WRC Lower Waikato 2D Modelling

Huntly, Ohinewai and Horotiu Model Build

Waikato Regional Council

Report

February 2020

The expert in **WATER ENVIRONMENTS**

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Huntly, Ohinewai and Horotiu Model Build

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Source: Wikipedia

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1 Introduction

Waikato Regional Council (WRC) engaged DHI via email on 26th September 2017 to extend the existing Lower Waikato-Waipa river model to include a two-dimensional (2D) representation of Huntly and surrounding areas. The initial focus was on the Huntly area, due to deadlines imposed by Waikato District Council (WDC), but as initially scoped, the model was eventually extended (2019) to cover Ohinewai and Horotiu. The purpose of the model is to produce maps of flood inundation for a variety of design events, including existing and future climate scenarios. This report summarises the model build process and the data used.

The final suite of models used to simulate validation and design events are based on WRC's pre-existing river model, which is designed for flood forecasting simulations. Four storms from July 1998, July 2002, March 2004 and April 2017 have been used for validation. For each flood scenario three simulations are carried out in series, firstly a 1 year-long rainfall-runoff simulation is carried out to warm-up the hydrological response from the catchments, secondly a 3 week-long hydrodynamic simulation of the main river and tributary channels is carried out, and finally the full flood model with flood plain representation is simulated using the results of the rainfall-runoff simulation as inflows and results of the river simulation as initial conditions. All simulations were carried out using MIIKE Release 2017 SP2 and the flood simulations were computed on machines with dual GPU's.

2 Existing River Model

The existing river model is an amalgam of two previously separate models: the Lower Waikato and Waipa MIKE 11 models. Legacies of the merger can be found in the catchment naming conventions. The model extends from Karapiro Dam to Port Waikato on the coast where a tidal boundary condition is applied. There are 92 catchments covering 6476 km^2. Each of the two northeastern-most catchments, 1 and 2, contain lakes: the catchment area upstream of these lakes is neglected, so these lakes contribute zero flow to the river model.

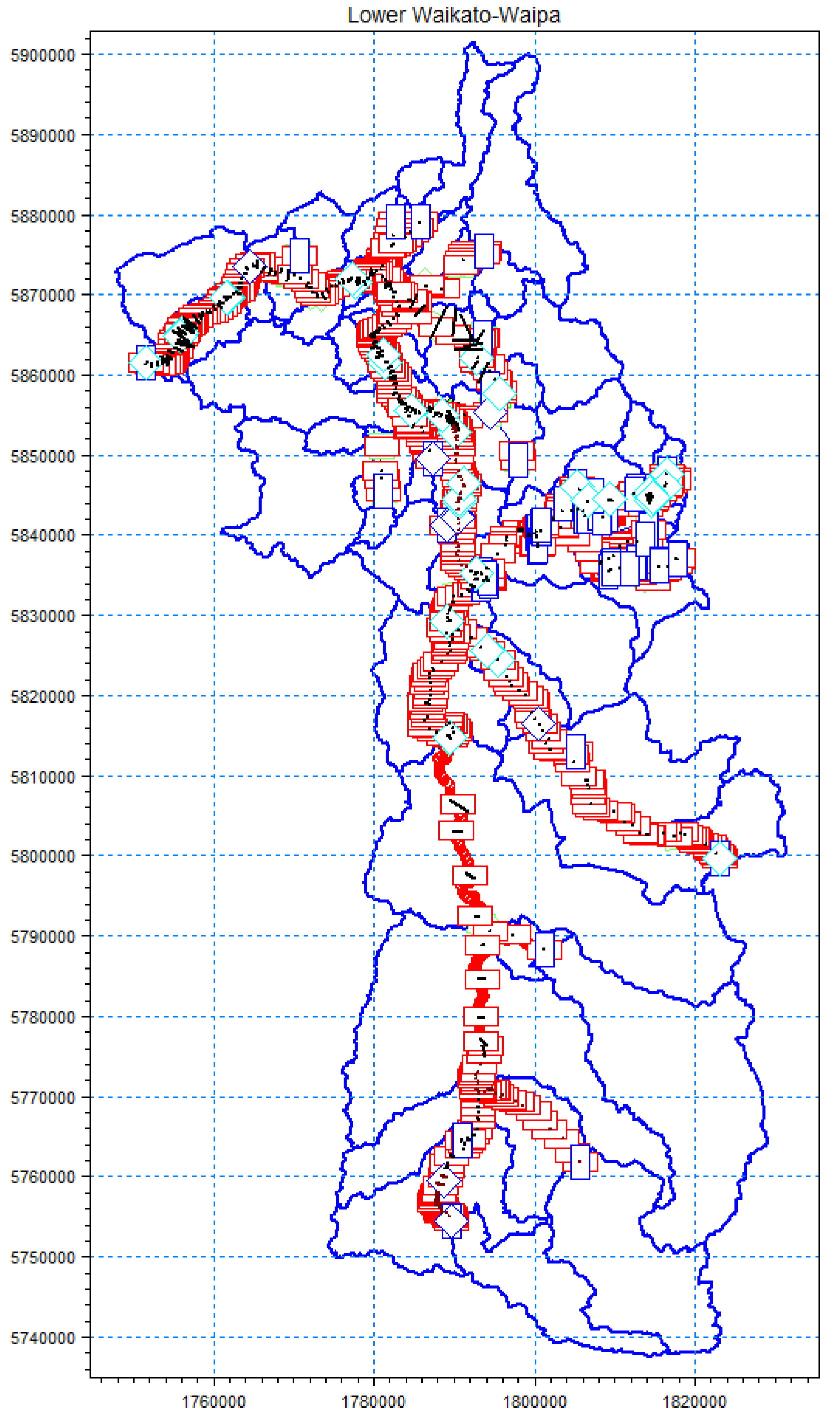


Figure 2-1 Pre-existing MIKE 11 model of the Lower Waikato River and Waipa River including river alignment and catchments.

Before the 2D floodplain was incorporated into the model, aspects of the river model were revised to better suit connection to the floodplain. These changes are listed below.

1. Survey marker coordinates and associated bank markers added to cross sections between cross sections 139 and 111. Survey marker locations estimated from Google Earth KMZ provided by WRC.
2. Alignment vertex locations and chainages were adjusted to coincide with cross section survey locations along a 38 km reach of the Waikato River branch between chainages 43270 and 81987. Vertices have also been aligned along the downstream 17 km reach of the Waipa River branch between chainages 112125 and 128900.
3. The entire Waahi Stream branch was realigned and the chainages reset. The length of the new branch is 2.1 km. The existing cross sections have been retained and additional cross sections required for flood-model linking purposes have been interpolated.
4. Lake Waahi is simulated in the overland flow model (MIKE 21 FM) in the flood model, but in the river model, used for initialising the flood model, the lake is represented as additional storage in the upper-most cross section so that the lake water level is correctly initialised. The additional storage curve used to represent Lake Waahi in the pre-existing model was fixed at 9580000.0 m^2 for all elevations; GIS analysis found that this overestimated storage for elevations less than 10.75 m RL, so based on the GIS analysis a new storage-elevation relationship was developed (see Figure 2-2).

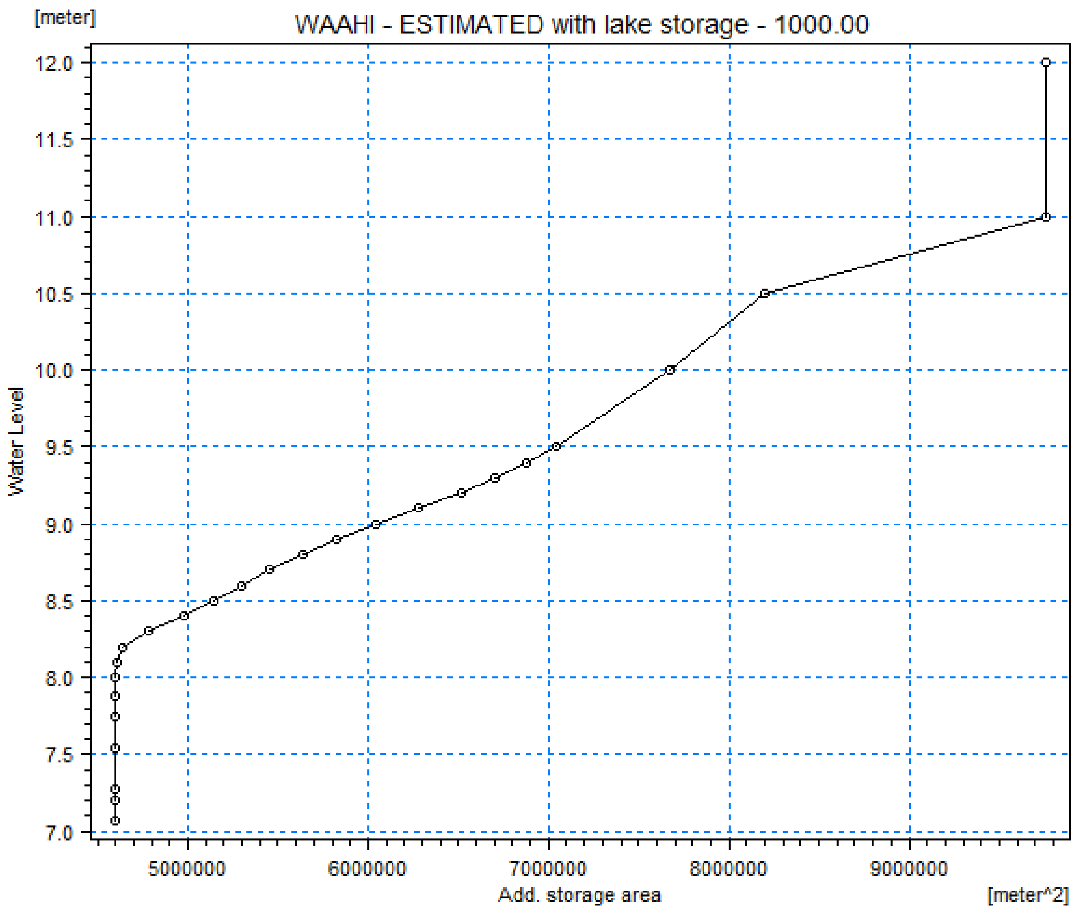


Figure 2-2 Storage-elevation relationship developed to represent Lake Waahi at the head of the Waahi Stream branch in the river model (MIKE 11), the results of which serve as the initialisation of the flood model.

5. The *Max dx* parameter, which controls grid point spacing, was reduced from 10000 m to 25 m for the Waikato River reach between chainages 53710 and 103703 and from 1000 m to 30 m for the Waahi Stream branch. These modifications are not vital for the river model, however, they facilitate appropriate linking between the river and flood plain in the flood model.
6. The pre-existing model was used in a live flood forecasting system, making use of measured and predicted precipitation timeseries for boundary conditions. In several cases rainfall timeseries from stations that have been decommissioned were still connected to the model, contributing zero rainfall. The rain gauge distribution across catchments has been completely revised to reflect the available data for the four validation events. Uniform Chicago-Temporal-Pattern based design storms have been used for design event simulation.

3 Data

3.1 Data source

Based on the data requirements specified in DHI's proposal, dated 13th September 2017, WRC staff sent all appropriate data available to them and directed DHI to other data sources where necessary. There are a number of sources of data and the licensing of this data varies. Table 3-1 summarises the data used in the model revision and upgrade process.

Table 3-1 Data used for model build.

Data description	Source	License
Flood forecasting MIKE 11 river model including associated GIS data such as catchment shapes, short range observed data, and rainfall and water level gauge locations.	WRC flood forecasting system maintained by DHI.	-
Hydrotel IDs spreadsheet providing WRC gauge locations, internal codes and gauge types.	WRC, provided to DHI on 15/4/2016.	-
Telemetry map providing associations between observation and prediction gauges.	WRC, undated.	-
Port Waikato tidal timeseries predictions based on calculated tidal constituents.	C-MAP.	Licensed via DHI MIKE C-MAP licensing agreement.
WDC stormwater asset GIS data. *(Note that this data was investigated but found to be incomplete and so was not incorporated in the final model)*	WDC care of WRC, provided to DHI on 2/10/2017, 13/11/2017 and 16/11/2017.	-
Drainage infrastructure asset GIS data.	WRC, provided to DHI on 5/10/2017.	WRC Data User Agreement (Doc #11168417, signed 4/10/2017).
Cross section survey data for 2006 and 2007 surveys, maps of aggradation and degradation, cross section locations in KMZ format, and report "River Bed Morphology Analysis - Huntly to Rangiriri, Waikato River (1468656).doc".	WRC, provided to DHI on 5/10/2017.	-
Building outlines (pilot) polygon GIS layers	Downloaded from LINZ website on 5/10/2017.	Creative Commons – Attribution 3.0 New Zealand (CC BY 3.0 NZ); creator: LINZ.
Stopbank design levels in GIS format.	WRC, provided to DHI on 6/10/2017.	-
Observed rainfall, discharge and water level gauge timeseries.	WRC, provided to DHI on 12/10/2017.	-
LiDAR flown in 2007/08 and 2010/11 for Lower Waikato region.	WRC, provided to DHI on 20/10/2017, 15/11/2017 and 21/11/2017.	WRC Data Use Agreement (Doc #3247537, signed 12/12/2014).

Data description	Source	License
Polygon shapefile of 1% AEP flood extent from Horotiu to Port Waikato.	WRC, provided to DHI on 20/10/2017.	WRC Data Use Agreement (Doc #11215581, signed 24/10/2017)
Observed discharge at Huntly gauge timeseries.	WRC, provided to DHI on 3/11/2017.	-
Design 1958 Model 100 year HEC-HMS Karapiro discharge timeseries.	WRC, provided to DHI on 16/11/2017.	-
Existing design 10 min-, 20 min-, 30 min-, 60 min-, 2 hour-, 6 hour-, 12 hour-, 24 hour-, 48 hour-, and 72 hour-duration rainfall depths for centroid locations of the 92 catchments.	Downloaded from NIWA's HIRDS website on 23/11/2018.	Creative Commons – Attribution 4.0 International (CC BY 4.0)
Lower Waikato River design flows and flood frequencies spreadsheet.	WRC, provided to DHI on 27/11/2017.	-
Road centre lines in GIS format.	Downloaded from LINZ website on 31/1/2018.	Creative Commons – Attribution 3.0 New Zealand (CC BY 3.0 NZ); creator: LINZ.
Property parcel polygons in GIS format.	Downloaded from LINZ website on 1/2/2018.	Creative Commons – Attribution 3.0 New Zealand (CC BY 3.0 NZ); creator: LINZ.
Ministry for the Environment LUCAS NZ land use map in GIS format.	Downloaded from LINZ website on 1/2/2018.	Creative Commons – Attribution 4.0 International (CC BY 4.0)
Mangawara detailed model	WRC provided to DHI on 05/07/2018	-
Stormwater structures (drainage points and bridges) in shapefile format. DHI's requested list is included in Appendix C.	Waikato District Alliance (WDA) provided to DHI on 26/11/2018	-
Stormwater assets	Link provided by WDC to DHI on 26/11/2018 https://data.waikatodistrict.govt.nz/search/?q=storm+water	Creative Commons – Attribution 4.0 International (CC BY 4.0)
Stormwater assets in MyMap format	Link provided by WDA to DHI on 27/11/2018 https://www.google.com/maps/d/u/0/viewer?mid=1j77bFWd4FIWGTal1018UkS0XDWQ&ll=-37.675500168758965%2C175.1522589038866&z=15	-
Stormwater as-builts for bridges and culverts	WDA provided to DHI on 27/11/2018	-
Kiwirail bridges and culverts, as-builts in pdf format	KiwiRail provided DHI on 6/12/2018	-

Data description	Source	License
WRC's floodgate and pumpstation data in GIS format	WRC provided DHI on 31/01/2019	-
Aerial Photography – Waipa River 2004 and Waikato River 1998	WRC provided DHI on 14/08/2019	Creative Commons – Attribution 4.0 International (CC BY 4.0)

3.2 Data Gap Analysis

3.2.1 Rainfall

We have received timeseries for the following rain gauges as listed in Table 3-2.

Table 3-2 Rain Gauges used in model

Gauge Name
RF_Puniu_818.2
RF_Te_Kuiti_414.49
RF_Otewa_1191.7
RF_Wharekiri_414.21
RF_Waintaguru_428.4
RF_Ngaroma_818.7
RF_Wairamarama_201.4
RF_Maukoro_Landing_749.12
RF_Hauturu_36.5
RF_Kararamu_1247.38
RF_ControlGate_1293.6
RF_Mangatangi_453.4
RF_Maungakawa_204.1
RF_Waingaro_1167.4
RF_Ruakaura_1131.168
RF_EW_Hamilton_1131.164
RF_Maungatautari_377.2

As mentioned in the meeting on 30/10/2017, in some of the rainfall timeseries there are "." and "---" entries. These entries have been read as 0.

3.2.2 Pump Stations and Flood Gates

One pump station and 3 floodgates have been added to the existing model. The positions of 13 other pump stations and 11 floodgates are available from the WRC GIS data, but the specifics of the structures are missing for:

- Flood gates: details of the shape, size and nature of the flow control;
- Pump stations: number of pumps, rising main specifications, Q-H/Q-dH pump curves, set-points (start and stop levels), pump type, wet well dimensions and levels, operations control information (duty/stand-by pumps, etc.) and associated storage.

The pump stations and floodgates present in the model are shown in Table 3-3 and Table 3-4. See Appendix C for a list of the excluded pump stations and floodgates.

