WAIPU/PAPAROA HYDRAULIC MODEL

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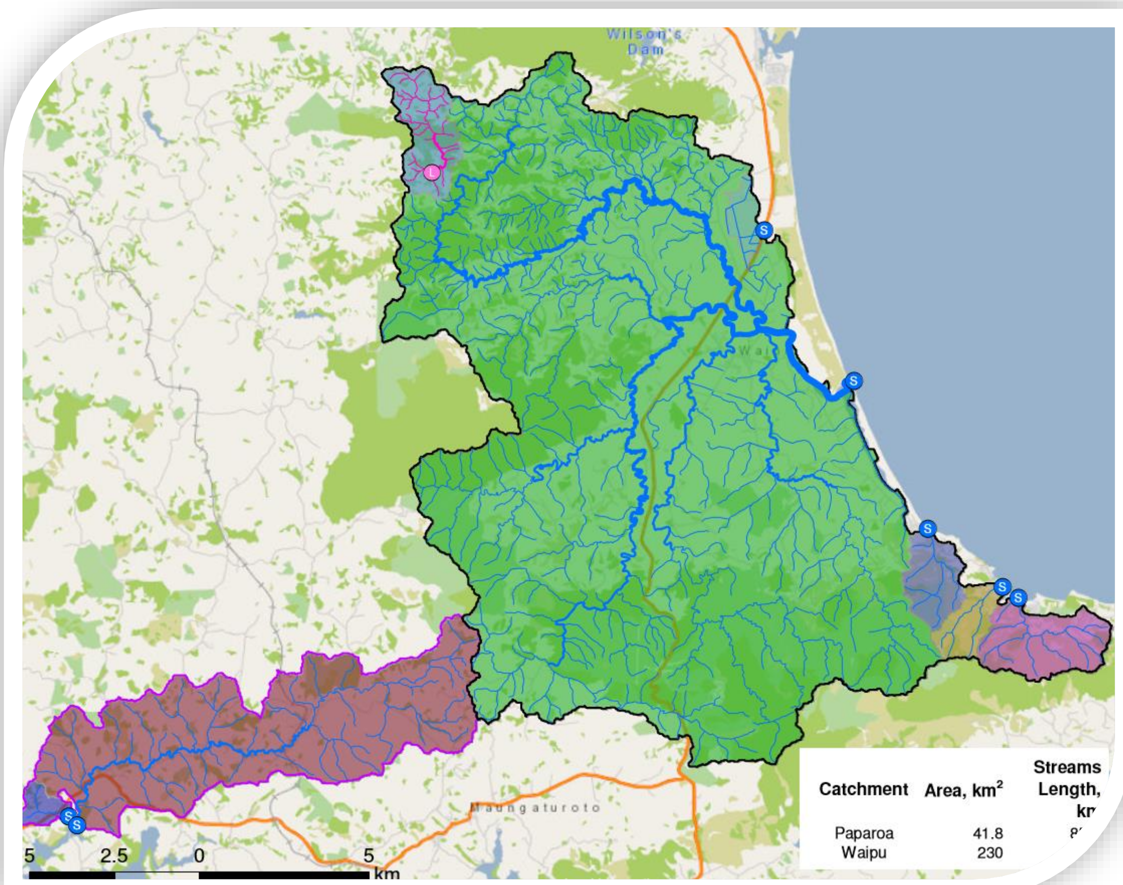

Waipu/Paparoa Hydraulic Model

Ewaters ProjNo 1720013

Ewaters New Zealand Ltd

First October 2018

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Project Waipu/Paparoa Hydraulic Model	Project No 1720013
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Revision	Description	By	Checked	Approved	Date
00	Final	JAC	JSW	JSW	01/10/18
01					
00					

Key words	Status ☐ Draft ☑ Final ☐ Issued

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INTRODUCTION

BACKGROUND

Northland Regional Council (NRC) required a hydrological and hydraulic flood modelling studies to be carried out on the Waipu and Paparoa river catchments.

The primary objective of the studies is to develop flood maps for both river catchments which provide the information necessary to inform:

- Strategic and site-specific development decisions, ensuring that development is safe and sustainable from a flood risk perspective.
- The development of flood risk management schemes.
- Communities and businesses of their flood risk, so that they can become more resilient to flooding.

SCOPE AND OBJECTIVES

AS STATED IN THE RFP:

The modelling studies includes:

- Review and quality assessment of existing data.
- Assessment of catchment hydrology.
- Development of rainfall-runoff models for current and future design rainfall events, as defined by NRC.
- Production of a 1D/2D coupled hydraulic model, for the river network extent defined by NRC.
- Determination of the sensitivity of model outputs against variations in key model parameters.
- Calibration and validation to ensure models are robust.
- Analysis of design flows and water levels across the specified current and future design rainfall events.
- The production of flood maps suitable for land use planning, and other deliverables (refer to section 0 for details).

VARIATIONS TO THE RFP - EROSION ANALYSIS

Through the development of the Waipu model, it was found that the Waipu River mouth required special attention in terms of its flow capacity and the role that sand banks and its erosion would play in it. Additional objectives are placed for the project to fulfil these particularities not previously foreseen. In this regard, the modelling studies also includes:

- Desktop analysis of erosion at the river mouth.

- Re-run March 2017 event with network modifications at the river mouth to account for erosion and enlarged flow capacity for that event.
- Simulation of design events with eroded network as per assumptions described in this document (refer to section 0 for its methodology). Each event might have different amount of erosion depending of hydraulic performances.
- Completion of the original Waipu deliverables based on model outputs which consider erosion at the Waipu river mouth.

DELIVERABLES

The final deliverables are listed below.

- Waipu and Paparoa Model Build and Calibration Report.
- Model files, including calibration events, design events without erosion, and design events with erosion (for Waipu only). Delivered as transportable database including all model objects required to reproduce the model outputs.
- Raster for depth, flood level and velocity for 10yr, 50yr, 100yr and 100yrs+CC events, for both: Waipu and Paparoa, For Waipu this will consider the adjusted network by erosion at the river mouth.
- Flood extent polygon shapes for Waipu and Paparoa, for 10yrs, 50yrs, 100yrs and 100yrs with climate change as per rasters.
- Other supporting shapes. All shapes and rasters compiled in separate ArcGIS packages for each of the two catchments.

Note that partial outputs and findings were delivered at various stages of the project, to review progress, for QA, to agree actions at various milestones of the RFP, or on simple client request. A brief description of these milestone deliverables is in section 0. The detail of the final deliverables items is described in section 0 and section 0.

CATCHMENT DESCRIPTION

Waipu catchment is approximately 220 square km and contains an estimated total stream length (main river and tributaries) of 591 km. Paparoa Catchment is approximately 41.8 square km and contains a total stream length of 85.7 km.

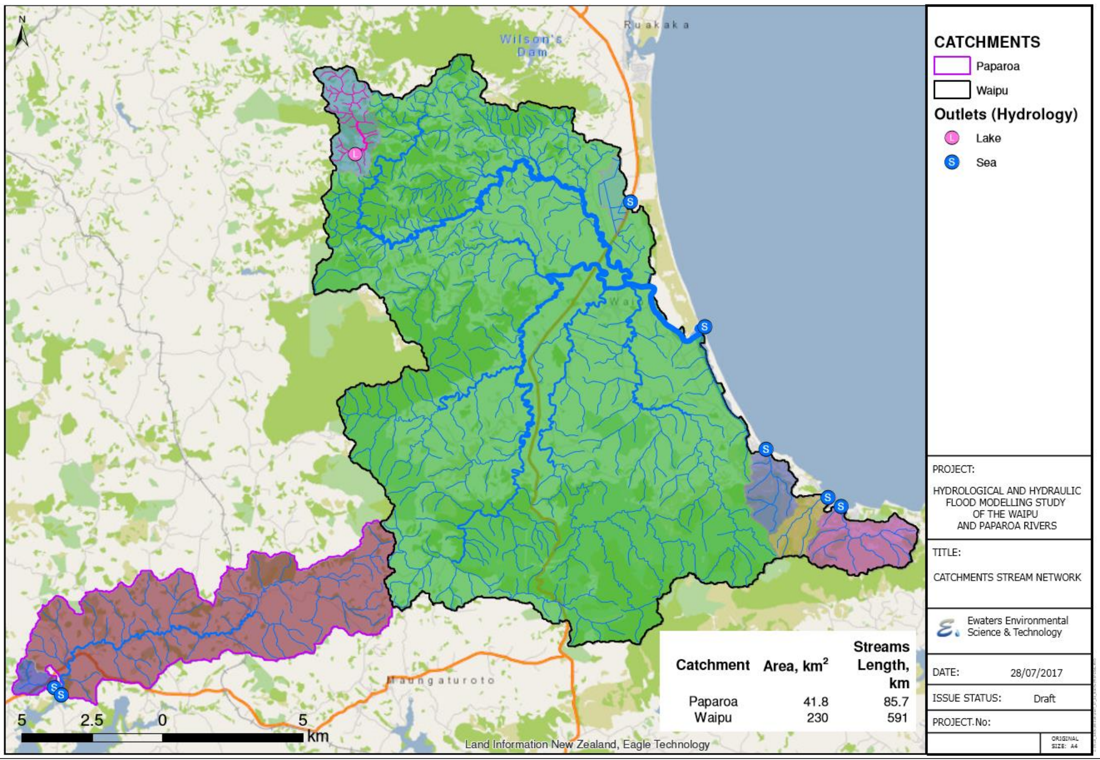


Figure 0.1. Waipu and Paparoa catchments.

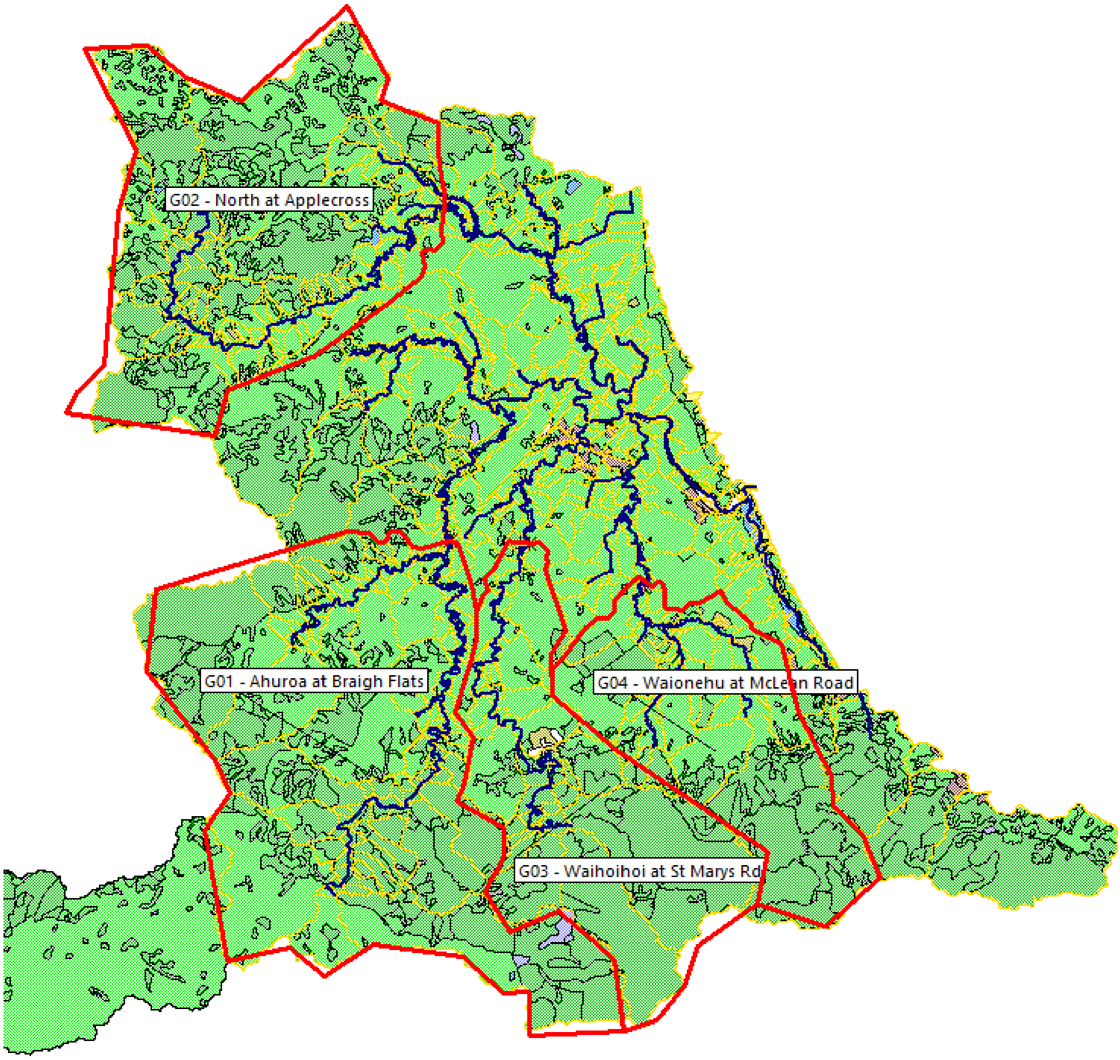


Figure 0.2. Waipu catchment land coverage

Geology, land use and land cover are available to describe the catchment. The three features are similar in distribution. Figure shows land coverage. In general (as an approximation), the land coverage is mainly one of two: grass or forest (various types). Grass coverage is well correlated to flat ground, with sedimentary or fine deposits. Forest coverage is characterized by steeper slopes, and harder rock geology composition.

The figure above shows a fairly homogeneous distribution of these features, where all four gauges are similar. Therefore, similar hydrological parameters are expected when comparing the four gauged catchments.

The river mouth at present has large sand dunes and bars along the coast line. The river mouth itself show signs of seasonal changes that could potentially affect the river mouth capacity and the overall performance of the drainage system.

METHODOLOGY

GENERAL APPROACH

Ewaters methodology for the Waipu and Paparoa Catchments are conforming to the proposed scope in the RFP and based on our extensive international experience in developing large scale river models as well as our previous experience with the Priority Rivers Project. Ewaters has used InfoWorks RS v13 (2013), which is the same version other NRC models are held.

It should be clarified that during the project development the progress was presented in different portions to comply with the client's requirements and to allow discussion and agreement of certain milestones before engaging in the succeeding tasks (as described in section 0). Below, there are 5 project stages which group the study into related tasks. These stages cover all model objectives as described on section 0.

Note that the methodology presented allows the incorporation of findings that later modified or complemented the approach. In this regard, the original methodology is described, and its findings and modifications are described along the relevant section from which they were developed.

STAGE 1 PROJECT SET UP, DATA REVIEW, COLLECTION AND RAPID FLOOD MODEL (RFM)

Following project kick off, these tasks refer to the general background and definition of the model extent and key model inputs. The objective is to gain a comprehensive understanding of the system and assess the most critical components in the model against the physical asset information (checking critical model components on system such as lake storage, weir curves or operational rules, maximum water level, cross section data, LiDAR, soil types, land cover, among others). It also considers the selection of viable rain events for calibration and validation based on the review of the available records. Additionally, an RFM is built and run to assist the definition of the model extent and key hydraulic and hydrological features.

Below, a list of the key projects tasks and required findings:

- Project kick off meeting with client.
- Data review.
- GIS analysis for main catchment features.
- Rapid Flood Model (RFM) to assist model extent and selection of key hydraulic/hydrological features.
- Revision of rain and flow gauge records to select rain events to calibrate/validate.
- Selection of storm durations for the design events of Waipu and Paparoa.
- Revision with client and feedbacks.

STAGE 2 MODEL BUILD

Utilising the RFM results and incorporating the client's feedback from Stage 1, the model extents is agreed with NRC staff. This stage considers the model build for all its components (hydraulic component such 1D cross sections, 2D mesh, structures, river bank spills, culverts, etc; hydrological components such sub-catchment delineations, abstractions, non-linear reservoir parameters, etc; boundary conditions, numerical setups, etc.). The stabilisation finalized with a preliminary run of the Calibration and Validation events for clients to comment. Below a list of the key project tasks and projected findings for Stage 2:

- Model build (incorporating all data inputs provided).
- Model stabilization.
- Preliminary simulation of calibration/validation events.
- Revision with client and feedbacks.

STAGE 3 MODEL CALIBRATION/VERIFICATION

Stage 3 covers the model calibration with the selected events for Waipu and Paparoa, with the knowledge basis established in the previous 2 stages. Since the two catchments are close enough, the hydrological zoning of features and the desk calibration enables relevant parameters with similar features and zonings to be shared between them maximizing the use of available data. Below a list of the key project tasks covered by this stage:

- Gauge record analysis and water balance
- Desk calibration (global parameters)
- Key parameters sensitivity tests
- Calibration of Waipu catchment. 3 events against 4 flow/stage gauges and flood level survey when available
- Validation of Paparoa catchment. 1 event against flood level survey only
- Calibration graphs, plots, long profiles for discussion
- Preliminary design event simulation runs
- Revision by client and feedback

STAGE 4 EROSION ANALYSIS (VARIATION)

As it is described in section 0, the calibration of March 2017 highlighted the importance of the river mouth capacity and the role that erosion plays on it. This stage considers a comprehensive analysis of the erosion dynamic and its key components, re-running March 2017 to adjust the calibration of flood level records and utilize the same developed methodology to assign customized erosion to each design event for final modelling. Below a list of the key project tasks in this category:

- Desktop analysis of erosion at the Waipu River mouth.
- Re-run March 2017 event for Waipu model, with network modifications at the river mouth to account for erosion and enlarged flow capacity for that event.

- Estimation of erosion for each design event as per assumptions described in this document (refer to section 0 for its methodology). Each event might have different amount of erosion depending of the hydraulic performances.
- Revision by client and feedbacks.

STAGE 5 DESIGN EVENTS (PLUS EROSION ANALYSIS) AND DELIVERABLES

This stage considers tasks related to the final model outputs and development of deliverables:

- Simulation of design events for Waipu catchment with eroded network as defined in Stage 4 (refer to section 0 for its methodology).
- Simulation of design events for Paparoa catchment (no erosion considered).
- Creation of raster for flood level and depths for both, Waipu and Paparoa, for 10yrs, 50yrs, 100yrs and 100yrs plus climate change design events.
- Development of velocity raster methodology to describe 1D and 2D objects over flood extent.
- Flood extent shapes cropped to the Lidar extent only.
- Deliverables (as per section 0).

PROJECT PROGRESS AND CLIENT FEEDBACK

As part of the methodology, milestones and key decisions are discussed with client before carrying on with succeeding tasks. Here a breakdown of the main milestones discussed.

The relevant information for these items is described in their respective section.

Draft deliverables for the project were delivered in various stages:

- Stage 1. Schematization:
  - model extent,
  - selection of calibration event,
  - selection of design event duration for Waipu catchment and Paparoa catchment respectively,
  - technical notes.
- Stage 2. Model build: preliminary model outputs.
- Stage 3. Calibration:
  - graphs of gauge records vs model outputs,
  - rating curves calibration/analysis,
  - technical note which includes water balance analysis,
  - sensitivity tests for Waipu river mouth erosion,
  - preliminary model files with calibration and design events outputs.
- Stage 4. Erosion analysis (Waipu catchment only):
  - calibration of March 2007 event considering erosion analysis,
  - preliminary erosion ranges for the design events.
- Stage 5. Design events and deliverables:
  - final deliverable package as described in section 0.

PROJECT DEVELOPMENT

This report and other deliverables of this project are developed to full the requirements of the NRC RFP in terms of QA and record keeping. This includes:

- how the model was created,
- why certain decisions in the model build process were taken,
- which versions of the model should be used to continue development or extract results from.

This is fulfilled by Ewaters NZ during the project mainly by providing regular updates with results and technical notes, open to discussion at each critical task. Also, the current report covers all relevant aspects in the respective sections, which address: how calculations were made, equations and main assumptions, engineering decisions and technical discussions. Other aspects of tracking include comments on model objects, deliverable of supporting shapes, supporting model objects such layers, survey points/lines (floods and ground) included in the networks and hyperlinks to photographs records.

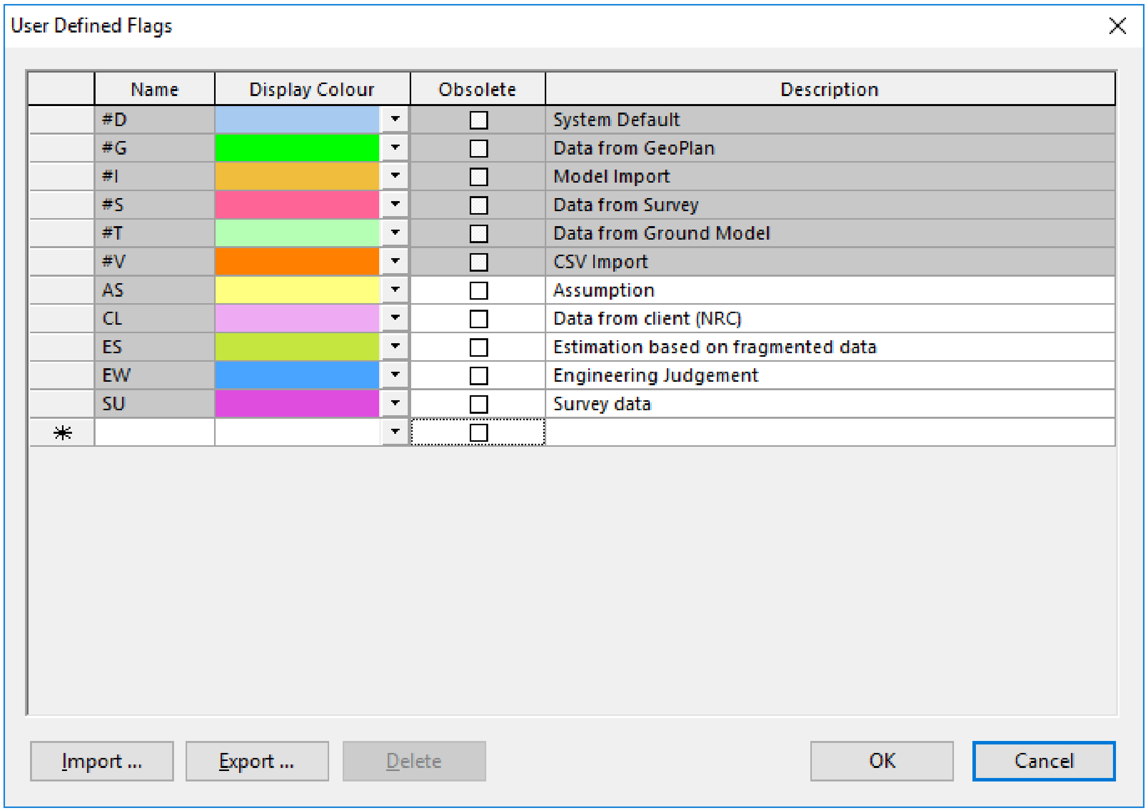
The information provided shall fulfil QA requirements and allow other engineers to continue the study if required.

DATA INPUTS

NRC has provided the following items for the competition of this study:

- Relevant reports
- LiDAR (and related reports)
- Aerial photography
- Survey data (cross sections and structures, with georeferenced photos)
- GIS layers and data
    - Catchment boundaries
    - Land use
    - Wastewater Infrastructure
    - Rain Gauge data
    - Flood records
    - Stormwater infrastructure
    - Soils, etc.
    - River level and flow gauge data
    - Roads
    - Parcel information
    - Proposed Land Use Planning
    - Geology
- Historic flood records and flood levels (with corresponding rain data)
- Photo records and description

Other supporting shapes were included by Ewaters to complement the catchment feature description (such roads, land features, bridges, depressions, etc.). Additionally, various pieces of information (such invert levels, culvert size, roughness manning, spill coefficients, hydrological and hydraulic parameters, etc.) are based whether on the data provided, estimated, calibrated or simply defined as assumption based on general engineering knowledge. To classify the quality and source of the data used in the model, these relevant values are flagged according to the codes shown in Figure 0.1. Some comments might be available in cases in the relevant object.


User Defined Flags

Name	Display Colour	Obsolete	Description
#D		☐	System Default
#G		☐	Data from GeoPlan
#I		☐	Model Import
#S		☐	Data from Survey
#T		☐	Data from Ground Model
#V		☐	CSV Import
AS		☐	Assumption
CL		☐	Data from client (NRC)
ES		☐	Estimation based on fragmented data
EW		☐	Engineering Judgement
SU		☐	Survey data

Figure 0.1. InfoWorks RS data flags defined for Waipu and Paparoa models

RAPID FLOOD MODELLING APPROACH

A rapid flood model is built with the LiDAR provided data. The catchment boundaries is then reviewed and revised as necessary using GIS spatial tools.

A ground elevation model is created for the catchment extents using the LiDAR data and 20m national grid. The new ground model is processed to be hydrologically correct by utilising the existing streams information and further process the existing data to ensure the stream network defined has the appropriate connectivity and direction.

A rain on grid simulation is run for an agreed upon extreme storm (approximately a 100yr plus climate change event) with a total rain depth that is constant for the entire catchment applied to an accepted design (6 and/or 12 hour) rainfall duration curve. Effective rainfall is determined through averaged hydrologic attributes of the available geospatial information and applied directly to the 2D model. The duration of the storm does not require in-deep analysis as this stage, as one of the purposes of this model is to highlight variables such time of concentration and lag times between branches, and any particularities in the hydrology and hydraulic features of each catchment.

This model is to highlight major flooding areas, potential blockages, and assisting to determine the most suitable extent for the model components, such as: hydrological resolution, 1D extent and 2D extent, against the preferable extent defined by NRC in the RFP. It also helps to provide insights of the main hydraulic features and issues to address in the detailed modelling. The rapid flood model results are to assist in identifying hotspots, verify the future preliminary model outputs, identify if and where survey and site visits is required (survey not considered for this project). The RFM does not have any sub-catchments as it is a rain on grid simulation, but it is effective for sub-catchment delineation, and having enough details to enable the model to simulate focused areas for each river catchment as identified in the Project Objectives.

INTEGRATED MODELLING APPROACH

SOFTWARE

InfoWorks RS version 13.0 as per all other previous models owned by NRC.

HYDROLOGY

Our team has previously assisted in the selection and build of non-linear reservoir models for the Kawakawa River and Ruakaka Rivers for NRC. The NLR more closely represented the runoff hydrographs for those large rural catchments, and it is expected to provide a more versatile option for the Waipu and Paparoa catchments. The NLR requires more careful analysis than the SCS method to effectively select the appropriate parameters. An understanding must be gained from a range of storm events to establish the relation of physical hydrologic attributes and the extended response of the catchment. Lessons learnt from our previous projects utilising NLR enables an efficient selection of parameters for these catchments. Through a rigorous process both: peak flow and runoff volumes, can be effectively calibrated.

Sub-catchment definition

Sub-catchments are defined utilising GIS spatial analysis tools. With the land-use planning, relevant sub-catchments could be described accordantly and use to test future development scenarios (not part of this scope). The catchment is subdivided in accordance with the results of the rapid flood modelling and the hydraulic extents of the model agreed with NRC staff. Hydrological parameters are processed within GIS, incorporating land-use, soil type, Lidar topographic features (slopes, length), imperviousness, among others. Note that these hydrological parameters are meant for the existing development state, which is assumed to be represented by the layers provided. If no impervious areas polygons are available, impervious portions will be estimated through alternative method, such the aerial photograph analysis or other GIS features.

Initial NLR Flow analysis (Runoff/Infiltration/Recharge/Evapotranspiration)

The water balance and desk calibration allows to narrow the value of the hydrological parameters. Abstractions can be represented by various methods, however, experience in NRC catchment has shown that constant infiltration method has shown better description of the rural hydrology, for which is also the preferred method of the client. Critical values are the baseflow, infiltration rates, runoff volumes and peak flows. The NLR parameters (storage coefficient, power and other parameters such as length, slope and shape, which are related to the time of concentration) are refined during the calibration stage.

HYDRAULICS

Based on the model extent defined in detail in stage 1 and agreed with NRC at the beginning for stage 2, the 1D river model (and other 1D nodes/links) are built. A hydraulic GIS model is first built containing key features, such river centre line, cross section locations, road crossings, and other features such bank lines and flood plain extents (potential storages), as well as Lidar data and other shapes. The whole set is then imported into InfoWorks RS to build the1D model. Surveyed cross sections are used in conjunction with LiDAR data to provide efficient and accurate interpolated cross sections for the 1D network.

All other hydraulic assets are defined and included in the 1D model as appropriate such as bridges, lakes, culverts etc., for which some survey data or photograph records is available. Hydraulic parameters are set accordingly, with preliminary values to be reviewed during the calibration tasks, along with some sensitivity tests.

Model stability is paramount and the 1D are tested and optimised during the 1D model stage and then when coupled to the 2D components.

BOUNDARY CONDITIONS

There are boundary conditions:

- Rain records for the hydrological model
- Tide levels for the hydraulic model.

Through the utilization of InfoWorks RS model capabilities, the hydrological and hydraulic models are integrated in one model network. Runoff flows are generated by the hydrological model and assigned to the hydraulic model directly. Only tides and rain series are to be provided to the integrated model to described any given storm scenario.

RAINFALL BOUNDARY CONDITION

For the calibration event, the rain boundary condition is fulfilled with the rain gauge records available for the selected calibration/validation storms defined in 0.

For the design events, the NRC rain profile is used (see Figure 0.2) for the storm duration and rain depth defined in section 0. The storm duration is defined by the analysis of the results of the RFM for Waipu and for Paparoa separately. The rain depth is defined for the relevant duration for each sub-catchment in the model according to the Hirds V3 database. The design events to model are 10yrs, 50yrs, 100yrs, and 100yrs with climate change. Further details in section 0.

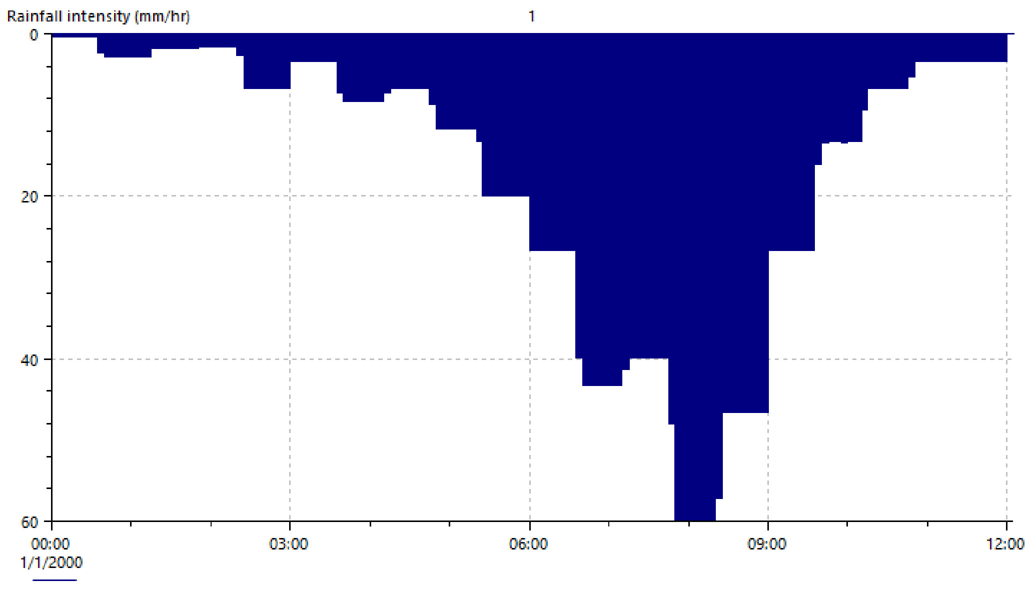


Figure 0.2. NRC rain profile. Example for 12hr duration.

The design event for 100yrs plus climate change considers 2.1°C of warming, which implies a 16.8% of rain depth increment as defined by Hirds V3 database.

TIDE BOUNDARY CONDITION

Paparoa River and Waipu River both discharge to the ocean, towards the west and east coast respectively. The nearest port gauge for Waipu River outlet is the Marsden Point in the east coast, and for Paparoa River outlet is Pouto Pt at the west coast.

Calibration events utilize tide records at the relevant gauge, and the design events utilize the 2yrs frequency tide series provided by NRC for each of these port locations (see Figure 0.3). Depending on the storm duration selected by the catchment, and the time of concentration of the catchment estimated from the RFM, the peak tide of the series are set to meet the peak flow at the respective river outlet.

The 100yrs plus climate change scenario considers a sea level rise of 1.0m as required by NRC. 0.5m sea level rise scenario was also simulated and is included in the model files delivered.

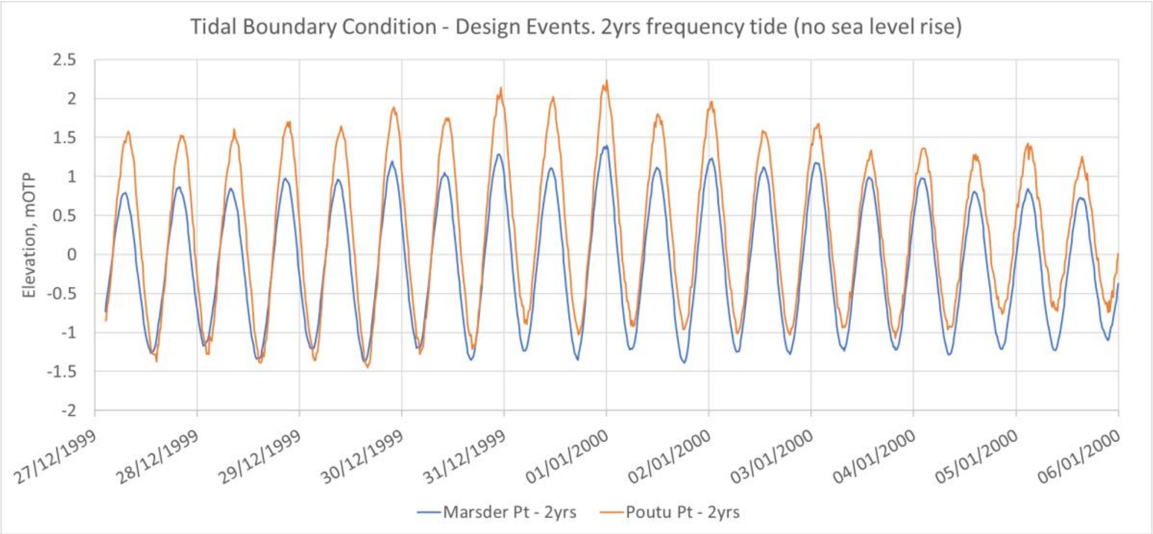


Figure 0.3. NRC tide series. 2yrs frequency for Marsden Point and Pouto Point. Peak tide centred to graph.

SENSITIVITY ANALYSIS

Sensitivity analyses are considered to understand the impact on various key parameters on the model outputs as part of the calibration. Among various potential critical variables are the river roughness, infiltration rates, hydrological methods and their respective parameters.

These parameters are tested directly or indirectly in the model. Most of these tests do not required running the whole model network with the integrated hydrologic and hydraulic models, but instead a portion of it (such as a river branch, hydrological model only, test over various flows using only the hydraulic model, or a combination of the previous). The final list of relevant tests is are listed along the findings of the water balance and model build preliminary simulation tests (refer to section 0).

Additionally, as consequence of the Waipu river mouth features, the erosion at the river mouth have a potential impact on results. The methodology to testing erosion sensitivity is not as direct as other calibration variables, as erosions requires an integration of features to be considered when estimating the erosion/deposition depths at any given portion of the river. Given its complexity, the methodology of the erosion sensitivity tests is described separately in section 0.

CALIBRATION

The calibration tasks start with the selection of the calibration event. At least one calibration event will be chosen, totalling 3 events together with the validation storms (as required by the RFP). When selecting the calibration/validation periods, many aspects are considered, such: size of the storm (rain depth), its duration, frequency (ARI), density of data (number of viable gauges), quality of data (gaps and consistency), flow/stage data vs rainfall data availability, rain gauge coverage and quality, amongst others.

Three events for Waipu catchment is suitable since it has 4 flow/stage gauges with enough records, along with few flood survey levels. Paparoa, however, does not have any flow/stage gauges, and only few flood levels surveyed. For this reason, Paparoa is validated only with these flood points using one storm event. Since the floods points available for Paparoa are for the storm of January 2011, this storm becomes a potential and desired calibration/validation event out of the set of 3. Details on the final calibration/validation storm selection is described in section 0.

Since the two catchments are close enough, the hydrological zoning of features and the desk calibration enable relevant parameters with similar features and zonings to be shared between them, maximizing the use of available data. Rain gauges used for the calibration/validation run are assessed for spatial distribution, and method such Thiessen polygons may be used to distributed over the sub-catchments.

Table 0.1 shows a summary of the calibration information available in Waipu and Paparoa catchments.

Table 0.1. Calibration data available in Waipu and Paparoa

Catchment	Waipu	Paparoa
Number of Flow/stage gauges	4 gauges	None
Rain gauges near the catchments	22 gauges (Table 0.10)	
Flood survey points	34 (March 2007 only)	7 (January 2011 only)
Closest tide station	Marsden Point	Pouto Point

A water balance analysis is done for all 4 flow/stage gauges, comparing against the catchment areas and rain volumes (from rain depth records). This water balance allows understanding the reliability and quality of the records and highlight possible gaps or issues to address during calibration. It also provides preliminary global parameters for the abstraction and NRL routing method.

Statistics quantifying the fit between simulated flow and water level and the

measured flow and water level for each individual event should fall within the

following maximum tolerances. These are based on the AC SW Modelling Specs and are alternative to what it has been proposed by the RFP. These were discussed and agreed with NRC prior to the calibration/validation tasks.

- Volumetric error. The difference in flow volume should lie in the range +20% to -10%. (Model – Gauge)
- Peak flow error. The difference in peak flow rate at each significant peak should lie in the range + 20% to - 10%. (Model – Gauge)
- Timing error. The difference in timing of the peaks should lie be in the range +1 hour to –1 hour (Model – Gauge).
- Coefficient of correlation, r2. The flow correlation should lie be in the range 0.60 to 1.0.
- Peak depth error. The difference in non-surcharged peak depth should be within ±15% (Model – Gauge). Alternatively, 300mm error for flood survey and 200mm for telemetry may also apply.

In general terms, all 3 calibration/validations storms should meet all these criteria upon the reliability of the data and the particularities of the system. If not, it is said the model should be calibrated by modifying the relevant parameters to match the gauged records. Although, in large catchments such as these, matters such as abstractions methods, baseflow, spatial/temporal rain distribution, and antecedent moisture conditions are critical for the calibration outputs. Most of these aspects can't be determined solely from records and even though the client and consultant might have a preference on the assumptions or methods to use, the comprehensive desk calibration is paramount to determine the critical variables and relevant inputs for a more effective and realistic calibration.

Similarly, the water balance and desktop calibration may highlight potential issues on records and missing modelling features that should be included (such gauge quality, upper catchment storage, flow volume vs rain gauge, etc.). Finally, parameters such as roughness, head losses, spill coefficients, and time of concentration, are used to adjust the model outputs to satisfactions.

At the end of this process, the model calibration maximizes the confidence in the model, and such is weighted by understanding the reliability of the inputs and the particularities of the event over the complex hydrologic and hydraulic system. The validation acceptance criteria (as defined on bullets) may not always be achieved, but there shall be enough understanding of the magnitude of error that may be acceptable for each condition or location. These situations were discussed and agreed with NRC as they arose.

Calibration/validation of the model is for three events selected and agreed in stage 1. The model results for the calibration/validation events are graphed and summarized accordingly to evaluate the quality, accuracy and confidence of the model.

EROSION ANALYSIS

SENSITIVITY ANALYSIS APROACH AND CLARIFICATIONS

The calibration of March 2007 event considers the review of several flood level survey points. In particularly, the lower catchment near the Waipu River mouth (section 0, Figure 0.8) shows a potential dependency to the capacity of the river mouth. The Waipu River mouth presents significant sand dunes and fine sediment deposits which are potentially sensible for erosion to the high velocities produced by the peak flows and head differences between the river mouth and tides levels.

For this reason, a sensitivity test was done to assess the impact on the river erosion. Contrary to other sensitivity tests performed for this study which only required variation of certain key parameters (such roughness, infiltration, NLR coefficients, etc.), an erosion requires a defined approach to represent the effect of this phenomena, which consider various aspect of hydraulic and physics interacting together. This section describes the methodology for such complex analysis. As a first approach, it is assumed a simplify and practical methodology which aims only to evaluate the hypothesis whether the impact of erosion at the river mouth is significant or not. The simplify approach is effective on its purpose, and it's described below along with its inherent limitations:

- Set a threshold velocity for erosion of the last 4.5km of the Waipu, and particularly near the river mouth.

- The threshold average velocity is chosen as the mode (most common value) observed on the model results for the March2007 event, for the last 4.5km of the Waipu river. This assumption responds to the fact the river bed is assumed to be on balance with the sediment transport at most cross sections, and that most of the erosions occurs where this value is exceeded. This hypothesis is suitable for the analysis given the assumption that the river bed near the river mouth is predominantly composed by sand of similar sizes and features. It is important to note that this is not entirely true, as the critical velocity will respond to other aspects as shear stress and vertical and transversal velocity profiles.
- The erosion was defined as a proportional enlargement of the area of flow based on the water depth, ensuring the reduction of the average velocity to be set to the defined threshold level.
- The network with modified cross sections at the river mouth is then run again for the event of March 2007 and assessed the changes compared with the flood level survey.

The findings of this exercise are described in section 0.

DESIGN EROSION METHODOLOGY

Discussions with client agreed that the same methodology used for the sensitivity test can be revised and applied for an actual calibration of the March 2007. It is important to recognize the limitation of the simplified approach, though, also with important practical application and effective use of resources.

Note that each event would have different levels of erosion, given the different flows and tides conditions which promote various velocity changes over the duration of the simulation. In theory, the velocities profiles (transversally and vertically) would define a shear stress that would compete against the forces settling the particles, as well as dynamic interactions by the increment of erosion/deposition over the longitudinal direction. Ewaters (outside of scope, but to ensure quality and confident of professional and technical outputs delivered) has also consider other ways to evaluate and gain confident on the results by testing the erosion estimations with the dynamic erosion routine implemented in InfoWorks RS. Various tests are done to settle the methodology to acceptable level of confident and applying the same criteria to the design event simulations for the Waipu catchment.

It is important to notice that the methodology was developed upon findings and critical aspects were discovered, and the method improved accordantly given the resources, time and scope.

The base criteria of the analysis are defined by the list of tasks below:

- Refine the sensitivity test approach for March 2007 event and achieve a suitable calibration for the lower Waipu River.
- Assess the erosion estimation with that calculated by InfoWorks RS routing. This requires calibration of certain sediment transport parameters for which there is not

data to compare against, other than the expected hydraulic performance defined by the surveyed flood levels for the event of March 2007. These parameters include the average sediment size and density, among others.

- Using the preliminary design evert results (without erosion considered), the erosion/deposition along the last 4.5km of the Waipu River is estimated, and the respective cross section geometry is modified accordantly for each of the 4 design events for Waipu catchment.
- The modified networks are simulated for the respective design events and the outputs processed as required by the original scope. The non-eroded model outputs are included in the model files as part of the deliverables, but they are only considered for the erosion routine, and not for deliverable purposes, neither to generate flood extents nor raster's.

Further details on the assumptions and criteria applied are described along the findings of the sensitivity tests and erosion analysis, in sections 0 and 0.

DESIGN EVENTS

Once the model network is calibrated, the design events are run with the respective rain and tide boundary conditions as defined in section 0 and developed in section 0.

Storm duration for the design events is defined for both catchments, Waipu and Paparoa, during the schematization and as part of the outputs extracted from the RFM and respective analysis. Findings of this exercise are described in section 0.

Pararoa catchment design events consider running a 10yrs, 50yrs, 100yrs and 100yrs plus climate change. The Paparoa catchment do not consider erosion analysis, as it was not found important (given the catchment features) neither there was sufficient data to assess any possible impact.

Waipu catchment design events consider running a 10yrs, 50yrs, 100yrs and 100yrs plus climate change. Since Waipu catchment considers an erosion analysis at the river mouth, these events are to be run twice. The first time without any erosion consideration, so to provide hydraulic output to feed the erosion analysis. Then the Waipu network is modified by erosion accordantly (as per sections 0, 0 and 0), and all design events run a second time for final model outputs.

DELIVERABLES

Models files are delivered as transportable database (icmt files) for all networks, events and simulations included in the scope, along a few extra tests and analysis of interest.

The raster's are created for all design events (10yrs, 50yrs, 100yrs and 100yrs plus climate change) for Waipu and Paparoa. Raster's are processed for flood levels, depths and velocities, completing a set of 24 raster's all together for Waipu and Paparoa.

At first stage, the Raster's are defined based on the peak model outputs over the entire composited DEM, which considers Lidar and portions of 20m contours grid, with a 1m resolution. The 20m contours portions is removed from the deliverables, as it is not fit for risk flood purposes, and only the Lidar portions are delivered.

The model resolution of the 2D domain is simplified for large flood plains to sizes so the model files and outputs are manageable. For practical purposes, the accuracy of the model is not compromised, and the outputs are post processed on GIS to produce raster's according to the Lidar information. This is true for all 3 raster's types: depth, flood elevation and velocities, but it is particularly challenging for the last, as the velocities are modelled by finite objects such 1D cross sections and 2D triangles. To avoid unrealistic representation of the velocities over the plan view and Lidar information, the following criteria is applied when creating velocity raster's from model outputs:

- 1D objects provide an average peak velocity, peak flow and flood level. The velocity is then distributed along the cross section using a transformation based on a simplified manning equation (Equation 0.1); with *Vi* the velocity at position *i*; $\bar{V}$ de average velocity (from model outputs); H_i the flood depth at any given point along the cross section (calculated in GIS from model outputs); and H_{max} the maximum depth along the cross section.

$$V_i = \bar{V} \cdot \left(\frac{H_i}{H_{max}}\right)^{2/3}$$

Equation 0.1

- The composite velocity is then check against the total modelled peak flow and adjusted accordantly.
- The resultant velocities are then interpolated between cross section by using few lines parallel to the river center line, to enforce interpolation over the main channel, banks and plains.
- The 1D velocities defined by this method then provide a boundary condition of velocities to be combined with the 2D triangles and produced a 1m resolution grid of the modelled velocities.

It is important to notice that the 1D model outputs do not produce the resolution of the velocities presented in the raster's, and that this representation is merely approximated. However, the approximation is based on hydraulic equations and topographic features. Likewise, the depth and water level raster's will have some limitations due of the projecting of results over the Lidar extent and the stitching of 1D and 2D objects.

MODELLING SCHEMATIZATION

RAPID FLOOD HAZARD MODELLING

A RFM type model (rain on cell) was run to determine the following aspect of the modelling work:

- Model extent, which allows identifying 1D and 2D portions, and main river crossings and other structures.
- Testing 6hrs and 12hrs storms, determining the time of concentration of the 2 catchments to be modelled: Paparoa and Waipu.
- Determining a preliminary and conservative flood extent, to define the extent of the modelling objects as well as for general understanding of the dynamic of the floods and extreme values.

An areal reduction factor (ARF) is applied over the total rain depths based on the work done by Tomlinson (1980), and presented in the Technical Publication No. 108, April 1999, Auckland Regional Council (TP108). This ARF has been applied in the Northland Region for other modelling studies, and it is summarized in Table 0.1.

Table 0.1. Areal Reduction Factor from TP108.

Area (km^2)	Time of Concentration (hrs)						
	0.5	1	2	3	6	12	24
≤10	1.0	1.0	1.0	1.0	1.0	1.0	1.0
20	0.90	0.91	0.93	0.94	0.95	0.96	0.97
50	0.72	0.75	0.82	0.86	0.92	0.94	0.96
100	0.71	0.74	0.79	0.83	0.86	0.89	0.90
200	0.70	0.72	0.75	0.79	0.82	0.85	0.86
500	0.68	0.70	0.72	0.74	0.76	0.79	0.81

Based on this table, the ARF for Waipu and Paparoa are shown in Table 0.2. These same values are used for the design events during the final stage of this project.

Table 0.2. Areal reduction factor for Waipu and Paparoa

Catchment	Area, km^2 *	Storm Duration, hrs	ARF
Waipu	239	12	0.842
Paparoa	47	6	0.923

The future design rainfall (with climate change) is estimated in accordance to the guideline provided by the Ministry for the Environment (2008). The guideline provides a table of percentage increase in rainfall per degree Celsius of warming for a range of ARIs and durations.

The projected average increase in annual mean temperature for Northland Region is 2.1°C for the period from 1990 to 2090. At an 8% extreme event increment per degree, this means a 16.8% of rain depth increment for the 100yrs plus climate change design event scenario. This is already implemented in HirdsV3 and the values extracted consider such climate change criteria.

The rain depth for various durations is shown in Table 0.3 and Table 0.4 for Waipu and Paparoa respectively. For the RFM, the rain is queried at 4 locations over each catchment (Hirds V3) to be used for the RFM simulations.

Table 0.3 Waipu Design Raindepths, climate change factor (CC factor) and ARF

Location	100yrs (without climate change)				100yrs with climate change				
	2h	6h	12h	24h	CC factor	2h	6h	12h	24h
R21	90.7	148.6	202.9	277.0	1.168	105.9	173.6	237.0	323.5
R22	90.8	149.3	204.4	279.7	1.168	106.1	174.4	238.7	326.7
R23	90.4	151.8	210.6	292.1	1.168	105.6	177.3	246.0	341.2
R24	95.6	164.0	230.5	324.0	1.168	111.7	191.6	269.2	378.4
ARF	0.7	0.812	0.842	0.853		0.746	0.812	0.842	0.853
R21	67.7	120.7	170.9	236.4	1.168	79.0	141.0	199.6	276.1
R22	67.7	121.3	172.1	238.7	1.168	79.1	141.6	201.1	278.8
R23	67.4	123.3	177.4	249.3	1.168	78.8	144.0	207.2	291.2
R24	71.3	133.2	194.1	276.5	1.168	83.3	155.6	226.7	323.0
Average	68.5	124.6	178.6	250.2	1.168	80.1	145.5	208.6	292.3

Table 0.4 Paparoa Design Raindepths, climate change factor (CC factor) and ARF

Location	100yrs (without climate change)				100yrs with climate change				
	2h	6h	12h	24h	CC factor	2h	6h	12h	24h
R001	82.5	130.5	174.3	232.8	1.168	96.4	152.4	203.6	271.9
R002	84.4	135.1	181.8	244.6	1.168	98.6	157.8	212.3	285.7
R003	87.4	142.9	194.8	265.5	1.168	102.1	166.9	227.5	310.1
R004	89.4	148.1	203.5	279.7	1.168	104.4	173.0	237.7	326.7
ARF	0.830	0.923	0.942	0.961		0.830	0.923	0.942	0.961
R001	68.5	120.4	164.2	223.7	1.168	80.0	140.7	191.7	261.3
R002	70.1	124.7	171.2	235.0	1.168	81.8	145.6	200.0	274.5
R003	72.6	131.9	183.5	255.1	1.168	84.7	154.0	214.3	298.0
R004	74.2	136.7	191.7	268.8	1.168	86.7	159.6	223.9	313.9
Average	71.3	128.4	177.6	245.7	1.168	83.3	150.0	207.5	286.9

The Figure 0.1 and Figure 0.2 show a general scheme of the Waipu and Paparoa catchments and their drainage, and the rain polygons used for the RFM simulation.

