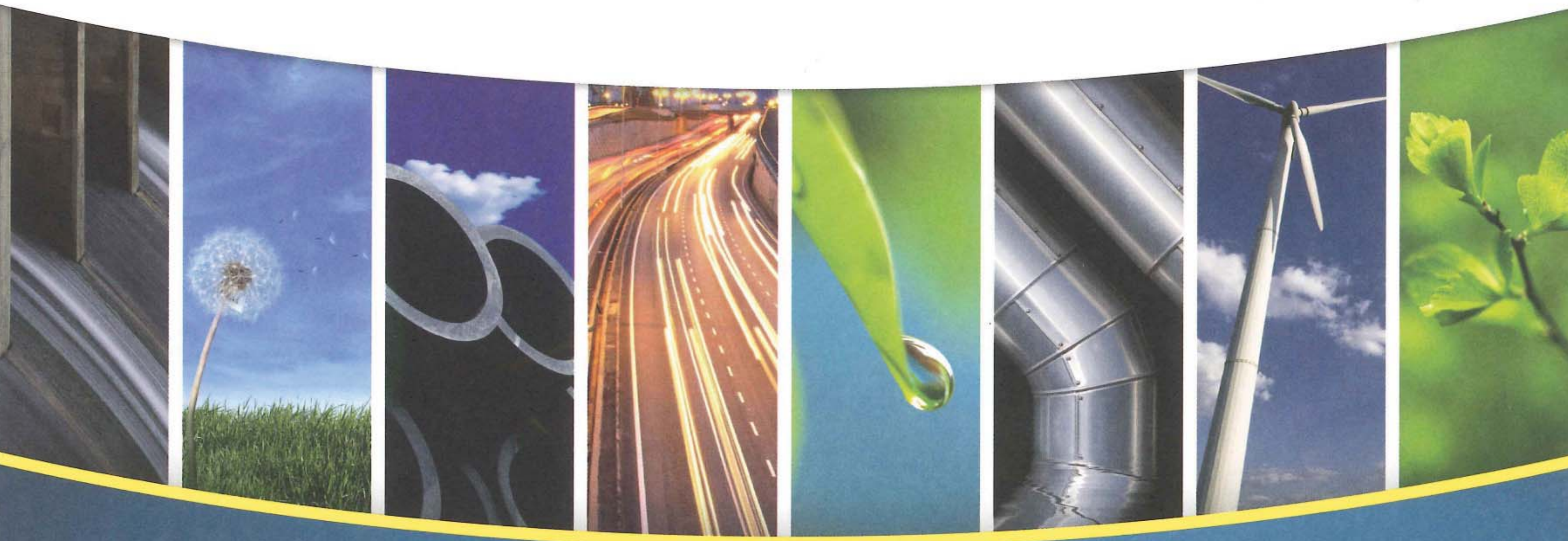
Waipoua River Rainfall- Runoff Modelling

Greater Wellington Regional Council

July 2016



MWH

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QUALITY STATEMENT

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REVISION SCHEDULE

Rev No	Date	Description	Signature or Typed Name (documentation on file).			
			Prepared by	Checked by	Reviewed by	Approved by
1	24/12/15	Draft Report	TK	AO	AO	
2	26/2/16	Final Report	TK	AO	AL	RP
3	10/3/16	Final Report Update	TK	KS	KS	TK
4	13/5/16	Update in response to review	TK	KS	KS	TK
5	16/6/16	Update in response to peer review	TK	KS	KS	TK
6	7/7/16	Update in response to meeting of 22/6/16	TK	KS	KS	TK

Greater Wellington Regional Council
Waipoua River Rainfall Runoff Modelling

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APPENDICES

1 Introduction

The main purpose of the project is to develop a rainfall runoff model of the Waipoua catchment to:

- Better assess the runoff contribution from the so called ungauged part of the catchment. That is, the area downstream of the Waipoua at Mikimiki Bridge flow gauge.
- Replicate a range of different rainfall scenarios including the impact of climate change
- Produce design flood peaks and hydrographs for the ungauged areas of the catchment
- Provide an estimate of uncertainty associated with results

A further objective of the work is to provide advice on how best apply the regional flood frequency contour approach and design hydrographs reported in PDP, (2013) to sub-catchments in GWRC's Waipoua hydraulic model. The impact on flood flows of different weather systems was also considered in brief.

In October 2015, discussions were held with GWRC and MDC to consider alternative methods to better model the relatively flat floodplain in the lower reaches of the catchment. It was agreed that a simple 2D model of the lower part of the catchment could provide a better estimate of attenuation within the floodplain. Accordingly, a 2D ICM hydraulic model of the lower reaches of the Waipoua catchment was developed but produced unrealistic results for the design rainfall simulations. Following further discussions with GWRC and MDC it was decided that hydrographs from the rainfall runoff model better represented the likely runoff response to design rainfall as opposed to results from the 2D model.

In May 2016, following discussions between the external peer reviewer, GWRC and MWH, a summary of recommended flows with estimated minimum and maximum values was produced.

The summary is listed in Table 1-1 below and discussed in more detail in Section 7. The recommended values are based on recorded values as these are considered more reliable than the results of the runoff modelling which are based on the recorded values.

Table 1-1: Recommended Flood Flows

Flood Event		Mikimiki Bridge (m^3/s)		Difference Between Recommended Value and Upper/Lower Estimate	Waipoua Rail Bridge/ Colombo Road Bridge (m^3/s)		Difference Between Recommended Value and Upper/Lower Estimate	Increase Between Mikimiki and Colombo Rd
		Ref			Ref			
1998 Flood	Upper Estimate	1a	439	23%	4a	547	23%	25%
	Recommended Value	1	356		4	445		25%
	Lower Estimate	1b	274	23%	4b	343	23%	25%
100 Year ARI	Upper estimate	2a	502	24%	5a	628	24%	25%
	Recommended Value	2	406		5	508		25%
	Lower Estimate	2b	309	24%	5b	386	24%	25%
50 Year ARI	Upper estimate	3a	446	23%	6a	558	23%	25%
	Recommended Value	3	363		6	454		25%
	Lower Estimate	3b	281	23%	6b	351	23%	25%

2 Site Visit/Data/ Literature Review

2.1 Site Visit

A site visit to meet with Masterton District Council and Greater Wellington Regional Council staff was undertaken on the 2nd of October followed by a visit to the Waipoua catchment at various locations from Colombo Bridge to the Mikimiki Bridge flow gauge. The floodplain upstream of the Waipoua rail bridge was also inspected.

2.2 Reports Received

Several reports related to the Waipoua catchment were provided along with recorded rainfall, flow data and GIS information. A description of rainfall and flow data is included in Section 2.3.

The following is a list of the reports received and comments on aspects of the reports which are directly relevant to this project:

Wairarapa Hydrological Investigations, Prepared for GRWC, PDP, July 2013.

- A HEC RAS model was used to estimate flows within the downstream reaches of the Waipoua River.
- The results of the modelling showed an average increase between Mikimiki and "the Masterton portion of the channel" of 15%.

Estimation of Flood Peak magnitude and return Period, Waipoua River at Mikimiki – 20^th^ October 1998, Prepared for MDC, NIWA, March 2015

- NIWA assessed the 20th October 1998 flood at Mikimiki to be 400 m^3/s +/- 40 m^3/s with an ARI of 75 years. This is 11% more than the peak flow value used by PDP in their assessment. The estimate of 400 m^3/s for the 1998 flood assumed a velocity of 5.0 m/s
- NIWA also estimated the 100 year ARI flood at the site to be about 430 m^3/s.

Lower Waipoua River Flood Protection, Masterton, Prepared for MDC, Evans Consulting Engineers, February 2000

- A 100 year ARI design flood of 494 m^3/s was determined for the lower reaches of the Waipoua River based on Regional Flood Frequency methods, (McKerchar and Pearson (1990). A check of the reported input parameters used in the analysis showed that the q100 contour value of 2.6 is from the outlet of the catchment (not the centroid) and the $Q/A^{0.8}$ value of 3.5 does not appear to apply anywhere near the Waipoua catchment. From McKerchar and Pearson 1989 the $Q/A^{0.8}$ contour value is less than 2.0 at the catchment outlet and 2.5 at the centroid. Applying contours from the McKerchar and Pearson (1989) for the centroid of the catchment and an area of 160 km2 gives a peak flow of 348 m^3/s.
- The 20th October 1998 flood was reported to have an estimated flow of 450 m^3/s at Masterton.

Review of PDP Report on Wairarapa Flooding, prepared for GWRC, NIWA, May 2013

- NIWA observed that a reported conclusion of the PDP report was that flood peaks at Masterton had an additional 16% on top of flood peaks at Mikimiki Bridge. However, the increase in catchment area between the two locations is around 80%. The review also found it was not clear whether it was appropriate to discard the 16% increase between Mikimiki and Masterton in favour of a more conservative 32% increase based on regional contours without comparing the errors of the two methods.

Masterton Flood Protection, Internal report prepared for MDC, Internal staff member

- The report agreed with NIWA (2015) findings that the 1998 flood had an estimated return period of 75 years and a flow of about 400 m^3/s at Mikimiki Bridge.
- It reported that a peak flow of 412 m^3/s was calculated by GWRC for the reach upstream of Colombo Road Bridge for the 1998 flood based on slope area methods.
- The 30% increase in flows between Mikimiki Bridge and Colombo Road recommended by PDP, (2013) was questioned but was used in calculations related to channel flood levels.

Meteorology and Hydrology of the 6-9 November 1994 Flood, Wellington Regional Council, November 1994

As a result of this event, flows in the Wairarapa were estimated to have an ARI of 38 years at Ruamahanga at Wardells and 50 years at Waihenga. Rainfall at Angle Knob was estimated to have a maximum hourly ARI of 3 years. Rainfall at the Waipoua at Mikimiki Bridge gauge was recorded but no flows were recorded within the Waipoua catchment during the event.

Hydrological Statistics of Surface Water Monitoring Sites in the Wellington Region, GWRC, 2008

The report provides summary statistics and descriptions of rainfall and flow gauges administered by GWRC. Flood frequency analysis of the record at Mikimiki Bridge gives an estimated 100 year ARI flow of 492 m^3/s. Regional Flood Frequency methods gives a 100 year ARI flow of 367 m^3/s. The site was re-established in 1995 for flood warning and it was noted in the report that there is a large margin of error in the upper part of the rating curve.

Comment on NIWA report, Estimation of Flood Peak Magnitude and Return Period; Waipoua River at Mikimiki, 20 October 1998, Brin Williman, May 2015

The report concluded that although the NIWA flood frequency relationship at Mikimiki Bridge was slightly different to that of PDP the analysis was insufficiently robust to prove whether the NIWA figures were any better than those of PDP.

The author questions the adoption of a velocity of 5 m/s for the 1998 event at Mikimiki.

The report also suggested that the 1998 flood could be used in a hydraulic model and increased to a “design” standard to better understand the issue.

Hydrological Summary of Flood 19 -21 October 1998, WRC

The two day rainfall event resulted in two peaks in the Waipoua River. The first peak is thought to have scoured the river bed changing the relationship between stage and flow and therefore giving a false value of the second peak. Peak flow through Masterton was estimated to be 450 m^3/s, the highest since 1978 and exceeding the flood levels of the November 1994 event.

2.3 Flow and Rain Data

Flow and rainfall data were provided by the GWRC as xml files which were imported to TIDEDA.

A graph of rainfall and flow sites and the duration of each record are shown in Figure 2-1 and the location of each site in Figure 2-2.

The gauges of most use to the understanding of rainfall and runoff in the Waipoua catchment are site 29257, Waipoua at Mikimiki where data are available from 1979 to 1983 and 1996 to present, site 1000 (temp site #) Waipoua at Colombo Road Bridge which operated from December 2009 to march 2011 and 575960 Waipoua at Westons rainfall which has operated from November 2007.