Table 3-3 Pump stations modelled

Asset_ID	ASSET_DESCRIPTION	Owner	Easting NZTM	Northing NZTM
25872	Whangamaire Pumpstation	WRC	1794045	5835619

The Whangamaire pump station has been taken from the Mangawara model provided by WRC on 05/07/2018.

Table 3-4 Floodgates modelled

ASSET_ID	ASSET_DESC	Type
25586	Whangamaire Floodgate	
	Whangamaire Pump non-return valve	Non-return valve
26579	Waahi Stream Floodgate	Flap-gated culverts
27323	Okowhao Floodgate 1 (Culvert Te Ohaki road 3a)	Non-return valve
	Rotongaro Floodgate	Gate

The Rotongaro and Waahi Stream floodgates are legacies of the Lower Waikato model. The Whangamaire structures have been taken from the Mangawara model provided by WRC on 05/07/2018.

3.2.3 Pipe Network

A brief analysis of the data indicates the following are missing from the available node data. Table 3-5 below summarises point-based invert information and is the percentage of missing data from the set delivered to DHI on 13/11/2017.

Table 3-5 Percentage missing invert data

Nodes (sw_point_point)	Count	% without invert info
No. catchpits	125	90%
No. discharge points	84	0%
No. outlets (overlap with discharge points)	158	89%
No. inlets	21	71%
No. soakholes	4	50%
No. manholes	1044	58%
No. sumps	161	84%
No. pipes	1231	17%

In Figure 3-1 the yellow circles indicate networks that seem to be disconnected from downstream drainage and the red circles indicate locations where there appears to be missing drainage asset data.

For a rain-on-grid approach to work well in suburban areas, it is recommended that all stormwater inlets are explicitly represented for at least a basic level. This requires that stormwater inlets are located, even if the grate, sump and lead parameters are not available. The available catchpit locations are identified as orange circles with black crosses in the image below and it is clear that this asset information is not complete. Digitising these stormwater inlets could be performed manually using aerial photos and this would be sufficient for inclusion in the model so long as standard grate, sump and lead parameters can be agreed on, however the stormwater main data would have to be substantially complete.

As agreed with WRC, based on the time-constraints and quality of the GIS drainage information, it was decided to exclude the pipe networks, open channels and pumps from the model and simply simulate flooding from the river over the design-level stopbanks, as the number of questions it would raise will outweigh any benefit of high-resolution flood mapping.

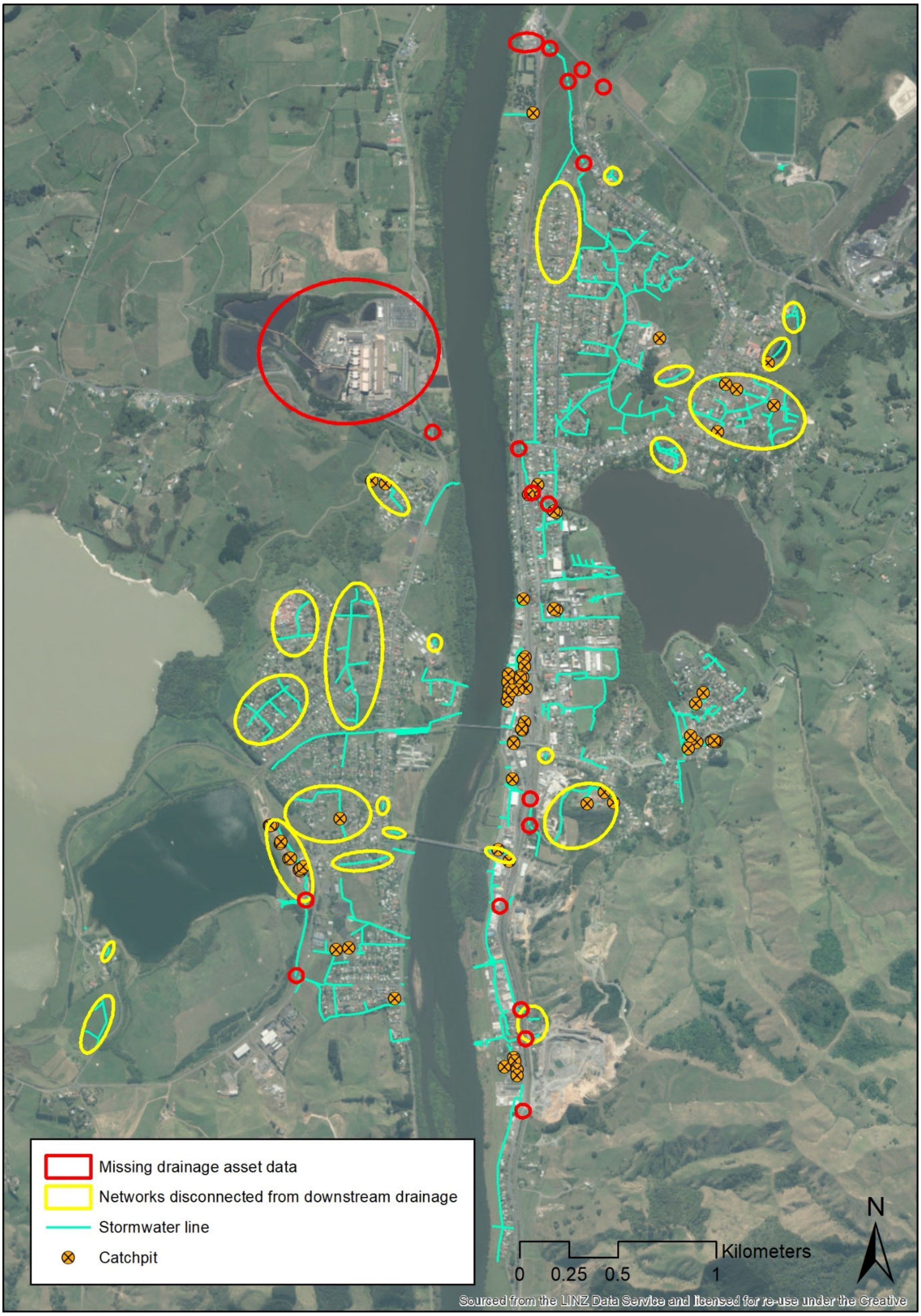


Figure 3-1 Data gap summary, showing areas where data appears incomplete

3.2.4 LiDAR

Two sets of LiDAR data have been provided by WRC to DHI, one collected in 2007-2008 and the other in 2010-2011. The extent of the data is shown in and the expected accuracy of the data is presented in Table 3-6.

Table 3-6 LiDAR Metadata

	Survey 2007-2008	Survey 2010-2011
Captured terrain model [m]	1.2	-
Vertical accuracy [m]	0.45	-
Horizontal accuracy [m]	0.15	0.11

The LiDAR data does not cover the upstream part of Firewood Creek, which becomes flooded during the simulations. An artificial wall is thus created, at the boundary of the model grid, resulting in a negligible backwater effect and skewing the existing storage capacity of Firewood Creek.

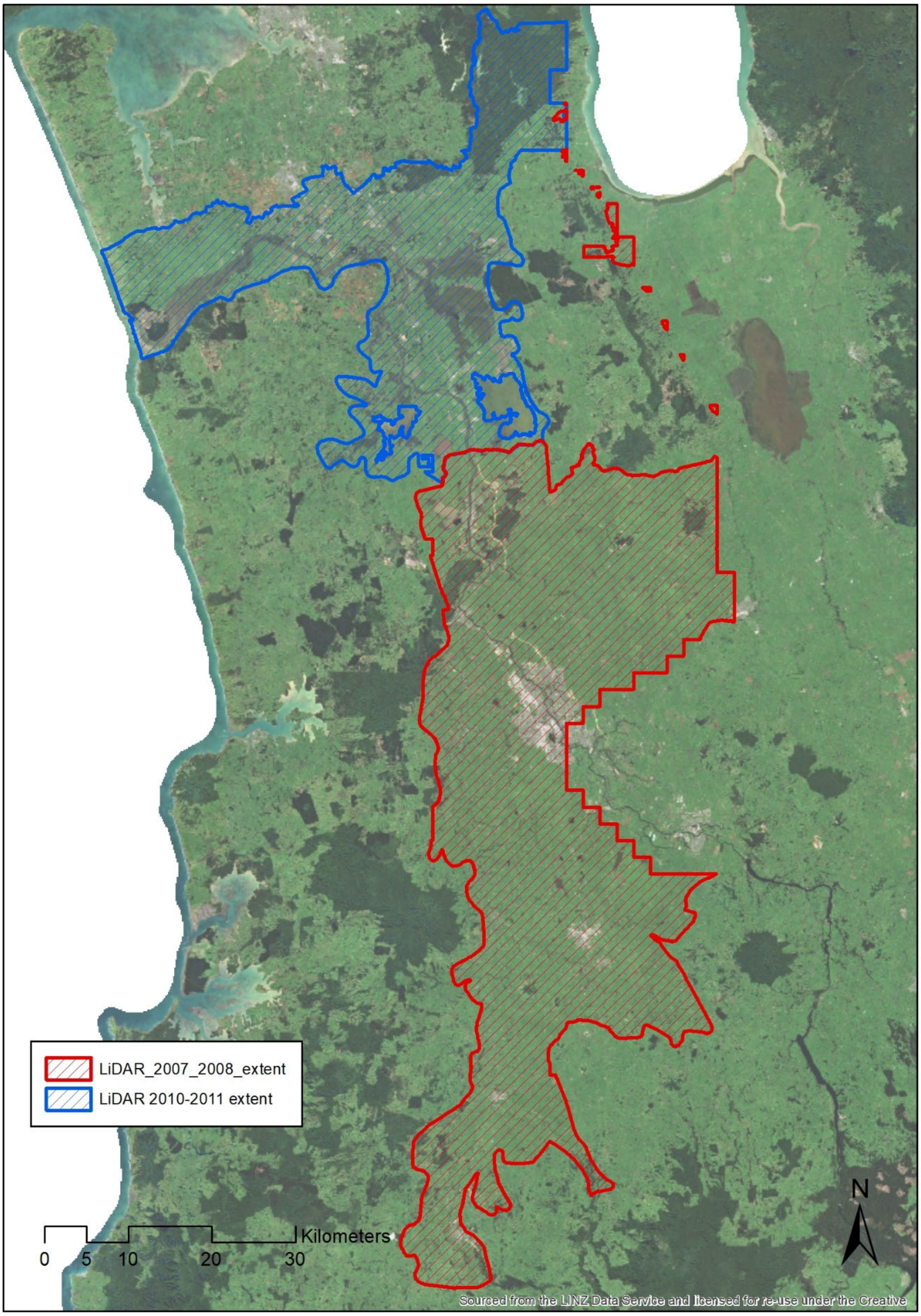


Figure 3-2 Extent of the LiDAR data provided by WRC

3.2.5 Floodplain Roughness

The building footprint, road centreline and land use GIS layers have been used to create the roughness map for the 2D model. Table 3-7 shows the roughness values used to represent the different land uses.

Table 3-7 Floodplain roughness values

Land use	Roughness (Manning's M)
Buildings	0.2
Urban areas	12.5
Rural areas	20.8
Roads	70

3.2.6 Stopbanks

All stopbank information was obtained, from WRC, on the 6/10/2017, with the following exceptions:

- Huntly college stopbanks levels are taken from LiDAR (email from Heather Craig 3/11/2017)
- South Highway 1 (SH1) upgrade represents the SH1 crossing over the Waikato near Hamilton, the stopbanks crest levels have been taken from the finished surface level on the bridge plans (Carl Johnson's email 09/03/2018)
- Lake Waahi Southwestern stopbank

Table 3-8 Stopbanks data used in the model

ASSET_ID	ASSET_DESCRIPTION	OWNERSHIP
22880	Huntly North Freeboard SB	Waikato Regional Council
22897	Wool Scourers to Fosters Landing SB	Waikato Regional Council
23456	Harris Street SB	Waikato Regional Council
23636	Huntly North SB	Waikato Regional Council
23656	Huntly West Section SB	Waikato Regional Council
25082	Hora Hora Section SB	Waikato Regional Council
25083	Okowhao Section SB	Waikato Regional Council
24360	Rangiriri Spillway to Wool Scourers SB	Waikato Regional Council
25816	Kimihia SB	Waikato Regional Council
27306	Hly Sth Tainui Bridge Up Stm SB	Waikato Regional Council
28014	Hly Sth Main Road: Between Tainui BR & Rail BR SB	Waikato Regional Council

ASSET_ID	ASSET_DESCRIPTION	OWNERSHIP
28029	Hills Section SB	Waikato Regional Council
28389	Parry Street SB	Waikato Regional Council
36456	Kimihia Internal SB	Waikato Regional Council
-	SH1 Upgrade	
-	Huntly College Stopbank	
	Lake Waahi Southwestern Stopbank	

3.2.7 Mesh Features

Roads and railways layers, created from aerial photography, have been used in the mesh generation to create detailed mesh elements around those features. Roads were defined using their centrelines in the first iteration of the mesh build, around the Huntly area, and then as polygons around Ohinewai, Taupiri and Ngaruawahia areas. Mesh elements adjacent to roads and railways have been generated with sides of 4m to ensure a high resolution of the grid along those preferential flow paths. All LiDAR points within the 2D model extent have been used for the interpolation of the mesh.

4 Hydrology

The scope of the project did not include for the calibration of the hydrological models, because the original Flood Forecasting model was calibrated. Four validation events were chosen to test the model performance, before simulating design flows.

4.1 Flood Events

The selection of the events is based on analysis performed using WRC's Waikato River level recordings at Huntly[1]. The analysis highlighted the flood events of 1998, 2002, 2004 and 2017, the largest four recorded events of the last two decades.

Mean Area Weighting (MAW) factors were generated with Thiessen polygons (Voronoi diagram), where a polygon is assigned to each rainfall gauge; any location within the polygon is closer to its associated rainfall gauge than any other gauge. Based on the catchment's area within the Thiessen polygon, a weighting factor is assigned to each time series in a list of rainfall time series to determine a mean areal rainfall for a sub-catchment.

As the rainfall gauges do not cover the same period, each event used a different weighting configuration based on the existence of valid stations (Figure 4-1). This analysis was performed over 17 rainfall stations. The Hamilton and Maungatautari stations, currently closed, were only used up to the 2004 event.

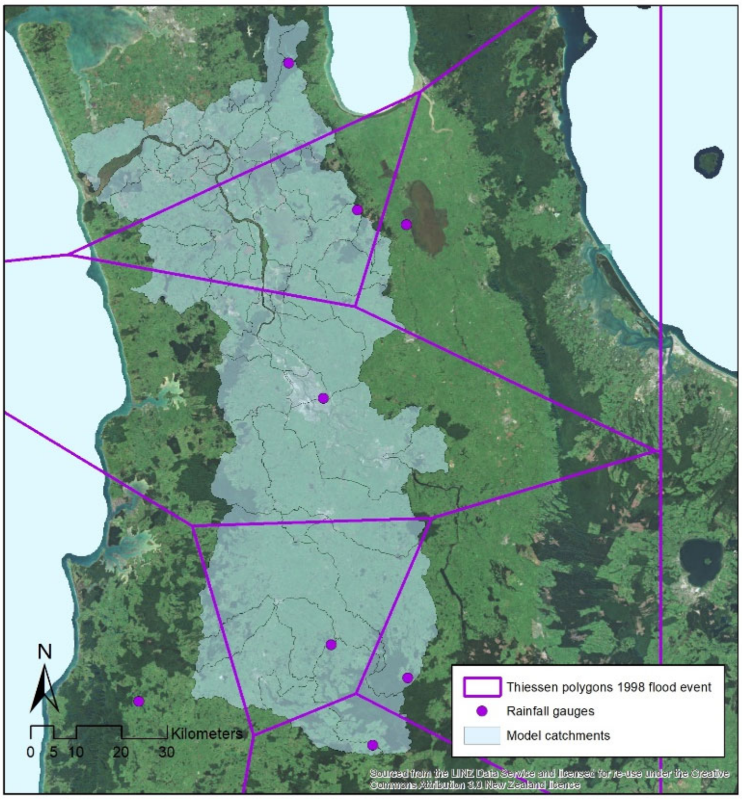


Figure 4-1 Rainfall gauges and Thiessen polygons used for the 1998 event

[1] http://riverlevelsmap.waikatoregion.govt.nz/cgi-bin/hydwebserver.cgi/points/details?point=41&catchment=17&trType=1&trParam=0\

4.2 Design Events

The design rainfall timeseries was produced based on the antecedent moisture conditions of the 1998 event, NIWA's High Intensity Rainfall Design System (HIRDS) v4 rainfall depths and a Chicago Temporal pattern, which describes the distribution of the rainfall over time.