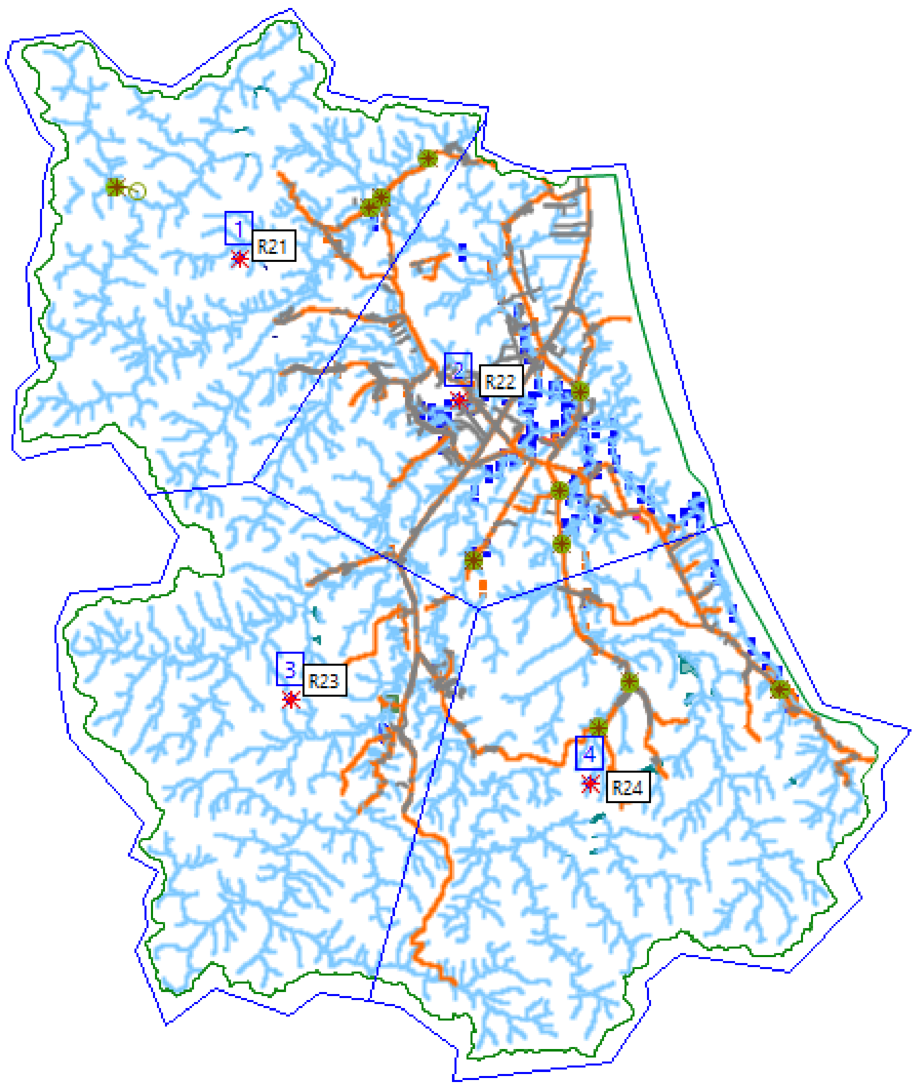


Figure 0.1 Waipu drainage and design rain polygons

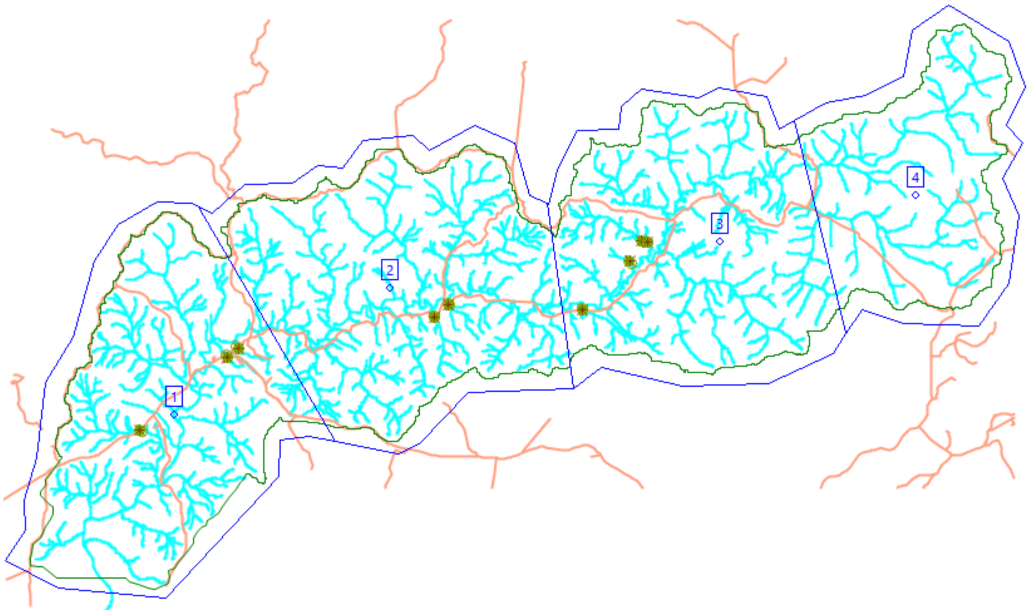


Figure 0.2 Paparoa drainage and design rain polygons

The Table 0.5 summarizes the most relevant parameters of the rain on cell model.

Table 0.5 Summary of Rapid Flood Modelling Parameters

Item	Waipu Catchment	Paparoa Catchment
Maximum Triangle Area, m2	100.0	5.0
Minimum element area, m2	2.0	3.0
Tidal condition	Marsden Pt, 2yrs + CC (0.5m), peak cte. WL=1.896 mOTP	Pouto Pt, 2yrs + CC (0.5m), peak cte. WL=2.736 mOTP
2D Roughness (Manning's n)	0.100	0.100
Number of triangles	7,744,583	2,319,883
Number of elements	6,405,126	1,959,992
2D Polygon Area, ha	22,926.26	4,597.00
Average element size, m2	35.8	23.5

Total number of culverts included at road crossings	13	9
Simulation time step (max value, adjustable, sec)	5.0	2.0
Simulation duration, hrs	24	24

As part of the modelling outputs, an estimation of the time of concentration is done based on the results of the first simulation (100yrs, no climate change, no abstractions). The relevant times of concentration are shown in Figure 0.3 and Figure 0.4.

Table 0.6 Waipu. Estimation of Time of Concentration (Tc)

Storm Dur	12	hrs			
Location	peak time (date/time)		Tp, hrs	Tc, hrs	WL, mRL
Rain	01/01/2001 08:10				
US Nova Scotia Br	01/01/2001 14:00		5.83	8.75	11.997
DS Nova Scotia Br	01/01/2001 14:10		6.00	9	6.482
Tide us	01/01/2001 14:35		6.42	9.625	5.008
Tide 2	01/01/2001 15:00		6.83	10.25	3.914
Tide ds	01/01/2001 15:35		7.42	11.125	4.914

Table 0.7 Paparoa. Estimation of Time of Concentration (Tc)

Storm Dur	6	hrs			
Location	peak time (date/time)		Tp, hrs	Tc, hrs	WL, mRL
Rain	01/01/2001 04:00				
P. Oakleigh Rd	01/01/2001 07:20		3.33	5	11.404
DS bridge	01/01/2001 07:50		3.83	5.75	5.845
Tide 02	01/01/2001 08:05		4.08	6.125	4.492
Tide 01	01/01/2001 08:35		4.58	6.875	3.539

It is then confirmed that a 6hrs storm is suitable for Paparoa catchment, and a 12 hr storm for the Waipu catchment. Model outputs and time of concentration shown in Figure 0.3 and Figure 0.4.

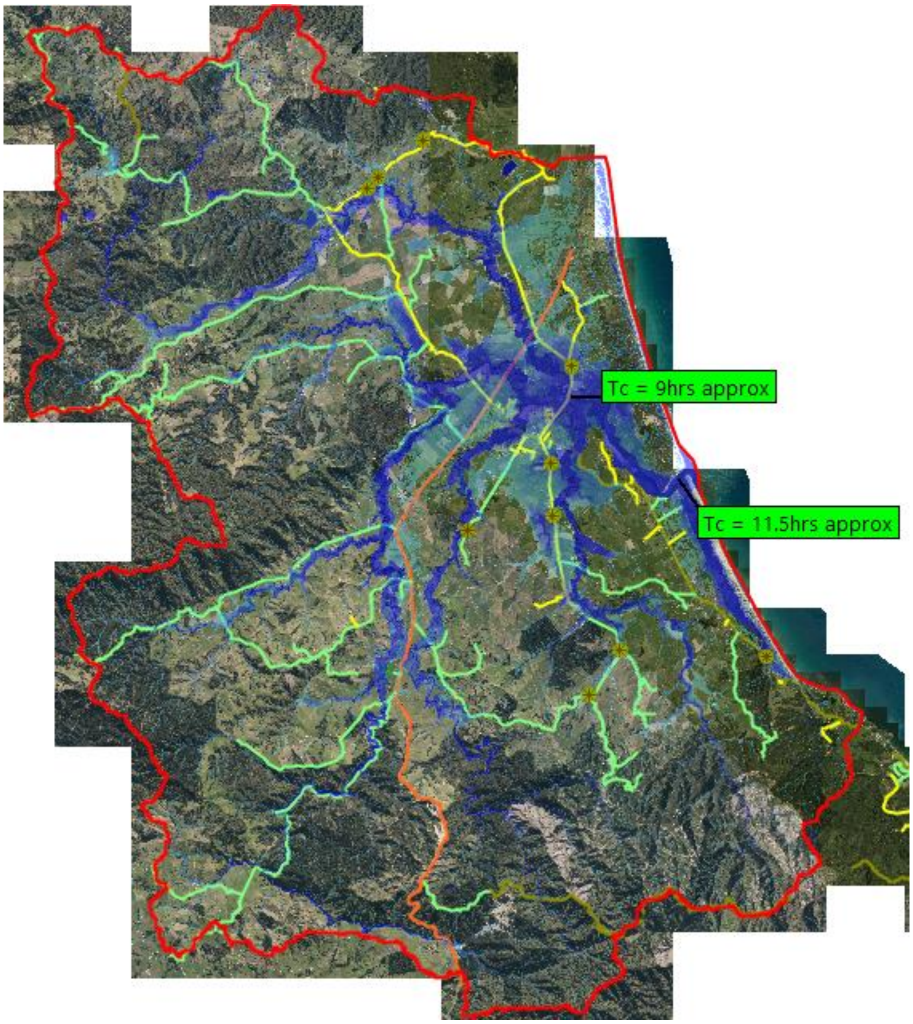


Figure 0.3 Waipu RFM outputs and Time of Concentration (Tc)

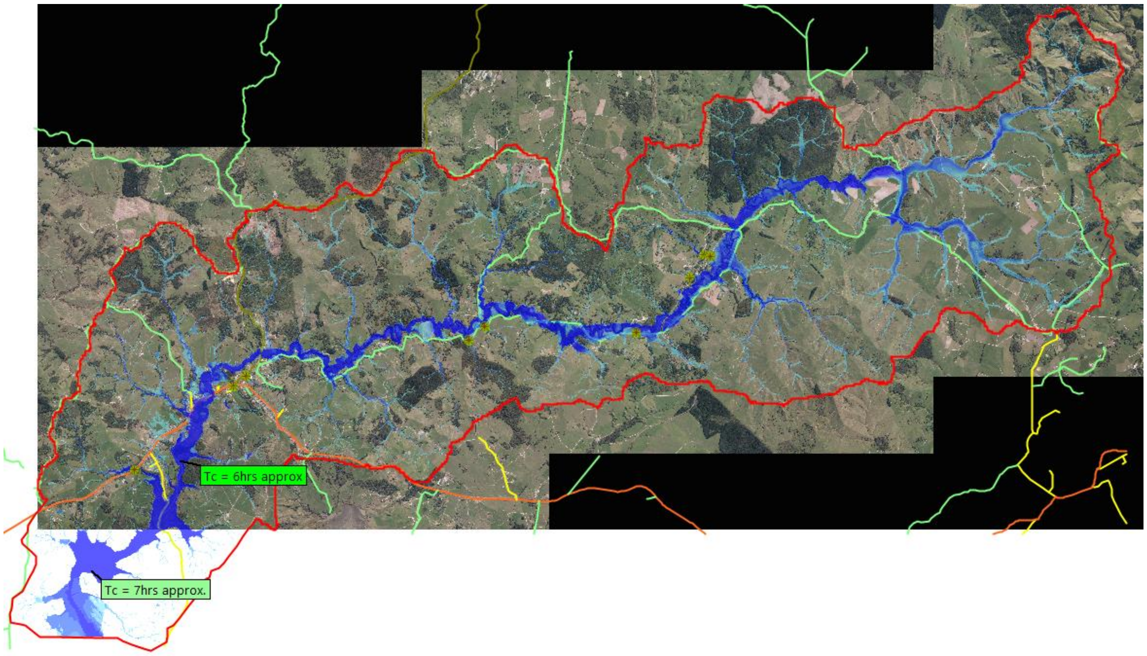


Figure 0.4 Paparoa RFM outputs and Time of Concentration (Tc)

The simulation matrix for the RFM is shown in Table 0.8. All simulations considered no abstractions, and the Priority Rivers rain profile provided by NRC.

Table 0.8 Simulation matrix. All simulations with no abstractions and NRC rain profile

Storm Duration	6hrs	12 hrs
Without Climate Change	Paparoa	Waipu/ Paparoa
With Climate Change	Paparoa	Waipu/ Paparoa

Figure 0.5 shows the NRC Priority Rivers rain profile. The example shows location *R21* for Waipu.

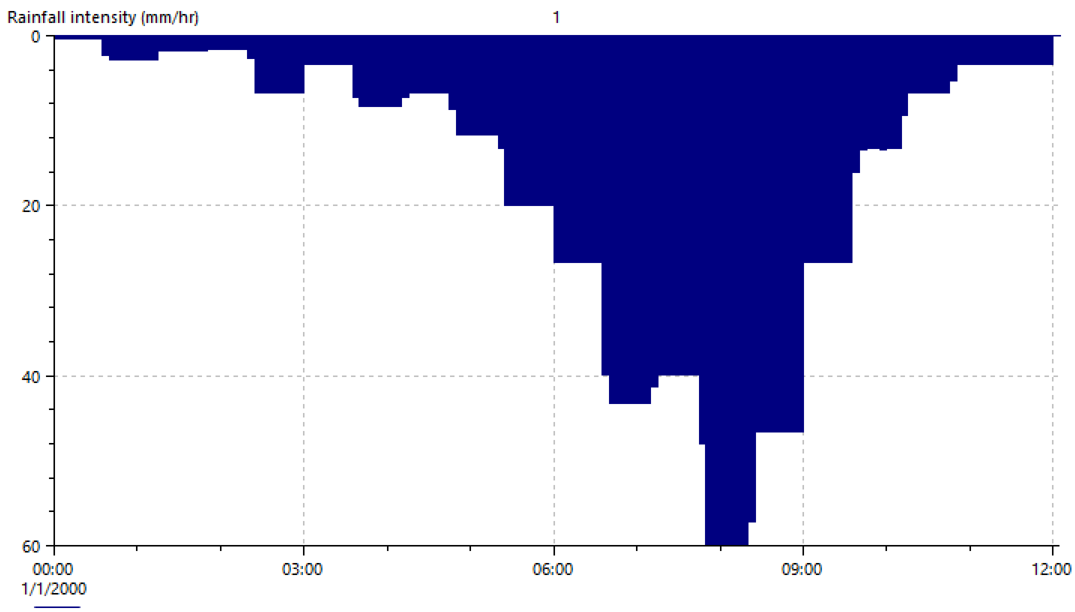


Figure 0.5 NRC Priority Rivers rain profile

MODEL EXTENT

GENERAL CRITERIA

The general criteria for the model extent are listed below:

- The hydraulic model extent shall cover at least the extent suggested by NRC, inside the Lidar extent.
- The hydrological model extent shall fit the hydraulic model extent and aim for sub-catchments no larger than 5% of total area.
- Relevant structures inside the hydraulic model extent to be included if they are surveyed. The relevancy of these was discussed with the client to decide whether are included or not.
- The final model extent is discussed and agreed with NRC prior to the model build end.

SUBCATCHMENT SIZE PARAMETERS

Table 0.9 summarized sub-catchment sizes for both, Waipu and Paparoa catchments.

Table 0.9 Summary of sub-catchment sizes after model schematization

	Subcatchment in Waipu		Subcatchment in Paparoa	
	Value	% of total area	Value	% of total area
Number of subcatchments	657		347	
Min area, m2	179	0.000079%	273	0.000588%
Max area, m2	9961334	4.4%	3683909	7.9%
Total area, m2	225364838	100%	46465310	100%

About Paparoa, there are 2 sub-catchments with an area larger than the 5% of the total Paparoa catchment area. These are U_001 and U_022, which are shown in Table 0.6. This figure also shows the preliminary 1D extent and the Lidar extent in the area. It is important to note that the sub-catchment size depends directly of the 1D and 2D model extent.

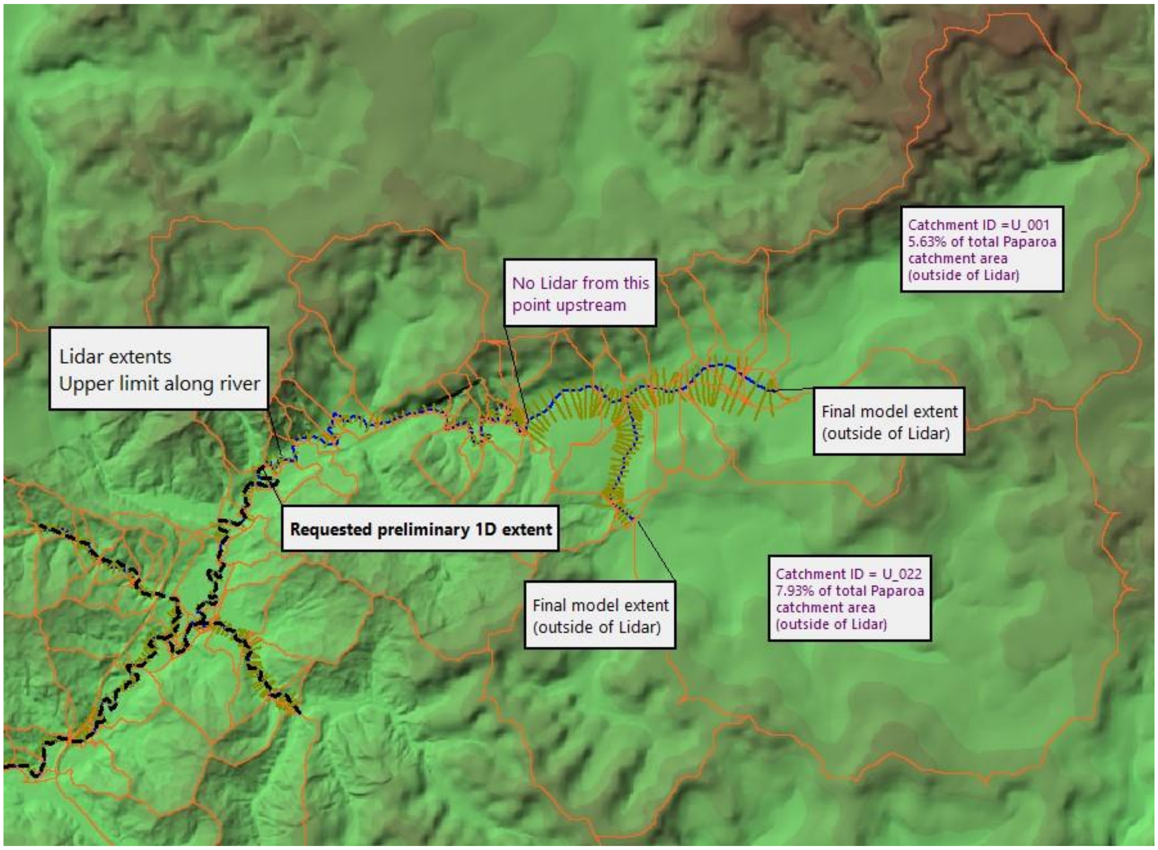


Figure 0.6 Paparoa upper catchment. Hydraulic and hydrological model extent

WAIPU

Figure 0.7 shows a broad view of the agreed model extent. The river model was extended further upstream of the Lidar boundary compared with the client suggested extent. The Lidar boundary is far from the upper catchment, implying large upper catchments for the hydrological model. In order to improve the quality of the runoff and routing times, the river model was extended using 20m contours data and an assumed channel geometry, so the sizes of the sub-catchments on Table 0.9 (section 0) could be achieved. The purpose of the hydraulic model outside of the Lidar is merely to provide a finer resolution to the hydrological model and improve the estimation of the runoff by accounting for the travel time, slopes and approximate river capacity on the 20m contour portion. An approximately total of 18.3km of river were added over the client suggested model extent, completing a river length of about 145km (details on Table 0.1 in section 0).

The 2D model extent is to cover the entire flooded plains inside the Lidar DEM as defined by the RFM results. This ensures a reliable description of the storage in the dynamic simulation. The total 2D areas total about 36km^2.

Bridges and culverts along the 1D extent are to be included, which were reviewed and agreed with the client before the model build was finalized. Other key structures inside the 2D domain were also included, such large culverts that are important for the drainage of the plains covered by the 2D mesh. The Waima reservoir was also included with its outlet structures as described by the survey data, photographs provided and site visit.

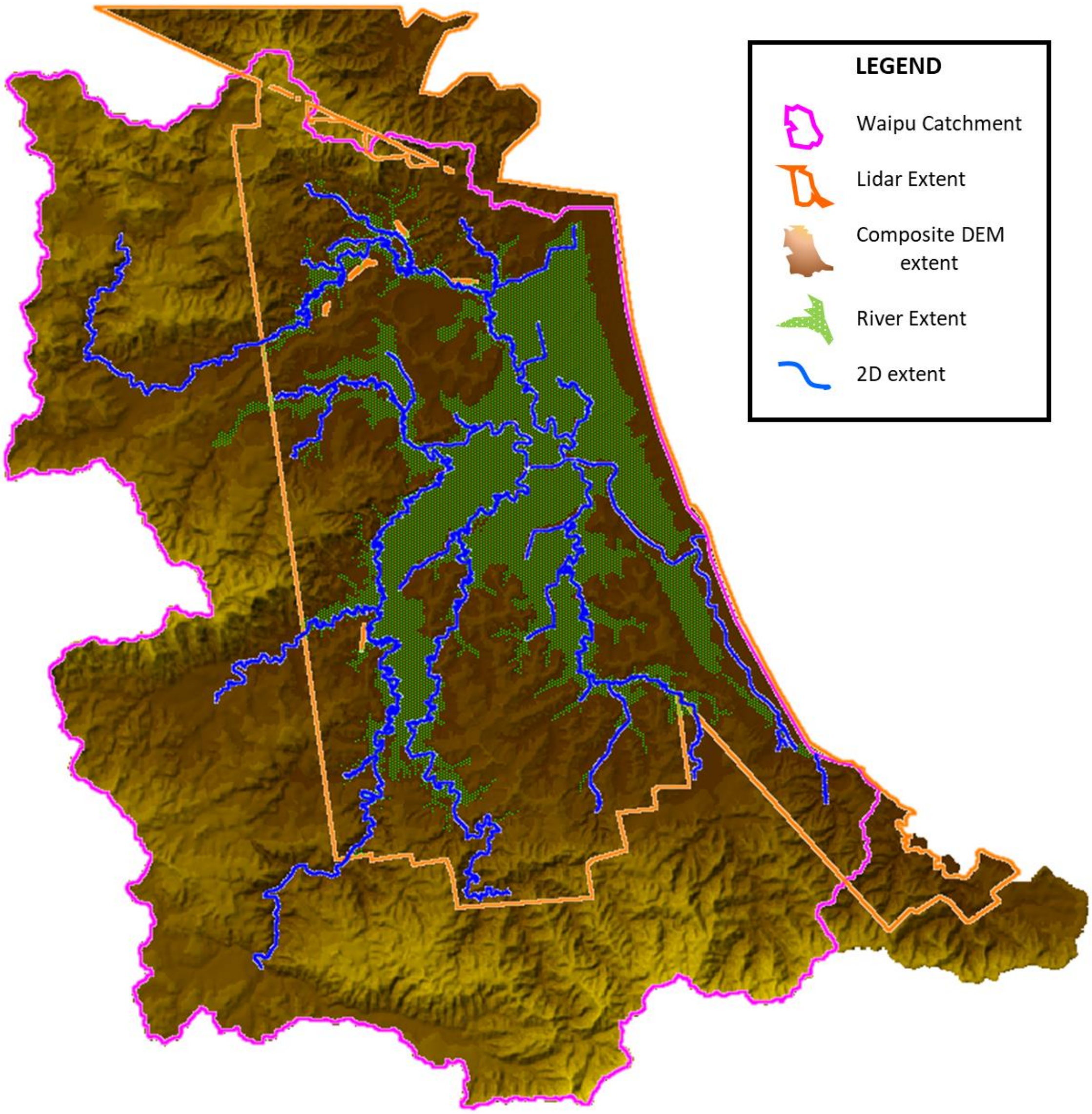


Figure 0.7 Waipu Catchment. General model extent, Lidar and composite DEM

PAPAROA

In similar fashion, Figure 0.8 shows a broad view of the agreed model extent. The criteria and general assumptions are the same than for Waipu. The model was also extended towards upstream inside the 20m contour DEM, as the catchment sizes were too large at the Lidar boundary. The river model was extended in 2 branches until the next large stream junction, so the hydrological resolution could be maximized with the minimum amount of assumption over the river portion. A total of approximately 2.9kms of river were extended outside the Lidar. In the case of Paparoa, 2 sub-catchments are larger than 5% of the total catchment area. In this case, the river model was not worth extending any further as the 20m contour data shows very flat areas which would be not well described in the hydraulic model with the available information (refer to Figure 0.6).

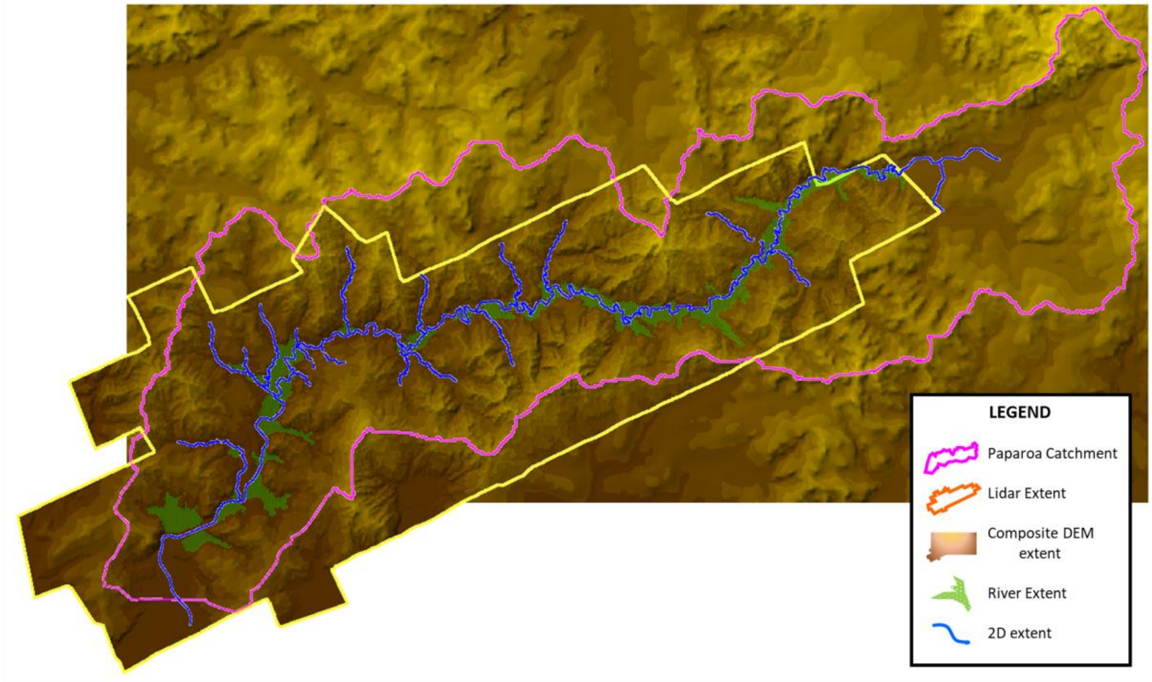


Figure 0.8 Paparoa Catchment. General model extent, Lidar and composite DEM

STORM SELECTION FOR CALIBRATION

OVERVIEW

Rain records provided by NRC were reviewed and analysed for maximum intensities, frequencies and durations, and assessed against the number of gauges available and data quality. There are 22 rain gauges available in the neighbourhood of the catchments. They are listed in Table 0.10.

Table 0.10 List of rain gauges near Paparoa and Waipu catchments

ID	Site_Name	Authority & type	Easting, m NZTM	Northing, m NZTM	Altitude, mOTP	Period	Open_Closed
S1	Ruakaka at Fosters	NRC manual	1732199	6028212	5	2000 -	Open
S2	Ahuroa at Sloanes	NRC manual	1723011	6028102	3	1969-1984	Closed
S3	Waikokopa at McDonnell Road	NRC Auto	1719360	6027698	200	2010-	Open
S4	Waiwarawara at Prescott	NRC manual	1727916	6025215	27	1980-2001	Closed
S5	Waiwarawara at Wilson's Dam	NRC Auto	1728099	6025886	60	2007-	Open
S6	Whangarei Harbour at Marsden Point Oil Refinery	NRC Auto	1734988	6033026	3	2016-	Open
S7	Manganui at Monymusk	NRC manual	1694270	6016138	20	1976	Open
S8	Manganui at Omana (Bull)	NRC manual	1685336	6024312	40	1981-1998	Closed
S9	Waikiekie	Met manual	1712733	6020874	107	1956-1977	Closed
S10	Taipuha ay Keay	NRC manual	1716238	6017689	40	1970-2007	Closed
S11	Taipuha at Settlement Rd	NRC manual	1717242	6015892	6	1963-1993	Closed
S12	Apple Cross Waipu	Met Auto	1726289	6022577	27	1954-1977	Closed
S13	Taipuha	Met manual	1715636	6015290	18	1948-1977	Closed
S14	Ahuroa at Finlayson Brook	NRC manual	1723548	6012708	31	1981-1996	Closed
S15	Waihoihoi at Glenmohr Rd	NRC manual	1729051	6010422	61	1969-2006	Closed
S16	Waihoihoi at Brynderwyn	NRC Auto	1727624	6010302	92	1981-	Open
S17	Waipu Cove	Met manual	1735139	6011350	61	1948-2009	Closed
S18	Paparoa 1	Met manual	1712520	6004236	30	1938-1970	Closed
S19	Paparoa 2	Met manual	1710989	6004255	28	1971-1994	Closed
S20	Paparoa at Higgins	NRC manual	1711072	6004082	10	1991-2003	Closed
S21	Paparoa at Maungaturoto	NRC Auto	1721626	6005201	116	2003-	Open
S22	Paparoa at Taylors	NRC Auto	1714086	6003156	90	2005-	Open

In the preliminary storm assessment, the following simplifications were done:

- All daily records assumed to be at 9am of actual recorded time.
- Daily gauges rainfall was split by the hour using the rain profile of the nearer auto gauge available.
- Displayed storm rain depths and intensities are an average of the surrounding gauges with available data (daily and auto gauges)

Table 0.11 summarized the findings, which allows to justify the selection of the calibration storms as Jul/1997, Mar/2007 and Jan/2011.

Table 0.11 Summary of Major Storm Available

No	1	2	3	4	5	6	Notes
Storm Event	**Mar 1995**	**Jul 1997**	**Jul 1998**	**Mar 2007**	**Jan 2011**	**Dec 2014**	
Max rainfall Day	30/03/1995	01/07/1997	26/07/1998	30/03/2007	29/01/2011	14/12/2014	
Rain Duration (h)	17	23	45	41	17	18	Rainfall > = 0.5mm
Max Daily Rainfall (mm)	112.4	134.8	103.9	154.8	197.6	78.2	Approx. 9am - 9am actual reading time. Average Rainfall
ARI (y)	2~5	5~10	2~5	5~10	10~20	<1.58	Based on Hirds V3
Max 1h Rainfall (mm)	36.5	64.4	11.8	28.3	27.9	14.2	Approx. average rainfall of all gauges
ARI (y)	5~10	80~100	<1.58	2~5	2~5	<1.58	Based on Hirds V3
Max 6h Rainfall (mm)	112.1	**161.2**	42.2	**91.2**	**145.1**	56.3	Approx. average rainfall of all gauges
ARI (y)	20~30	**>100**	<1.58	**10~20**	**80~100**	2~5	Based on Hirds V3
Max 12h Rainfall (mm)	138.6	**200.2**	61.3	**131.7**	**183.8**	74.9	Approx. average rainfall of all gauges
ARI (y)	10~20	**>100**	<1.58	**10~20**	**50~60**	2~5	Based on Hirds V3
Max 24h Rainfall (mm)	146.1	228.4	116.3	179.0	197.7	82.9	Approx. average rainfall of all gauges
ARI (y)	5~10	40~50	2~5	10~20	20~30	<1.58	Based on Hirds V3
Rain Gauges Available	9	8	7	5	7	7	Aauto and daily gauges
Auto Gauge	1	1	1	2	5	5	All records time at 9am NZST
Manual Gauge	8	7	6	3	2	2	Assumed record time is 9am NZST
Flow Data Available	4	4	4	4	4	4	All Gauge Rating Curves Available
Stage Data Available	3	4	4	4	4	4	
Flood Points Survey				34 FP for Waipu	7 FP for Paparoa		
Marsden Pt Tidal (Waipu)		Yes		Yes	Yes		
Poutu Pt Tidal (Paparoa)					Yes		
Calibration/Validation		**YES**		**YES**	**YES**		

Each calibration storm is reviewed in more detail in the following sections. They are shown in chronological order. General notes that apply to all events are described below.

When looking the daily gauges, the following assumptions are made, as advised by NRC.

- All daily gauges are, by default, read at 9am actual time (whether summer or winter hours). When daylight saving happens (from last Sunday of September), 2am becomes 3am. So, during daylight saving time, 9am it is actually 8am in NZST.
- All auto gauges (rainfall and flow/stage) should be recording in NZST (winter hours).

Table 0.12 shows the 3 selected calibration/validation events and its seasonal time to account for the daily records time of reading.

Table 0.12 Calibration storms and seasonal time

Jul/1997	Winter time (NZ Standard Time)
Mar/2007	Summer time (Daylight saving)
Jan/2011	Summer time (Daylight saving)

Based on the RFM outputs and discussion with NRC, Table 0.13 shows the storm durations to be used for each catchment.

Table 0.13 Duration for design storm at each catchment

Waipu Catchment	12hrs storm
Paparoa Catchment	6hrs storm

Following, an overview of each of the 3 selected storms for calibration.

STORM OF JULY 1997

The main rainfall happens between the 29/June/1997 and the 1/July/1997. Figure 0.9 shows the gauges available for this storm. There is essentially one auto gauge (S16) which can be used for the rain profile, and several other daily gauges to account for the spatial distribution of rain.

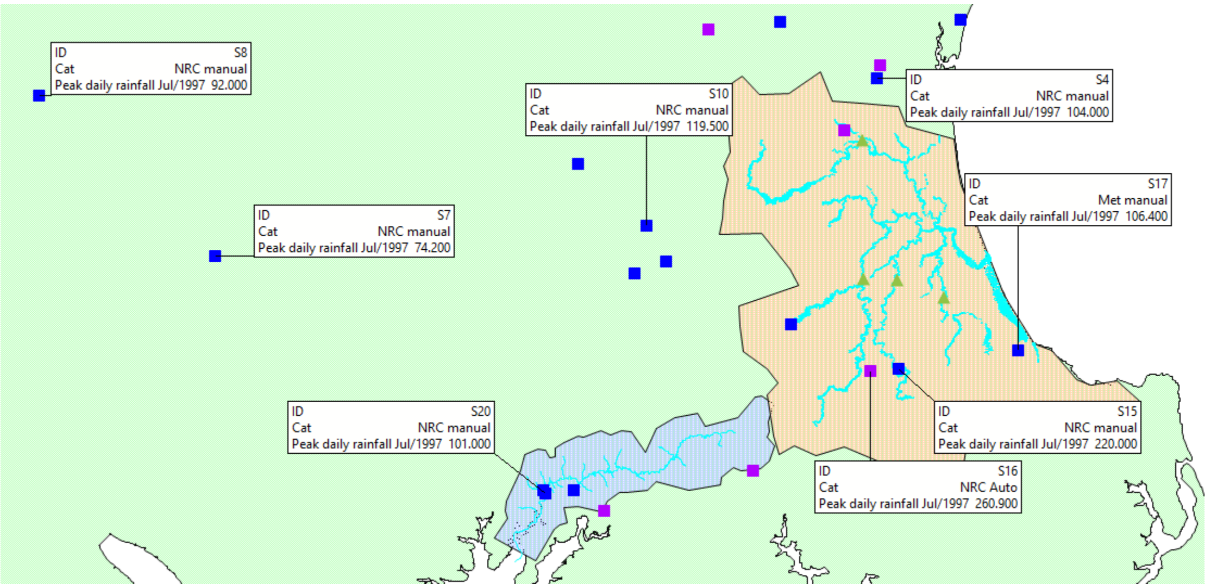


Figure 0.9 Gauges available for the storm of July 1997

The storm happened during the winter season, so the NZST should apply for all times of reading for daily and auto gauges, which is by default at 9am. Following, there are few graphs and technical notes regarding the quality of the data.

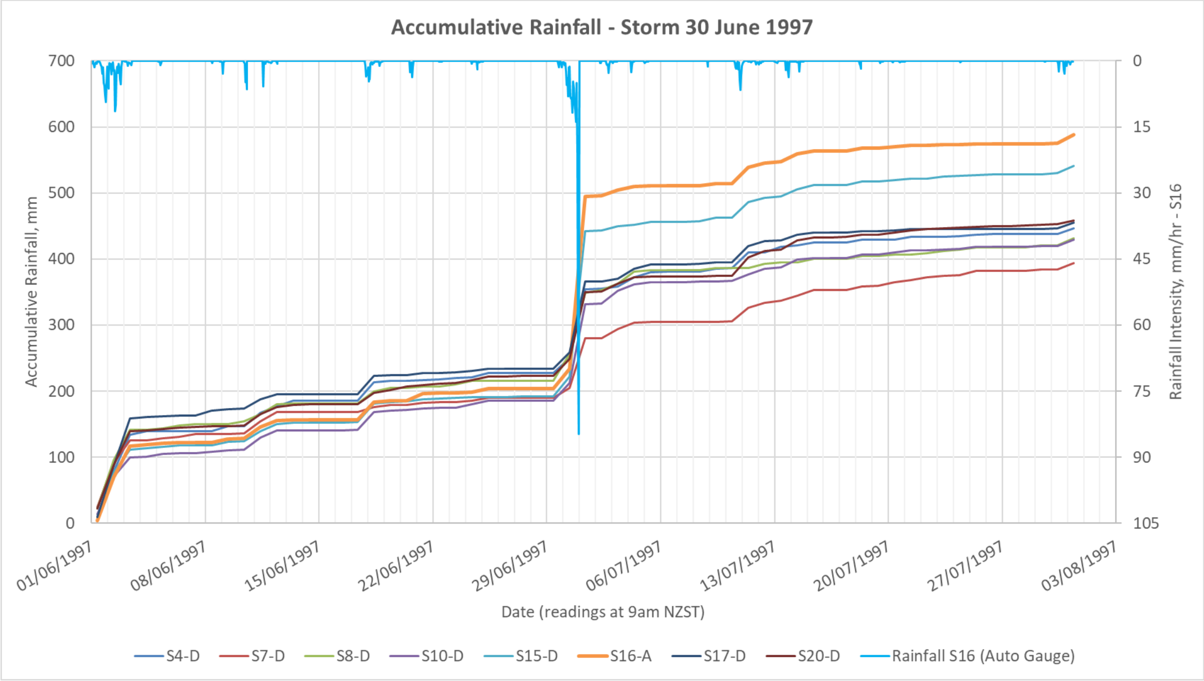


Figure 0.10 Accumulative Rainfall for the Storm of July/1997

The accumulative rainfall plot shown in Figure 0.10 looks consistent among all gauges (daily and auto). The graph shows the peak intensity happening during the 30/June/2011.

Table 0.14 Daily rainfall records for all gauges

Time (NZST)	S4-D	S7-D	S8-D	S10-D	S15-D	S16-A	S17-D	S20-D
Sat 28/Jun/1997	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00
Sun 29/Jun/1997	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.50
Mon 30/Jun/1997	22.30	15.70	40.50	27.00	29.50	30.00	25.00	25.00
Tue 01/Jul/1997	104.00	74.20	92.00	119.50	220.00	260.90	106.40	101.00
Wed 02/Jul/1997	1.00	0.00	5.00	1.00	1.00	2.00	0.50	1.50
Thu 03/Jul/1997	4.00	14.00	9.00	19.00	7.00	8.50	4.50	12.00
Fri 04/Jul/1997	14.00	9.70	19.00	10.00	1.50	4.50	14.60	9.00

Figure 0.9 and Table 0.14 provide a description of the spatial distribution of the storm. It shows stronger rainfall at the south of the Waipu catchment, with a rainfall more than double than the rest of Waipu and Paparoa catchments. It is noticeable that gauge S15 and S16 are relatively close to each other, however, with a difference of 40mm of rain.

This storm presents challenges to calibrate the peak time of the rainfall, as there is only one auto gauge for this storm, and the temporal distribution of the event might not be well represented. However, the only auto gauge available should be well positioned to describe the 3 southern flow gauges in the Waipu catchment.

Table 0.15 shows the maximum rain intensities for the relevant durations, using the only auto gauge available. It is possible to conclude that the peak intensities are well contained in one daily record, and that this should reduce the uncertainties related to the daily gauge reading time. The daily records shown in Table 0.14 are consistent with this conclusion, even though there might be still unknown variation on the peak times across the catchments.

Table 0.15 Peak intensities for auto gauge S16

Hrs	Item	Rainfall	From	To	Notes
1	Peak hourly	84.741	30/06/1997 22:00	30/06/1997 23:00	Fully contained in 1 daily record
6	Peak 6hrs rainfall	202.234	30/06/1997 17:00	30/06/1997 23:00	Fully contained in 1 daily record
12	Peak 12hrs rainfall	251.441	30/06/1997 11:00	30/06/1997 23:00	Fully contained in 1 daily record

Finally, following there are two graphs showing correlations between the accumulated rainfalls. These provide further details regarding the quality of the data.

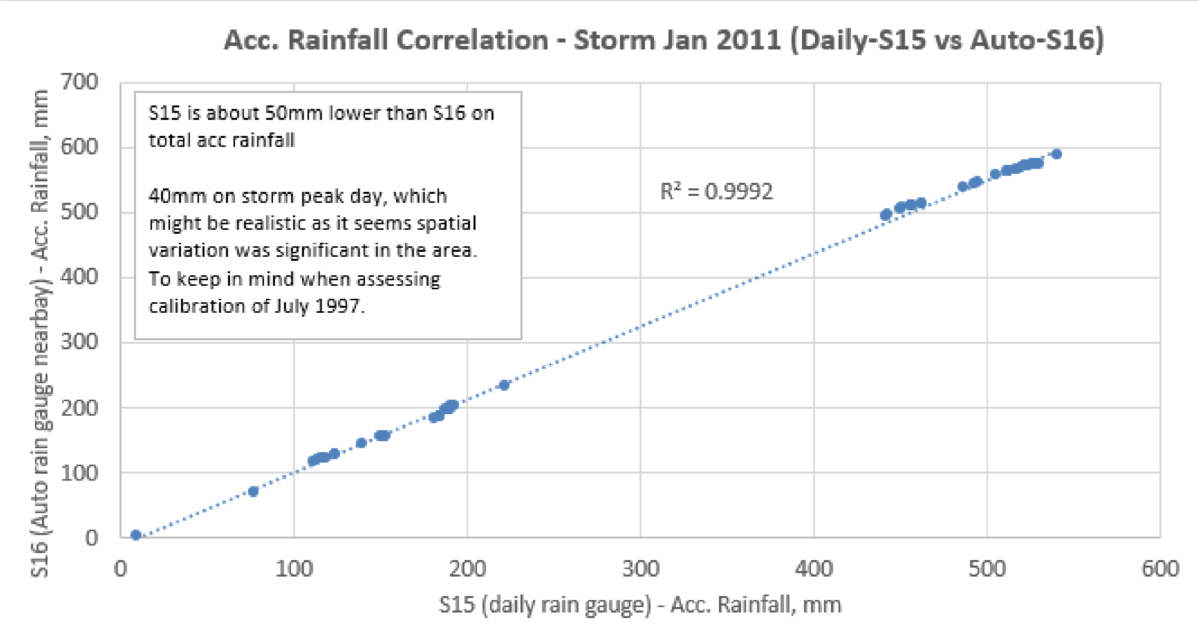


Figure 0.11 Accumulated Rainfall Correlation between S15 and S16

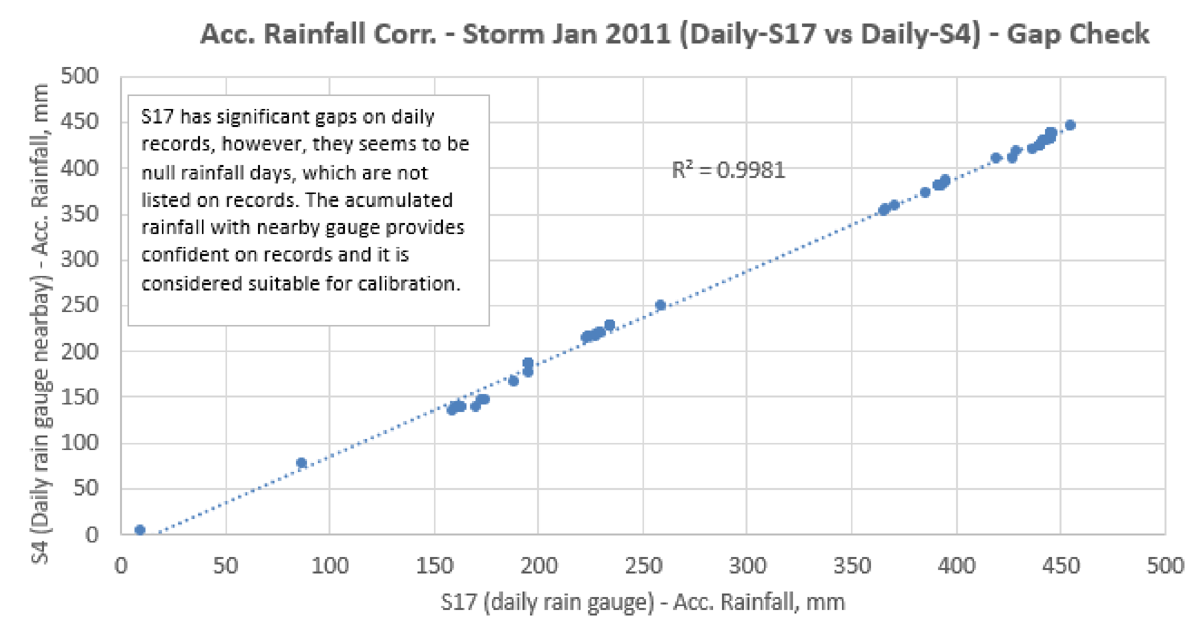


Figure 0.12 Accumulated Rainfall Correlation between S17 and S4

STORM OF MARCH 2007

The main rainfall happens between the 28/March/2007 and the 30/March/2007. Figure 0.13 shows the gauges available for this storm. There are two auto gauge (S16 and S21) which can be used for the rain profile, and three daily gauges to account for the spatial distribution.

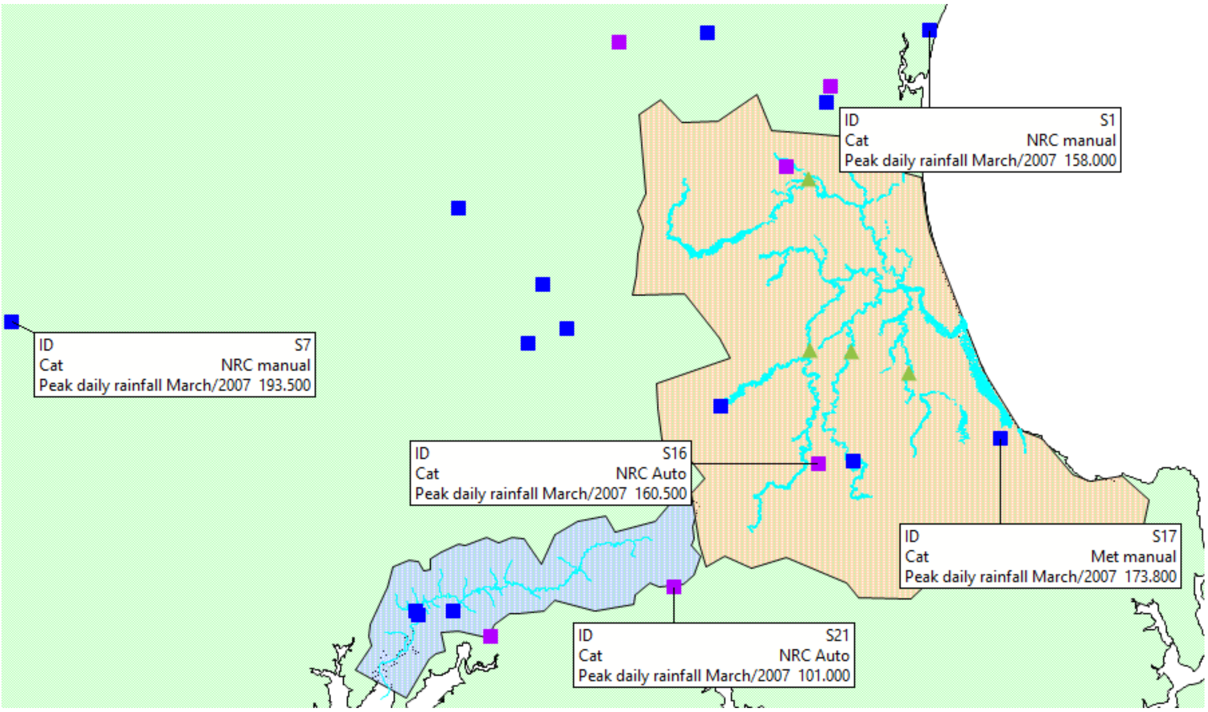


Figure 0.13 Gauges available for the storm of March 2007

The storm happened during the summer season, so the daily gauges should be considered at 8am NZST. For consistency, when comparing with the auto gauges, the daily rain will be calculated between 8am of each day.

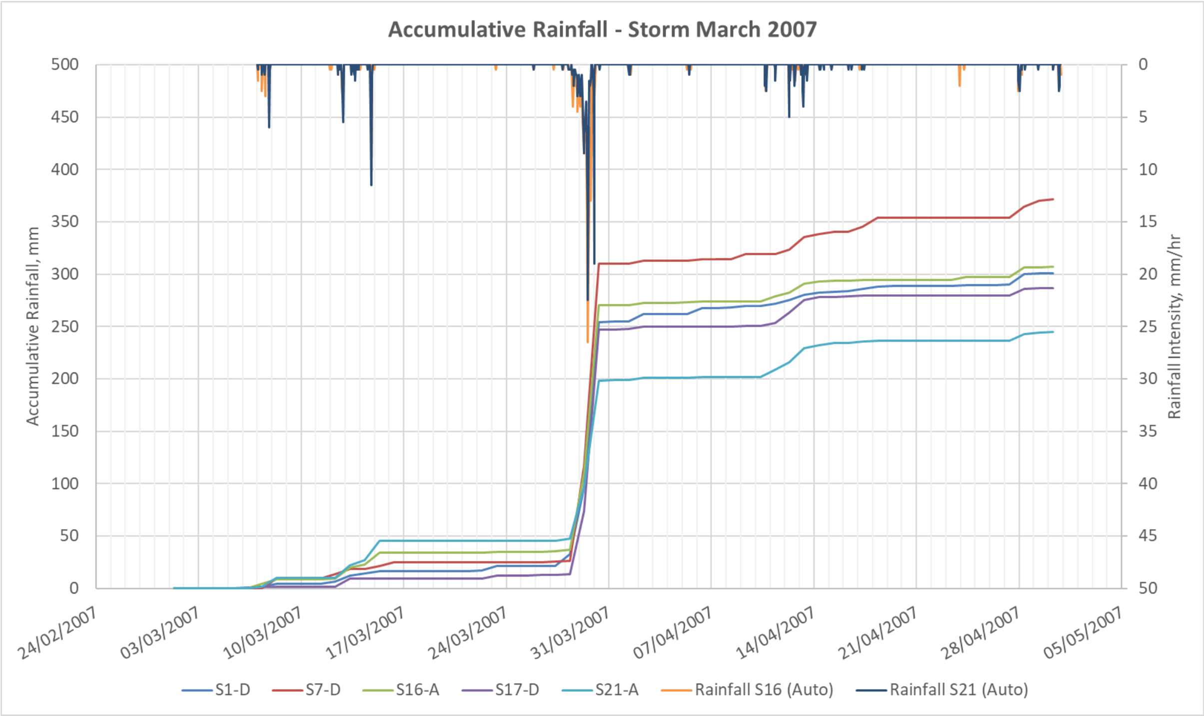


Figure 0.14 Accumulative Rainfall for the Storm of March/2007

The accumulative rainfall plot shown in Figure 0.14 looks consistent among all gauges (daily and auto). The graph shows the peak intensity happening during the 29/March/2011, with significant rain also happening the day before (before 8am of the day, which means a different daily record).

Table 0.16 Daily rainfall records for all gauges

Time (reading time NZST)	S1-D	S7-D	S16-A	S17-D	S21-A
26/03/2007 08:00:00	0.5	0.0	0.5	1.0	0.5
27/03/2007 08:00:00	0.0	1.0	0.5	0.0	0.0
28/03/2007 08:00:00	11.0	1.0	1.5	0.4	2.0
29/03/2007 08:00:00	63.5	90.0	72.5	60.0	49.5
30/03/2007 08:00:00	158.0	193.5	160.5	173.8	101.0
31/03/2007 08:00:00	0.5	0.0	0.0	0.0	0.5
01/04/2007 08:00:00	0.0	0.0	0.0	0.2	0.5

Table 0.17 Peak intensities for auto gauges S16 and S21

Gauge	Hrs	Item	Rainfall	From	To	Notes
S16	1	Peak hourly	26.500	29/03/2007 13:00	29/03/2007 14:00	Fully contained in 1 daily record
S16	6	Peak 6hrs rainfall	102.500	29/03/2007 11:00	29/03/2007 17:00	Fully contained in 1 daily record
S16	12	Peak 12hrs rainfall	149.500	29/03/2007 06:00	29/03/2007 18:00	Partially contaned in 2 daily records
S21	1	Peak hourly	22.500	29/03/2007 13:00	29/03/2007 14:00	Fully contained in 1 daily record
S21	6	Peak 6hrs rainfall	65.000	29/03/2007 09:00	29/03/2007 15:00	Fully contained in 1 daily record
S21	12	Peak 12hrs rainfall	96.000	29/03/2007 04:00	29/03/2007 16:00	Partially contaned in 2 daily records

Figure 0.13, Table 0.16 and Table 0.17 provide a description of the spatial and temporal distribution of the storm. The 6 hours peak intensity is well contained in a single daily gauge record (reading at 8am NZST). The 12hrs duration, which is relevant for Waipu catchment, is split in 2 daily gauge readings. It is also noticeable that the peak intensity happens during the same hour, and the general shape of the rain profiles for both gauges, S16 and S21, are similar, variating mainly the total rain depth which is significantly higher for S16. From the data available, it is not possible to accurately infer how the temporal distribution is changing, though, the instantaneous peak intensity (5 min) happens about 30minutes earlier in S21 (than S16), and 2hrs apart for 6hrs duration (Table 0.17). Since these gauges are relatively close to each other, the temporal variation might be important at farther extremes of the catchments. S16 should represent well the catchment of the 3 southern flow gauges, but the northern flow gauge might be too far to accurately represent the peak time property, with a possible challenging calibration. These aspects are kept in mind during the calibration stage.

