarises the comparison of 1% AEP peak flow estimates with the modelled values at streamflow gauging stations in the Bay of Islands Coast 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 km^2.The catchment size for Rangitane at Stirling gauge is 23 km^2. These equations are therefore subject to great uncertainty in summarising catchment characteristics.

At the Rangitane at Stirling gauge, the modelled design flow has a good match to the two NIWA estimates while the other two empirical estimates tend to underestimate the design flow. It should be noted that this gauge does not provide any historic flow records.

The use of empirical method estimations provides an additional degree of verification for streamflow gauges with no historic flow records. Overall, the modelled peak flow at this gauge tends to sit within a reasonable range of the design flow estimates.

TABLE 6-1 SUMMARY OF 1% AEP PEAK FLOW COMPARISON

Gauge location	Hydraulic model (m^3/s)		Empirical estimates (m^3/s)		NIWA Flood Frequency Tool 2018 (m^3/s)	
	Critical duration	Modelled peak	SCS	Rational method	NIWA – Rational method	NIWA – H&C 2018
Rangitane at Stirling*	6 hr	193	58.3	60.7	150.6	177

*This gauge has no flow record available.

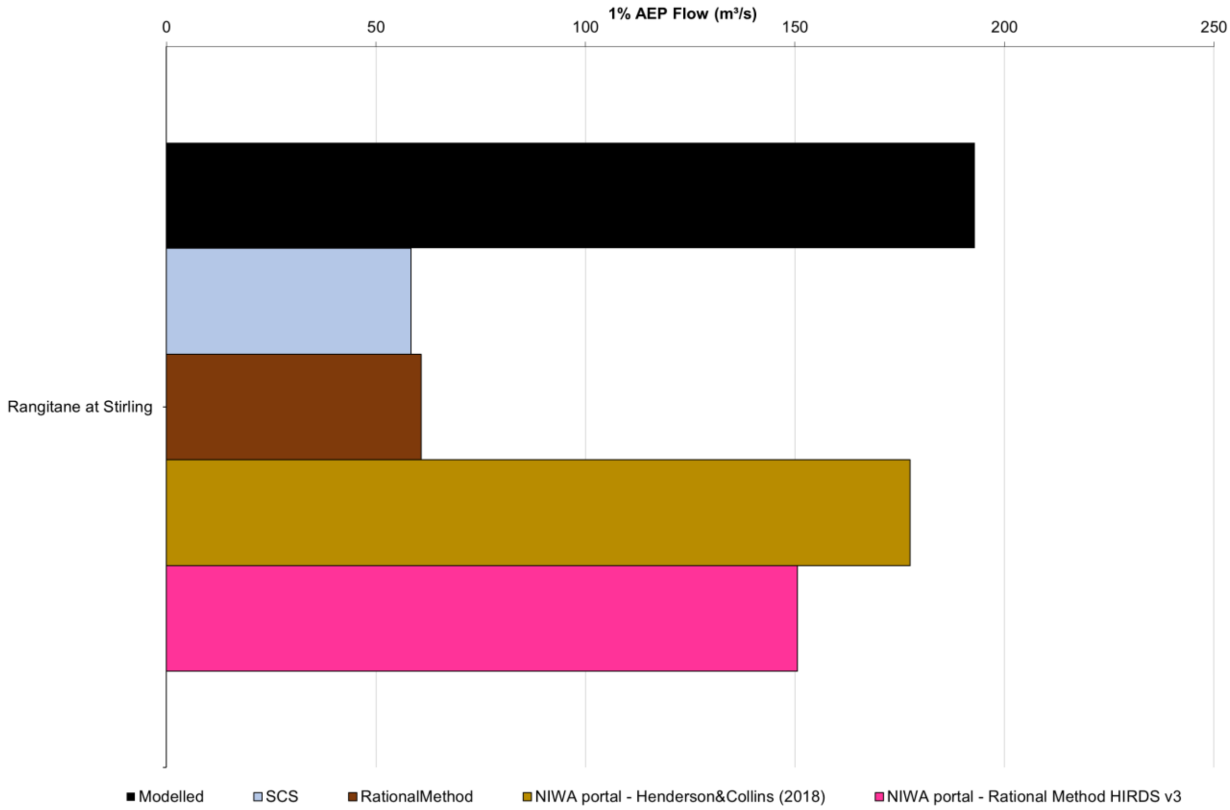

FIGURE 6-2 VERIFICATION OF DESIGN MODELLING RESULTS AGAINST HYDROLOGICAL ESTIMATES

7 SUMMARY

The Bay of Islands Coast catchment model (M07) was calibrated to 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 flow was verified against several design flood estimation methods at Rangitane at Stirling gauge. It is noted that FFA and historic maxima are not applicable as this gauge has no historic flow records. 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. Overall, the modelled design flow at Rangitane at Stirling 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.