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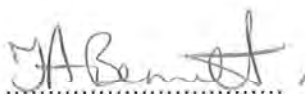
Taumarere Modelling and Calibration Report

12 OCTOBER 2012

Prepared for
Northland Regional Council
36 Water Street
Whangarei 0140
42071138

URS

Project Manager:

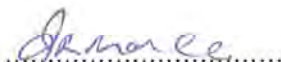


Justine Bennett
Principal Environmental
Scientist

URS New Zealand Limited

URS Centre, 13-15 College Hill
Auckland 1011
PO Box 821, Auckland 1140 New
Zealand

Principal-In-Charge:



John Male
Principal Hydrologist

T: 64 9 355 1300
F: 64 9 355 1333

Author:



Jorge Astudillo
Senior Water Resources
Engineer

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- Appendix A Debris Levels
- Appendix B Rating Curves
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Introduction

1.1 Project Background

The Priority Rivers 2011/2012 project seeks to improve the work that was done for the Priority Rivers Flood Risk Reduction Project. The Taumarere Catchment Model was found by the Northland Regional Council (NRC) to be in need of improvement in order to provide confidence in the flood mapping in the catchment.

The January 2011 storm event presented an opportunity to calibrate the improved model as it was identified as a good calibration storm since the original calibration. NRC has installed a new automatic rain gauge in the catchment at Motatau, and one new river gauge on the Tirohanga Stream. Both of these two new gauges recorded the Jan 2011 event. NRC has also carried out a substantial amount of additional channel and structure survey in the catchment since the previous modelling was completed by MWH in 2010. A comprehensive flood level dataset was obtained following the January 2011 flood.

1.2 Catchment Description

The Taumarere River drains approximately 450 km² of central Northland, following an easy grade through several large wetland areas before discharging to the drowned valley system of the Bay of Islands, northeast of the Kawakawa urban area. The wetlands have been the result of a series of fault blocks across the course of the river and, in its lower reaches, a relatively recent lava flow from a volcanic cone near Kawiti. The Taumarere River Catchment has been divided into 12 smaller drainage sub-catchments. Figure 1-1 provides a general location plan of the catchment.

The catchment is generally rural, with small built up areas distributed throughout. The main urban areas are Kawakawa and Moerewa. Both of these areas are located close to the northern border of the catchment, relatively low down in the system. To the north the Taumarere River Catchment is bounded by the Waitangi River Catchment.

1.2.1 Maromaku-Taikirau

The main tributary of the Taumarere River begins as the Ramarama Stream at the head of the Maromaku Valley. Willow tree clearance and channel straightening during the 1960's triggered off stream bank and channel erosion in this section. Free-draining alluvial soils were being eroded and sediment carried downstream to sections of the stream with lesser grades, causing the channel to silt up. Extensive willow and poplar tree planting controlled this erosion, but these plantings, above Towai Road, are now in need of thinning and maintenance.

Between Towai Road and Taikirau, the channel is undersized for the catchment and is blocked with willow trees. Tributary streams have been trapped inside valleys and peat basins have developed. Both road and rail culverts and the embankment for the railway line increase the ponding effects in this valley.

The Ramarama Stream flows through a gorge between Taikirau and Motatau. Through this gorge section, fallen native trees, low-level bridges and privet trees block the stream.

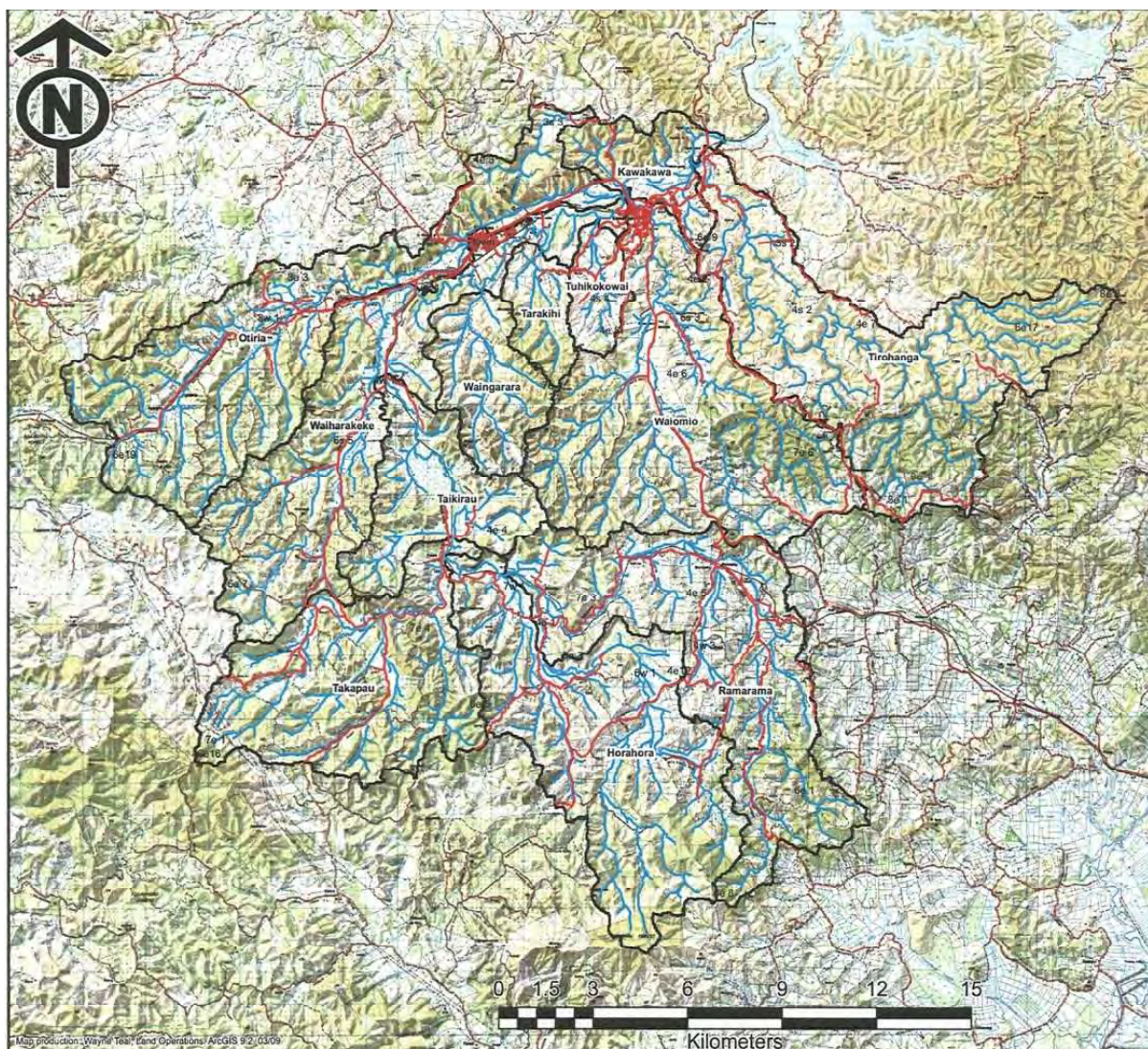
1.2.2 Motatau

At Motatau, the Ramarama Stream joins the Horahora-Taikirau Stream to become the Taikirau Stream. A limestone fault block at Opahi has trapped the river and created the large Motatau wetland. The railway line, which passes through the middle of this wetland, is raised up on an embankment,

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and the under-sized bridges associated with the embankment, restrict the flow of floodwaters through the valley. Willow trees also block parts of the river channel, restricting flood flows and causing permanent water levels (PWLs) to rise. Land that was being grazed and cut for hay in 1967 has now reverted to raupo swamp. The permanent water level is rising in the swamp and indigenous species (cabbage trees and kahikatea) are being drowned. Aquatic weed species, particularly *Glyceria maxima*, are threatening to smother out the indigenous wetland species. Access to Motatau is cut off during floods and the permanently high water levels increase the maintenance costs of roads in the area.

Figure 1-1: General Location Plan of the Taumarere River Catchment



1.2.3 Opahi

Downstream of the Motatau Swamp at Opahi, the Taikirau Stream passes between limestone hills before entering another wetland basin between Opahi and Pokapu. The railway embankment and willow tree blockages through this stretch restrict the river in the same manner as it does through the

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Motatau Swamp. Again, high water levels are affecting adjoining farmland and the integrity of indigenous wetlands is being threatened by rising water levels and invading exotic wetland species.

1.2.4 Pokapu-Taumarere

At Pokapu, the Ramarama Stream joins Te Tahunaakura Stream to become the Waiharakeke Stream. The Waiharakeke Stream flows across an alluvial valley within which a lava flow (which ran down from Kawiti through Moerewa towards Kawakawa) limits drainage flow down the Ngapipito Valley. The Waiharakeke Stream flows along the southern side of the lava flow and the Otiria Stream along the northern side at the foot of a greywacke scarp slope. Both these streams are blocked with willows through the lower reaches, either side of Moerewa and down to where they join to form the Taumarere River at State Highway 1. The Otiria Stream also carries a gravel load, including softer, finer gravel from the shales in the vicinity of Ngapipito and harder greywacke gravel from the scarp slope.

1.3 General Modelling Approach

The present project work carried on with the modelling methodology explained in the NRC Priority Rivers Modelling Report, Feb 2010. This modelling report has been 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 provides a comprehensive model, more accurate outputs and the ability to be continually upgraded.

1.4 Modelling Scope

The scope of work incorporates additional network in the Otiria area, including overflow from the Waiharakeke Stream and culverts under the railway line as 1D or 2D elements as required. Refer to Figure 1-2 for details.

Model modifications were required to get the model to run smoothly and to improve hydraulic performance. The non-linear reservoir method was used for the hydrological model in this work.

There are two flow/level gauges (Waiharakeke at Willow Bank and Tirohanga below Old Mill), three rain gauges (Waiharakeke at Okaroro, Motatau at Okaroro, and Kawakawa WTP) located within the catchment and several rain gauges outside of the catchment. The station names, site IDs, gauge types, and their exact locations of the rain gauges are summarised in Table 2-1. Detailed information on the flow/level gauges are presented in Chapter 4.

The modelling work and re-calibration are based on the January 2011 storm event.

Modelling Objectives

The general objective of the model improvement and calibration was to increase the accuracy of the model results in comparison to known flooding and gauged flood events. The four main objectives are as follows:

- Incorporate new survey and extend the model to include new network areas
- Review the hydrologic model and employ a non-linear reservoir model
- Recalibrate the model based on the Jan 2011 Ex TC Wilma flood
- Rerun design storms for the new calibrated model and generate new flood maps

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Issues identified in the original model verification

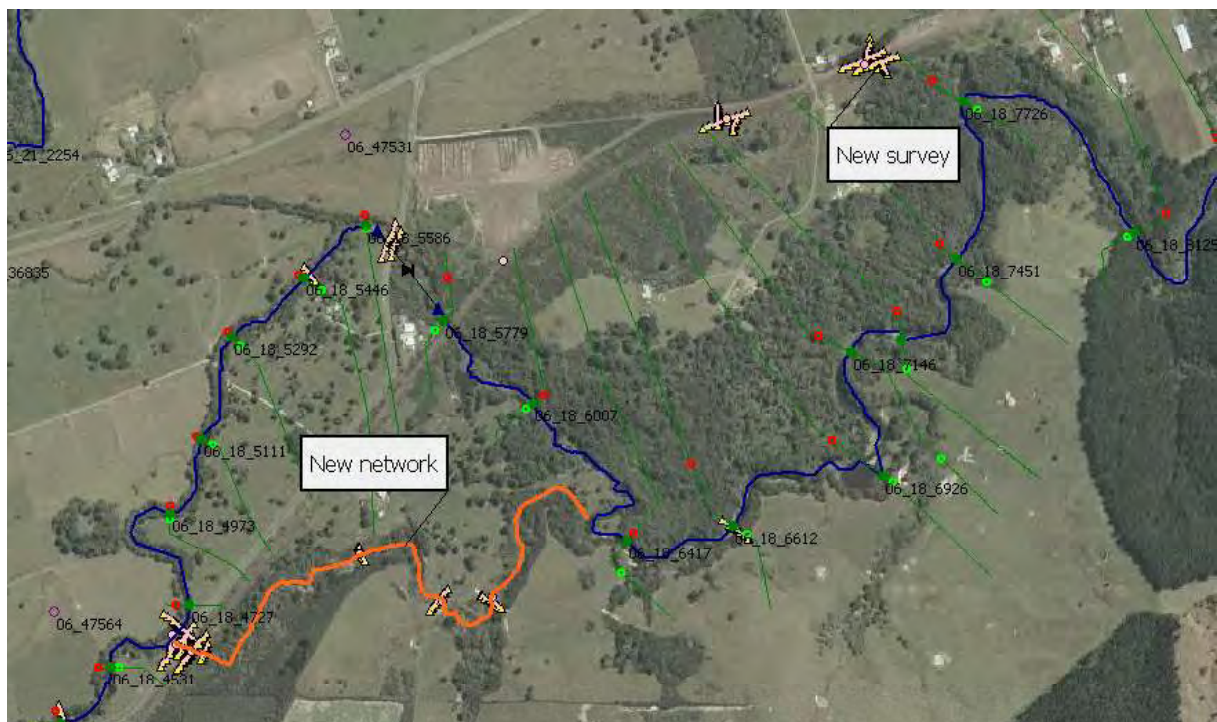
Issues identified in the Taumarere Model verification that have been addressed by this model are as follows:

- Flows predicted by the ratings are likely to be inaccurate for large events. It may be better to rely on the gauged flood levels at the high stage for re-calibration rather than the flow.
- Overly rapid catchment response due to insufficient detail on storage areas in the upper catchment.
- Lack of flood level survey data across the catchment.

Other issues identified during model improvement and re-calibration

- Some of the sub-catchments were incorrectly connected to the river network.
- Some sub-catchments did not have a proper definition in the hydrological model.
- Significant revisions to network spills and links.
- Incomplete storage areas.
- Bottom of the channels had to be corrected in some areas for the main river.

**Figure 1-2: Model extension and example of new survey for Taumarere catchment model;
Intersection of Pukapu Road and Otiria Road**



Data Collection

2.1 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 new channel detail (shape file),
- New survey with photos (cross sections, bridges, culverts, flow/level stations)
- Rain gauges and rainfall for event of January 2011,
- Level/flow gauges and time series data for event of January 2011,
- Debris level for event of January 2011, and
- Verification of gauge datum (except for old station at Tirohanga downstream of County Take)

2.1.1 Survey

Survey data consisted of the following items:

- Cross sections of streams where more detail was required,
- Cross sections of new streams or branches to be included in the model,
- Cross section of channel at water level gauge sites,
- Some critical culverts, and
- Gauge datum verification.

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

2.1.2 Calibration Event Data

The following information was received for the event of the 29th January 2011.

- Daily and auto rain gauge record. Table 2-1 lists the sites provided by NRC.
- Level/Flows for Waiharakeke at Willowbank station and Tirohanga below Old Mill station.
- Rating curves for Tirohanga below Old Mill station, Waiharakeke at Willowbank station, and old station Tirohanga downstream of County Take.
- Tide records for Veronica Channel at Opua Wharf.
- Satellite images of the storm at different times (12 images). Figure 2-1 shows some of these.
- Debris flood levels.

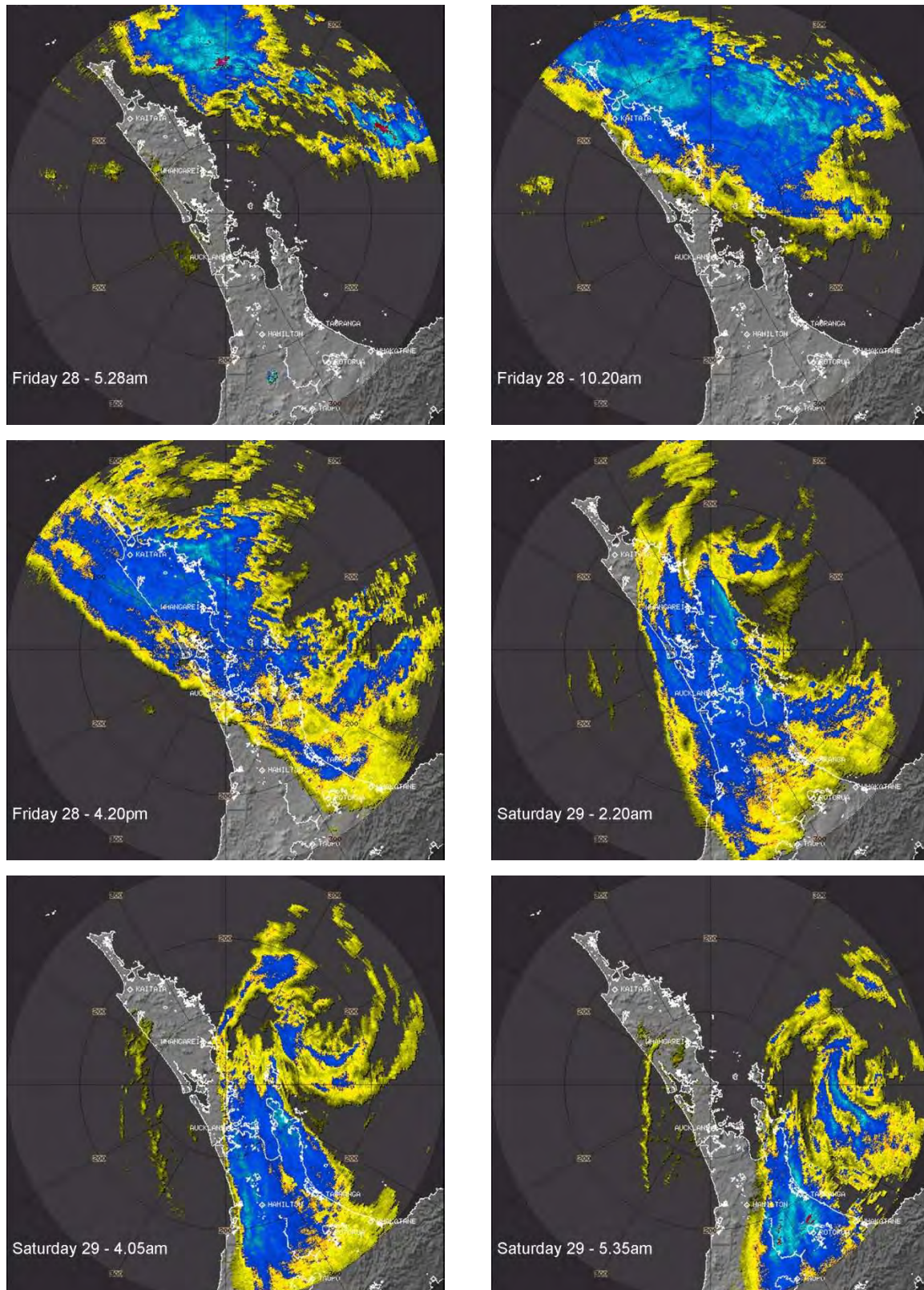
2 Data Collection

Table 2-1 Rain gauge provided by NRC for the event of January 2011

Site ID	Station name	Gauge type	Catchment	Location	Recording Authority
545014	Waiharakeke at Okaroro	Auto (5 mins)	Waiharakeke	Inside catchment (South)	NRC
546216	Okarika at Rowland Road	Auto (5 mins)	Wairua	Outside catchment (6.3 kms SE)	NRC
536816	Mangakahia at Twin Bridges	Auto (5 mins)	Mangakahia	Outside catchment (11.6 kms SW)	NRC
A53487	Kaikohe AWS	Auto (1 min)	Punakitere	Outside catchment (4.2 kms West)	Met Service
533817	Waitangi at Ohaeawai	Auto (2 min)	Waitangi	Outside catchment (6.9 kms NW)	NRC
543010	Waitangi at McDonald Road	Auto	Waitangi	Outside catchment (2.3 kms North)	NRC
545201	Whakapara at Puhipuhi	Auto	Whakapara	Outside catchment (9.4 kms SE)	NRC
543312	Oakura Bay at Te Kapua Street	Auto	Oakura	Outside catchment (10.4 kms East)	NRC
543111	Opua at Veronica Channel	Auto (5 min)	Kawakawa Estuary	Outside catchment (5.7 kms NE)	NRC
A54301	Kawakawa WTP	Daily	Tirohanga	Inside catchment (East)	Met Service
543012	Waitangi at Whangae	Daily	Whangae Stream	Northern catchment boundary	NRC
545013	Motatau at Okaroro	Daily	Waiharakeke	Inside catchment (South)	NRC
545111	Dawson at Waiotu	Daily	Waiotu	Outside catchment (2 kms SE)	NRC
544311	Kaimamaku at Peach Orchard Rd	Daily	Whakapara	Outside catchment (9.6 kms SE)	NRC
545213	Morgans at Hukurenu	Daily	Waiotu	Outside catchment (6.3 kms SE)	NRC

2 Data Collection

Figure 2-1: Satellite images of Wilma storm; January 2011.



Modelling Methodology

3.1 Previous IWRM Model Analysis

The Taumarere catchment was defined as a Priority 1 catchment during the Priority River Flood Risk Reduction Project. A model of Taumarere catchment was developed, built and calibrated by MWH. NRC provided the MWH model, as the starting point of the current work.

In general the previous model was stable, but was not well defined in many areas. The model presented some irregularities and deficiencies in critical areas. Improvements to the model were essential to assure a reliable calibration and accurate results.

The following is a description and analysis of the important aspects that were corrected and/or improved in the model.

3.2 Boundary Conditions

There are two boundary conditions:

- The downstream boundary condition takes the form of a stage – time tidal condition that required a stage time series to define the downstream boundary levels.
- The upstream boundary condition consists of a hydrological model to calculate runoff inflows from rainfall

3.2.1 Downstream Boundary Condition (Tidal Boundary)

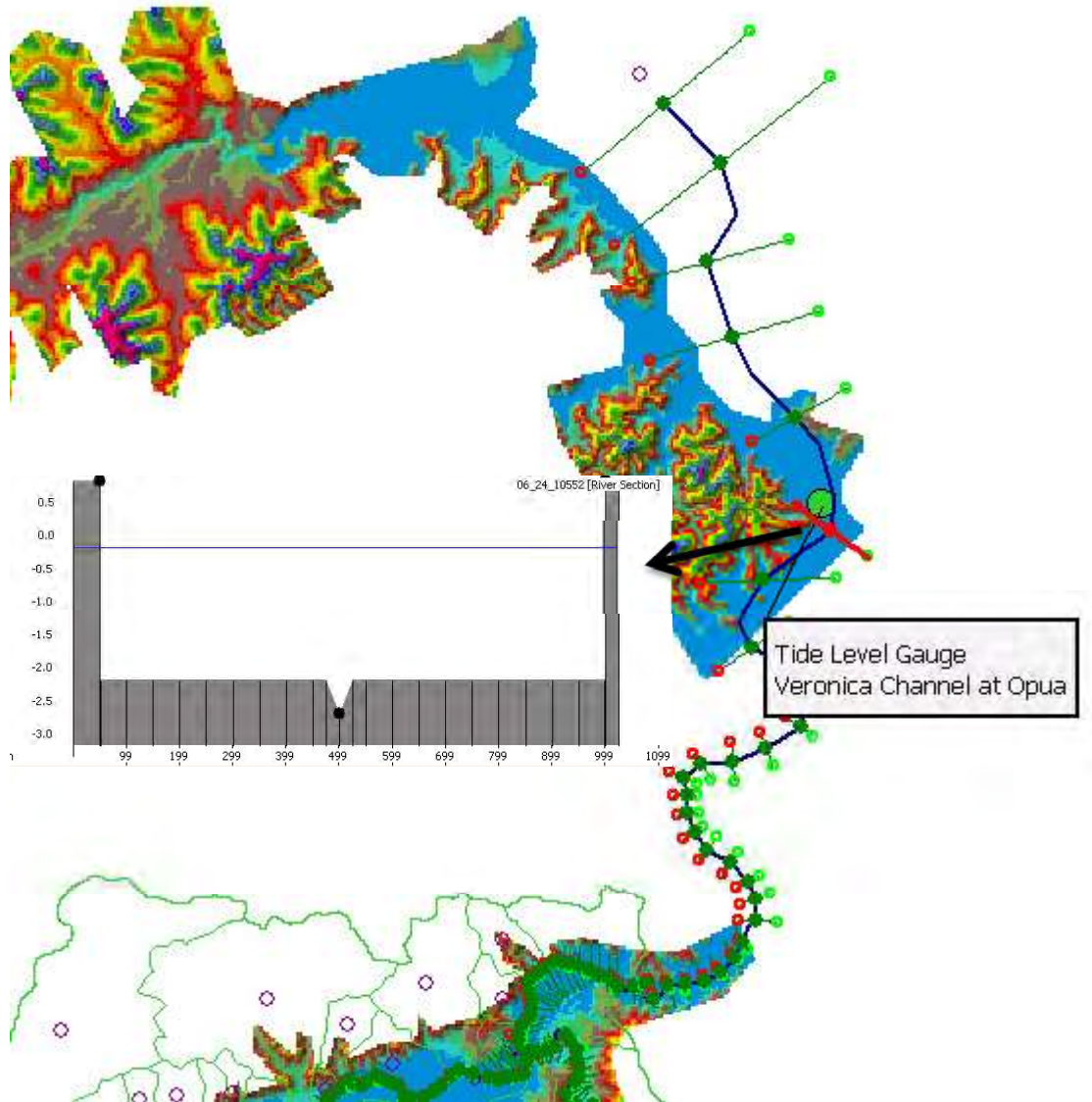
The network has been extended downstream far enough for the influence of the tidal boundary at the mouth of the river. This provides good definition of the water levels at the discharge point of the river into the sea. Therefore it is considered that the downstream boundary condition is well defined in the model.

Despite the correct downstream configuration, the river mouth of Kawakawa River is not contained in the LiDAR information, and the cross sections on the estuary were found to be critical in extreme events, where its current capacity seems to delay the discharge of the flow into the sea. For that reason model improvements were made in the estuary, estimating the missing section area in the cross sections and locating the tidal boundary close to the actual location of the tide gauge. Figure 3-1 shows the previous model cross section at a location outside of the LiDAR. Cross sections in the previous model in this area were considered to be rectangular with a small slot at the bottom; the width and depth were arbitrary and in some areas they seem too wide or too short compared with the aerial photograph. For the new model the limited LiDAR around the estuary and the aerial images were used to estimate the width of the estuary at this location. That width was used to estimate an area of flow to be distributed along the cross section. Even though they remain as assumptions, this approach is more realistic as the final cross sections properly describe contractions and expansions along the estuary that might be important in big events. Figure 3-2 shows the new estuary extent and an example of a modified cross section in this area.

For the new improved model the tidal boundary condition used for the calibration was the Opuia gauge stage data for the Jan 2011 event. For the design storms the sea level time series for downstream boundary was the Opuia time series developed for the 2010 Priority Rivers project.