Given the importance of recording continuous flows at Colombo Road is recommended that this gauge be reinstated.

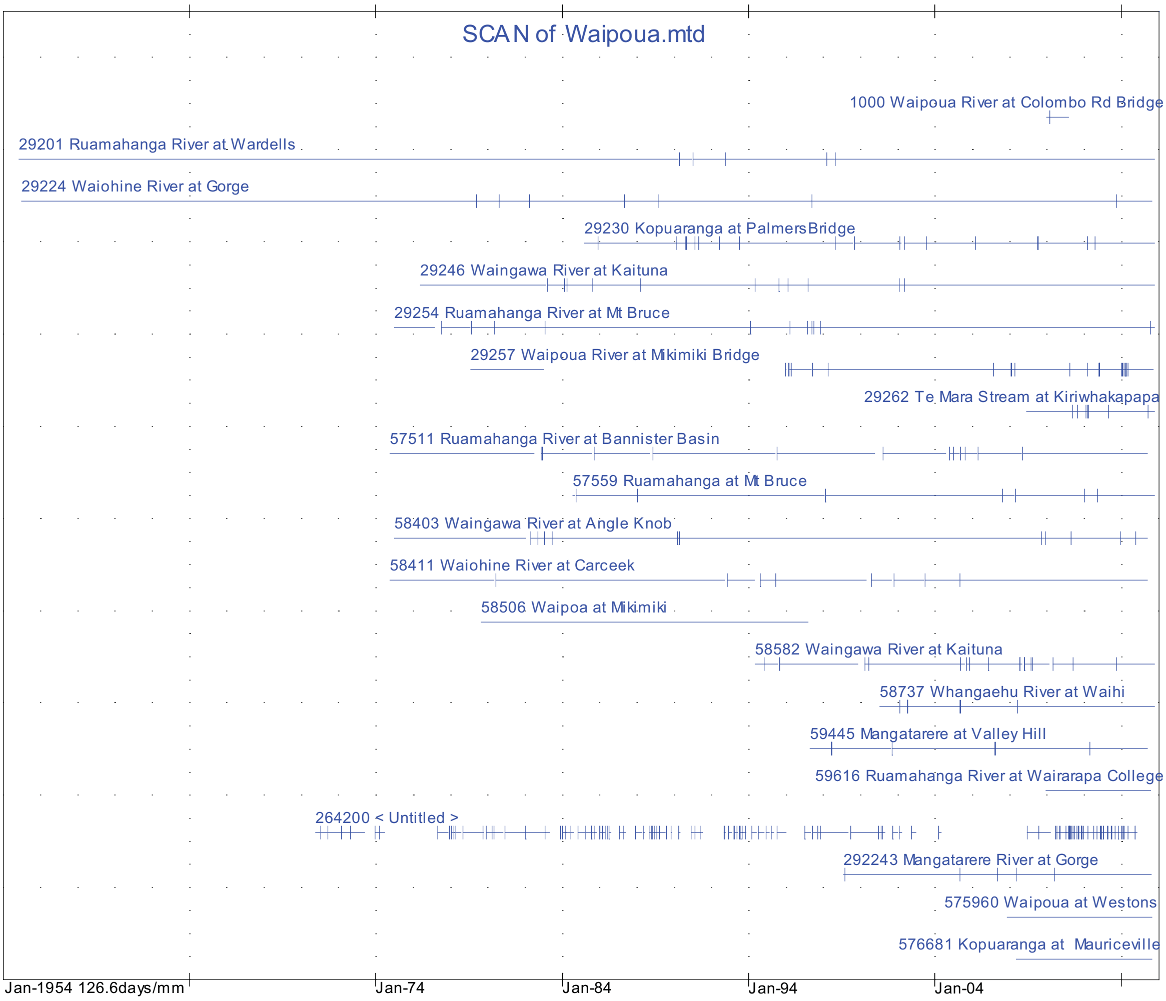

Figure 2-1: Summary of Hydrometric Data Provided - Including Duration of Record

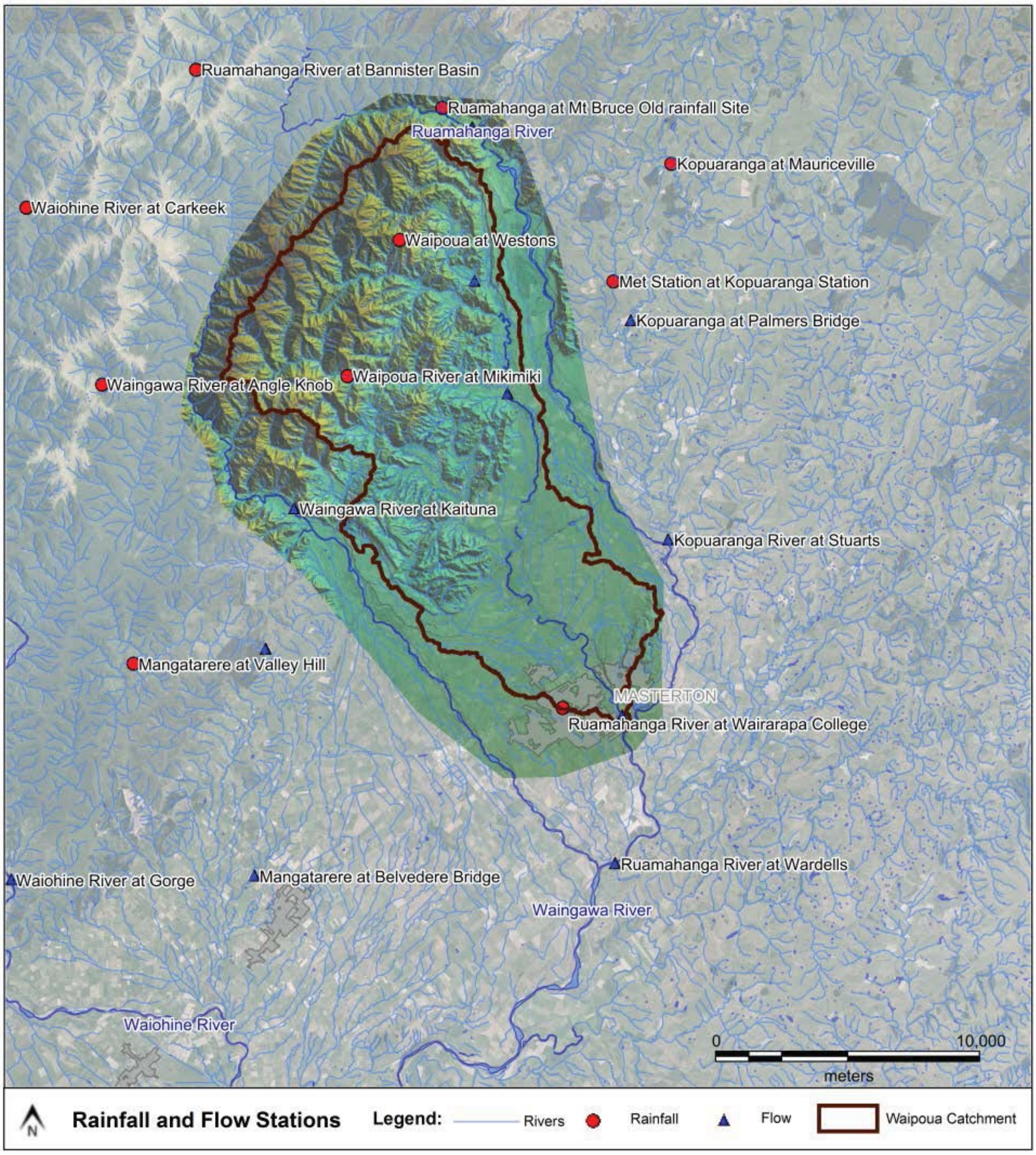

Figure 2-2: Location of Rainfall and Flow Stations

2.4 Additional Flow and Level Data

Estimates of peak discharge events upstream of the Colombo Road Bridge were provided in various documents and calculation sheets and are summarised in Table 2-1. Of most interest to this project are flood events where flows are available for Mikimiki Bridge and Colombo Road and where adequate rainfall is available.

Table 2-1: Peak Flow Estimates

Date	Flow Mikimiki Bridge (m^3/s)	Flow Colombo Rd Bridge (m^3/s)	Comment
19//05/88	-	247*	
08/11/94	-	291*	
20/10/98	365**	412*	
07/10/08	228**	-	
22/07/09	173**	-	
06/09/10	131**	161**	
03/03/12	265**	-	Incomplete hydrograph

* Estimated from slope area method
**Estimated from continuous rated stage record

A summary of catchment statistics is listed in Table 2-2.

Table 2-2: Summary of Catchment Statistics

Parameter	Unit	Value
Catchment Area (Mikimiki Bridge)	km^2	80.3 km^2
Catchment Area (Waipoua Rail Bridge)	km^2	163 km^2
Catchment Area (Colombo Road)	km^2	Assumed to be similar to Waipoua Rail Bridge (due to stop banks)
Catchment Area (Confluence with Ruamahanga River)	km^2	170 km^2
Peak Recorded* Flow Mikimiki Bridge	m^3/s	356* 20-Oct-1998 02:15:00
Peak Gauged** Flow Mikimiki Bridge	m^3/s	203** 2-Oct-2000 15:35:00
Peak Recorded Flow Colombo Bridge	m^3/s	162* 6-Sep-2010 14:45:00
Peak Gauged Flow Colombo Bridge	m^3/s	413** 20-Oct-1998 4:00:00

*Continuous rated water level recording
**Instantaneous gauging

3 Hydrology

3.1 Comparison of Flow at Mikimiki and Colombo Road

Several flood peak estimates have been made in the lower Waipoua catchment at or adjacent to the Colombo Road Bridge. These are summarised in Section 2 above.

Continuous flows have also been recorded at Colombo Road between December 2009 and March 2011. Although no extreme floods were recorded during this period the record provides a valuable comparison of flows between the two locations. This comparison is shown in the figures below and includes the highest four recorded flood hydrographs recorded coincidently at Mikimiki Bridge and Colombo Road.

