



Report

Whangarei Modelling Report

18 OCTOBER 2013

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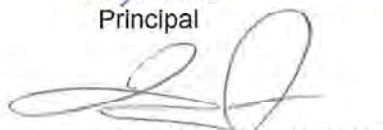
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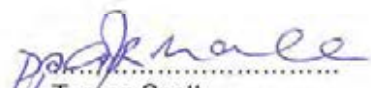
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Date: 18 October 2013
Reference: 42071138/R001/C
Status: Final

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Introduction

1.1 Project Background

This project seeks to improve the work that was done for the Priority Rivers Flood Risk Reduction Project. Under the URS project 2010, the Whangarei area was originally covered by two river flood models, the Hatea model, and the Waiarohia / Raumanga model. In order to have a higher level of confidence in the flood mapping, the Northland Regional Council (NRC) commissioned URS to merge the two models, and recalibrate the unified model with a more recent calibration event. The single unified model is hereafter referred to as the 'Hatea River model', as the Waiarohia stream is a tributary of the Hatea River at their confluence in the CBD. The Waiarohia and Raumanga catchments are thus referred to as being a part of the Hatea catchment.

It was also identified by NRC that areas of the model should be modified to improve the description of features within the model. The details of these modifications are listed in the Modelling Scope.

This model upgrade was initially undertaken by EWaters under contract to URS, and then completed by URS.

1.2 Catchment Description

The Hatea catchment is located on the east coast of Northland. It flows south from its origins in the Glenbervie Forest, reaching the Whangarei CBD and discharging into the Whangarei Harbour.

Figure 1-1 provides a general location plan of the catchment.

The Hatea catchment consists of eight main tributaries:

- Mangakino Stream: Located near the northern boundary of the catchment
- Wairau Stream: Located near the northern boundary of the catchment
- Putanui Stream: Located near the northern boundary of the catchment
- Waitaua Stream: Located along the northern western boundary of the catchment
- Otangarei Stream: Located in the central part of the catchment
- Waiarohia Stream: Located in the central part of the catchment
- Te Hihi Stream: Located from the southern boundary of the catchment
- Nihotetea Stream: Located from the southern boundary of the catchment

The confluence of the Mangakino Stream, Wairau Stream and Putanui Stream is downstream of Burma Road.

The confluence of the Mangakino Stream and Waitaua Stream is adjacent to Balmoral Road.

The confluence of the Mangakino Stream and Otangarei Stream is located north of Dobbies Park.

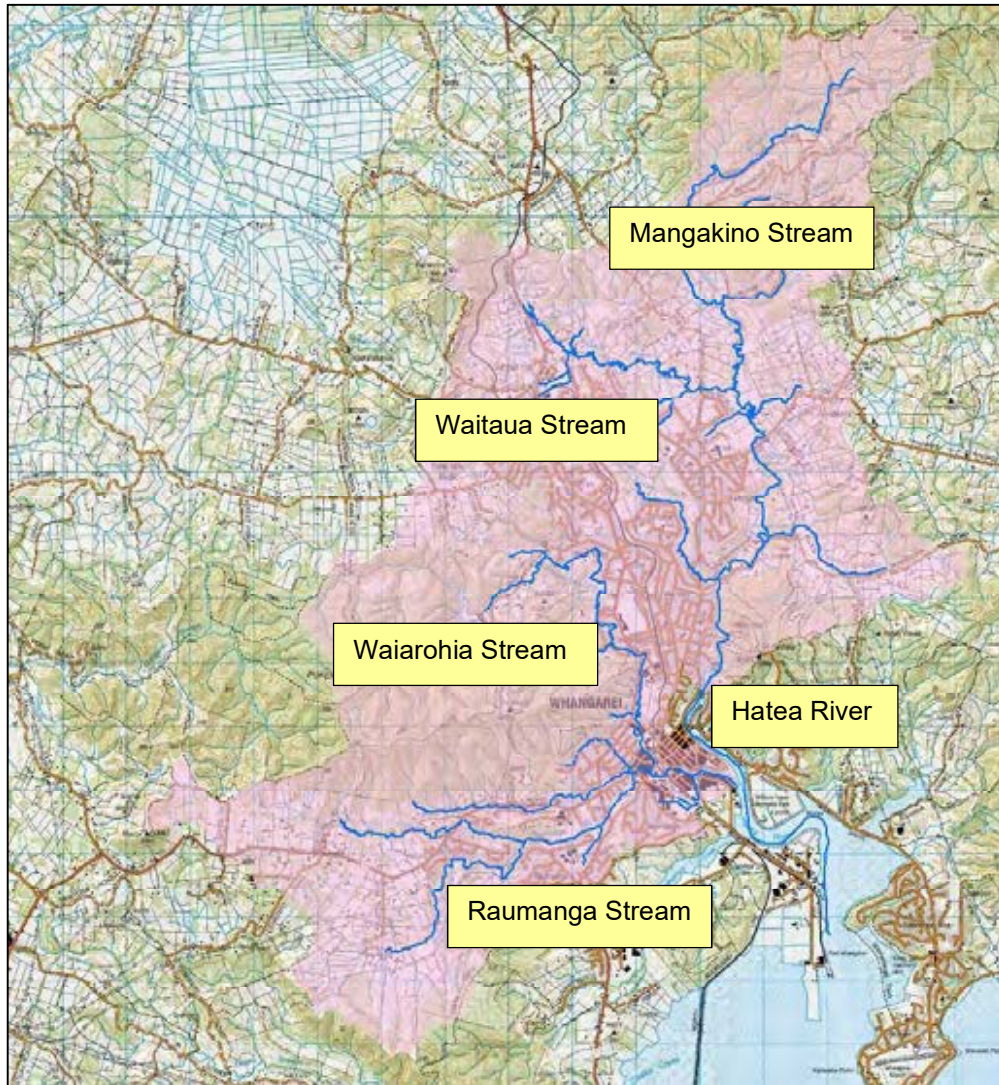
The Te Hihi Stream and the Nihotetea Stream combine into the Raumanga Stream at the Raumanga Valley Reserve.

The Kirikiri Stream and the Raumanga Stream join just upstream of Porowini Avenue Bridge, and the confluence of the Raumanga Stream and Waiarohia Stream is at Lower Tarewa Road bridge.

All of the above streams combine together into the Hatea River that discharges into the Whangarei Harbour.

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Figure 1.1 General location plan of the Hatea catchment and tributaries



Topography

The Hatea River has its origins in the Glenbervie Forest. The high point within this area is Hurupaki, at 349 m above sea level (aSL). The upper areas of the catchment are characterised by steep incised gullies draining well defined sub-catchment areas. The outlet of the Hatea catchment is the Whangarei Harbour.

The Raumanga Stream drains a flatter area with less well defined boundaries. The headwaters are located along the southern boundary of the catchment with average height of approximately 100m above sea level.

The Whau Valley dam is located approximately four kilometres North West of the Whangarei CBD and discharges into the Waiarohia Stream.

The Whangarei Falls and the Paranui Falls are located about four to five kilometres upstream from the Whangarei CBD. Both waterfalls are about 25 to 26m high.

1 Introduction

1.3 General Modelling Approach

The present project work uses the modelling methodology explained in the NRC Priority Rivers Modelling Report, Feb 2010. This modelling report is prepared as a supplementary report to the NRC Priority Rivers Modelling Report, Feb 2010. GIS and integrated modelling are central to the modelling methodology. This method assures a comprehensive model, accurate outputs and the ability to be continually upgraded.

1.4 Modelling Scope

The general objective of the model improvement and verification is to increase the accuracy of the model results in comparison to known flooding and gauged flooding events. The scope covers a variety of modifications in different areas. Details of the scope are listed and described below.

1.4.1 Merging of Hatea and Waiarohia River models

The work package includes the merging of Hatea and Waiarohia River models into one RS model. The extension of the Hatea model downstream of the confluence of the Limeburner's catchment and minor extension of channels in the upper Hatea catchment (separate from the Waitaua catchment channel extension). The model merge does not include the Limeburners catchment, and the flood mapping shown for the Limeburners area does not reflect inflows from that catchment.

1.4.2 Model Extensions

Incorporate the stormwater network for Morningside

The Morningside storm water network is to be incorporated as provided by NRC. This will more accurately represent the area and its sub-catchment discharging directly within RS local network. This includes the cost for building a new DTM for the Morningside area, from the information delivered by NRC.

Extend the Waitaua catchment channel network to Springs Flats

The Waitaua catchment will incorporate the extended channel definition within the catchment area. The model extension will allow for flood mapping that is consistent for the area. As this area is an upper sub-catchment of the Hatea River, the local storm water model should be adequate for the management of the catchment.

1.4.3 Run Jan 2011 Ex TC Wilma flood calibration event

A validation run for the calibration event of the January 2011 storm event previously done by Ewaters.

1.4.4 Further Model Extensions

Extend 2D area at Wharowharo stream

Extra two 2D polygons at each side of the Wharowharo stream, connected through a spill to a 1D channel.

1 Introduction

Extend 2D US of Porowini Avenue

The 2D polygon at Whangarei town is to be extended along Tarawera Rd to SH1 (based on NRC additional 2D polygon shapes) and connected to Raumanga stream.

Extend tributary and flood plain DS of Whau dam

The modification considers extra 2D mesh connections over the Waiarohia River and its tributary in the area of Whau Valley.

Extra 2D areas at Whareora Road

Some new 2D polygons are to be added at the location of the Whangarei falls. The 2D polygons are to be properly linked to the 1D main channel of the Hatea River.

2D area in Raumanga Valley

Add additional 2D area to convey overflow from the 1D Raumanga channel network in the Raumanga Valley Road area.

1.4.5 Model Improvements

Review and modify description of Porowini Ave Bridge

Review and modify the model description of the bridge. NRC will re-survey the bridge and channel sections for updating of the model.

Morningside catchment inflows location

Review the modelled flow paths resulting from run off being assigned directly to the 2D grid on the slopes of the Morningside Basin. Modify discharging point of runoff from Morningside sub-catchments to be applied on the flood plains and channels in the lower land of the area.

DTM merging for Morningside and corrections

Due to development in the Morningside Basin, including Porowini Avenue extension, and earthworks associated with new site development, the land elevations, and channel network have changed from the LIDAR captured in 2009. NRC is to provide survey data for new building platforms, road elevation data, and channel sections (as of 2012). Merge and re-mesh to be done for the 2D objects in the area.

2D areas at US of Waitaua stream

Ewaters new 1D extension of the model will be replaced partially for a full 2D upstream of Great North Road; all flood plains in the area to be kept in 2D. Some other areas will be fixed to add more detail in the 1D representation.

Correction and extension of the cross sections of the Waitaua stream to include the flood plains and obtain a better representation of flooding areas for large events.

1 Introduction

Modify representation of culverts

Change the representation of short culverts for orifices for a more stable and reliable solution. Long culverts (such the one from Morningside to the Waiarohia River) will add an orifice at the entrance to represent correctly the entrance flow restrictions of the pipe network.

1.4.6 Calibration of rating curve at Waiarohia Stream DS of Russell Rd site

Previous site information relating to this site, including gauging data and site rating, was retrieved from NIWA archives. The Russell Road site (5519) was operational between 1957 and 1968. Maximum gauged flow was 69.5 m³/s. The model network stage flow relationship in this reach to be re-calibrated to the site rating.

1.4.7 Model Verification

The model is to be re-run for the storm of Jan 2011 as a verification event to control any major change in the previous calibration due of all the model alterations done after this task.

1.4.8 Final Model Improvements and Recalibration

Review and recalibration of the Hydrological Model

As part of the conclusions of the Model Verification it was agreed that the model was overestimating the flows for the Waiarohia-Raumanga catchment. It was agreed then that the hydrological model would be reviewed and recalibrated.

Hydraulic Model Modifications

As part of the model verification review it was found that there were a few areas which hydraulic adjustments were required for a more reliable representation. This included, among others, adjustment of manning's values in the Waiarohia River, adjustments at the Whareora Road Bridge on Hatea River, smoothing of the bed levels at the Low Waiarohia River, adjustments on the head loses, spill coefficients and roughness in several areas to improve the previous calibration state.

June 2013 Survey Incorporation

Several weirs and culverts along the Raumanga River were surveyed and incorporated into the model. Also a few surveyed cross sections were taken along the lower Raumnaga and Waiarohia Rivers to adjust and improve the description of the bottom levels as the previous model used a survey from 2006 that was incomplete and unreliable. Also data from Hatea River was available to adjust the bottom levels.

Model Recalibration Storm January 2011

The latest model was then re-calibrated for the storm of January 2011 which has flow/level gauges and debris levels in several locations over the whole Hatea-Waiarohia river catchment.

Model Adjustments Storm January 2011

Two extra modifications were done to improve the calibration results:

1 Introduction

- One existing manhole was added in the Commerce Street area to allow for backflow from the Morningside drain adjacent to Cowleys yard. It should be noted that the Commerce Street stormwater network has not otherwise been represented in this version of the model.
- A couple of culverts were added in the Raumanga Valley to allow water spilt from the river to drain out on the flood plain.

The storm event of January 2011 is then to be re-run for a final version of the calibration.

1.4.9 Rerun design storms

Set and re-run design storms as defined by the Priority Rivers Flood Risk Reduction project.

1.4.10 Reproduce flood extent maps

The same procedure will be followed as defined in the Priority Rivers Project.

Data Collection

NRC provided all of the data used to improve, extend and calibrate the model for the January 2011 event. The data received is listed and described below:

- Proposed 1D model extension (shape file),
- Proposed 2D polygons extension (shape file)
- New survey with photos (estuary survey, cross sections, bridges, culverts, flow/level stations),
- Rain gauges for the event of January 2011,
- Level/flow gauges and series for the event of January 2011,
- Debris level for the event of January 2011,
- Verification of some gauges datum.

Survey data consisted in the following items:

- Cross sections of previous streams where more detail was required (including some bridges)
- Cross sections of new streams or branch to be included in the model.
- Cross section of channel at level gauges location.
- Some culverts in main streams.
- Gauge datum verification.

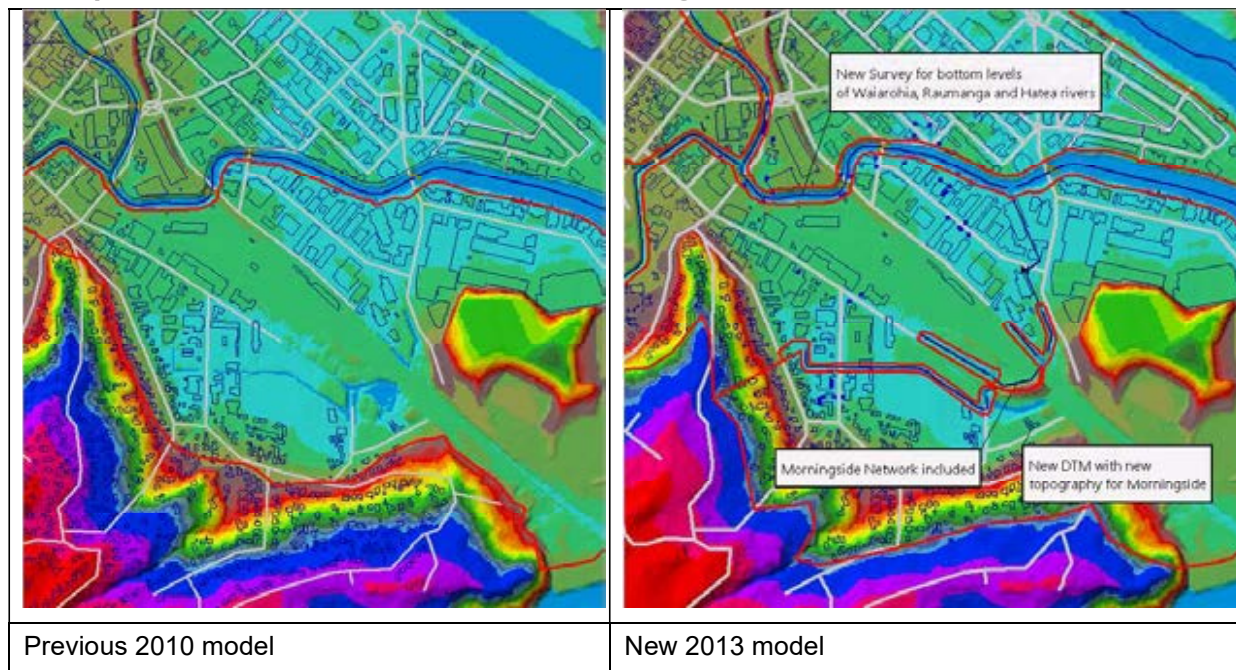
This survey was processed in GIS and included in the model.

All surveyed levels, including channel survey, LIDAR and flood levels used for model set up and calibration are relative to One Tree Point Vertical Datum (OTP 1964). The model set up and results files also relate to this datum. The coordinate system used for this project was New Zealand Transverse Mercator (NZTM / NZGD 2000).

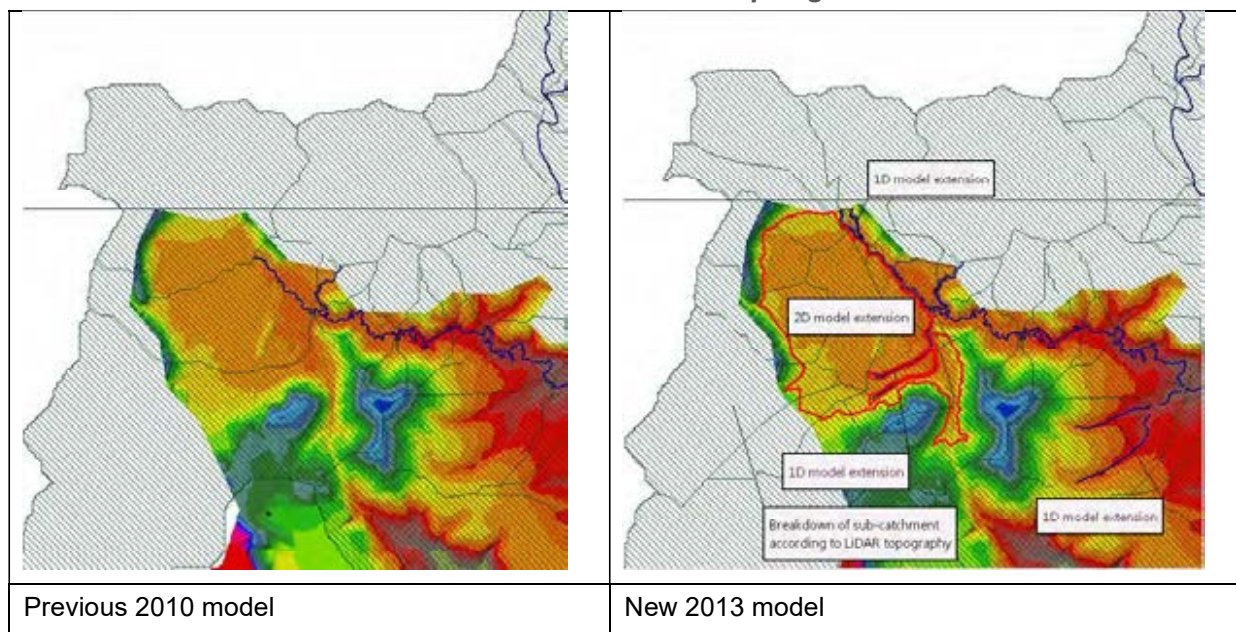
Modelling Modifications

Some areas of model modifications as described in Section 1.4 are shown below.

Incorporate the stormwater network for Morningside



Extend the Waitaua catchment channel network to Springs Flat



3 Modelling Modifications

Extend 2D US of Porowini Avenue

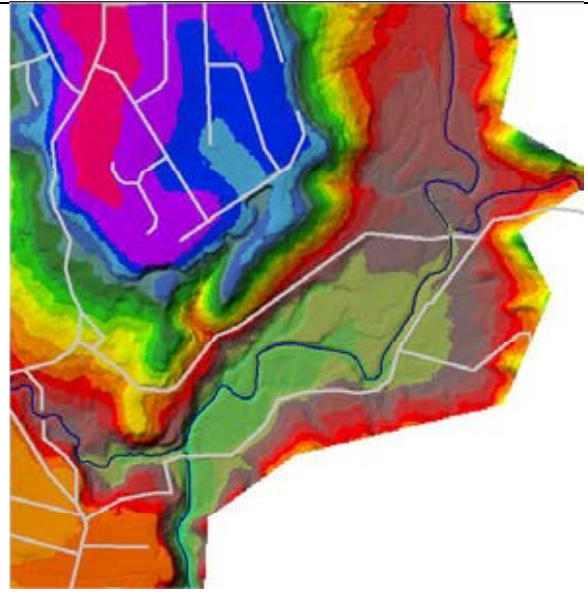
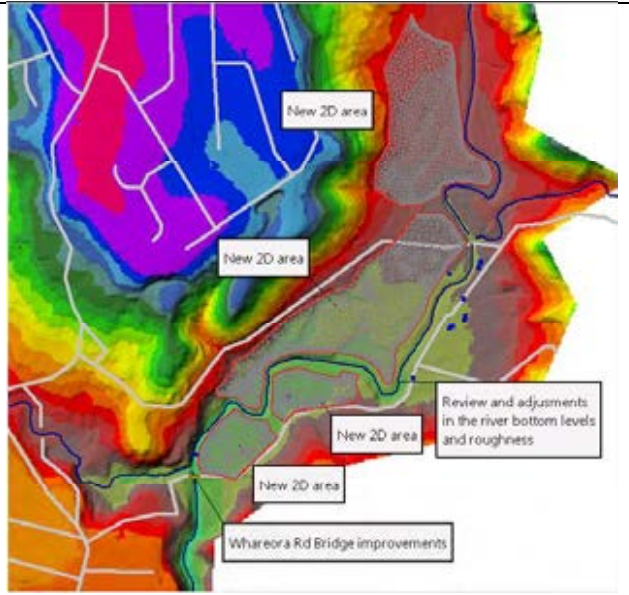
	 1D model extent including culverts Extra survey in Waiarohi to adjust river bottom levels 1D model extent including culverts Extension of 2D polygon New 2D polygon New Bridge New Survey Waiarohia, Kaumanga Mataia rivers Review of Porowini Bridge description
Previous 2010 model	New 2013 model

Extend tributary and flood plain DS of Whau dam

	 1D model extension New 2D polygon New 2D polygon Review of roughness for calibration
Previous 2010 model	New 2013 model

3 Modelling Modifications

Extra 2D areas at Whareora Road

	
Previous 2010 model	New 2013 model

2D area in Raumanga Valley

	
Previous 2010 model	New 2013 model

3 Modelling Modifications

3.1 Hydrological Model

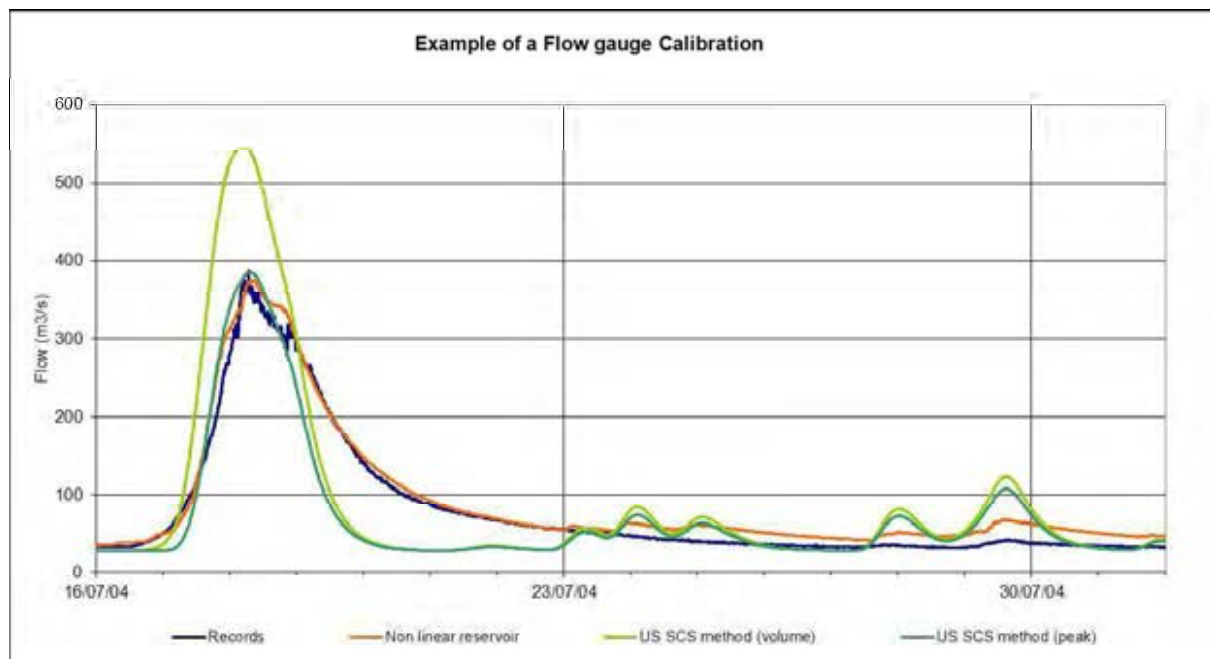
3.1.1 US SCS Method

The previous model used an US SCS unit hydrograph method as the hydrological model. A CN value was to be derived for each sub-catchment based on the land-use and soil type. The main concern with the US SCS method for Northland catchments of larger size is that, in general, peak flows and flow volumes cannot be calibrated simultaneously. This was found to be true of the previous calibration. The results are not satisfactory and do not represent the hydrologic behavior of the sub-catchments properly.

Further experience and analysis in NRC catchments, as well as other catchments in New Zealand, suggests that a better and more versatile hydrologic model alternative to simulate the sub-catchment runoff is the Non Linear Reservoir method.