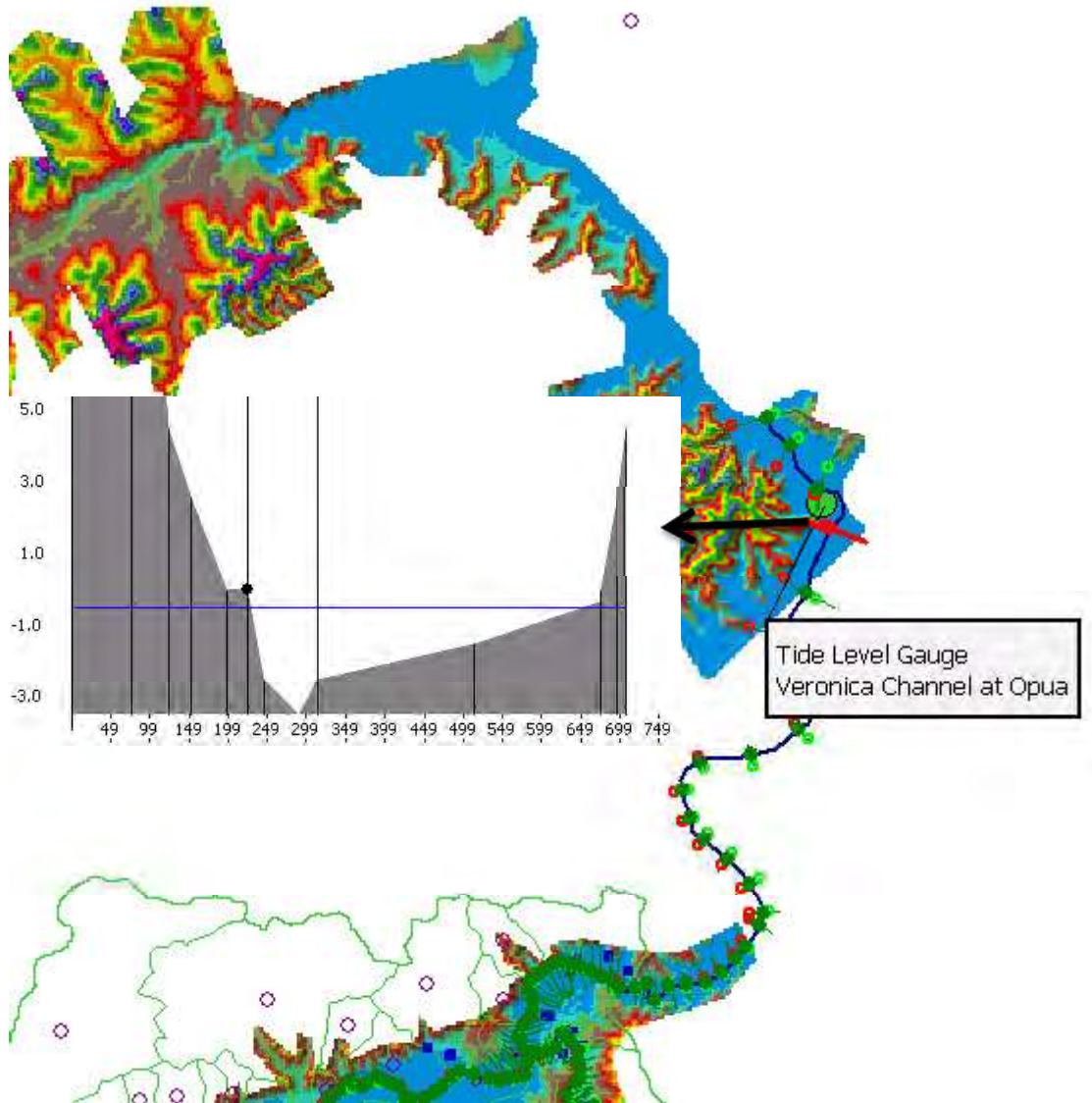
3 Modelling Methodology

Figure 3-1: Veronica Channel previous model cross section



3 Modelling Methodology

Figure 3-2: Veronica Channel modified model cross section



3 Modelling Methodology

3.2.2 Upstream Boundary Condition (Sub-catchment hydrological model)

The hydrological model forms the upstream boundary condition and is contained within a boundary node defined for each sub-catchment. These nodes discharge runoff into the network as a lateral inflow or a point inflow. The boundary nodes contain all pertinent hydrological parameters required to run the US SCS method implemented in InfoWorks RS. These parameters are in agreement with the criteria defined for the NRC Priority catchment as explained in the NRC Priority Rivers Modelling Report, Feb 2010.

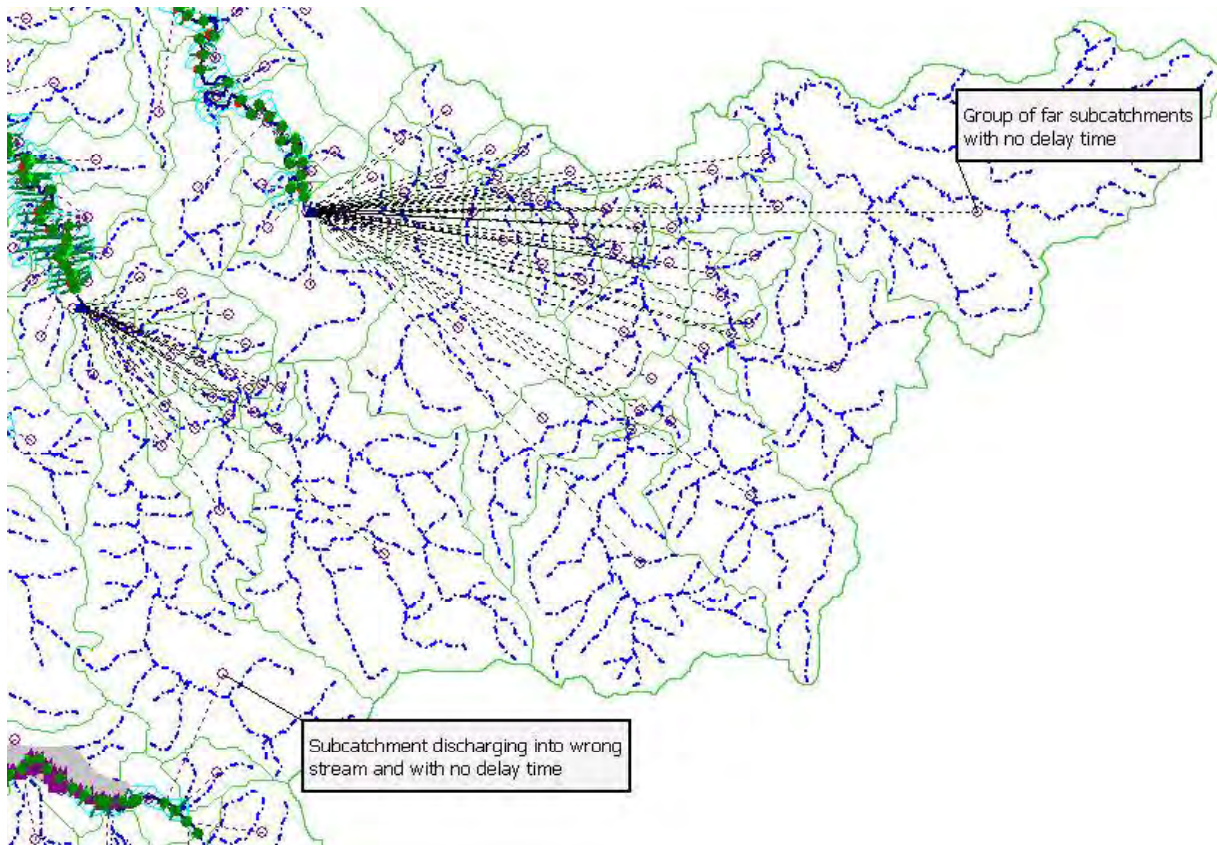
It was discovered that many of the points of discharge to the network were not well defined. There were many situations where sub-catchments were located a great distance from their discharge point to the network. This would not pose a problem if they were connected to the river system at the proper point, with the appropriate delay time. There were two issues noted. The first issue was that a few sub-catchments were not connected to the river network at the correct point. The second issue was more serious as many sub-catchments that had long travel times (time of concentration) to the network did not have any time delay incorporated into their nodes. These particular sub-catchments discharged their runoff directly to the river network immediately after the runoff was generated. This was the case for most of the sub-catchments that were connected to the network from significant distances, therefore the time of delay is not negligible. Without the inclusion of the time of delay, the routing of the flow from these sub-catchments incorrectly impacted the modelling of the network and compromised the calibration.

Figure 3-3 shows an example of this situation. The problem was corrected by using the ARC TP108 formulation to estimate a time of delay for each sub-catchment based on the stream link. This calculation was conducted by using GIS tools based on the long profiles of the missing streams and differences in elevations.

More details about the modifications of the hydrological model are presented in Section 3.6.

3 Modelling Methodology

Figure 3-3: Example of issues in previous sub-catchment connections (Upper catchment of Tirohanga and Waioomio streams)



3.3 Network Model Objects

As part of the scope, it was considered necessary to improve certain specific areas of the model as previously described. However, it was also necessary to review the general model structure details (e.g. variables, connections, assumptions) to assure the model could meet the new requirements defined for this project.

All of the hydraulic network physical attributes and how to represent them in the model appropriately need to be well understood. Typical network objects include river cross sections, spills, bridges, storages areas, 2D areas, river links, and junctions.

The critical network objects that required correction in order to achieve good calibration results are discussed in sections 3.3.1 - 3.3.5.

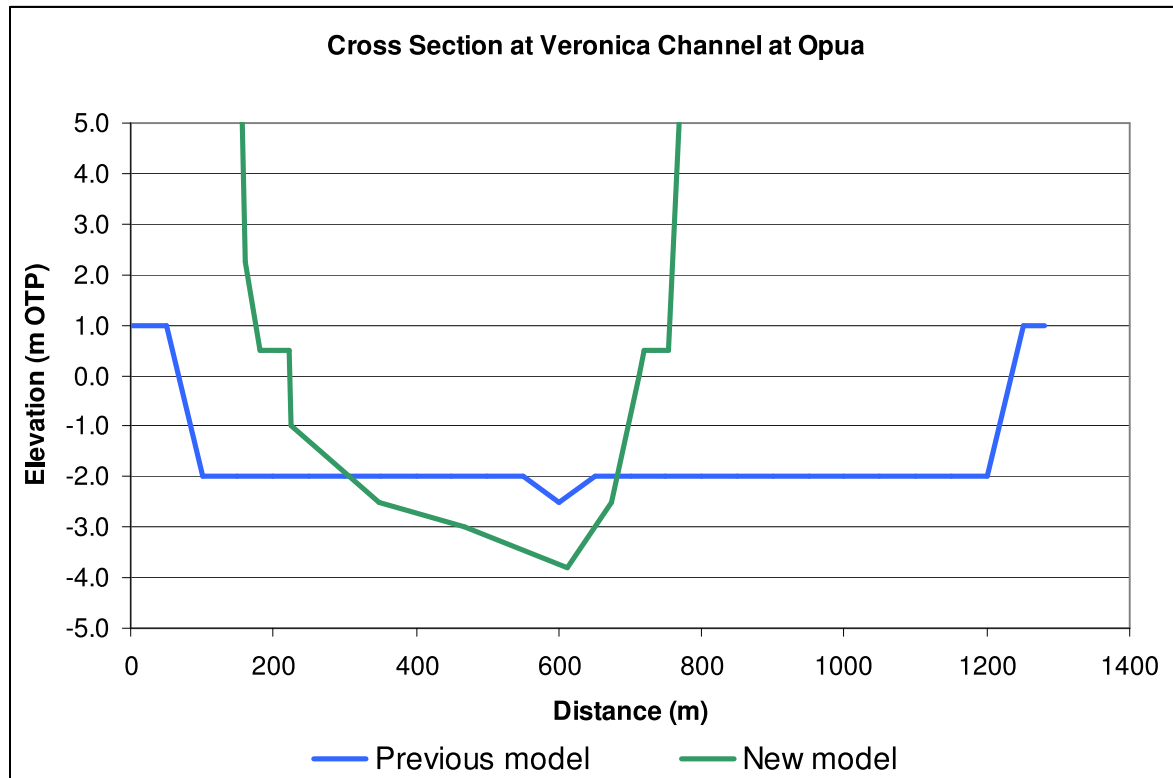
3.3.1 River Sections

As mentioned above, the cross sections at the estuary were improved. The bottom part of the section was generally increased based in the limited LiDAR information and aerial photographs; flood plains were then extended based on the 20 metre contours. Early calibration results confirmed that this aspect was affecting the quality of results as water was being delayed by the limited capacity of some of the previous cross sections at the estuary.

3 Modelling Methodology

Cross sections were corrected along the lower 10.0 kilometres of the model extent from the tide level boundary condition at Veronica Channel at Opuia station.

Figure 3-4: Example of correction of cross section at estuary

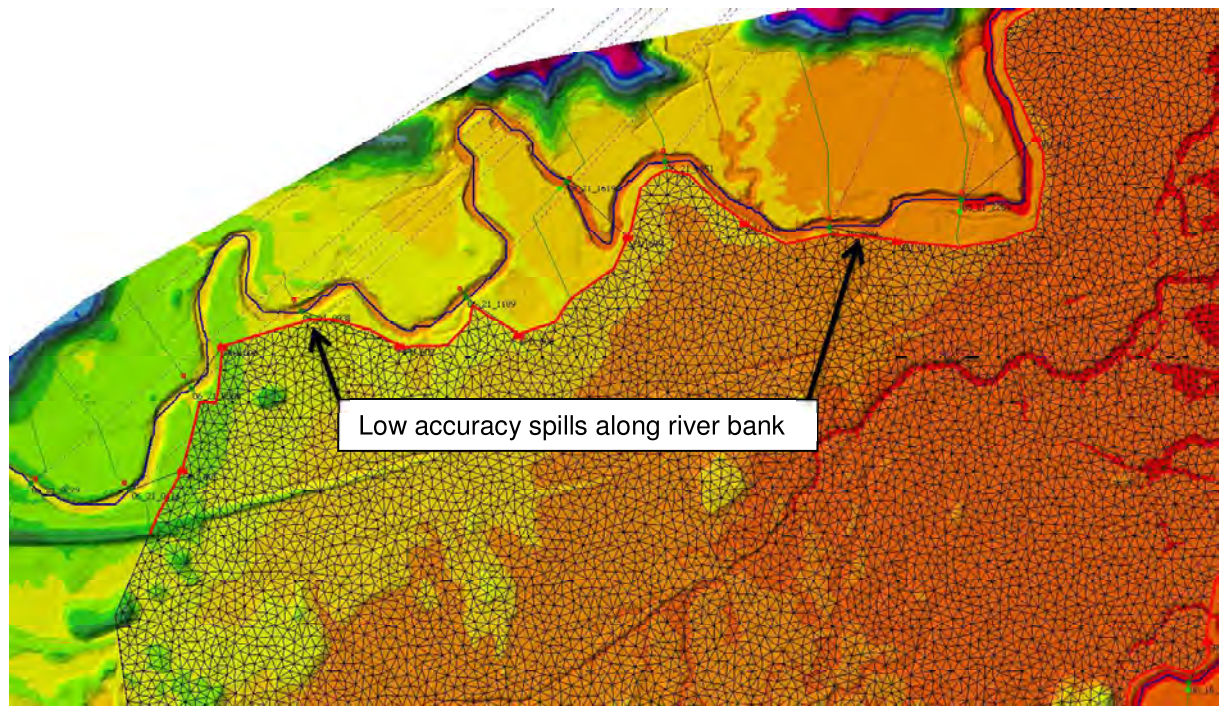


3.3.2 Spills (1D-2D connections)

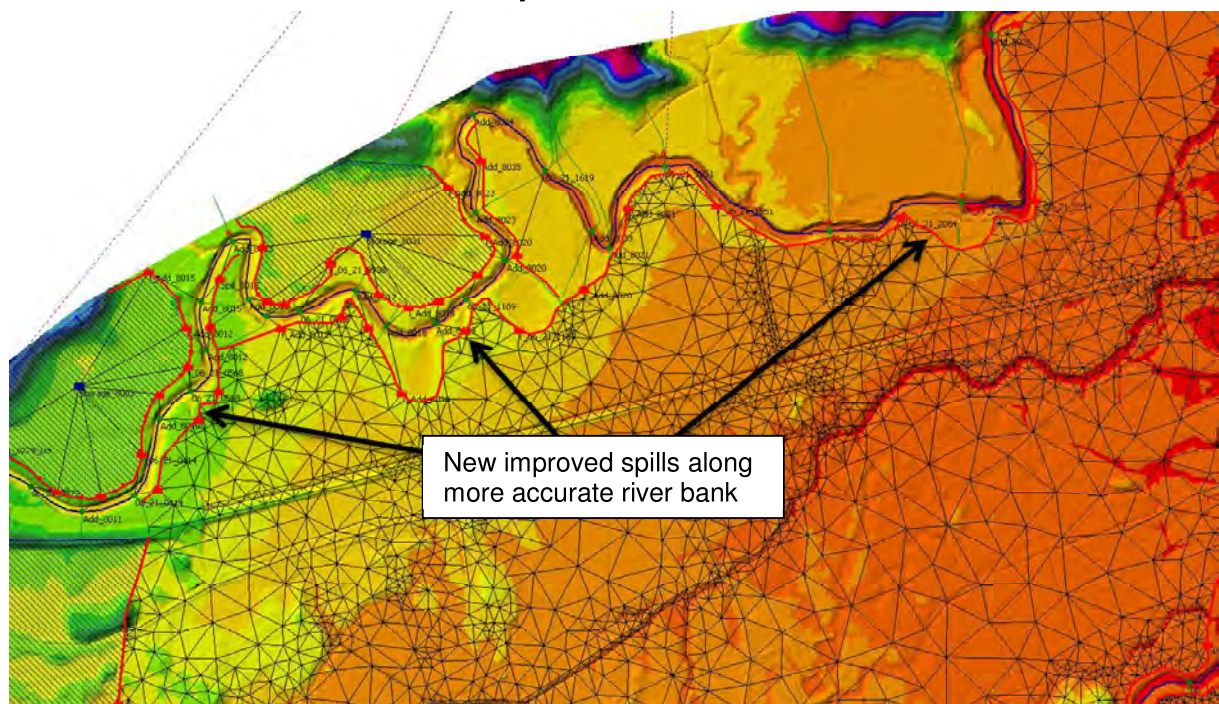
The scope of this project included the extension and modification of some critical 2D areas. This involved modification of the spills connecting the river with the respective 2D areas. However, in many areas where 2D modifications were not required, spills were represented poorly. These spills typically did not follow the banks along the river or their section resolution was so poor that it incurred an inaccuracy in the solution of the flows spilt over 2D Areas. The example below shows a set of spills that were defined with low accuracy, and spilling a large amount of water from the Orauta stream upstream of Otiria into the 2D area that would cross the flood plains and discharge into Waiharakeke river reach to the south.

3 Modelling Methodology

Figure 3-5 Example of spill corrections at Orauta stream; Otiria Road at Orauta settlement



Previous spills and 2D area borders



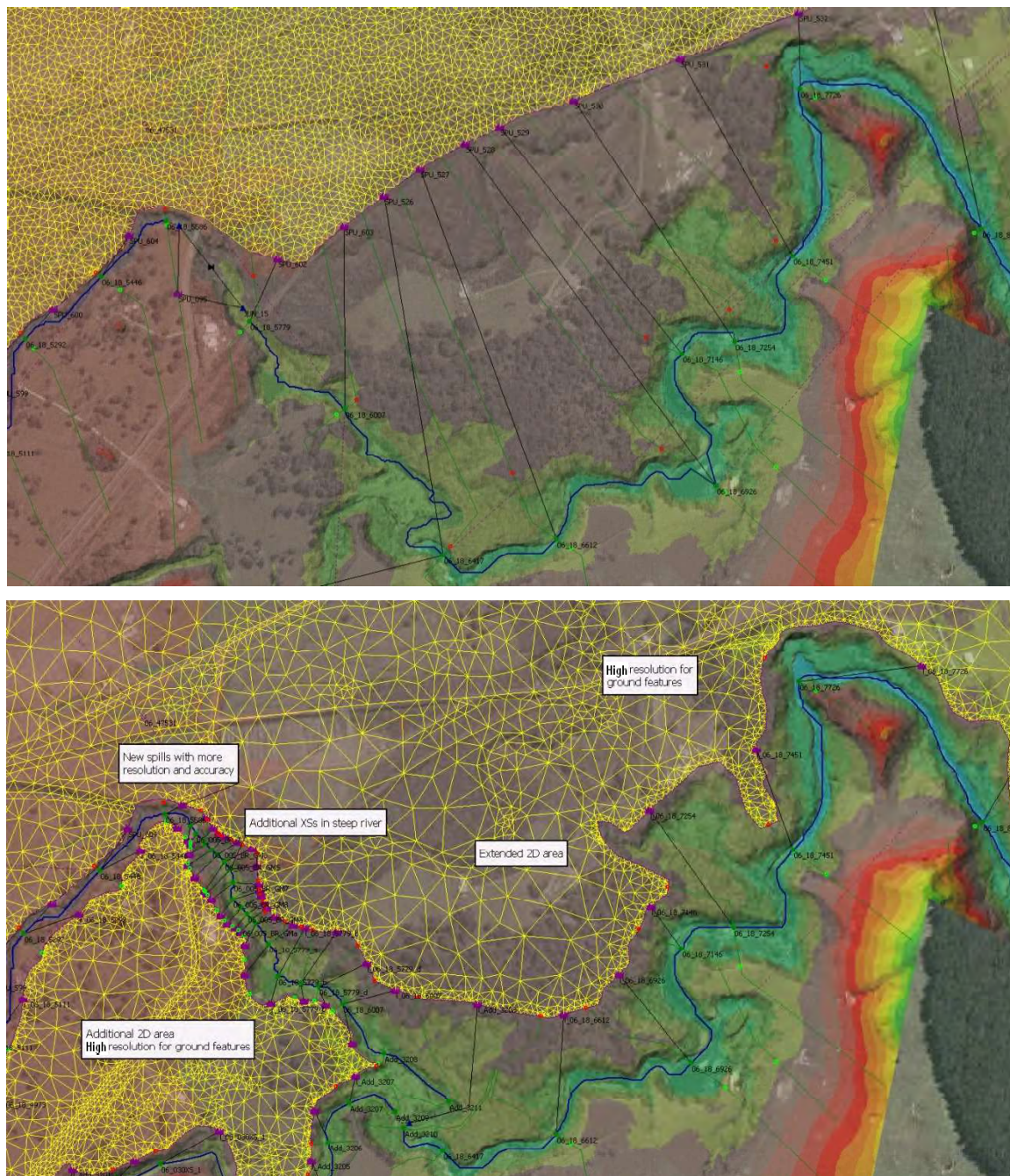
Corrected spills and 2D area borders

3 Modelling Methodology

3.3.3 2D Polygons

The resolution of the previous model's 2D polygons was sufficient to provide only a rough description of the flood plains. Break lines and better resolution in many areas were required in order to meet requirements of calibration. Additional 2D areas were also added to assure a good description of the flooding in terms of flood extents, overland flow paths and representative storage capacities. Other areas were reduced in resolution as they were either in high lands or flat flood plains.

Figure 3-6 Example of previous and improved 2D mesh; Waiharakeke river downstream of Pokapu road



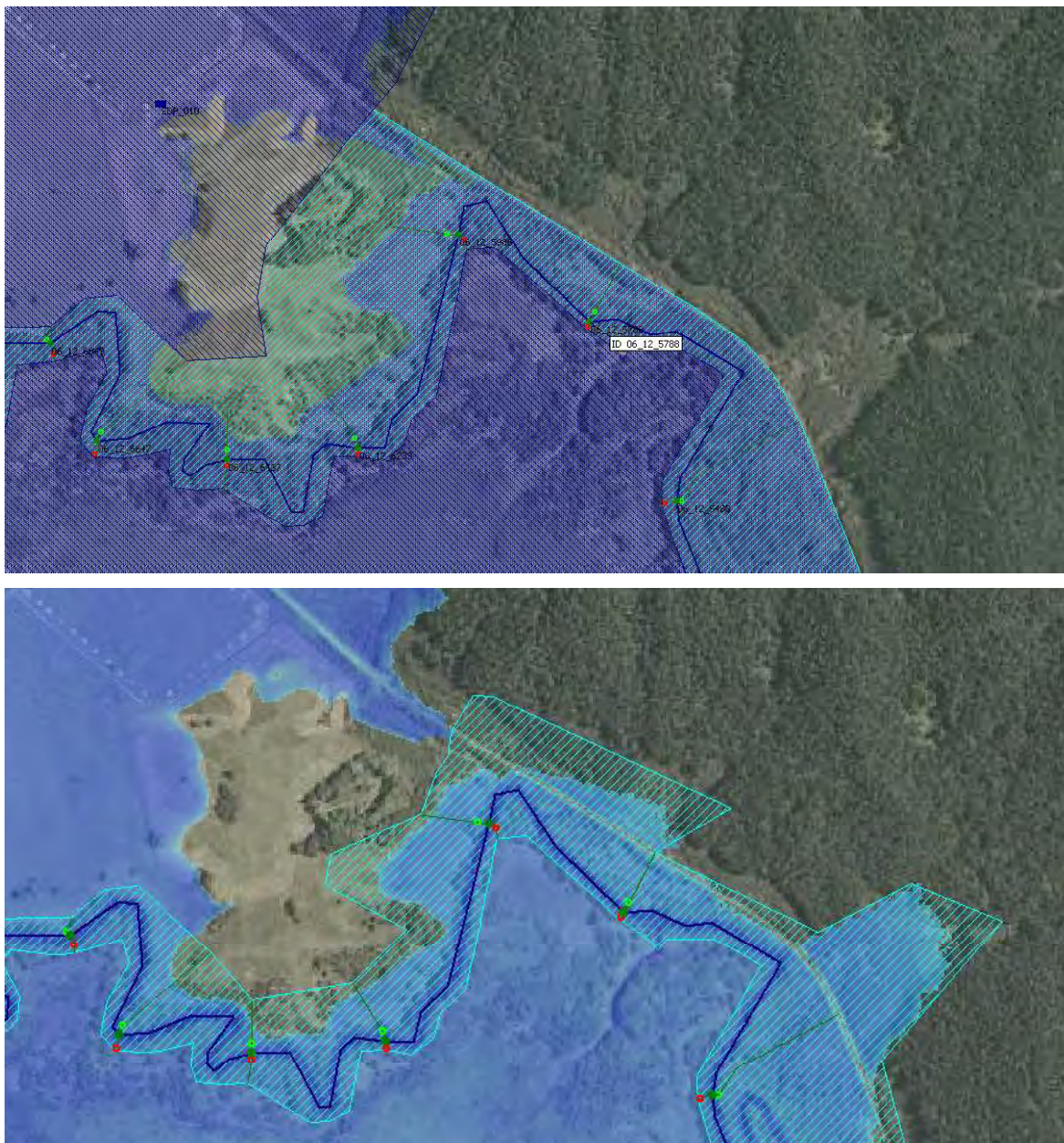
3 Modelling Methodology

3.3.4 Flood Compartments

Flood compartments are necessary to interpolate model level results into a water surface and generate the flood maps over the LiDAR ground model. If the flood compartments are not well defined or they do not cover areas that flood, the flood mapping would show erroneous wet/dry areas. These compartments required correction to ensure a good representation of the flooded areas.

Flood compartments were corrected, extended or created in areas where more detail was required. Extension of the flood compartment alone is advisable when the storage of the flooded area is not important; otherwise a storage unit was generally added together with the extended flood compartment.

Figure 3-7 Example if flood compartment corrections; Taikirau Stream between Pokapu and Pokere settlements



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3.3.5 Storage Areas

In the previous model many sub-catchments were found to be draining directly to the main stream even though there were important flood plain storage areas that they should have drained to before reaching the river. This had to be corrected in order to get a good fit for the calibration, especially in the Taumarere catchment where the inclusion of natural storage areas was critical for accurate representation of reality. The newly calibrated 2012 model has 72 additional storage areas covering more than 13km². This improved the flood plain areas and the routing of the water between sub-catchments and rivers.

