Calibration Report

NRC Region-wide River Flood Model

Northland Regional Council

25 March 2021

Document Status

Version	Doc type	Reviewed by	Approved by	Date issued
01	Draft	Lachlan Inglis	Bertrand Salmi	7/12/2020
02	Final	Ben Hughes	Bertrand Salmi	25/03/2021

Project Details

Project Name	NRC Region-wide River Flood Model
Client	Northland Regional Council
Client Project Manager	Sher Khan & Matt De Boer
Water Technology Project Manager	Bertrand Salmi
Water Technology Project Director	Ben Hughes
Authors	Alvin Min Li, Lachlan Inglis
Document Number	20010434_R01_V03b.docx

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

15 Business Park Drive
Notting Hill VIC 3168

Telephone	(03) 8526 0800
Fax	(03) 9558 9365
ACN	093 377 283
ABN	60 093 377 283

Quality ISO 9001 SAI GLOBAL
Environment ISO 14001 SAI GLOBAL
Health & Safety AS 4801 SAI GLOBAL

25 March 2021

Sher Khan
Rivers and Natural Hazards Engineer
Northland Regional Council
Private Bag 9021
Whangārei Mail Centre
Whangārei 0148
New Zealand
Via email

Dear Sher

NRC Region-wide River Flood Model

This report details the methodology adopted to inform the region-wide flood modelling study. It provides an overview of the selected software used for the hydraulic modelling and the assumptions underlying the work. As such, the report provides a summary of the meteorological data collection, gauged hydrologic analysis and the development of the preliminary hydraulic models, including their calibration against past events.

The report has been reviewed by Beca (the peer reviewer) and Northland Regional Council, with comments incorporated by Water Technology into the updated report.

If you have any queries, please do not hesitate to contact.

Kind Regards,

Bertrand

Yours sincerely

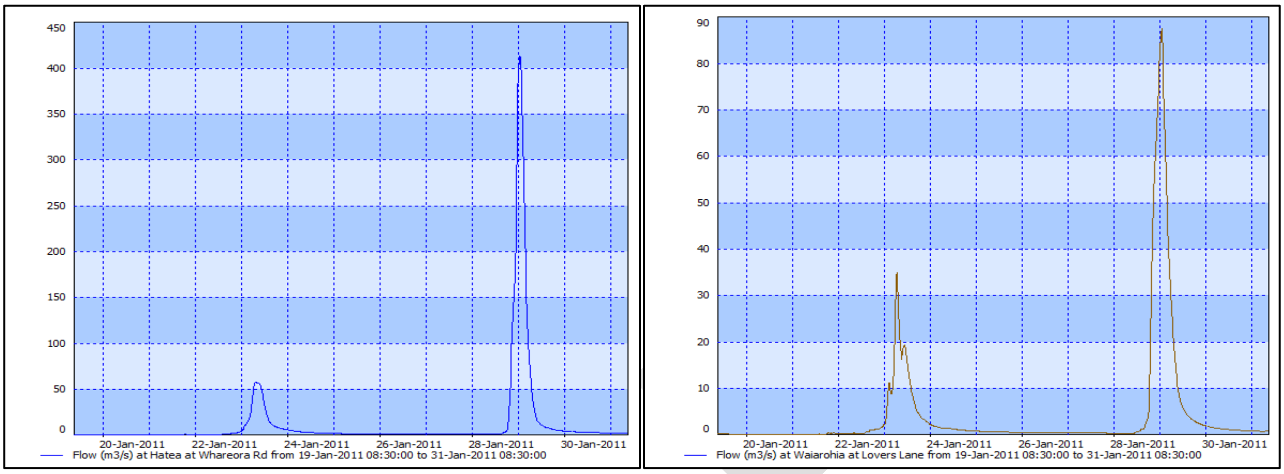
Bertrand Salmi
Principal Engineer

bertrand.salmi@watertechnology.co.nz

WATER TECHNOLOGY PTY LTD

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.

The initial model delineation was adopted from the hydrological catchment delineation provided in the project brief. Where possible, to reduce the number of models yet still achieve reasonable model simulation times, several small catchments were joined. Further to this, several larger catchments were also broken into a number of smaller models that will require a staged simulation sequence. A preliminary model delineation is shown in Figure 1-1. To cover the study area, a total of 19 models are being constructed including the Awanui River catchment.

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 is used to build hydraulic models for this project. TUFLOW is widely used software that is suitable for the analysis of flooding. The TUFLOW model routes overland flows across the topographic surface (2D Domain) to create flood extents, depths, and velocities. 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.

Model calibration

A calibration/validation process was adopted to verify the hydraulic model before design modelling. This involved three priority catchments including Awanui, Whangarei (Model 01) and Kawakawa (Model 15) and two additional catchments (Model 13 and Model 14). These five catchments were calibrated to at least one historic flood event.

For a number of the initial catchments assessed in the calibration/validation process, the January 28th 2011 event was selected. This event was found to be one of the largest recorded flood events for a number of existing streamflow gauges. The January 2011 event has also been used in several previous studies. For the Awanui catchment, the July 2020 flood event was also used for calibration due to the significant earthworks around Kaitaia being completed after the LiDAR was flown in 2018. The calibration of the July 2020 event allows the Awanui model to represent current flood characteristics in Kaitaia.

These five catchment models were calibrated to 19 streamflow gauges. Model calibration requires iterative processes adjusting the model parameters until the modelled results provide a suitable match against the observed flood information collected in historic events. The calibration of these hydraulic models determined a range of model parameters (rainfall/infiltration losses, roughness) to be adopted for the other catchment models. At this stage, the results of an event calibration were compared to these items:

- Recorded water levels (timing, shape and peak)
- Gauged streamflow
- Calibration results from existing flood studies
- Surveyed flood levels where available

During the initial stage of model calibration, several factors can affect the calibration of a model. Key factors of the assessment include the uncertainty in the accuracy of the existing gauged rating curve, streamflow gauge locations (close to bridge or structures), model topography especially in river channels (LiDAR cannot penetrate the water level) and available rainfall data.

Having a good calibration on both flows and water levels at the same time becomes difficult as a result of the uncertainty in these factors, especially the uncertainty related to streamflow rating curves at high flows. To achieve the best outcome in a limited timeframe and for what is a 2D model only, model calibration has focused on replicating the recorded flood levels, flood behaviour and recorded flood extent. A quantitative assessment was undertaken to summarise the performance of the model calibration for each catchment model. The ability to capture the flood behaviour and replicate peak flood levels across each of the five catchments assessed as part of this study has shown the hydraulic modelling approach adopted will provide suitable and fit for purpose model results.

The initial methodology has been reviewed and discussed with Northland Regional Council as well as through an independent technical review process (details can be found in Appendix B). Following acceptance of the results of the initial five catchments used in the calibration/validation process, a further five catchments will be modelled based on similar methodology and process and calibrated to at least one historic flood event. Following this, design modelling of all 19 catchments will be undertaken with verification to Flood Frequency Analysis and Design flow estimation being undertaken for the 1% AEP event.

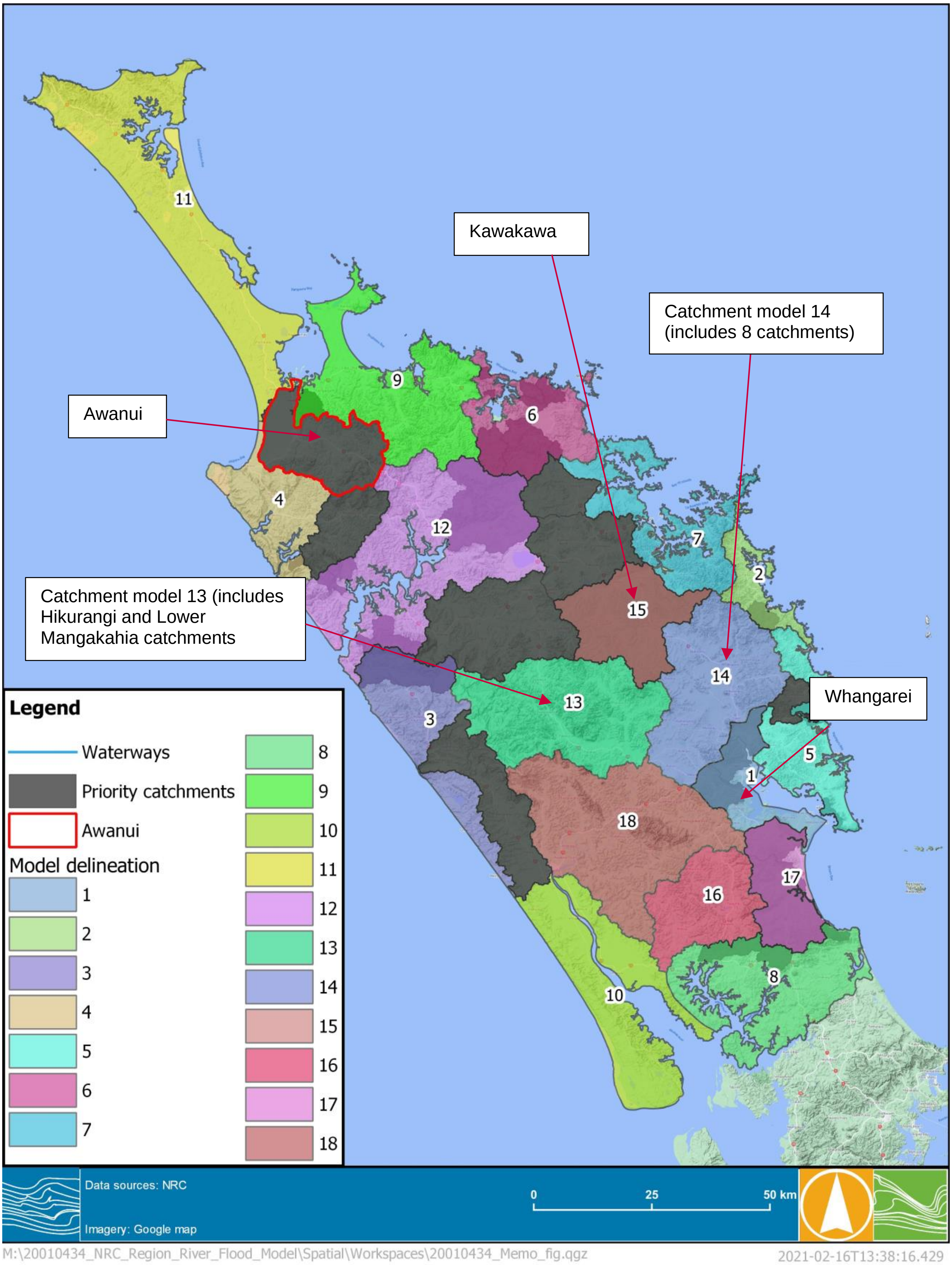


FIGURE 1-1 MODEL DELINEATION

2 DATA COLLECTION

Historical streamflow, water level and rainfall records at gauging stations throughout the study area have been collected for this study. These datasets are utilised for hydrologic analysis, inputs for hydraulic models and model calibration and validation. The available gauging stations within the study area are shown in Figure 2-1.

2.1 Water level stations

There are 61 water level stations found within the study area with historic records available. The majority of the water level stations consist of streamflow and water level records with a small number of them recording only water levels (including tidal gauges). The entire records in each of these stations were downloaded via the Northland Regional Council website[1]. An analysis was undertaken to identify the available data type, the length of the records, significant flood events within the period of record, maximum data values and the year of occurrence. These stations were grouped based on the catchments and the associated flood models being constructed. The analysis, as summarised in Table 2-1, provides an understanding of the available data in each model and the events that can be used for model calibration and validation.

2.2 Rainfall stations

The number of rainfall stations within the study area is 179. Rainfall records range from 1927 to present. Of these, only 48 stations include records post 2000 year with even fewer stations still active currently. 79 our 179 stations consist of both daily and sub-daily rainfall records. The rainfall data was accessed and downloaded via either the Northland Regional Council website[1] or the NIWA Climate Database portal[2]. The data was used in the model calibration/validation by applying rainfall totals directly into the hydraulic model. Daily rainfall gauges were used to provide spatial variation in rainfall totals, while sub-daily rainfall gauges were used to provide temporal patterns across the hydraulic models for the calibration events.

Rainfall IFD and design temporal pattern data have been provided from NIWA's High Intensity Rainfall Design System (HIRDS)[3]. This data will be used to for design modelling across the study area. This is discussed further in Section 4.

[1] River and rainfall data, accessed via https://www.nrc.govt.nz/environment/river-and-rainfall-data/river-and-rainfall-data/
[2] The National Climate Database, accessed via https://cliflo.niwa.co.nz/
[3] IDF data, accessed via https://hirds.niwa.co.nz/

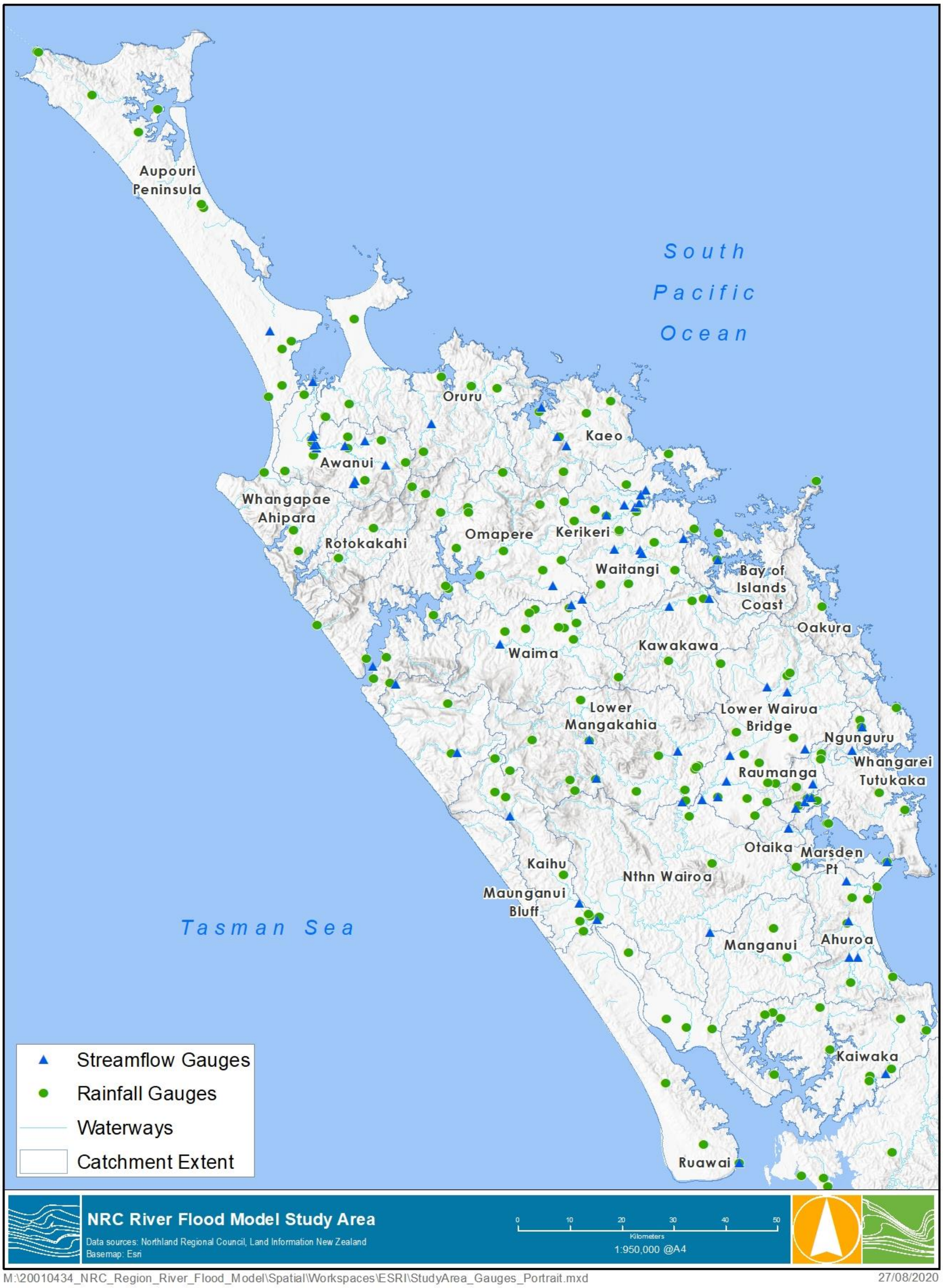


FIGURE 2-1 GAUGING STATION DISTRIBUTION WITHIN STUDY AREA

TABLE 2-1 SUMMARY OF WATER LEVEL STATIONS AND RECORD ANALYSIS

Catchment	Model No	Gauge Name	Gauge Record type	Record length	Max Flow (m3/s)	Max Stage (mm)	Year of Max
MarsdenPt	Model 1	Whangarei Harbour at Marsden Point	stage	1989 to 2020	-	3415	1997
Hatea		Hatea at Whareora Rd	stage and flow	1986 to 1995; 2007 to 2020	512.93	10711	2020
		Hatea at Town Basin	stage	1986 to 2020	-	3925	1988
Waiarohia		Waiarohia at Lovers Lane	stage and flow	1979 to 2020	113.35	5112	2020
Raumanga		Raumanga at Bernard St	stage and flow	1979 to 2020	87.048	5604	2011
		Raumanga at Kotuku Dam Intake	stage	2016 to 2020	-	58419	2020
Otaika		Otaika at Kay	stage and flow	2011 to 2020	136.23	4623	2011
Oakura	Model 2	-	-	-	-	-	-
Waimamaku	Model 3	Waiotemarama at u_s of FNDC intake	stage and flow	2013 to 2020	15.8	852	2020
WhangapaeAhipara	Model 4	-	-	-	-	-	-
WhangareiTutukaka& Horahora	Model 5	-	-	-	-	-	-
EastWhangaroa	Model 6	Whangaroa Harbour at Game Fish Club	stage	2008 to 2020	-	3293	2019
Kaeo		Kaeo at Fire Station	stage	2008 to 2020	-	3886	2011
		Kaeo at Waiare Road	stage and flow	2008 to 2020	210	5178	2011
BayofIslandsCoast	Model 7	Rangitane at Stirling	stage	2001 to 2020	-	5239	2007
		Veronica Channel at Opua Wharf	stage	1990 to 2020	-	3216	2011
Hakaru	Model 8	Hakaru at Topuni Creek Farm	stage and flow	2011 to 2020	121.5	4626	2014
Oruru	Model 9	Oruru at Saleyards	stage and flow	1988 to 2020	101.14	5221	2011
Pouto Peninsula	Model 10	Kaipara Harbour at Pouto Point	stage	2001 to 2020	-	4491	2020
AupouriPeninsula	Model 11	Selwyn Swamp at Big Flat Rd	stage and flow	1965 to 1974; 1987 to 2020	2.74	1229	1998
		Awanui at Ben Gunn Wharf	stage	2004 to 2020	-	5304	2017
Omapere	Model 12	Hokianga Harbour at Opononi	stage	2017 to 2020	-	3567	2019
Hikurangi	Model 13	Hikurangi at Moengawahine	stage and flow	1960 to 1969; 1984 to 2020	349.32	9992	2011
LowerMangakahia		Mangakahia at Gorge	stage and flow	1960 to 2020	1174	6452	2014

Catchment	Model No	Gauge Name	Gauge Record type	Record length	Max Flow (m3/s)	Max Stage (mm)	Year of Max
		Opouteke at Suspension Br	stage and flow	1984 to 2020	507	4403	1985
LowerPurua	Model 14	Wairua at Purua	stage and flow	1960 to 2020	312.85	7957	2014/1978
LowerWairuaBridge		Wairua at Wairua Br	stage	1961 to 2020	-	5600	1966
Mangahahuru		Mangahahuru at County Weir	stage and flow	1968 to 2020	33.82	4240	2011
Mangere		Mangere at Knights Rd	stage and flow	1983 to 2020	116.43	6165	2011
Waipao		Waipao at Draffin Road	stage and flow	1979 to 2020	28.3	4310	2011
Waiotu		Waiotu at SH1 Br	stage and flow	1987 to 2020	237.63	8675	2007
Whakapara		Whakapara at Cableway	stage and flow	1959 to 2020	428.42	9435	2020
Kawakawa	Model 15	Tirohanga at Below Old Mill	stage and flow	2010 to 2020	249.87	4804	2011
		Waiharakeke at Willowbank	stage and flow	1967 to 2020	268.62	6385	2014
Manganui_	Model 16	Manganui at Permanent Station	stage and flow	1960 to 2020	320.43	8505	1976
Ahuroa	Model 17	Ahuroa at Braigh Flats	stage and flow	1983 to 2020	170	6485	1997
North		North at Applecross Rd	stage and flow	1982 to 2020	70.51	5627	2007
Ruakaka		Ruakaka at Flyger Rd	stage and flow	1984 to 2020	152.37	4789	2011
Waihoihoi		Waihoihoi at St Marys Rd	stage and flow	1984 to 2020	65.32	7186	1997
NorthernWairoa	Model 18	Mangakahia at Titoki Br	stage and flow	1983 to 2020	1368.84	14685	2011
		Northern Wairoa at Dargaville	stage	1981 to 2020	-	5935	2000
					-	-	-
Awanui	-	Awanui at School Cut	stage and flow	1958 to 2020	268.26	8089	2003
	-	Awanui at Waikuruki	stage and flow	1990 to 1992; 2016 to 2020	53.43	5857	2020
	-	Takahue at Crene Road	stage and flow	2018 to 2020	45.28	2594	2020
	-	Tarawhataroa at Puriri Place	stage and flow	2006 to 2020	172.84	5294	2007
	-	Te Puhi at Meffin Rd	stage and flow	1990 to 1992; 2014 to 2020	74.18	3947	2007
	-	Victoria at Victoria Valley Road	stage and flow	2006 to 2020	79.19	2984	2017
	-	Whangatane Spillway at Donald Rd	stage and flow	2004 to 2020	183.59	4180	2007
	-	Awanui at Ben Gunn Wharf	stage	2004 to 2020	-	5304	2017
	-	Victoria at Double Crossing	stage	1990 to 2020	-	6760	2020
Kaihu	-	Kaihu at Gorge	stage and flow	1970 to 2020	398.29	5141	1988

Catchment	Model No	Gauge Name	Gauge Record type	Record length	Max Flow (m3/s)	Max Stage (mm)	Year of Max
Kerikeri	-	Kerikeri at Peacock Garden	stage and flow	2005; 2012 to 2020	450	2496	1979
	-	Kerikeri at SH 10 Bridge	stage and flow	2015 to 2020	171.69	73676	2020
	-	Maungaparerua at Tyrees Ford	stage and flow	1967 to 2020	103.941	3102	2007
	-	Puketotara at BOI Golf Club	stage and flow	2011 to 2020	197.58	30526	2014
Lower Kaihu	-	Kaihu at Parore Cut	stage	2006 to 2020	-	3755	2007
Ngunguru	-	Ngunguru at Dugmores Rock	stage and flow	1969 to 2020	125.84	3318	2008
Waima	-	Punakitere at Taheke	stage and flow	1994 to 2020	164.806	3498	2014
	-	Wairoro at FNDC Weir	stage and flow	2019 to 2020	0.986	645	2020
Waipapa	-	Waipapa at Doonside Road	stage	2012 to 2020	-	4138	2014
Waitangi	-	Waitangi at SH10	stage and flow	2012 to 2020	353.619	5904	2014
	-	Waitangi at Waimate North Radar	stage and flow	2016 to 2020	104.429	6130	2020
	-	Waitangi at Wakelins	stage and flow	2001 to 2020	5714.037	13956	2014
	-	Waiaruhe at Puketona	stage	1984 to 2020	-	6127	1997

3 HYDRAULIC ANALYSIS

3.1 Overview

A "Direct Rainfall" modelling approach was adopted for this study with verification of the methodology carried out within the five aforementioned catchments. The hydraulic model delineation was initially determined based on hydrological catchment delineation. The model delineation was then optimised to deliver the least number of models while achieving reasonable model simulation time with a grid size that will provide suitable resolution for the use of the model outputs as flood hazard intelligence. This was completed by joining catchments together that drain to a central location or catchments which are close in proximity to each other. Several of the larger catchments were broken into smaller catchment models that will require a staged simulation sequence to accurately represent the runoff generated upstream of each catchment model.

The entire NRC LiDAR DEM has been split into separate 1m DEMs for each major catchment. These DEMs were manipulated and processed in the NRC LiDAR catchment analysis and Hydro-enforced DEM preparation project to produce DEMs suitable for hydraulic modelling of the entire NRC area. These DEMs (called the hydrologically enforced DEM), have gaps burnt into the LiDAR through roadways and bridges which cause a blockage, to ensure that waterways and major drainage paths can continue to drain to the catchment outlet whilst small sinks are also required to be filled. Two sets of DEMs were tested in the initial catchment model (Awanui) as follows:

- The 'hydro-enforced' DEM with the gaps in the roadway burnt through and the sinks filled
- DEM with the gaps in the roadway burnt through, but not having the sinks filled

The preliminary modelling results have shown that the 'hydro-enforced' DEM results in increases in water level due to the artificial filling of waterway channels and natural depressions. This reduced channel capacity and floodplain storage but also removed some connectivity across the floodplain, resulting in some flooding areas being missed. It is recommended that the second version of DEM be adopted for all catchment models.

The development of each catchment model using TUFLOW consists of the following key components:

- Model extent
  - Determined by catchment delineation using LiDAR DEMs
- Topography
  - Based on the processed 1m LiDAR DEMs
- Model boundaries (i.e. input hydrograph/ rainfall, outflow conditions)
  - Location of available rainfall records and downstream tailwater boundary conditions
- Materials layer
  - Assignment of hydraulic roughness and rainfall losses/infiltration based on land use types

3.2 Tuflow Modelling Techniques

The 2020 TUFLOW release provides a significant update on modelling techniques available. New features of the software include Quadtree mesh refinement and Sub-Grid Sampling (SGS). Both updates offer an opportunity to produce higher detailed modelling results using a coarse model grid (e.g. 10m) without sacrificing run time generally associated with using a finer resolution. A brief description of both techniques are as follows:

- Quadtree mesh refinement

  - This allows for dynamic nesting of a finer grid resolution in areas where it is necessary within an overall model domain, to provide more accurate and detailed mapping in those areas. This is commonly known as grid nesting or multi-domain modelling. Quadtree mesh refinement was tested to township areas where higher resolution is commonly required.
- Sub-grid sampling
  - Involves the extraction of Sub-Grid Sampling (SGS) scale topographic characteristics at the resolution of the underlying LiDAR (1m resolution) into conveyance tables that describe the variation within each cell. This provides a much richer description of the hydraulic behaviour of the cell compared a traditional grid that has a single topographic elevation. This is particularly useful for models with coarse grid resolution and the rain on grid modelling approach adopted in this study.

The preliminary Awanui River catchment model was tested using different TUFLOW modelling techniques:

- Base scenario: 10m grid resolution for the entire catchment
- SGS scenario: 10m grid resolution with 1m sub-grid sampling distance
- Quadtree scenario: 10m base grid resolution along with 2.5m grid resolution at Kaitaia township
- Quad-tree + SGS: a combination of SGS scenario and Quad Tree (QT) scenario above
- SGS + 5m grid: 5m grid resolution with 1m sub-grid sampling distance

Table 3-1 shows the run time required for each modelling scenario and the comparison to the traditional modelling technique. Increases in run time using SGS or Quadtree refinement (or both) are expected. This is still a significant improvement compared to the option of a 1m model resolution which would likely result in a significantly longer run time and is also highly unpractical (due to computing and storage requirements).

TABLE 3-1 SUMMARY OF MODELLING SCENARIOS TESTED

Scenario	Run time (hour)	Compared to base scenario
Base	3.25	-
SGS	5	1.5 times
Quadtree	12	3.7 times
SGS + QT	20	6 times
SGS + 5m grid	30	9 times

An advantage of using SGS is to allow models with coarse grid resolution to make use of the high detail LiDAR without the need for a finer grid resolution. Models with SGS can identify incised and narrow waterways within the floodplain that potentially carry a significant portion of the flow but are not well defined at a coarse resolution in the typical model setup.

With SGS enabled, higher flows are carried in narrow waterways and results in higher peak flows throughout the catchment. A comparison of the four scenarios modelled at the downstream gauge in the Awanui River catchment is shown in Figure 3-1. The timing of rising limb in the hydrograph was shown to be slightly earlier and the peak flow matched the gauged record much better than those without SGS enabled. This is due to the flow paths being more well defined in the model and water was less likely to get “trapped” in coarse grid cells. An increase in grid resolution would be required to overcome this.

Although the peak water levels are shown to match the gauged record better, the timing of peak was slightly later than those with SGS enabled. Both the SGS and the Quadtree runs captured the water levels better in low flow regimes as shown in Figure 3-2. This was due to the topography at the gauge location showing higher definition.

An additional SGS simulation (at 1m sampling size) was undertaken with the model grid resolution reduced to 5m. The results showed the finer grid resolution has negligible impact on the gauged hydrograph and water levels but it required more than 25 hours of run time.

Figure 3-3 and Figure 3-4 show the flood level difference plots comparing SGS and QT to the base case. Both plots show significant increases in flood level downstream of the catchment with SGS or Quadtree enabled. While Quadtree was only applied in the township area, SGS has impact on the entire catchment.

In light of the benefits of each modelling technique, it was decided to model all the NRC catchments using a 10m grid resolution with SGS enabled with a 1m sub-grid sampling distance (LiDAR was provided at 1m resolution). The additional run time was considered acceptable for the increase connectivity of flow paths throughout the catchment.

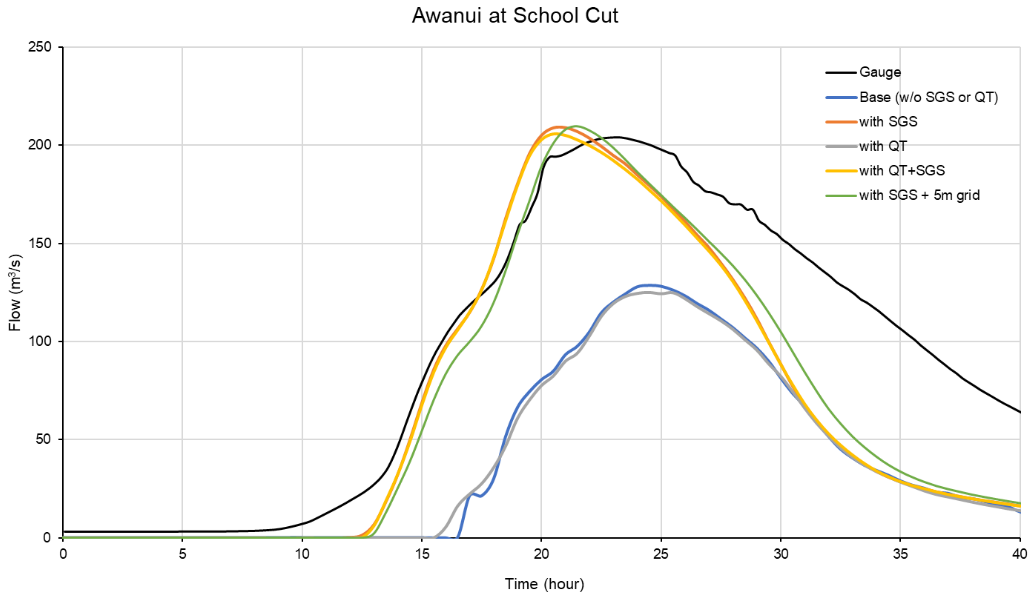


FIGURE 3-1 PRELIMINARY MODELLED FLOW IN AWANUI RIVER AT SCHOOL CUT STATION

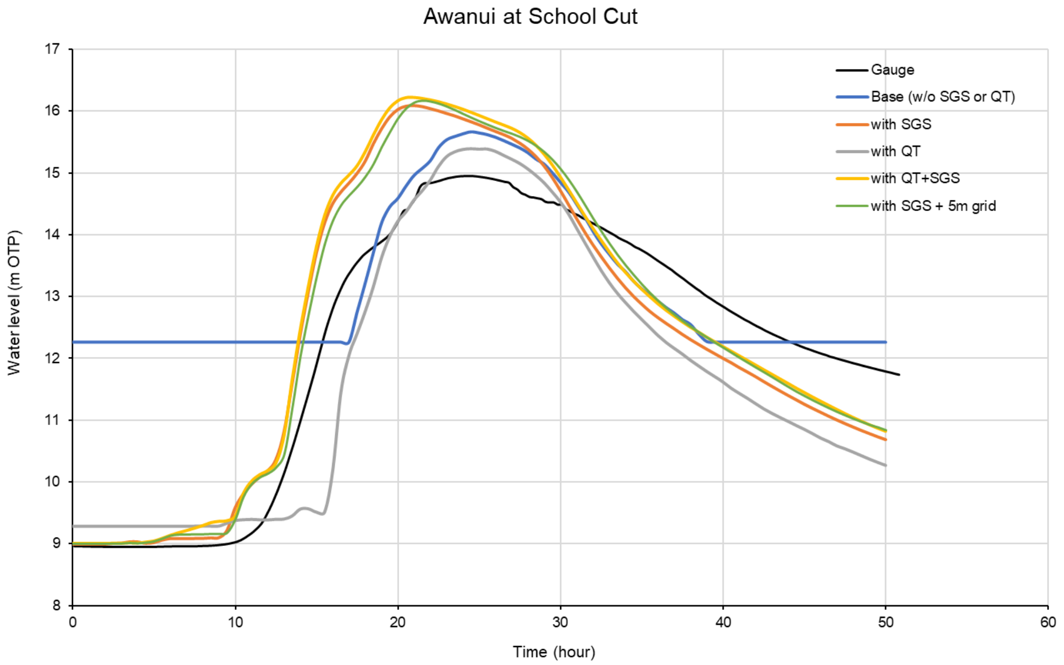


FIGURE 3-2 PRELIMINARY MODELLED WATER LEVEL IN AWANUI RIVER AT SCHOOL CUT STATION

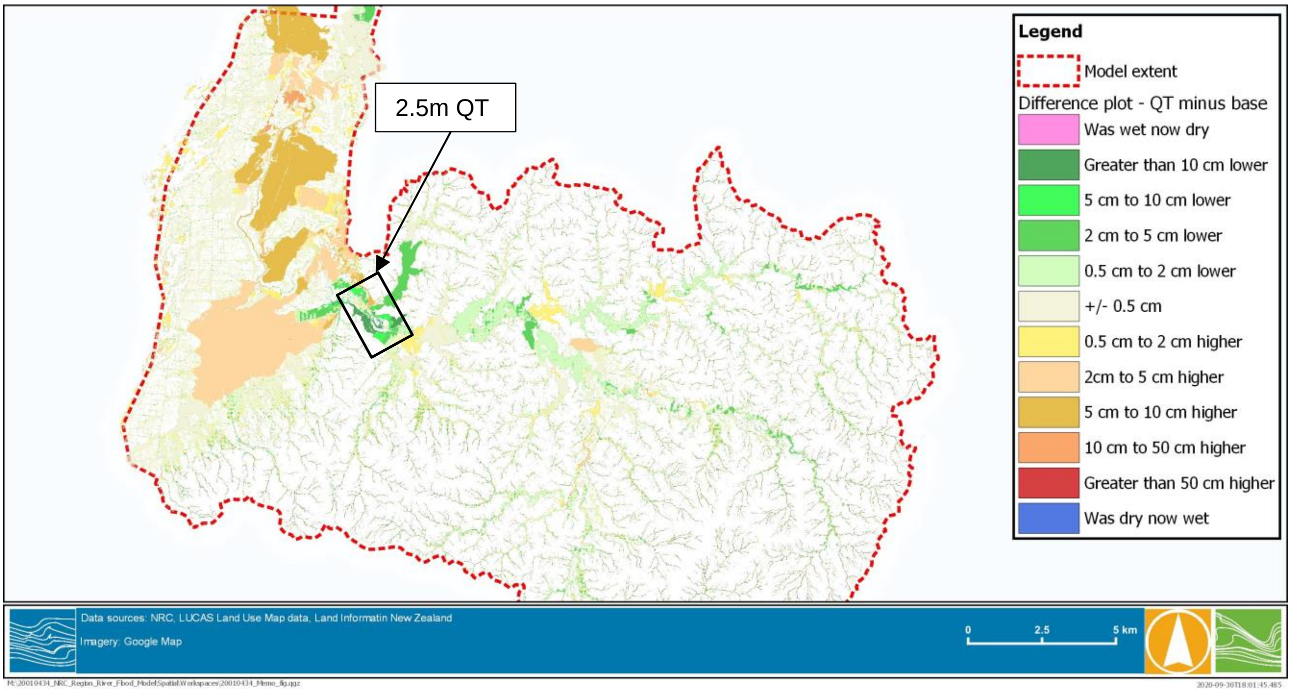


FIGURE 3-3 FLOOD LEVEL DIFFERENCE PLOT (QUADTREE AND BASE SCENARIO)

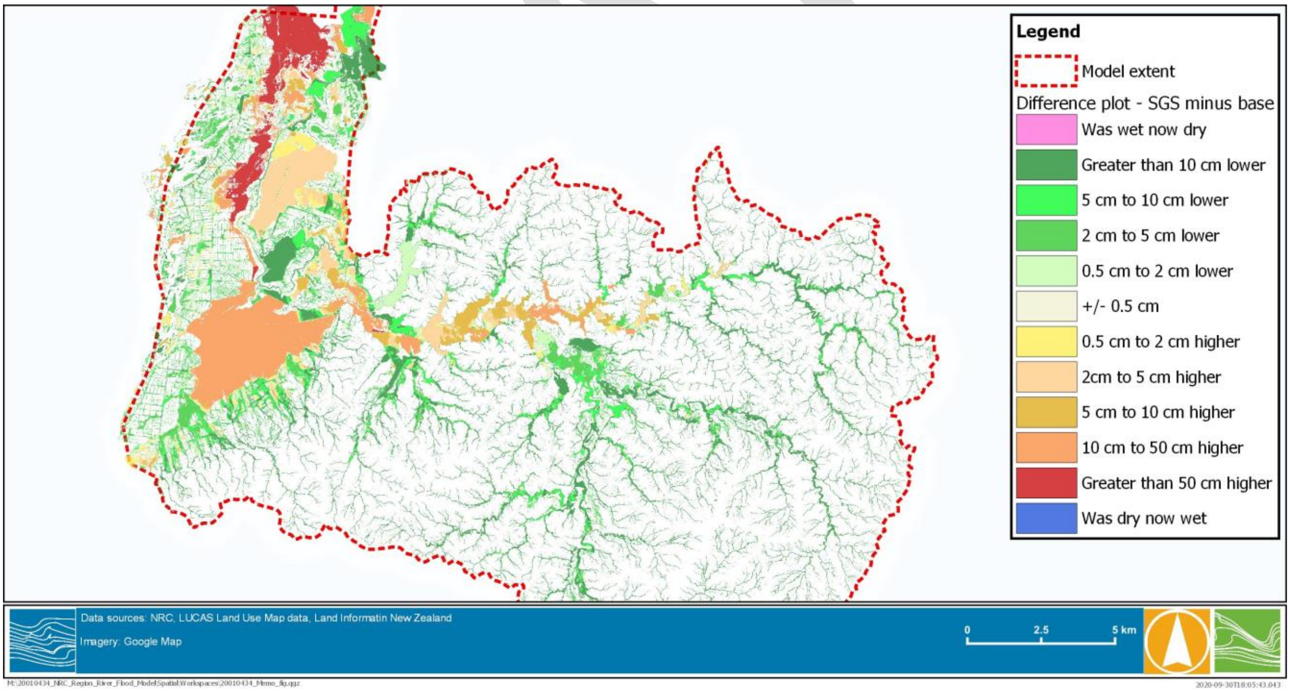


FIGURE 3-4 FLOOD LEVEL DIFFERENCE PLOT (SGS AND BASE SCENARIO)

Hydro-enforced LiDAR DEM testing

As mentioned previously, the ‘hydro-enforced’ LiDAR DEMs were created for use in the hydraulic models. These DEMs have small depression areas filled which may lead to some hazardous flooding areas being downgraded or missed out from the flood mapping. With the filling of sinks, the catchment storage will be reduced which may result in an unreliable assessment. This may show an increase in flooding elsewhere by artificially increasing the peak flows downstream.

Figure 3-5 shows the channel capacity is underestimated in the Hydro-enforced DEM when comparing to the DEM without filling of sinks. This is likely to result in higher flood levels and result in increases in the flood extent. More noticeable effects are some nuisance flooding areas being missed. Figure 3-6 shows an example where flooding areas were missed out using the Hydro-enforced DEM. This is mainly because of either some small waterways or small depression areas were filled, resulting in a loss of connectivity and these areas being modelled as dry.

Figure 3-7 shows the impacts on the modelled hydrograph at Puriri Place station using the Hydro-enforced DEM. There is little change in the first flood peak, but the second peak is more than 20 m^3/s higher than that using the DEM without filling of sinks. This is mainly caused by the reduction in channel capacity and the filling of the sink. It should be noted that the first peak was driven by the local Tarawhataroa catchment while the second peak was driven by the Awanui River catchment. Hence the impact of filling is greater on the second peak given flows were coming from a larger catchment.

Overall, it is recommended that the DEM without filling of sinks be adopted for all the catchment models. This dataset includes the ‘burning of creek alignments’ through embankments also ensuring that connectivity of flow paths is maintained. This will enable hydraulic modelling to capture existing depression and therefore assessing catchment flood regime with natural flood storage.

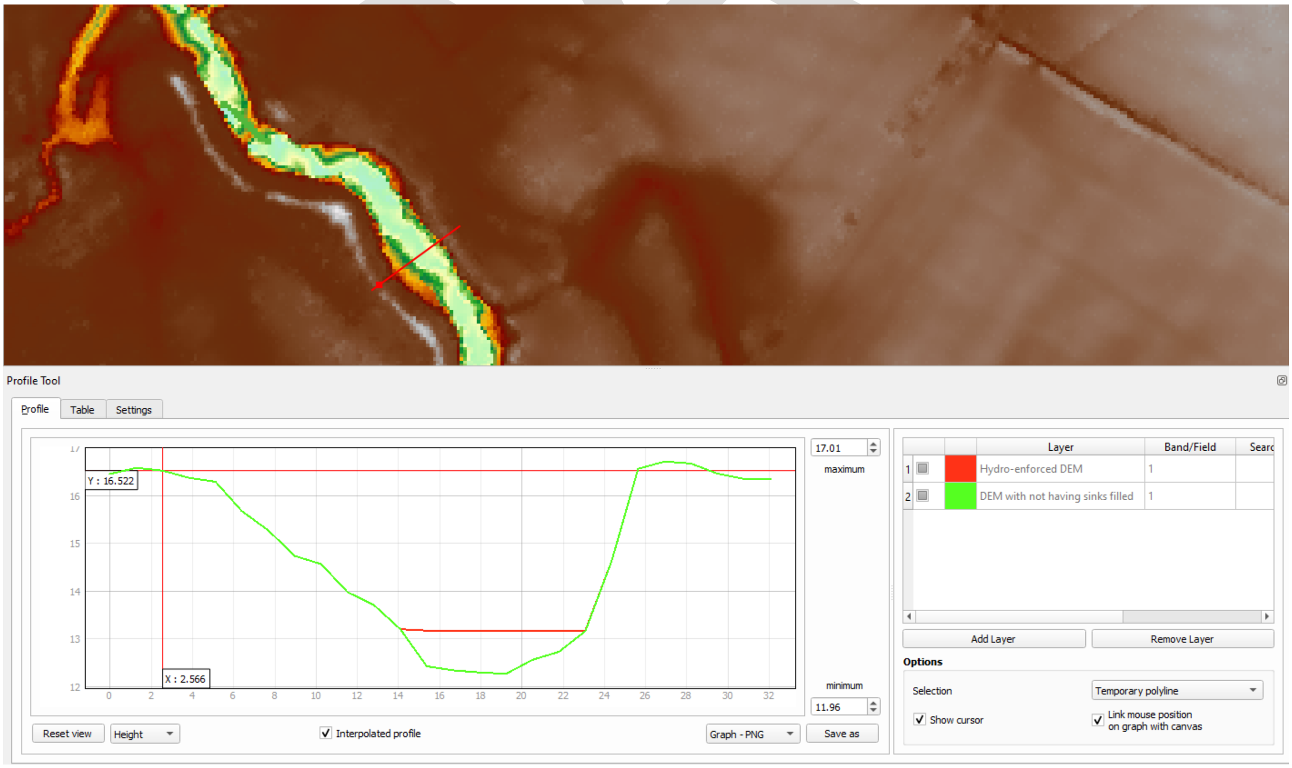


FIGURE 3-5 DRAINAGE TOPOGRAPHY IN HYDRO-ENFORCED DEM

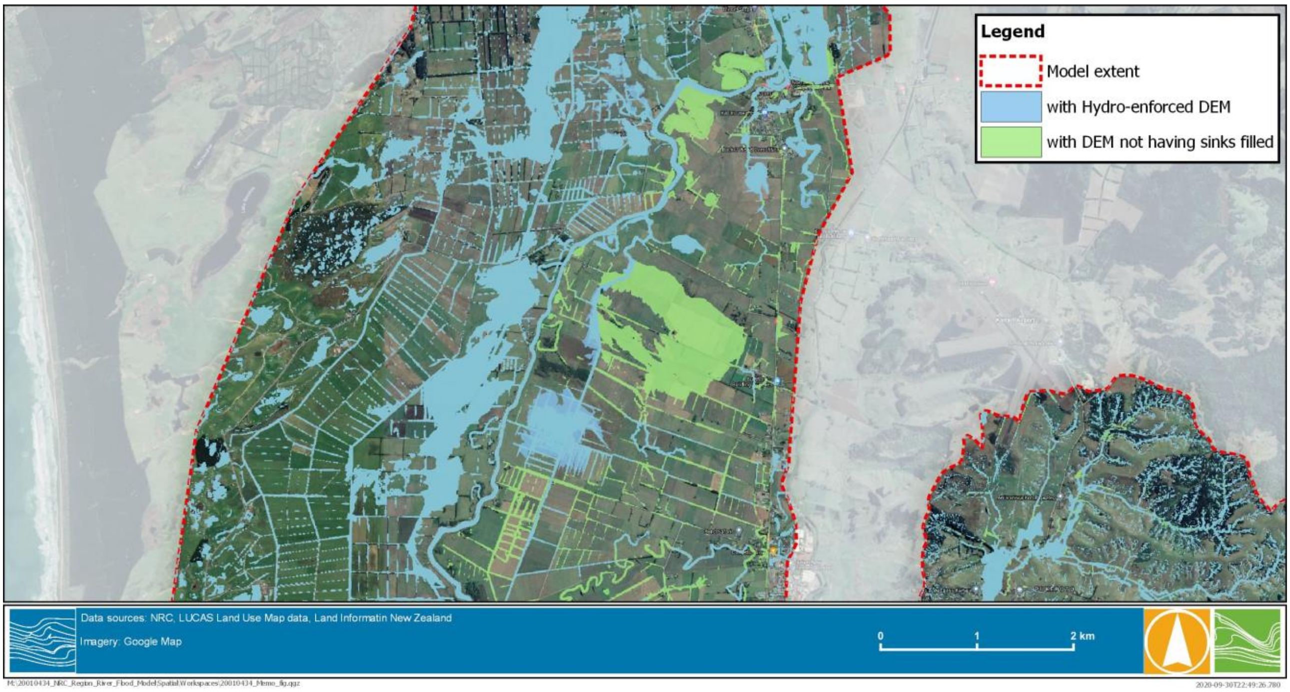


FIGURE 3-6 MISSING OF FLOODING AREAS USING HYDRO-ENFORCED DEM

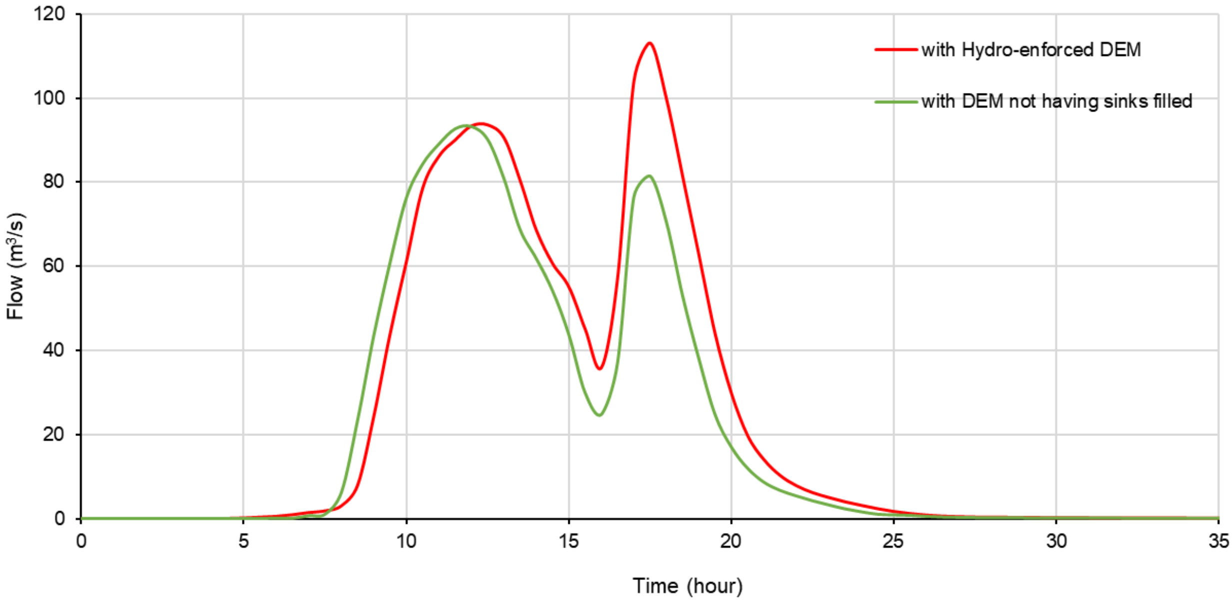


FIGURE 3-7 PRELIMINARY MODELLED HYDROGRAPH – TARAWHATAROA RIVER AT PURIRI PLACE

3.3 Calibration

Five catchment models include Awanui, Whangarei (Model 01), Kawakawa (Model 15), Model 13 (Hikurangi and Lower Mangakahia catchment) and Model 14 (includes 8 catchments) were used in the calibration/validation process. The January 2011 flood event was selected for calibration event for each of the five catchments with the July 2020 event also used in the Awanui catchment as listed below:

- Awanui catchment – calibrated to January 2011 flood and July 2020 flood

- Whangarei catchment (M01) – calibrated to January 2011 flood
- Kawakawa catchment (M15) - calibrated to January 2011 flood
- Catchment Model 13 - calibrated to January 2011 flood
- Catchment Model 14 - calibrated to January 2011 flood

These five catchment models were calibrated to 19 streamflow gauges in total. Model parameters including rainfall/infiltration losses and roughness were adjusted iteratively until the modelled results show a good match against the observed flood information collected in the historic event as mentioned in Section 1. The model parameters were mainly differentiated by the land use types. During the model calibration, it was found that losses parameters should be varied from different sub-catchment areas due to the geology and soil type variation across the catchment. This resulted in better calibration results.

As discussed in Section 1, uncertainty in gauge ratings led the calibration/validation process to rely heavily on matching recorded flood levels and ensuring the hydraulic model matches the recorded flood behaviour throughout each catchment. In general, rating curves are unreliable at high flow regimes where gaugings do not exist and theoretical rating curves are extrapolated. This results in both peak flows and flood volumes being difficult to match. It was noticed that several existing gauged rating curves appear to only account for flows within the channel and do not account for overland flows on the floodplain. This was noticed when the modelled flows extracted from the channel match better to the gauged flows compared to those were extracted across the floodplain.

A quantitative assessment was undertaken to summarise the performance of the model calibration for each catchment model. The key calibration requirements for streamflow gauge and surveyed flood levels required by NRC are as follows:

- Peak flow within 15% of recorded
- Volume within 15% of recorded
- Peak water levels within 300mm of recorded (at gauge and surveyed levels)
- Timing to peak within 1-hour
- Modelled flow within 10% of recorded flow at the same stage

4 AWANUI CATCHMENT

4.1 Model development

Model extent

The Awanui catchment covers a total area of approximately 370 km^2 with Kaitaia its main township located in the centre of the catchment. The Awanui River is fed by several upstream tributaries, including the Takahue River, Victoria River, Karemuhako River and Tarawhataroa Stream. The hydraulic model extent of the Awanui catchment is displayed in Figure 4-1.

