Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

TECHNICAL REPORT Investigations and Monitoring Group

Waiau River floodplain investigation

Report No. R15/74
ISBN 978-0-478-15269-2 (print)
ISBN 978-0-478-15270-8 (web)

Waiau River floodplain investigation

Report No. R15/74
ISBN 978-0-478-15269-2 (print)
ISBN 978-0-478-15270-8 (web)

Nick Griffiths
Michelle Wild

June 2015

	Name	Signature	Date
Prepared by :	*Nick Griffiths* *Hazards Analyst (Flooding)* *Michelle Wild* *Hazards Analyst (Flooding)*		*September 2015*
Reviewed by :	*Brodie Young* *Environmental Science & Hazards Manager*		
Approved by:	*Ken Taylor* *Director Investigations & Monitoring*		

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

Report No. R15/74
ISBN 978-0-478-15269-2 (print)
ISBN 978-0-478-15270-8 (web)

PO Box 345
Christchurch 8140
Phone (03) 365 3828
Fax (03) 365 3194

75 Church Street
PO Box 550
Timaru 7940
Phone (03) 687 7800
Fax (03) 687 7808

Website: www.ecan.govt.nz
Customer Services Phone 0800 324 636

Summary

Background
The township of Waiau is located at the confluence of the Waiau and Mason Rivers. Prior to this study, the flood risk to Waiau township and the surrounding area from these rivers was relatively unknown. This study has been undertaken to provide more detailed information on the likely extent and depth of flooding associated with large flood events in both the Waiau and Mason Rivers.

What we did
This study used a combined one and two dimensional hydraulic computer model to estimate flood extent, depths, and flood levels for the 50, 200 and 500 year Average Recurrence Interval (ARI) flood events.

What we found
During a 50 year ARI flood in either river, no significant flooding is likely in Waiau township. During a 200 year ARI flood, maximum water levels in the Waiau River are expected to be lower than the ground on which most of Waiau township is located. Some flood water may back up into the area between the river and St Helens Street/Mendip Street. Shallow overflows are also likely from Parnassus Street Drain, flowing towards Fernihurst Street and out into the Waiau River, for many of the design flood events.

During a 200 year ARI flood in the Mason River it is expected that the Mason River stopbanks will be breached, with the most likely breach location being upstream of the Inland Road Bridge. Should this occur, floodwaters are likely to flow across Inland Road, with most of the water flowing down the floodplain adjacent to the true left bank of the Mason River. A small amount of shallow overland flow may also pass back over Inland Road and into Parnassus Street Drain. Water on the Mason River floodplain may also flow over River Road near the Inland Road intersection. This would cause shallow overland flows downstream of River Road.

The Lyndon area (upstream of the Mason confluence on the north side of the Waiau River) is likely to be flooded in 50 and 200 year ARI flood events from both the Waiau River and overflows from the numerous streams that flow through this area. River Road is likely to be impassable during both the 50 and 200 year flood events.

Although some flooding is likely to occur in Waiau township during a 500 year ARI flood event, there are no ‘high hazard’ flood areas in the township. The Lyndon area is more prone to flood inundation, with significant ‘high hazard’ areas in the vicinity of River Road.

What does this mean?
Maps showing predicted 50 year and 200 year ARI flood levels and depths, and ‘high hazard’ flood areas, will assist land use planning within the area. The 50 and 200 year ARI flood maps will allow appropriate floor levels for new buildings and extensions to be determined. The model developed as part of this study could also be used in the future to analyse existing and/or any proposed flood protection works, and for emergency planning purposes.

December 1993 Flood
Looking downstream along the Mason River to the Waiau River confluence, with Waiau township to the left.

Table of contents

List of Figures

List of Tables

1 Introduction

The township of Waiau is located in North Canterbury at the confluence of the Waiau and Mason Rivers (Figure 1-1). As of 2013, the township comprised 120 households, with a total population of 261 (Statistics New Zealand). Much of the township is relatively low lying compared to the adjacent bed levels of both rivers, and the alignment of the rivers is such that the township is potentially vulnerable to flooding during periods of high flow in either river.

The Waiau River catchment extends back to the Main Divide, and is the third largest catchment of any Canterbury river, at over 3300 km^2. The Waiau is fed by a number of substantial tributary rivers and streams, including the Mason River, which enters the Waiau immediately north of Waiau township. The Mason has a catchment area of approximately 215 km^2 and is predominantly fed from the south-eastern slopes of the Amuri Range.