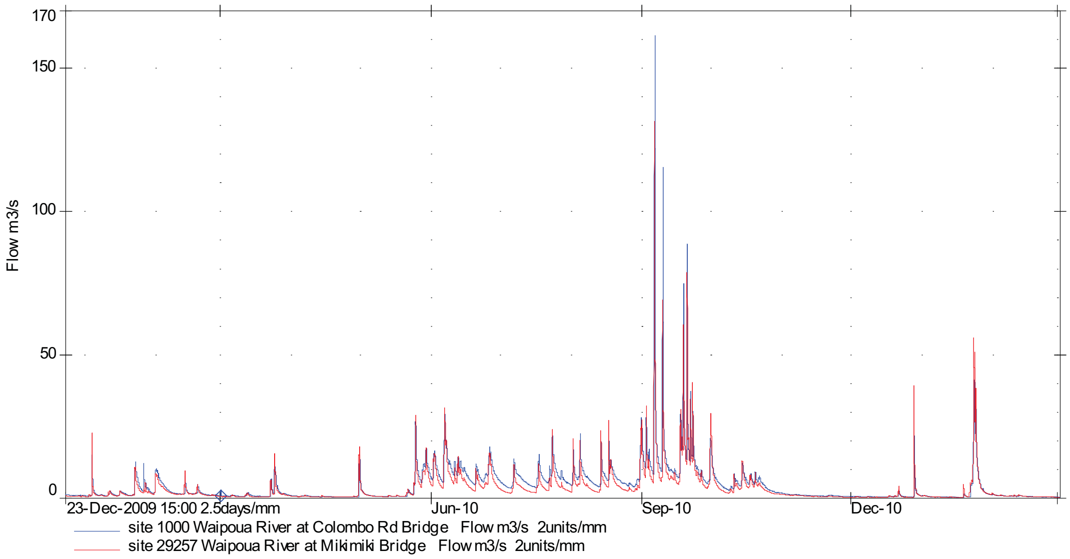

Figure 3-1: Comparison of flows between Mikimiki and Colombo Road

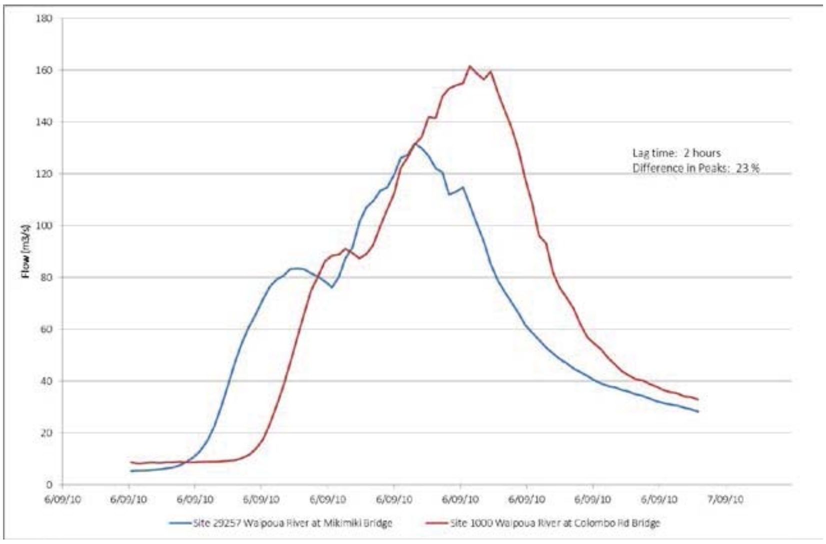

Figure 3-2: Comparison of flows between Mikimiki and Colombo Road

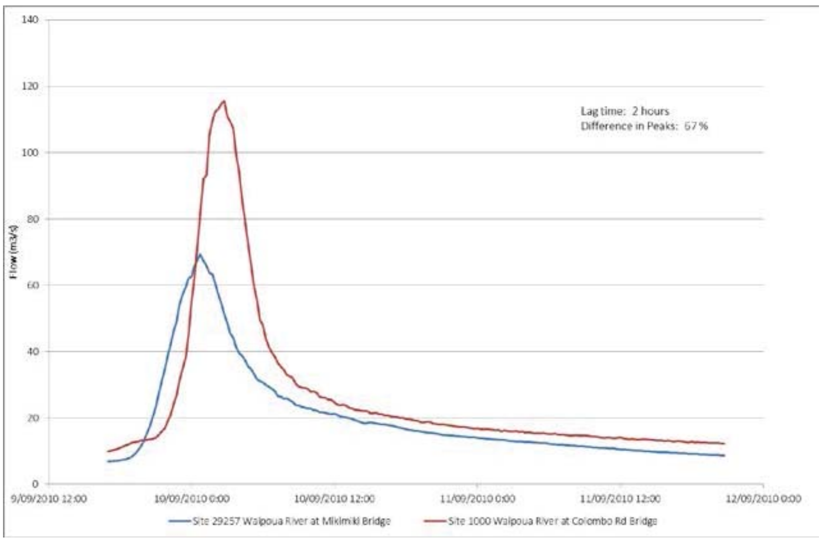

Figure 3-3: Comparison of flows between Mikimiki and Colombo Road

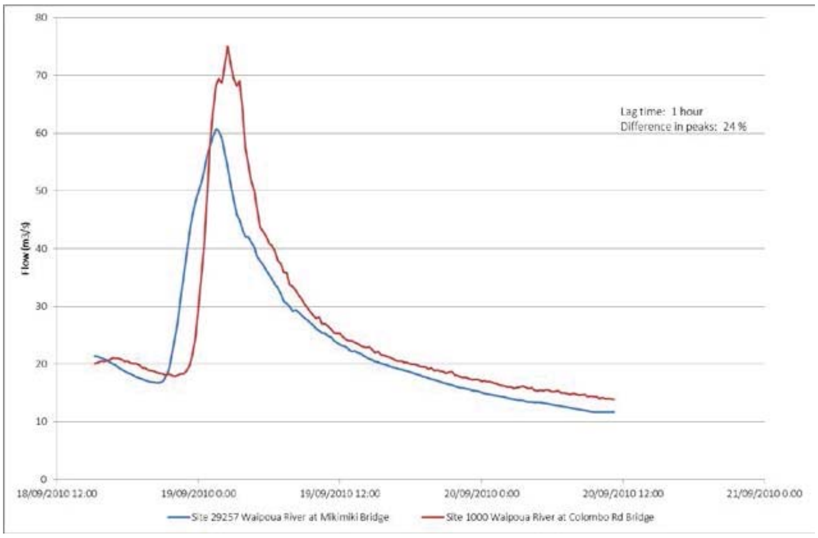

Figure 3-4: Comparison of flows between Mikimiki and Colombo Road

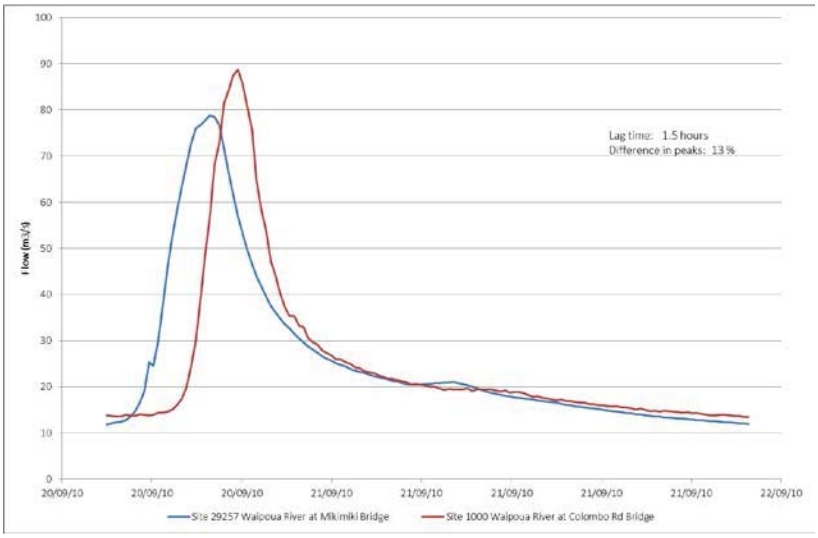

Figure 3-5: Comparison of flows between Mikimiki and Colombo Road

Comparison of these floods show a lag time between Mikimiki Bridge and Colombo Road of between 1.5 and 2 hours and a difference in peak flow of between 13% and 67%. This compares with an average difference of three recorded and modelled flows reported in PDP's Wairarapa Hydrological Investigations, (2013) of 15%.

It is clear that for some floods the difference in peak flow between Mikimiki Bridge and Colombo Road can be relatively small given there is an increase in catchment area between the two locations of around 100%.

The difference in flows can also be quite large as is shown in the flood of 10th September 2010 which recorded a 67% increase between Mikimiki Bridge and Colombo Road.

Some of the difference is due to less rainfall in the lower reaches of the catchment as described in Section 3.2, however, based on the rainfall contours shown in Figure 3-11 there is a 65% increase in rainfall between Mikimiki Bridge and Colombo Road.

Overall, the relatively small difference in flow between Mikimiki Bridge and Colombo Road is attributed to the significant storage provided in the flat floodplain between the two locations.

3.2 Rainfall

Sub-daily rainfall data are available from three intensity rain gauges within the Waipoua catchment as shown in Figure 2-2. These are Westons, Mikimiki and Wairarapa College. In addition to these gauges, rainfall for Mangatarere at Valley Hill and Ruamahanga at Mt Bruce are relatively close to the Waipoua catchment and are similar in elevation to the upper reaches of the catchment. Accordingly, these gauges were also used in the analysis of rainfall and calibration of the rainfall runoff model.

3.2.1 Impact of North-West, North-East and Southerly Weather Systems

Data for rain events that coincided with adequate recorded flow data were plotted to identify one of three weather systems. That is, north-west, north-east or a southerly wind direction.

Wind direction data was obtained for Castlepoint from 1985 and Masterton from 1997. The information is plotted in Figures 3.3 to 3.6. Castlepoint data was used for the 2008 event as no Masterton data were available.

All four floods commenced during west to north westerly systems and show a coincidence in the rainfall peak falling at Mangatarere and Mt Bruce and Westons for periods where this data is available. The peak rainfall at Angle Knob occurs at about the same time as the other gauges except during the 1998 event when it peaks ahead of rainfall at lower elevations.

At this stage there is insufficient information to establish the impact of a paticular weather system direction on rainfall in the Waipoua catchment. It is therefore not possible at this stage to consider the impact of a particular rain storm direction of travel on flood flows or incorporate this into the calibration of a rainfall runoff model.

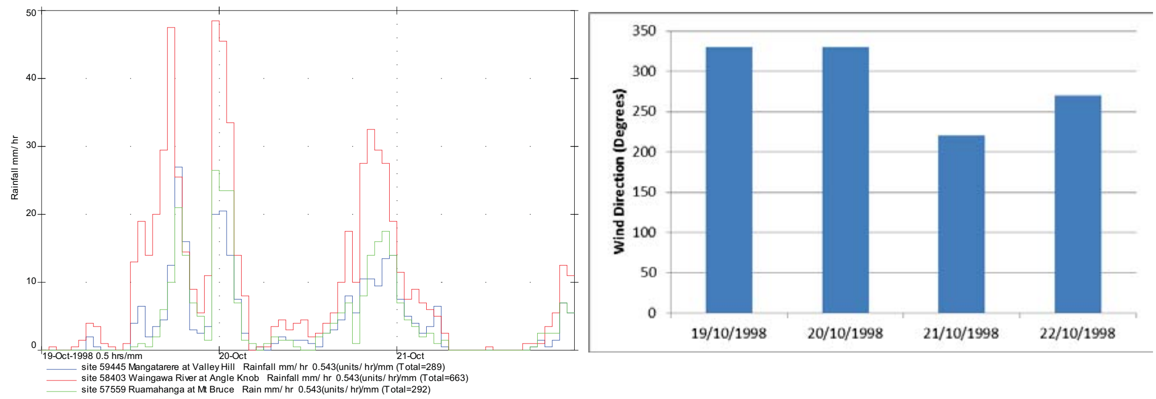

Figure 3-6: Rainfall for 1998 Flood and Wind Direction Masterton (NW)

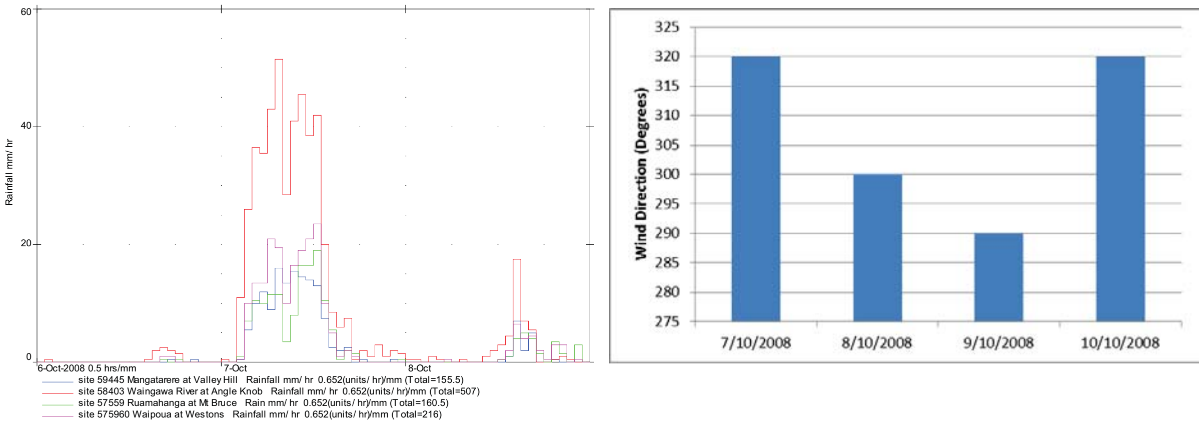

Figure 3-7: Rainfall for 2008 Flood and Wind Direction Castlepoint (NW)