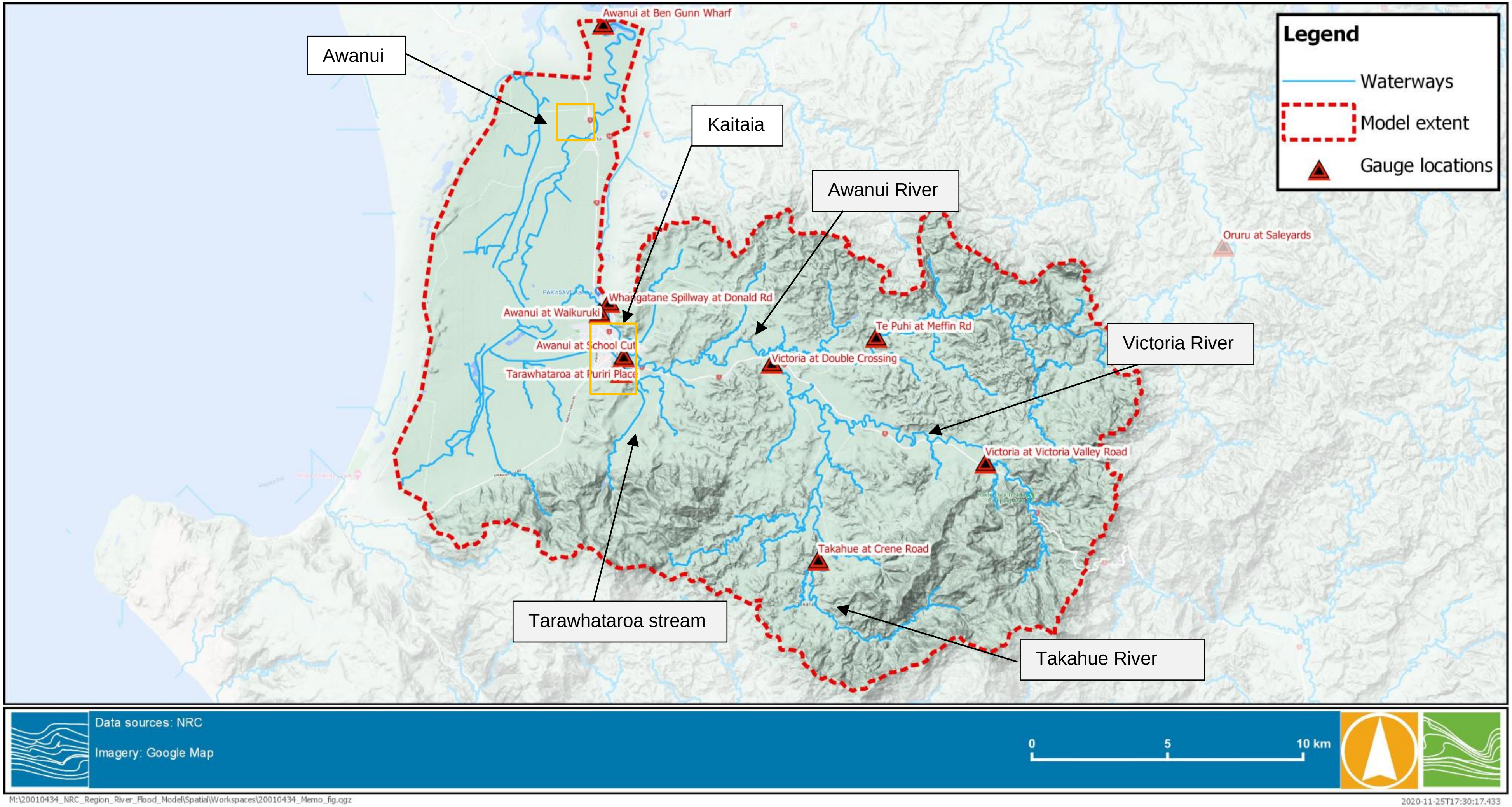


FIGURE 4-1 HYDRAULIC MODEL EXTENT AND STREAMFLOW GAUGE LOCATIONS– AWANUI CATCHMENT

Topography

Model topography is a critical modelling parameter for 2D hydraulic model to accurately replicate flood behaviour. 1-m LiDAR datasets were used to create the digital elevation model (DEM) for the hydraulic model which covers the entire study area. This LiDAR data is of sufficient resolution to represent the topographic features within the catchment. The catchment topographic data is shown in Figure 4-2.

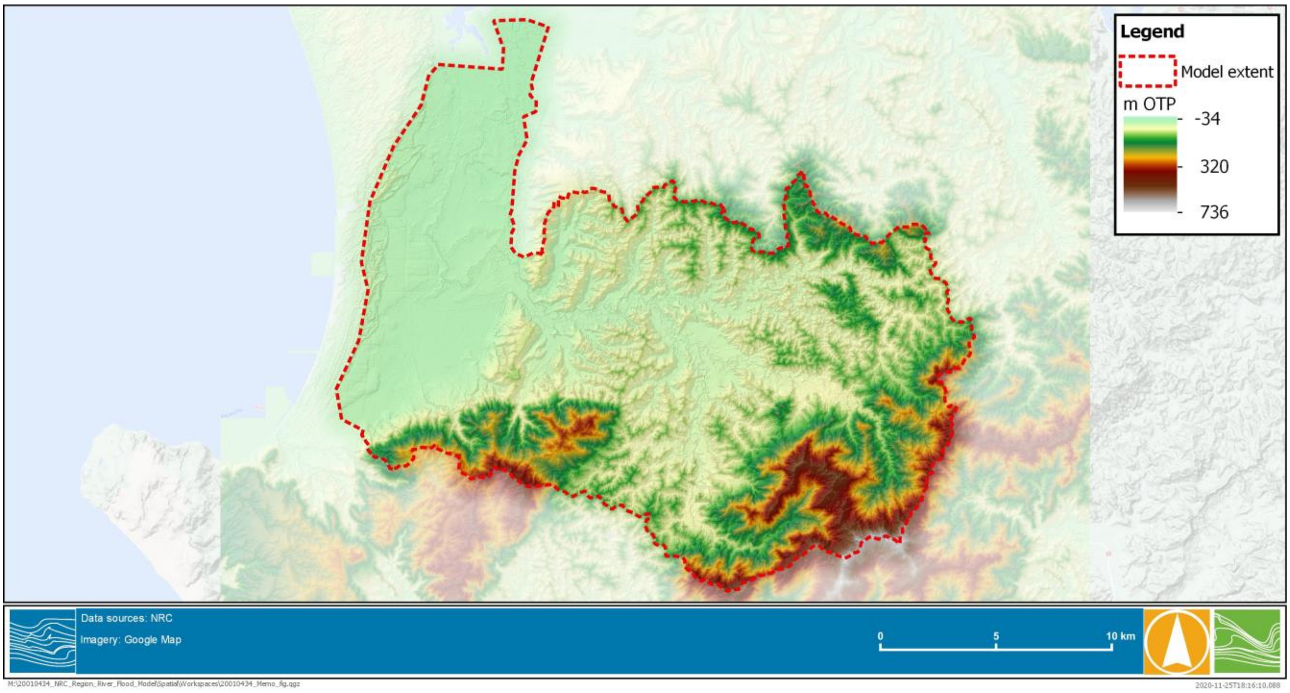


FIGURE 4-2 HYDRAULIC MODEL TOPOGRAPHY – AWANUI CATCHMENT

While this LiDAR was flown in 2018, some earthworks were completed for the Awanui River channel at Kaitaia in 2019. NRC has provided the survey for these channel upgrade works as shown in Figure 4-3. The model DEM for July 2020 event and subsequent design events was adjusted by overlaying this survey on top of the LiDAR.

FIGURE 4-3 CHANNEL UPGRADE WORKS COMPLETED IN 2019

Model boundary

The hydraulic model boundaries consist of input rainfall and outflow boundaries. A downstream tailwater boundary (Water Level vs Time type HT) was applied to the Awanui River at Ben Gun Wharf gauge and the Whangatane Spillway at Donald Road based on recorded water levels from the calibration event. Stage-discharge (Water level vs Flowtype HQ) outflow boundaries were also applied to the western end of the model in order to allow water to leave the model.

There are 5 rainfall stations with available records for the 2011 event and 6 stations for the 2020 event within or near the catchment. A review of the Awanui at School Cut gauge found the July 2020 event was equivalent to a 1 in 10 year event and the 2011 event is larger than a 1 in 5 year event. The input rainfall depths across the catchment area were interpolated using the Inverse Distance Weighted (IDW) average method based on the rainfall gauge location allowing for an accurate spatial representation of rainfall variation across the catchment. Figure 4-4 shows the hydraulic model boundaries for Awanui catchment and Figure 4-5 shows an example of rainfall depth for the calibration event variation within the catchment.

Temporal patterns for the rainfall events were calculated based on the available sub-daily rainfall stations. All 6 rainfall stations have sub-daily rainfall data and their temporal patterns of the July 2020 event are shown in Figure 4-6.

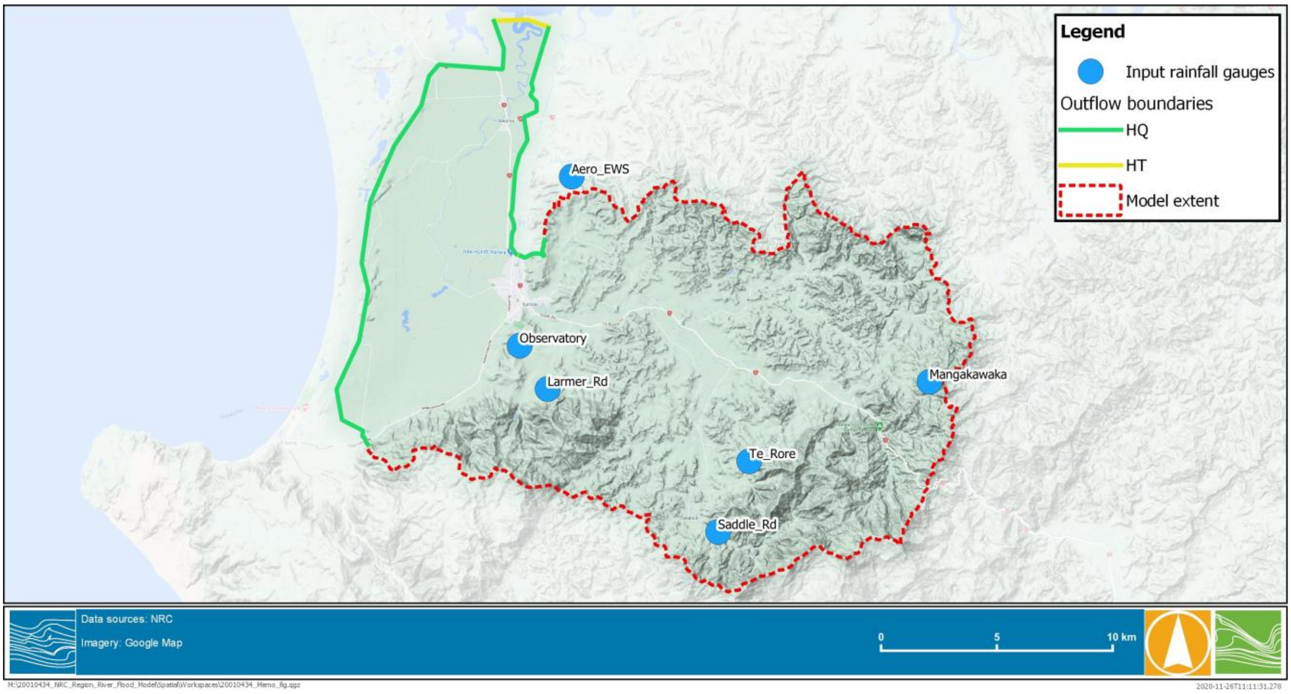


FIGURE 4-4 HYDRAULIC MODEL BOUNDARIES - AWANUI CATCHMENT

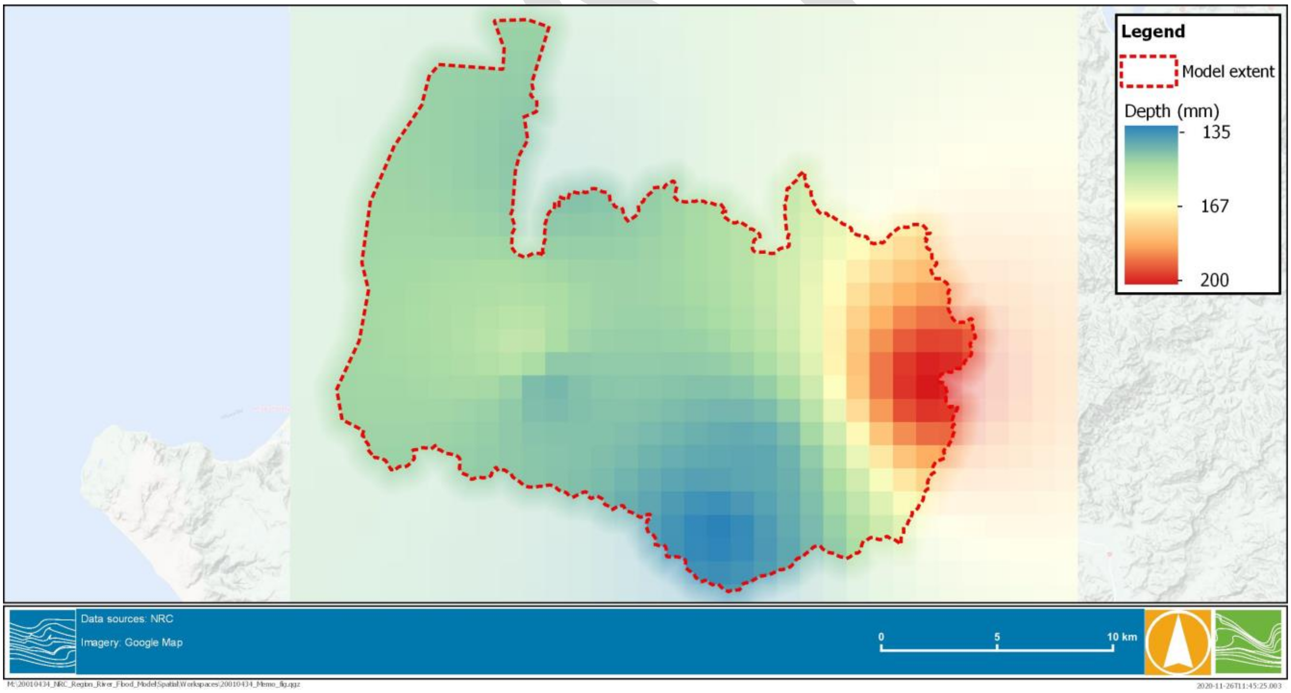


FIGURE 4-5 INTERPOLATED RAINFALL DEPTHS FOR JULY 2020 EVENT – AWANUI CATCHMENT

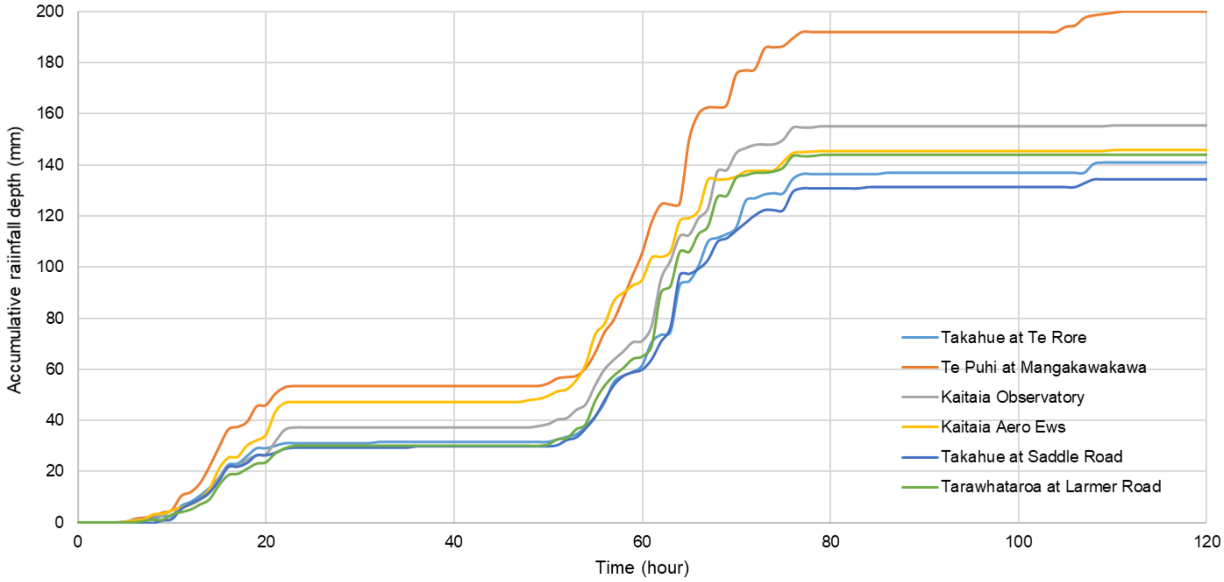


FIGURE 4-6 TEMPORAL PATTERN FOR JULY 2020 EVENT AT SUB-DAILY RAINFALL STATIONS – AWANUI CATCHMENT

Material Roughness layer

The material roughness layer was created based on the 2016 LUCAS land use map data released by the Ministry for the Environment[4] and the waterway data from Land Information New Zealand. Figure 4-7 displays the material layer used for Awanui catchment model.

The hydraulic roughness values and rainfall losses were initially assigned in accordance with the classification of land use types. The values of these parameters were modified during the model calibration with the use of a soil type layer used to verify likely geology in the area. This allowed for a better understanding of soil infiltration/loss values within the model. The calibration phase also included significant sensitivity testing to identify the impacts of losses and roughness values on modelled results.

[4] Land use and carbon analysis system (LUCAS) 2016, *Land Use Map Data*, prepared for New Zealand Ministry for the Environment.

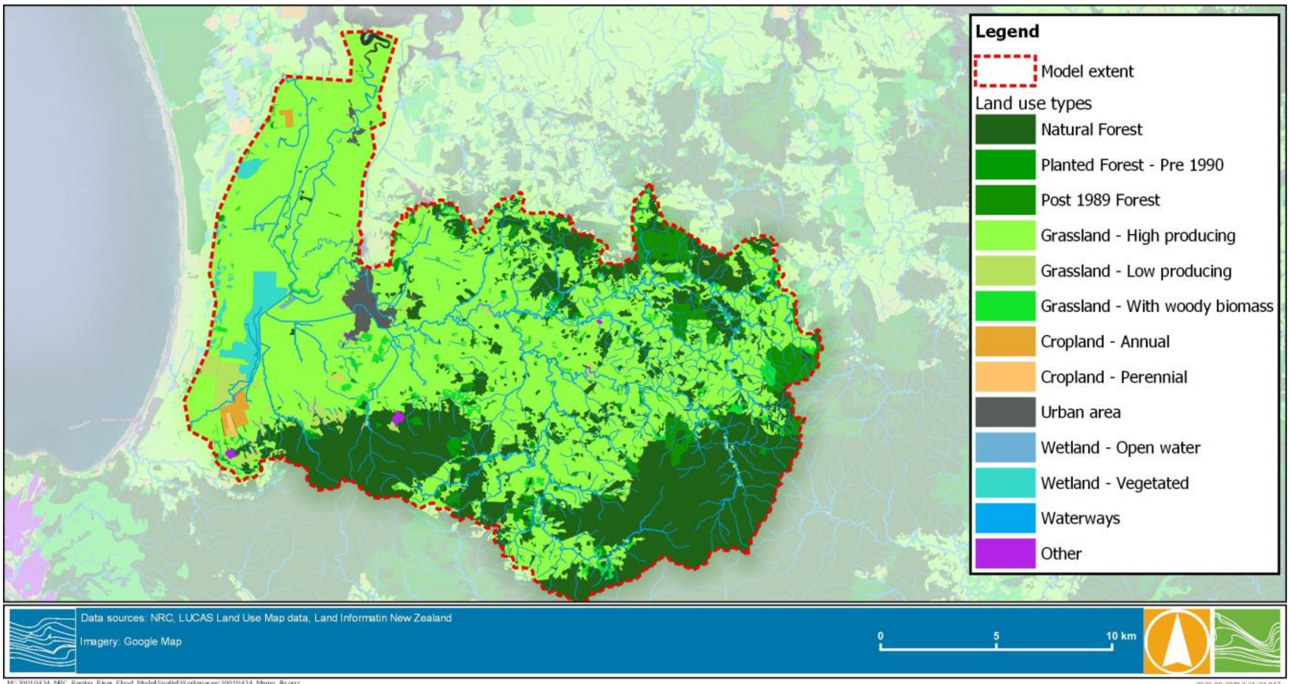


FIGURE 4-7 HYDRAULIC MODEL MATERIAL LAYER – AWANUI CATCHMENT

4.2 Model calibration

Model parameters

The January 2011 event was initially used for the calibration of the Awanui catchment model. This was selected as the event had been modelled in previous studies with extensive detail undertaken for the calibration of this event in the DHI report[5]. Full details of the calibration for this event can be found in Appendix A.

During the model calibration, NRC informed Water Technology that there had been modifications to topography and channel geometry around Kaitaia since LiDAR was flown in 2018. To ensure design modelling would replicate the current flood characteristics in Kaitaia, the current channel geometry was included in the model and the July 2020 flood event was used to calibrate the model to. The final calibrated model parameters are based on the July 2020 calibration.

The available rainfall records in this event within the catchment are summarised in Table 4-1. The July 2020 flood event saw around 150 mm of rainfall in total across the catchment. The event firstly occurred in 15th of July at 5 p.m. and lasted for about 18 hours with an average of around 40mm of rainfall recorded across the catchment. About 20 hours later, a much larger rainfall burst occurred with a 80 mm falling in 12 hours during the event seeing a relatively fast catchment response. In the lead up to the storm event, the catchment conditions could be considered highly saturated with a small rainfall event (60mm) falling in the week leading up to the event. The water level at the streamflow gauges downstream started to rise in 10 hours after the rainfall started falling.

TABLE 4-1 RAINFALL STATION DETAILS FOR JULY 2020 EVENT

Station name	Site ID	Source	Rainfall total in 15th July 2020 (mm)	Rainfall total in 17th to 18th July 2020 (mm)	Rainfall total (mm)	Data type
Kaitaia Aero Ews	A53026	NIWA	47.4	98.6	146	Hourly
Kaitaia Observatory	A53125	NIWA	37.2	118.4	155.6	Hourly
Takahue at Saddle Road	-	NRC	29.5	105	134.5	1-min
Takahue at Te Rore	531313	NRC	31	110	141	5-min
Te Puhi at Mangakawakawa	531415	NRC	53.5	146.5	200	5-min
Tarawhataroa at Larmer Road	-	NRC	30	114	144	1-min

The 2020 Awanui Flood Model Upgrade study[5] provided valuable information during the calibration process. Given a different hydrology and hydraulic modelling approach being adopted in the DHI study, the calibrated model parameters in the existing study cannot be directly used in TUFLOW model. Despite this, the study report illustrates that the existing hydraulic model were calibrated with losses parameters varied from different sub-catchment areas due to the geology and soil type variation across the catchment.

Rainfall loss and soil infiltration methods were tested during the calibration process to identify the most practical and suitable method to adopt for design modelling. The calibrated model parameters are summarised in Table 4-2 and Figure 4-8 displays the delineated hydrological and soil type areas within the catchment.

[5] DHI 2020, *Awanui Flood Model Upgrade - Model Build*, report prepared for NRC

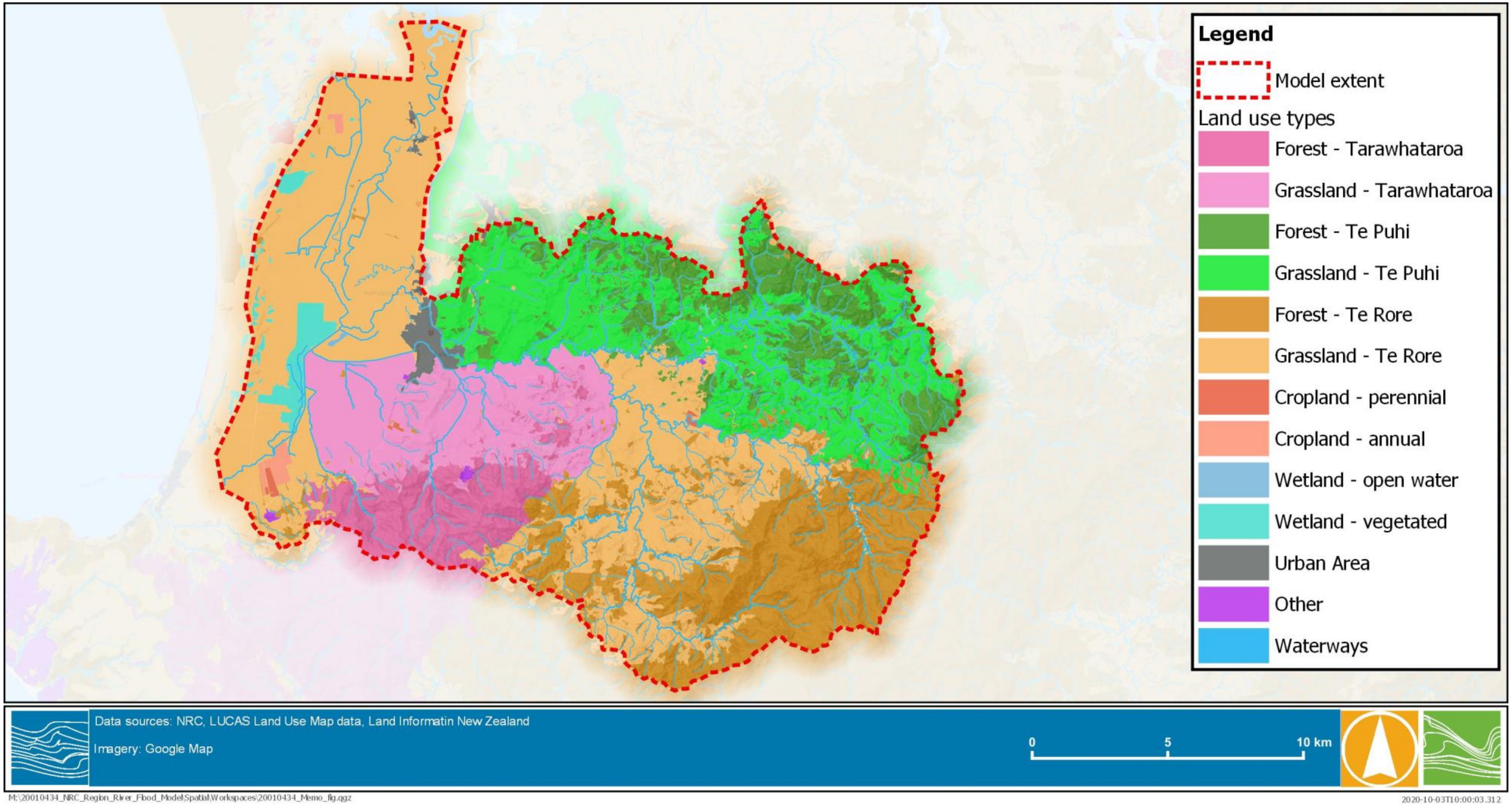


FIGURE 4-8 HYDRAULIC MATERIAL LAYER WITH DELINEATED HYDROLOGICAL AREAS

TABLE 4-2 CALIBRATED HYDRAULIC ROUGHNESS AND RAINFALL LOSSES VALUES

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

Calibration results

Table 4-3 provides a summary of the calibration results and the quantitative assessment against the key calibration requirements outlined in the project brief. Figure 4-9 to Figure 4-12 show the modelled flow and water level compared to the gauge records.

The modelled hydrographs at both gauges show a good match to the gauged records in terms of shape. In comparison to the peak recorded water levels, the peak modelled water levels are slightly lower but within the 300 mm range. The timing of peak flood levels at both gauges is slightly early, however considered a reasonable match. There is no surveyed flood level of the July 2020 event for comparison within the Awanui catchment model extent, however the January 2011 event extent provided a suitable match.

In contrast to the water levels and general shape of modelled and recorded flood behaviour, the peak flows and volumes are underestimated by the hydraulic model when compared with the theoretical rating curve. Given the modelled shape of the two streamflow gauges is well represented and the general flood extent provides a suitable comparison, the reliability of the rating curve at high flows is a potential issue. Other issues which were discussed with Northland Regional Council for the discrepancies included:

- Whether the channel geometry was captured properly in the LiDAR.
- The impact of localised rainfall bursts in the immediate catchment upstream of the gauge which may have caused the initial peak. Figure 4-4 shows the 6 available rainfall gauges are not evenly distributed within the catchment.

Following a review of the available data from the 2011 and 2020 flood events, it was identified that the rating curve used was the factor most likely to cause uncertainty.

Figure 4-13 and Figure 4-14 show the modelled rating curves at these two gauges compared with the recorded water levels and streamflow. Both gauges show higher levels in the hydraulic model compared with the recorded data. Several tests assessing the impact of the hydraulic roughness parameter adopted for the channel and floodplain area were undertaken and were not found to make a significant impact that would resolve the differences currently observed in the model.

No information on the development of the rating curves was found within the Northland Regional Council or NIWA website. Previous flood study[7] has identified issues and discrepancies with streamflow rating curves at high flows. It is widely accepted that a lack of accurate gauging information can carry significant errors when developing flow estimates. Therefore, a rating curve review may be needed to be undertaken to verify the rating curve's extrapolation at high flows.

Given the nature of work required to undertake rating curve information, assessing this catchment and others in the study area against the recorded water levels appears to carry more weight in ensuring the hydraulic model is performing as expected and is fit for purpose.

TABLE 4-3 SUMMARY OF JULY 2020 CALIBRATION FOR AWANUI CATCHMENT

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)
Puriri Place	19	27	-30%	-1.4	318	2304	-86%	13.15	12.94	212.00
School Cut	146	224	-35%	-2.2	9311	27803	-67%	14.54	14.78	-236.60

TABLE 4-4 QUANTITATIVE ASSESSMENT OF JULLY 2020 CALIBRATION

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 (Y/N)	Model flow within 10% of recorded flow at the same stage (Y/N)
Puriri Place	N	N	Y	N	N
School Cut	N	N	Y	N	N

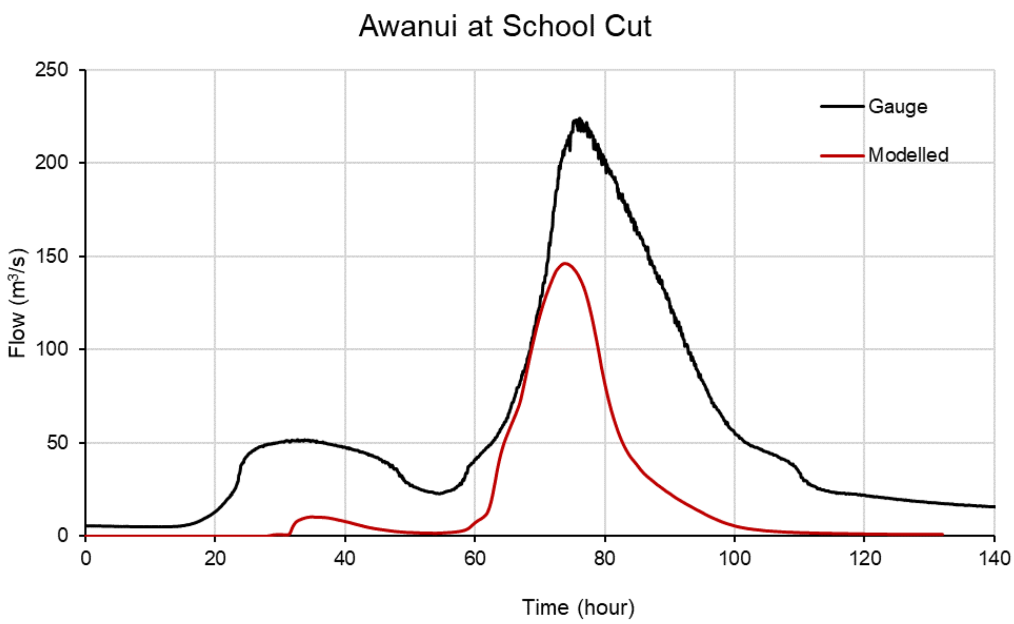


FIGURE 4-9 MODELLED AND GAUGED FLOWS AT AWANUI RIVER AT SCHOOL CUT – 2020 FLOOD EVENT

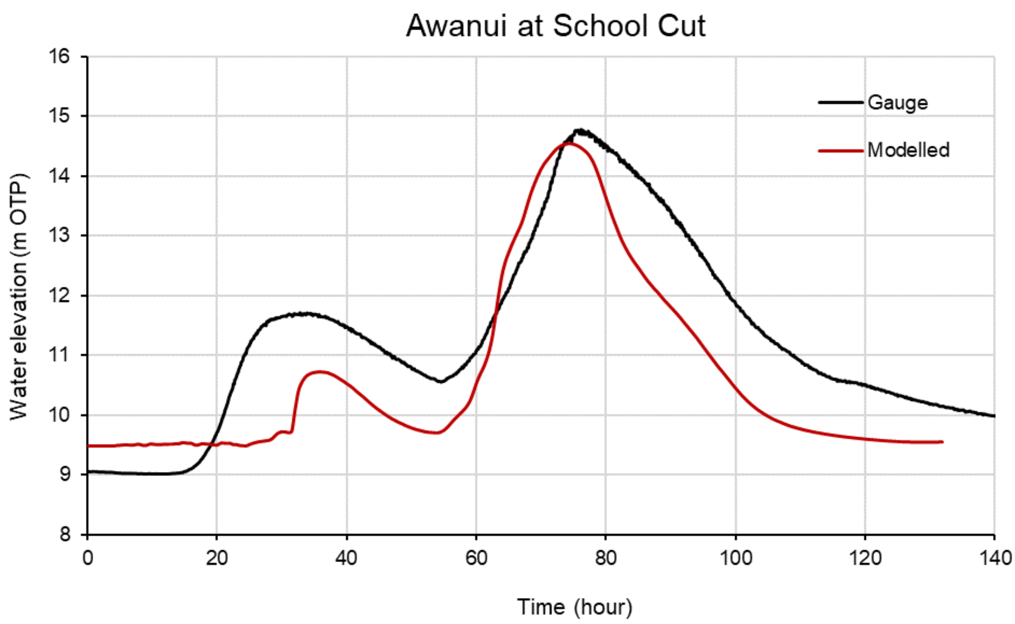


FIGURE 4-10 MODELLED AND GAUGED WATER LEVELS AT AWANUI RIVER AT SCHOOL CUT – 2020 FLOOD EVENT

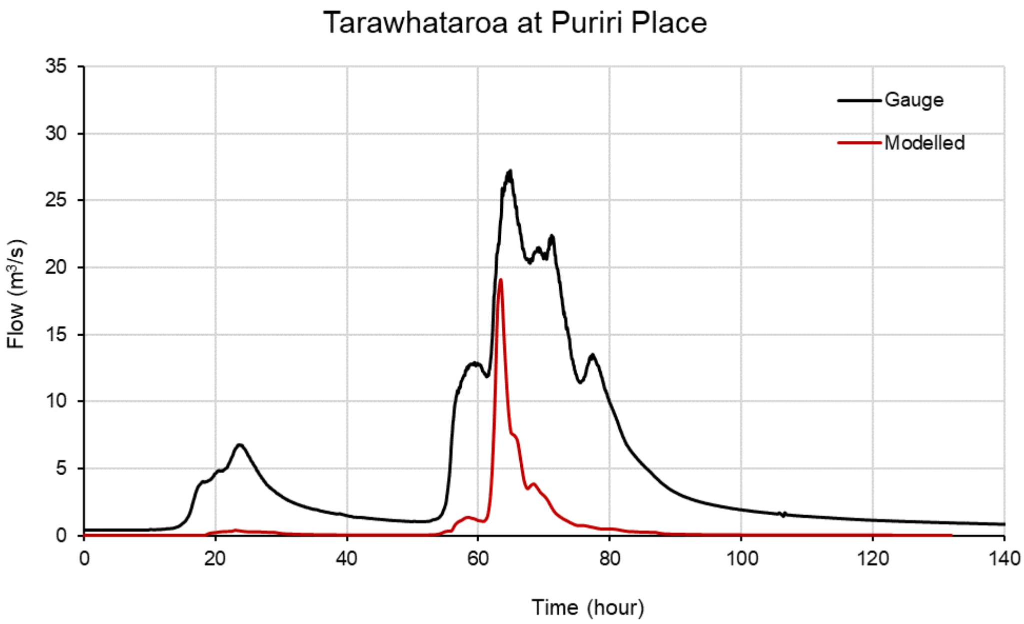


FIGURE 4-11 MODELLED AND GAUGED FLOWS AT TARAWHATORA RIVER AT PURIRI PLACE – 2020 FLOOD EVENT

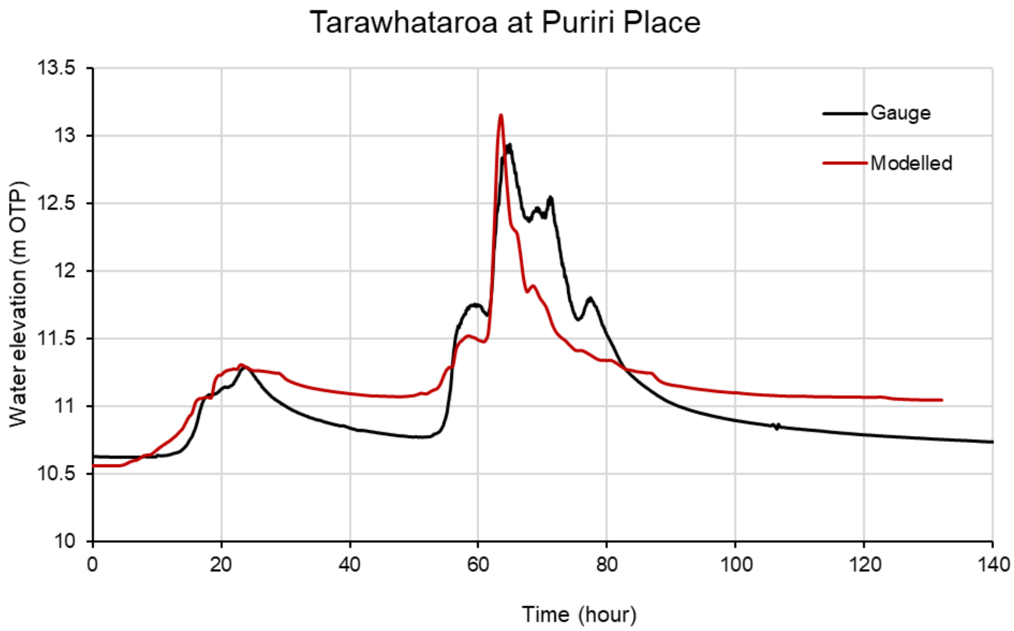


FIGURE 4-12 MODELLED AND GAUGED WATER LEVELS AT TARAWHATORA RIVER AT PURIRI PLACE – 2020 FLOOD EVENT

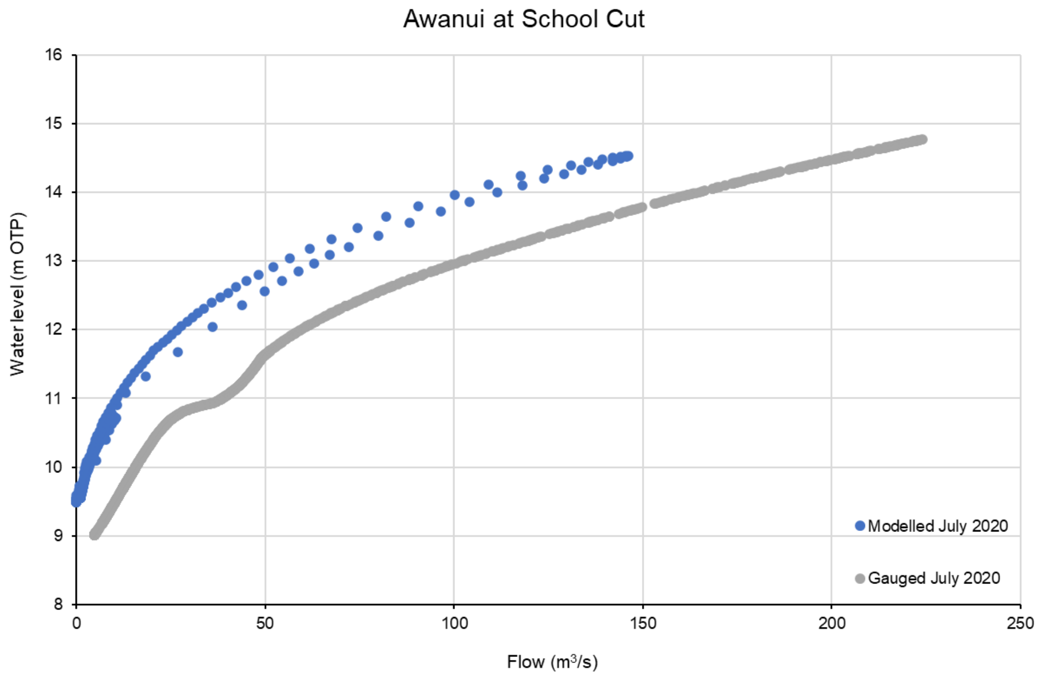


FIGURE 4-13 MODELLED AND GAUGED RATING CURVE COMPARISON AT SCHOOL CUT

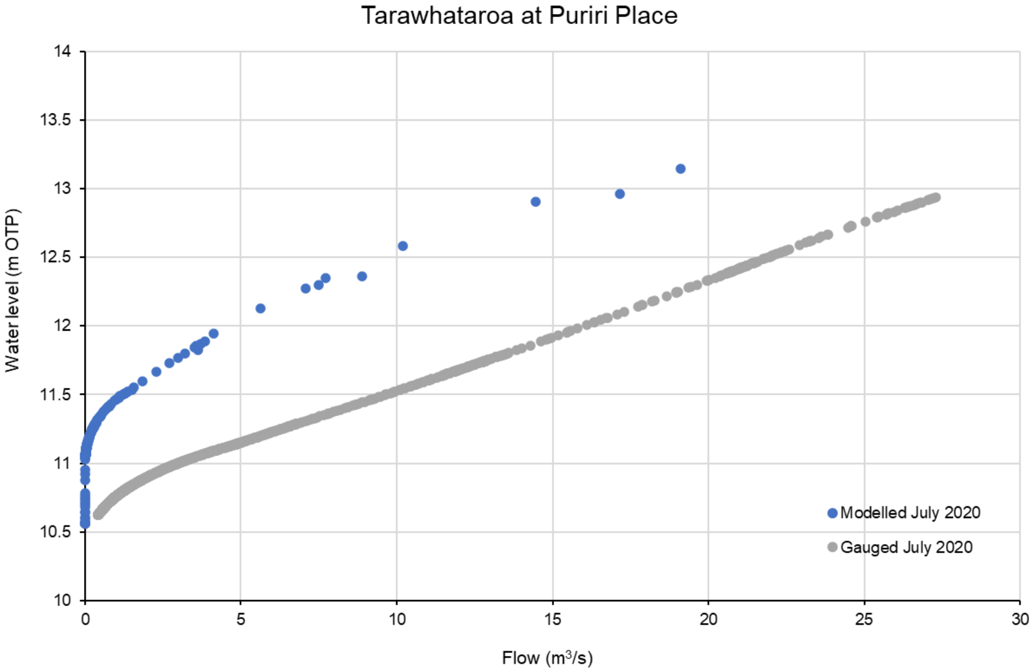


FIGURE 4-14 MODELLED AND GAUGED RATING CURVE COMPARISON AT PURIRI PLACE

5 KAWAKAWA CATCHMENT (MODEL 15)

5.1 Model development

Model extent

The Kawakawa catchment covers an area of 443 km^2, with Moerewa and Kawakawa its main townships. The Kawakawa River is the main waterway in the catchment with numerous other streams joining it to the north of the town before flowing east to the Waikare Inlet. The hydraulic model extent of Kawakawa catchment is displayed in Figure 5-1 and the catchment topography is shown in Figure 5-2.

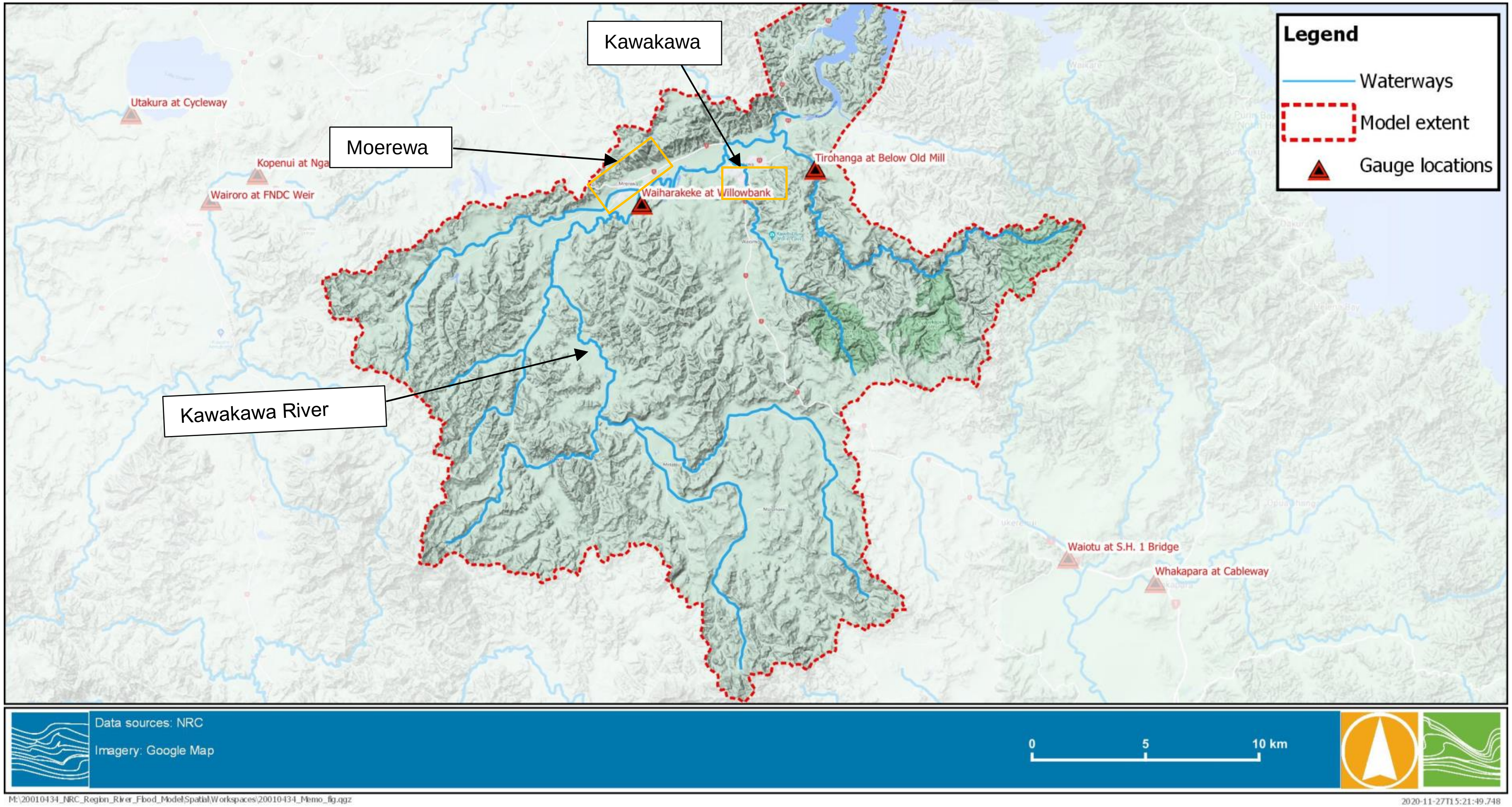


FIGURE 5-1 HYDRAULIC MODEL EXTENT – KAWAKAWA CATCHMENT

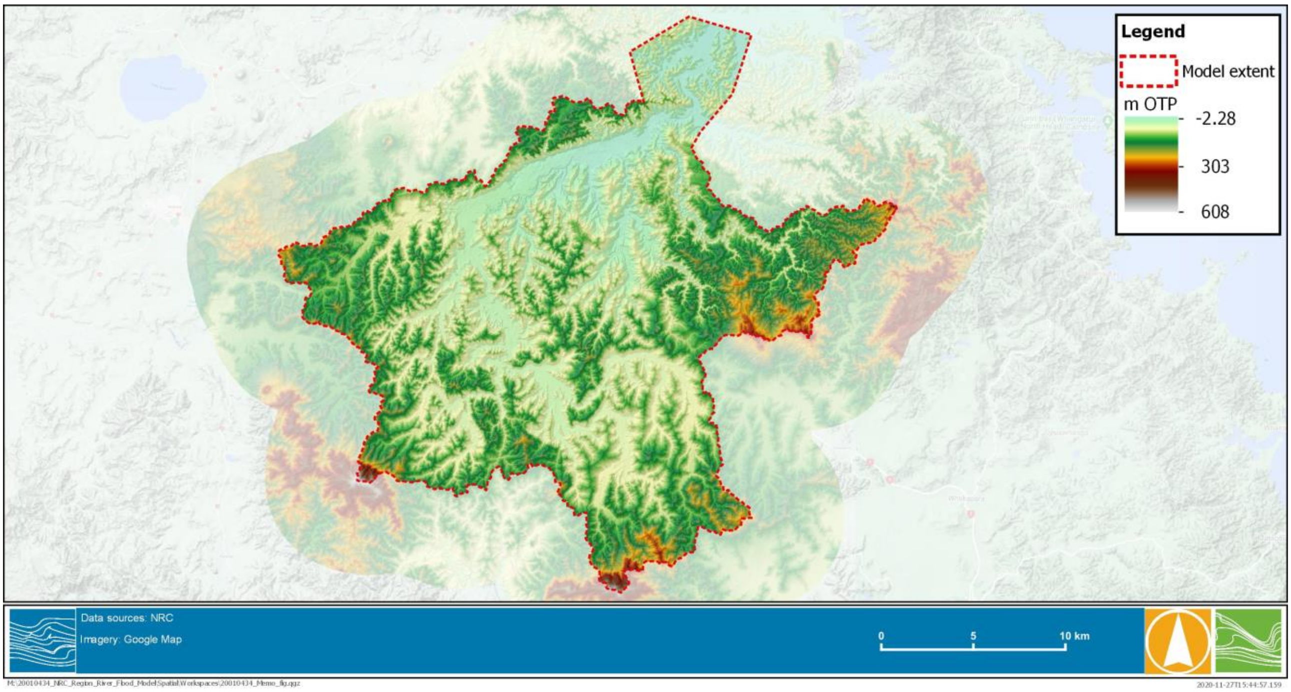


FIGURE 5-2 HYDRAULIC MODEL TOPOGRAPHY – KAWAKAWA CATCHMENT

Model boundary

The hydraulic model boundaries consist of input rainfall depths and outflow boundaries. A downstream tailwater boundary (i.e. type HT) was applied to the Veronica Channel at Opua Wharf using the water levels recorded during the 2011 flood event. HQ (stage-discharge) outflow boundaries were also applied to the edge of the model upstream of Opua Wharf.

The January 2011 event was used for the calibration of the Kawakawa catchment model. The available rainfall records for this event are summarised in Table 5-1. The January 2011 flood event saw over 200 mm of rainfall fall in parts of the catchment including a burst of close to 170 mm of rainfall in 6 hours. In the lead up to the flood event, the catchment conditions could be considered relatively saturated with 150 mm of rainfall occurring one week prior. The streamflow gauges towards the lower part of the catchment started to rise around 10 hours after the start of the rainfall.

TABLE 5-1 RAINFALL STATION DETAILS FOR JAN 2011 EVENT

Station name	Site ID	Source	Rainfall total in 28th Jan 2011(mm)	Data type
Veronica Channel at Opua Wharf	543111	NRC	237	5-min
Waitangi at McDonald Road	543010	NRC	276	5-min
Waitangi at Whangae	543012	NRC	231	Daily
Waitangi at Ohaeawai	533817	NRC	223.5	5-min
Kaikohe Aws	A53487	NIWA	210.4	Hourly
Waiharakeke at Okaroro Road	545014	NRC	217	5-min
Dawson at Waiotu	545111	NRC	238.5	Daily
Veronica Channel at Opua Wharf	543111	NRC	237	5-min

The input rainfall depths across the catchment area were interpolated using the Inverse Distance Weighted (IDW) average method based on the location and the rainfall records in these stations. Figure 5-3 shows the hydraulic model boundaries for Kawakawa catchment and Figure 5-4 shows the interpolated rainfall depths within the catchment highlighting the heavier falls in the north of the catchment in the 2011 flood event.

Temporal patterns for the rainfall events were calculated based on the available sub-daily rainfall gauges, shown in Figure 5-5. Five gauges were used for this, with the temporal patterns for the Whangae and Waiotu gauges based on McDonald Road station and Okaroro Road station respectively. The temporal patterns across the catchment do not appear to differ making this approach suitable for the calibration process.