4.2.1 Drainage Analysis

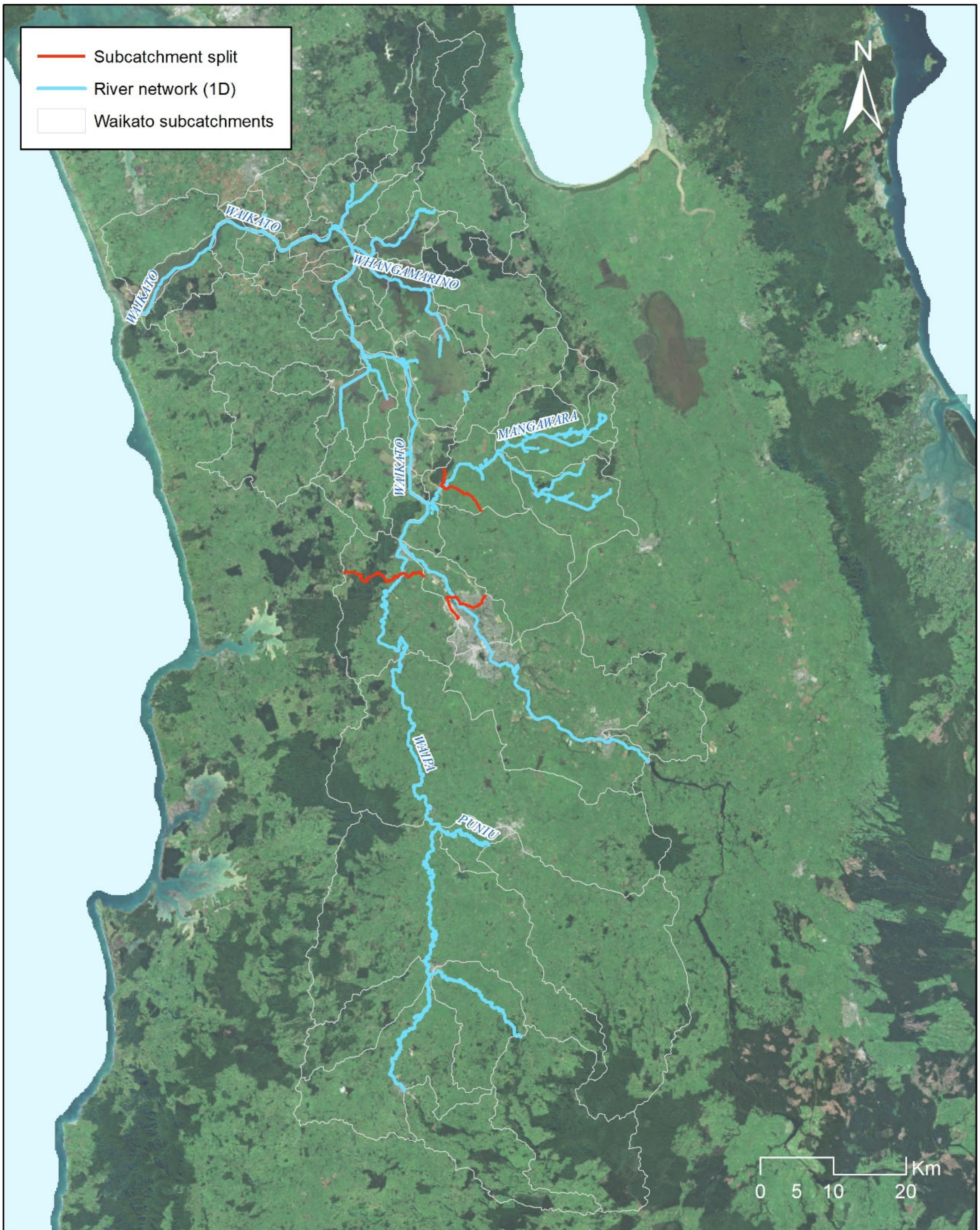
A rainfall-on-grid approach was initially considered for the floodplain area that drains to Huntly, but the stormwater main data was not complete and the Waikato-Waipa Flood Forecast hydrological model approach, subcatchment-based, was maintained in the flood mapped area and adjusted for three sub-catchments, to enable the connection between the channel and floodplain:

- Mangawara subcatchment 70 (Chainage 28000 M11 model);
- Waikato subcatchment 34 (Chainage 42642 M11 model);
- Waipa subcatchment 33 (Chainage 123825 Waipalower M11 model).

The sub-catchment delineation were based on supplied LiDAR, 1:150 000 LINZ contours and the Hamilton City Council Otama-ngenge Integrated Catchment Management Plan[2].

Figure 4-2 shows the Waikato-Waipa subcatchment delineation and the areas where the rainfall-runoff component was split to allow for a higher discretisation of flow in overland flow areas. The original sub-catchment distribution is included in APPENDIX A.3.

[2] https://www.hamilton.govt.nz/our-council/strategiesandplans/Documents/Otama-ngenge%20ICMP%20-%20Version%201-0%20-%20FINAL%20-%20September%202015.PDF



ID	Area (km²)	Split (km²)	Network ID	Chainage US	Chainage DS
33	231.3	182.64-48.71	WAIPAlower	100000	128900
34	92.6	48.72-43.92	Waikato	33808	53710
70-Tenfoot_Drain	9.91	7.61-2.3	Mangawara River	16056	31336

Figure 4-2 Waikato hydraulic model sub-catchment distribution

The extension of the pure 1D model to include overland flow required a more accurate representation of the river thalweg, where the floodplain is represented in 2D. The modified thalweg combined with the addition of bridge structures to the network and a more rigorous spatial discretisation of the drainage network, required the catchment loads to the network at sub-catchments 28, 31, 32 and 34 to be moved.

4.2.2 Storm Pattern

Raster files containing the rainfall depth were downloaded from NIWA's Open Geospatial Data website[3].

Rainfall depth corresponding to the base storm event, the 1% AEP, was extracted from the raster files and then used to generate a nested storm event using Python scripts (see Appendix A.2).

The nested hyetograph has a duration of 72 hours and is non-symmetrical during a 1 hour period at the centre of the event. Table 4-1 and Figure 4-3 show the nested storm pattern used to create each sub-catchment's hyetograph.

Table 4-1 Nested storm pattern used to create the catchments hyetographs

Hyetograph time (h)	Critical duration depth formula
12	(72h-48h) / 2)
24	(48h-24h) / 2)
30	(24h-12h) / 2)
33	(12h-6h) / 2)
35	(6h-2h) / 2)
35.5	(2h-60m) / 2)
35.8	(60m-30m) * 2 / 3)
36	20m-10m
36.2	10m
36.3	30m-20m
36.5	(60m-30m) / 3)
37	(2h-60m) / 2)
39	(6h-2h) / 2)
42	(12h-6h) / 2)
48	(24h-12h) / 2)
60	(48h-24h) / 2)
72	(72h-48h) / 2)

[3] https://data-niwa.opendata.arcgis.com/datasets/edcbe0a99d7f4df59501ba55973648f5?geometry=-180%2C13.576%2C180%2C79.496

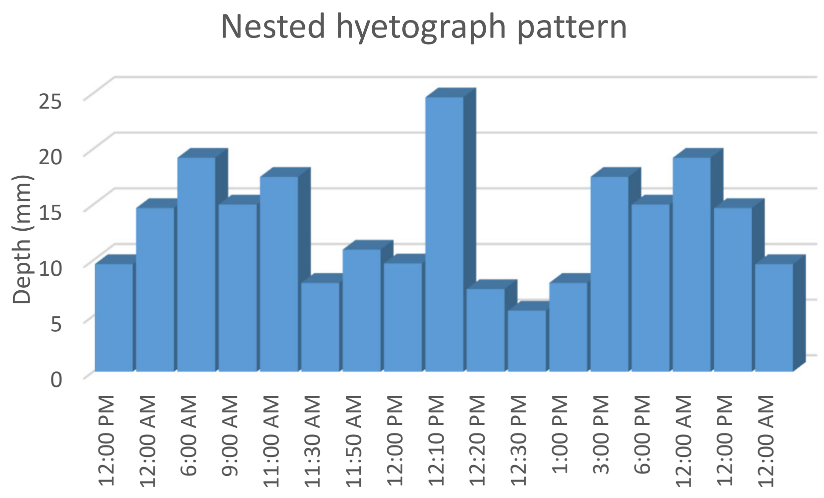


Figure 4-3 Design event nested hyetograph pattern

The choice of hyetograph shape and timing of the peak has a significant influence on the results. The hyetograph used the lead up to the 1998 event, positioning the 1% AEP design rainfall on the 8th of July, before the 1998 event occurred.

4.2.3 Karapiro Power Station Outflow

Mercury Energy (former Mighty River Power) controls the outflows from the Karapiro Dam through flow management rules. The Karapiro outflow represents the model upstream boundary condition for this Waikato River model.

The design events hydrograph, obtained from WRC, were generated in HEC-HMS (Jowett, 2009) and uses the February 1958 event temporal pattern with land use estimated from the New Zealand Land Cover Database (LCDB2, satellite imagery from 1996/97); the hydrograph takes into account the hydropower dam flood rules. The start of the design hydrograph coincides with the start of the design rainfall.

The hydrograph was not scaled for design events incorporating climate change.

4.2.4 Climate Change (CC)

In addition to the current climate change scenario (1%AEP), two climate change scenarios were modelled. The projected temperature increases are based on greenhouse gas concentration trajectories, i.e., the Representative Concentration Pathway (RCP) scenarios adopted by the Intergovernmental Panel on Climate Change (IPCC):

- Current climate (0°C temperature increase)
- Projected New Zealand land-average temperature increase between 1986–2005 and 2101–2120 for the scenario RCP6.0: 2.3°C[4]
- Projected Waikato region temperature increase between 1986–2005 and 2101–2120 for the scenario RCP8.5: 3.8°C[5]

For a specific temperature (T) increase, the projected rainfall depth is calculated using the following formula and percent changes factor taken from NIWA's HIRDS v4 Usage page[6] (see Figure 4-4 for percent changes).

$$Projected\ rainfall\ depth =$$

$$\left(\frac{temperature\ increase * percentage\ change\ factor}{100} + 1\right) * current\ rainfall\ depth$$

Duration/ARI	2 yr	5 yr	10 yr	20 yr	30 yr	40 yr	50 yr	60 yr	80 yr	100 yr
1 hour	12.2	12.8	13.1	13.3	13.4	13.4	13.5	13.5	13.6	13.6
2 hours	11.7	12.3	12.6	12.8	12.9	12.9	13.0	13.0	13.1	13.1
6 hours	9.8	10.5	10.8	11.1	11.2	11.3	11.3	11.4	11.4	11.5
12 hours	8.5	9.2	9.5	9.7	9.8	9.9	9.9	10.0	10.0	10.1
24 hours	7.2	7.8	8.1	8.2	8.3	8.4	8.4	8.5	8.5	8.6
48 hours	6.1	6.7	7.0	7.2	7.3	7.3	7.4	7.4	7.5	7.5
72 hours	5.5	6.2	6.5	6.6	6.7	6.8	6.8	6.9	6.9	6.9
96 hours	5.1	5.7	6.0	6.2	6.3	6.3	6.4	6.4	6.4	6.5
120 hours	4.8	5.4	5.7	5.8	5.9	6.0	6.0	6.0	6.1	6.1

Figure 4-4 Percentage change factors to project rainfall depths to a future climate 1 degree warmer

[4] www.mfe.govt.nz/sites/default/files/media/Climate Change/Climate-change-projections-2nd-edition-final.pdf#page=100

[5] www.mfe.govt.nz/sites/default/files/media/Climate Change/Climate-change-projections-2nd-edition-final.pdf#page=42

[6] https://www.niwa.co.nz/information-services/hirds/help

5 Hydraulic Model

The hydraulic model is based on the Lower Waikato Flood Forecasting System model and it consists of a rainfall-runoff component, a MIKE 11 warm-up component and a MIKE FLOOD model, which all run one after the other. The warm-up model is 1D only and covers a duration of three weeks prior to the design event (24/06/1998 to 17/07/1998). The MIKE FLOOD model is a 2-way coupled model (MIKE 11 and MIKE 21) which uses a cropped version of the warm-up model for its 1D component.

5.1 MIKE 11

5.1.1 Model Domain

The MIKE 11 warm-up model consists of the Waikato River from the Karapiro dam down to its mouth at Port Waikato and its main tributaries Waipa and Mangawara Rivers. It is made up of 131 branches. The MIKE 11 component of the MIKE FLOOD model has a reduced extent, from the Claudelands Road bridge in Hamilton down to its junction with the Mangatawhiri River.

5.1.2 NAM Rainfall-Runoff

5.1.2.1 Validation

The simulations of the four validated events are comprised of:

- the MIKE 11 NAM rainfall-runoff module, warmed-up for one year to represent the contributing sub-catchments and generate lateral inflows to the river network. The relative soil moisture ratio (L/Lmax) parameter was maintained from the Flood Forecast model to initialise the flood event model (0.5 for the Waipa and 0.3 for the remaining catchments). The upper level storage ratio (U/Umax) value of 0.5 was kept for most catchments (exception for catchment J0 and J1).
- the MIKE 11 HD module, with a simulation run time of one month, including the validation event.

The validation was performed prior to the development of the 2D component, at four gauges in the Waipa catchment. The Waikato gauge at Hamilton (upstream of the confluence between the Waipa and the Waikato rivers) was not considered since the flow follows the Karapiro dam discharge. The comparison of observed and simulated event flows (Appendix B1) showed a close agreement between the two.

5.1.2.2 Design Events

The design event construction followed a pragmatic approach agreed with WRC, involving the following steps:

- run the four validation scenarios to estimate the most appropriate initial conditions for the 100 year design event;
- analysis of the correlation of the AEP events with Antecedent Moisture Conditions;
- choice of hot-start parameters L/U to warm up the NAM (RR11);
- choice of Areal Reduction Factors;
- choice of hot-start period leading up to the event (purely 1D);
- assign calculated catchment runoff directly to the overland component;
- run the design event (1D+2D).

Mean Area Weighting

Initial consideration was performed on the impact of using different distributions of rainfall between the flood forecasting model, which was calibrated, and the current model. Different rainfall distributions were ultimately used since it was envisaged to update the model network (i.e. cross-sections) requiring a new calibration; also, the potential use of the model for flood forecasting required active stations.

Initial Conditions

The initiation of runoff from the MIKE-11 NAM model is largely influenced by the initial soil moisture in the root zone (L) and to a lesser extent the amount of moisture in the surface storage (U). The root-zone soil moisture fraction (L/Lmax) lead up to the flood events was analysed and the storage ratio indicated values higher than 0.7, for all events, in the majority of the subcatchments. Figure 5-1 shows the root-zone soil moisture fraction for the 1998 flood event; the remaining events are shown in ANNEX B.1.

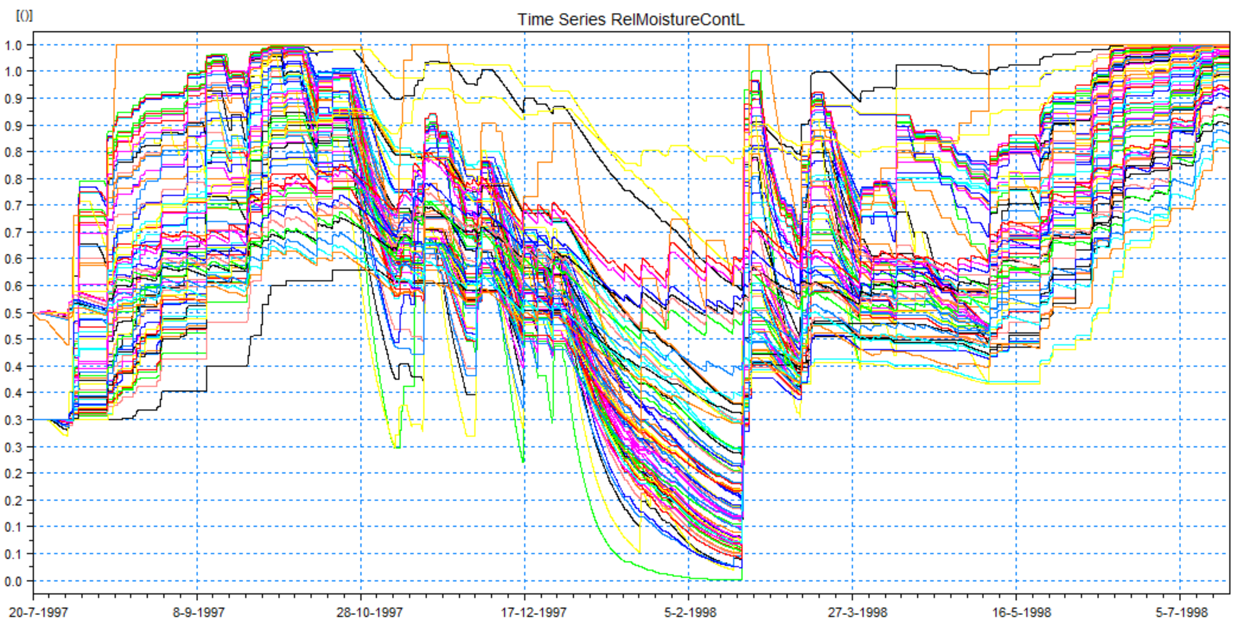


Figure 5-1 1998 event warm-up period (L/Lmax)

In order to identify a relationship to determine the 1%AEP initial conditions, for each sub-catchment, the variable of interest (i.e. L, GWL) was averaged over the month prior to each flood event and the four averaged values were plotted against the validation flood event AEP's.

The purpose of this analysis of the distribution of soil moisture and groundwater was to select appropriate initial conditions, which reflect realistic results in terms of observed flood frequencies.

The following figures (Figure 5-2 - Figure 5-4) are examples of the correlation between the moisture content and the AEP for each of the validation events. Timeseries data were extracted from the results of each validation RR simulation; across one month, a seven-day period was chosen as the most representative of the moisture conditions leading up to the event and the choice of sub-catchments represents the geographic variability of the Waikato catchment.