Chapter 11 of the Canterbury Regional Policy Statement (CRPS) includes policy which requires new buildings in areas subject to inundation to have floor levels above the 200 year average recurrence interval (ARI) flood level. The CRPS also requires development to be avoided in ‘high hazard’ flood areas, which are areas where the water depth (m) or the product of water depth (m) and water velocity (m/s) is greater than or equal to 1, in a 500 year ARI flood event.

This investigation uses detailed topographic data and a combined one and two-dimensional hydraulic computer model to determine the likely extent and depth of flooding in and around Waiau township for 50 year and 200 year ARI flood events, and to quantify the extent of any ‘high hazard’ flood areas in a 500 year ARI flood event. This information will enable the implementation of the CRPS policies referred to above.

Figure 1-1: Location of Waiau township

2 Background

2.1 Study area

The primary focus of this investigation is to quantify the flood risk to Waiau township from the Waiau and Mason Rivers. The study area effectively includes the entire Waiau River catchment, however, particular attention has been given to the section of the Waiau River downstream of Rotherham to downstream of Waiau township, and the section of the Mason River from below the Lottery confluence to the Waiau confluence (Figure 2-1).

Several streams flow across the Waiau floodplain and into the main channel along this reach of the river, and these have been incorporated into the detailed study area. Focussing the investigation on this area has enabled detailed results to be produced whilst minimising model run times. The computational modelling is described in more detail in Section 3.

2.1.1 Waiau River catchment

The Waiau is a large alpine river with a total catchment area of over 3300 km^2. The catchment extends back to the Spenser Mountains which rise to over 2200 m, and form part of the Main Divide to the north of Lewis Pass (Figure 2-2). The upper part of the catchment (from the headwaters through to the Hanmer Plain) is predominantly comprised of steep mountainous conservation land, with native bush and tussock cover below the vegetation line. Substantial tributaries in the upper catchment include the Ada, Henry, Boyle and Hope Rivers. The remainder of the catchment mostly consists of tussock and pasture covered foothills and plains with some areas of native bush and exotic forest. The Waiau is also fed by the Percival and Hanmer Rivers which flow through the Hanmer Plain, and by several smaller streams which drain the southern slopes of the Amuri Range. The Mason River enters the Waiau immediately upstream of Waiau township.

2.1.2 Mason River catchment

The Mason River catchment is a sub-catchment of the Waiau (Figure 2-2 and Figure 2-3), and covers an area of approximately 215 km^2. The Mason River also has a number of tributaries, the most significant of which is the Lottery River. The Lottery is fed from the south-eastern slopes of the Amuri Range, and enters the Mason approximately 6 km upstream of Waiau township. This part of the Amuri Range is relatively steep and rises to over 1700 m, with similar land cover to the upper Waiau catchment. The remainder of the Mason River catchment is primarily comprised of pastoral farmland with some areas of exotic forest.

2.1.3 Other stream catchments

Within the study area, there are several streams that flow into the Waiau River upstream of the Mason confluence. These streams drain the southern slopes of the Amuri Range and have a combined catchment area of approximately 132 km^2. This part of the Amuri Range is less mountainous than that extending into the Mason catchment, rising to just over 1000 m and primarily covered in pasture. For the purposes of this investigation, this area has been split into 6 catchments based on the main watercourses; Blind Stream, Home Stream, Lyndon Stream, Longford Stream, Counting Stream and Dog Brook.

The hillslopes to the north-east of Waiau township also contribute runoff to the Waiau River via the Parnassus Street Drain. This drain has a small catchment area (~3 km^2), but has been included to account for local runoff through the township.

The extents of these catchments are shown in Figure 2-2 and Figure 2-3.