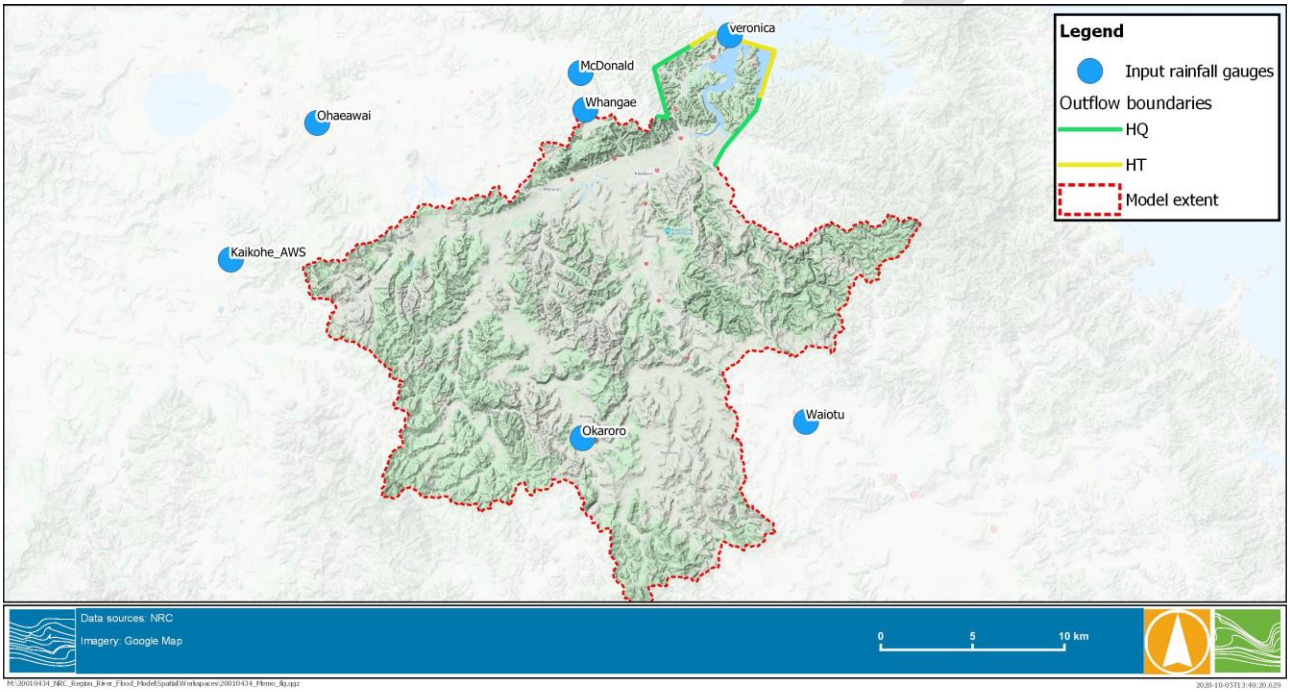


FIGURE 5-3 HYDRAULIC MODEL BOUNDARIES – KAWAKAWA CATCHMENT

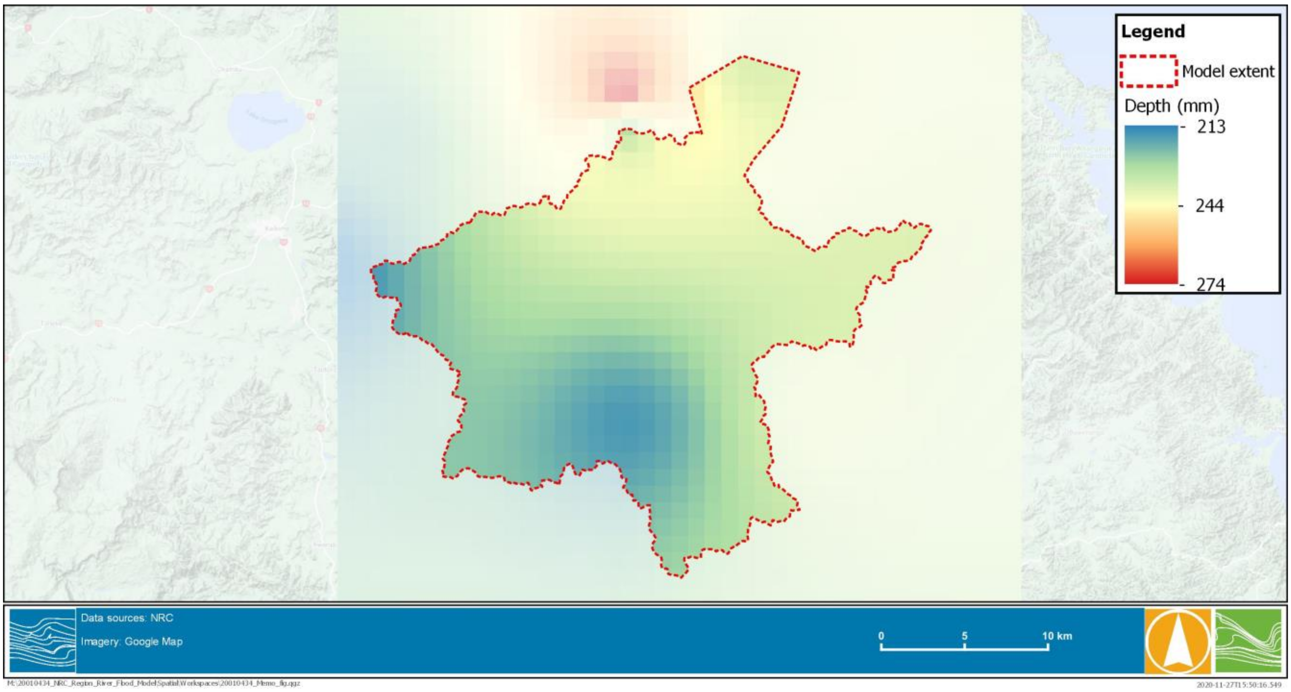


FIGURE 5-4 INTERPOLATED RAINFALL DEPTHS FOR JAN 2011 EVENT – KAWAKAWA CATCHMENT

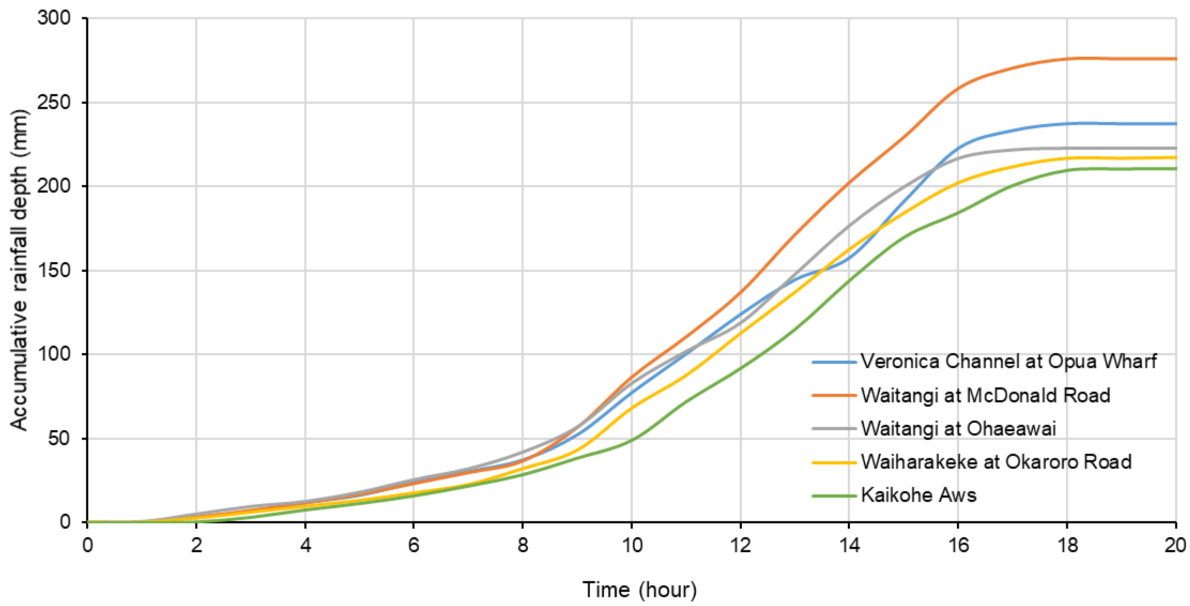


FIGURE 5-5 TEMPORAL PATTERN FOR JANUARY 2011 EVENT AT SUB-DAILY RAINFALL STATIONS – KAWAKAWA CATCHMENT

Material layer

The material layer was created based on the 2016 LUCAS land use map data4 and the waterway data from Land Information New Zealand. Figure 5-6 displays the material layer used for Kawakawa catchment model. As for the Awanui catchment, the hydraulic roughness values and rainfall losses were assigned in accordance with the land use types, the sub-catchment areas and soil types[6]. The Kawakawa catchment was divided into upper and lower sub-catchments to achieve a suitable match against the two streamflow gauges within the catchment.

[6] P.F.J. Newsome, R H Wilde, E J Willoughby 2008, *Land Resource Information System Spatial Data Layers*, Landcare Research New Zealand Ltd.

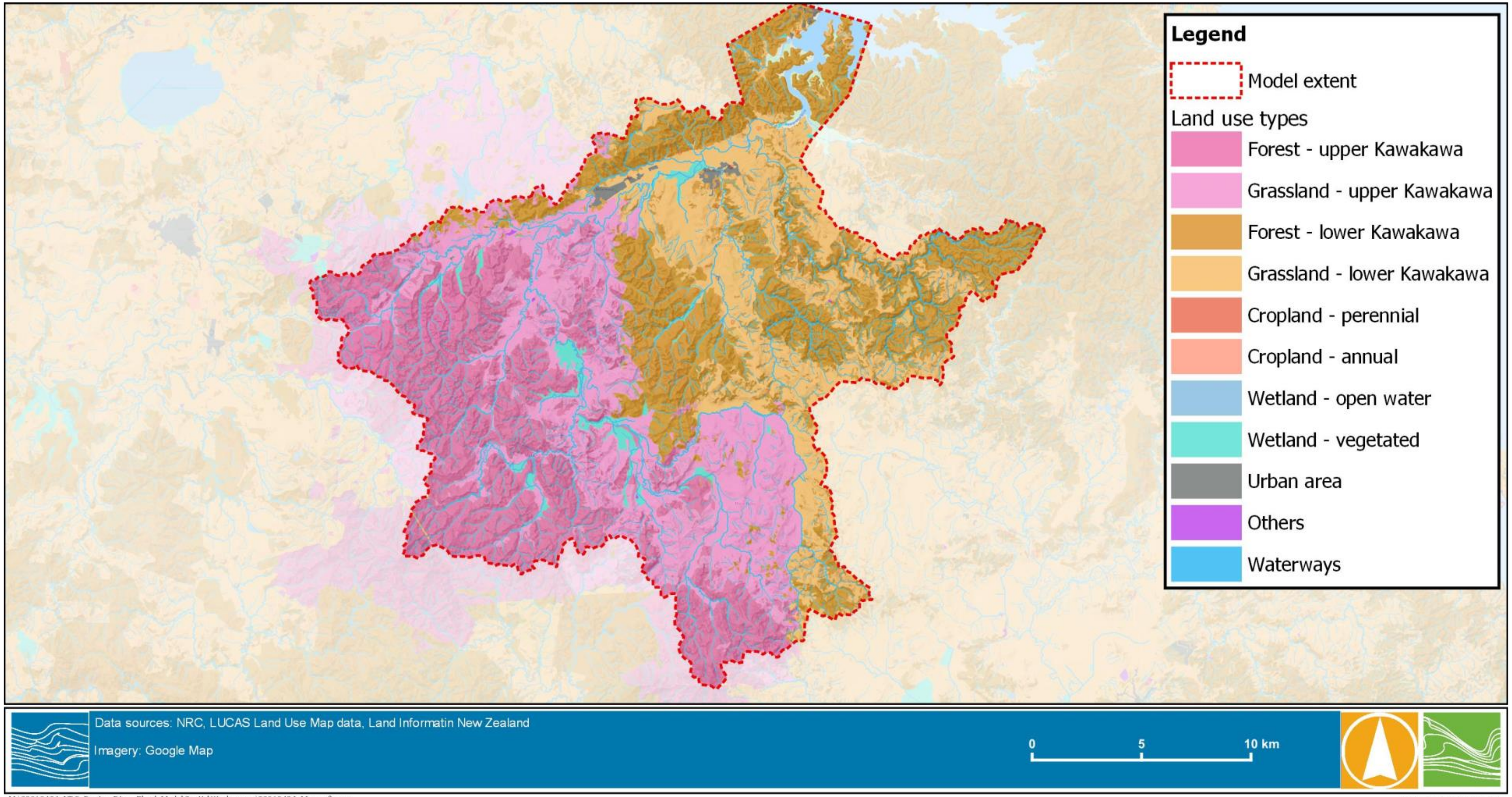


FIGURE 5-6 HYDRAULIC MODEL MATERIAL LAYER – KAWAKAWA CATCHMENT

5.2 Model calibration

Model parameters

The streamflow gauges used for model calibration are Waiharakeke at Willobank station and Tirohanga below Old Mill. Both of these gauges have the flow and water level records for the entire event.

The Taumarere Modelling and Calibration Report[7] provided a basis for the initial loss parameter values and the responsiveness of the sub-catchment upstream of the water level stations. Table 5-2 summaries the details of the final adopted calibration parameters for the Kawakawa catchment model.

TABLE 5-2 CALIBRATED HYDRAULIC ROUGHNESS AND RAINFALL LOSSES VALUES – KAWAKAWA CATCHMENT

Hydrological areas	Land use types	Manning's n	Initial loss (IL) - mm	Continuing loss (CL) – mm/hr
Upper Kawakawa	Forest	0.18	40	6.5
	Grassland	0.16	40	6.5
Lower Kawakawa and other areas	Forest	0.06	45	11.5
	Grassland	0.04	45	11.5
Entire Kawakawa 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

Calibration results

Table 5-3 summarises the comparison between the observed and the modelled values and Table 5-4 shows the quantitative assessment of the calibration performance. Figure 5-7 to Figure 5-10 show the modelled flow and water levels compared to the gauged records.

The model results at the Willowbank gauge show a faster catchment response than the recorded levels. The occurrence of high flows during the January 2011 event lasted for more than 10 hours. Although the modelled peaks were more than 16 hours earlier than that observed, the modelled hydrograph and water level plot show a good match to the gauged records in terms of their shape and peak values. The modelled flows at this gauge were within 10% of the recorded flow. A comparison of the modelled rating shows a good match to the gauged rating curve as shown in Figure 5-11. It should be noted that the modelled results at this gauge have been improved comparing to that produced in Taumarere Modelling report[7].

The modelled results at Old Mill station show a good match to the gauged records for hydrograph shape, timing, peak flow and water level. The modelled peaks were less than 30 minutes earlier than that observed. The modelled flow volume was underestimated in the model and may be the result of discrepancy between the modelled and gauged rating curve (especially between low-moderate flows of 50-100m^3/s) resulting in the

[7] URS 2012, *Taumarere Modelling and Calibration Report*, Prepared for Northland Regional Council

modelled volume being lower than recorded. The 2012 URS report also identified there being a high degree of uncertainty with the rating curve for the Old Mill gauge.

Figure 5-13 and Figure 5-14 display the difference plot of the modelled water level compared with the surveyed flood level points. It should be noted that some of the points are overlapped with others in these maps. There are 189 flood level points were captured. Of 127 flood level points (approx. 70%), the modelled flood levels are within 300 mm difference compared to that observed.

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

TABLE 5-3 SUMMARY OF CALIBRATION RESULTS FOR KAWAKAWA CATCHMENT

	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)
Willowbank	259	238	8.84%	-16.5	26773	29832	-10.26%	14.97	15.23	-258.70
Below Old Mill	242	250	-2.97%	-0.42	5821	8048	-27.67%	11.13	10.89	240.10

TABLE 5-4 QUANTITATIVE ASSESSMENT OF JANURAY 2011 CALIBRATION FOR KAWAKAWA CATCHMENT

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)
Willowbank	Y	Y	Y	N	Y
Below Old Mill	Y	N	Y	Y	N

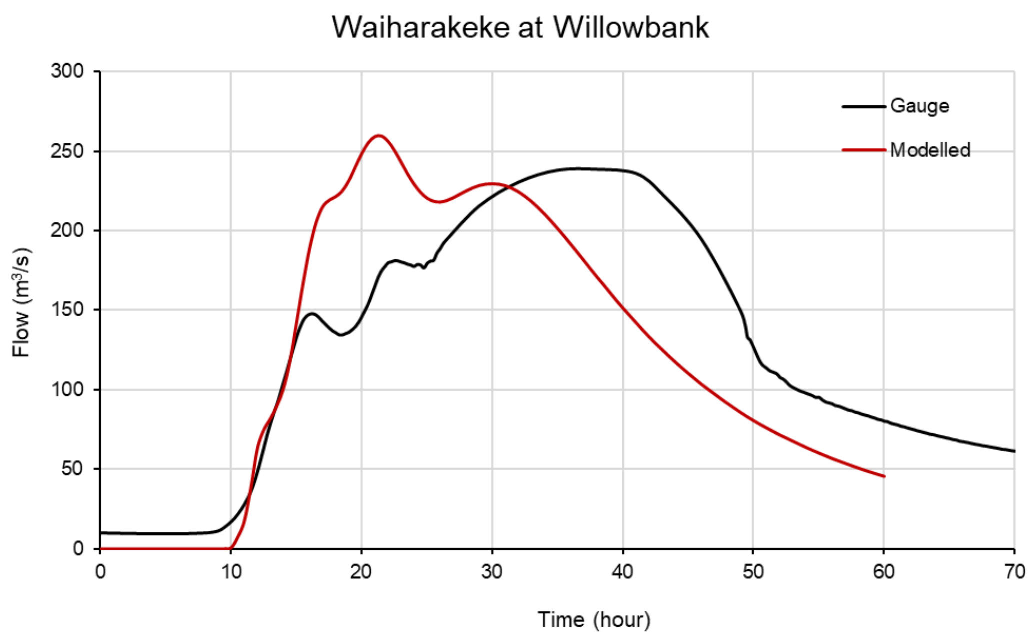


FIGURE 5-7 MODELLED AND GAUGED FLOWS AT WAIHARAKEKE RIVER AT WILLOWBANK

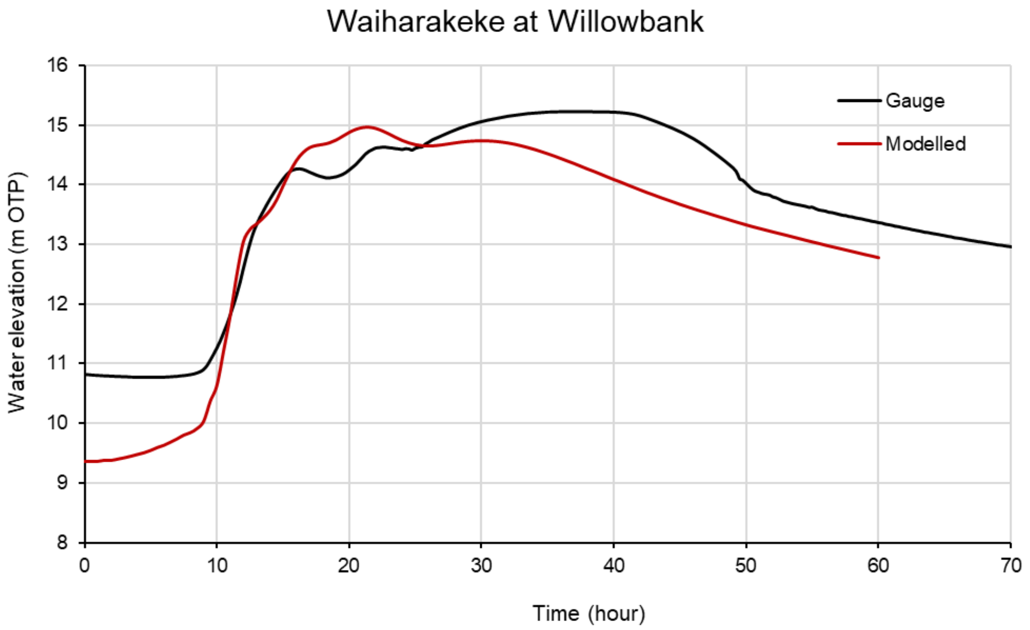


FIGURE 5-8 MODELLED AND GAUGED LEVELS AT WAIHARAKEKE RIVER AT WILLOWBANK

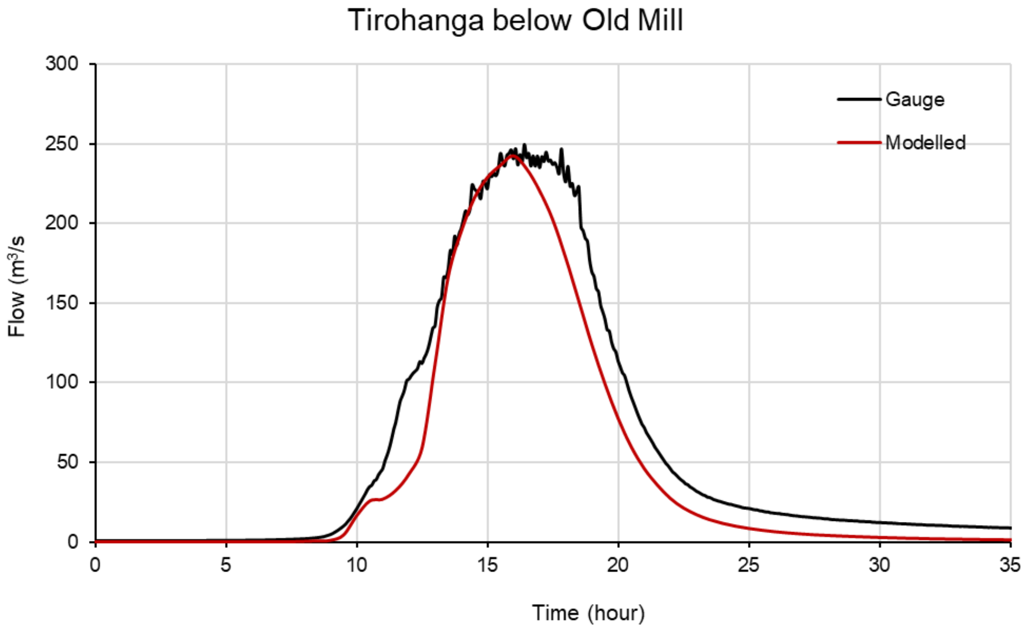


FIGURE 5-9 MODELLED AND GAUGED FLOWS AT TIROHANGA RIVER BELOW OLD MILL

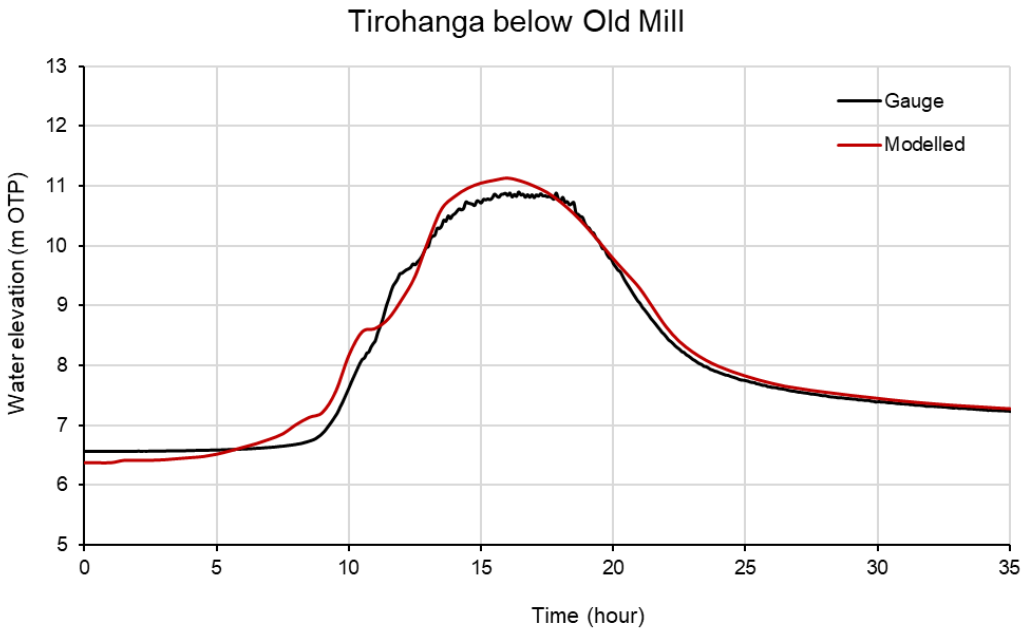


FIGURE 5-10 MODELLED AND GAUGED WATER LEVELS AT TIROHANGA RIVER BELOW OLD MILL

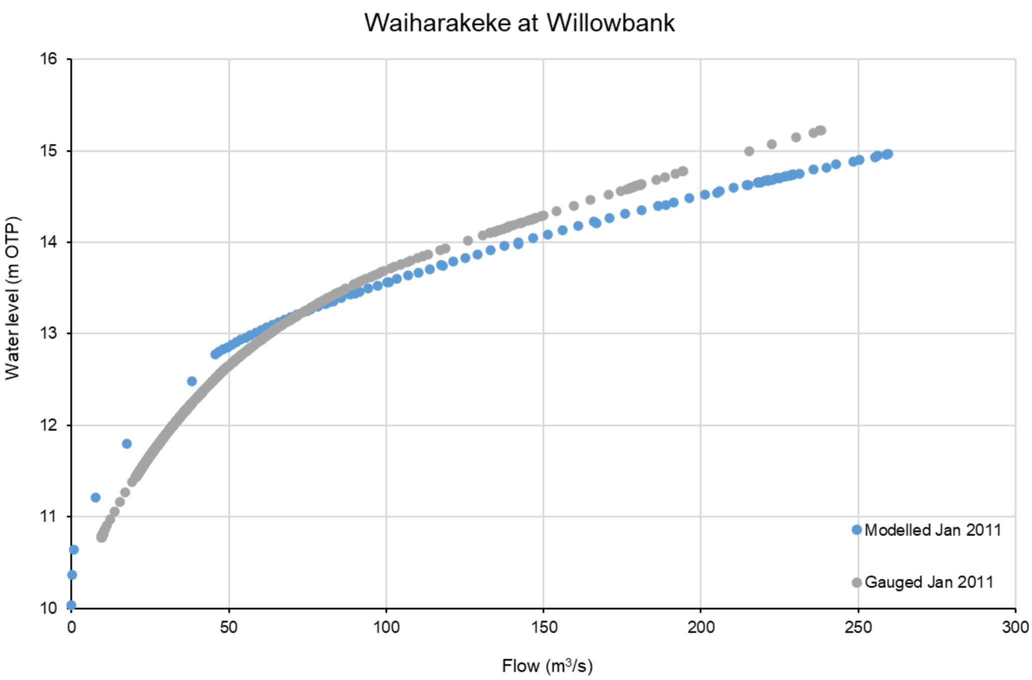


FIGURE 5-11 MODELLED AND GAUGED RATING CURVE COMPARISON AT WILLOWBANK GAUGE

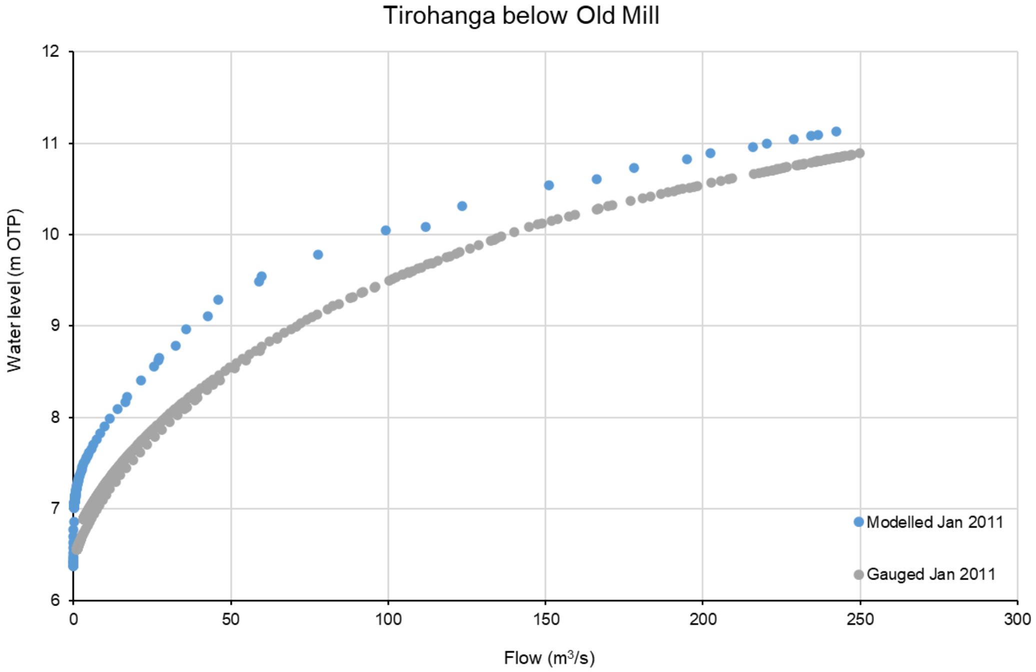
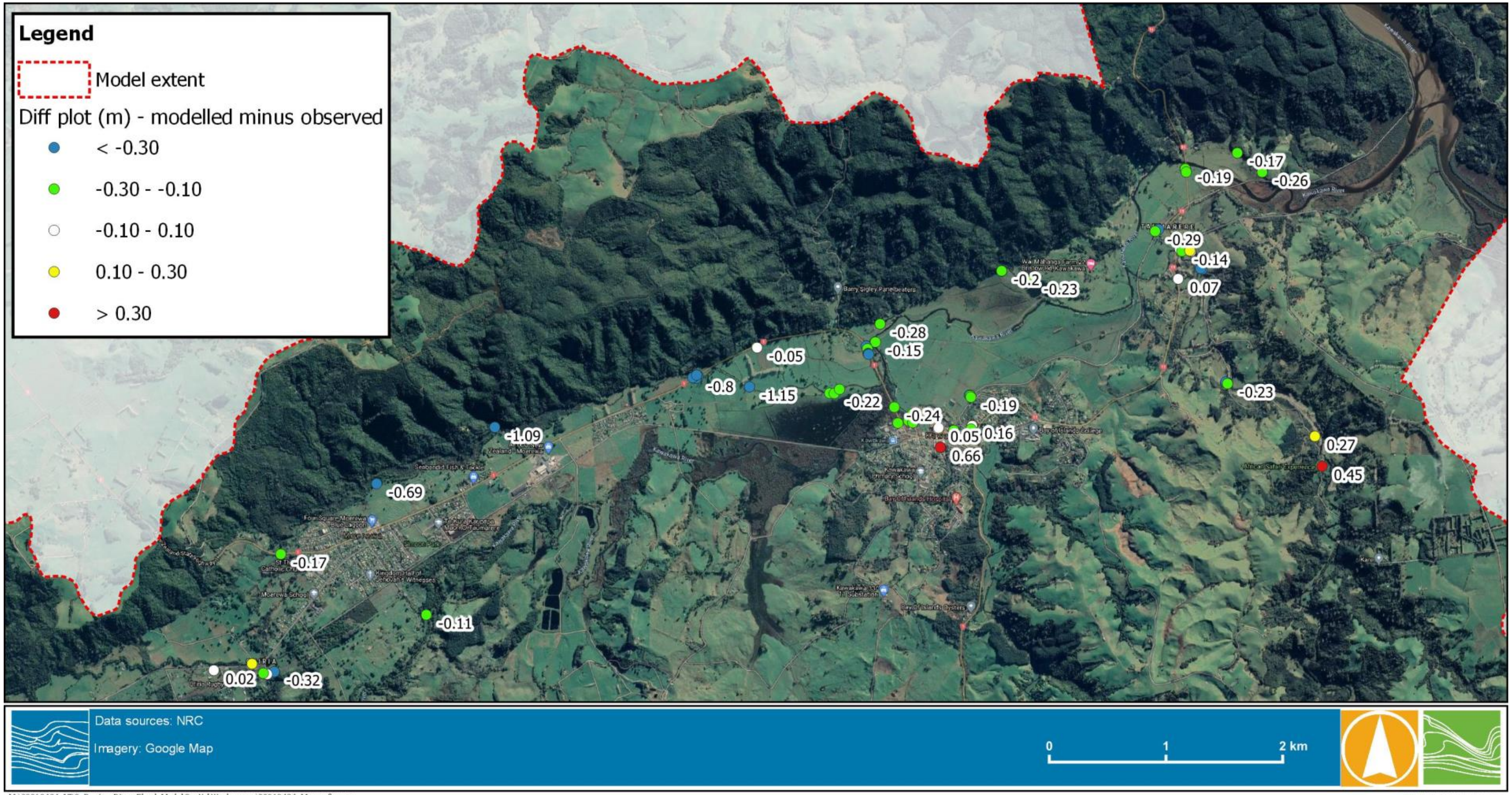
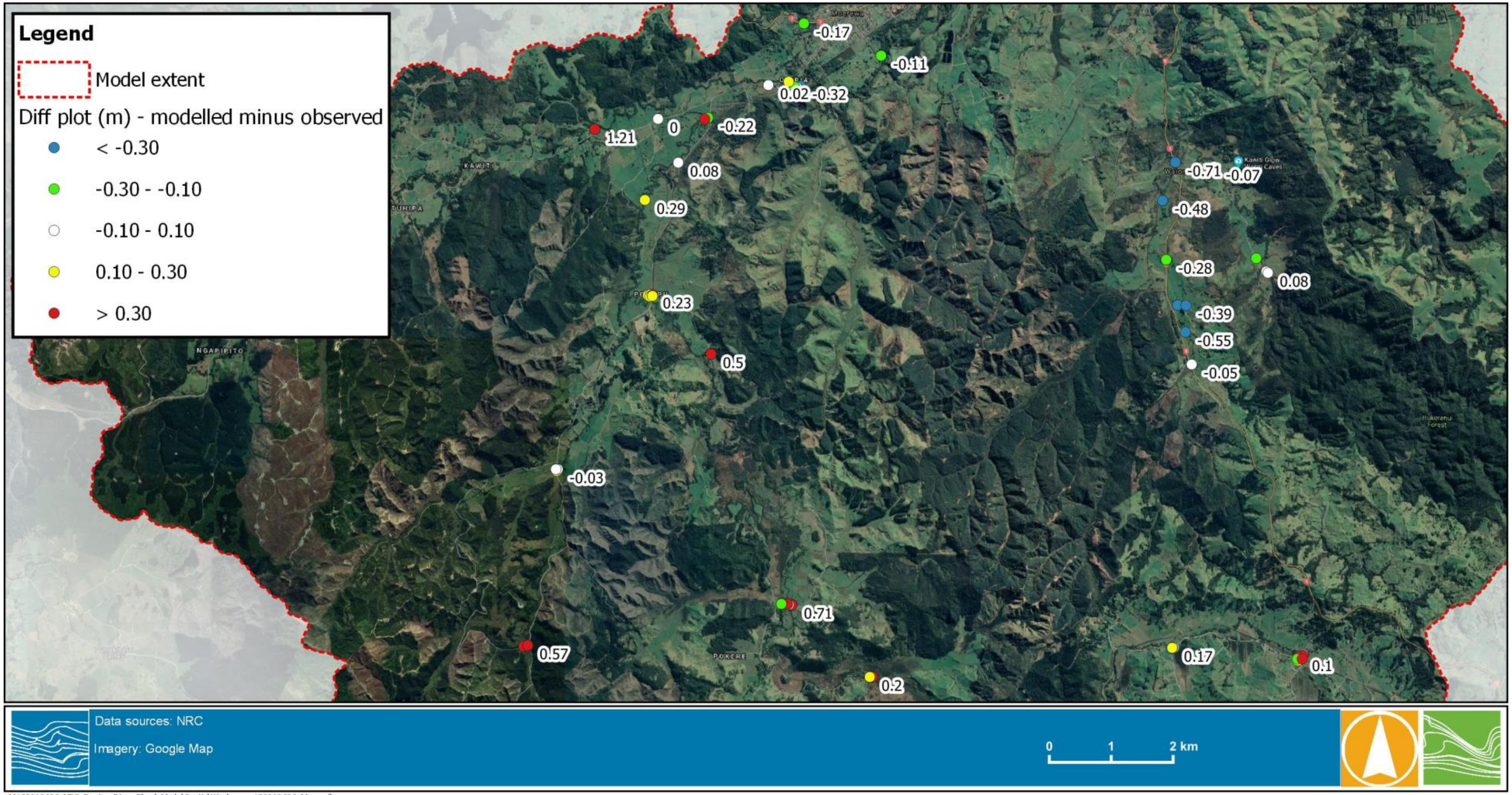


FIGURE 5-12 MODELLED AND GAUGED RATING CURVE COMPARISON AT OLD MILL GAUGE



M:\20010434_NRC_Region_River_Flood_Model\Spatial\Workspaces\20010434_Memo_fig.qgz
2020-11-27T17:30:24.362

FIGURE 5-13 COMPARISON BETWEEN MODELLED FLOOD LEVEL AND SURVEY FLOOD LEVEL – JANUARY 2011 EVENT (LOWER KAWAKAWA CATCHMENT)



M:\20010434_NRC_Region_River_Flood_Model\Spatial\Workspaces\20010434_Memo_fig.qgz 2020-11-27T17:32:39.748

FIGURE 5-14 COMPARISON BETWEEN MODELLED FLOOD LEVEL AND SURVEY FLOOD LEVEL – JANUARY 2011 EVENT (UPPER KAWAKAWA CATCHMENT)

6 WHANGAREI CATCHMENT (MODEL 01)

6.1 Model development

Model extent

The Whangarei catchment covers a total area of approximately 232 km^2 with Whangarei its largest urban area. The major waterways include Hatea River to the north, Raumanga Stream to the west, Otaika Stream to the south of the Whangarei. Figure 6-1 shows the model extent of Whangarei catchment and catchment topographic data is shown in Figure 6-2.

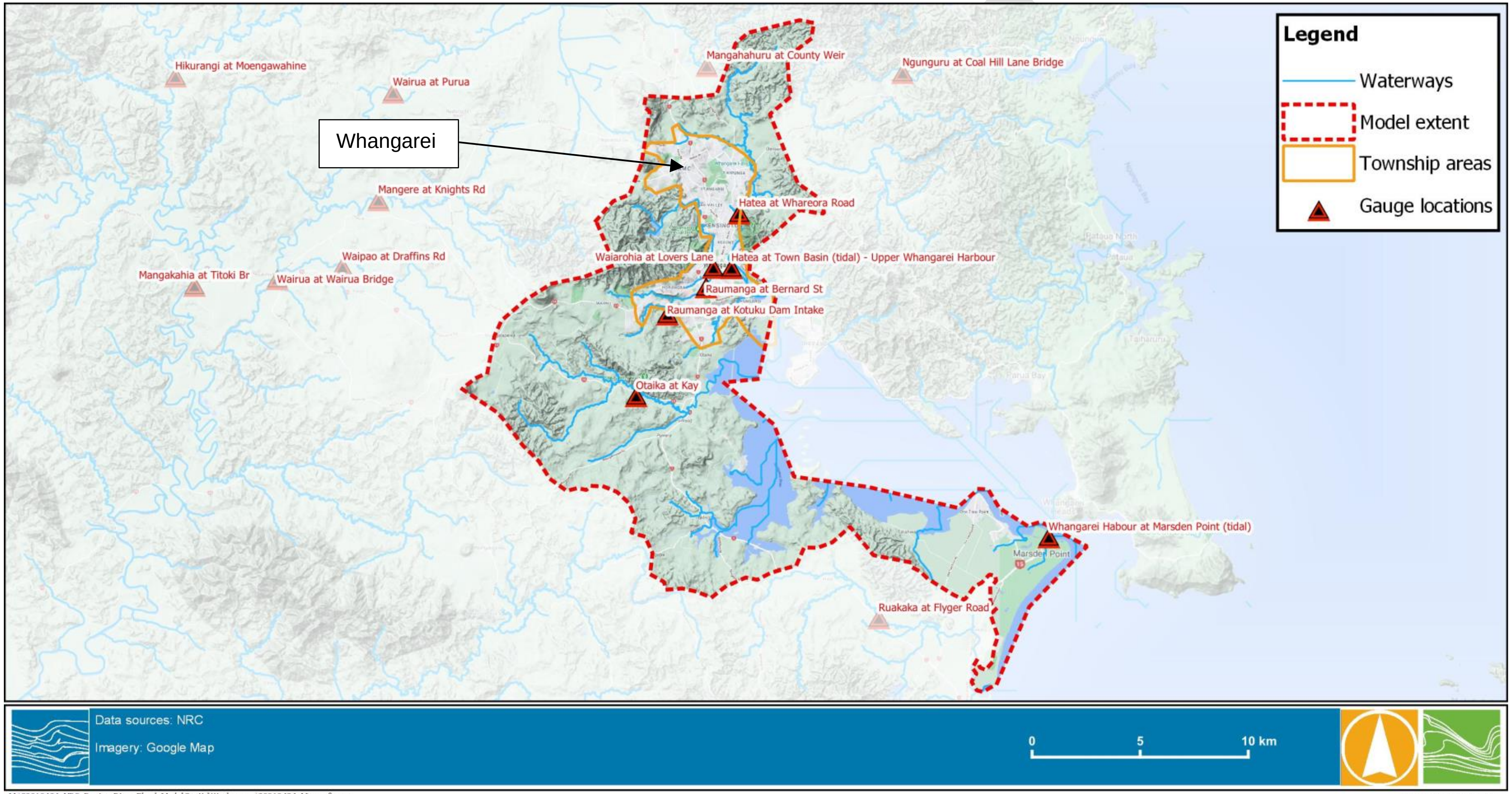


FIGURE 6-1 HYDRAULIC MODEL EXTENT – WHANGAREI CATCHMENT

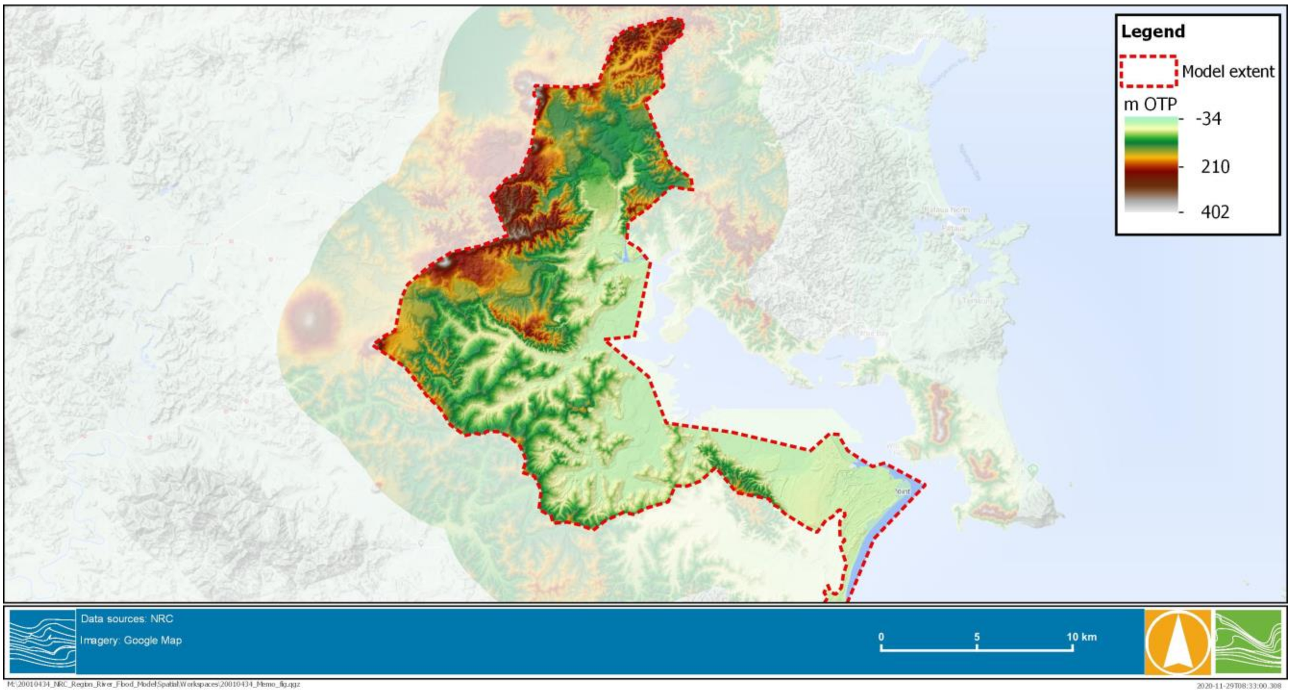


FIGURE 6-2 HYDRAULIC MODEL TOPOGRAPHY – WHANGAREI CATCHMENT

Model boundaries

The hydraulic model boundaries consist of input rainfall depths and outflow boundaries. A downstream tailwater boundary (i.e. type HT) was applied to Whangarei Harbour at Marsden Point using the water level records during an event. HQ (stage-discharge) outflow boundaries were also applied to the downstream of Mangapai River and the eastern side of the Harbour (Figure 6-3).

The January 2011 event was used for the calibration of the Whangarei catchment model. The available rainfall records in this event within the catchment are summarised in Table 6-1. The January 2011 flood event followed around 222 mm of rainfall across the catchment. About 166 mm of rainfall fell in 6 hours during the event. In the lead up to the storm event, the catchment conditions could be considered wet because the rainfall leading up to the event included about 167 mm of rainfall occurred in the past two weeks. The water level at the stations downstream started to rise in about 10 hours after the rainfall started falling.

TABLE 6-1 RAINFALL STATION DETAILS FOR 2011 EVENT – WHANGAREI CATCHMENT

Station name	Site ID	Source	Rainfall total (mm)	Data type
Hatea at Glenberview Forest	546301	NRC	257	5-min
Whangarei Air Shed at Robert Street	547338	NRC	228	2-min
Waiarohia at NRC Water Street	547339	NRC	240	1-min
Waipao at Draffin Rd	547119	NRC	165	5-min
Waikokopa at McDonnell Rd	-	NRC	189	5-min
Waiwarawara Rain at Wilson's Dam	548412	NRC	254	5-min

The input rainfall depths across the catchment area were interpolated using the Inverse Distance Weighted (IDW) average method based on the location and the rainfall records in these stations (Figure 6-4) with higher falls in the north and south of the catchment.

All 6 rainfall stations within the catchment are sub-daily rainfall stations. their temporal patterns for 2011 event are shown in Figure 6-5.

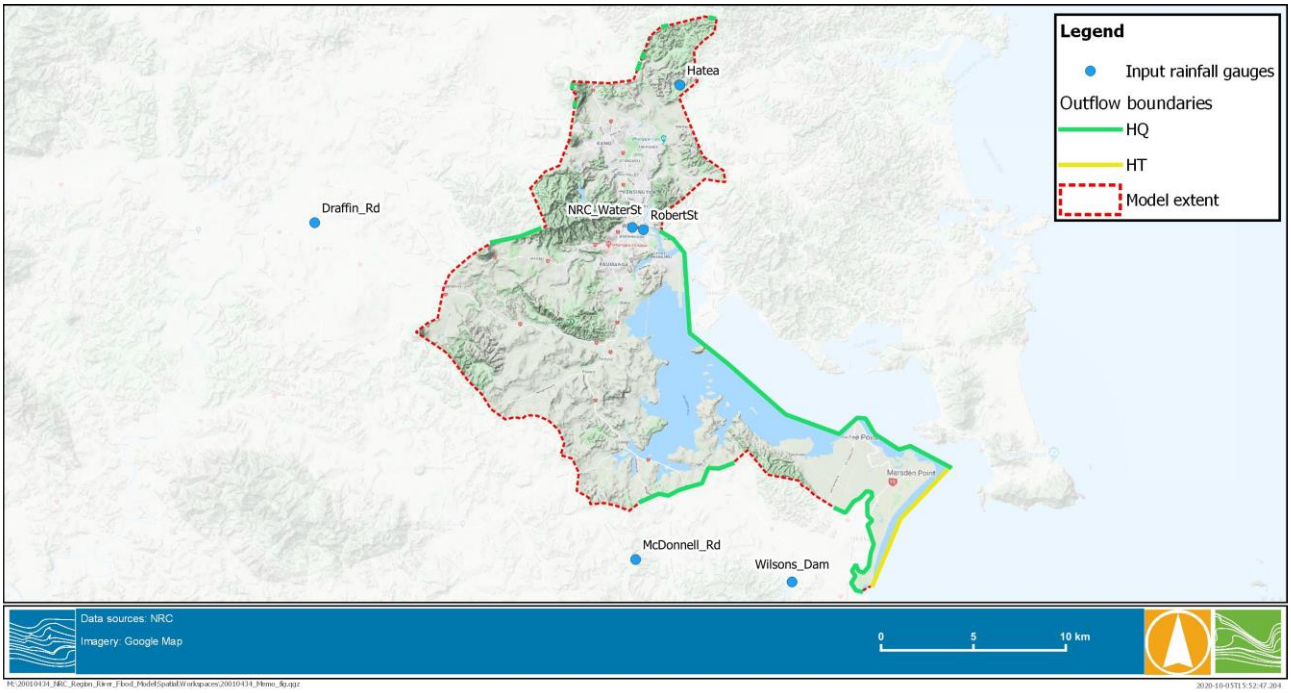


FIGURE 6-3 HYDRAULIC MODEL BOUNDARIES – WHANGAREI CATCHMENT

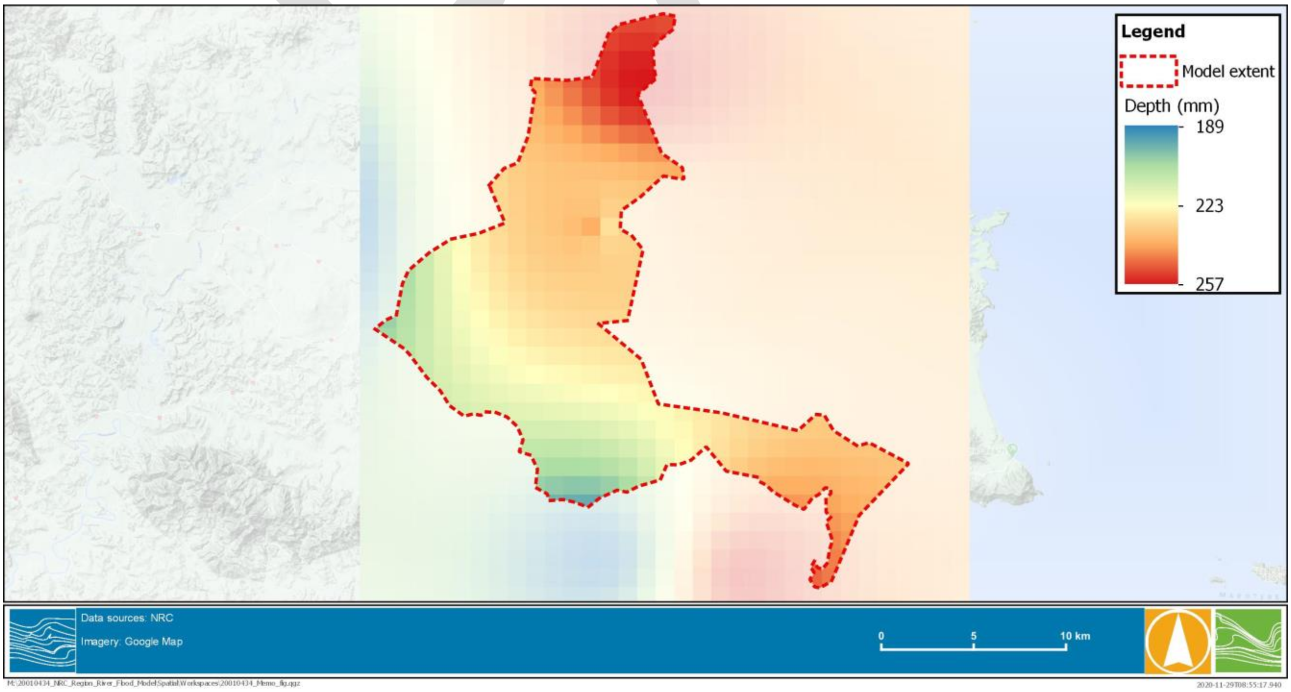


FIGURE 6-4 INTERPOLATED RAINFALL DEPTHS FOR JAN 2011 EVENT – WHANGAREI CATCHMENT

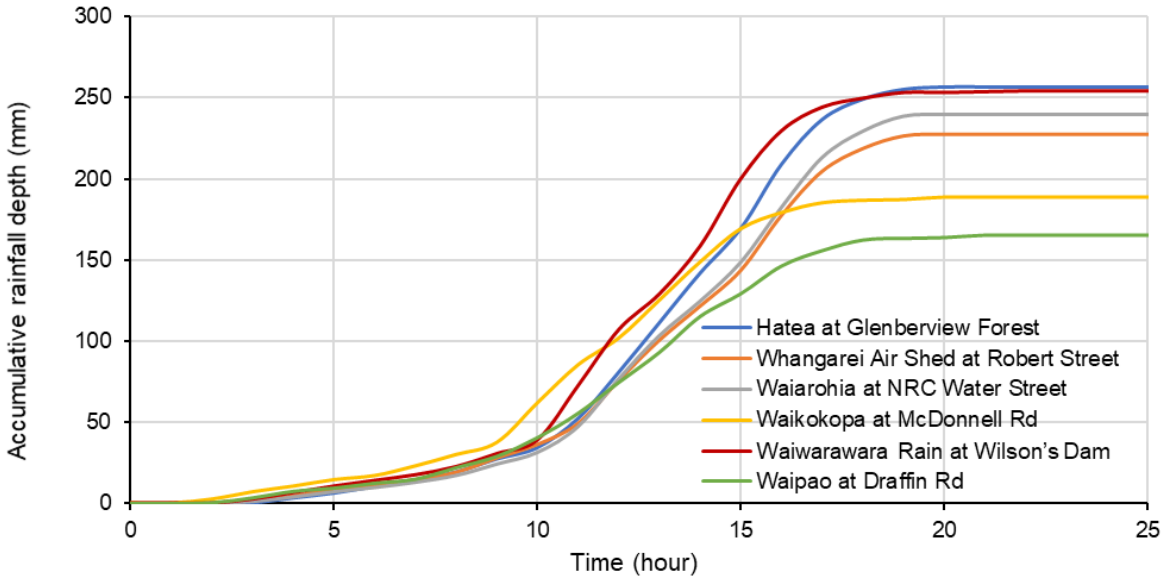


FIGURE 6-5 TEMPORAL PATTERNS FOR JANUARY 2011 EVENT AT SUB-DAILY STATIONS – WHANGAREI CATCHMENT

Material layer

The material layer was created based on the 2016 LUCAS land use map data4, the waterway data from Land Information New Zealand and the soil type data from Landcare research New Zealnd[6]. Figure 6-6 displays the material layer used for Whangarei catchment model. The hydraulic roughness values and rainfall losses were assigned in accordance with the land use and soil classification types within the catchment.