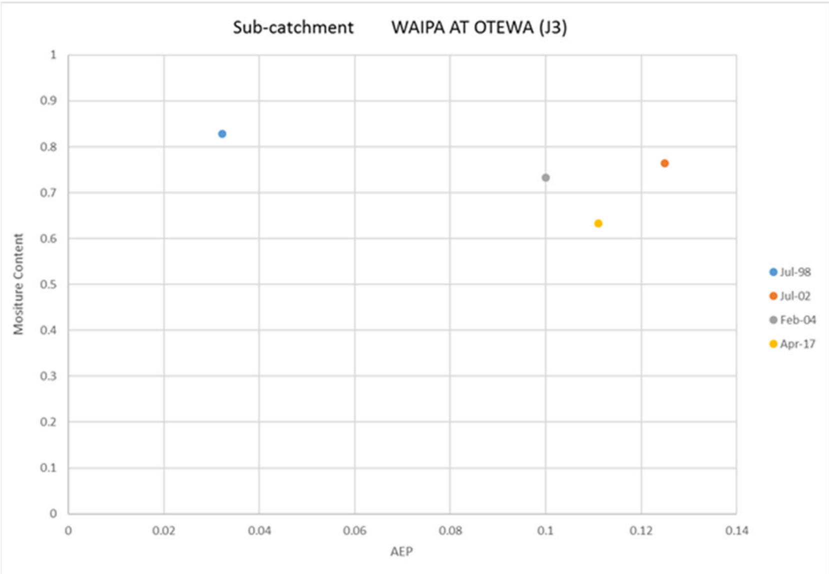


Figure 5-2 Moisture content vs AEP at sub-catchment J3

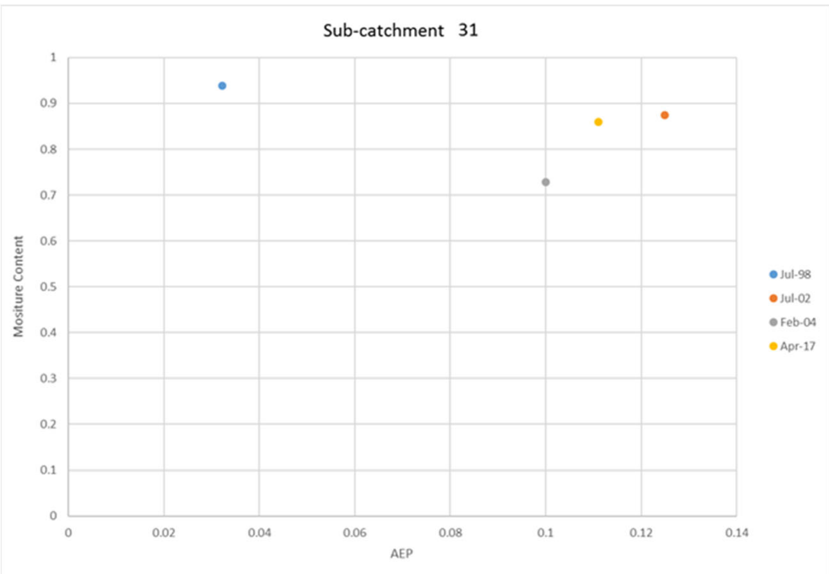


Figure 5-3 Moisture content vs AEP at sub-catchment 31

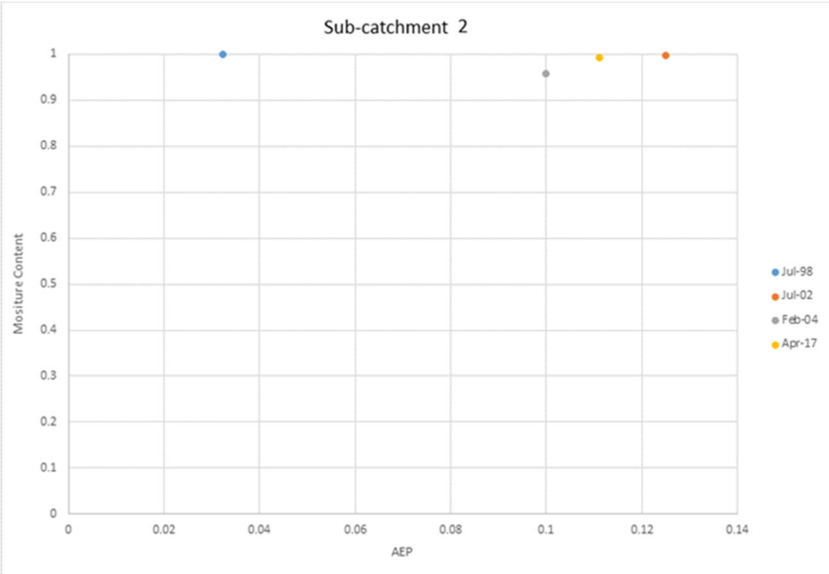


Figure 5-4 Moisture content vs AEP at sub-catchment 2

The correlation of the antecedent moisture conditions and the four estimated events, revealed a distinct behaviour between summer and winter months. The water stored before summer months shows a consistent pattern above the initially used L-value of 0.3-0.5.

Looking at the 1998 event, with a flood frequency less than a 1% AEP, if we were to include higher AEPs into the analysis we would obtain values of saturation close to 1, for this reason the 1998 initial conditions parameters were adopted by the 100 year design event, reflecting a realistic scenario across all sub-catchments, instead of approximating best fit lines (i.e. averaging) across the different validation events (i.e., different exceedance probabilities).

Areal Reduction Factor

An areal reduction factor (ARF) of 0.7 was used for all sub-catchments and all nested rainfall durations. The Auckland Council's TP108 (Section 2.3) was used as reference, acknowledging its limitation of only validating catchments below an area of 500 km². Figure 5-5 shows the extrapolation of the ARF to the Karapiro catchment and the whole Waikato catchment, considering a time of concentration of 2 days and 5 days, respectively.

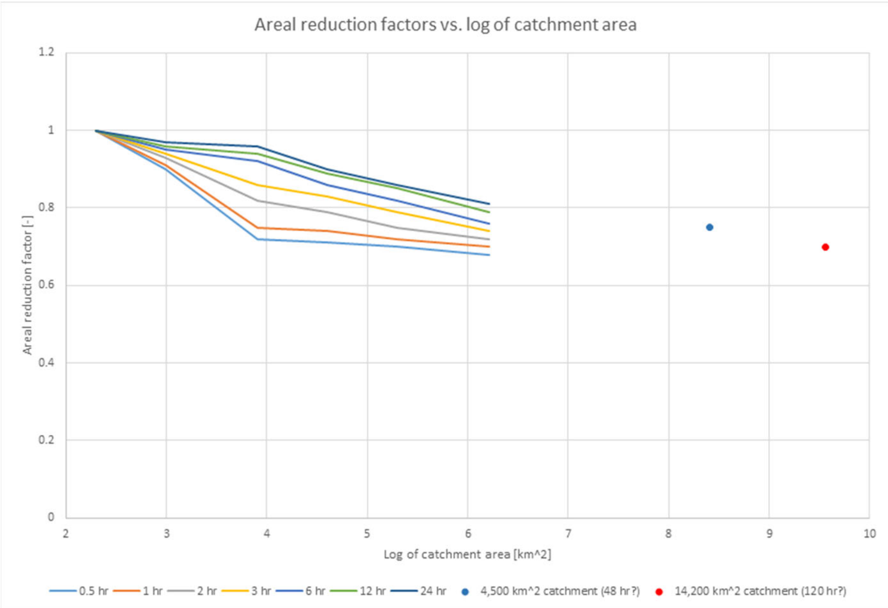


Figure 5-5 Areal Reduction Factor vs catchment area based on TP108

Hydrodynamic Simulation

A three week warm-up hydrodynamic 1D simulation was applied to the main river and tributary channels, which was necessary because it takes nearly two weeks to route a flood hydrograph along the whole river. The simulation incorporated the rainfall-runoff parameters from the previous year leading to the 1998 event.

Through a series of batch files which connect the different components of the model, the flood model with flood plain representation is simulated using the results of the rainfall-runoff simulation as inflows and results of the river simulation, from the 8^{th} of July, as initial conditions.

5.1.3 Cross Sections

It was agreed with WRC to use existing Flood Forecast model cross-section data and re-assess with the expansion of the model beyond the Huntly area. The cross-section data for the Waikato upstream of Ngaruawahia is from 1987-1994 survey and downstream of Ngaruawahia and at the Waipa River is from 1998. The processed data levels and position of markers were adjusted where the channel conveyance was incorrectly calculated. The cross-section radius type was also adjusted to ensure consistency across the river reach.

5.1.4 Stormwater Network

Table 5-1 shows the number of 1D structures present in the warm-up and MIKE FLOOD models. The floodgates modelled are simple one-way flow gates without specific control.

Table 5-1 MIKE 11 structures

	MIKE 11 warm-up model	MIKE FLOOD model
Culverts	51 (including 5 floodgates)	47 (including 5 floodgates)
Pumps	1	1
Bridges	5	5
Weirs	14	8
Control structures	9	6

Details of these structures (branch, ID, dimensions) are provided in Appendix B.

Additional structures were identified for potentially influencing the stormwater flooding, however those structures have not been added for one of the following reasons:

- lack of information on their dimensions, or
- due to their small dimensions, it has been assumed that the structures would get blocked during the event thus having no influence. All structures with a diameter (or corresponding geometry) smaller than 450mm have been excluded from the model. A list of those structures can be found in Appendix C.

If available, the operation of most structures was retained from the original flood forecasting model, such as the Waikare canal gate.

The Mangawara River system within the overall Waikato-Waipa model differs from the standalone model used for the Mangawara Service Level Review. The overall Waikato Waipa Model has a simplified representation, with the Te Mimihia, Tenfoot and Uapoto Outlets modelled as simple branches with additional storage. Each of these branches have control structures at the upstream end for stability purposes.

5.1.5 Boundary Conditions

The model upstream boundary condition, for all design events (Karapiro Dam discharge), was obtained from WRC, and was created by Jowett (2009). The hydrograph, generated in HEC-HMS, used the February 1958 event temporal pattern with land use estimated from the New Zealand Land Cover Database (LCDB2, satellite imagery from 1996/97) and it takes into account the hydropower dam flood rules.

The downstream boundary is a fixed tidal level of 1.69m for the Port Waikato.

The cropped model, designed to allow faster simulation times, has four boundary conditions that differ from the original model, three at the main branches with an overland flow component, Waikato (ch. 33806, the Waipa (ch. 100000) and the Mangawara (ch. 16056), and also a downstream boundary as a rating curve at the Waikato (ch. 110611).

5.1.6 Channel Resistance, Initial Conditions and other .HD11 File Parameters

The initial water level and discharge for the warm-up simulation was set to 0 in all branches of the model with the exceptions described in Table 5-2. The 1D bed roughness was left to the default constant value of 0.0333 with the exceptions described in Table 5-3. The improved representation of the river thalweg moved the location of the hydrodynamic points (roughness) in the order of meters; this fact is not relevant since the channel roughness is uniform across the network.

The ‘delta’ parameter was adjusted to 0.9 and the NoIter to 2, to ensure model stability.

Table 5-2 Warm-up simulation initial conditions

Branch	Chainage	Initial h	Initial Q
lake rotongaroiti	0	0.1	0.1
Lake_Waikere-Northern Spillway	0	5.5	0.1
WAIKATO	0	18	0.5
WAIKATO	35000	12	0.5
WAIKATO	70000	7	0.1
WAIKATO	130000	0	0.1
MANGAOKEWA	3543	48.5	0.1
MANGAOKEWA	12000	37.5	0.1
WAAHI	1000	8.77	0
WAAHI	3100	7	0
Firewood Creek	0	11.357	0.1
Firewood Creek trib	0	11.488	0.1
Whangamaire Stream	0	9	0.1

Table 5-3 MIKE 11 Bed roughness parameters

Branch	Chainage	Resistance (Manning n)
North Mangatea Stream	0	0.05
North Mangatea Stream	2731	0.05
Waiti Stream	0	0.05
Waiti Stream	1352	0.05
WAIPALOWER	100000	0.055556
WAIPALOWER	128875	0.055556
WAIPAlower_bridge	128875	0.055556
WAIPAlower_bridge	129210	0.055556

5.2 MIKE 21

5.2.1 Topography

The MIKE 21 topography was derived from the 2010/2011 LiDAR survey for the Ohinewai area and the 2007/2008 LiDAR survey for the rest of the model. The outline of the MIKE 21 Flexible Mesh (FM) model was determined primarily with drainage analysis. Water levels from the original 1D model and contour lines were used to refine the outline. The model was run and results used to refine areas were the outline had to be extended or could be reduced to improve model speed; Figure 5-6 shows the final adopted layout. It was agreed to exclude Lake Waikare to allow for faster simulation times.

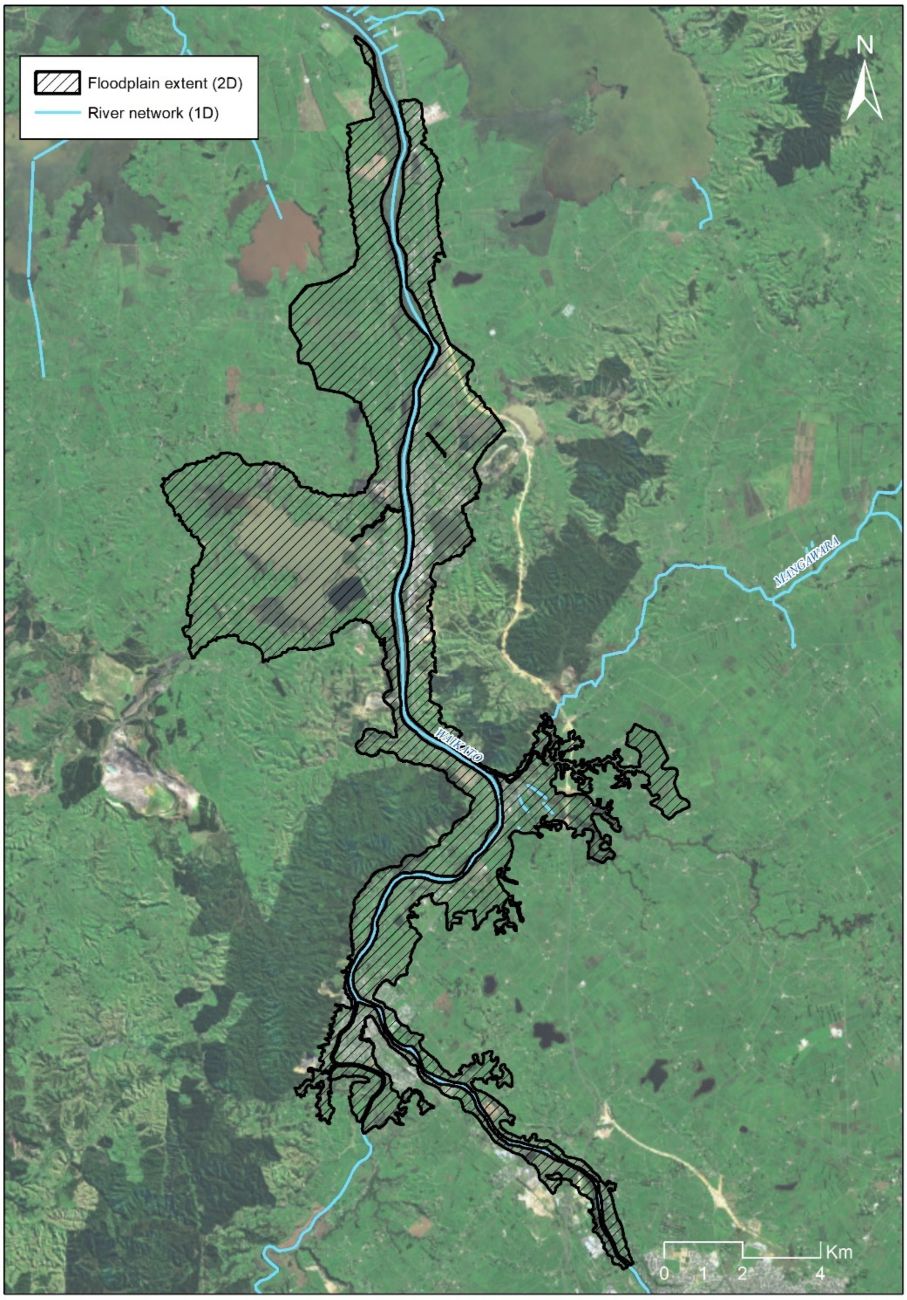


Figure 5-6 2D model extent

A depth correction file derived from the mesh was used to adapt individual cells elevation where the mesh interpolation creates unwanted smoothing. The depth correction is mainly used at standard links to ensure the invert level of the MIKE 11 and MIKE 21 components are matching (MIKE 11 cross section invert vs MIKE 21 cell elevation). The input mesh file is then only used to define the mesh resolution.

The MIKE 11 cross-sections, which represent the floodplain in the original FF model and the hydrodynamic warm-up, were trimmed to represent only the main channel in areas coupled with the 2D floodplain.

5.2.2 Structures

5.2.2.1 Culverts and Weirs

Where culverts were adjacent or included in the 1D network, they were represented within MIKE11; for two structures (Table 5-4), on the floodplain, where the 1D network was not contiguous, the representation was made in directly in the MIKE 21 FM model, using a combination of culvert and weir. These are the cases of the Wright bridge at the junction of Riverview and Hakarimata roads and the railway bridge at Waikere.

Table 5-4 Structures included in 2D model

Description	Geometry	Bridge soffit	Length	X_NZTM	Y_NZTM
Wright Bridge	Irregular	11.28	5	1790425.596	5836613.103
Waikere Railway Bridge	Irregular	12.77	11	1792437.107	5833148.163

5.2.2.2 Stopbanks

Seventeen stopbanks were included in the model as dikes (Table 3-8) so that model resolution would not limit the accuracy of spilling levels. Crest levels were taken from the GIS layer WRC_STOPBANK_DESIGN_POINTS and interpolated along the GIS layers RACS_EMBANKMENT.