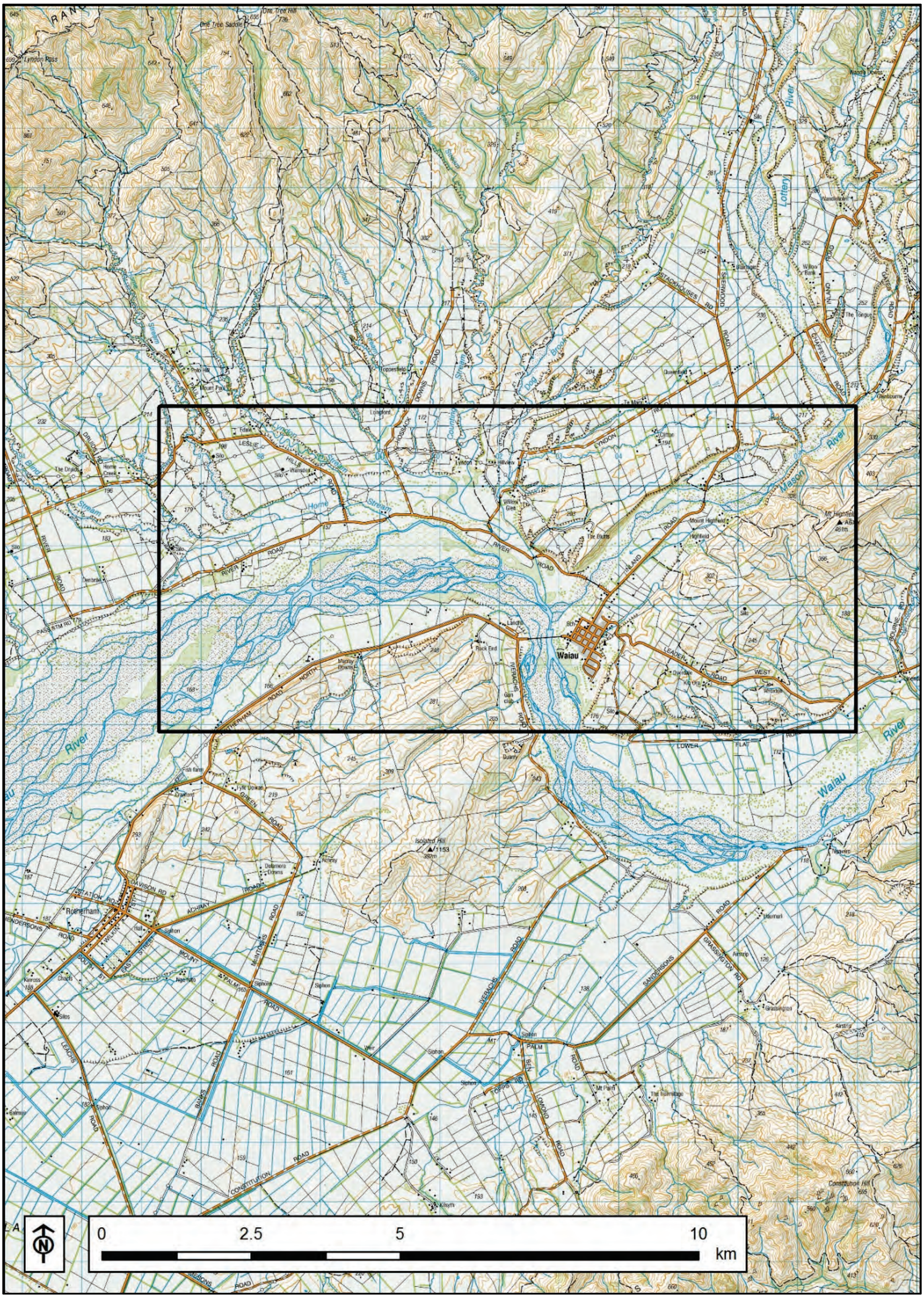


Figure 2-1: Main study area

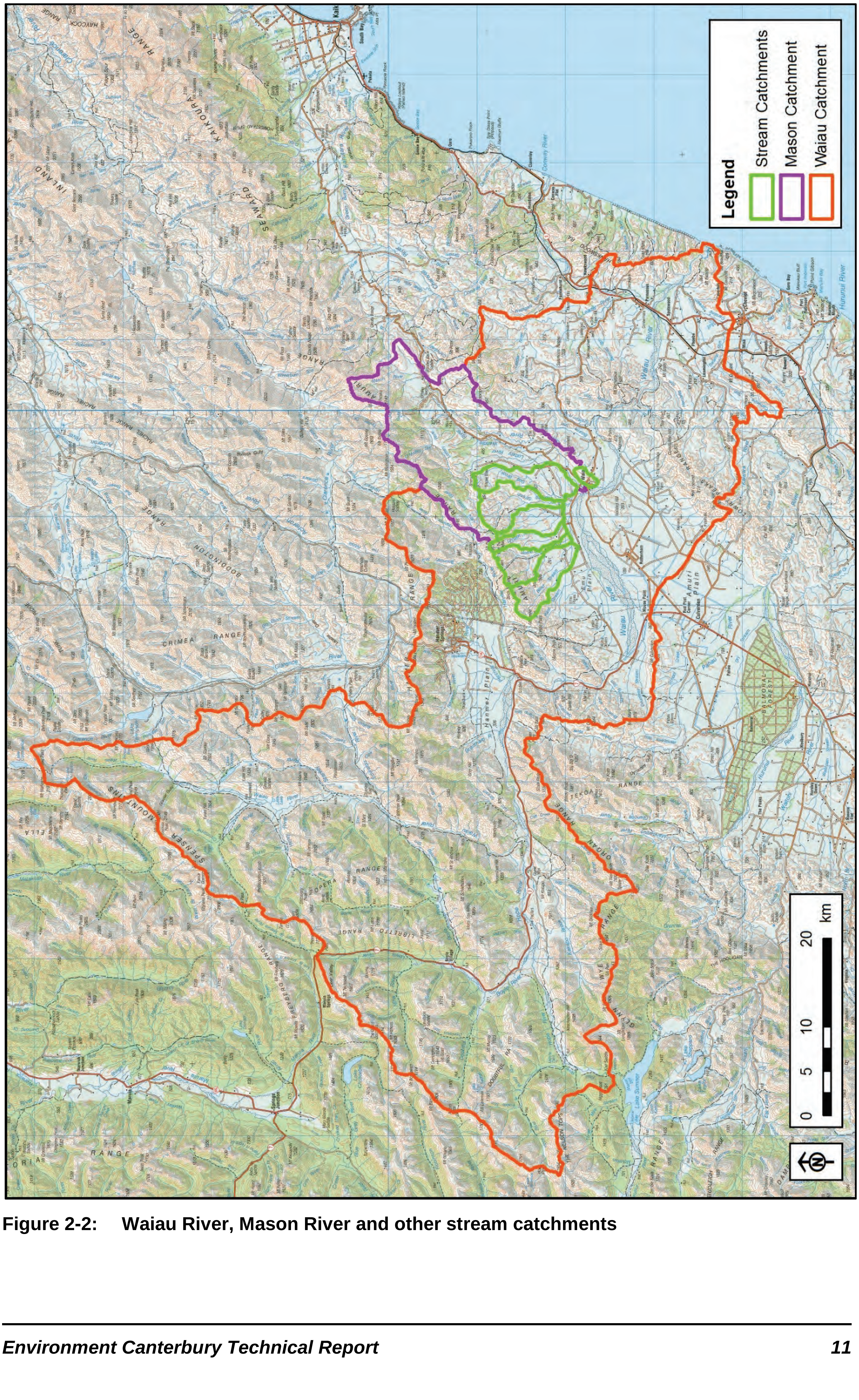


Figure 2-2: Waiau River, Mason River and other stream catchments

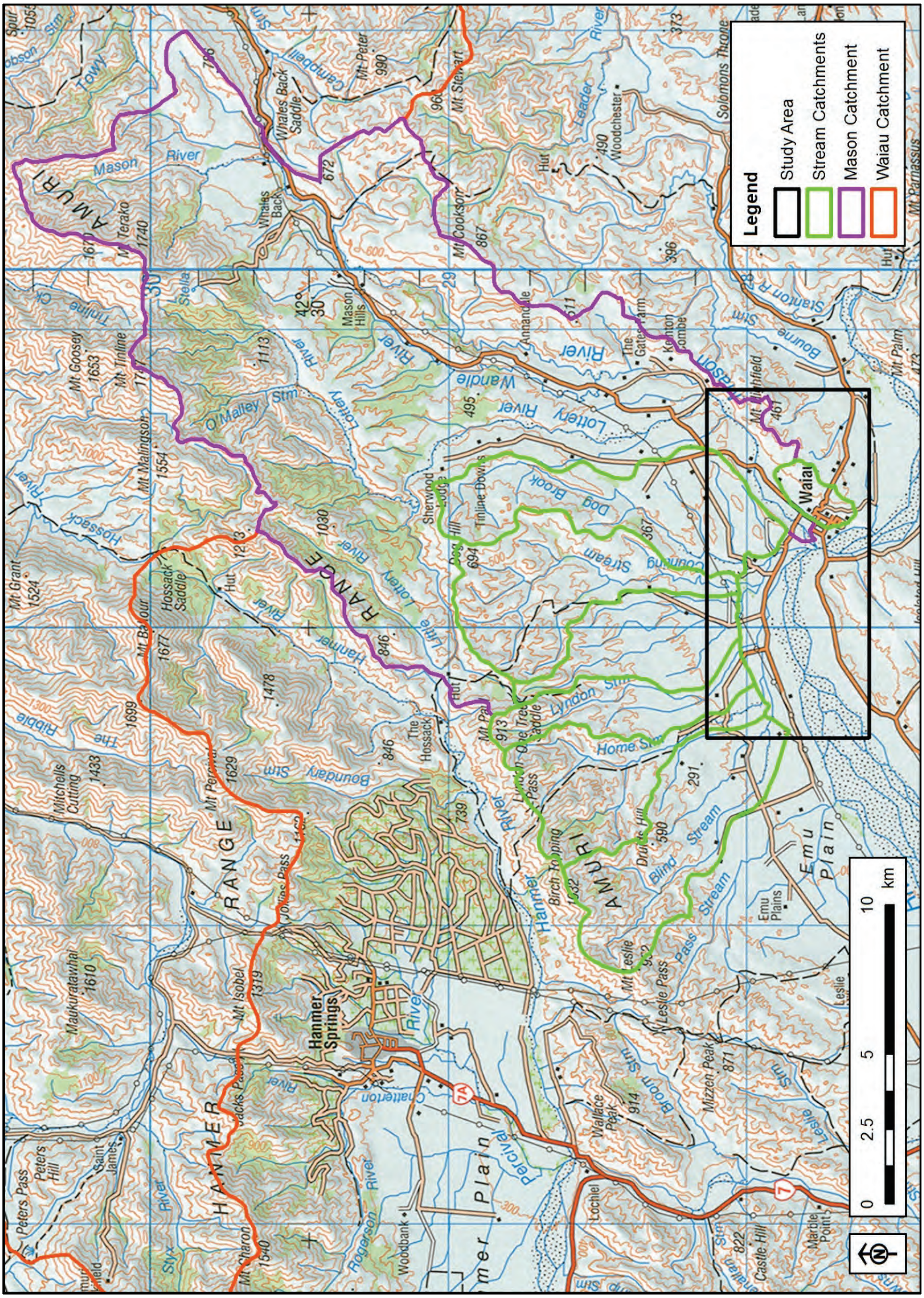


Figure 2-3: **Mason River Catchment and (from west to east) Blind Stream, Home Stream, Lyndon Stream, Longford Stream, Counting Stream, Dog Brook and Parnassus Street Drain Catchments**

2.2 Historic flooding

As with other large alpine fed North Canterbury rivers such as the Rakaia, Waimakariri and Hurunui, high flows in the Waiau River usually occur when north-westerly weather systems bring spill-over rainfall to the upper part of the catchment (e.g. September 1988 and October 2007). These events do not tend to bring substantial rainfall to the Mason River and Waiau tributary stream catchments – unlike northerly, easterly or southerly (or combinations thereof) weather systems which tend to produce the higher rainfalls in the Canterbury foothills. However, even though the Waiau catchment extends back to the Main Divide, it still has a substantial foothills catchment, and is therefore capable of producing reasonably high flows during north-easterly, easterly, south-easterly or southerly events (e.g. May 1923, February 1936, December 1993 and August 2000).