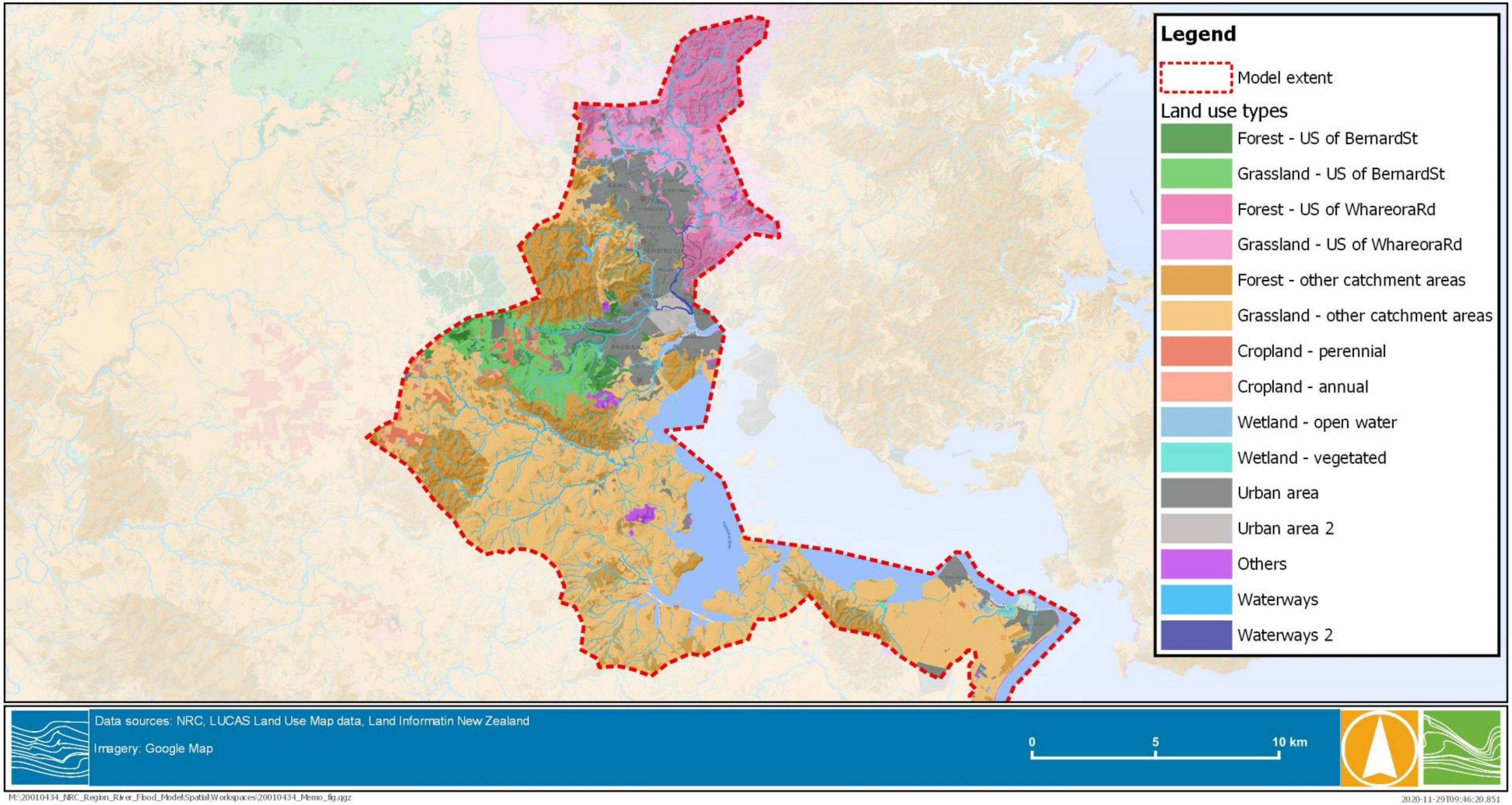


FIGURE 6-6 HYDRAULIC MATERIAL LAYER – WHANGAREI CATCHMENT

6.2 Model calibration

Model parameters

There are 4 streamflow gauges within the catchment used for model calibration include Hatea at Whareora Rd, Waiarohia at Loavers Lane, Raumanaga at Bernard St and Otaika at Kay. All of these gauges have the flow and water level records for the entire event. Table 6-2 summaries the calibrated parameters for the Whangarei Catchment.

TABLE 6-2 CALIBRATED HYDRAULIC ROUGHNESS AND RAINFALL LOSSES VALUES – WHANGAREI CATCHMENT

Hydrological areas	Land use types	Manning's n	Initial loss (IL) - mm	Continuing loss (CL) – mm/hr
Upstream of Bernard St	Forest	0.08	20	4
	Grassland	0.05	20	4
Upstream of Whareora Rd	Forest	0.04	55	10
	Grassland	0.02	55	10
Other areas within Whangarei catchment	Forest	0.08	30	5
	Grassland	0.05	30	5
Entire Whangarei 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	0.08	5	1.5
	Urban areas 2	0.02	5	1.5
	Waterways	0.055	0	0
	Waterways 2	0.035	0	0
	Other	0.06	15	1.5

Calibration results

Table 6-3 summarises the comparison between the observed and the modelled values and the quantitative assessment of the model calibration is shown in Table 6-4.

The modelled results at these stations have shown a good match to the gauged records in terms of their shape and timing. The modelled water levels match well with the gauged records with all the 4 gauges having the peak water levels within 300 mm difference compared with that observed. However, the modelled flows are generally lower than recorded flows with the exception of an overestimated flow at the Otaika at Kay gauge. TAs discussed with the previous catchments, it is likely that uncertainty in the development of the rating curve may have led to this underestimation of flows. Figure 6-7 to Figure 6-14 show the modelled and recorded hydrographs and water level (rating curve) comparison. Model results were found to closer where the rating curves provided a closer match. The Hatea River at Whareora Rd showed the biggest difference in rating curve shapes between the modelled and recorded.

Figure 6-19 to Figure 6-21 display the difference plot of the modelled water level compared with the surveyed flood level points. It should be noted that some of the points are overlapped with others in these maps. There are 127 flood level points within the catchment, with 79 flood level points (approx. 62%)within 300 mm of recorded. Flood levels through the urban area appear to be over-estimated. This is likely the result of a lack of pit and pipes in the model within the urban area.

TABLE 6-3 SUMMARY OF CALIBRATION RESULTS – WHANGAREI CATCHMENT

	Peak flow (m^3/s)			Time to peak diff. (hour)	Volume (ML)			Peak WSE (m OTP)		
Location	Modelled	Gauged	Diff.		Modelled	Gauged	Diff.	Modelled	Gauge	Diff. (mm)
Whareora Rd	255.51	412.53	-38%	0.75	5540471	9647089	-43%	15.33	15.19	136.50
LoversLane	78.50	87.43	-10%	0	1918745	2854975	-33%	5.68	5.81	-129.70
BernardSt	67.21	87.05	-23%	0.67	2735009	2319260	18%	6.91	7.09	-177.10
Otaika_Kay	207.29	136.23	52%	1.33	5067763	4305984	18%	14.45	14.35	104.20

TABLE 6-4 QUANTITATIVE ASSESSMENT OF JANUARY 2011 EVENT FOR WHANGAREI CATCHMENT

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)
Whareora Rd	N	N	Y	Y	N
LoversLane	Y	N	Y	Y	N
BernardSt	N	N	Y	Y	N
Otaika_Kay	N	N	Y	N	Y

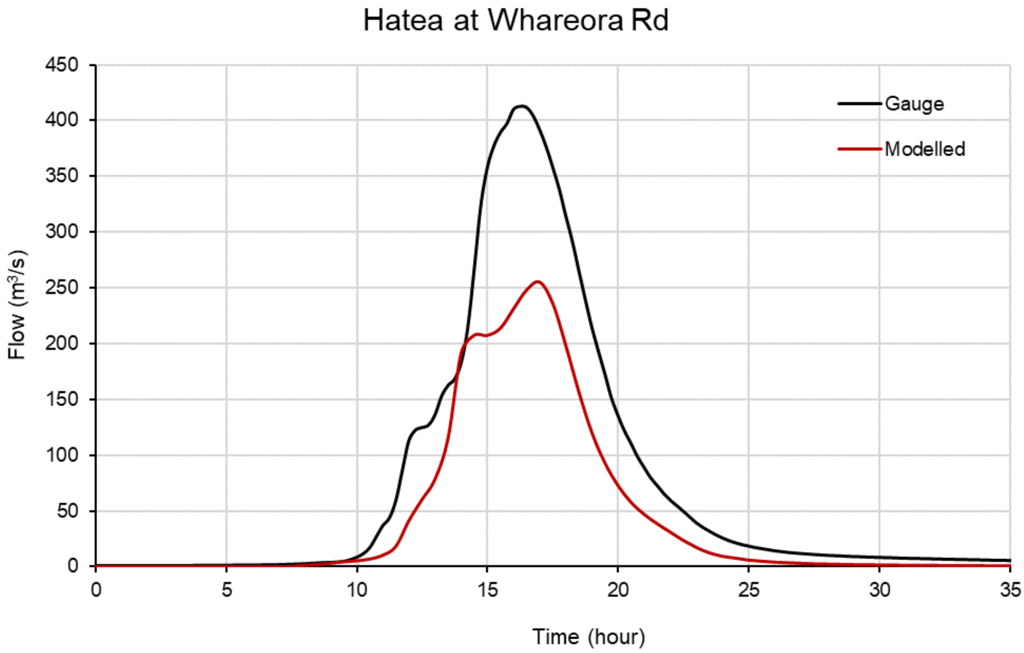


FIGURE 6-7 MODELLED AND GAUGED FLOW AT HATEA RIVER AT WHAREORA RD – 2011 FLOOD EVENT

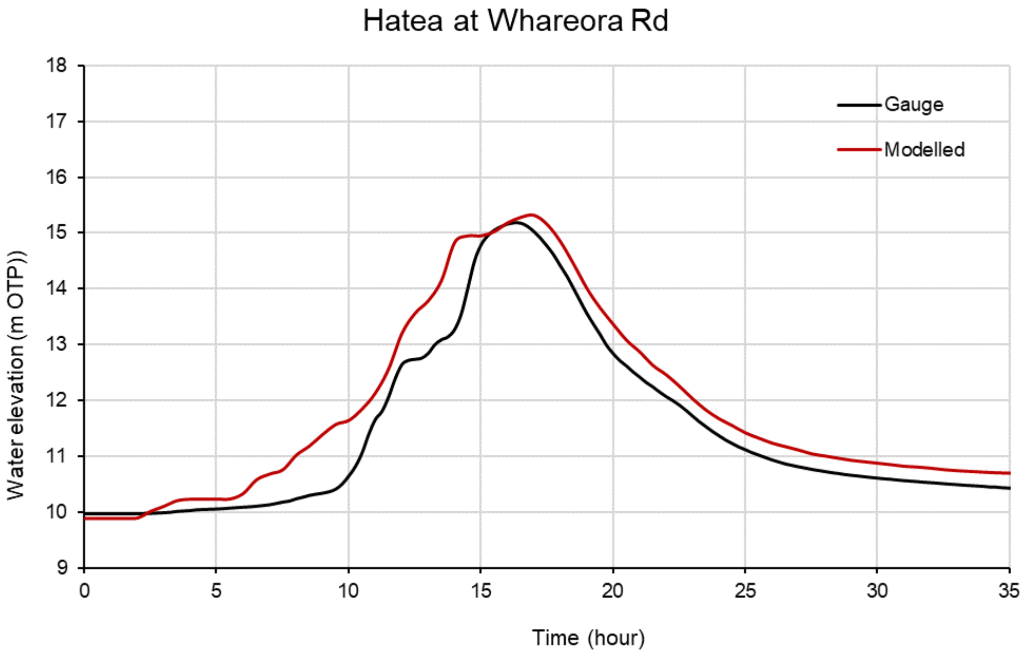


FIGURE 6-8 MODELLED AND GAUGED WATER LEVELS AT HATEA RIVER AT WHAREORA RD – 2011 FLOOD EVENT

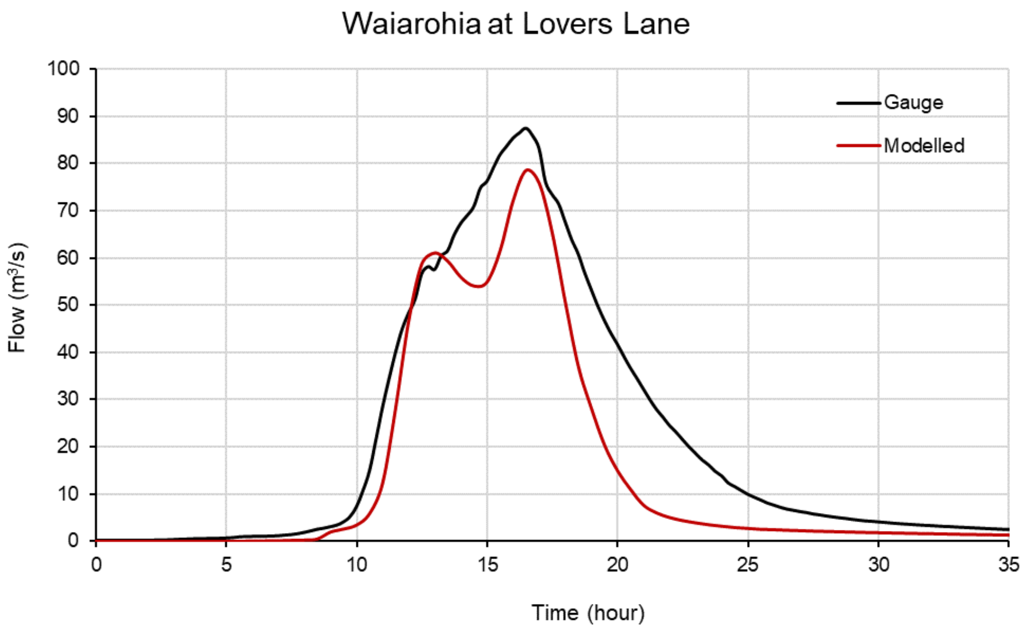


FIGURE 6-9 MODELLED AND GAUGED FLOWS AT WAIAROHIA RIVER AT LOVERS LANE – 2011 FLOOD EVENT

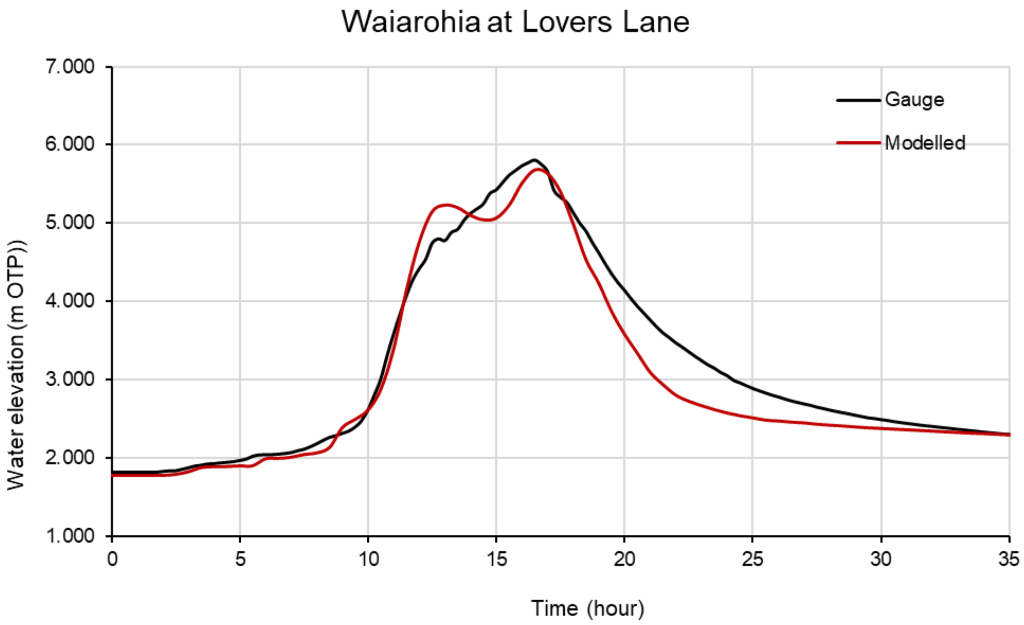


FIGURE 6-10 MODELLED AND GAUGED WATER LEVELS AT WAIAROHIA RIVER AT LOVERS LANE – 2011 FLOOD EVENT

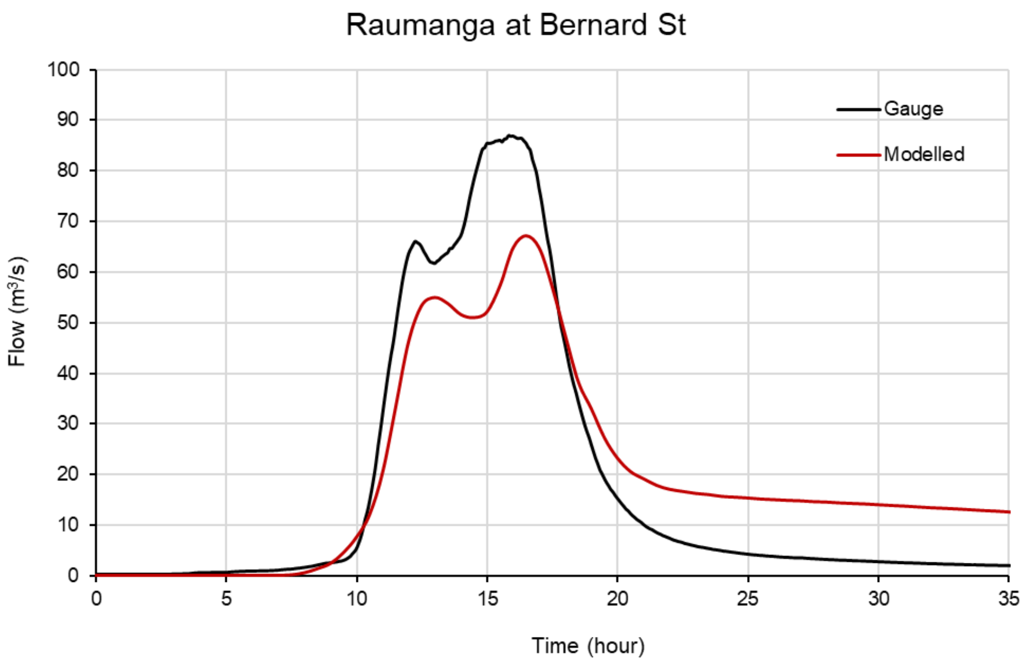


FIGURE 6-11 MODELLED AND GAUGED FLOWS AT RAUMANGA CREEK AT BERNARD ST – 2011 FLOOD EVENT

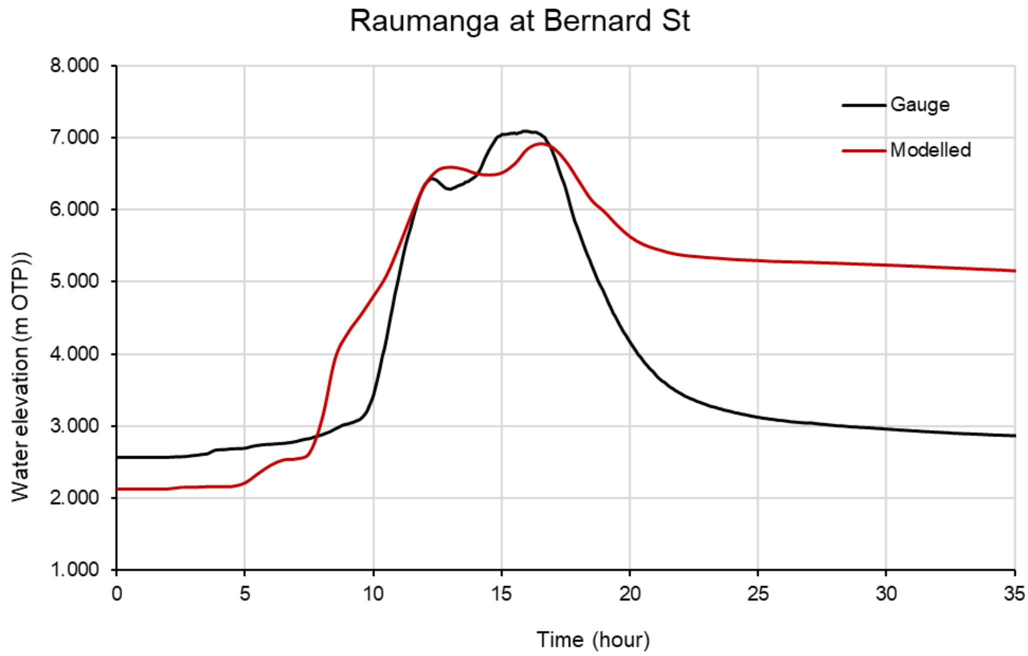


FIGURE 6-12 MODELLED AND GAUGED LEVELS AT RAUMANGA CREEK AT BERNARD ST – 2011 FLOOD EVENT

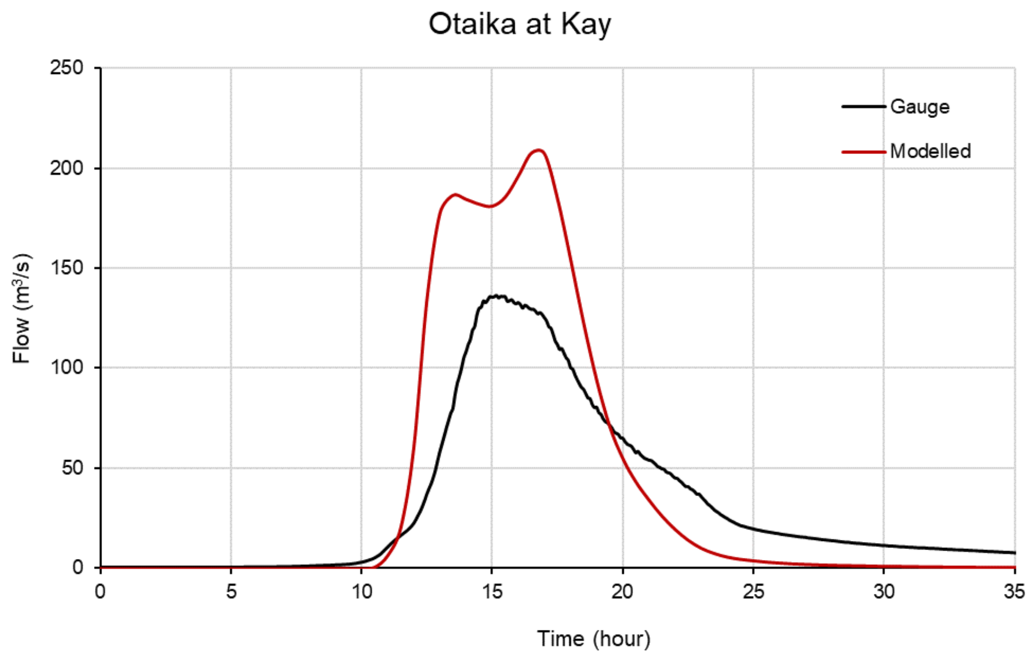


FIGURE 6-13 MODELLED AND GAUGED FLOWS FOR OTAIKA RIVER AT KAY – 2011 FLOOD EVENT

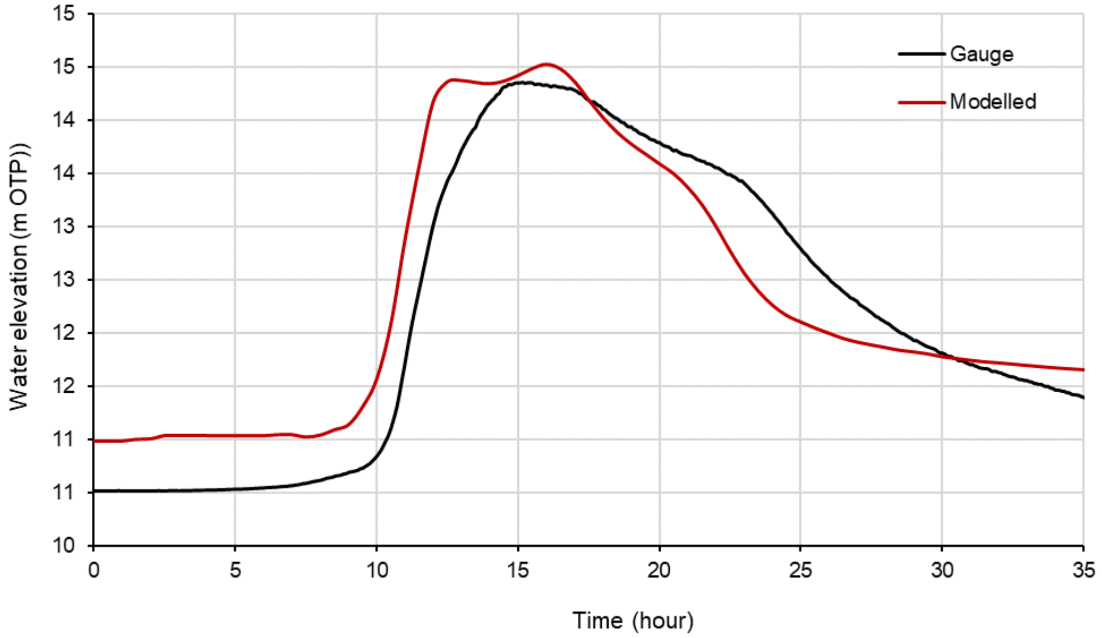


FIGURE 6-14 MODELLED AND GAUGED LEVELS AT OTAIKA RIVER AT KAY – 2011 FLOOD EVENT

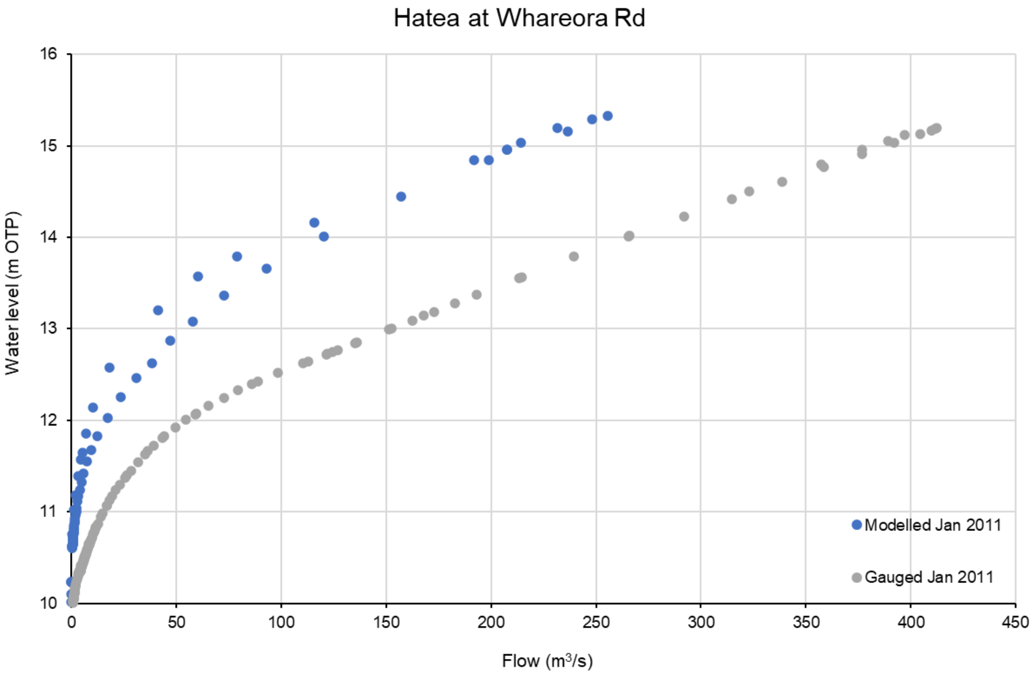


FIGURE 6-15 MODELLED AND GAUGED RATING CURVE COMPARISON AT WHAREORA RD GAUGE

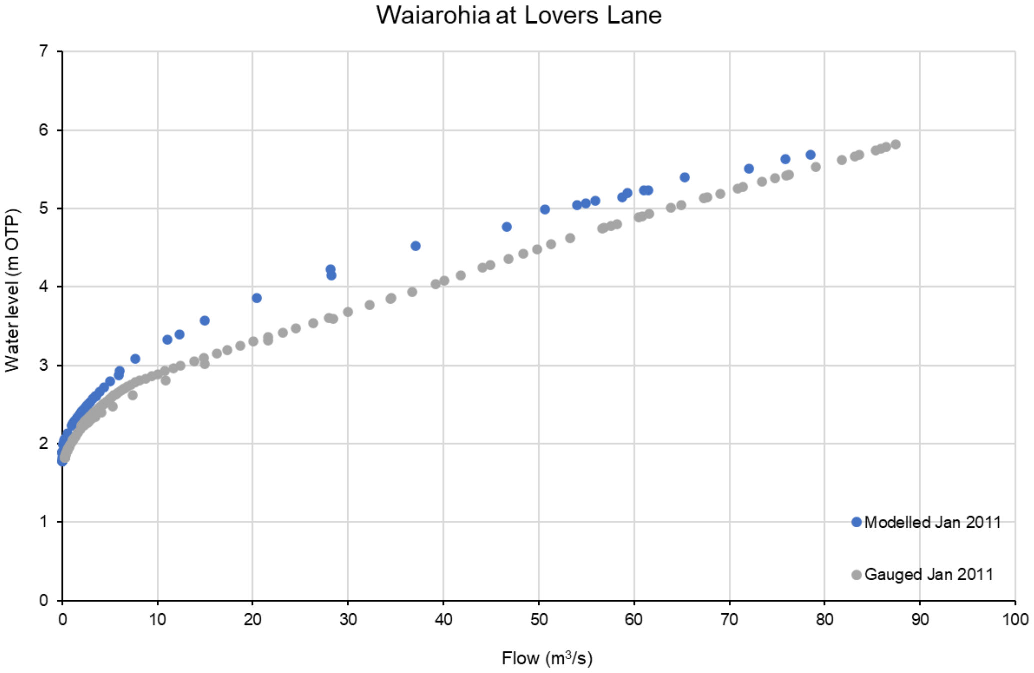


FIGURE 6-16 MODELLED AND GAUGED RATING CURVE COMPARISON AT LOVERS LANE GAUGE

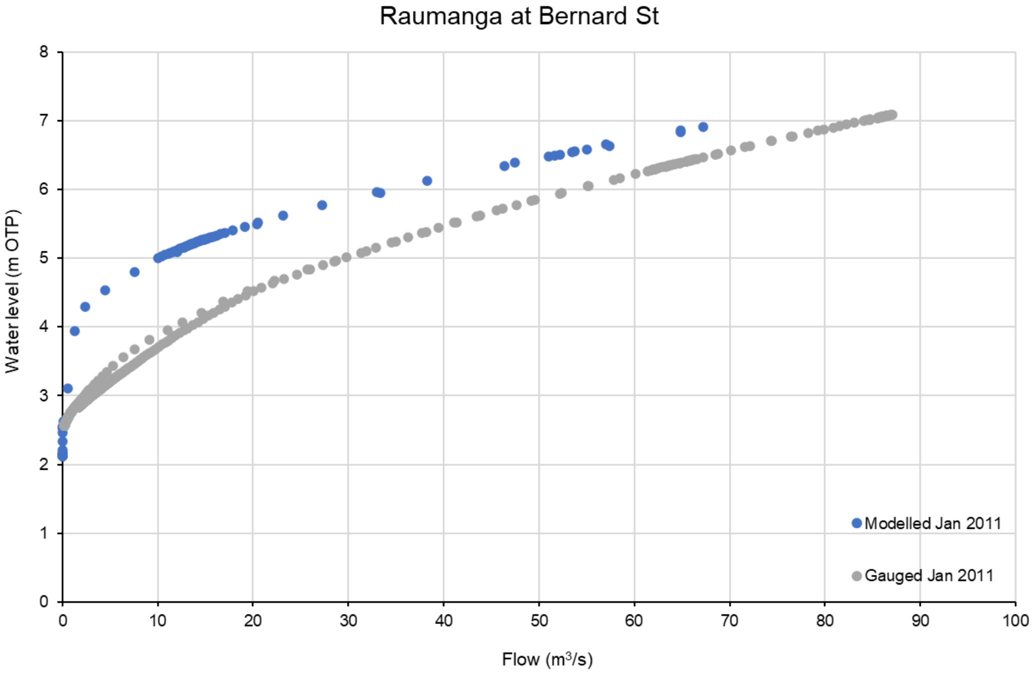


FIGURE 6-17 MODELLED AND GAUGED RATING CURVE COMPARISON AT BERNARD ST

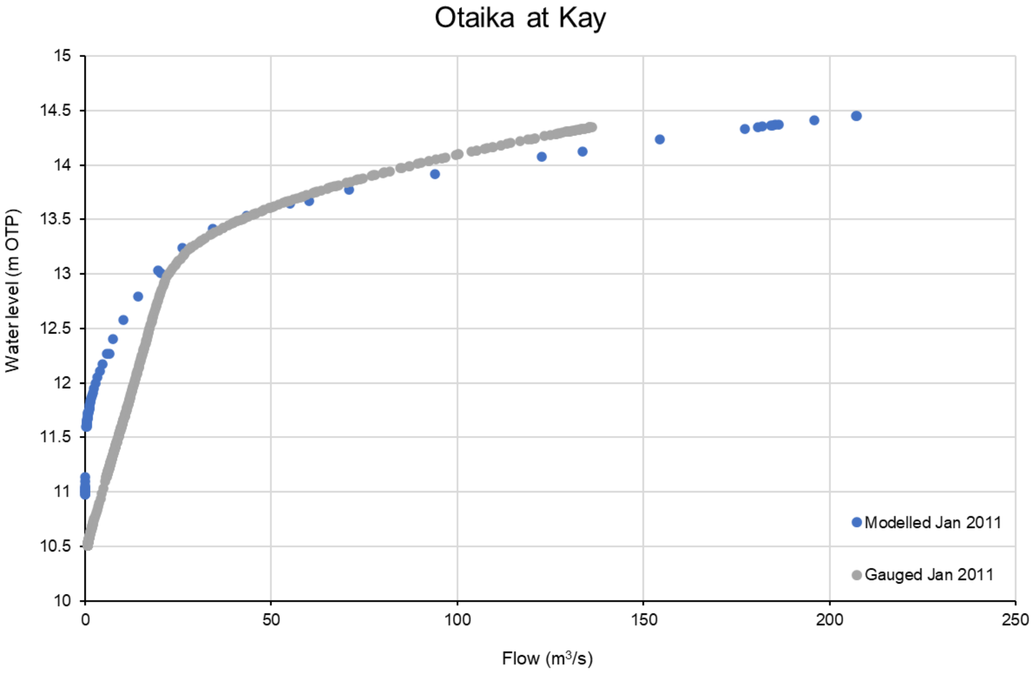


FIGURE 6-18 MODELLED AND GAUGED RATING CURVE COMPARISON AT KAY

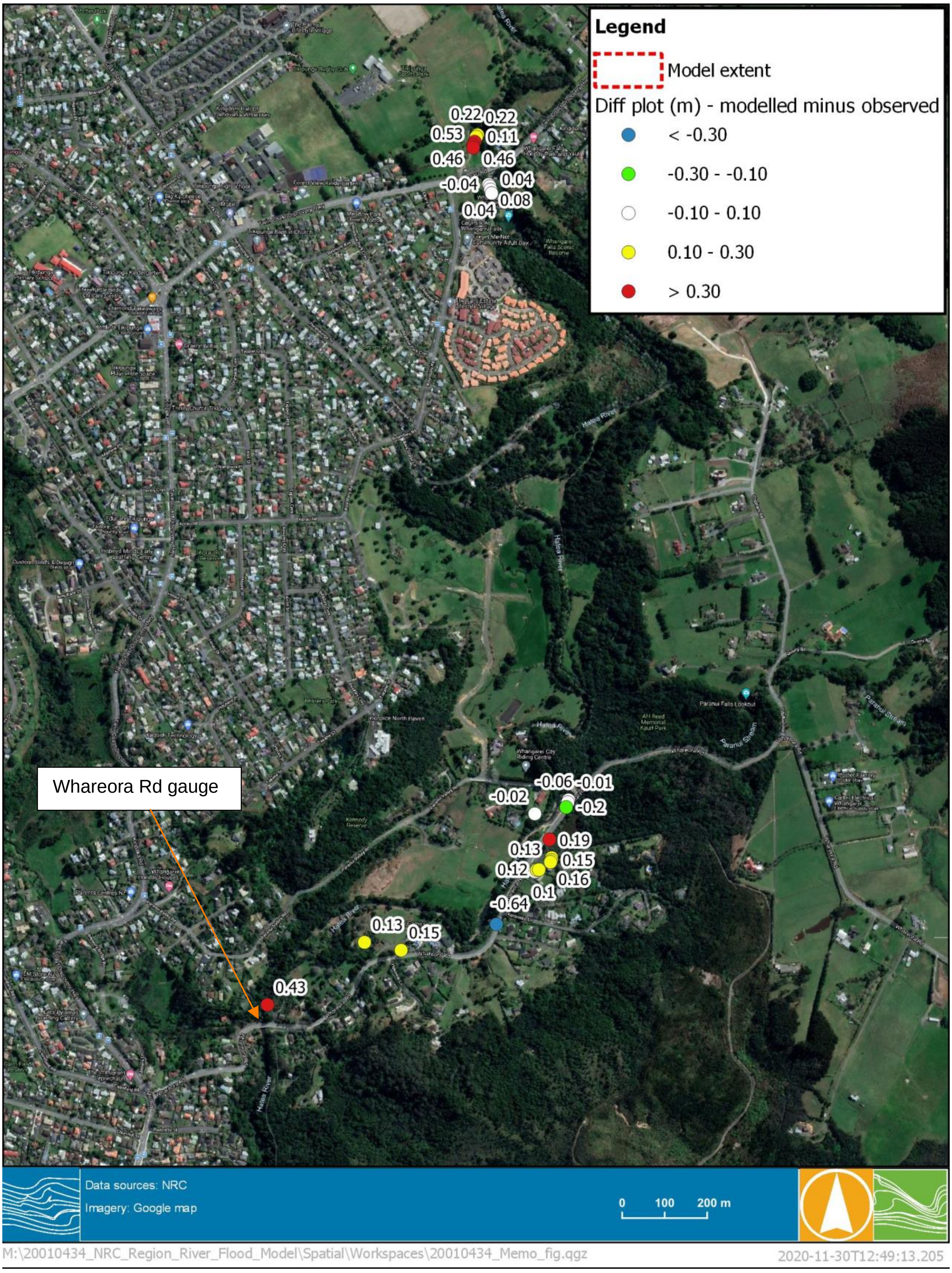
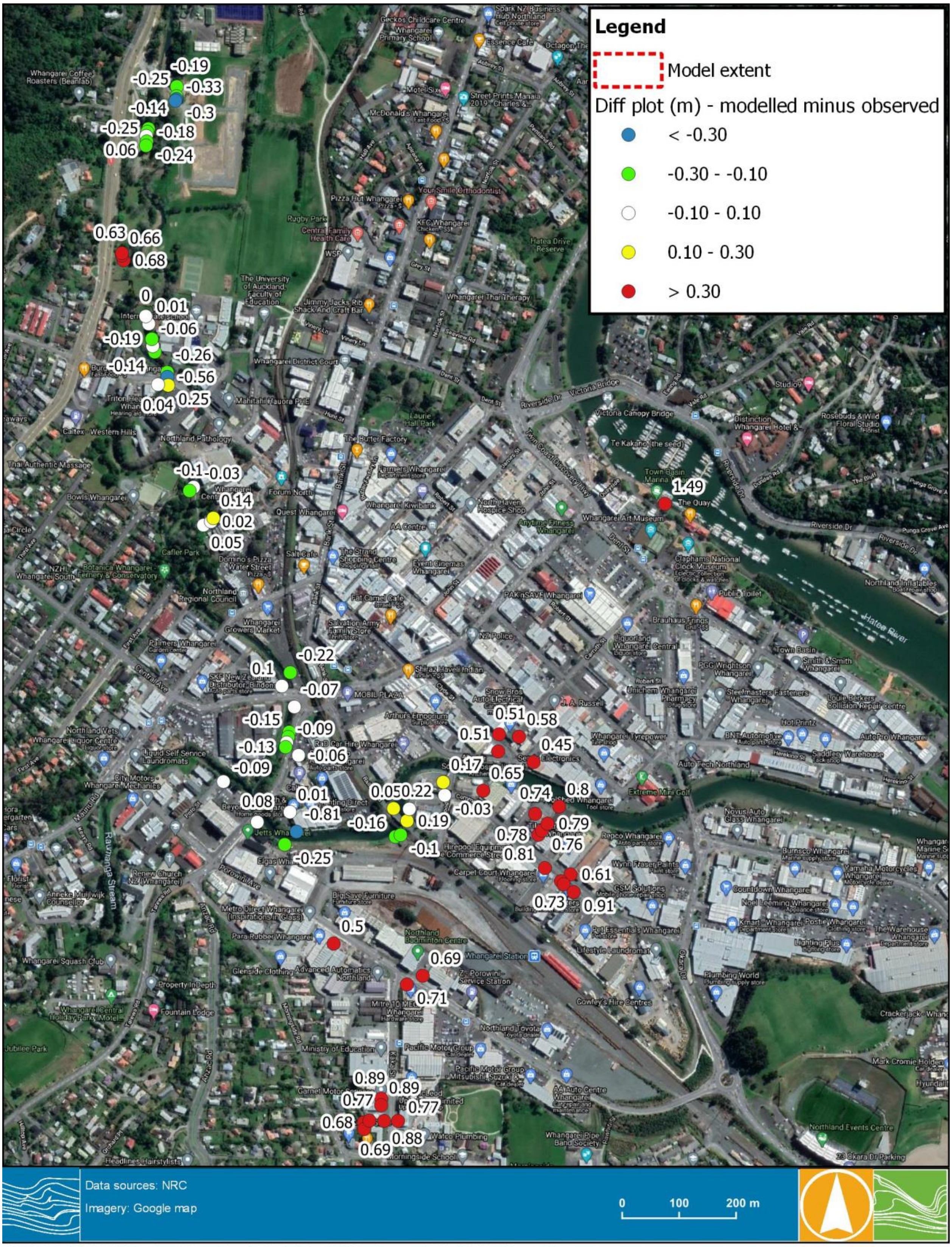


FIGURE 6-19 COMPARISON BETWEEN MODELLED FLOOD LEVEL AND SURVEY FLOOD LEVEL – JANUARY 2011 EVENT (UPSTREAM OF WHAREORA RD GAUGE)



M:\20010434_NRC_Region_River_Flood_Model\Spatial\Workspaces\20010434_Memo_fig.qgz 2020-11-30T12:50:02.332

FIGURE 6-20 COMPARISON BETWEEN MODELLED FLOOD LEVEL AND SURVEY FLOOD LEVEL – JANUARY 2011 EVENT (TOWNSHIP OF WHANGAREI)

FIGURE 6-21 COMPARISON BETWEEN MODELLED FLOOD LEVEL AND SURVEY FLOOD LEVEL – JANUARY 2011 EVENT (EAST OF OTAIKA VALLEY RD)

7 CATCHMENT MODEL 13

7.1 Model development

Model extent

The catchment model 13 (M13) includes the Hikurangi and Lower Mangakahia catchments, covering a total area of approximately 810 km^2. Kaikou River and Mangakahia River are two major waterways within the catchment. The hydraulic model extent of the catchment model 13 is displayed in Figure 7-1 and catchment topographic data is shown in Figure 7-2.

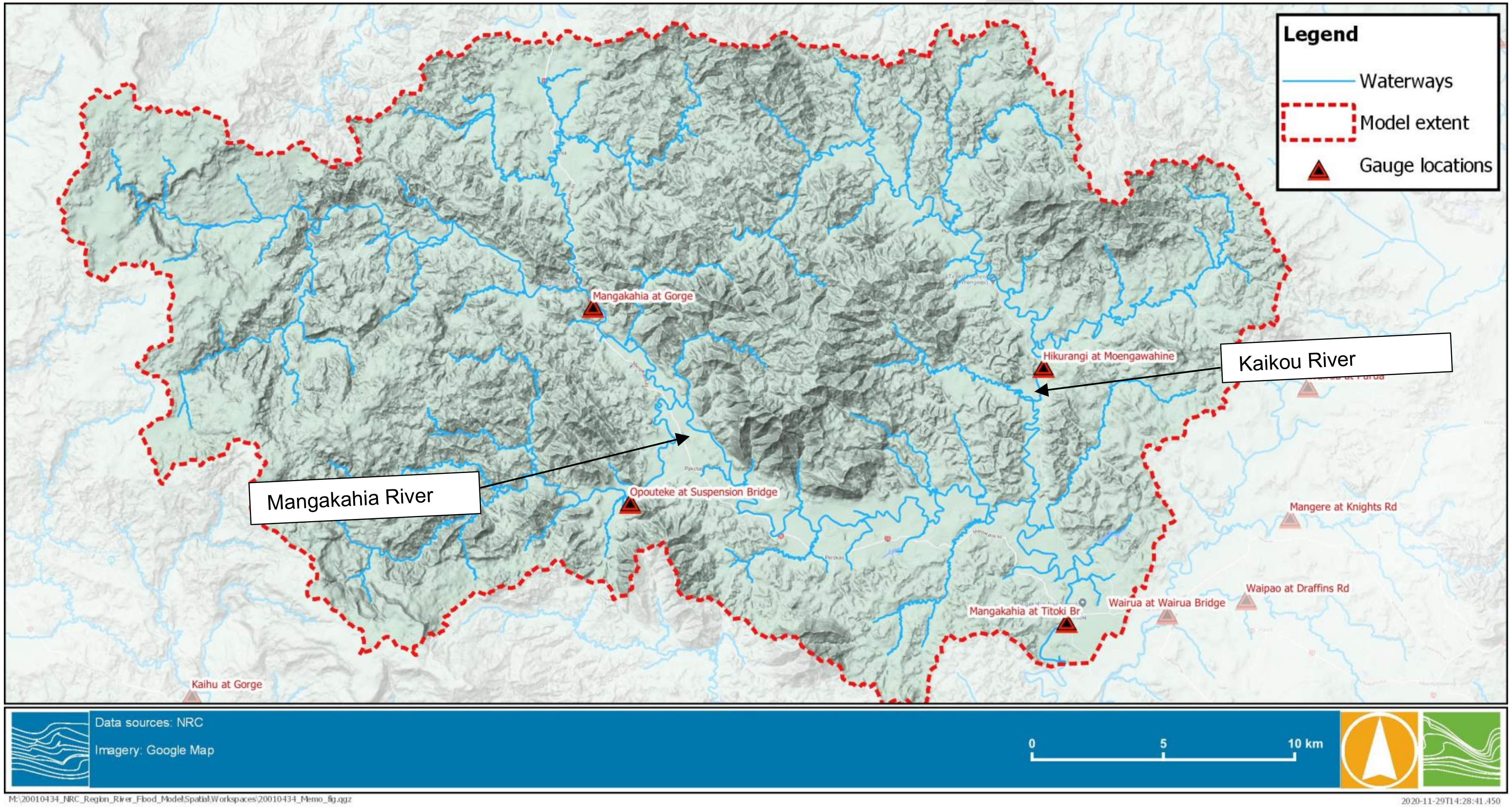


FIGURE 7-1 HYDRAULIC MODEL EXTENT – M13

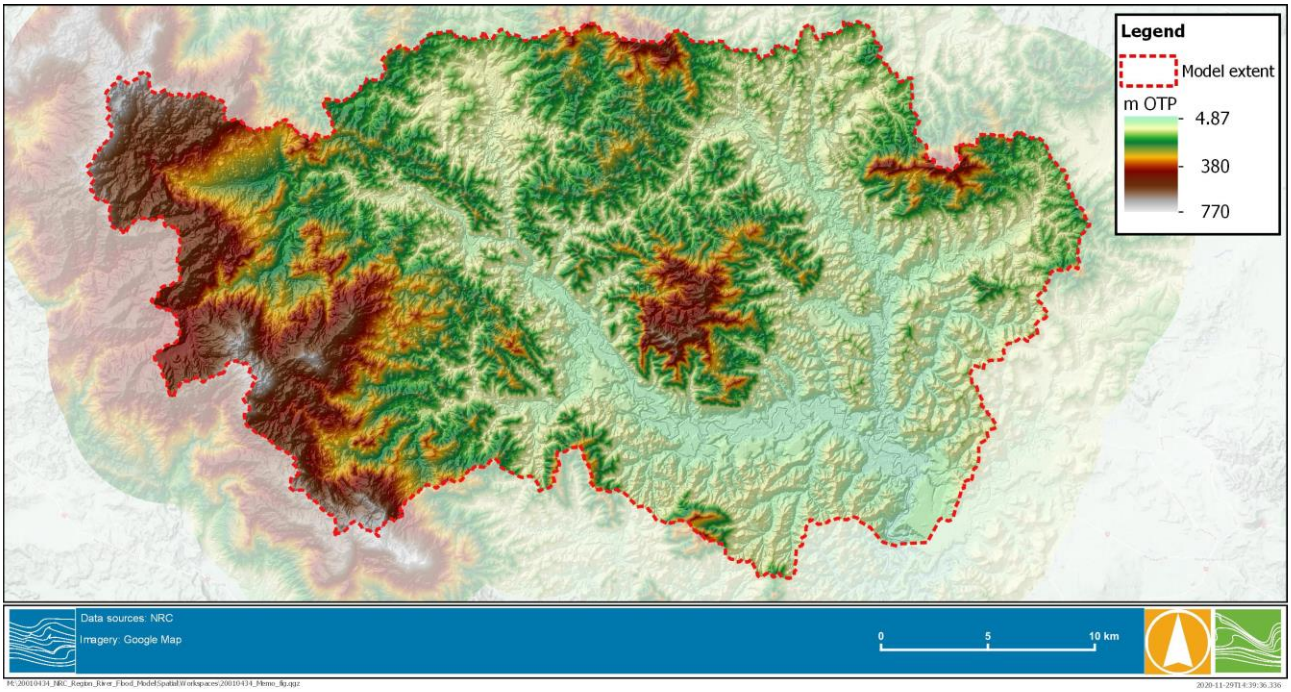


FIGURE 7-2 MODEL TOPOGRAPHY – M13

Model boundaries

The hydraulic model boundaries consist of input rainfall depths and outflow boundaries. A stage-discharge (i.e. type HQ) outflow boundary was applied to the downstream of Mangakahia River. Figure 7-3 shows the hydraulic model boundaries for Whangarei catchment.

The January 2011 flood event saw about 180 mm of rainfall in total across the catchment model including a burst of close to 160 mm of rainfall in 9 hours. There are six rainfall stations with available records for the calibration of January 2011 event. The input rainfall depths across the catchment area were interpolated using the Inverse Distance Weighted (IDW) average method based on the location and the rainfall records in these stations. Figure 7-4 is the interpolated rainfall depths within the catchment for January 2011 event, showing higher rainfall occurred on the east of the catchment.

Five of the six rainfall gauges within the catchment have sub-daily records. The Parakao gauge contains only a daily total rainfall for the event. The sub-daily rainfall for this location was created by using the temporal pattern derived from nearby Opouteke at Brookvale gauge.