The following figure shows a comparison between the US SCS method (applied to calibrated peak flows and flow volumes separately) and the Non Linear method (calibrated both peak and volumes). This example is of the Rangitaiki River catchment in New Zealand.

Figure 3-1 Example of a flow gauge calibration using different hydrological models



3.1.2 Non-Linear Reservoir Method

The Non Linear method consists of representing each sub-catchment as a reservoir with a non-linear discharge. Two parameters are required to calibrate the shape of the hydrograph, K and p :

$$V(t) = K \cdot Q(t)^p$$

Where V is the storage volume in the reservoir, and $Q(t)$ is the flow or runoff from the sub-catchment.

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Then, the volume balance defines a differential equation to solve the function $Q(t)$.

$$\frac{dV}{dt} = K \cdot p \cdot Q(t)^{(p-1)} \cdot \frac{dQ(t)}{dt} = I(t) - Q(t)$$

The previous differential equation cannot be solved analytically unless $p=1$. This equation is solved numerically by InfoWorks RS over each sub-catchment to obtain its respective runoff as a response to a given rain series $I(t)$ as intensity.

Parameter K can be estimated based on catchment features such as length, slope and land cover. Those are available for all Hatea sub-catchments.

3.1.3 IWRS Non-Linear Reservoir parameters

InfoWorks has a Non-Linear Reservoir hydrological model implemented as part of its boundary condition alternatives. Volume parameters can be defined whether using a runoff coefficient or an infiltration rate in mm/hr. Both methods have advantages and disadvantages, and as a part of this work they were tested and analysed to establish which method is more appropriate for NRC projects. This approach does not estimate runoff volumes and infiltration rates (depths) based on a runoff parameter such as US SCS method which has been developed in conjunction with the CN value.

The infiltration method has been used as it offers a better description of the rain losses for big events, and it showed partial advantages over the runoff coefficient method.

The hydrograph shape is controlled by the parameters K and p shown in the previous section. These parameters estimate the shape of the hydrograph to find the best match for flow volume, peak and tail flows. Coefficient p defines the order of the reservoir. If $p=1$ that would describe a Linear Reservoir method and would allow for the estimation of a unit hydrograph for each sub-catchment, and allowing the use of other methods available for rain losses (like US SCS), however, most of the time $p \neq 1$.

A time of delay was assigned to those sub-catchments that were discharging into streams a great distance from the respective sub-catchment point of discharge.

3.1.4 Constant Infiltration Rate

There is an important difference between the methodology used previously with the US SCS method based on CN values, and the current approach using the infiltration rate and the non-linear reservoir method. The CN value was previously defined for each sub-catchment based in local land use; the current methodology has instead selected a unique infiltration rate to be applied over the whole catchment.

3.1.5 Base flow expected ranges

The base flow was estimated to be between 1 m³/s to 2m³/s at the 5539 (Hatea at Whareora Road) gauge. The peak flow at the same location is about 220m³/s as records show, but further analysis suggests that the flow might be up to 450m³/s. The peak flow compared with the base flow is negligible and found not to be important. However, for stability issues the total base flow for the

3 Modelling Modifications

smaller stream branches was defined for different simulations to be between 0 m³/s to 1m³/s; this range is still negligible compared with the maximum flows for the 2011 event.

Data Analysis

4.1 Survey data process and other GIS tasks

As per the methodology, modelling tasks were assisted by GIS. New and previous surveys, location and details of rain and level gauges were processed in GIS before being imported into the IWRS model.

Other calculations, such as time of delay for hydrologically routed sub-catchments, 2D break lines and sub-catchment re-delineation were also assisted by GIS analysis.

4.2 Calibration Event Analysis

The calibration event is the storm of January 2011. To compare the calibration results for the modified model against the previous calibration results, the same gauges were used. Also, debris levels for the storm of January 2011 were used to validate the results of the modified model against the previous calibration results and provide more information of the expected flooding areas.

4.2.1 Rainfall distribution for Calibration Event

The rainfall analysis utilised 14 rain gauges, 8 auto gauges and 6 daily gauges. Table 2.1 below summarises the available information. Figure 4-1 shows the distribution of rain gauges in the Whangarei area.

Table 4-1 Rain gauge details

Site ID	X_NZTM (Easting)	Y_NZTM (Northing)	Record
A54737	1723299	6040999	Auto
547219	1712798	6042773	Daily
547223	1708504	6041063	Daily
547214	1717303	6043801	Daily
546316	1726365	6054003	Daily
546315	1721080	6050858	Daily
546218	1716326	6049481	Daily
A54737	1723299	6040999	Auto
547339	1719175	6045713	Auto
547340	1718863	6047420	Auto
547335	1718063	6048860	Auto
8020111	1719764	6045550	Auto
546301	1721842	6053482	Auto
546216	1705783	6058346	Auto

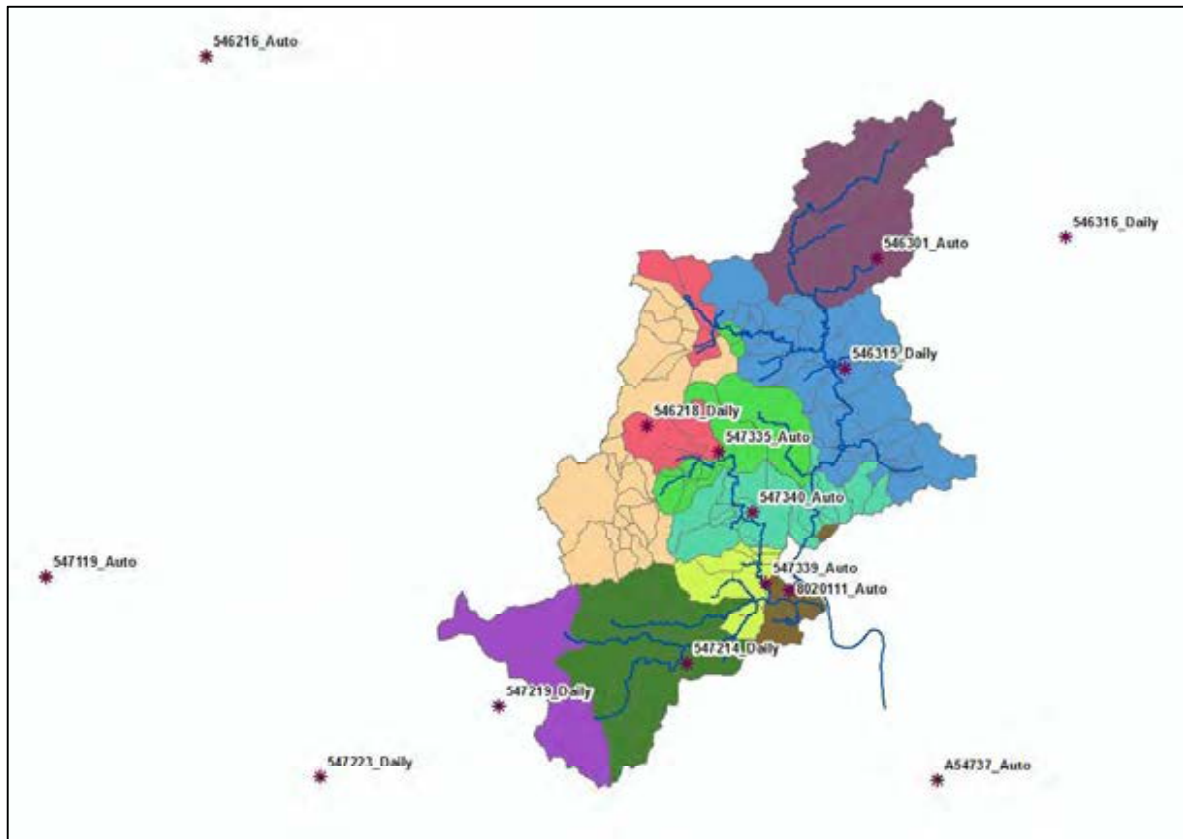
All auto gauges were analysed and compared against their respective daily record. They were then processed to compare their accumulated rainfall profile against each other. This was done to establish similarity of spatial distribution and gain understanding in the delays in temporal distribution.

Figure 4-1 shows the area of influence of the gauges for the storm of 2011.

4 Data Analysis

The previous analysis helped to understand the dynamics of the calibration event developing the respective floods.

Figure 4-1 Rain gauge location and gauge assignment over Whangarei catchment



4 Data Analysis

4.3 Flow/Level gauges analysis for Calibration Event

There are eight water level gauges available in the catchment. They are listed below in Table 4-2 with their details and data availability summarized in Table 4-3.

Table 4-2 Level gauges details

Site ID	Site Name	X_NZTM (Easting)	Y_NZTM (Northing)	SG Zero (m OTP)	Recording Authority	Record
5525	Kirikiri at Cheviot Street	1718142	6044886	14.930	NRC	Auto (5 mins)
5528	Raumanga at Bernard Street	1718759	6044938	1.486	NRC	Auto (5 mins)
5527	Waiarohia at Lovers Lane	1719096	6045838	1.575	NRC	Auto (15 mins)
Dam 020 LT01	Whau Valley Reservoir Level	1716461	6047713	91.245	WDC	Auto (irregular)
5519	Waiarohia at Russell Road	1718945	6047175	13.46		
5538	Hatea at Whareora Road	1720303	6048369	5.248	NRC	Auto (15 mins)
5539	Hatea at Town Basin	1719931	6045815	-1.675	NRC	Auto (5 mins)
5801	Marsden Point (Tidal)	1734608	6033357	-1.680	NRC	Auto (1 min)

Table 4-3 Level gauges data available

Site ID	Site Name	Time Flow	Time Stage	Rating Curve	Significant Event (Maximum Values)
5525	Kirikiri at Cheviot Street		X		X
5528	Raumanga at Bernard Street	X	X	X	X
5527	Waiarohia at Lovers Lane	X	X		
Dam 020 LT01	Whau Valley Reservoir Level		X		
5519	Waiarohia at Russell Road			X	
5538	Hatea at Whareora Road	X	X		
5539	Hatea at Town Basin		X		
5801	Marsden Point (Tidal)		X		

4.3.1 Debris levels

There are 108 surveyed debris levels available for the Hatea catchment. The points refer to the storm of January 2011 and provide a description of the flood extent.

Validation Results

The model was validated against the previous calibration event for January 2011, with the respective recorded levels and flows, as described in Sections 2 and 4.

Table 5-1 summarises the validation variables.

Table 5-1 Validation parameters

HYDRAULIC MODEL	Value
Manning	
Main channels	0.02 - 0.095
Flood plains	0.02 - 0.20
2D polygons	0.055 - 0.075
Spill coefficients	
Natural banks	0.90
Roads	1.1 – 1.7
Upper storage outlets	1.0 – 1.4
Orifice coeff (culverts)	0.90
HYDROLOGICAL MODEL	
Non-linear Reservoir	
K (variable based on catch parameters)	2.0 - 70
p (upper catchment)	0.30
p (middle catchment)	0.45
p (lower catchment)	0.60

The results of the final verification results are shown in the following sections. In some cases there is a mismatch between site data and model results. The differences between model rating and site rating for the gauges sites 5527, 5528 and 5538 was investigated in the EWaters / URS report “Whangarei Model Calibration Quality Assessment” Dec 2012.

The report concluded that Ewaters calibration for the gauges located at Bernard Street and Lovers Lane is accurate and reliable.

It also showed that Ewaters representation of the river sections roughness, cross section shapes, bridge description, CN values and other critical variables is within realistic ranges that properly describe the main features of the hydrological and hydraulic system.

Once it was recognized that the flow records are underestimated for these two gauge locations, and that the model critical variables are in an acceptable range, the fine fit of the level records proved a good quality model that can be used for NRC purposes, such as flood and risk assessment.

The EWaters report also stated that rating curves in NRC catchments should be revised closely, as the methodology applied for their conception might have deficiencies. Analysis like the ones undertaken in the report could be useful to assist the rating curve estimation, and the hydraulic models are a powerful tool to contribute with precision and confidence.

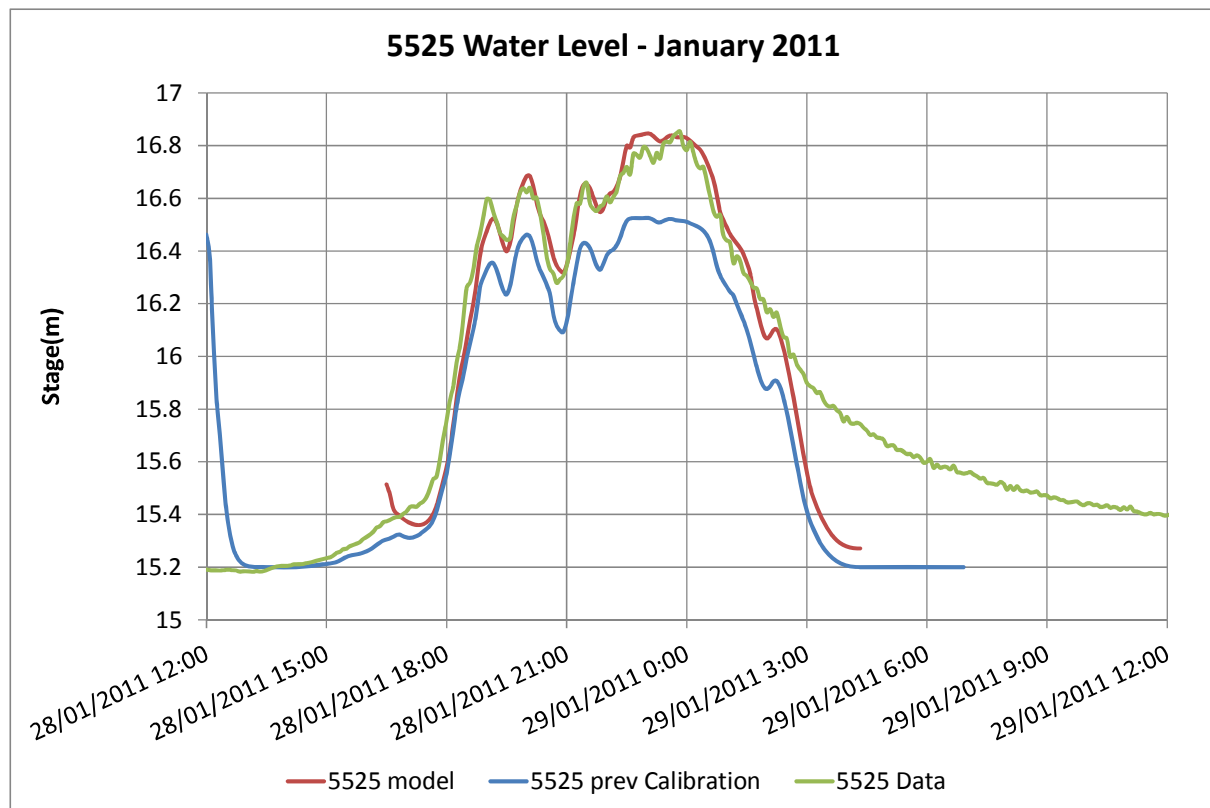
In developing rating curves for 5527 and 5528, it should be noted that gaugings have not yet been done for high flow, and there is uncertainty in the site rating. For site 5538, there is bank overflow at high stage downstream of the gauge site, and this will not be reflected in the site rating.

5 Validation Results

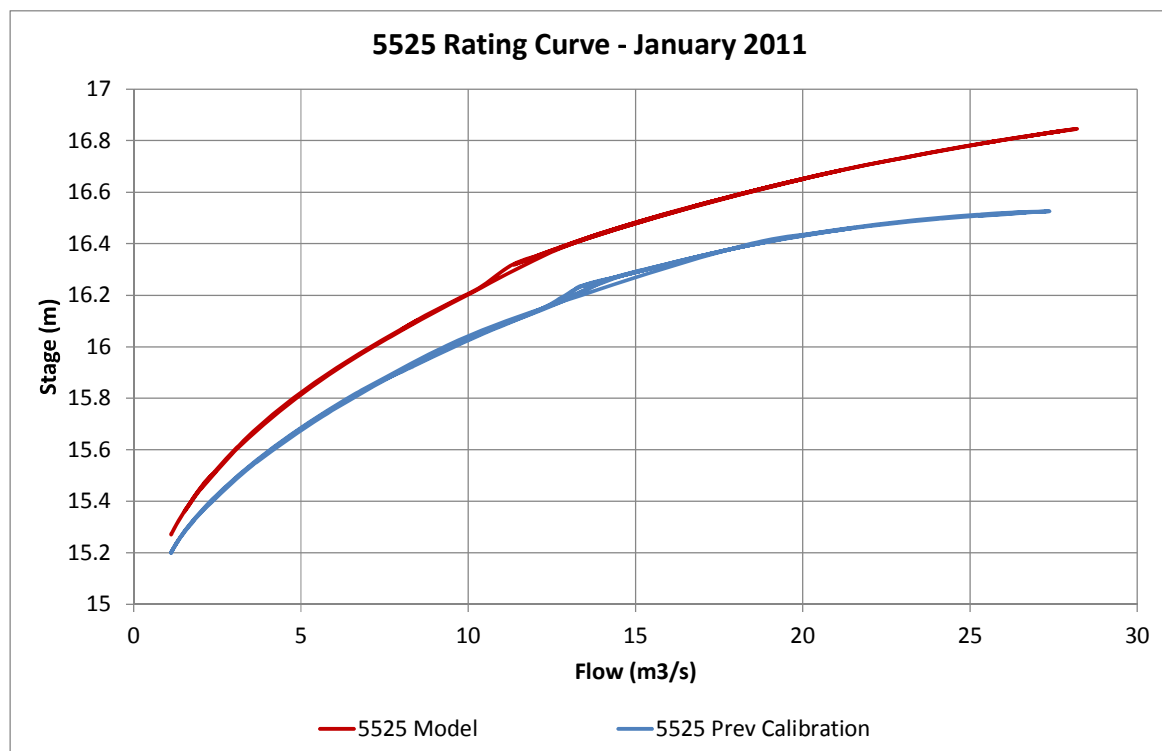
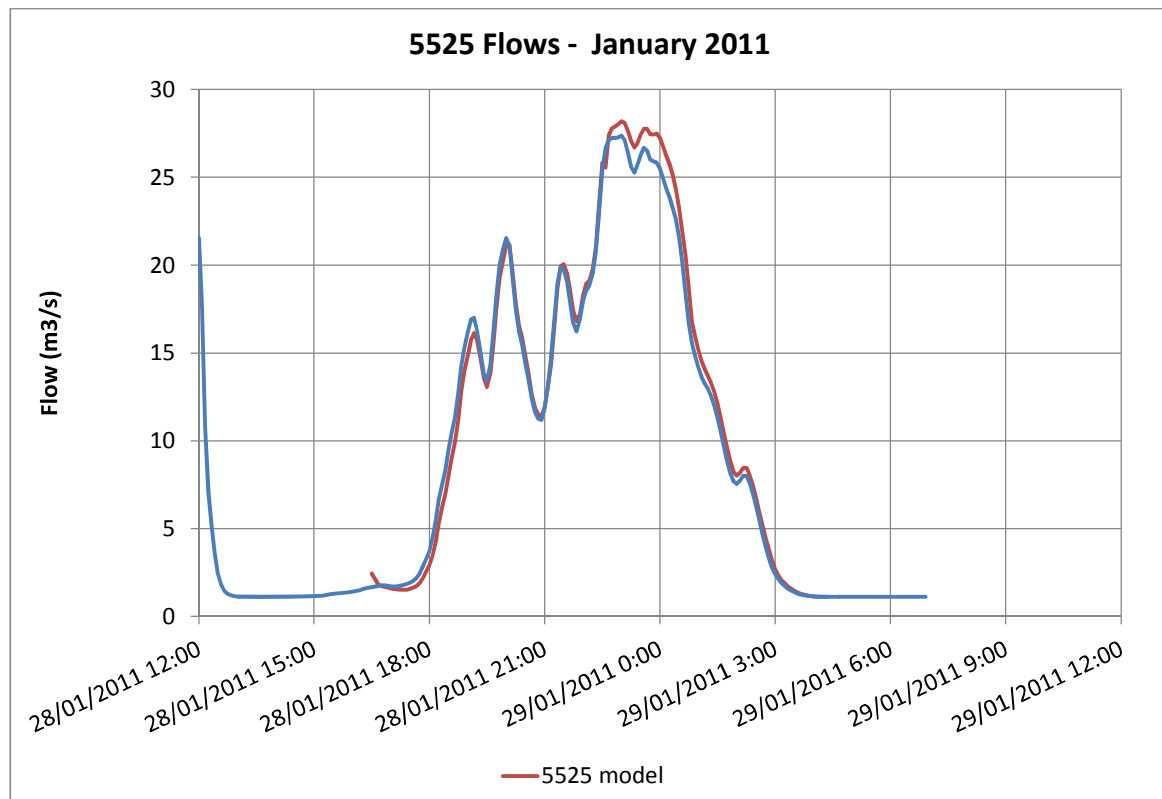
Further in the runoff model the CN value was reduced from 79 to between 70 and 75 for the Waiarohia-Raumanga catchment. The following figures, indicate that the peak flows in the Waiarohia were largely unaffected by the change in CN value but the peak flow in the Hatea, Raumanga and Kirikiri actually increased from the previous calibration results.

5.1 Validation - January 2011

Site 5525 – Kirikiri at Cheviot Street

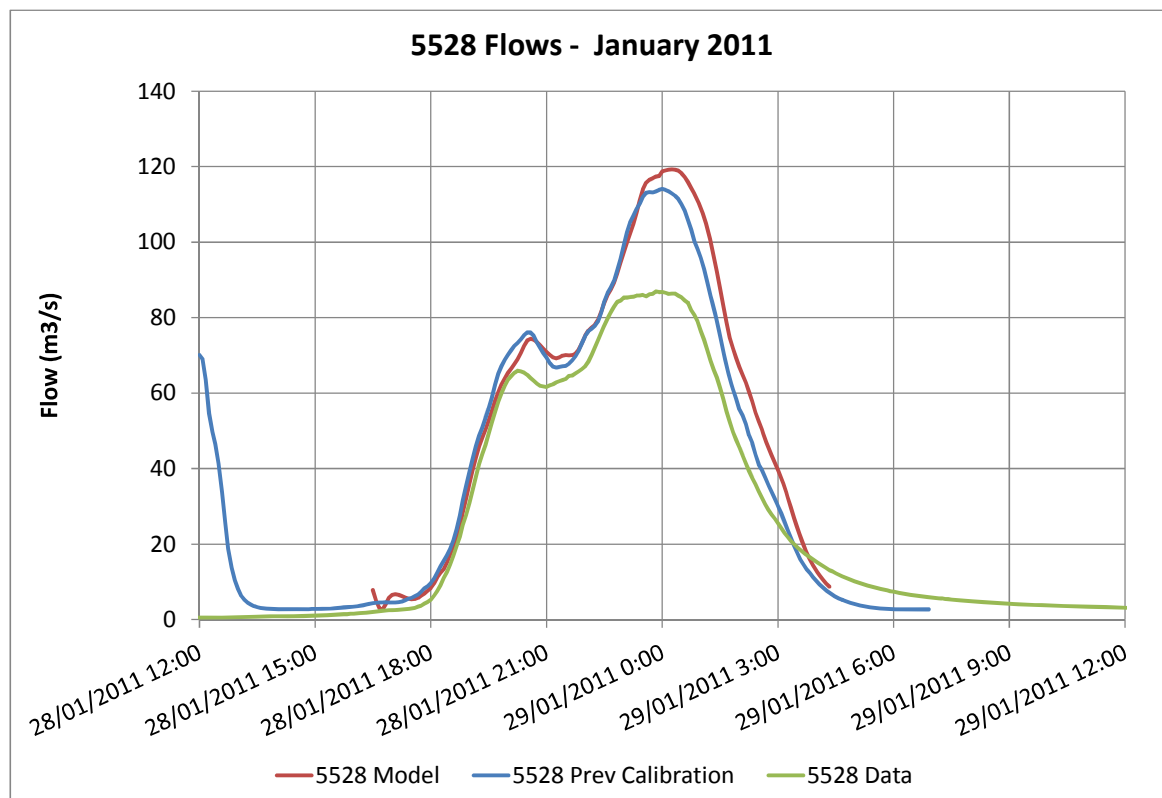
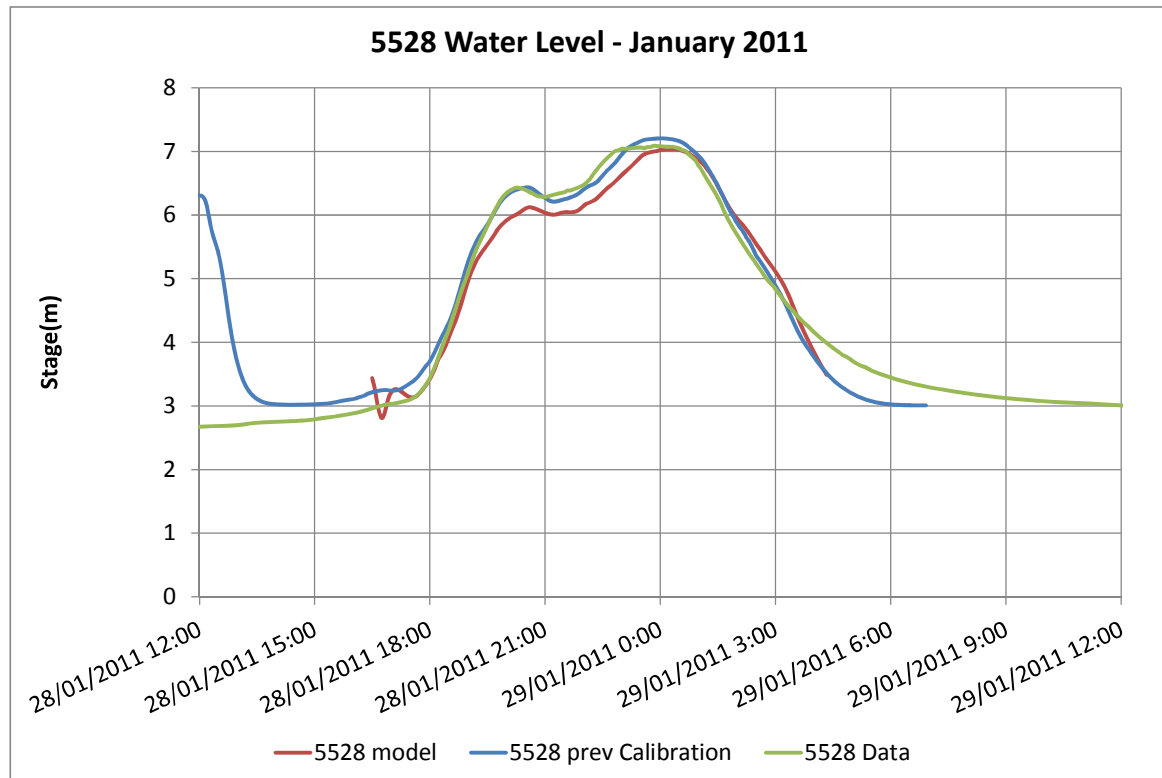