STORM OF JANUARY 2011

The main rainfall happens between the 28/March/2007 and the 30/March/2007. The figure below shows the gauges available for this storm. There are five auto gauge which cover the entire modelling extent for both catchments, with no need to utilize any daily gauge. Additionally, there are 2 daily gauges to check for consistency. Out of the 3 calibration events, this one has the best spatial and temporal distribution.

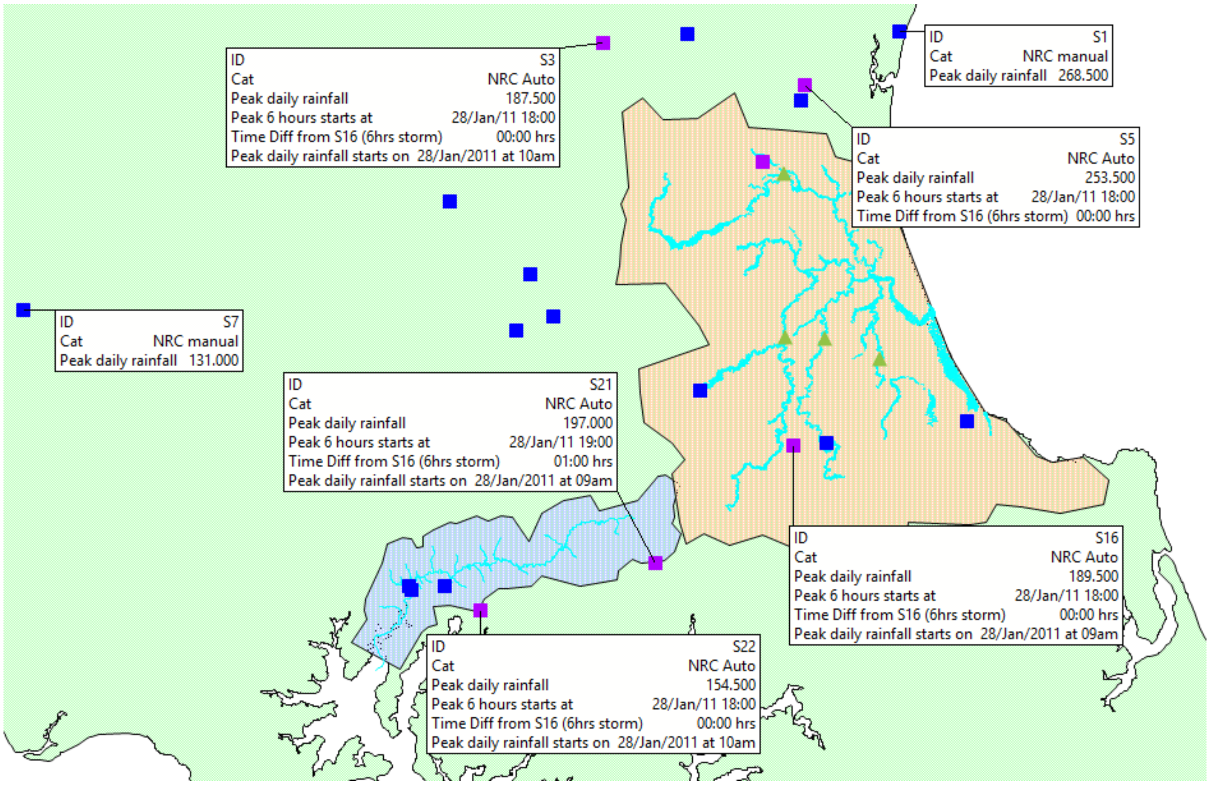


Figure 0.15 Gauges available for the storm of January 2011

The storm happened during the summer season, so the daily gauges should be considered at 8am NZST. For consistency, when comparing with the auto gauges, the daily rain will be calculated between 8am of each day.

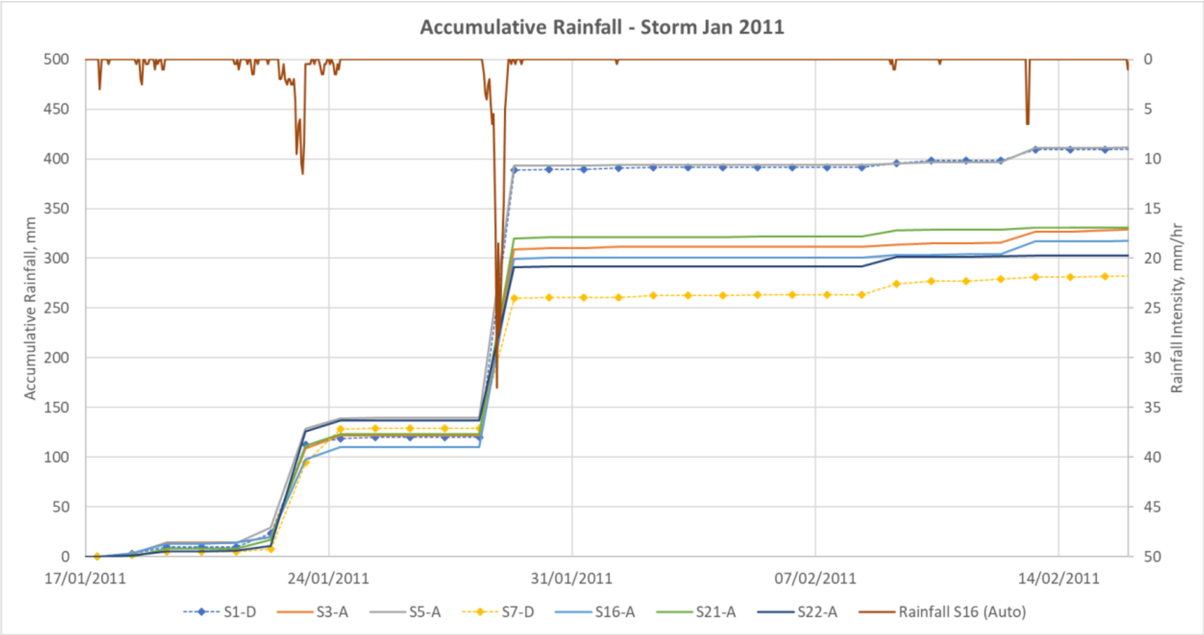


Figure 0.16 Accumulative Rainfall for the Storm of January 2011

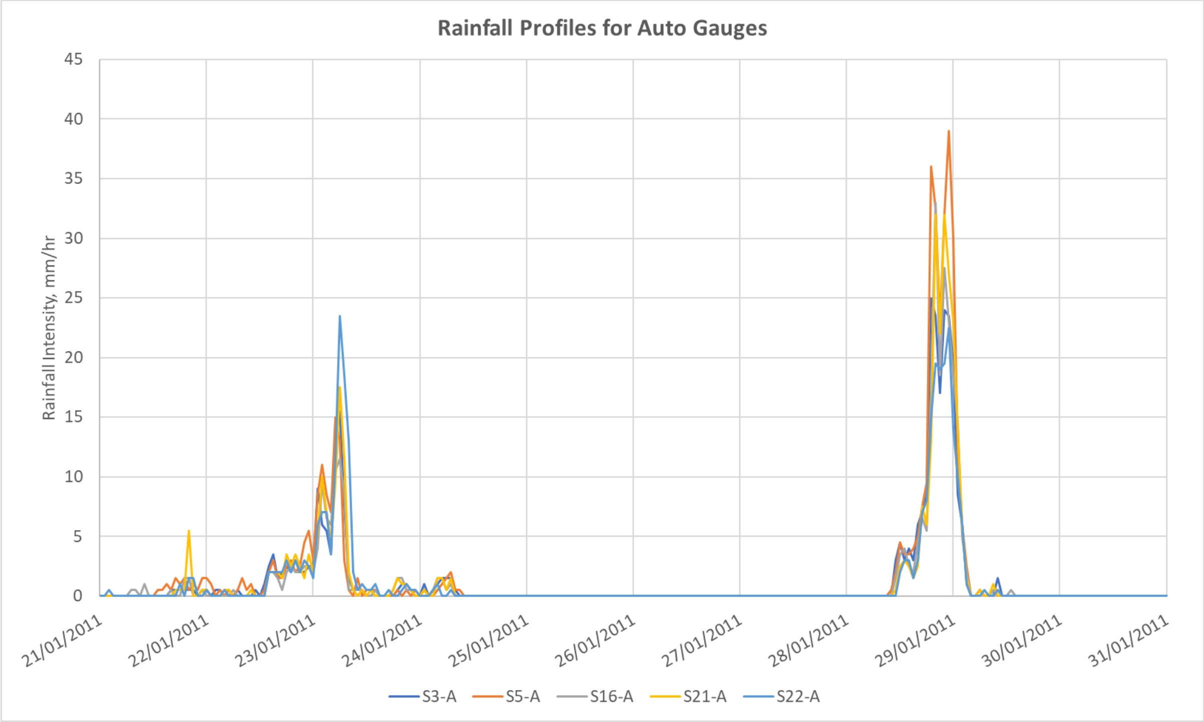


Figure 0.17 Rainfall Profile for Auto Gauges

Table 0.18 Daily rainfall records for all gauges

Time (NZST)	S1-D	S3-A	S5-A	S7-D	S16-A	S21-A	S22-A
Fri 21/Jan/2011 08:00:00	0.0	0.0	0.0	0.0	1.0	0.0	0.5
Sat 22/Jan/2011 08:00:00	13.5	5.5	15.5	2.5	5.5	9.0	5.0
Sun 23/Jan/2011 08:00:00	89.0	89.5	99.5	87.0	78.5	94.5	115.0
Mon 24/Jan/2011 08:00:00	6.5	12.5	10.5	34.0	12.0	11.5	10.5
Tue 25/Jan/2011 08:00:00	1.0	0.0	0.5	0.5	0.0	0.0	0.0
Wed 26/Jan/2011 08:00:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thu 27/Jan/2011 08:00:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fri 28/Jan/2011 08:00:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sat 29/Jan/2011 08:00:00	268.5	187.5	253.5	131.0	189.5	197.0	154.5
Sun 30/Jan/2011 08:00:00	1.0	1.5	0.5	0.5	1.0	1.0	0.5

Table 0.19 Peak intensities for auto gauges

Gauge	Duration	Item	Rainfall, mm	From	To	Notes
S3	5 min	5 min peak rain	7.5	07/01/2011 15:45	07/01/2011 15:50	Fully contained in 1 daily record
S3	1 hrs	Peak hourly	25.0	28/01/2011 18:00	28/01/2011 19:00	
S3	6 hrs	Peak 6hrs rainfall	132.5	28/01/2011 18:00	29/01/2011 00:00	
S3	12 hrs	Peak 12hrs rainfall	171.5	28/01/2011 14:00	29/01/2011 02:00	
S5	5 min	5 min peak rain	5.0	28/01/2011 21:55	28/01/2011 22:00	Fully contained in 1 daily record
S5	1 hrs	Peak hourly	39.0	28/01/2011 22:00	28/01/2011 23:00	
S5	6 hrs	Peak 6hrs rainfall	192.5	28/01/2011 18:00	29/01/2011 00:00	
S5	12 hrs	Peak 12hrs rainfall	236.5	28/01/2011 14:00	29/01/2011 02:00	
S16	5 min	5 min peak rain	5.0	28/01/2011 19:35	28/01/2011 19:40	Fully contained in 1 daily record
S16	1 hrs	Peak hourly	33.0	28/01/2011 19:00	28/01/2011 20:00	
S16	6 hrs	Peak 6hrs rainfall	137.5	28/01/2011 18:00	29/01/2011 00:00	
S16	12 hrs	Peak 12hrs rainfall	175.5	28/01/2011 15:00	29/01/2011 03:00	
S21	5 min	5 min peak rain	4.0	28/01/2011 19:50	28/01/2011 19:55	Fully contained in 1 daily record
S21	1 hrs	Peak hourly	32.0	28/01/2011 19:00	28/01/2011 20:00	
S21	6 hrs	Peak 6hrs rainfall	150.0	28/01/2011 19:00	29/01/2011 01:00	
S21	12 hrs	Peak 12hrs rainfall	186.5	28/01/2011 15:00	29/01/2011 03:00	
S22	5 min	5 min peak rain	3.5	23/01/2011 06:55	23/01/2011 07:00	Fully contained in 1 daily record
S22	1 hrs	Peak hourly	23.5	23/01/2011 05:00	23/01/2011 06:00	
S22	6 hrs	Peak 6hrs rainfall	109.5	28/01/2011 18:00	29/01/2011 00:00	
S22	12 hrs	Peak 12hrs rainfall	145.0	28/01/2011 14:00	29/01/2011 02:00	

Figure 0.16, Figure 0.17, Table 0.18 and Table 0.19 show different aspect of the recorded rain data. Based on those it can be concluded:

- Spatial distribution is significant over the whole catchments, but generally well described by the auto gauges
- Daily gauges are not required for modelling, though they were used to gain confident on data.
- Temporal distribution is between one hour, and generally well described by the auto gauges.
- The storm happens during summer season, with a significant rainfall happening about 6 days prior the main storm.
- The rainfall profile is generally similar for all gauges.

DESIGN EVENTS

Section 0 described the RFM outputs and findings. From that analysis it is confirmed that the most suitable storm duration for the design events if 12hrs for Waipu and 6hrs for Paparoa. The rain depths for those durations is extracted for all sub-catchments centroids defined in the hydrological model extent for each catchment (details in section 0), providing a good rain resolution over the catchments.

The non-linear reservoir, as its name describes, is a non-linear transformation, for which the ARF can only be applied over the rain depth of each sub-catchment. There are 657 sub-catchments for Waipu and 347 sub-catchments for Paparoa. To avoid having an excessive amount of rain time series with marginal additional benefit, a limited number of classes has been defined for each. Each class considers an ARF and a spatial distribution factor (SDF) based on the HirdsV3 rain distribution over each catchment for what a factor of 1 refers to the average rain depth defined over the entire catchment. Details of these series are shown in Table 0.20 and Table 0.21.

The rain depth is distributed over the NRC rain profile provided (Figure 0.2) for the respective catchment storm duration.

Table 0.20 Rain series details for Waipu model

WAIPU CATCHMENT Rain depth defined in model, with respective areal reduction factor (ARF) and spatial distribution factors (SDF)						
			Design rain depth, 12 hours duration storm (mm)			
Event ID name	**ARF**	**SDF**	**10yrs**	**50yrs**	**100yrs**	**100yrsCC**
Design_Rain_ARF=0.842_fc=0.92	0.842	0.92	93.2	140.0	166.2	194.2
Design_Rain_ARF=0.842_fc=0.93	0.842	0.93	94.2	141.5	168.1	196.3
Design_Rain_ARF=0.842_fc=0.94	0.842	0.94	95.3	143.0	169.9	198.4
Design_Rain_ARF=0.842_fc=0.95	0.842	0.95	96.3	144.5	171.7	200.5
Design_Rain_ARF=0.842_fc=0.96	0.842	0.96	97.3	146.1	173.5	202.6
Design_Rain_ARF=0.842_fc=0.97	0.842	0.97	98.3	147.6	175.3	204.7
Design_Rain_ARF=0.842_fc=0.98	0.842	0.98	99.3	149.1	177.1	206.8

Design_Rain_ARF=0.842_fc=0.99	0.842	0.99	100.3	150.6	178.9	208.9
Design_Rain_ARF=0.842_fc=1.00	0.842	1.00	101.3	152.2	180.7	211.1
Design_Rain_ARF=0.842_fc=1.01	0.842	1.01	102.3	153.7	182.5	213.2
Design_Rain_ARF=0.842_fc=1.02	0.842	1.02	103.4	155.2	184.3	215.3
Design_Rain_ARF=0.842_fc=1.03	0.842	1.03	104.4	156.7	186.1	217.4
Design_Rain_ARF=0.842_fc=1.04	0.842	1.04	105.4	158.2	187.9	219.5
Design_Rain_ARF=0.842_fc=1.05	0.842	1.05	106.4	159.8	189.7	221.6
Design_Rain_ARF=0.842_fc=1.06	0.842	1.06	107.4	161.3	191.5	223.7
Design_Rain_ARF=0.842_fc=1.07	0.842	1.07	108.4	162.8	193.4	225.8
Design_Rain_ARF=0.842_fc=1.08	0.842	1.08	109.4	164.3	195.2	227.9
Design_Rain_ARF=0.842_fc=1.09	0.842	1.09	110.5	165.8	197.0	230.1
Design_Rain_ARF=0.842_fc=1.10	0.842	1.10	111.5	167.4	198.8	232.2
Design_Rain_ARF=0.842_fc=1.11	0.842	1.11	112.5	168.9	200.6	234.3
Design_Rain_ARF=0.842_fc=1.12	0.842	1.12	113.5	170.4	202.4	236.4
Design_Rain_ARF=0.842_fc=1.13	0.842	1.13	114.5	171.9	204.2	238.5
Design_Rain_ARF=0.842_fc=1.14	0.842	1.14	115.5	173.5	206.0	240.6
Design_Rain_ARF=0.842_fc=1.15	0.842	1.15	116.5	175.0	207.8	242.7
Design_Rain_ARF=0.842_fc=1.16	0.842	1.16	117.5	176.5	209.6	244.8

Table 0.21 Rain series details for Paparoa model

PAPAROA CATCHMENT Rain depth defined in model, with respective areal reduction factor (ARF) and spatial distribution factors (SDF)						
Event ID name	ARF	SDF	Design rain depth, 6 hours duration storm (mm)			
			10yrs	50yrs	100yrs	100yrsCC
Design_Rain_ARF=0.842_fc=0.92	0.923	0.92	66.1	98.9	117.3	137.0
Design_Rain_ARF=0.842_fc=0.93	0.923	0.93	66.8	100.0	118.5	138.4
Design_Rain_ARF=0.842_fc=0.94	0.923	0.94	67.5	101.0	119.8	139.9
Design_Rain_ARF=0.842_fc=0.95	0.923	0.95	68.3	102.1	121.1	141.4
Design_Rain_ARF=0.842_fc=0.96	0.923	0.96	69.0	103.2	122.4	142.9
Design_Rain_ARF=0.842_fc=0.97	0.923	0.97	69.7	104.3	123.6	144.4
Design_Rain_ARF=0.842_fc=0.98	0.923	0.98	70.4	105.3	124.9	145.9
Design_Rain_ARF=0.842_fc=0.99	0.923	0.99	71.1	106.4	126.2	147.4
Design_Rain_ARF=0.842_fc=1.00	0.923	1.00	71.8	107.5	127.5	148.9
Design_Rain_ARF=0.842_fc=1.01	0.923	1.01	72.6	108.6	128.7	150.4
Design_Rain_ARF=0.842_fc=1.02	0.923	1.02	73.3	109.6	130.0	151.8
Design_Rain_ARF=0.842_fc=1.03	0.923	1.03	74.0	110.7	131.3	153.3
Design_Rain_ARF=0.842_fc=1.04	0.923	1.04	74.7	111.8	132.6	154.8
Design_Rain_ARF=0.842_fc=1.05	0.923	1.05	75.4	112.9	133.8	156.3
Design_Rain_ARF=0.842_fc=1.06	0.923	1.06	76.2	113.9	135.1	157.8
Design_Rain_ARF=0.842_fc=1.07	0.923	1.07	76.9	115.0	136.4	159.3
Design_Rain_ARF=0.842_fc=1.08	0.923	1.08	77.6	116.1	137.7	160.8

Design_Rain_ARF=0.842_fc=1.09	0.923	1.09	78.3	117.2	138.9	162.3

MODEL BUILD

SURVEY AND LIDAR MODIFICATIONS

1m Lidar information looks reliable and with sufficient detail to describe the flow and storage capacities of the river basins and flood plains. However, it is not sufficient to describe the river bottom, which is blinded by the water surface.

The river survey has sufficient detail for the river bottom, but not enough coverage to describe the river solely by the survey. For that reason, the survey data and Lidar were combined in GIS to burn the river bottom level into the 1m grid based on Lidar. The main criteria are listed below:

- River survey replaces Lidar for the low flow portions. The low flow is described primarily by the edge of the water surface described by the Lidar.
- In between survey cross sections, the long profile is interpolated by following the same long profile of the Lidar.
- This exercise if done for all portions which have river data, which is primarily the main rivers and lower catchment basins.
- For other areas, the lidar was kept unchanged, and in some cases a small channel was burn (typically no deeper than 0.5m).

Figure 0.1 shows an example of the outcomes of this process. A typical long profile composed by survey and Lidar cross sections would show unrealistic ups and downs in the river bottom. The main gain of combining the survey and Lidar in this way it is a more realistic long profile of the river, and a better description of the flow capacity, especially for low flows and areas where the missing flow area is significant (such tidal zones). This exercise leads to various considerations and benefits:

- The calibration of the lower range of the rating curve was significantly improved by modifications of the river bottom. The modifications consider mainly the method explained above, though, as part of the calibration process, the rating curves required some additionally modifications to account for obstructions (particularly North at Applecross and Waihoihoi at St. Mary's Rd).
- River bottoms tend to go deeper at contractions (such bridges). This require further considerations when processing the survey to choose what would be the most realist interpolated long profile. These aspects also support the modifications done near the flow/stage gauges to calibrate the lower flows of the rating curves.
- Changes on the river bottom in the last few kilometres (4-5kms) of the river and at the river mouth are of significant impact on the drainage of the low plains. This was found to be critical in the calibration of some events. This is described further in this document with the calibration results.

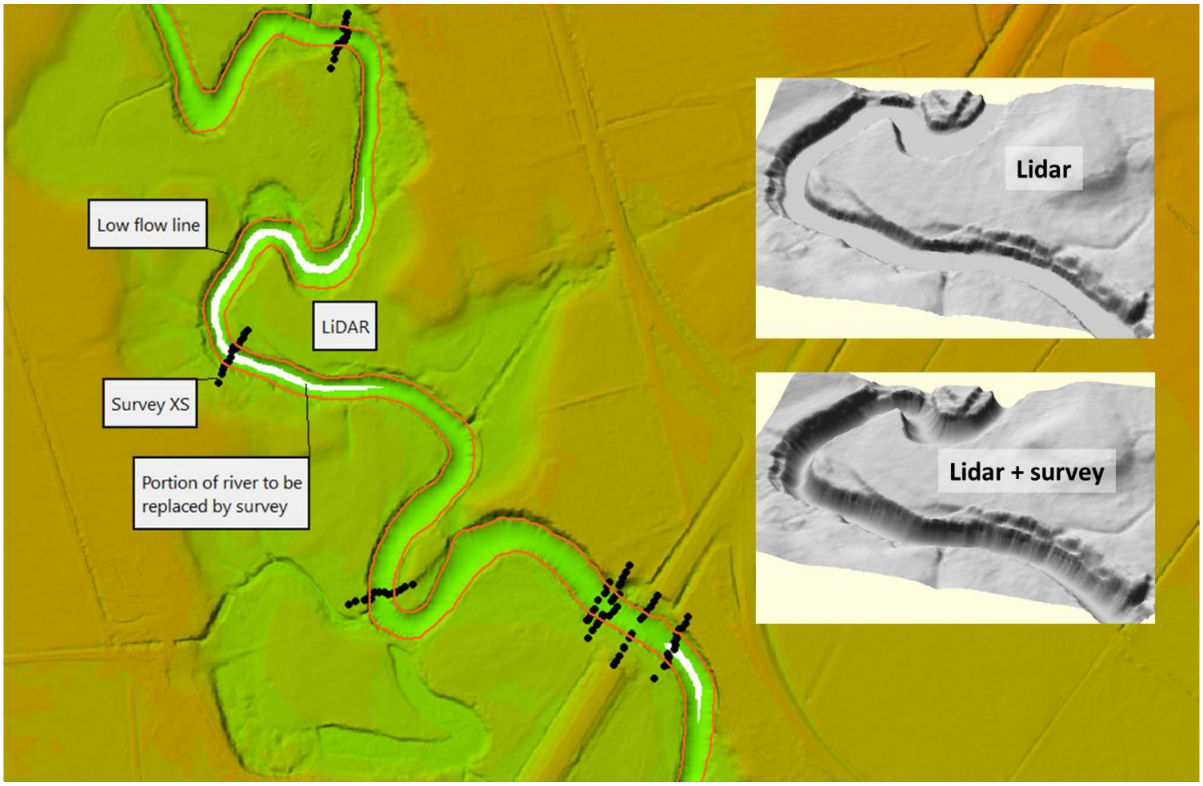


Figure 0.1 Waipu. Survey DEM burn. Example.

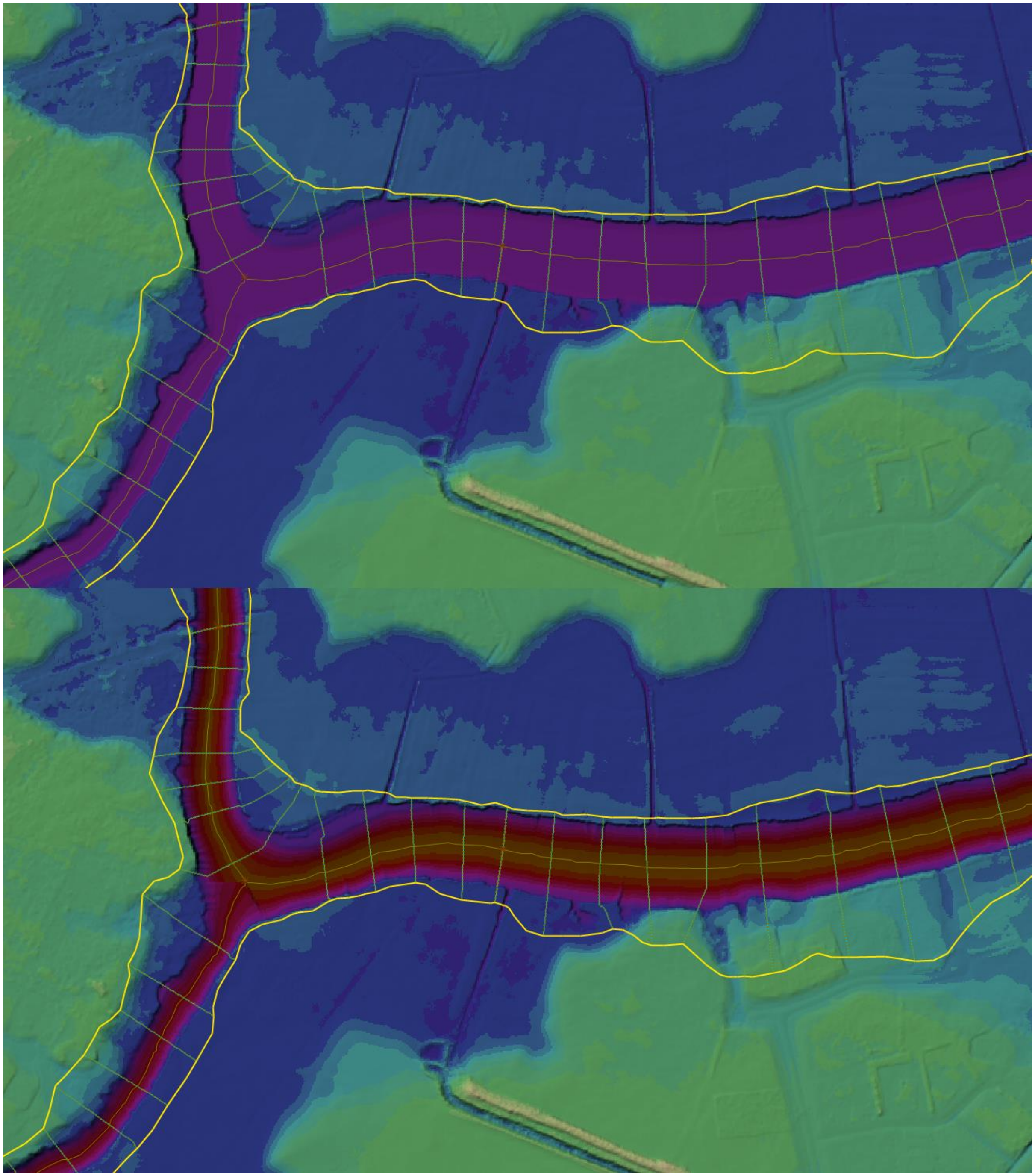


Figure 0.2 Waipu. Survey DEM burn. Example.

There were also a few gaps in the Lidar along the main model extent, in-between Lidar, where the 20m contour was not suitable for detail modelling. In those cases, some assumptions were done to fill those gaps with interpolated lines between the known portions, filling gaps at flood plains and main rivers over the hydraulic model extent. The assumption generally considers linear interpolation of features, such river banks, river bottom or other features than can be seen from Lidar or aerial photograph. Even though the quality of the interpolation looks reliable, the information is not real, and those areas were filled for modelling purposes only to account for the hydraulic conveyance and storage capacity; they are not suitable for mapping. The three locations are shown in Figure 0.3, Figure 0.4 and Figure 0.5.

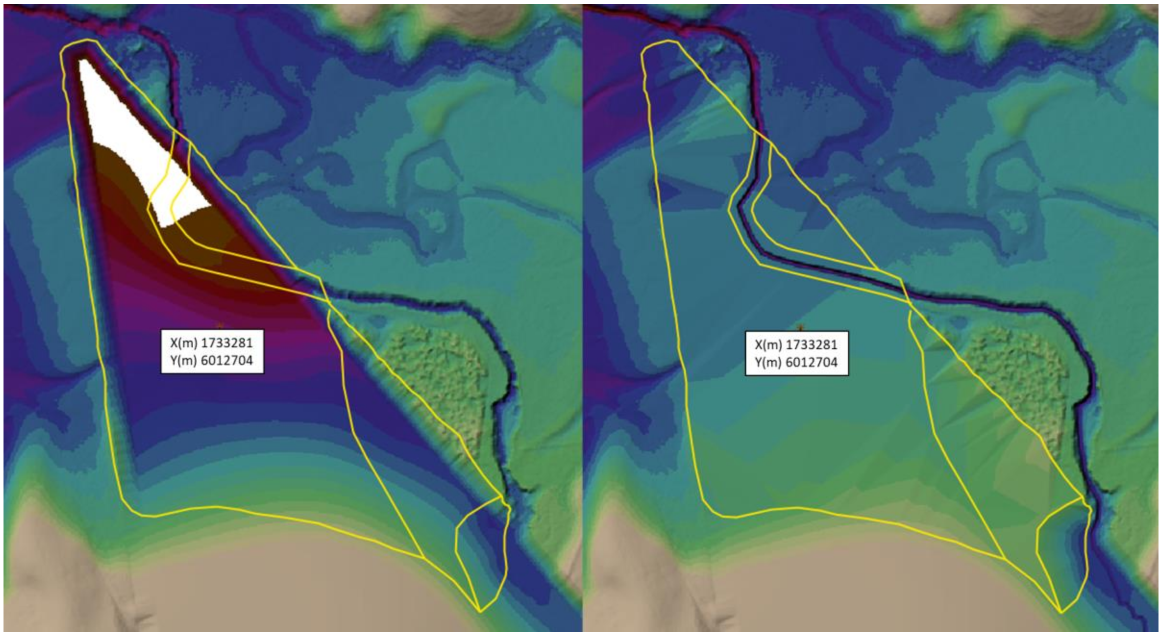


Figure 0.3 Waipu 1st Lidar gap interpolation (assumptions)

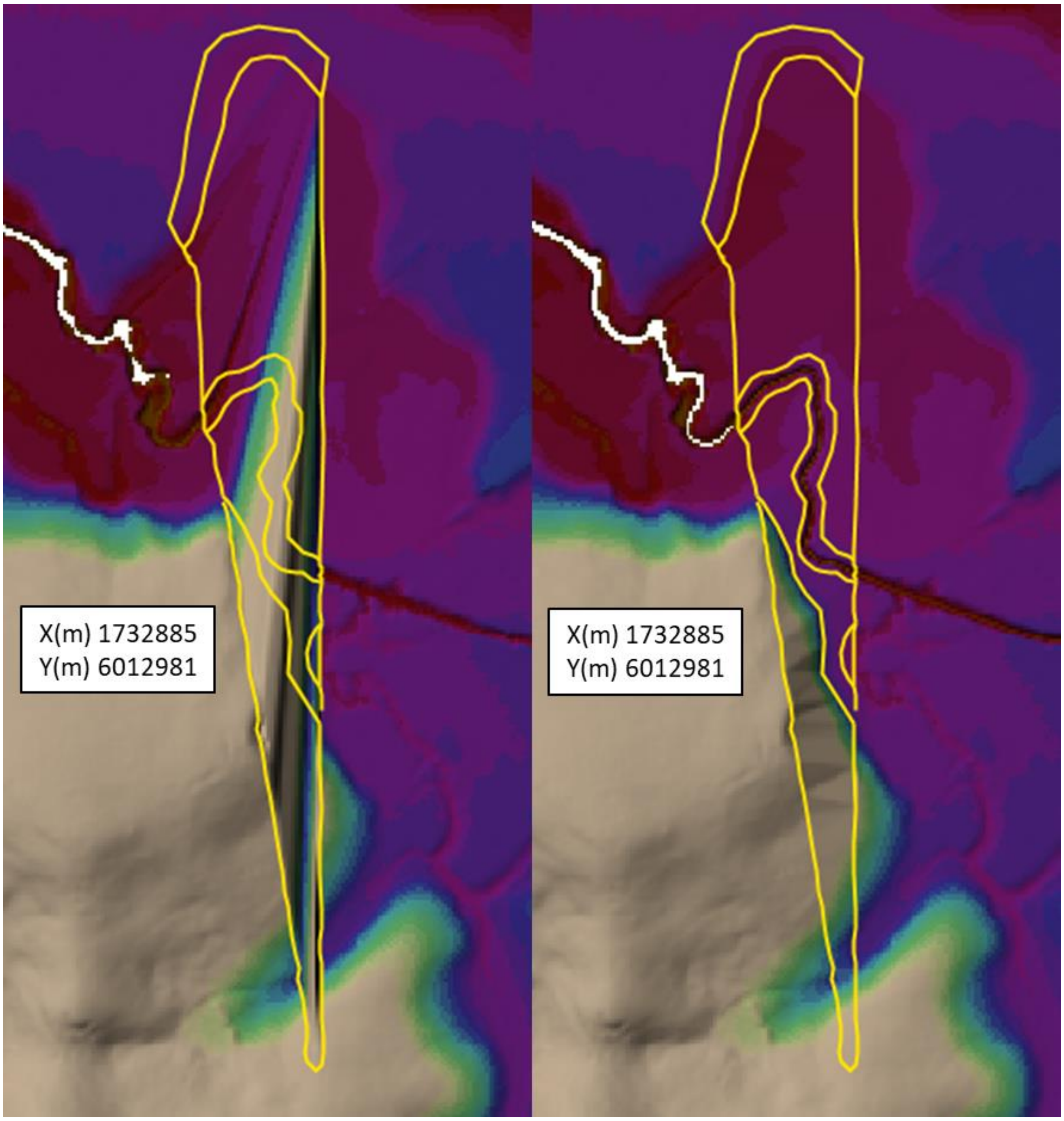


Figure 0.4 Waipu 2nd Lidar gap interpolation (assumptions)

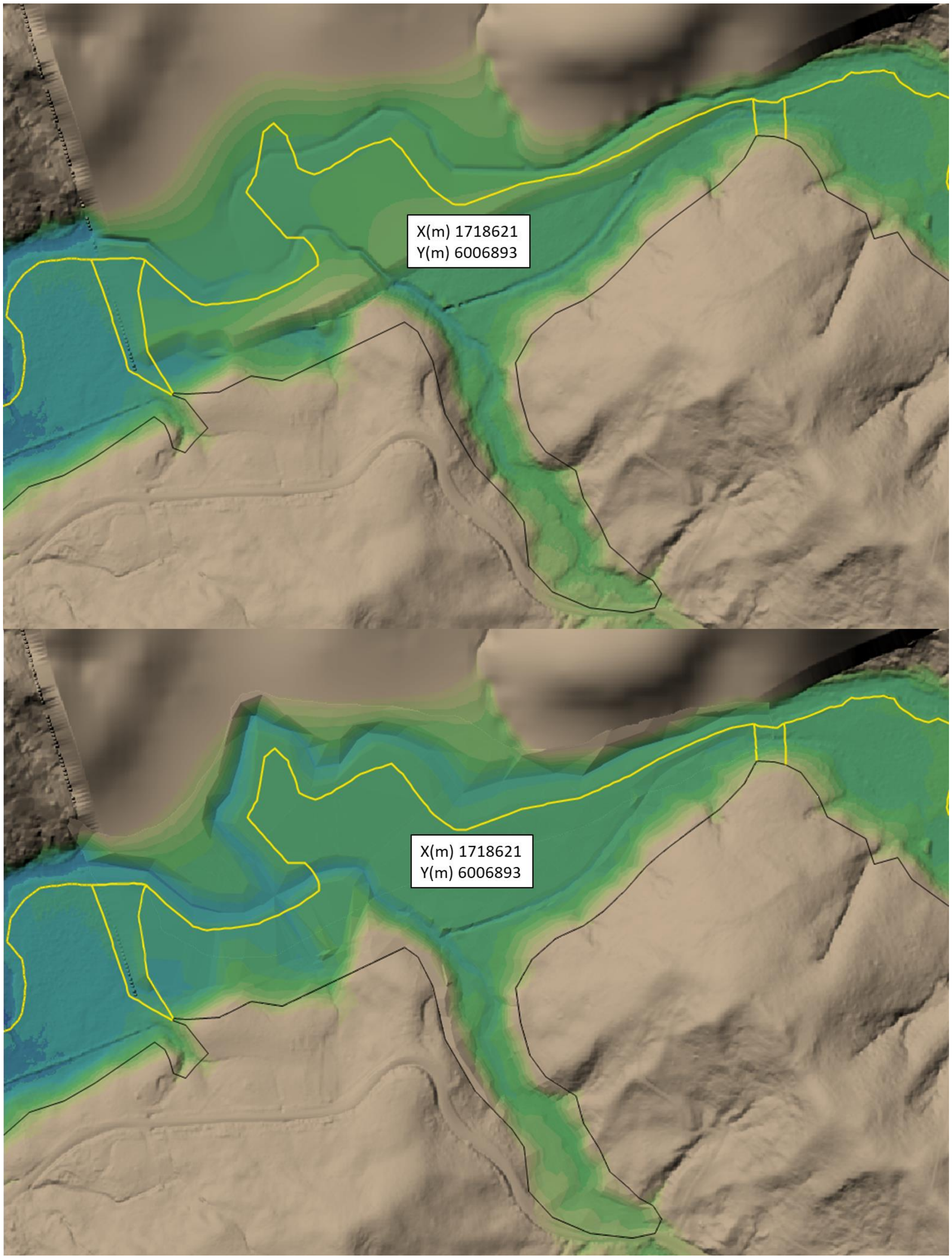


Figure 0.5 Paparoa Lidar gap interpolation (assumptions)

HYDRAULIC MODEL

The hydraulic is mainly governed by the Lidar and survey data, which were combined as described in section 0. Beside survey cross section, several other cross sections were defined based on this DEM, with an average distance of about 25m, which define a very good resolution for the hydraulic model, incorporating details such river contractions and expansions, changes on slope, and river conveyance.

The 1D cross-section roughness for the main channel is generally between 0.040 – 0.085, which has been set as a function of the river bottom level, so higher values are set for steeper and more energetic portions, compared with the lower river features. The 1D flood plains are generally between 0.100 and 0.120. These high values are inside standard ranges when accounting for the dense vegetation at the rivers, and the performance captured by the gauge records. Other values might have been defined for particularities in the network, such an obstruction or in places such the general rule does not applies for the main channel and vegetation coverage.

Storages and 2D polygons are also defined based on the combined DEM, accounting for the Lidar, 20m contours, survey and gaps corrections as described in section 0. The extent of these objects covers the outputs of the RFM described in section 0. Storages define their volume capacity by sampling the area of various levels, typically every 0.25m to 0.5m intervals, though it could be greater at higher depths where resolution is not critical. In the case of Waima reservoir, the storage curve is estimated from the Lidar water surface and the interpolated stream profile from the upper end of the water surface to the river bottom downstream of the dam wall.

2D zones take most of the engine capacity when simulating large meshes. For a more efficient performance of the model and numerical solution, the mesh is generally large at flat and wide plains, and fine at overland flows and key ground features (such roads, banks, lateral streams, channels, etc.). Given the difference on the catchment sizes and the area covered by 2D polygons in the two catchments, the maximum triangle size for Waipu -with significant flat plains- is set to 5000m² (0.5ha) and 1000m² (0.1ha) for Paparoa. The minimum triangle size is set to 3.0m and it is guided by the utilization of break lines which have been digitalized to follow key features of the DEM. A summary of the 2D polygon details, along other model objects, is shown in Table 0.1 in section 0. The 2D zones roughness is set with a constant value of n=0.100, which describes typical vegetation and ground surface in urban areas.

Culverts and bridges have been included in the model according to the agreed model extent and based on the survey information provided. If missing information was required for a particular object, then assumptions were done based on fragmented data or general engineering judgments. These were flagged according to the codes shown in Figure 0.1. Most culverts are represented by an orifice link to describe the inlet control and its capacity; however, some exception uses other objects, including slots in the 2D mesh or 1D cross section, where found suitable.

Bridges are described with a bridge link using survey and DEM data, as well as an assessment of survey photos and aerial imagens. Bridges include a description of its piers as shown by survey and photos, which is included in the respective bridge link. In most cases it also considers an over-road spill, unless the conservative RFM shows that the maximum possible water level is far below the deck level defined by DEM or survey.

Coupling between the 1D objects (primarily rivers and storages) and 2D objects (2D polygons) is done through spill units, which are based on the DEM data (as a georeferenced irregular weirs) requiring a spill coefficient which typically goes between 0.0 and 1.85. For Waipu and Paparoa networks the typical values are defined as below:

- Roads or bridges overflow: generally, between 0.8 to 1.0, based on visual assessment on-site or photographs.
- River banks: generally, between 0.80 and 0.95 based on visual assessment of layers.
- Other connectivity spills (such between storages and 2D) take a value of 1.7.

Besides the active model objects (such as river sections, bridges, 2D polygons, boundary nodes, etc.), there are other assisting objects (such break lines, river bank lines, river centre lines, etc.) which help to define key features over the active objects. Additionally, other supporting objects include ground survey points, flood survey points and photographic records that include hyperlinks to JPG files which can be queried directly from the InfoWorks RS interface. Figure 0.6 and Figure 0.7 show few screen shots of these model objects.

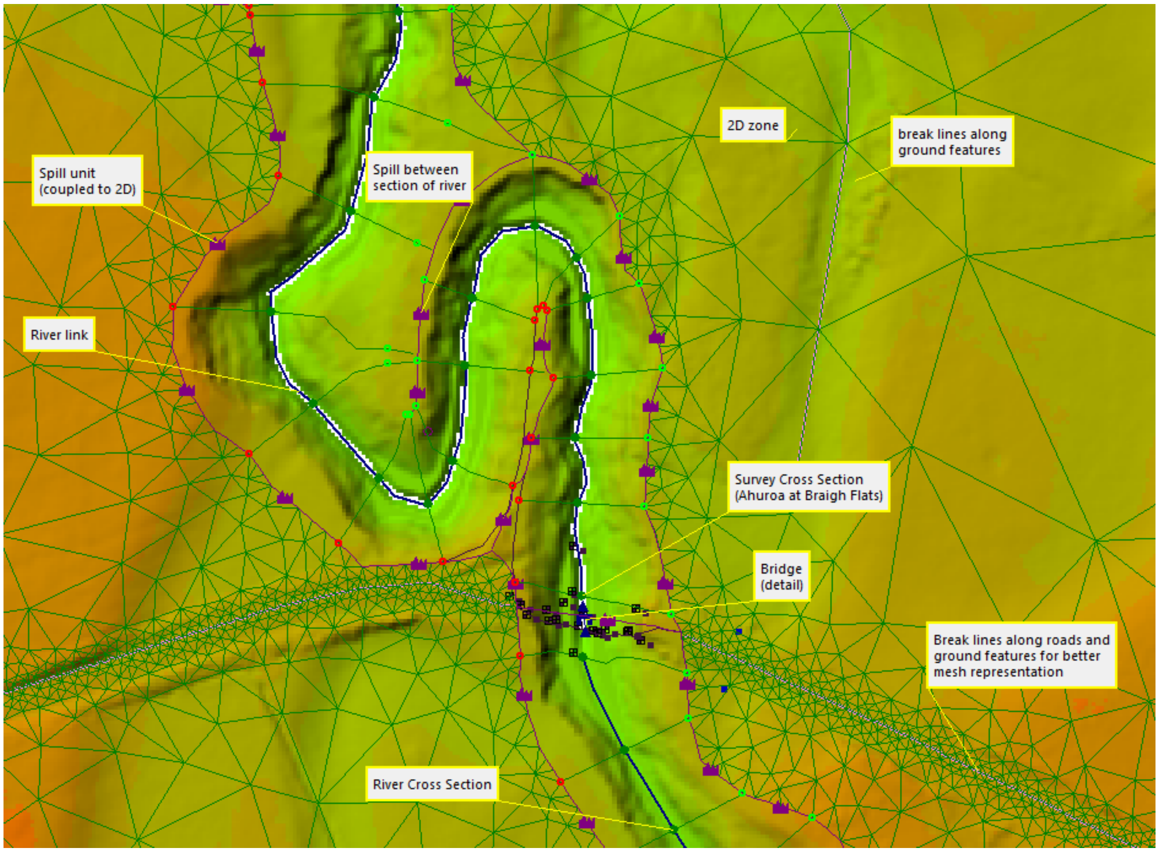


Figure 0.6 Typical hydraulic model detail. Example of 1D and 2D features at Ahuroa at Bridge Flats.

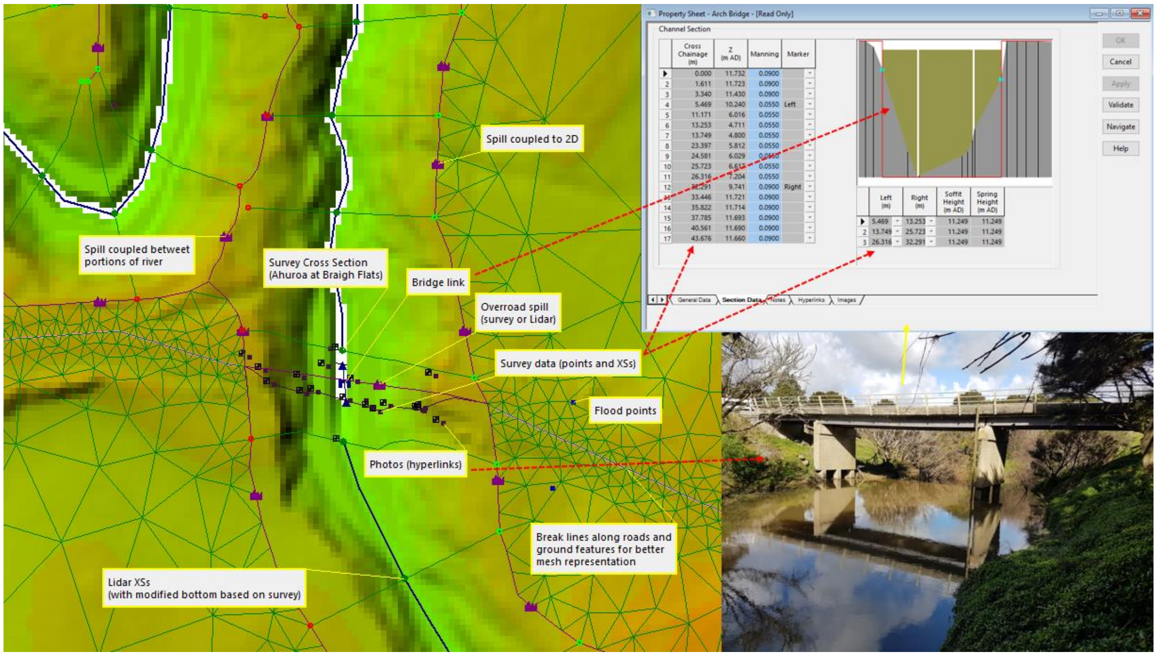


Figure 0.7 Typical hydraulic model details. Example of bridge features at Ahuroa at Bridge Flats.

HYDROLOGIC MODEL

The hydrology starts with the definition of the catchment and sub-catchment break down. The catchment is fist defined on GIS based on Lidar and 20m contours, and the sub-catchments are then broken down to fit the hydraulic model extent defined during the schematization stage (section 0). Detail of this are described in the schematization stage in section 0.

Each sub-catchment is then populated with topographical parameters extracted from the DEM and other layers, such as slope, longest overland flow path, time of concentration, imperviousness, etc. The imperviousness of the catchment is negligible compared with the pervious areas and given the abstractions method is set by a constant infiltration rate, there is no need to be defined in the model. However, along with time of concentration and CN numbers, these parameters still serve a preliminary purpose to understand the general hydrology of the catchment and provide hints on the related parameters to be set for the abstraction and routine models, which compose the hydrological to be defined.

The abstraction refers to the rain loses, and as requested by NRC, it utilizes a steady infiltration rate. Other abstractions methods (such US SCS, Horton, Runoff Coefficient, etc.) have been tested in previous projects and a steady infiltration rate has been found to better represent the rural catchment of the Northland Region. This infiltration rate might differ over the catchment, however, as later is described in section 0, the calibration considers a constant infiltration rate. Details of this and the values selected for infiltration are explained in the calibration section **Error! Reference source not found.**.

The routine method has also been tested in other catchments in the region, and the Non-Linear Reservoir has been found to be the best fit. Ground water recharge is not considered, so the NLR is set to describe most of the runoff volume, leaving out only the far portion of the recession flow, which overtime becomes the new baseflow. Baseflow, however, it is analyzed during the water balance analysis and desk calibration, and it is defined as an input of the NLR method. As it is described in section 0, the total baseflow is small compared with the volumes of calibration and design events but provides small adjustments to volume analysis and stability to the overall model performance. This baseflow (section 0) is distributed proportional to each of the sub-catchment areas.

NUMERICAL PARAMETERS

InfoWors RS default numerical parameters are enough for the modelling of Waipu and Paparoa networks. The exceptions are some parameters related to numerical stability such the Preissmann "Box" Weighting (theta) and the Under-Relaxation factor (alpha), as well as a Preissmann slot to control stability on low flows, and consequently essential for the model stabilization. The time step is also important and given the features of the Waipu and Paparoa model, a time step of 1 second is the default option. These parameters were assessed along the calibration tests to maximize stability and overall numerical performance.

SUMMARY

In Table 0.1 shows an overview of the model objects for Waipu and Paparoa networks. Preliminary model outputs show satisfactory to initiate the calibration analysis

Table 0.1 Summary of model objects for Waipu and Paparoa

Network Item	Waipu	Paparoa
Total network objects	**47194**	**16321**
Total nodes	**13109**	**3923**
Total links	**14574**	**4973**
Links - computational length (m)	**145121**	**39925**
Links - geographic length (m)	**145121**	**39925**
All links (incl. connectivity) (m)	**719980**	**223675**
Total computational reaches	**136**	**100**
Sub-catchments	**657**	**347**
Sections	**12317**	**3480**
River Section	5654	2058
Spill Unit	6663	1422
Other Nodes	**792**	**443**
Storage Area	53	14
Boundary Node	662	348
Junction Node	77	76
General connectivity	**14523**	**4932**
Link (rivers)	5562	1990

Connectivity	212	155
Lateral Flow	1731	1245
Spill Link	7018	1542
Structures	**51**	**41**
Bridges	26	16
Orifice (culverts)	25	25
2D Zones polygons	105	53
2D Zone total area (m2)	36413569	2108647
Total number of 2D triangles	893803	127974
Average triangle size, m2	40.7	16.5
Minimum triangle size, m2	3.0	3.0
Maximum triangle size, m2	5000	1000

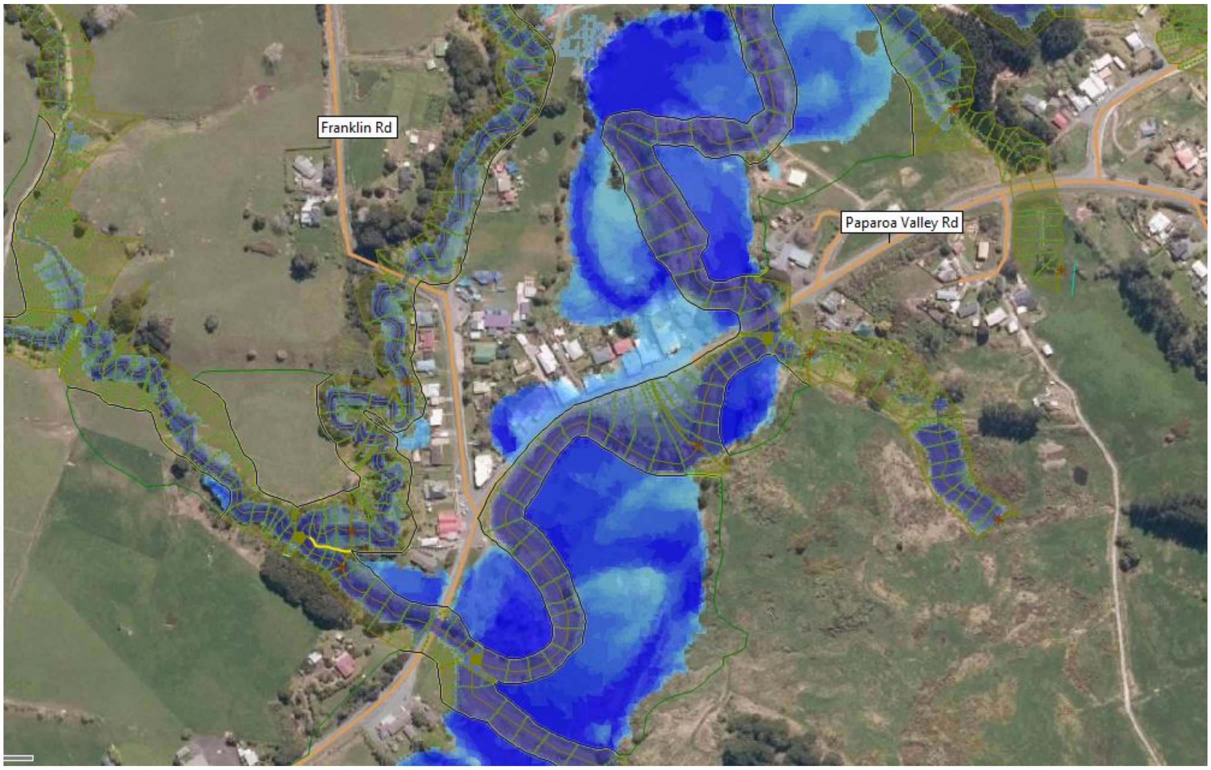


Figure 0.8 Example of preliminary model results.