5.2.3 Initial Conditions

Initial conditions were automatically extracted from an initial 2D extent for the Huntly area and extended to Horotiu and Ohinewai using 1D water levels.

5.2.4 Hydraulic Parameters

- Solution technique: low order, fast algorithm. This solution replaces a second order (Runge Kutta) numerical method by a 1st order explicit method (Euler), for the approximate solutions of ordinary differential equations. No stability issues or flow retardation was observed by using this method.
- The explicit formulation divides the timestep into a series of substeps (down to 0.005) to ensure a Courant criteria of 0.8 (default value) is not exceeded, maintaining the model stable and accurate. The minimum timestep was achieved through an iterative process and best practice.
- The drying/flooding/wetting parameters differ in configuration between rainfall-on-grid hydrology and sub-catchment based. This model incorporates values of 0.001, 0.01 and 0.03, respectively, since the hydrology is sub-catchment based; allowing for higher parameter values without impacting on artificial retardation of shallow flow (and mass balance).

- The constant flux eddy viscosity is the recommended for flooding applications and the most stable of the available formulations. A value of 0.1m²/s was chosen based on experience, but a lower value would also be acceptable, with roughness parameters more determinant than viscosity in shallow depths.

5.2.5 Sources

MIKE 21 sources, Table 5-5, are limited to Lake Waahi and the Mangawara tributaries where the 1D network was replaced by the 2D storage, with the catchment runoff (RR) for each of these components directly assigned to the overland component.

Table 5-5 MIKE 21 Sources

Catchment	Description	X_NZTM	Y_NZTM
19	To lake Waahi	1788095	5840924
30	To Mangawara at Taupiri (33%)	1793099.612	5835059.619
30	To Mangawara at Komakorau (67%)	1793477.649	5835181.105

5.3 Results Discussion

Ideally, a calibration and sensitivity analysis should have been performed with the 1998 event flood extents, but aerial photography of the event was only obtained after the modelling exercise was complete. This calibration is particularly important at the Waipa river, since the Waikato is largely dominated by the Karapiro flows.

Validation of the model was performed with four events, exclusively with the 1D component. The analysis below compares the 1D and 2D components to evaluate the appropriateness of the validation and assess the need for a calibration of the MIKE FLOOD model.

Pre-2D refers to the model before development of the MIKE FLOOD model, which was validated with four events. The main differences between the pre- and post-2D are:

- the splitting of catchments 33, 34 and 70 (at the Waikato, Waipa and Mangawara branches), allowing the maximum dx to be smaller in the area coupled to the 2D without the need to interpolate cross-sections. The hydrograph at Huntly remains unchanged after the catchments were split/redistributed; the Ngaruawahia area (Waipa catchment) shows the biggest change, with the improved model showing a better agreement in terms of flood extents;
- changes to the cross sections radius and processed data levels. Only branches with inconsistent radius's were individually modified and all cross-sections adopted equidistant processed levels (50).
- the lateral links upstream Ngaruawahia have revised marker locations (1/3) and 2D connections (lateral links) to keep the entire active channel in the 1D component.

Figure 5-7 below shows the 1D comparison (warm-up, only 1D) of the two models, and the observed 1998 event. The Pre-2D corresponds to the combined legacy models with minimal changes and the Post-2D corresponds to the latest model.

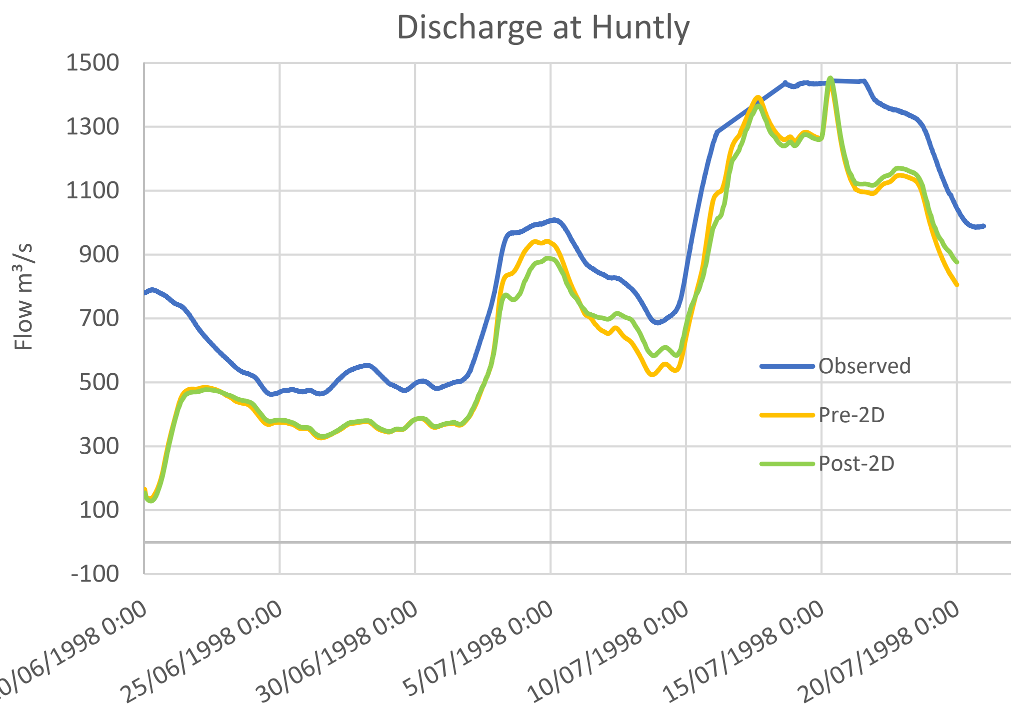


Figure 5-7 Discharge at Huntly, pre-2D, post-2D and observed data comparison

Table 5-6 Comparison between 1998 maximum flow, aerial photography and the 1% AEP event

1998 Maximum Flow m³/s	1998 Aerial Flow m³/s	Design Flow m³/s	1998 Maximum Level	1998 Aerial Level	Design Level
820	685	783	19.56	18.48	20.33

An approximate validation between the design event and the 1998 event showed a good agreement of flood extents, corroborating the 1D validation at the four Waipa gauge stations. This evidence contrasts with the flow/levels figures at Whatawata, where the design event is currently underpredicting flows (Table 5-6); this difference is exacerbated by the fact that the aerial photo was taken approximately 2 days after the peak of the event (at Whatawhata), with a peak flow of 685 m³/s.

The design model predicts a peak flow at Huntly of 1520 m³/s, which is 16% lower than the 1982 Scheme Review-old model (1820-1846 m³/s), but it is consistent with the flood frequency analysis (1560 m³/s) of the 1% AEP.

The frequency analysis was undertaken using the continuous series of annual maxima and the method of L-Moments, and the fit achieved with a Gumbel (EV1) distribution. The Huntly data used a combination of three sites (Huntly Rail Bridge, Huntly Power Station and Huntly North).

5.4 Future considerations

1. Taking into account the complexity of the model, using NAM, and four different components, a unified script could help future users to perform changes in each component without having to launch them individually;
2. The 2D calibration was not scoped under this project, but if the floodplain storage information is to be used for Flood Forecasting, then it should be performed. A sensitivity analysis could also be done, for example on vegetation roughness;
3. The inflow at the Karapiro could be adapted for climate change, using a nominal increase of flow adapted from the % increase obtained by HIRDS; or use the estimated AEP for the climate change scenarios of 2.3 and 3.8 degrees to scale the Karapiro design hydrograph; the 2009 study includes the 0.02% AEP hydrograph;
4. The testing of higher return periods, such as the 0.5% AEP or 0.2% AEP;
5. The investigation of breach points and the simulation of breach scenarios to identify Residual Risk Zones;
6. Simulate flood gates operation and/or emergency procedures (e.g. Parry Street and Huntly North stopbank);
7. Include joint-probability for tidal climate change.

This model is suited for the analysis of riverine flooding originated from the Waipa and Waikato rivers, this model should not be used to assess local runoff or to simulate other scenarios without further refinement within areas of interest.

6 References

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Carey-Smith, T., R. Henderson, and S. Singh. (2018). *High Intensity Rainfall Design System, Version 4*. NIWA Client Report 2018022CH, NIWA.

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APPENDICES

A Hydrology

A.1 Sub-catchment centroid

The coordinates in the following table are in the New Zealand Map Grid coordinate system.

Sub-catchment name	No.	Easting	Northing
1	1	2708344	6444118
2	4	2701954.3	6451242
3	6	2683576.4	6438783
4	7	2678396.5	6437208.2
5	11	2666178.5	6433488.1
6	14	2669764.6	6426423.5
7	15	2676000.6	6431710.9
8	10	2679599.2	6431536.3
9	8	2686474.1	6434142.2
10	12	2688291.7	6432311.4
11	18	2683064.6	6428662.3
12	13	2690394.6	6430376.6
13	16	2689755.5	6428568.1
14	19	2687947.3	6424542.4
15	22	2690444.5	6421048.6
16	25	2679638.6	6420756
17	31	2681390.1	6406619.7
18	29	2696509.8	6414638.5
19	49	2694937.8	6399411.5
20	53	2700757.9	6424263
21	9	2706557.6	6432894.1
22	17	2703873.7	6429472.3
23	20	2712850.2	6424696.5
24	23	2708481.5	6420934.2
25	28	2704972.9	6414595.6
26	26	2714676.2	6413658.8
27	50	2703528.2	6404769.5
28	48	2701865.6	6399251.2
29-UPPER_MANGAWARA	32	2723614.1	6413350.5
30-KOMAKURU	43	2714558.5	6388812.9
31	44	2702756.6	6392810.6
32	46	2699754.1	6396387.7
33	41	2697691.6	6382455.5
34	42	2708055.9	6383305.4
57	2	2696089.8	6445741.3
58	5	2693654	6442638.8
59	3	2691992.6	6439178.2
60	21	2693732.8	6425083.7

61	24	2695790	6419488.3
62	27	2685559.9	6413900.3
63	36	2692117.8	6409996.6
64	37	2690805.5	6403298.7
65	30	2696510.3	6408937.9
66	35	2699127.3	6410023.8
67-ORINI	34	2719389	6406490.5
68-UPPER_PARANUI	33	2727030.2	6409165.5
69-MID&LOWER-TAUHEI	45	2723248.3	6396701.7
70-TENFOOT_DRAIN	47	2709613	6400347.5
71	40	2721210.5	6369070
72	39	2736298.6	6366376.7
75	54	2696253.2	6428249.2
76	55	2700629.5	6433909.7
77	56	2698537.2	6437640
78	57	2694400.1	6432718
69-JORDAN_DAM	45	2723248.3	6396701.7
67-LOWER_PARANUI	34	2719389	6406490.5
69-MAORI_AFFAIRS_DAM	45	2723248.3	6396701.7
67-MID_MANGAWARA	34	2719389	6406490.5
67-NORTH_MANGATEA	34	2719389	6406490.5
67-ORAKI_DAM	34	2719389	6406490.5
67-ORCHARD_DRAIN	34	2719389	6406490.5
69-SOUTH_MANGATEA	45	2723248.3	6396701.7
69-TRUBSHAW_DAM	45	2723248.3	6396701.7
69-UPPER_TAUHEI	45	2723248.3	6396701.7
68-WAITI_DAM	33	2727030.2	6409165.5
67-SLUDGE_CREEK	34	2719389	6406490.5
69-CRAWLEY_DAM	45	2723248.3	6396701.7
MANGAPU(J0)	63	2703212.6	6338528
J1	63	2703212.6	6338528
MANGAOKEWA AT TE KUITI (J2)	51	2710884.5	6308096
WAIPA AT OTEWA (J3)	58	2721969.3	6311707.7
J4	38	2710026.1	6326073.6
J5	62	2694116.2	6325899.8
J6	64	2697966.4	6318524.4
BARTONSC (J7)	59	2727434.1	6332992.6
J8	60	2715851.8	6357364.1
J9	52	2708926.8	6350282.4
J10	61	2696526.9	6361996.8
J11	63	2703212.6	6338528

A.2 Scripts extracting and processing data from HIRDS v4

Python script (partial) extracting rainfall depth from NIWA's raster files:

```python
### Import catchment name and coordinates from csv
print('Reading csv...')
csvIn = csv.reader(open(catchmentDataCSV, 'r'))
headers = csvIn.next()
X, Y, name = [], [], []
rowCount = 0
for row in csvIn:
    # Check coordinate system
    if rowCount == 0 and row[4] != 'NZMG':
        print('\n--->  Warning!! Projection coordinate system not NZMG.  <---\n')
    rowCount += 1
    # Get catchments name and coordinates
    name.append(row[0])
    X.append(float(row[2]))
    Y.append(float(row[3]))

### Rewrite points coordinates as string for GetCellValue
points = ['{0} {1}'.format(i,j) for i,j in zip(X,Y)]

### If not existing create directory for output csv files
if not os.path.exists('csvOutputs'):
    os.makedirs('csvOutputs')

### Extract values from raster
catchmentCount = 0
for i in points:
    minutes, seconds = divmod(time.time()-start_time, 60)
    print('Executing Get Values for catchment {0} ({1}/{2})  --  {3:0>2}:{4:0>2}'.format(name[catchmentCount],catchmentCount+1,len(points), int(minutes),int(seconds)))
    catchmentValues = []
    # Loop through ARI
    for j in ARI:
        ARIValues = []

        # Loop through rasters and extract values for all durations for current ARI
        for k in durations:
            inRaster = r'rasters\hirds_rainfalldepth_duration{0}_ARI{1}.tif'.format(k,str(j))
            result = (arcpy.GetCellValue_management(inRaster, i))
            ARIValues.append(float(result.getOutput(0)))
        # Store values for all durations for current ARI
        catchmentValues.append(ARIValues)

    # Create the csv for current catchment
    with open('csvOutputs\\' + name[catchmentCount] + '.csv', 'w') as f:
        f.write('ARI,AEP,10m,20m,30m,1h,2h,6h,12h,24h,48h,72h,96h,120h\n')
        for i in range(0, len(catchmentValues)):
            f.write('{0}, {1}, '.format(ARI[i],AEP[i]) + ', '.join(map(repr, catchmentValues[i]))+'\n')
        del f
    catchmentCount += 1
```

Python script (partial) generating nested storm event and creating time series:

```
# open relevant HIRDS data csv and use it to create a nested storm event
# and add it to the end of the boundary timeseries
with open(r'csvOutputs\{0}.csv'.format(name), 'r') as csvHIRDS:
    csvHIRDS = csv.reader(csvHIRDS)
    c = list(csvHIRDS)

# find the existing depth table
headings = [s.strip() for s in c[0]]
AEPi = headings.index('AEP')
fAEP = float(AEP)
table = c[1:13]
# CCfactors are percentage of increase corresponding to durations 10min, 20m, 30min, 1h, ..., 120h for the 100year ARI
CCfactors = [13.6, 13.6, 13.6, 13.6, 13.1, 11.5, 10.1, 8.6, 7.5, 6.9, 6.5, 6.1]

for line in table:
    # allow the AEP decimal to be within about 5 % to account for rounding
    if abs(float(line[1].strip()) - fAEP) < (0.05 * fAEP):
        d = [float(i) for i in line[2:14]]
        # print("Values from HIRDS rasters: {}".format(d)) # for debug
        # apply effects of temperature increase
        if temperatureIncrease != 0:
            d = [(1+(i*temperatureIncrease)/100)*j for i,j in zip(CCfactors,d)]
        d = [s * ARF for s in d]
        break
# assume that the durations are 10m, 20m, 30m, 60m, 2h, 6h, 12h, 24h, 48h, 72h
# the time offsets are in seconds and the depths are in millimeters
designHyetograph = [(43200, (d[9]-d[8]) / 2.0),
                    (86400, (d[8]-d[7]) / 2.0),
                    (108000, (d[7]-d[6]) / 2.0),
                    (118800, (d[6]-d[5]) / 2.0),
                    (126000, (d[5]-d[4]) / 2.0),
                    (127800, (d[4]-d[3]) / 2.0),
                    (129000, (d[3]-d[2]) * 2.0 / 3.0),
                    (129600, d[1]-d[0]),
                    (130200, d[0]),
                    (130800, d[2]-d[1]),
                    (131400, (d[3]-d[2]) / 3.0),
                    (133200, (d[4]-d[3]) / 2.0),
                    (140400, (d[5]-d[4]) / 2.0),
                    (151200, (d[6]-d[5]) / 2.0),
                    (172800, (d[7]-d[6]) / 2.0),
                    (216000, (d[8]-d[7]) / 2.0),
                    (259200, (d[9]-d[8]) / 2.0)]

data = Array[Single]([0])
t0 = TimeSpan(designStormStartDateTime.Ticks - timeseriesStartDateTime.Ticks)
for tOffset, value in designHyetograph:
    data[0] = value
    fOut.WriteItemTimeStepNext(t0.TotalSeconds + tOffset, data)

# add a final depth 4 weeks after the last entry
data[0] = 0.0
fOut.WriteItemTimeStepNext(t0.TotalSeconds + designHyetograph[-1][0] + 4 * 7 * 24 * 60 * 60, data)
```