The example shown below in Figure 3-8 shows the previous and current model detail of large flooding areas of the upper catchments that discharge over the main river flood plains before reaching it. Originally, these areas were not included thus underestimating important storage areas. The new approach incorporated as many storage areas as possible and connected them to the main 2D flood plain if present; otherwise they were connected directly into the main river. As new objects and new and larger 2D areas were incorporated in the model, the high resolution of the 2D mesh was kept only for the important ground features (such as streams, banks, and roads). The 2D was reduced or removed over the flat and homogenous flood plains; this enabled the simulation to run more efficiently and increased the model stability, and reducing run times.

3.4 Survey and Model Extent

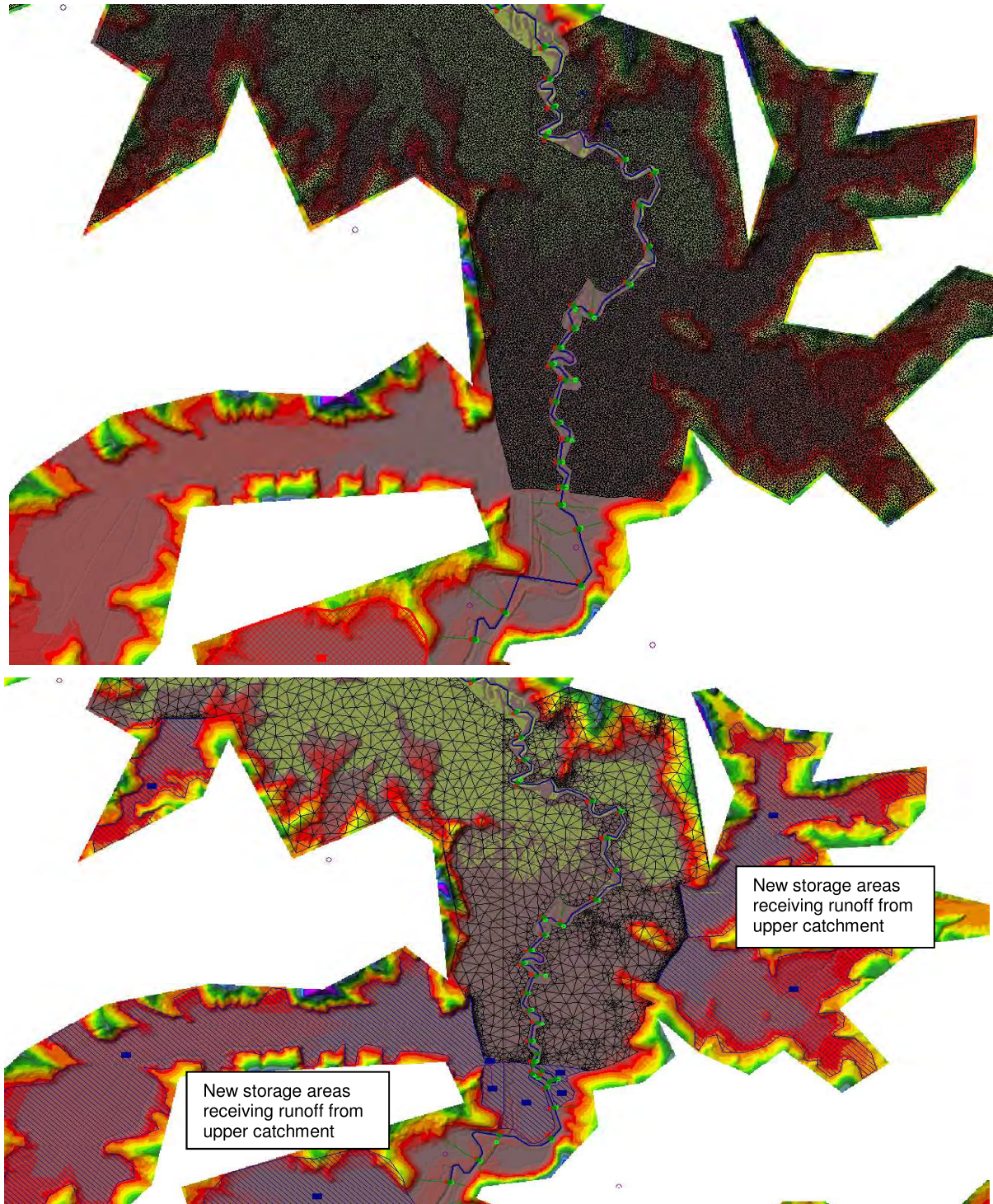
The previous channel survey taken in 2010 was available in the model and represented as cross sections lines or bank lines. The survey was useful for analysis of results and model performance. Most of the critical survey information was included in the model as river cross sections. Survey data in the model was reviewed in the critical areas and corrected if necessary.

New survey data was provided by NRC in 2011 and 2012. This information was added to the model and linked to their survey photos. This data was used to improve and/or add stream cross sections in areas where more detail was required. It was also necessary to add some bridges and culverts to improve the hydraulic performance of the model.

Figure 3-9 shows an example where the 1D river network was improved and extended using new survey information.

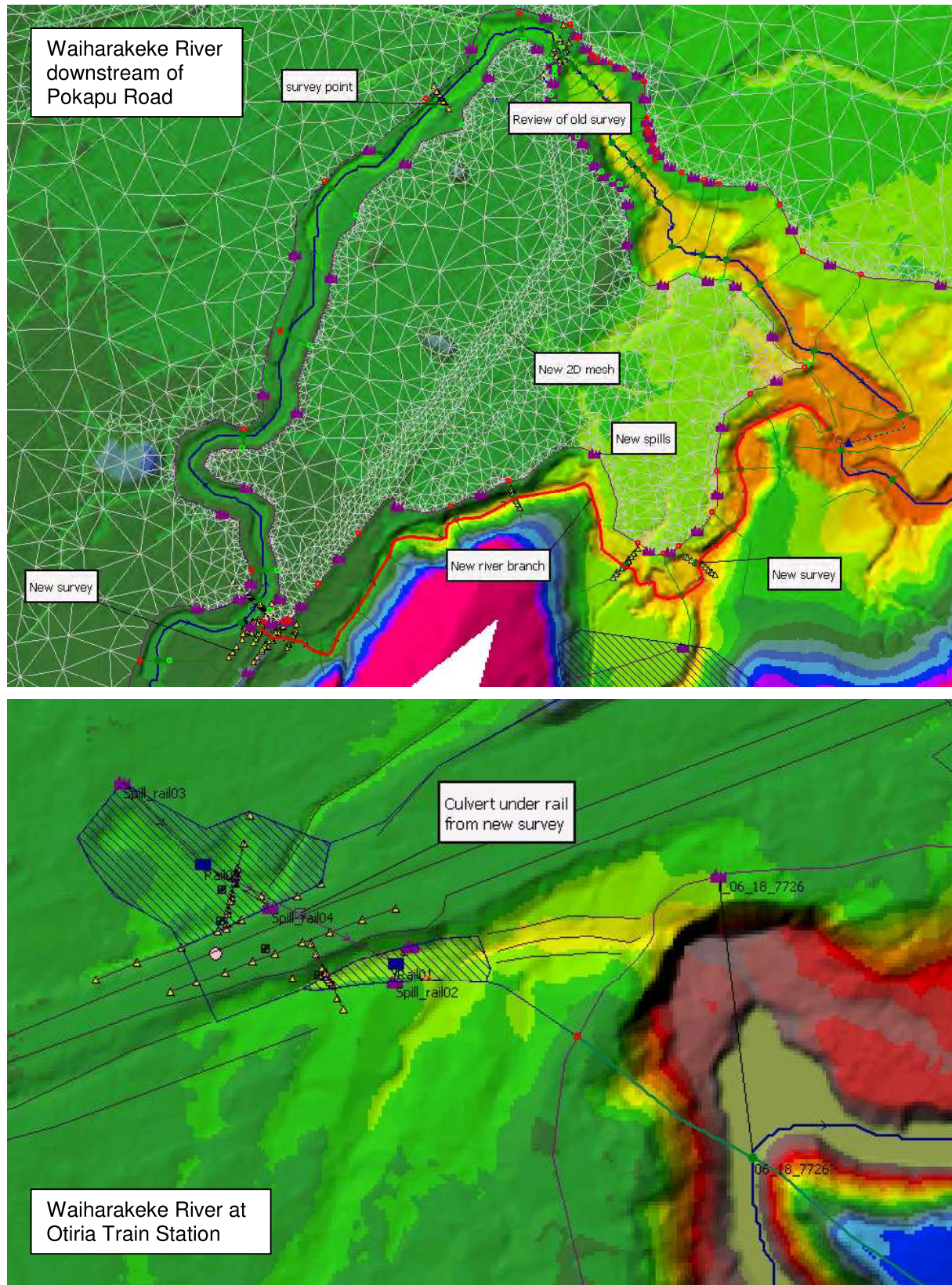
3 Modelling Methodology

Figure 3-8 Example of additional storage areas connected to 2D to assist runoff; Taikirau Stream at Kupa Road (Pokere settlement)



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Figure 3-9 Example of improved extension of the 1D and 2D models using the new survey;



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3.5 Sub-catchment delineation

The sub-catchment delineation is defined by the resolution and extent of the hydrological catchment. In the 2010 Priority Rivers Flood Risk Reduction project these sub-catchments were based on 20m contours for the catchment. As the size of Taumarere catchment is considerable, the previous resolution of the sub-catchments was found to be appropriate for the purposes of the 2011/2012 scope of work, and any modification was considered to have negligible affect over the whole catchment performance.

However, some sub-catchment shapes were missing on the previous version of the model, and they were loaded and linked back to the model. Even though sub-catchment shapes are not necessary for numerical purposes, they are critical for information purposes as they graphically show the extent of each catchment draining into the different areas of the model.

3.6 Hydrological Model

3.6.1 US SCS Method

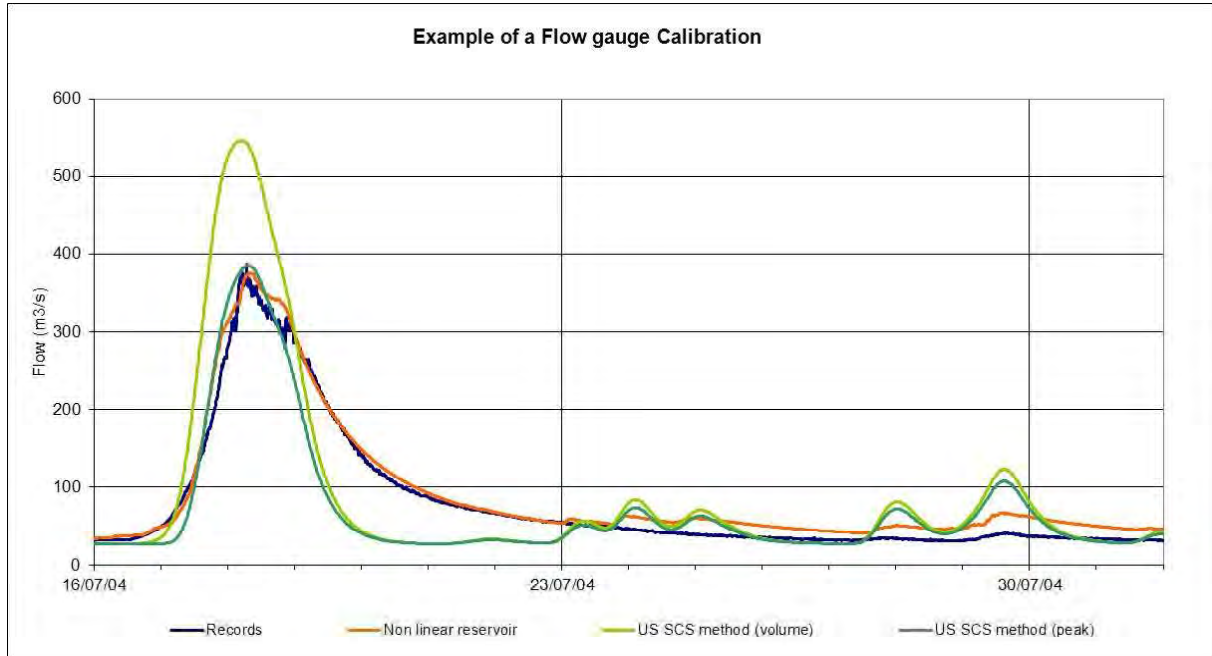
The previous Taumarere catchment model used an US SCS unit hydrograph method as the hydrological model. A CN value was to be derived for each sub-catchment based on the land-use and soil type. The main concern with the US SCS method for Northland catchments of larger size is that, in general, peak flows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

Further experience and analysis in NRC catchments, as well as other catchments, suggested that a better and more versatile hydrologic model alternative exists to simulate the sub-catchments runoff. The alternative method is known as the Non Linear Reservoir method.

The following figure 3-10 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 for the Rangitaiki River catchment in New Zealand. The figure shows that the non-linear reservoir method appeared to be more capable of fitting both volume and peaks for this large catchment.

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Figure 3-10 Example of a flow gauge calibration using different hydrological models



3.6.2 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.

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 Taumarere sub-catchments. The estimated values for K and p are summarized in Chapter 5.

Part of this project is to calibrate Taumarere catchment with an alternative and more suitable hydrological model. Based on the previous explanations, a Non-Linear Reservoir Method has been used to calibrate the storm of January 2011 for Taumarere catchment.

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3.6.3 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 and particularly for the Taumarere catchment.

The infiltration method was used as it offers a better description of the rainfall losses for large events, and it showed partial advantages over the runoff coefficient method and other methods. Refer to Section 3.6.4 Infiltration Rate for a more detailed discussion.

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 recession flow. Coefficient p defines the order of the reservoir. If $p=1$, that would describe a Linear Reservoir and would allow for the estimation of a unit hydrograph for each sub-catchment. However, most of the time $p \neq 1$. Parameters K and p can be estimated from geometrical catchment parameters such as slope, length and area, as well as features such CN or time of concentration. Several tests involving iterative estimation using Izzard formula were done around these parameters to ensure a good representation of the hydrological features.

As described in Section 3.2.2, a time of delay was assigned to those sub-catchments that were discharging into streams a significant distance from the respective sub-catchment point of discharge.

3.6.4 Infiltration Rate

The rain losses to be applied in the Non-Linear Reservoir method are calculated through an infiltration rate, in contrast with the US SCS method that is based on a CN value. The infiltration rate can be estimated based on many different methodologies. In other NRC models (such as Ruakaka), a constant infiltration rate was adequate as a volume balance from records showed a consistent and homogenous infiltration rate. The Taumarere catchment was more complicated and it was necessary to try a more elaborate method as described below to achieve a more reliable outcome. The main reason for the added complexity is the large size of individual flood storage areas available in the catchment. Considering these large flood areas (such as wetlands) in conjunction with the numerous amount of bridges and culverts (smaller flow constrictions), makes estimating the hydrology of the upper catchments based on the available flow records of a limited number of gauges located well downstream of the runoff source and storage areas exceedingly difficult.

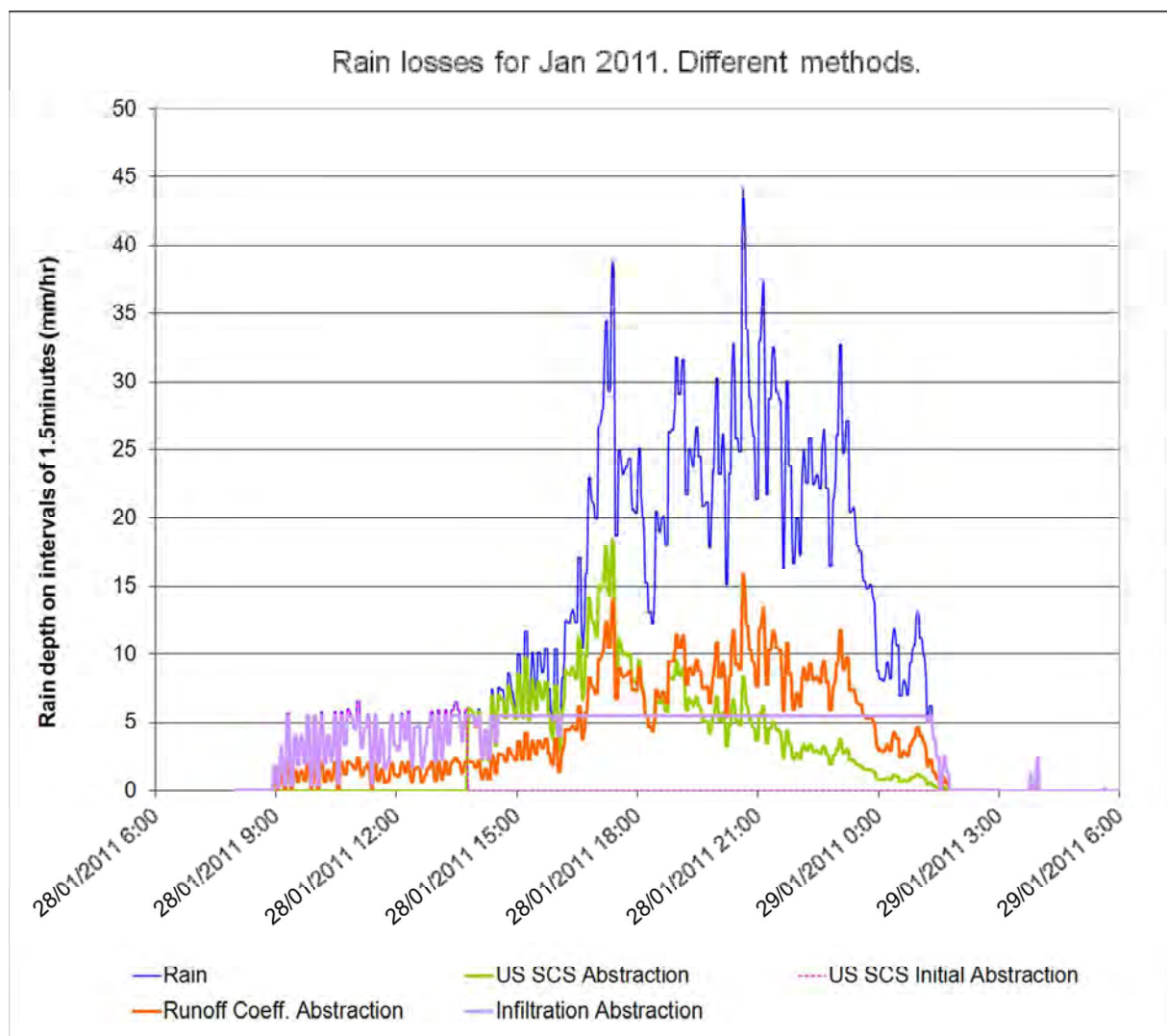
The following methods were tested and their results can be seen in Figure 3-11:

- Non-Linear Reservoir (NLR) with a constant infiltration rate (depth) estimated from a record volume balance (in Figure 3-11 as the Infiltration Abstraction curve)
- NLR with a variable infiltration rate. To estimate the rainfall losses, the US SCS method was used to estimate the total losses and initial abstractions over the calibration storm for each sub-catchment, based on the previous spatially distributed CN values. Then the CN values were adjusted with a factor to match the total rainfall losses of the NLR method with the total volume balance determined from the records (in Figure 3-11 same as Infiltration Abstraction, but variable for each sub-catchment).

3 Modelling Methodology

- A constant runoff coefficient was applied over the rainfall. The runoff coefficient was calculated for the whole Taumarere catchment based on the volume balance done from flow records (in Figure 3-11 as the Runoff Coeff. Abstraction curve).
- Finally, a preliminary model was calibrated using a constant infiltration rate, and with the Non-Linear Reservoir method with constants $p=1$ (linear) and K defined for each sub-catchment based on geometric features. The constants K and p were used to calculate a unit hydrograph for each sub-catchment (as explained in Section 3.6.2). The unit hydrographs were then run using the US SCS method and the previous CN values variably distributed on Taumarere catchment based on land cover and soil type (in Figure 3-11 as the US SCS Abstraction and US SCS Initial Abstraction curves).

Figure 3-11 Rain abstraction for the storm of January 2011 from different methods



The analysis showed that the infiltration rate resulted in an abstraction estimate that is close to the average of all tested methods, and provides enough detail for the model considering the limited amount of flow data available to calibrate. Even though the moistures conditions and rain distribution

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are still important uncertainties, a variable infiltration rate (varied among sub-catchments based on a distributed CN) offers an additional dependency on the CN value that is related to these variables. In addition, a variable infiltration rate is also a more efficient way to set up the model and offers a more detailed description of catchment abstractions.

This approach applied the best available information, such as recorded flow data, into the calculation of the variable infiltration rates. Improved estimation of the CN values may be possible should a detailed soil map for the region becomes available in the future.

3.6.5 Base Flow and Infiltration Rate Expected Ranges

Limited information is available to establish a reliable base flow estimate for each sub-catchment. The best information was determined to be that from the Willowbank gauge that showed a flow of about 8.7 cumecs occurring before the 29 Jan 2011 storm used for calibration; however, most of this flow is likely to be a residual discharge from the rainfall event that occurred a week earlier (event of 23/01/2011), instead a realistic base flow.

The Willowbank catchment is close to half of the whole Taumarere catchment, so if we consider the previous rate as a base flow for the whole of the catchment we would obtain about 16 cumec of base flow at the mouth of Taumarere River. That flow may not be considered negligible, but relative to the 750-800 cumecs peak flow expected at the river mouth during the calibration event it was decided that the importance of the base flow in the calibration was minor and it was considered to be negligible to minimise further complications.

Infiltration was found to be between 2.5-10.5 mm per hour for the calibration event (spatially variable infiltration). the estimate of infiltration rate is dependent on a variety of factors, including the quality of the rainfall data to establish a rainfall distribution over the catchment, as well as the initial moisture conditions, land cover and soil type. The wide infiltration range found for the Taumarere catchment justified the use of a variable infiltration rate throughout the catchment area.

Base flow and infiltration rates changed for each scenario, and needed to be chosen with care to provide a well-defined scenario considering different levels of soil moisture relative to that specific rain fall event. Therefore, calibrating the model for a different rainfall event, other than the Jan 2011 storm, also required the same detailed consideration when selecting these values.

3.6.6 Design Storm Profile

The twenty four hour design storm duration was used for 10, 50, 100 and 100yrs with climate change ARI events. The design storms were simulated with the calibrated model of the Taumarere catchment. The rainfall depths, profile, spatial distribution and duration were taken directly from the modelling completed during the Priority River Flood Risk Reduction project 2010. The rain duration of 24 hours was previously selected for the Taumarere catchment following a catchment analysis of its time of concentration. For more details regarding this aspect refer to the "NRC Priority Rivers Modelling Report", section "Hydrology".

Table 3-1 summarises the design event rainfall depths before and after the areal reduction factor. Note that the design rainfall depth is variable over the catchment as it was taken from HirdsV3 for each sub-catchment centre point.

Appendix C contains the final flood maps for all design events.

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3.6.7 Areal Reduction Factor

As advised by NRC, a new areal reduction factor was applied to the newly calibrated version of Taumarere catchment model. The new coefficient was provided by NRC and corresponded to a value of 0.932, as defined by Taumarere catchment size and the 24 hours storm duration.

3.6.8 Rainfall Spatial Distribution Factor approach

In the previous NRC Priority Rivers Project all of the rainfall's spatial distribution was implemented through a factor applied directly over the hydrograph, instead the hyetograph. This was possible because the previous method used the US SCS method as its hydrological model. The US SCS method determines a flow hydrograph based on a unit hydrograph approach which calculates runoff through a linear operation.

This was a convenient method as one rain depth was required as an input in the model for each sub-catchment (boundary node). The sub-catchment would hold a coefficient factor that was applied over the hydrograph to adjust the rain depth spatially.

As the Non-Linear Reservoir method is indeed non-linear (unless $p=1$), such a procedure cannot be executed easily, and therefore such factors need to be applied directly to the rain profile. In theory each sub-catchment has a different value for this coefficient, which means that individual rain series are needed for each sub-catchments (376 sub-catchments).

To reduce the number of input rain series, the spatial distribution factor was organized with a resolution of 0.01, from the minimum 0.69 to the maximum 1.00. In this way, only 32 rain series are required, each of them with the design storm event weighted by its respective coefficient.

Table 3-1 shows the rain depths for the design events. As the rain depth varies for each sub-catchment, the second column of the table shows the average of the rain weighted by each contributing sub-catchment area, followed by the maximum and minimum rain depth applied in a singular sub-catchment. The final column shows the same average rain depth multiplied by areal reduction factor of 0.936 that is the actual rainfall applied over each design event.

Table 3-1 Design storm rainfall depths

Design Storm	24 hrs Average rain depth (mm)	24 hrs max rain depth (mm)	24 hrs min rain depth (mm)	[24 hrs average rain depth] x ARF (mm)
Distribution factor	0.766	1.000	0.690	-
ARF	-	-	-	0.932
ARI 002	189.4	247.4	130.7	176.5
ARI 010	174.6	228.1	120.5	162.8
ARI 050	251.5	328.5	173.5	234.4
ARI 100	293.4	383.2	202.4	273.4
ARI 100F	342.7	447.6	236.4	319.4

Data Analysis

4.1 Survey Data Processing 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, as well as geo-referenced analysis of satellite images from the storm of January 2011.

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 for the Taumarere catchment is the storm recorded the 29th January 2011. This storm was approximately 17 hours in duration. Comparison with HIRDS v3 rain depths showed that this event was approximately a 50 year ARI storm with 18 hours duration.

An interesting feature of this event is that it happened during the summer time, when the soil is typically drier and therefore the infiltration rate is typically higher. However, just a week before, on the 23rd of January 2011, another significant storm, estimated to be approximately a 2 year ARI event, had taken place and had added moisture to the soils.

Before the calibration, it was necessary to perform a few analytical processes in order to estimate the:

- Rainfall distribution (temporal and spatial)
- Base flow
- Rainfall losses and effective rainfall volume

4.3 Rainfall Distribution for Calibration Event

The rainfall analysis utilised 15 rain gauges including 9 auto gauges (with readings between 1min and 1hr) and 6 daily gauges. Table 4-1 below summarises the available information and Figure 4-1 shows the distribution of rain gauges in the Taumarere catchment.

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 an understanding of the delays in temporal distribution. Satellite images were also available to compliment the analysis, providing valuable information regarding the dynamics and distribution of the event.

From this analysis and considering the large area covered by the catchment, the difference between times of maximum rainfall intensity, for remote locations in the catchment, is about 40 minutes. This relatively small temporal difference can be confidently represented with a few rain gauges used to distribute the rainfall throughout the catchment.

There are six rain gauges that have an important influence in the catchment (based on Thiessen polygons). Those gauges are;

- 545014 (auto),
- 53487 (auto),
- 533817 (auto),
- 54301 (daily),
- 545111 (daily), and
- 534012 (daily).