CALIBRATION

GAUGES AND RECORDS

WATER BALANCE ANALYSIS

There are 3 calibration/validation events for 4 flow/stage gauges (Table 0.1) and few surveyed flood levels. Rain and flow/stage gauge records allowed the analysis of volumes through a water balance analysis of each gauge catchment and records.

Table 0.1 Flow/Stage gauges in Waipu Catchment

Flow/Stage Gauge Name	Ewaters ID	Catch Size, ha	Length, m	Slope
Ahuroa at Braigh Flats	G01	5598.4	25410	0.00396
North at Applecross	G02	3884.9	24144	0.00418
Waihoihoi at St. Marys Rd.	G03	2696.7	22200	0.00581
Waionehu at McLean Rd.	G04	2456.5	13897	0.00792

There are many aspects to consider in the water balance, some of the most relevant are listed below:

- Baseflows, which also serve as an indication of the ground water table and moisture conditions of the soil.
- Total runoff from flow records should consider the various portions of the hydrograph: direct runoff, percolation and ground water recharge (baseflow). The non-linear reservoir method should describe well the direct runoff, and a fraction of the percolation portion of flow, which is typically seen during 1-2 days after the storm has passed. The records and modelled runoff volumes should account for the portions that are comparable.
- The rainfall considers the respective portions of the surrounding rain gauges using Thiessen polygons. The importance of the rainfall is significant, as variations on the rain profile or spatial/temporal distribution of the rain have noticeable impact on the model outputs.

Following Table 0.2, Table 0.3 and Table 0.4 show the runoff coefficients (accounting for all hydrograph portions), precedent rainfall and baseflow (minimum flow before storm begins) based on recorded data for all 4 gauges.

Table 0.2. Runoff coefficient as per gauge flow records

Flow/Stage Gauge Name	Ewaters ID	Runoff coefficient as per records		
		Jul-97	Mar-07	Jan-11
Ahuroa at Braigh flats	G01	0.455	0.460	0.530
North at Applecross	G02	0.741	0.532	0.463
Waihoihoi at St. Mary's Rd.	G03	0.360	0.374	0.422
Waionehu at McLean Rd.	G04	0.366	0.380	0.347

Table 0.3. Precedent rain for all 3 calibration events (mm)

Precedent period	Precedent rainfall, mm		
	Jul-97	Mar-07	Jan-11
3 days before	0	4	0
7 days before	8	6	116
14 days before	39	13	126

Table 0.4. Baseflow for based on flow records (m^3/s)

Flow/Stage Gauge Name	Ewaters ID	Baseflow, m^3/s		
		Jul-97	Mar-07	Jan-11
Ahuroa at Braigh flats	G01	0.681	0.132	0.414
North at Applecross	G02	0.399	0.129	0.661
Waihoihoi at St. Mary's Rd.	G03	0.315	0.062	0.225
Waionehu at McLean Rd.	G04	0.216	0.023	0.228

The water balance and the analysis of the flow/stage records against the rainfall records is important to determine the hydrological parameters, particularly the rain abstractions which are described by the initial abstractions and infiltration rates.

When looking the water balance and overall model performance, it becomes evident that the records suggest unusual low rain volumes with rain abstractions higher than 60% (of total rain) for storms close to 100yrs return period (refer to Table 0.2). If such low runoff coefficients are considered unrealistic, the differences could be explained by whether inaccurate rain records or inaccurate flow records. Rain records might well vary among near sub-catchments, but those differences are unlikely to account for such low runoff values. Furthermore, calibration results show rating curves to be well represented for low and mid flow ranges, but significantly overestimated for higher levels.

Further arguments are provided to clarify these statements (section 0 following), which would lead to a closer review of the rating curves as possible cause of the misleading flow records and volumes. This will have significant impact on the water balance analysis, which would affect the selection of the infiltration rates and initial abstractions.

Regarding baseflow and initial abstraction, the impact on results is marginal. Based on records, an average baseflow is assigned to each sub-catchment according to its size, with an average value of 0.10 l/sec/ha. This value was used for calibration and design events, for Paparoa and Waipu catchments. This means a total baseflow of 2.25m^3/s for Waipu and 0.46m^3/s for Paparoa.

For the initial abstractions, the catchment storage has been set with a maximum of 25mm. This is based roughly on observation of the rain/flow records, and estimations of the SCS storage (I_a=0.2*(25400/CN-254)) based on soil B or C and a mainly rural green coverage. Initial abstractions have been set as 20mm, 5mm and 15mm for the 1997, 2007 and 2011 storm events respectively. The parameter has small impact on the initial flow rates and none on the peak and recession flows. The design event initial abstraction is set to saturated for conservative considerations, being its abstractions composed only by the infiltration rates to calibrate.

Description of the catchment in section 0 shows various different features such land use, geology and land cover, and they all show fairly homogenous distributions, which suggest parameters such infiltration rates should not be driven by those attributes. Then, the saturated infiltration rate could be about the same for all scenarios. Initial abstractions and infiltration rates would naturally change between storm events depending on the ground water table, moisture conditions, precedent rain and season with its atmospheric changes (summer, winter, etc; temperature, evaporation, evapotranspiration, absorption from vegetation, wind, etc). However, the data available doesn't lead to a certain conclusion, as each piece of data might suggest higher or lower infiltration rates when looked separately (such season, baseflows, precedent rain and runoff coefficients). The desk calibration proposes a constant infiltration rate for all storms (calibration and design events) with possible values between 2.5mm/hr and 4.5mm/hr, depending of the conclusions of the rating curve analysis and volume issues covered the next section 0 and sensitivity tests of section 0.

RATING CURVE ASSESSMENT

A flow/stage gauge measures the stage of the water level which relies on a datum to calculate the measured water level. Then, based on gauged flow records, a transformation curve is developed to estimate the flow based on a water level record.

Preliminary model outputs and the water balance analysis provides a preliminary range of values to assess the quality of the recorded data. Even though a calibration stage would do the opposite (adjust model to fit records), this is possible because the calibration parameters can only partially modify the model outputs, and the main governing aspects are Lidar and survey for the hydraulics, and rain volumes for the hydrology, which are set inputs defined by the DEM and rain records.

The datum was the first aspect to review. Through these analyses it was confirmed the consistency of the datum for 3 of the 4 gauges, being the exception North at Applecross. The identification of this issue lead to further investigations and measurements that settle on the final values shown in Table 0.5.

Table 0.5. Vertical datum for stage gauges.

<table>
<tr><th>Site</th><th colspan="2">RL ZERO (m OTP)</th><th>Comments</th></tr>
<tr><td>Ahuroa at Braigh Flats</td><td colspan="2">5.831</td><td>No issues</td></tr>
<tr><td>North at Applecross</td><td>11.138 (before 13/Apr/2010)</td><td>10.138 (from 13/Apr/2010)</td><td>11.138mOTP for July/1997 and March/2007 events.
10.138mOTP for January/2011 event.</td></tr>
<tr><td>Waihoihoi at St Marys’ Road</td><td colspan="2">3.525</td><td>No issues</td></tr>
<tr><td>Waionehu at McLean Road</td><td colspan="2">3.386</td><td>No issues</td></tr>
<tr><td>Kaipara harbour at Poutu Point</td><td colspan="2">0.000</td><td>No issues</td></tr>
<tr><td>Whangarei harbour at Marsden Point</td><td colspan="2">-1.680</td><td>No issues</td></tr>
</table>

Volumes and peak flows were also crossed checked. The recorded flows already suggested unrealistic low volumes (section 0) which required a proper analysis. Additionally, the preliminary (and later the calibrated) model outputs show large differences with the site rating curves for the high flow range. Sensitivity tests on various matters reassured the findings (section 0) and place the modelling outputs as being more reliable in terms of general trend for the high flow range. The gauged flows do not cover this portion of the rating curve, and the model outputs represent the lower and mid flow ranges with satisfactory accuracy. The previous statement is founded on various aspects:

- Changes on roughness can't account for the differences shown in the high flow ranges.
- Higher water levels require larger volumes, as storage on plains is of significant.
- Larger volumes in runoff would also address the low runoff coefficients suggested by the records.
- The modelled rating curves are consistent with the ground features, as it is shown by Figure 0.1 and Figure 0.2, and explain in the next paragraph.

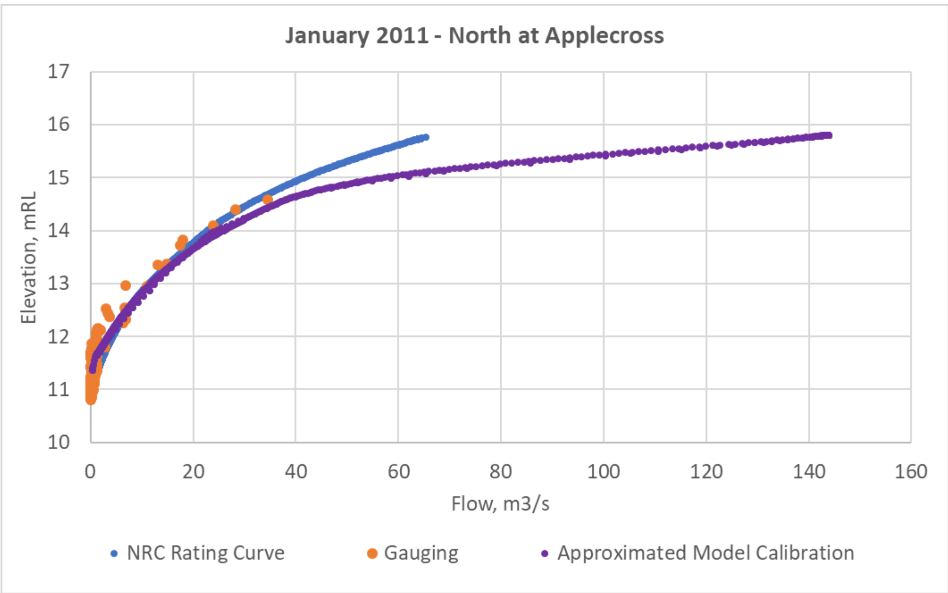


Figure 0.1 Example of modelled rating curve against records.

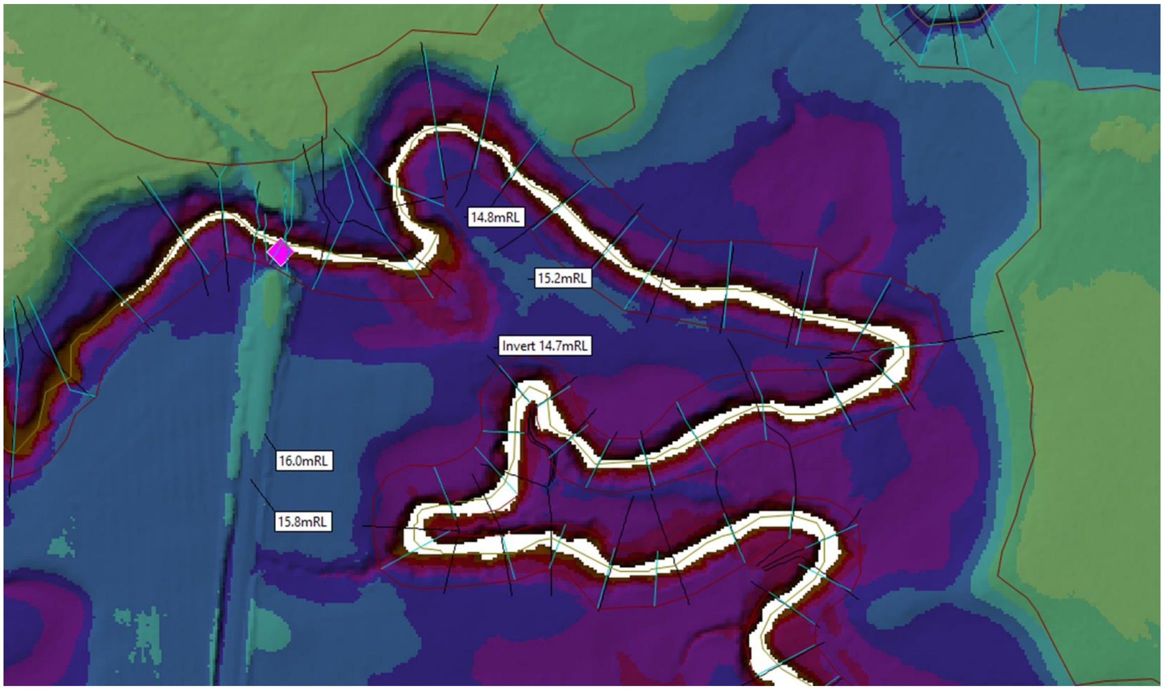


Figure 0.2 Example ground features near rating curve of Figure 0.1

Figure 0.2 shows a theme for the ground sounding North at Applecross flow/stage gauge. There are few ground levels labelled for reference. The rating curve of Figure 0.1 shows consistency with the ground features, as around 14-15mOTP the amount of storage in the river basins increases significantly, suggesting a rating curve as shaped by the model outputs should be more expected than the propose high flows ranges of the provided site rating curve. It is understood that the rating curves are generally estimated from gauge flows that often are far from the high range flows for reliable extrapolation, on those means, the modelled rating curve might well be more accurate, fits the gauged flows, and address the volume issues identify on the water balance (water balance 0)

This conclusion will have significant implications in various aspects of the modelling. For this reason, this hypothesis is tested in various aspects and used as underlying true for the final calibration assumptions. This implies the rating curve and flow records are no longer calibrated, but instead, the modelled rating curve should be consistent with gauged flows and realistic volumes expressed by the runoff coefficient. The last is primarily assessed by the water level records, which includes gauges and surveyed flood levels when and where available.

SENSITIVITY TESTS

The sensitivity tests play an important role in the calibration quality and complement the water balance analysis which highlights various limitations on the data and uncertainties which require further study and testing. Ultimately, the calibration is based on the combined lessons learned from all portions of analysis, to build a comprehensive understanding of the whole and the most likely description of the reality and the dynamic of the system.

As part of the water balance (which makes the basis of the desk calibration), model build, preliminary tests and calibration process, various aspects of uncertainty were identify for testing for model sensitivity. Among the most important aspects to tests are:

- Hydrological method selection based on most suitable performance for Waipu and Paparoa.
- The rating curve reliability, for low, mid and high flow ranges.
- The runoff volumes and impact on calibration.
- Higher water levels as consequence of higher manning's vs higher volumes.
- River capacity against roughness, volumes and erosion considerations

All these were tested directly or indirectly in the model. Most of these tests did not required running the whole model network with the integrated hydrologic and hydraulic models, but instead a portion of it (such a particular river branch, hydrological model only, test over various flows using only the hydraulic model, or a combination of the previous).

The various matters to test are summarized by the findings shown in the following sub-sections.

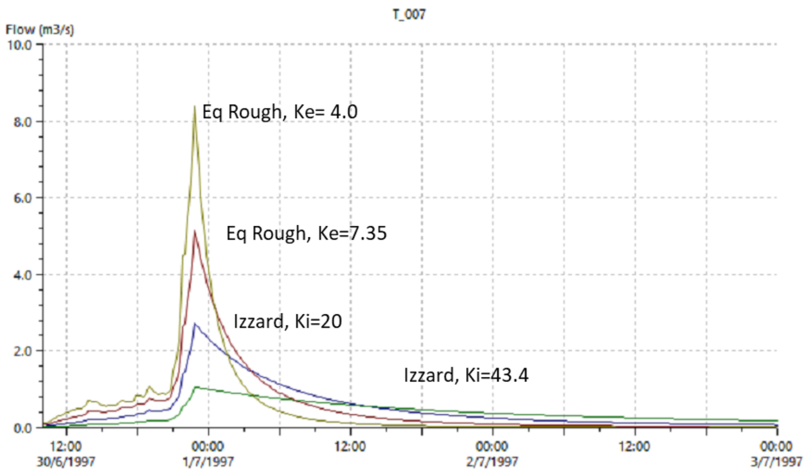
HYDROLOGIC METHOD

Several test runs were done to analyse the significant of various parameters of the hydrological model. This allows to find the suitable ranges and configuration of the variables to later calibrate the non-linear reservoir method (flow, level, volume, time, etc.). These tests took as reference preliminary model results of the calibration event. Some of the relevant tests are shown in Figure 0.3, Figure 0.4 and Figure 0.5.

Figure 0.3 shows two methods: Equivalent Roughness method, and Izzard method, with 2 values for their respective storage parameter. Both of these two methods use topographical features (such slope and length of sub-catchments) to estimate the NRL parameters *K* and p for each location (Equation 0.1 described next in this section). Note that the time of peak does not seem to change.

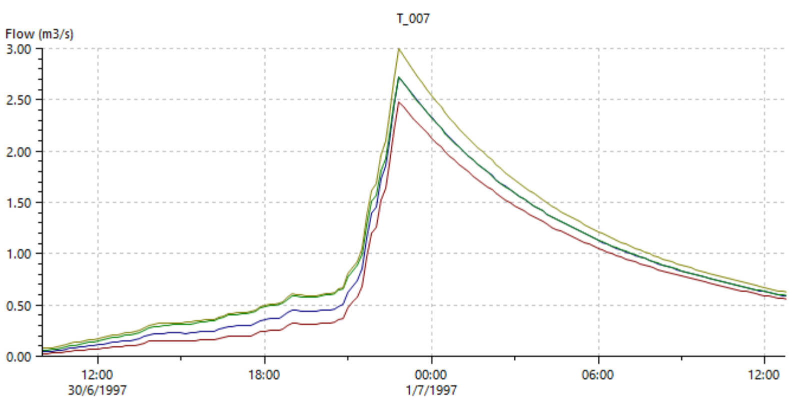
Figure 0.4 shows various abstractions method and the sensitivity of their parameters. The infiltration rate method was required by NRC, as it was previously proven to be more representative of Northland than other methods in InfoWorks RS.

Figure 0.5 shows the sensitivity of combined changes for parameters *K* and *p* of the non-linear reservoir method. Key to shape the flow and distribute runoff volume in the hydrograph.



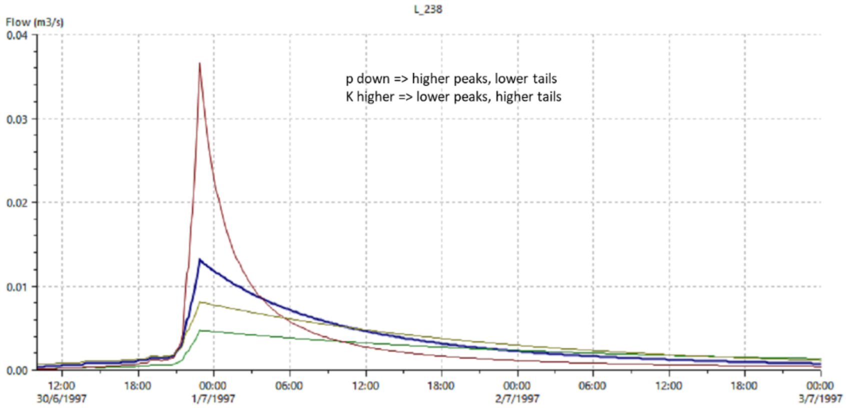
	Flow	
	Min	Max
...up>Waipu 2D H02e (1d BNs)>Cali Jul 1997!#1	0.045	2.727
...D H02e (1d BNs) K1=43.4 (20)>Cali Jul 1997!#1	0.020	1.056
...Routine=EqRough #D (Izzard)>Cali Jul 1997!#1	0.028	5.153
...=EqRough,K=4 (7.35) (Izzard)>Cali Jul 1997!#1	0.011	8.380

Figure 0.3 Sensitivity test of parameter *K* of the NLR routine



	Flow	
	Min	Max
...oup>Waipu 2D H02e (1d BNs)>Cali Jul 1997!#1	0.045	2.727
...F1RSA 0.4/0.9/20 (Infiltration)>Cali Jul 1997!#1	0.058	2.722
...s) Infiltration=4mm (2.5mm)>Cali Jul 1997!#1	0.028	2.484
...s) Infiltration=1mm (2.5mm)>Cali Jul 1997!#1	0.080	2.994

Figure 0.4 Sensitivity test of abstraction methods for a NLR routine



	Flow	
	Min	Max
...a)>Run Group>Waipu 2D H02e (1d BNs)>Cali Jul 1997!#1	0.000	0.013
...p>Waipu 2D H02e (1d BNs) K1=43.4 (20)>Cali Jul 1997!#1	0.000	0.005
...p>Waipu 2D H02e (1d BNs) p=0.4 (0.693)>Cali Jul 1997!#1	0.000	0.037
...p>Waipu 2D H02e (1d BNs) p=1.0 (0.693)>Cali Jul 1997!#1	0.001	0.008

Figure 0.5 Sensitivity test of a combined parameters *K* and *p* of the NLR routine

The sensitivity test allowed to set the preliminary values of the hydrological model for the calibration. The general conclusions are as below:

- Abstraction method described with a constant infiltration and initial abstractions. Initial abstractions will depend of the storm event. Tests suggest infiltration rates in a range between 1.5mm/hr and 5mm/hr, which are to be refined during the calibration stage. These are subjected to the water balance and the rating curve reliability for high flows.
- Routine method to be defined with a non-linear reservoir. The NLR method requires the definition of two parameters: coefficients *K* and *p* from Equation 0.1. In this equation, *S* and *q* are the storage and flow respectively. Equation 0.2 completes the NRL method with its deferential form, on which r_e and *q* are the effective rain (hydrological boundary condition) and runoff respectively.
- Parameter *K* and *p* are defined with an *Equivalent Roughness* method, which are described by Equation 0.3 and Equation 0.4. In the first equation, *I* and *L* corresponds to the slope and length of each sub-catchments which are defined in GIS. The parameter *N* is the equivalent roughness, which is defined as *N=0.080*. The factor C is then the calibration parameters to be refined during the calibration stage. In this method, *p* takes the value of 0.6 for all sub-catchments as defined in Equation 0.4.

$$S = K \cdot q^p$$ **Equation 0.1**

$$\frac{dS}{dT} = r_e - q$$ **Equation 0.2**

$$K = C \cdot \left(\frac{NL}{I^{1/2}}\right)^{0.6}$$

Equation 0.3

$$p = 0.6$$

Equation 0.4

INFILTRATION RATES

Infiltration rate tests and findings shown in graphs below. Note this test were done in early stages of the calibration, meaning the rest of the calibration parameters have not been yet set. The model results are to give general trends of the parameters.

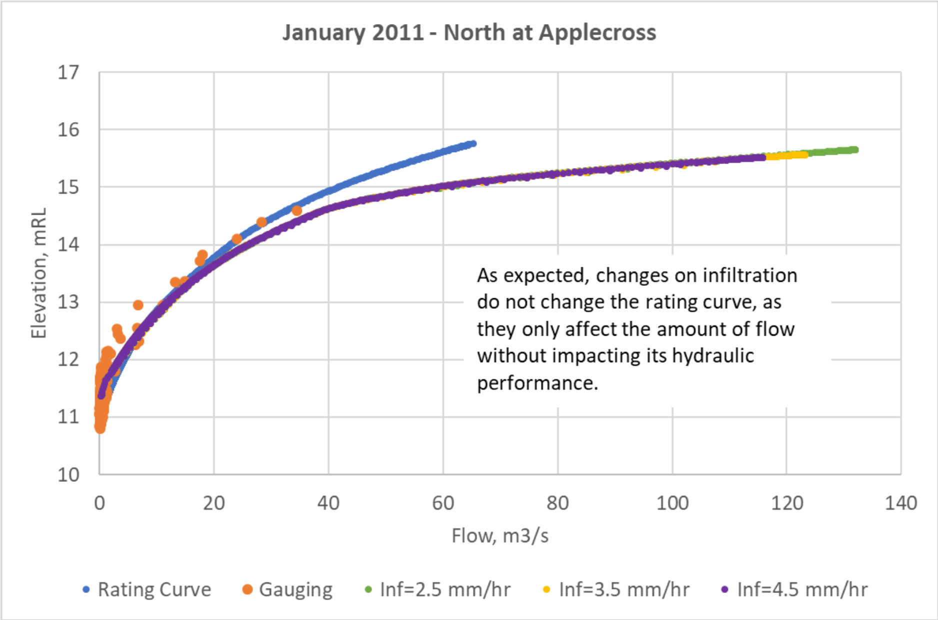


Figure 0.6 Sensitivity tests of infiltration rates. Rating curve example.

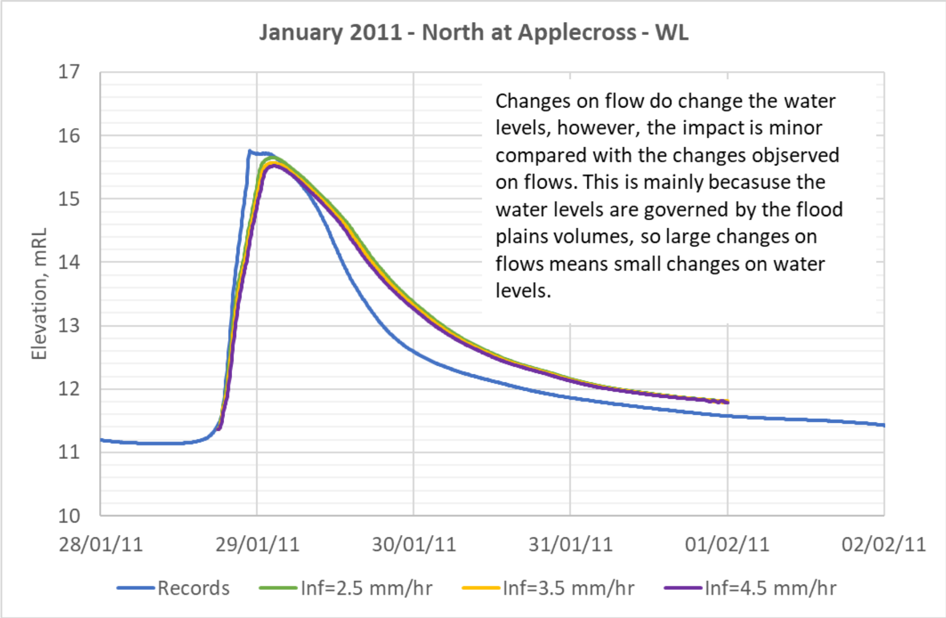


Figure 0.7 Sensitivity tests of infiltration rates. Water level example.

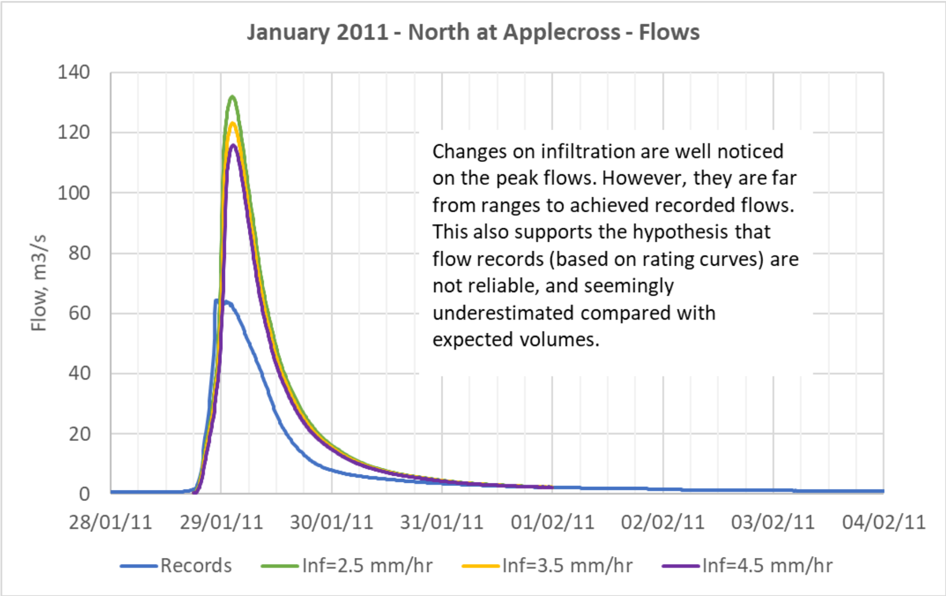


Figure 0.8 Sensitivity tests of infiltration rates. Flow example.

Table 0.6. Vertical datum for stage gauges.

	WL max	WL diff	Depths	Depth Diff	Q max	Q diff	Q diff
Scenario	mRL	m	m	%	m3/s	m3/s	%
Inf=2.5 mm/hr	15.650	0.083	5.924	1.42%	131.931	8.822	7.2%
Inf=3.5 mm/hr	15.567	0.000	5.841	0.00%	123.109	0.000	0.0%
Inf=4.5 mm/hr	15.519	-0.048	5.793	-0.82%	115.806	-7.303	-5.9%

Few rates were tested between 2.5 and 4.0mm (range from previous NRC catchment calibrations). The model presented close match for all events when using an infiltration, *Inf*=3.5mm/hr, homogeneous over the whole catchment. This is tested during the calibration stage.

EQUIVALENT ROUGHNESS PARAMETER AND 2D ROUGHNESS

The Equivalent Roughness parameter C Equation 0.3 is one of the most relevant parameters to calibrate, which controls volumes at a given time and, by implication, water levels.

In the followings graphs, changes in *C* are shown along an alternative 2D roughness value which was found to be of marginal impact compare with other calibration parameters. In the same context, the last is true as the water levels are mainly governed by the volumes (as peak rates) that parameter *C* imply, as large storage capacity require large changes on volume to notice increment on floods depths.

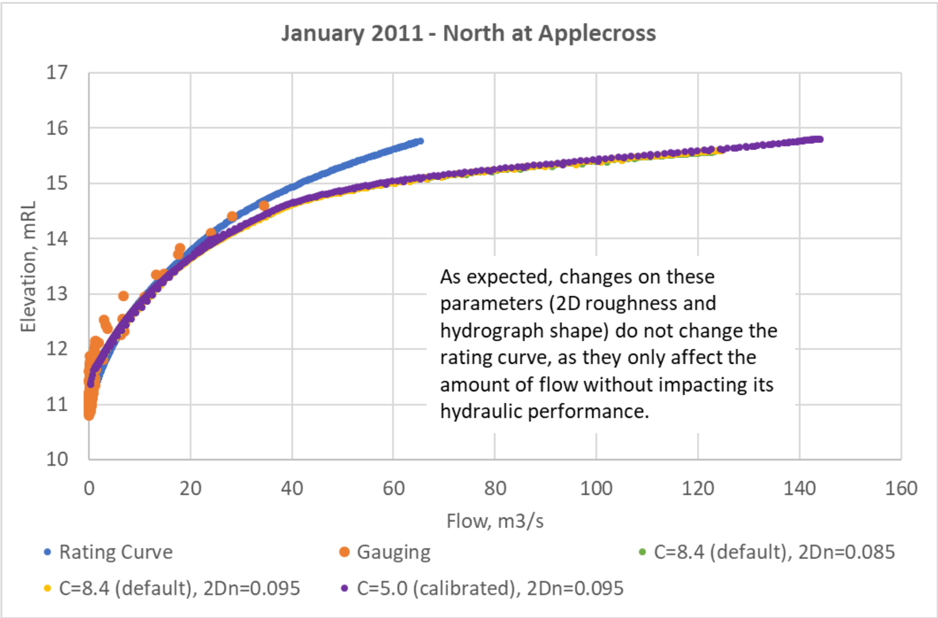


Figure 0.9 Sensitivity tests of hydrological parameter and 2D roughness. Rating curve example.

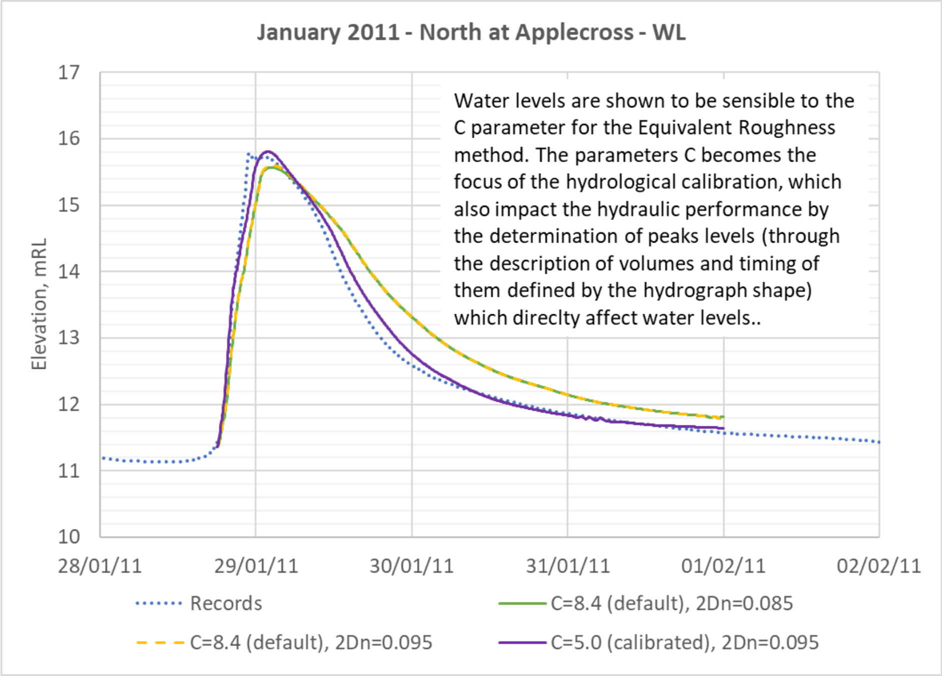


Figure 0.10 Sensitivity tests of hydrological parameter and 2D roughness. Water level example.

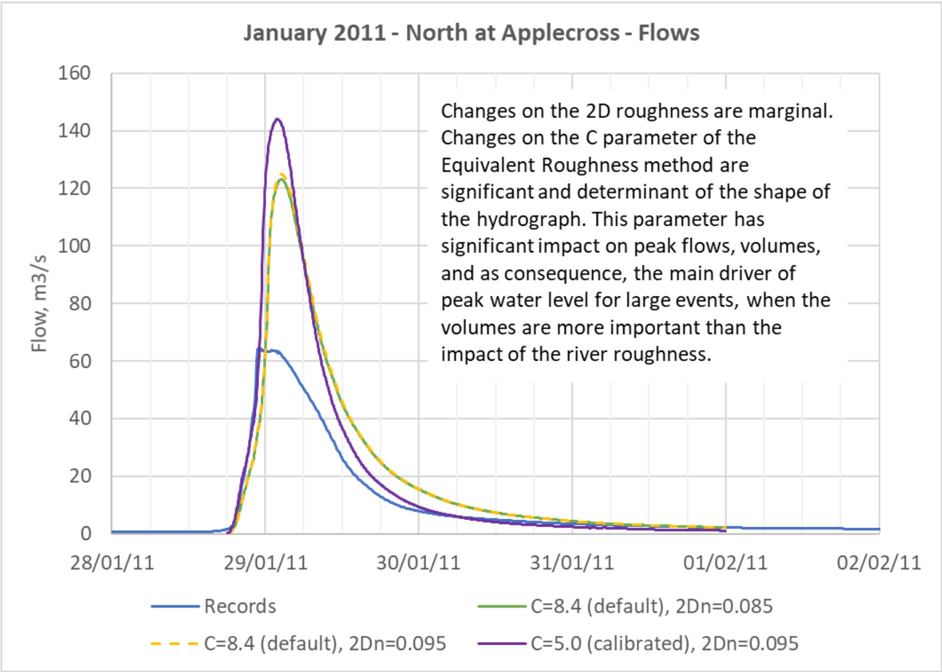


Figure 0.11 Sensitivity tests of hydrological parameter and 2D roughness. Flow example.

RIVER ROUGHNESS (1D)

The 1D river cross section roughness was tested for sensitivity at the gauge locations. A base line was set based on general features and preliminary tests. Volume issues imply the need to tests higher roughness values to assess whether the lower water level values could be adjusted. A sensitivity test was then done by increasing the roughness by a 10% of the base values. Note that the base roughness already consider high roughness but still inside standard ranges. Figure 0.12, Figure 0.13, Figure 0.14 and Figure 0.15 summarized the conclusions.

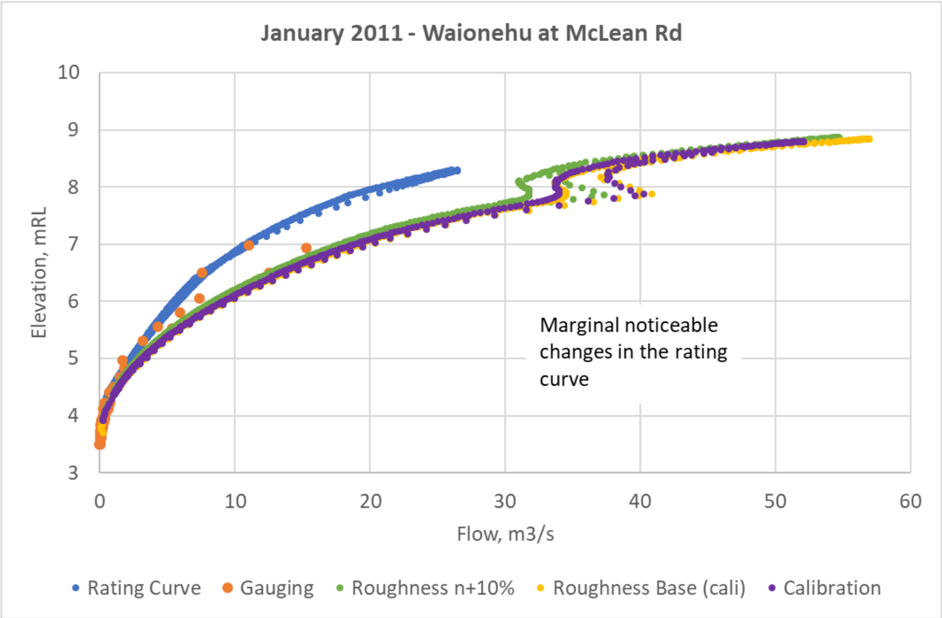


Figure 0.12 Sensitivity tests river roughness (1D). Rating curve example. 10% roughness increment.

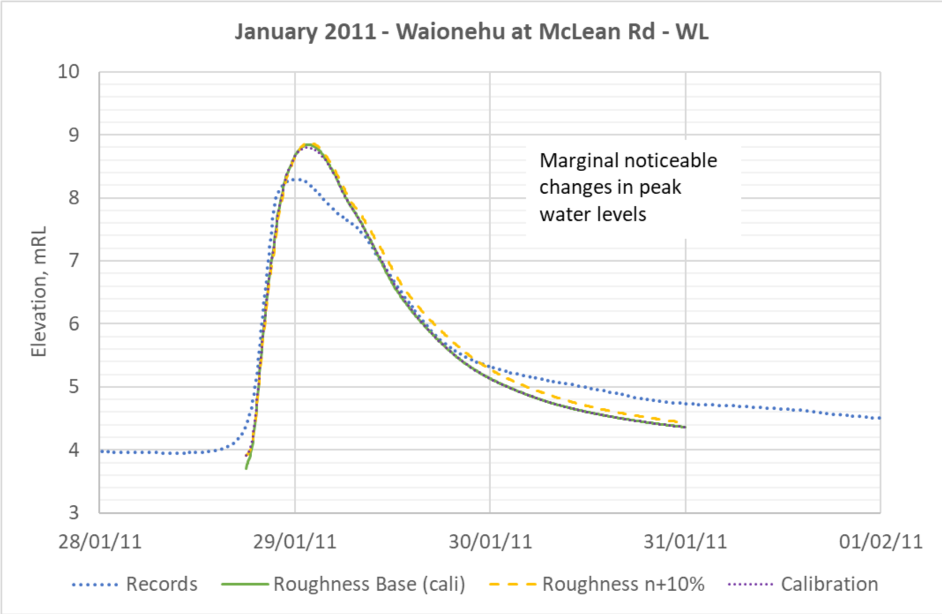


Figure 0.13 Sensitivity tests river roughness (1D). Water level example. 10% roughness increment.

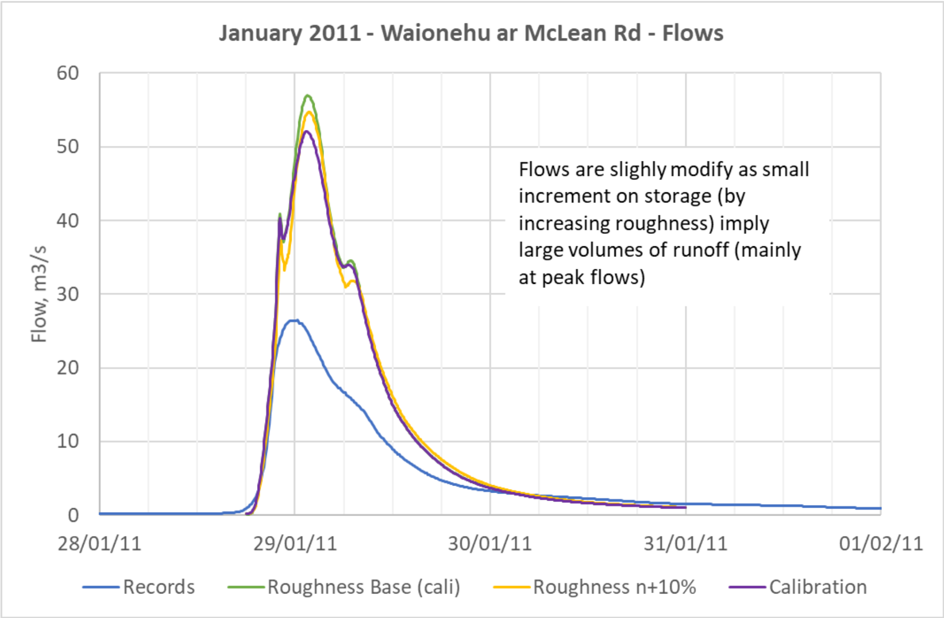


Figure 0.14 Sensitivity tests river roughness (1D). Flow example.

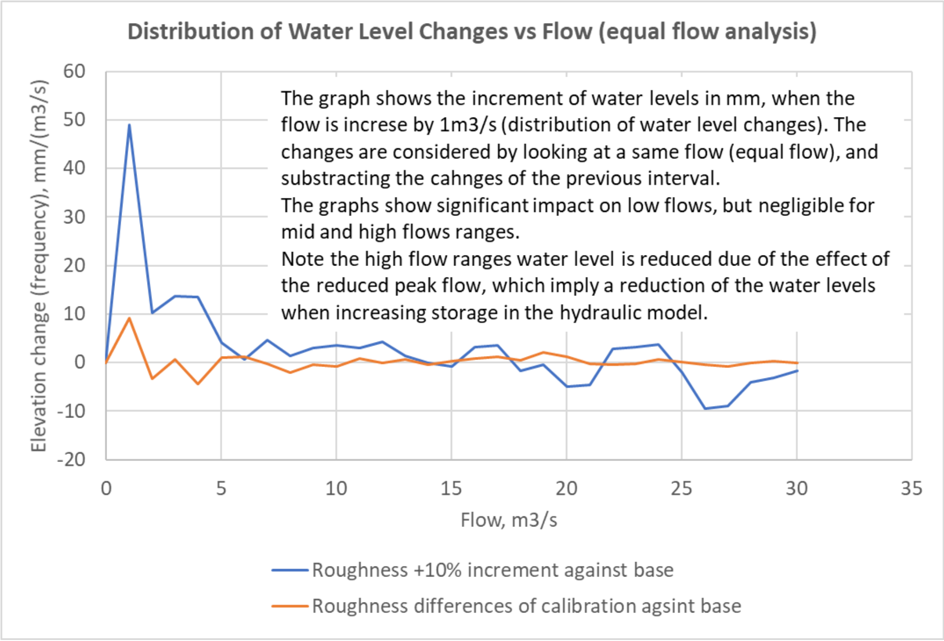


Figure 0.15 Sensitivity tests river roughness (1D). Rating curve differences.

RIVER MOUTH SENSITIVITY TEST

The event of March 2007 has several flood points which were used to attempt the calibration of the model and lower Waipu river features. At that stage, the water balance analysis and calibration of the stage/flow gauges had provided with satisfactory model outputs and a coherent description of the river dynamic. However, the model consistently overestimated the levels in the lower plains. At first sight, this would suggest lower runoff volumes (also suggested by original flow records). Though, the lower runoff volume hypothesis was previously discharged by the several pieces of information extracted from data, water balance analysis, sensitivity tests and model performance. Lowering the volumes will imply significant challenges to justify the higher water levels and storage volumes required in the upper catchment.

There is, however, an alternative explanation: The low plains of the Waipu catchment have a large sand bars along the costal line, which controls the size of the river mouth. In the northern side of the river month, the northern bar is too large and tall to expect any breaches, but the southern sand bar might well open some breaches with the push of flows from large events, and the erosion of strong winds and tides. In particular, the river mouth itself is likely to wide with large flows (see Figure 0.16 which shows preliminary results at mouth, along surveyed bottom showing possible sand deposits).

On the other hand, the portion of river that is tidal influenced is significant, going far inside the Waipu plains for over 13kms along a portion of the main river basins. This means that the river bottom of the lower plains is likely to be composed primarily of sands and small gravels, which would move towards upstream and downstream at the tidal influenced portions of the river. The volumes could be significant given the size and features of the Waipu catchment.

Based on this hypothesis, the March 2007 event tested for two scenarios:

- Base Network: Calibrated network (under higher runoff hypothesis as described in this document). This scenario showed higher water levels at the low plains, with errors as high as 700mm.
- Eroded River Mouth Network. Following the methodology described in section 0, the hydraulic river outputs were assessed against changes on the river geometry at the river mouth. The last portion of the river (4.5kms at the river month, as shown in Figure 0.17) is modified based on an estimated erosion as described by section 0 for the sensitivity tests. The Base Network result shows velocities generally between 0.6 – 1.5 (and a few higher than 2m2/s near the month). For the sensitivity test it was considered that the sand deposit would be eroded by average velocities higher than 0.80 m/s, and the river bottom was lowered accordantly with amounts between 0 – 1.5m (based on velocity). This is a realistic assumption that considers:
    - Erosion of sand typically starts at velocities as low as 0.5 m/s.
    - Extra depth is estimated by assuming the equilibrium velocity is near 0.8 m/s, so the area of flow should be increased accordantly.
    - Only the last portion of the river is eroded by this method (4.5kms), though the tidal influenced zone goes as far as 13kms into the catchment.
    - Sand deposits at the river mouth are significant, and history of sediment movement and bank erosion is known. Through these assumptions, the

erosion is primarily located at the river mouth (see Figure 0.16 with long profile, which levels are driven by survey data, and interpolated values in-between; note the large sand deposit before the river mouth).

- Even though is likely, no estimations of the loss of volume are considered through breaches in the southern sand bar, nor because of infiltration through the sand bar when tides are significantly lower than plains water levels (as it was the tidal conditions for March 2007 event).

The result of the analysis shows that not only the levels of nearby points are reduced, but all those at the tidal influenced zone, as the volume of the plains if better drained with a wider river mouth. This conclusion might be important when considering flood mitigation options for this catchment.

Following is Figure 0.8 (from section 0) which shows the sensitivity test results, comparing survey flood points levels vs the results for both: Base Network and Eroded River Mouth Network.

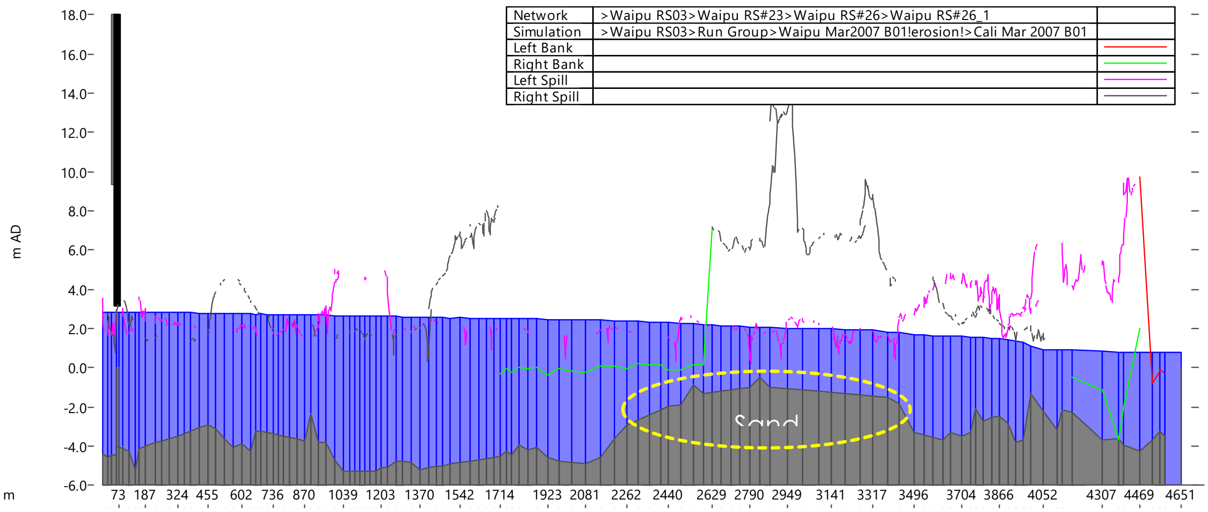


Figure 0.16 Last 4.5km of model outputs at Waipu River, showing sand deposits in profile.