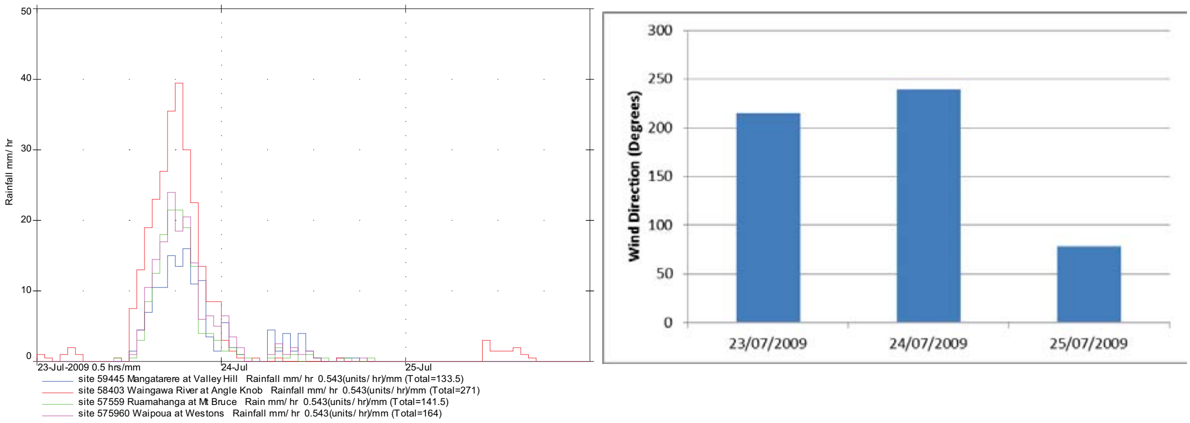

Figure 3-8: Rainfall for 2008 Flood and Wind Direction Masterton (W)

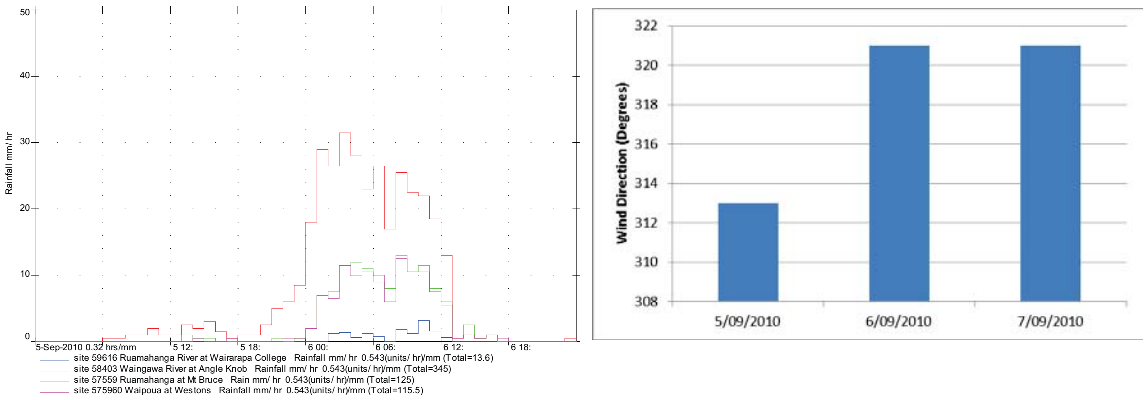

Figure 3-9: Rainfall for 2010 Flood and Wind Direction Masterton (NW)

3.2.2 Calibration Rainfall

As shown in Figure 3-10, there is considerable variation in elevation within the Waipoua catchment.

To account for the variation in rainfall distribution associated with change in elevation and in the absence of recorded rainfall in the catchment other than the Westons gauge, 24 hour duration 100 year ARI contours supplied by NIWA were used.

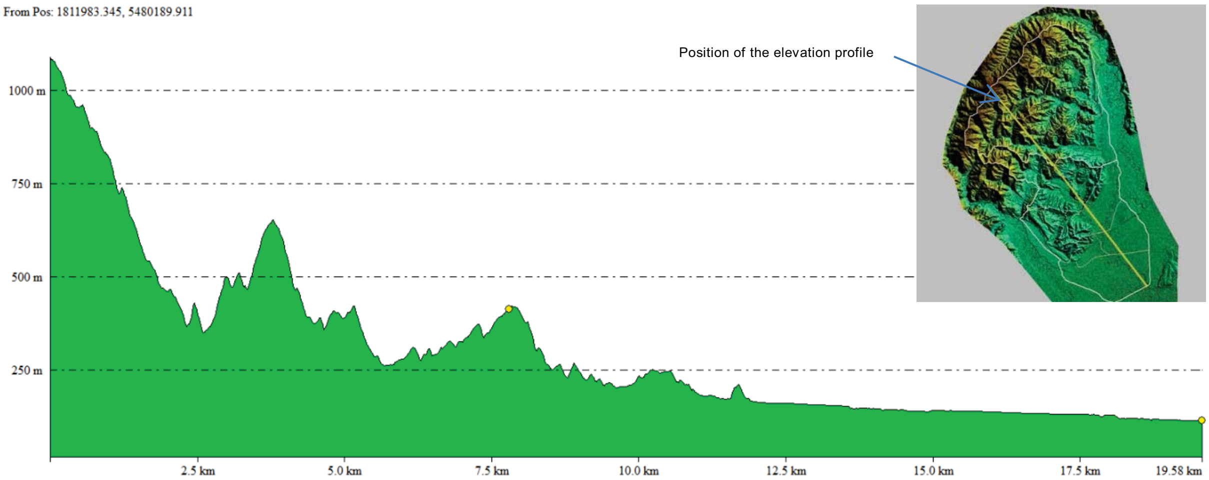

Figure 3-10: Elevation Profile through Catchment

Figure 3-11 shows the rainfall distribution used for the Waipoua catchment based on NIWA supplied isohyets as well as numbered sub- catchments.

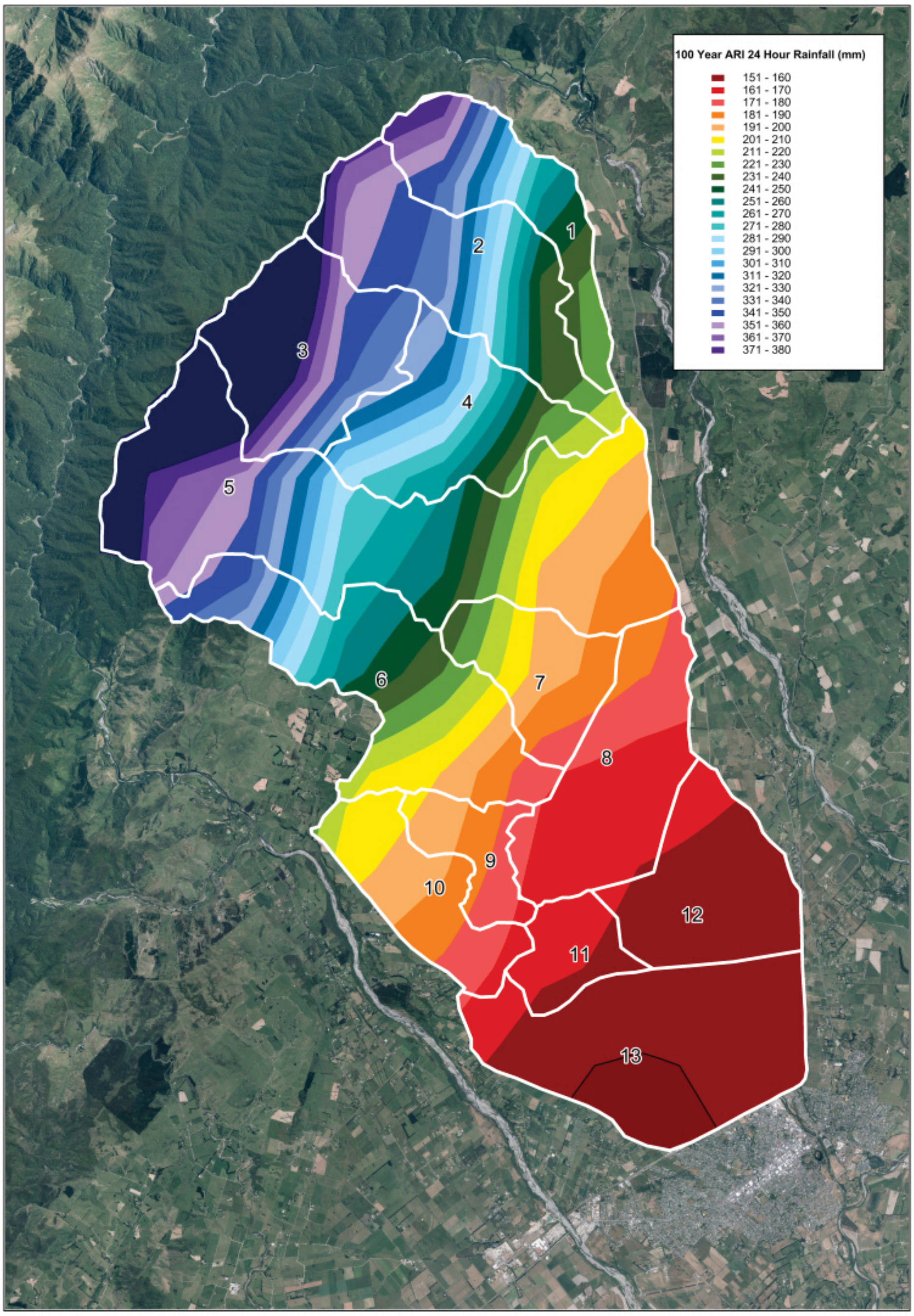

Figure 3-11: 100 year ARI 24 Hour Rainfall Contours (mm) and Sub-Catchments

Recorded rainfall for the calibration of the rainfall runoff model and simulated design events were distributed across the catchment by applying a weighting factor to account for the difference in rainfall depth at the Waipoua at Westons or Ruamahanga at Mt Bruce rain gauges and the average depth for each sub-catchment. A summary of sub-catchment rainfall weighting factors based on 24 hour 100 year ARI contours is listed in Table 3-1.

Table 3-1: Sub-catchment Rainfall Weighting Factors

Sub-Catchment	Area km^2	Weighting Factor
1	9.3	0.84
2	14.4	0.87
3	12.4	1.09
4	11.9	0.82
5	33.5	0.81
6	16.9	0.79
7	7.2	0.57
8	12.6	0.49
9	4.1	0.55
10	7.7	0.57
11	4.0	0.48
12	10.5	0.46
13	18.6	0.46

3.2.3 Design Rainfall

Design rainfall was taken from HIRDS version 3 for both the existing and climate change case for the location of the Waipoua at Westons rain gauge. 2.5 degrees increase in atmospheric temperature was applied to estimate the impact of climate change on rainfall. This is estimated by GWRC to give a 20% increase in Masterton rainfall in 2090.

Rainfall was distributed within each sub catchment based on the weighting factors listed in Table 3-1.

The HIRDS Intensity Duration Frequency (IDF) tables are included in Appendix A.

3.2.4 Critical Duration

Design rainfall for durations of 2, 3, 4, 6, 8, 12, 24, 36, 48 and 72 hours were input to the rainfall runoff model to determine a critical duration for various parts of the catchment.