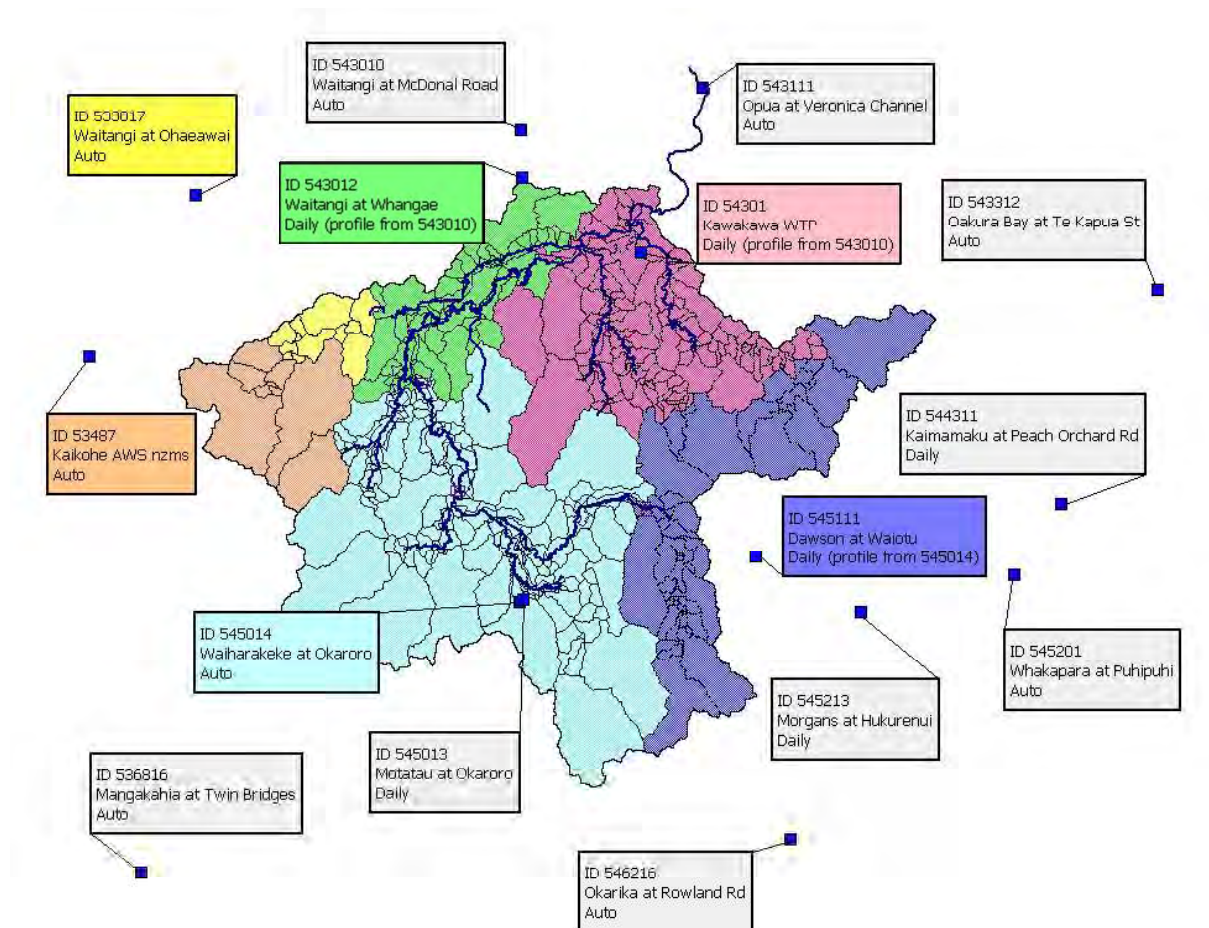
4 Data Analysis

The influential gauges have differences in temporal distribution of less than 20 minutes when compared with Waiharakeke at Okaroro rain gauge (545014). Figure 4-1 shows the area of influence of those three gauges over the catchment based on Thiessen polygons.

The initial analysis of this storm performance, helped to understand the dynamics of the calibration event and development of the resulting floods. Also it enabled an estimate of the temporal rainfall pattern for the daily gauges.

Rain gauges 545014 (auto), 53487 (auto), 533817 (auto), 54301 (daily/estimated pattern), 545111 (daily/estimated pattern) and 534012 (daily/estimated pattern) were used as inputs to the model for calibration. Figure 4-2 shows the rainfall intensity and accumulated rainfall for these six rain gauges.

Figure 4-1 Rain gauge location and Thiessen distribution over the Taumarere catchment



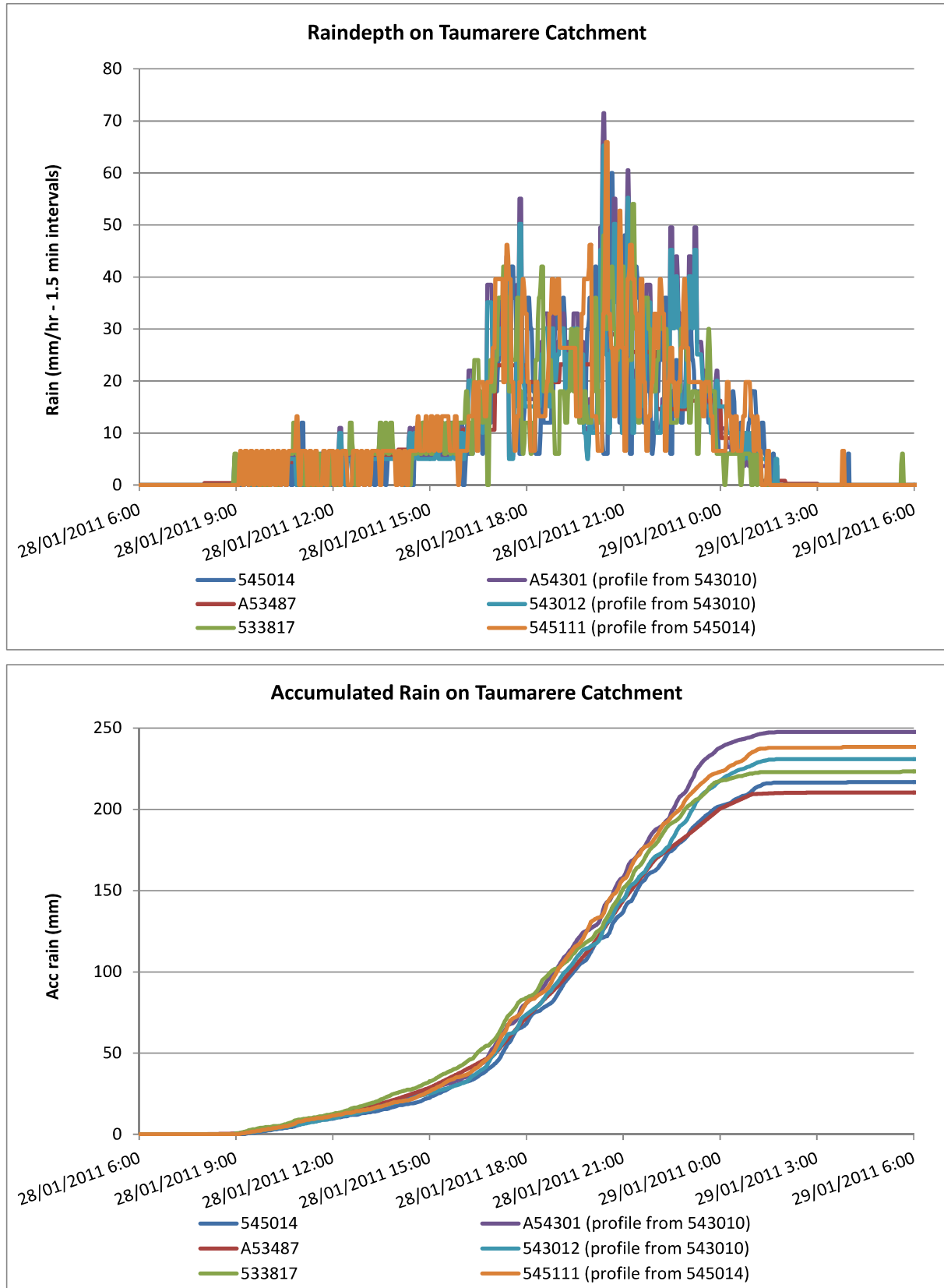
4 Data Analysis

Table 4-1 Rain gauge details for January 2011 event

NZMS1	Auto Gauges										Daily Gauges				
NZMS260															
X NZTM (Easting)	1693756	1705783	1676967	1674639	1679407	1693794	1715719	1722060	1701905	1699145	P05-047497	P06-047309	Q06-150328	1717819	Q06-197303
Y NZTM (Northing)	6088908	6058346	6056867	6079827	6087015	6089872	6070093	6082766	6091780	6084431	6087808	6069015	6070941	6073275	6068454
Catchment	Waiharakeke	Wairua	Mangakahia	Punakitere	Waitangi	Waitangi	Whakapara	Oakura	Kawakawa Estuary	Tirohanga	Whangae Stream	Waiharakeke	Waiotu	Whakapara	Waiotu
Location	Inside catchment (South)	Outside catchment (6.3 kms SE)	Outside catchment (11.6 kms SW)	Outside catchment (4.2 kms West)	Outside catchment (6.9 kms NW)	Outside catchment (2.3 kms North)	Outside catchment (9.4 kms SE)	Outside catchment (10.4 kms East)	Outside catchment (5.7 kms NE)	Inside catchment (East)	Northern catchment boundary	Inside catchment (South)	Outside catchment (2 kms SE)	Outside catchment (9.6 kms SE)	Outside catchment (6.3 kms SE)
Altitude (m)	60m	106m	70m	204m	122m	80m	215m	5M	5m	8m		50m	120m		122m
Record	Auto (5 mins)	Auto (5 mins)	Auto (5 mins)	Auto (1 min)	Auto (2 min)	Auto	Auto	Auto	Auto (5 min)	Daily at 00:00	Daily at 09:00	Daily at 09:00	Daily at 09:00	Daily at 09:00	Daily at 09:00
Recording Authority	NRC	NRC	NRC	Met Service	NRC	NRC	NRC	NRC	NRC	Met Service	NRC	NRC	NRC	NRC	NRC
Site ID	545014	546216	536816	A53487	533817	543010	545201	543312	543111	A54301	543012	545013	545111	544311	545213
Station name	Waiharakeke at Okaroro	Okarika at Rowland Road	Mangakahia at Twin Bridges	Kaikohe AWS	Waitangi at Ohaeawai	Waitangi at McDonald Road	Whakapara at Puhipuhi	Oakura Bay at Te Kapua Street	Opua at Veronica Channel	Kawakawa WTP	Waitangi at Whangae	Motatau at Okaroro	Dawson at Waiotu	Kaimamakau at Peach Orchard Road	Morgans at Hukurehuni
Daily Gauges match with which AUTO record	Daily totals to 09:00	Daily totals to 9:00	Daily totals to 09:00	Daily totals to 09:00	Daily totals to 09:00	Daily totals to 09:00	Daily totals to 09:00	Daily totals to 09:00	Daily totals to 09:00	End of day totals to midnight 00:00	Daily totals to 09:00	Daily totals to 09:00	Daily totals to 09:00	Daily totals to 09:00	Daily totals to 09:00
20/01/2011	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.5
21/01/2011	0.5	0.0	0.0	0.8	1.5	2.0	3.5	1.0	1.5	0.8	1.5	1.0	4.5	9.0	6.5
22/01/2011	0.0	0.0	1.5	0.2	0.0	0.0	17.5	8.5	1.0	46.2	20.0	0.0	3.5	19.0	4.5
23/01/2011	124.5	121.5	102.5	106.6	114.0	140.0	156.5	235.0	131.5	137.8	107.0	114.0	133.5	156.0	130.0
24/01/2011	15.5	9.0	21.5	26.4	18.5	14.0	27.0	3.0	7.5	0.0	21.5	23.5	20.5	22.5	13.5
25/01/2011	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26/01/2011	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27/01/2011	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28/01/2011	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	237.0	0.0	0.0	0.0	0.0	0.0
29/01/2011	217.0	206.0	161.5	210.4	223.5	276.0	277.0	227.5	237.0	10.6	231.0	208.0	238.5	278.0	221.5
30/01/2011	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
31/01/2011	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1/02/2011	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2/02/2011	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3/02/2011	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4/02/2011	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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Figure 4-2 Distributed and accumulated rain for the calibration event



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4.4 Flow/Level Gauges Analysis for Calibration Event

There are four level gauges in the catchment. They are listed below with their details and data availability.

Table 4-2 Level gauges details

	Water Level Sites			
X NZTM (Easting)	1692624	1700259	1701913	1699491
Y NZTM (Northing)	6082780	6084306	6091757	6084749
Recording Authority	NRC	NRC	NRC	
SG Zero (m OTP)	9.100	6.086	-1.560	Unknown
catchment name	Waiharakeke	Tirohanga	Estuary	Tirohanga
Catchment area km2	229	57	Sea level	
Record	Auto	Auto	Auto	
Period of Record	02.02.1967 -	15.10.2010 -	26.04.1990 -	
Site ID	3819	3817	3835	3829
Site Name	Waiharakeke at Willow bank	Tirohanga below Old Mill	Veronica Channel at Opuia	Tirohanga DS County Take
Max Stage event Jan 2011 (SG) m	6.126	4.806	2.539 (serie)	Not available
Max flood elevation Jan 2011 (m OTP)	15.226	10.892	0.979 (tide serie)	9.2 (debris)
Time of peak	29/01/2011 22:00	29/01/2011 0:25	29/01/2011 2:40	Not available
Max Gauging at site - Level (SG) mm	4140	652		
Max Gauging at site Flow (m3/s)	72.100	1.280		
Confidence in predicted peak flow estimate	Medium	Low		
Predicted Peak Flow Jan 2011 (from rating curve) m3/s	238.3	148.4		
Rating Curve	Available	Available	Not available	Available

Level records are available for three of these gauges. Flow records are available for the station of Willowbank and Tirohanga. The Tirohanga gauge below Old Mill has a low reliability for flow estimation. The tide station was only used as a boundary condition, so calibration does not apply for it. There is also a rating curve for an old station at Tirohanga downstream of County Take, just 1 km downstream of the other station in Tirohanga, however it does not have any records or a known datum. Hence it was not included in the assessment.

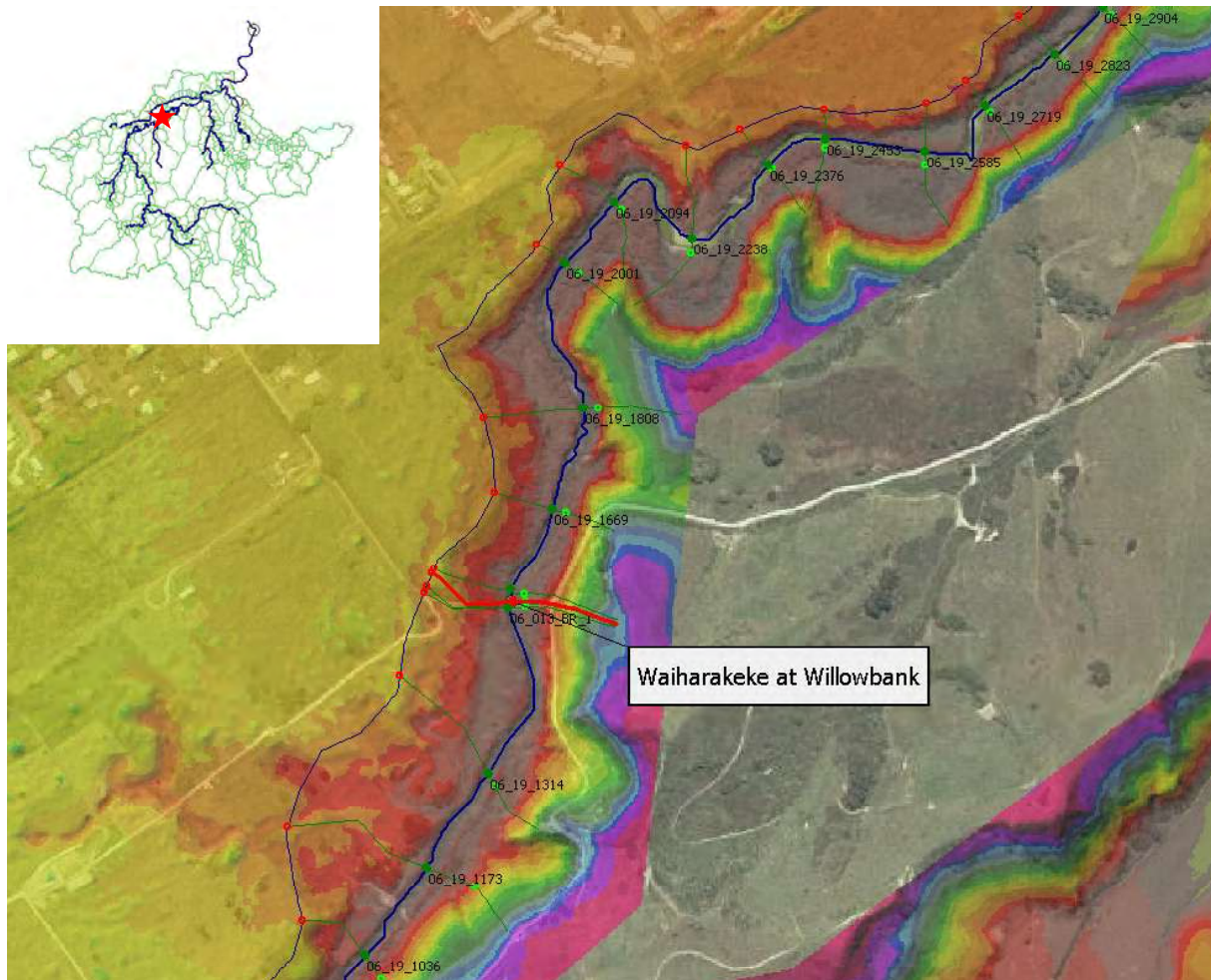
Datum and levels records were checked against LiDAR information and debris level survey. Below are brief descriptions of all four stations and the quality of their data.

4.4.1 Waiharakeke at Willowbank

The Willowbank gauging station is located right at the centre of the catchment. The level gauge is located in a narrow valley that extends for a couple of kilometres upstream and downstream of the gauge making this location a good place for level measurements. The Figure 4-3 shows the location of the Willowbank Station.

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Figure 4-3 Waiharakeke at Willowbank station



The catchment draining to the Willowbank station is approximately 230 km², or 52% of the total Taumarere catchment.

During the storm of January 2011 this recorder malfunctioned from 29/01/2011 at 10:30 to 30/01/2011 at 9:30, when the maximum flows occurred. The peak stage at the gauge site was surveyed post event at 15.226m OTP (6126mm SG), which is only 450mm above the level that the recorder started malfunctioning. NRC hydrologists then processed this information and adjusted the records generating a synthetic data for the peak. Figure 4-4 shows the completed adjusted record series.

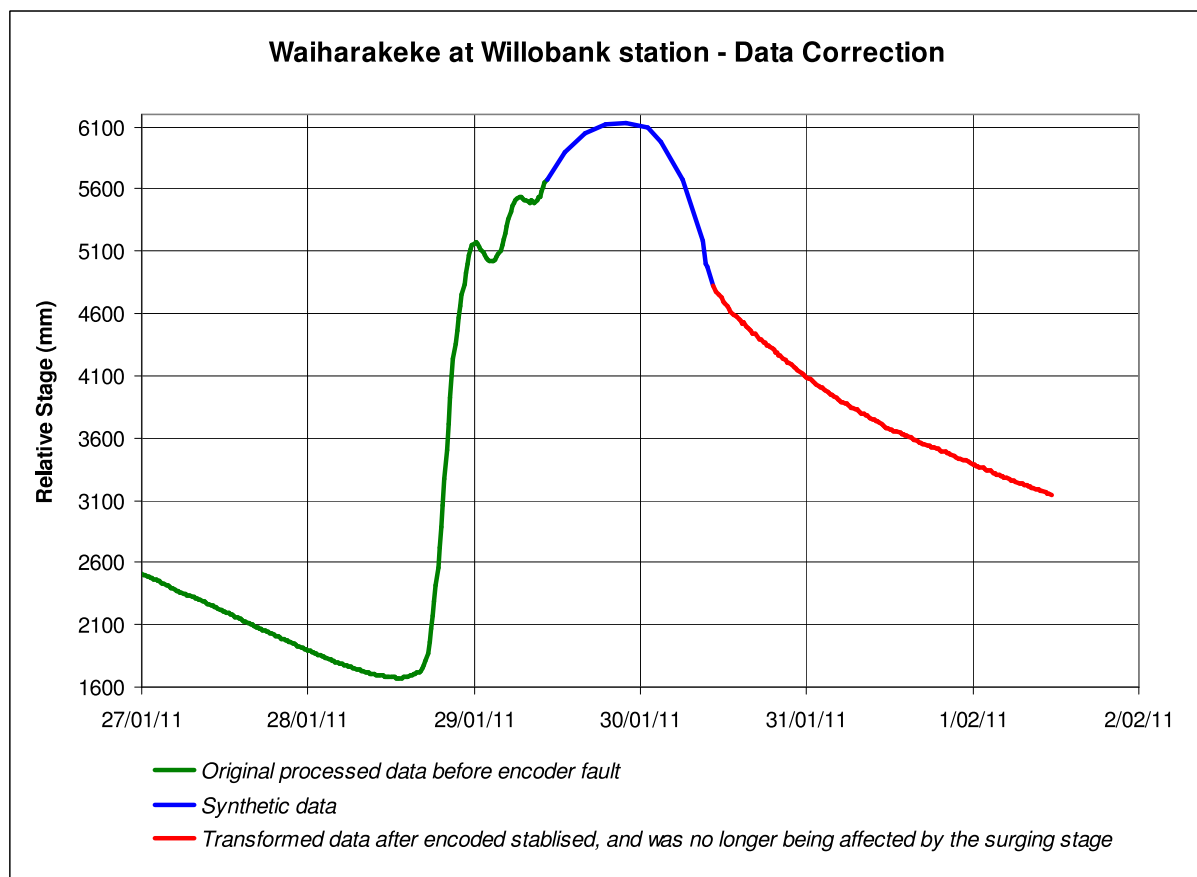
The rainfall volume was compared against the flow volume of this station for the 29th of January 2011 storm. The flow volume calculated also considered several days following the storm in order to account for the slow response of the catchment. Through this exercise a runoff coefficient of 0.55 to 0.73 was estimated for the upper catchment as being applicable to the calibration storm. The relatively wide range of the runoff estimate comes from the extended “tail” of the hydrograph. This tail extends for five days after the storm event and is quite important in accounting for the total storm volume. The Non-Linear Reservoir method enables a better representation of the hydrograph tail than the SCS method. But considering the large size of the gauged catchment and the great amount of storage

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contained within it, it was determined to be necessary to exclude a portion of the Willowbank hydrograph tail from calibration (refer to Figure 4-5). The reason for the exclusion is due to an uncertainty of the rate and amount of infiltration for the catchment. The runoff coefficient of 0.73 corresponds to the overall flood volume, considering the totality of the tail. The value of 0.55 considers mainly the fast response of the hydrograph, with a shorter tail.

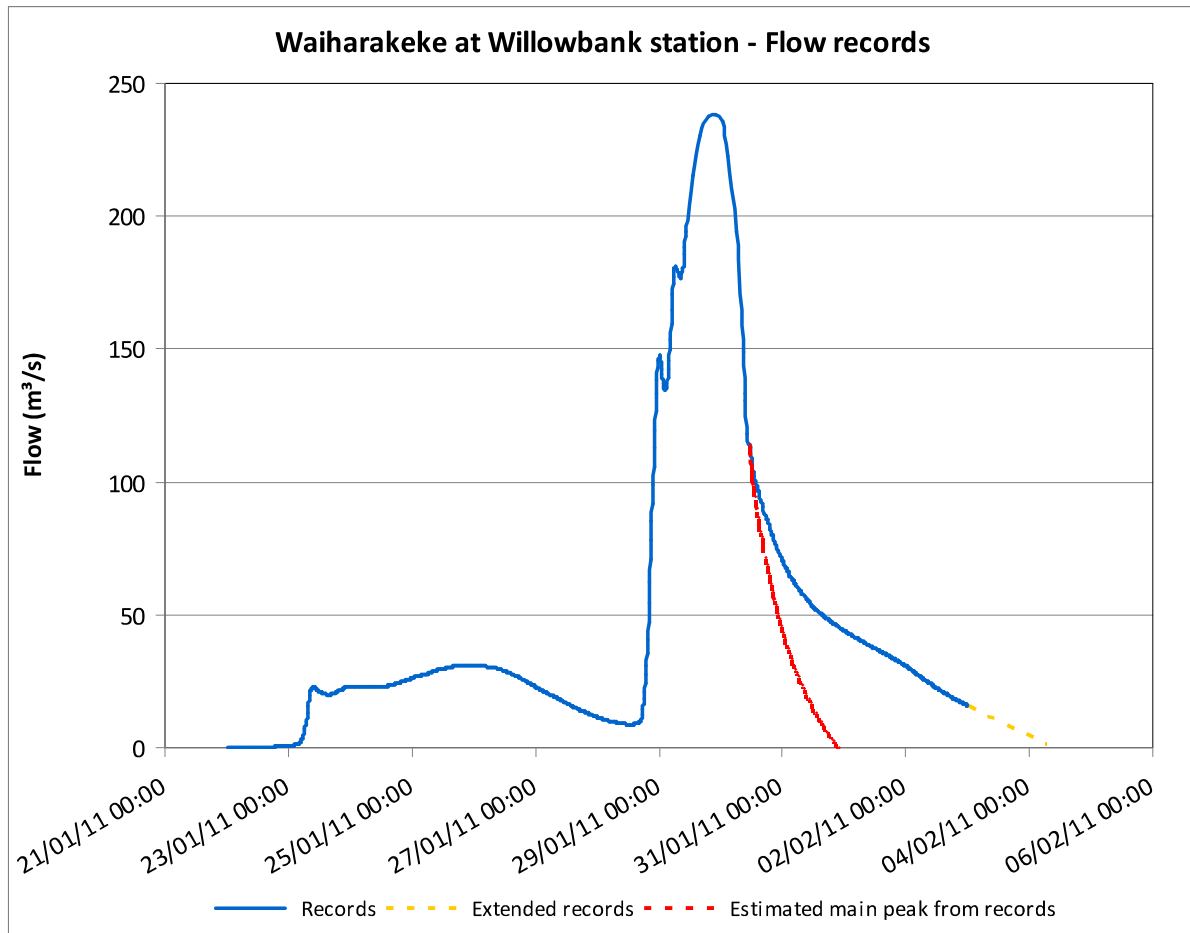
The runoff coefficient range translates to infiltration rates of 7.5mm/hr (RC=0.55) and 4.3mm/hr (RC=0.73) respectively. Figure 4-5 shows the flow records from Willowbank and the volume estimations related to the tail of the hydrograph.

Figure 4-4 Adjusted records for Waiharakeke at Willobank, with Synthetic data at the peak



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Figure 4-5 Waiharakeke at Willowbank station



4.4.2 Tirohanga below Old Mill

The gauge below the Old Mill is located on the lower part of the Tirohanga stream, a tributary that drains directly into Kawakawa River just upstream of that river estuary. Its catchment is 57 km^2 or 12.9% of the whole Taumarere catchment. The rainfall volume was compared against the flow volume of this station for the 29th of January 2011 storm. The flow volume calculated also considered several days following the storm to take into account the slow response of the catchment. Through this exercise a runoff coefficient of 0.47 was estimated for Tirohanga catchment for the calibration storm (equivalent to an infiltration of 10.6 mm/hr). The runoff coefficient is quite small, considering the volumes delivered by Willowbank and also other catchments in the Northland area during the storm of January 2011. This volume estimation considers flow records that are based on level records and a rating curve for the station.