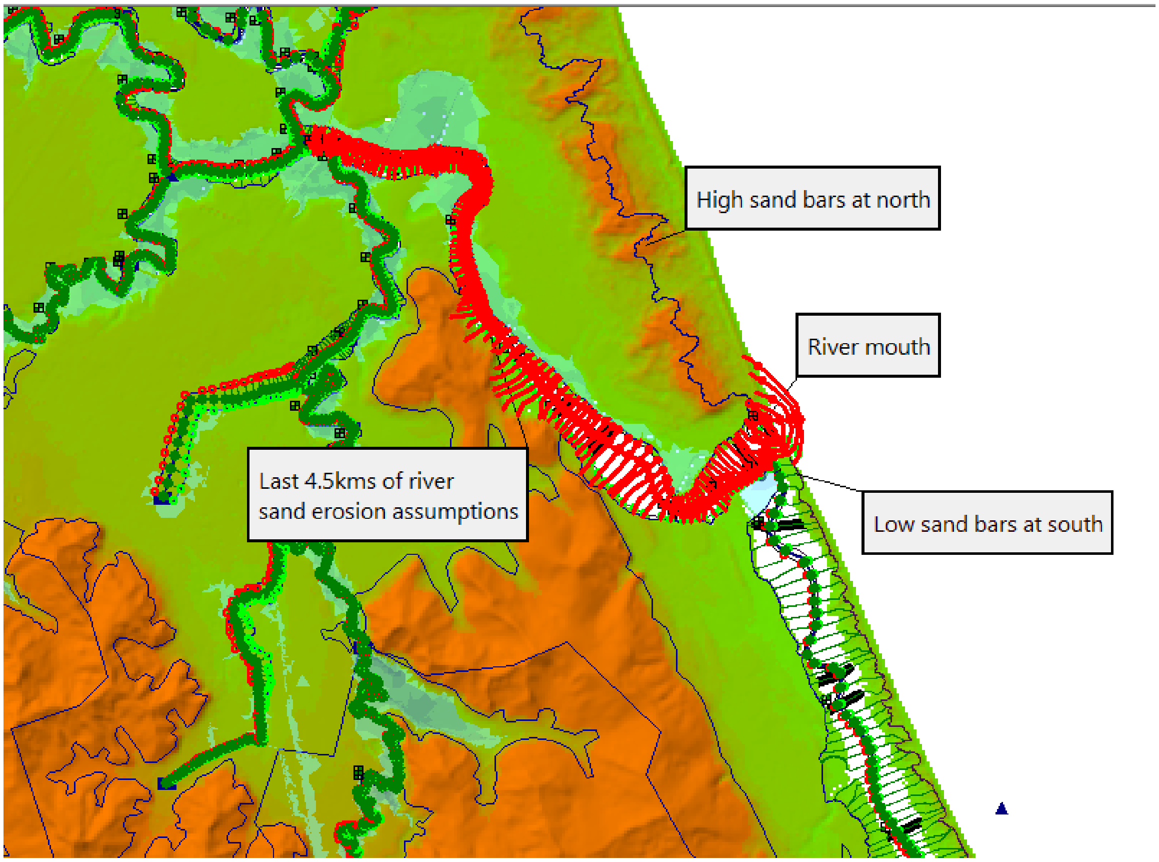


Figure 0.17 **River mouth sensitivity test. Analysis extent.**

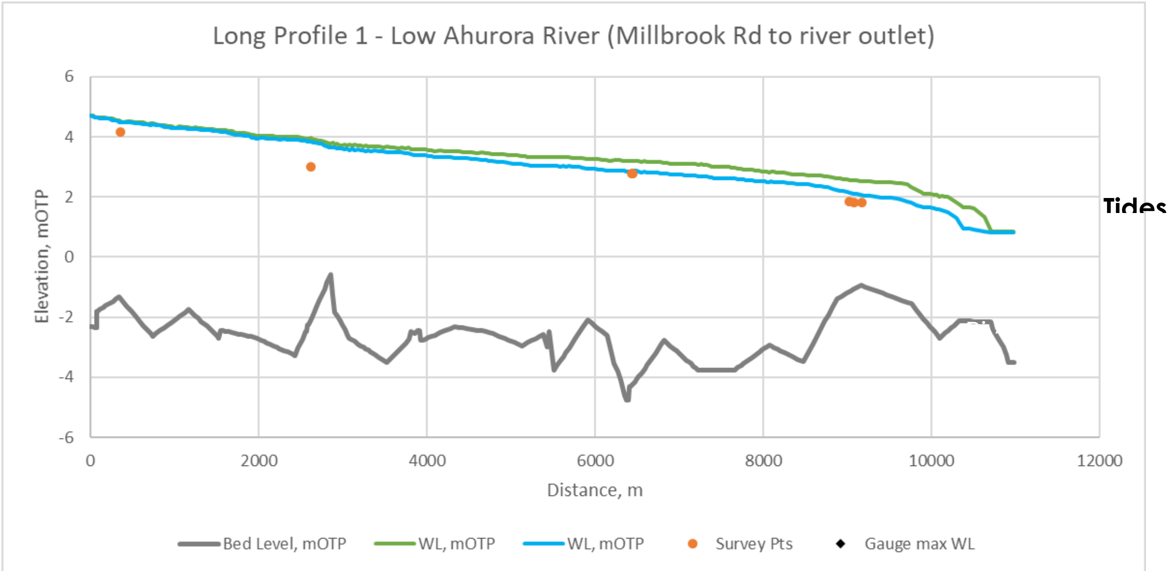


Figure 0.8 Long profile 1. Lower Waipu River.

PRELIMINARY CONCLUSIONS

Overall, there are key conclusions to consider when calibrating:

- Abstraction method described with a constant infiltration and initial abstractions. Infiltration rates calibration is subjected to the water balance and the rating curve reliability for high flows.
- Routine method to be defined with a non-linear reservoir. The NLR method requires the definition of two parameters: coefficients *K* and *p* which are shown in Equation 0.1 and Equation 0.2.
- Parameter *K* and *p* are defined with an *Equivalent Roughness* method, which are described by Equation 0.3 and Equation 0.4. Its parameter *C* is calibrated to match water balance analysis and recorded water levels.
- When assessing water levels, the model results are sensitive to flows. Roughness and small storage adjustments are minor compared with the impact in changes on flow. This is under the assumption that the Lidar is the main driver of storage and cross section geometry, which is consider reliable and not to be modified.
- In this regard, modifications of the river bottom are important for the low range of the rating curve calibration, but little impact on the mid and high flow ranges. Some assumptions are done for the river bottom of some of the flow/stage gauges, based on survey/Lidar and site visit, to adjust the low flow range of the rating curve.
- When assessing volumes, the infiltration rates is the most important parameter. The initial abstractions have a minor impact on flows and volumes compared with the impact of infiltration.
- When assessing flows, parameters *K* and *p* are important to shape the runoff volume into the flow hydrograph. The rain series are also key for the hydrograph shape. Any inaccuracy of the rain profiles and records (of spatial and temporal distribution) are combined and contained in the parameters *K* and *p* to best represent the rain records vs flow/stage records.
- When assessing time of peak (water level and flow), the rain records are the key input. Hydrological and hydraulic parameters have little impact in the time of peak, being the key input the time of the peak intensity for the critical duration (embedded in the rain records). In this regard, the time of peak can't be effectively calibrated with a poor temporal and spatial rain records. This is evident in some of the calibration events with poor rain data.
- Erosion is determinant of the river mouth capacity, and it is to be included in the final simulation runs for Waipu catchment.

Further conclusions developed based on the model respond to various scenarios.

HYDRAULIC AND HYDROLOGICAL PARAMETERS

The infiltration rate is the most relevant parameter to calibrate, as the model was shown to be sensitive to flows and governed by the storage and river capacity. However, the volume analysis showed several and critical gaps on data, which related the reliability of the rating curves and the runoff volumes. In this regard, the selection of the infiltration rates responded to several analysis and sensitivity tests which lead to the most likely scenario. Given the flow records were found to be underestimated by the gauge sites, the volumes, peak flows and hydrograph are not calibrated, but based on the relevant analysis. The ultimate calibration is only performed on the water levels, which is the actual recorded variable. On an integrated analysis, the infiltration rate was set to 3.5mm/hr, which is consistent with previous NRC catchments and water balance analysis. The roughness of river governs the low and mid flow range of the rating curve. As per water balance analysis and sensitivity tests, the rating curve is to be calibrated for the flow gauging, which covers this range. The roughness then is set as per model build between 0.040 – 0.085 as described in section 0. Storage areas and 2D mesh features are mainly defined by the DEM. The 2D roughness is of little impact on final model outputs and set at *n*=0.100 as described in section 0. For the hydraulic model, the calibration parameters did not require major adjustments from what the standard values, model build and sensitivity tests originally suggested.

The hydrological model is mainly defined by the parameter *C* of Equation 0.3, which is set at a value of *C*=5.0. Parameter *p* of the NRL is set a *p*=0.6 as defined by the Equivalent Roughness method in Equation 0.4.

Other less important parameters are the baseflow and initial abstractions, which have shown little no null impact on flows. Based on records, an average baseflow is assigned to each sub-catchment according to its size, with an average value of 0.10 l/sec/ha. This value was used for calibration and design events, for Paparoa and Waipu catchments. This means a total baseflow of 2.25m^3/s for Waipu and 0.46m^3/s for Paparoa.

For the initial abstractions, the catchment storage has been set with a maximum of 25mm. This is based roughly on observation of the rain/flow records, and estimations of the SCS storage (I_a=0.2*(25400/CN-254)) based on soil B or C and a mainly rural green coverage. Initial abstractions have been set as 20mm, 5mm and 15mm for the 1997, 2007 and 2011 storm events respectively. The parameter has small impact on the initial flow rates and none on the peak and recession flows. The design event initial abstraction is set to saturated for conservative considerations, being its abstractions composed only by the infiltration rates to calibrate.

EROSION ANALYSIS

Given the impact of erosion at the river mouth, as shown by the sensitivity tests and calibration results of March 2007 (section 0). A second round of calibration was done for March 2007 event to account for the mouth erosion, for which its methodology is described in section 0, and aims to calibrated the flood level survey point for the lower part of Waipu River.

Note that the objective of the exercise is not only calibrated the event of March 2007, but to develop a methodology that allow estimating the respective erosions for the various design events. Each event would have different levels of erosion, given the different flows and tides conditions which promote various velocity changes over the duration of the simulation. In theory, the velocities profiles (transversally and vertically) would define a shear stress that would compete against the forces settling the particles, as well as dynamic interactions by the increment of erosion/deposition over the longitudinal direction. Besides the original scope of work, the study has also considered other ways to evaluate and gain confident on the results by testing the erosion estimations with the dynamic erosion routine implemented in InfoWorks RS. Various tests were done to settle the methodology to acceptable level of confident and applying the same criteria to the design event simulations for the Waipu catchment.

In simplified terms, the approach required the calibration of two parameters which related to settling forces and bed shear stress: particle size and its density. It is important to clarify that sediment transport phenomenon is a complex subject, and the proposed simplified methodology is based on discussions with client to suit NRC needs and preferences.

The Waipu and Paparoa model already showed several data gaps and uncertainties on various subjects which are all related. Hydrology, water volumes, rating curves and river erosion are, among others, the most critical aspects to account when providing a comprehensive understanding of the dynamic of the Waipu catchment system and the impact on the flooding scenarios. The erosion is the attention of this section, and it considers that the general assumptions and hypothesis regarding the other subjects are the starting point of this analysis, especially the derived flows and velocities as they are key inputs for the erosion analysis.

On the other hand, there isn't any sediment transport measurement, granulometry or survey of seasonal variations in geometry for the mouth or any other location of Waipu River. The exercise is based on observed features on site visits and the general characteristic of this catchment. The only reference available are the expected flood levels available from survey, which will drive the selection of the erosion parameters, given the hydraulic and hydrological conditions already set for the model, and based on the calibration of the upper catchment stage/flow gauges.

Finally, the calibration of the flood survey levels was adjusted by setting a maximum roughness manning of n=0.040 for the portion of the river covered by this exercise.

The calibration of the InfoWorks RS erosion module is summarized in Table 0.7:

Table 0.7. Erosion Calibration Parameters.

Erosion calibration variable	Unit	Value
Particle size, d_{50}	mm	0.5
Particle density, ρ_s	kg/m^3	2100
Maximum lower river manning, *n*	s/[m$^{1/3}$]	0.040
Method of XS erosion	method	3 – proportional to shear stress

SUMMARY OF CALIBRATION PARAMETERS

Though the various analysis done, the critical parameters in the calibration are:

- Roughness, inside a standard range of values: 0.040 – 0.085.
- Particularities of the river bottom, especially around some of the gauges. This was mainly to calibrate the low flow range of the rating curves and have minor impact on the high flows performance.
- Runoff volumes described by the infiltration rates (and based on the water balance analysis), with infiltration *Inf*=3.5mm/hr.
- Runoff hydrograph as a Non-Linear Reservoir, and using the Equivalent Roughness method with constant *C*=5.0. NLR parameter K is calculated based on the ER method, with a p=0.6.
- Erosion parameters: particle size 0.5mm, sand density 2100kg/m^3.
- Minor changes of head losses by the adjustment of coefficients related to bridges, spills, orifices and other structures.
- Less important are baseflow and initial abstractions. Baseflows uses a 0.10 l/s/ha assigned to all sub-catchments. Initial abstractions vary per event, with a saturated state for design events.

CALIBRATION/VALIDATION MODEL OUTPUTS

AHUROA AT BRAIGH FLATS (G01)

At south west of catchment, it should be fairly well represented by the auto rain gauges for the 3 events. The exception is July 1997, which shows poor rain coverage.

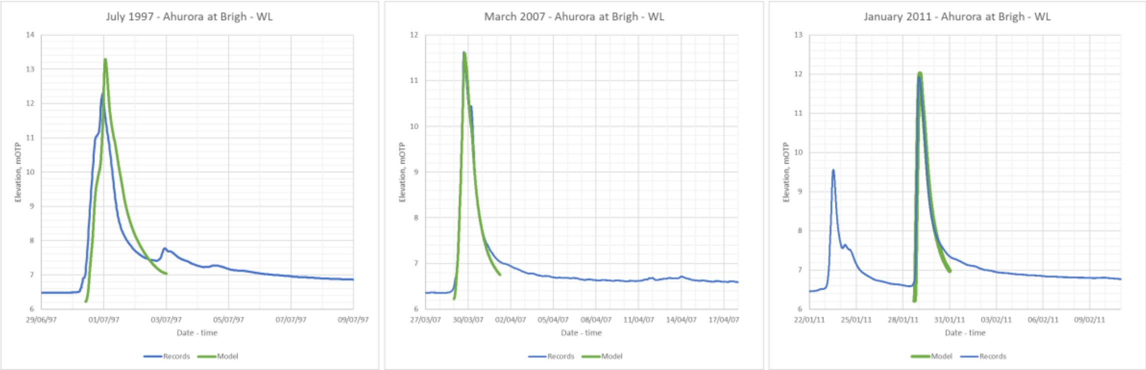


Figure 0.1 Water level calibration. Ahuroa at Braigh Flats.

Table 0.1. Calibration outputs. Ahuroa at Braigh Flats.

Ahuroa at Braigh	G01 - July 1997	G01 - March 2007	G01 - January 2011
Catchment Area, m2	56006176	56006176	56006176
Rain depth, mm	269.1	223.8	191.4
Recorded RC	0.43	0.45	0.50
Modelled RC	0.64	0.57	0.69
Baseflow (model), m3/s	0.559	0.559	0.559
Mod. peak WL, mOTP	13.292	11.604	12.015
Modelled time WL peak	01/07/1997 01:10	29/03/2007 18:20	29/01/2011 02:10
Mod. peak flow, m3/s	290.105	170.296	197.171
Mod. time flow peak	01/07/1997 01:00	29/03/2007 18:10	29/01/2011 01:55
Rec. WL peak, mOTP	12.316	11.629	11.931
Rec. WL time peak	30/06/1997 23:15	29/03/2007 16:45	29/01/2011 01:00
Rec. flow peak, m3/s	170	118.75	129.999
Rec. flow time peak	30/06/1997 23:15	29/03/2007 16:30	29/01/2011 01:00
error Water Level, m	0.976	-0.025	0.084
error WL time	01:55:00	01:35:00	01:10:00
error flow, m3/s	120.105	51.546	67.172
error flow time	01:45:00	01:40:00	00:55:00

NORTH AT APPLECROSS (G02)

The storm of January 2011 is well represented by the rain gauges over this gauge catchment. However, March 2007 and July 1997 is only represented by one rain profile far south (refer to section 1.2).

Furthermore, March 2007 do not have enough manual gauges nearby to represent the rain depth at this area. July 1997 event has a poor rain coverage.

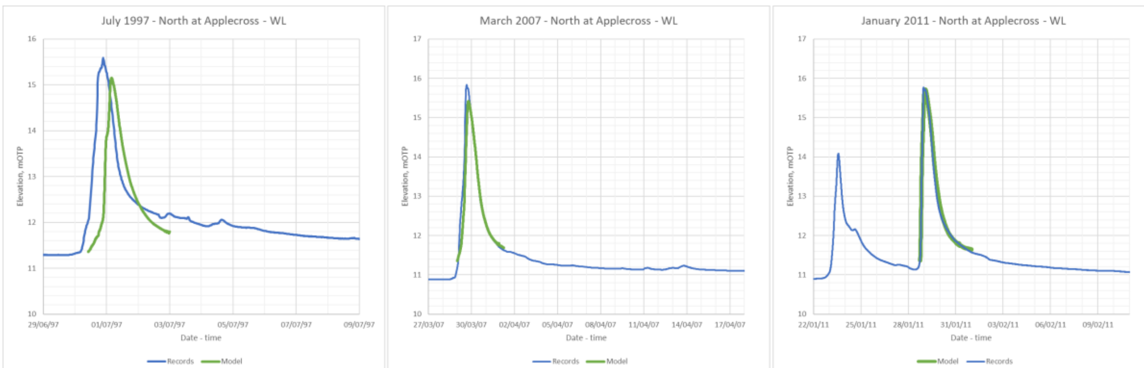


Figure 0.2 Water level calibration. North at Applecross.

Table 0.2. Calibration outputs. North at Applecross.

North at Applecross	G02 - July 1997	G02 - March 2007	G02 - January 2011
Catchment Area, m2	38919385	38919385	38919385
Rain depth, mm	129.0	230.8	228.6
Recorded RC	0.66	0.51	0.43
Modelled RC	0.59	0.54	0.70
Baseflow (model), m3/s	0.396	0.396	0.396
Mod. peak WL, mOTP	15.151	15.416	15.712
Modelled time WL peak	01/07/1997 03:45	29/03/2007 18:50	29/01/2011 01:50
Mod. peak flow, m3/s	74.148	103.865	147.794
Mod. time flow peak	01/07/1997 03:45	29/03/2007 18:40	29/01/2011 01:55
Rec. WL peak, mOTP	15.591	15.84	15.765
Rec. WL time peak	30/06/1997 21:15	29/03/2007 15:45	28/01/2011 22:55
Rec. flow peak, m3/s	62.683	70.513	65.336
Rec. flow time peak	30/06/1997 21:15	29/03/2007 15:30	28/01/2011 22:55
error Water Level, m	-0.44	-0.424	-0.053
error WL time	06:30:00	03:05:00	02:55:00
error flow, m3/s	11.465	33.352	82.458
error flow time	06:30:00	03:10:00	03:00:00

WAIHOIHOI AT ST MARYS' ROAD (G03)

January 2011 event is consistently the best calibration, as it has the best set of records for rain coverage. For gauge G03, despite the poor coverage for July 1997 and partial coverage for March 2007, the rain auto gauge S16 is close enough to adequately represent the volumes and respective flood levels at this location.

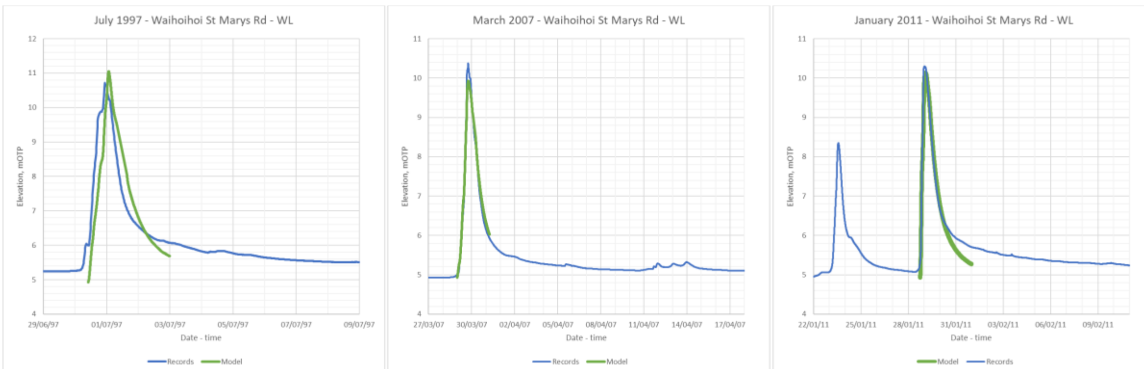


Figure 0.3 Water level calibration. Waihoihoi at St. Mary's Rd.

Table 0.3. Calibration outputs. Waihoihoi at St. Mary's Rd.

Waihoihoi at St Mary's Rd	G03 - July 1997	G03 - March 2007	G03 - January 2011
Catchment Area, m2	26965359	26965359	26965359
Rain depth, mm	274.9	234.0	190.5
Recorded RC	0.35	0.36	0.40
Modelled RC	0.71	0.56	0.72
Baseflow (model), m3/s	0.269	0.269	0.269
Mod. peak WL, mOTP	11.046	9.926	10.135
Modelled time WL peak	01/07/1997 01:35	29/03/2007 18:30	29/01/2011 02:00
Mod. peak flow, m3/s	233.068	83.091	103.409
Mod. time flow peak	01/07/1997 01:30	29/03/2007 18:20	29/01/2011 02:00
Rec. WL peak, mOTP	10.711	10.374	10.299
Rec. WL time peak	30/06/1997 22:30	29/03/2007 18:15	29/01/2011 00:25
Rec. flow peak, m3/s	65.322	50.087	46.837
Rec. flow time peak	30/06/1997 22:30	29/03/2007 18:15	29/01/2011 00:25
error Water Level, m	0.335	-0.448	-0.164
error WL time	03:05:00	00:15:00	01:35:00
error flow, m3/s	167.746	33.004	56.572
error flow time	03:00:00	00:05:00	01:35:00

WAIONEHU AT MCLEAN ROAD (G04)

Note the water levels of July 1997. This storm showed (based on the available auto gauge) the greater maximum rainfalls for durations of 1hrs, 6hrs, 12hrs and 24hrs (see section 1.2). It is unlikely then that the water level records for 1997 are lower than any other calibration event. There are some uncertainties that -if not record error- are unclear on how to be justified.

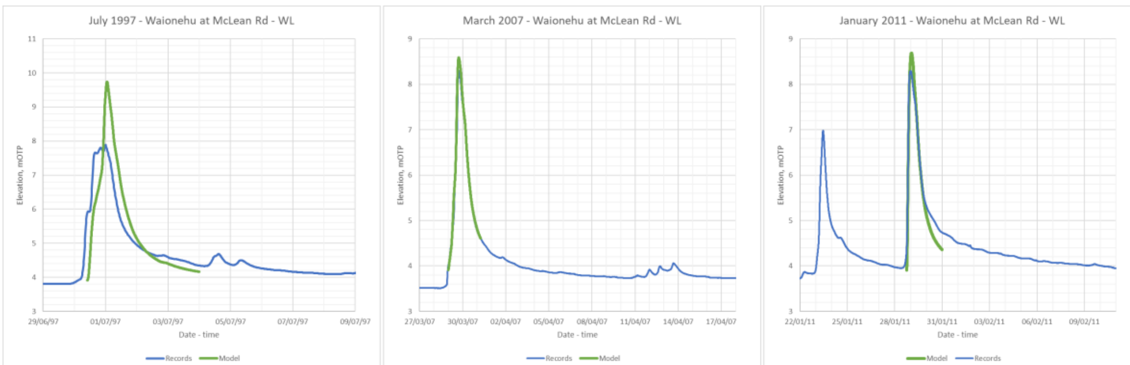


Figure 0.4 Water level calibration. Waionehu at McLean Road.

Table 0.4. Calibration outputs. Waionehu at McLean Road.

Waionehu at McLean Rd	G04 - July 1997	G04 - March 2007	G04 - January 2011
Catchment Area, m2	24367524	24367524	24367524
Rain depth, mm	253.7	234.1	190.5
Recorded RC	0.33	0.38	0.33
Modelled RC	0.50	0.45	0.53
Baseflow (model), m3/s	0.243	0.243	0.243
Mod. peak WL, mOTP	9.329	8.585	8.797
Modelled time WL peak	01/07/1997 00:40	29/03/2007 17:30	29/01/2011 01:25
Mod. peak flow, m3/s	81.562	46.378	52.065
Mod. time flow peak	01/07/1997 00:30	29/03/2007 17:20	29/01/2011 01:25
Rec. WL peak, mOTP	7.888	8.302	8.294
Rec. WL time peak	01/07/1997 00:00	29/03/2007 17:15	29/01/2011 00:30
Rec. flow peak, m3/s	28.594	35.486	26.493
Rec. flow time peak	01/07/1997 00:00	29/03/2007 17:15	29/01/2011 00:20
error Water Level, m	1.441	0.283	0.503
error WL time	00:40:00	00:15:00	00:55:00
error flow, m3/s	52.968	10.892	25.572
error flow time	00:30:00	00:05:00	01:05:00

MARCH 2007 DEBRIS FLOODS POINTS

Table 0.5 shows the comparison and comments between model and records. This table do not consider erosion, which is relevant and replaced by the information in Table 0.6 of section 0 Erosion Results March 2017.

Table 0.5. Flood level survey calibration. No erosion. March 2007.

ID	Name	Catchment	Surveyed Z, mOTP	Base model, mOTP	Error, m	Eroded Model, mOTP	Error, m	Notes
3089	P01	lower plains	2.827	3.201	0.374	2.85	0.02	river mouth dependant
3089	P02	lower plains	2.827	3.201	0.374	2.85	0.02	river mouth dependant
1004	P03	lower plains	4.339	3.944	-0.395	3.94	-0.40	Point outside of modelled flood extent, in small channel that discharge into main river. Surveyed leved is not represented by the model extent.
1017	P04	lower plains	3.129	3.450	0.321	3.20	0.07	river mouth dependant
1057	P05	lower plains	2.72	3.354	0.634	3.10	0.38	river mouth dependant
1059	P06	lower plains	1.842	2.530	0.688	2.07	0.22	river mouth dependant
1060	P07	lower plains	1.901	2.530	0.629	2.07	0.17	river mouth dependant
1063	P08	lower plains	1.862	2.550	0.688	2.11	0.25	river mouth dependant
1064	P09	lower plains	1.892	2.578	0.686	2.16	0.27	river mouth dependant
1079	P10	Catchment G04	7.817	8.660	0.843	8.66	0.84	Surveyed level does not seem reliable
1097	P11	Catchment G04	10.187	10.969	0.782	10.97	0.78	Overestimated: (not achieved) - unknown
1104	P12	Catchment G04	23.282	23.131	-0.151	23.13	-0.15	
1112	P13	Catchment G04	23.108	23.131	0.023	23.13	0.02	Survey of wate level inside culvert. US value used in model, as culvert hydraulic profile is not directly modelled).
1122	P14	Catchment G03	18.364	18.778	0.414	18.78	0.42	Overestimated: US of road, contriction or obstruction dependant, flow/volume dependant
1124	P15	Catchment G03	18.037	18.047	0.010	18.04	0.01	
1164	P16	Catchment G01	26.332	26.564	0.232	26.56	0.23	
1166	P17	Catchment G01	26.207	26.362	0.155	26.36	0.15	
1186	P18	Catchment G01	24.345	24.678	0.333	24.68	0.33	Slightly conservative. Zone of turbulance and secondary OLFPs
1187	P19	Catchment G01	24.274	24.670	0.396	24.67	0.40	Slightly conservative. Zone of turbulance and secondary OLFPs
1192	P20	Catchment G01	16.39	16.296	-0.094	16.29	-0.10	
1228	P21	Catchment G01	11.88	11.660	-0.220	11.65	-0.23	Zone of rapidily variating flow. Modelled water level picked at road invert (survey at road overflow).
1231	P22	Catchment G01	11.912	11.703	-0.209	11.71	-0.21	
1251	P23	lower plains	4.197	4.546	0.349	4.49	0.29	river mouth dependant (slightly; 10k from mouth)
1304	P24	Catchment G02	16.341	15.730	-0.611	15.73	-0.61	Underestimated: Upstream of bridge. Level depends of peak flows/volumes and bridge losses. G02 gauge (North at Applecross) was also underestimated for this catchment by 45cms.
1321	P25	Catchment G02	16.634	16.680	0.046	16.68	0.05	
1322	P26	Catchment G02	17.154	16.662	-0.492	16.65	-0.50	(G02 generally underestimated by small amount in March 207)
1326	P27	Catchment G02	21.279	20.692	-0.587	20.69	-0.59	(G02 generally underestimated by small amount in March 207)
1340	P28	Catchment G02	21.388	21.160	-0.228	21.16	-0.23	
1354	P29	Catchment G02	10.4	9.890	-0.510	9.89	-0.51	Underestimated: (not achiaved) - G02 generally underestimated by small amount in March 207
1360	P30	Catchment G02	10.453	9.780	-0.673	9.78	-0.67	
1372	P31	lower plains	8.189	7.442	-0.747	7.44	-0.75	Underestimated: possible poor detail of 2D zones, and underestimated peak flow/volume. Right downstream of G02 (<1km), which was sligtly underestimated.
1377	P32	lower plains	8.438	7.350	-1.088	7.34	-1.10	
1417	P33	lower plains	3.034	3.926	0.892	3.85	0.81	Overestimated. Slithgly dependant of river mouth and river erosion (tidal zone).
1434	P34	lower plains	2.825	3.341	0.516	3.07	0.25	river mouth dependant

Following, long profiles and plan view of the flood levels for the March 2007 model results.

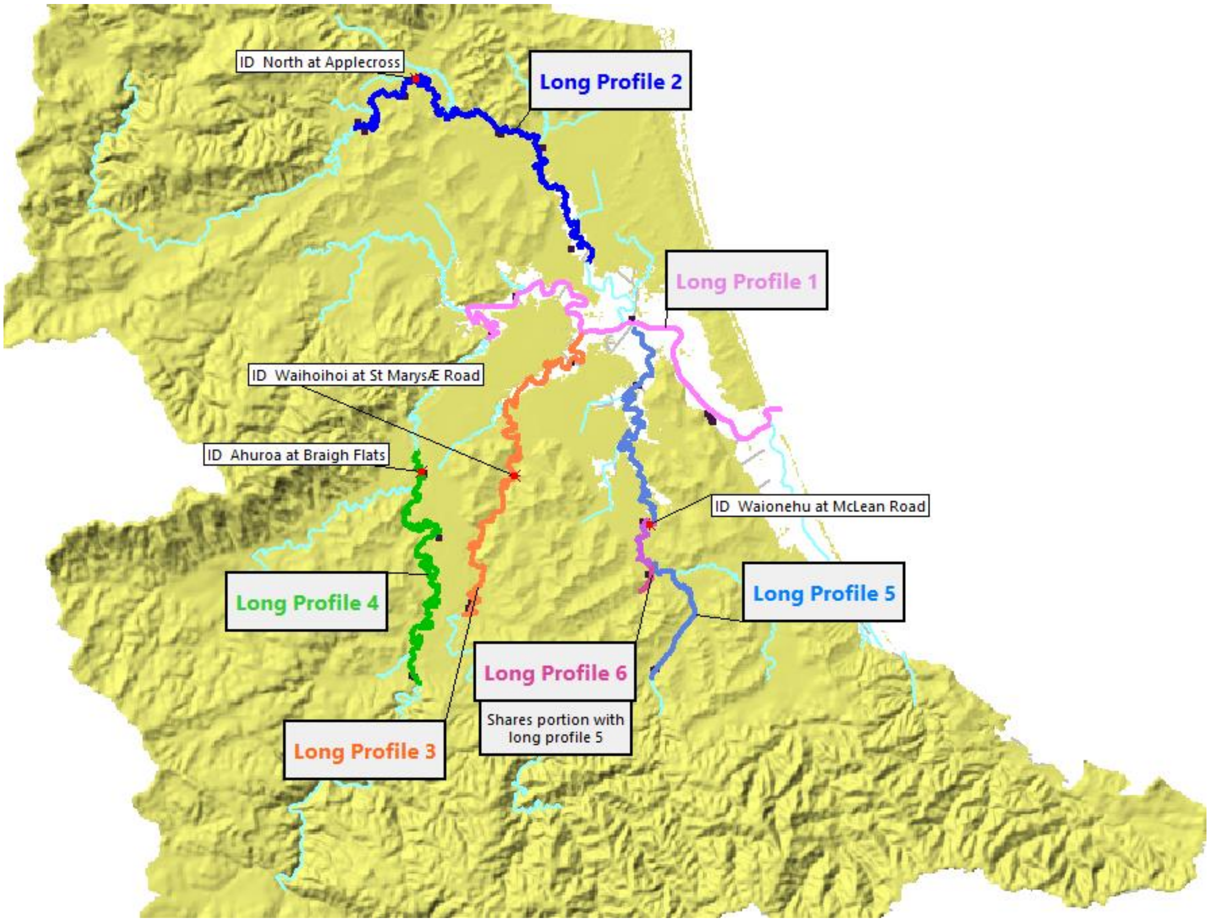


Figure 0.5 Waipu Catchment. Long profile locations. Lower catchment.

Figure. Long profiles for March 2007, as shown in following figures. Note that many points are over the 2D extent. In those cases, the projection over the long profile might not be accurate. The next figures show a detail of the location of all flood points related to the respective long profile. Note that this plan view figures are at scale, so small distances in the figure might still be significant in reality.

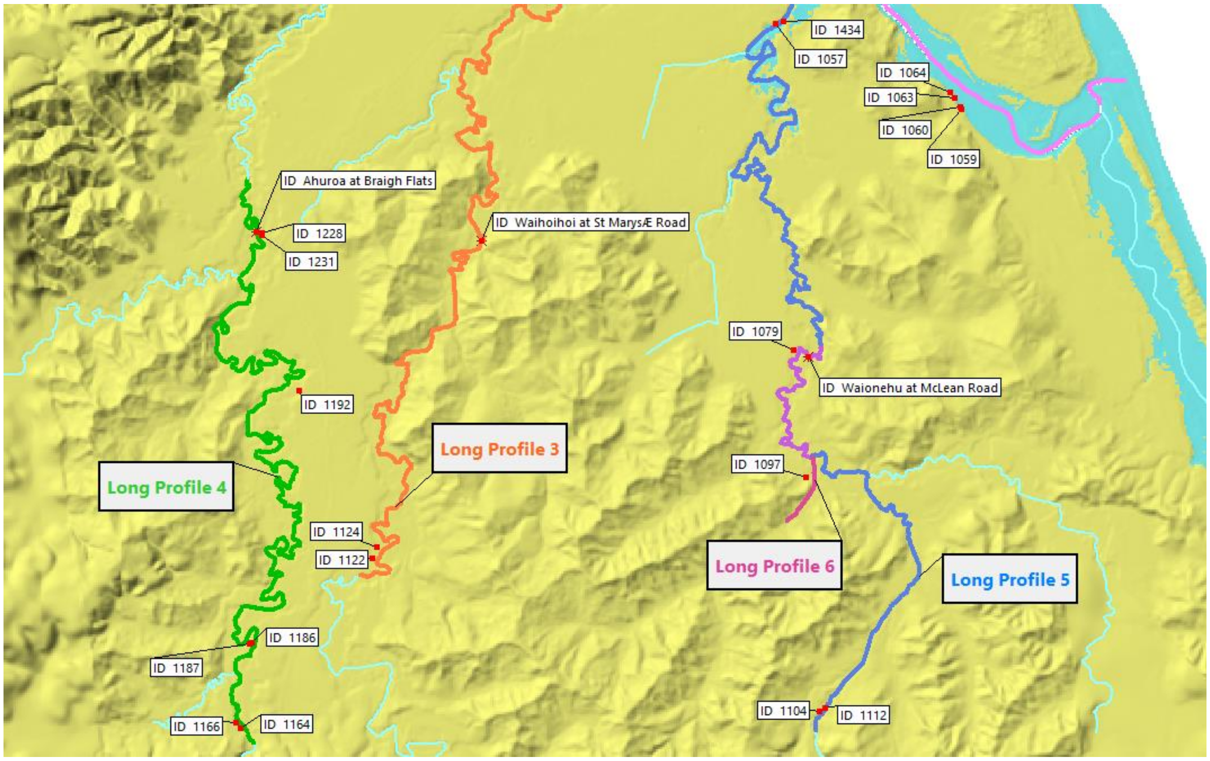


Figure 0.6 Waipu Catchment. Long profile locations. Southern catchment.

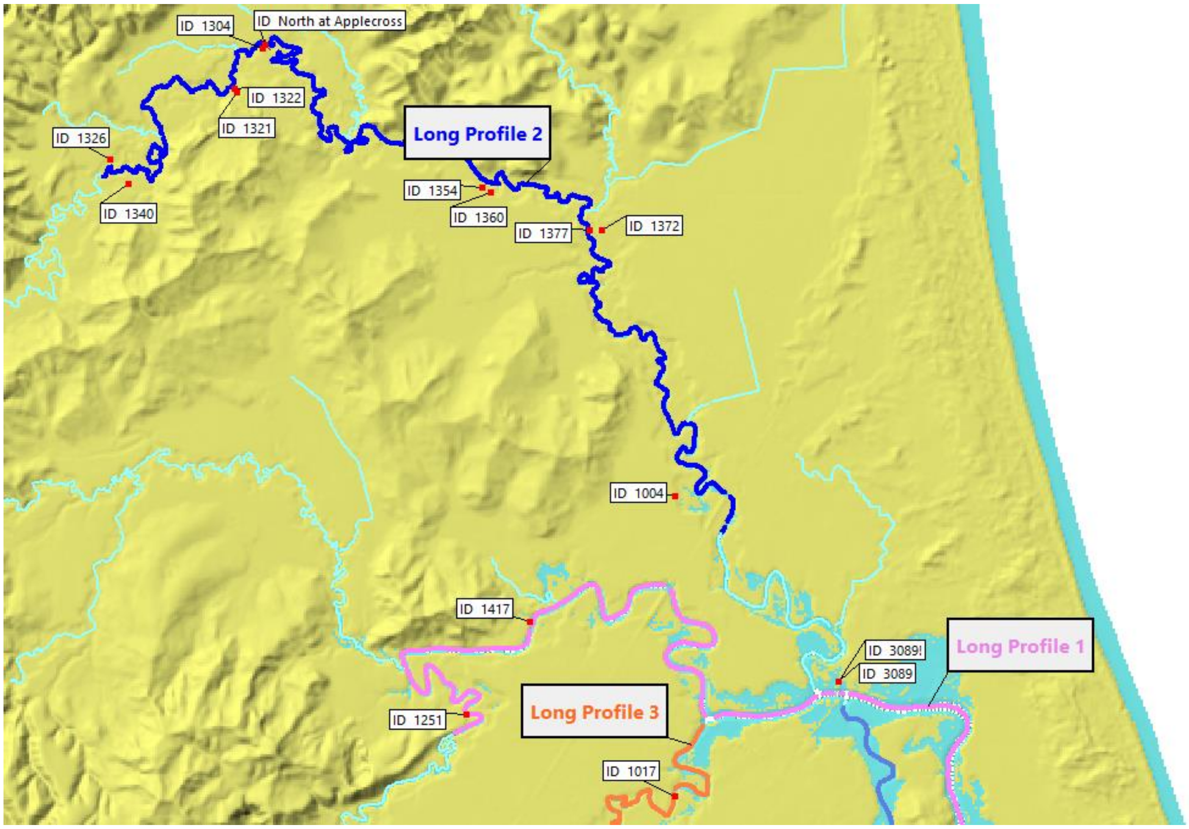


Figure 0.7 **Waipu Catchment. Long profile locations. Northern catchment.**

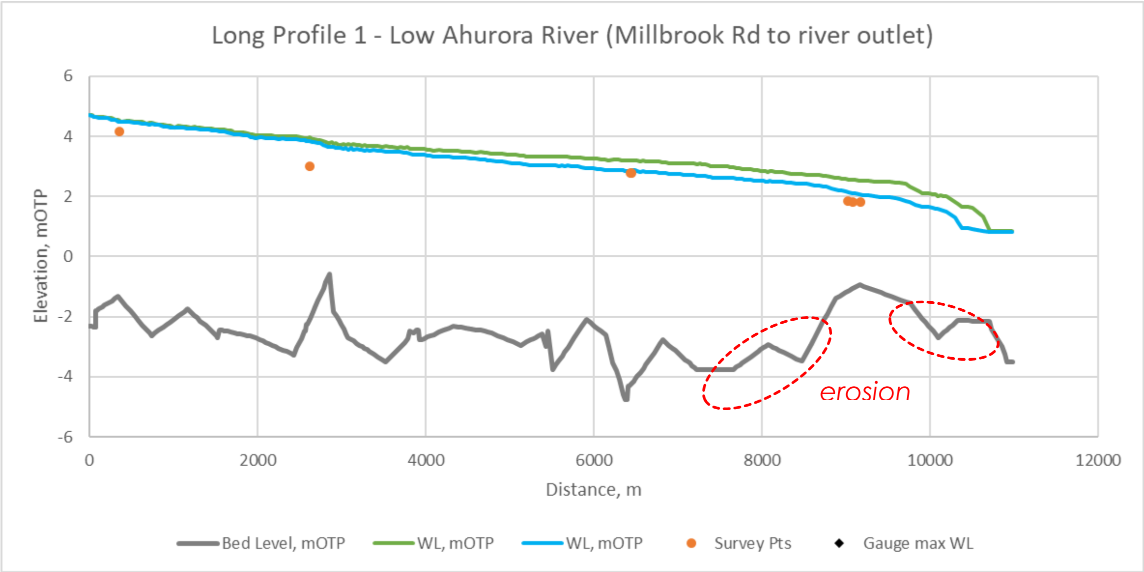


Figure 0.8 Long profile 1. Lower Waipu River.

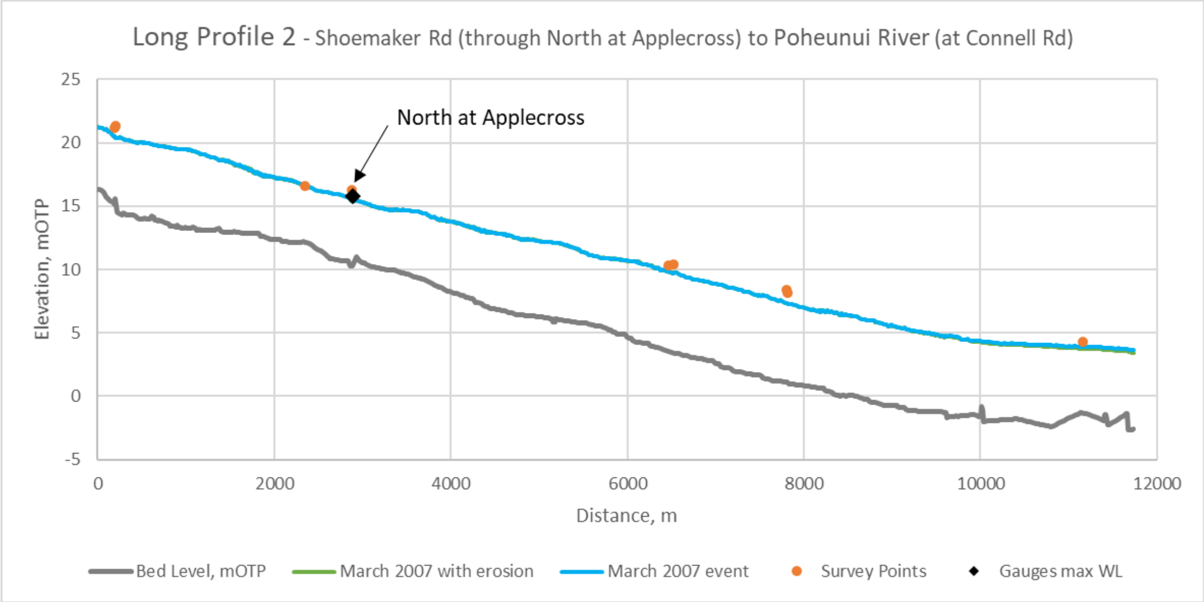


Figure 0.9 Long profile 2. At North at Applecross.

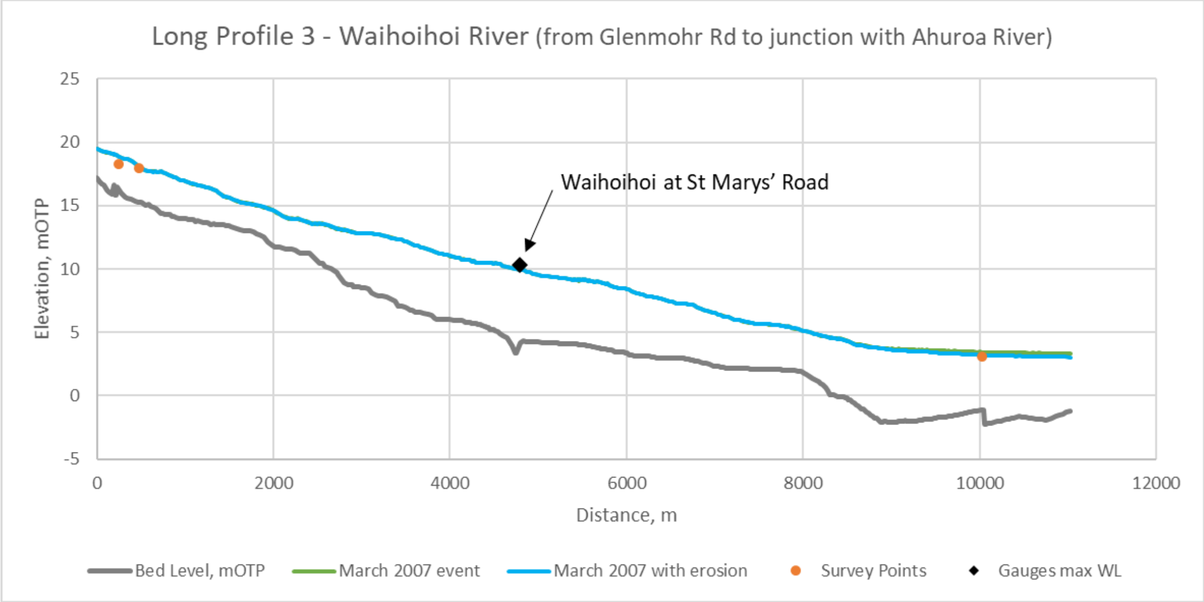


Figure 0.10 Long profile 3. At Waihiohio at St. Mary's Rd.

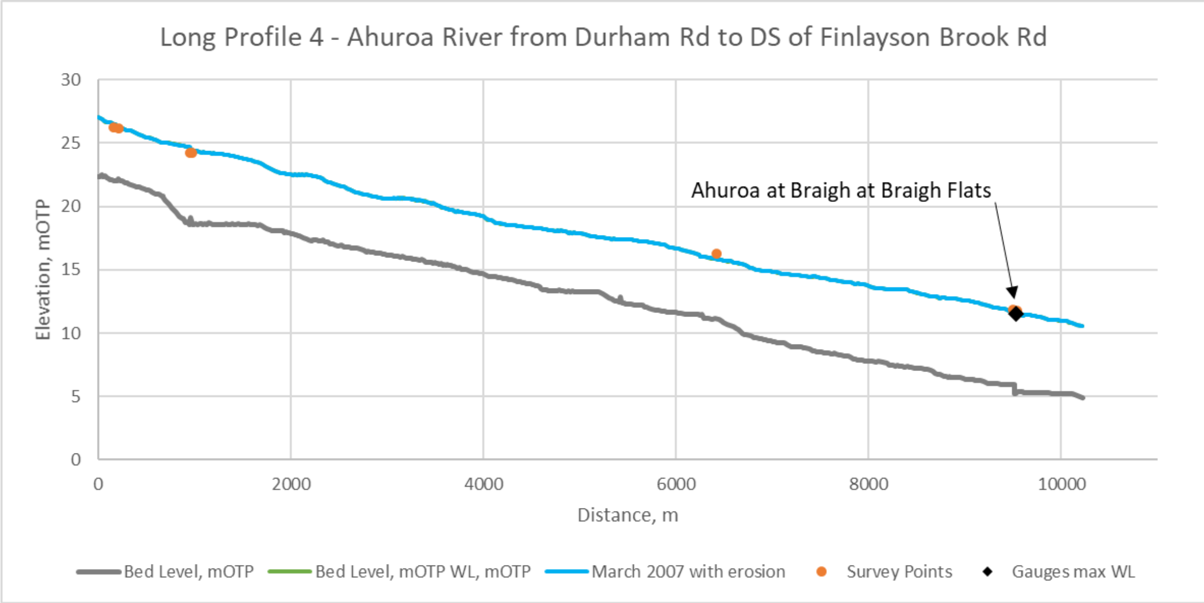


Figure 0.11 Long profile 4. At Ahuroa at Braigh Flats.

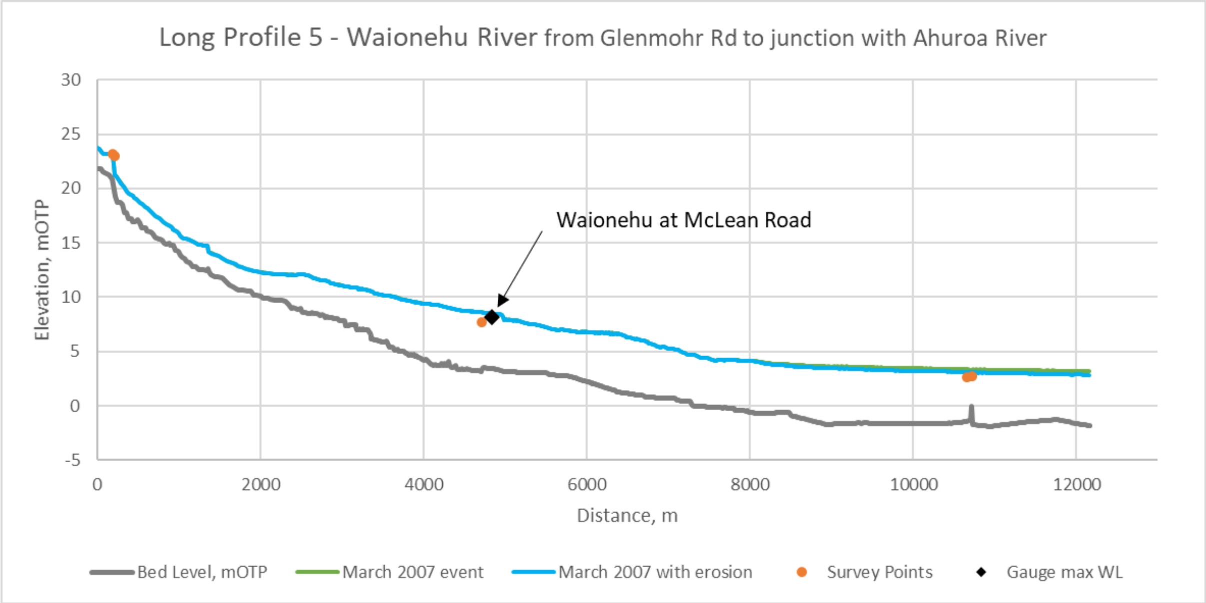


Figure 0.12 Long profile 5. At Waionehu at McLean Rd.

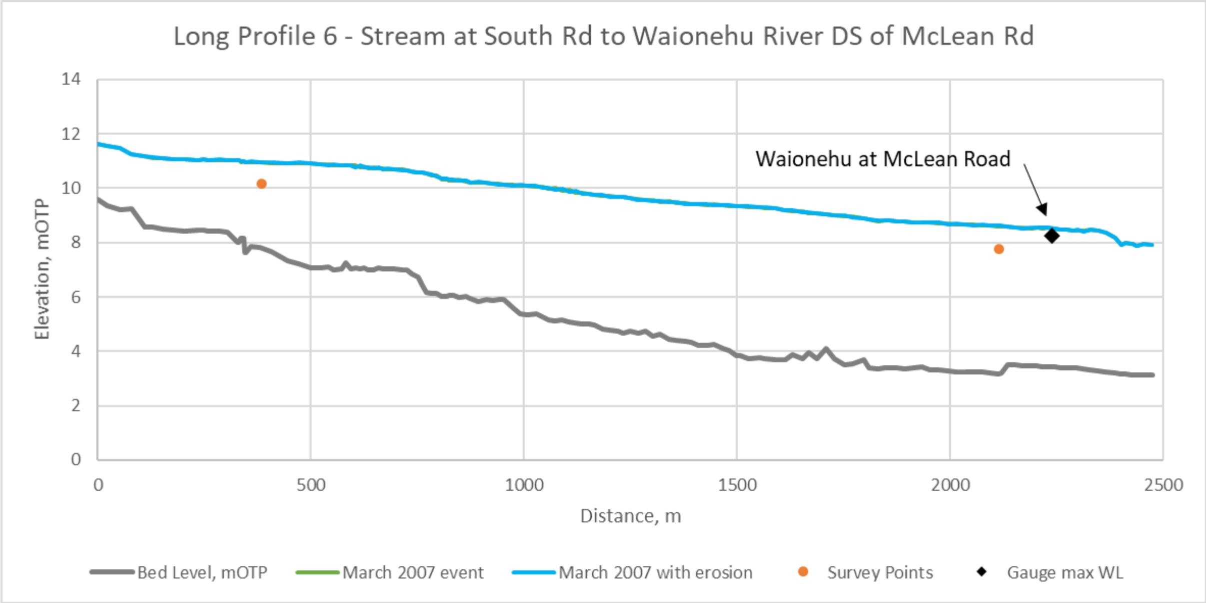


Figure 0.13 Long profile 5. Upstream of Waionehu at McLean Rd.

PAPAROA MODEL CALIBRATION RESULTS

The key parameters calibrated in Waipu are described below. The same criteria were used to define the Parameters in the Paparoa catchment.

- Ground from Lidar and survey cross sections. Burnt river bottom for main channels along long profile for portions where survey is available.
- Rougness manning, same range of roughness for same general features (river bottom elevation, surrounding roughness features as described by aerial and site visit).
- Non-linear reservoir parameters consider the same Equivalent Roughness method, which uses the topographical features of the sub-catchments (length and slope) to defined K and p based on secondary constant parameters. Paparoa uses the same method and parameters used for Waipu calibration.
- Rain abstractions were defined the same as Waipu, with a constant infiltration rate of 3.5mm/hr.

The Paparoa model results are consistent with the previous analysis done in Waipu. However, there are some of the differences that might be attributed to the survey quality, as it seems odd that some points are higher than their predecessor upstream. Figure 0.14 and Figure 0.15 summarized the results. Other sources of discrepancies might be the river mouth, tidal records, and the similarity between catchment features in terms of the criteria used to transfer the calibration parameters from Waipu into Paparoa catchment.