5 Validation Results

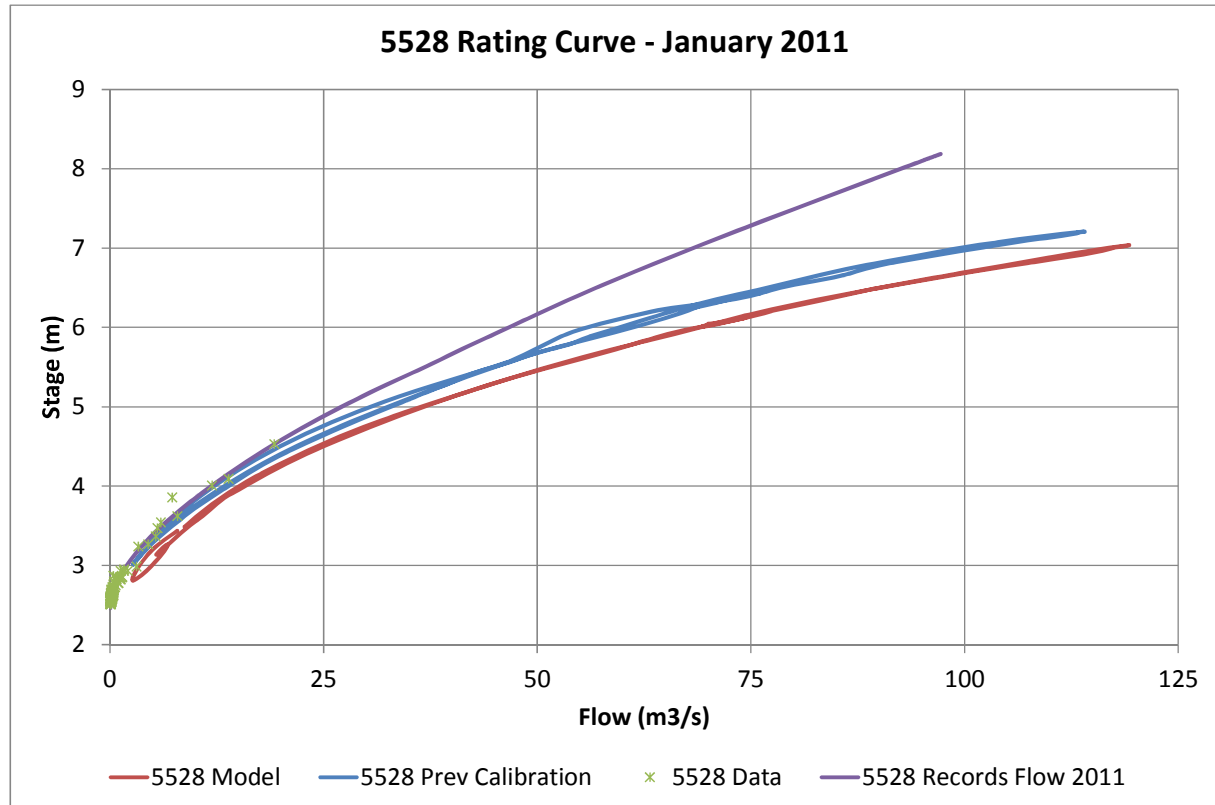


5 Validation Results

Site 5528 – Ruamanga at Bernard Street

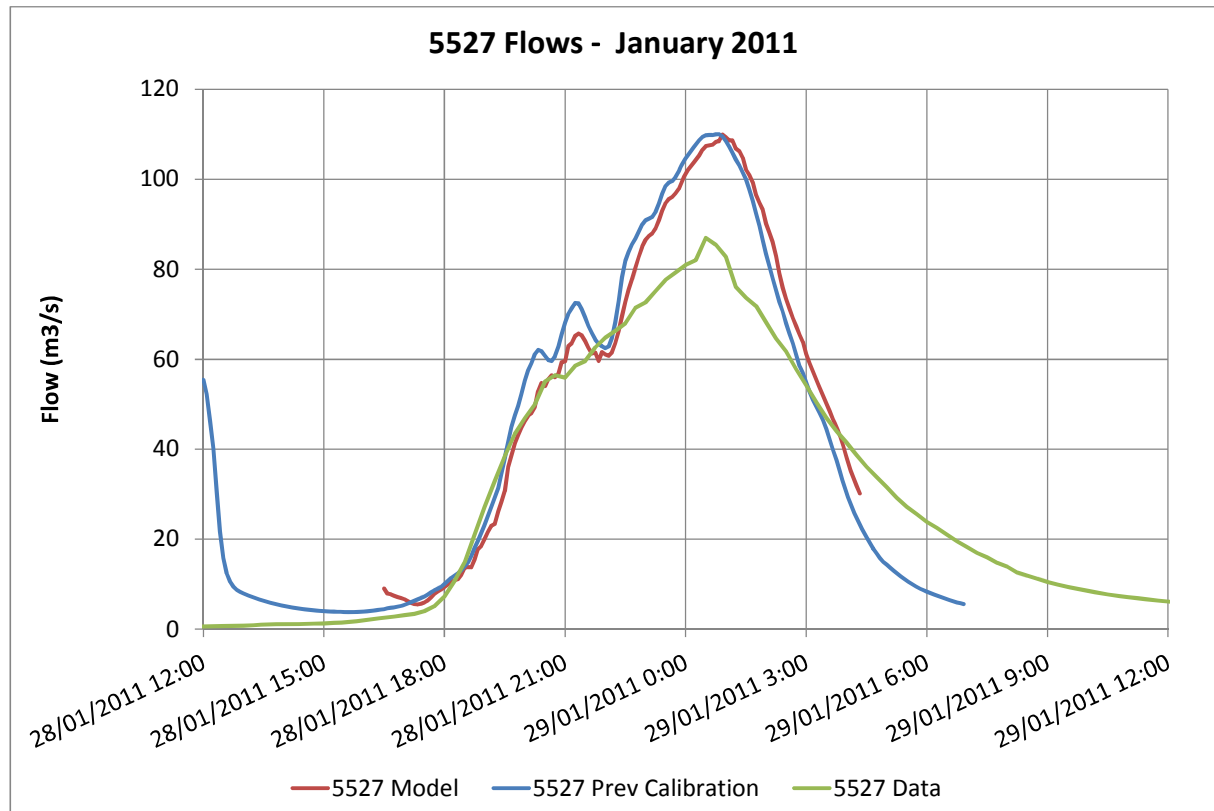
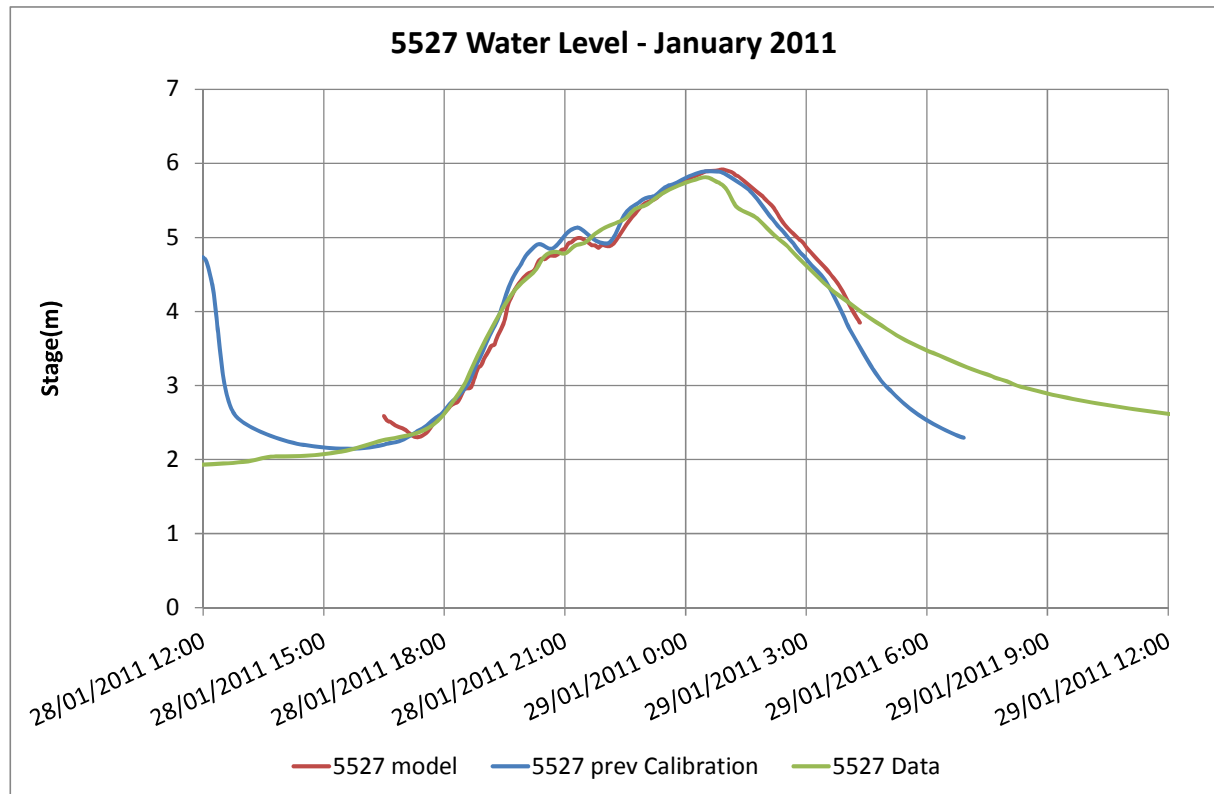


5 Validation Results

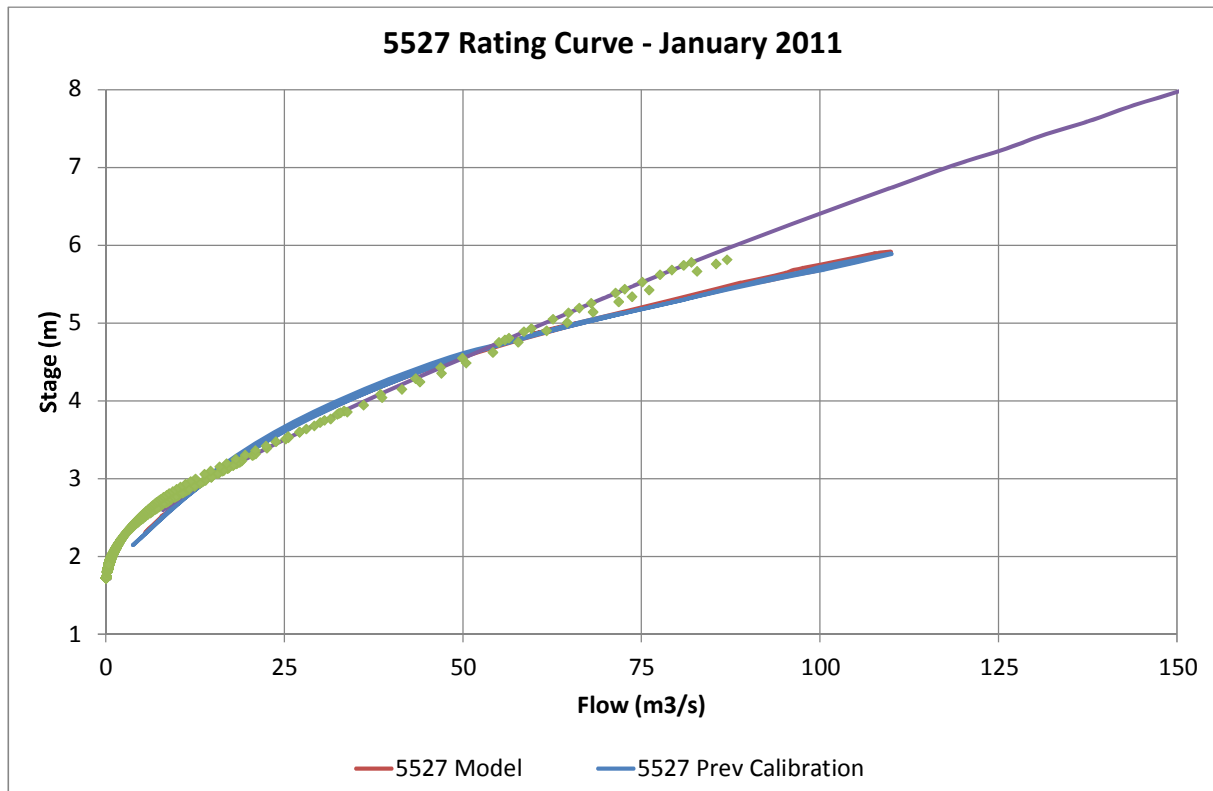


5 Validation Results

Site 5527 – Waiarohia at Lovers Lane

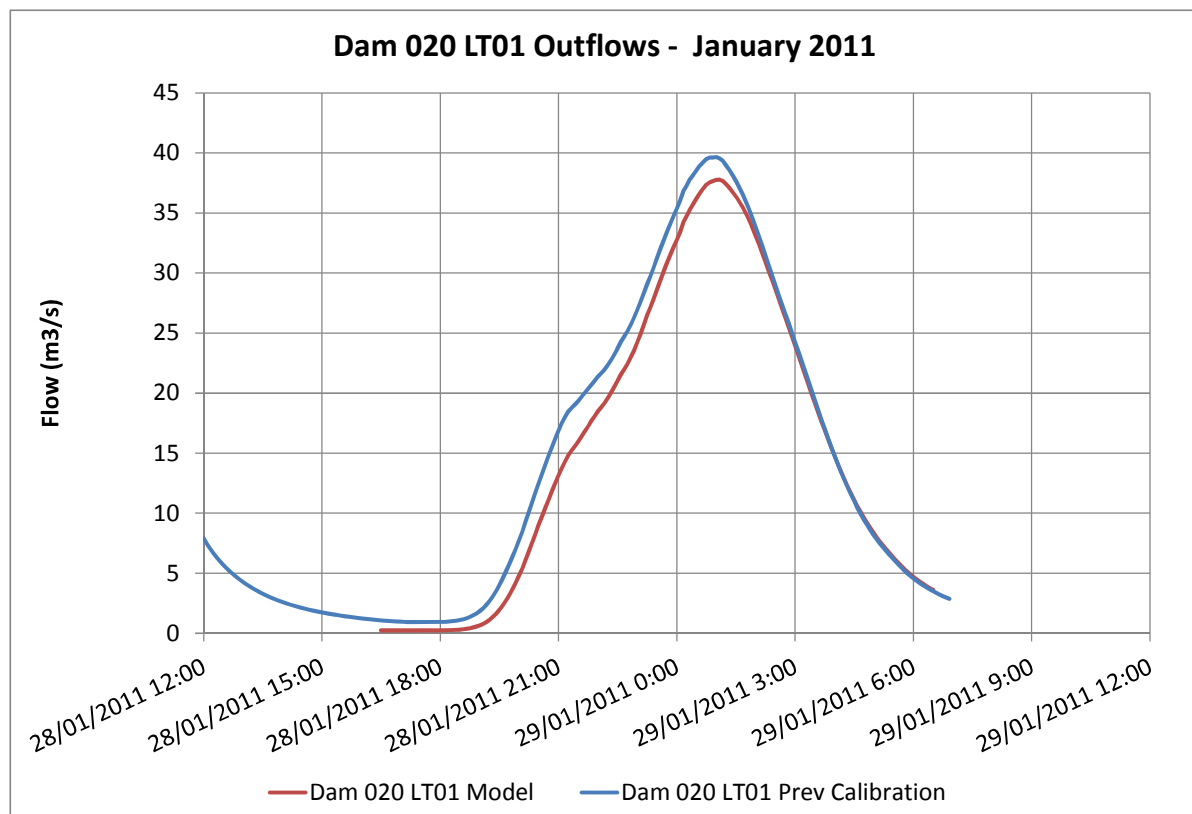
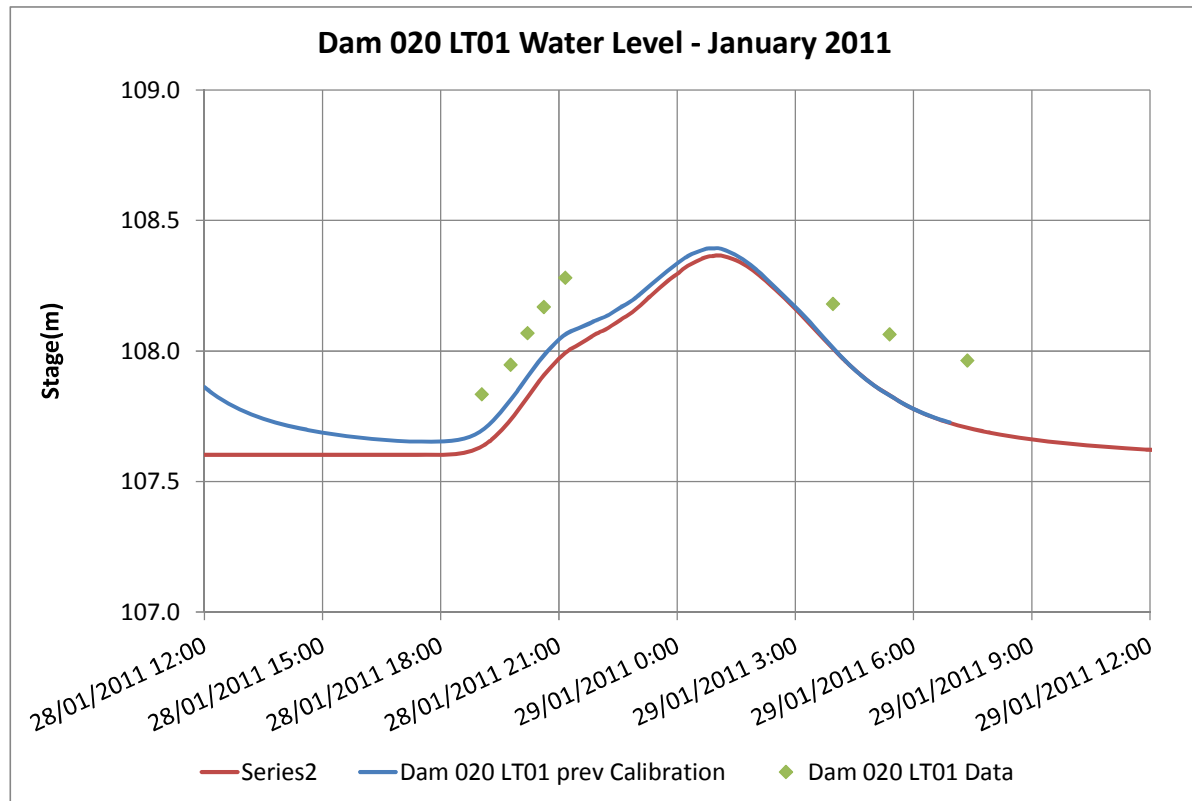


5 Validation Results



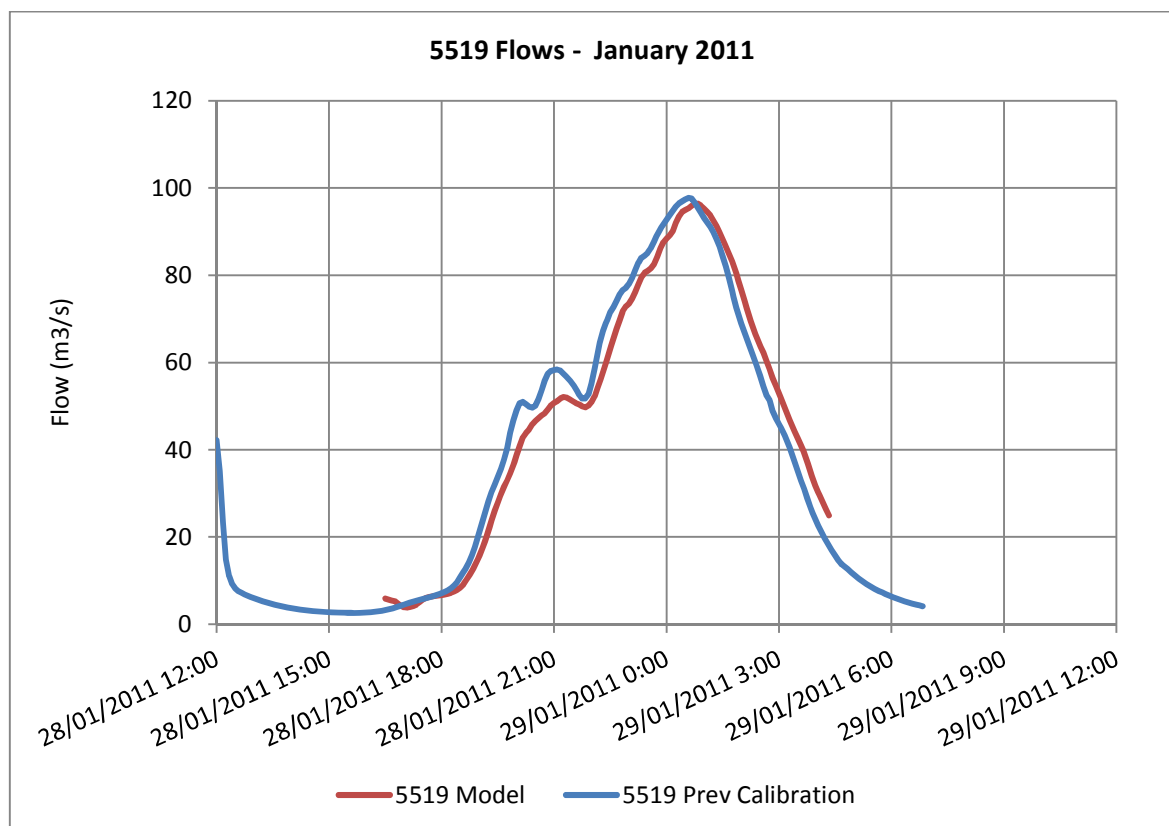
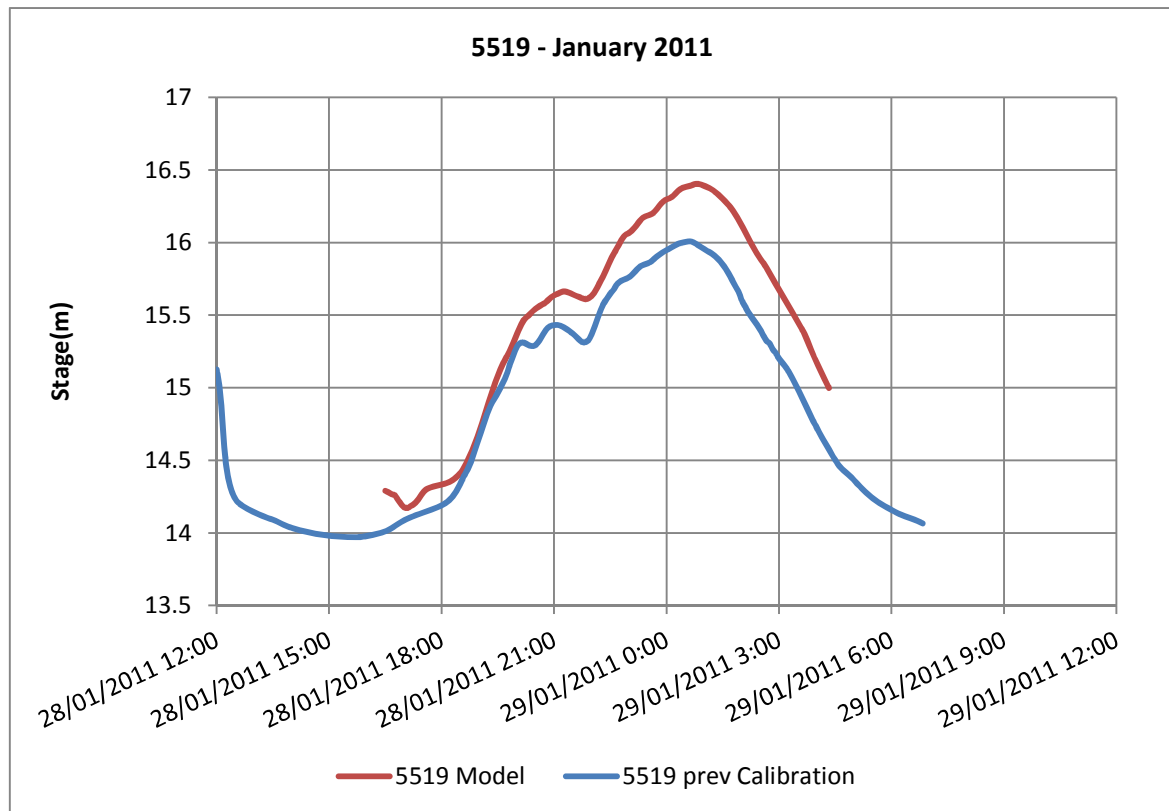
5 Validation Results