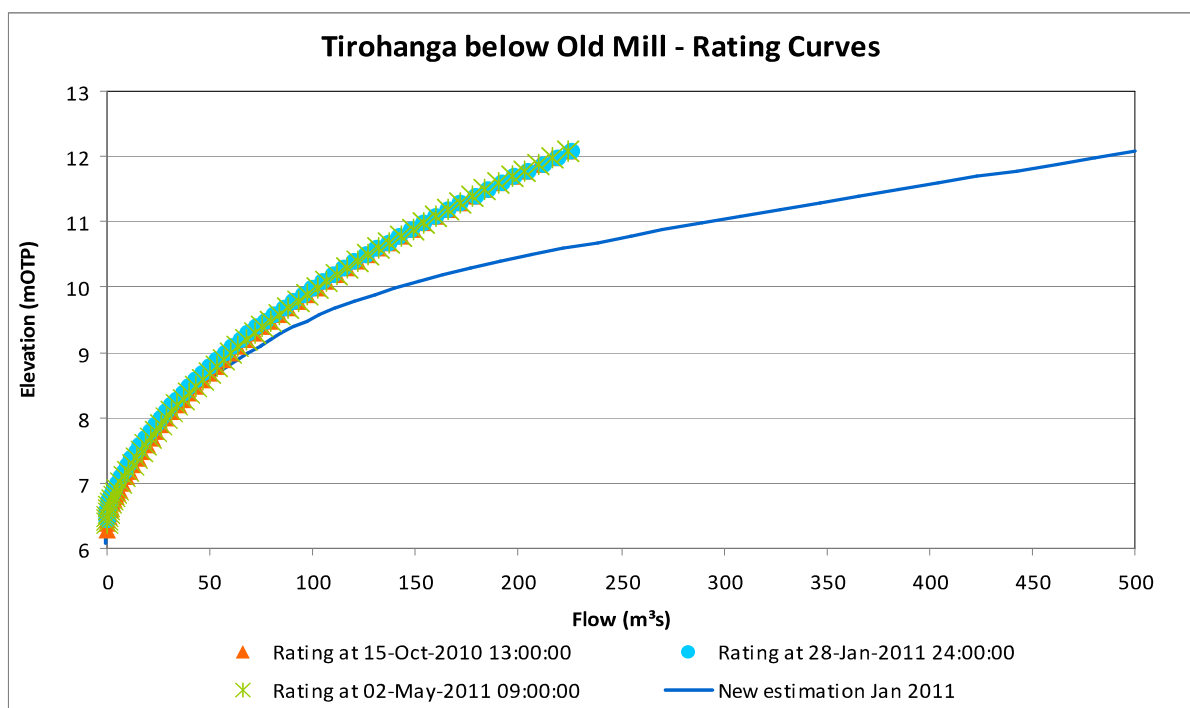
Information related to this station shows a low confidence for high flow prediction, as the rating curve was extrapolated for this range. During preliminary calibrated models, the modelled rating curve for Tirohanga station was compared against the records. The correlation was good for low flows (under 50 m^3/s), but poor for high levels. The model rating was considered more reliable as the flood hydraulic grade line upstream and downstream is well represented for the January 2011 flood data. In this way, the rating curve was corrected for high flows and the flow series recalculated giving higher

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flows for the peak. Figure 4-6 and Figure 4-7 shows the record rating curves and the flow records against the estimations. This new flow series provides a second guide for the calibration of this gauge. The runoff coefficient calculated based on the new flow series is 0.56 which seems more correct (equivalent to an infiltration of 5.5 mm/hr). In addition, a runoff discharge of up to approximately 5 m³/s/km² is the expected range for a 50-yr ARI event in Northland. This provided further justification for the rating curve modification.

The calibration of Tirohanga station is explained in detail in Section 5.2 and 6.2.

Figure 4-6 Tirohanga below Old Mill; rating curve



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Figure 4-7 Tirohanga below Old Mill; estimated and recorded flow

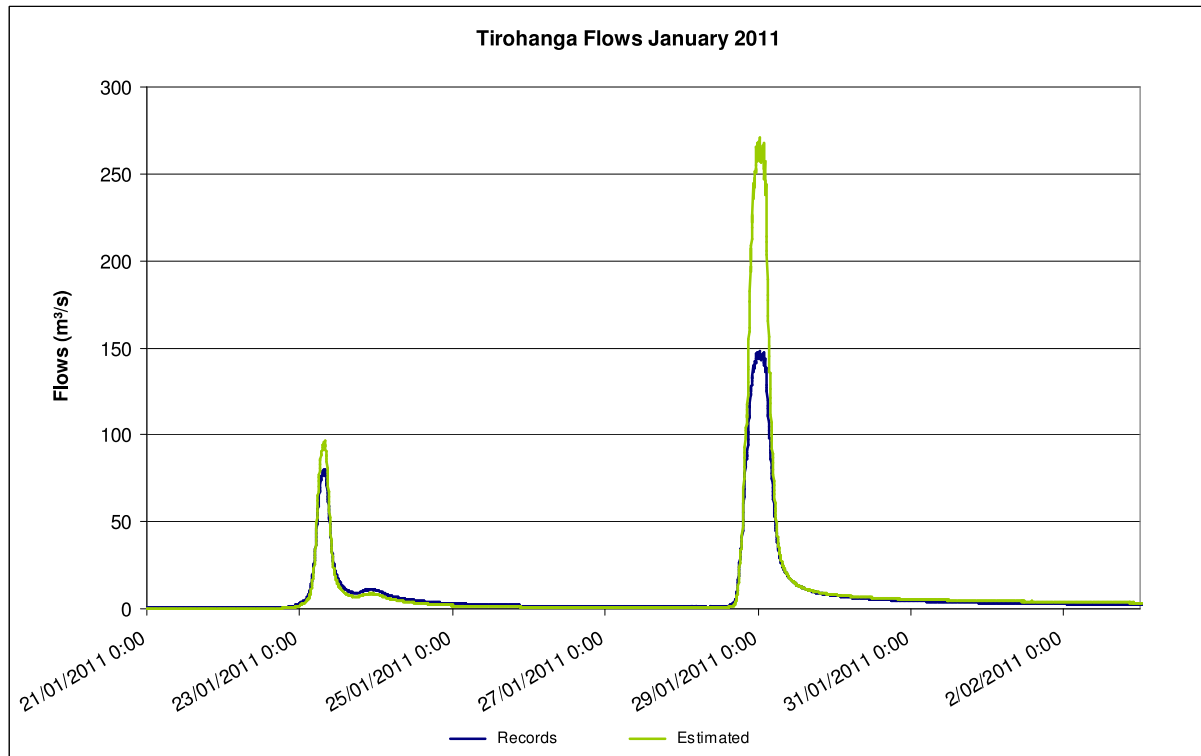
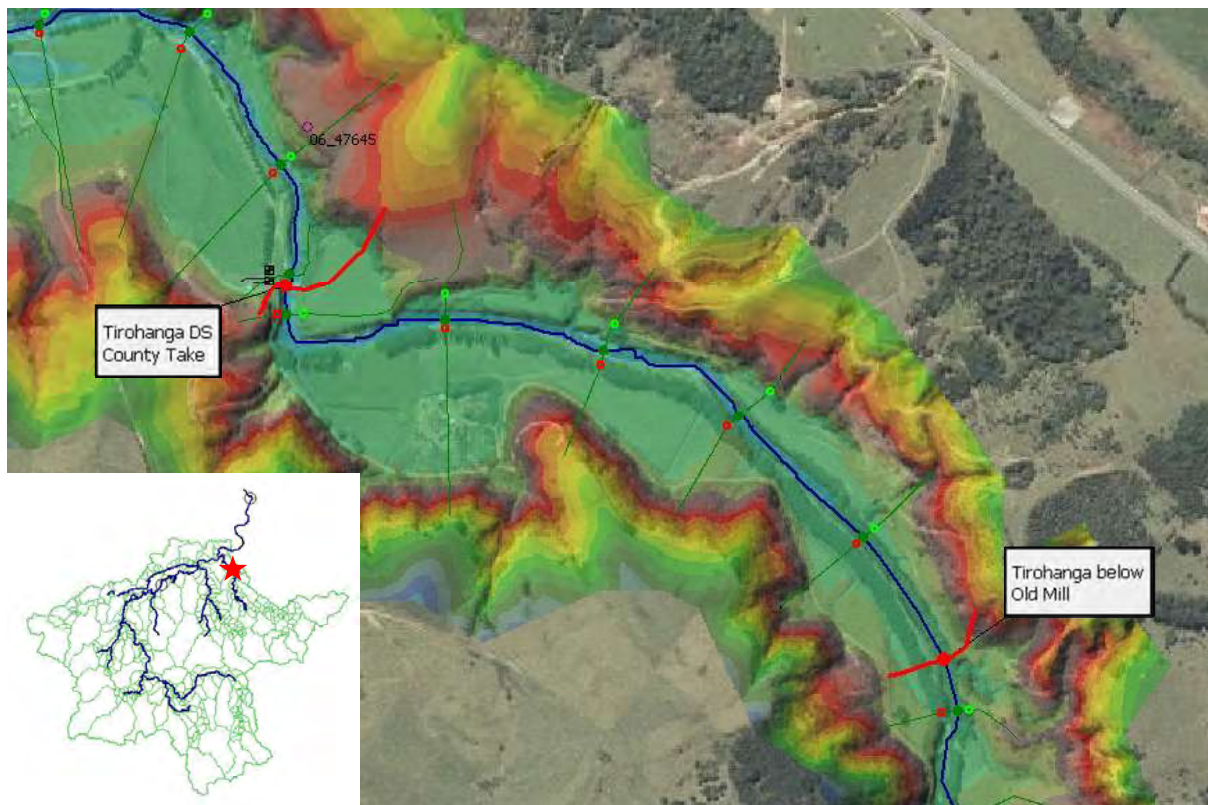


Figure 4-8 Tirohanga stations; location



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4.4.3 Tirohanga downstream of County Take

Located 1 km downstream of the station, Tirohanga below Old Mill, this is an abandoned gauge that does not have any records for the storm of January 2011. It has a rating curve, however, with an unknown datum level. This station was anticipated to be more reliable in terms of high flow predictions; however, the rating curve is only available for flows up to 100m³/s, and the last flow measurement was taken below 40m³/s. With such limited information this rating curve is not very useful. Calibration results have been graphed against the rating curve using an estimated datum. Analysis involving this gauge was not considered further in the evaluated calibration performance. Figure 4-9 shows the available rating curve for Tirohanga downstream of County Take. Section 5.3 shows model results at this site.

4.4.4 Tidal Gauge – Veronica Channel at Opua

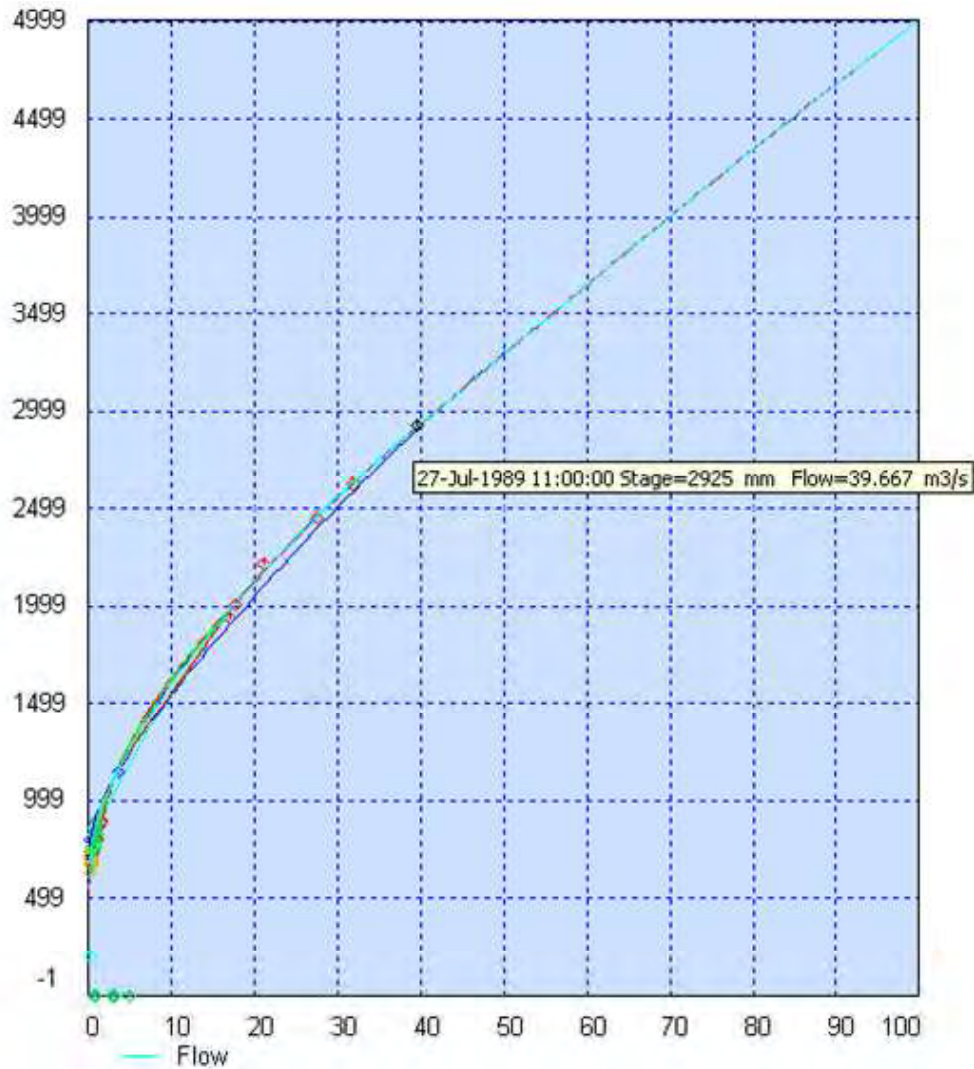
Veronica Channel at Opua is a tidal station located in the estuary of Kawakawa River. Its records were used as the tidal level boundary condition for the calibration event.

4.5 Debris Level Points for Calibration Event

One hundred and ninety debris level points were surveyed and were available for the calibration event. These level points were checked against LiDAR for evaluation. The full set of points cover the majority area of the catchment providing valuable information for the calibration event.

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Figure 4-9 Tirohanga downstream County Take; rating curve showing maximum gauging at site



Calibration

The model was calibrated against the recorded levels and flows available, as described in Sections 2 and Section 4.

The most critical portion of the calibration was to accurately represent and well define hydraulic features within the model and the appropriate hydrology in the modelling of the sub-catchments, especially in relation to the large amount of storage available in the catchment. Some storage areas outside of the LiDAR area were also considered and estimated. The critical hydraulic components defined in the model included bridges, spills (banks and roads), 2D areas and storage areas. The definition of hydraulic features (e.g. bridge size, spill length, invert levels, and storage array curve) was more essential to achieving good calibration results than hydraulic parameters such as roughness and discharge coefficients.

As stated the hydrological model was also important to describe flows and volumes to achieve a good model calibration. The non-linear reservoir method allowed us to have a more realistic description of the hydrograph and a better match of volumes and flows for the hydrographs' peak and tail.

The following table summarises the important calibration variables.

Table 5-1 Calibrated parameters

Variable	Value
HYDRAULIC MODEL	
Manning	
Main channels	0.024 - 0.055
Flood plains	0.060 - 0.160
Open bridges or culverts	0.070 - 0.080
2D polygons	0.075 - 0.085
Spill coef	
Natural bank	0.25 - 0.50
Roads	0.50 - 0.60
Upper storage outlets	0.60 - 0.75
Orifice coeff (culverts)	0.8 - 1.0
HYDROLOGICAL MODEL	
Non-Linear Reservoir	
K =	1.25 - 20.1
p =	0.60
Infiltration Rate (mm/hr)	5.4 - 9.2
Time lag (minutes)	as per TP108

5.1 Debris Levels Points Results Match

The table below shows the elevation from the survey and model for a selection of debris points. This selection was chosen as recommended by NRC. The full set is included in Appendix A.

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Table 5-2 Measured and Modelled debris level points

Point	X (m)	Y (m)	Description	Flood Level (mOTP)	Model (mOTP)	dZ (m)	Comments
ID=89	1699763.6	6086566.3	DEBRI	4.01	4.334	0.324	
ID=90	1699762.1	6086562.6	DEBRI	4	4.332	0.332	
ID=91	1699760.5	6086559.9	DEBRI	4	4.331	0.331	
ID=93	1699548.0	6086726.7	DEBRI	3.99	4.466	0.476	
ID=97	1699101.0	6086592.2	DEBRI	4.06	4.56	0.5	
ID=84	1698869.4	6086071.6	FLV	4.42	4.87	0.45	
ID=85	1698871.8	6086069.2	FLV	4.41	4.87	0.46	
ID=88	1698843.3	6086053.4	FLV	4.39	4.87	0.48	
ID=1001	1699071.8	6085881.9	TREE	6.002	5.557	-0.445	Improved
ID=1002	1699148.5	6085880.9	DEBRI	5.976	5.816	-0.16	Improved
ID=1003	1699148.5	6085880.9	DEBRI	5.996	5.816	-0.18	Improved
ID=1004	1699140.3	6085886.0	SILT	5.999	5.802	-0.197	Improved
ID=102	1699462.0	6084753.0	DEBRI	9.2	8.882	-0.318	
ID=103	1699445.3	6084754.2	DEBRI	9.24	8.818	-0.422	
ID=104	1699448.2	6084761.2	DEBRI	9.22	8.816	-0.404	
ID=105	1699462.9	6084746.9	DEBRI	9.19	8.86	-0.33	
ID=107	1700211.4	6084295.1	Debris line	10.84	10.942	0.102	
ID=106	1700273.5	6084038.6	DEBRI	11.5	11.506	0.006	
ID=39	1697797.2	6085645.5	DEBRI	4.96	5.31	0.35	
ID=40	1697798.6	6085639.1	DEBRI	4.97	5.31	0.34	
ID=41	1697790.4	6085633.3	DEBRI	4.98	5.31	0.33	
ID=42	1697785.2	6085629.8	DEBRI	4.99	5.31	0.32	
ID=43	1697778.5	6085623.3	DEBRI	5.01	5.31	0.3	
ID=44	1697774.6	6085619.9	DEBRI	4.98	5.31	0.33	
ID=45	1697528.0	6085710.6	DEBRI	5.03	5.31	0.28	
ID=46	1697526.8	6085711.7	DEBRI	5.09	5.31	0.22	
ID=47	1697528.0	6085713.4	DEBRI	5.11	5.31	0.2	
ID=81	1697251.9	6084648.8	DEBRI	5.07	5.346	0.276	2D at flood plain correct. Correct in 2D.
ID=82	1697259.6	6084642.7	DEBRI	4.99	5.346	0.356	2D at flood plain correct. Correct in 2D.
ID=83	1697264.1	6084631.3	DEBRI	4.96	5.346	0.386	2D at flood plain correct. Correct in 2D.
ID=50	1696487.8	6085258.9	DEBRI	5.08	5.378	0.298	
ID=51	1696487.1	6085258.3	DEBRI	5.07	5.378	0.308	
ID=31	1696442.7	6085103.4	DEBRI	4.98	5.41	0.43	
ID=32	1696446.8	6085102.7	DEBRI	4.95	5.409	0.459	
ID=23	1696367.8	6085068.3	DEBRI	5.43	5.451	0.021	
ID=24	1696378.5	6085045.3	DEBRI	4.96	5.423	0.463	
ID=26	1696383.8	6085005.5	DEBRI	5.28	5.467	0.187	
ID=27	1696386.5	6085001.4	DEBRI	5.32	5.467	0.147	

5 Calibration

Point	X (m)	Y (m)	Description	Flood Level (mOTP)	Model (mOTP)	dZ (m)	Comments
ID=28	1696388.6	6084998.1	DEBRI	5.29	5.467	0.177	
ID=21	1695427.3	6085058.2	DEBRI	5.23	5.467	0.237	
ID=22	1695433.0	6085055.2	DEBRI	5.19	5.467	0.277	
ID=9	1696054.8	6084664.8	FLV	5.33	5.467	0.137	
ID=10	1696094.3	6084663.0	FLV	5.27	5.467	0.197	
ID=11	1696139.2	6084698.2	FLV	5.33	5.467	0.137	
ID=52	1696608.9	6084545.0	DEBRI	5.13	5.455	0.325	
ID=54	1696633.7	6084410.0	SILT	5.08	5.521	0.441	
ID=55	1696639.9	6084408.6	SILT	5.13	5.516	0.386	
ID=59	1696763.7	6084487.6	FLV	5.18	5.432	0.252	
ID=60	1696730.1	6084429.4	FLV	5.24	5.463	0.223	
ID=61	1696767.0	6084411.7	FLV	5.25	5.457	0.207	
ID=77	1696987.4	6084355.9	SILT	5.73	5.587	-0.143	
ID=78	1696987.4	6084355.9	SILT	5.73	5.587	-0.143	
ID=79	1696982.9	6084362.1	SILT	5.72	5.572	-0.148	
ID=80	1696988.1	6084367.4	FLV	5.76	5.578	-0.182	
ID=68	1697279.9	6084393.7	DEBRI	6.21	6.497	0.287	
ID=69	1697279.0	6084390.3	DEBRI	6.25	6.497	0.247	
ID=70	1697275.3	6084384.9	FLV	6.39	6.528	0.138	
ID=71	1697275.5	6084385.0	FLV	6.39	6.528	0.138	
ID=72	1697275.5	6084385.1	FLV	6.39	6.528	0.138	
ID=73	1697266.2	6084357.7	DEBRI	7	6.62	-0.38	
ID=B	1697155.0	6080428.0	FL03 - silt in tree	14.783	14.755	-0.028	
ID=C	1697146.0	6080424.4	FL03 - brid se silt lev	15.043	14.721	-0.322	
ID=F	1697388.7	6078734.2	FL06 - post debris	23.119	22.932	-0.187	2D at flood plain correct. Correct in 2D.
ID=G	1697523.4	6078729.7	FL06 - debris in fce	23.217	23.678	0.461	
ID=H	1697514.8	6078298.7	FL05 - debris in rail	26.367	25.926	-0.441	
ID=I	1697616.6	6077776.8	FL07 - edge erosion swept	28.497	28.402	-0.095	
ID=J	1697994.1	6080984.1	FL01 - ht debris	15.711	15.981	0.27	
ID=K	1697975.2	6080973.6	FL01 - ht debris in fce	15.691	15.994	0.303	
ID=M	1698822.5	6079279.1	FL08 - fce debris	26.577	26.665	0.088	
ID=13	1695368.5	6084719.5	DEBRI	6.23	5.941	-0.289	
ID=14	1694928.1	6084812.8	FLV	7.46	7.425	-0.035	
ID=15	1694907.0	6084794.9	DEBRI	7.64	7.476	-0.164	
ID=16	1694911.6	6084792.5	DEBRI	7.58	7.41	-0.17	Point at bank; surrounding levels are correct. 2D Ok.

5 Calibration

Point	X (m)	Y (m)	Description	Flood Level (mOTP)	Model (mOTP)	dZ (m)	Comments
ID=17	1694883.9	6084799.8	DEBRI	7.8	7.39	-0.41	
ID=18	1694882.6	6084798.5	DEBRI	7.85	7.401	-0.449	
ID=19	1694917.1	6084821.4	DEBRI	7.85	7.36	-0.49	
ID=2027	1691352.9	6083284.9	FL45 - silt line in vegetation	19.451	19.475	0.024	
ID=2019	1691296.9	6082277.0	FL56 - debris in fce	28.204	27.935	-0.269	2D at flood plain correct. Correct in 2D.
ID=2029	1691235.5	6082255.8	FLV - Photo evidence	28.794	28.7	-0.094	2D at flood plain correct. Correct in 2D.
ID=2000	1691203.1	6082264.2	FLV - Photo evidence	28.952	28.793	-0.159	2D at flood plain correct. Correct in 2D.
ID=2026	1691106.2	6082345.2	FL55 - silt line in vegetation	29.124	29.017	-0.107	
ID=2003	1690778.8	6082289.6	FLV - Owner report	30.932	30.873	-0.059	At large flood plain. Correct in 2D.
ID=2025	1688996.8	6081743.2	FL50 - debris in gate	38.036	37.993	-0.043	2D at flood plain correct. Correct in 2D.
ID=2022	1689804.3	6081762.0	FL54 - debris in fce	34.936	34.776	-0.16	Correct in 2D (at bridge)
ID=2023	1689751.2	6081741.7	FL53 - silt line in vegetation	34.707	34.912	0.205	
ID=2020	1689323.8	6081037.0	FL51 - silt line at btm fce	37.715	37.685	-0.03	
ID=2021	1688784.1	6080433.7	FL48 - silt line in vegetation	38.961	39.217	0.256	
ID=2100	1688883.9	6078907.0	MUD	40.501	40.8	0.299	
ID=1005b	1688832.5	6078893.5	DEBRI	40.572	40.555	-0.017	
ID=1006b	1688876.6	6078908.5	MUD	40.485	40.785	0.3	
ID=1007	1688881.9	6078869.7	MUD	40.469	40.807	0.338	
ID=1008	1688867.7	6078872.2	MUD	40.589	40.783	0.194	
ID=1009	1688910.1	6078901.4	MUD	40.533	40.799	0.266	
ID=1010	1688906.2	6078882.5	MUD	40.471	40.796	0.325	
ID=1016	1687350.7	6076073.7	FL	51.23	51.029	-0.201	
ID=1017	1687361.1	6076054.6	FL	51.08	51.001	-0.079	
ID=1021	1687376.1	6076082.3	DEBRI	51.182	50.999	-0.183	
ID=1022	1687376.2	6076082.2	DEBRI	51.282	50.999	-0.283	
ID=1023	1687346.6	6076081.9	DEBRI	51.337	51.118	-0.219	
ID=2004	1691162.5	6073894.1	FL	47.793	48.069	0.276	
ID=2006	1691106.1	6073895.7	FL	48.705	49.118	0.413	
ID=2007	1691085.1	6073898.6	DEBRI	48.668	49.031	0.363	
ID=2009	1690997.4	6073921.6	DEBRI	48.177	48.28	0.103	Looks ok, but 2D has small instabilities in this area. Maximum values seem wrong, but average around

5 Calibration

Point	X (m)	Y (m)	Description	Flood Level (mOTP)	Model (mOTP)	dZ (m)	Comments
							variations is good.
ID=2011	1694536.2	6071256.2	DEBRI	53.029	53.319	0.29	
ID=2018	1694548.9	6071235.3	DEBRI	52.993	53.381	0.388	
ID=2036t1	1693741.3	6069996.9	MUD	54.088	54.52	0.432	
ID=2040t1	1693745.9	6069998.3	MUD	54.109	54.525	0.416	
ID=2041t1	1693727.6	6069989.9	MUD	54.111	54.511	0.4	
ID=2042t1	1693725.3	6069988.5	MUD	54.111	54.51	0.399	
ID=2043t1	1693724.1	6069977.5	MUD	54.084	54.505	0.421	
ID=2044t1	1693730.5	6069982.0	MUD	54.139	54.509	0.37	
ID=2045t1	1693741.9	6069986.5	MUD	54.114	54.517	0.403	
ID=2046t1	1693751.4	6069988.2	MUD	54.107	54.523	0.416	
ID=2006t1	1699395.8	6073068.5	FL	66.372	66.746	0.374	
ID=2007t1	1699421.1	6073086.0	FL	66.868	66.788	-0.08	
ID=2009t1	1697289.4	6073181.7	DEBRI	60.98	60.89	-0.09	
ID=2010t1	1697329.9	6073202.0	MUD	60.727	60.89	0.163	
ID=2011t1	1697312.7	6073203.4	GRASS	60.669	60.923	0.254	
ID=2012t1	1697301.5	6073197.5	GRASS	60.48	60.866	0.386	
ID=2013t1	1699369.2	6073046.6	FL	66.504	66.638	0.134	
ID=2014t1	1699341.8	6073054.5	MUD	66.081	66.372	0.291	
ID=2015t1	1699330.0	6072991.4	DEBRI	66.851	67.026	0.175	
ID=2016t1	1699321.9	6073017.0	DEBRI	66.898	67.026	0.128	
ID=Q	1691573.3	6083261.2	FL	19.6	19.656	0.056	

Some significant differences between the modelling results and recorded debris levels may be caused by the quality of the survey data, which requires further investigation.