A.3 Sub-catchment distribution 1D network

Name	Area	Branch	Ch. US	Ch. DS
1	157.5	Mangatangi Stream	0	0
2	54.9	Mangatawhiri Upper	0	0
3	42.2	Whakapipi	0	0
4	21.2	Waikato	124126	128247
5	128.4	Waiksn	135017	142681
6	46.1	Waiksn	135017	142681
7	24.9	Waikato	125299	133477
8	22.3	Waikato	120038	125299
9	12.9	Waikato	110611	121450
10	19	Waikato	110611	118334
11	28.5	Waikato	118656	119306
12	13.2	Waikato	102960	106557
13	8.3	Waikato	100404	102145
14	36.3	Waikato	99339	100155
15	10.9	Waikato	92148	95900
16	216.2	Waikato	91517	91517
17	209.7	Lake Whangape us	100	100
18	15.4	Rotongaro	1000	5000
19	94.9	Lake Waahi	0	0
20	67.3	Whangamarino River	698	6903
21	38	Maramarua River	572	4525
22	11.3	Whangamarino River	698	6903
23	139.6	Whangamarino River	0	0
24	27.1	Waikare Canal	3868	3869
25	104.7	Lake_Waikere-Northern Spillway	0	0
26	103.3	Matahuru	0	0
27	7.5	Waikato	69656	69656
27	27.3	Waikato	73808	73808
28	6	Waikato	61550	66672
29-Upper_Mangawara	34.54	Mangawara River	0	0
30-KOMAKURU	142.29	Komakorau Pond Dummy	0	0
30-KOMAKURU	70	Freshfield Pond Dummy	0	0
31	23.2	Waikato	56964	61550
32	27.3	Waikato	52210	66672
33	231.3	WAIPAlower	100000	128900
34	92.6	Waikato	33808	53710
57	24.4	Mangatawhiri Upper	0	0
58	2.6	Mangatawhiri Trib	0	0
59	31.6	Mangatawhiri Upper	0	4357

59	23.7	Mangatawhiri Trib	0	3932
59	19.4	Mangatawhiri	922	5488
60	30.3	Waikato	104278	106557
61	18	Waikato	84631	93290
62	26.7	Lake Whangape us	100	100
63	57.7	Lake Whangape us	100	100
64	20.5	Whangape	0	0
65	19.5	lake rotongaroiti	0	0
66	26.4	Waikato	70742	85020
67-Lower_Paranui	11.27	Paranui Drain	0	0
67-Mid_Mangawara	20.99	Mangawara River	0	9787
67-North_Mangatea	19.73	North Mangatea Stream	0	0
67-Oraki_Dam	10.32	Orakei Dam	380	380
67-Orchard_Drain	4.95	Orchard Drain	0	0
67-Orini	17.77	Northern Outlet Pond Dummy	0	0
67-Orini	15.61	Murchie Pond Dummy	0	0
67-Orini	10.2	Mangawara River	10393	15744
67-Sludge_Creek	8.77	Sludge Creek	0	0
68-Upper_Paranui	15.19	Paranui Stream	613	2914
68-Waiti_Dam	12.55	Waiti Stream	325	325
69-Crawley_Dam	1.27	Crawley	150	150
69-Jordan_Dam	2.49	Jordan	150	150
69-Maori_Affairs_Dam	3	Maori Affairs	1238	1238
69-Mid&Lower-Tauhei	34.55	Tauhei Stream	0	15145
69-Mid&Lower-Tauhei	31.07	Eastern Outlet Pond Dummy	0	0
69-South_Mangatea	24.3	South Mangatea Stream	0	0
69-Trubshaw_Dam	1.02	Trubshaw	150	150
69-Upper_Tauhei	43.58	Tauhei Stream	0	0
70-Tenfoot_Drain	26.23	Uapoto Pond Dummy	0	0
70-Tenfoot_Drain	41.75	Tenfoot Pond dummy	0	0
70-Tenfoot_Drain	26.39	Te Mimiha Pond Dummy	0	0
70-Tenfoot_Drain	9.91	Mangawara River	16056	31336
71	208	Mangaonua	0	0
71	96	Waikato	14328	14328
71	55	Waikato	21943	21943
71	75	Waikato	24280	31891
72	85.6	Waikato	7377	7377
75	22.2	Whangamarino River	6903	12077
76	42.6	Maramarua River	0	10352
77	37.6	Maramarua River	6800	6800
78	8	Whangamarino River	12077	14510
BARTONSC (J7)	517.38	PUNIU	0	0
J1	121.13	MANGAOKEWA	3543	32846
J10	185.21	WAIPA	78110	111107

J11	338.24	WAIPA	45655	78100
J4	142.25	WAIPA	22389	42872
J5	109.88	WAIPA	43324	45655
J6	264.41	WAIPA	42872	76125
J8	487.5	WAIPA	76125	111107
J9	41.8	PUNIU	0	15665
MANGAOKEWA AT TE KUITI (J2)	173.37	MANGAOKEWA	3543	3543
MANGAPU(J0)	135.65	MANGAPU	0	0
WAIPA AT OTEWA (J3)	319.32	WAIPA	22389	22389

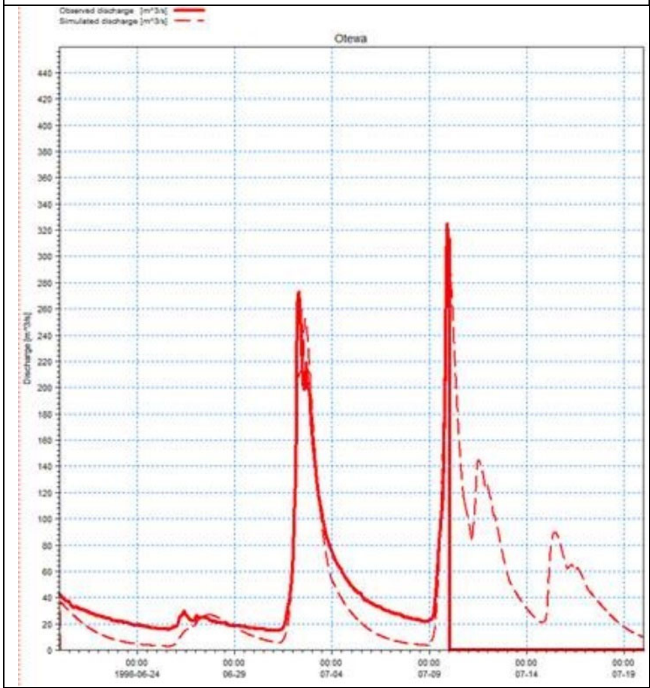
B Hydraulics

B.1 Validation

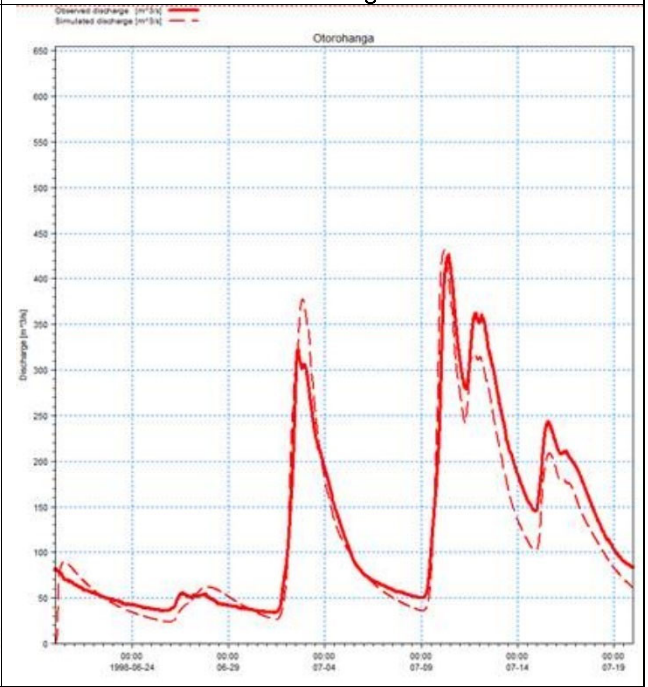
1998 event

Note: Dashed lines - simulation results, continued lines – observed

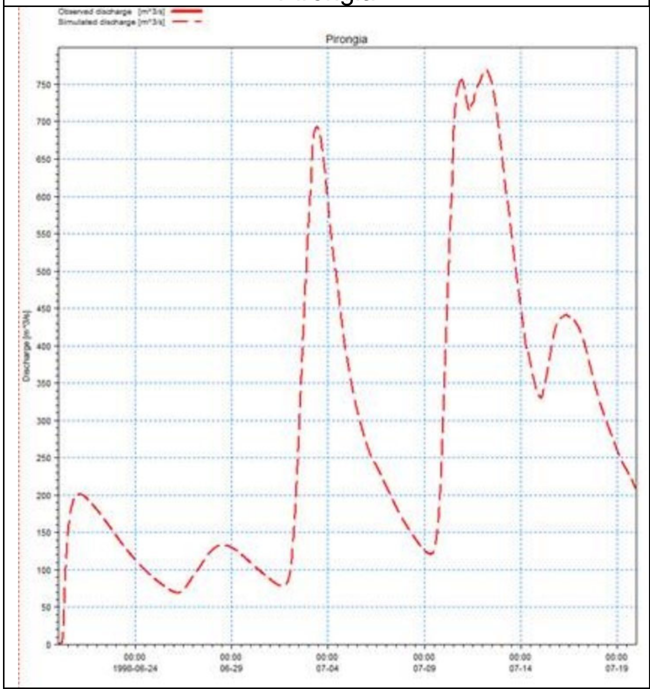
Otewa



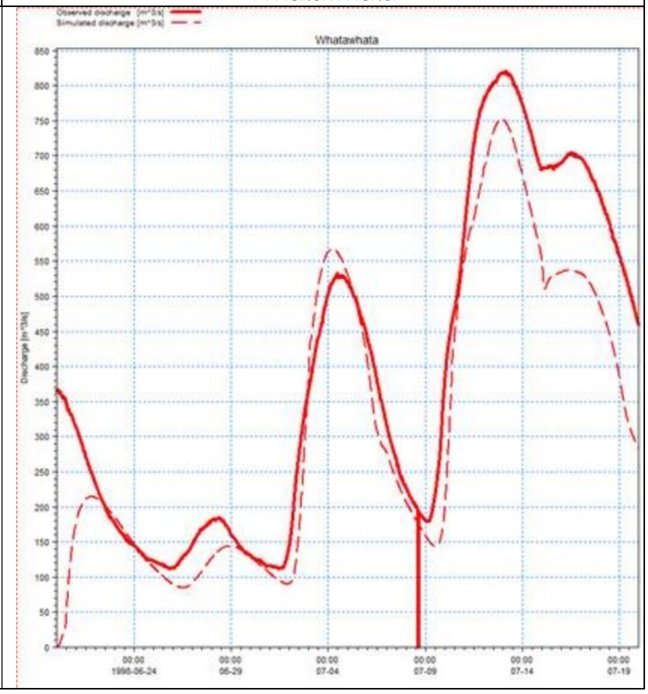
Otorohanga



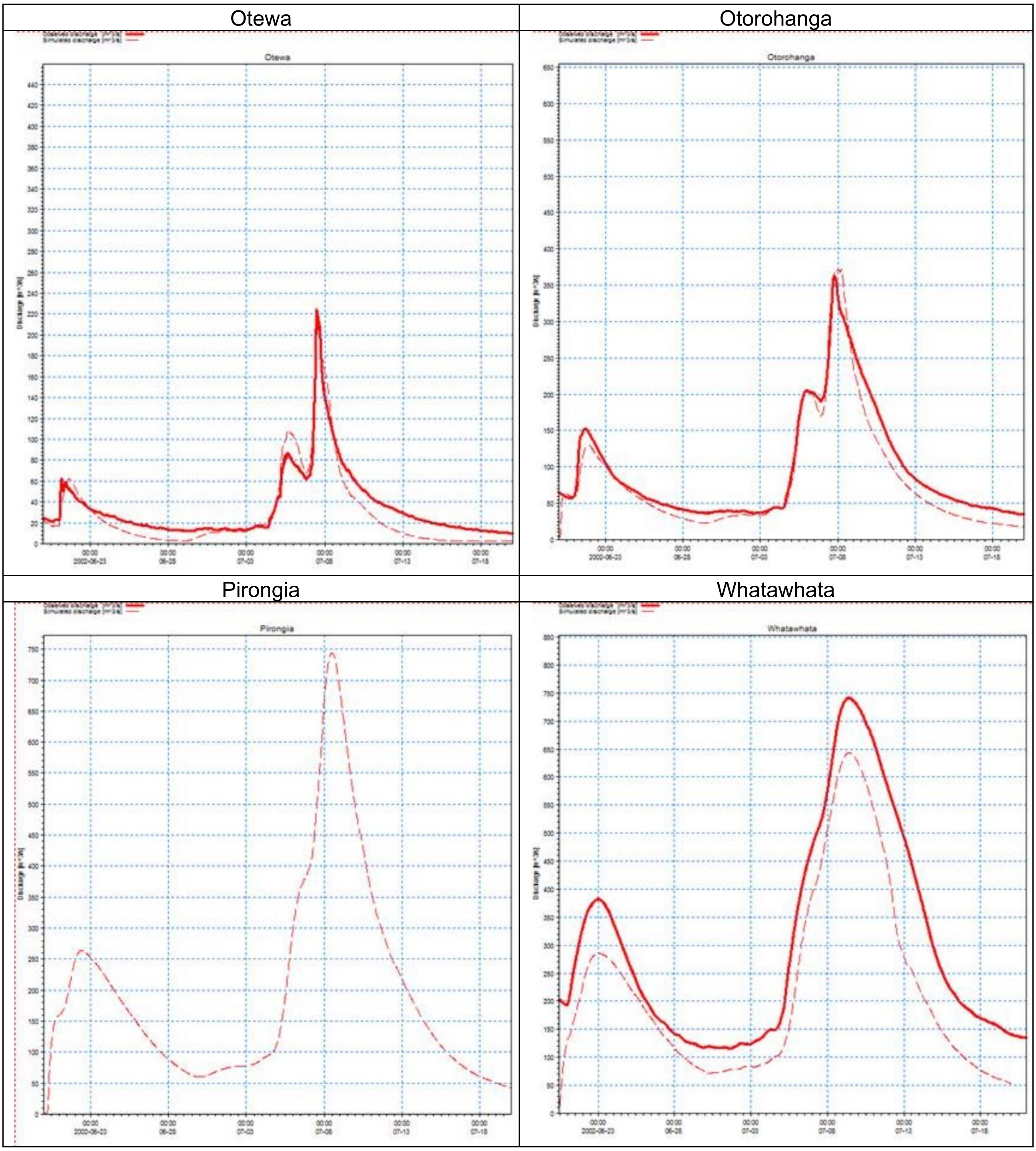
Pirongia



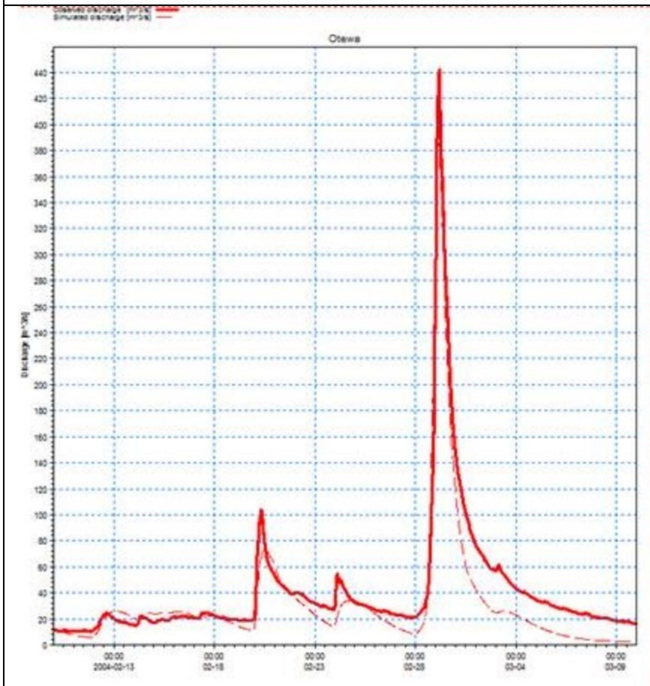
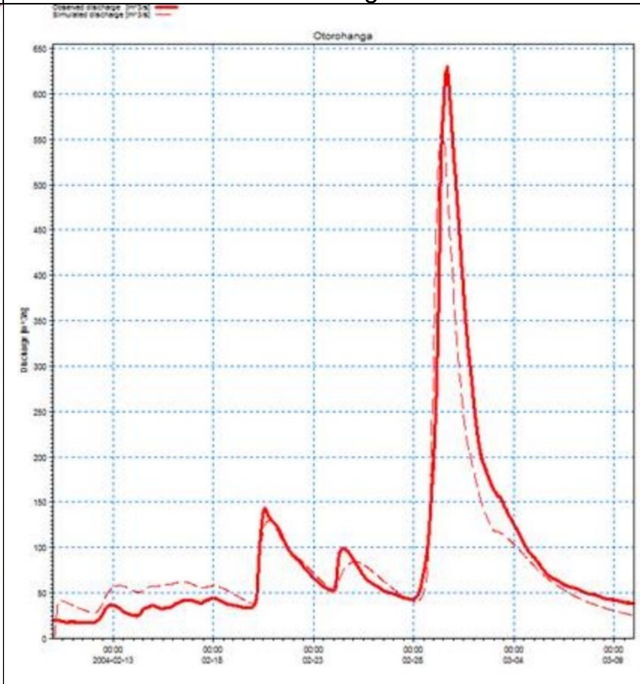
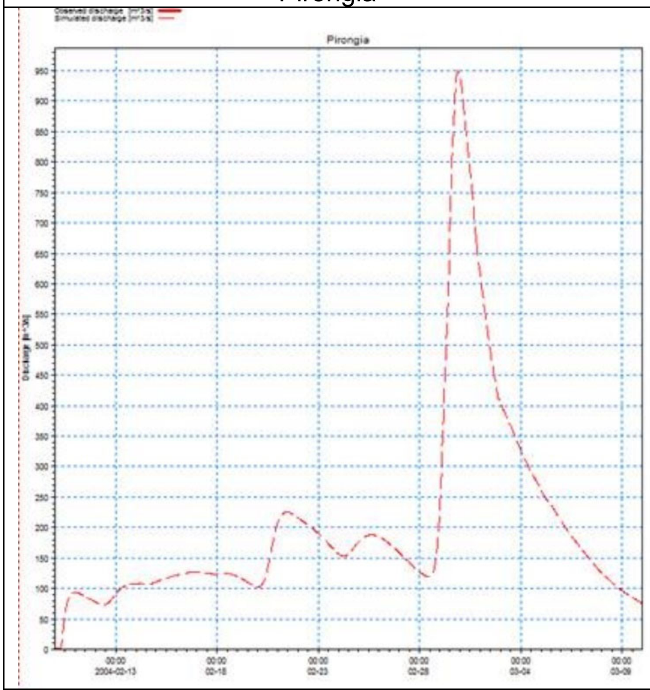
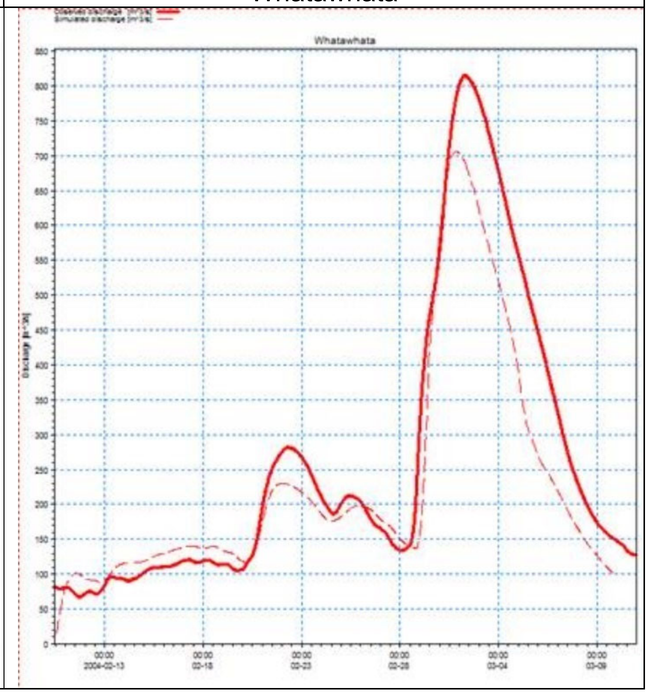
Whatawhata