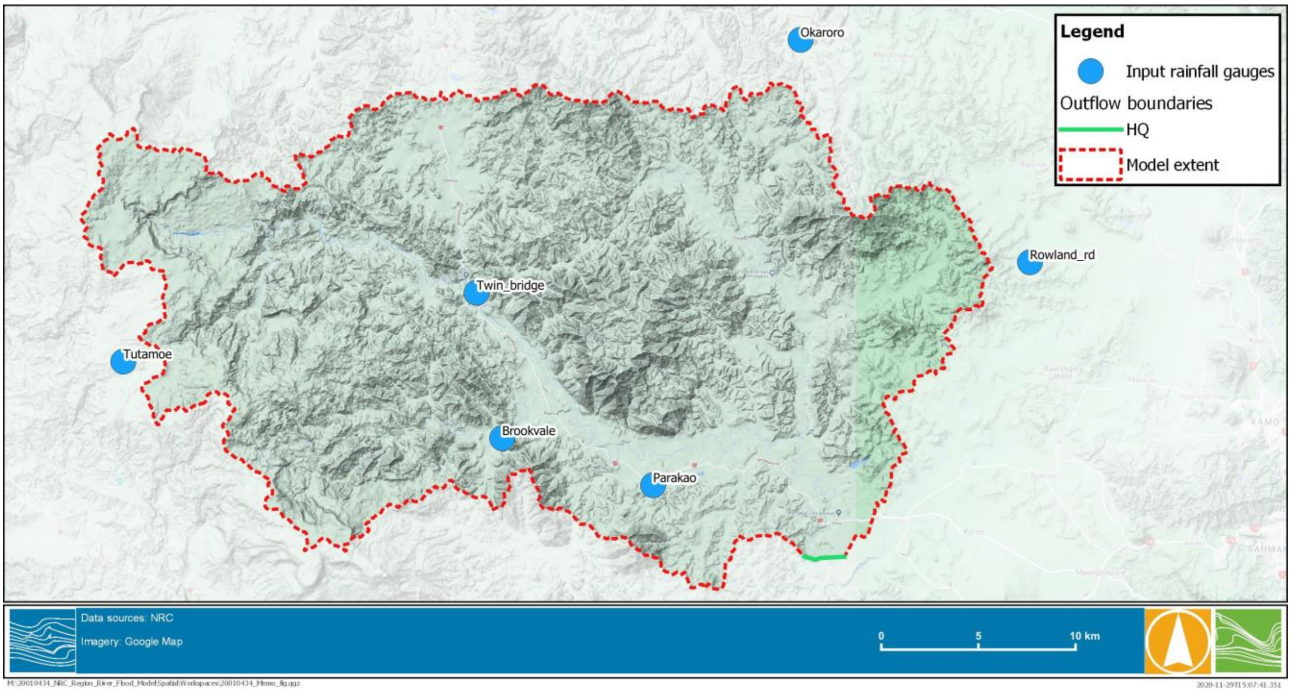


FIGURE 7-3 HYDRAULIC MODEL BOUNDARIES – M13

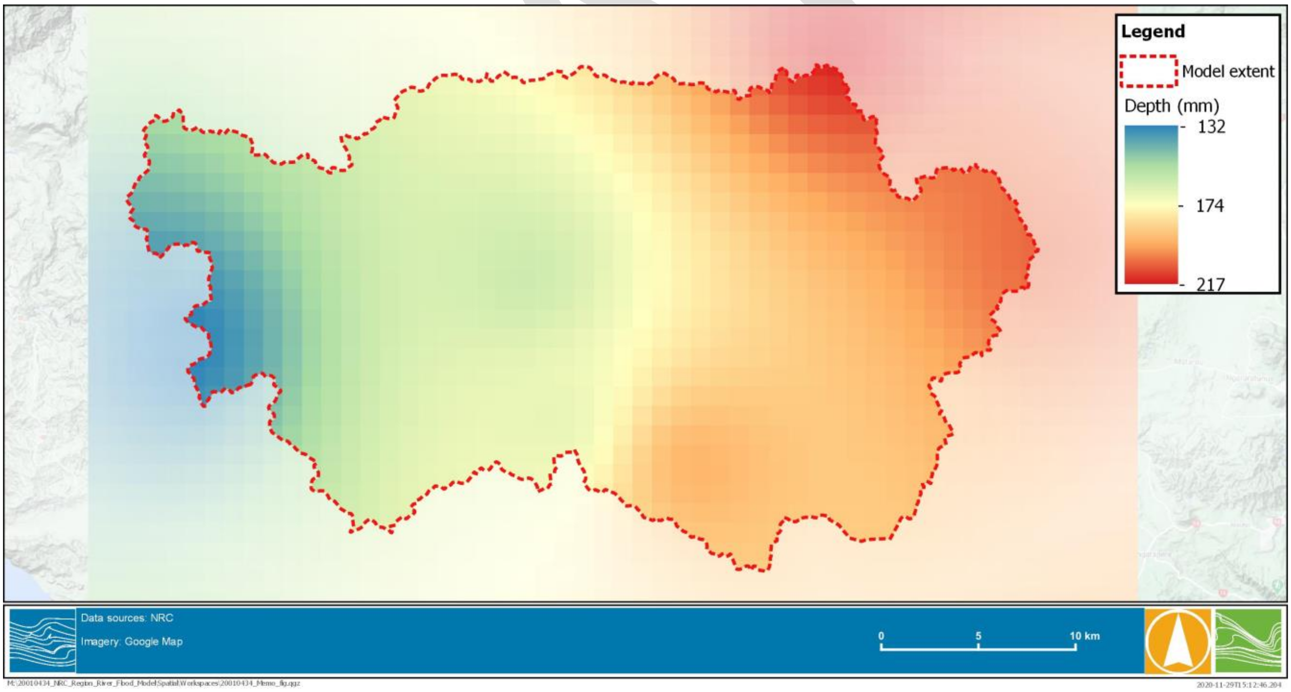


FIGURE 7-4 INTERPOLATED RAINFALL DEPTHS FOR JAN 2011 EVENT – M13

Material layer

The material layer was created based on the 2016 LUCAS land use map data4, the waterway data from Land Information New Zealand and the soil type data from Landcare research New Zealnd[6]. Figure 7-5 displays the material layer used for Model 13. The hydraulic roughness values and rainfall losses were assigned in accordance with the land use and soil classification types within the catchment.

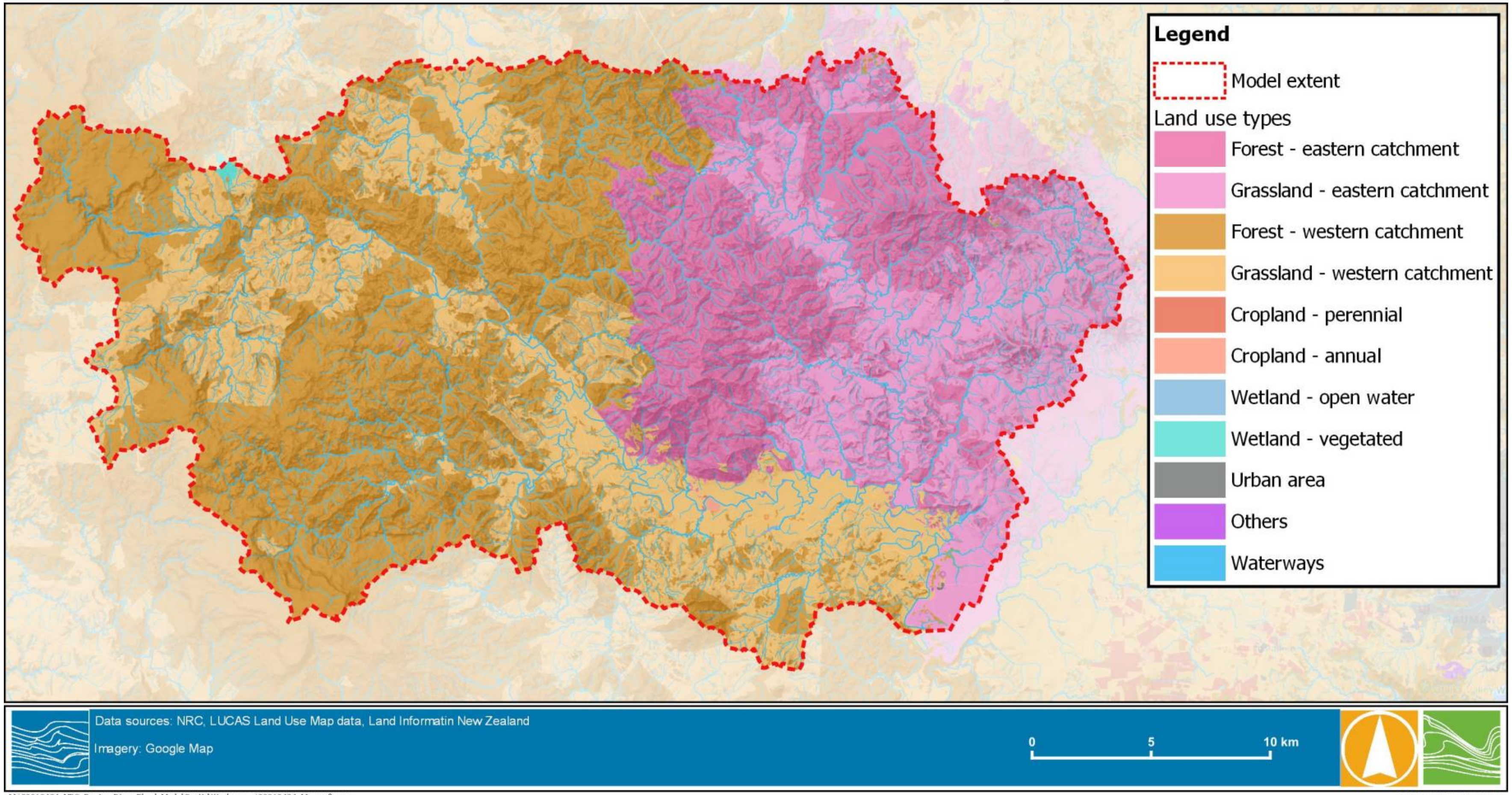


FIGURE 7-5 MODEL MATERIAL LAYER – M13

7.2 Model calibration

Model parameters

The January 2011 event was used for the calibration of the Model 13 catchment. As a starting point of model calibration, the model parameters for M13 were initially adopted from Kawakawa catchment model and then they were adjusted by an iterative process. The calibrated model parameters are summarised in Table 7-1.

TABLE 7-1 CALIBRATED HYDRAULIC ROUGHNESS AND RAINFALL LOSSES VALUES – M13

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

Calibration results

The comparison between the modelled values and gauged records is shown in Table 7-2 and the quantitative assessment of the model calibration is summarised in Table 7-3. In general, the modelled hydrographs and water levels match the gauged records well in terms of shape and timing. The Moengawahine gauge provided the best fit among the four gauges within the catchment, with flow volume, peak water level and timing being replicated well in the model.

The Mangakahia at Gorge did not replicate the recorded flows or levels well with the water levels being well above those recorded and peak flow being well below gauged flows. Figure 7-7 shows the gauge zero (i.e. 33.003m OTP) for Mangakahia at Gorge gauge is around 2.5 metres higher in the LiDAR. The gauge location was checked against that shown in NRC river data portal[1]. It is suspected that the LiDAR might not capture the bottom of the river channel (Figure 7-14). This location is also close to a series of falls/drops which may impact on the sensitivity of flood levels (Figure 7-15). A survey of the cross section of the river channel may be required to improve the calibration at this gauge.

Figure 7-9 shows the Suspension Bridge gauge zero (i.e. 44.14 m OTP) is underestimated in the model DEM by more than 1 metre. A long section profile up and downstream of the gauge was inspected in the model DEM as shown in Figure 7-15. Based on the current model DEM, the expected gauge location should be around 100 metres upstream of current defined location. To improve the calibration at this gauge, a survey of the location of this gauge is required.

The Mangakahia at Titoki Bridge gauge did not replicate the recorded flows or levels well with the peak water level and peak flow being well below those recorded. Given this gauge is located at the downstream of the catchment where flows from Gorge gauge and Suspension Bridge gauge both match flows and levels reasonably well it suggests there may be an issue with the gauging location. Verification of the rating curves and cross section survey of this and the upstream gauges may be required to provide further verification of this rating curve.

TABLE 7-2 SUMMARY OF CALIBRATION RESULTS – MODEL 13

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)
Gorge	588	953	-38.30%	-1.25	13910	32198	-56.80%	43.03	38.93	4103.60
SuspensionBri	356	313	13.63%	-0.33	6915	10891	-36.51%	46.93	47.61	-682.70
Moengawahine	592	349	69.39%	0.50	17226	18860	-8.66%	27.14	27.38	-245.70
Titoki bridge	790	1369	-42.31%	1.25	58071	97778	-40.61%	15.60	17.58	-1983.20

TABLE 7-3 QUANTITATIVE ASSESSMENT OF JANUARY 2011 EVENT – MODEL 13

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)
Gorge	N	N	N	N	N
SuspensionBri	Y	N	N	Y	N
Moengawahine	N	Y	Y	Y	N
Titoki bridge	N	N	N	N	N

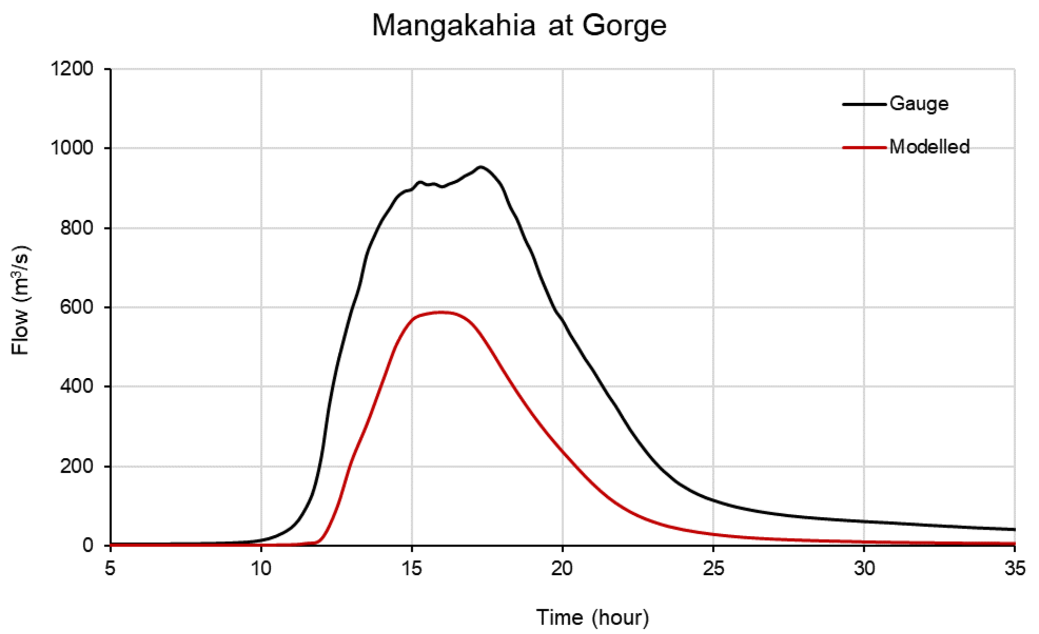


FIGURE 7-6 MODELLED AND GAUGED HYDROGRAPH COMPARISON AT GORGE GAUGE – M13

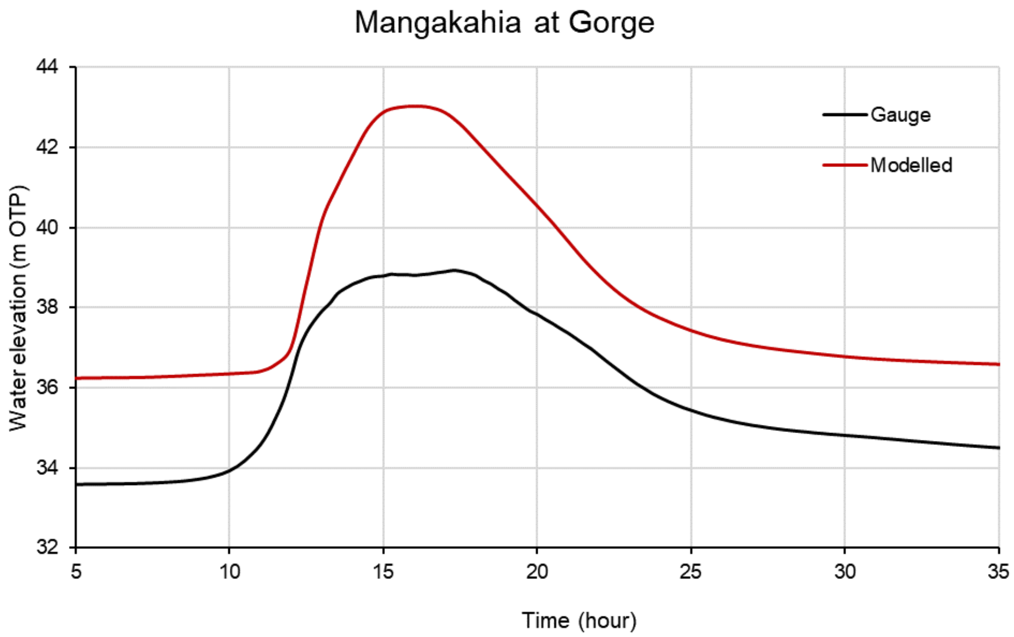


FIGURE 7-7 MODELLED AND GAUGED WATER LEVEL COMPARISON AT GORGE GAUGE – M13

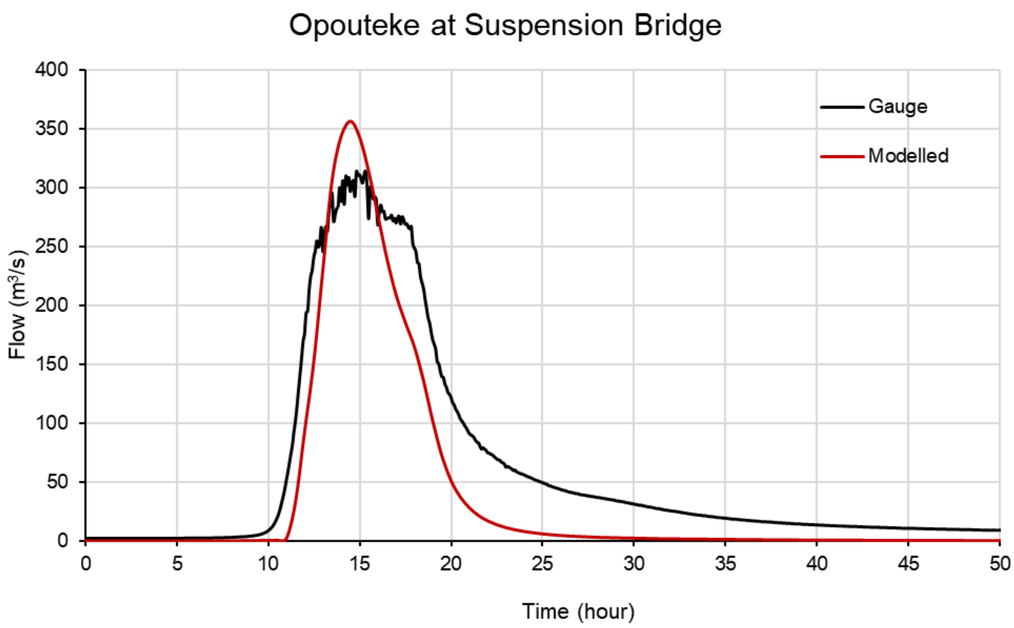


FIGURE 7-8 MODELLED AND GAUGED HYDROGRAPH COMPARISON AT SUSPENSION BRIDGE GAUGE – M13

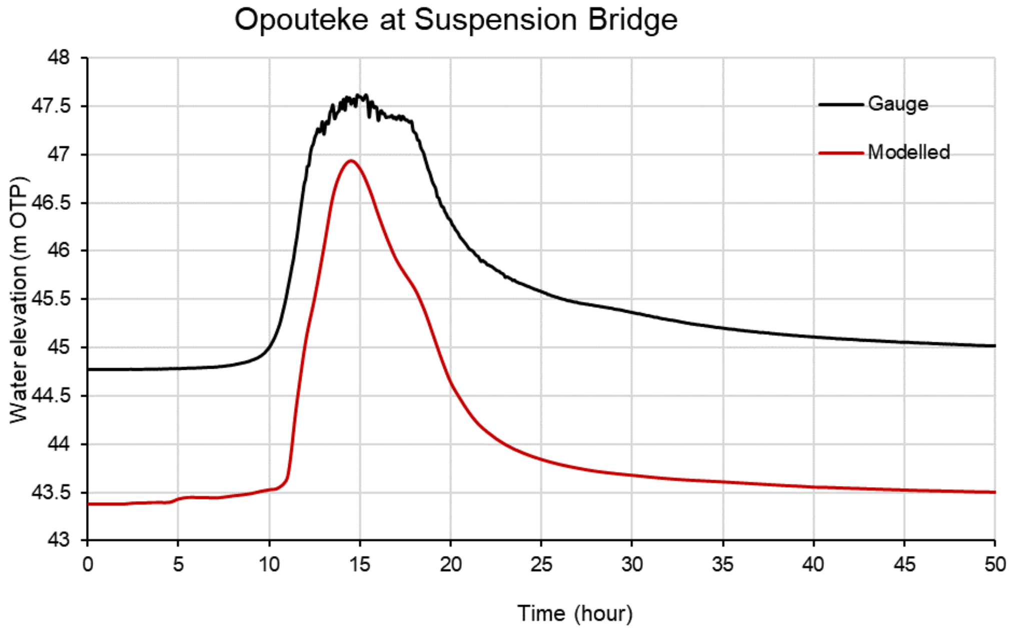


FIGURE 7-9 MODELLED AND GAUGED WATER LEVEL COMPARISON AT SUSPENSION BRIDGE GAUGE – M13

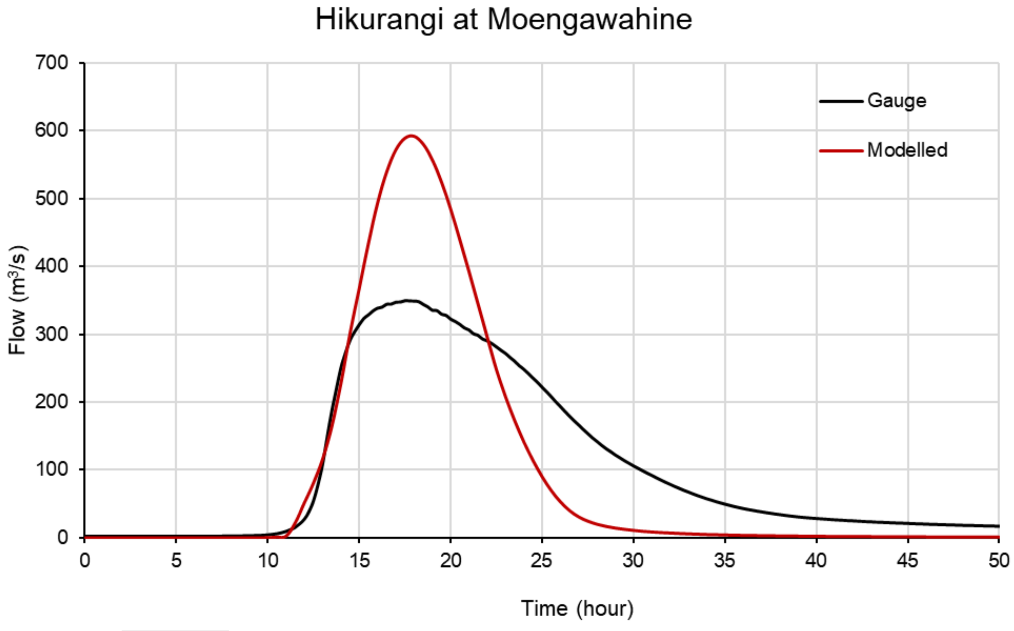


FIGURE 7-10 MODELLED AND GAUGED HYDROGRAPH COMPARISON AT MOENGAWAHINE GAUGE – M13

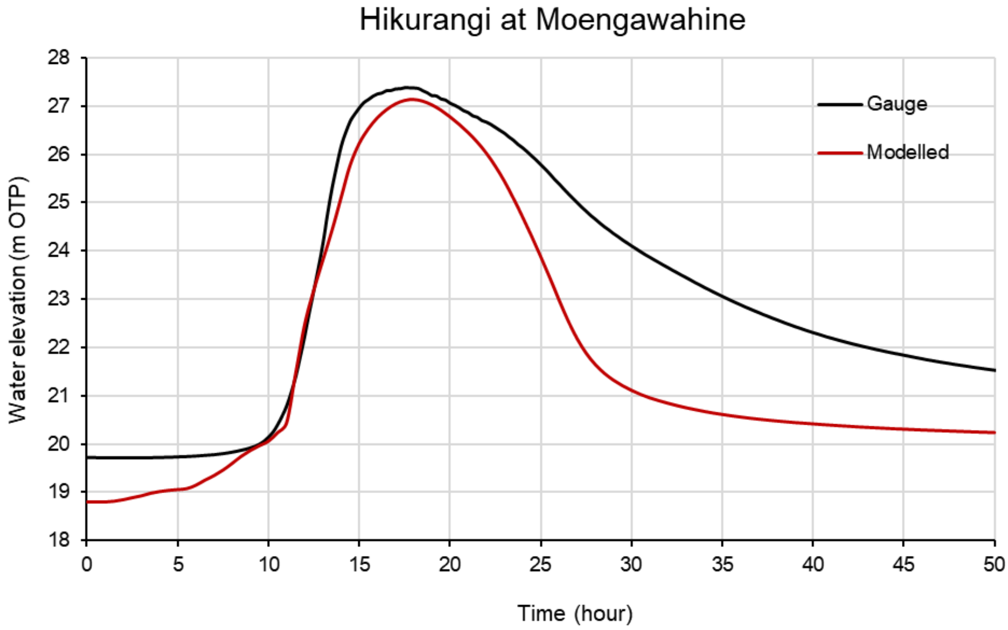


FIGURE 7-11 MODELLED AND GAUGED WATER LEVEL COMPARISON AT MOENGAWAHINE GAUGE – M13

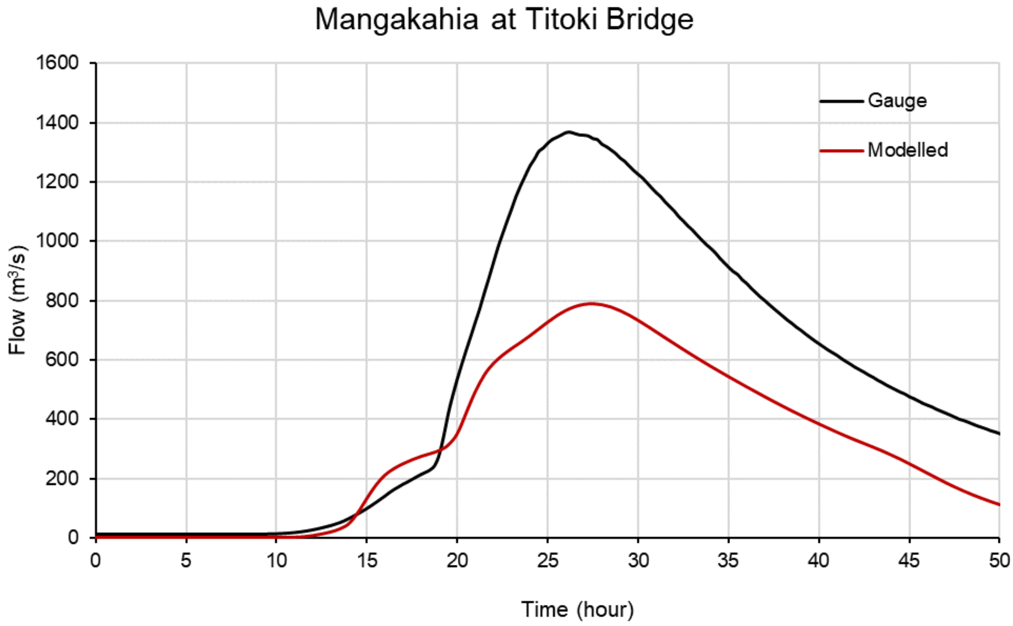


FIGURE 7-12 MODELLED AND GAUGED HYDROGRAPH COMPARISON AT TITOKI GAUGE – M13

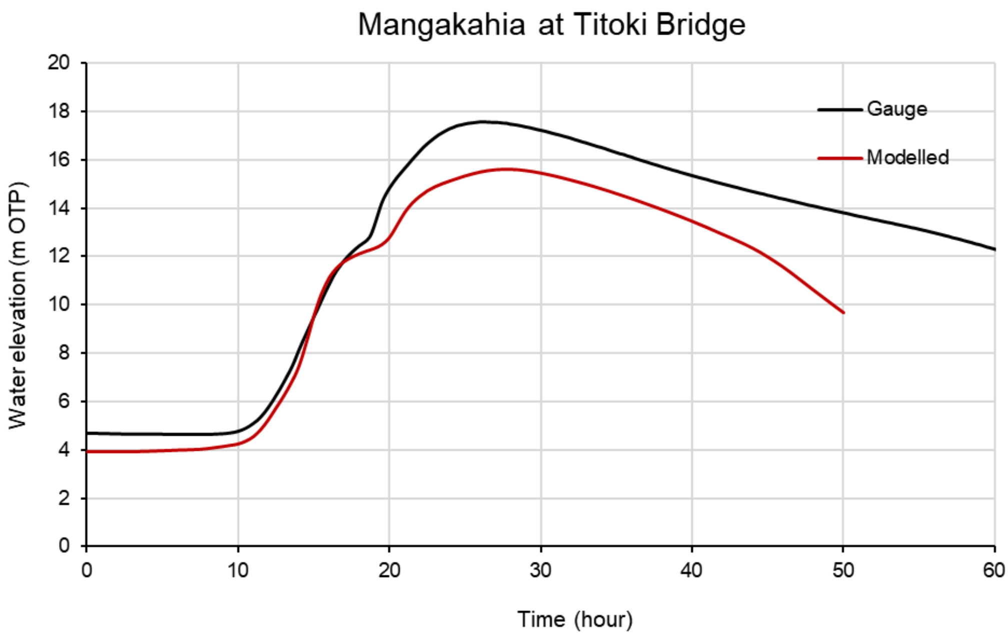


FIGURE 7-13 MODELLED AND GAUGED WATER LEVEL COMPARISON AT TITOKI GAUGE – M13

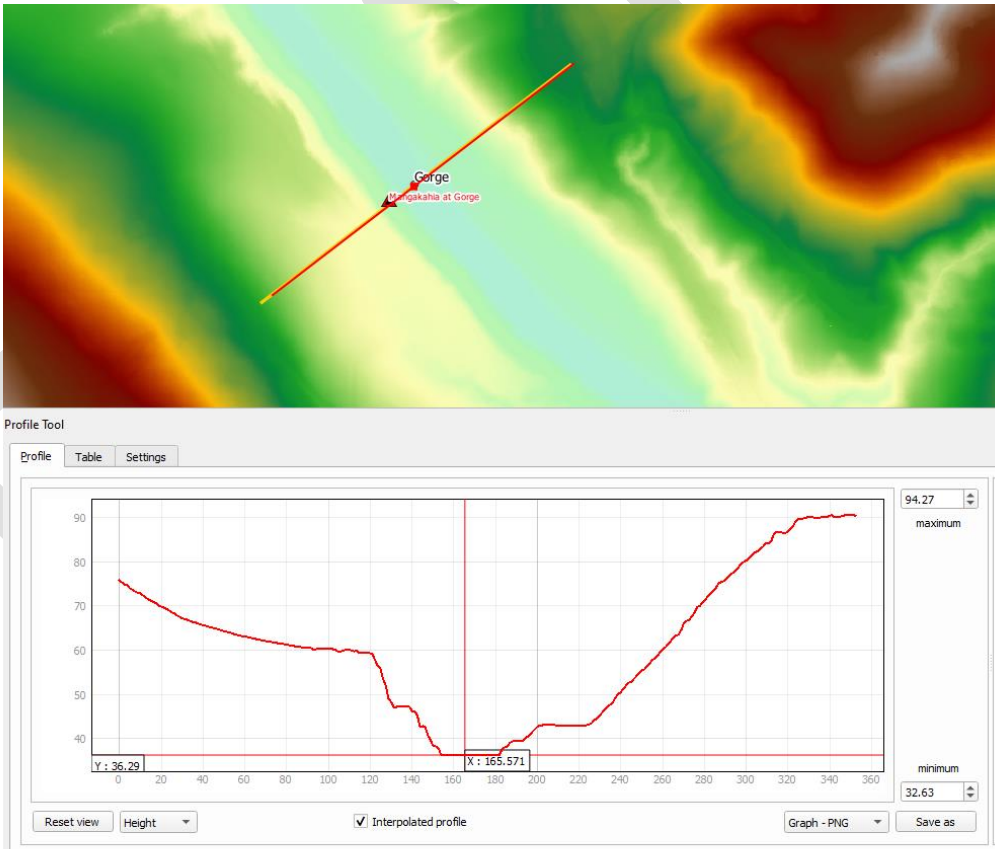


FIGURE 7-14 CHANNEL CROSS SECTION AT GORGE GAUGE

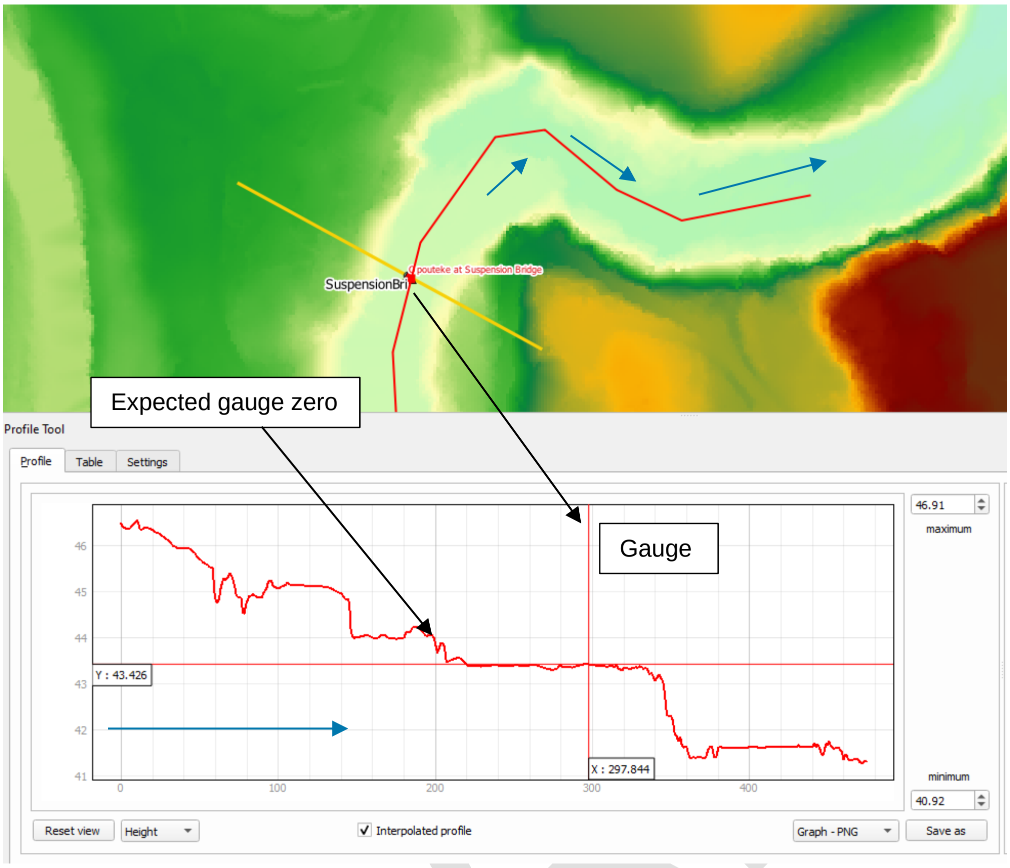


FIGURE 7-15 LONG SECTION PROFILE UP AND DOWNSTREAM OF SUSPENSION BRIDGE GAUGE

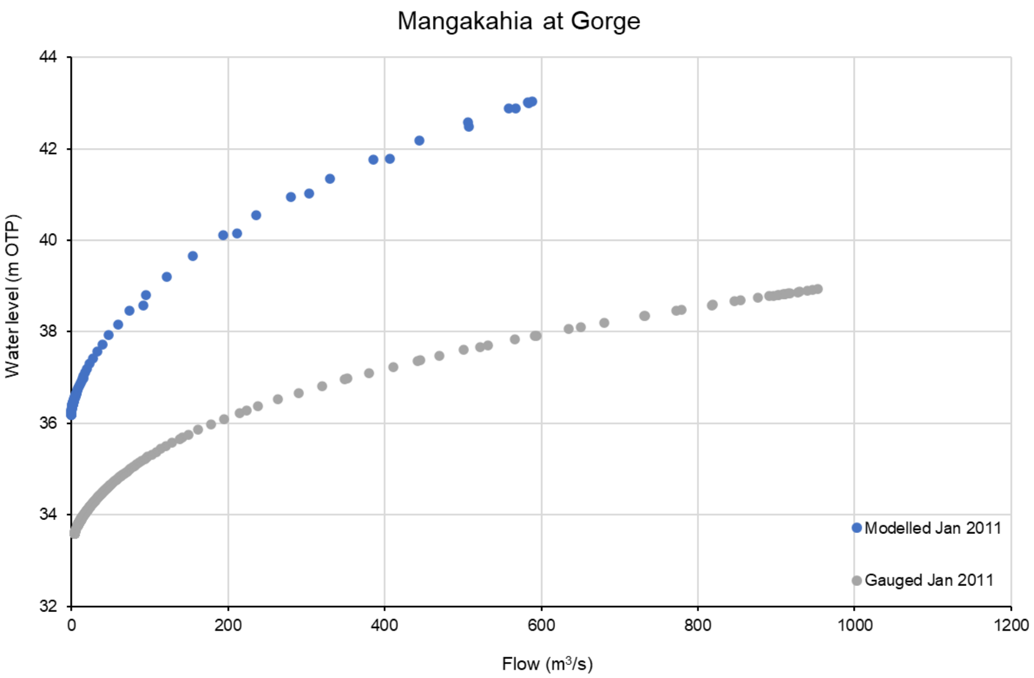


FIGURE 7-16 MODELLED AND GAUGED RATING CURVE COMPARISON AT GORGE GAUGE

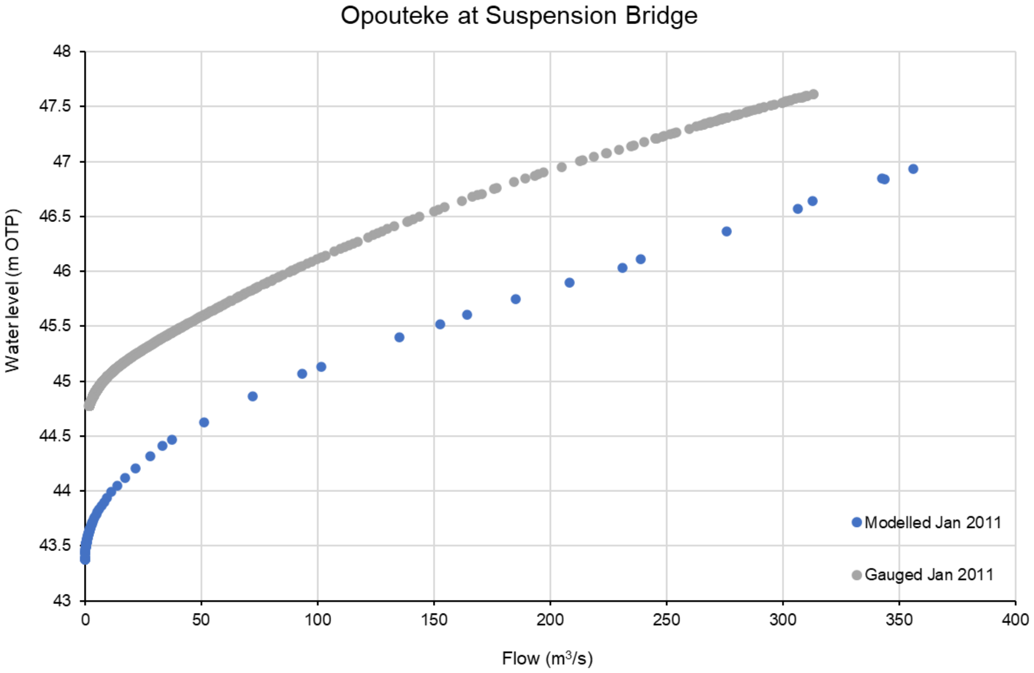


FIGURE 7-17 MODELLED AND GAUGED RATING CURVE COMPARISON AT SUSPENSION BRIDGE

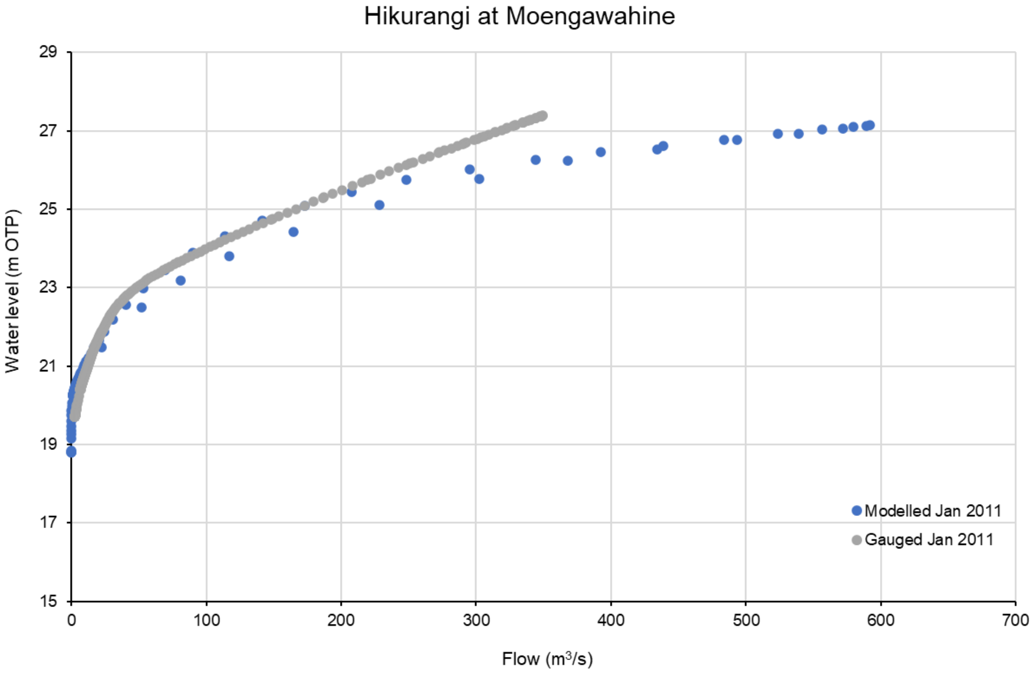


FIGURE 7-18 MODELLED AND GAUGED RATING CURVE COMPARISON AT MOENGAWAHINE

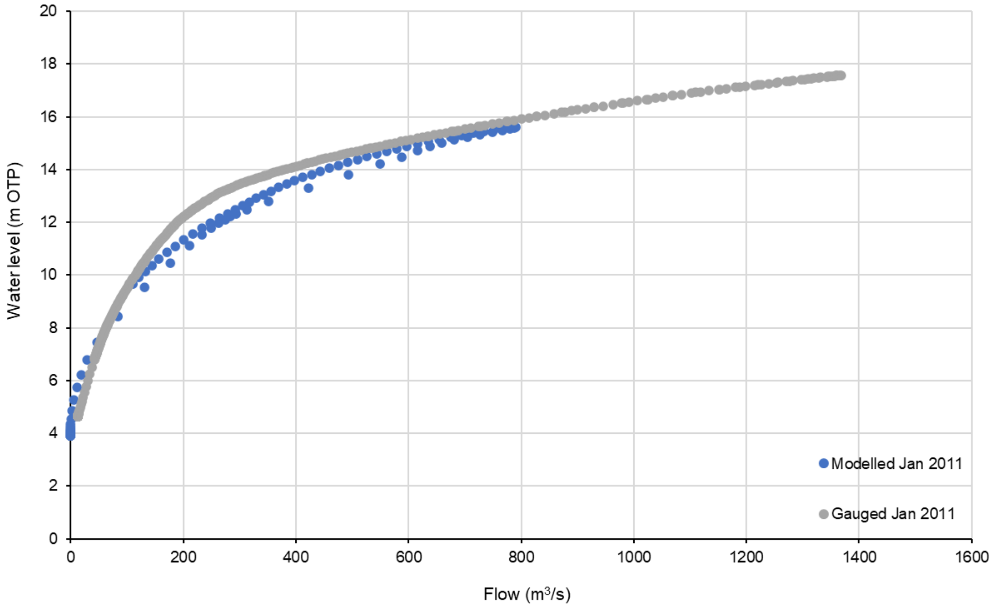


FIGURE 7-19 MODELLED AND GAUGED RATING CURVE COMPARISON AT TITOKI BRIDGE

7.3 Discussion

During the investigation of the discrepancy between the modelled and gauged rating curves, it was found that existing gauged rating curve of Moengawahine gauge may only account for flows within the channel and may not include overland flows across the floodplain. This can be a common mistake in the extrapolation of rating curves in high flows due to a lack of gaugings at high flows.

Figure 7-20 shows the modelled flows extracted from the river channel match to the gauged flows better than those extracted from across the floodplain. This demonstrates that the gauged rating curves are unreliable for high flows. The extrapolation of this rating curve needs to be reviewed.

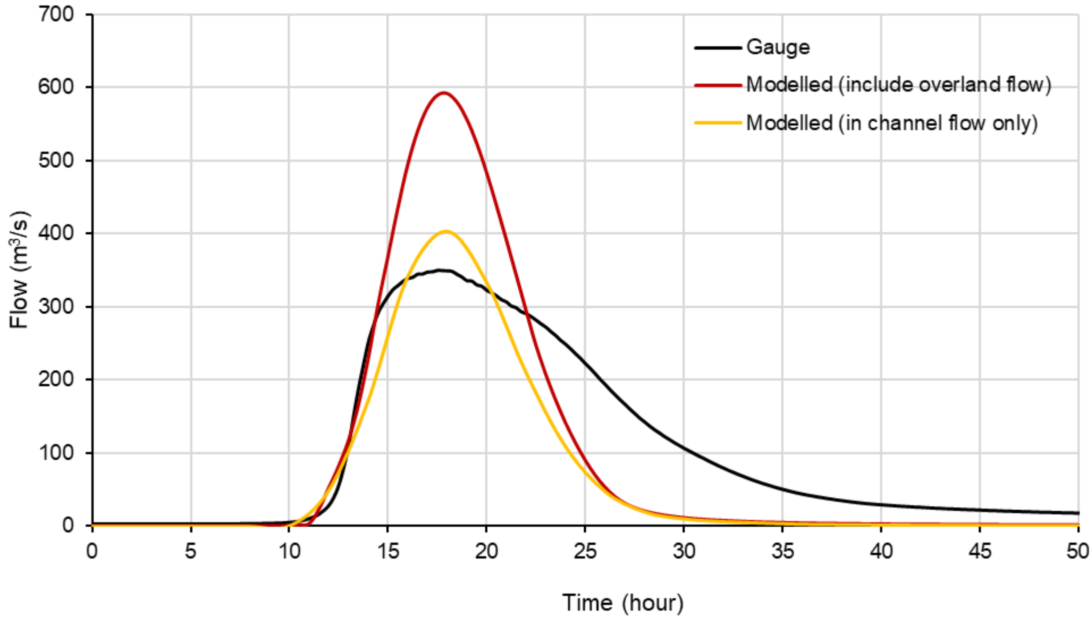


FIGURE 7-20 IN CHANNEL FLOWS AND OVERLAND FLOWS AT MOENGAWAHINE GAUGE

8 CATCHMENT MODEL 14

8.1 Model development

Model extent

The catchment model 14 (M14) includes a number of smaller catchments including the Waiotu, Waiariki, Whakapara, Lower Purua, Mangahahuru, Lower Wairua Bridge, Mangere and Waipao catchments. The model covers a total area of approximately 707 km^2. The hydraulic model extent of the catchment 14 model is displayed in Figure 8-1. Each smaller catchment outfalls to the Wairoa River with the catchment draining south. catchment topographic data is shown in Figure 8-2.

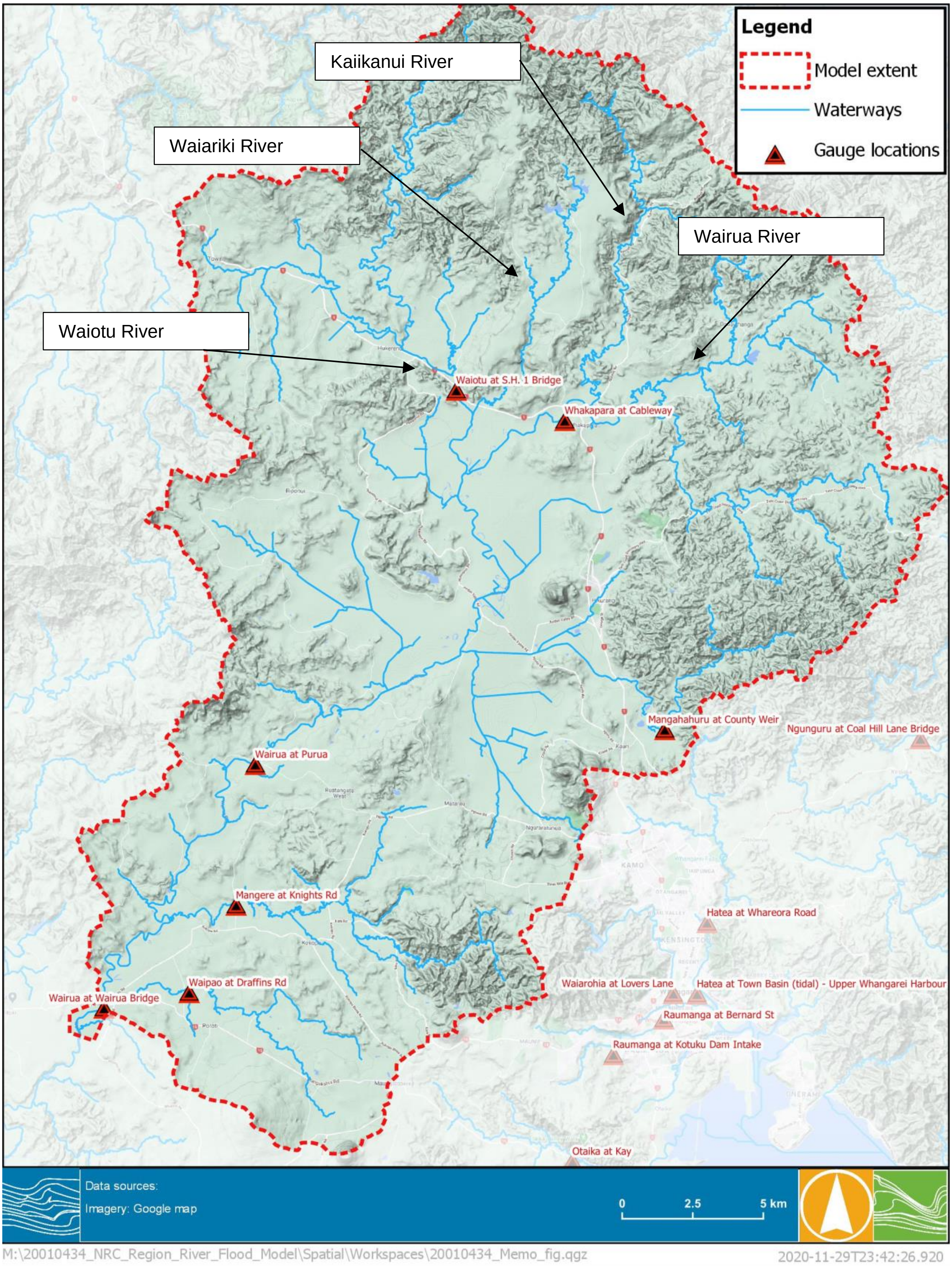


FIGURE 8-1 HYDRAULIC MODEL EXTENT – M14

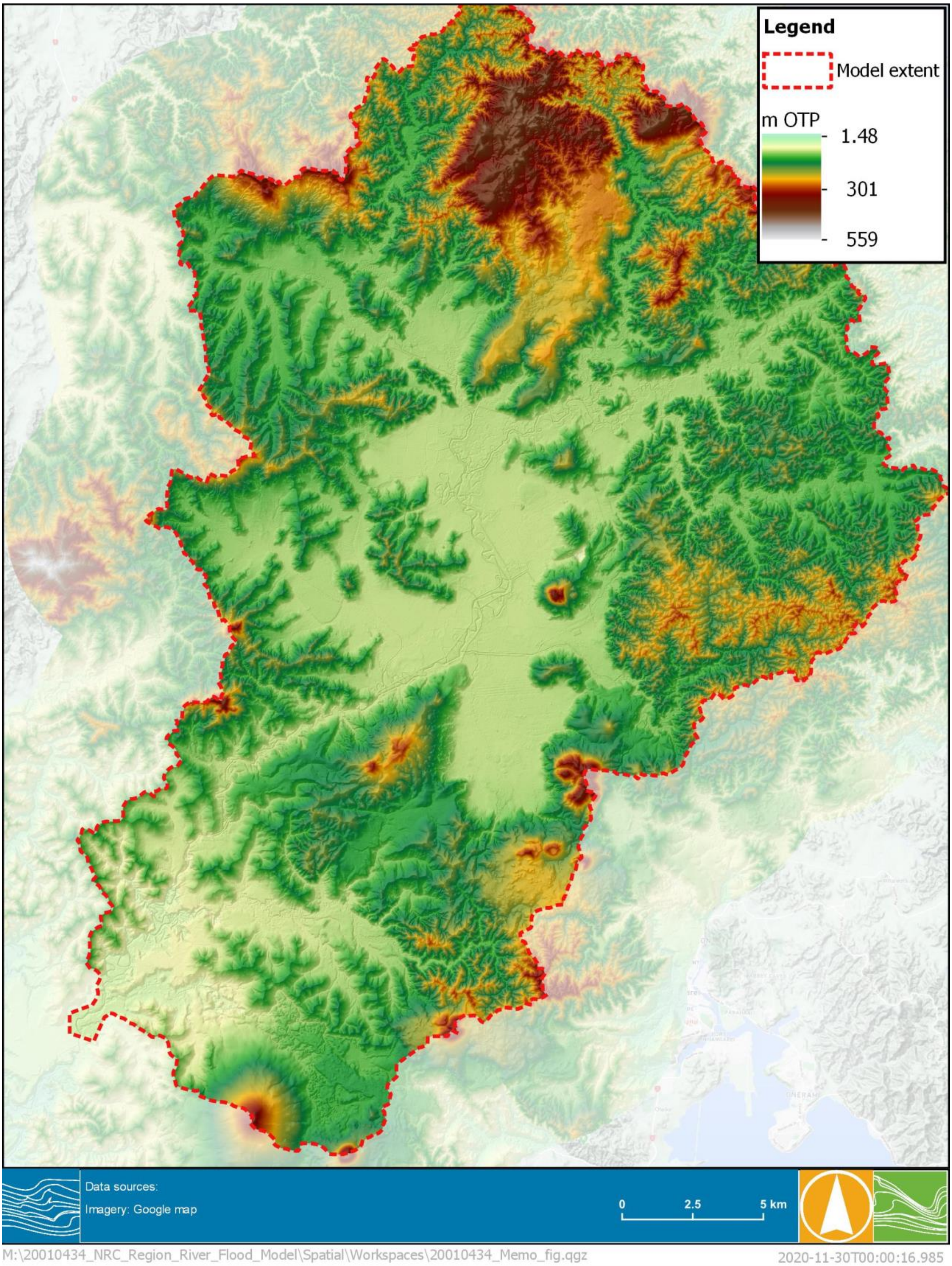


FIGURE 8-2 HYDRAULIC MODEL TOPOGRAPHY – M14

Model boundaries

Figure 8-3 shows the hydraulic model boundaries for catchment M14. The hydraulic model boundaries consist of input rainfall depths and outflow boundaries. A HQ type (stage-discharge) outflow boundary was applied to the downstream of Wairua Bridge gauge at the south of the catchment.