For the purposes of comparing model results with reassured floods it is assumed that flows at the Waipoua Rail Bridge and Colombo Road Bridge are similar given there are no significant inflows between the two locations

It was found that a six hour duration event caused the peak flow at Mikimiki Bridge and 12 hour duration rainfall caused the highest peak at the Waipoua Rail Bridge. It is noted that the 12 hour critical duration for the Waipoua Rail Bridge is a coarse estimate given the relatively few durations simulated around the 12 hour value.

3.2.5 Temporal Distribution

Design rainfall temporal distribution was based on Tomlinson, 1992, The NZ Hydrological Society publication Waters of NZ presented in chapter 4). The distribution is based on rainfall accumulation during 17 annual maximum storms in the Wellington area. The curve envelopes all 17 events with a high intensity during the early to middle part of the event.

A graph of the distribution is given in Figure 3-12.

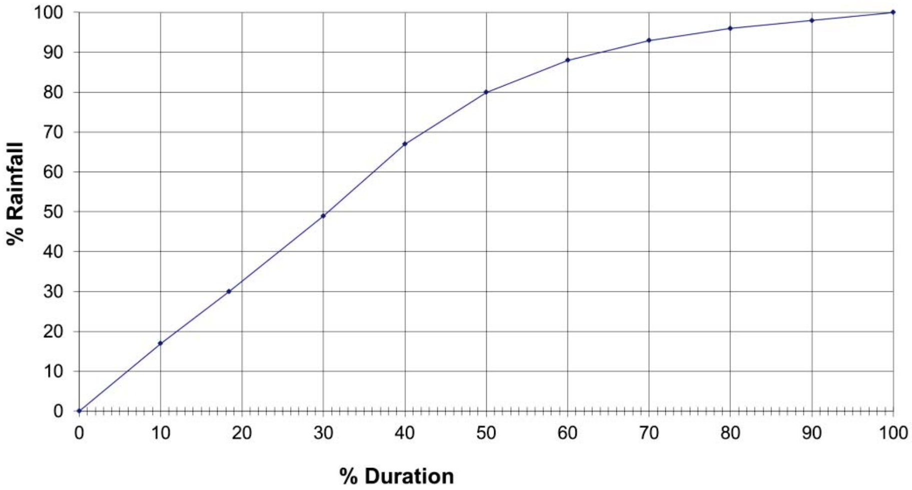

Figure 3-12: Rainfall Temporal Distribution

4 Hydrological Modelling

A rainfall run off model of the catchment was developed using Kisters Time Studio Modelling software platform. An initial loss, continuing loss model based on the commonly used RORB runoff model (developed by Monash University) was calibrated for the upper half of the catchment using flow data from the Mikimiki Bridge gauge and rainfall from the Waipoua at Westons and Ruamahanga at Mt Bruce rain gauges.

The model assumes an initial loss of IL mm before rainfall becomes effective runoff. After this amount is satisfied a continuing loss rate of CL mm per hour is applied to the rainfall input. Non-linear channel routing is used to convey channel flow within the model.

The Mikimiki gauge is not fully rated but provides an approximation of high flows. The model was also calibrated to flows at the Waipoua Rail Bridge based on measurements at the Colombo Road Bridge. As there are few tributary inflows between the Waipoua Rail Bridge and Colombo Road it was assumed that flows at these two locations would be similar.

A schematic diagram of the runoff model is shown in Figure 4-1.

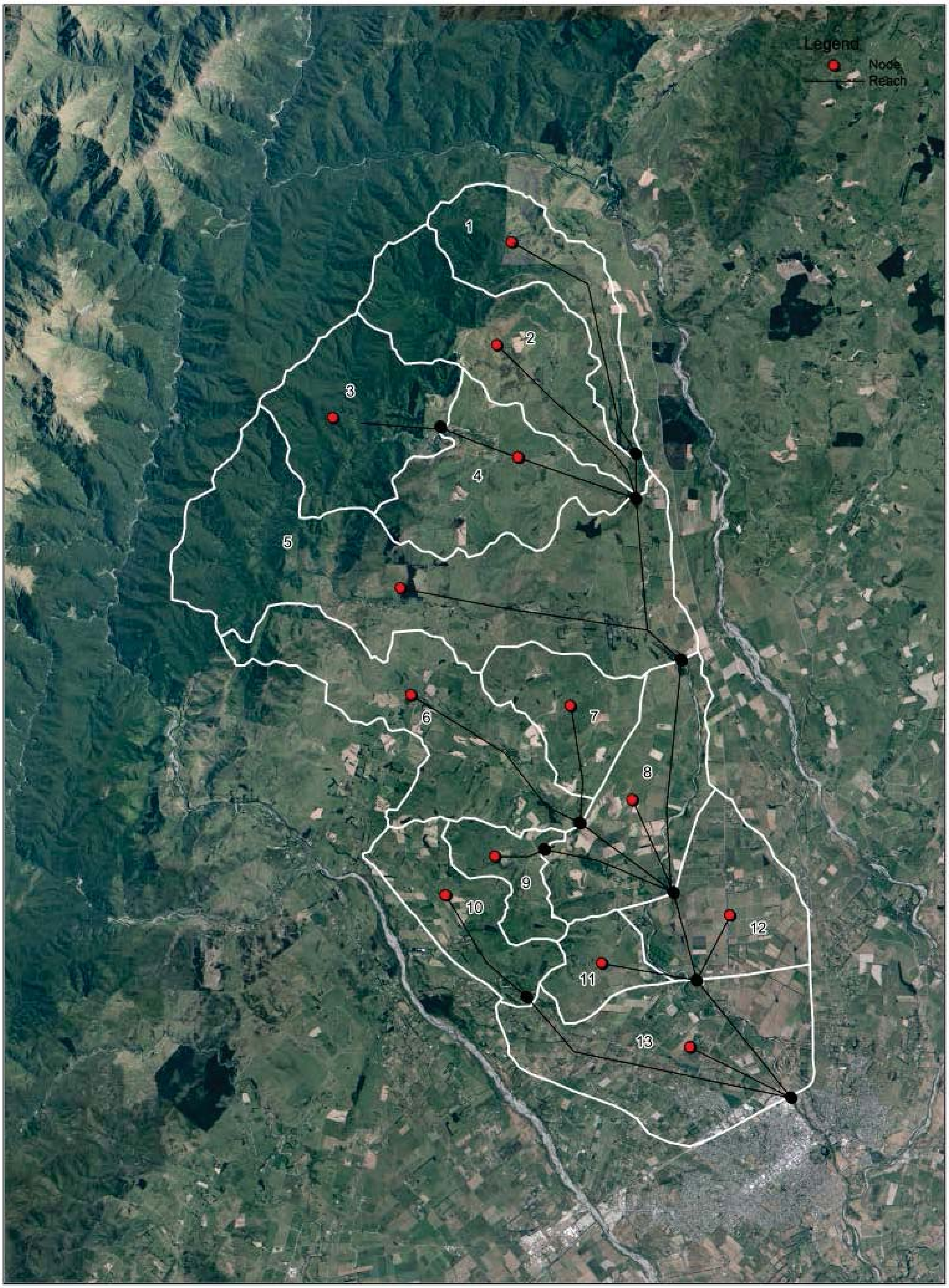

Figure 4-1: Runoff Model Schematic

4.1 Runoff Model Calibration

The runoff model was calibrated using recorded rainfall and runoff described in Section 3.2.

The four highest flood events recorded simultaneously at Mikimiki Bridgeand Colombo Road were selected along with the 1998 flood which was recorded at Mikimiki Bridge and flow estimated at Colombo Road using slope area methods.

Figures Figure 4-2 to Figure 4-5 compare recorded and simulated flows for Mikimiki Bridge. Figure 4-6 and Figure 4-7 show recorded and simulated flows for Colombo Road Bridge. The red trace is the simulated hydrograph and the blue line is the recorded hydrograph or estimated maximum flood peak.

Differences between recorded and simulated flows are likely to be a result of basing the simulated runoff on just one rain gauge.

Rainfall is available for the Westons gauge for the 2008 to 2010 floods but not for the 1998 event. For this event Ruamahanga at Mount Bruce rainfall was used instead of Westons rainfall and adjusted to account for the difference in average storm depths between the two sites.