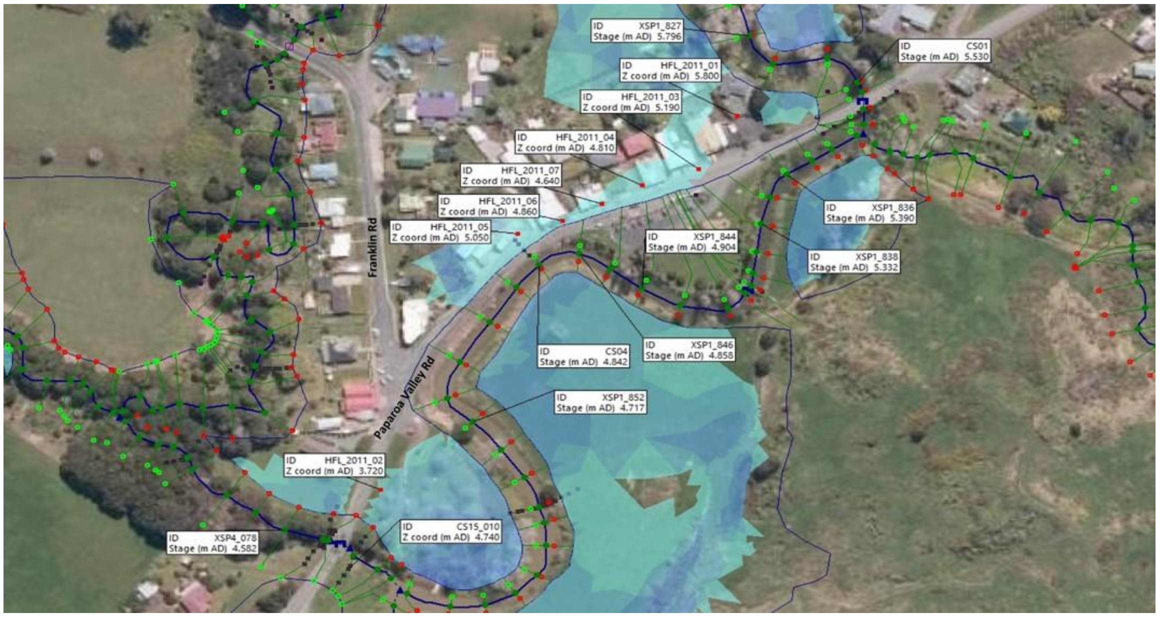


Figure 0.14 Paparoa Verification. Plan view of survey flood points.

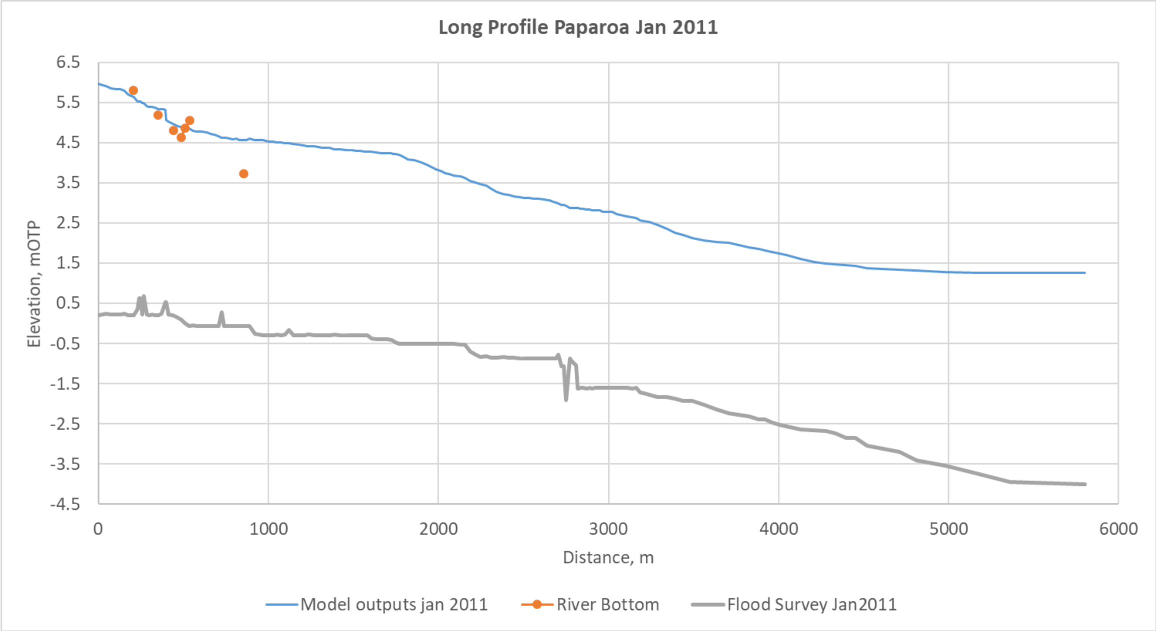


Figure 0.15 Paparoa Verification. Long profile of survey flood points.

EROSION RESULTS MARCH 2017

Figure 0.16 shows the long profile of the Waipu River at the river outlet, for March 2007 event.

The figure compares the outputs of the 3 erosion scenarios run for March 2007. Note that some erosion may also apply further upstream, but as per scope, the analysis was focused on the river mouth. For the mouth, the changes are not minor.

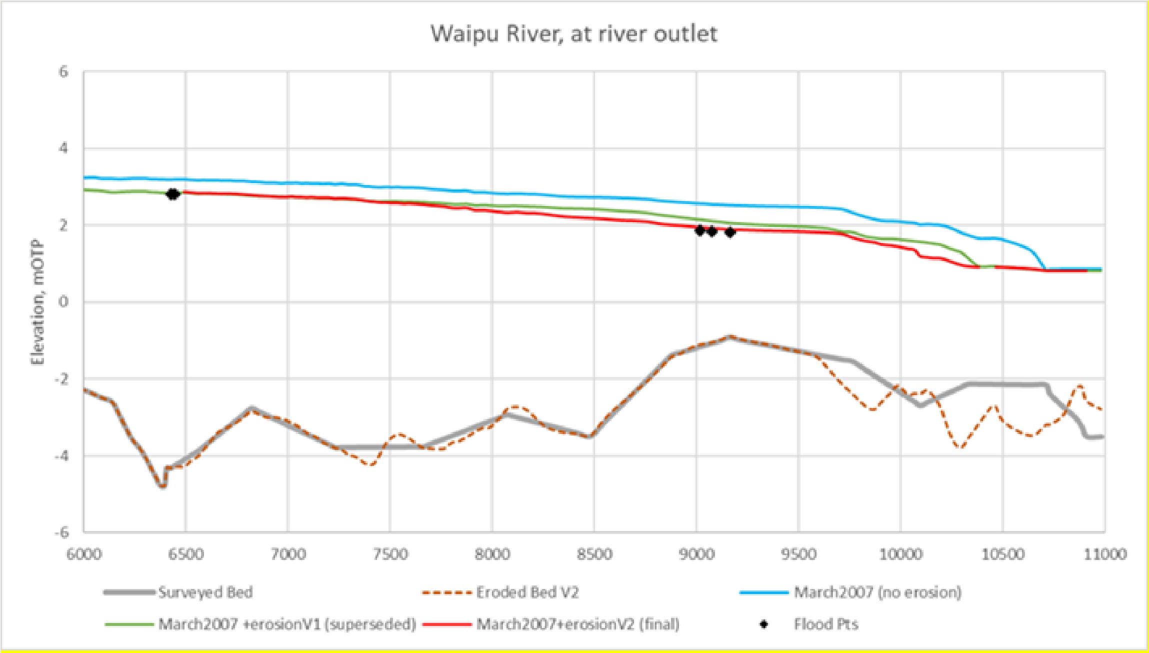


Figure 0.16 Low Waipu River long profile. March 2007 calibration with erosion.

The lump of sediment, around 9.0kms and 9.5kms of horizontal axe of Figure 0.16, does not experience significant erosion as it would be expected. The river is wider at this location, and velocities increase at the tilting point of the water when meeting the lower tides. This increase of velocities triggers erosion which travels upstream as the storm develops. This zone (around 9.0kms-9.5kms) is highly tidal, so sediment deposits here are consequence of the long term of low flows and tidal interaction (you might want to consider future studies on how to naturally remove sediment in this area to control floods).

Only the rising portion of the hydrograph has been used to estimate the final erosion. The new geometry is then run again for the entire duration of the storm.

Table below shows the 5 survey flood points results compared against the 3 scenarios described above.

Table 0.6. Calibration of low Waipu River. Flood points with erosion, which replace points in Table 0.5

Nearest XS	Survey Pt	RS Network ID	Chainage (from profile)	Surveyed WL, mOTP	March 2007 no erosion mOTP	March 2007 erosion V1 mOTP	March 2007 erosion V2 FINAL, mOTP
Br28_ds	3089	P02	6423.541	**2.827**	3.196	2.852	**2.869**
CS083	3089	P01	6440.843	**2.827**	3.196	2.852	**2.869**
XSW43_065	1064	P09	9012.57	**1.892**	2.577	2.164	**1.956**
XSW43_067	1063	P08	9070.159	**1.862**	2.548	2.112	**1.92**
CS110	1059	P06	9162.846	**1.842**	2.528	2.066	**1.891**

Table below shows some indication of the impact on water levels results for March 2007 and design events.

The design event model results have not yet been simulated, so except for March 2007, these are estimated values based on preliminary tests which are meant for the erosion estimations before the final run is simulated.

Additionally, 100yr+CC estimations are to be further adjusted and water level reduction expected to be smaller. This is because the current estimations still use the previous run which considers 0.5m of climate change. The scenario 100+cc(1m)-no-erosion is running and stable, and the table below will be adjusted accordantly before final design+erosion events are run (expected during next week if NRC agrees with calibration outputs).

The values show the maximum variations over the long profile above (between 6.5k and 11k). Average differences will be smaller.

Note, deposition happens mainly at the sea floor, as sediment are pushed out of the river and velocities reduced.

Table 0.7. Maximum erosion for Waipu river mouth. All erosion events.

Event	Min Erosion, m	Max Erosion, m	Max WL reduction, m
10yr	-0.833	0.327	0.180
50yr	-1.543	0.731	0.472
100yr	-1.709	1.086	0.715
100yr+CC (1m)	-1.293	0.769	0.480
Mar.07	-1.578	1.057	0.940

OTHER GENERAL CALIBRATION INPUTS/OUTPUTS

GRID SIZE

Table 0.8 below summarized the triangle size used in the model.

Table 0.8. Summary of 2D polyogns. Waipu and Paparoa.

	Waipu	Paparoa
Number of 2D polygons	105	53
Total 2D area, m2	36,413,569	2,108,647
Min element size, m2	3.0	3.0
Maximum element size, m2	5000	1000
Total number of elements	893803	127974

The small size triangles are distributed mainly along the river banks, streams, roads and features of interest. Large triangles are mainly for large plains.

TIME STEP

The time steps for both catchments and all events is between 0.2 – 1 seconds. Table 0.9 summarized the values used.

Table 0.9. Summary of time steps for all simulations runs.

Simlation Time Steps		
Event	Waipu	Paparoa
Jul-97	1 sec	
Mar-07	1 sec	
Jan-11	1 sec	0.20 - 1 sec
10yrs	1 sec	0.20 - 1 sec
50yrs	1 sec	0.25 sec
100yrs	1 sec	0.20 - 1 sec
100yrsCC	1 sec	0.25 sec

1D COURANT NUMBER

The Courant number for the model is to be defined for both 1D and 2D objects.

For the 1D model objects, InfoWorks RS technical documents advises:

"In so-called explicit computational schemes this [Courant Number] is limited to a maximum value of 1.0 which tends to result in very short timesteps, but in the implicit scheme used by InfoWorks it can be larger. Thus, for computational economy, CR is preferred large - say up to 5 or 10."

The Courant Number is generally defined by

$$CR = c \cdot \frac{\Delta t}{\Delta x} = (d \cdot g)^{0.5} \cdot \frac{\Delta t}{\Delta x}$$

Equation 0.1

Where c is the celerity of a water wave, which can be defined with the water depth (d) and gravitational acceleration (g). Δt and Δx are the time step and the computational distance, which is the distance between cross sections.

As per Equation 0.1, the Courant Number is defined then for each model object. Below the table summarized the model range of values to determine the range of Courant numbers described in the models.

Table 0.10. 1D Courant Number and relating parameters. Waipu Catchment.

Waipu	*Δx*	*Δt*	*h*	*CR*
Extreme max	5	1	5.3	1.44
Extreme min	150	1	2	0.03
Average	12	1	1.2	0.29

For Waipu, the average cross section distance is about 12 meters, with some minimum values around 5 meters, and some other maximum values over 100m only at tidal zones and outside of lidar (about 12 links). About the Courant number, the maximum between 1-1.44 happens for 9 cross sections (out of 5654 XSs).

Table 0.11. 1D Courant Number and relating parameters. Paparoa Catchment.

Paparoa	*Δx*	*Δt*	*h*	*CR*
Extreme max	2.5	1	5.0	2.80
Extreme min	150	0.2	4	0.01
Average	12	0.25	1.4	0.08

In Paparoa, there is hand full of links with distances larger than 100m, and only at the end of the tidal zone, by the river mouth (where cross sections are equally wide). Values of the Courant number largen than 1 (and *CR* < 2.80) happened in no more than in 15 locations. This is at few locations where the distance is short (around 5m). However, the time step used in Pararoa was 0.25 or adaptative between 0.2 – 1 sec. This means that the extreme value of *Δt*=1sec (which related to the higher *CR* numbers) might have not happen at all, as the engine would select the time step inside this range to fulfil the most stable model output.

In all cases, the Courant number was well inside InfoWorks RS advised range, and with average values well under CR=1.0.

2D COURANT NUMBER

For the 2D Courant number, InfoWorks RS technical documents advises:

The shallow water equations (SWE), that is, the depth-average version of the Navier-Stokes equations, are used for the mathematical representation of the 2D flow. The SWE assume that the flow is predominantly horizontal and that the variation of the velocity over the vertical coordinate can be neglected.

The conservative formulation of the SWE is essential in order to preserve the basic fundamental quantities of mass and momentum. This type of formulation allows the representation of flow discontinuities and changes between gradually and rapidly varied flow. The conservative SWE are discretised using a first-order finite volume explicit scheme. Finite volume schemes use control volumes to represent the area of interest. With finite volume methods the modelling domain is divided into geometric shapes over which the SWE are integrated to give equations in terms of fluxes through the control volume boundaries. The scheme that is used to solve the SWE is based upon the Gudunov numerical scheme, with the numerical fluxes through the boundaries of the control volumes computed using the standard Roe's approximate Riemann solver. Finite volume methods are generally considered to have a number of advantages in terms of conservativeness, geometric flexibility and conceptual simplicity.

As the scheme is an explicit solution it does not require iteration to achieve stability within defined tolerances like the 1D scheme. Instead, for each element, the required timestep is calculated using the Courant-Friedrichs-Lewy condition in order to achieve stability, where the Courant-Friedrichs-Lewy condition is:

$$\alpha \cdot \frac{\Delta t}{\Delta x} \leq 1$$

Equation 0.2

Where α is the constant defined as 0.95.

InfoWorks uses an unstructured mesh to represent the 2D zone and this together with the scheme used allow robust simulation of rapidly varying flows (shock capturing) as well as super-critical and transcritical flows.

In simpler terms, the InfoWorks RS 2D engine first set the Courant number to be < 1 (by using a value of 0.95) and defines a 2D time step for the explicit solution of 2D equations. In other words, by definition, InfoWorks RS solve the 2D equations by setting the Courant number <1.

MASS ERROR

Mass error was checked for all calibration model outputs. The table below summarized the error for the 2D polygons, by showing only the 2D polygon with the larger mass error of the simulation, the global mass error is much smaller.

Table 0.12. Mass error summary for 2D polygons.

Event	Max mass error for 2D polygons (%)	
	Waipu	Paparoa
July 1997	-2.6	N/A
March 2007	-2.0	N/A
January 2011	-1.8	0.00

WAIPU RUNOFF VOLUMES

Volumes required extensive analysis to determine suitable and reliable calibration parameters. As stated in previous sections of this report, the volume analysis implies an increment of the volumes compared with the recorded data. The table below summarized the calibration achieved in terms of volumes:

Table 0.13. Summary of water volumes for all gauges and calibration/validation events.

Ahuroa at Braigh	G01 - July 1997	G01 - March 2007	G01 - January 2011
Catchment Area, m2	56006176	56006176	56006176
Rain Volume, m3	15069209	12534905	10721360
Rain depth, mm	269.1	223.8	191.4
Rec Runoff, m3	6531847	5618893	5392388
Rec RC	0.43	0.45	0.50
Modelled Runoff, m3	9608694	7169595	7449565
Modelled RC	0.64	0.57	0.69
North at Applecross	G02 - July 1997	G02 - March 2007	G02 - January 2011
Catchment Area, m2	38919385	38919385	38919385
Rain Volume, m3	5019372	8984003	8896584
Rain depth, mm	129.0	230.8	228.6
Rec Runoff, m3	3302334	4586948	3869705
Rec RC	0.66	0.51	0.43
Modelled Runoff, m3	2948816	4952672	6247623
Modelled RC	0.59	0.55	0.70
Waihoihoi at St Mary's Rd	G03 - July 1997	G03 - March 2007	G03 - January 2011
Catchment Area, m2	26965359	26965359	26965359
Rain Volume, m3	7413230	6311073	5136901
Rain depth, mm	274.9	234.0	190.5
Rec Runoff, m3	2610098	2276663	2036304
Rec RC	0.35	0.36	0.40
Modelled Runoff, m3	5298874	3520497	3705627
Modelled RC	0.71	0.56	0.72
Waionehu at McLean Rd	G04 - July 1997	G04 - March 2007	G04 - January 2011
Catchment Area, m2	24367524	24367524	24367524
Rain Volume, m3	6181580	5704944	4642013
Rain depth, mm	253.7	234.1	190.5
Rec Runoff, m3	2009420	2144972	1529774
Rec RC	0.33	0.38	0.33
Modelled Runoff, m3	3106611	2588213	2449993
Modelled RC	0.50	0.45	0.53

Note that July 1997 storm is known to had significant changes overt the catchment, and records are described by only one auto gauge. This makes the recorded volumes (and respective runoff coefficient) not as reliable as the other storms. In that regard, the storm of Jan 2011 has the most reliable records in terms of rain volumes and its distribution over the catchment.

The final runoff is generally between 0.55 and 0.70, which it might still look a bit low compared with other catchments in the Northland Region. In this regard, Waipu has shown to have various particularities which can't be fully understood with the current data, especially with the potential inaccuracy of the records.

DESIGN EVENT RESULTS

Design events are simulated following the methodology and finding regarding the model performance and model calibration described in this report. Below a general summary of the final design events outputs, which also has erosion considerations for the Waipu model.

Table 0.1. Summary of design event water balance outputs. Paparoa catchment.

Paparoa	Unit	10yrs	50yrs	100yrs	100yrsCC
Total baseflow (outlet)	m/s	0.43	0.43	0.43	0.43
Rain depth min	mm	66	99	117	137
Rain depth max	mm	78	117	139	162
Rain depth average	mm	71.8	107.5	127.4	148.8
RC min		0.59	0.70	0.73	0.77
RC max		0.77	0.83	0.85	0.87
RC average		0.70	0.78	0.81	0.84
Total catchment size	m2	46,465,310	46,465,310	46,465,310	46,465,310
Total rain volume	m3	3,338032	4,994,220	5,921,609	6,916,187
Total runoff volume	m3	2,339,508	3,898,785	4,800,136	5,776,227

Table 0.2. Summary of design event water balance outputs. Waipu catchment.

Waipu	Unit	10yrs	50yrs	100yrs	100yrsCC
Total baseflow (outlet)	m/s	2.25	2.25	2.25	2.25
Rain depth min	mm	93	140	166	194
Rain depth max	mm	118	176	210	245
Rain depth average	mm	101.3	152.1	180.6	211.0
RC min		0.66	0.75	0.78	0.81
RC max		0.73	0.80	0.82	0.84
RC average		0.70	0.78	0.81	0.83
Total catchment size	m2	225,364,838	225,364,838	225,364,838	225,364,838
Total rain volume	m3	22,826,109	34,273,789	40,704,890	47,543,134
Total runoff volume	m3	15,893,433	26,687,487	32,794,009	39,328,197

DELIVERABLES AND DISCUSION

DISCUSSION

Various uncertainties are present on the development of this catchment study. Key aspects are the runoff volumes and rating curve reliability for high flows, which was studied on extent to settle on most likely description based on the available data. As consequence of these analysis, the flows records were replaced by correction done over the rating curves, and the calibration was focused on the water level records while providing consistent runoff volumes and calibration parameters. Flood level survey also complemented the calibration, and together with an erosion analysis, led to erosion considerations for the design events which increase the river mouth capacity for a given flow and tidal conditions.

The analysis described are well developed in the various sections of this report and aim to provide a comprehensive understanding of all parts of the hydrological and hydraulic features which reflects in a calibrated model consistent with recorded data, ground features and catchment characteristics. The result is a reliable calibrated integrated catchment model to represent the dynamic of floods and assist with the assessment of flood risk and catchment management.

The calibrated model is finally run for design events, which uses the same hydrological and hydraulic parameters of calibration, except for boundary conditions (rain and tides) and the initial abstractions, which is set to be saturated at the beginning of the storm. The last has little to null impact on results, and a slightly conservative approach for the risk of floods.

RECOMENDATION

It is important to understand the limitations of the model by understanding the various matters that made this study a challenging exercise. The model outputs are consistent with the available data, but there are various uncertainties and significant gaps which were approached with broad assumptions and based on our expertise with the subjects, as well as discussions with the client. These matters are also focus of interest as they play critical roles in the description of the catchment drainage and its dynamic. Further studies are recommended for the subjects listed below, to assess the potential benefits to incorporate them into the catchment management practices, and to provide confirmation of the approach developed and confident on the quality of the final model outputs delivered by this project.

Review of rating curves for high flows. There are not flow measurements for high flows, especially for the portion of the rating curve utilized by the large storms and main source of volume data. It is recommended that further research is done on the subject, starting from the measurement methodologies utilized (to address large flow event measurements), as well as the development of rating curves itself. For the latter, it is recommended that rating curves are assisted by modelling, which can integrate river capacity, flood plain storage capacities, roughness, vegetation, bridges and other obstructions, lateral spills, backwaters and other boundary conditions. Waipu and Paparoa models could assist to provide key locations for alternative flow measurements, and possible alternative measurement methods.

- River mouth erosion. Broad assumptions were made for the erosion analysis, and the calibration is based on fragmented data. The impact of the erosion showed to be of significance at the river mouth, and further studies could provide confirmation on the approach developed and the quality of the final mode outputs. In this regard, the outputs might still be well conservative, and the impact of erosions and sand bars could well be engineered to keep the river drainage in optimums conditions whenever a storm event might hit. This could include tidal controls, periodic or programmed sand dragging, river bank protections, seasonal secondary outlets, infiltration through sand bars, controlled flushes, storage river gates, among others.

DELIVERABLES

The list of deliverables is shown in Appendix 0. This considers:

- Model files, with model outputs for calibration/validation events and design events.
- Model files for erosion analysis
- Supporting files for model, such linked photographs and layers.
- Processed model outputs in GIS package, which contains rasters, flood extents, model outputs shapes and other supporting layers.
- Report

APPENDICES

LIST OF DELIVERABLES

- GIS Packages
- Model Files
- Model Report

APPENDIX A - GIS PACKAGES

2 packages: Waipu and Paparoa. They are ArcGIS 10 packages and delivered in zipped file.

- GIS Packages\Waipu.ZIP
- GIS Packages\Paparoa.ZIP

APPENDIX B - MODEL FILES

There are five InfoWorks RS v13 transportable databases (*.iwc). Each of them containing a portion of the whole. Pararoa model files are contained in a single file, and the rest relate all to Waipu model.

Some model objects, mainly objects contained in the model networks (such as general points, survey lines, layers, etc), are linked to external data such as shapes files and photographic records. In order to reproduce these features in the receiving device, all files should be transferred in the same folder structure as delivered. The exceptions are the icmt files, which shall be replace by one or more Master Databases containing the information held on each. Note that various icmt files can be loaded on the same Master Database, however, the size of the holding file should not exceed 2Gbs for an adequate performance of the software. The creating and transferring of data from a transportable database (.iwc) to a master database (*.iwm) is done through the InfoWorks RS Admin v13.

A list of files provided is below:

- Model files….
- Survey files (photos)…
- Layers (shpes, aerial)….

Table 0.1. Rain series details. Waipu catchment.

WAIPU CATCHMENT Rain depth defined in model, with respective areal reduction factor (ARF) and spatial distribution factors (SDF)						
			Design rain depth, 12 hours duration storm (mm)			
Event ID name	**ARF**	**SDF**	**10yrs**	**50yrs**	**100yrs**	**100yrsCC**
Design_Rain_ARF=0.842_fc=0.92	0.842	0.92	93.2	140.0	166.2	194.2
Design_Rain_ARF=0.842_fc=0.93	0.842	0.93	94.2	141.5	168.1	196.3
Design_Rain_ARF=0.842_fc=0.94	0.842	0.94	95.3	143.0	169.9	198.4
Design_Rain_ARF=0.842_fc=0.95	0.842	0.95	96.3	144.5	171.7	200.5
Design_Rain_ARF=0.842_fc=0.96	0.842	0.96	97.3	146.1	173.5	202.6
Design_Rain_ARF=0.842_fc=0.97	0.842	0.97	98.3	147.6	175.3	204.7
Design_Rain_ARF=0.842_fc=0.98	0.842	0.98	99.3	149.1	177.1	206.8
Design_Rain_ARF=0.842_fc=0.99	0.842	0.99	100.3	150.6	178.9	208.9
Design_Rain_ARF=0.842_fc=1.00	0.842	1.00	101.3	152.2	180.7	211.1
Design_Rain_ARF=0.842_fc=1.01	0.842	1.01	102.3	153.7	182.5	213.2
Design_Rain_ARF=0.842_fc=1.02	0.842	1.02	103.4	155.2	184.3	215.3
Design_Rain_ARF=0.842_fc=1.03	0.842	1.03	104.4	156.7	186.1	217.4
Design_Rain_ARF=0.842_fc=1.04	0.842	1.04	105.4	158.2	187.9	219.5
Design_Rain_ARF=0.842_fc=1.05	0.842	1.05	106.4	159.8	189.7	221.6
Design_Rain_ARF=0.842_fc=1.06	0.842	1.06	107.4	161.3	191.5	223.7
Design_Rain_ARF=0.842_fc=1.07	0.842	1.07	108.4	162.8	193.4	225.8

Design_Rain_ARF=0.842_fc=1.08	0.842	1.08	109.4	164.3	195.2	227.9
Design_Rain_ARF=0.842_fc=1.09	0.842	1.09	110.5	165.8	197.0	230.1
Design_Rain_ARF=0.842_fc=1.10	0.842	1.10	111.5	167.4	198.8	232.2
Design_Rain_ARF=0.842_fc=1.11	0.842	1.11	112.5	168.9	200.6	234.3
Design_Rain_ARF=0.842_fc=1.12	0.842	1.12	113.5	170.4	202.4	236.4
Design_Rain_ARF=0.842_fc=1.13	0.842	1.13	114.5	171.9	204.2	238.5
Design_Rain_ARF=0.842_fc=1.14	0.842	1.14	115.5	173.5	206.0	240.6
Design_Rain_ARF=0.842_fc=1.15	0.842	1.15	116.5	175.0	207.8	242.7
Design_Rain_ARF=0.842_fc=1.16	0.842	1.16	117.5	176.5	209.6	244.8

Table 0.2. Rain series details. Paparoa catchment.

PAPAROA CATCHMENT Rain depth defined in model, with respective areal reduction factor (ARF) and spatial distribution factors (SDF)						
Event ID name	**ARF**	**SDF**	**Design rain depth, 6 hours duration storm (mm)**			
			10yrs	**50yrs**	**100yrs**	**100yrsCC**
Design_Rain_ARF=0.842_fc=0.92	0.923	0.92	66.1	98.9	117.3	137.0
Design_Rain_ARF=0.842_fc=0.93	0.923	0.93	66.8	100.0	118.5	138.4
Design_Rain_ARF=0.842_fc=0.94	0.923	0.94	67.5	101.0	119.8	139.9
Design_Rain_ARF=0.842_fc=0.95	0.923	0.95	68.3	102.1	121.1	141.4
Design_Rain_ARF=0.842_fc=0.96	0.923	0.96	69.0	103.2	122.4	142.9
Design_Rain_ARF=0.842_fc=0.97	0.923	0.97	69.7	104.3	123.6	144.4
Design_Rain_ARF=0.842_fc=0.98	0.923	0.98	70.4	105.3	124.9	145.9
Design_Rain_ARF=0.842_fc=0.99	0.923	0.99	71.1	106.4	126.2	147.4
Design_Rain_ARF=0.842_fc=1.00	0.923	1.00	71.8	107.5	127.5	148.9
Design_Rain_ARF=0.842_fc=1.01	0.923	1.01	72.6	108.6	128.7	150.4
Design_Rain_ARF=0.842_fc=1.02	0.923	1.02	73.3	109.6	130.0	151.8
Design_Rain_ARF=0.842_fc=1.03	0.923	1.03	74.0	110.7	131.3	153.3
Design_Rain_ARF=0.842_fc=1.04	0.923	1.04	74.7	111.8	132.6	154.8
Design_Rain_ARF=0.842_fc=1.05	0.923	1.05	75.4	112.9	133.8	156.3
Design_Rain_ARF=0.842_fc=1.06	0.923	1.06	76.2	113.9	135.1	157.8
Design_Rain_ARF=0.842_fc=1.07	0.923	1.07	76.9	115.0	136.4	159.3
Design_Rain_ARF=0.842_fc=1.08	0.923	1.08	77.6	116.1	137.7	160.8

Design_Rain_ARF=0.842_fc=1.09	0.923	1.09	78.3	117.2	138.9	162.3

MODEL OUTPUTS

Calibration graphs and tables.

AHUROA AT BRAIGH FLATS (G01)

A. STORM OF JULY 1997

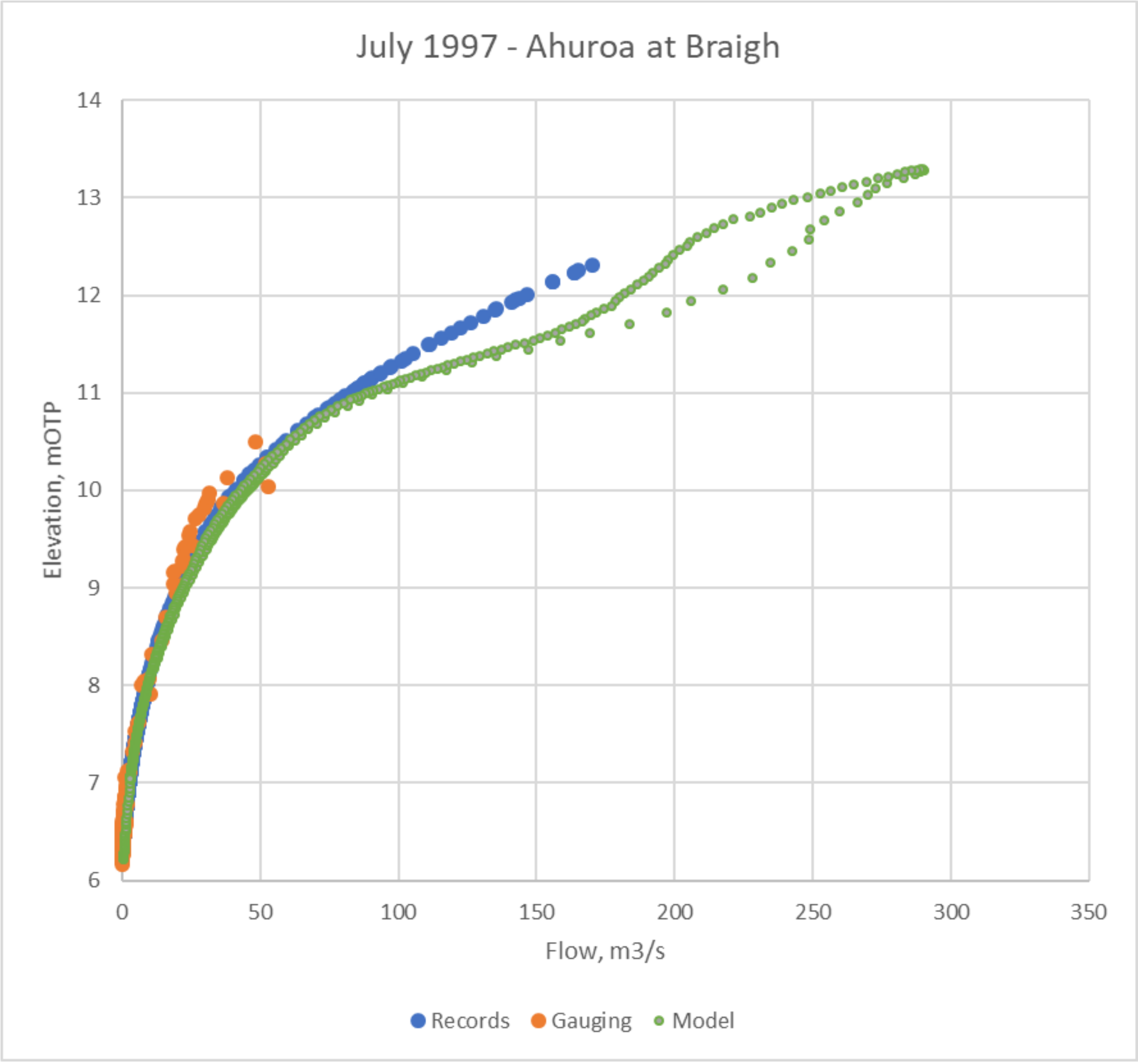


Figure 0.1 Rating Curve Calibration July 1997 – Ahuroa at Braigh

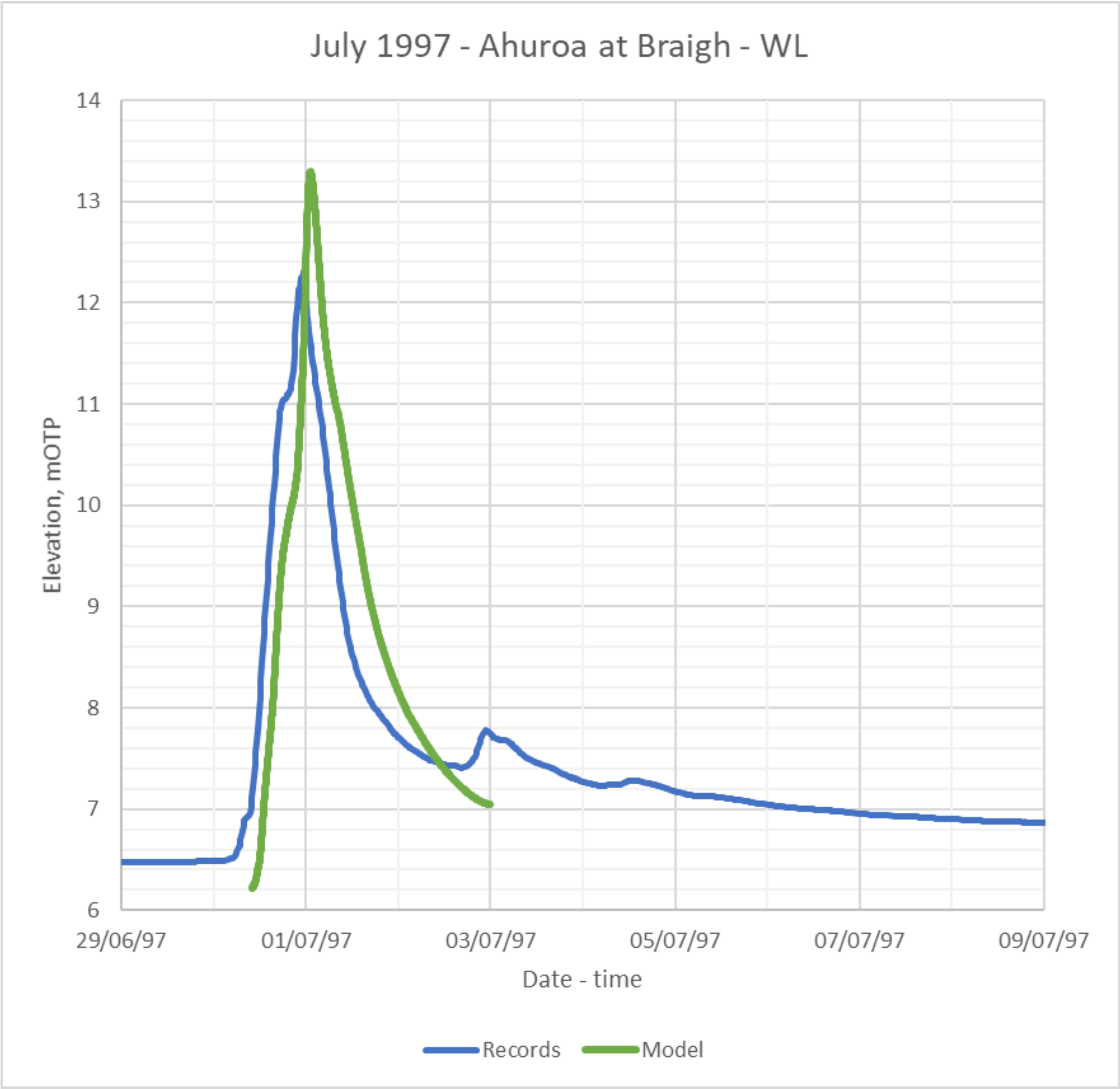


Figure 0.2 Water Level Calibration July 1997 – Ahuroa at Braigh

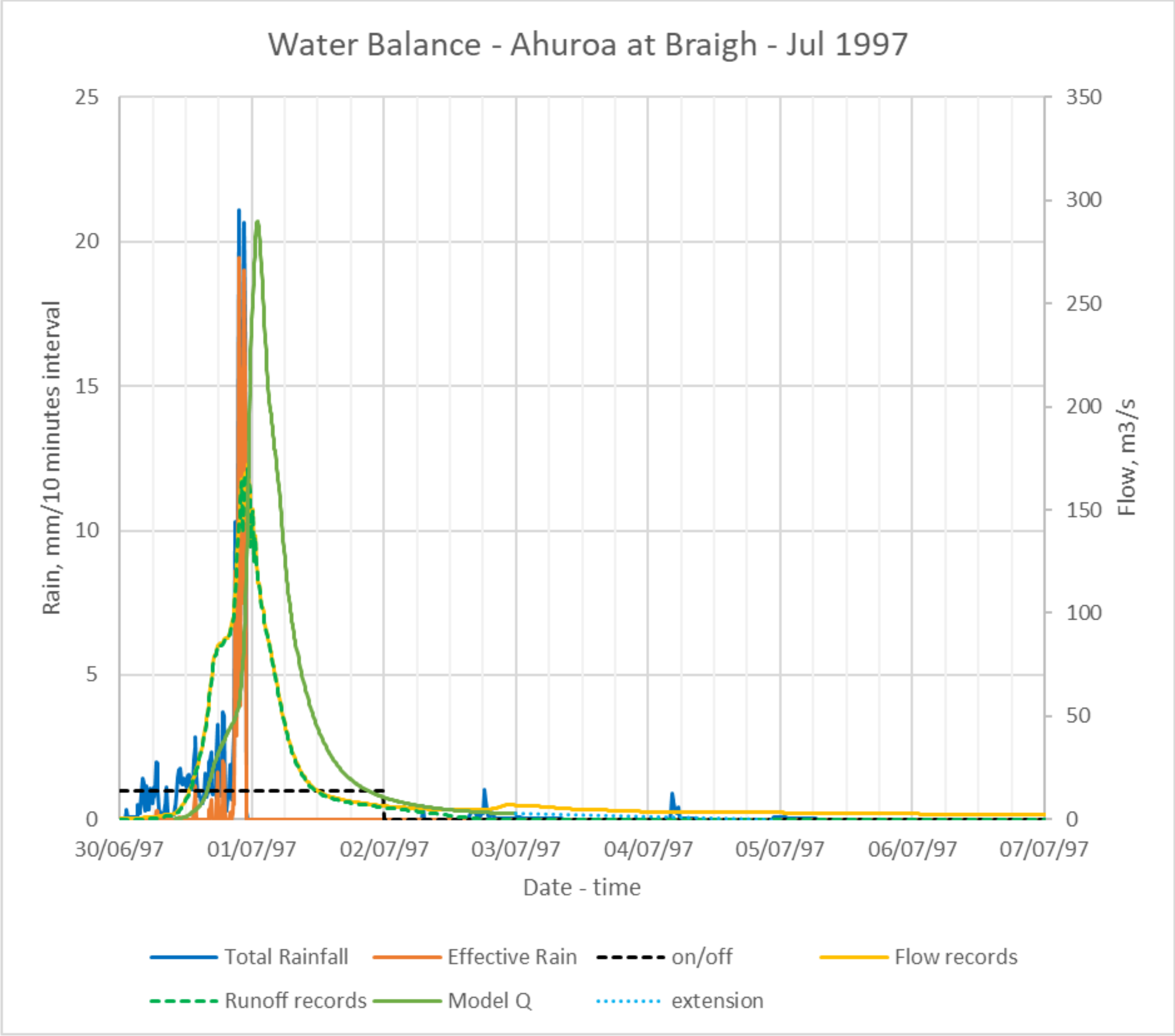


Figure 0.3 Water Balance and Flow Calibration July 1997 – Ahuroa at Braigh

Figure 0.4 Rating Curve Calibration March 2007 – Ahuroa at Braigh

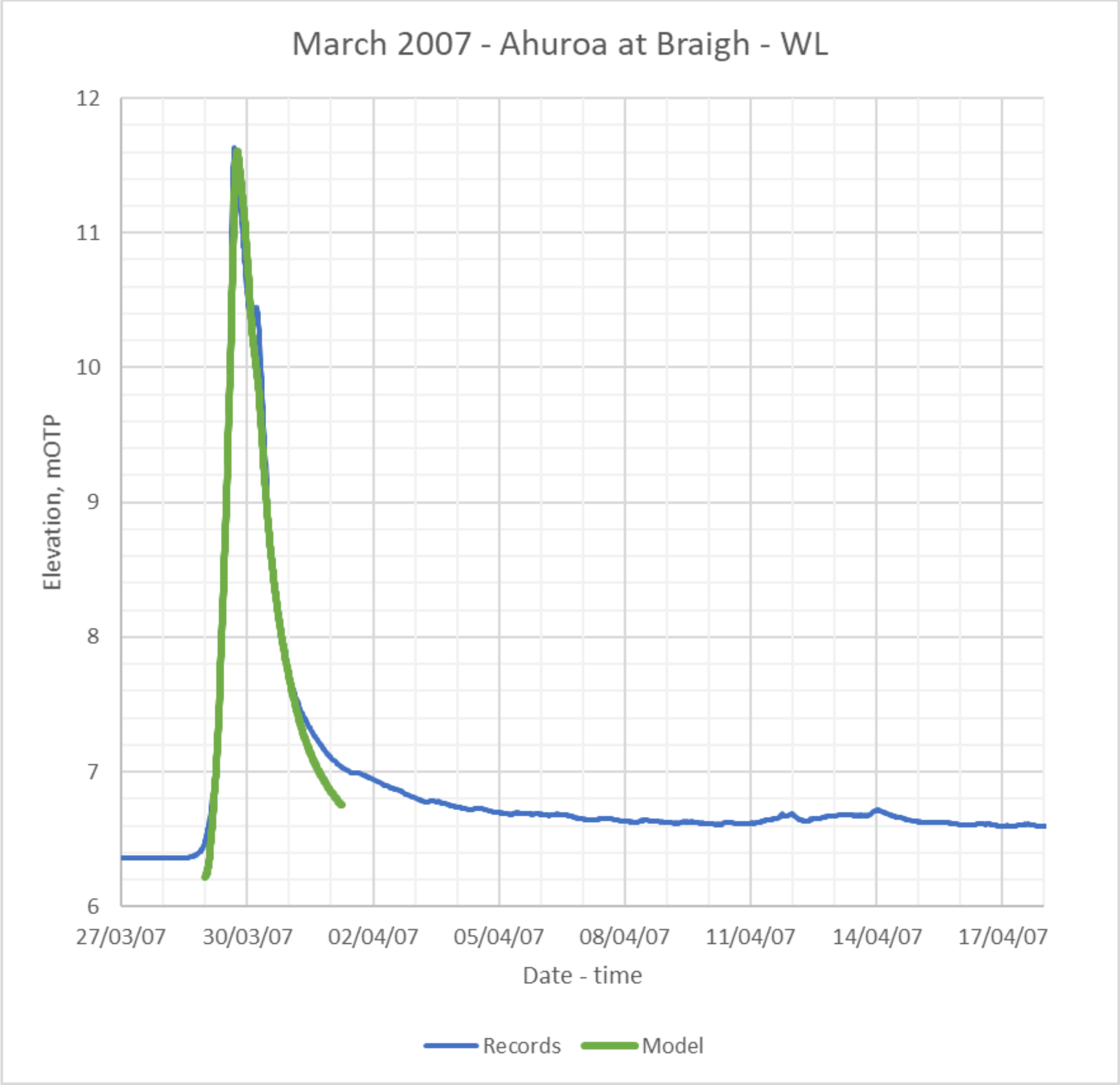


Figure 0.5 Water Level Calibration March 2007 – Ahuroa at Braigh

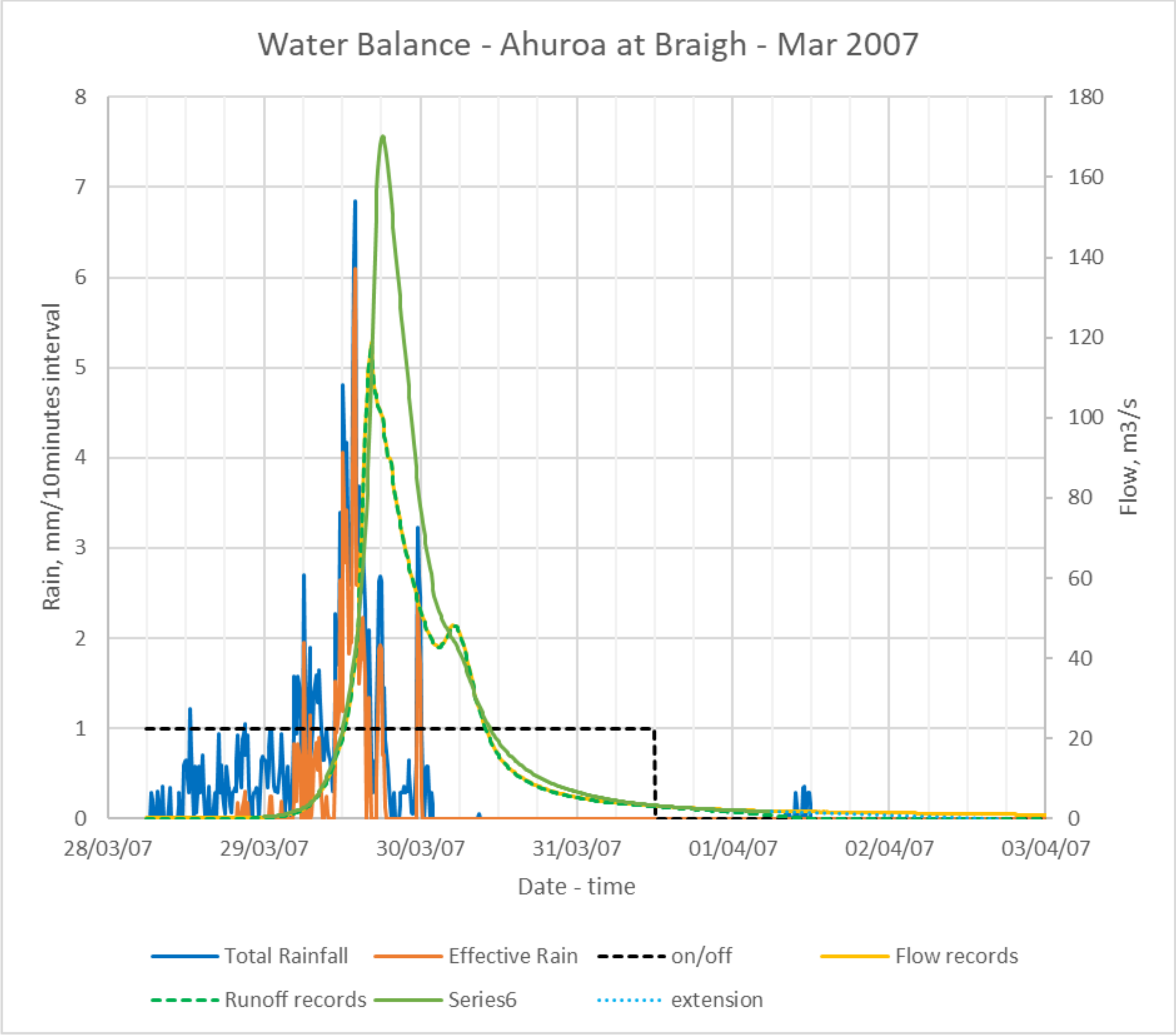


Figure 0.6 Water Balance and Flow Calibration March 2007 – Ahuroa at Braigh

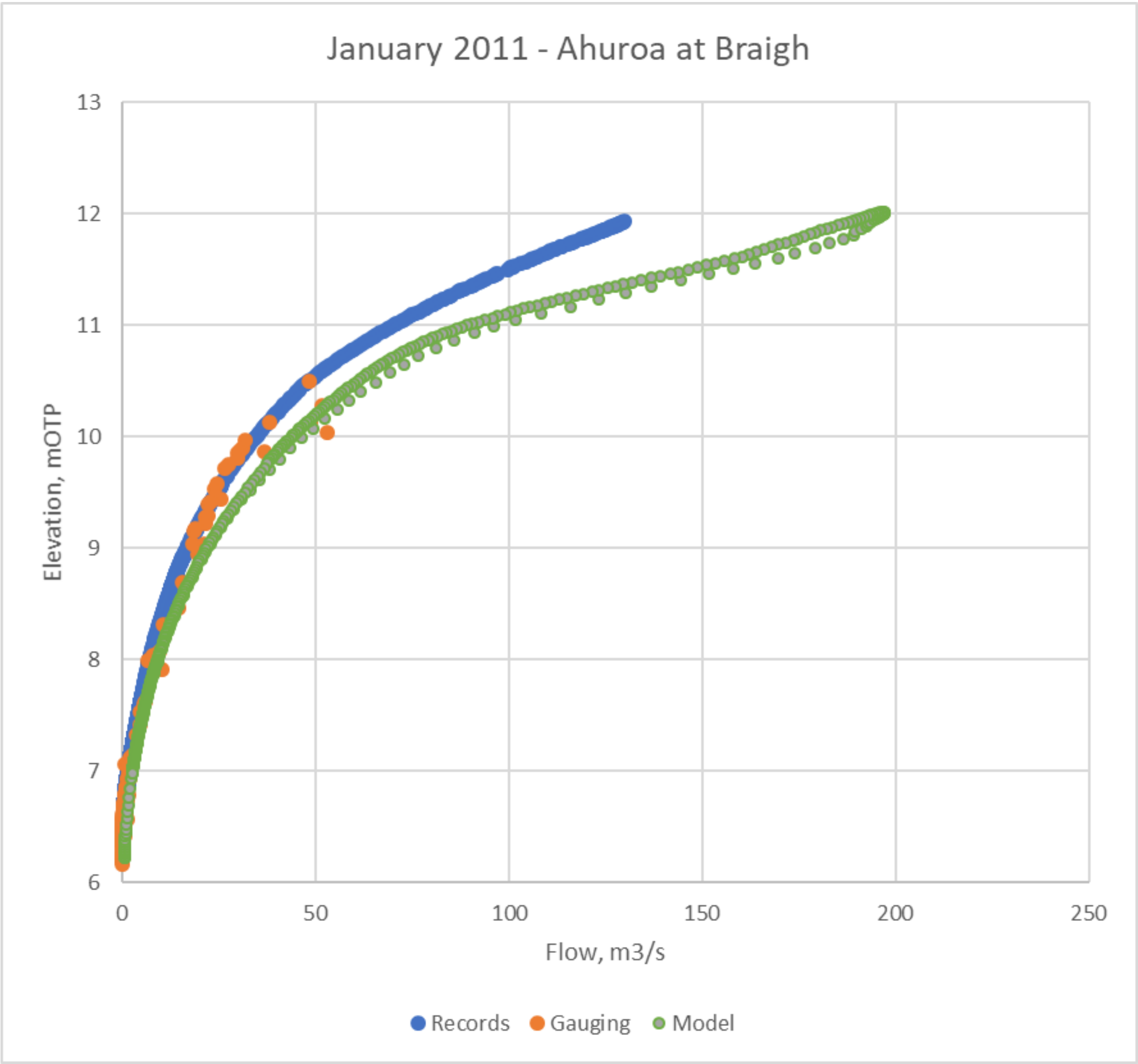


Figure 0.7 Rating Curve Calibration January 2011 – Ahuroa at Braigh

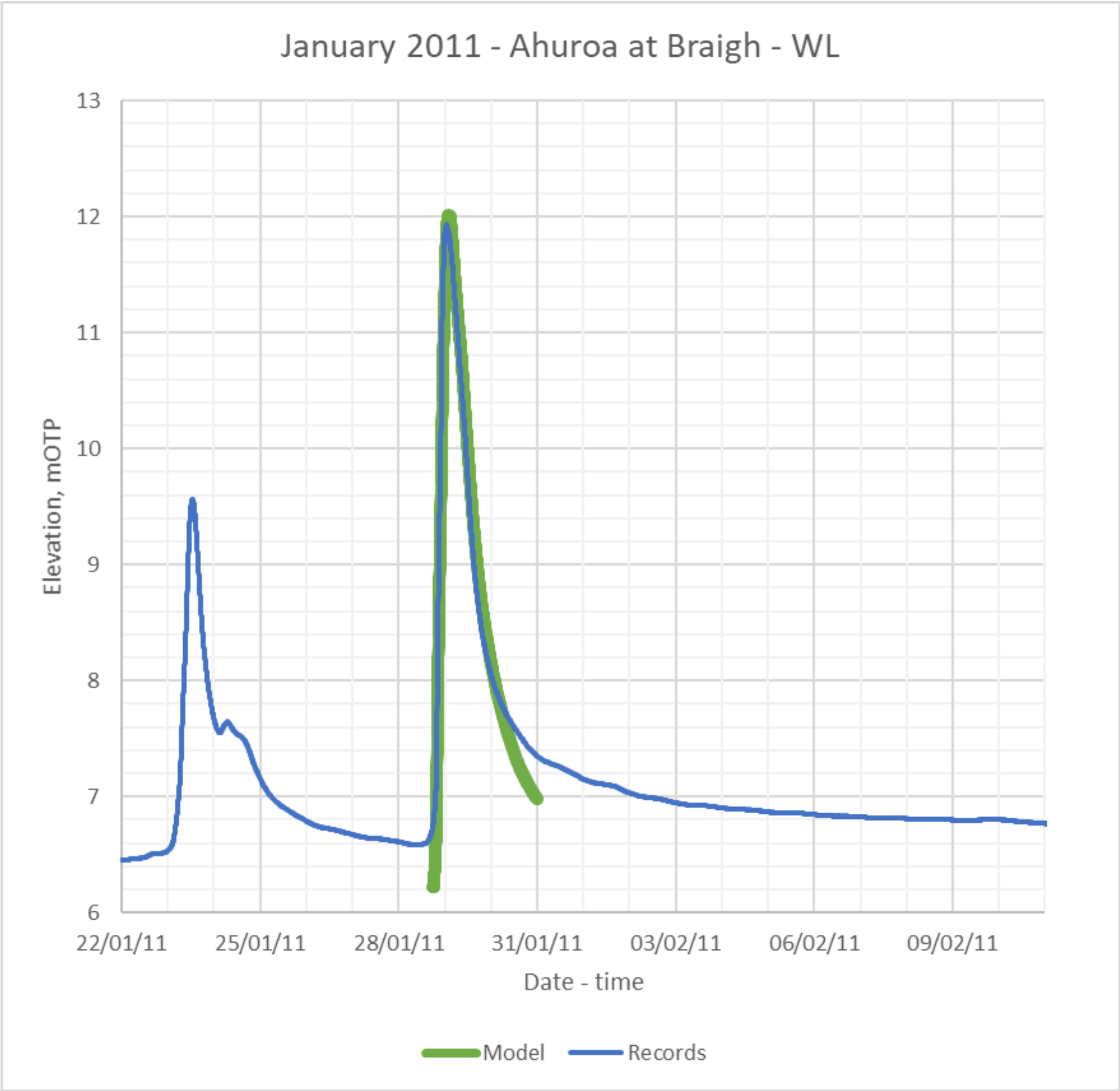


Figure 0.8 Water Level Calibration January 2011 – Ahuroa at Braigh

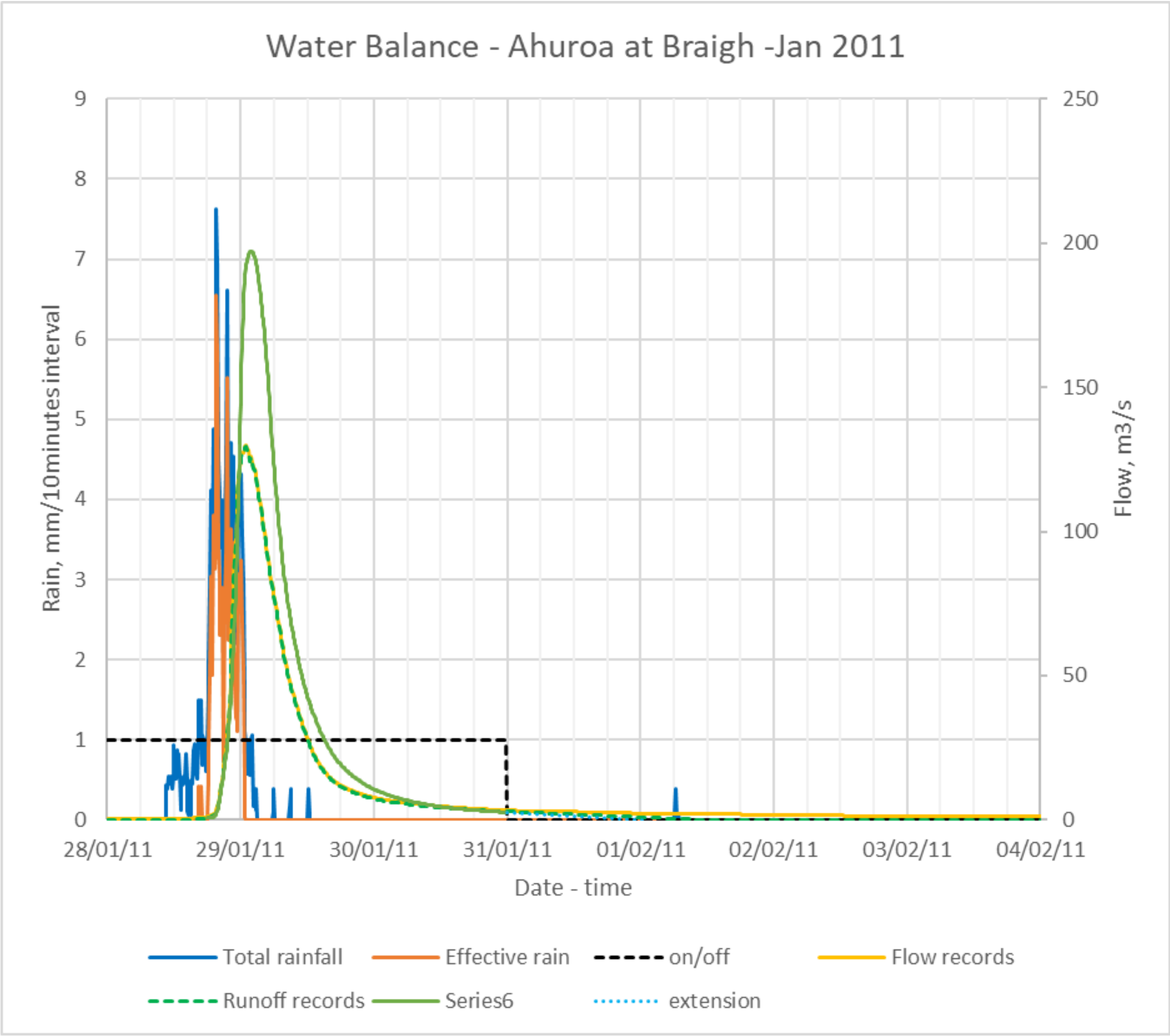


Figure 0.9 Water Balance and Flow Calibration January 2011 – Ahuroa at Braigh

SUMMARY AHUROA AT BRAIGH FLATS

Table 0.3. Calibration volume summary. Ahuroa at Braigh Flats.