Site Dam 020 LT01 – Whau Valley Reservoir Level

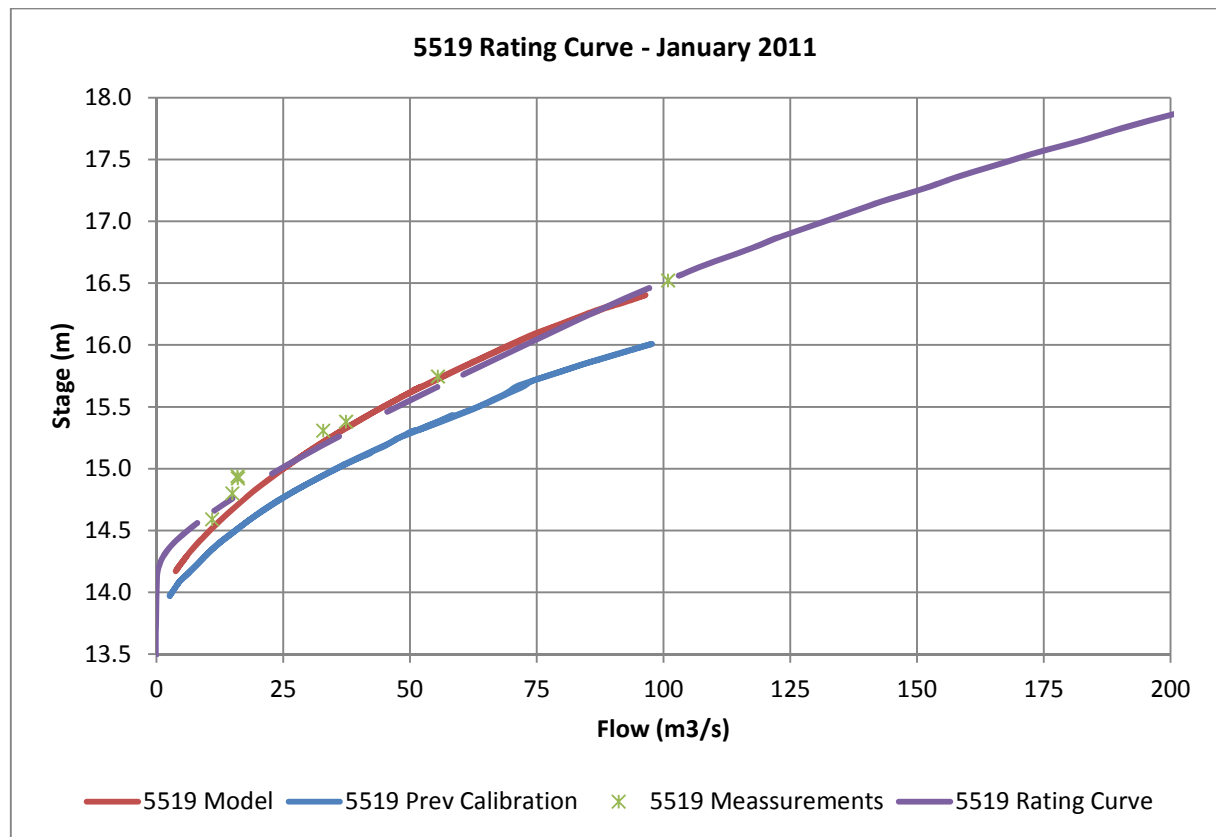


5 Validation Results

Site 5519 – Waiarohia at Russell Road

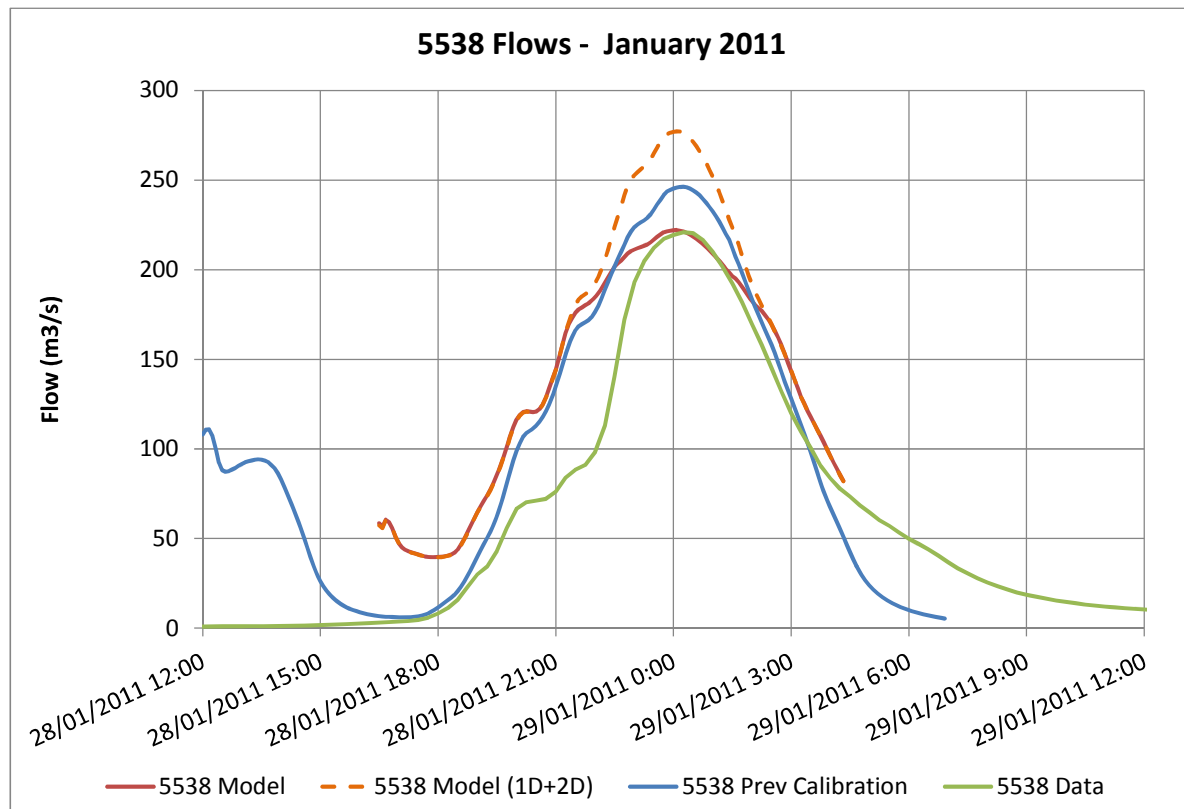
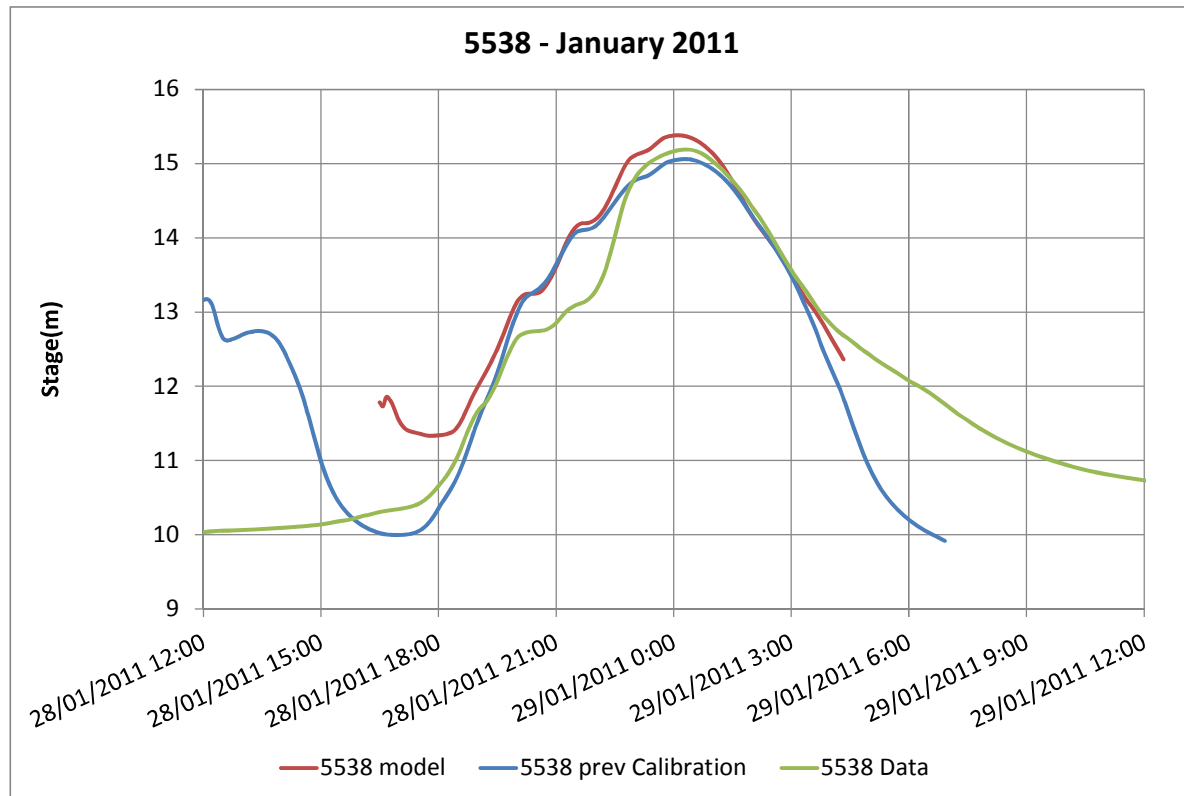


5 Validation Results

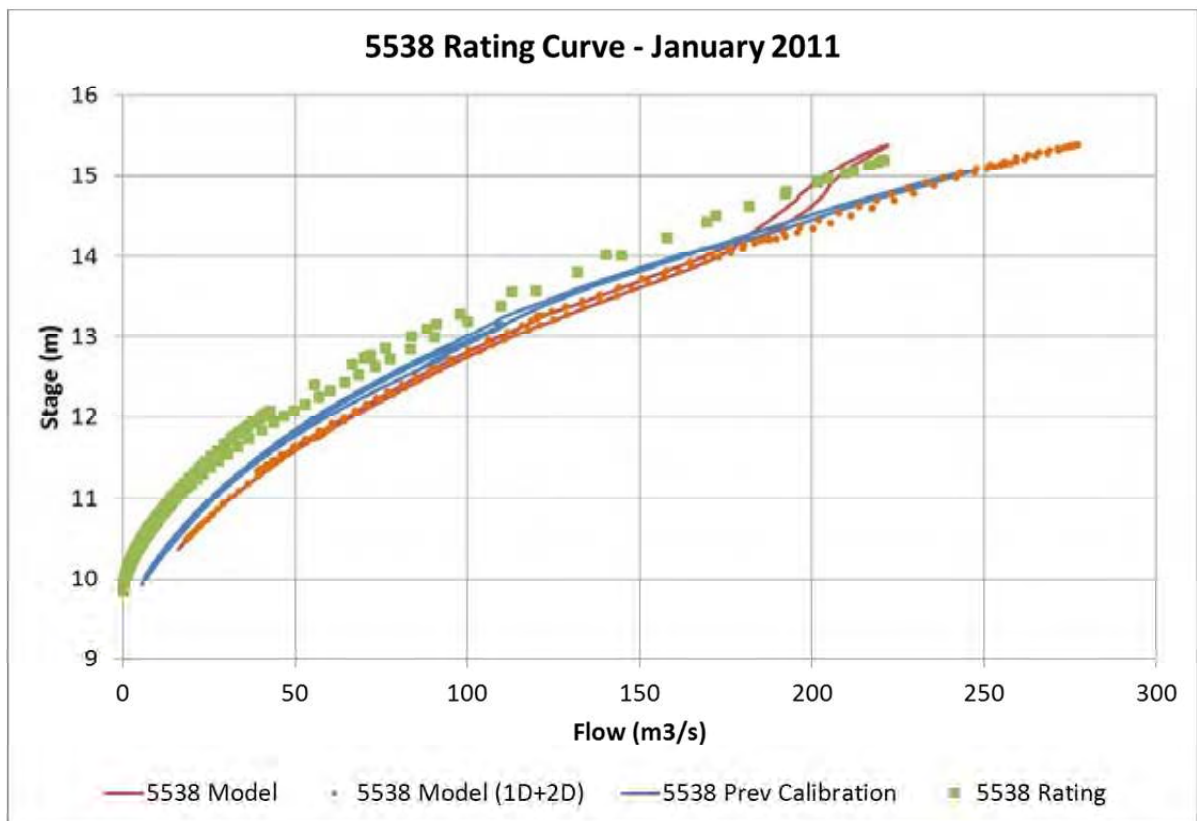


5 Validation Results

Site 5538 – Hatea at Whareora Road

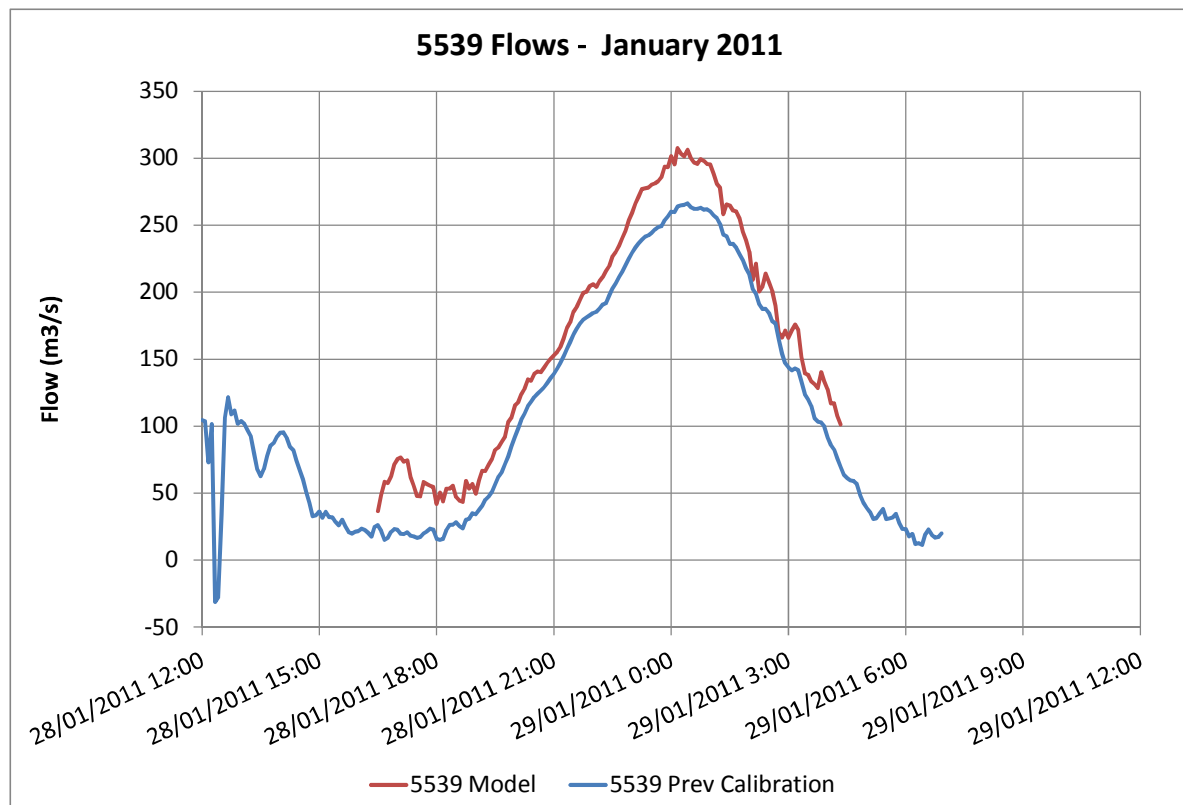
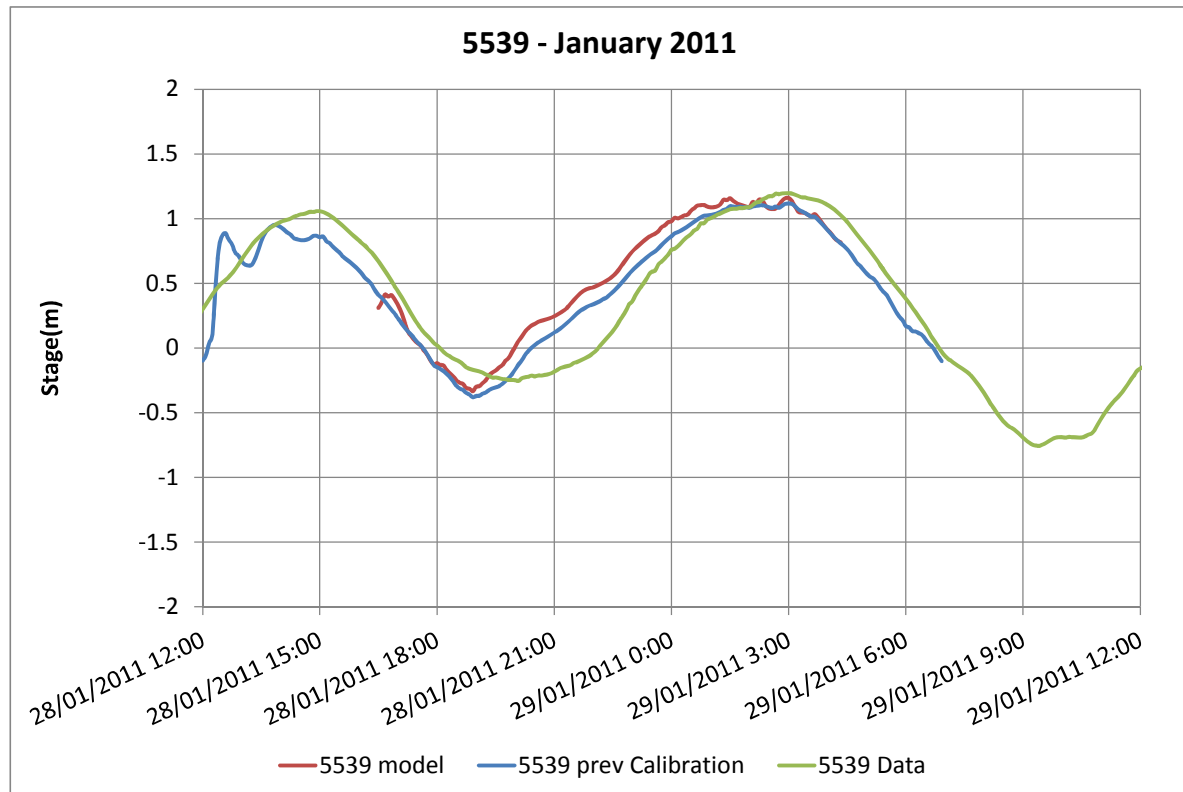


5 Validation Results



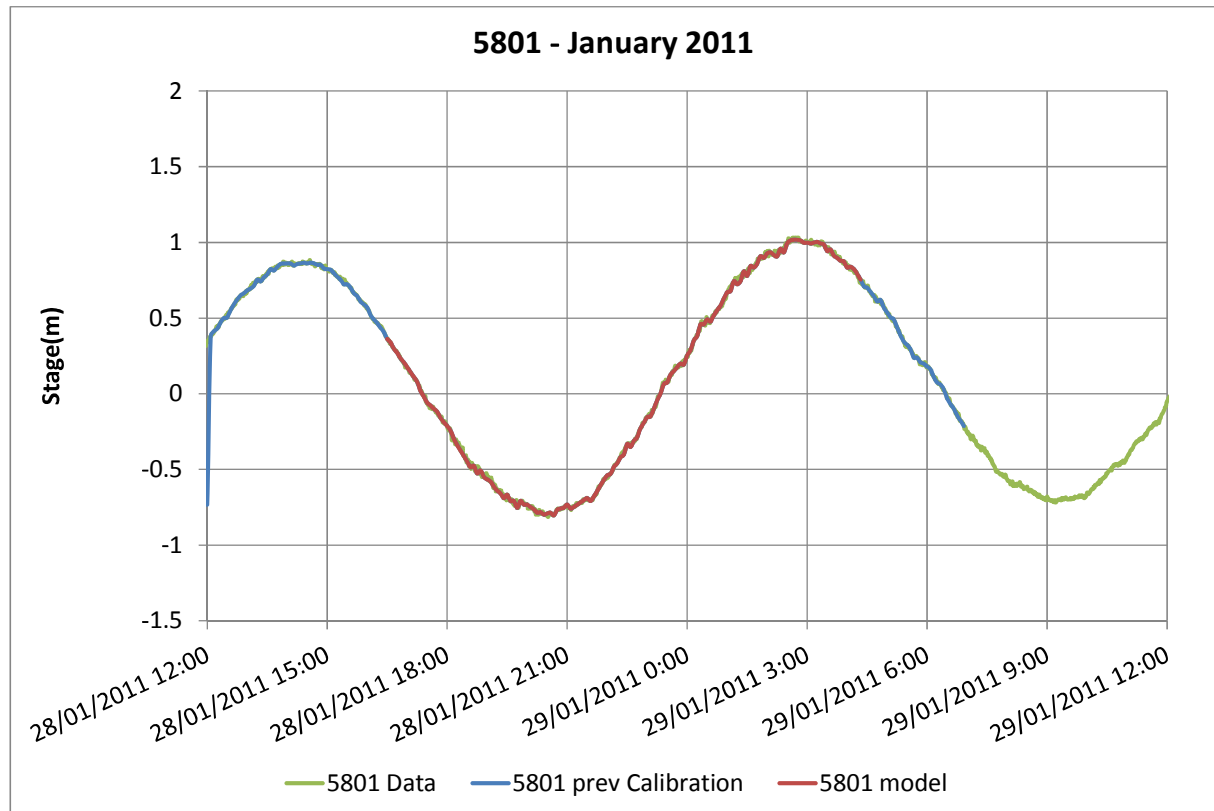
5 Validation Results

Site 5539 – Hatea at Town Basin



5 Validation Results

Site 5801 – Marsden Point (Sea level time series applied to downstream model boundary at Whangarei Port)



5 Validation Results

Table 5-2 Validation Results for Sites

Site ID	Site Name	Max flood elevation (m OTP)	Time of flood peak	Predicted peak flow (m ³ /s)	Model level	Model flow	Model peak time
5525	Kirikiri at Cheviot Street	16.9	23:50 on 28/01		16.9	28.2	28/01/2011 23:00
5528	Raumanga at Bernard St	7.1	23:50 on 28/01	86.9	7.0	119.3	29/01/2011 00:15
5527	Waiarohia at Lovers Lane	5.8	00:30 on 29/01	87.0	5.9	109.9	29/01/2011 00:55
Dam 020 LT01	Whau Valley Reservoir Level	108.3	Estimated 23:30 on 28/01 to 00:00 on 29/01		108.4	37.8	29/01/2011 01:00
5519	Waiarohia at Russell Rd				16.4	96.4	29/01/2011 08:20
5538	Hatea at Whareora Road	15.2	00:15 on 29/01	221.0	15.4	222.1	29/01/2011 00:05
5539	Hatea at Town Basin	1.2	Estimated 01:00 on 29/01 (before Tidal peak)		1.2	307.5	29/01/2011 03:00
5801	Marsden Point (Tidal)	1.0	High tide on 29/01 @ 02:43		1.0	552.6	29/01/2011 02:40

Table 5-3 Measured and modelled debris level points

Flood Levels				Model		Comparison		
Code	X [m NZTM]	Y [m NZTM]	Z [mOTP]	Ground Level (m AD)	Max Flood Level (m AD)	Flood Depth (m AD)	Diff. (mAD)	Comments
1001	1720797.32	6050416.98	75.31	75.382	75.39	0.006	0.078	
1002	1720794.39	6050412.39	75.15	75.219	75.32	0.105	0.174	
1003	1720790.37	6050400.77	74.71	74.878	75.15	0.267	0.433	US of waterfall and bridge. Many changes in long profile. Bottom levels not well known. Assumptions made.
1004	1720787.04	6050393.17	74.68	74.848	75.04	0.194	0.358	
1005	1720787.08	6050387.08	74.62	74.728	74.99	0.265	0.376	
1006	1720823.69	6050300.46	72.95	72.984	73.08	0.100	0.131	
1007	1720826.28	6050295.88	72.80	72.826	73.00	0.177	0.204	
1008	1720827.98	6050288.10	72.83	72.975	72.86	-0.112	0.029	
1009	1720830.52	6050279.68	72.85	72.857	72.69	-0.165	-0.155	
1010	1720797.32	6050416.98	75.31	75.382	75.39	0.006	0.078	
1011	1720794.39	6050412.39	75.15	75.219	75.32	0.105	0.174	
1012	1720790.37	6050400.77	74.71	74.878	75.15	0.267	0.433	Repeated point