Available information on notable flood events in the Waiau and Mason Rivers is summarised below. Note that measuring flood flows is a difficult process, and therefore the flows quoted below (especially from older events) may not be accurate. As there is limited information on flood flows for the Mason River, rainfall data for the Mason flood events are also summarised in Section 2.3.

2.2.1 May 1923

A south-west storm led to high flows in the Waiau and Mason Rivers, and the Mason overflowed upstream of Waiau township. On the 8th, The Press reported:

'*No longer could the meeting line of the streams of the Waiau and Mason be distinguished, the two combining to form a rushing, boiling, turbid stream a mile or so in width*' and that '*The Mason had overflowed at a point above the township, and a stream of considerable dimensions was rushing through meadow lands and along a road between the river and the township. As the flood waters continued to rise this stream crossed the road between the north end of the bridge and Mr Roger's store* (located at the corner of Leslie and Lowry Streets). *On the other side of the township at the foot of the terrace was a rushing torrent, which spread out and completely inundated the tennis courts and the flat land in the vicinity. At the entrance to the Highfield Estate the water was rushing through the gateway and reaching up to the second bar of the gate. Between there and the Mason bridge the road was impassable except for anyone on horseback. The residents on the flat below the township who had been surrounded by water all day, were last evening removed to the township*'.

On the 9th, The Press reported that:

'*The Waiau and Mason rivers were still seething torrents, and the greater volume of the Waiau had forced the waters of the Mason over against the north end of the bridge. A further rise of a few inches in the Waiau would have forced its tributary to break through between the bridge and the township*'.

The rainfalls recorded in the Mason catchment during this event were extremely high, and are discussed in more detail in Section 2.3.

2.2.2 February 1936

A south-west rainstorm affected much of Canterbury. The railway line between Waiau and Rotherham was washed out and the approach to the Home Creek Bridge was washed away (The Press). The Press also reported on the 21st that '*the Waiau and Mason Rivers were running bank high yesterday afternoon and many creeks were overflowing. Houses on the flat below the township were flooded by the overflowing of a stream*'.

2.2.3 July 1963

North Canterbury was affected by an easterly storm:

'*At Waiau township the Mason River threatened to overflow its banks and flood the township. But county workmen built a stopbank and prevented really severe flooding*' (The Press).

