Design Modelling

Kaeo Catchment (M06)

Northland Regional Council

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 PROJECT OVERVIEW

Overview

Water Technology was commissioned by Northland Regional Council (NRC) to undertake a region-wide flood modelling study. The study area encompasses 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 is to map river flood hazard zones across the entire Northland region and update existing flood intelligence.

Modelling approach

This project uses a 2D Direct Rainfall (also known as Rain on Grid) approach for hydraulic modelling and will provide flood extents for a defined range of design storms. The modelling software TUFLOW has been used to build hydraulic models for the region. TUFLOW is a widely used software package that is suitable for the analysis of flooding. The TUFLOW model routes overland flows across the 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, 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 the design modelling methodology for Whangaroa (East and West) and Kaeo Catchments (M06), noting that this catchment was calibrated to the January 2011 flood event.

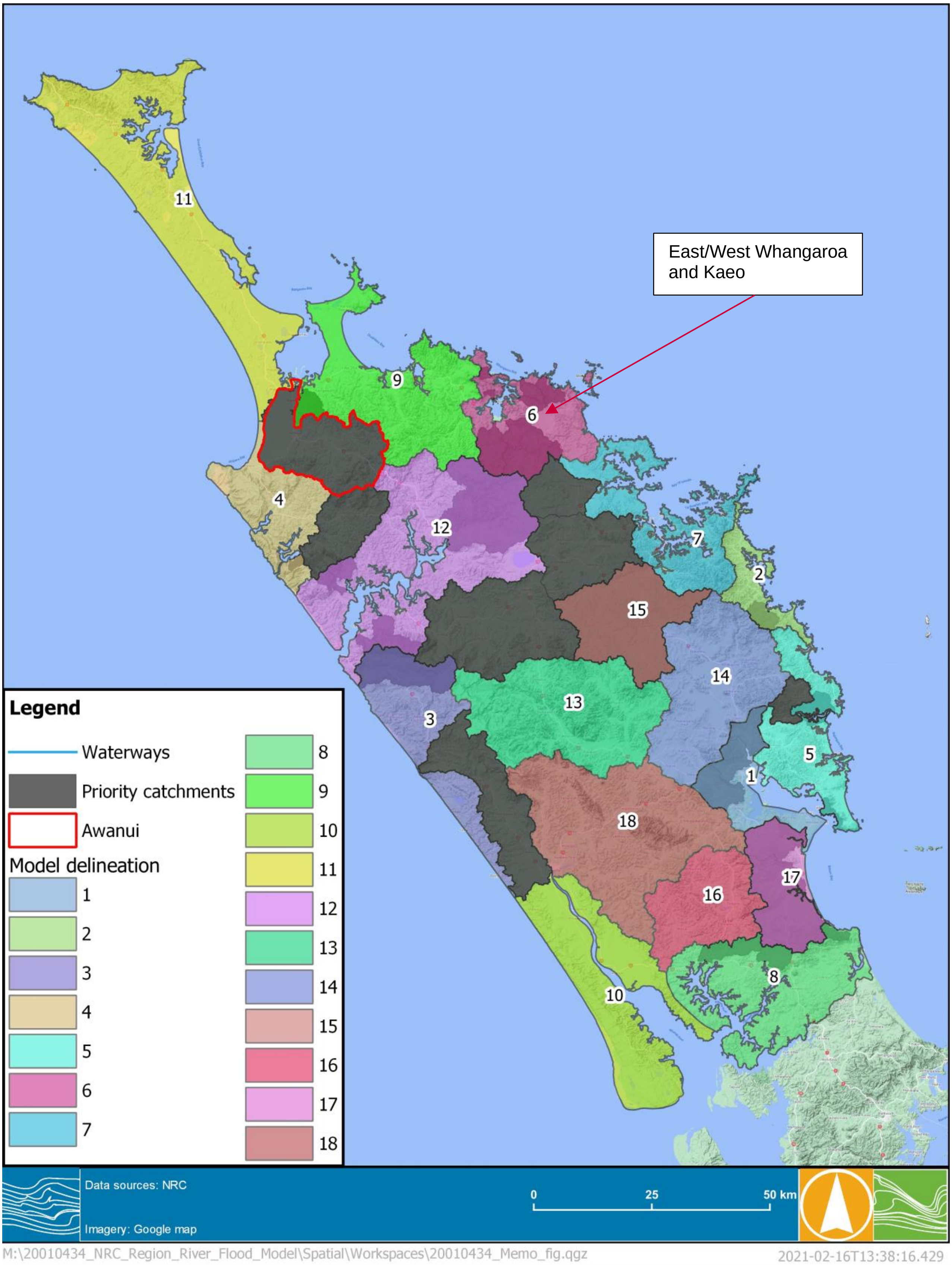

FIGURE 1-1 MODEL DELINEATION

2 STUDY AREA

The Model 06 catchment is mountainous to the south and coastal to the north, consists of the Whangaroa and Kaeo catchments, covering a total area of approximately 445 km^2 with several small towns, such as Matauri Bay, Kaeo and Whangaroa. The major waterways within the catchment include Kaeo River, Pupuke River, Takou River and Hikurua River. The Kaeo River and Pupuke River run toward Wangaroa Bay to the north while Hikurua River joins Takou River before draining into Takou Bay to the east. Figure 2-1 displays the study area of the catchment Model 06.