5 Validation Results

Flood Levels				Model		Comparison		
								(same as 1003)
1013	1720787.04	6050393.17	74.68	74.848	75.04	0.194	0.358	Repeated point (same as 1004)
1014	1720787.08	6050387.08	74.62	74.728	74.99	0.265	0.376	Repeated point (same as 1005)
1015	1720932.12	6048818.65	21.81	20.829	21.77	0.936	-0.044	
1016	1721011.51	6048851.16	22.72	22.701	22.52	-0.180	-0.196	
1017	1721009.72	6048845.68	22.72	22.562	22.48	-0.086	-0.247	
1018	1721005.91	6048834.19	22.62	22.718	22.36	-0.357	-0.255	Hatea river US of bridge. Steep area with many changes. Hard to calibrated as real bed level is unknown.
1019	1720966.83	6048758.32	20.98	20.595	21.40	0.806	0.422	
1020	1720971.80	6048715.14	20.65	20.776	20.81	0.036	0.165	
1021	1720971.17	6048709.31	20.66	20.695	20.73	0.030	0.067	
1022	1720969.09	6048705.06	20.63	20.757	20.68	-0.075	0.050	
1023	1720932.63	6048682.21	20.35	20.468	20.34	-0.129	-0.011	
1024	1720936.78	6048686.30	20.41	20.480	20.39	-0.092	-0.018	
1025	1720941.84	6048687.13	20.47	20.509	20.44	-0.071	-0.033	
1026	1720841.86	6048558.42	19.23	19.119	18.81	-0.310	-0.420	Hatea river US of bridge. Steep area with many changes. Hard to calibrated as real bed level is unknown.
1027	1720617.53	6048497.54	16.19	15.365	16.49	1.123	0.298	
1028	1720531.29	6048516.1	16.07	14.422	16.30	1.878	0.230	
2000	1719073.59	6046547.93	11.15	11.243	11.31	0.071	0.165	
2001	1719073.01	6046530.88	11.15	11.149	11.23	0.082	0.082	
2002	1719072.71	6046525.96	11.16	11.202	11.19	-0.014	0.024	
2003	1719071.16	6046523.16	11.18	11.087	11.18	0.097	0.003	
2004	1719023.72	6046473.77	10.88	10.881	10.90	0.017	0.019	
2005	1719021.61	6046468.31	10.83	10.803	10.88	0.076	0.047	
2006	1719019.93	6046460.98	10.86	10.963	10.84	-0.124	-0.025	
2007	1719020.74	6046451.48	10.78	10.942	10.79	-0.156	0.011	
2008	1719019.42	6046444.34	10.78	10.856	10.72	-0.133	-0.052	
2009	1718980.26	6046242.87	8.60	8.693	9.10	0.403	0.496	Points behind Waiarohia right bank. Debris levels are similar to model results at junction. Results are sensitive to flow over bank (and levels in Waiarohia should be near bank level)
2010	1718977.31	6046251.33	8.64	8.772	9.09	0.322	0.450	
2011	1718977.17	6046255.35	8.68	8.746	9.10	0.355	0.425	
2012	1719034.94	6046081.73	8.11	8.118	8.05	-0.070	-0.057	
2013	1719031.26	6046092.29	8.15	8.102	8.12	0.022	-0.027	
2014	1719029.73	6046104.61	8.27	8.279	8.24	-0.042	-0.035	

5 Validation Results

Flood Levels				Model		Comparison		
2015	1719024.27	6046131.14	8.19	8.082	8.50	0.416	0.304	Irregular long profile levels when comparing with 2012, 2013 and 2014.
2016	1719018.93	6046144.57	8.18	8.252	8.59	0.339	0.413	
2017	1719056.83	6046045.98	8.35	8.125	7.93	-0.192	-0.419	
2018	1719056.96	6046037.96	8.41	5.977	7.93	1.953	-0.484	Irregular long profile levels when comparing with 2012, 2013 and 2014.
2019	1719058.45	6046023.22	7.56	7.453	7.73	0.275	0.169	
2020	1719040.50	6046024.54	7.81	7.716	7.71	-0.006	-0.097	
2021	1719102.90	6045844.29	5.88	5.429	5.82	0.395	-0.060	Cafler Park
2022	1719120.39	6045777.53	5.74	5.567	5.65	0.079	-0.097	
2023	1719133.56	6045783.75	5.70	5.682	5.67	-0.017	-0.036	
2024	1719137.67	6045789.95	5.75	5.739	5.67	-0.067	-0.081	
2025	1719258.01	6045494.90	4.31	4.610	4.67	0.056	0.355	Whangarei CBD
2026	1719272.81	6045518.65	4.71	4.857	4.86	0.000	0.143	
2027	1719280.06	6045458.32	4.45	4.450	4.60	0.152	0.157	
2028	1719271.01	6045414.04	4.44	3.253	4.48	1.226	0.036	
2029	1719269.14	6045405.41	4.45	2.560	4.47	1.913	0.026	
2030	1719266.49	6045395.46	4.39	4.042	4.48	0.435	0.083	
2031	1719264.66	6045387.79	4.42	4.091	4.48	0.389	0.058	
2032	1719287.31	6045373.16	4.27	4.445	4.47	0.022	0.199	
2033	1719272.29	6045273.61	3.72	3.869	4.13	0.259	0.406	
2034	1719283.76	6045239.13	3.72	3.508	3.53	0.023	-0.187	
2035	1719263.00	6045216.61	3.68	4.015	3.58	-0.440	-0.103	
2036	1719214.85	6045255.97	3.68	3.797	3.83	0.032	0.152	
2037	1719155.42	6045327.08	4.33	4.279	4.50	0.217	0.165	
2038	1719457.67	6045230.37	3.25	3.837	3.34	-0.493	0.095	
2039	1719466.55	6045233.36	3.27	3.711	3.32	-0.395	0.046	
2040	1719477.92	6045258.07	3.03	3.064	2.95	-0.114	-0.084	
2041	1719481.88	6045279.01	2.75	2.747	2.80	0.050	0.052	
2042	1719454.16	6045279.87	2.71	3.360	3.03	-0.328	0.323	
2043	1719543.99	6045303.08	2.71	2.115	2.61	0.493	-0.100	
2044	1719541.34	6045326.10	2.59	2.078	2.66	0.585	0.075	
2045	1719611.80	6045311.18	2.05	1.956	2.38	0.426	0.334	
2046	1719637.85	6045380.02	2.18	1.944	2.24	0.292	0.054	
2047	1719639.47	6045410.16	2.18	1.979	2.24	0.256	0.053	
2048	1719674.55	6045405.82	2.12	2.120	2.23	0.115	0.119	
2049	1719700.13	6045361.38	2.28	2.273	2.23	-0.041	-0.047	
2050	1719708.59	6045233.62	1.92	1.902	2.12	0.220	0.200	
2051	1719714.79	6045241.15	1.94	1.811	2.09	0.280	0.148	

5 Validation Results

Flood Levels				Model		Comparison		
2052	1719724.63	6045253.12	1.91	1.651	2.06	0.405	0.142	
2053	1719745.05	6045283.23	1.90	1.745	1.94	0.192	0.036	
2054	1719702.87	6045270.42	1.96	1.905	2.09	0.182	0.128	
2055	1719765.12	6045164.02	2.09	2.028	2.17	0.137	0.080	
2056	1719748.33	6045151.95	1.97	1.756	2.17	0.410	0.195	
2057	1719752.97	6045146.76	1.98	1.858	2.17	0.308	0.188	
2058	1719770.47	6045133.10	1.78	1.868	2.17	0.297	0.387	
2059	1719720.06	6045175.31	1.89	1.809	2.17	0.356	0.271	
2060	1719349.03	6045042.61	2.71	2.629	2.70	0.074	-0.003	Morningside area.
2061	1719505.36	6044986.07	2.52	2.619	2.70	0.084	0.180	
2062	1719477.54	6044970.67	2.50	2.349	2.70	0.354	0.206	
2063	1719402.11	6044728.34	2.53	1.825	2.70	0.876	0.172	
2064	1719402.57	6044716.83	2.52	2.033	2.70	0.669	0.183	
2065	1719411.70	6044731.46	2.44	2.237	2.70	0.465	0.259	
2066	1719462.01	6044730.94	2.44	2.453	2.70	0.250	0.265	
2067	1719432.69	6044770.03	2.32	2.366	2.70	0.337	0.388	
2068	1719432.39	6044758.64	2.32	2.191	2.70	0.512	0.381	
2069	1719437.64	6044730.95	2.33	2.230	2.70	0.473	0.369	
2070	1717612.55	6044759.62	28.30	28.303	28.12	-0.179	-0.171	Culvert shows to have very high head losses (about 2m)
2071	1716906.11	6043681.62	52.84	52.850	52.75	-0.100	-0.094	Kotuku Street, steep section of stream.
2072	1716904.51	6043685.74	52.91	52.841	52.85	0.006	-0.065	
2073	1716903.70	6043690.30	53.10	52.833	52.93	0.095	-0.175	
Bernard Street	1718759.00	6044938.00	7.09	2.700	7.12	4.421	0.031	
Cheviot Street	1718141.53	6044885.94	16.853	15.300	16.82	1.523	-0.030	
Lovers Lane	1719096.00	6045838.00	5.813	1.900	5.85	3.948	0.035	
Town Basin	1719931.00	6045815.00	1.197	1.567	1.16	-0.407	-0.037	
Whareora Road	1720303.00	6048369.00	15.191	10.918	15.33	4.416	0.143	
Whau Valley Res.	1716461.00	6047713.00	108.280	107.200	108.37	1.166	0.086	

Design Events

6.1 Introduction

The 10, 50, 100 and 100yrs plus climate change events were simulated with the verified Hatea model. The details of these simulations are listed below:

6.2 Rain depths and profile

All design events have a storm duration of 12hrs and a profile defined by NRC in its Hydrological report of 2010. The areal reduction factor is defined by Shamseldin (2008) equal to 0.953 for the Hatea catchment. The rain depth is defined by HirdsV3 for all sub-catchment centroids for the respective extreme event. For that reason each event has a variable rain depth distribution over the catchment. The table below shows the rain depth for each design event after applying the respective areal reduction factor.

Table 6-1 Summary of global values

EVENT	Design Average Rain depth (mm)	ARF	Average Model Rain depth (mm)
10yrs	134.6	0.953	128.3
50yrs	188.5	0.953	179.7
100yrs	217.3	0.953	207.1
100yrsCC	253.8	0.953	241.9

6.3 Rain abstractions

The rain abstractions for the design event are defined with a constant infiltration rate as required by the NLR hydrological method. As for other NRC catchment models, a conservative 2mm/hr. infiltration rate was used for all design events for the Hatea model. This considers that high levels of moisture are in the soil at the moment the design storms hit the catchment.

6.4 Downstream Tidal Border Condition

The Tidal condition is defined by the 2yrs generic tide series produced by NRC and explained in the report of 2010. The peak of time of each series has been preliminarily adjusted to approximately match the time of arrival of the flow peak at the tidal influenced zone.

6.5 Flood Maps

The 10, 50, 100 and 100yrs plus climate change 12 hours design events were simulated and the model results exported to GIS to produce the respective flood maps. The flood maps are included in Appendix A of this report.

6 Design Events

6.6 Design Event Results

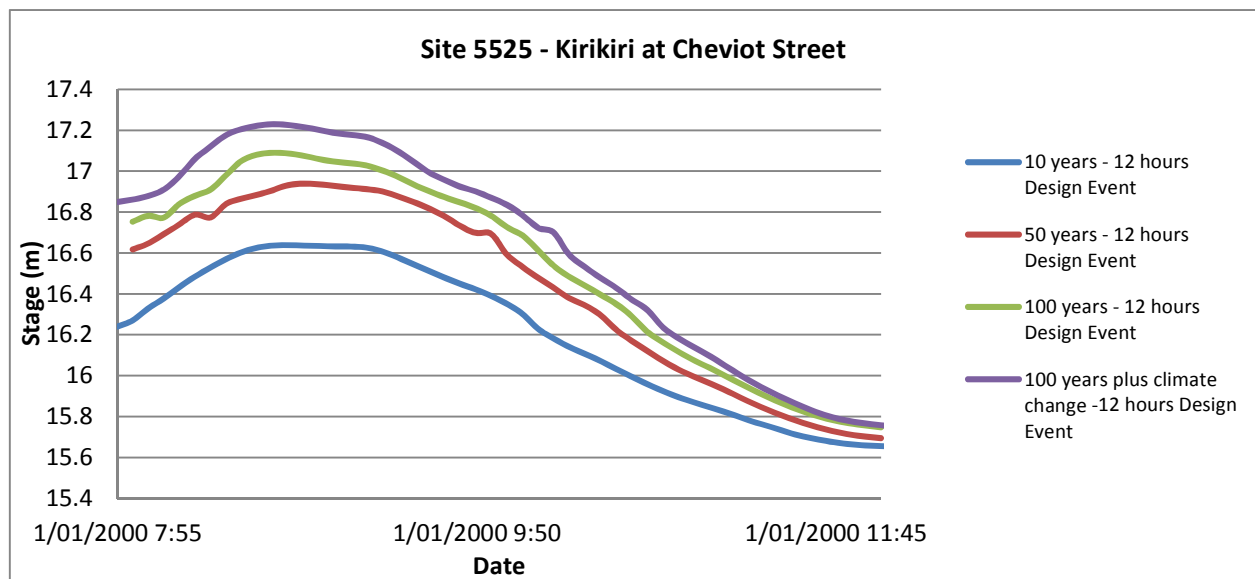
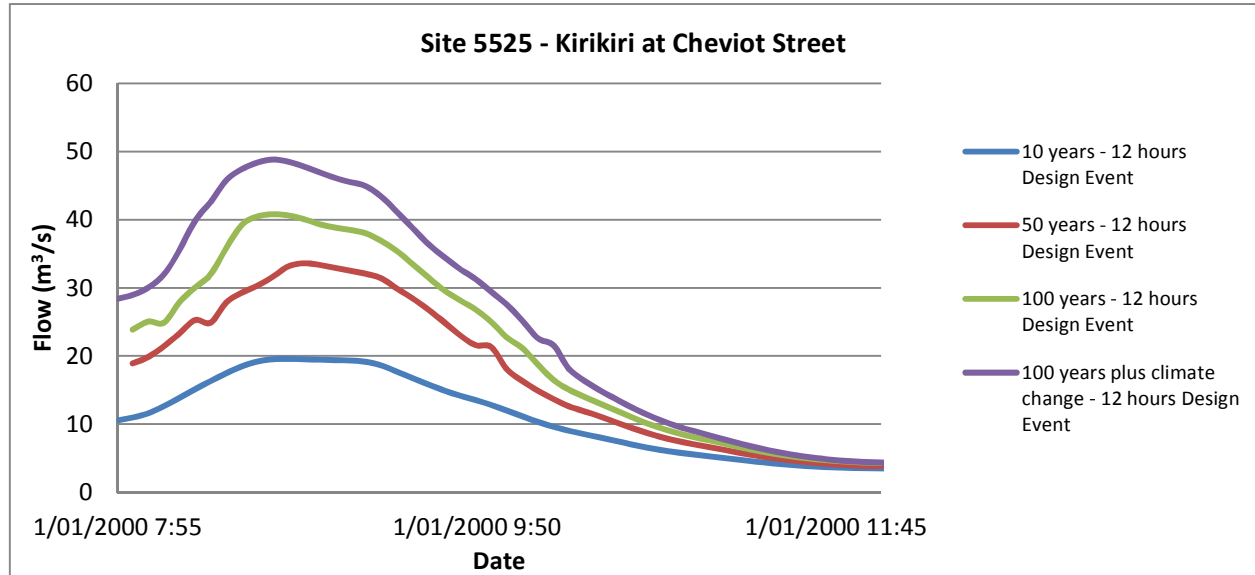
The maximum flow and level results for the four design events at the sites are summarized below in Table 6-2.

Table 6-2 Level gauges –Design Event Results Summary

Site ID	Site Name	Model Maximum Flow (m ³ /s)	Model Maximum Level (m OTP)	Model Time of Peak
10 years - 12 hours				
5525	Kirikiri at Cheviot Street	19.7	16.6	1/01/2000 8:50
5528	Raumanga at Bernard St	72.6	6.1	1/01/2000 9:45
5527	Waiarohia at Lovers Lane	77.8	5.2	1/01/2000 9:20
5519	Waiarohia at Russell Rd	64.2	15.9	1/01/2000 9:15
5538	Hatea at Whareora Road	181.6	14.2	1/01/2000 10:25
5539	Hatea at Town Basin	196.3	1.5	1/01/2000 10:40
5801	Marsden Point (Tidal)	281.8	1.4	1/01/2000 11:15
50 years - 12 hours				
5525	Kirikiri at Cheviot Street	33.6	16.9	1/01/2000 8:55
5528	Raumanga at Bernard St	117.8	7.0	1/01/2000 9:45
5527	Waiarohia at Lovers Lane	125.6	6.2	1/01/2000 9:20
5519	Waiarohia at Russell Rd	104.1	16.5	1/01/2000 9:15
5538	Hatea at Whareora Road	244.6	15.9	1/01/2000 10:00
5539	Hatea at Town Basin	335.5	1.5	1/01/2000 10:15
5801	Marsden Point (Tidal)	453.1	1.4	1/01/2000 10:05
100 years - 12 hours				
5525	Kirikiri at Cheviot Street	40.8	17.1	1/01/2000 8:45
5528	Raumanga at Bernard St	143.8	7.4	1/01/2000 9:45
5527	Waiarohia at Lovers Lane	152.1	6.8	1/01/2000 9:25
5519	Waiarohia at Russell Rd	130.2	16.8	1/01/2000 9:15
5538	Hatea at Whareora Road	283.1	16.5	1/01/2000 9:55
5539	Hatea at Town Basin	403.0	1.6	1/01/2000 9:50
5801	Marsden Point (Tidal)	563.3	1.4	1/01/2000 10:05
100 years plus climate change - 12 hours				
5525	Kirikiri at Cheviot Street	48.8	17.2	1/01/2000 8:45
5528	Raumanga at Bernard St	174.7	7.7	1/01/2000 9:50
5527	Waiarohia at Lovers Lane	179.7	7.4	1/01/2000 9:25
5519	Waiarohia at Russell Rd	161.8	17.2	1/01/2000 9:15
5538	Hatea at Whareora Road	311.1	16.8	1/01/2000 9:30
5539	Hatea at Town Basin	451.2	2.0	1/01/2000 9:35
5801	Marsden Point (Tidal)	648.8	1.9	1/01/2000 11:15

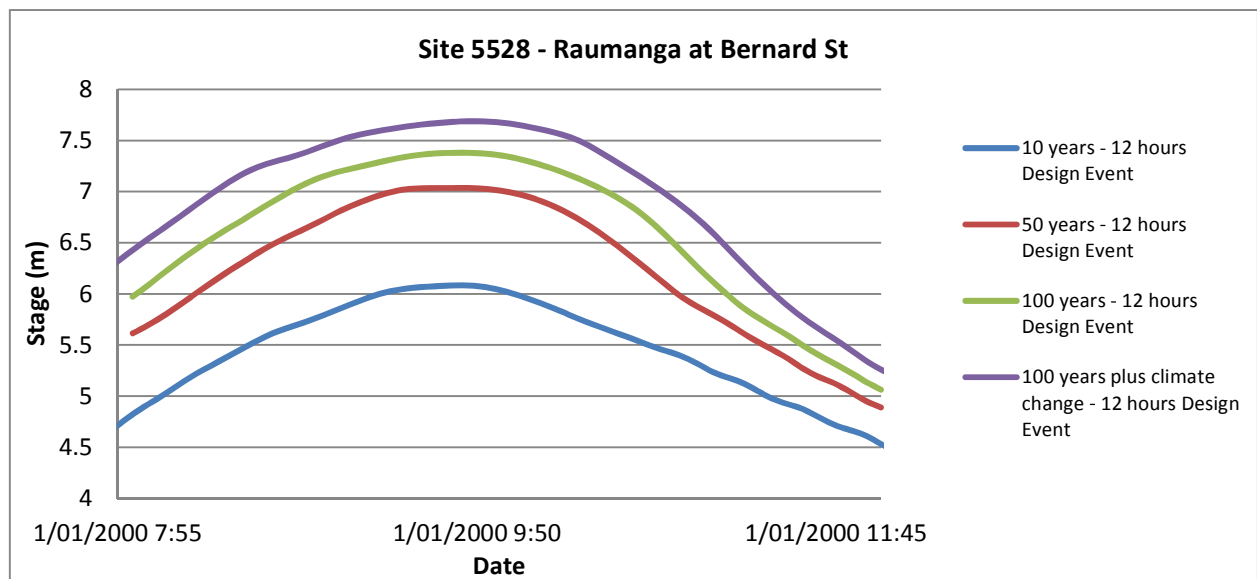
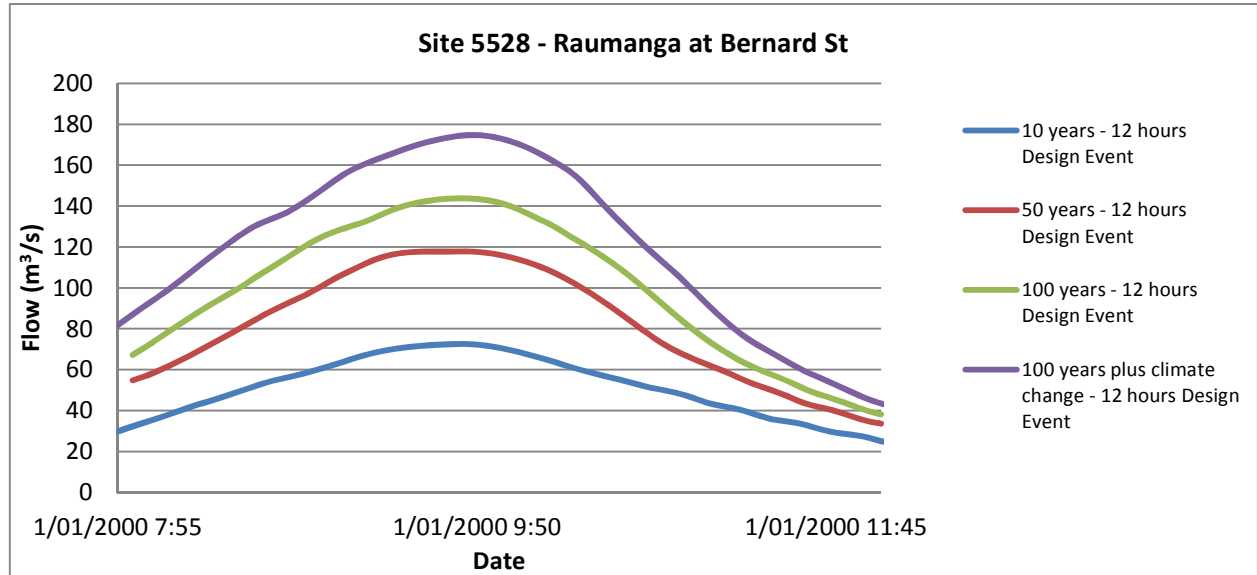
6 Design Events

Site 5525 - Kirikiri at Cheviot Street



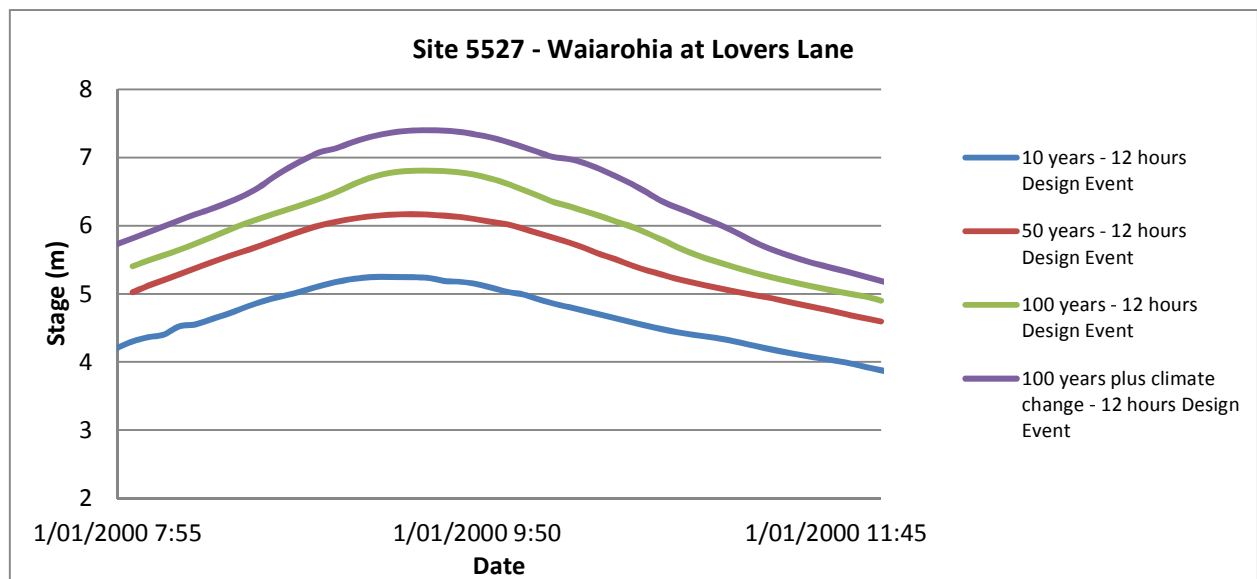
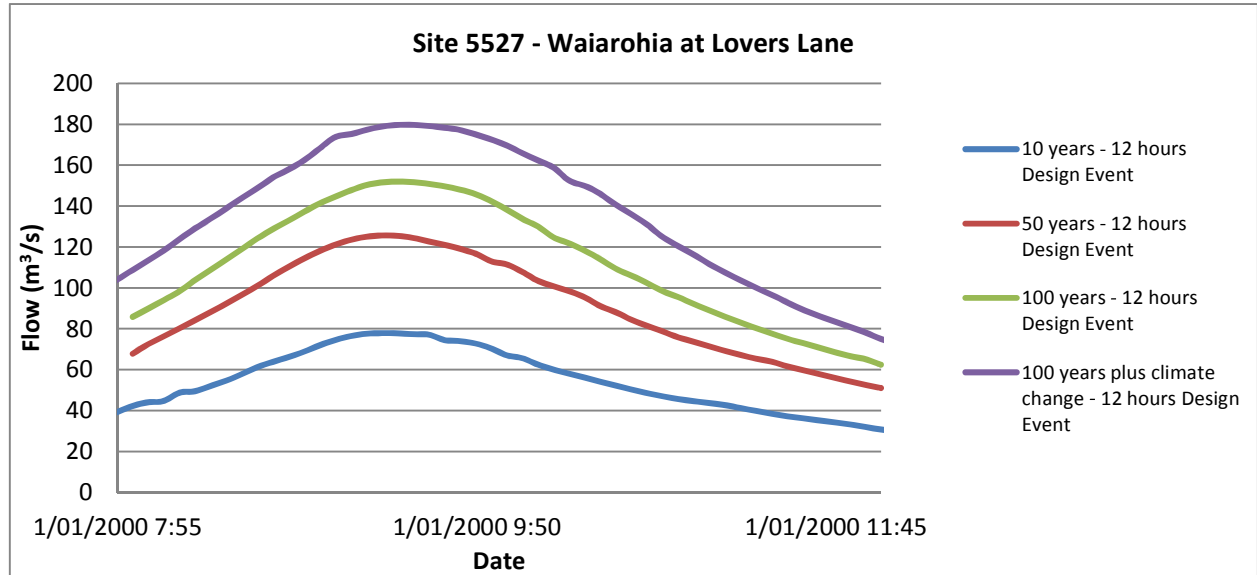
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Site 5528 - Raumanga at Bernard St