2.2.4 June 1982

'*Water overtopped the bank at the lower Mason Bridge on Inland Road and flowed through farmland and down the State Highway towards the township of Waiau*'. The flow in the Mason River was assessed at the time to be an approximately 5 year return period event, and was characterised by a 'lengthy' peak duration (Blackmore, 1984). A peak flow of 602 m^3/s was recorded in the Waiau River at Marble Point.

2.2.5 November 1984

A peak flow of 1503 m^3/s was recorded in the Waiau River at Marble Point, which resulted in flooding around the Lyndon area (Engineering Lifelines, 2000).

2.2.6 May 1988

A peak flow of 1650 m^3/s was recorded in the Waiau River at Marble Point, which is the highest recorded flow since records began in 1967.

2.2.7 September 1988

A peak flow of 1460 m^3/s was recorded in the Waiau River at Marble Point during a north-west rainfall event. Figure 2-4 shows substantial overflows from the Waiau River adjacent to River Road. The Mason River appears to be carrying only a relatively normal flow, which is consistent with the rainfall data provided in Table 2-1.

2.2.8 December 1993

A peak flow of 1312 m^3/s was recorded in the Waiau River at Marble Point during an easterly storm event. Substantial rainfall was also recorded in the Mason River catchment (see Section 2.3). Figure 2-5 shows the Mason and Waiau Rivers at approximately 1:30 p.m. on the 24th of December. This is approximately 15 hours after the Waiau River peak flow passed this area.

2.2.9 August 2000

An easterly rainstorm led to flooding across much of Canterbury:

'*The Mason River threatened to break out at Waiau, with some overflow from close to the Lower Mason Bridge*' (Engineering Lifelines, 2000).

2.2.10 October 2007

A peak flow of 1112 m^3/s was recorded in the Waiau River at Marble Point during a north-west rainfall event. The river overflowed its north bank upstream of the Mason confluence, adjacent to River Road. One dwelling was temporarily evacuated as a precautionary measure (Environment Canterbury media release). Figure 2-6 shows the breakout location several hours after the breach occurred.

2.2.11 July 2008

On 31 July 2008 the east coast of the South Island – and in particular North Canterbury – experienced a large rainfall event. The Mason River (at the recorder site downstream of the Lottery River confluence) recorded the highest water level in the relatively short record available. The flow is estimated to have been approximately 320 m^3/s. The maximum flow recorded in the Waiau River during this event was 560 m^3/s.

Figure 2-4: Waiau River looking downstream toward Waiau township with the Mason River to the left of the frame. Photo was taken on 13 September 1988 at ~5:10 pm (Waiau River is estimated to have peaked at this location at ~8 pm on 13 September 1988)

Figure 2-5: Mason River looking downstream toward the Waiau River confluence and the Waiau township (left of frame). Photo was taken on 24 December 1993 at ~1:30 pm (Waiau River is estimated to have peaked at this location at ~10:30 pm on 23 December 1993)

Figure 2-6: Looking west along River Road to the breakout from the Waiau River. Photo was taken on 9 October 2007 at ~10:30 am (Waiau River is estimated to have peaked at this location on 8 October 2007 at ~8 pm)

2.3 Historic rainfall

The National Institute of Water and Atmospheric Research (NIWA) operate, or have operated, several rain gauges in the Mason River catchment. The location of these gauges and their periods of operation are shown in Figure 2-7. The available rainfall data for the Mason River flood events referred to in Section 2.2 is presented in Table 2-1.

Rainfall frequency data is also provided for each gauge location in Table 2-2. This data has been obtained from NIWA's High Intensity Rainfall Design System – Version 3 (HIRDS), a web-based programme that can estimate the frequency of rainfall events at any point in New Zealand up to a 100 year ARI. This provides some quantification of the scale of each event in the absence of any flow data for the Mason River.

Of particular note is the extreme rainfall recorded during the May 1923 flood event, which is more than double that recorded during any of the other events, and that estimated by HIRDS to be a 100 year ARI event. Extrapolating the data from HIRDS indicates that the 48 and 72 hour rainfall recorded at Keinton Combe in May 1923 would have an ARI of at least 3,000 years.