Ahuroa at Braigh	G01 - July 1997	G01 - March 2007	G01 - January 2011
Catchment Area, m2	56006176	56006176	56006176
Rain Volume, m3	15069209	12534905	10721360
Rain depth, mm	269.1	223.8	191.4
Rec Runoff, m3	6531847	5618893	5392388
Rec RC	0.43	0.45	0.50
Modelled Runoff, m3	9608694	7186047	7449565
Modelled RC	0.64	0.57	0.69
Baseflow (model), m3/s	0.559	0.559	0.559

Table 0.4. Calibration peak values summary. Ahuroa at Braigh Flats.

Variable	G01 - July 1997	G01 - March 2007	G01 - January 2011
peak WL	13.292	11.604	12.015
time WL peak	01/07/1997 01:10	29/03/2007 18:20	29/01/2011 02:10
peak Q	290.105	170.296	197.171
time Q peak	01/07/1997 01:00	29/03/2007 18:10	29/01/2011 01:55
Rec WL peak	12.316	11.629	11.931
Rec WL time peak	30/06/1997 23:15	29/03/2007 16:45	29/01/2011 01:00
Rec Q peak	170	118.75	129.999
Rec Q time peak	30/06/1997 23:15	29/03/2007 16:30	29/01/2011 01:00
err WL, m	0.976	-0.025	0.084
err WL time	01:55:00	01:35:00	01:10:00
err Q, m3/s	120.105	51.546	67.172
err Q time	01:45:00	01:40:00	00:55:00
RC model	0.62	0.57	0.69
Adjusted modelled RC	0.64	0.57	0.69
Data RC (short tail)	0.43	0.45	0.50
Data RC (est. max.)	0.46	0.46	0.53
Infiltration	3.5	3.5	3.5

NORTH AT APPLECROSS (G02)

A. STORM JULY 1997

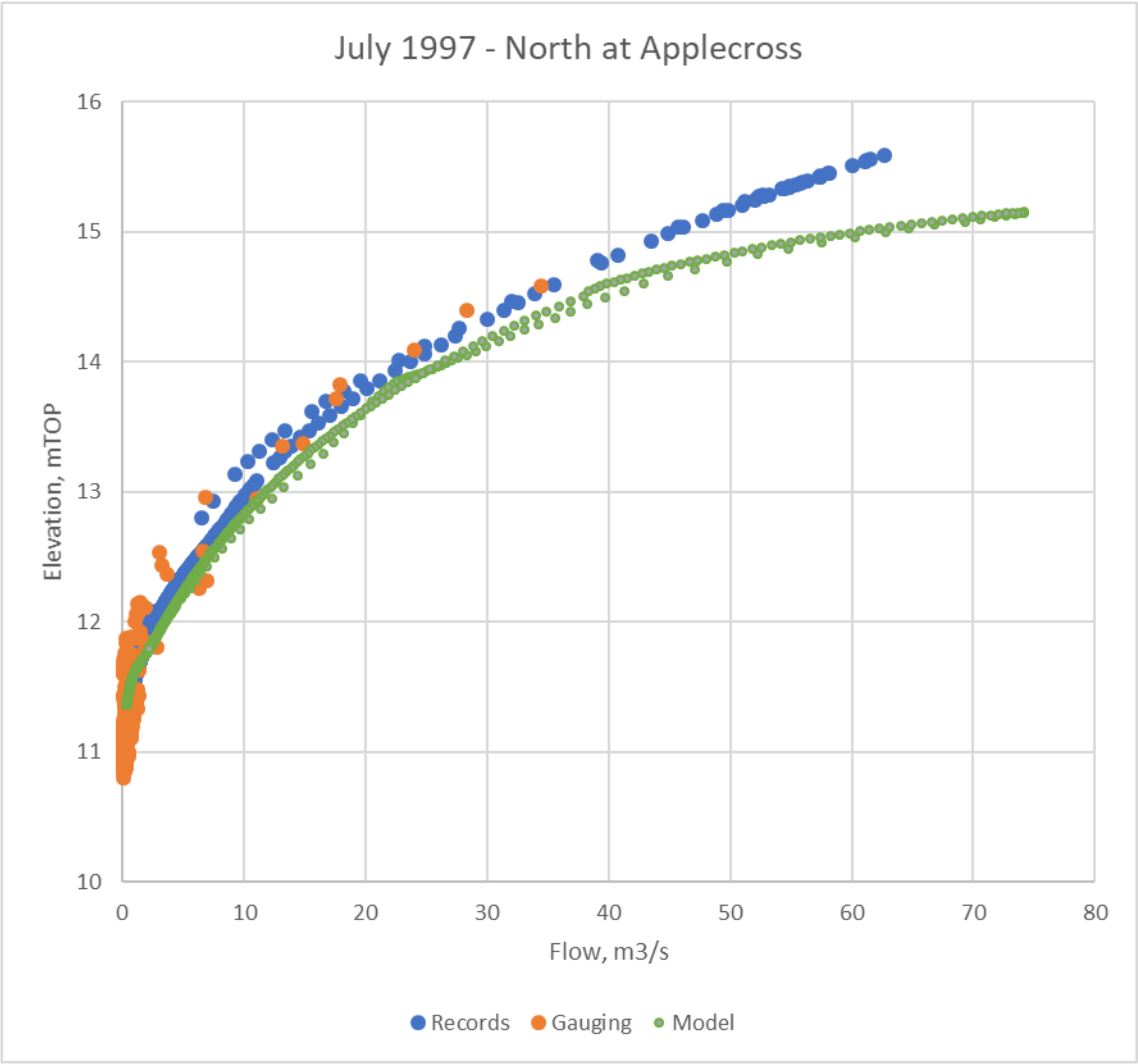


Figure 0.10 Rating Curve Calibration July 1997 – North at Applecross

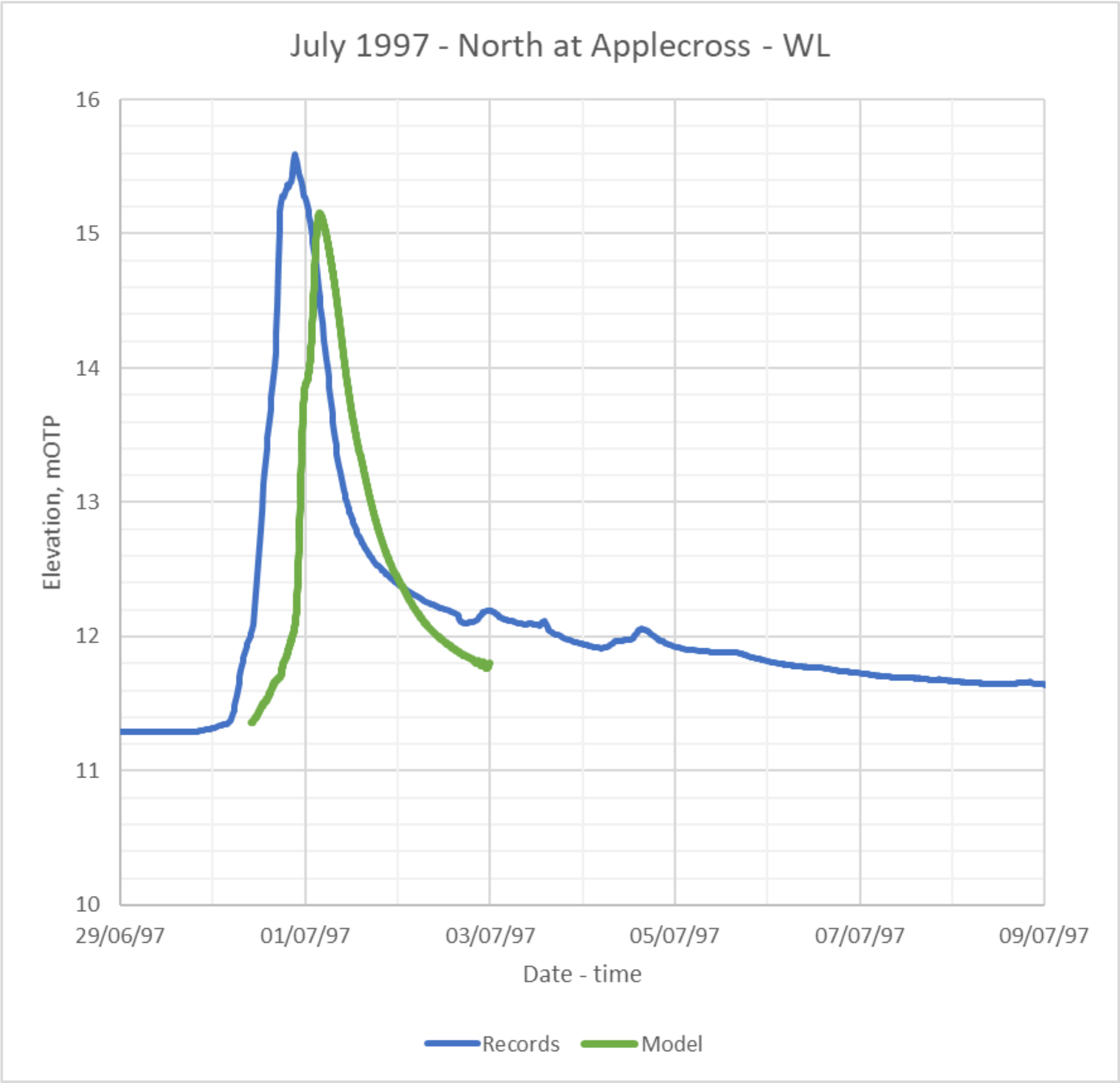


Figure 0.11 Water Level Calibration July 1997 – North at Applecross

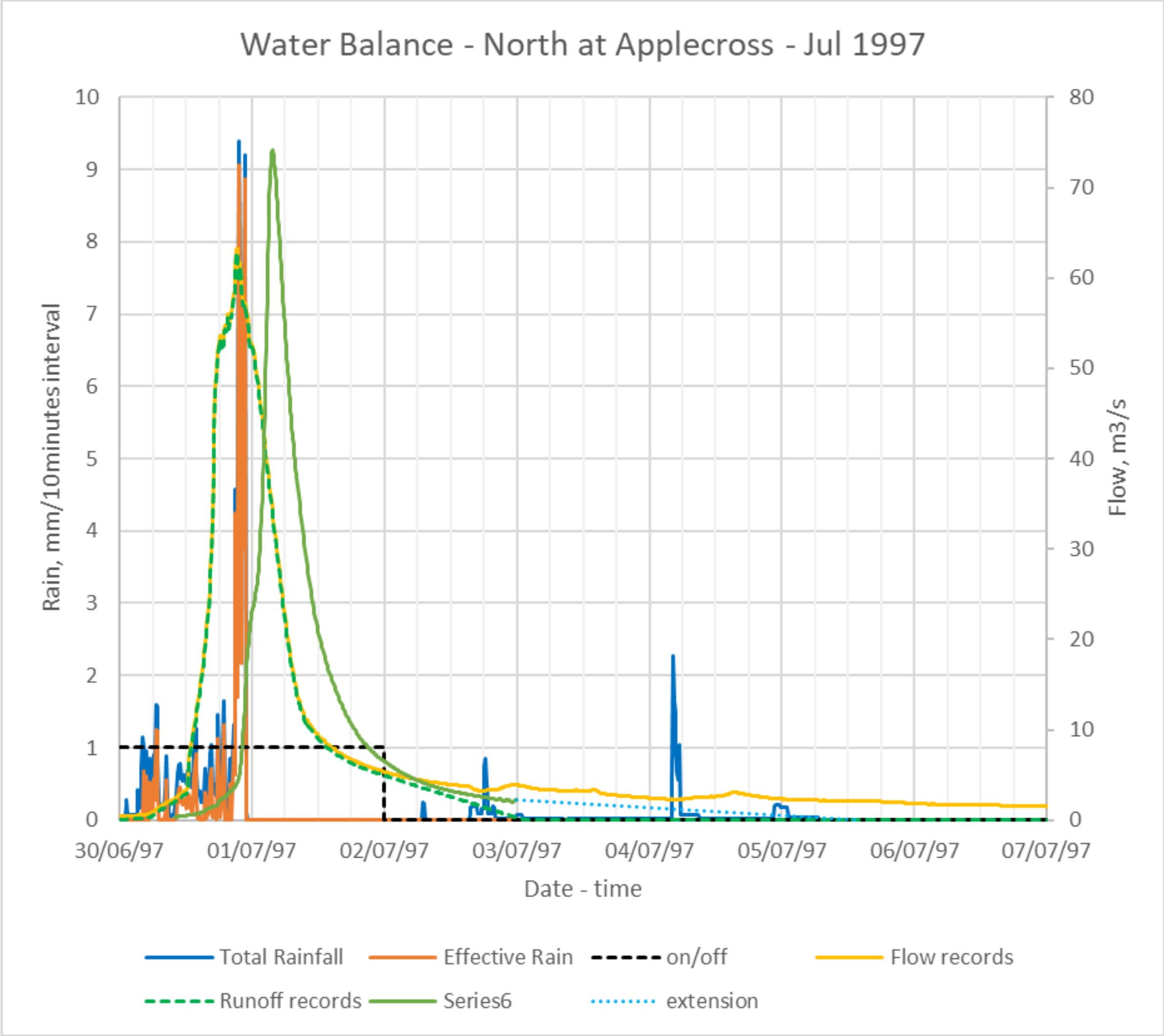


Figure 0.12 Water Balance and Flow Calibration July 1997 – North at Applecross

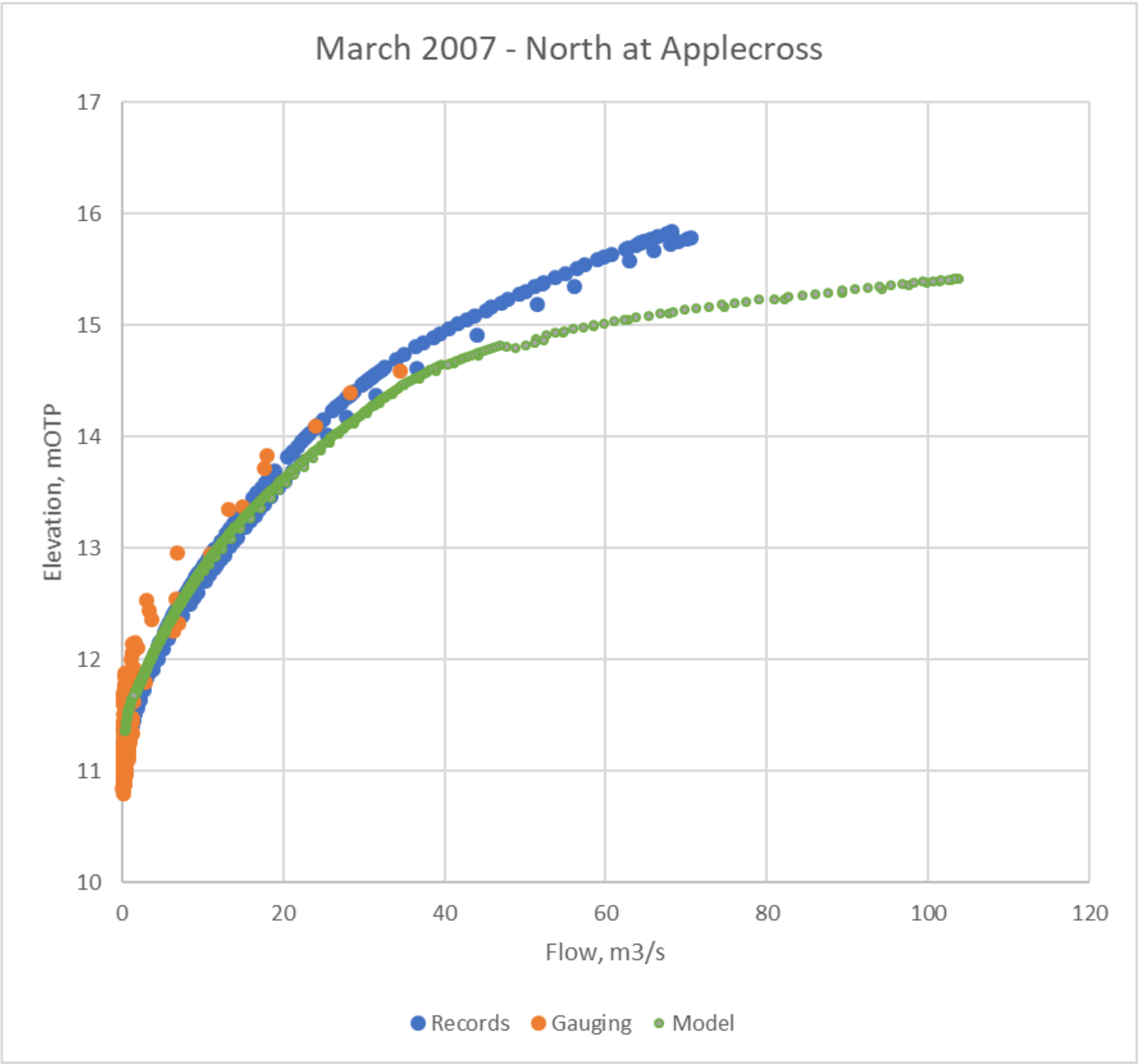


Figure 0.13 Rating Curve Calibration March 2007 – North at Applecross

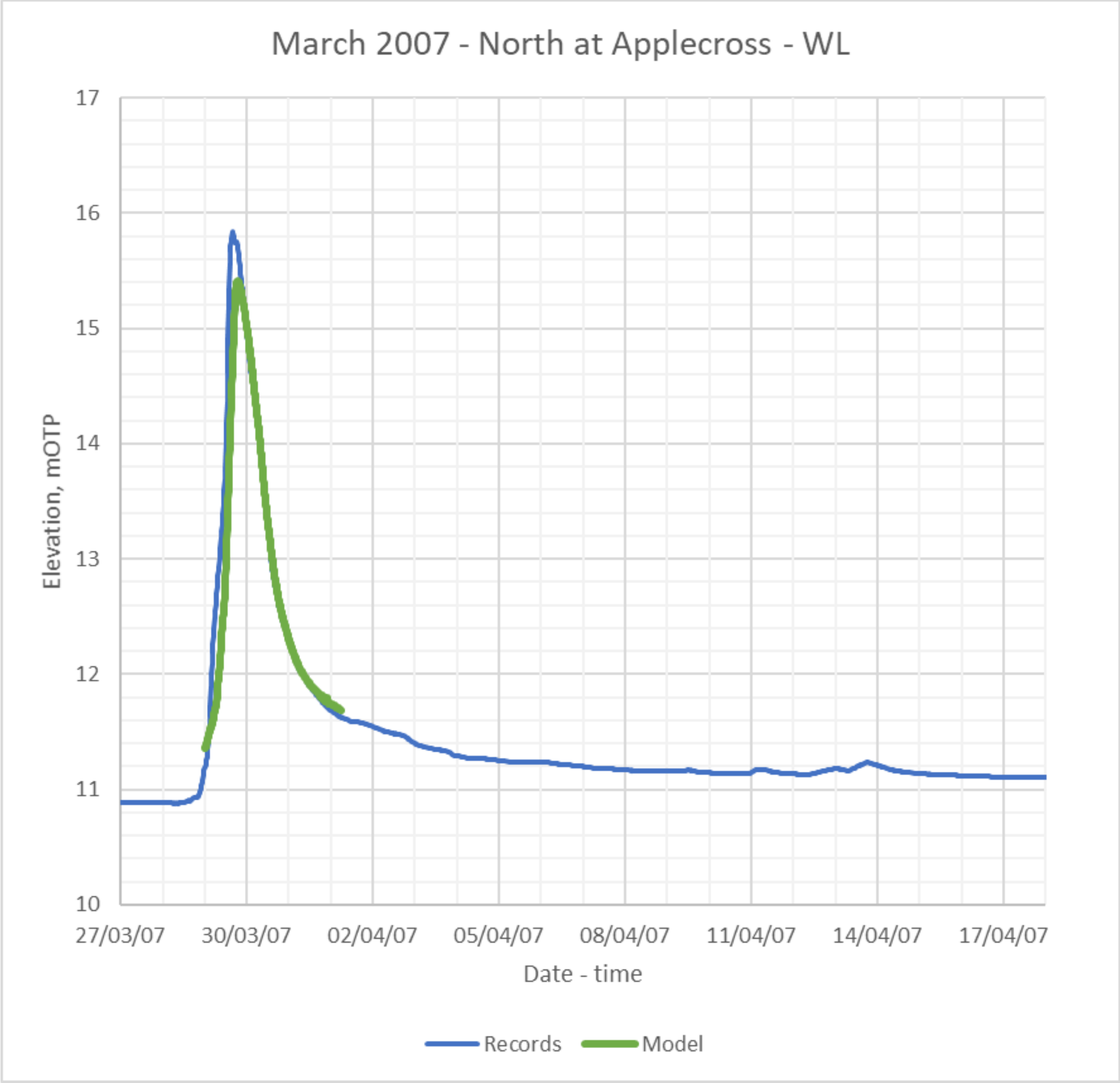


Figure 0.14 Water Level Calibration March 2007 – North at Applecross

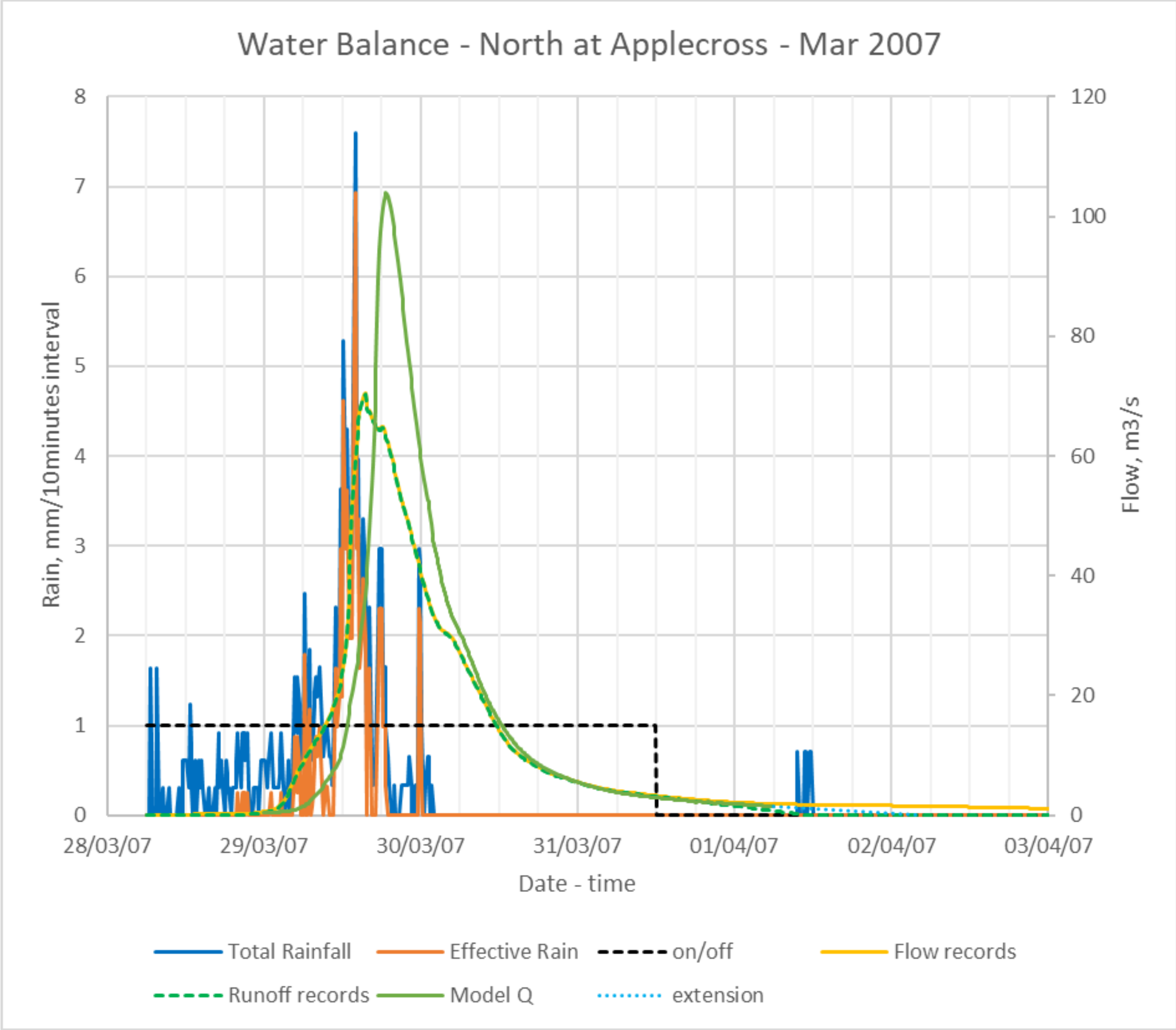


Figure 0.15 Water Balance and Flow Calibration March 2007 – North at Applecross

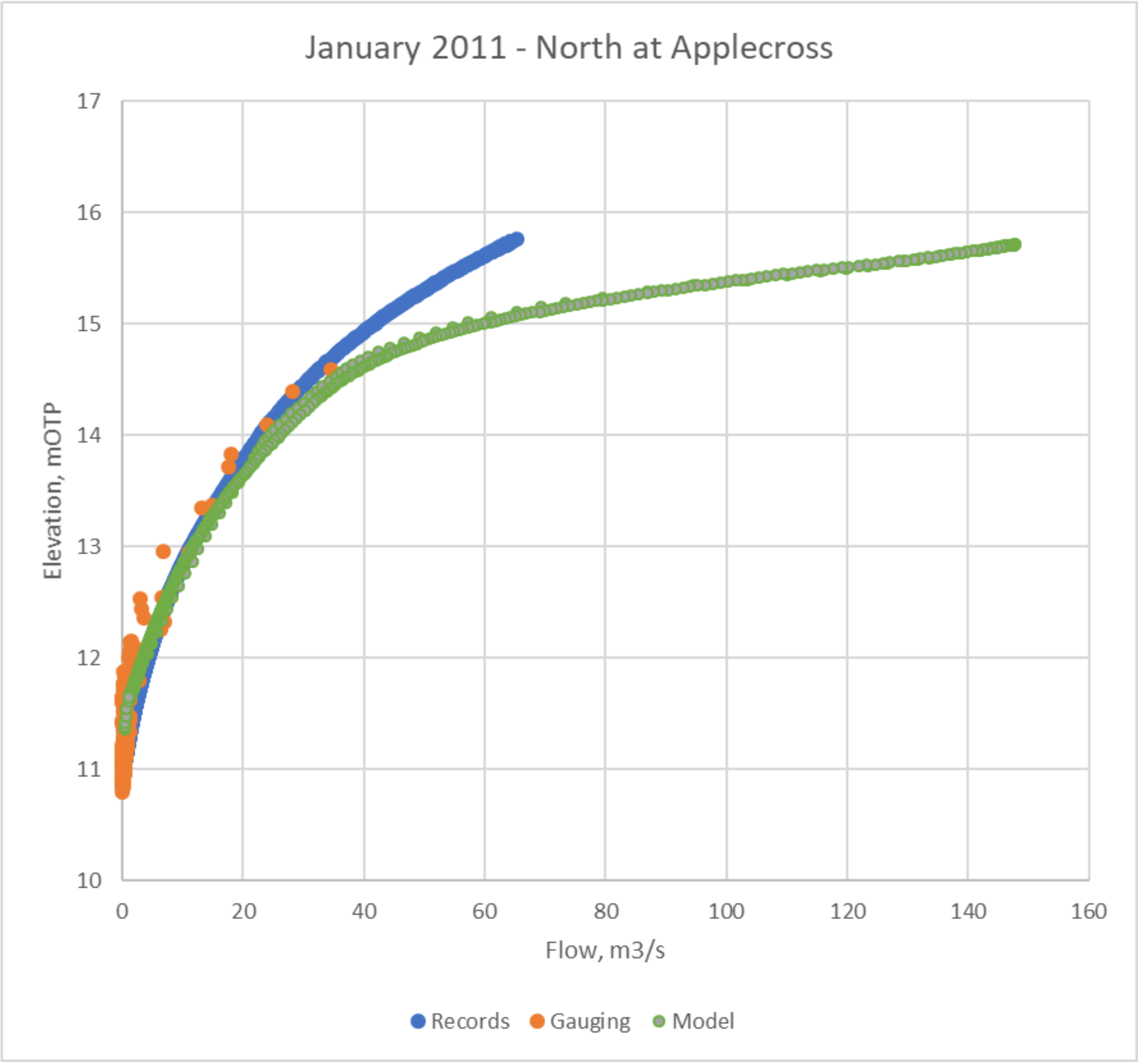


Figure 0.16 Rating Curve Calibration January 2011 – North at Applecross

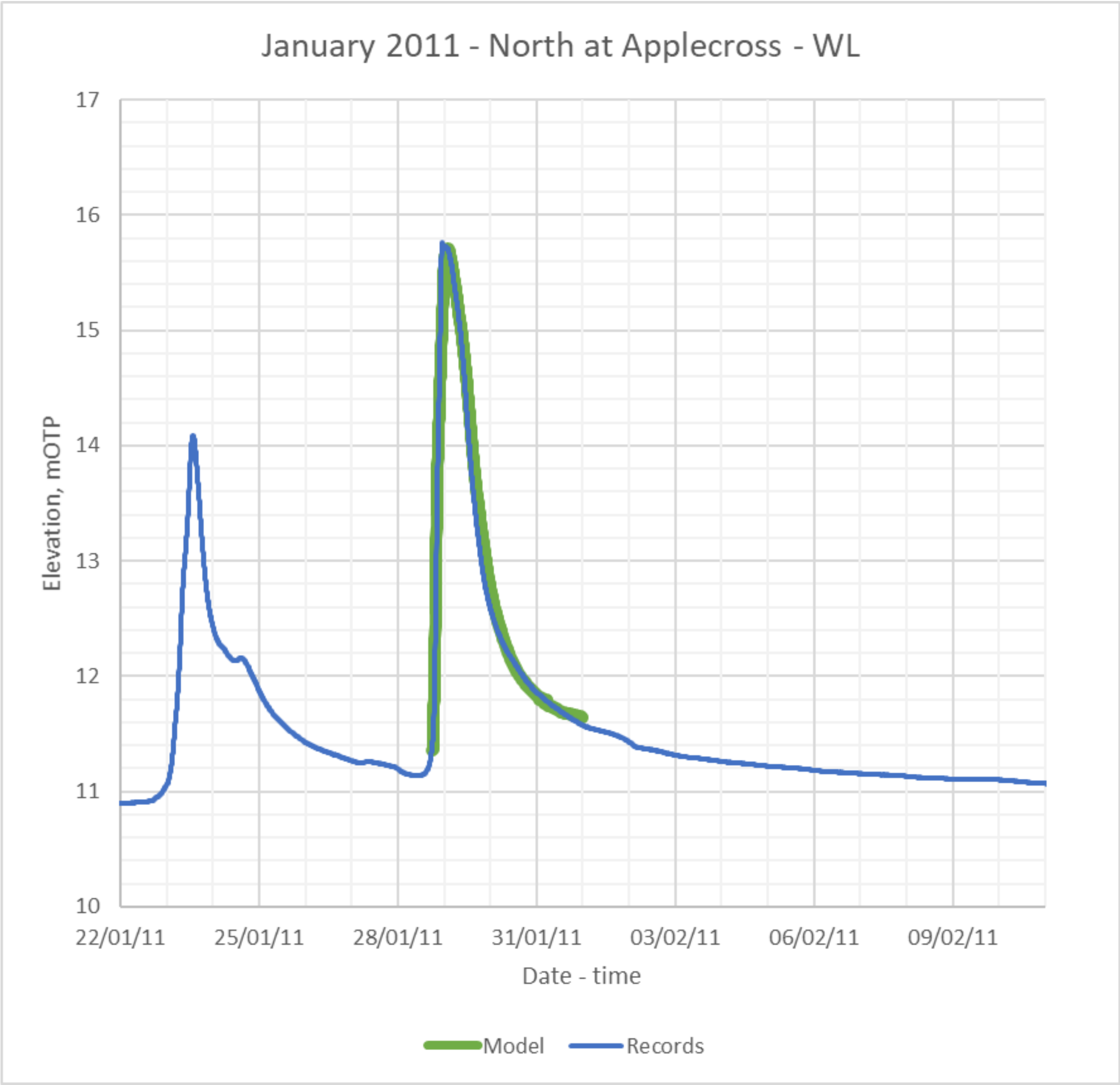


Figure 0.17 Water Level Calibration January 2011 – North at Applecross

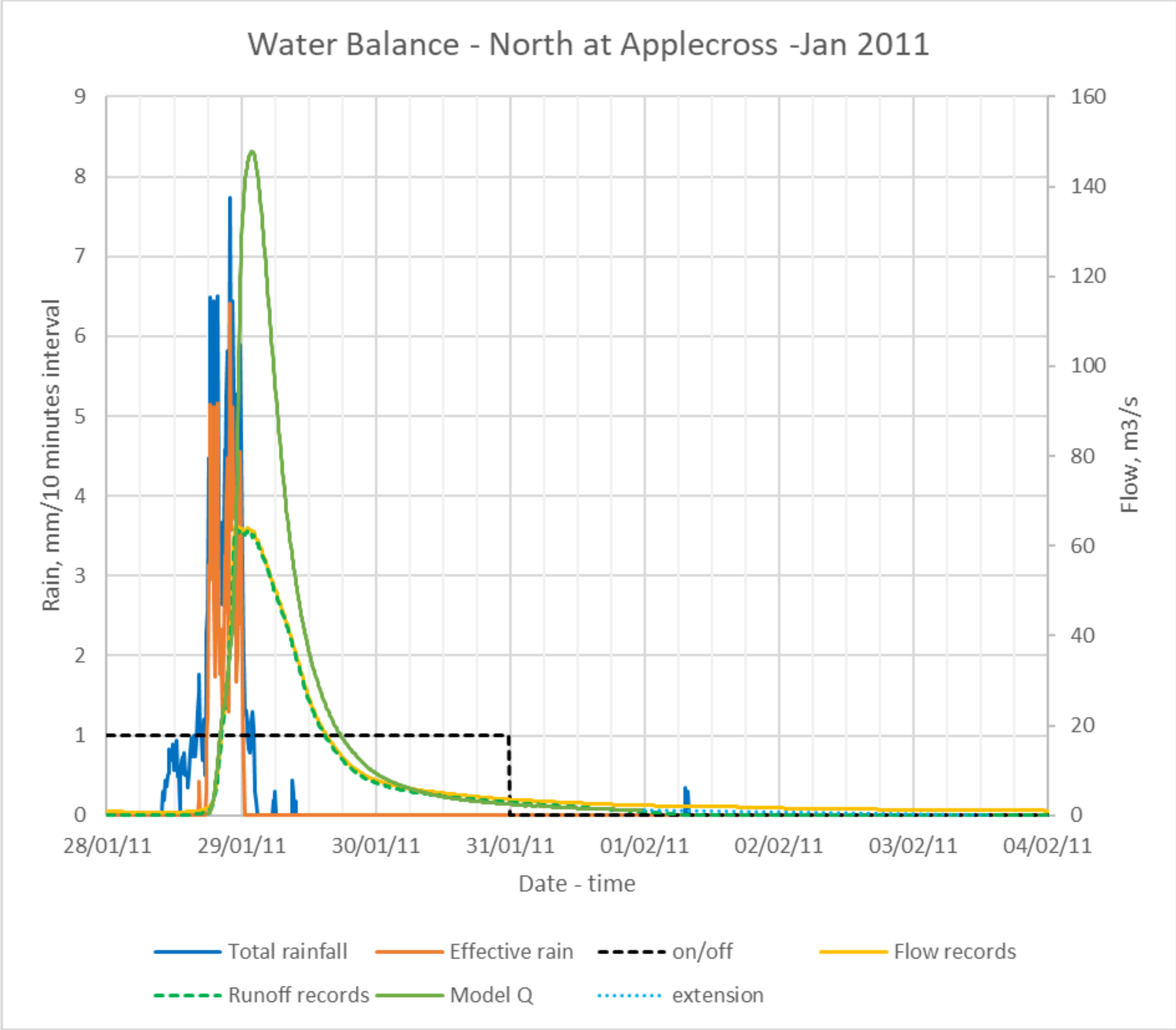


Figure 0.18 Water Balance and Flow Calibration January 2011 – North at Applecross

SUMMARY NORTH AT APPLECROSS

Table 0.5. Calibration volume summary. North at Applecross.

North at Applecross	G02 - July 1997	G02 - March 2007	G02 - January 2011
Catchment Area, m2	38919385	38919385	38919385
Rain Volume, m3	5019372	8984003	8896584
Rain depth, mm	129.0	230.8	228.6
Rec Runoff, m3	3302334	4586948	3869705
Rec RC	0.66	0.51	0.43
Modelled Runoff, m3	2948816	4881836	6247623
Modelled RC	0.59	0.54	0.70
Baseflow (model), m3/s	0.396	0.396	0.396

Table 0.6. Calibration peak values summary. North at Applecross.

Variable	G02 - July 1997	G02 - March 2007	G02 - January 2011
peak WL	15.151	15.416	15.712
time WL peak	01/07/1997 03:45	29/03/2007 18:50	29/01/2011 01:50
peak Q	74.148	103.865	147.794
time Q peak	01/07/1997 03:45	29/03/2007 18:40	29/01/2011 01:55
Rec WL peak	15.591	15.84	15.765
Rec WL time peak	30/06/1997 21:15	29/03/2007 15:45	28/01/2011 22:55
Rec Q peak	62.683	70.513	65.336

Rec Q time peak	30/06/1997 21:15	29/03/2007 15:30	28/01/2011 22:55
err WL, m	-0.44	-0.424	-0.053
err WL time	06:30:00	03:05:00	02:55:00
err Q, m3/s	11.465	33.352	82.458
err Q time	06:30:00	03:10:00	03:00:00
RC model	0.55	0.54	0.69
Adjusted modelled RC	0.59	0.54	0.70
Data RC (short tail)	0.66	0.51	0.43
Data RC (est. max.)	0.74	0.53	0.46
Infiltration	3.5	3.5	3.5

WAIHOIHOI AT ST MARYS' ROAD (G03)