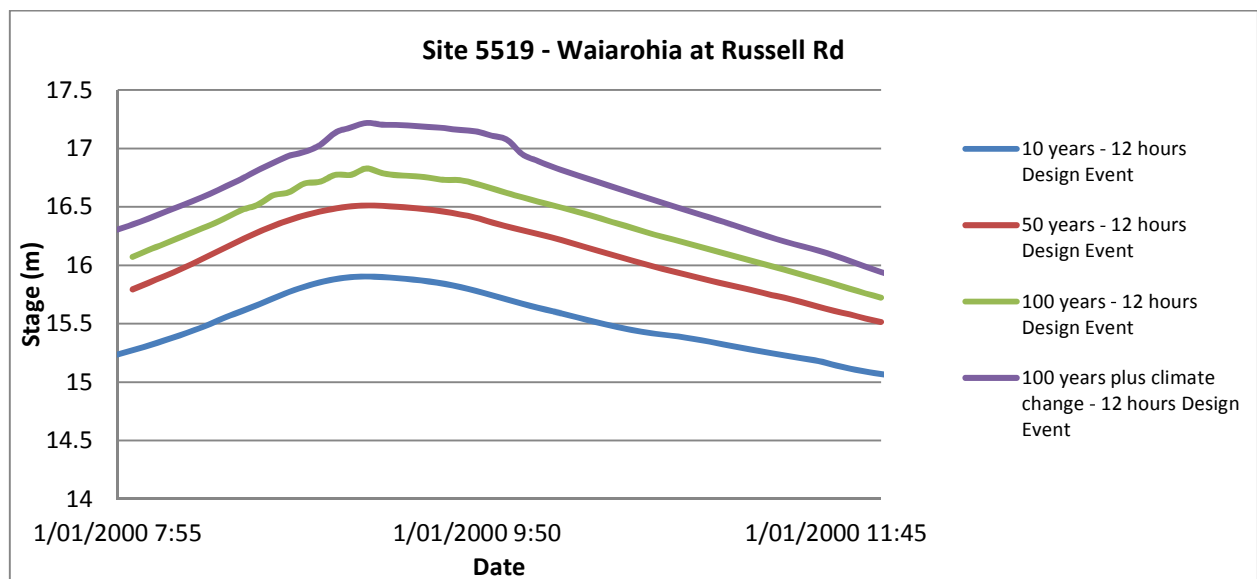
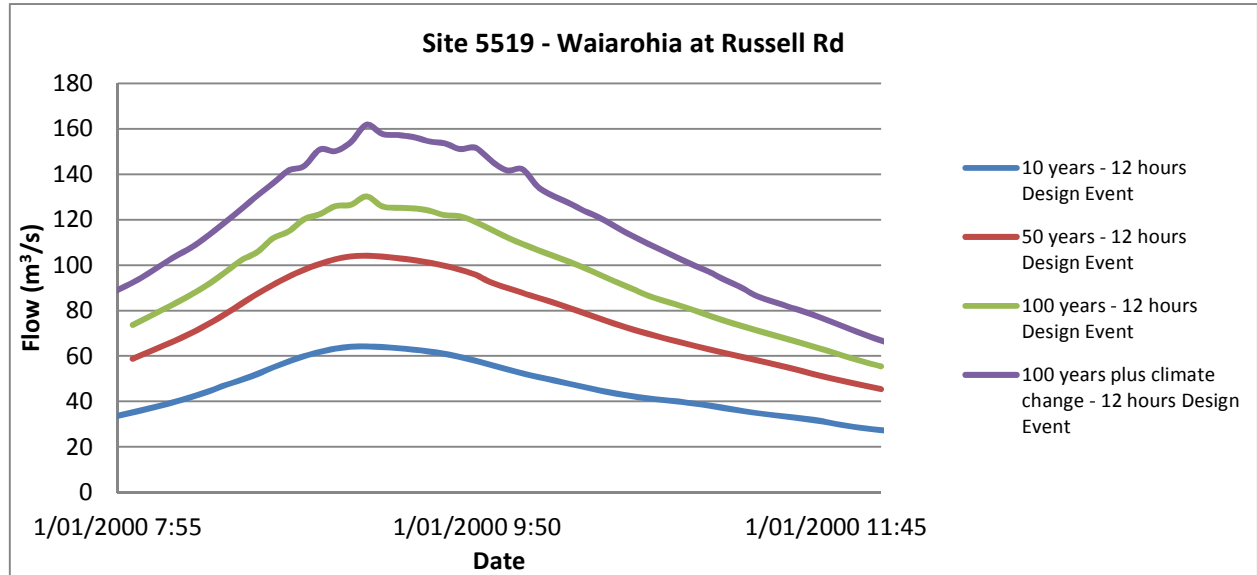
6 Design Events

Site 5527 - Waiarohia at Lovers Lane



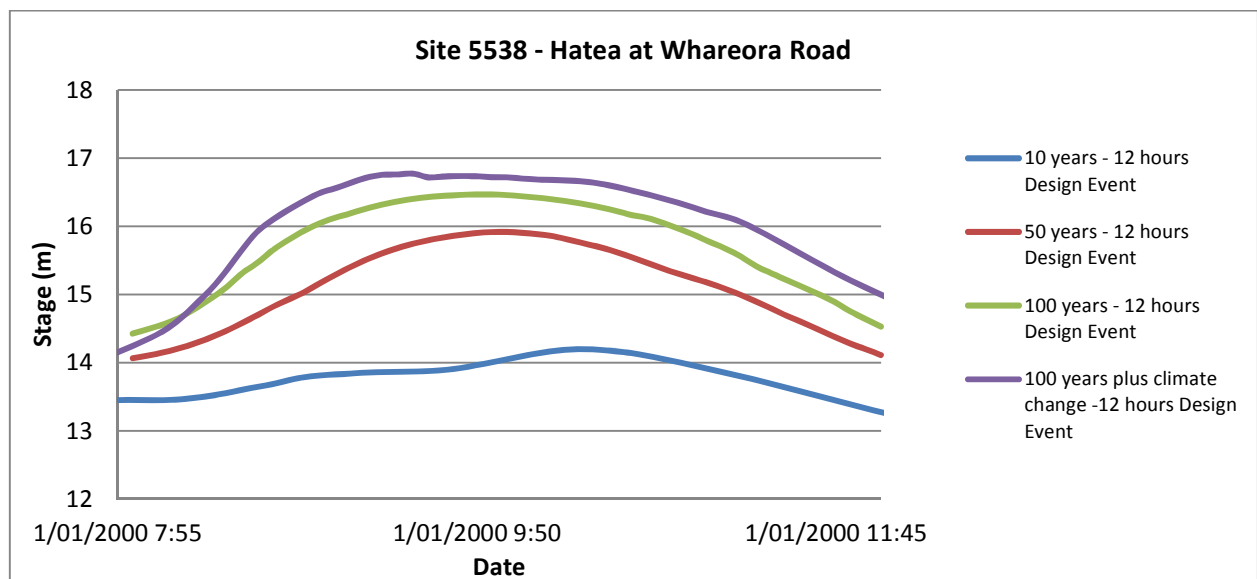
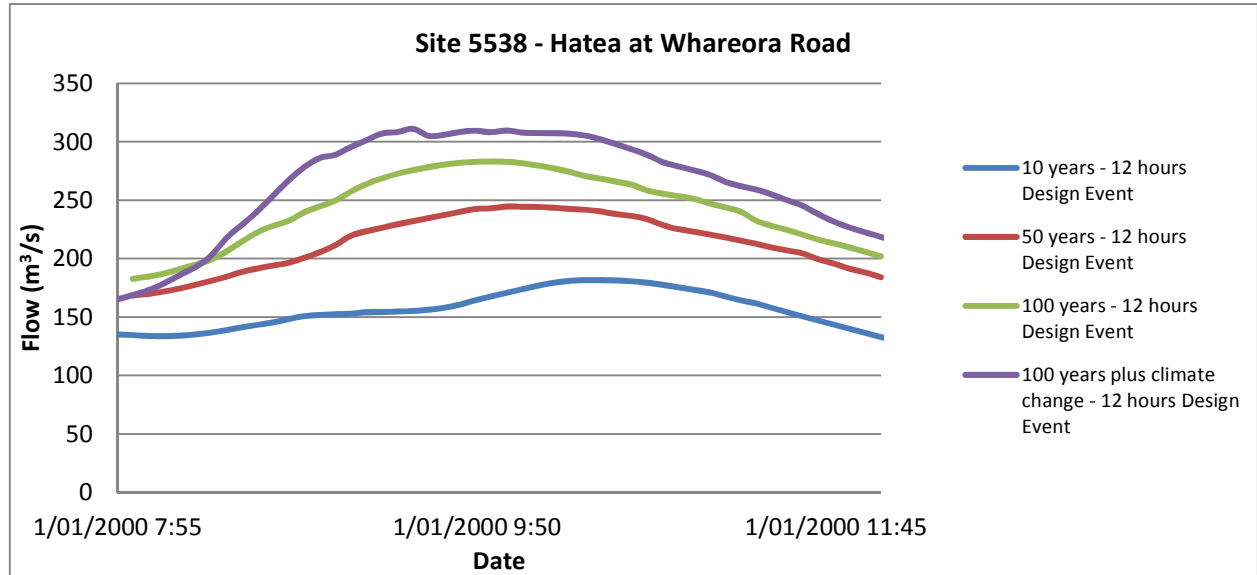
6 Design Events

Site 5519 - Waiarohia at Russell Rd



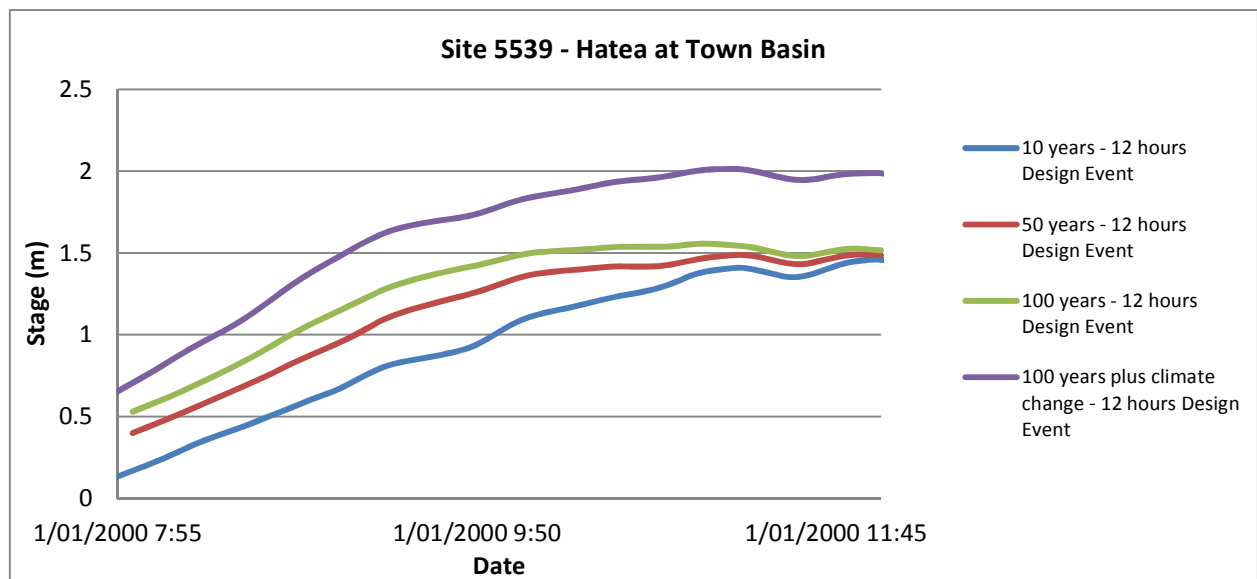
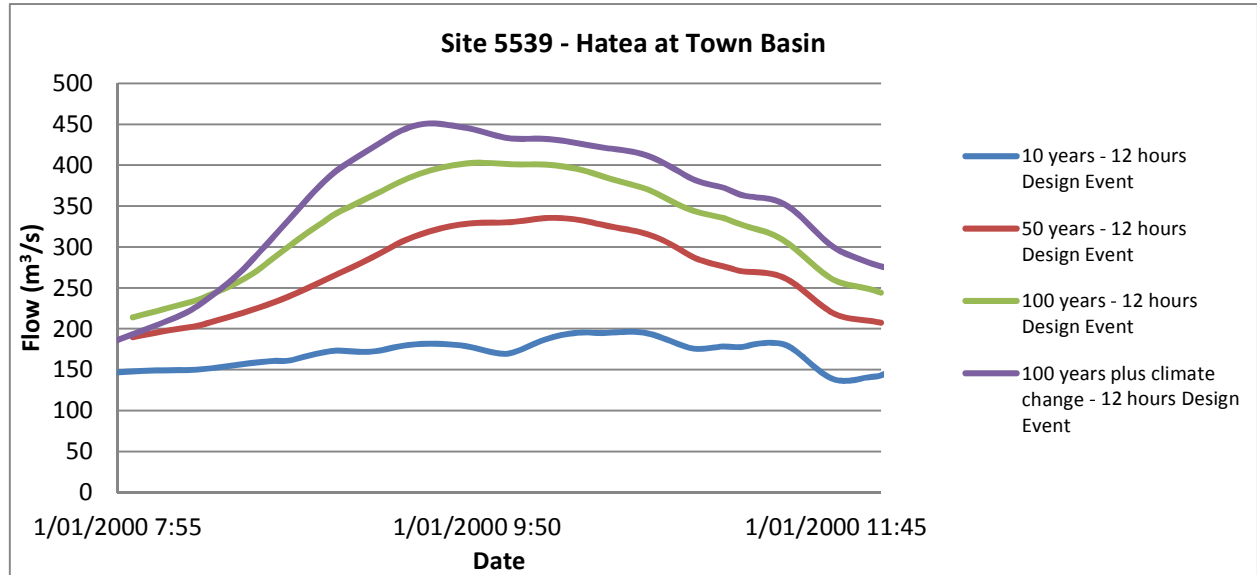
6 Design Events

Site 5538- Hatea at Whareora Road



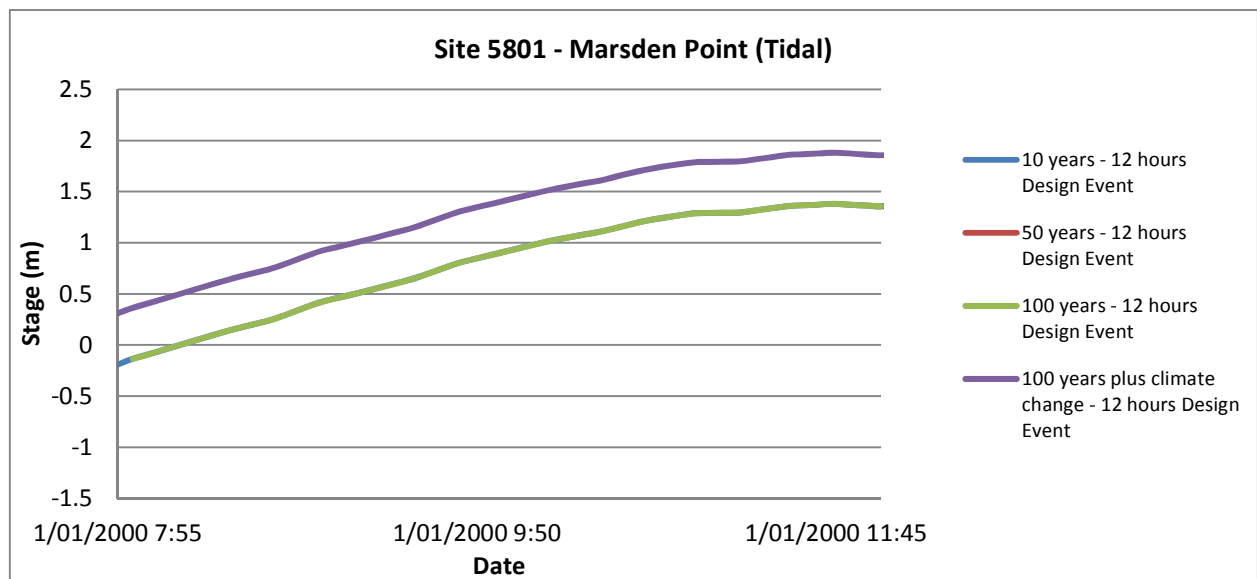
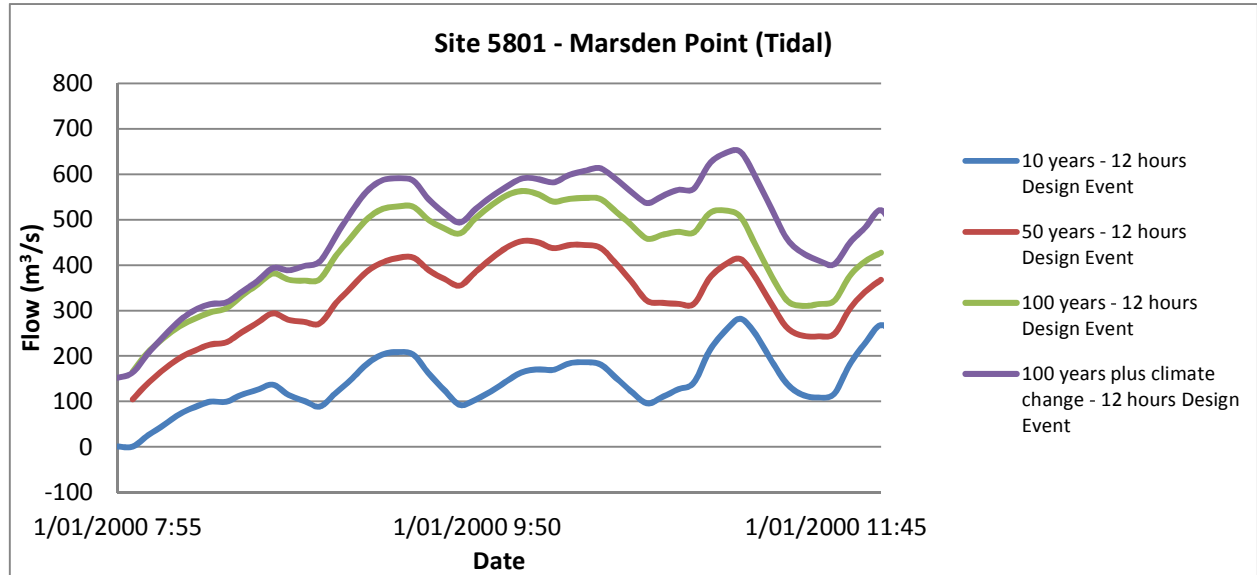
6 Design Events

Site 5539 - Hatea at Town Basin



6 Design Events

Site 5801 - Marsden Point (Tidal)



Discussion and Conclusion

7.1 Discussion Overview

The most critical portion of the verification was proper and well defined hydraulic features represented in the model of the catchment. Some of the critical hydraulic components are bridges, storage areas, spills, 2D areas and well interpolated use of various survey data. In total 10 new storage polygons were created, 161 new river sections, 16 new 2D polygons and an additional 634 spill units among several other type of objects such as bridges and junctions. These aspects were essential to achieving the verification results and were complemented with the hydraulic parameters such as roughness and discharge coefficients.

The final calibration was closely reviewed by URS and NRC and accepted.

The records of flows and rain in Northland catchments suggest that the base flow in all catchments is not of significance, and it has been considered negligible in the design events. However, some base flow (up to $1\text{m}^3/\text{s}$) was input into the model to avoid instabilities during the low flow periods at the beginning and end of storms.

For the design events it is important to note that the level of saturation of the soil is a decision that would depend upon the scenario to be modelled. A conservative infiltration rate of 2mm/hr was adopted for all design storms to account for the saturated soils that would be expected during winter months. This is considerably lower than the 10mm/hr estimated from the US SCS method.

An additional assumption for the design storm model runs was that the Whau Valley reservoir level is full (at Bellmouth invert level) prior to the storm event.

The final flood maps for 10, 50, 100 and 100yrs with climate change AEP are included in the Appendix A.

Limitations

URS New Zealand Limited (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Northland Regional Council and only those third parties who have been authorised in writing by URS to rely on this Report.

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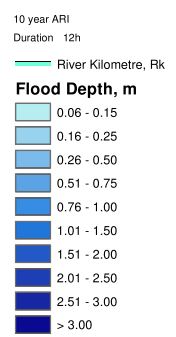
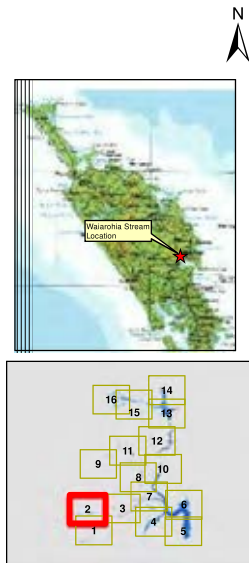
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Any estimates of potential costs which have been provided are presented as estimates only as at the date of the Report. Any cost estimates that have been provided may therefore vary from actual costs at the time of expenditure.