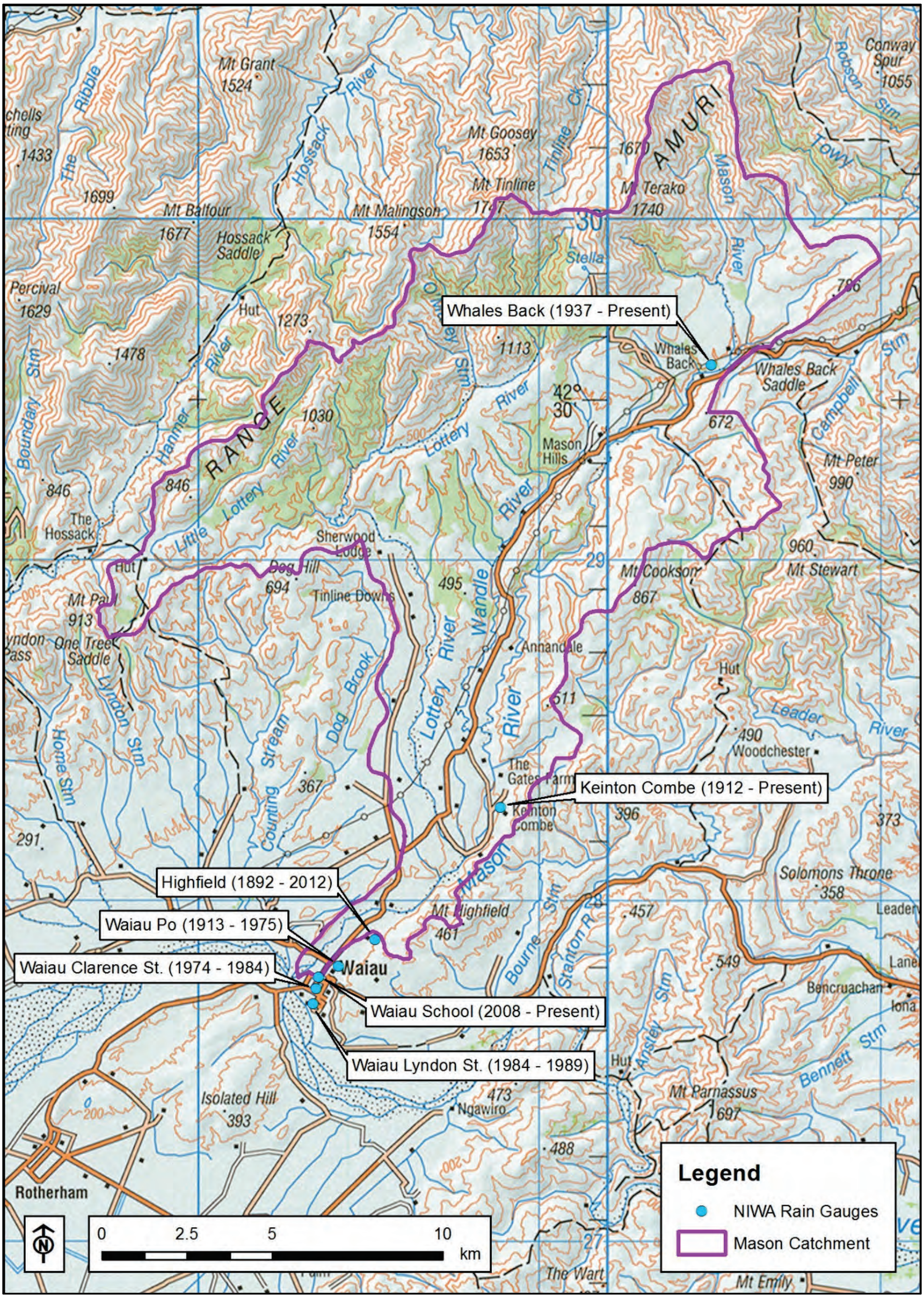


Figure 2-7: NIWA rain gauge locations and periods of operation

Table 2-1: Mason River catchment rainfall during significant historic flood events

Event	Gauge	24 Hour	48 Hour	72 Hour	Total for Event
May 1923	Keinton Combe	366	624	682	769
	Highfield	243	440	498	570
	Waiau (Po)	241	406	450	510
February 1936	Keinton Combe	177	202	215	218
	Highfield	129	250	262	262
	Waiau (Po)	129	212	223	225
July 1963	Whales Back	115	208	240	326
	Keinton Combe	115	167	218	273
	Highfield	83	123	159	201
	Waiau (Po)	93	132	160	207
June 1982	Whales Back	115	202	204	204
	Keinton Combe	79	113	119	119
	Highfield	59	76	77	77
	Waiau (Clarence St.)	52	65	72	74
December 1993	Whales Back	178	233	253	253
	Keinton Combe	116	160	163	192
	Highfield	99	99	120	120
August 2000	Whales Back	115	207	207	207
	Keinton Combe	87	134	135	135
	Highfield	68	105	111	111
July 2008	Whales Back	111	176	206	206
	Keinton Combe	135	167	189	189
	Highfield	129	143	156	156

Table 2-2: Rainfall frequency data for rain gauges in the Mason River catchment (NIWA-HIRDS version 3)