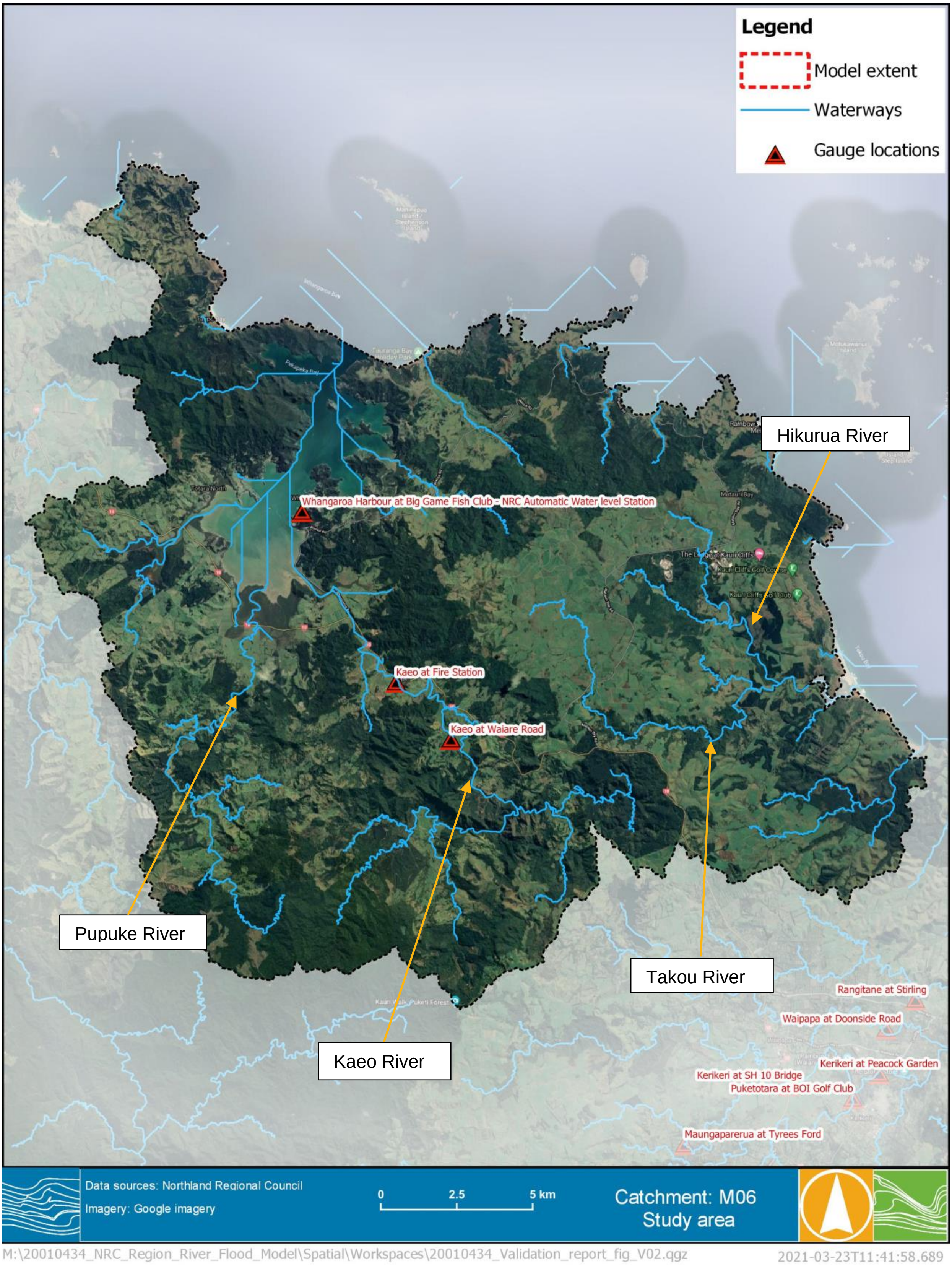

FIGURE 2-1 STUDY AREA

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.

The streamflow gauges used for model calibration are Kaeo at Waiare Road and Kaeo at Fire Station. Waiare Road gauge has both flow and water level records while Fire Station gauge only has water level records for the January 2011 event.

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 to Figure 3-3 show the modelled flows/water levels compared to the gauged records.

The modelled results at the Kaeo at Waiare Rd gauge show a good match to the gauged records for the water level hydrograph shape, timing and peak water level. The modelled peaks were less than 2 hours earlier than that observed while the peak water level was slightly underestimated. In contrast, the modelled flow volume and peak flow were significantly overestimated. However, if the modelled flows extracted within the river channel, a better match to the gauged records could be obtained as shown in Figure 3-2. This demonstrates that there is uncertainty in the gauged rating curve.

The modelled water levels at the Kaeo at Fire Station show a good match to that recorded at the gauge. The modelled peak water level was 155mm higher that observed and was only slightly more than an hour earlier.

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

TABLE 3-1 SUMMARY OF CALIBRATION RESULTS FOR CATCHMENT MODEL 06

	Peak flow (m^3/s)			Time to peak diff. (hour)	Volume (ML)			Peak WSE (m OTP)		
Location	Modelled	Gauged	Diff.		Modelled	Gauged	Diff.	Modelled	Gauged	Diff. (mm)
Kaeo@WaiareRd	298	210	42.07%	-1.8	10513	7891	33.23%	11.34	11.59	-248.40
Kaeo@FireStation	68	N/A		-1.25	3539	N/A	N/A	5.07	4.91	155.90

TABLE 3-2 QUANTITATIVE ASSESSMENT OF JANURARY 2011 CALIBRATION FOR CATCHMENT MODEL 06

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)
Kaeo@WaiareRd	N	N	Y	N	N
Kaeo@FireStation	N/A	N/A	Y	N	N/A