Appendix A Flood Maps





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FLOOD MAPS

WAIAROHIA_HATEA RIVERS 10 YEAR ARI



FLOOD MAPS

WAIAROHIA_HATEA RIVERS 10 YEAR ARI



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FLOOD MAPS

WAIAROHIA_HATEA RIVERS 10 YEAR ARI

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WAIAROHIA_HATEA RIVERS 10 YEAR ARI

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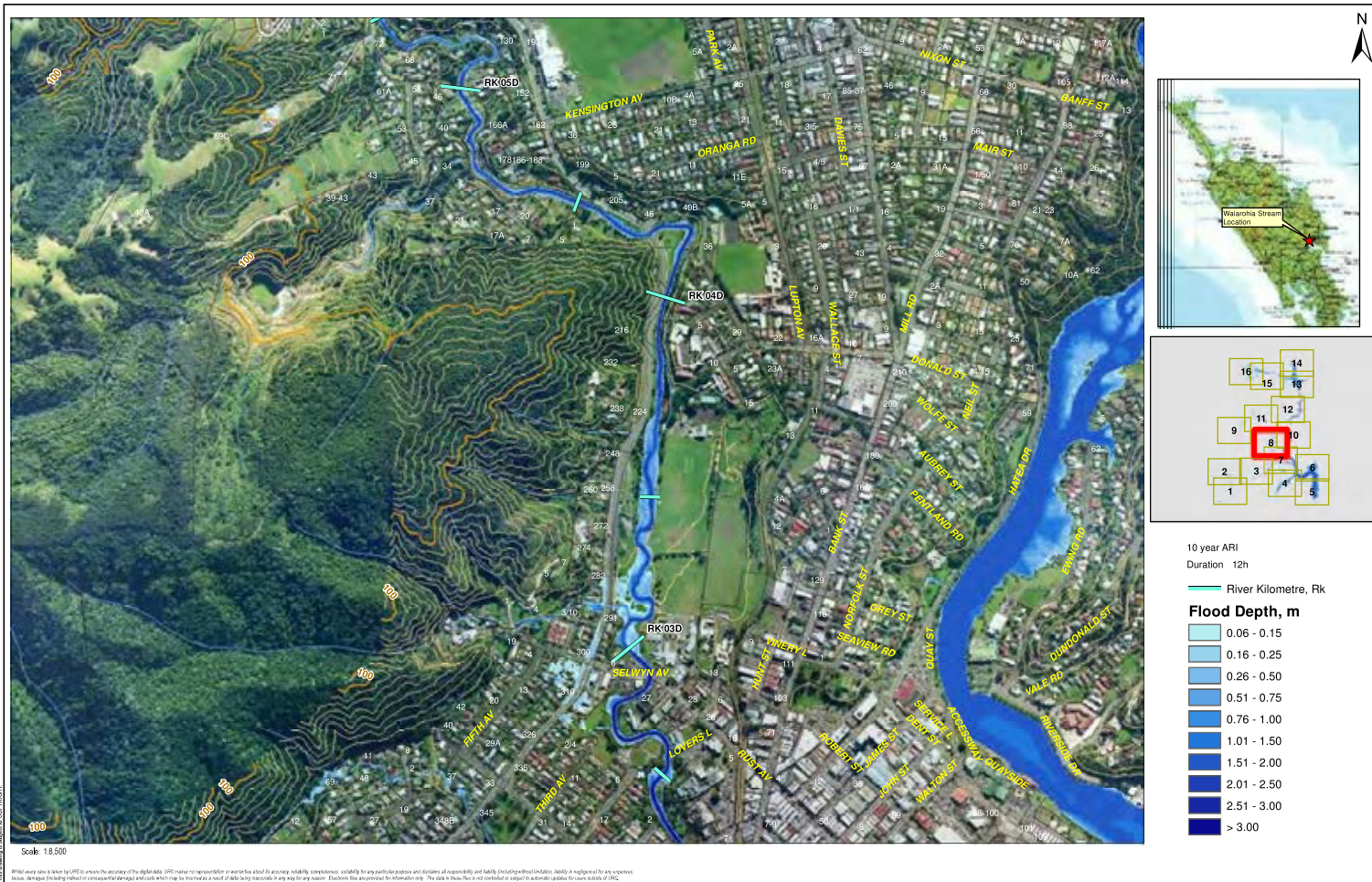
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WAIAROHIA RIVERS 10 YEAR ARI FLOOD MAPS



FLOOD MAPS

WAIAROHIA_HATEA RIVERS 10 YEAR ARI



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WAIAROHIA_HATEA RIVERS 10 YEAR ARI

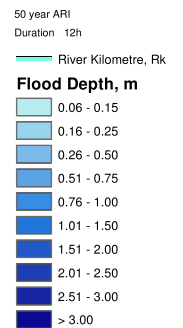
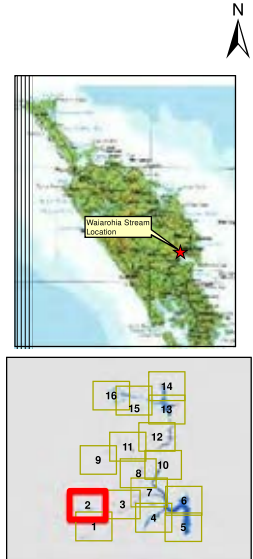
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FLOOD MAPS

WAIAROHIA_HATEA RIVERS 50 YEAR ARI

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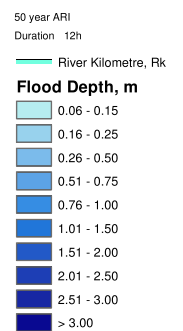
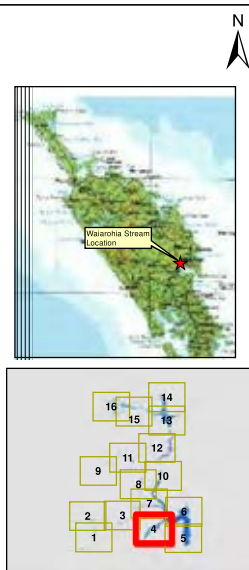
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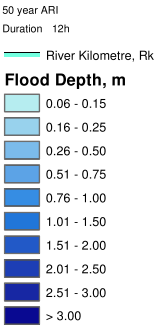
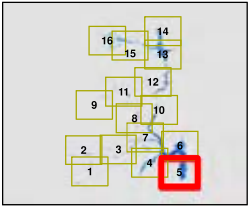
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FLOOD MAPS

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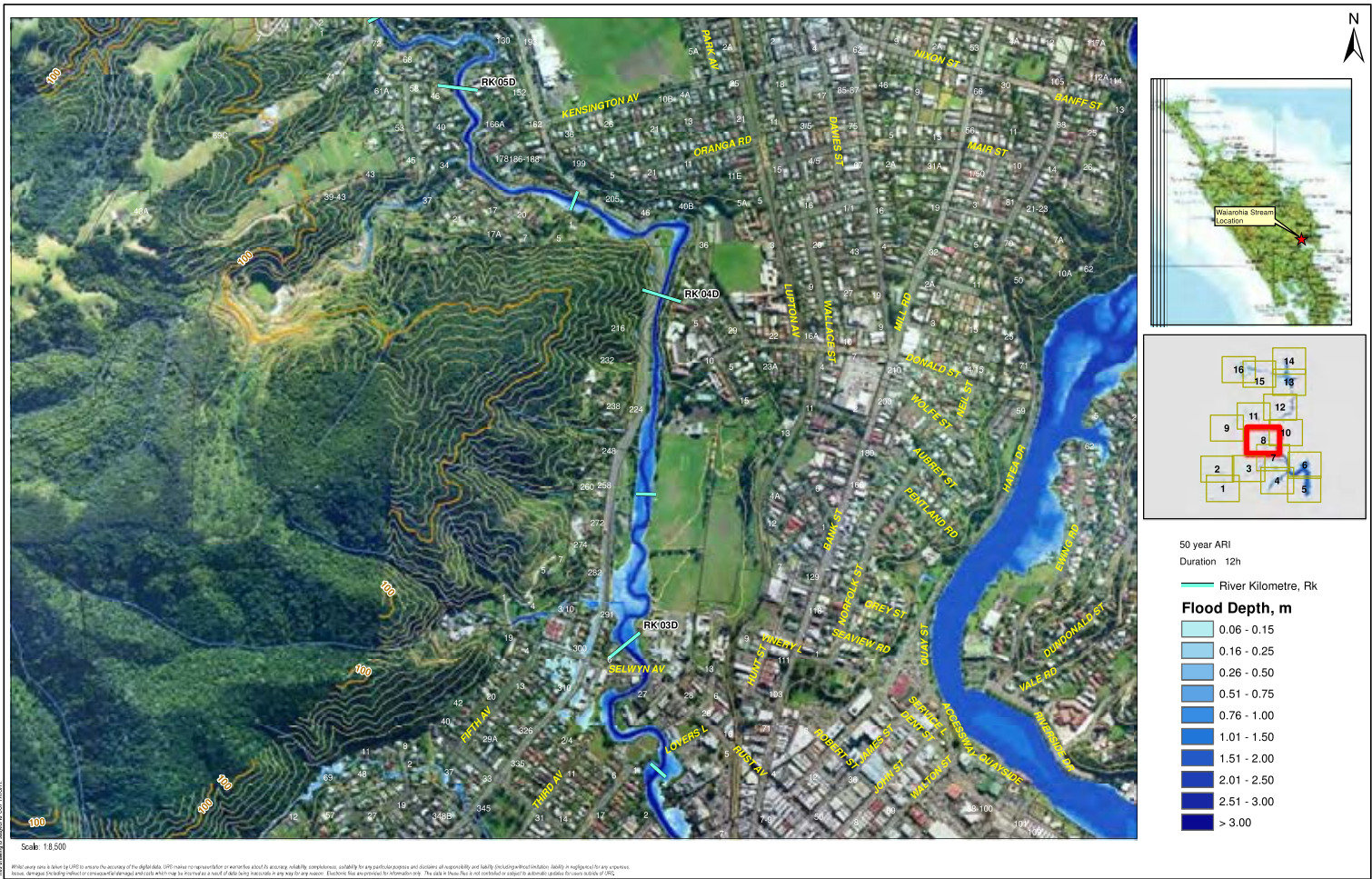
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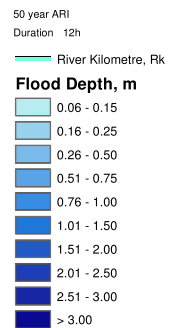
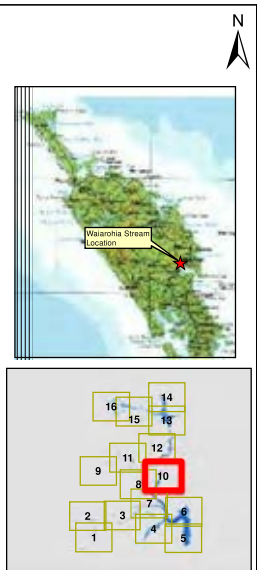
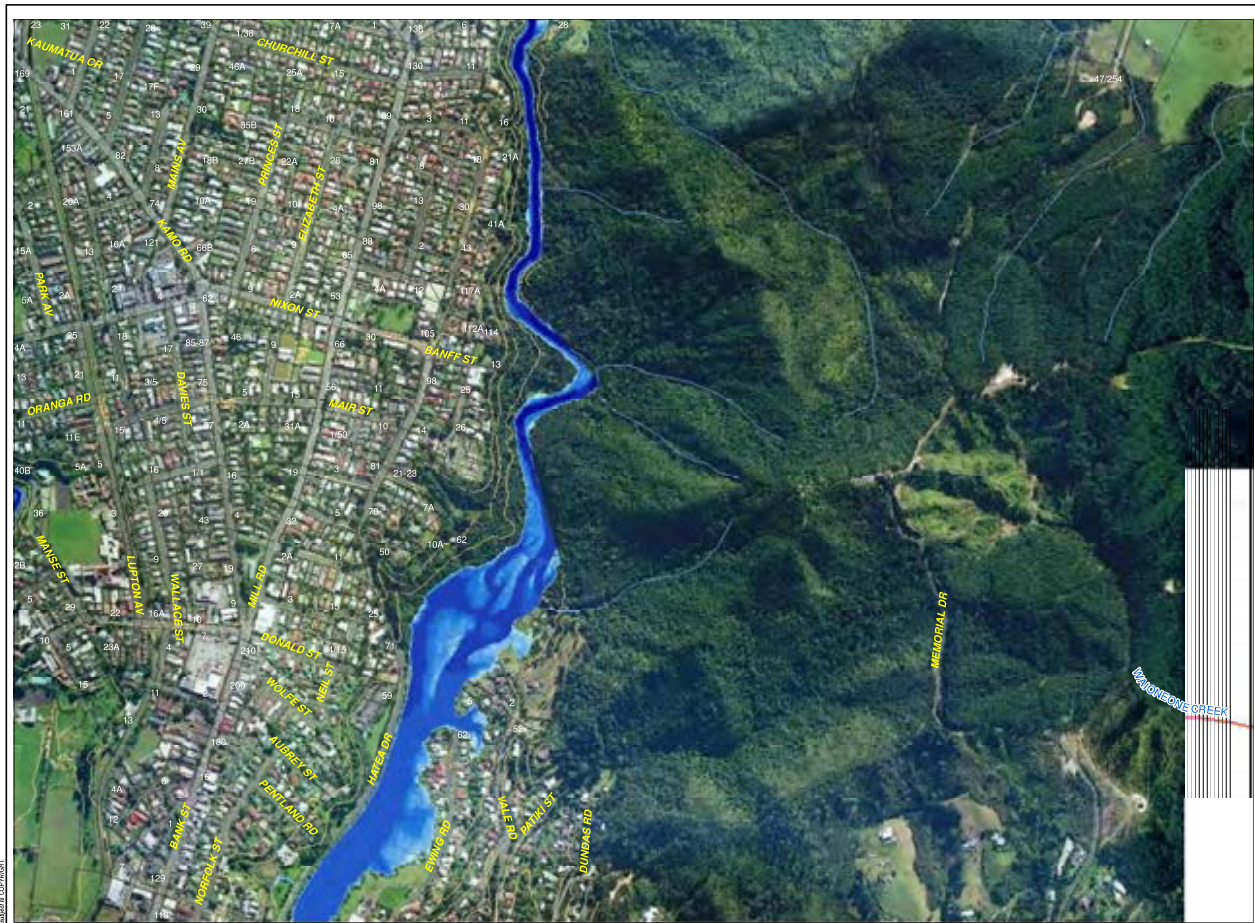
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WAIAROHIA_HATEA RIVERS 50 YEAR ARI

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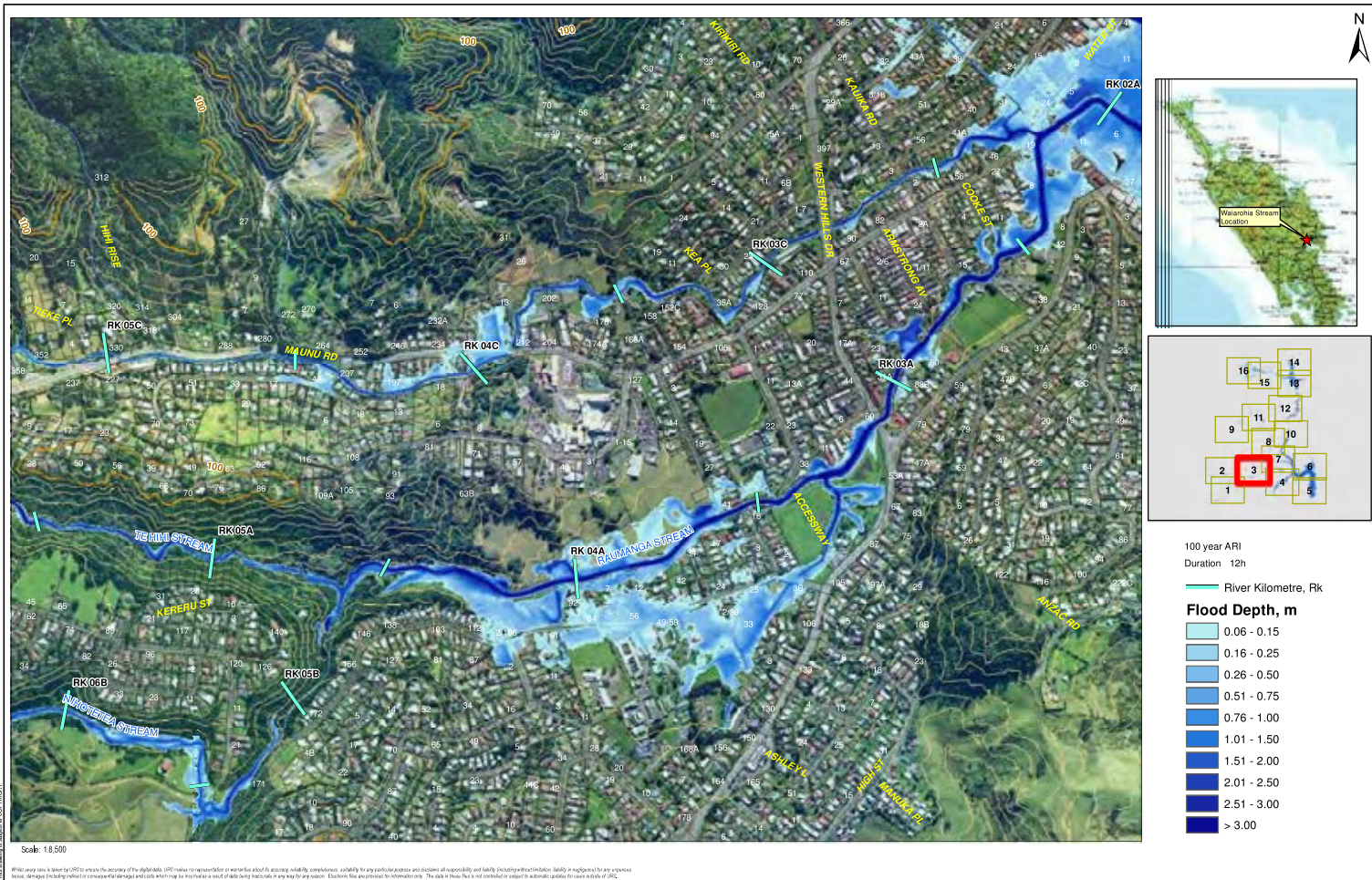


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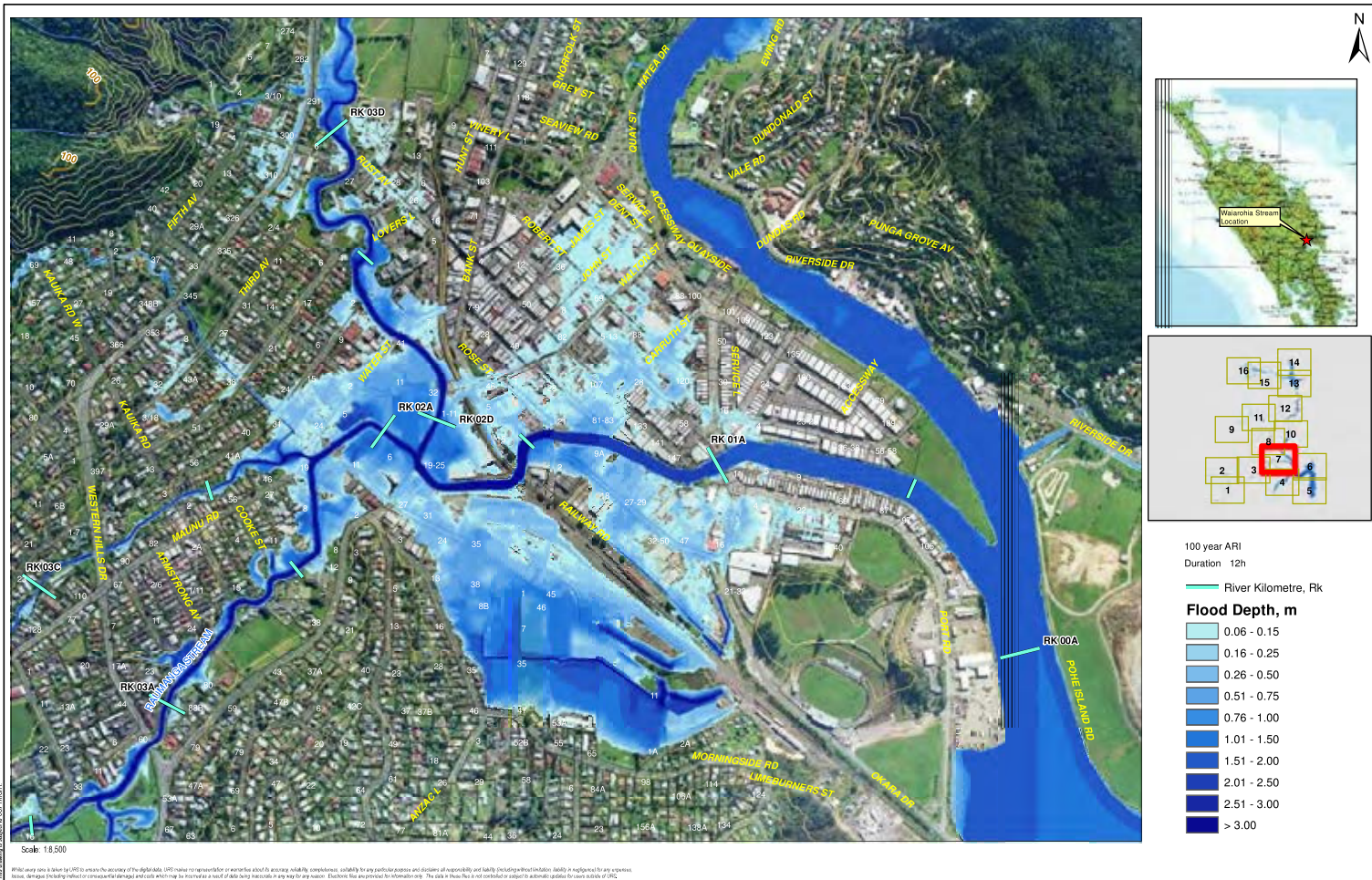
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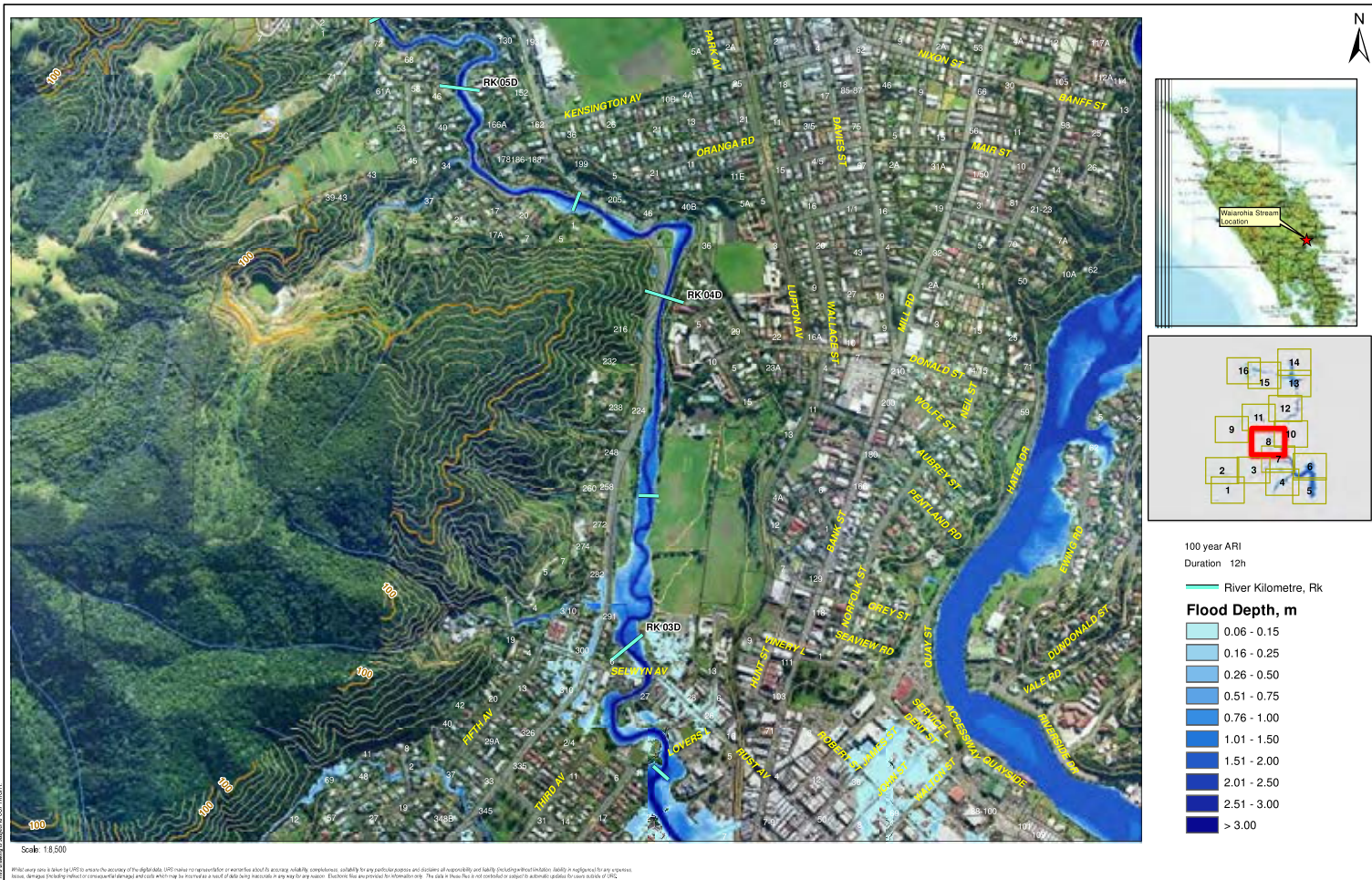
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WAIAROHIA HATEA RIVERS 100 YEAR ARI