5.2 Tirohanga below Old Mill

Figure 5-1 and Figure 5-2 show the comparison between model prediction and stage/flow records at Tirohanga below Old Mill.

5 Calibration

Figure 5-1 Measured and modelled levels at Tirohanga blow Old Mill station

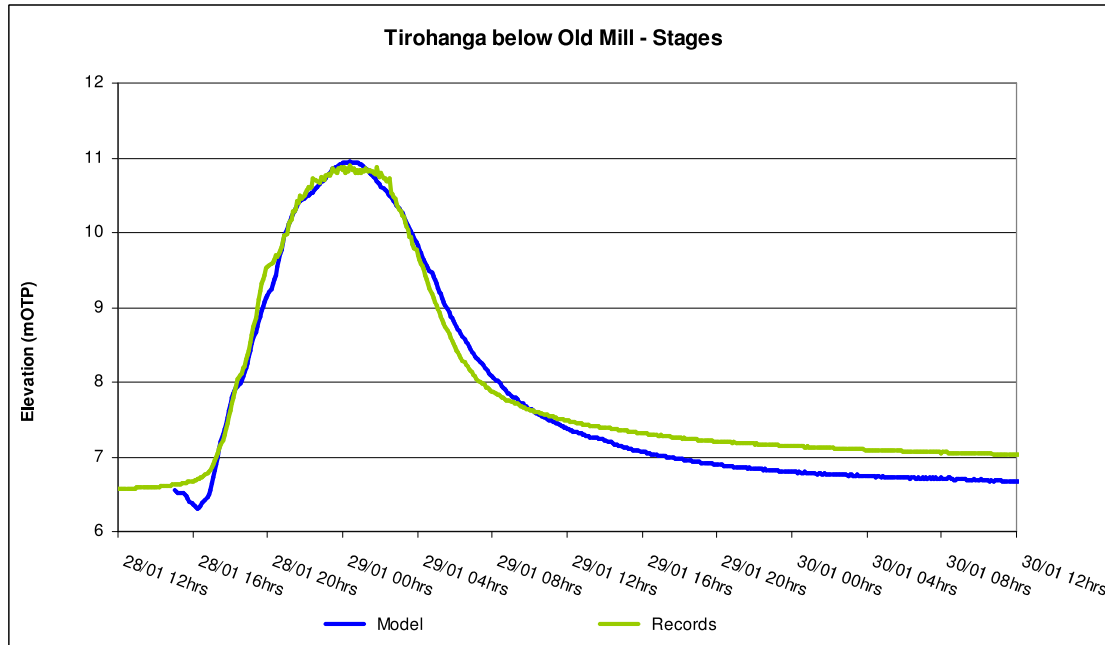
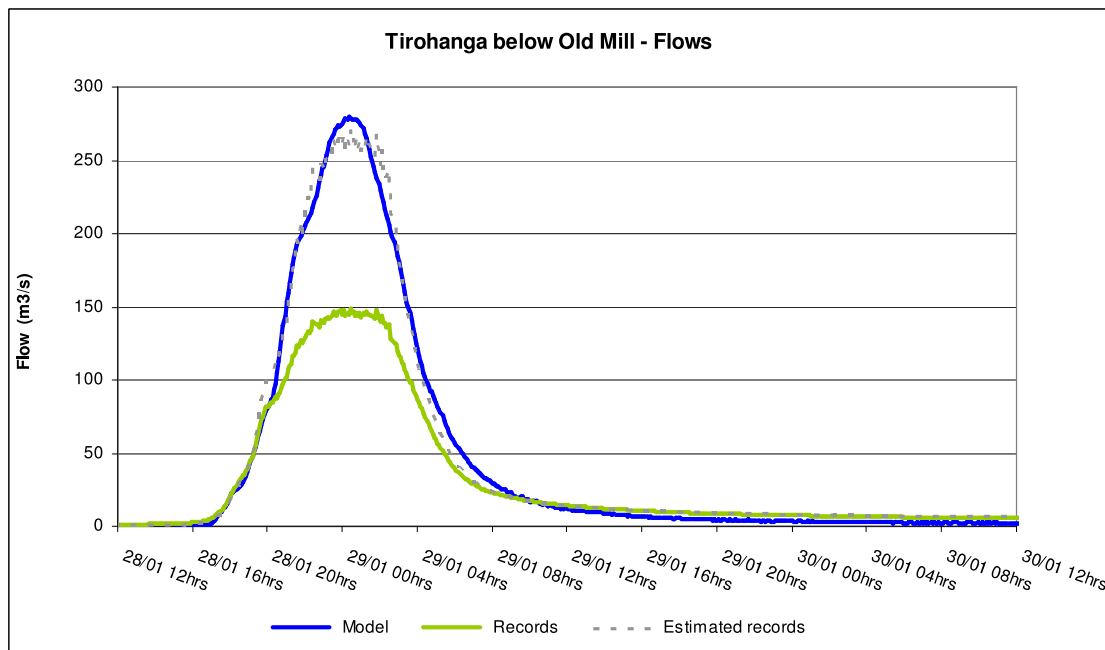


Figure 5-2 Measured, estimated and modelled flows at Tirohanga blow Old Mill station



5 Calibration

Figure 5-3 Measured, estimated and modelled rating curve in Tirohanga below Old Mill

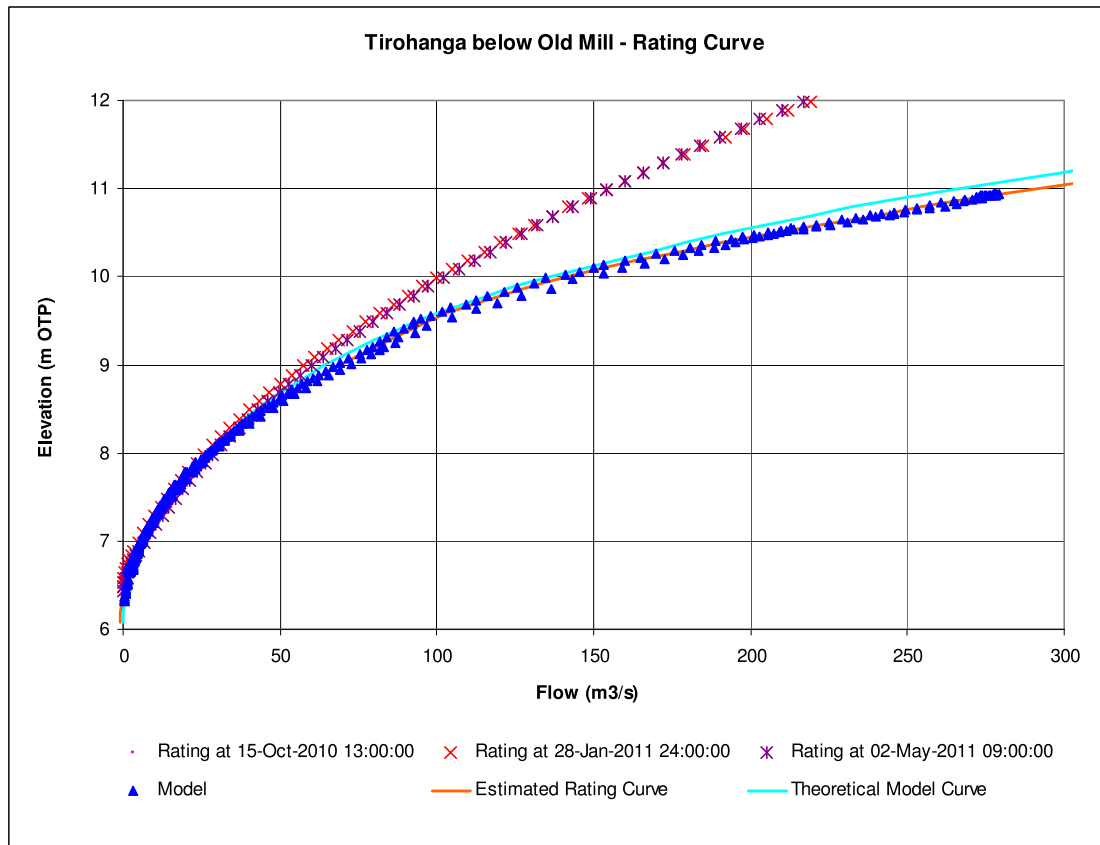


Figure 5-3 shows the rating curves of the gauge at Tirohanga below Old Mill. It shows three site rating curves provided by NRC and related to three different dates. The Estimated Rating Curve is explained in section 4.4.2.

The Theoretical Model Curve is a rating curve that is calculated by the model as a property of each river section included in the network. It is a calculated rating curve based on the conveyance and geometrical properties. This approximated curve is used to assist the computation.

The Model Curve is a plot of the actual model results. The model results would take into account that the flow might be dependant of upstream and downstream conditions, and different flow regimes that might happen during a hydrograph, calculating the flow and levels in each location as a result of the whole system interacting together.

The model rating curves for the gauge at Tirohanga below Old Mill is included in Appendix B of this report.

5 Calibration

5.3 Tirohanga downstream of County Take

Figure 5-4 shows the rating curve of the gauge at Tirohanga DS of County Take.

Figure 5-4 Recorded and modelled rating curve at Tirohanga DS of County Take (estimated datum)

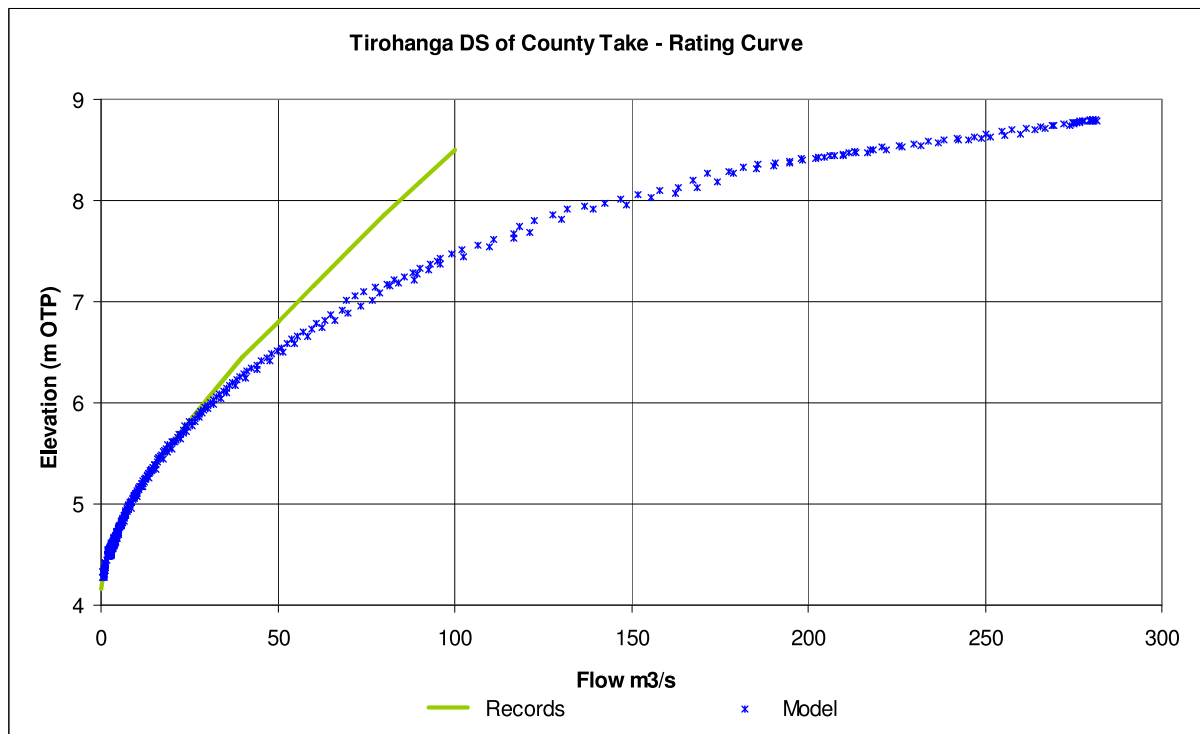
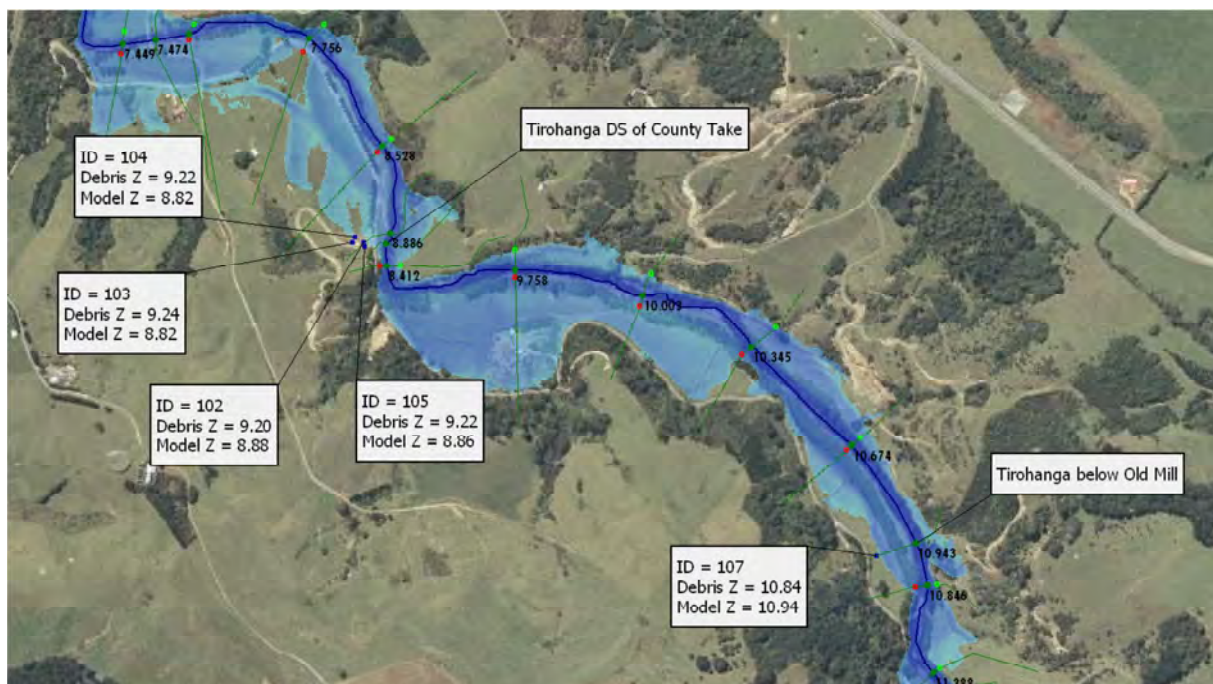


Figure 5-5 January 2011 flood levels at Tirohanga stream



5 Calibration

5.4 Waiharakeke at Willowbank

Figure 5-6 and Figure 5-7 show the comparison between model prediction and stage/flow records at Waiharakeke at Willowbank Station.

Figure 5-6 Recorded and modelled levels at Waiharakeke at Willowbank station

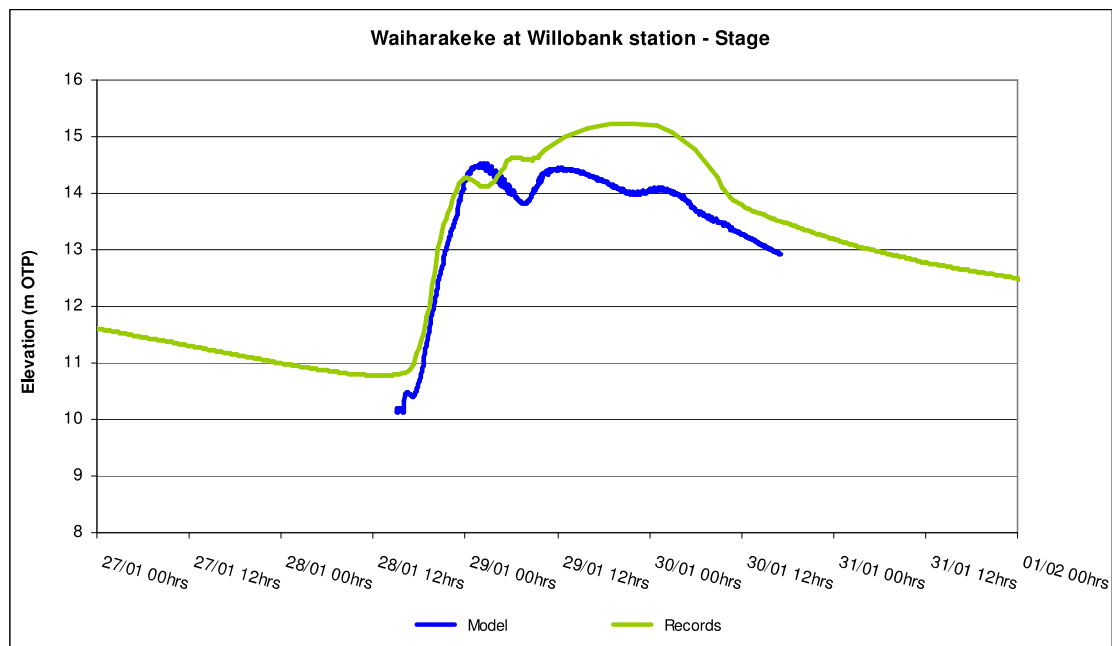
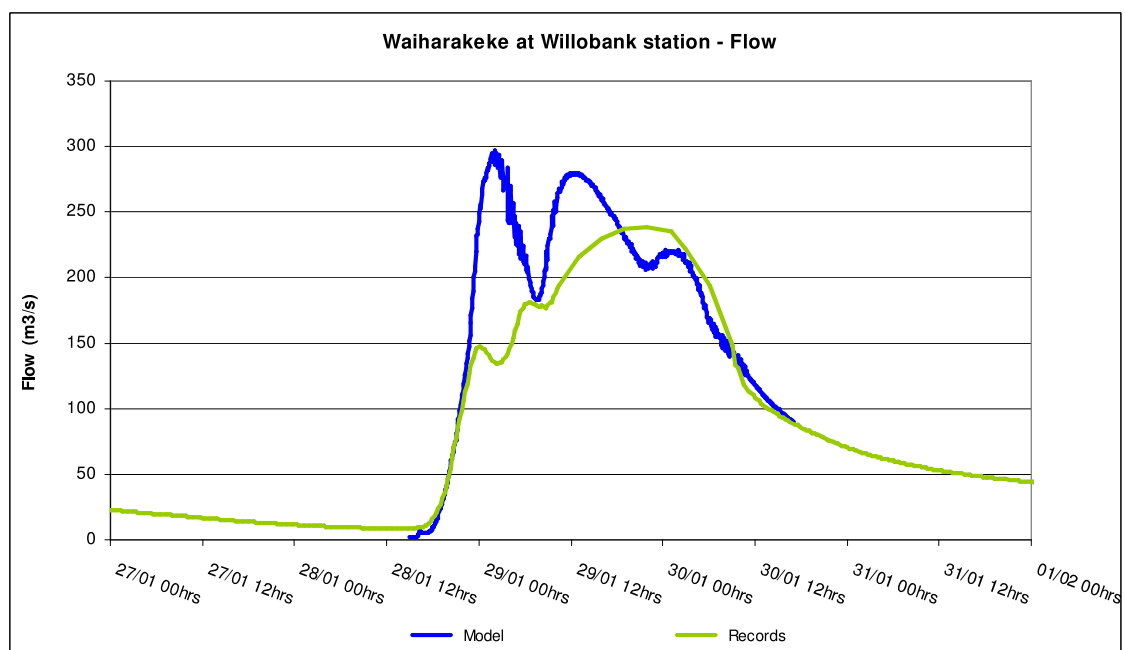


Figure 5-7 Recorded and modelled flows at Waiharakeke at Willowbank station



5 Calibration

Figure 5-8 Measured, estimated and modelled rating curve at Waiharakeke at Willobank station

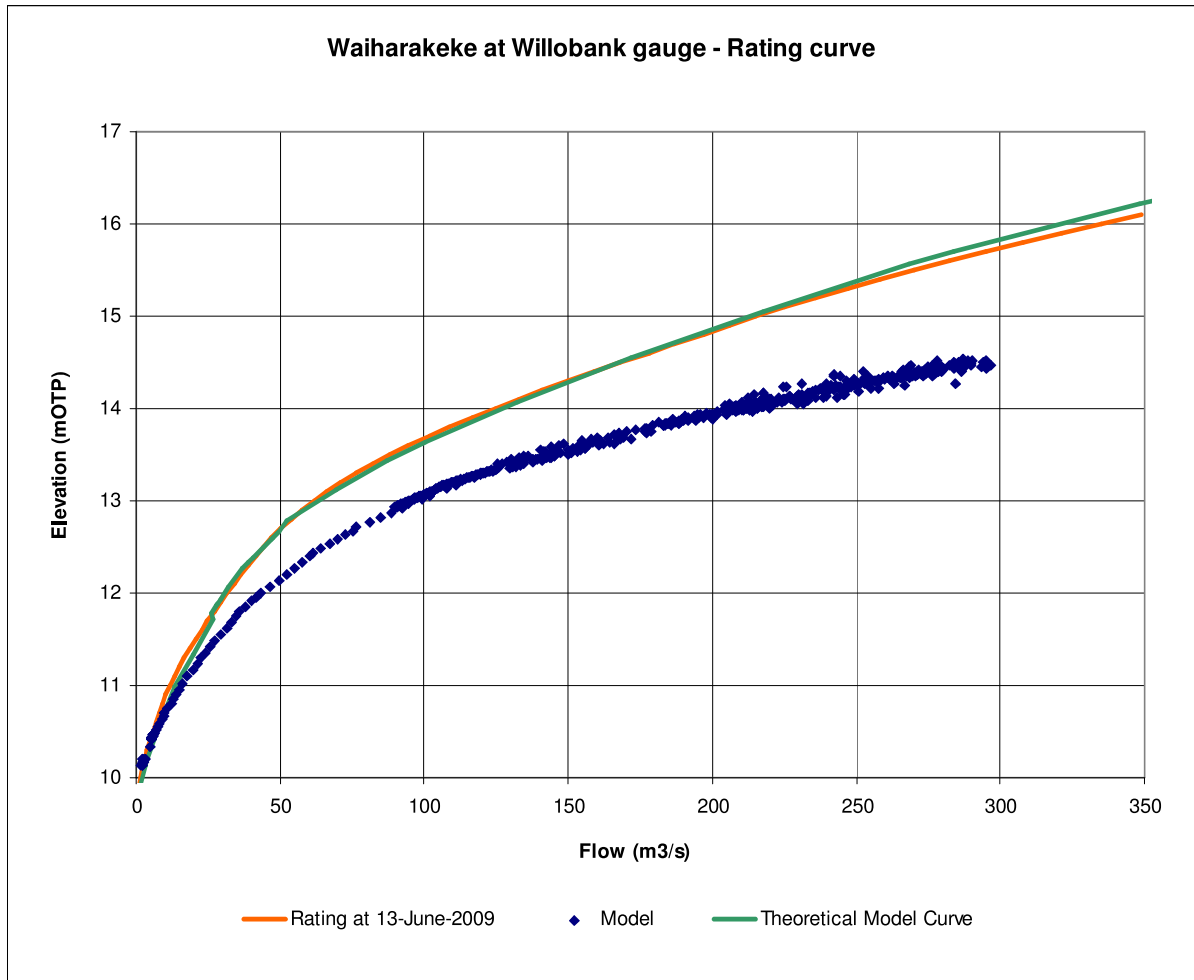


Figure 5-8 shows the rating curves of the gauge at Waiharakeke at Willobank. It shows one rating curve provided by NRC and related to the 13 of June of 2009.

The model rating curve for the gauge Waiharakeke at Willobank is included in Appendix B of this report.

5.5 Veronica Channel at Opua

Veronica Channel records have been used as a boundary condition input. No calibration was required at this location.

5.6 Maximum Values

The maximum flows and levels at the four gauge stations as estimated by the current model, along with the actual monitoring data are summarised in Table 5-3.

5 Calibration

Table 5-3 Summary of global values

Site Name		Waiharakeke at Willowbank	Tirohanga below Old Mill	Veronica Channel at Opuā	Tirohanga DS County Take
Site ID		3819	3817	3835	3829
Type of record for Jan 2011		Auto	Auto	Auto	Flood debris survey
RECORDS	Max Elevation Records (mQTP)	15.226	10.892	0.979	9.200
	Recorded time of peak	29/01/2011 @ 22:00	29/01/2011 @ 00:25	29/01/2011 @ 02:40	Not available
	Max Gauging at site Flow (m ³ /s)	72.100	1.280	Tidal records	39.670
	Estimated Peak Flow (from records, m ³ /s)	238.313	148.453	Tidal records	Not available
	Estimated runoff coefficient	0.72 - 0.55	0.47 - 0.56	Tidal records	Not available
MODEL	Calibration max flow	296.80	279.16	Tidal records	277.000
	Calibration max level	14.53	10.94	1.003	8.899
	Model Level Peak Time	29/01/2011 @ 2:30 & 12:10	29/01/2011 @ 00:25	29/01/2011 @ 02:25	29/01/2011 @ 0:25
	Modelled runoff coefficient	0.55	0.56		

Discussion and Conclusion

6.1 Discussion Overview

The Taumarere catchment model provides a tool to assist with understanding and management of the storm water system of this catchment. As part of this 2011/2012 scope of work, critical changes made to the model improved performance. Improvements were made to both the hydraulic and hydrological features. This enabled better calibration results to be achieved. The hydrological model was redefined using the Non-Linear Reservoir method. The hydraulic model was improved considerably in several locations, putting more detail into the critical spills, large storage areas and improving cross sections in critical areas.

Even with the modifications made to the modelling objects in order to achieve these results, it should be noted that there are critically sensitive variables that need to be better understood for calibration. It is considered that the Taumarere catchment flow records are one of the key components to be considered for further investigation and refinement to further improve calibration.

6.2 Sensitivity Analysis and Uncertainties

As the Taumarere catchment is of considerable size, the spatial distribution of certain variables such as runoff coefficients, and infiltration rates, is important to achieve a good calibration. The analysis of spatial distribution began with understanding the rainfall distribution. This distribution was then related to understanding the gauged levels within the rivers and establishing the relationship between the levels and the flow within the rivers. The only way to support such an interdependent relationship of varying parameters is through a good set of data gathered from a reliable set of gauge stations, a high quality set of survey and GIS data to accurately represent the catchment.

Below is a description of the most important and critical variables and their application in the model. Where required, some suggestions are given which will further improve the understanding of the catchment and may inform future model upgrades. These suggestions are a consequence of the experience gained during the process of this project plus the conclusions learned from the model results analysis.

6.2.1 Rain distribution

A good representation of the spatial and temporal rainfall distribution is the first key component required to achieve a reliable calibration. In a large catchment, such as Taumarere, the rainfall depth might vary considerably throughout the catchment area (spatial distribution). The timing of peak rainfall must be understood as well (temporal distribution). The combination of the temporal and spatial distribution accuracy when applied to the sub-catchments would directly affect the quality of the calibration, because the sub-catchments have different times of concentration and runoff coefficients which in turn build up the major flows in the catchment.