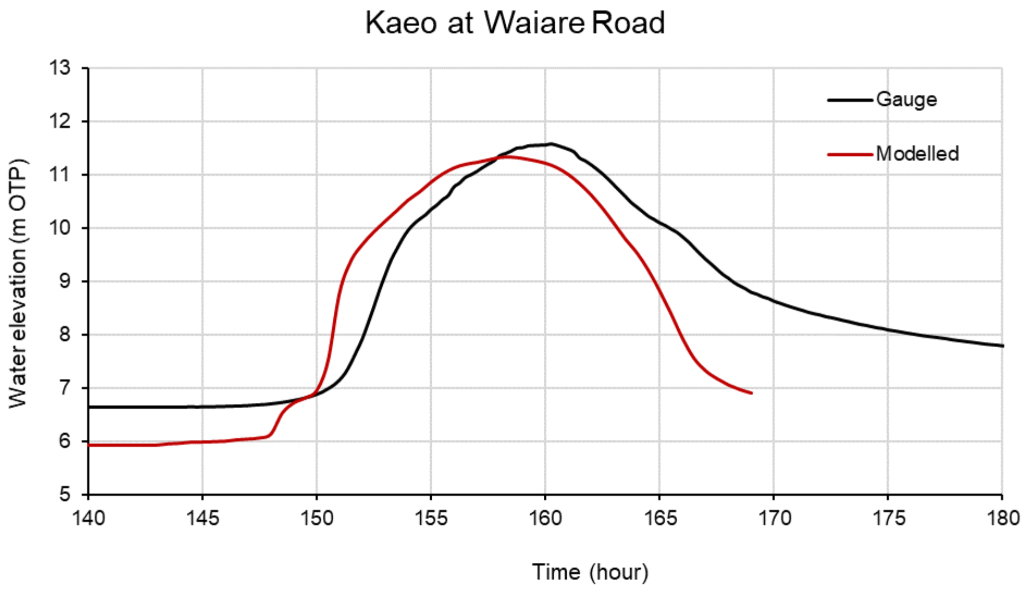

FIGURE 3-1 MODELLED AND GAUGED LEVELS AT KAEO AT WAIARE ROAD GAUGE

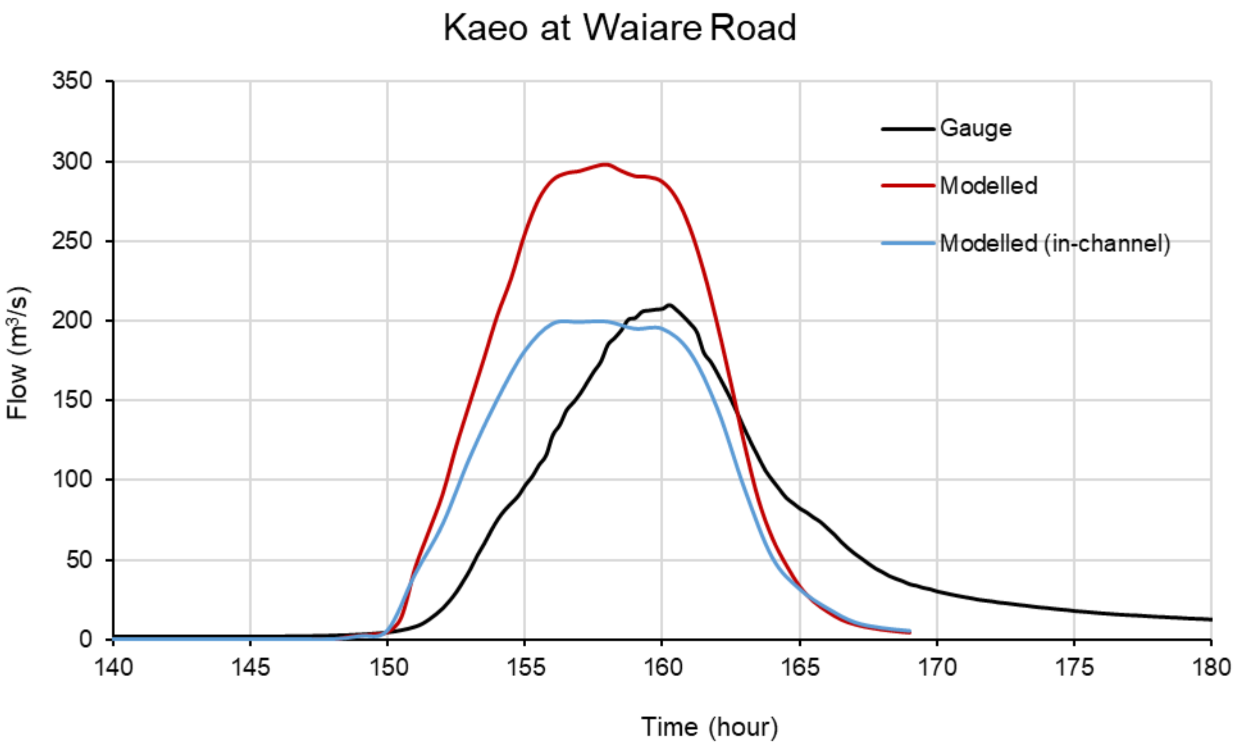

FIGURE 3-2 MODELLED AND GAUGED FLOWS AT KAEO AT WAIARE ROAD GAUGE

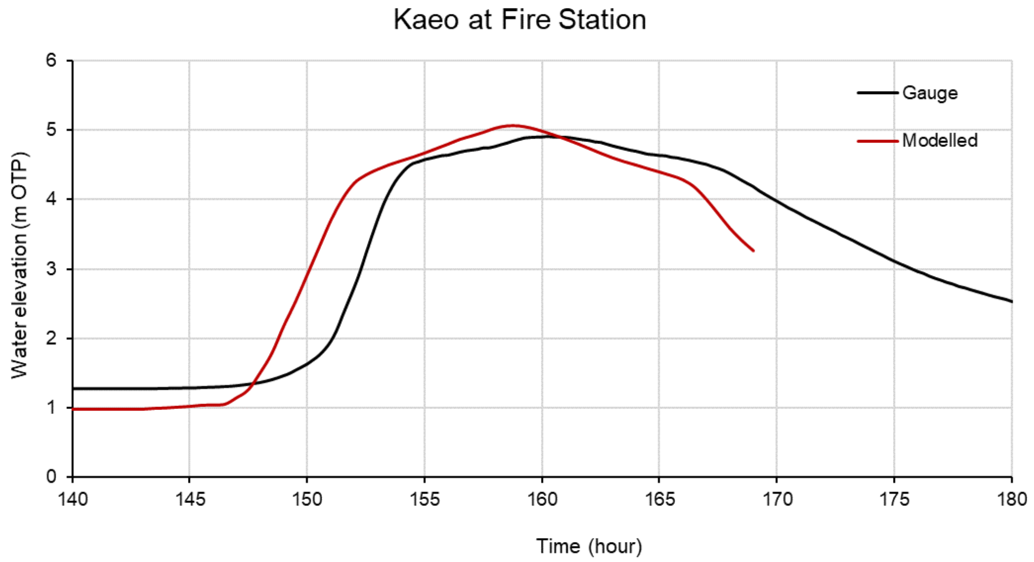

FIGURE 3-3 MODELLED AND GAUGED LEVELS AT KAEO AT FIRE STATION GAUGE

4 DESIGN MODELLING

4.1 Overview

A range of storm durations was run and results for each AEP event has been enveloped to ensure the critical duration is well represented across each part of the study area. The merged results will capture the maximum flood level and depth of the range of design events modelled.

Table 4-1 and the sections below show key modelling information used in the development of this 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 4.2.2
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 have been adopted, based on the calibration to the January 2011 event. Details of these are outlined below.

4.2.1 Rainfall Intensity-Duration-Frequency

Intensity-Duration-Frequency (IDF) tables have been 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, seven 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 of the 1% AEP event along with the rainfall gauge locations used to create the grid.