A. STORM JULY 1997

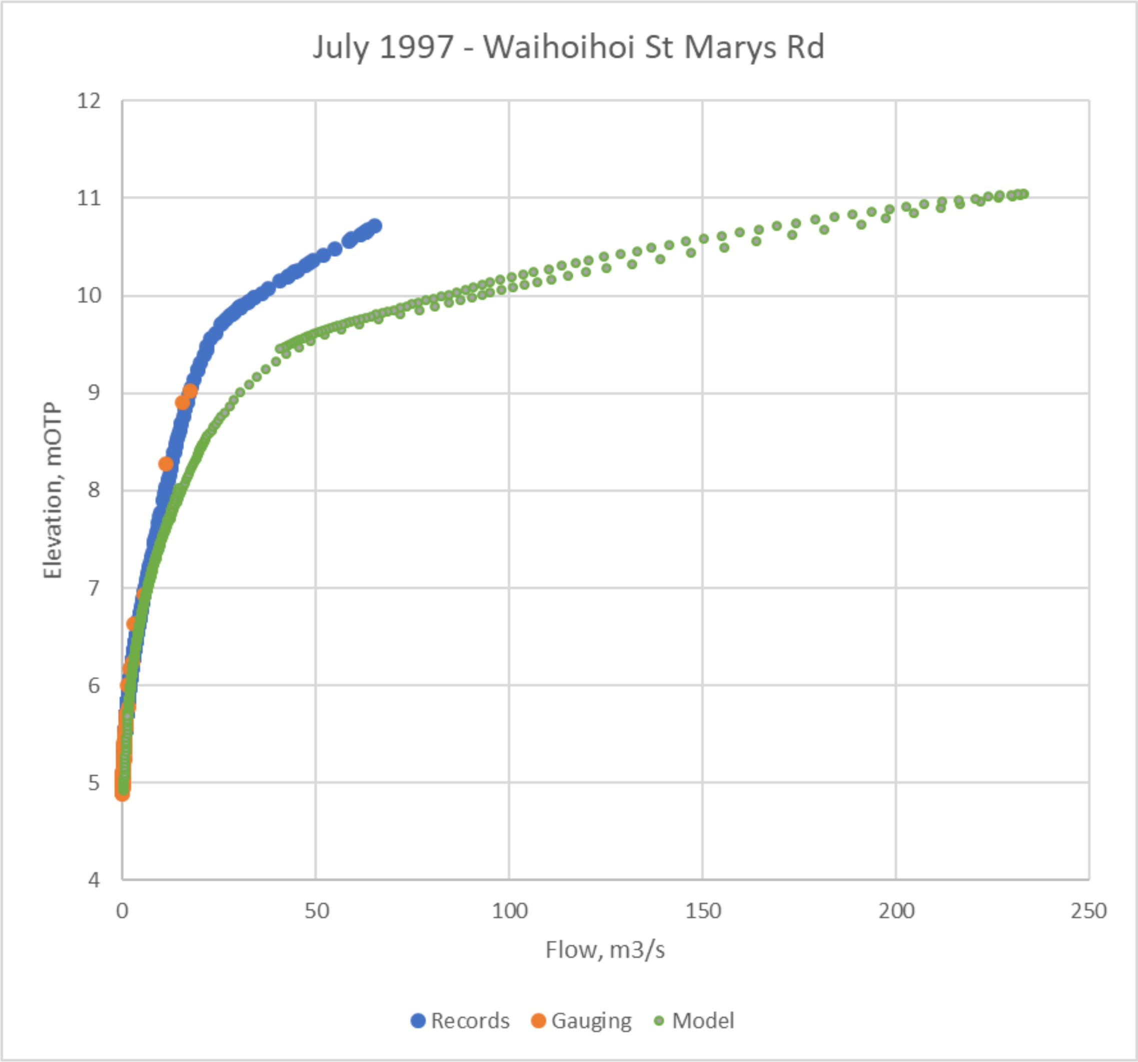


Figure 0.19 Rating Curve Calibration July 1997 – Waihoihoi St at Marys'Rd

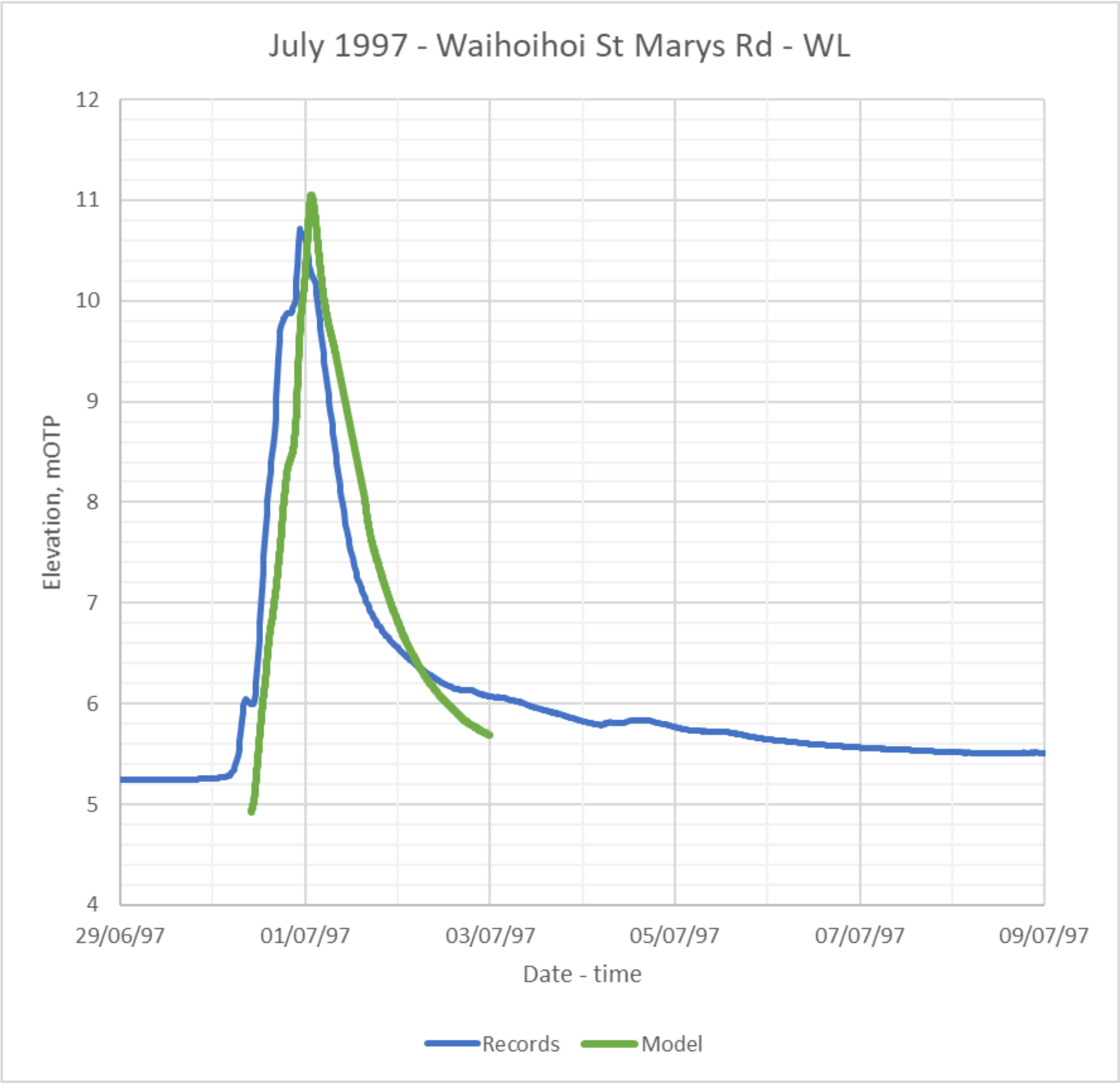


Figure 0.20 Water Level Calibration July 1997 – Ahuroa at Braigh

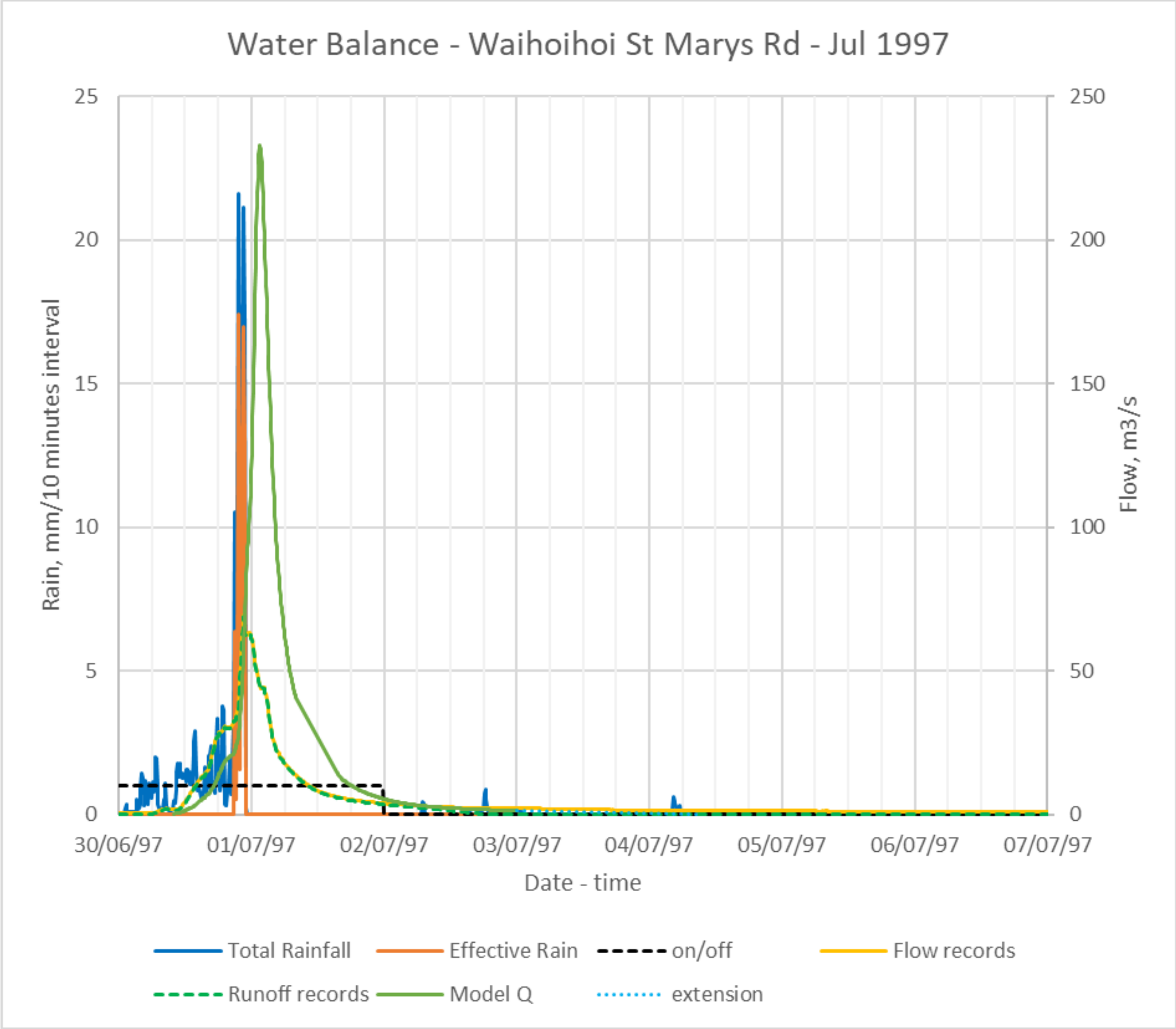


Figure 0.21 Water Balance and Flow Calibration July 1997 – Ahuroa at Braigh

Figure 0.22 Rating Curve Calibration March 2007 – Ahuroa at Braigh

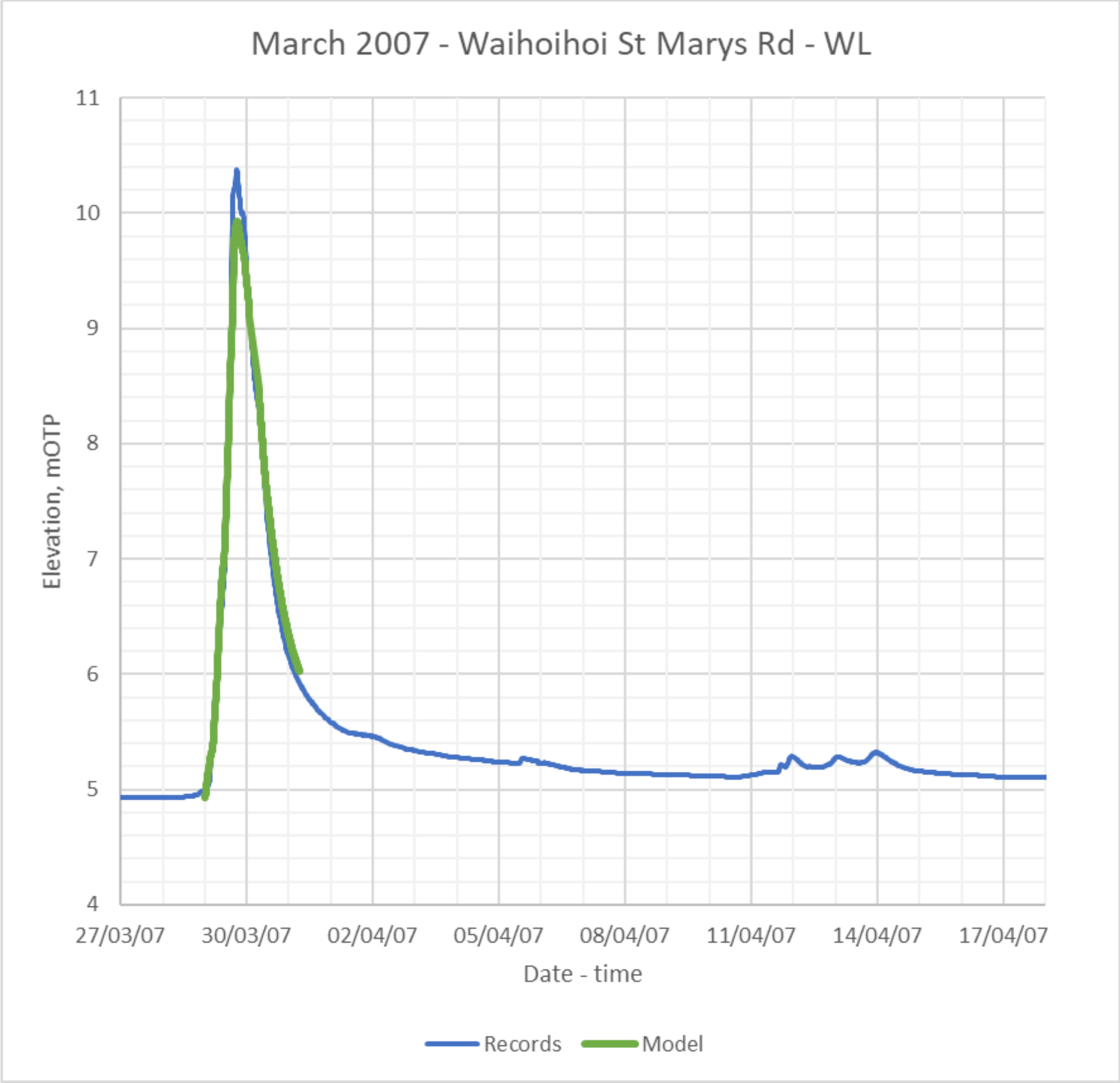


Figure 0.23 Water Level Calibration March 2007 – Ahuroa at Braigh

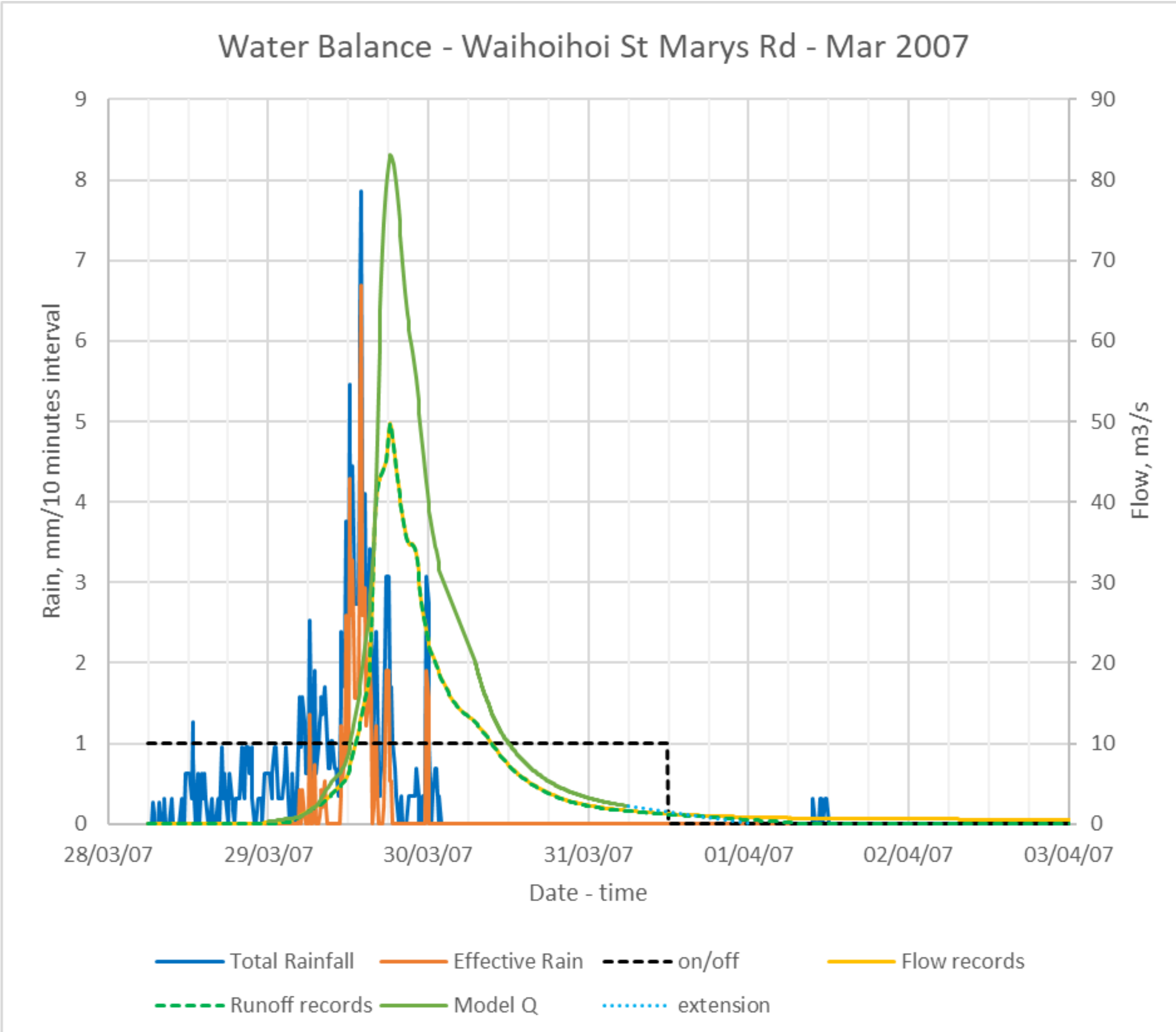


Figure 0.24 Water Balance and Flow Calibration March 2007 – Ahuroa at Braigh

Figure 0.25 Rating Curve Calibration January 2011 – Ahuroa at Braigh

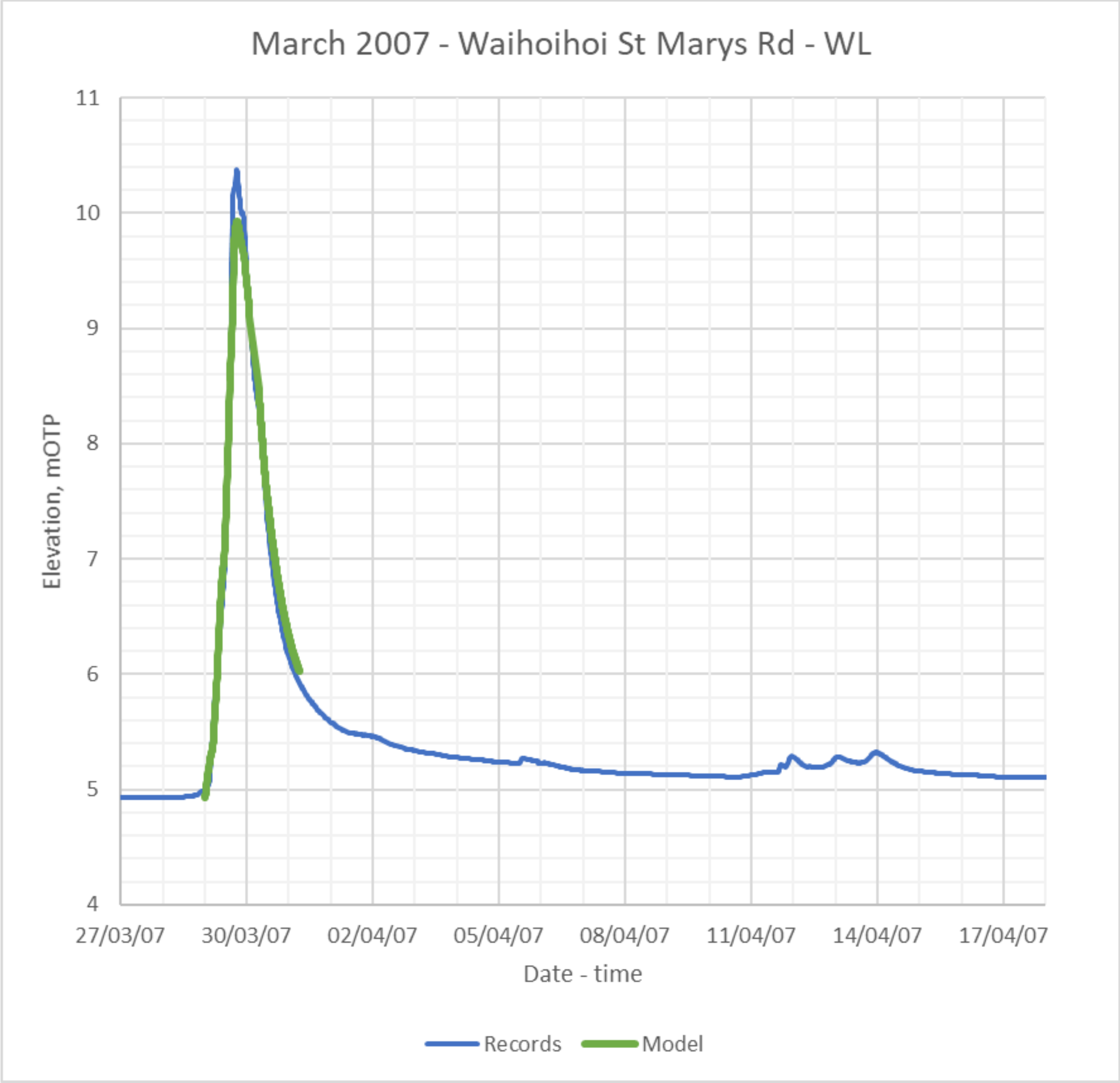


Figure 0.26 Water Level Calibration January 2011 – Ahuroa at Braigh

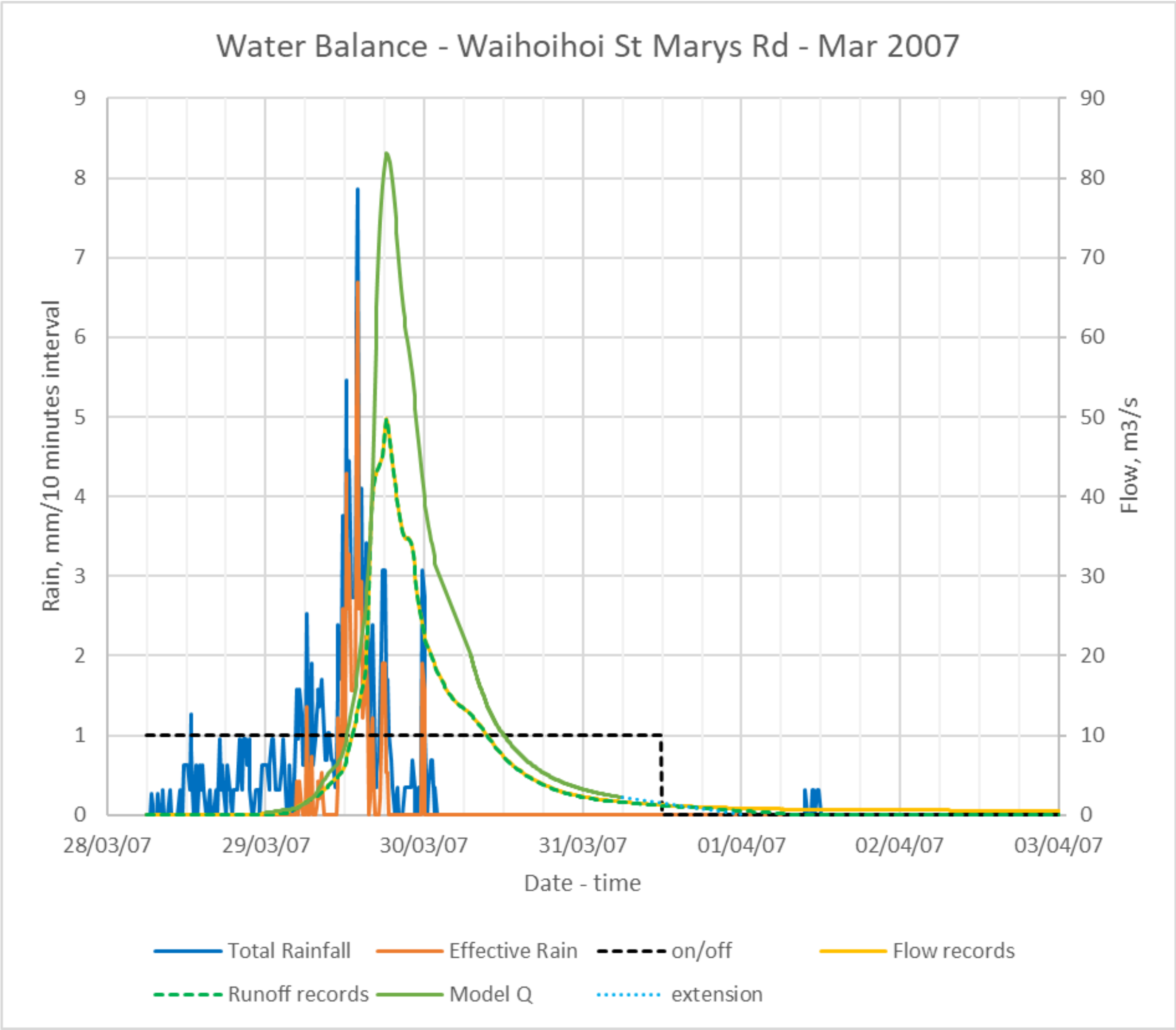


Figure 0.27 Water Balance and Flow Calibration January 2011 – Ahuroa at Braigh

SUMMARY WAIHOIHOI AT ST MARYS' ROAD

Table 0.7. Calibration volume summary. Waihoihoi at St. Mary's Road.

Waihoihoi at St Mary's Rd	G03 - July 1997	G03 - March 2007	G03 - January 2011
Catchment Area, m2	26965359	26965359	26965359
Rain Volume, m3	7413230	6311073	5136901
Rain depth, mm	274.9	234.0	190.5
Rec Runoff, m3	2610098	2276663	2036304
Rec RC	0.35	0.36	0.40
Modelled Runoff, m3	5298874	3516416	3705627
Modelled RC	0.71	0.56	0.72
Baseflow (model), m3/s	0.269	0.269	0.269

Table 0.8. Calibration peak values summary. Waihoihoi at St. Mary's Road.

Variable	**G03 - July 1997**	**G03 - March 2007**	**G03 - January 2011**
peak WL	11.046	9.926	10.135
time WL peak	01/07/1997 01:35	29/03/2007 18:30	29/01/2011 02:00
peak Q	233.068	83.091	103.409
time Q peak	01/07/1997 01:30	29/03/2007 18:20	29/01/2011 02:00
Rec WL peak	10.711	10.374	10.299
Rec WL time peak	30/06/1997 22:30	29/03/2007 18:15	29/01/2011 00:25
Rec Q peak	65.322	50.087	46.837
Rec Q time peak	30/06/1997 22:30	29/03/2007 18:15	29/01/2011 00:25

err WL, m	0.335	-0.448	-0.164
err WL time	03:05:00	00:15:00	01:35:00
err Q, m3/s	167.746	33.004	56.572
err Q time	03:00:00	00:05:00	01:35:00
RC model	0.71	0.55	0.72
Adjusted modelled RC	0.71	0.56	0.72
Data RC (short tail)	0.35	0.36	0.40
Data RC (est. max.)	0.36	0.37	0.42
Infiltration	3.5	3.5	3.5

WAIONEHU AT MCLEAN ROAD (G04)

A. STORM JULY 1997

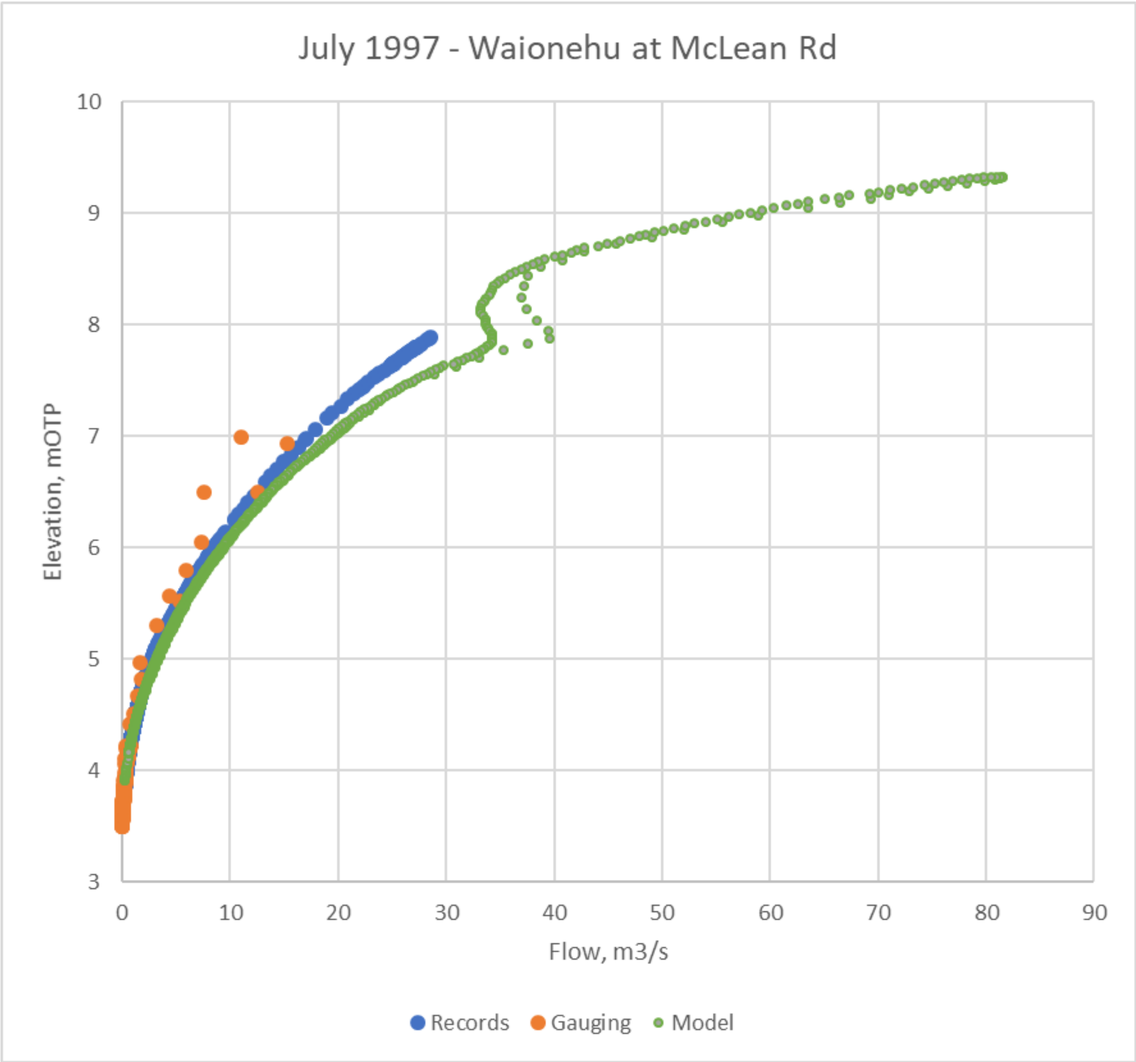


Figure 0.28 Rating Curve Calibration July 1997 – Ahuroa at Braigh

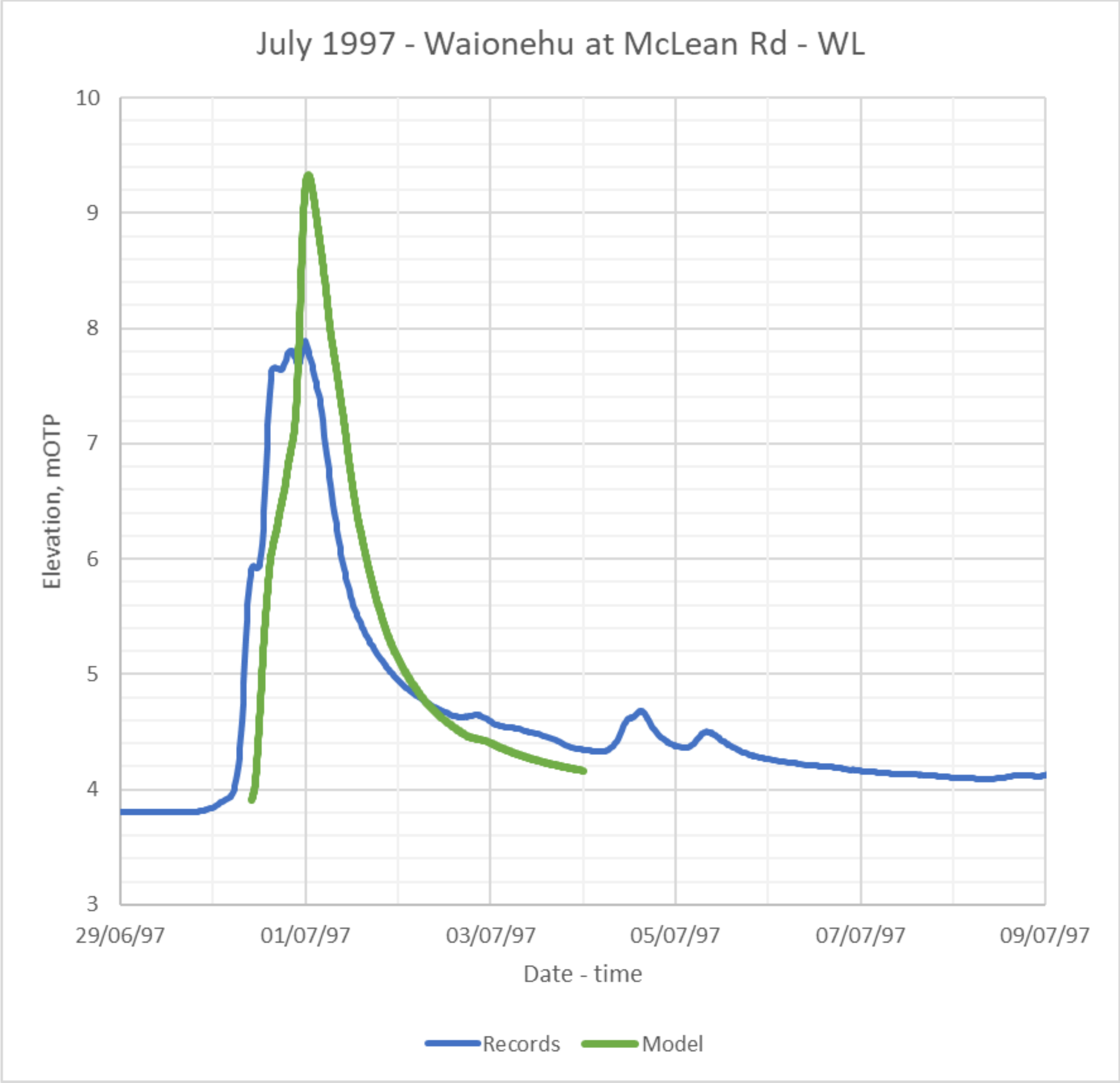


Figure 0.29 Water Level Calibration July 1997 – Ahuroa at Braigh

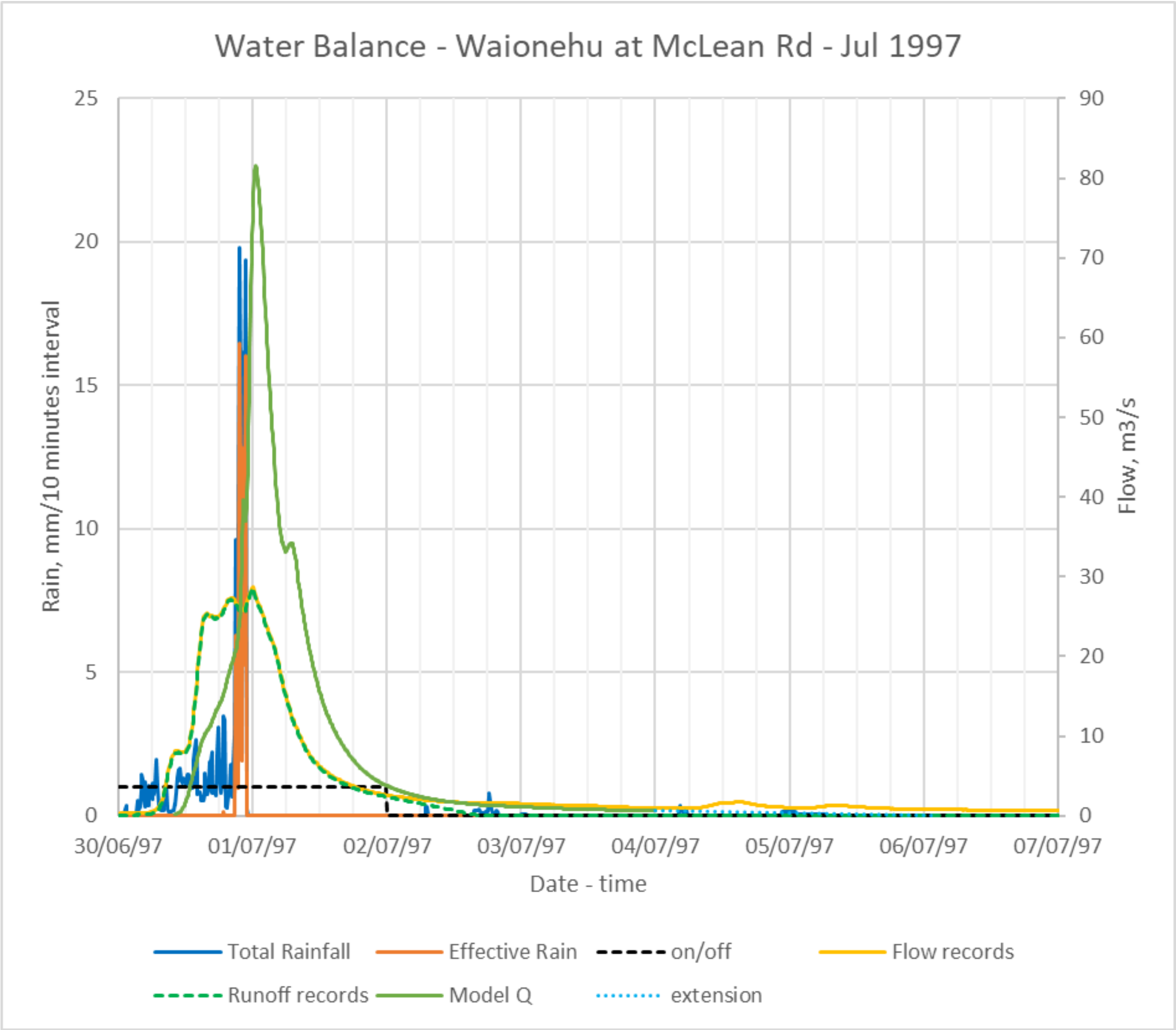


Figure 0.30 Water Balance and Flow Calibration July 1997 – Ahuroa at Braigh

Figure 0.31 Rating Curve Calibration March 2007 – Ahuroa at Braigh

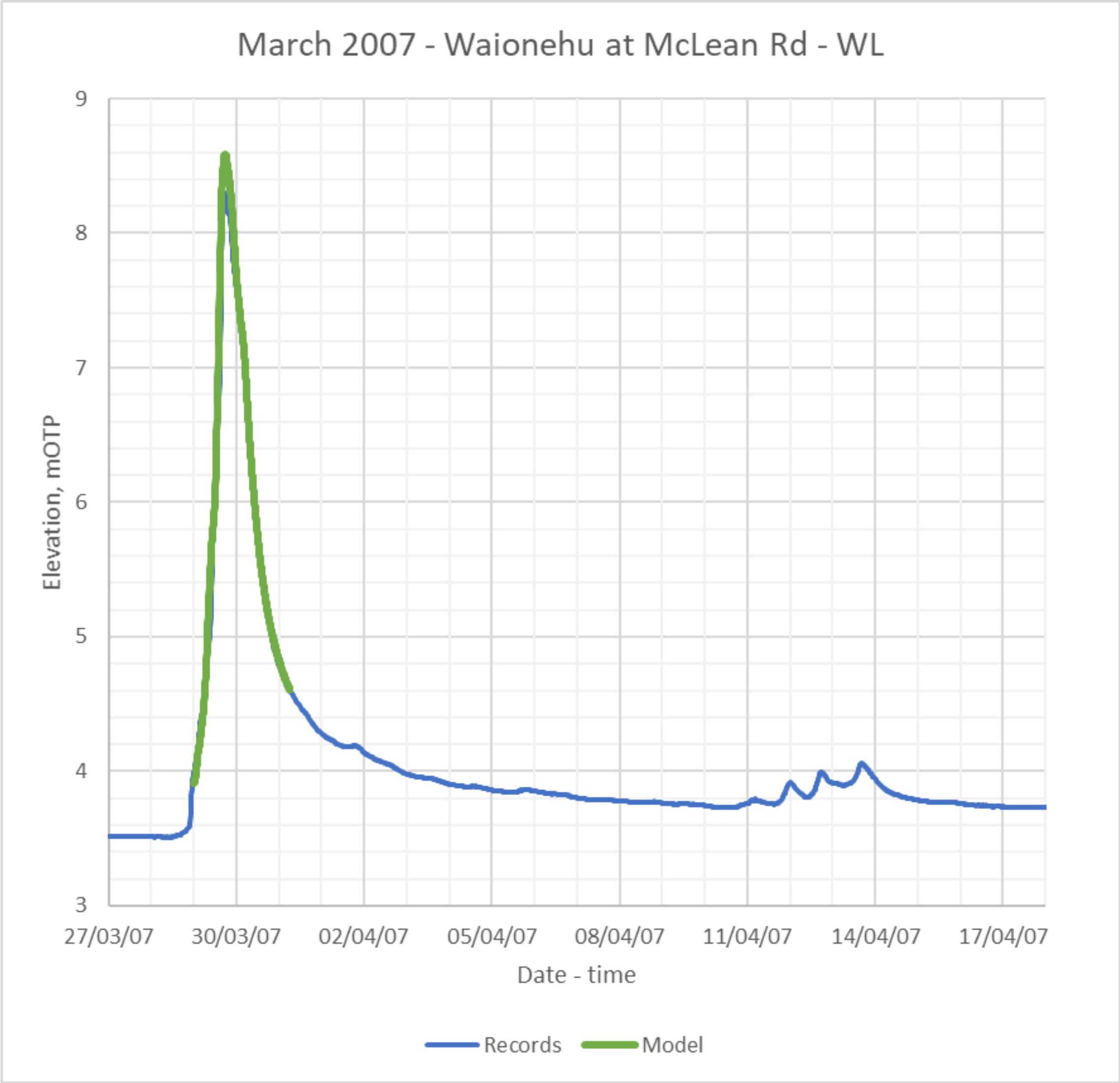


Figure 0.32 Water Level Calibration March 2007 – Ahuroa at Braigh

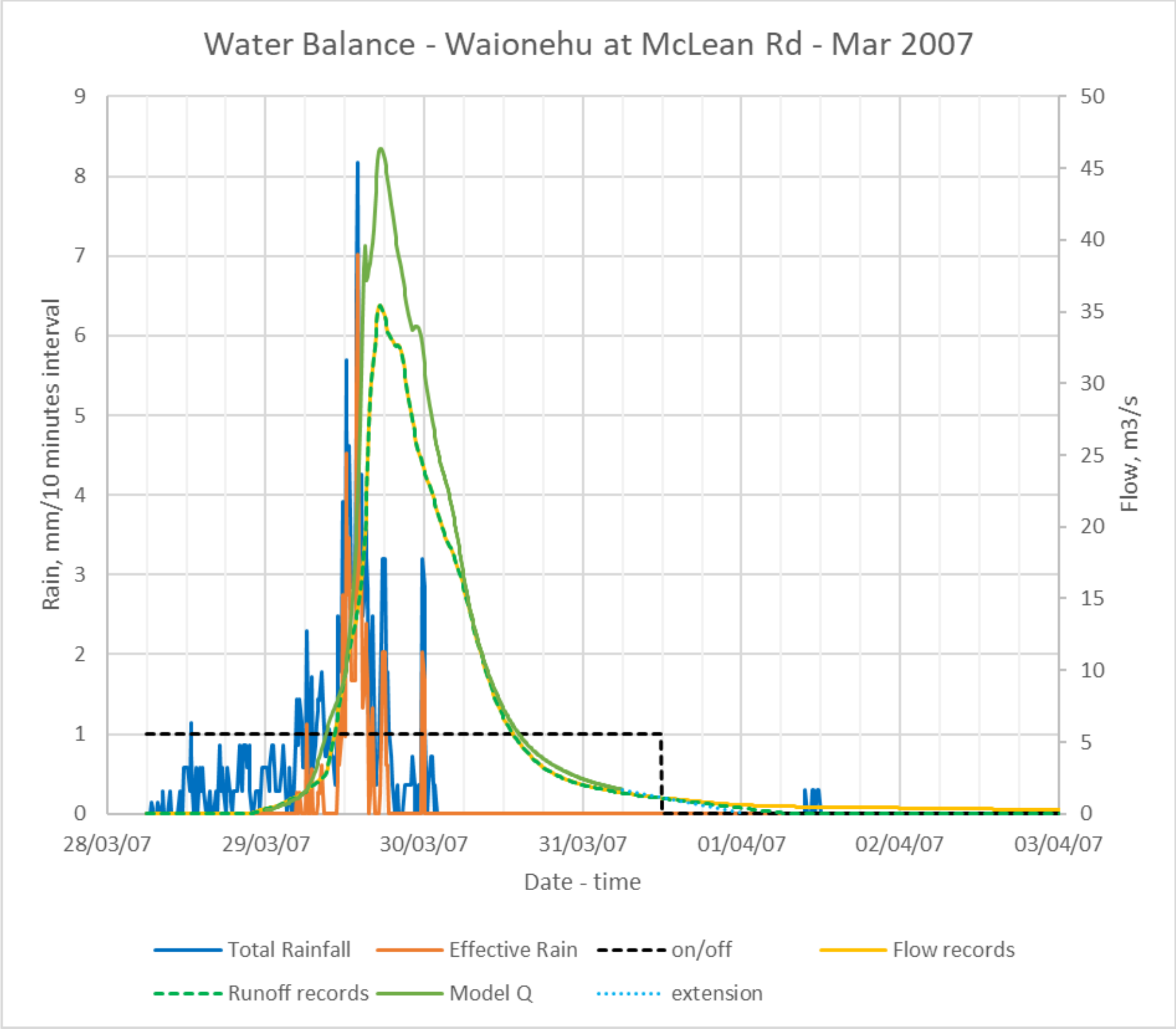


Figure 0.33 Water Balance and Flow Calibration March 2007 – Ahuroa at Braigh

Figure 0.34 Rating Curve Calibration January 2011 – Ahuroa at Braigh

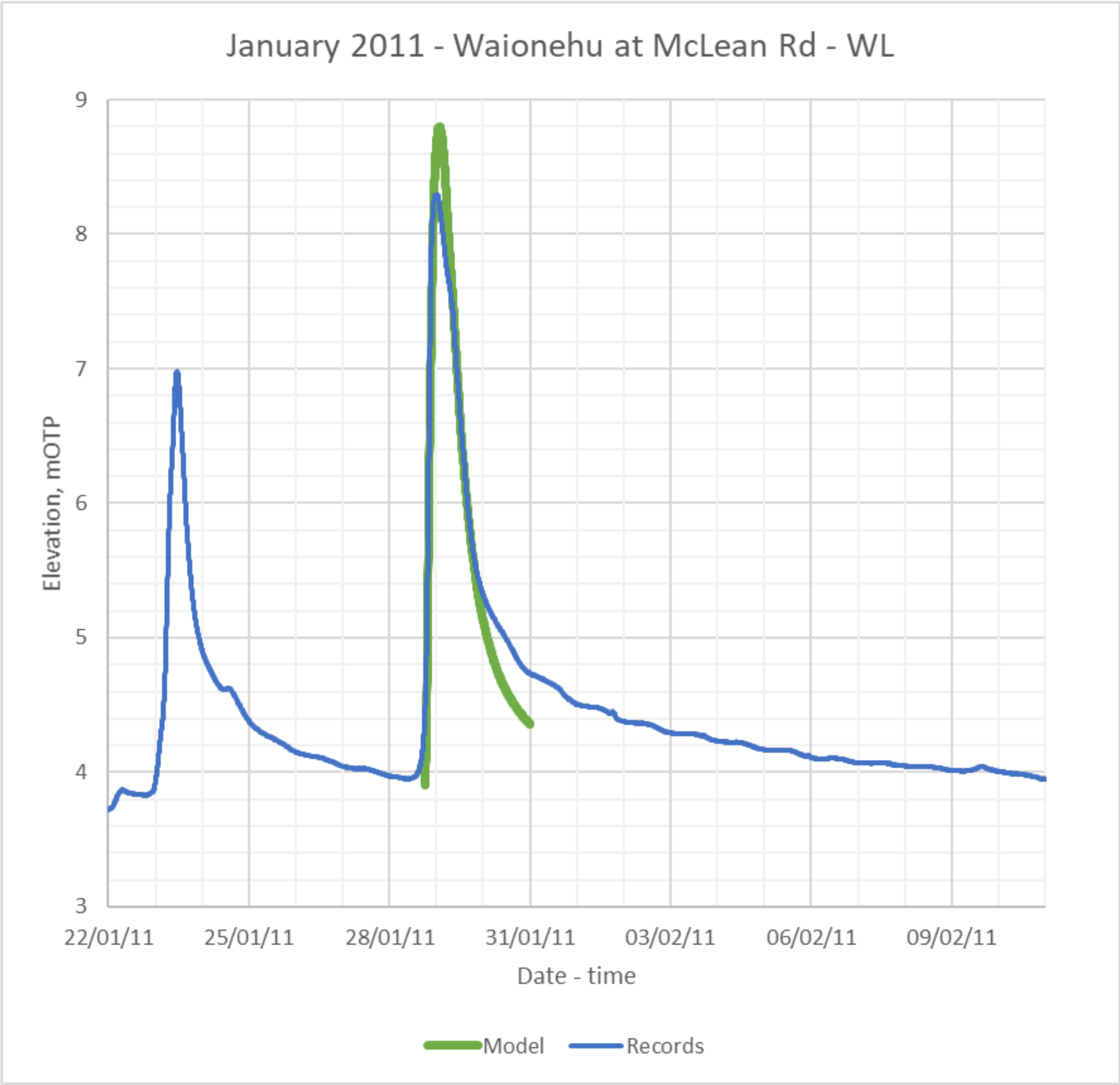


Figure 0.35 Water Level Calibration January 2011 – Ahuroa at Braigh

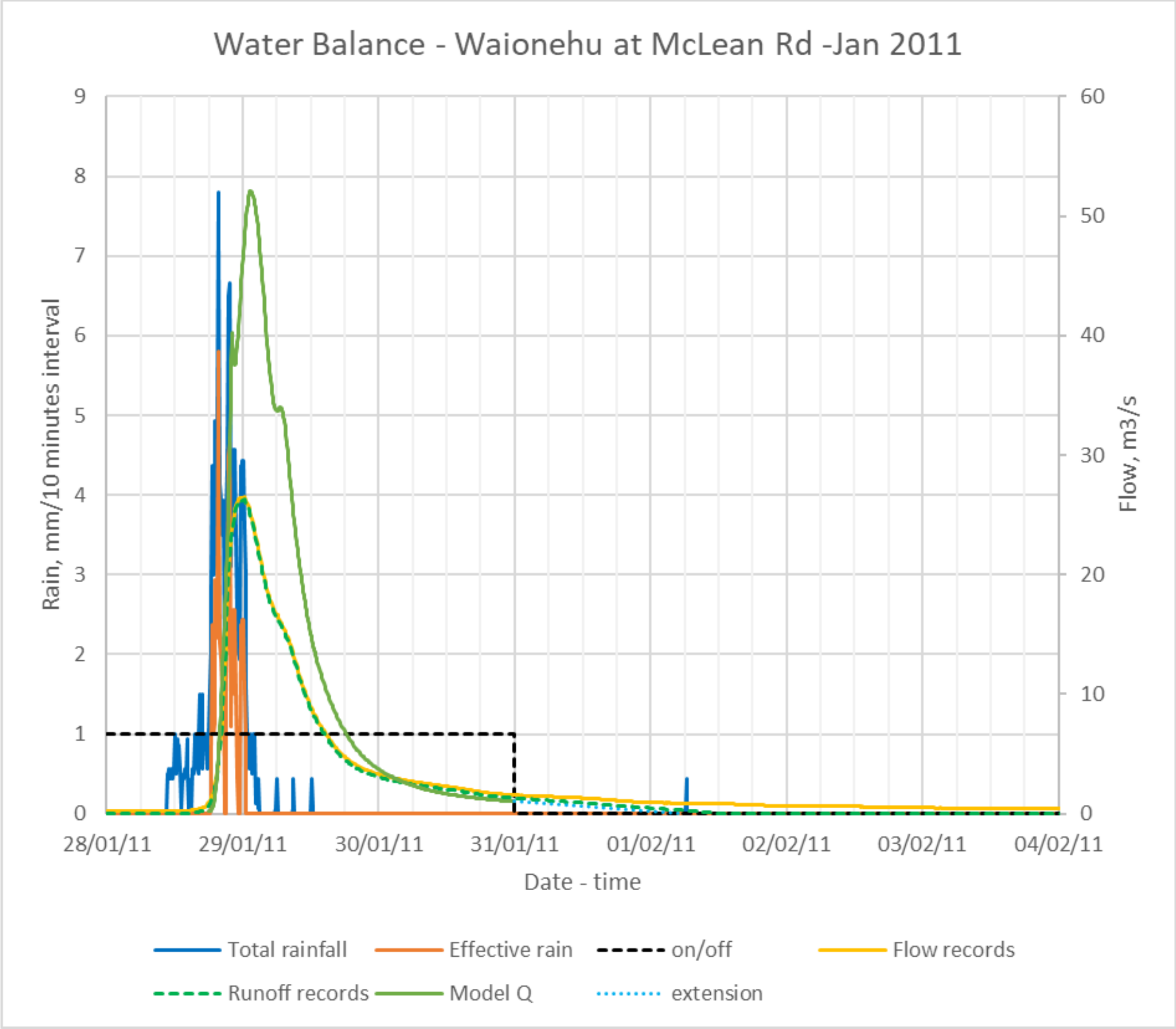


Figure 0.36 Water Balance and Flow Calibration January 2011 – Ahuroa at Braigh

SUMMARY WAIONEHU AT MCLEAN ROAD

Table 0.9. Calibration volume summary. Waionehu at McLean Road.

Waionehu at McLean Rd	G04 - July 1997	G04 - March 2007	G04 - January 2011
Catchment Area, m2	24367524	24367524	24367524
Rain Volume, m3	6181580	5704944	4642013
Rain depth, mm	253.7	234.1	190.5
Rec Runoff, m3	2009420	2144972	1529774
Rec RC	0.33	0.38	0.33
Modelled Runoff, m3	3106611	2588213	2449993
Modelled RC	0.50	0.45	0.53
Baseflow (model), m3/s	0.243	0.243	0.243

Table 0.10. Calibration peak values summary. Waionehu at McLean Road.

Variables	**G04 - July 1997**	**G04 - March 2007**	**G04 - January 2011**
peak WL	9.329	8.585	8.797
time WL peak	01/07/1997 00:40	29/03/2007 17:30	29/01/2011 01:25
peak Q	81.562	46.378	52.065
time Q peak	01/07/1997 00:30	29/03/2007 17:20	29/01/2011 01:25
Rec WL peak	7.888	8.302	8.294
Rec WL time peak	01/07/1997 00:00	29/03/2007 17:15	29/01/2011 00:30
Rec Q peak	28.594	35.486	26.493
Rec Q time peak	01/07/1997 00:00	29/03/2007 17:15	29/01/2011 00:20

err WL, m	1.441	0.283	0.503
err WL time	00:40:00	00:15:00	00:55:00
err Q, m3/s	52.968	10.892	25.572
err Q time	00:30:00	00:05:00	01:05:00
RC model	0.50	0.45	0.52
Adjusted modelled RC	0.50	0.45	0.53
Data RC (short tail)	0.33	0.38	0.33
Data RC (est. max.)	0.37	0.38	0.35
Infiltration	3.5	3.5	3.5

NORTH AT APPLECROSS RECORDS – DATUM ANALYSIS

Figure 0.37 shows long records at the stage/flow gauge North at Applecross. Note the shift of about 1m on the record base line, near the 13 of April of 2013.

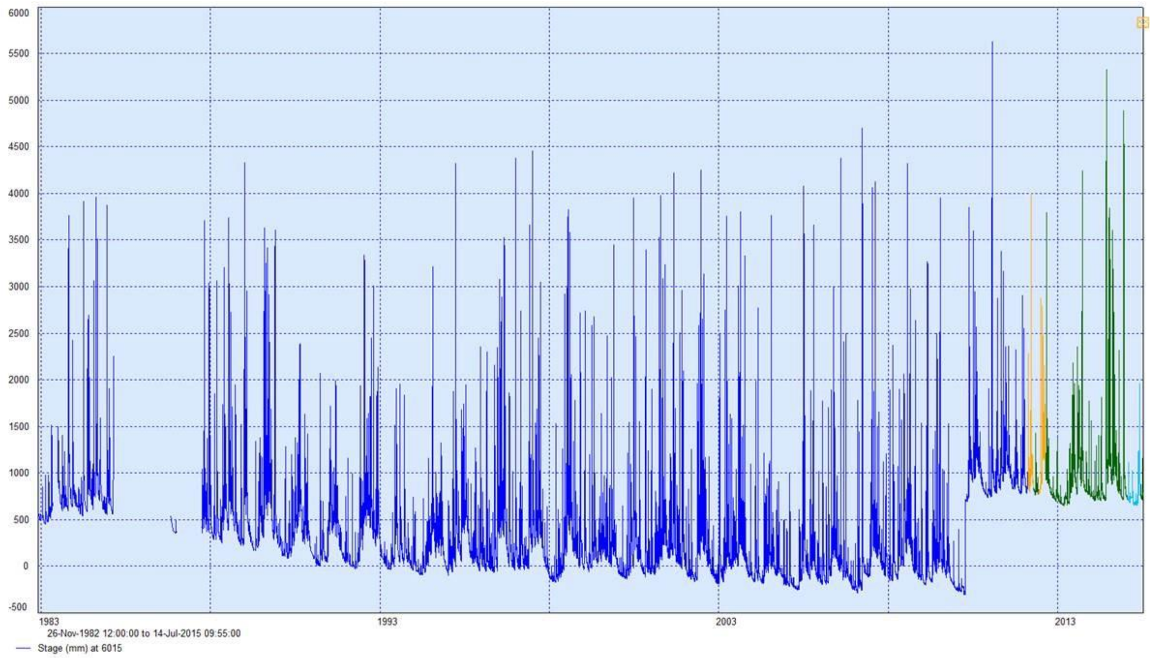


Figure 0.37 Long series stage records at North at Applecross showing datum shift.

Also, a couple of ground survey points are available at the deck and water surface, which along with some site observations and bridge opening measurement, they serve to confirm the gauge datum:

- Survey on 01/09/2017 10:31:

  WL=11.22mOTP; Stage = 1093mm ➔ Gauge Zero = **10.127mOTP.**

- Site visit on 02/02/2018.

  Kicker Level = 17.71mOTP (survey location seems to be on Kicker, not in deck);

  Deck level = 17.71mOTP- 0.30m approx. = 17.41mOTP approx.;

  Height from Deck to WL = 6.2m approx. ➔ WL = 11.21mOTP approx.;

  Gauge reading = 1000mm approx. ➔ Gauge Zero = **10.21mOTP approx**.

- Both estimations are consistent with data and correct Gauge Zero, suggesting a shift of 1m:

Gauge Zero = 11.138mOTP (as provided) – 1.0m = **10.138mOTP.**

- The change of datum or gauging zero seems to have happened around the 13/April/2010, as advised by client and based on stage/time graph of Figure 0.37. In that graph, the stage looked 1m higher after the 13/April/2010, suggesting the WL from records should be lowered 1m for data after that date. On in other words, the datum should be 10.138mOTP after the 13/April/2010, and 11.138mOTP before the same date.

The datum defined this way is consistent with the records and model results, and used for all analysis and modelling tasks.