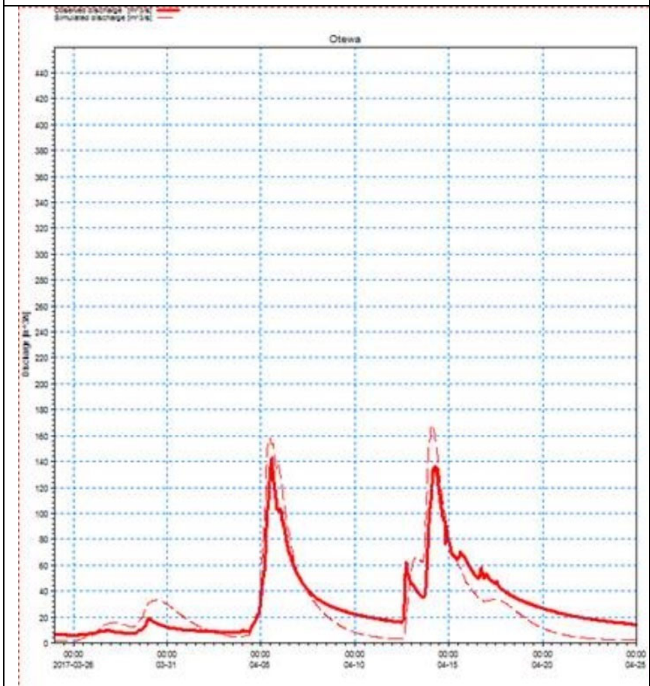
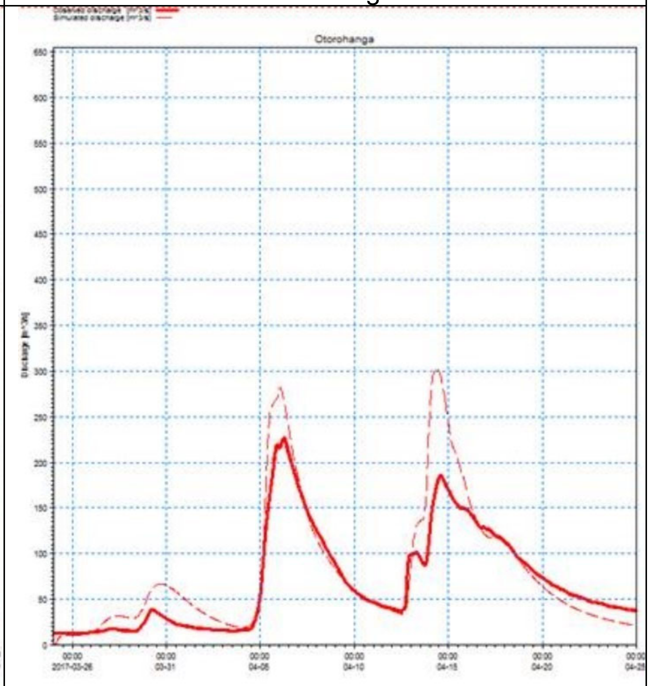
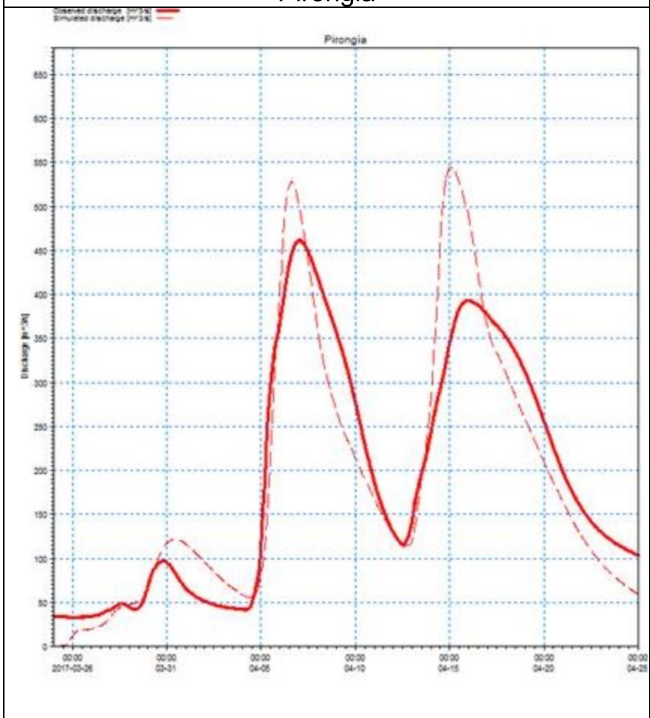
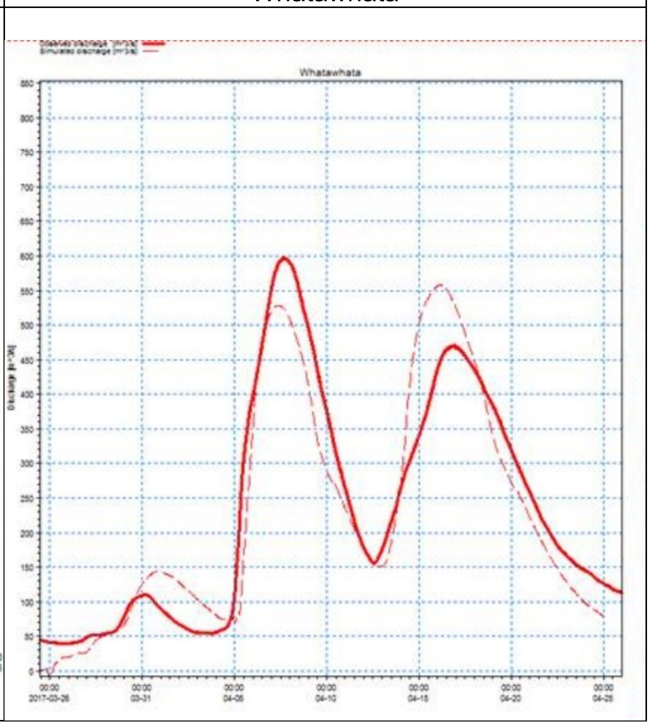
2002 event


Otewa
Otorohanga
Pirongia
Whatawhata
00:00
2002-06-23
06-28
07-03
07-08
07-13
07-18

2004 event

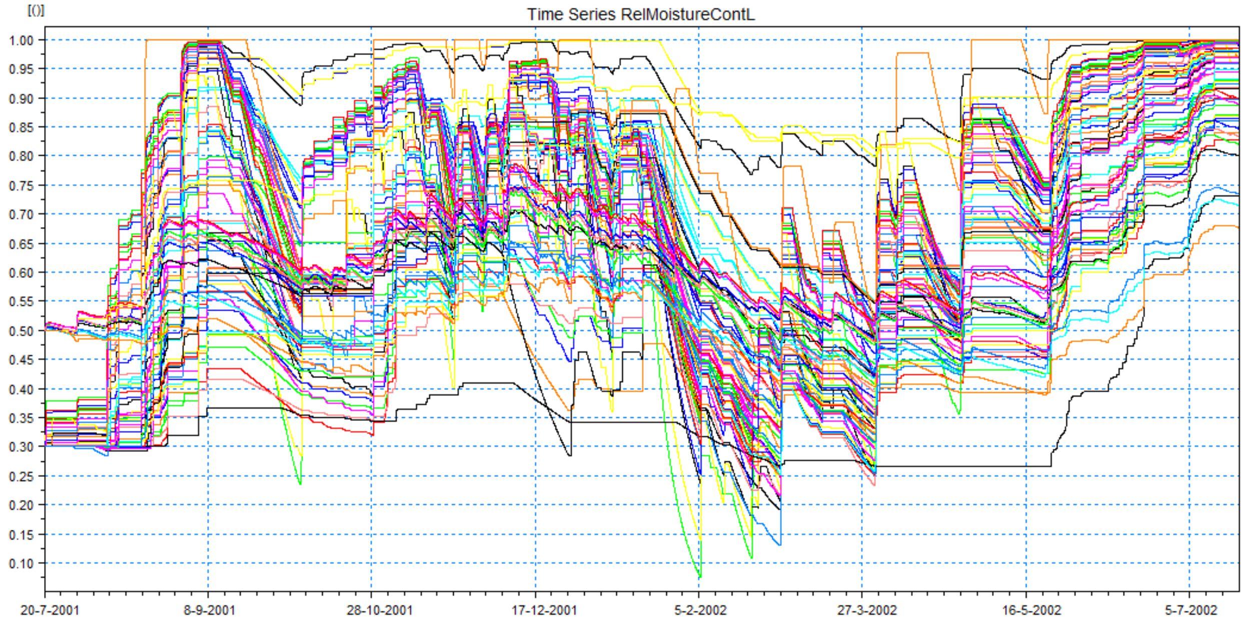
Otewa	Otorohanga
	
Pirongia	**Whatawhata**
	

2017 event

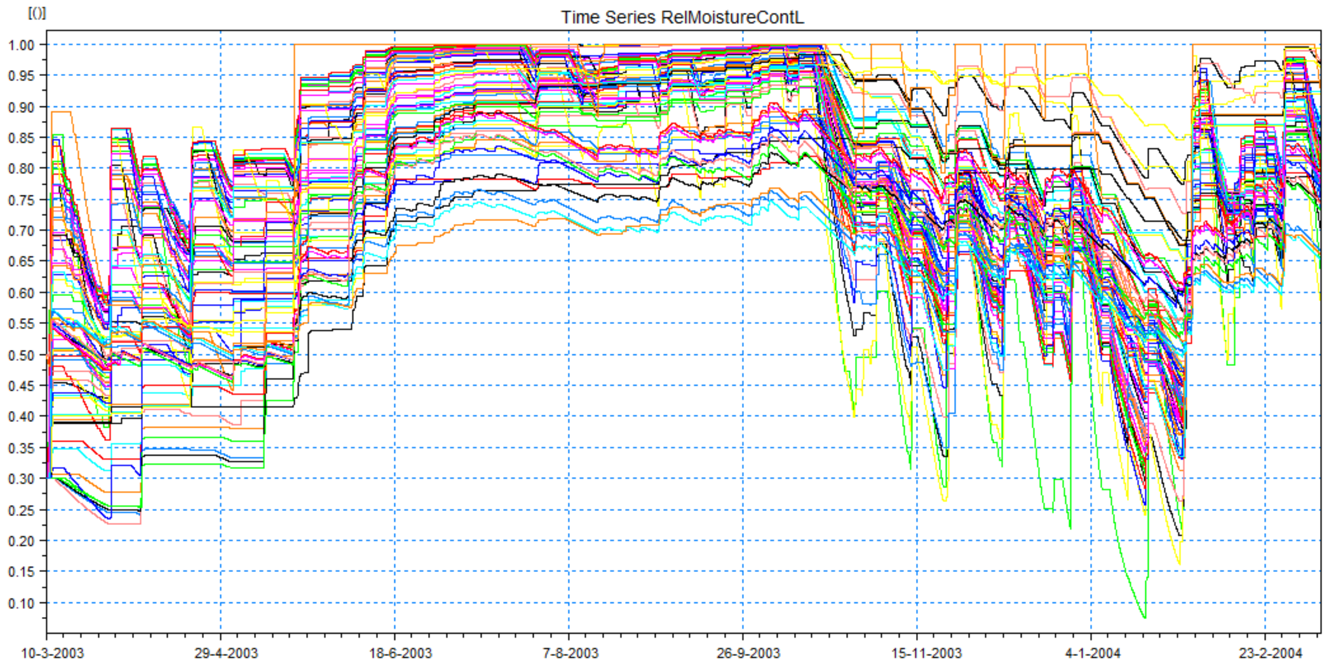
Otewa	Otorohanga
	
Pirongia	**Whatawhata**
	

B.2 Initial Conditions

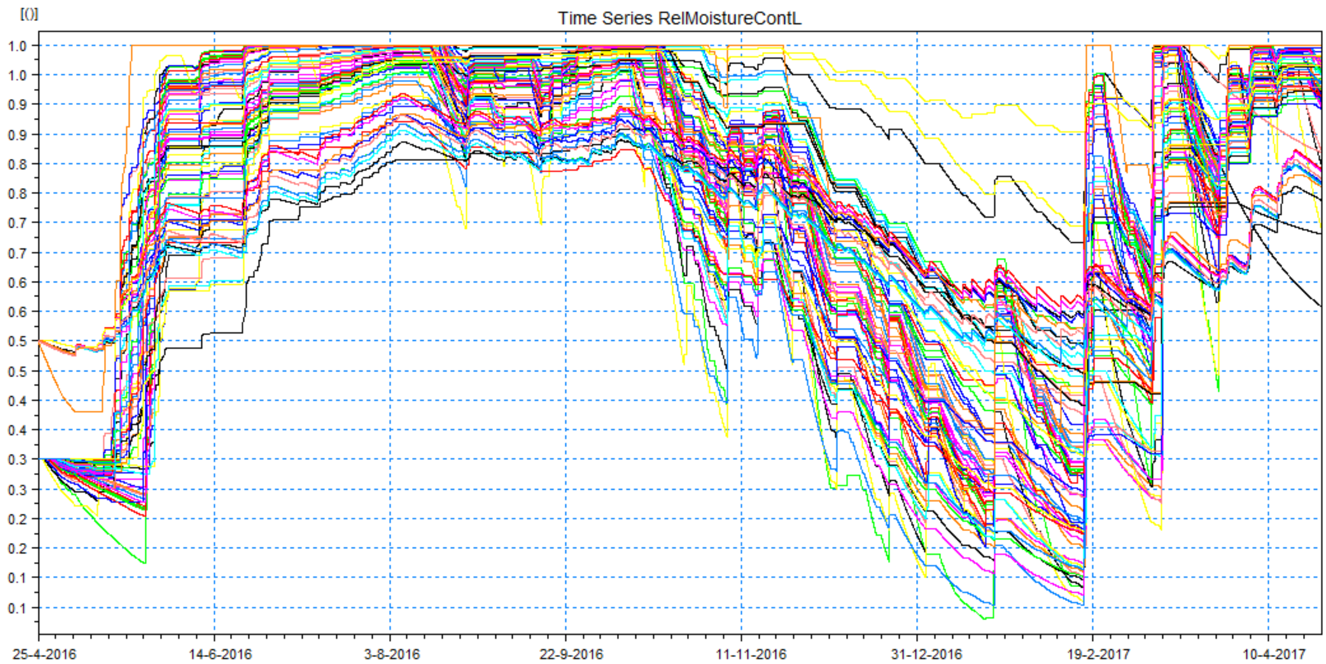
2002 event warm-up period



2004 event warm-up period



2017 event warm-up period



B.3 MIKE 11 structures

Culverts

All modelled culverts are listed in Table 6-1. The rows highlighted in yellow indicate the floodgates and the rows highlighted in blue indicate the structures not included in the MIKE FLOOD model.