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

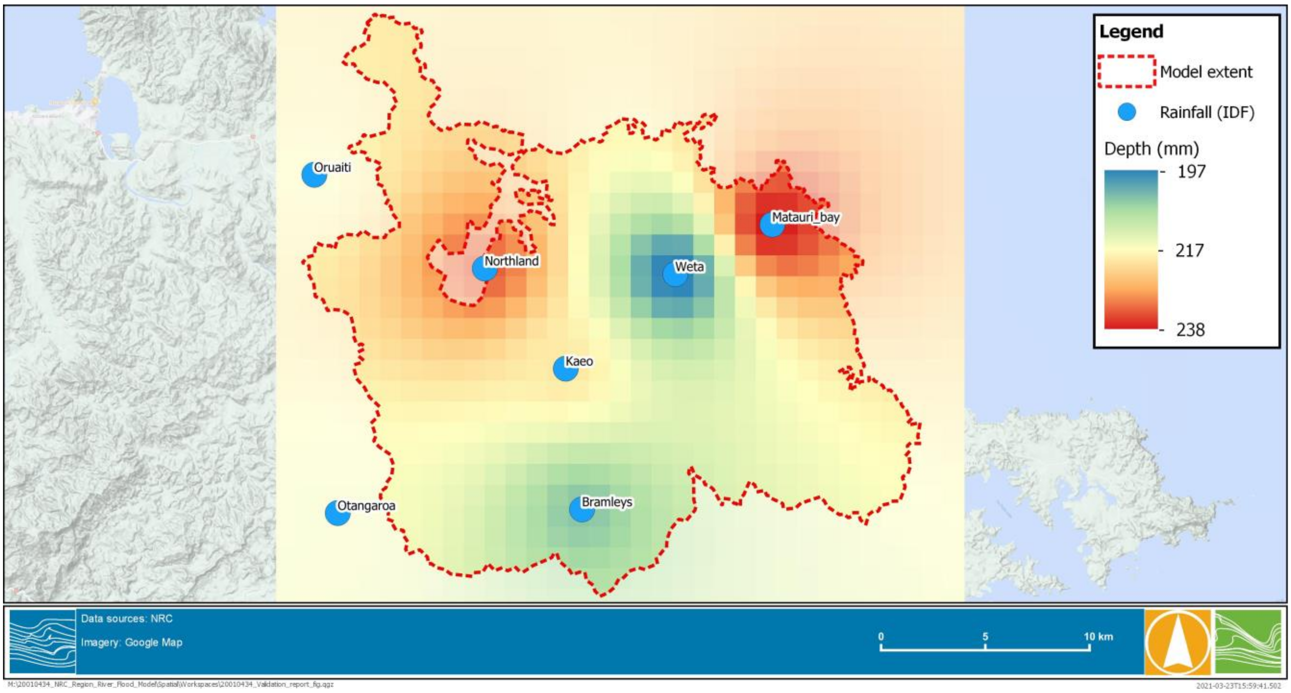

FIGURE 4-1 EXAMPLE OF DESIGN RAINFALL GRID (12-HOUR, 1% AEP RAINFALL) FOR M06

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[2]. 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[2], 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
Kaeo_A53171	63	157	215	283
Kaeo Bramleys_531717	67	171	230	298
Kaeo Northland_A53071	61	150	202	259
MatauriBay_A53081	70	155	197	240
Oruaiti_A53061	63	160	217	286
Touwai at Weta_531718	71	178	239	307
Waipapa at Otangaroa_531610	64	161	218	288

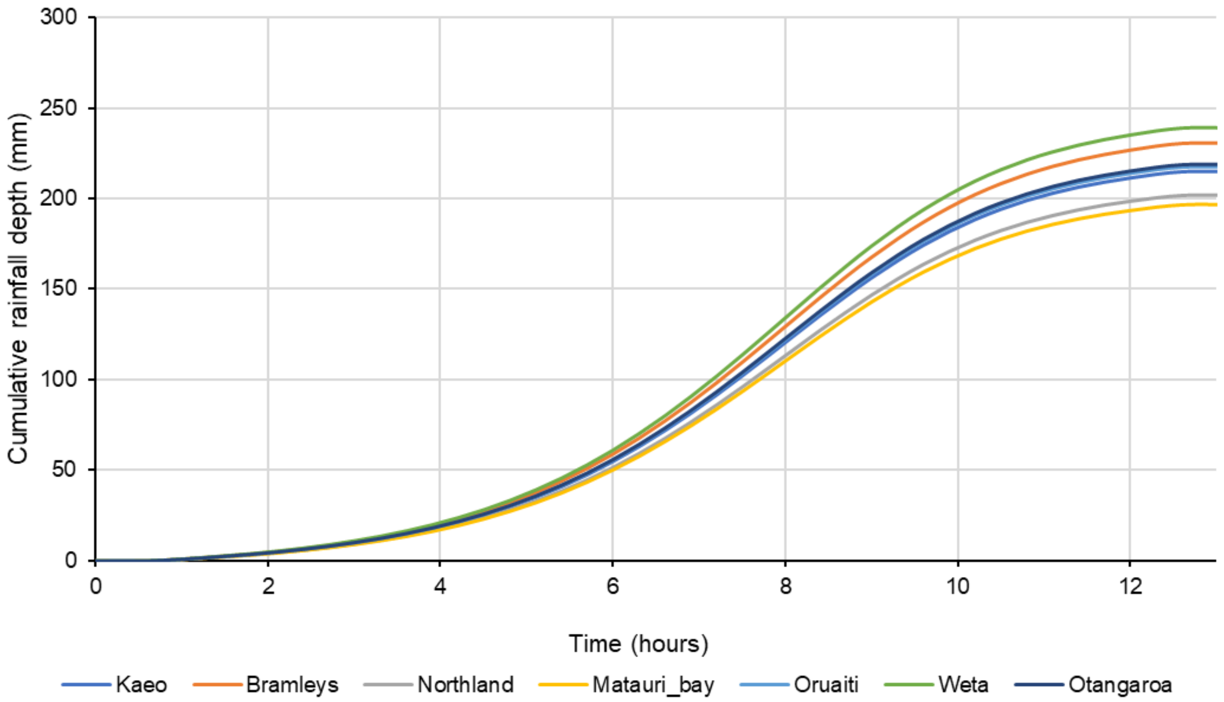

FIGURE 4-2 TEMPORAL PATTERN FOR DESIGN RAINFALL OF 12-HOUR, 1% AEP EVENT

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 M06 catchment	Forest	0.08	10	4
	Grassland	0.04	8	3
	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	0.06	0	0
	Other	0.06	15	1.5