The January 2011 event was used for the calibration of the catchment model 14. The January 2011 flood event saw about 230 mm of rainfall in total across the catchment model including a burst of close to 185 mm of rainfall in 7 hours.

There are seven rainfall stations with available records for the calibration of January 2011 event. The input rainfall depths across the catchment area were interpolated using the Inverse Distance Weighted (IDW) average method based on the location and the rainfall records in these stations. The interpolated rainfall depths of 2011 event as shown in Figure 8-3 highlights the higher rainfall totals in the north of the catchment.

Six of the seven rainfall gauges have sub-daily records with the exception of the Waiotu gauge, that provides only daily totals. The sub-daily rainfall for this location was created by using the temporal pattern derived from the nearby Puhipuhi gauge.

Material layer

The material layer was created based on the 2016 LUCAS land use map data4 and the waterway data from Land Information New Zealand. Figure 8-4 displays the material layer used for Model 14. The hydraulic roughness values and rainfall losses were assigned in accordance with the land use and soil classification types within the catchment.

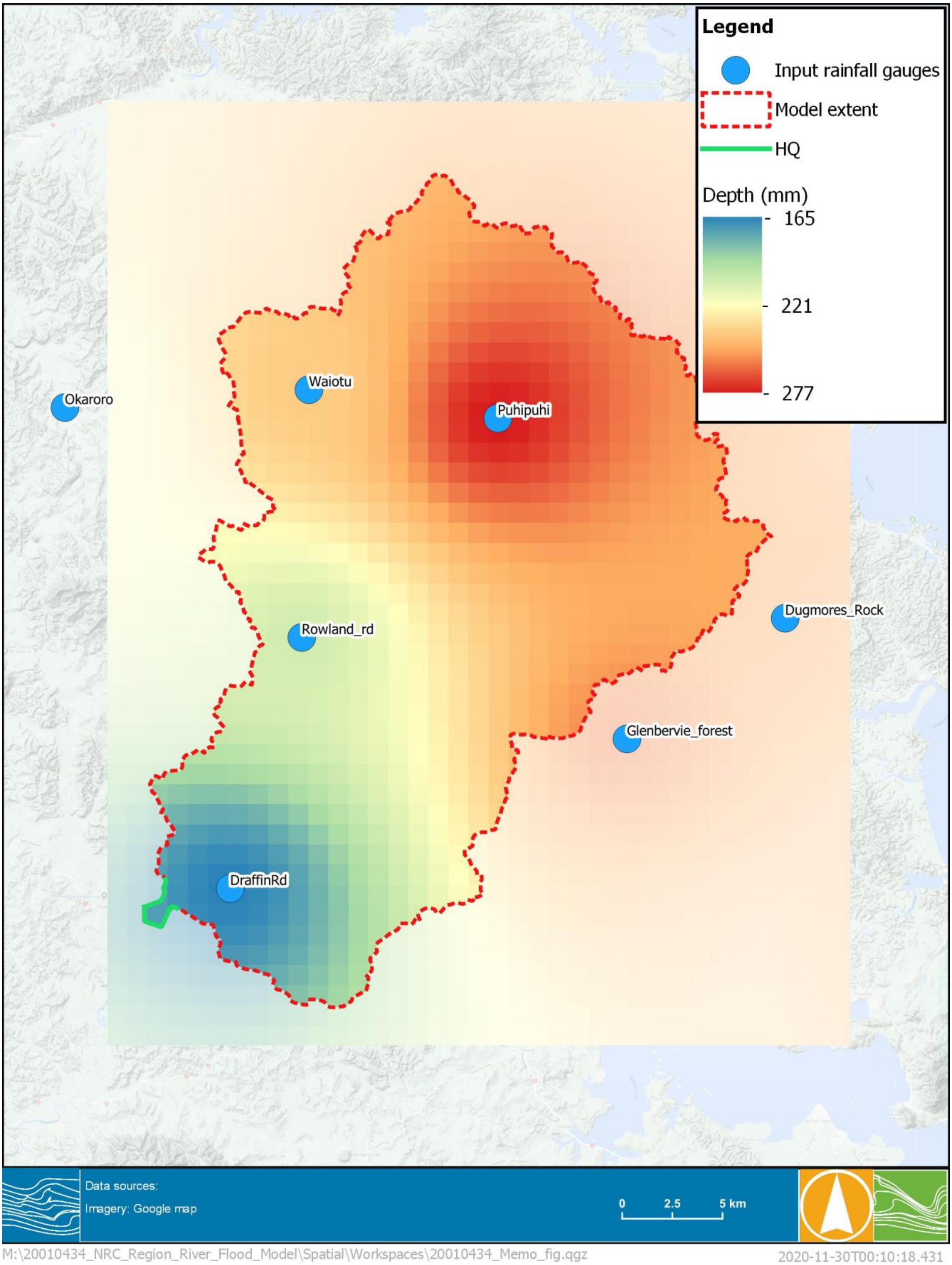


FIGURE 8-3 HYDRAULIC MODEL BOUNDARIES AND INTERPOLATED RAINFALL DEPTH – M14

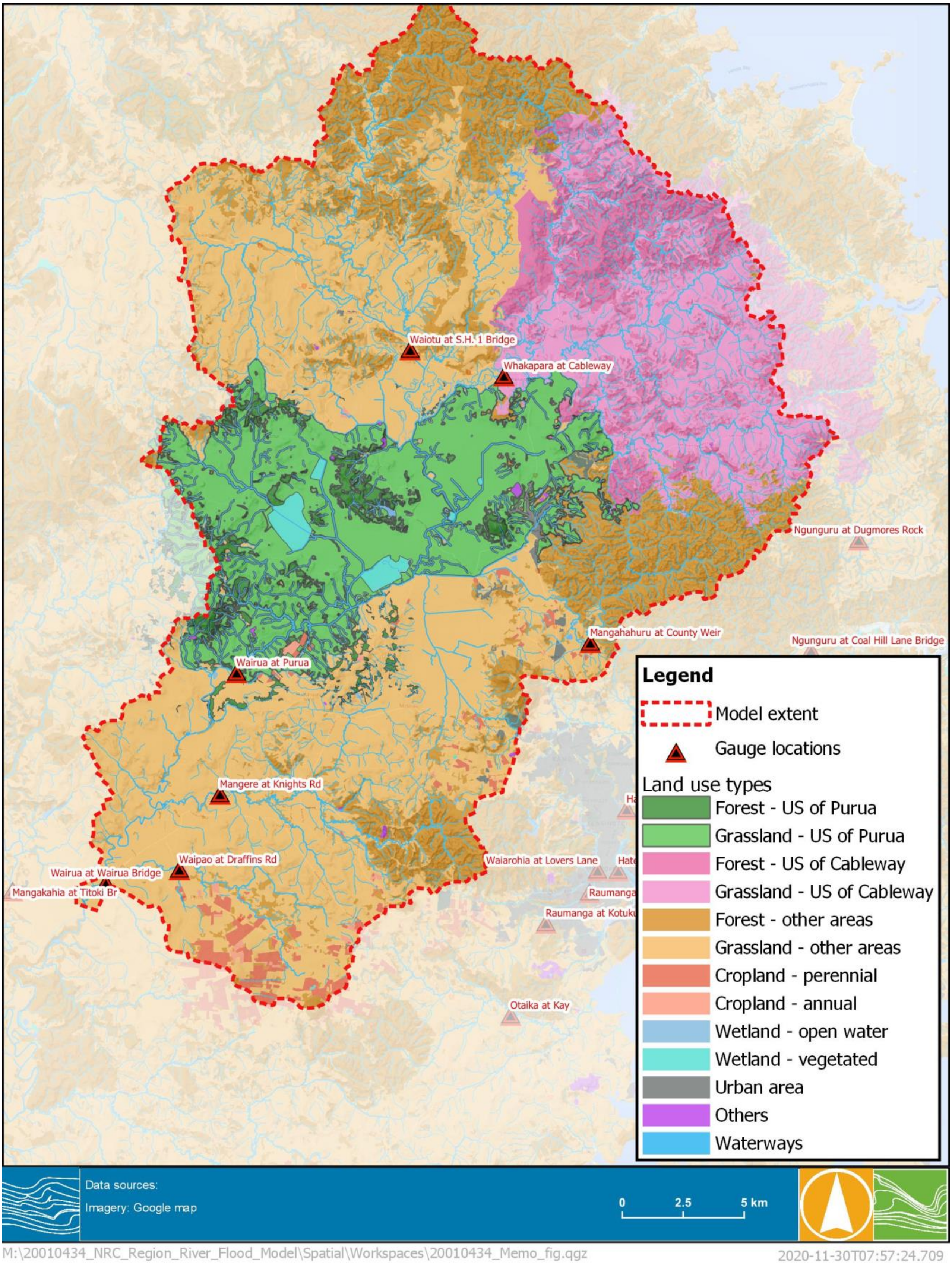


FIGURE 8-4 HYDRAULIC MODEL MATERIAL LAYER – M14

8.2 Model calibration

Model parameters

As a starting point of model calibration, the model parameters for M14 were initially adopted from Kawakawa catchment model and then they were adjusted by an iterative process. The calibrated model parameters are summarised in Table 8-1.

TABLE 8-1 CALIBRATED HYDRAULIC ROUGHNESS AND RAINFALL LOSSES VALUES – M14

Hydrological areas	Land use types	Manning's n	Initial loss (IL) - mm	Continuing loss (CL) – mm/hr
Upstream catchment of Purua	Forest	0.10	25	2.5
	Grassland	0.08	25	2.5
Upstream catchment of Cableway	Forest	0.10	40	4.5
	Grassland	0.08	40	4.5
Other catchment areas	Forest	0.10	55	6.5
	Grassland	0.08	55	6.5
Entire M14 catchment areas	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

Calibration results

The comparison between the modelled results and the gauged records is summarised in Table 8-2 and the quantitative assessment of the model calibration is shown in Table 8-3.

The hydraulic model replicates the peak water level within 300 mm of the gauged records in six of the seven gauges, with the exclusion of Purua gauge which is below the recorded level. In contrast, the model does not match the peak flow and volume well to the gauged records. The flows in the model either significantly overestimated or underestimated gauged records. There is discrepancy between the modelled and gauged rating curves as shown in Figure 8-12 to Figure 8-17. To improve the model performance of replicating the flows, a revision of existing gauged rating curves is required.

TABLE 8-2 SUMMARY OF CALIBRATION RESULTS – M14

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)
S.H. 1 bridge	456	218	109.31%	-0.75	16293	14998	8.64%	94.18	93.90	281.40
Cableway	249	366	-32.00%	1.00	16146	26625	-39.36%	93.54	93.81	-267.10
County Weir	17	34	-49.07%	2.25	333	1549	-78.51%	110.13	109.96	171.10
Purua	84	245	-65.81%	-26.75	9933	29978	-66.87%	87.87	89.15	-1273.20
Knight Rd	306	116	163.13%	0.00	7222	6750	6.99%	79.73	79.65	77.40
Draffins Rd	65	28	131.55%	-2.50	2252	1825	23.42%	57.76	57.69	68.70
Wairua Bridge	314	-	-	0.33	19293	-	-	54.55	54.70	-149.90

TABLE 8-3 QUANTITATIVE ASSESSMENT OF THE JANUARY 2011 EVENT – M14

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)
S.H. 1 bridge	N	Y	Y	Y	Y
Cableway	N	N	Y	Y	N
County Weir	N	N	Y	N	N
Purua	N	N	N	N	N
Knight Rd	N	Y	Y	Y	N
Draffins Rd	N	N	Y	N	N
Wairua Bridge	-	-	Y	Y	N

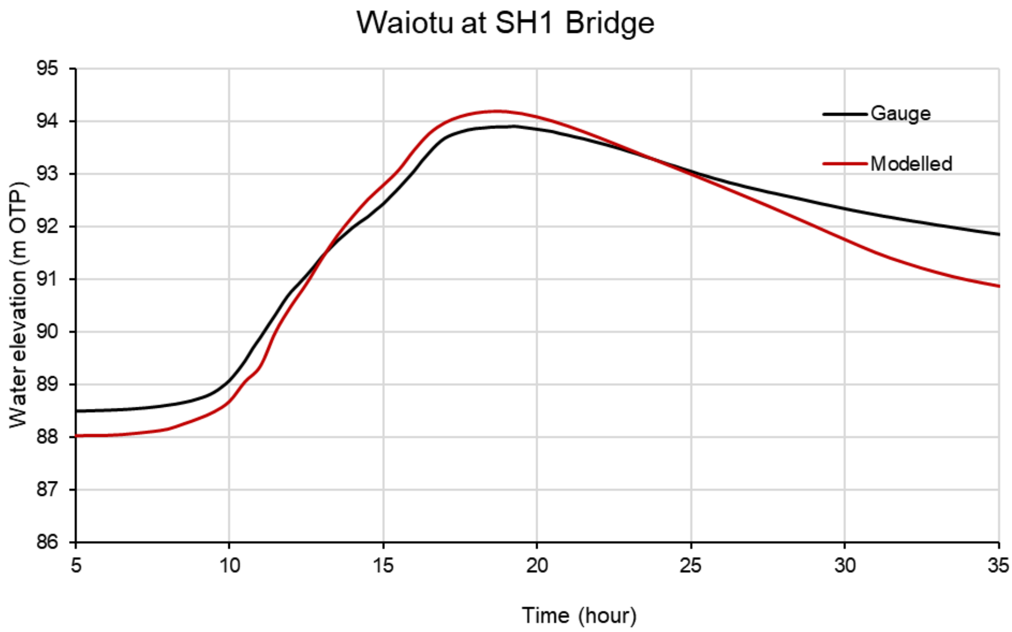


FIGURE 8-5 MODELLED AND GAUGED WATER LEVEL COMPARISON AT S.H. 1 BRIDGE GAUGE – M14

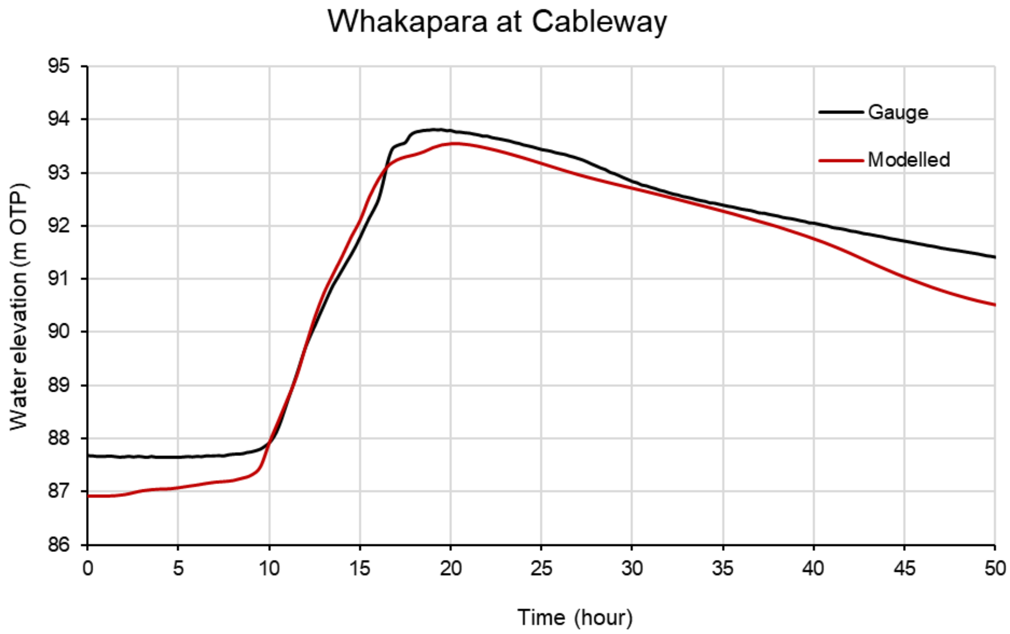


FIGURE 8-6 MODELLED AND GAUGED WATER LEVEL COMPARISON AT CABLEWAY GAUGE – M14

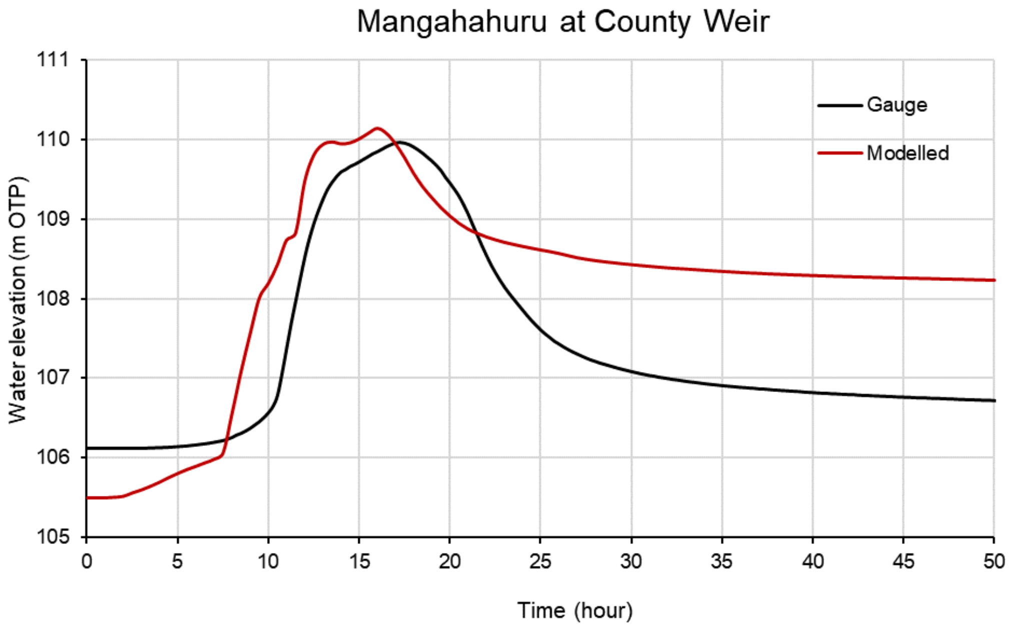


FIGURE 8-7 MODELLED AND GAUGED WATER LEVEL COMPARISON AT COUNTY WEIR GAUGE – M14

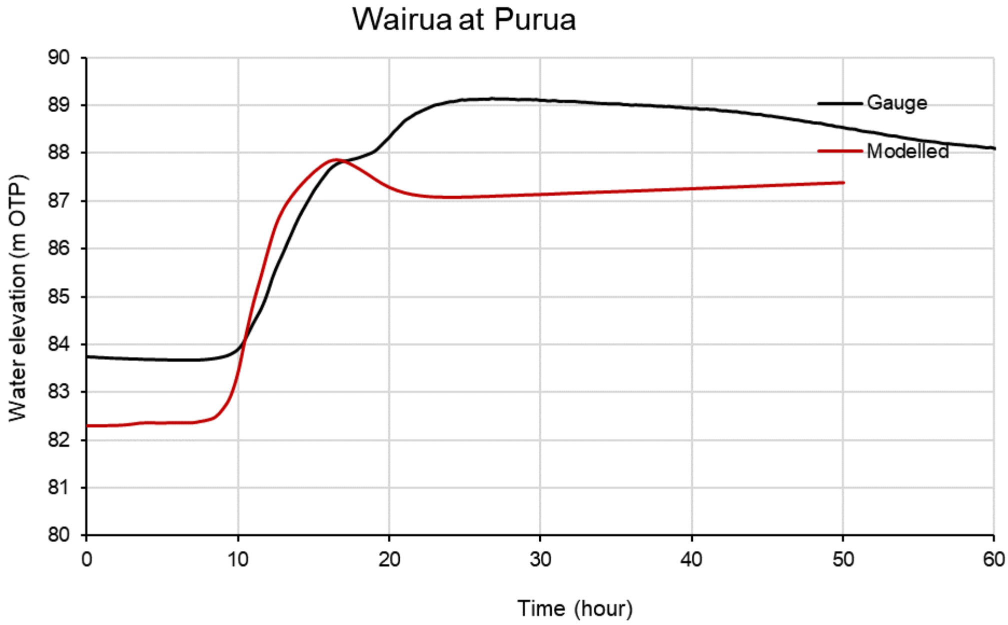


FIGURE 8-8 MODELLED AND GAUGED WATER LEVEL COMPARISON AT WAIRUA AT PURUA GAUGE – M14

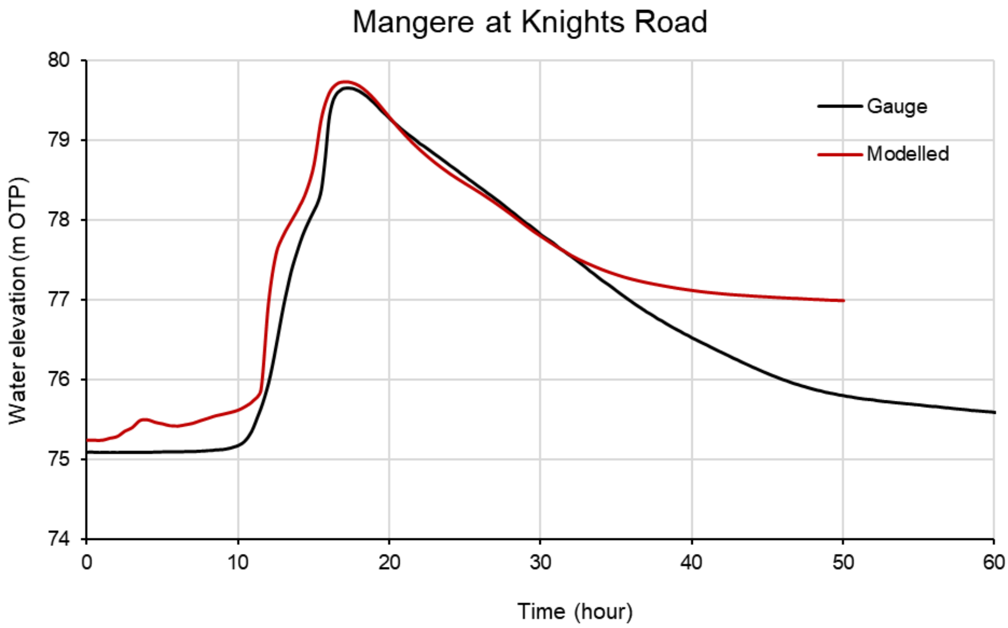


FIGURE 8-9 MODELLED AND GAUGED WATER LEVEL COMPARISON AT KNIGHTS RD GAUGE – M14

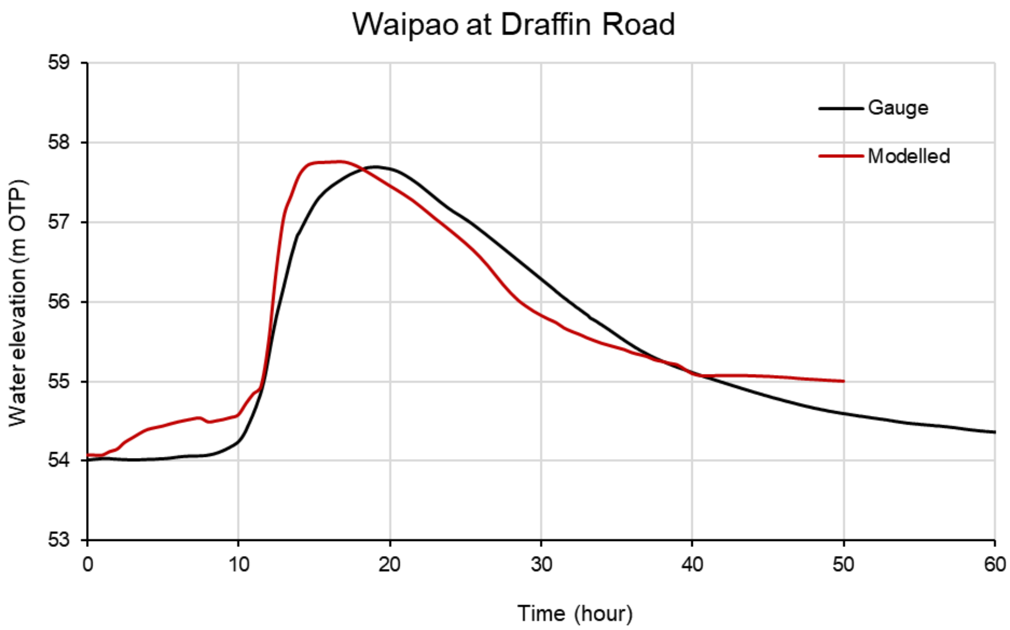


FIGURE 8-10 MODELLED AND GAUGED WATER LEVEL COMPARISON AT DRAFFIN RD GAUGE – M14

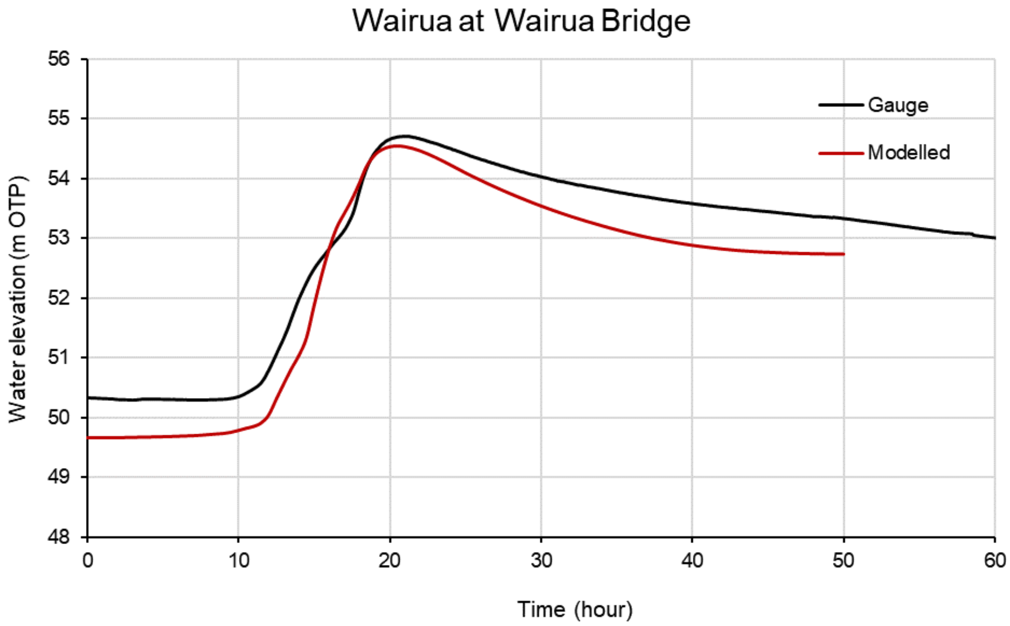


FIGURE 8-11 MODELLED AND GAUGED WATER LEVEL COMPARISON AT WAIRUA BRIDGE GAUGE – M14

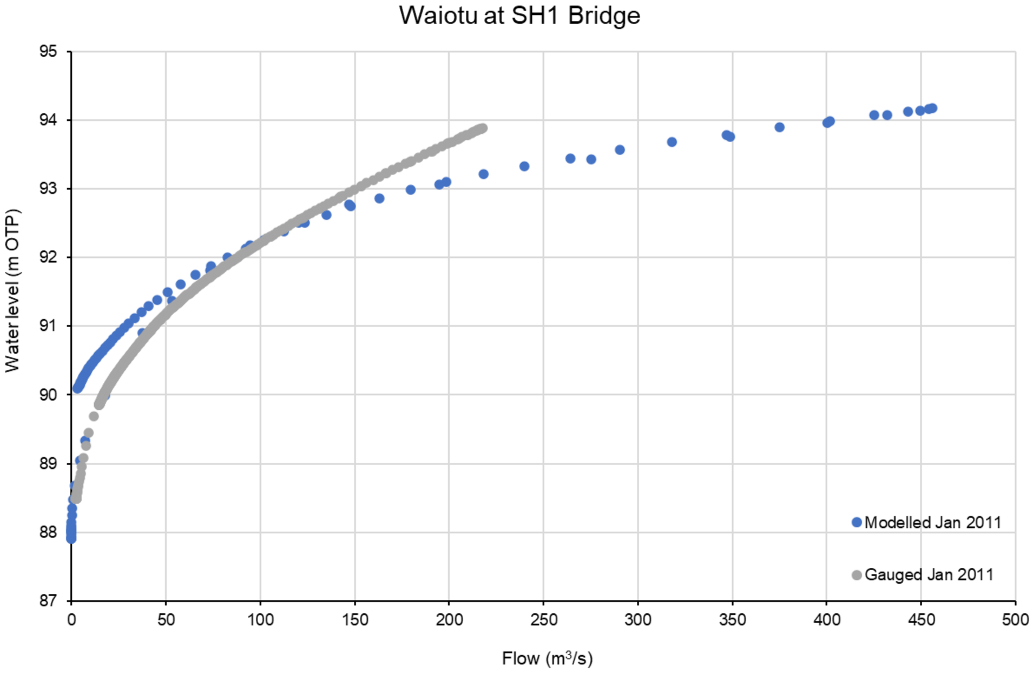


FIGURE 8-12 MODELLED AND GAUGED RATING CURVE COMPARISON AT S.H. 1 BRIDGE GAUGE

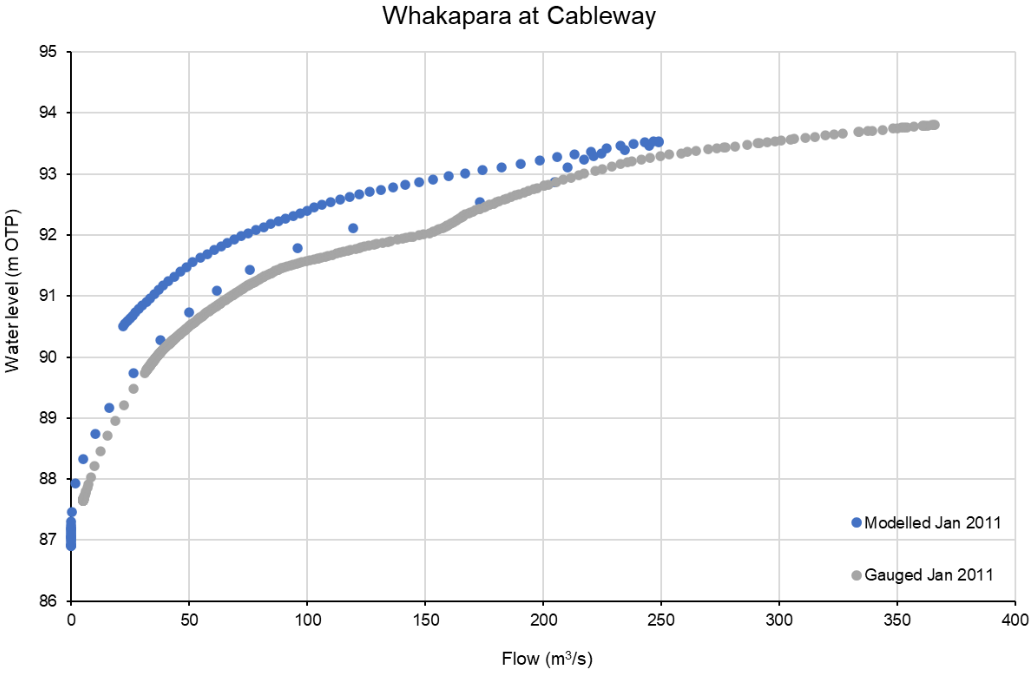


FIGURE 8-13 MODELLED AND GAUGED RATING CURVE COMPARISON AT CABLEWAY GAUGE

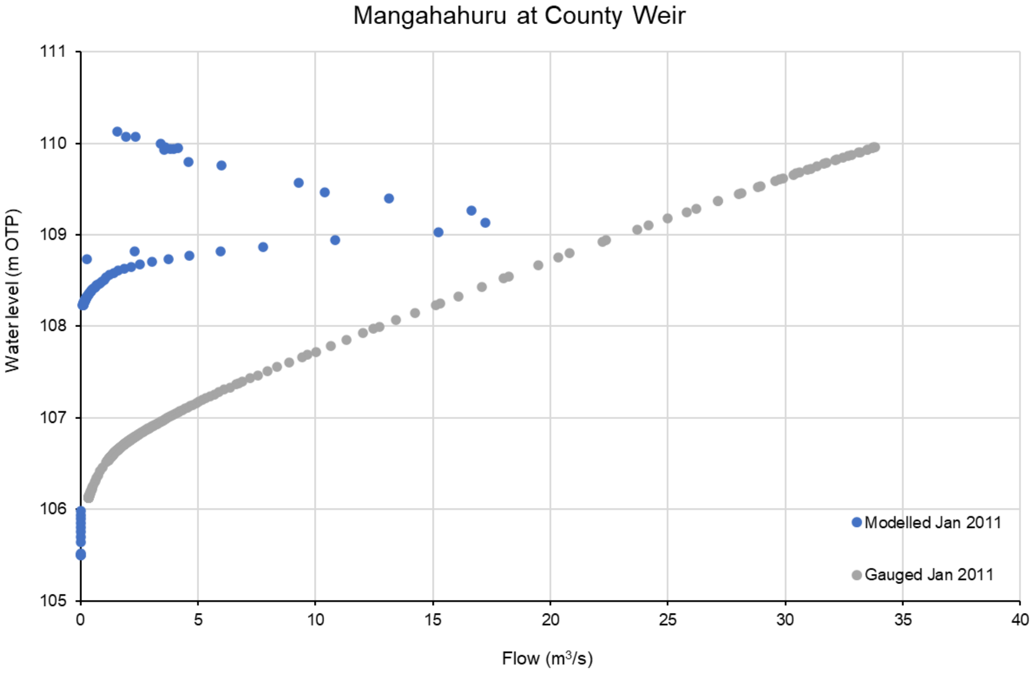


FIGURE 8-14 MODELLED AND GAUGED RATING CURVE COMPARISON AT COUNTY WEIR GAUGE

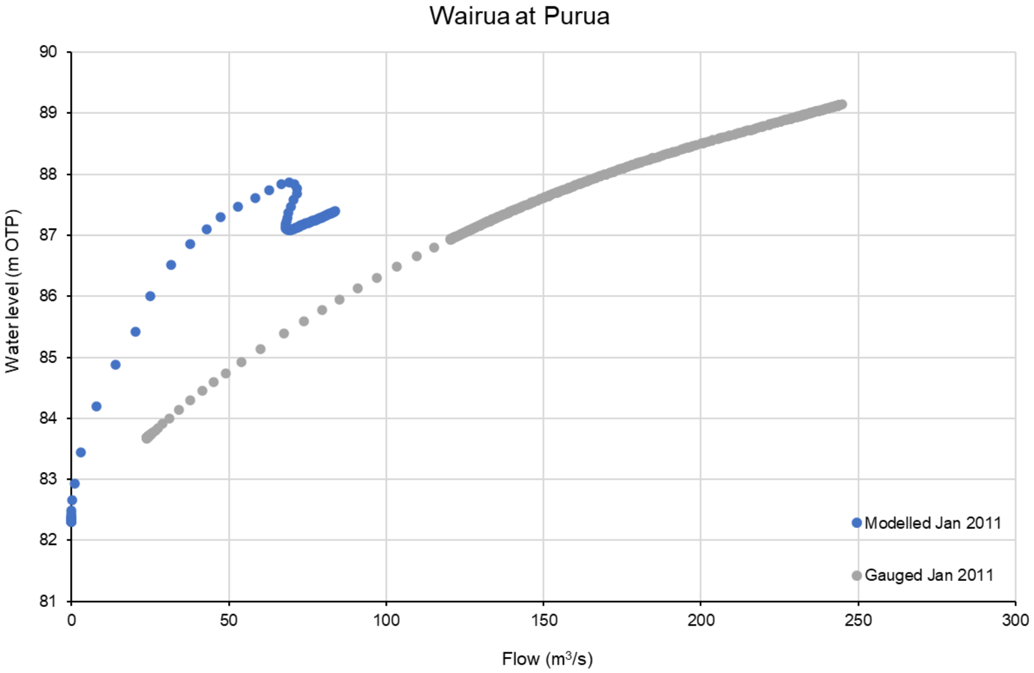


FIGURE 8-15 MODELLED AND GAUGED RATING CURVE COMPARISON AT PURUA GAUGE

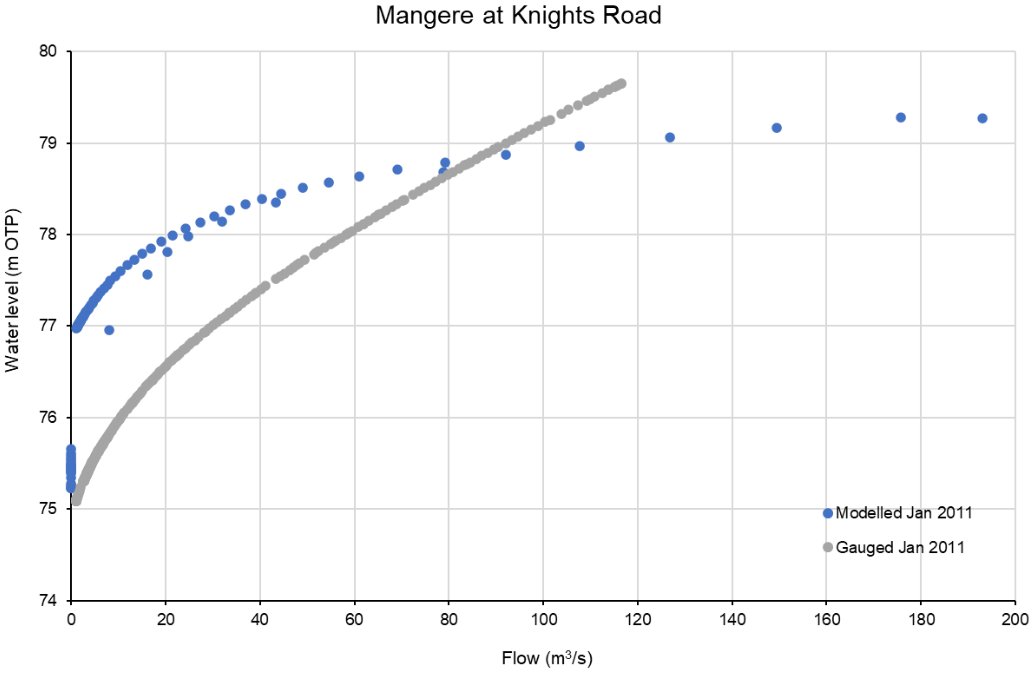


FIGURE 8-16 MODELLED AND GAUGED RATING CURVE COMPARISON AT KNIGHT RD GAUGE

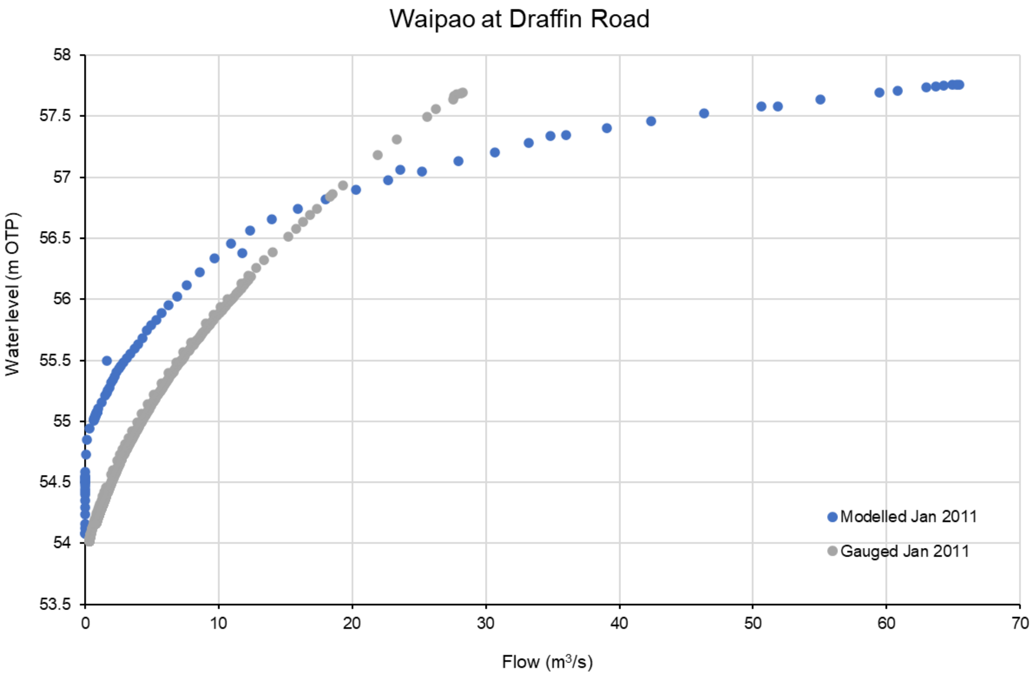


FIGURE 8-17 MODELLED AND GAUGED RATING CURVE COMPARISON AT DRAFFIN RD GAUGE

8.3 Discussion

During the investigation of the discrepancy between the modelled and gauged rating curves, it was found that several existing gauged rating curves might not take into account overland flows on the floodplain. These gauges include S.H.1 Bridge gauge, Knights Road gauge and Draffin Road gauge.

Figure 8-18 to Figure 8-20 shows the modelled flows extracted from the river channel match to the gauged flows better than those extracted from across the floodplain. This demonstrates that the gauged rating curves are unreliable for high flows. The extrapolation of these rating curves needs to be reviewed.

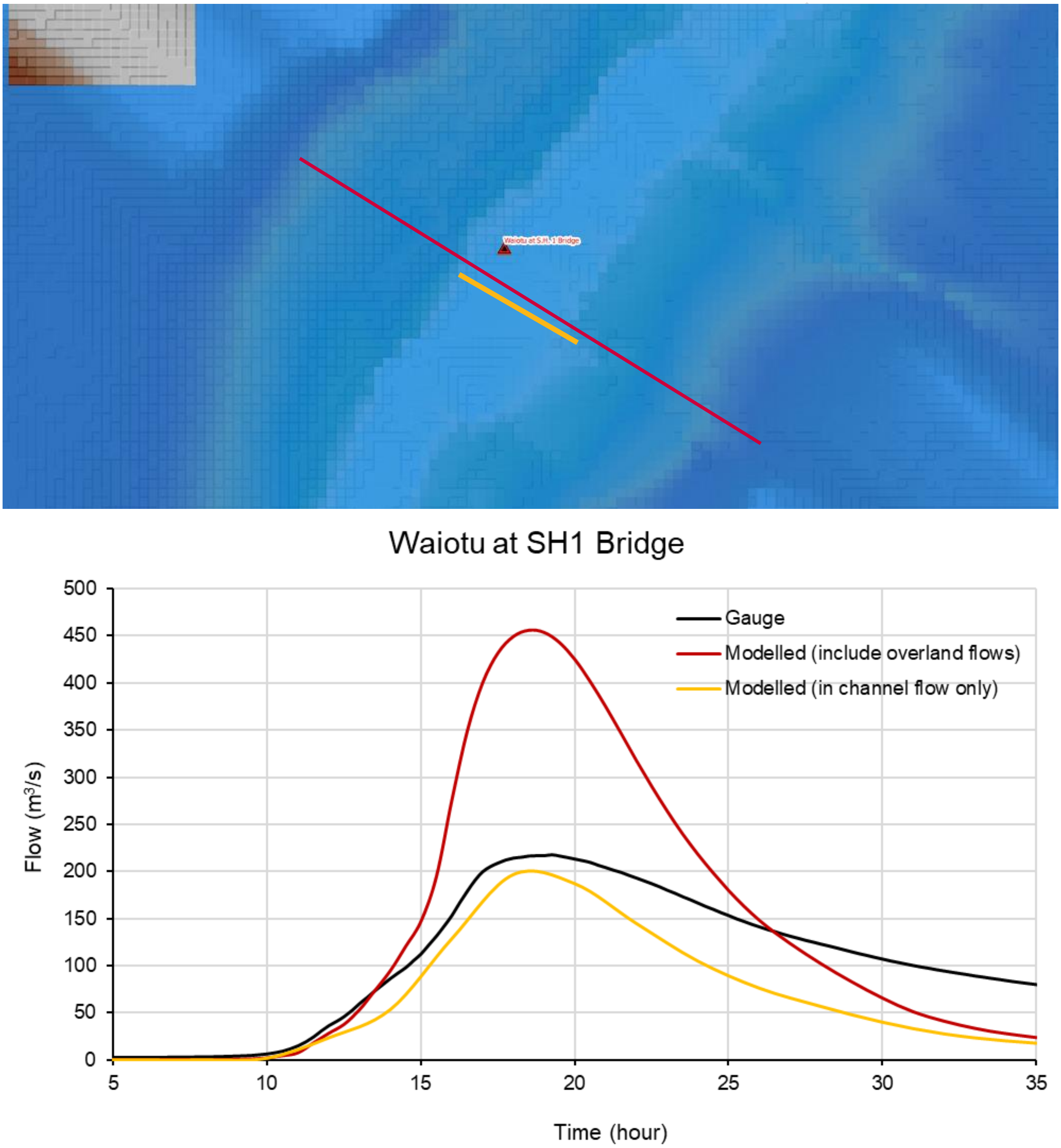
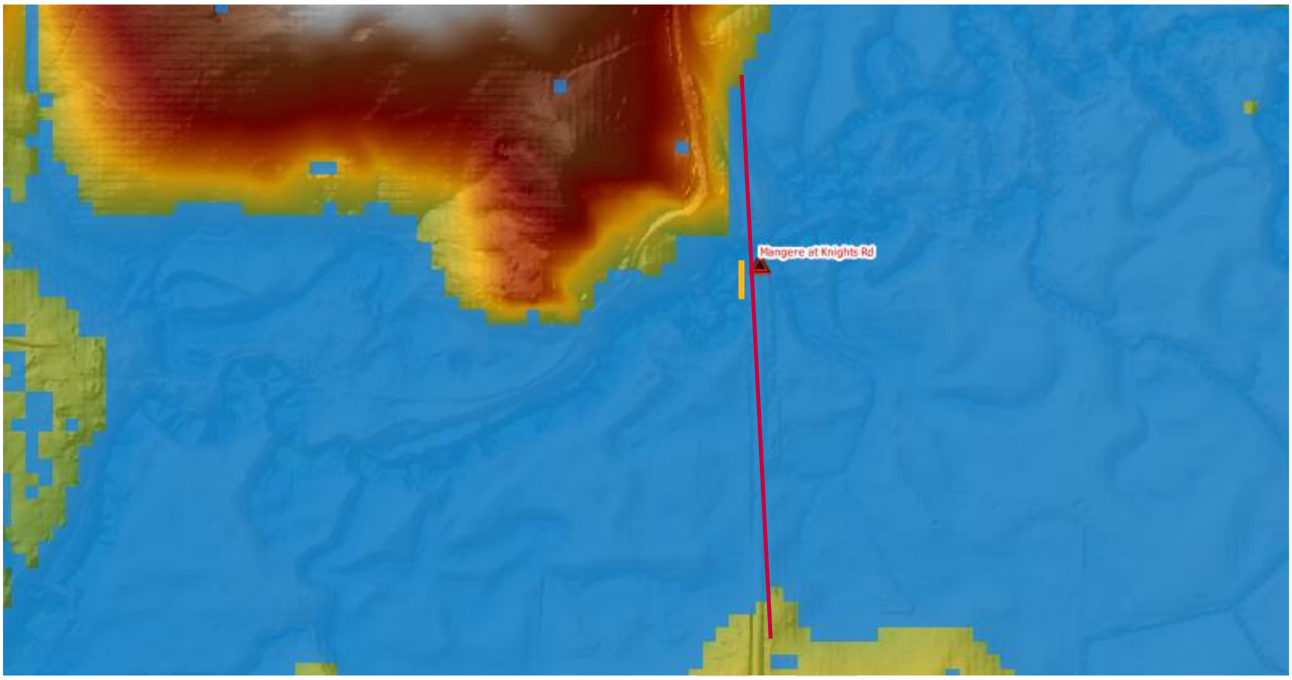


FIGURE 8-18 IN CHANNEL FLOWS AND OVERLAND FLOWS AT S.H.1 BRIDGE GAUGE



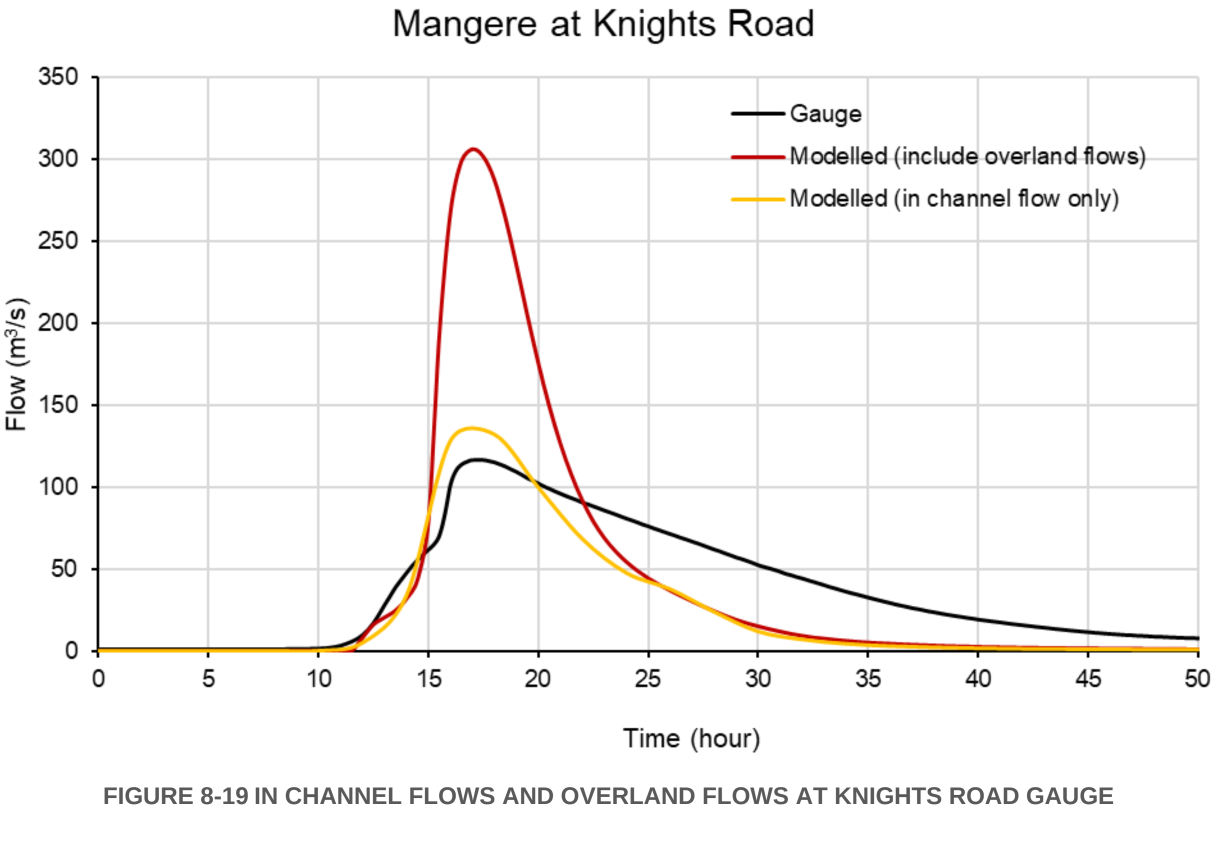
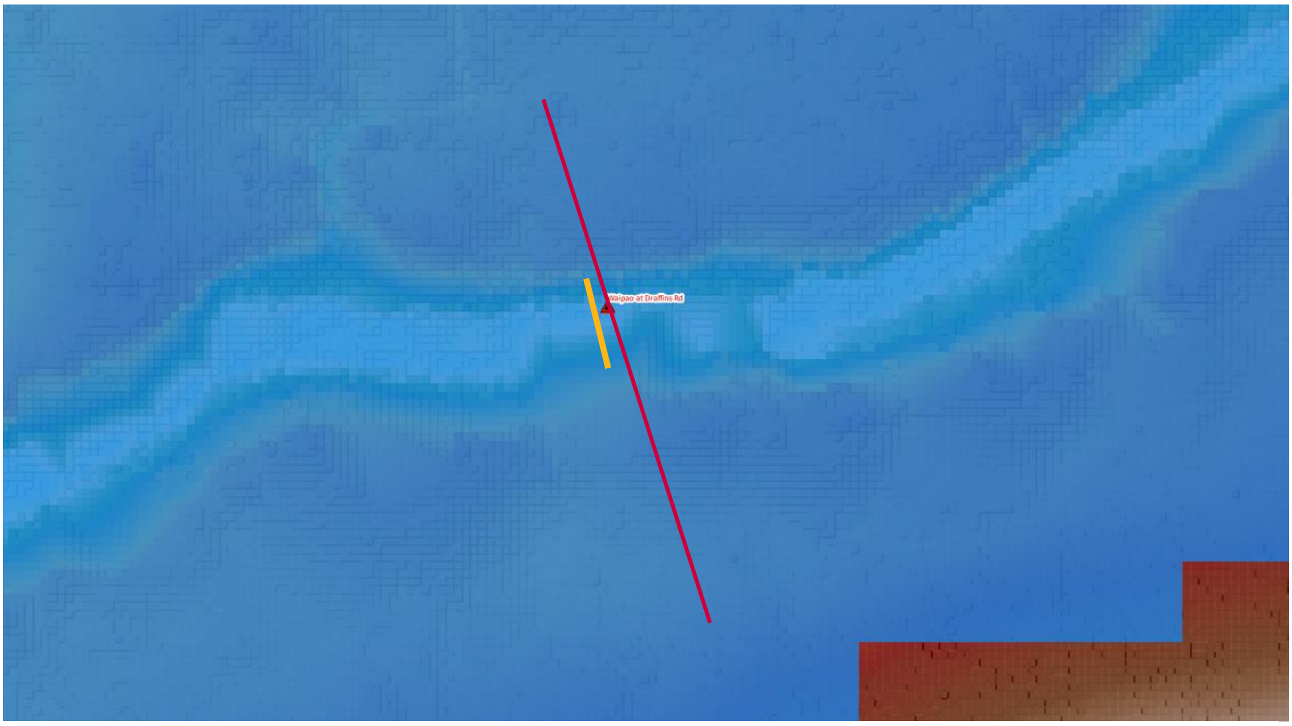


FIGURE 8-19 IN CHANNEL FLOWS AND OVERLAND FLOWS AT KNIGHTS ROAD GAUGE



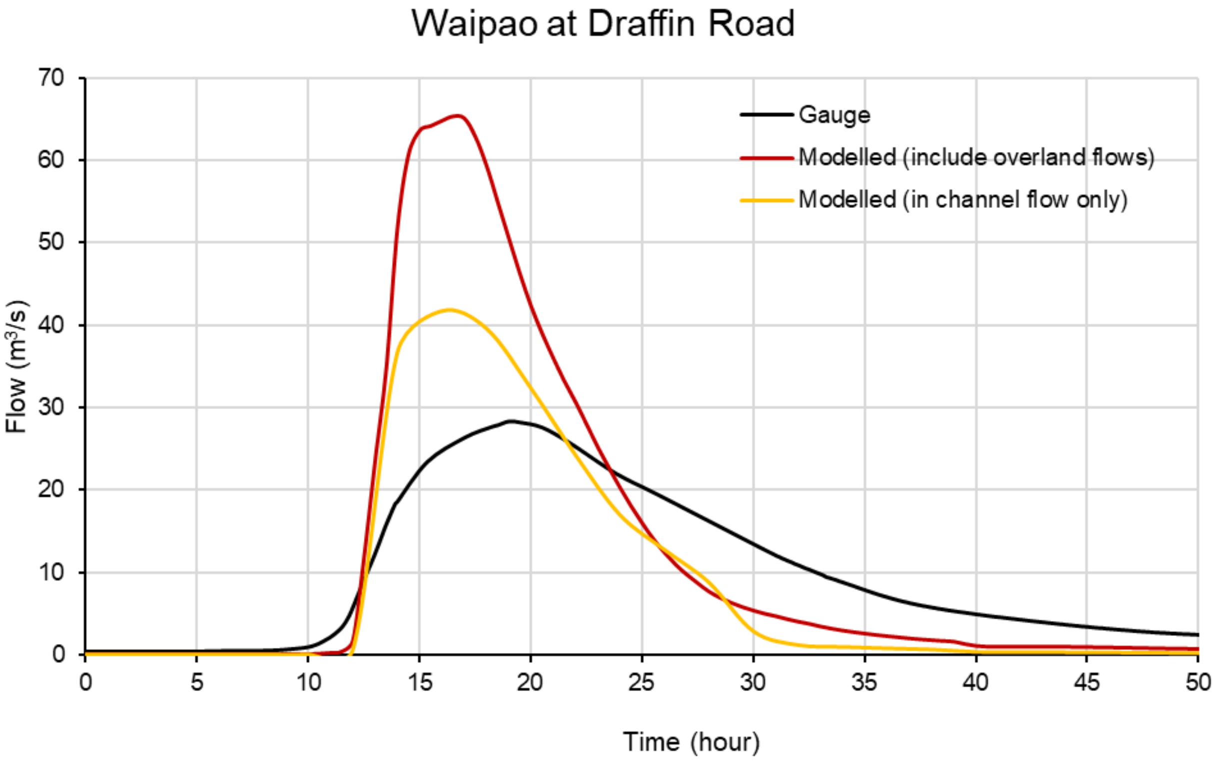


FIGURE 8-20 IN CHANNEL FLOWS AND OVERLAND FLOWS AT DRAFFIN ROAD GAUGE

Figure 8-21 shows the modelled peak flow at County Weir gauge is much lower than that recorded in the gauge. The main reason likely during in channel flows, the water is travelling in an east-direction. As flows increase and the floodplain is engaged the majority of flood water is flowing from north to south as shown in Figure 8-23. This would increase the uncertainty of the gauged rating curve for high flows.