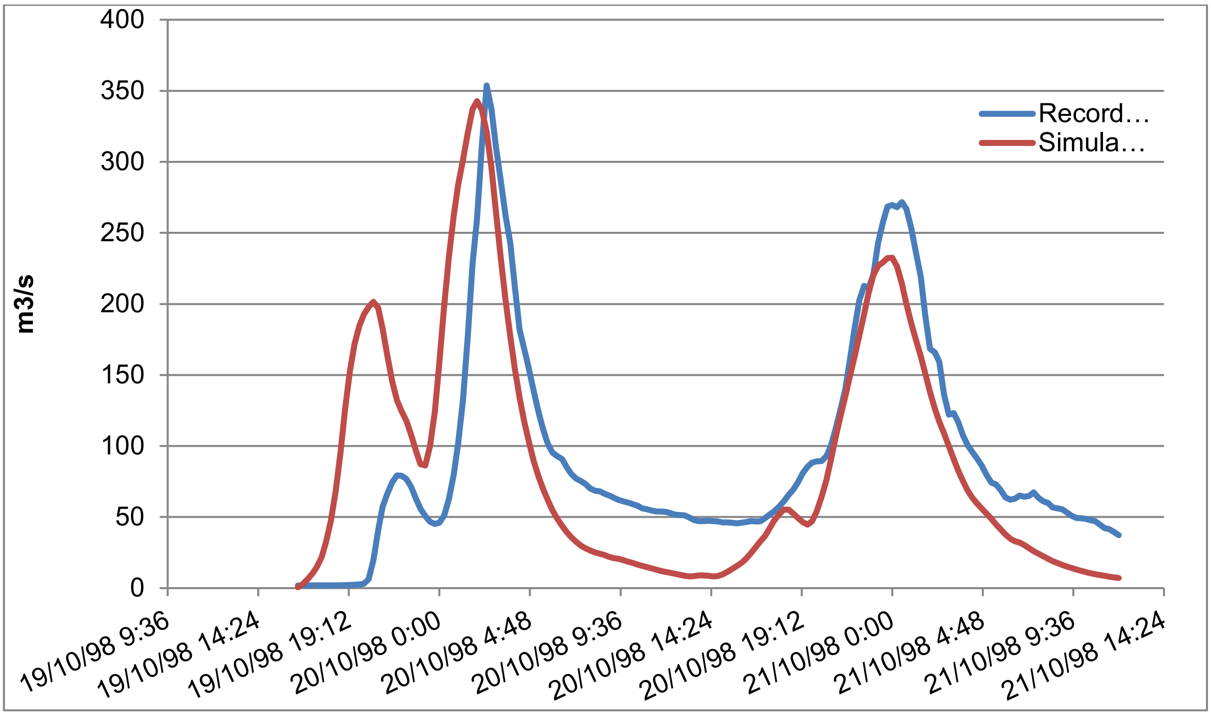

Figure 4-2: 19/10/98 at Mikimiki Bridge

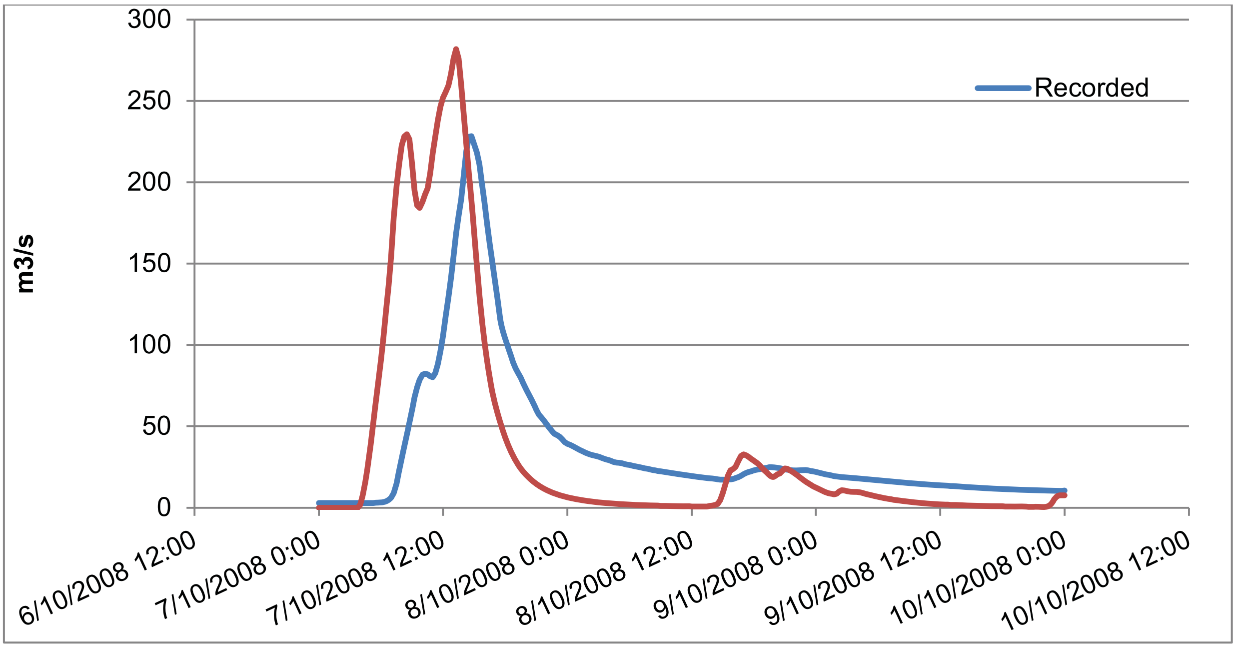

Figure 4-3: 7/10/08 at Mikimiki Bridge

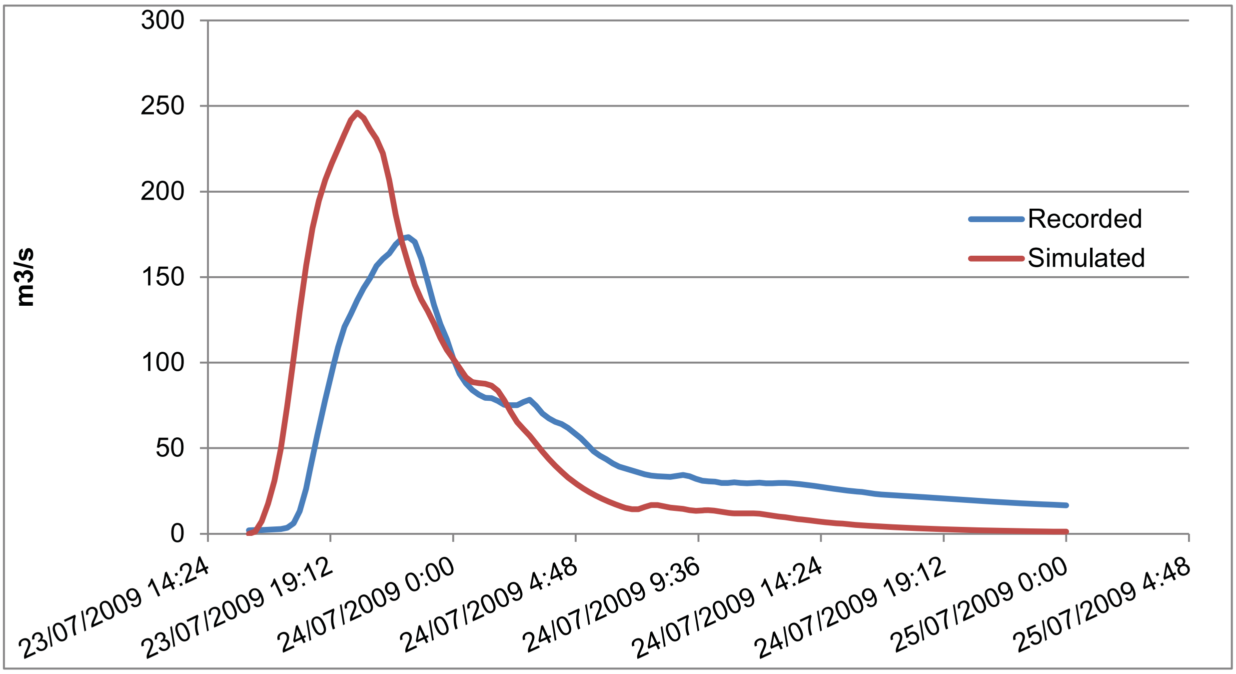

Figure 4-4: 23/7/09 at Mikimiki Bridge

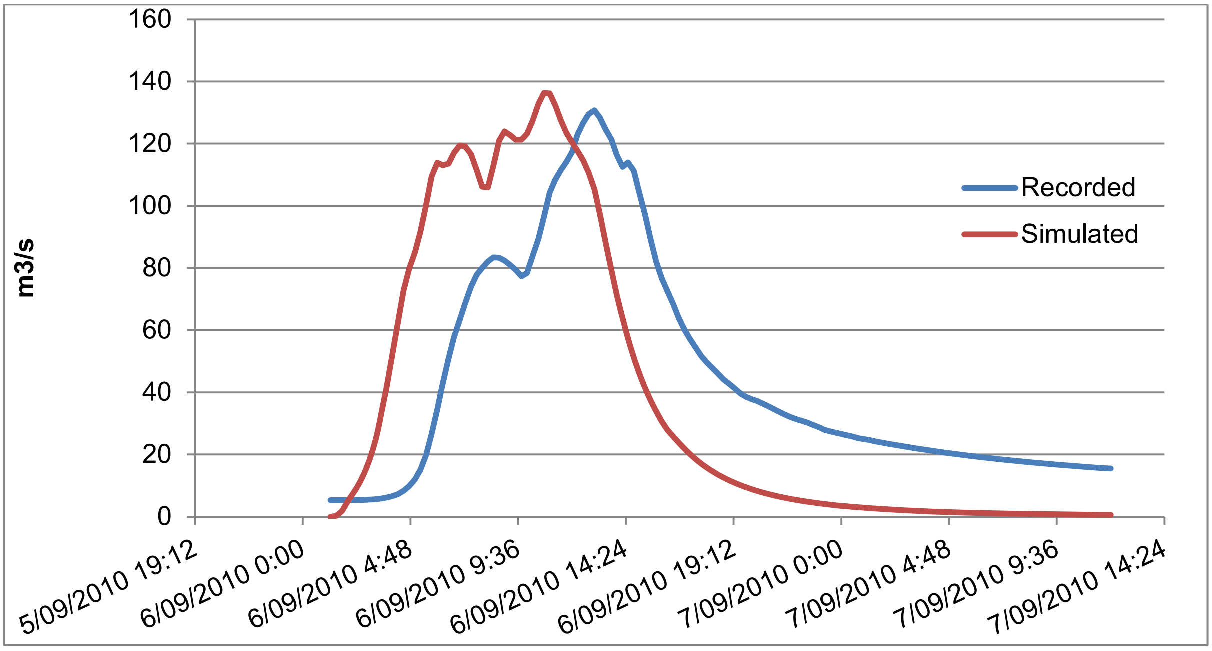

Figure 4-5: 06/09/10 at Mikimiki Bridge

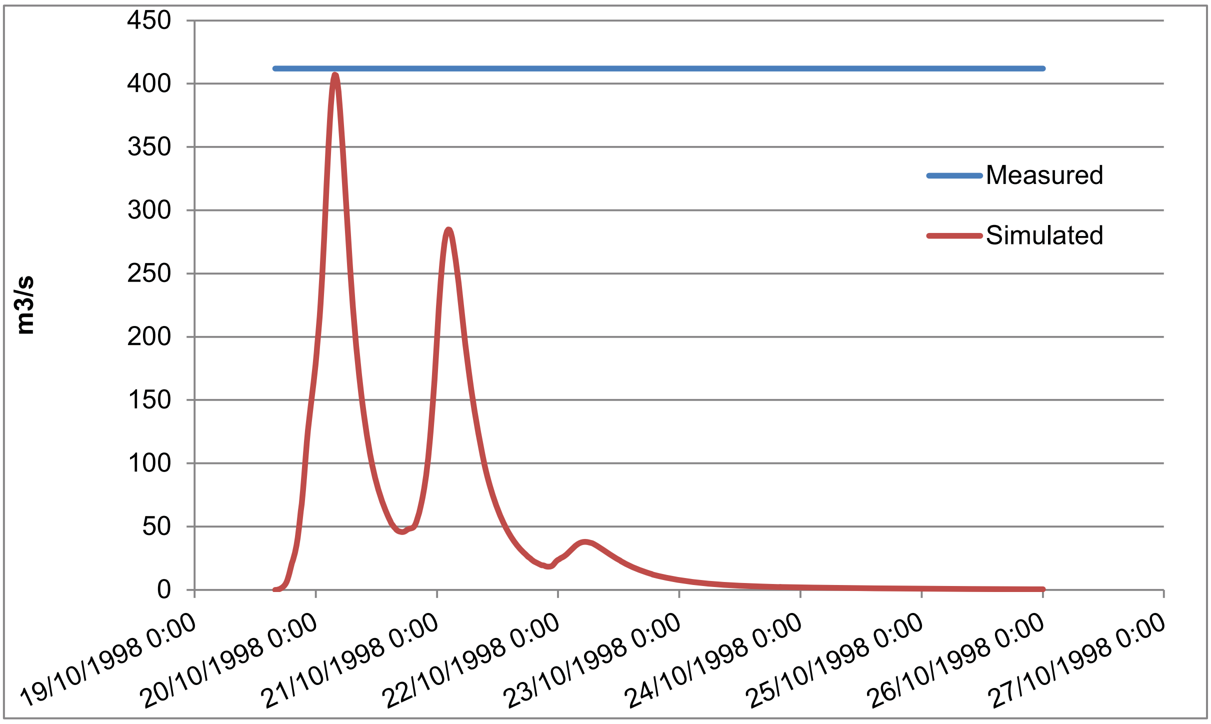

Figure 4-6: 19/10/98 at Waipoua Rail Bridge/ Colombo Rd Bridge

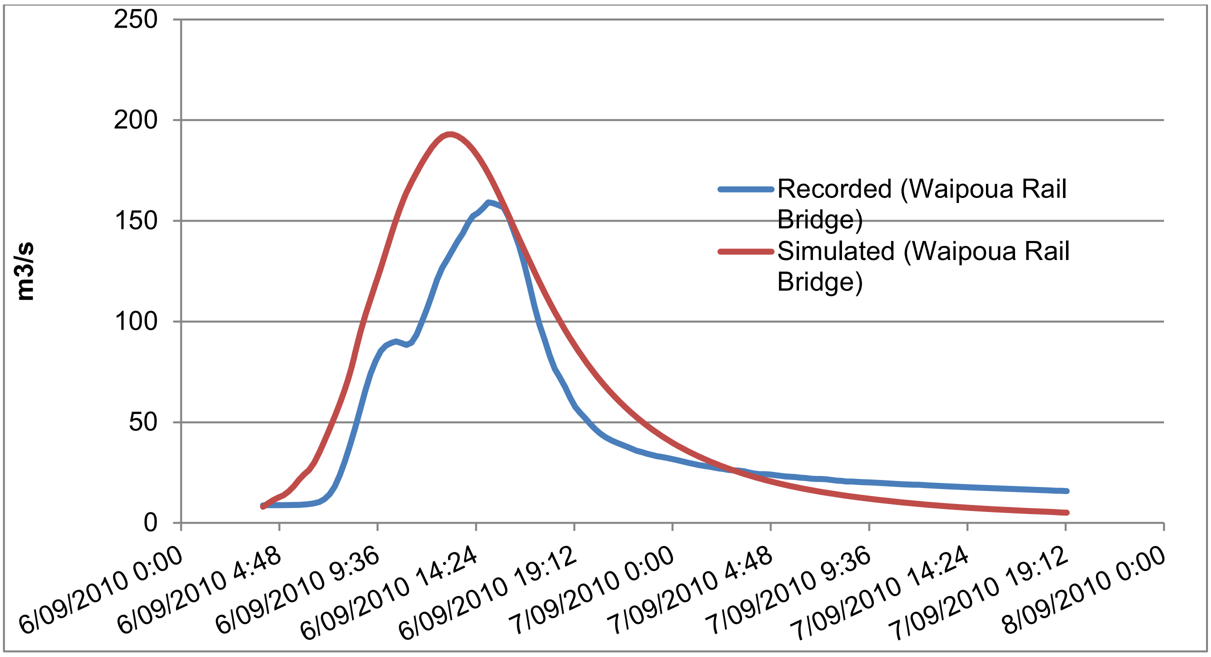

Figure 4-7: 06/09/10 at Waipoua Rail Bridge/ Colombo Rd Bridge

An initial loss of 5mm and a continuing loss of 1mm was adopted along with Alpha (channel storage parameter) and n (non-linearity parameter) values of 1.1 and 0.7 respectively for the upper catchments. 5mm and 1mm were adopted for IL/CL and Alpha and n values 3.5 and 0.64 for the floodplain catchments.