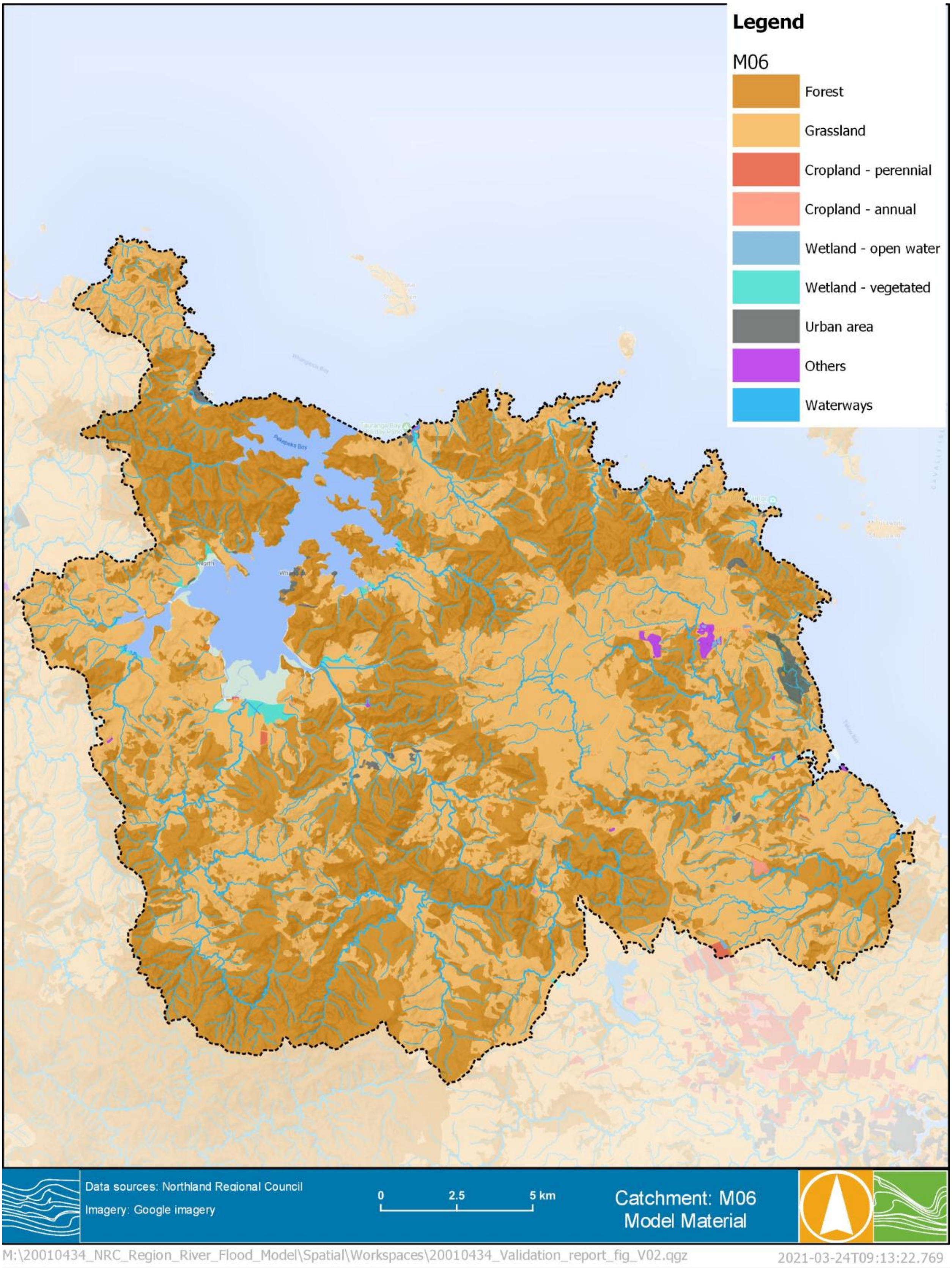

FIGURE 4-3 HYDRAULIC MODEL MATERIAL LAYER

4.2.4 Boundaries

The downstream boundary of catchment M06 is a coastal boundary, 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 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 level records during the event at Big Game Fish Club 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

The design modelling consists 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 is well represented across each part of the catchment. Each model run produces gridded results, including depth, water surface elevation (WSE), flood hazard (Z0) and velocity. Several post-processing steps are 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 2000 m^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 M06. Figure 5-4 shows the flood depth map zoomed in at Kaeo 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