Table 6-1 MIKE11 Culverts parameters

Branch	chainage	ID	Geometry	Size	Length
crawley dam	75	$LINK	Circular	0.45	10
Culvert_Bayley_Street	13.5	Clv_Bailey_Street	Circular	1.2	27
Culvert_Clark_road	12.5	Culvert_Clark_road	Circular	0.6	25
Culvert_Coal_HaulageRd	8.5	Clv_Coal_Haulage	Cross Section DB		17
Culvert_Great_S_road	25	Culvert_Great_S_road	Circular	0.45	50
Culvert_Great_S_road_rail	15	Culvert_Great_S_road_ra il	Circular	0.5	30
Culvert_Hakarimata_road _1	6.5	Culvert_Hakarimata_road _1	Circular	2.7	13
Culvert_Hakarimata_road _2	12.78284 5	Culvert_Hakarimata_road _2	Circular	0.75	12.2
Culvert_Hakarimata_road _3	6.1	Culvert_Hakarimata_road _3	Circular	0.45	12.2
Culvert_Kainui_road	6	Culvert_Kainui_road	Circular	0.6	12
Culvert_Kauri_Ridge_driv e	15	Culvert_Kauri_Ridge_driv e	Circular	1.2	30
Culvert_Mangarata_ds	10	Culvert_Mangarata_ds	Circular	0.075	19.14
Culvert_Mangarata_us	8	Culvert_Mangarata_us	Circular	0.75	16.12
Culvert_Ngaruawahia_ds	16	Culvert_Ngaruawahia_ds	Circular	0.875	33

Culvert_Ngaruawahia_road_1	12.060468	Culvert_Ngaruawahia_road_1	Circular	0.9	25
Culvert_Ngaruawahia_road_2	12.5	Culvert_Ngaruawahia_road_2	Circular	1.5	25
Culvert_Ngaruawahia_us	20	Culvert_Ngaruawahia_us	Circular	0.75	35
Culvert_old_taupiri_road	12	Culvert_old_taupiri_road	Circular	3	18
Culvert_Parker_road	10	Culvert_Parker_road	Circular	0.9	15
Culvert_River_road_2	17.5	Culvert_River_road_2	Circular	2.4	37
Culvert_Riverview_road	7	Culvert_Riverview_road	Circular	1	21.96
Culvert_Riverview_road_2	5	Culvert_Riverview_road_2	Circular	0.45	10
Culvert_Rotowaro_railway_1	12.5	Culvert_Rotowaro_railway_1	Circular	0.45	25
Culvert_Rotowaro_railway_10	8	Culvert_Rotowaro_railway_10	Circular	0.6	16
Culvert_Rotowaro_railway_2	7.5	Culvert_Rotowaro_railway_2	Circular	0.45	12
Culvert_Rotowaro_railway_3	6	Culvert_Rotowaro_railway_3	Rectangular	0.5 x 0.45	12
Culvert_Rotowaro_railway_4	6	Culvert_Rotowaro_railway_4	Circular	0.6	12
Culvert_Rotowaro_railway_5	6	Culvert_Rotowaro_railway_5	Circular	1.2	12
Culvert_Rotowaro_railway_7	6	Culvert_Rotowaro_railway_7	Circular	0.8	12
Culvert_Rotowaro_railway_9	8	Culvert_Rotowaro_railway_9	Circular	0.45	16
Culvert_Rotowaro_road_1	10	Culvert_Rotowaro_road_1	Circular	0.6	20
Culvert_Rotowaro_road_2	12.5	Culvert_Rotowaro_road_2	Circular	1.2	25
Culvert_Rotowaro_road_4	10	Culvert_Rotowaro_road_4	Circular	1.2	20
Culvert_Tataekohia_ds	6.1	Culvert_Tataekohia_ds	Circular	1.5	12.2
Culvert_Tataekohia_ds_2	6.1	Culvert_Tataekohia_ds_2	Circular	0.9	12.2
Culvert_Te_Ohaki_road_1	8.4303634	Culvert_Te_Ohaki_road_1	Circular	2.4	20
Culvert_Te_Ohaki_road_2	8.2735253	Culvert_Te_Ohaki_road_2	Rectangular	3.1 x 3	20
Culvert_Te_Ohaki_road_3a	22.5	Culvert_Te_Ohaki_road_3	Circular	1.5	45
Culvert_Te_Ohaki_road_3b	22.5	Culvert_Te_Ohaki_road_3b	Circular	0.6	45
Culvert_Waikeri	20	Culvert_Waikeri	Rectangular	3 x 3	15
Culvert_Waingaro_road	11	Culvert_Waingaro_road	Circular	0.6	22.5
Culvert_Weavers_crossing_road	15	Culvert_Weavers_crossing_road	Circular	1.2	30
Firewood Creek trib	13	US	Circular	0.9	20
Jordan upper	75	$LINK	Circular	0.45	10
Maori Affairs	3900		Rectangular	3 x 2.5	40
Maori Affairs Link	50	$LINK	Circular	0.45	10
Orakei Dam up	120	$link	Circular	0.9	31.2
Rotongaro	3601	Glen Murray Rd Bridge	Irregular, Depth-Width Table	N/A	20
Rotongaro	4970	Gate	Circular	1.25	54
trubshaw dam	75	$link	Circular	0.45	10
Waahi	2971	1	Rectangular	2.25 x 2.25	27

Waiti dam crest	243	$link	Circular	1.2	30
Waiti Stream	450		Circular	1.2	20
Whangamaire Stream	230	Whangamaire Pump NRV	Circular	0.762	10
Whangamaire Stream	55	Whangamaire Floodgate	Rectangular	2.1336 x 2.1336	25

Bridges

Waingaro Rd 305 bridge (Waipa)

The Waingaro road 305 bridge is located at modelled chainage 128910 of the Waipalower branche.

Pier representation: The combined pier width is 3 x 1.118 m = 3.354 m, subtracted to the total channel opening (112.05 m) gives the modelled bridge opening of 108.696 m. This is equivalent to a 3% total blockage.

Soffit and deck representation: The bridge has a slight degree of curvature with a soffit level of 16.65 m (kerb 20.05 m) at the edge of the bridge and 16.79 m (kerb 20.19 m) in the centre of the bridge. A soffit level of 16.72 m and a kerb level of 20.12 m have been taken as representative for submergence and overflow respectively.

Waingaro Rd 2160 bridge (Firewood Creek)

The Waingaro road 2160 bridge is located at modelled chainage 41 of the Firewood Creek branch.

Pier representation: The bridge has 3 piers of varying dimensions and with a combined width of 1.828m. With a total channel opening of 33.25 m the percentage of blockage is 5.5%.

Soffit representation: The bridge is sloping downhill from the left bank to the right bank. An average soffit level of 13.81 m and an average deck level of 14.85 m have been used for submergence and overflow respectively.

Great South road bridge & North Island Main trunk rail bridge over Waikato river

The Great south road bridge is located at modelled chainage 53280 on the Waikato river.

The road bridge and rail bridge are very close to each other at that location and have been modelled as a combined structure to represent the most obstructive features of the combined bridges (worst-case scenario). With width of 10.19m (from plan) for the road bridge and 4.2m (measured from GIS) for rail bridge, the structure has a combined width of 14.39 m.

Pier representation: No information on piers width from the road bridge. On the rail bridge there are 2 central piers with protection structures whose width has been measured from aerial photography and approximated to 5m. The total span of the bridge is 80m, thus the pier blockout is 6.25%.

Soffit and deck representation: The road under the bridge is at 14.4m RL (LiDAR) + 3.6m from road to soffit (using sign under the bridge, Google Earth) = 18m. The inspection report indicates 4.9m between rail level and ground level at the road location, thus deck thickness is 4.9 - 3.6 = 1.3 m and deck level is 19.3m.

Tainui bridge over Waikato river

The Tainui bridge road is located at modelled chainage 67670 on the Waikato river.

Pier representation: There are 4 cylindrical piers, each 1.37m in width with a base 2.2m in width. Using an average of 1.55m to take into account the effect of the wider base, the total blockage width is 4*1.55 = 6.2 m. The total channel width being 183m, the blockage represents 3.4%.

Soffit and deck representation: The soffit and deck are curved, average values of 14.067 m and 15.82 m have been used, respectively.

Mangawara river rail bridge at Ngaruawahia - NIMT 272

The Mangawara railway bridge is modelled at chainage 30970 on the Mangawara river.

A new bridge appears to have been built between 2015 and 2016 with new piers (from Google Earth aerial photography), with the old bridge still in place. The bridge is 72m long, however, only 48 are represented in the 1D model due to overlap with the 2D component.

The bridge is 10m long (measure from GIS).

Pier representation: The bridge is modelled with 2 piers of width 1.8 m and a channel opening of 48 m, thus a pier blockout of 7.5 %.

Soffit representation: The rail level is taken from the LiDARand is 14.8 on the north side and 14.5m on the south side, with an average of 14.65m. From the inspection report the deck thickness appears to be 1.3m, thus the soffit is taken as 13.35m.

Table 6-2 MIKE11 Bridges parameters

Name	Branch	Chainage	Waterway length
WAIPAlower_bridge	Waingaro road 305	128912.5	10.06
Firewood Creek	Waingaro road 2160	41	9.144
Waikato_bridges	Great South Road	53280	14.39
Waikato_bridges	Tainui bridge road	67670	15
Mangawara_river_bridges	Mangawara rail bridge	30970	10

Weirs

Table 6-3 MIKE11 Weirs parameters

Name	Branch	Chainage	Geometry
Weir to improve spillway performance	Mangawara River	850	Broad Crested Weir
	Smith	950	Broad Crested Weir
	Smith	10	Broad Crested Weir
	Southe	725	Broad Crested Weir
	Southe	10	Broad Crested Weir
steep	Waiti Dam	880	Broad Crested Weir
road overflow	ROTONGARO	3601	Broad Crested Weir
	Whangamarino River	12570	Broad Crested Weir
	Waahi	3010	Broad Crested Weir
	SPILLWAY1	1	Broad Crested Weir
	SPILLWAY2	1	Broad Crested Weir
	SPILLWAY3	1	Broad Crested Weir
	SPILLWAY4	1	Broad Crested Weir
	SPILLWAY5	1	Broad Crested Weir

Control structures

Table 6-4 MIKE 11 Control structures parameters

Name	Branch	Chainage	Type
Northern Outlet Drainage	Northern Outlet Pond	150	Discharge
Murchie Drainage	Murchie Pond	150	Discharge
Tenfoot Drainage	Tenfoot Pond	150	Discharge
Eastern Outlet Drainage	Eastern Outlet Pond	150	Discharge
Te Mimiha Drainage	Te Mimiha Pond	150	Discharge
Uapoto Drainage	Uapoto Pond	150	Discharge
Te Onetea Box Culvert	Te Onetea Stream	151	Underflow
Whangamarino CS	Whangamarino River	14535	Underflow
Waikare Canal Gate	Waikare Canal	2	Underflow

C Additional information

Figure 6-1 Culverts with potential impact on flooding, not modelled because of lack of information or to simulate blockage

Name	Easting NZTM	Northing NZTM	Reason why not included
Lake Waahi connection	1786349.665	5842297.913	Lack of dimensions information
Lake Waahi	1786564.716	5840695.410	Lack of dimensions information
Waikeri_rail	1792438.980	5833145.697	Lack of dimensions information
Firewood_creek_trib_ds	1788535.231	5827670.272	Lack of dimensions information
Tatahekoia_us	1789244.630	5831032.558	Lack of dimensions information
Culvert Rotowaro_railway_6	1787805.581	5839080.552	Lack of dimensions information
Culvert Rotowaro_railway_8	1786806.016	5839197.865	Lack of dimensions information
Rotowaro_road_3	1787082.276	5838809.648	Diameter under 450mm (300)

Table 6-5 Floodgates with unknown specifics

ASSET_ID	ASSET_DESC
22895	Rangiriri - Fosters #5 Floodgate
23637	Lake Hakanoa Floodgate
25075	Kimihia Downstream Floodgate
24346	Kimihia Upstream Floodgate
25084	Rangiriri - Fosters #3 Floodgate
24359	Rangiriri - Fosters #2 Floodgate
25828	Rangiriri - Fosters #4 Floodgate
27110	Kimihia Main Outlet Floodgate
27324	Okowhao Floodgate 2
27327	Rangiriri - Fosters #1 Floodgate
28542	Harris Street Floodgate

Table 6-6 Pumpstations with unknown specifics

Asset_ID	System_Nam	ASSET_DESCRIPTION	Owner	XNZTM	YNZTM
20020824143416	WRC Owned Stormwater		WDC	1791150	5842488

20170124100738	Parry Street SW Pump Station		WDC	1790377	5840952
26567		Huntly South Pumpstation/Floodgate 2	WRC	1790558	5839523
27305		Huntly South Pumpstation/Floodgate 1	WRC	1790652	5838772
28015		Huntly South Pumpstation/Floodgate 3	WRC	1790669	5840405
23659		Okowhao Pumpstation	WRC	1790289	5844942
25813		Huntly North Pumpstation	WRC	1790715	5844221
36114		Kimihia Internal Pumpstation	WRC	1791549	5845852
47458		Lake Hakanoa Pumpstation/Floodgate	WRC	1790708	5842128
22896		Higgins Pumpstation	WRC	1790543	5851774
22898		Tabenels Pumpstation	WRC	1790747	5847620
25829		Kitcheners Pumpstation	WRC		
26585		Halls Pumpstation	WRC	1790510	5850210
28030		Golf Course Pumpstation	WRC	1790183	5847204
22894		Hills Pumpstation	WRC	1789715	5849908

Okowhao pumpstation is present in the model with a no-flow regulation as the specifics of the pump are unknown.

Table 6-7 List of structures identified and requested by DHI

Description	easting NZTM	northing NZTM	Ranking
Waingaro road bridge	1789149.2	5829223	1
Railway bridge at Ngaruawahia	1789535.1	5829473.8	1
Great S. road bridge at Ngaruawahia	1789568.4	5829459.5	1
Horotiu Bridge road bridge	1794549	5825433.2	1
SH1 Bridge	1794909.3	5825248.3	1
Tainui Bridge road bridge	1790271.8	5840135.9	1
Bridge street railway bridge	1790483.9	5840725.2	1
Kauri ridge culvert	1789362	5827353.1	1
Clark road culvert	1789523.2	5827423	1
Clark road 23 culvert	1788506.1	5827545.2	1
Clark road 23 culvert	1788535.7	5827670.8	1
Waingaro 223 road culvert	1788366	5827721.7	1
Waipa Esplanade 35 culvert	1788904.9	5828681.6	1
Waingaro road 81 culvert	1788699.4	5828560.7	1
Thickpenny lane culvert	1789011.8	5829293.9	1
Hakarimata road 151 culvert	1789148.9	5830667.8	1
Hakarimata road 185 culvert	1789265	5830967.8	1
Hakarimata road 334 culvert	1789807.7	5832421.2	1
Railway culvert	1792439	5833145.7	1
Railway culvert	1792987.7	5833809.3	1

Riverside way culvert	1791808.4	5833629.9	1
Hakarimata road 698a culvert	1792652.1	5834549.1	1
Orini road 32 culvert	1793482.6	5835178.6	1
Parker road culvert	1790588.6	5836029.1	1
Riverview road culvert	1790421.4	5836614.5	1
Riverview road culvert	1790094.4	5839317.3	1
Fairfield avenue culvert	1789827.6	5841336.1	1
Rotowaro road 282 culvert	1788020.5	5838984.4	1
Rotowaro road 351 culvert	1787260.4	5838943.8	1
Mahuta rail culvert	1786806.3	5839199.2	1
Lake Waahi culvert	1786564.9	5840694.5	1
Coal Haulage road / Waahi culvert	1786350.1	5842298.1	1
Te Ohaki road culvert	1790320.2	5844919.7	1
Coal Haulage road / Awaroa stream culvert	1785683.9	5840640.9	1
Great S. road culvert	1790796.3	5844215.7	1
Te Ohaki road 515 culvert	1789995.4	5847122.9	1
Te Ohaki road 475 culvert	1790026	5846409.9	1
Bailey street culvert	1791023.8	5843589.8	1
Ngaruawahia road culvert	1789623.7	5826777.2	1
Ngaruawahia road culvert	1789967.3	5827563.3	1
Old Taupiri road culvert	1791023.4	5832478.6	1
Great S. road 5113 culvert	1792405.3	5833210.9	1
Great S. road 127 culvert	1792951.4	5833867	1
Weavers crossing road culvert	1788446.2	5839655.5	2
Lot 35 Te Puroa road culvert	1788396.2	5827244.5	2
Durham street 32 culvert	1789169.4	5828470.3	2
River road culvert	1792009.1	5827629.8	2
Hakarimata road 185 culvert	1789244.7	5831032.7	2
Wadham road culvert	1790007.9	5832641	2
Culvert	1792655.6	5832735.2	2
Gordonton road culvert	1793119.6	5834973.5	2
Riverview road culvert	1790236.6	5837946.3	2
Mahuta rail culvert	1786443.2	5839261.7	2
Mahuta rail culvert	1786217.2	5839305	2
Lake Waahi culvert	1787165.2	5840257.1	2
Rotowaro road 422 culvert	1787082.3	5838809.6	2
Rotowaro road 319 culvert	1787843.8	5839064.4	2
Railway culvert	1790851.1	5844174.1	2
Orini road 126 culvert	1794037.8	5835632.9	2
Russell road culvert	1790938.2	5844004.3	2
River road culvert	1795537.5	5824807	2
River road culvert	1795587.7	5824808.6	2
Lot 2 DPS 19658 culvert	1790010.5	5827427.4	2
Sullivan road culvert	1794113.5	5825968.9	3
Mahuta rail culvert	1786092.9	5839326.2	3

Russell road culvert	1791008.9	5844058.2	3
Kainui road culvert	1793057	5833277.2	3
Okowhao road culvert	1788589.3	5843399.9	5