Table 4-1 lists the volumes of recorded and simulated flood volumes for the calibration events and the percentage difference.

Table 4-1: Summary of Recorded and Simulated Flood Volumes

Flood Event Date	Location	Recorded Flood Volume m^3	Simulated Flood Volume m^3	Difference
1998	Mikimiki Bridge	14,841,831	13,887,890	6%
2008	Mikimiki Bridge	9,570,869	9,696,564	1%
2009	Mikimiki Bridge	5,954,824	6,050,501	2%
2010	Mikimiki Bridge	5,619,431	4,856,324	14%
2010	Waipoua Rail Bridge/ Colombo Rd Bridge	6,931,057	8,448,998	22%

4.2 Design Hydrographs

4.2.1 Critical Duration

NIWA's High Intensity Rainfall Design (HIRDS v3) rainfall was used to model a range of durations for Waipoua at Mikimiki Bridge, and are shown in Figure 4-8. The six hour rainfall event generated the maximum peak flow.

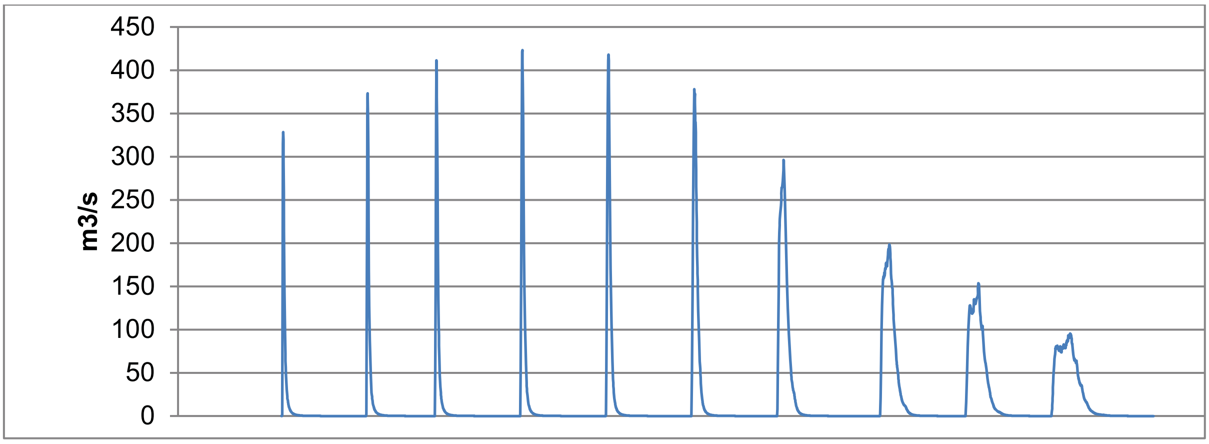

Figure 4-8: 100 year ARI Design Hydrographs at Mikimiki Bridge (2, 3, 4, 6, 8, 12, 24, 36, 48 & 72 hour)

Design hydrographs for the outlet of the floodplain at the Waipoua Rail Bridge are shown in Figure 4-9 where the 12 hour rainfall event caused the highest peak flow. As noted in Section 3.2.4 the critical duration could be somewhere between the 8 and 24 hours and these are the values either side of the 12 hour rainfall duration.

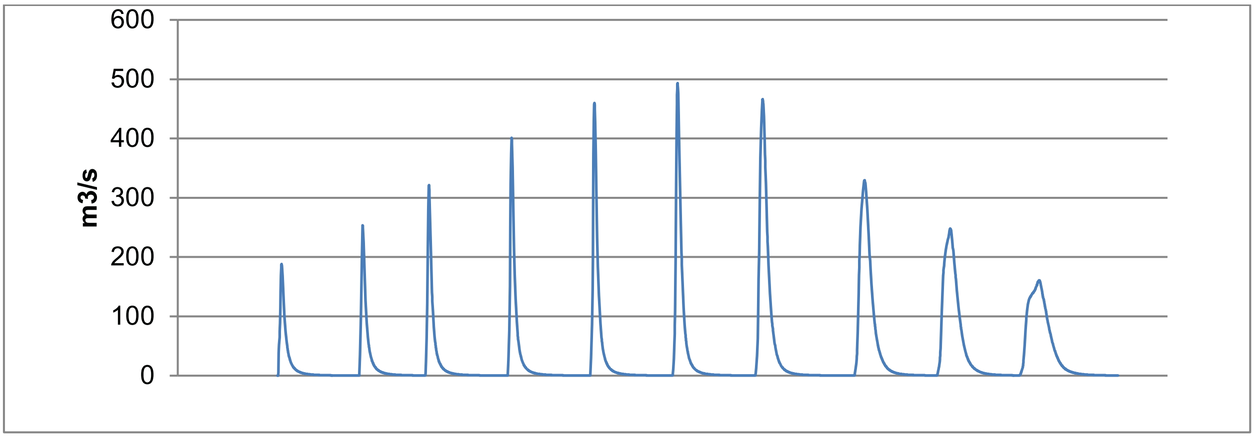

Figure 4-9: 100 year ARI Design Hydrographs at Rail Bridge (2, 3, 4, 6, 8, 12, 24, 36, 48 & 72 hour)

Modelled hydrographs for a range of durations for the Waipoua River at the Rail Bridge are shown in Figure 4-10. As with non-climate change rainfall, the 12 hours rainfall event generated peak runoff.

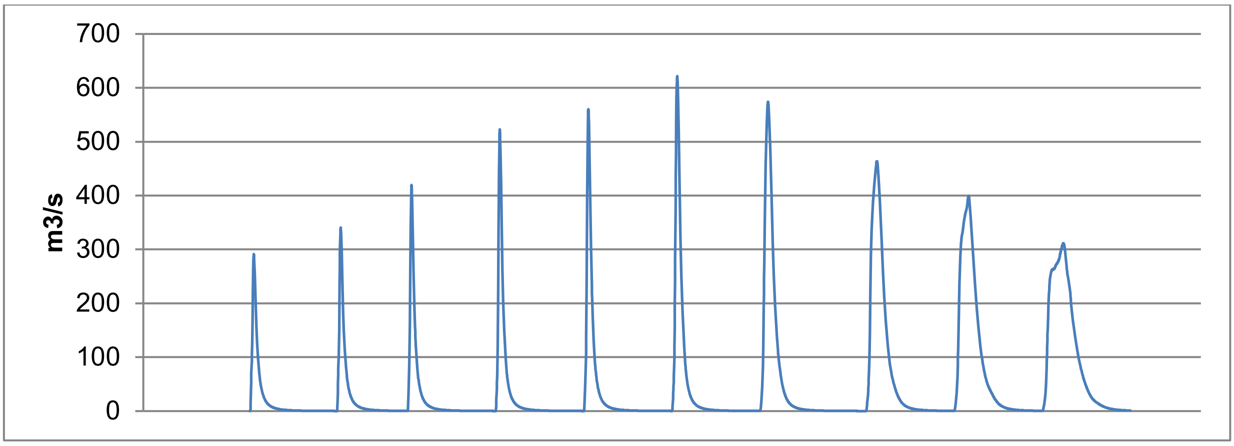

Figure 4-10: Design Hydrographs at Rail Bridge with Climate Change (2, 3, 4, 6, 8, 12, 24, 36, 48 & 72 hour)

4.2.2 Existing Scenario Design Hydrographs

Selected design hydrographs are shown below with all rainfall runoff model results listed in Table 4-2.

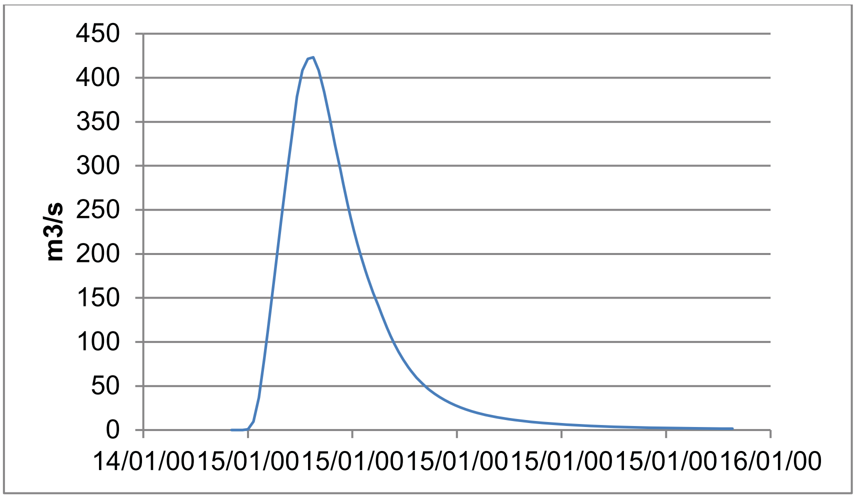

Figure 4-11: 100 year ARI Design Hydrograph at Mikimiki Bridge

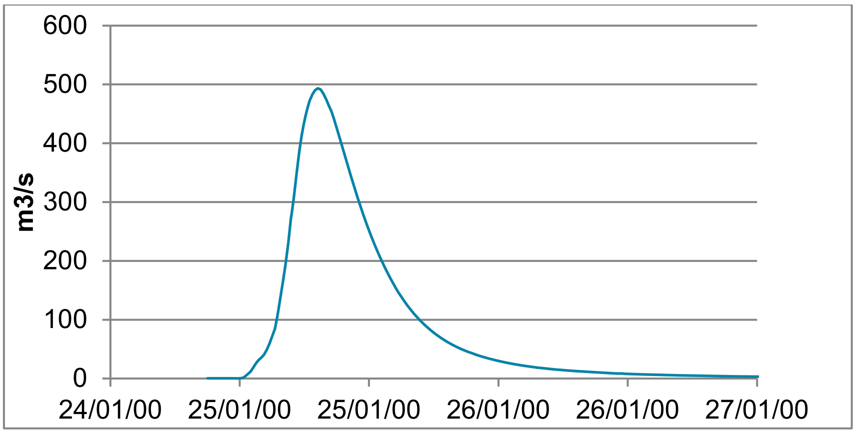

Figure 4-12: 100 year ARI Design Hydrograph at Waipoua Rail Bridge

4.2.3 Climate Change Scenario Design Hydrographs

The simulated 100 year ARI flood flow with allowance for the predicted impact of 2.5 degrees increase in atmospheric temperature on rainfall is 525 m^3/s (6 hour) for Mikimiki Bridge and 621 m^3/s.(12 hour) for the Waipoua River at the Rail Bridge. These hydrographs are shown in Figure 4-13 and Figure 4-14.