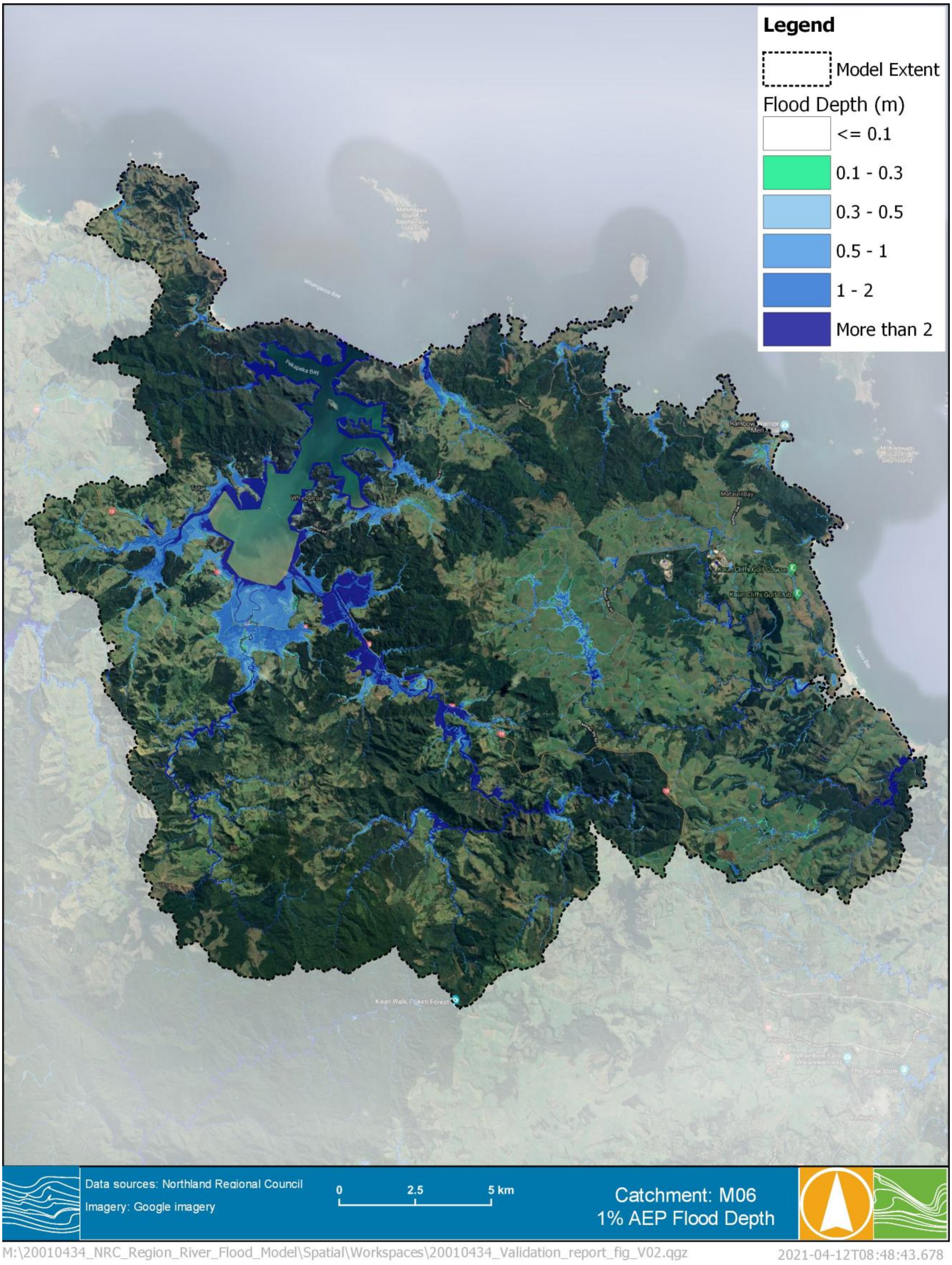

FIGURE 5-1 DESIGN MODELLING OF 1% AEP FLOOD DEPTH

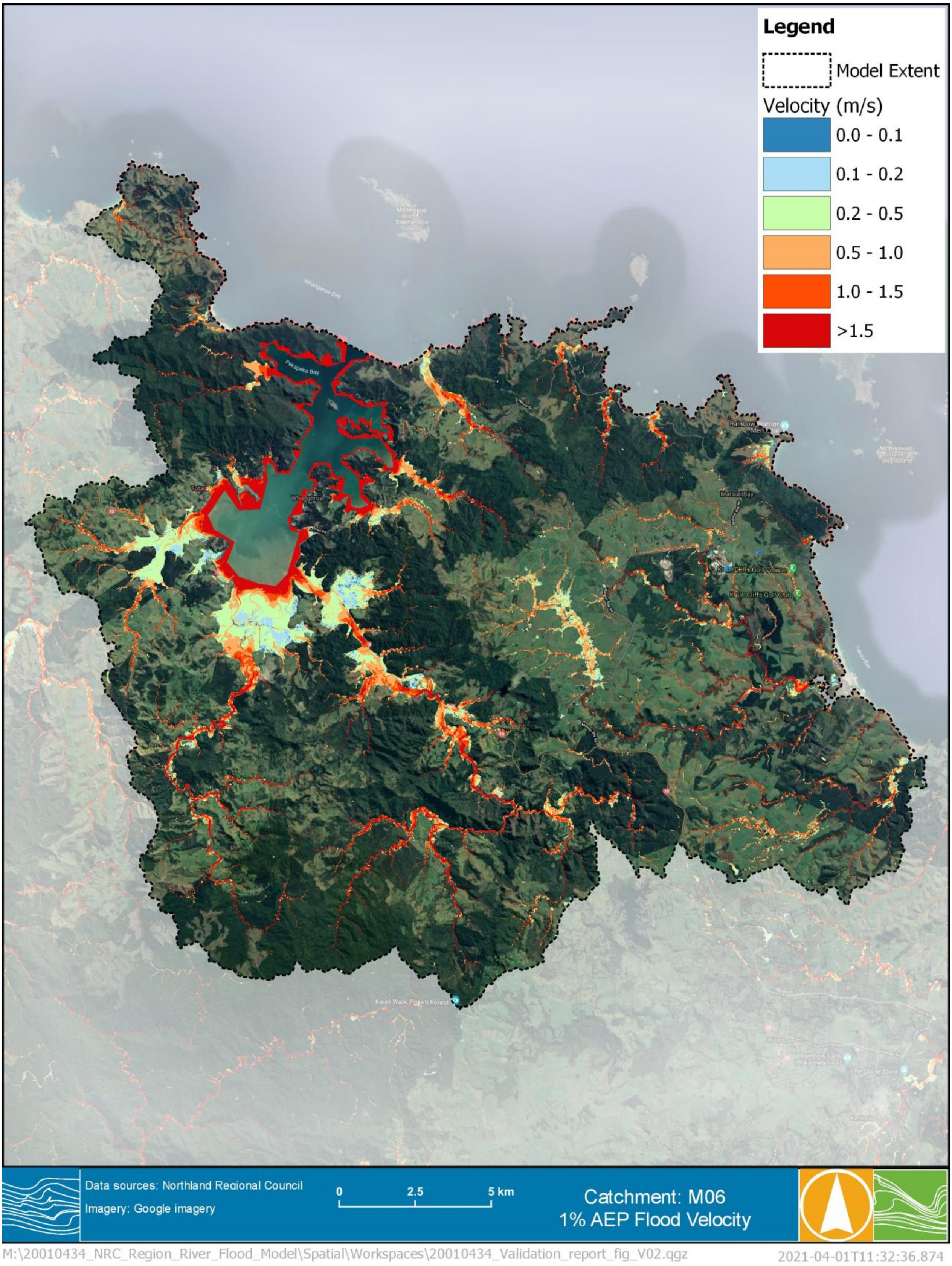

FIGURE 5-2 DESIGN MODELLING OF 1% AEP FLOOD VELOCITY

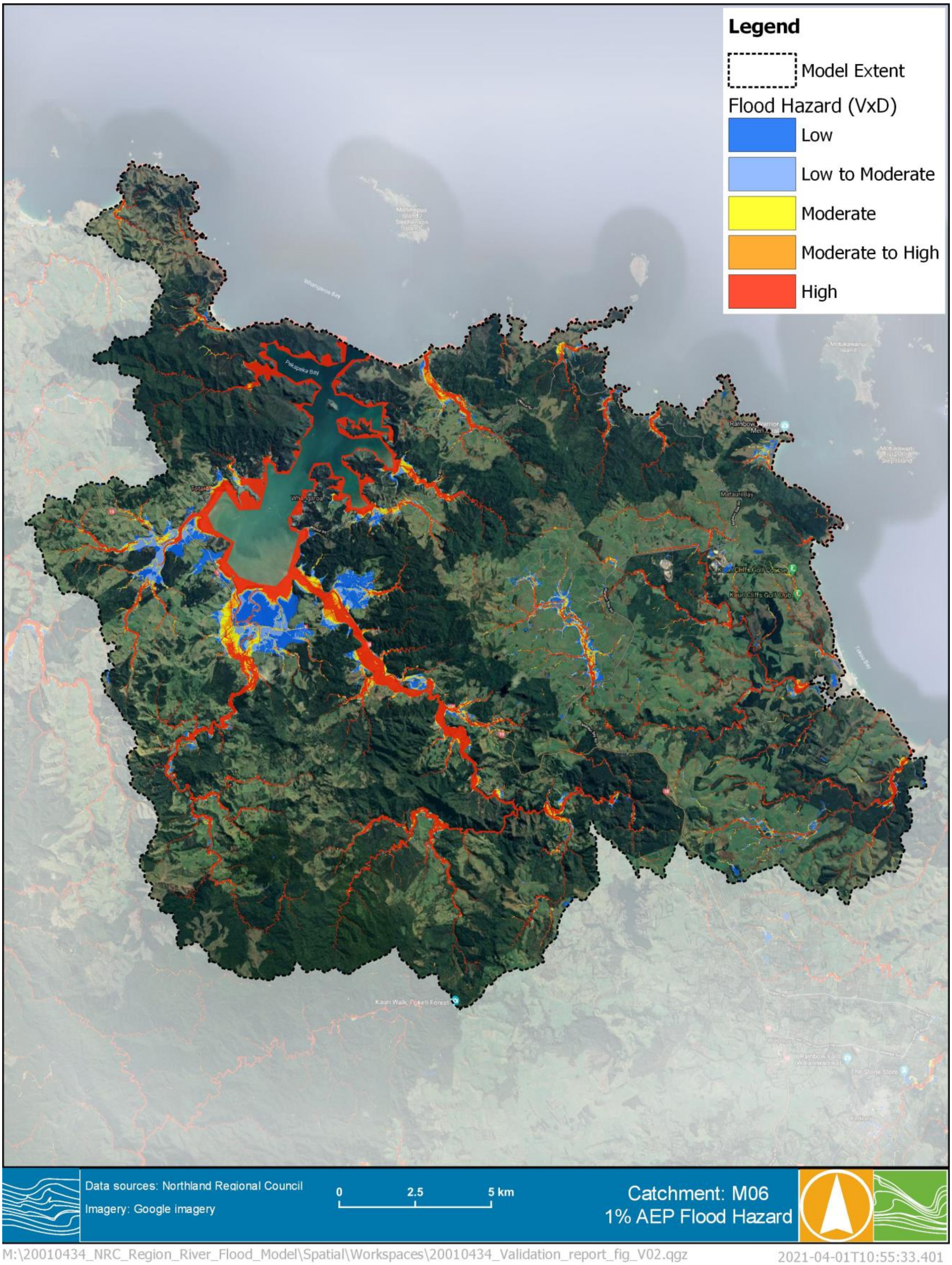

FIGURE 5-3 DESIGN MODELLING OF 1% AEP FLOOD HAZARD

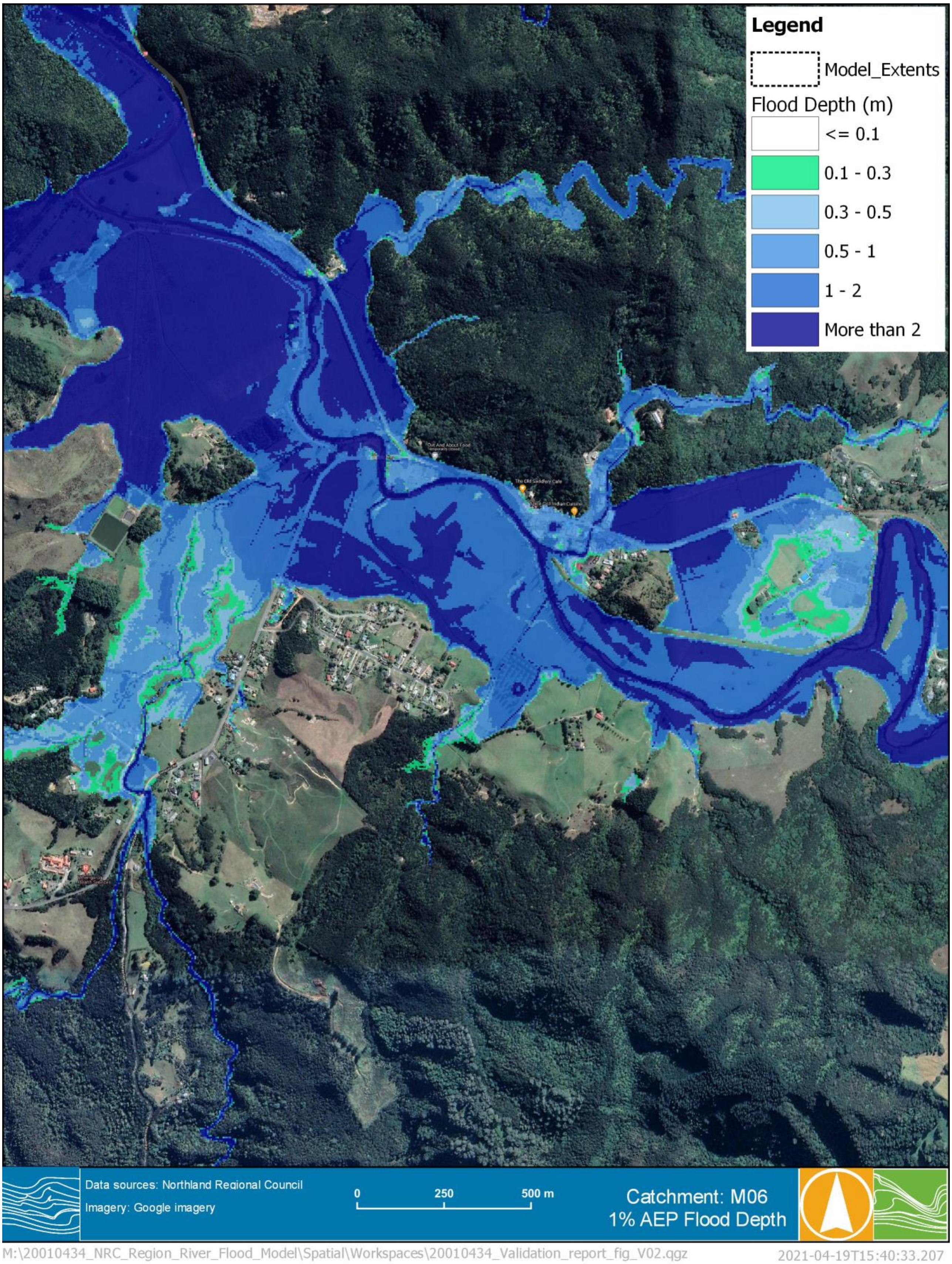

FIGURE 5-4 DESIGN MODELLING OF 1% AEP FLOOD DEPTH AT KAEO

6 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 6-1 displays the location of streamflow gauges in the Kaeo catchment. It should be noted that the Whangaroa harbour at Big Game Fish Club gauge is a tidal levels gauge and hence, it was not included in the verification.