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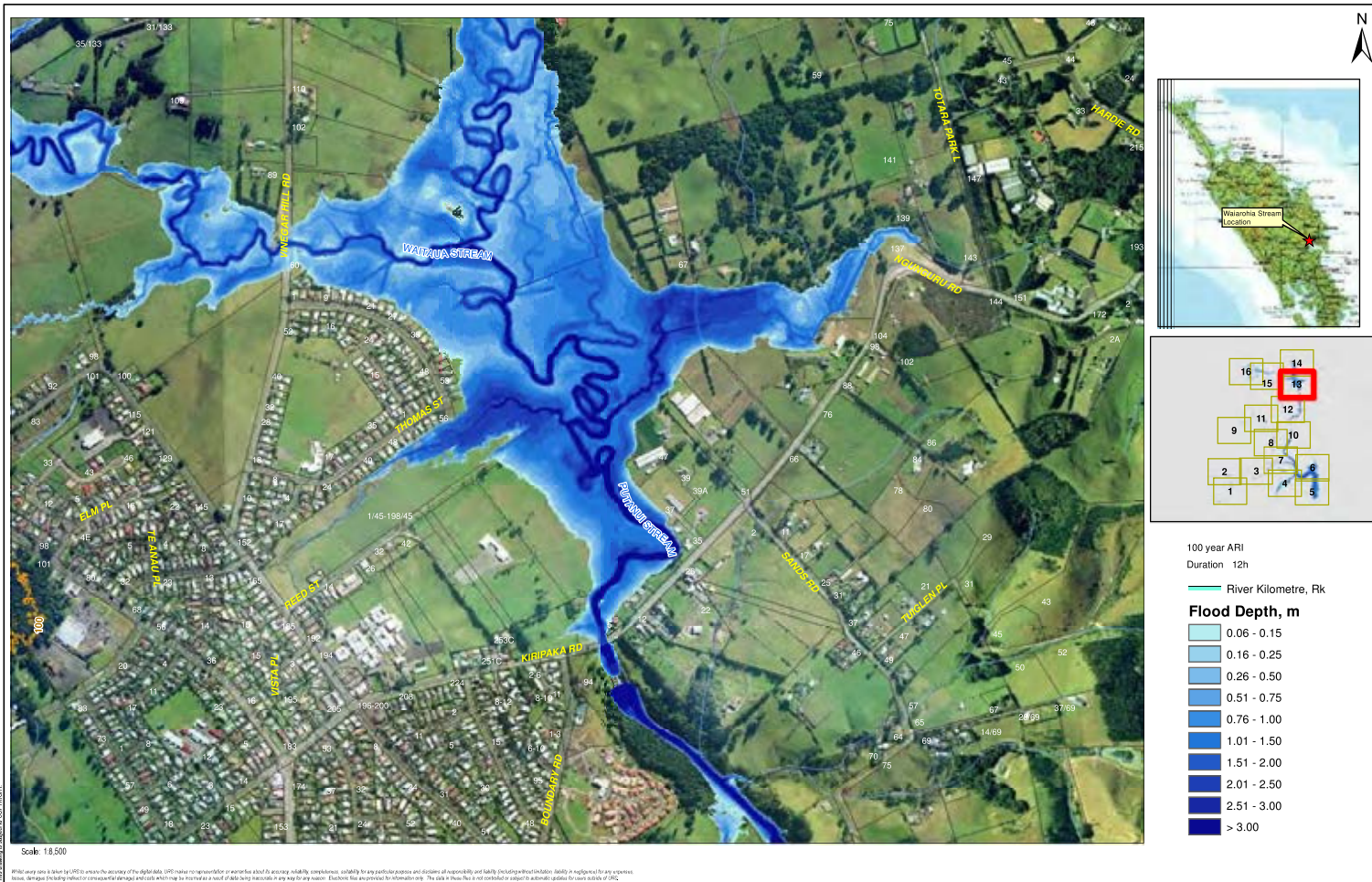
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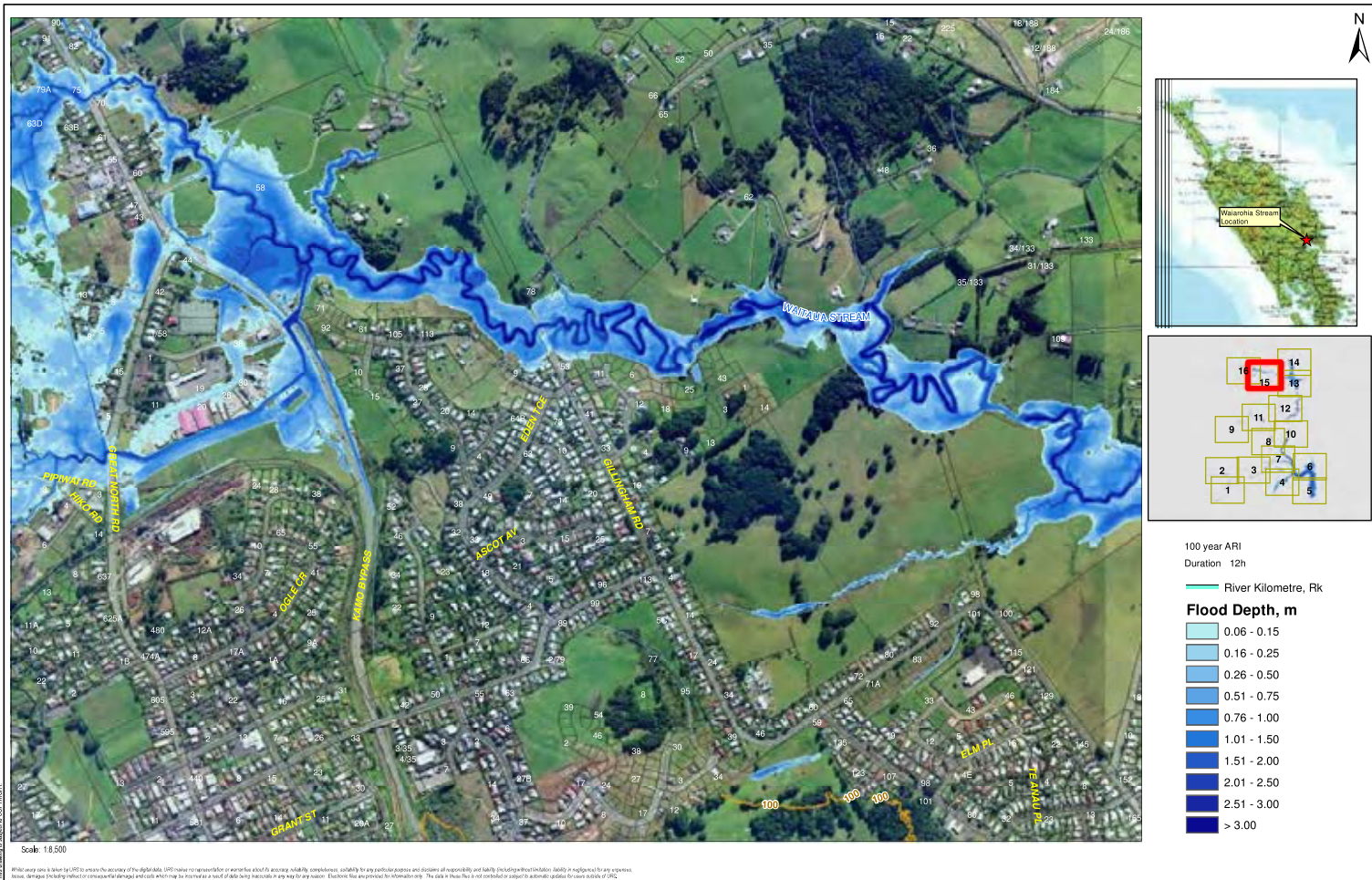
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FLOOD MAPS

WAIAROHIA_HATEA RIVERS 100 YEAR ARI PLUS CLIMATE CHANGE

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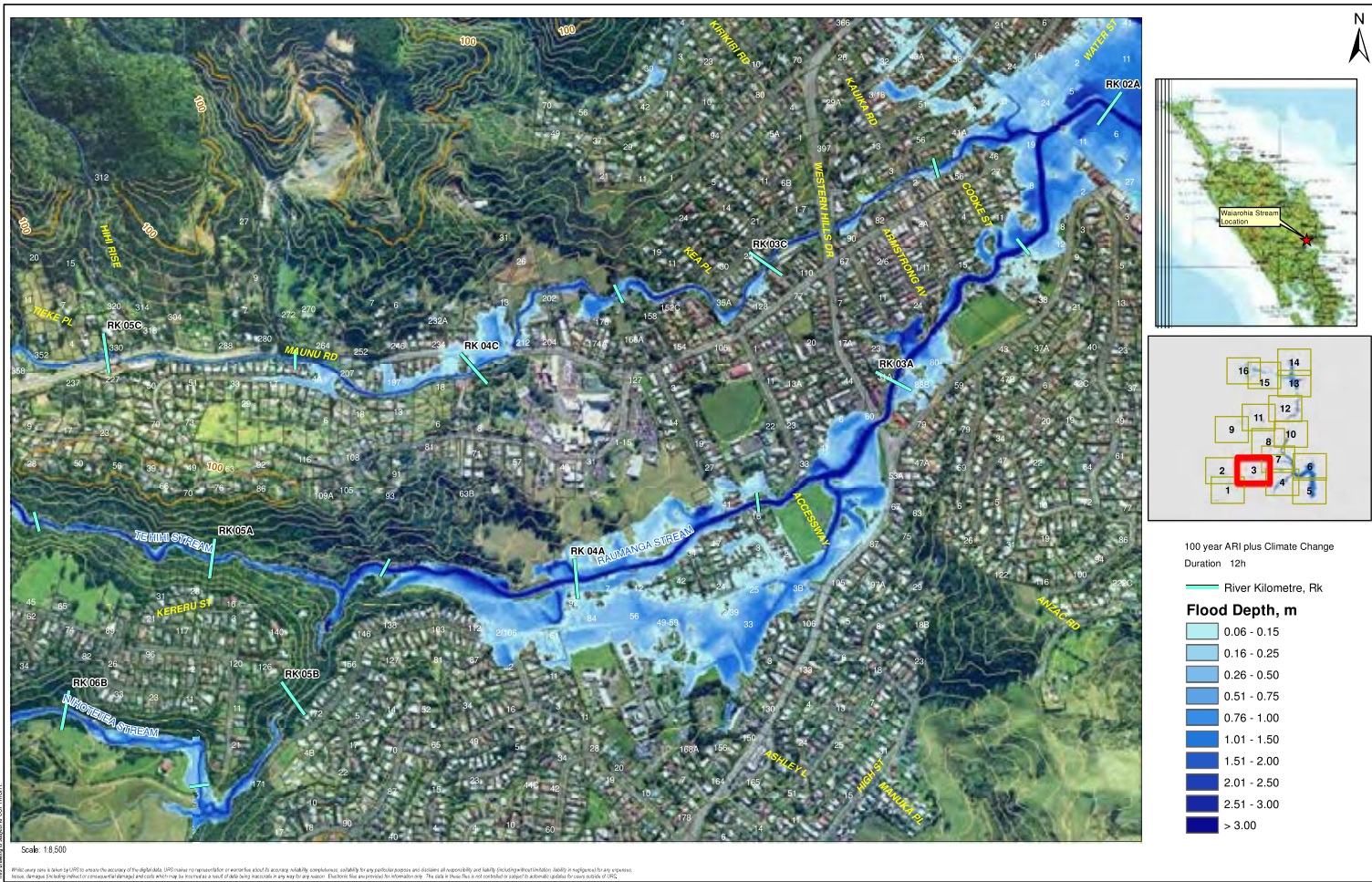
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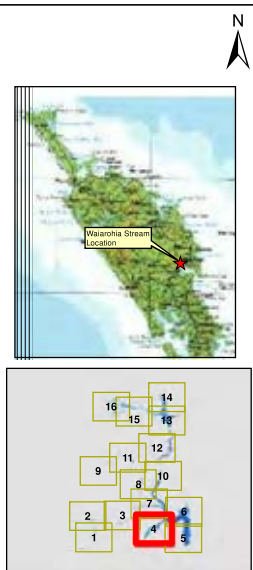
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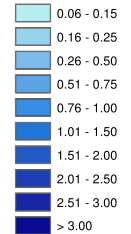
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100 year ARI plus Climate Change
Duration: 12h

— River Kilometre, Rk

Flood Depth, m



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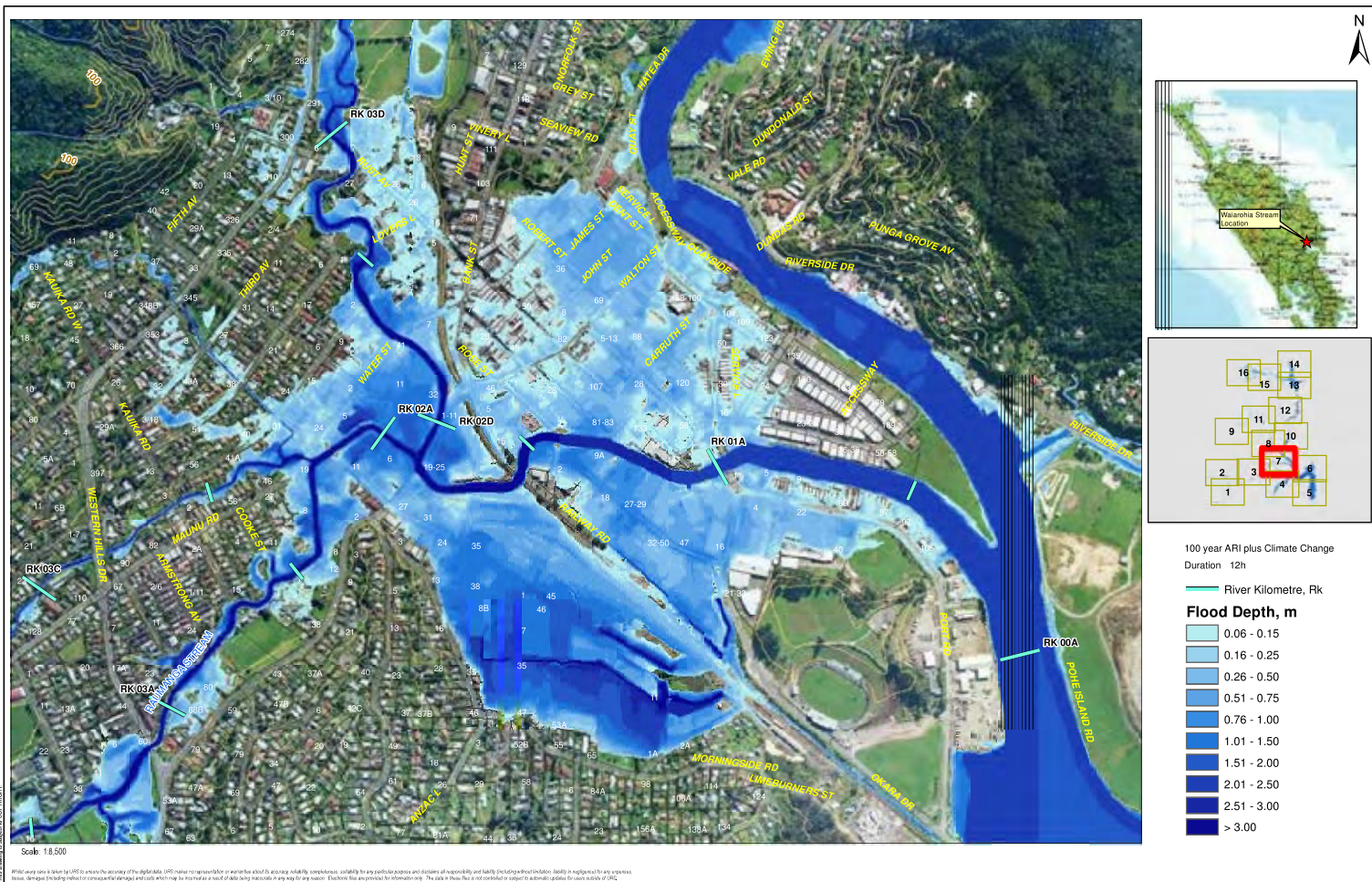
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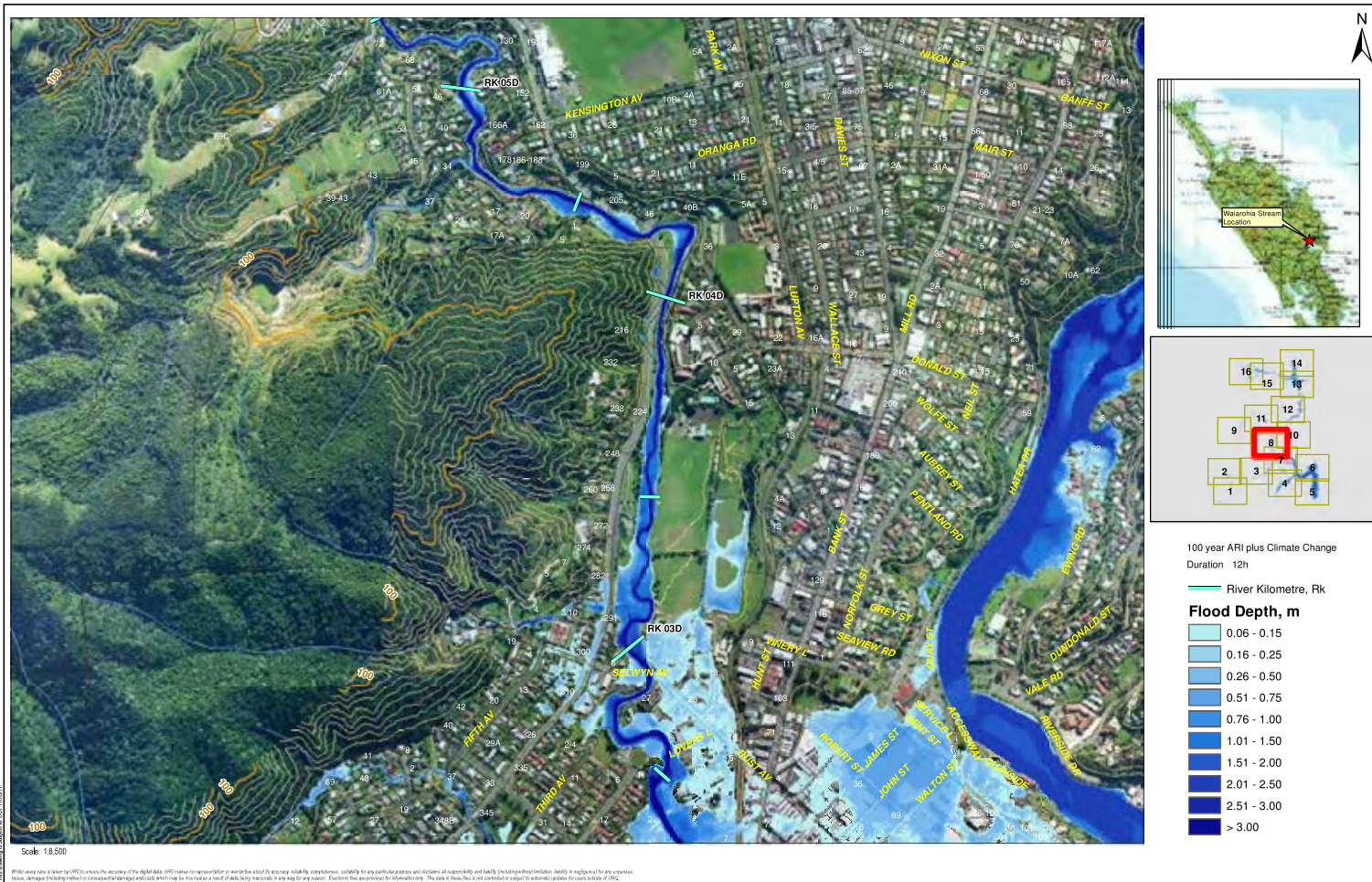
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FLOOD MAPS

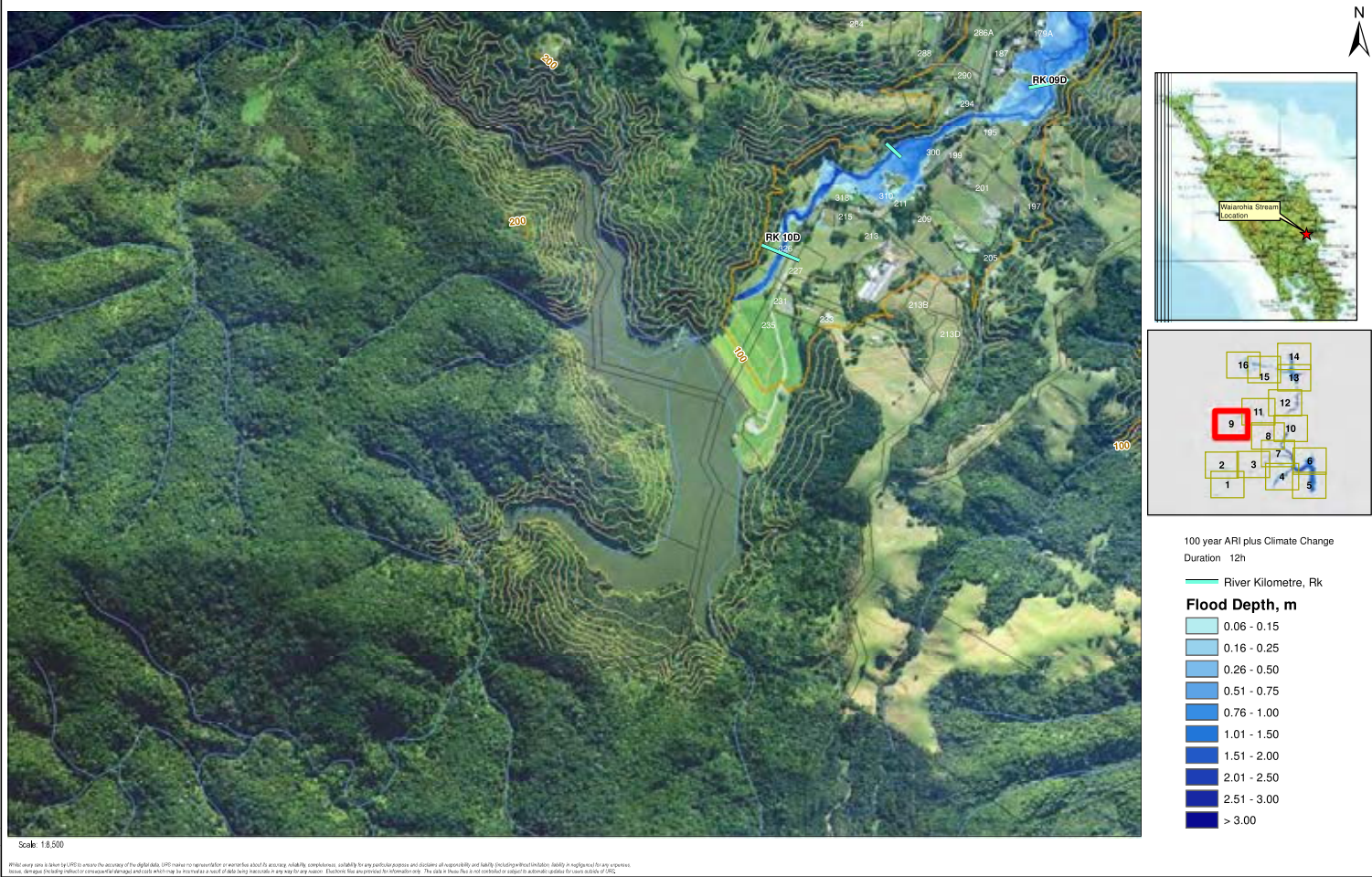
WAIAROHIA_HATEA RIVERS 100 YEAR ARI PLUS CLIMATE CHANGE

URS

File: 42071138 FloodMaps01_WAIAROHIA_RAUMAUNGA_RIVERS_Flood_Maps.mxd Drawn: FP Approved: JM Date: 18/10/2013

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FLOOD MAPS

WAIAROHIA_HATEA RIVERS 100 YEAR ARI PLUS CLIMATE CHANGE

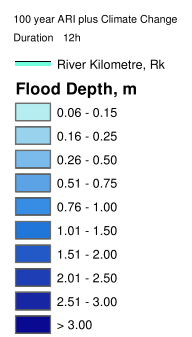
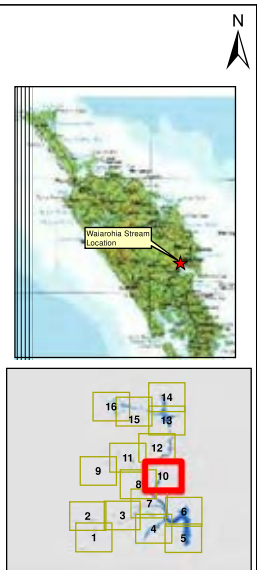
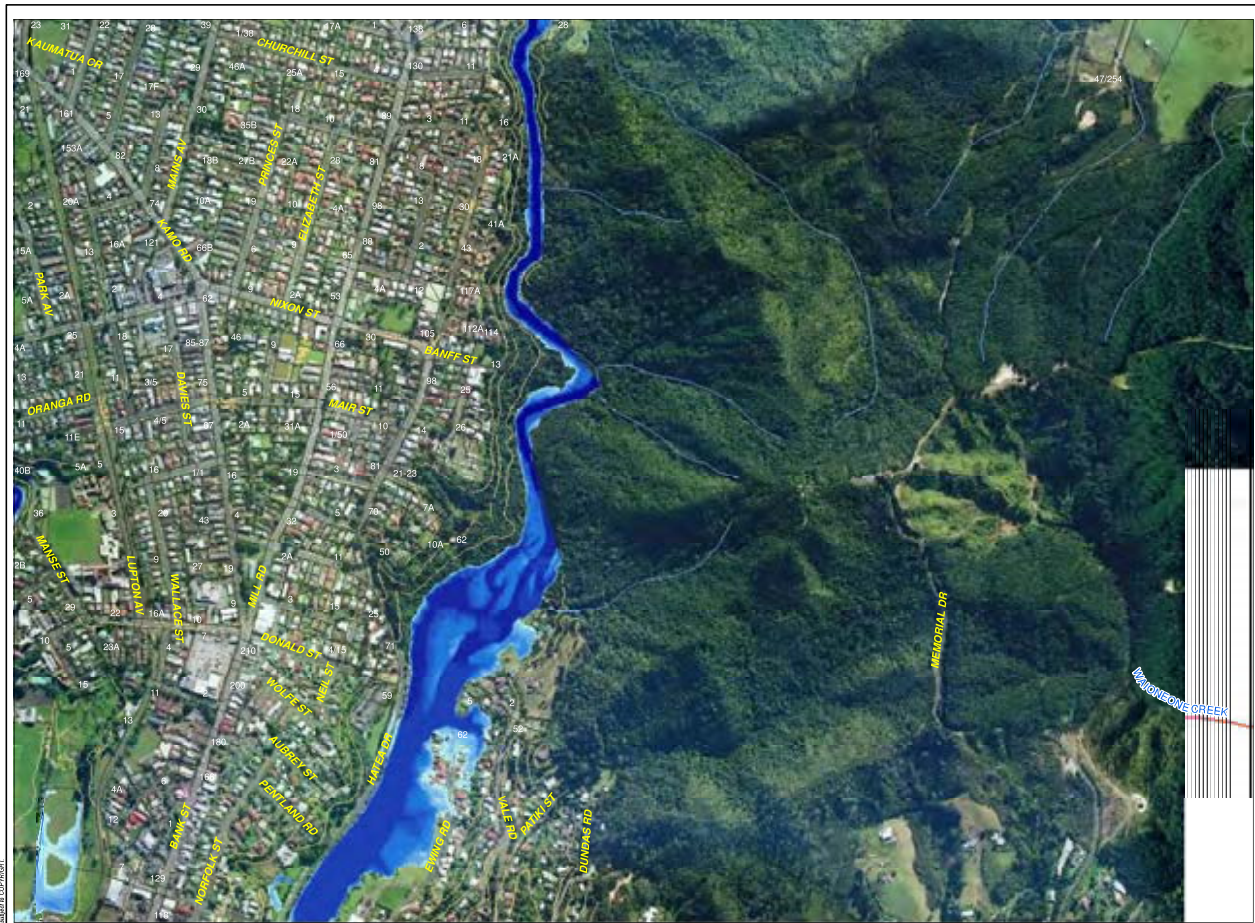
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Scale: 1:8,500

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