Spatial analysis was carried out using the auto rain gauges in the Taumarere catchment. This was critical as an accurate pattern and time to peak rainfall had to be established for the daily gauges, which only had a single value for the calibration event. There are three rain gauges inside the Taumarere catchment, two of them in a similar location, and only one of them is an auto gauge with a 5 minute recording interval. There are twelve gauges outside of the catchment area. The calibration was done with five gauges, two inside of the catchment and two auto gauges (one inside the assessment of catchment and one outside). Rainfall radar from the storm was used to assist with a qualitative rainfall distribution pattern. The distribution used was sufficient but could be improved with

6 Discussion and Conclusion

further auto gauges, especially in the upper catchment. The upper catchment is mainly linked to gauges outside the area of the catchment boundary, where the orographic effect of a storm may have an important impact on the distribution. It is also noted that the total rainfall volume uncertainties are not negligible for the catchment and this is discussed further in the effective rainfall section.

A way to reduce these uncertainties is by increasing the number of rain gauges inside the catchment. Two potential locations for new rain gauge stations are Waiomio and Pokapu. Approximate locations are in the table below.

Table 6-1 Suggested new rain gauges

Suggest rain gauge	X (m NZTM)	Y (m NZTM)	Description
Pokapu	1688821	6078584	At Pokapu settlement
Waiomio	1698540	6079496	At Waiomio settlement

6.2.2 Effective rain

The effective rainfall is the ultimate variable that defines runoff volumes for the catchment. It is the total runoff volume and can be estimated from the flow records. Each sub-catchment has varying effective rainfall. To achieve a proper calibration it is necessary to have an accurate distribution of the effective rainfall and therefore the flows derived from the records over the entire catchment.

Unfortunately only two flow gauges are available in the catchment: Tirohanga and Willowbank. Tirohanga gauge is considered to have a good representation of the stage data from its catchment for much of the storm, but it is not reliable for the high flows. The Tirohanga catchment data was therefore adjusted to produce more realistic flows that meet the levels records both upstream and downstream.

Willowbank station is right in the middle of the Taumarere catchment, and its flows are the result of many hydrological sub-catchments with many hydraulic unknowns, such as several large storage areas, numerous bridges, contractions, road overflows, overbank flows, culverts, and diversions. These, together with parameters such as time of concentration, time of delay, non-linear reservoir coefficients (K and p), CN or infiltration rates, river and flood plain roughness's, amongst others, make the Willowbank station a very hard location to calibrate. The number of hydrologic uncertainties is important, and the influence of any of these hydrologic variables is overshadowed by the hydraulic unknowns along the flow paths. Also, by covering a large catchment, Willowbank station presents long lasting hydrograph tails. It was simply not possible to reproduce accurately the hydrograph tail, even with the non-linear reservoir method, considering the amount of unknowns. Factors that may further complicate the situation include soakage and groundwater recharge. It is likely that an in-depth secondary model is required to represent the interaction between the river and groundwater. In addition, it is not possible to ensure the accuracy of the flow records for high levels for this gauge.

All of the Taumarere sub-catchments were analysed individually to estimate a time of delay, K and p coefficients and infiltration based on general features derived from GIS analysis of sub-catchment area, length, slope, soil group and runoff coefficient. Then they were adjusted to meet the volume balances from records. Global changes to the hydrologic parameters and specific changes for the hydraulic parameters were made based on the different criteria for the model to establish the relationships. These results were tested against the two available flow/level records and readjusted to find a good fit. Due to the issues discussed, the Willowbank station was used for calibration in a less traditional and therefore less stringent manner. The adjustments for the Willowbank station were more

6 Discussion and Conclusion

focused on the hydraulic features along the flow path such as storages and bridges. As previously shown critical changes were made to the hydraulic parameters in several areas in order to improve the response of the model with relation to the Willowbank flow records. Debris survey levels were also used to analyse the behaviour of flow in different locations. These were used as a fine tuning procedure to affect the design flood. These adjustments cannot be calibrated as the volumes at Willowbank were calibrated, because the distribution of volumes and peak flows over the rest of the catchment is unknown.

The uncertainties related to the effective rainfall over the catchment for the calibration event are quite important. However it is believed that the treatment of the effective rainfall is as good as it can be based on the available information.

Additional flow gauges in key locations would provide valuable information that would reduce these uncertainties. Table 6-2 summarises some of the locations that have been selected as suitable for gauging based on the analysis of the model results.

Table 6-2 Suggested new flow/level gauges

Location description	Approximate location		Comment	Priority
	X (m)	Y (m)		
Otiria stream on SH1, upstream of confluence with Waiharakeke stream	1694913	6084807	Important catchment flow	1
Taikirau stream on the rail bridge, 3km upstream of Pokapu	1689848	6077067	Main river	1
Ramarama stream on Matawaia Maromaku Road	1694504	6071269	Main river	1
Waiomio stream 2.3km upstream of confluence with Ruakaka River	1697449	6083423	Important catchment flow	1
Waiharakeke stream on Pukako road bridge (at Otiria).	1689817	6081800	Main river	2
Orauta stream near Orauta	1688004	6081655	Important catchment flow	2
Taikirau stream on the rail bridge at Pokere	1690950	6073546	Main river	2
Orauta stream downstream of SH1 at Moerewa	1691484	6083465	Important catchment flow	2
Kawakawa River on SH11 bridge	1699107	6086656	Only level gauge	3

6.2.3 Rainfall abstractions

The rainfall abstractions, or rain losses, are estimated from the difference between the estimated effective rain and the recorded rain on the respective sub-catchment. Inaccuracies in the rain distribution caused by lack of reliable rain gauges and in the effective rain (by lack of reliable flow records) would result in an inexact representation of rain losses. The rain loss distribution should be related to ground features (e.g. slope, soil, land cover, CN, and moisture) to establish a relationship that would allow different scenarios to be run with confidence. For example, if in a certain area the rain was underestimated, and flow volumes (effective rain) overestimated, the abstractions would be much more underestimated for other scenarios, giving an overestimation of flooding. Initial moisture is also critical as it defines the infiltration capacity for the rain abstractions.

6 Discussion and Conclusion

6.2.4 Water Levels

Surveyed debris levels were abundant over the Taumarere catchment, and they were useful in specific areas to improve the hydraulic performance of the model. As previously stated the distribution of volumes and peak flows over the catchment is unknown and therefore the level of calibration cannot be improved or justified. Consideration must be given to the possibility that the hydraulic features might be incorrectly modified to improve the water level calibration in some areas and therefore result in a decrease in the accuracy of the modelled flow. Several tests were applied to the general hydraulic parameters (such as spill discharge coefficients, manning roughness in river and over 2D areas, and orifice discharge coefficients) to improve calibration whilst keeping these parameters within a consistent value range.

6.2.5 Hydraulic uncertainties

The Taumarere is a 450 km² catchment with several hydraulic features that are critical to the prediction of the flows and levels of this river system.

The storage areas and the associated volumes and release rates are very important to the Taumarere catchment model. There are presently more than 89 storages units and 26 2D polygons covering more than 36km² of flooding areas within the model. This is considered to be a large number of storage and 2D area for a model of this size. There are also many storage areas not included in the model that are known to be outside of the LiDAR areas as identified by the large flat areas derived from the 20m contours. These undefinable storage areas can almost completely erase any trace of the original rainfall hydrograph. The resultant effective flows are a combination of these large storage areas, their effective volumes and their natural outlet. These outlets are generally the critical cross sections such as bridges, road profiles, bank profiles, and culverts. A poor estimation of the storage within the catchment affects the hydraulic performance of the model and the reliability of results.

The cross sections for river modelling are important, and LiDAR offers a high quality source from which to define river sections. However, in many areas, especially on bigger rivers, part of the river channels hydraulic capacity is not captured by LiDAR. In this case, the survey data is only available for certain sections of the river, but not for the majority of the length of the river. Local survey was available in several different locations and it may improve hydraulic results, but in most cases a singular or limited survey in an isolated location did not produce significant improvements for the estimation of the rivers hydraulic capacity. This is the case when the flow and level of the river is dependent on the performance of the downstream and upstream sections that are derived from LiDAR. In many cases adjustments were made to a few of the upstream and downstream sections in the immediate vicinity of the available survey. This approach did appear to increase the level of benefit from the limited extra cross section information. It should be noted that the uncertainties regarding the use of this survey information is still significant.

Other variables such as the roughness and spill coefficients were tested and assisted by the large set of images available from survey, as well as aerial photographs and other GIS layers.

There are undoubtedly many other uncertainties in the model, but the ones discussed in this section are the most critical for the Taumarere catchment model calibration.

For future model upgrades, hydraulic uncertainties can be reduced by:

- Reprocessing the 2010 survey to fit OTP datum and NZTM coordinate system. The value of that survey was limited because of the improper datum.

6 Discussion and Conclusion

- Processing all available survey to create a continuous interpolated bottom section. This would increase the value of the survey to the rest of the network.
- Incorporate new survey, if possible, for areas of interest and where the available survey is not enough to obtain a good main channel interpolation. Areas such as the long section without survey in: Waiomio stream, Waiaharakere Stream upstream of Otiria, and Orauta Stream upstream of Moerewa.

This would provide more value to the available survey creating a more continuous and realistic section shape in the model. Further improvements can be obtained with a more detailed sub-catchment delineation based on LiDAR information instead the original 20 meters contours. This would also help to identify in detail the drainage system and areas where information might be missing or require more analysis. Also, additional storages and 2D areas to separate the main channel from flood plains would improve the results in many areas.

6.2.6 Base Flow and Infiltration Rate

Base flow and infiltration rate have an intrinsic relationship with the soil moisture. This can be understood by categorising the relationships into the three antecedent moisture conditions (AMC). For instance, the antecedent moisture condition III -high soil moisture, or saturated soils, corresponds to lower surface infiltration rate and greater base flows. Conversely, if the soil moisture is low, but still wet, then surface infiltration rates would typically be higher and have lowered base flow. The AMC group I is relevant to drought conditions and was not considered for this project due to the storm that preceded the calibration event.

The calibration for the particular storm event presented satisfactory outputs for this project, however the calibration relied on the well understood and therefore specifically selected parameters based on the available data from January 2011 event. If other scenarios are required to be simulated (e.g. AMC group I), a comprehensive analysis is necessary in order to estimate these parameters properly.

The event of January 2011 occurred with somewhat unique conditions; it happened during summer season, but occurred a week after a significant storm event. Under this specific circumstance an average infiltration rate of 7.5mm/hr and a null base flow was considered appropriate. Under similar circumstances, without the preceding storm event a higher infiltration rate may be expected in summer with the exception of drought conditions. It is also reasonable to assume that a lower infiltration rate would be more appropriate for a typical winter storm event.

In this case, the final calibration used a Non-Linear Reservoir (NLR) approach with a variable infiltration rate based on the spatially distributed CN values. If it is found appropriate, the overall CN value for the Taumarere catchment might be modified to increase or reduce the total infiltration over other scenarios.

As was mentioned previously, serious consideration should be given to establishing a more in depth relationship between the catchments surface water storage, groundwater storage and base flow. This approach was not necessary for this project, as the main purpose of this work was to generate flooding risk information. However it may be considered if future needs regarding water availability and water quality become critical needs of the community. NRC has initiated a number of extensive gauging programmes in the catchment, which would give better records for flow calibration and provide improved measures to estimate spatial variability of some key hydrological parameters. These will help improve the future modelling work.

6 Discussion and Conclusion

6.2.7 Non-Linear Reservoir

The selection of an appropriate hydrological model for the Taumarere catchment was also a critical component. The non-linear reservoir model was best suited for modelling of the catchment with consideration given to the catchment characteristics and the available information. The initial losses selected for this model are not well defined because the purpose of these models is to calibrate and run large storm events (over 10yrs). The initial losses are relatively unimportant as they represent a small portion of the rainfall and are typically inconsequential shortly after the beginning of the storm event of a significant duration.

We encourage further analysis in terms of the soil moisture condition, infiltration and base flow values. These can be used to create relationships and catchment volume balance from the historical records of the level/flow gauges present within the NRC catchments to estimate effective rain and base flow under varying conditions.

6.2.8 Design Event Infiltration and Base Flow

The calibration storm of January 2011 has a total duration of approximately 18 hours with an estimated total rainfall depth, over the Taumarere catchment, of 228mm. 211mm of the rainfall occurs within 12 hours. This puts the event of January 2011 close to a 50-yr ARI event.

The calibrated infiltration rate of 7.5 mm/hr corresponds to an approximated CN of 68. The previous calibration equivalent CN value used, with the US SCS method, for the Taumarere catchment on the calibration event of March 2007, was 73.6. Note that the CN value also considered the initial moisture conditions for the January 2011 and it appears to be low (mainly dry soil).

On the other hand, the 24 hour design event produced an approximated average infiltration rate at the peak time of about 8mm/hr (CN=68).

It is clear that the effective rainfall depends upon several variables related to the rain such as storm duration, initial moisture condition (soil moisture) and also rainfall intensity (as US SCS method suggests).

It is interesting that the calibration event presented an infiltration rate around 7.5mm/hr even when the storm happened during the summer season. That may suggest that for the same storm happening in winter time the infiltration rate would be lower. It is noted that a 2 year storm event occurred a week before the calibration storm, as previously stated, and this may have provided moisture conditions that were optimal for infiltration or could have reduced infiltration rates due to saturated soils. It is not possible to be certain about this without more in-depth data regarding the soil moisture conditions.

Other catchments in Northland region have presented different infiltration rates dependent on the antecedent moisture conditions relative to soil types. Those values range from 1mm/hr to 6mm/hr.

Conclusions

In conclusion, this current model for Taumarere catchment has shown satisfactory calibration results against the 29th of January 2011 storm event records. This was accomplished by incorporating additional key hydraulic elements into the model such as new survey cross sections, extra storage areas, detailed estuary definition; and improvements to the hydrological model including newly defined rainfall distribution and a non-linear reservoir method for runoff routing calculations. Nevertheless, it should be noted that a number of assumptions have been applied to suit the particular purpose of this project. Therefore due to the inherent limitations of the modelling methodology, several areas of uncertainties should be taken into consideration and could be improved in the future:

- New rain gauges and flow/level gauges are essential. Suggestions for new gauges locations are given. They would reduce the level of uncertainty for future studies and model upgrades.
- The records of flow and rainfall in Northland catchments suggest that the base flow in all catchments is not of great importance as it is relatively small compared to the design events. Therefore base flow has been considered negligible for the simulation of the design events.
- For the purpose of this study the calibrated infiltration rate was determined to be 7.5 mm/hr. A conservative infiltration rate equivalent to a CN of 73.6, as used in the original model, was adopted for all design storms to account for the saturated soils that would be expected during the winter months. This is equivalent to infiltration rates between 4.24mm/hr and 6.85mm/hr. This is considerably lower than the 8.0mm/hr estimated from the US SCS method, and lower than the calibration estimate of 7.5mm/hr. A new modelling exercise for other scenarios may require further comprehensive analysis of factors such as soil moisture, infiltration rate and base flows.
- Substantial assumptions and channel interpolation has been applied in the current hydraulic network due to the limited LiDAR area coverage, the large number of undefinable storage areas, and limited cross section survey data. Further reduction in hydraulic uncertainties will rely on additional survey of channel geometry and improved understanding of the upstream catchment.

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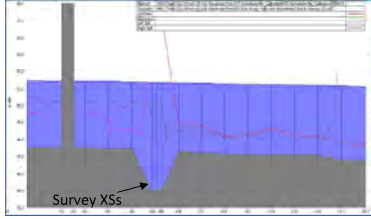
Appendix A Debris Levels

Point Code (old ID)	Model Point ID	X (m)	Y (m)	Description	Flood Level (mOTP)	Model (mOTP)	dZ (m)	ABS(d Z)	Comments	New Comments
89	ID=89	1699763.57	6086566.25	DEBRI	4.01	4.334	0.324	0.324		
90	ID=90	1699762.12	6086562.63	DEBRI	4	4.332	0.332	0.332		
91	ID=91	1699760.51	6086559.86	DEBRI	4	4.331	0.331	0.331		
93	ID=93	1699547.95	6086726.69	DEBRI	3.99	4.466	0.476	0.476		
94	ID=94	1699546.92	6086724.11	DEBRI	3.96	4.466	0.506	0.506		
97	ID=97	1699101.04	6086592.15	DEBRI	4.06	4.56	0.5	0.5		
98	ID=98	1699102.01	6086586.18	DEBRI	4.11	4.68	0.57	0.57		
100	ID=100	1699109.13	6086560.75	DEBRI	4.12	4.708	0.588	0.588		
84	ID=84	1698869.44	6086071.64	FLV	4.42	4.87	0.45	0.45		
85	ID=85	1698871.80	6086069.23	FLV	4.41	4.87	0.46	0.46		
88	ID=88	1698843.25	6086053.39	FLV	4.39	4.87	0.48	0.48		
101	ID=101	1699040.37	6085644.77	DEBRI	5.82	5.291	-0.529	0.529	Improved	
1000	ID=1000	1699054.81	6085899.19	PEG	5.912	5.312	-0.6	0.6	Improved	
1001	ID=1001	1699071.77	6085881.94	TREE	6.002	5.557	-0.445	0.445	Improved	
1002	ID=1002	1699148.51	6085880.93	DEBRI	5.976	5.816	-0.16	0.16	Improved	
1003	ID=1003	1699148.49	6085880.92	DEBRI	5.996	5.816	-0.18	0.18	Improved	
1004	ID=1004	1699140.33	6085885.99	SILT	5.999	5.802	-0.197	0.197	Improved	
1005	ID=1005	1699245.64	6085726.82	TREE	6.536	5.909	-0.627	0.627	Improved	
1006	ID=1006	1699232.75	6085733.86	TREE	6.411	5.906	-0.505	0.505	Improved	
102	ID=102	1699461.99	6084753.02	DEBRI	9.2	8.882	-0.318	0.318		
103	ID=103	1699445.32	6084754.19	DEBRI	9.24	8.818	-0.422	0.422		
104	ID=104	1699448.24	6084761.17	DEBRI	9.22	8.816	-0.404	0.404		
105	ID=105	1699462.89	6084746.92	DEBRI	9.19	8.86	-0.33	0.33		
107	ID=107	1700211.44	6084295.07	Debris line	10.84	10.942	0.102	0.102		
106	ID=106	1700273.54	6084038.60	DEBRI	11.5	11.506	0.006	0.006		
39	ID=39	1697797.22	6085645.51	DEBRI	4.96	5.31	0.35	0.35		
40	ID=40	1697798.63	6085639.10	DEBRI	4.97	5.31	0.34	0.34		
41	ID=41	1697790.39	6085633.30	DEBRI	4.98	5.31	0.33	0.33		
42	ID=42	1697785.20	6085629.81	DEBRI	4.99	5.31	0.32	0.32		
43	ID=43	1697778.48	6085623.30	DEBRI	5.01	5.31	0.3	0.3		
44	ID=44	1697774.55	6085619.93	DEBRI	4.98	5.31	0.33	0.33		
45	ID=45	1697528.00	6085710.57	DEBRI	5.03	5.31	0.28	0.28		
46	ID=46	1697526.77	6085711.65	DEBRI	5.09	5.31	0.22	0.22		
47	ID=47	1697527.96	6085713.42	DEBRI	5.11	5.31	0.2	0.2		
									2D at flood plain correct. Correct in 2D.	
81	ID=81	1697251.94	6084648.82	DEBRI	5.07	5.346	0.276	0.276	2D at flood plain correct. Correct in 2D.	
									2D at flood plain correct. Correct in 2D.	
82	ID=82	1697259.56	6084642.74	DEBRI	4.99	5.346	0.356	0.356	2D at flood plain correct. Correct in 2D.	
									2D at flood plain correct. Correct in 2D.	
83	ID=83	1697264.11	6084631.33	DEBRI	4.96	5.346	0.386	0.386	2D.	
50	ID=50	1696487.78	6085258.85	DEBRI	5.08	5.378	0.298	0.298		
51	ID=51	1696487.06	6085258.33	DEBRI	5.07	5.378	0.308	0.308		
31	ID=31	1696442.70	6085103.43	DEBRI	4.98	5.41	0.43	0.43		
32	ID=32	1696446.78	6085102.73	DEBRI	4.95	5.409	0.459	0.459		
23	ID=23	1696367.81	6085068.29	DEBRI	5.43	5.451	0.021	0.021		
24	ID=24	1696378.49	6085045.31	DEBRI	4.96	5.423	0.463	0.463		
26	ID=26	1696383.79	6085005.53	DEBRI	5.28	5.467	0.187	0.187		
27	ID=27	1696386.46	6085001.38	DEBRI	5.32	5.467	0.147	0.147		
28	ID=28	1696388.56	6084998.13	DEBRI	5.29	5.467	0.177	0.177		
21	ID=21	1695427.30	6085058.24	DEBRI	5.23	5.467	0.237	0.237		
22	ID=22	1695432.98	6085055.24	DEBRI	5.19	5.467	0.277	0.277		
9	ID=9	1696054.77	6084664.82	FLV	5.33	5.467	0.137	0.137		
10	ID=10	1696094.30	6084662.97	FLV	5.27	5.467	0.197	0.197		
11	ID=11	1696139.22	6084698.16	FLV	5.33	5.467	0.137	0.137		
52	ID=52	1696608.93	6084545.01	DEBRI	5.13	5.455	0.325	0.325		
54	ID=54	1696633.67	6084409.99	SILT	5.08	5.521	0.441	0.441		
55	ID=55	1696639.90	6084408.57	SILT	5.13	5.516	0.386	0.386		
59	ID=59	1696763.69	6084487.63	FLV	5.18	5.432	0.252	0.252		
60	ID=60	1696730.08	6084429.37	FLV	5.24	5.463	0.223	0.223		
61	ID=61	1696766.95	6084411.73	FLV	5.25	5.457	0.207	0.207		
77	ID=77	1696987.38	6084355.91	SILT	5.73	5.587	-0.143	0.143		

78	ID=78	1696987.37	6084355.91	SILT	5.73	5.587	-0.143	0.143		
79	ID=79	1696982.86	6084362.07	SILT	5.72	5.572	-0.148	0.148		
80	ID=80	1696988.11	6084367.39	FLV	5.76	5.578	-0.182	0.182		
67	ID=67	1697118.29	6084345.69	DEBRI	6.58	5.99	-0.59	0.59		
68	ID=68	1697279.85	6084393.73	DEBRI	6.21	6.497	0.287	0.287		
69	ID=69	1697278.96	6084390.32	DEBRI	6.25	6.497	0.247	0.247		
70	ID=70	1697275.25	6084384.94	FLV	6.39	6.528	0.138	0.138		
71	ID=71	1697275.46	6084385.04	FLV	6.39	6.528	0.138	0.138		
72	ID=72	1697275.46	6084385.05	FLV	6.39	6.528	0.138	0.138		
73	ID=73	1697266.24	6084357.74	DEBRI	7	6.62	-0.38	0.38		
62	ID=62	1697005.58	6084199.85	DEBRI	6.82	5.827	#N/A	#N/A	In Lidar but out of Model extent. Contained in FC near river. Underestimated levels as expected.	
63	ID=63	1697002.57	6084200.81	DEBRI	6.88	5.821	#N/A	#N/A	In Lidar but out of Model extent. Contained in FC near river. Underestimated levels as expected.	
	ID=A	1697353.18	6081043.11	FL02 - ht silt in tree	15.137	14.635	-0.502	0.502	2D 0.5m lower than survey. Only one point survey in the whole surrounding area. Not enough data to justify.	
	ID=B	1697155.04	6080427.97	FL03 - silt in tree	14.783	14.755	-0.028	0.028		
	ID=C	1697145.96	6080424.38	FL03 - brid se silt lev	15.043	14.721	-0.322	0.322		
	ID=D	1697215.59	6079467.11	FL04 - edge sweeping	20.064	19.198	-0.866	0.866		
	ID=E	1697205.07	6079468.49	FL04 - edge sweep	19.914	19.114	-0.8	0.8	Missing bridge 2010 not included in previous model. Including bridge would improve model results.	
	ID=F	1697388.71	6078734.22	FL06 - post debris	23.119	22.932	-0.187	0.187	2D at flood plain correct. Correct in 2D.	
	ID=G	1697523.45	6078729.72	FL06 - debris in fce	23.217	23.678	0.461	0.461		
	ID=H	1697514.84	6078298.66	FL05 - debris in rail	26.367	25.926	-0.441	0.441		
	ID=I	1697616.64	6077776.76	FL07 - edge erosion swept	28.497	28.402	-0.095	0.095		
	ID=J	1697994.06	6080984.10	FL01 - ht debris	15.711	15.981	0.27	0.27		
	ID=K	1697975.23	6080973.57	FL01 - ht debris in fce	15.691	15.994	0.303	0.303		
	ID=L	1698659.73	6079491.92	FL09 - fce debris	25.885	25.24	-0.645	0.645		
	ID=M	1698822.53	6079279.06	FL08 - fce debris	26.577	26.665	0.088	0.088		
	ID=N	1698848.80	6079256.76	FL08 - extent silt on road	26.317	26.836	0.519	0.519		
13	ID=13	1695368.47	6084719.54	DEBRI	6.23	5.941	-0.289	0.289		
14	ID=14	1694928.14	6084812.81	FLV	7.46	7.425	-0.035	0.035		
15	ID=15	1694906.97	6084794.85	DEBRI	7.64	7.476	-0.164	0.164		
16	ID=16	1694911.59	6084792.48	DEBRI	7.58	7.41	-0.17	0.17	Point at bank; surrounding levels are correct. 2D Ok.	