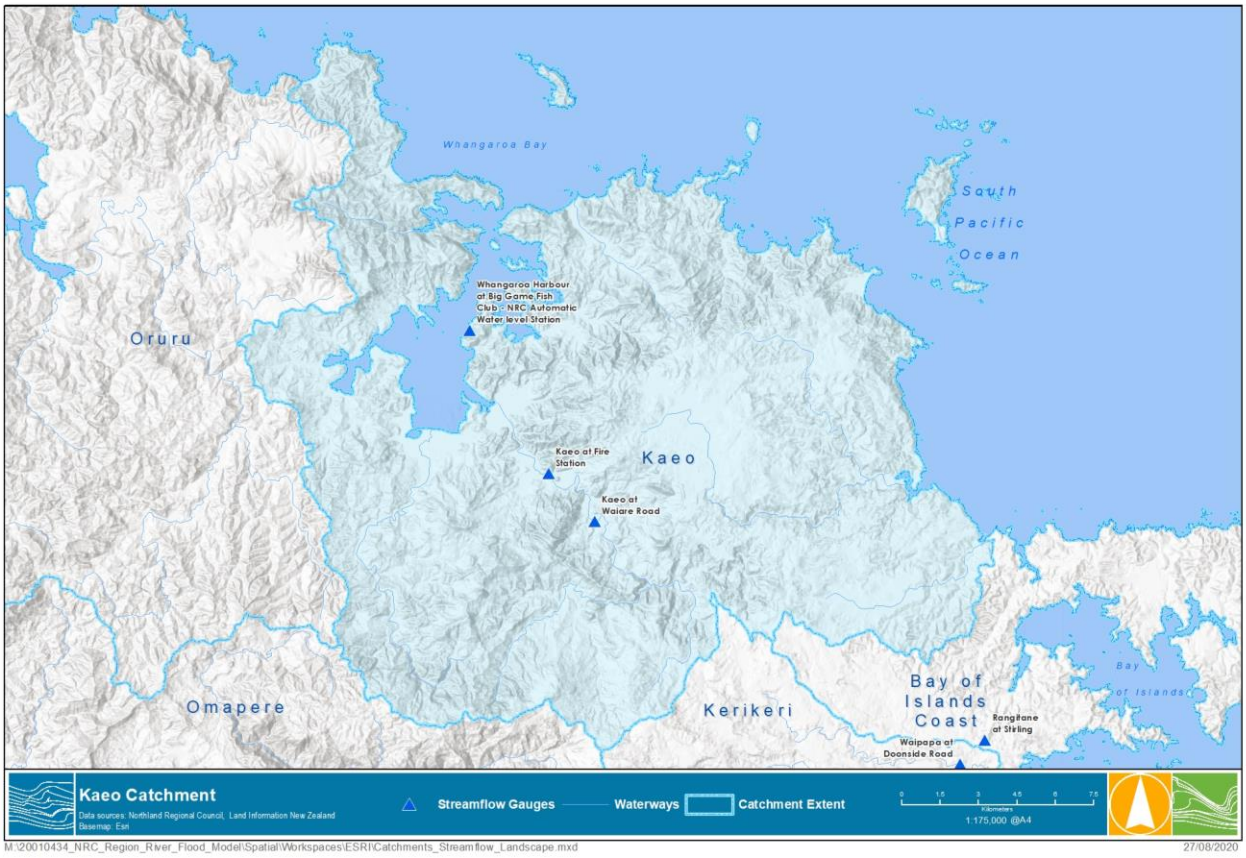

FIGURE 6-1 AVAILABLE STREAMFLOW GAUGES WITHIN KAEO AND WHANGAROA CATCHMENTS

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 observations from 2011 and historic maxima from streamflow gauge records.

6.1 Regional Estimation Methods

For catchments where a suitable streamflow gauge record is 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 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

[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 Kaeo 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 sizes for these two gauge locations within this study area range from 70 to 80 km². These equations are therefore subject to great uncertainty in summarising catchment characteristics.

At the Kaeo at Waiare Rd gauge, the modelled design flow has a good match to the Henderson&Collins 2018 estimate. This gauge only has 12 years of records available, making the FFA estimate is not applicable. The modelled flows at the Fire Station gauge tends to underestimate the estimated design flows. But it should be noted that this gauge has no flow records and therefore, it is subject to great uncertainty in these estimated design flows. Overall, the modelled peak flow at the Waiare Rd gauge tends to sit within a reasonable range of design flow estimates while the modelled peak flow at Fire Station gauge cannot be verified given the lack of flow data.

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	Jan 2011 peak	Highest on record	SCS	Rational method	NIWA – H&C 2018
Kaeo at Waiare Rd	6 hr	388	210	210	214	157	406
Kaeo at Fire Station*	6 hr	84	N/A	N/A	262	193	441

*Flow record is not available

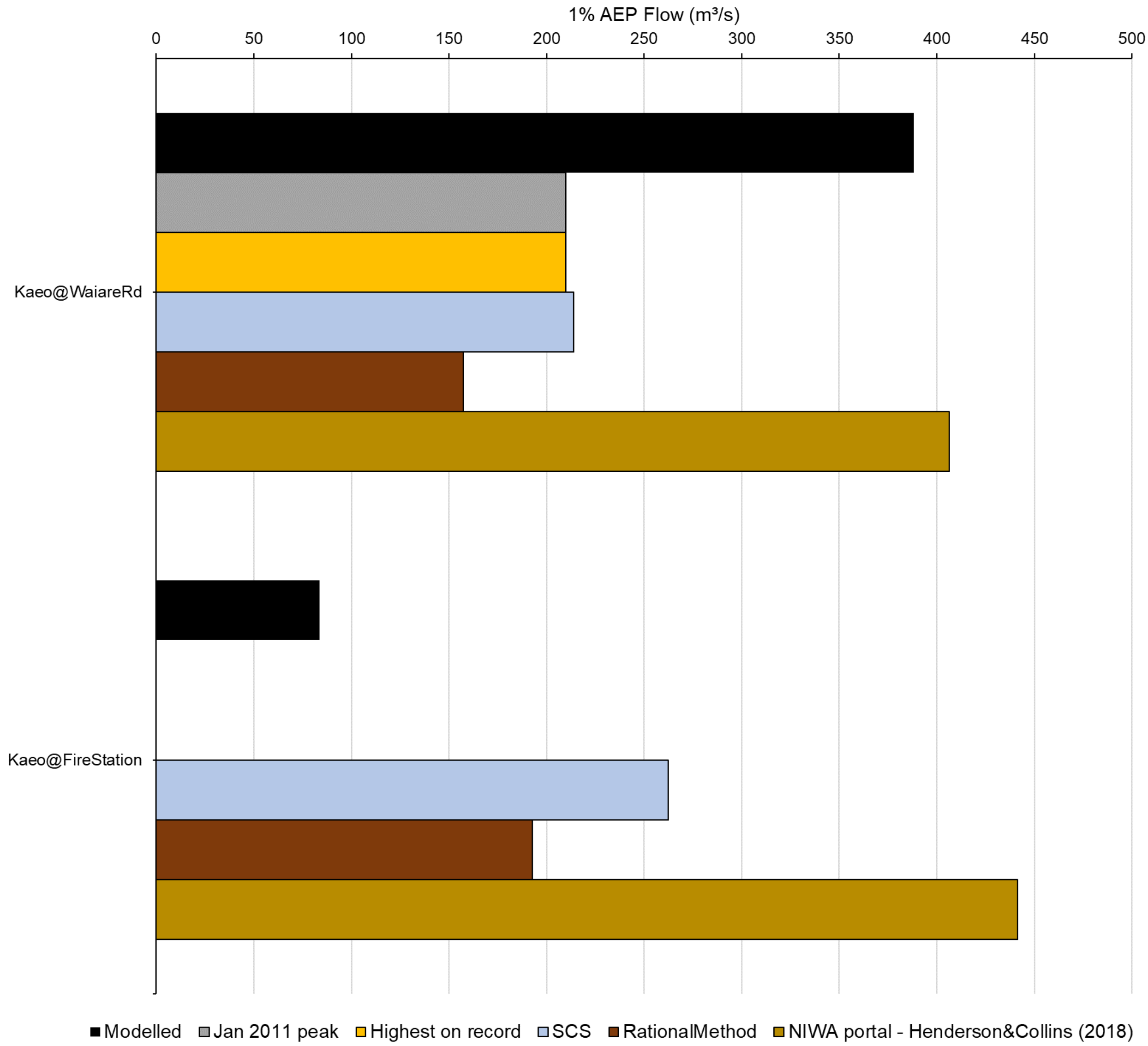

FIGURE 6-2 VERIFICATION OF DESING MODELLING RESULTS AGAINST HYDROLOGICAL ESTIMATES

7 SUMMARY

The Kaeo catchment model (M06) was calibrated and results are documented in this report. 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 have been 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/availability of gauged flow records (where used, length of records) and general limitations with empirical design estimates. Overall, the modelled design flows at Kaeo at Waiare Rd streamflow gauge within the study area provide a reasonable fit to design flow estimates.

When considering the scope and the scale of this project, it is believed that the current modelling results are 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.