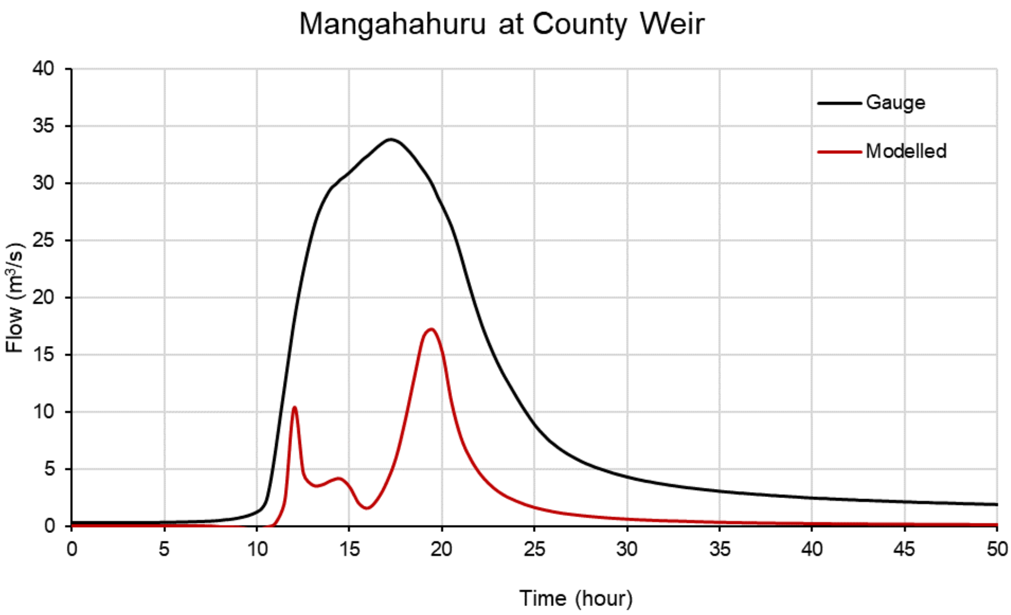


FIGURE 8-21 MODELLED AND GAUGED HYDROGRAPHS COMPARISON AT COUNTY WEIR GAUGE

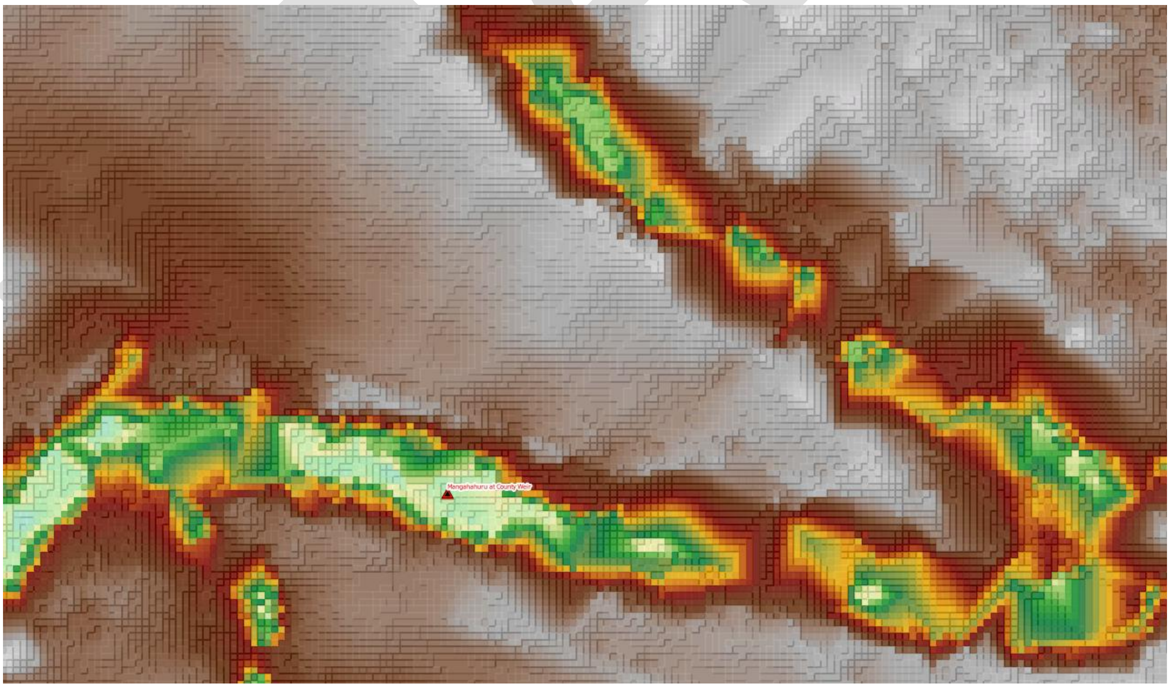


FIGURE 8-22 CHANNEL TOPOGRAPHY UP AND DOWNSTREAM OF COUNTY WEIR GAUGE

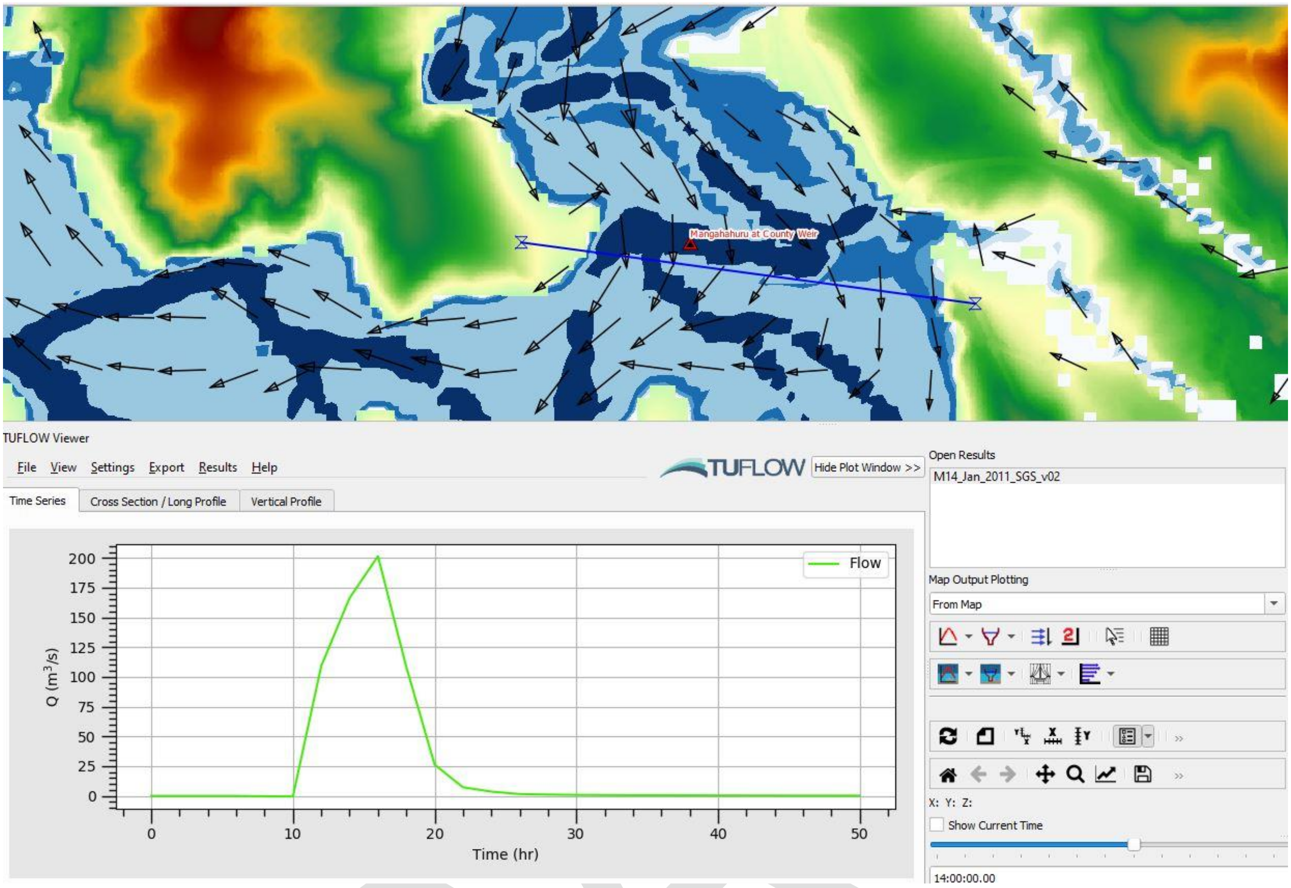


FIGURE 8-23 PEAK FLOOD FLOW DIRECTION AT COUNTY WEIR GAUGE

9 SENSITIVITY ANALYSIS

9.1 Loss method

During the model calibration process, the model parameters required adjustment to help fit the modelled results to the gauged records. Grassland and forest areas are the major land use types found in the upstream of the catchment. Hence, the calibration of parameters focused on these areas and parameters on other land uses remained the same.

Several loss methods were tested initially before reaching the final calibration. These include initial continuing rainfall losses (Rainfall ILCL), the Green-Ampt approach to infiltration and the Horton approach to infiltration. Each of these methods was tested with a range of different parameter values. An example of comparison between these methods was summarised in Table 9-1 and the modelled results are shown in Figure 9-1 to Figure 9-4. It is noted that this sensitivity analysis was undertaken during the calibration of the January 2011 event.

The modelled hydrographs generated by Rainfall ILCL and Horton infiltration methods match the shape well to the gauged records but they mismatch the timing and overestimated the peak values. In contrast, Green-Ampt method is likely to overestimate the losses from infiltration resulting in underestimation of flows. For ease of modelling, the Rainfall ILCL appears to provide suitable model results and can easily applied across the catchment. It can also be easily manipulated if required and provides a concise method that is showing appropriate calibration of flood behaviour.

TABLE 9-1 DETAILS OF DIFFERENT LOSS METHOD BEING TESTED (GRASSLAND- LOAMY SOIL)

<table>
<tr><th>Method</th><th colspan="3">IL (mm)</th><th colspan="3">CL (mm/hr)</th></tr>
<tr><td>Rainfall ILCL</td><td colspan="3">30</td><td colspan="3">6</td></tr>
<tr><th>Method</th><th>IL (mm)</th><th>Initial infiltration rate (mm/h)</th><th>Final infiltration rate (mm/h)</th><th>Exponential decay rate (1/s)</th><th>Porosity</th><th>Initial moisture</th></tr>
<tr><td>Horton</td><td>30</td><td>6</td><td>1.5</td><td>0.0085</td><td>0.4</td><td>0.3</td></tr>
<tr><th>Method</th><th colspan="2">Suction (mm)</th><th colspan="2">Hydraulic conductivity (mm/h)</th><th colspan="2">Porosity (fraction)</th></tr>
<tr><td>Green-Ampt (Loam)</td><td colspan="2">88.9</td><td colspan="2">7.6</td><td colspan="2">0.434</td></tr>
</table>

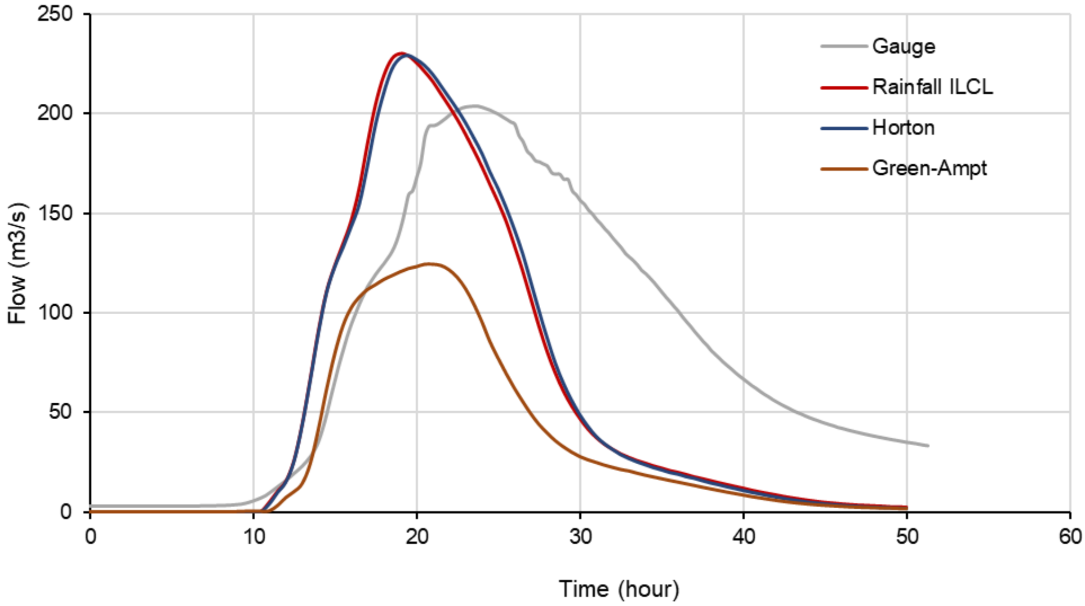


FIGURE 9-1 FLOW COMPARISON OF DIFFERENT LOSS METHODS – AWANUI RIVER AT SCHOOL CUT

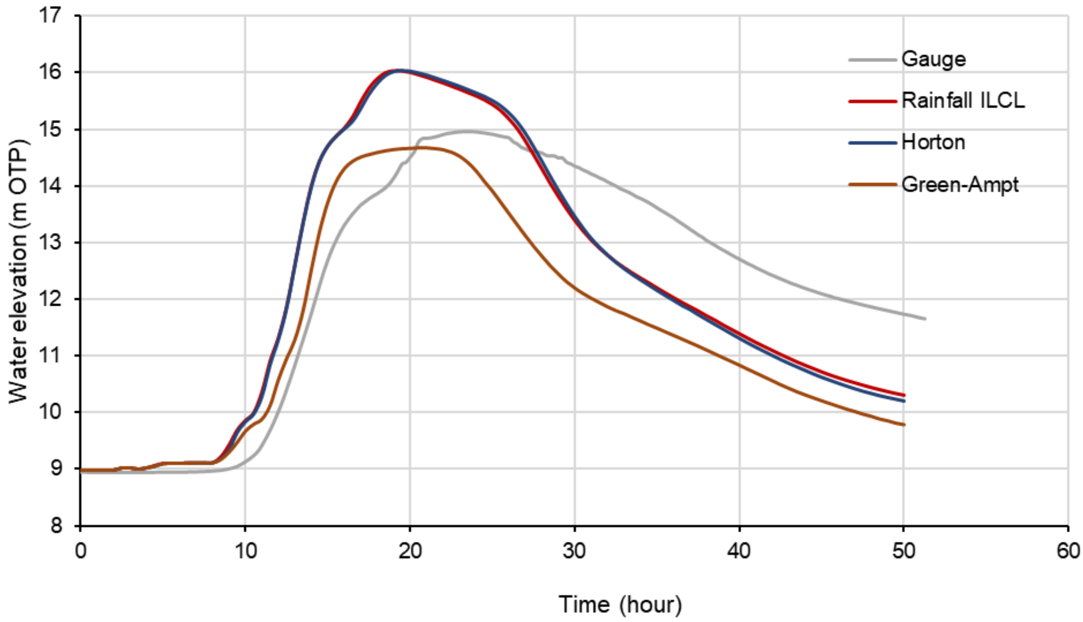


FIGURE 9-2 WATER LEVEL COMPARISON OF DIFFERENT LOSS METHODS – AWANUI RIVER AT SCHOOL CUT

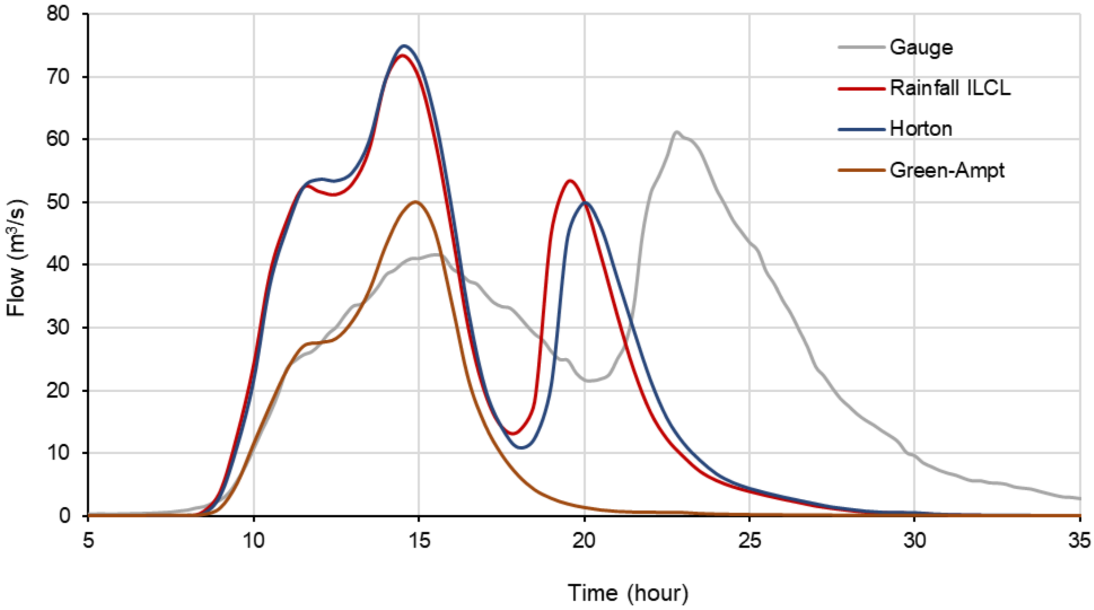


FIGURE 9-3 FLOW COMPARISON OF DIFFERENT LOSS METHODS – TARAWHATAROA RIVER AT PURIRI PLACE

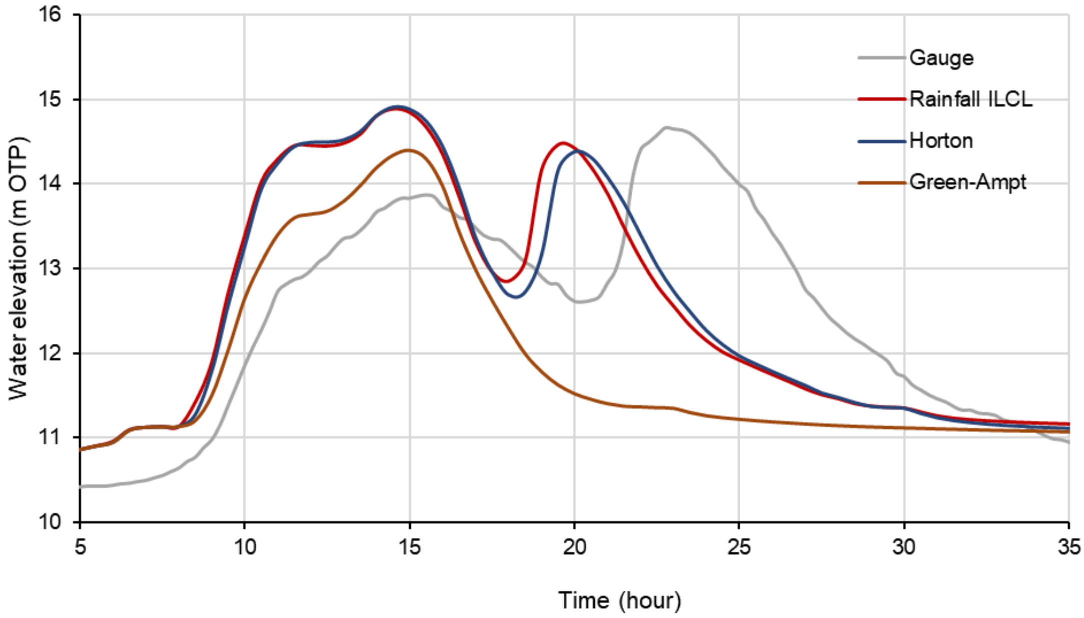


FIGURE 9-4 WATER LEVEL COMPARISON OF DIFFERENT LOSS METHODS – TARAWHATAROA RIVER AT PURIRI PLACE

9.2 Model parameters

Multiple peaks in the hydrograph of the Puriri Place streamflow gauge was the result of flooding from two separate sub-catchments. The second rise was driven by the flow breaking out from Awanui River and overtopping South Road and entering the waterway. Both the second rise in Puriri Place and the rise in School Cut are the result of runoff from the same upstream sub-catchments. Following the selection of the ILCL approach, several changes based on varying the loss values were undertaken based on hydrological conditions (soil types) and adjusted separately based on the delineated areas. A similar approach was adopted in the 2020 DHI report[8], where geological conditions were assessed to vary soil infiltration within the catchment. This is an important consideration and will be adopted throughout the remaining catchments in the study area.

Three simulations testing the impacts of the three parameters (surface roughness, initial loss and continuing loss) were undertaken. Table 9-2 summaries the model parameters tested during the January 2011 calibration runs. Figure 9-5 and Figure 9-6 show the changes on the modelled water levels of these runs.

While each of the model simulations show a reasonable match to the shape of the gauged hydrographs. V03c matched the Awanui River at School Cut peak well and the first peak of the Tarawhataroa River at Puriri Place in timing but the modelled flow and water level were underestimated in the second peak at Puriri Place. For V03d, the roughness values within the waterway were lowered to adjust timing as well as the levels that overtop the State Highway (South Road) providing a better fit to both gauges.

TABLE 9-2 MODEL LOSS AND ROUGHNESS PARAMETERS TESTED IN MODEL RUNS

Hydrological areas	Land use types	Manning's n	Initial loss (IL) - mm	Continuing loss (CL) – mm/hr
V03b				
Tarawhataroa	Forest	0.10	55	8
	Grassland	0.05	55	8
Te Puhi	Forest	0.10	30	5
	Grassland	0.05	30	5
Te Rore and other areas	Forest	0.10	40	6
	Grassland	0.08	40	6
V03c				
State Highway	Road	0.02	2	1
Tarawhataroa	Forest	0.16	55	10
	Grassland	0.10	55	10
Te Puhi	Forest	0.16	25	4
	Grassland	0.10	25	4
Te Rore and other areas	Forest	0.16	40	6
	Grassland	0.10	40	6
V03d				
State Highway	Road	0.02	2	1
Tarawhataroa	Forest	0.10	55	10
	Grassland	0.05	55	10
Te Puhi	Forest	0.10	25	4
	Grassland	0.05	25	4

Te Rore and other areas	Forest	0.10	40	6
	Grassland	0.05	40	6

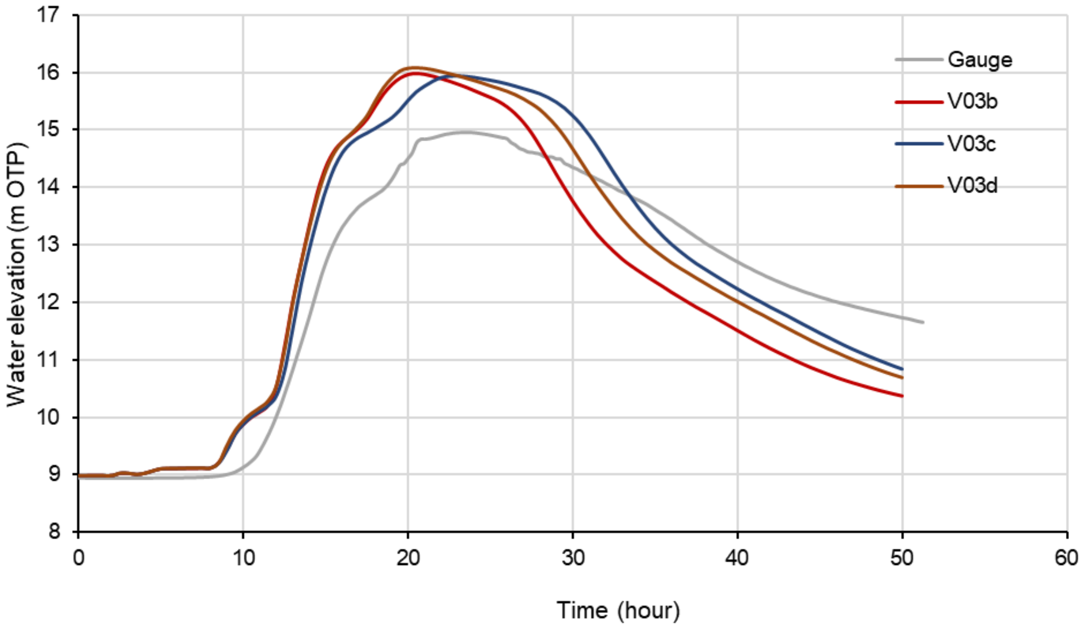


FIGURE 9-5 COMPARISON OF MODELLED AND GAUGED WATER LEVELS FOR AWANUI RIVER AT SCHOOL CUT

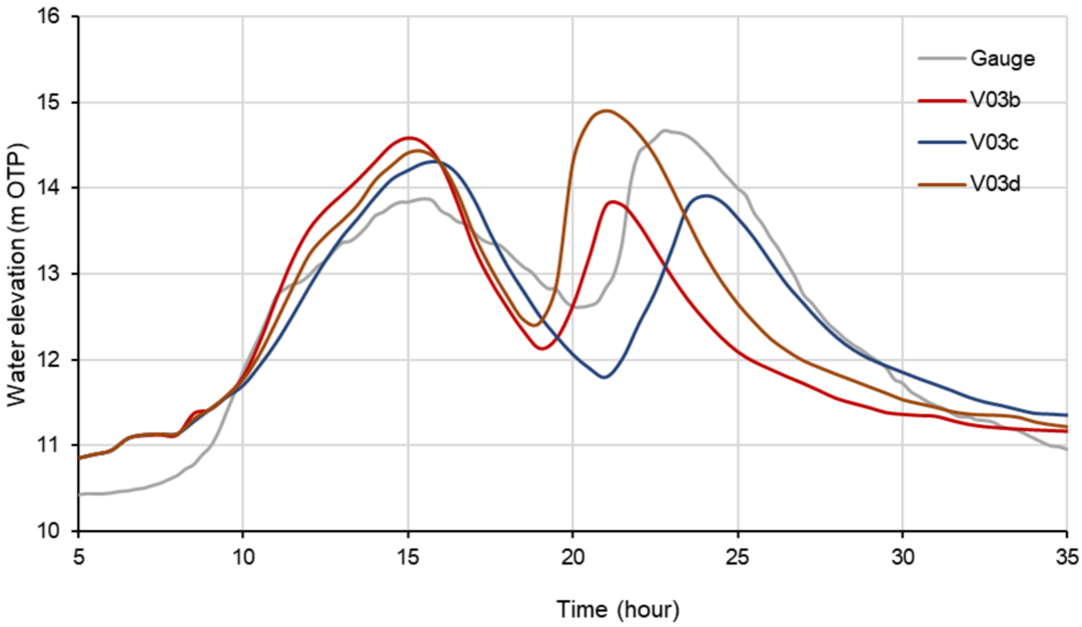


FIGURE 9-6 COMPARISON OF MODELLED AND GAUGED WATER LEVELS FOR TARAWHATAROA AT PURIRI PLACE

9.3 Antecedent condition

9.3.1 Pre-burst rainfall

THE HISTORICAL FLOOD EVENT USED FOR THE MAJORITY OF MODEL CALIBRATIONS WAS THE 28TH JANUARY, 2011 RAINFALL EVENT. THIS EVENT WAS PRECEDED BY A SIGNIFICANT RAINFALL EVENT ACROSS THE REGION AROUND A WEEK PRIOR TO THE MAJOR STORM EVENT.

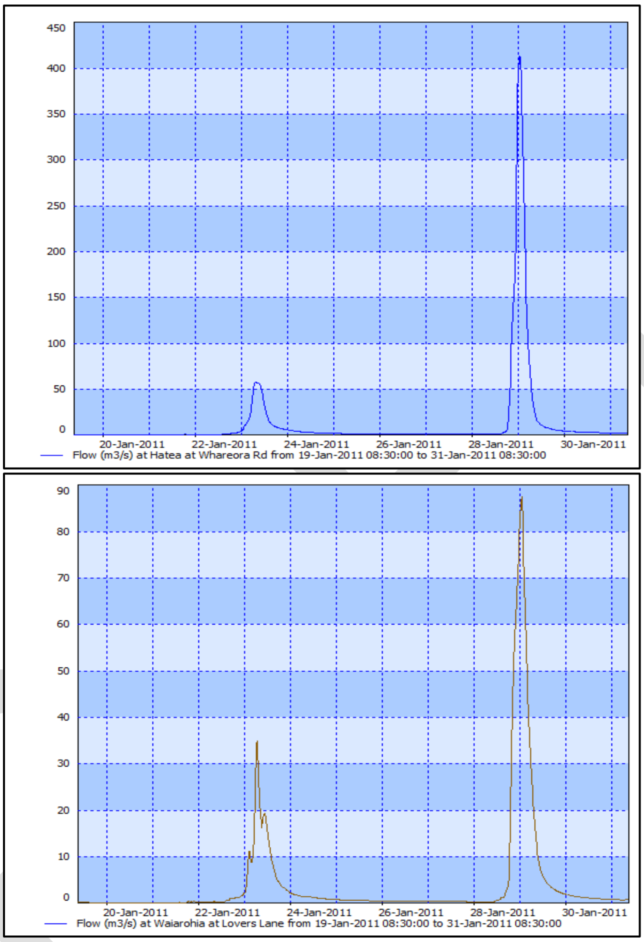


Figure 9-7 shows the rainfall hyetograph and the flow hydrographs within the Whangarei catchment dated from 19th to 31st January 2011 and To evaluate the impact on the antecedent conditions, a sensitivity test which included a pre-burst rainfall of 10 mm 5 hours prior the calibration event was undertaken. This allowed for a comparison of a 'wet' and 'dry' catchment as there is a reduction in available floodplain storage and soils are more saturated prior the major event.

Figure 9-8 and Figure 9-9 display the difference plots of the sensitivity runs with pre-burst rainfall. The impact on the modelled water levels found in Whangarei catchment is minor, with only several small spots showing changes in peak flood levels. The impact on the modelled water levels found in Kawakawa catchment is more noticeable. The increase in water levels ranges from 2 to 5 cm in most of the locations where changes were found and from 5 to 10cm in some locations in the upstream of the catchment. This impact on water levels is not considered significant in Kawakawa catchment.

Considering the impact on the increase in water levels will be likely much smaller for rare events (i.e. 1% AEP event), it is believed that the antecedent conditions and the appropriate hydrological processes have been taken into account during the phrase of model calibration by adjusting the loss parameters and developing a range of parameters through the calibration process to adopt in design modelling.

summarises the rainfall total of the flood event for three gauges within each of the three calibrated catchments.

The impact of the rainfall event in the preceding week may have the potential impact on the antecedent conditions of the catchment. The catchment is likely to still be saturated and incidental catchment storage (local depressions, wetlands and dams) might have not yet fully drained prior to the second event. When undertaking the calibration of the major event (i.e. 28th Jan), loss values in the model were tested to account for these antecedent conditions. The modelling results provided closely matched water levels at the streamflow gauge. These conditions also help identify a range of catchment antecedent conditions that can be used for design modelling noting that they are on the conservative side having lower loss values than a dry catchment.

The hydrographs below show the flows at the gauge locations from the first flood event have passed through the system and are back to baseline conditions prior the calibration event. This indicates that flows within the system were not likely to contribute to the second event and that some incidental storage within the catchment may have reduced capacity.

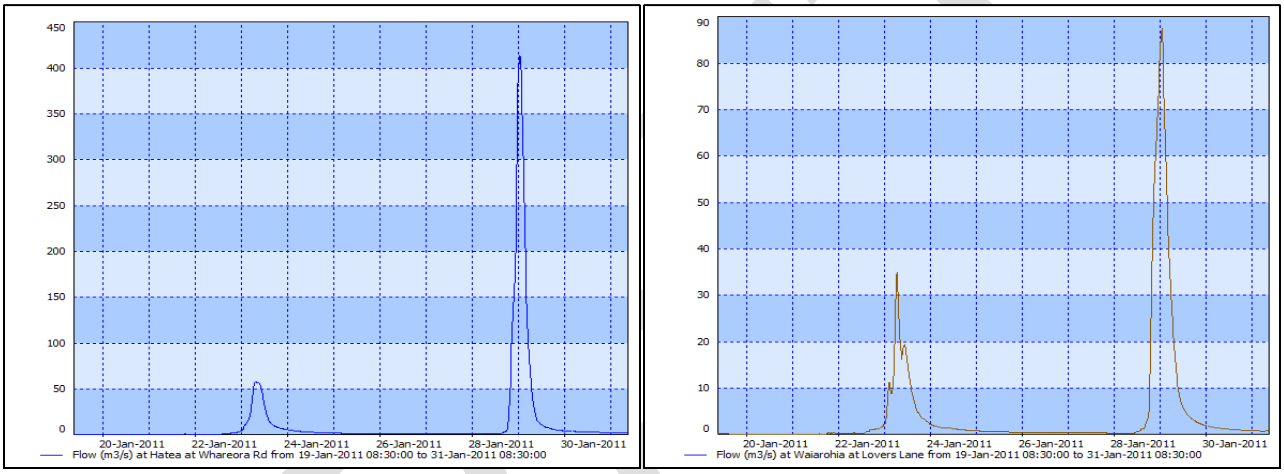


FIGURE 9-7 WHANGAREI CATCHMENT FLOW HYDROGRAPH FROM 19 TO 31 JANUARY 2011 LEFT: HATEA AT WHAREORA RD RIGHT: WAIAROHIA AT LOVERS LANE

TABLE 9-3 RAINFALL TOTAL FOR GAUGES IN THREE CALIBRATED CATCHMENTS

Catchment (rainfall gauge)	21st /23rd Jan 2011	28th/29th Jan 2011
Awanui (Te Rore)	105 mm	116 mm
Kawakawa (Okaroro Rd)	130 mm	217 mm
Whangarei Glenbervie (Forest HQ)	175 mm	257 mm

To evaluate the impact on the antecedent conditions, a sensitivity test which included a pre-burst rainfall of 10 mm 5 hours prior the calibration event was undertaken. This allowed for a comparison of a 'wet' and 'dry' catchment as there is a reduction in available floodplain storage and soils are more saturated prior the major event.

Figure 9-8 and Figure 9-9 display the difference plots of the sensitivity runs with pre-burst rainfall. The impact on the modelled water levels found in Whangarei catchment is minor, with only several small spots showing changes in peak flood levels. The impact on the modelled water levels found in Kawakawa catchment is more noticeable. The increase in water levels ranges from 2 to 5 cm in most of the locations where changes were found and from 5 to 10cm in some locations in the upstream of the catchment. This impact on water levels is not considered significant in Kawakawa catchment.

Considering the impact on the increase in water levels will be likely much smaller for rare events (i.e. 1% AEP event), it is believed that the antecedent conditions and the appropriate hydrological processes have been taken into account during the phrase of model calibration by adjusting the loss parameters and developing a range of parameters through the calibration process to adopt in design modelling.

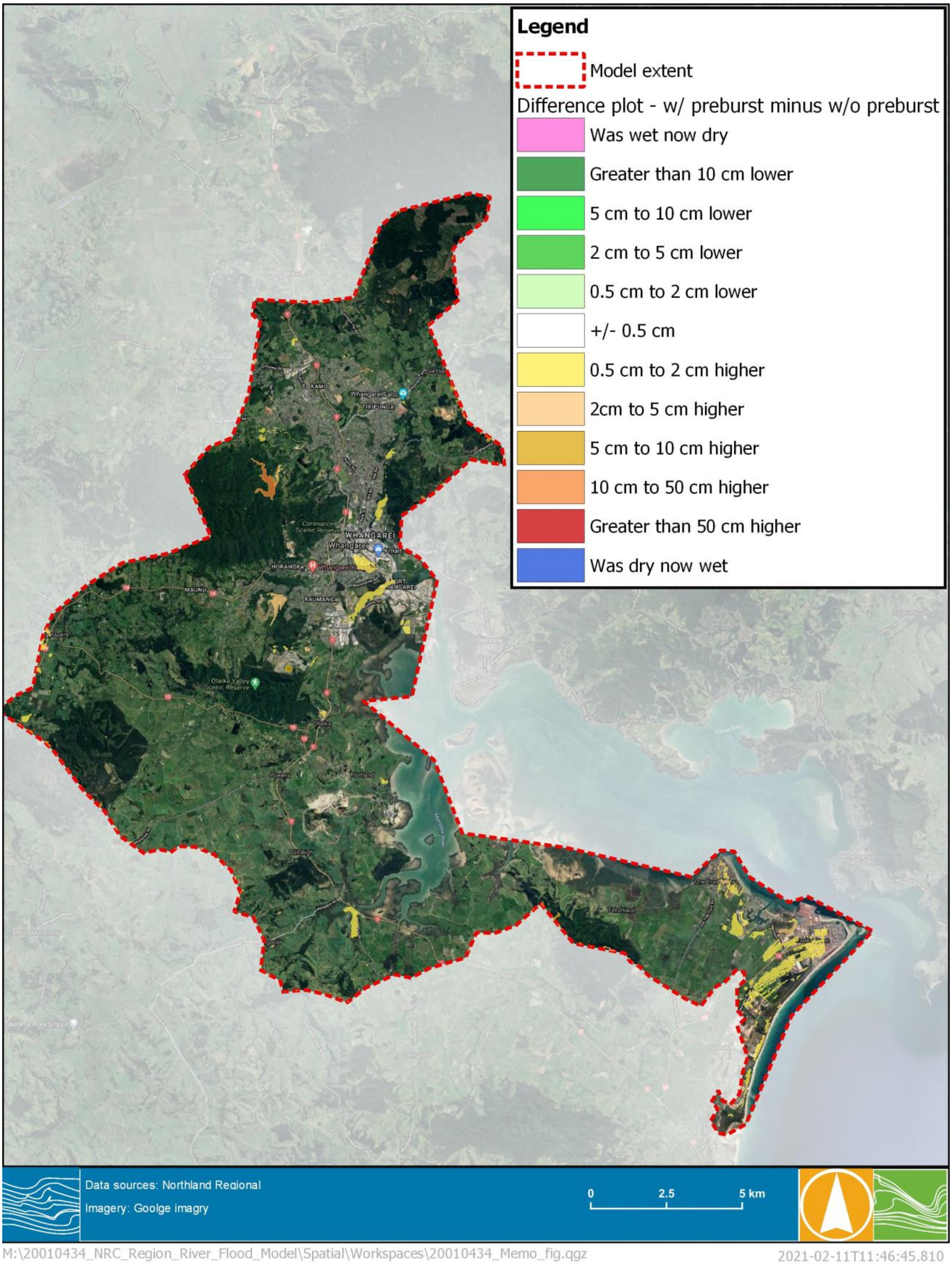


FIGURE 9-8 DIFFERENCE PLOT OF PREBURST SENSITIVITY TEST IN WHANGAREI CATCHMENT

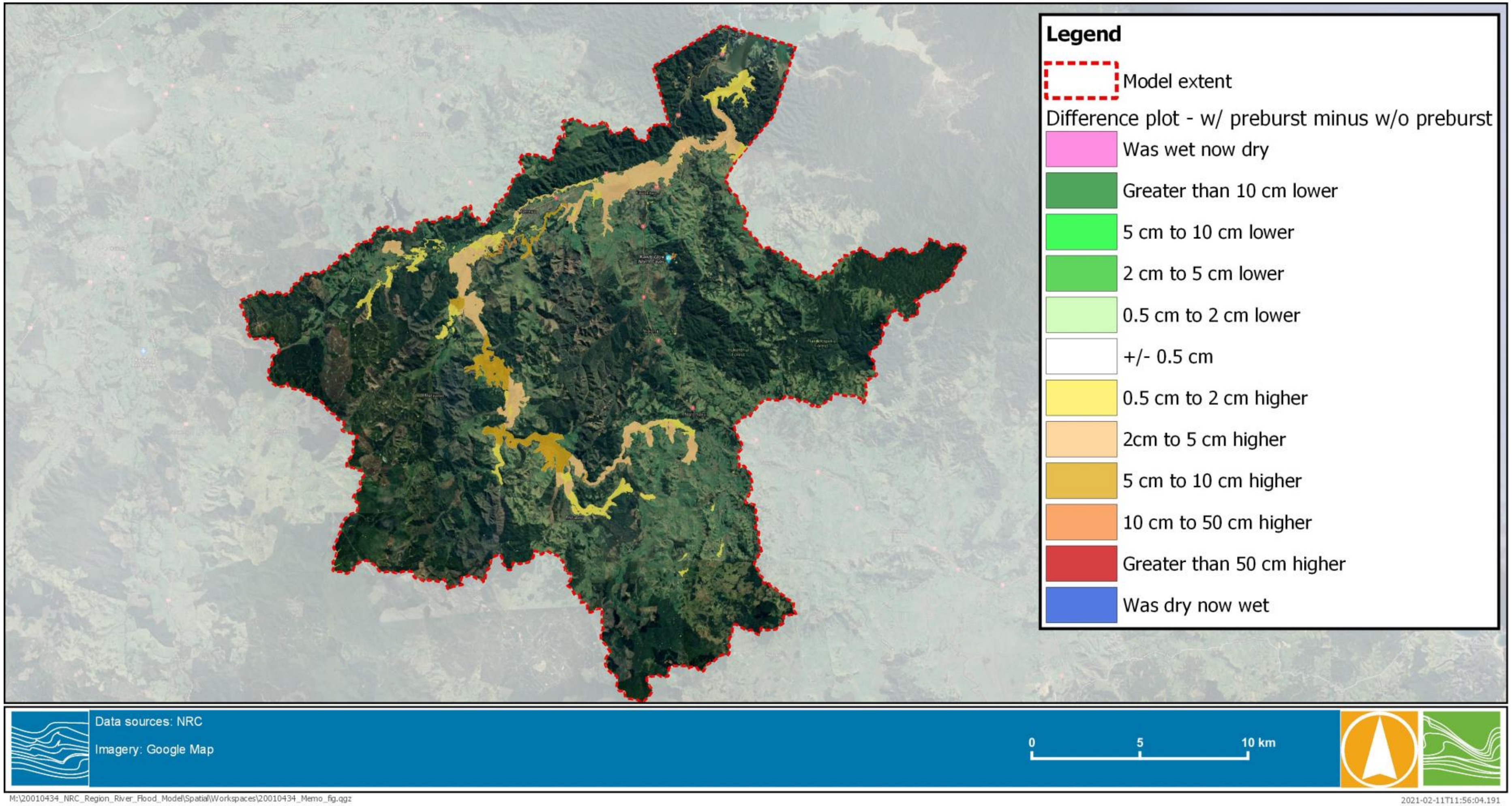


FIGURE 9-9 DIFFERENCE PLOT OF PREBURST SENSITIVITY TEST IN KAWAKAWA CATCHMENT

9.3.2 Inclusion of preceding rainfall event

Additional calibration runs with the inclusion of preceding rainfall on 21st January 2011 were conducted in the Kaeo catchment (M06) and the Bay of Island Coast catchment (M07). Further details of these catchments can be found within each catchment's validation report.

These catchment models were initially calibrated using only the 28th to 29th January rainfall event. Additional models were run for the inclusion of the preceding rainfall event on the 21st January and the modelled gauge water level and flow results shown in Figure 9-10 to Figure 9-12 to assess if they were likely to impact on peak calibration levels and timing of the main calibration event. The results indicate the inclusion of the preceding rainfall event has negligible impact on the second rainfall event in terms of timing of peak, flow volume and water levels. As a result, it can be confirmed that the inclusion of the preceding rainfall event in the calibration modelling is unlikely to affect the calibration performance. For the remaining catchment models, the preceding rainfall event (21st – 23rd January) was excluded from the calibration.

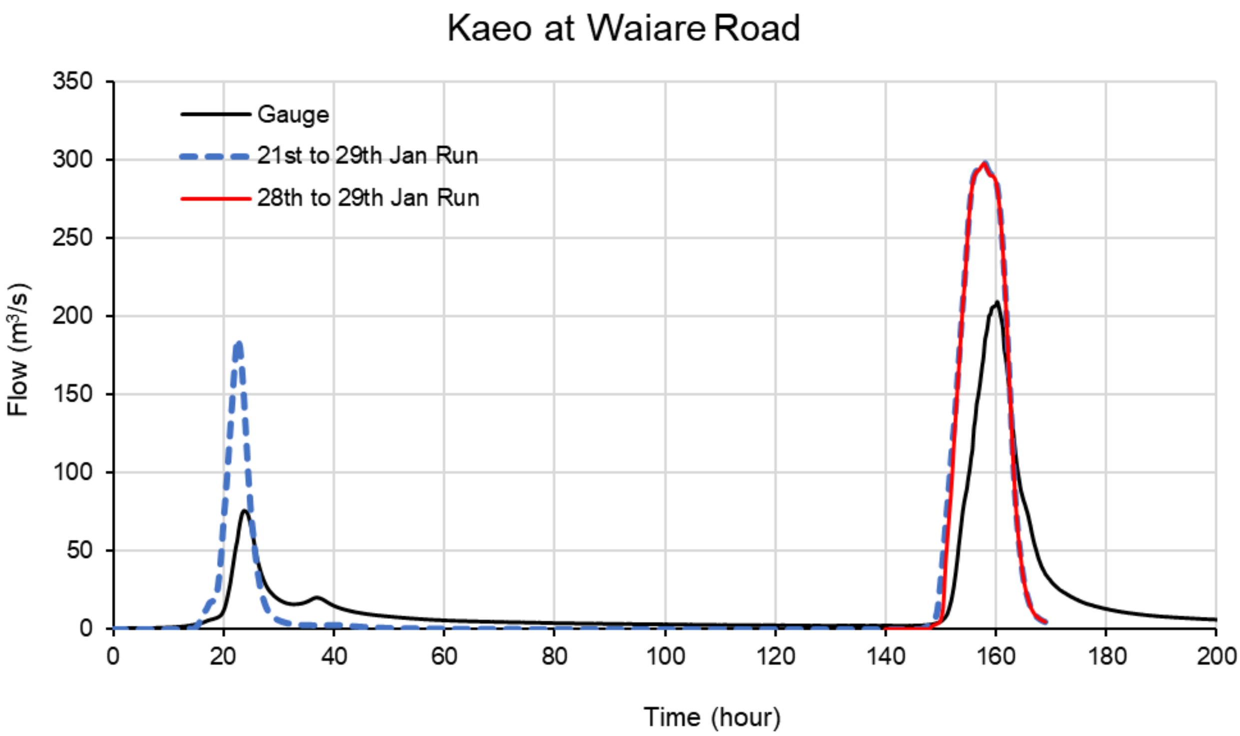


FIGURE 9-10 MODELLED FLOW HYDROGRAPHS FROM 21ST TO 29TH JANUARY RAINFALL– M06

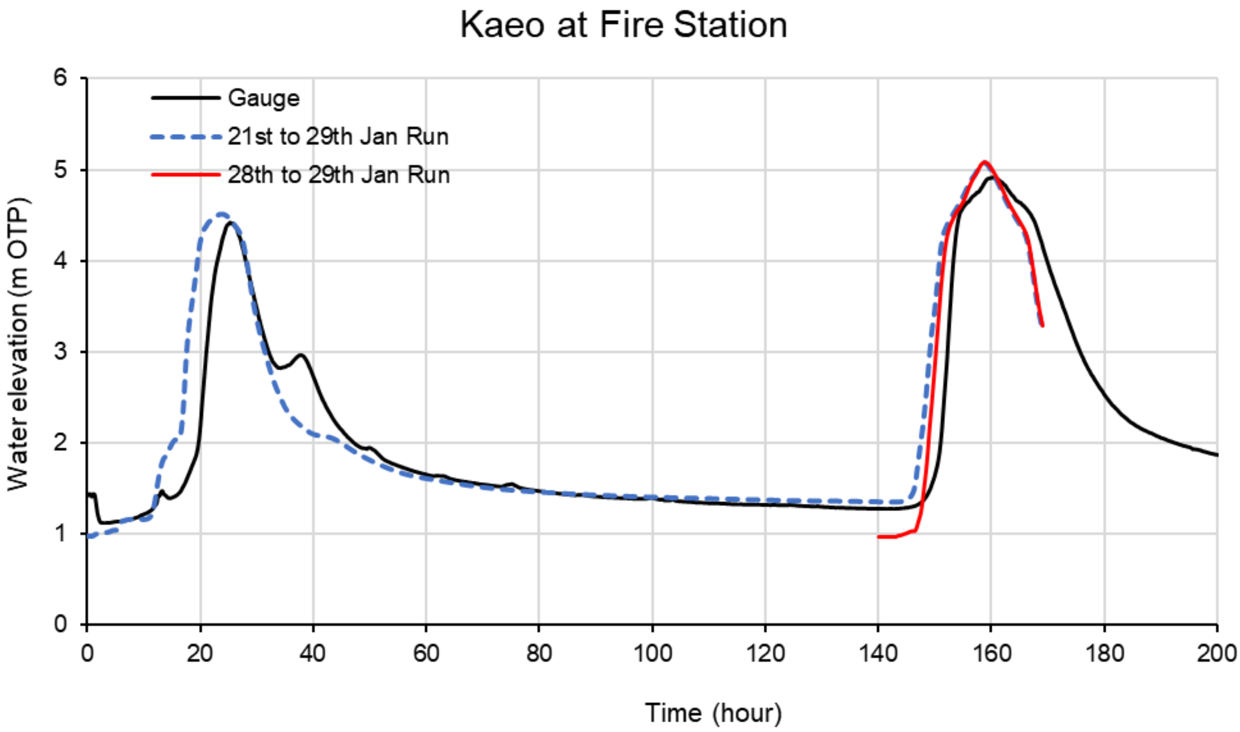


FIGURE 9-11 MODELLED WATER LEVEL HYDROGRAPHS FROM 21ST TO 29TH JANUARY RAINFALL – M06

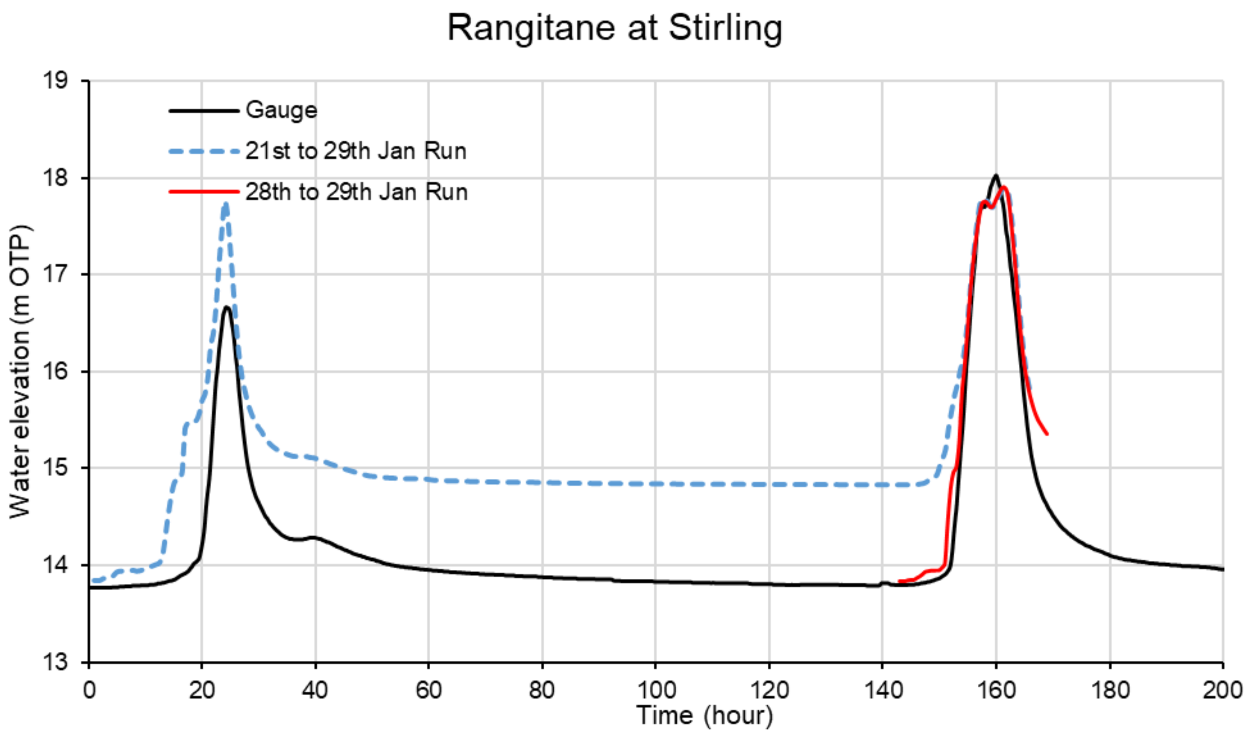


FIGURE 9-12 MODELLED WATER LEVEL HYDROGRAPHS FROM 21ST TO 29TH JANUARY RAINFALL – M07

10 MODEL REVIEW

10.1 Model Review

An independent peer review of the hydraulic modelling was undertaken by Beca. This technical peer review focused on the review of the Kawakawa (Model 15) and the Whangarei (Model 01) catchment models and calibration reporting. It also assessed whether the modelling approach is fit for purpose and the model calibration performance is acceptable. This section will discuss issues identified in the peer review and summarise the response to these comments and how they were incorporated into the remaining calibration and design modelling. The full details of the comments made by Beca in the peer review and responses from Water Technology are included in the Appendix B.