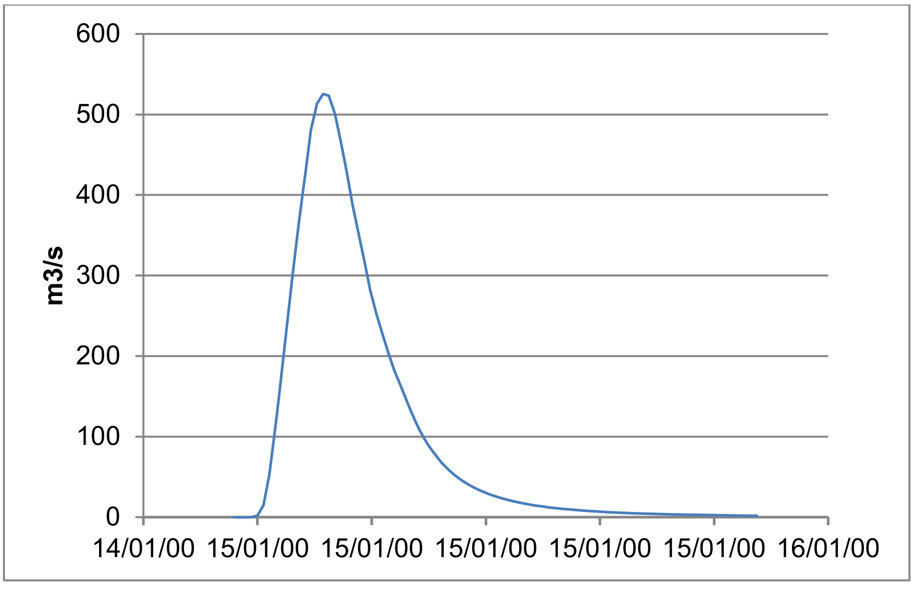

Figure 4-13: 100 year ARI Design Hydrograph at Mikimiki Bridge (with allowance for CC)

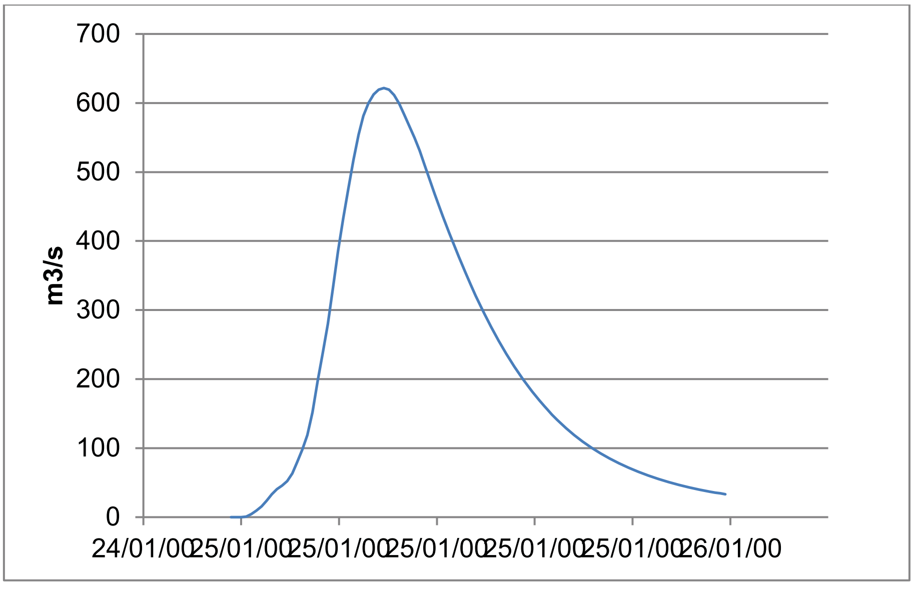

Figure 4-14: 100 year ARI Design Hydrograph at Waipoua Rail Bridge (with Allowance for CC)

4.3 Rainfall Runoff Results Summary

Table 4-2: Mikimiki Bridge Runoff Model Results and Measured Values

Flood Event	Simulated Peak Flow (m^3/s)	Duration of Design Rainfall (hrs)	Measured/ Estimated Peak Flow (m^3/s)
1998 Flood	343		*356
2008 Flood	223		*228
2009 Flood	246		*173
2010 Flood	136		*131
50 year ARI	364	6	**387
50 year ARI with CC	446	6	
100 year ARI	423	6	**406
100 year ARI with CC	525	6	

*Estimated from continuous rated stage record
** Estimated from at site flood frequency

Table 4-3:Waipoua Rail Bridge Runoff Model Results and Measured Values

Flood Event	Simulated Peak Flow (m^3/s)	Duration of Design Rainfall (hrs)	Measured/ Estimated Peak Flow (m^3/s)
1998 Flood	407		***412
2008 Flood	308		
2009 Flood	263		
2010 Flood	193		*161
50 year ARI	413	12	
50 year ARI with CC	524	12	
100 year ARI	493	12	
100 year ARI with CC	621	12	

* Estimated from continuous rated stage record
*** Estimated from slope – area methods

Results of the rainfall runoff modelling show a 100 year ARI peak flow of 423 m^3/s (6 hour) at Mikimiki Bridge. This is slightly higher than the 100 year ARI flood estimate of 406 m^3/s based on a flood frequency analysis of the Mikimiki Bridge record shown in Appendix B.

The simulated 100 year ARI flood at the Rail Bridge is 493 m^3/s (12 hour).

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5 Hydraulic Modelling

To provide a check of the impact of storage within the floodplain area covered by the rainfall runoff model, a 2D hydraulic model was developed using Innovyze's ICM (Integrated Catchment Modelling) (v6.5) software. ICM is industry recognised software and has been developed, in part, to simulate 2-dimensional overland flow. A fully 2D approach was adopted for the modelling.

The extent of the model (2D simulation polygon) is shown in Figure 5-1.The model extent is approximately 70km^2 in area and covers a 17km stretch of the Waipoua River from Mikimiki Bridge to its confluence with the Ruamahanga River. The effect of flows in the Ruamahanga River was not modelled.

The ground surface of the area is represented in the model using a Triangular Irregular Network (TIN) mesh. The elevation of each triangle (mesh element) is calculated from a ground model developed from available topographic information.

The maximum triangle size for the TIN mesh has been set to 100m^2, with a minimum area of 10m^2, however additional ground surface definition has been achieved using mesh zones (Figure 5-1), polygon features within which the TIN mesh element sizes can be varied. Mesh zone was applied over the river and stream channels within the model extent as well as the plains. Details of the varied triangles sizes in the mesh zones are given in Table 5-1.

Table 5-1: Maximum and Minimum Triangle Areas Applied in the Model (Figure 5-1)

	Description	Maximum Triangle Area (m^2)	Minimum Triangle Area (m^2)
2D Zone	General ground	100	10
Mesh Zones A	Plains	1000	50
Mesh Zones B	Channels	25	2.5

Four inflow boundaries have been applied to the model representing the inflow from the Waipoua River at Mikimiki Bridge and three catchments contributing to local tributaries that join the Waipoua upstream of Masterton. The inflow locations are shown in Figure 5-1. Inflow location 1 represents the location of the Waipoua River entering the model extent.

Surface roughness provides the primary resistive force which affects the flow of surface water, impacting the timing of flow through a catchment. For this stage of modelling only three roughness values have been adopted within the model extent (Figure 5-1). For the full 2D extent an average roughness value of Manning's *n* 0.06 has been applied to represent the varied land cover in the model area. In addition to this two roughness zones in and within the vicinity of the channels have also been applied to represent lower roughness in the extent of the river and stream channels.

Within the extent of the active channel (identified from the available aerial photography) a roughness of Manning's *n* 0.03 has been applied. For the ground adjacent to channel a roughness of Manning's *n* 0.035 has been applied.

An open, normal condition boundary has been applied to the full extent of the model area so as to allow any flow that reaches the model boundary to leave the model without energy losses.

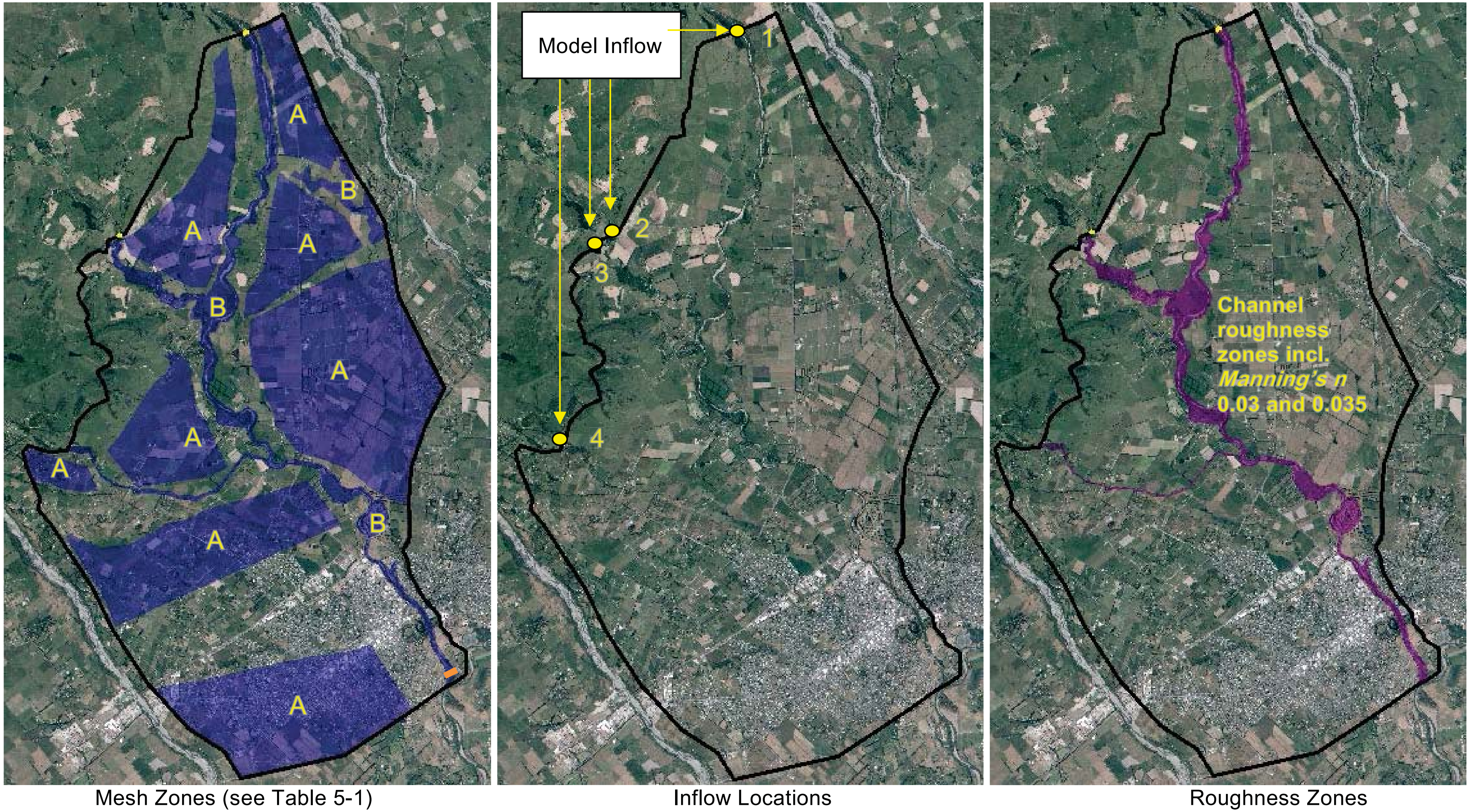

Figure 5-1: Hydraulic Model Components