17	ID=17	1694883.90	6084799.78	DEBR	7.8	7.39	-0.41	0.41		
18	ID=18	1694882.63	6084798.49	DEBR	7.85	7.401	-0.449	0.449		
19	ID=19	1694917.13	6084821.41	DEBR	7.85	7.36	-0.49	0.49		
20	ID=20	1694915.47	6084819.79	DEBR	7.91	7.36	-0.55	0.55		
	ID=O	1693186.17	6084373.20	FL42 - silt line	12.906	11.953	-0.953	0.953		Quasi-2D flow at meander. Improvement in 1D XS would improve results. XS just US has level of 12.18mOTP. This is also part of branch I suspect flows might be underestimated (explained below)
2014	ID=2014	1692173.73	6083888.80	FL44 - silt line in grass	16.946	16.098	-0.848	0.848		Maybe underestimation of flow for exessive spill over flood plains US of location. Spill is defined by water levels that might be overestimated as survey is not available for bottom part in this area.
2027	ID=2027	1691352.87	6083284.91	FL45 - silt line in vegetation	19.451	19.475	0.024	0.024		
	ID=P	1692599.69	6082765.12	NRC Hydro post flood survey	15.22	14.535	-0.685	0.685		
2019	ID=2019	1691296.93	6082276.98	FL56 - debris in fce	28.204	27.935	-0.269	0.269	2D at flood plain correct. Correct in 2D.	
2029	ID=2029	1691235.46	6082255.84	FLV - Photo evidence	28.794	28.7	-0.094	0.094	2D at flood plain correct. Correct in 2D.	
2000	ID=2000	1691203.06	6082264.19	FLV - Photo evidence	28.952	28.793	-0.159	0.159	2D at flood plain correct. Correct in 2D.	
2026	ID=2026	1691106.17	6082345.24	FL55 - silt line in vegetation	29.124	29.017	-0.107	0.107		
2003	ID=2003	1690778.77	6082289.61	FLV - Owner report	30.932	30.873	-0.059	0.059	At large flood plain. Correct in 2D.	
2025	ID=2025	1688996.82	6081743.21	FL50 - debris in gate	38.036	37.993	-0.043	0.043	2D at flood plain correct. Correct in 2D.	
2024	ID=2024	1687974.79	6081577.62	FL49 - debris in grass	44.313	45.08	0.767	0.767	At model border. Not accurate. Higher levels might indicate that flow in coming river has been overestimated. Not enough data not justify. No more survey around to confirm.	Overestimated flows? Then excess of flows spilling over flood plains?
2022	ID=2022	1689804.30	6081762.05	FL54 - debris in fce	34.936	34.776	-0.16	0.16	Correct in 2D (at bridge)	
2023	ID=2023	1689751.22	6081741.70	FL53 - silt line in vegetation	34.707	34.912	0.205	0.205		
2020	ID=2020	1689323.75	6081036.97	FL51 - silt line at btm fce	37.715	37.685	-0.03	0.03		
2021	ID=2021	1688784.11	6080433.70	FL48 - silt line in vegetation	38.961	39.217	0.256	0.256		
2100	ID=2100	1688883.85	6078907.02	MUD	40.501	40.8	0.299	0.299		
1005	ID=1005b	1688832.52	6078893.50	DEBR	40.572	40.555	-0.017	0.017		
1006	ID=1006b	1688876.55	6078908.51	MUD	40.485	40.785	0.3	0.3		
1007	ID=1007	1688881.87	6078869.65	MUD	40.469	40.807	0.338	0.338		
1008	ID=1008	1688867.69	6078872.19	MUD	40.589	40.783	0.194	0.194		
1009	ID=1009	1688910.06	6078901.39	MUD	40.533	40.799	0.266	0.266		
1010	ID=1010	1688906.21	6078882.54	MUD	40.471	40.796	0.325	0.325		

1011	ID=1011	1689846.97	6077952.32	MUD	42.61	43.16	0.55	0.55		
1015	ID=1015	1689853.78	6077943.88	MUD	42.643	43.172	0.529	0.529		
1016	ID=1016	1687350.68	6076073.65	FL	51.23	51.029	-0.201	0.201		
1017	ID=1017	1687361.06	6076054.56	FL	51.08	51.001	-0.079	0.079		
1021	ID=1021	1687376.07	6076082.32	DEBRI	51.182	50.999	-0.183	0.183		
1022	ID=1022	1687376.17	6076082.20	DEBRI	51.282	50.999	-0.283	0.283		
1023	ID=1023	1687346.60	6076081.89	DEBRI	51.337	51.118	-0.219	0.219		
1024	ID=1024	1686868.57	6073212.57	MUD	60.401	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
1028	ID=1028	1686827.16	6073222.43	MUD	60.352	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
1029	ID=1029	1686894.30	6073229.99	MUD	60.403	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
1030	ID=1030	1686891.93	6073237.42	MUD	60.333	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
									US of large storage, might not be large enough. More storage might be in the US catchment.	Might be quite important that survey bottom level is 2.09 meters lower than LIDAR. Survey XS have been included, however, the rest of the XS are from LIDAR. This means that the flow is actually controlled by the majority of the XSs that use levels from LIDAR that are higher.
1031	ID=1031	1688800.37	6071309.92	FL	57.643	58.663	1.02	1.02		
1037	ID=1037	1688797.51	6071331.54	DEBRI	57.44	58.652	1.212	1.212		
1038	ID=1038	1688776.94	6071325.10	DEBRI	57.47	58.651	1.181	1.181		
1039	ID=1039	1688776.01	6071305.27	GRASS	57.702	58.659	0.957	0.957		
2000	ID=2000b	1688771.62	6071303.71	GRASS	57.685	58.657	0.972	0.972		
2001	ID=2001	1690167.83	6071367.27	FL	54.869	56.05	1.181	1.181	Upper catchment flow might be overestimated (?). Roughness analysis was done, not sensitive.	
2002	ID=2002	1690122.45	6071411.61	FL	55.086	56.138	1.052	1.052	Same as above. Survey available with bottom level 0.8m lower than survey. Only survey XSs available in this area, all the rest are LIDAR XS.	
2003	ID=2003b	1690126.17	6071411.51	FL	55.008	56.137	1.129	1.129		
2004	ID=2004	1691162.47	6073894.11	FL	47.793	48.069	0.276	0.276		
2005	ID=2005	1691161.12	6073887.41	FL	47.894	48.433	0.539	0.539		
2006	ID=2006	1691106.07	6073895.71	FL	48.705	49.118	0.413	0.413		
2007	ID=2007	1691085.11	6073898.61	DEBRI	48.668	49.031	0.363	0.363		
2008	ID=2008	1691084.54	6073907.47	DEBRI	47.805	48.704	0.899	0.899	Survey point over road at DS side. Result level in point is an interpolation of US and DS level. Actual result should be referred to DS XS that is 48.35m OTP. Difference then is -0.545m. Besides, bottom part of XS is 2.24m higher in LIDAR than available survey. Survey is available in this location, but the rest of the stream uses LIDAR levels that control levels from of culvert from the DS part. Bottom levels of the rest of the stream have been adjusted in most cases, but not all and assumptions were made.	
2009	ID=2009	1690997.43	6073921.63	DEBRI	48.177	48.28	0.103	0.103	Looks ok, but 2D has small instabilities in this area. Maximum values seem wrong, but average around variations is good.	
2010	ID=2010	1690989.00	6073906.87	DEBRI	48.583	49.17	0.587	0.587		

										Same issue as previous. Figure below shows survey XSs and LIDAR XSs along long profile.
2023	ID=2023b	1692457.97	6072722.70	MUD	50.559	51.351	0.792	0.792		
2024	ID=2024b	1692462.13	6072729.91	MUD	50.182	51.352	1.17	1.17		
2025	ID=2025b	1692416.99	6072726.76	MUD	50.724	51.352	0.628	0.628		
2011	ID=2011	1694536.19	6071256.21	DEBRI	53.029	53.319	0.29	0.29		
2018	ID=2018	1694548.93	6071235.33	DEBRI	52.993	53.381	0.388	0.388		
2019	ID=2019b	1694515.02	6071276.29	MUD	52.554	53.226	0.672	0.672		
2020	ID=2020b	1694495.61	6071269.37	DEBRI	52.715	53.292	0.577	0.577		
2022	ID=2022b	1694495.70	6071280.43	DEBRI	52.596	53.233	0.637	0.637		
20361	ID=20361	1693741.30	6069996.92	MUD	54.088	54.52	0.432	0.432		
20401	ID=20401	1693745.95	6069998.33	MUD	54.109	54.525	0.416	0.416		
20411	ID=20411	1693727.60	6069989.90	MUD	54.111	54.511	0.4	0.4		
20421	ID=20421	1693725.27	6069988.45	MUD	54.111	54.51	0.399	0.399		
20431	ID=20431	1693724.07	6069977.50	MUD	54.084	54.505	0.421	0.421		
20441	ID=20441	1693730.55	6069982.01	MUD	54.139	54.509	0.37	0.37		
20451	ID=20451	1693741.94	6069986.52	MUD	54.114	54.517	0.403	0.403		
20461	ID=20461	1693751.39	6069988.24	MUD	54.107	54.523	0.416	0.416		
20311	ID=20311	1694685.24	6067845.17	DEBRI	63.184	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
20331	ID=20331	1694686.08	6067847.75	DEBRI	63.114	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
20341	ID=20341	1694690.52	6067836.97	FL	63.228	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
20351	ID=20351	1694686.62	6067834.23	DEBRI	63.085	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
20061	ID=20061	1699395.81	6073068.53	FL	66.372	66.746	0.374	0.374		
20071	ID=20071	1699421.06	6073085.96	FL	66.868	66.788	-0.08	0.08		
20081	ID=20081	1699417.23	6073072.18	GRASS	65.775	66.789	1.014	1.014	Lower than surrounding points (IDs 20061, 20071, 20131, 20141, 20151, 20161)	
20091	ID=20091	1697289.43	6073181.65	DEBRI	60.98	60.89	-0.09	0.09	Point near (ID=20071) shows levels at 66.79mOTF, with a difference < 1cm from survey. This point might be wrong, but not sufficient data to confirm.	
20101	ID=20101	1697329.93	6073202.00	MUD	60.727	60.89	0.163	0.163		
20111	ID=20111	1697312.73	6073203.43	GRASS	60.669	60.923	0.254	0.254		

2012t1	ID=2012t1	1697301.46	6073197.45	GRASS	60.48	60.866	0.386	0.386		
2013t1	ID=2013t1	1699369.16	6073046.61	FL	66.504	66.638	0.134	0.134		
2014t1	ID=2014t1	1699341.81	6073054.46	MUD	66.081	66.372	0.291	0.291		
2015t1	ID=2015t1	1699329.97	6072991.44	DEBR	66.851	67.026	0.175	0.175		
2016t1	ID=2016t1	1699321.88	6073017.04	DEBR	66.898	67.026	0.128	0.128		
2017t1	ID=2017t1	1699403.66	6073018.79	MUD	65.893	67.04	1.147	1.147	Lower than surrounding points (IDs 2006t1, 2007t1, 2013t1, 2014t1, 2015t1, 2016t1)	Point near (at DS flow path with ID=2015t1) shows levels at 66.03mOTP, and for being DS cannot be lower than ID=2017t1, that is before a culvert. Inconsistent data, but not sufficient data to confirm.
2027	ID=2027b	1700956.04	6071186.55	CORN	74.35	0	#N/A	#N/A	In Lidar but out of Model extent	
2003t1	ID=2003t1	1701006.70	6071189.12	FL	74.351	0	#N/A	#N/A	In Lidar but out of Model extent	
2018t1	ID=2018t1	1701006.57	6071208.58	FL	74.094	0	#N/A	#N/A	In Lidar but out of Model extent	
2019t1	ID=2019t1	1700984.07	6068570.76	DEBR	87.934	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
2020t1	ID=2020t1	1700992.49	6068569.95	BANK	87.971	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
2021t1	ID=2021t1	1700982.45	6068559.24	DEBR	87.96	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
2004t1	ID=2004t1	1701018.03	6068561.52	DEBR	88.2	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
2005t1	ID=2005t1	1700991.16	6068550.51	FL	88.44	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
2022t1	ID=2022t1	1698957.15	6070585.58	DEBR	70.97	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
2023t1	ID=2023t1	1698950.31	6070582.41	DEBR	70.918	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
2024t1	ID=2024t1	1698949.98	6070577.07	DEBR	71.244	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
2025t1	ID=2025t1	1698945.17	6070580.98	DEBR	71.309	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
2026t1	ID=2026t1	1698942.02	6070581.26	DEBR	71.288	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
2027t1	ID=2027t1	1698965.12	6070573.60	DEBR	71.209	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
2028t1	ID=2028t1	1697216.49	6068595.93	GRASS	68.52	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
2029t1	ID=2029t1	1697230.02	6068597.88	DEBR	68.593	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
2030t1	ID=2030t1	1697223.40	6068612.27	DEBR	68.729	-9999	#N/A	#N/A	Out of Lidar. Not to calibrate	
	ID=t1	1691573.29	6083261.24	FL	19.6	19.656	0.056	0.056		

Appendix B Rating Curves

Waiharakeke at Willowbank

SG Zero	9.100	m OTP
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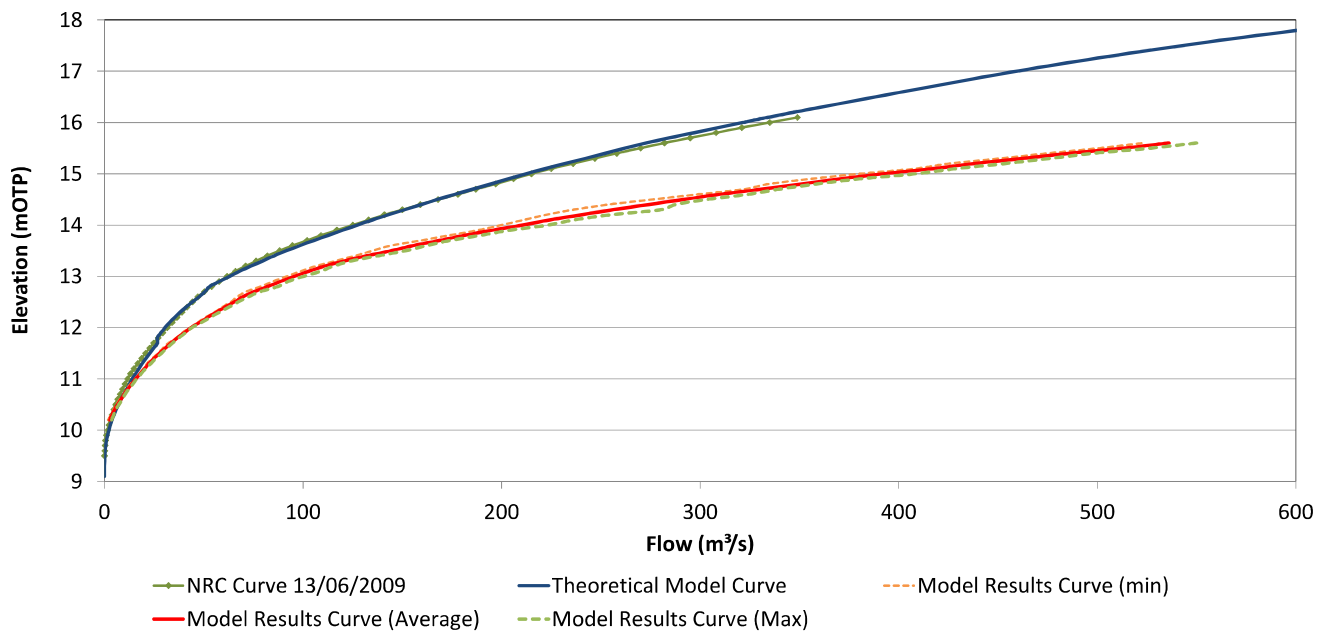
SG Stage (mm)	Water Level [mOTP]	Recorded Rating Curve	Theoretical Model Curve	Model Results Curve		
		Rating curve of 13 - June - 2009		Minimum	Average	Maximum
		Flow (m3/s)	Flow (m3/s)	Flow (m3/s)	Flow (m3/s)	Flow (m3/s)
0	9.100	-0.170	0.000			
100	9.200	-0.138	0.000			
200	9.300	-0.100	0.000			
300	9.400	-0.057	0.036			
400	9.500	0.000	0.121			
500	9.600	0.094	0.272			
600	9.700	0.256	0.599			
700	9.800	0.550	0.963			
800	9.900	0.983	1.533			
900	10.000	1.530	2.236			
1000	10.100	2.180	2.939			
1100	10.200	2.950	3.819	1.886	2.644	3.602
1200	10.300	3.800	4.847	3.114	3.722	4.655
1300	10.400	4.660	5.875	4.453	5.041	5.590
1400	10.500	5.660	7.005	6.178	6.659	7.243
1500	10.600	6.730	8.265	7.732	8.297	8.831
1600	10.700	7.870	9.670	9.606	9.904	10.375
1700	10.800	9.040	11.075	11.136	11.708	12.150
1800	10.900	10.300	12.480	13.042	13.737	14.282
1900	11.000	11.600	13.943	15.441	15.716	16.159
2000	11.100	13.100	15.639	17.576	17.869	18.411
2100	11.200	14.800	17.334	19.549	20.200	20.743
2200	11.300	16.700	19.029	21.423	22.328	23.353
2300	11.400	18.700	20.884	24.148	24.943	25.813
2400	11.500	20.700	22.808	27.041	27.727	28.690

2500	11.600	22.700	24.731	29.363	30.553	31.366
2600	11.700	24.800	26.655	32.231	33.478	34.224
2700	11.800	27.000	26.576	36.190	36.599	37.373
2800	11.900	29.300	28.418	39.259	40.078	40.823
2900	12.000	31.600	30.485	43.341	43.676	43.993
3000	12.100	34.000	32.791	46.908	47.866	48.798
3100	12.200	36.500	35.354	50.993	51.991	53.315
3200	12.300	39.000	38.030	55.398	56.292	57.895
3300	12.400	41.600	41.003	59.256	60.597	62.676
3400	12.500	44.300	44.251	63.634	65.378	67.263
3500	12.600	47.000	47.540	66.808	69.460	72.375
3600	12.700	50.300	50.595	71.363	75.207	78.339
3700	12.800	53.900	52.815	78.593	82.058	87.231
3800	12.900	57.700	57.902	84.804	88.597	92.471
3900	13.000	61.700	62.990	91.900	95.594	100.259
4000	13.100	66.000	68.077	98.965	103.084	108.877
4100	13.200	71.000	73.751	106.426	110.810	115.257
4200	13.300	76.300	79.572	116.517	120.647	124.196
4300	13.400	82.000	85.392	126.280	132.052	138.029
4400	13.500	88.200	91.778	135.112	144.595	151.770
4500	13.600	94.700	98.406	144.333	155.606	162.266
4600	13.700	102.000	105.491	159.574	168.821	174.224
4700	13.800	109.000	112.770	173.538	181.320	189.476
4800	13.900	117.000	120.050	188.432	195.517	204.257
4900	14.000	125.000	127.329	199.856	210.671	223.238
5000	14.100	133.000	134.893	211.156	224.484	236.732
5100	14.200	141.000	143.121	222.516	240.448	255.217
5200	14.300	150.000	151.348	236.378	256.523	280.560
5300	14.400	159.000	159.576	253.879	274.364	287.419
5400	14.500	168.000	167.803	276.156	291.820	303.373
5500	14.600	178.000	176.426	299.263	310.111	324.394
5600	14.700	187.000	185.443	322.159	330.956	339.717
5700	14.800	197.000	194.461	334.543	351.021	358.408

5800	14.900	206.000	203.479	355.711	370.619	380.397
5900	15.000	215.000	212.496	380.421	392.765	408.748
6000	15.100	225.000	221.984	408.481	417.541	429.030
6100	15.200	236.000	232.047	425.440	438.366	453.632
6200	15.300	247.000	242.110	451.080	462.663	476.417
6300	15.400	258.000	252.173	475.384	486.177	497.996
6400	15.500	270.000	262.235	501.229	513.452	527.011
6500	15.600	282.000	272.876	523.381	536.267	550.222
6600	15.700	295.000	284.445			
6700	15.800	308.000	296.814			
6800	15.900	321.000	309.183			
6900	16.000	335.000	321.552			
7000	16.100	349.000	333.920			
7500	16.600		402.419			
8000	17.100		475.011			
8500	17.600		561.578			
9000	18.100		667.087			
9500	18.600		785.838			
10000	19.100		916.956			
11000	20.100		1220.363			
12000	21.100		1581.540			
13000	22.100		1997.273			
14000	23.100		2468.837			
15000	24.100		3007.301			
16000	25.100		3651.412			
17000	26.100		4350.486			
18000	27.100		5105.277			
19000	28.100		5916.399			
20000	29.100		6781.769			
21000	30.100		7702.932			
22000	31.100		8678.271			
24000	33.100		10769.054			
26000	35.100		13030.594			

28000	37.100		15393.874			
30000	39.100		18211.512			
32000	41.100					
34000	43.100					

Waiharakeke at Willowbank - Rating Curve



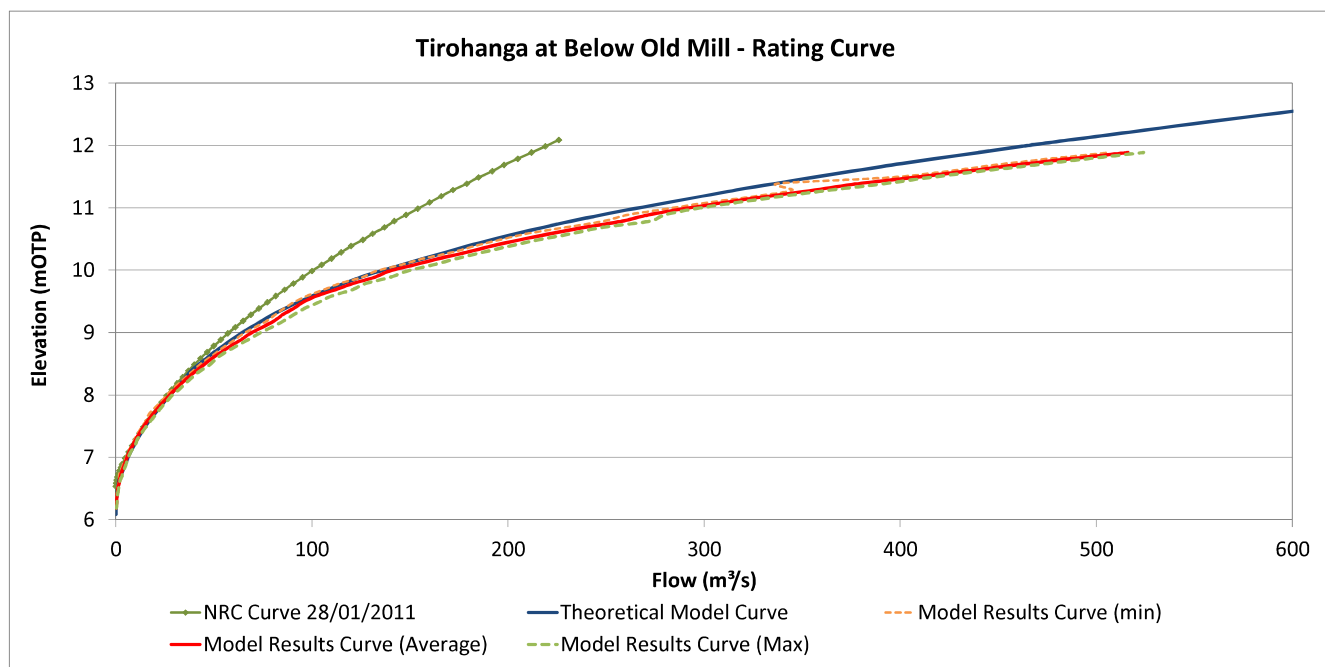
Tirohanga at Below Old Mill

SG Zero	6.086	m OTP
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SG Stage (mm)	Water Level [mOTP]	Recorded Rating Curve	Theoretical Model	Model Results Curve		
		Rating at 28-Jan-2011 24:00:00	Curve	Minimum	Average	Maximum
		Flow (m3/s)	Flow (m3/s)	Flow (m3/s)	Flow (m3/s)	Flow (m3/s)
0	6.086	-1.200	0.039			
100	6.186	-0.987	0.107	0.165	0.235	0.339
200	6.286	-0.754	0.242	0.332	0.442	0.679
300	6.386	-0.491	0.494	0.484	0.665	0.855
350	6.436	-0.338	0.711	0.571	0.884	1.137
400	6.486	-0.184	0.928	0.738	1.102	1.425
450	6.536	0.008	1.145	1.033	1.375	1.665
500	6.586	0.200	1.304	1.321	1.665	1.938
550	6.636	0.450	1.716	1.541	1.943	2.263
600	6.686	0.800	2.295	1.531	2.316	3.076
650	6.736	1.250	2.927	1.769	2.761	3.445
700	6.786	1.820	3.560	2.402	3.307	4.007
750	6.836	2.500	4.193	3.110	3.869	4.652
800	6.886	3.200	4.825	3.733	4.404	5.214
900	6.986	4.750	6.091	5.059	5.609	6.247
1000	7.086	6.500	7.546	6.346	6.962	7.602
1100	7.186	8.270	9.225	7.983	8.498	9.784
1200	7.286	10.100	10.903	9.536	10.196	11.008
1300	7.386	12.100	12.880	11.319	12.047	13.063
1400	7.486	14.100	14.906	13.199	14.073	15.433
1500	7.586	16.300	17.059	15.315	16.327	17.751
1600	7.686	18.600	19.573	16.776	18.783	20.458
1700	7.786	20.900	22.087	19.687	21.385	22.784
1800	7.886	23.300	24.601	22.807	24.074	25.727
1900	7.986	25.900	27.395	25.793	27.095	28.483
2000	8.086	28.500	30.278	28.656	30.155	32.194
2100	8.186	31.200	33.058	32.268	33.625	35.599

2200	8.286	34.100	35.715	35.637	36.972	39.038
2300	8.386	37.000	38.427	39.254	40.959	43.023
2400	8.486	40.000	42.288	42.888	45.042	48.008
2500	8.586	43.200	46.236	47.212	49.075	51.389
2600	8.686	46.600	50.200	51.542	53.783	56.054
2700	8.786	50.000	54.610	55.933	58.521	61.613
2800	8.886	53.600	59.050	60.804	63.948	67.573
2900	8.986	57.200	63.846	65.195	68.557	73.039
3000	9.086	61.000	69.068	71.090	74.824	79.532
3100	9.186	64.900	74.451	77.009	80.667	85.507
3200	9.286	68.900	79.956	81.289	85.106	90.753
3300	9.386	73.000	86.354	85.803	90.684	96.259
3400	9.486	77.300	93.064	90.766	95.453	103.616
3500	9.586	81.600	100.272	97.309	102.424	110.164
3600	9.686	86.100	107.953	105.960	112.006	120.537
3700	9.786	90.600	116.246	114.102	120.889	127.412
3800	9.886	95.300	124.681	125.561	131.880	139.917
3900	9.986	100.000	134.655	132.754	139.453	148.579
4000	10.086	105.000	145.822	145.660	152.289	161.756
4100	10.186	110.000	156.990	156.824	164.636	173.884
4200	10.286	115.000	168.157	171.688	178.751	186.926
4300	10.386	120.000	179.324	183.000	191.447	200.771
4400	10.486	126.000	191.311	195.786	205.993	215.450
4500	10.586	131.000	204.390	209.773	221.848	232.436
4600	10.686	137.000	218.106	228.996	239.347	248.276
4700	10.786	142.000	232.347	248.682	258.291	272.475
4800	10.886	148.000	247.740	260.938	271.601	279.832
4900	10.986	154.000	264.389	281.529	289.814	295.630
5000	11.086	160.000	281.772	302.169	310.406	316.951
5100	11.186	166.000	299.154	326.537	332.956	339.749
5200	11.286	172.000	316.537	345.064	356.434	365.028
5300	11.386	179.000	335.455	336.917	378.420	391.658
5400	11.486	185.000	354.918	394.462	406.518	414.872
5500	11.586	192.000	375.234	424.168	433.474	440.792
5600	11.686	198.000	395.550	448.028	458.680	468.383

5700	11.786	205.000	417.576	475.807	486.845	495.703
5800	11.886	212.000	439.880	506.854	516.159	524.115
5900	11.986	219.000	462.185			
6000	12.086	226.000	485.763			
6500	12.586		610.652			
7000	13.086		752.855			
7500	13.586		910.926			
8000	14.086		1082.869			
8500	14.586		1268.219			
9000	15.086		1466.855			
9500	15.586		1679.809			
10000	16.086		1905.376			
10500	16.586		2143.898			
11000	17.086		2395.209			
11500	17.586		2658.324			
12000	18.086		2933.844			
12500	18.586		3220.821			
13000	19.086		3519.799			
13500	19.586		3830.693			
14000	20.086		4152.789			
15000	21.086		4831.167			
16000	22.086		5555.136			
17000	23.086		6325.044			
18000	24.086		7140.931			
19000	25.086		8001.670			
20000	26.086		8906.641			
21000	27.086		9857.313			
22000	28.086		10853.822			
23000	29.086		11907.739			
24000	30.086		13020.711			
25000	31.086		14171.878			
26000	32.086					
27000	33.086					



Appendix C Flood Maps



URS New Zealand Limited
URS Centre, 13-15 College Hill
Auckland 1011
PO Box 821, Auckland 1140 New Zealand

T: 64 9 355 1300

F: 64 9 355 1333

www.urscorp.co.nz