10.2 Calibration Discussion

- ***The hydraulic models are 2D only***

Given the purpose and scale of this project, 1D structures (i.e. pipes, channels etc.) were not included as part of the scope of the project to ensure the large study area could be modelled with reasonable simulation times. The use of Sub-Grid Sampling from an underlying 1m LiDAR dataset provides a good representation of channel capacity. It is also noted that in high flow events as there is generally a higher portion of flow across the floodplain than within the channel itself.

Several hydraulic structures identified across the study area were found to have significant impacts on the calibration results or flood behaviour and were included in the model as 1D components. A large outlet culvert structure was added at the Kotuku Dam as a 1D component to allow flood water from the upstream flow through the dam.

- ***The impact of the preceding event a week earlier before the major event used for model calibration***

The impact of the rainfall event in the preceding week was found to not have impact on the antecedent conditions. When undertaking the calibration for this event, suitable loss values were used to account for this and provided closely match modelled water levels at the streamflow gauges. This helps identify a range of catchment antecedent conditions that can be used for design modelling.

A sensitivity test for the catchment models which modelled pre-burst rainfall shows only minor impacts are likely on the modelling results. This is also discussed further in Section 9.3

- ***Model health and difficulty in Rain-on-Grid modelling of steep catchments***

Adaptive timestepping was applied for all the catchment models as the TUFLOW HPC scheme was used in the modelling. A model health check was undertaken for each model by investigating the variation of the "dt" values along with several other health check were undertaken over the simulation time to ensure model stability. Steep catchments have previously presented instability issues when using rain-on-grid within TUFLOW Classic. TUFLOW HPC (which is adopted for this study) is inherently more stable due to being an explicit finite solver.

- ***Model calibration performance and existing gauged rating curves***

During the model calibration, a large discrepancy between the modelled and gauged rating curves was identified at high flows. The reliability of the existing gauge rating's appears uncertain given several gauge rating curves were found only account for in-channel low flows and do not appear reliable at high flows when the broader floodplain is engaged. This results in difficulty of calibrating the model to the gauged flow hydrographs and matching flow volumes during the calibration event. Instead of trying to meet all the desired calibration criteria as required by NRC due to the uncertainty of the ratings, the model calibration focused on matching the gauged water levels. Discussions with NRC, Water Technology and BECA were held regarding this topic and the modelling appears fit for purpose as agreed by NRC.

The development of a model-based rating curve with further feature survey of each site may provide more information on the rating curves at high flows when compared with extrapolation of small in-channel gauging.

11 CALIBRATION SUMMARY

At the time of the initial submission of this draft report, five catchment models have been modelled for historic flood events for the purposes of developing calibration parameters. Currently, this has included calibration to 19 gauges, of which are showing reasonably good fits to the recorded water levels. Uncertainty in the rating curves at high flows is likely leading to a discrepancy between modelled and recorded peak flows and flow volume estimates. A review of rating curves is outside the scope of this report, however significant work has been undertaken to date which may assist in further analysing or validating existing streamflow rating curves. For the purposes of this study, it is recommended that the remaining five catchments that will undergo calibration/validation utilise recorded water levels and place less emphasis upon the recorded streamflows due to the uncertainty in the rating curves at high flows.

The Awanui Catchment model has assessed two historic flood events that have shown a reasonable fit to the two streamflow gauges for both the 2011 and 2020 flood event. Due to the uncertainty of the rating curve and river channel geometry, the modelled flows at two streamflow gauges are lower than the recorded flows. However, modelled water levels have been calibrated well to both gauges in both events.

The Kawakawa Catchment model assessed the January 2011 flood event and has shown a good fit to the two streamflow gauges in terms of shape and peaks. Although the modelled peak at Willowbank gauge occurred much earlier than that recorded, the overall calibration at this gauge has been improved compared to the previous study calibration (URS 2012)[7].

The Whangarei Catchment model assessed the January 2011 event and was able to show a reasonable fit to the four streamflow gauges in terms of shape, timing and peak water levels. There was difficulty of calibrating the modelled flow to the gauged records (likely due to rating curve uncertainty) as discussed earlier.

The Catchment 13 model has shown a reasonable fit to recorded water levels at four streamflow gauges for the January 2011 flood event. There was uncertainty of two gauge locations, both within steep sections of the waterway which has resulted in difficulty of calibrating the modelled flow to the gauged records.

The Catchment 14 model assessed the January 2011 event and showed a reasonable fit to the seven streamflow gauges in terms of timing, shape and peak water levels. The model does not calibrate well to the peak flows and flow volume due to uncertainty in the reliability of the gauged rating curves.

Results of the calibration of the remaining models as well as the validation to design flow estimates is included within each catchment models relevant validation report.

Currently the model results appear to be providing a suitable and fit-for purpose representation of flooding behaviour (good fit to water levels) within the catchments. A key assessment of the flood behaviour including catchment response, hydrograph shapes and assessment of modelled flood levels to surveyed flood levels also shows the modelling is providing suitable results. It is accepted that while additional time could be spent ensuring the calibration comparisons provide a closer match, the current modelling approach appears adequate to meet the purposes of the flood study.

12 DESIGN MODELLING

12.1 Overview

Once the design model parameters are confirmed and approved following the peer review, further calibration of another five catchments and the design modelling of all 19 catchment models across the study area (including the above catchments) will be undertaken. A range of storm durations will be run and results for each AEP event will be 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.

12.2 Model Parameters

Through the calibration/validation phase of the project a range of model parameters have and will be used to provide suitable verification of the catchment models to the historic flood levels. These parameters will form a range that will be used to select design parameters within the final modelling. Details of these are outlined below.

12.2.1 Rainfall Intensity-Depth-Frequency

Design rainfall totals for durations for durations from 10 minute up to 120 hours have been developed for design modelling purposes. This has been undertaken at 179 rainfall gauge sites across the study area. These Intensity-Depth-Frequency (IDF) tables have been developed by NIWA through the High Intensity Rainfall Design System (HIRDSV4). A range of magnitude events from 1 in 1.58 ARI through to 1 in 250 ARI along with climate change predictions (RCP 4.6, 6 & 8.5) up to 2100. Where applicable, multiple rainfall gauges will be used within each model area, with a spatially weighted grid of rainfall totals used in a similar manner outlined earlier in the calibration section.

12.2.2 Design Rainfall Temporal Patterns

Design temporal patterns (rainfall hyetographs) have been provided by NRC for the purposes of design modelling. These have been developed as part of a previous project undertaken by Macky & Shamseldin (2020)[8]. The project was aimed to provide multiple design hyetographs to provide a better representation of rainfall variability across the Northland Region, replacing the single set of design hyetographs previously developed.

"This project is intended to address part of this concern, the temporal rainfall pattern (the shape of the hyetograph) and identify the most suitable design hyetograph shapes for flood modelling."

The design temporal patterns for the gauges developed will be used to provide accurate variability across the study area in conjunction with the Rainfall IDF data.

12.2.3 Losses

Based on the first three model areas used in the calibration/validation process, a series of land use types and importantly hydrological areas have been assigned a range of values to represent Mannings "*n*" (surface roughness), initial loss and continuing losses. These ranges will form the basis for the next stage of calibration and ultimately the parameters used in the design modelling.

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

TABLE 12-1 DRAFT DESIGN PARAMETER THRESHOLD

Hydrological areas	Land use types	Manning's n	Initial loss (IL) - mm	Continuing loss (CL) – mm/hr
Heavy Soil Types	Forest	0.1 – 0.2	15 - 25	1 - 3
	Grassland	0.06 – 0.16	15 – 25	1 – 3
	Wetland – open water	**0.04**	**0**	**0**
Loam Soil Types	Forest	0.1 – 0.2	25 - 40	4 - 7.5
	Grassland	0.08 – 0.15	25 - 40	3 - 7.5
Pumice/Sandy Soil Types	Forest	0.1 – 0.2	30 - 45	5 - 10
	Grassland	0.08 – 0.15	30 -45	5 - 10
Base catchment conditions	Cropland	0.04 – 0.06	20 – 30	2 - 4
	Wetland – open water	0.04 – 0.06	0	0
	Wetland – vegetated	0.05 - 0.1	5 - 10	0.5 – 2
	Urban areas	0.10	5	1.5
	Waterways	0.05 - 0.1	0	0

12.2.4 Boundaries

Where boundary level information is available (i.e., ocean outfalls), tailwater boundaries will be applied either using a constant HT (set water level) or a tidal boundary. Outside of these areas, a stage-discharge (i.e. type HQ) outflow boundary based on the catchment slope will be applied (as per the calibration models). Sensitivity of these tailwater boundaries including climate change modelling will be undertaken.

13 VERIFICATION OF DESIGN FLOWS

The flow lines at gauge locations and other key locations of interest will be added in the hydraulic model before running the models for design events. This will allow peak flows to be extracted at these locations. The modelled peak flow for the 1% AEP design flood will be compared with hydrological estimates including FFA, rational method etc.

13.1 Flood Frequency Analysis

A Flood Frequency Analysis (FFA) was undertaken for streamflow gauging stations with at least 25 years of streamflow records. The length of records can affect the reliability of the FFA especially for the estimation of major flood events (e.g. 1% AEP). Table 2-1 shows the streamflow gauging stations that were highlighted for FFA and the corresponding 1% AEP flow estimates. These design flow estimates will provide verification against the design hydraulic modelling results in later stage of the project.

The annual series (maximum streamflow values for each year of gauge record) of selected streamflow gauging stations 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 was chosen to fit streamflow records and the FFA results have shown that this probability distribution has a relatively good fit in all the stations that selected.

Table 13-1 shows the annual maximum streamflow values for the Awanui at School Cut streamflow gauging station and an example of the flood frequency curve of Log Pearson III is displayed in Figure 13-1. The Awanui at School Cut streamflow gauging station has almost 62 years of streamflow records. 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 it seems to slightly overestimate the design flows for rare events (e.g. 1% AEP flow). This is understandable when considering the length of records and the limited number of extreme flow values observed at this station. Overall, the design curve shows a good fit with the tight confidence intervals indicating low uncertainty within these estimates.

TABLE 13-1 ANNUAL MAXIMUM STREAMFLOW VALUES IN AWANUI AT SCHOOL CUT STATION

Year	Flow rate (m^3/s)	Year	Flow rate (m^3/s)	Year	Flow rate (m^3/s)
1958	221.42	1979	202.73	2000	206.32
1959	111.14	1980	198.65	2001	248.93
1960	145.85	1981	132.51	2002	257.38
1961	138.86	1982	78.31	2003	268.26
1962	148.13	1983	57.60	2004	256.56
1963	99.33	1984	104.60	2005	147.34
1964	176.68	1985	111.80	2006	136.49
1965	159.29	1986	151.96	2007	257.85
1966	136.56	1987	84.21	2008	147.41
1967	182.33	1988	160.94	2009	93.66
1968	197.22	1989	198.83	2010	98.99
1969	193.72	1990	74.78	2011	203.83
1970	26.98	1991	116.87	2012	129.93
1971	185.79	1992	155.53	2013	91.45
1972	101.70	1993	78.21	2014	127.87
1973	144.59	1994	80.77	2015	87.75

Year	Flow rate (m^3/s)	Year	Flow rate (m^3/s)	Year	Flow rate (m^3/s)
1974	71.72	1995	173.04	2016	126.40
1975	114.74	1996	144.71	2017	160.48
1976	213.99	1997	215.22	2018	109.15
1977	130.48	1998	200.99	2019	62.11
1978	74.36	1999	168.41	2020 (until August)	224.10

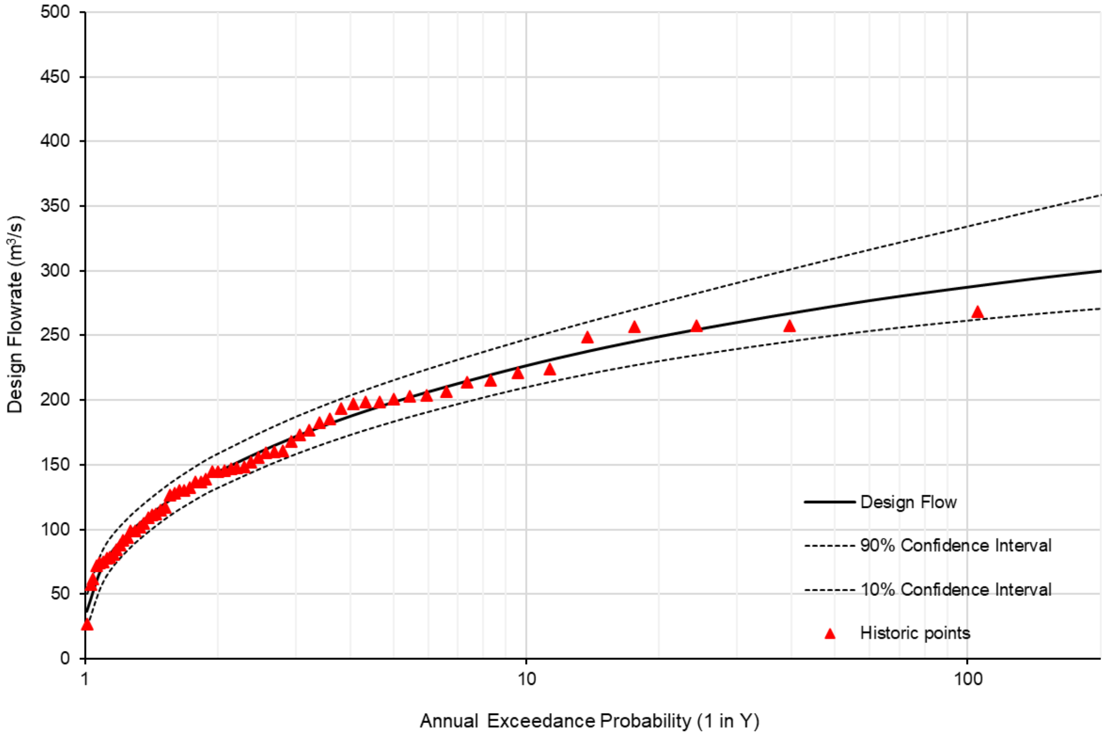


FIGURE 13-1 EXAMPLE OF FLOOD FREQUENCY CURVE OF LOG PEARSON III - AWANUI AT SCHOOL CUT STREAMFLOW GAUGING STATION

13.2 Regional Estimation Methods

For catchments where a suitable streamflow gauge record, additional estimation methods based on empirical estimations using catchment area and design rainfall totals can be used to verify design flows. These methods will be checked for each catchment outlet or streamflow gauge location.

These include

13.2.1 Mean Annual Flow Method (North Island)

$Q100 = 2.2 \times 10^{-8} \times A^{0.88} \times P^{2.57} \times HI_{4\text{-}5}{}^{0.14} \times HI_{6\text{-}8}{}^{-0.25} \times z^{-0.19}$

- where A is the catchment area (km^2),
- P is the FWENZ-based mean annual precipitation (mm),
- HI4-5 is the catchment fraction associated with Hutchinson's hydrological indices 4-5 (Hutchinson 1990),

- HI6-8 is the catchment fraction associated with Hutchinson's hydrological indices 6-8 and;
- z is mean catchment elevation (m).

13.2.2 SCS method

The SCS method calculates peak flood flow based on rainfall and land-cover-related parameters. 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:

$S = (1000/CN – 10)\ 25.4.$

This can then be applied to catchment size

13.2.3 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 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.

14 NEXT STEPS

14.1 Remaining Calibration

An additional five catchments distributed throughout the study area have since been be calibrated to a single historic flood event since the submission of the initial draft report. This was undertaken to establish suitable model parameters for the design modelling. Several of these catchments have modelled a smaller magnitude event than those that have currently been modelled (2007 and 2011 are considered large flood events) to ensure the range of the design parameters outlined fit well to a smaller flood event.

14.2 Climate Change

Climate change modelling will be undertaken for an additional 1% AEP climate change projections for rainfall intensity and sea level rise. The IDF tables developed by NIWA through the High Intensity Rainfall Design System include climate change projections for RCP 4.6, 6 and 8.5 and up to 2100. For this study, a 1% AEP climate change scenario will be modelled for the 2081 – 2100 timeframe, for RCP8.5. For catchments that have coastal downstream boundaries, a sea level rise of 1.2m will be included in the climate change runs.

14.3 Design Validation Reporting

A validation report for each of the catchment model will be generated and this includes a total of 19 validation reports. Each validation report will provide a summary of the design modelling parameters (i.e. rainfall IFD, losses etc.), design modelling results/output processing followed by the verification of the modelled design flows at streamflow gauge or outlet (if no gauge available) locations. For catchment models that were calibrated but not included in this calibration report, a short summary of the calibration results would be presented.

14.4 Final Reporting

A final summary report will be provided to summarise the data, hydrology and hydraulic calibration method, design modelling, outputs conclusions and recommendations of the study.

14.5 Deliverables

List the mapping reporting and GIS/model deliverables. I've included an example below:

The model result data, including grids and extents, have been provided for each flood event. The following result components were generated:

- Flood level, flood depth, flood velocity and flood hazard grids
- Flood elevation contours
- Flood extent data
- Hydrographs at key locations

Grids and shapefiles (ESRI/VFD format), and Data tables (Excel csv/xlsx format) will be made available upon completion of the study.

14.5.1 Data Sets

The following datasets were provided as final deliverables to NRC.

Grids

Gridded datasets of model results were provided for the following:

- Design events (50%, 20% 10%, 5%, 2%, 1%, 0.5%, 0.2% and 0.1%) – maximum depth, velocity, velocity x depth, Flood Hazard
- Calibration events (2007, 2011 and 2020 events) – maximum depth velocity, velocity x depth, and water surface elevation.
- Model Topography

The hydraulic analysis provides regular grids of flood elevations across the hydraulic model study area. The flood extent was defined by converting the 2.5 m grid flood elevations to an extent polygon. The extent was smoothed to remove the sharp edges of the grid cells for cartographic / presentation purposes. For the requirement of NRC, a version of flood extent was created that only contain the riverine flooding.

Flood depths were classified for mapping using the following classifications:

- 0 m to 0.20 m
- 0.20 m to 0.30 m
- 0.30 m to 0.50 m
- 0.50 m to 1.00 m
- 1.00 m to 2.00 m
- Greater than 2.00 m

Vector Data

ERSI shapefiles in to be provided for the following:

- Peak flood extents
- Peak flood elevation contours
- Mapping limits
- Study Area Extent

Maps

The flood maps will be produced for the following design flood events:

- 1% AEP event
- 2% AEP event
- 10% AEP event
- 1% AEP event with Climate Change

Each map includes:

- Flood extent,
- Flood level,
- Depth of inundation,
- Hazard,
- Velocity

Copies of the maps were provided in PDF format.

15 SUMMARY

The initial calibration process has shown the rain-on-grid TUFLOW model with an initial and continuing loss model is suitable to replicate large flood events such as the 2011 event across four catchments and the 2020 event for Awanui catchment. The calibration and validation process has relied heavily on the use of gauged data, with a larger reliance upon streamflow levels due to inherent uncertainty of streamflow rating curves in large flood events. Following a review of the five catchments which have undertaken calibration, an additional four catchments have been calibrated and 10 further catchments have undergone design modelling.

APPENDIX A
JANUARY 2011 CALIBRATINO AND JULY 2007 VALIDATION FOR AWANUI CATCHMENT

Model parameters

The January 2011 event was firstly used for the Awanui model calibration until it was informed that the channel upgrade works were completed in 2016 and 2019. The calibration results shown below did not revert the topography at Whangatane spillway intake and Matthews Park back to the conditions prior 2016.

The available rainfall records in this event are summarised in Table 15-1 and Figure 15-1 displays their locations. The January 2011 flood event saw around 130 mm of rainfall across the catchment. A significant burst of 70 mm fell in 4 hours during the event seeing a relatively fast catchment response. In the lead up to the storm event, the catchment conditions could be considered highly saturated with a significant rainfall event (115mm) falling in the week leading up to the event. The water level at the streamflow gauges downstream started to rise in 10 hours after the rainfall started falling.

TABLE 15-1 RAINFALL STATION DETAILS FOR JANUARY 2011 EVENT

Station name	Site ID	Source	Rainfall total in 28th Jan 2011(mm)	Data type
Kaitaia Aero Ews	A53026	NIWA	126.6	Hourly
Kaitaia Observatory	A53125	NIWA	136.9	Hourly
Kaitaia	A53121	NIWA	132.5	Daily
Takahue at Te Rore	531313	NRC	116.5	5-min
Te Puhi at Mangakawakawa	531415	NRC	139.5	5-min

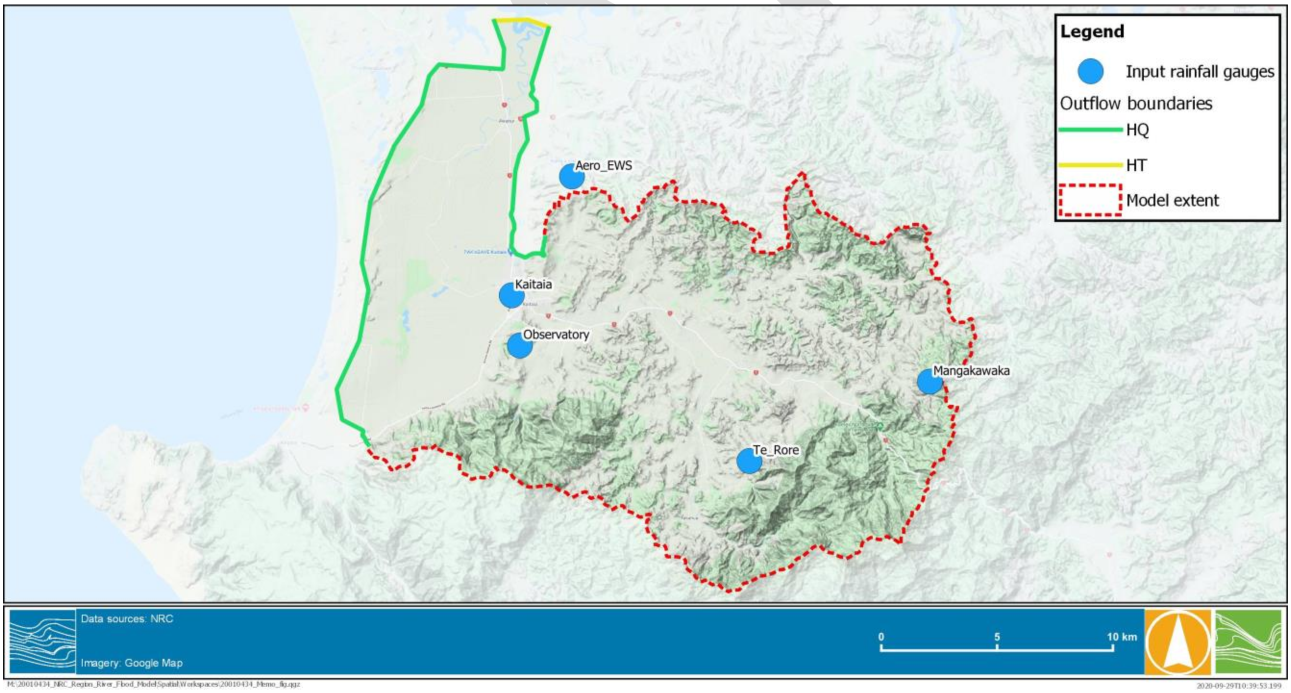


FIGURE 15-1 AVAILABLE RAINFALL GAUGE LOCATIONS FOR JANUARY 2011 EVENT

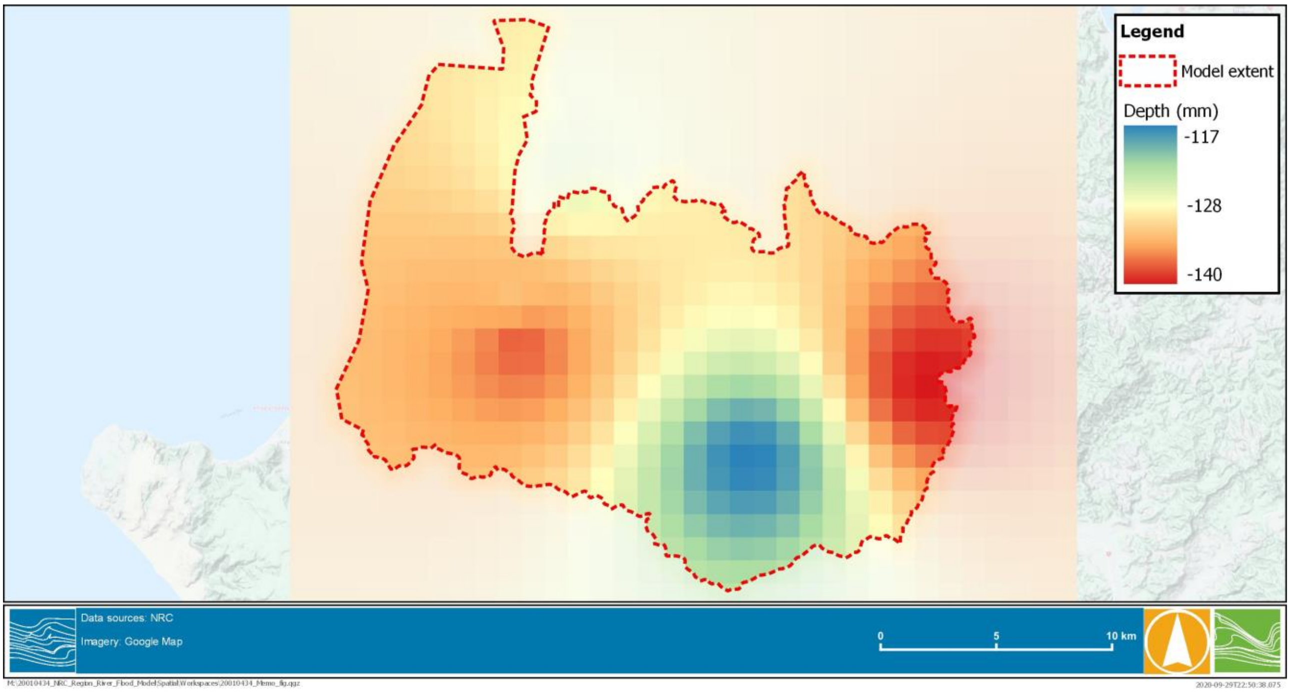


FIGURE 15-2 INTERPOLATED RAINFALL DEPTHS FOR JANUARY 2011 EVENT – AWANUI CATCHMENT

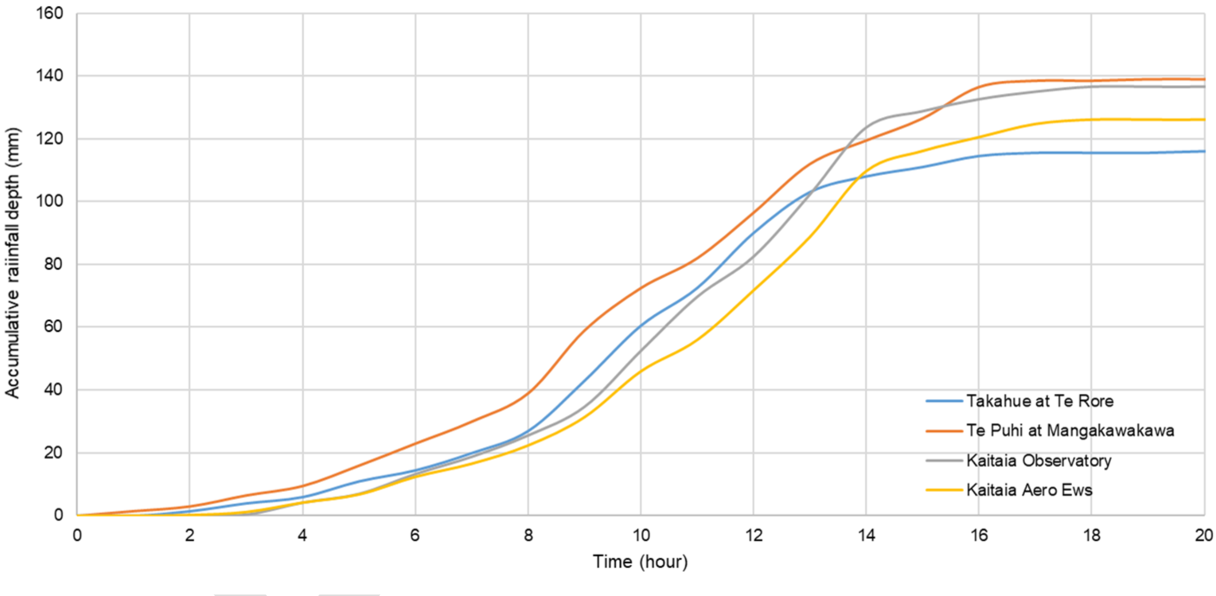


FIGURE 15-3 TEMPORAL PATTERNS OF RAINFALL IN JANUARY 2011 EVENT

The calibrated model parameters are summarised in Table 15-2.

TABLE 15-2 CALIBRATED HYDRAULIC ROUGHNESS AND RAINFALL LOSSES VALUES FOR JANUARY 2011 EVENT

Hydrological areas	Land use types	Manning's n	Initial loss (IL) - mm	Continuing loss (CL) – mm/hr
Tarawhataroa	Forest	0.10	55	10
	Grassland	0.05	55	10
Te Puhi	Forest	0.10	25	4
	Grassland	0.05	25	4
Te Rore and other areas	Forest	0.10	40	6
	Grassland	0.05	40	6
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	0.07	0	0
	Other	0.06	15	1.5

Calibration results

Table 15-3 summarises the peak values between the observed and the modelled values and Figure 15-4 to Figure 15-7 show the modelled flow and water level compared to the gauge records.

The modelled peak flow slightly overestimated the observed values at the Awanui River at School Cut station by 2% and Tarawhataroa River at Purri Place by 8%. The modelled flood levels are also higher (1.13m and 0.55m) in the hydraulic model. The modelled peak at School Cut streamflow gauge occurs 3 hours earlier than the observed peaks. Overall, the modelled results show a good match to the gauged hydrograph and water level. Following a review of the previous flood modelling reports on the catchment and discussions with NRC staff, it is understood that the flow balance between the two gauges at Kaitaia is sensitive to the flow balance as flows overtop South Road.

The gauged hydrograph for Tarawhataroa River at Puriri Place has two distinctive peaks during the 2011 event. It was found that the first peak was driven by the upstream Tarawhataroa River catchment and the second peak was driven by flood water breaking out from Awanui River and overtopping South Road. In the first peak, the modelled peak flow and water level are slightly higher than the observed peaks (+3m^3/s and +0.55m respectively). The differences in the second peak are to the first peak (+4m^3/s and +0.23m). The timing of the first peak is slightly earlier (30 minutes) than that observed while the second peak was 1.75 hours earlier than that observed. Overall, the modelled results show a good match to the gauged records in terms of the shape, timing and the peaks.

TABLE 15-3 SUMMARY OF CALIBRATION RESULTS FOR AWANUI CATCHMENT

	Peak flow (m3/s)			Time to peak diff. (hour)	Volume (ML)			Peak WSE (m OTP)		
Location	modelled	gauged	Diff.		modelled	gauged	Diff.	modelled	Gagued	Diff. (mm)
Puriri Place	65	61	6.50%	-1.75	1589	2551	-37.71%	14.90	14.67	235.50
School Cut	209	204	2.38%	-3.00	10625	15116	-29.71%	16.09	14.96	1130

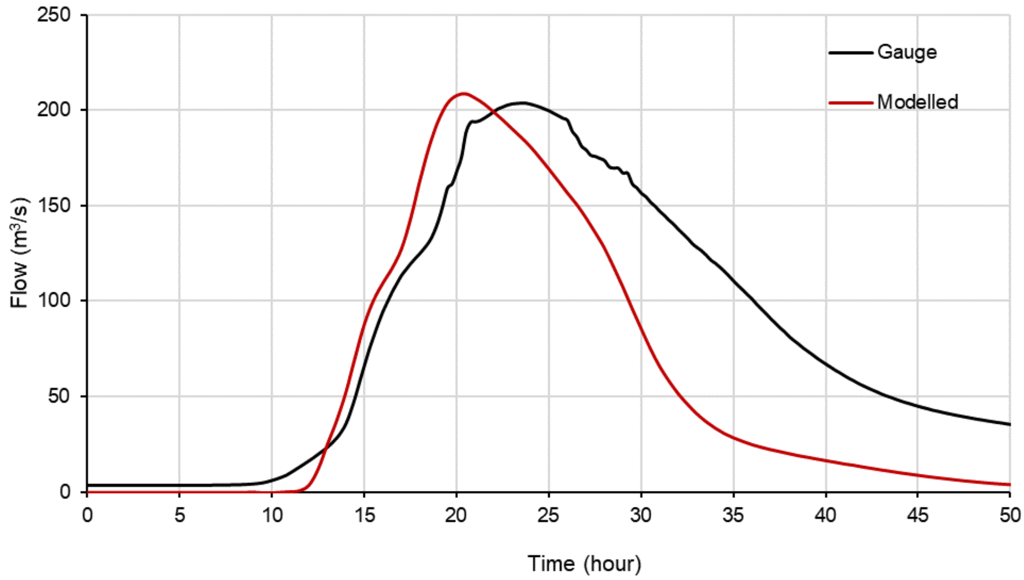


FIGURE 15-4 MODELLED AND GAUGED FLOWS AT AWANUI RIVER AT SCHOOL CUT – 2011 FLOOD EVENT

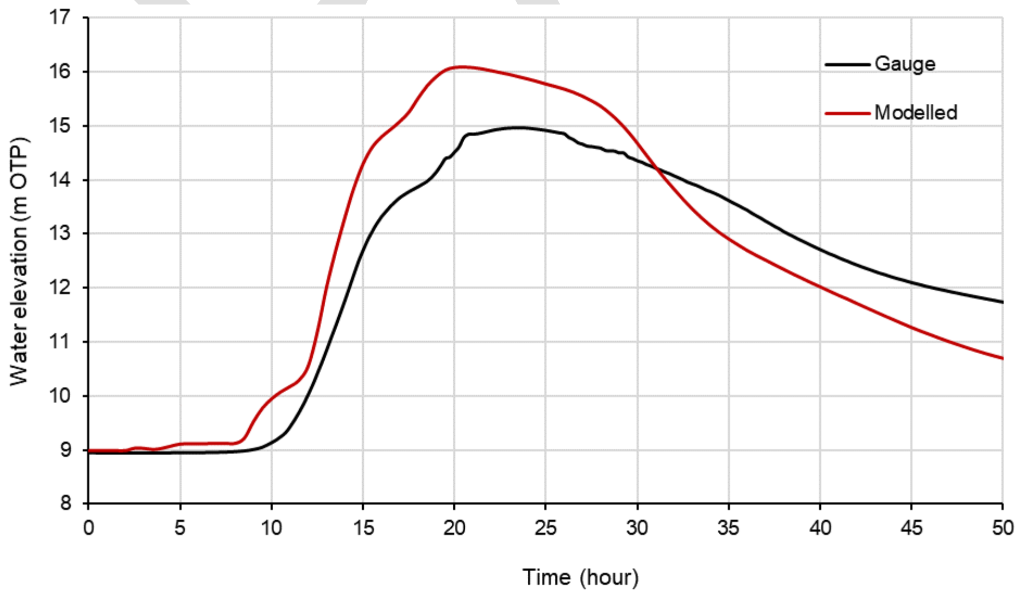


FIGURE 15-5 MODELLED AND GAUGED WATER LEVELS AT AWANUI RIVER AT SCHOOL CUT – 2011 FLOOD EVENT

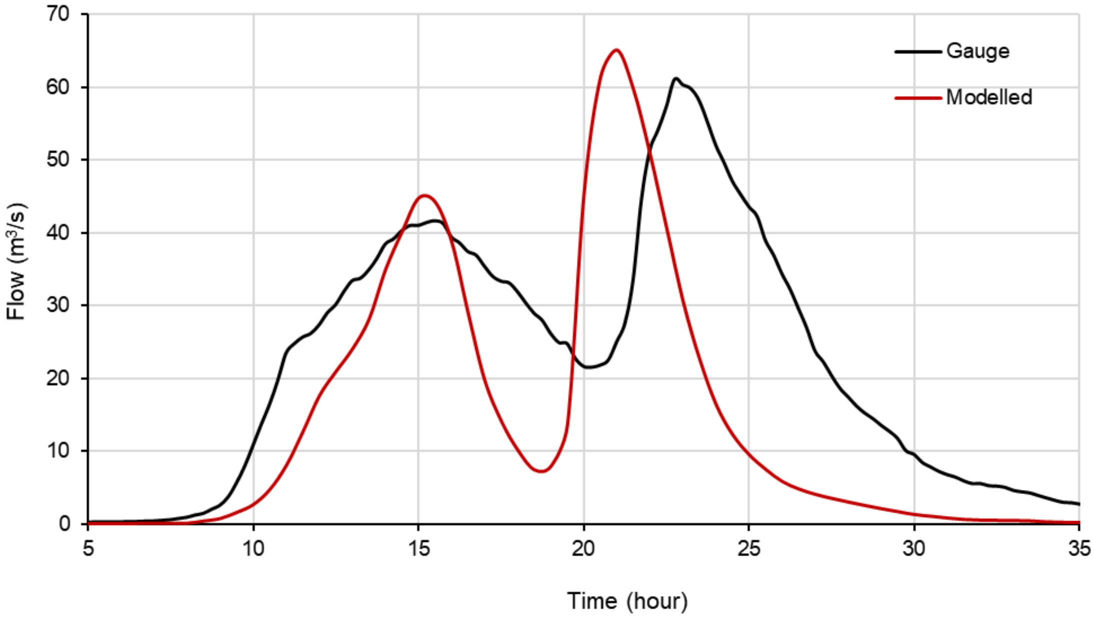


FIGURE 15-6 MODELLED AND GAUGED FLOWS AT TARAWHATORA RIVER AT SCHOOL CUT – 2011 FLOOD EVENT

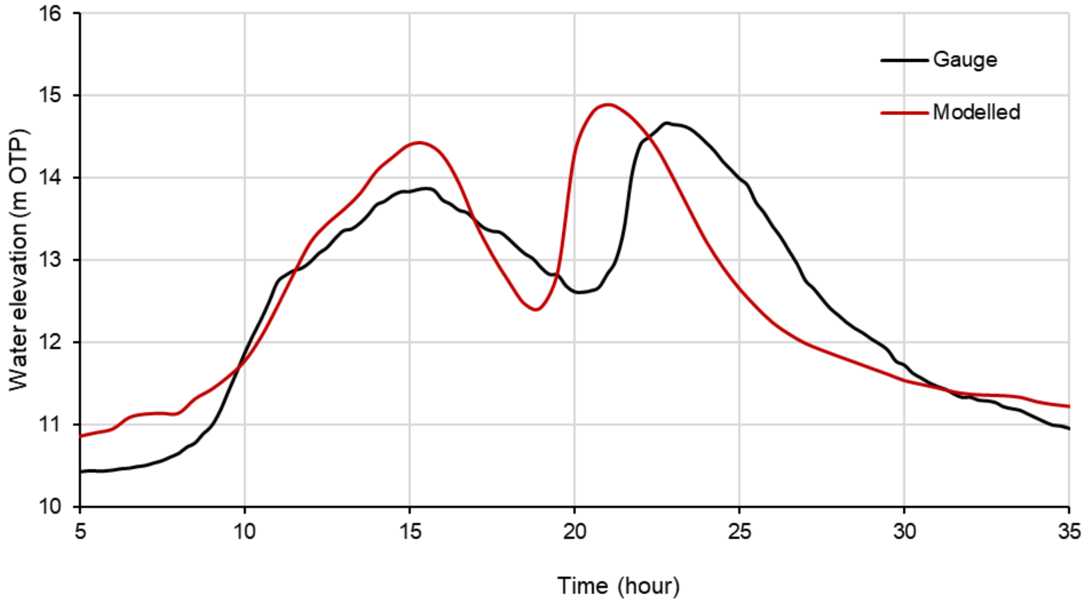


FIGURE 15-7 MODELLED AND GAUGED WATER LEVELS AT TARAWHATORA RIVER AT SCHOOL CUT – 2011 FLOOD EVENT

Model validation

The July 2007 event was used for model validation using the 2011 calibration model parameters. Table 15-4 provides a summary of the modelled peak flows and water levels compared to the observed values. Figure 15-8 to Figure 15-11 show the modelled hydrographs and water levels compared to the gauge records.

The modelled peak flows are lower than the observed values in both School Cut and Puriri Place by 11% and 14% respectively. The differences of the water levels between the modelled values and the observed values are smaller, of only 4% higher in School Cut and 1% lower in Puriri Place.

In contrast to the peak estimates, the modelled hydrographs match to the gauged records well in the shape and timing. The modelled peaks occurred only 0.5 hour earlier in Puriri Place and 1.5 hour later in School Cut.

TABLE 15-4 SUMMARY OF VALIDATION RESULTS FOR AWANUI CATCHMENT

	Peak flow (m3/s)			Time to peak diff. (hour)	Volume (ML)			Peak WSE (m OTP)		
Location	modelled	Gauged	Diff.		modelled	Gauged	Diff.	modelled	Gagued	Diff. (mm)
Puriri Place	149	173	-13.74%	1.50	2859	5341	-46.46%	15.87	16.07	-198.70
School Cut	229	258	-11.29%	-0.50	11518	20381	-43.49%	16.28	15.63	657.10

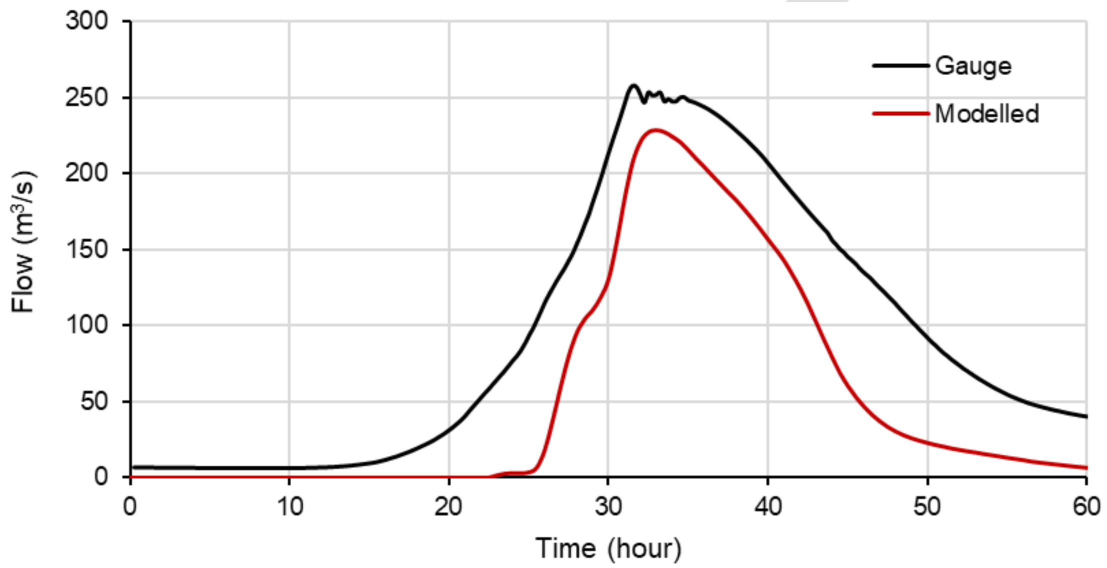


FIGURE 15-8 MODELLED AND GAUGED FLOWS AT AWANUI RIVER AT SCHOOL CUT - JULY 2007 EVENT

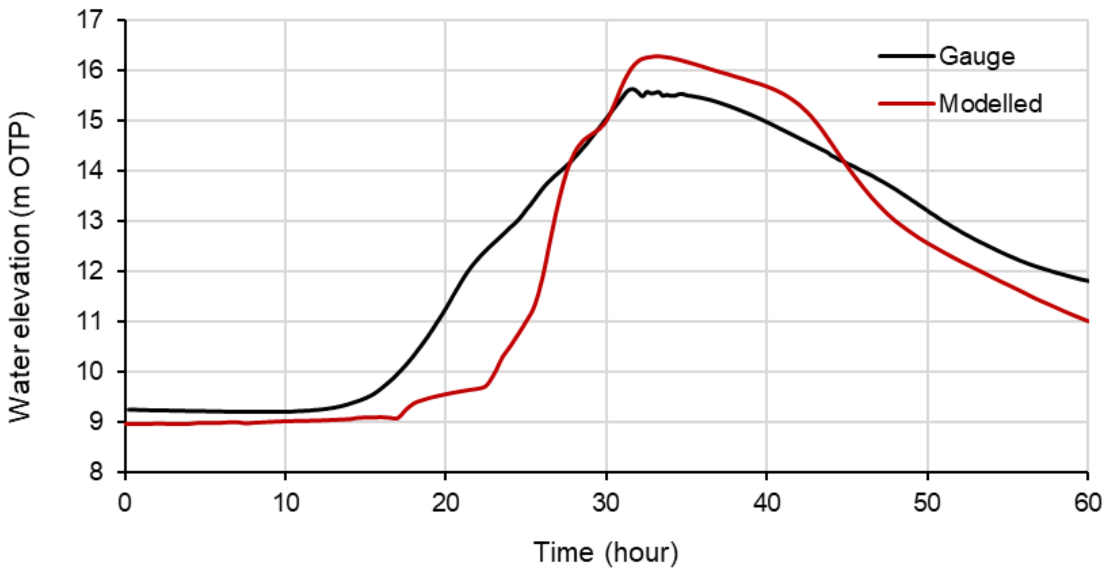


FIGURE 15-9 MODELLED AND GAUGED WATER LEVELS AT AWANUI RIVER AT SCHOOL CUT – JULY 2007 EVENT

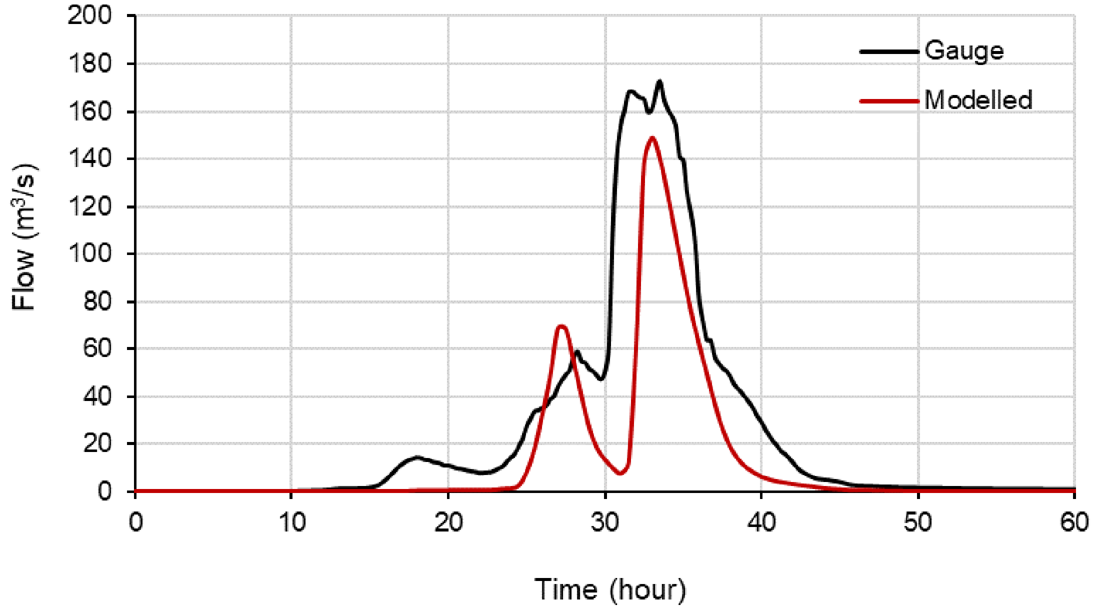


FIGURE 15-10 MODELLED AND GAUGED FLOWS AT TARAWHATORA RIVER AT SCHOOL CUT - JULY 2007 EVENT

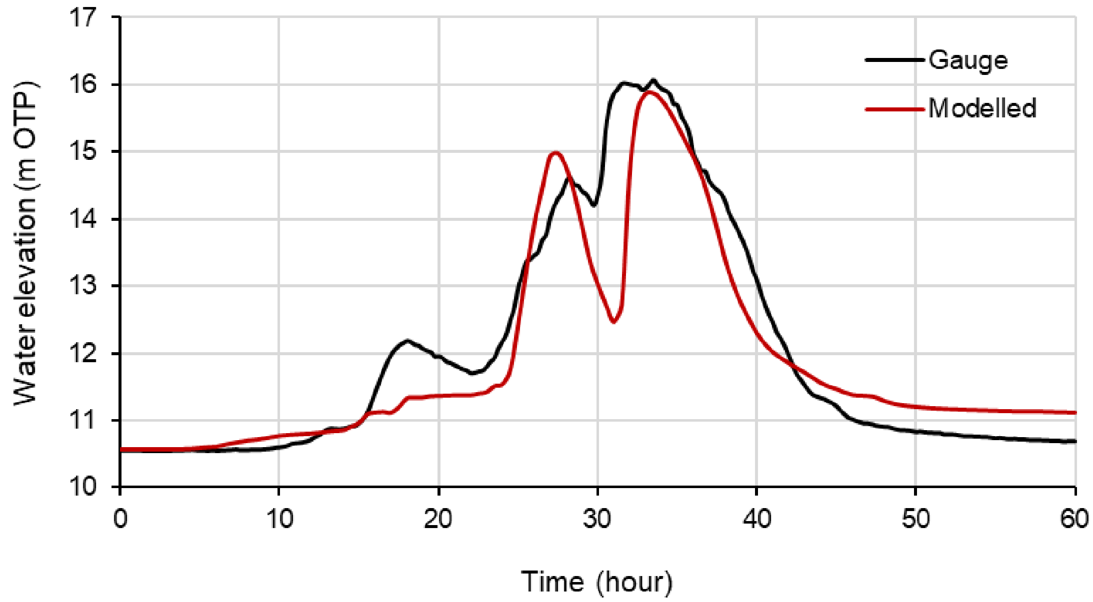


FIGURE 15-11 MODELLED AND GAUGED WATER LEVELS AT TARAWHATORA RIVER AT SCHOOL CUT – JULY 2007 EVENT

APPENDIX B
FLOOD MODEL PEER REVIEW