Gauge	ARI (Years)	24 Hour	48 Hour	72 Hour
Whales Back	5	109	136	154
	10	129	161	182
	20	152	189	214
	50	187	232	264
	100	219	272	308
Keinton Combe	5	96	111	122
	10	116	135	147
	20	139	161	176
	50	175	204	223
	100	209	243	266
Highfield	5	90	105	115
	10	109	127	138
	20	130	151	165
	50	163	190	208
	100	194	226	247
Waiau	5	86	101	110
	10	103	121	132
	20	123	143	157
	50	153	179	196
	100	181	212	232

2.4 Flood protection works

The first 'Waiau Township River District' was established in 1906 and acted as an active rating body until 1922 when the Rating District was abandoned. It is understood that much of the work done over this period was in the Mason River, and included gabion groynes, planting and stopbanking. From 1922, flooding and erosion problems from the Mason River were addressed in an 'ad hoc' way by roading authorities and adjoining landowners. In more recent times, flooding and erosion from the Waiau and lower Mason Rivers have been addressed as required by local residents, with advice from the North Canterbury Catchment Board and the Canterbury Regional Council (Environment Canterbury) (Environment Canterbury - Asset Management Plan).

A proposal to establish a River Rating District over approximately 6 km of the Waiau River and 3 km of the Mason River upstream of Waiau township was prepared in the mid-1990s, however, the proposal did not attract the necessary support. The proposal was revisited in 2004 and the Waiau Township Rating District was established by Environment Canterbury. The Rating District objectives are to mitigate against flooding and erosion of adjoining assets by providing: a clear river fairway with appropriate braid alignments to maximise flood capacity and minimise bank erosion, and a continuous and strongly vegetated buffer flanking the fairway. Further details on the background and objectives of the rating district are available in the Asset Management Plan. The geographical extent of the rating district is shown in Figure 2-8.

Stopbanking exists at various locations within the study area of this investigation. Key areas of banking include:

- The short length (approximately 300 m) along the left bank of the Mason, immediately upstream of the Lower Mason Bridge on Inland Road.
- The stopbank adjacent to River Road (beginning at the intersection of Hossack Downs Road) which then follows the left bank of the Waiau toward the Mason confluence.
- Various lengths of banking along the left bank of the Mason, between the River Road Bridge and the Waiau confluence.

The location of these banks is shown in Figure 2-9.

Three options for the design of the stopbank immediately upstream of the Lower Mason Bridge were presented in a letter from the Ministry of Works and Development to the Amuri County Council (Blackmore, 1984). The options afforded various standards of flood protection, ranging from a 20 year ARI design standard with no freeboard to a 100 year ARI design standard with 0.5 m freeboard, however it is not clear which of these designs the stopbank was built to. The designs were based on a 20 year ARI flow of 500 m^3/s and a 100 year ARI flow of 800 m^3/s, which are notably higher than the flows calculated for this investigation. The flood hydrology is discussed further in Section 3.1.

The lengths of stopbanking along the left bank of the Waiau River adjacent to River Road, and along the lower reach of the Mason River, have been constructed in a more 'ad hoc' fashion over the years in reaction to past flood events, rather than being designed and constructed to contain floods of a particular size.

2.5 Climate change

The impacts of future climate change on the Waiau River catchment are complex and, at present, not fully known. Some of the likely changes that are relevant to this flood modelling study include:

<u>Air temperature</u>
It is widely accepted that in the 100 years from 1990 (1980-1999) to 2090 (2080-2099) the mean annual air temperature in Canterbury is likely to increase by ~2ºC (Mullan *et al.,* 2008).

Rainfall

In general, rainfall varies more significantly spatially and temporally than temperature. For the Canterbury region average annual rainfall is expected to increase in the west (i.e. in the alpine areas), by up to 10% between 1990 and 2090, while in the east and north it is expected to decrease by over 5% in places during the same time period (Renwick *et al.,* 2010).

However, rising air temperatures are also likely to produce an increase in the intensity of extreme rainfalls since warmer air contains ~8% more moisture for each 1ºC increase in temperature (Mullan *et al.,* 2008). Mullan *et al.* (2008, Table 1, p 9) states with 'moderate confidence' that the magnitude of change in extreme rainfall in New Zealand is likely to be within the range of 'no change through to halving of heavy rainfall return period by 2040; no change through to fourfold reduction in return period by 2090' – with areas where average annual rainfall is predicted to increase being more susceptible to increases in rainfall intensity ((Mullan *et al.,* 2008). Based on HIRDS version 3, an increase in extreme rainfall intensity of 16% (in 100 years, 1990-2090) in the Waiau and Mason catchments would be consistent with approximately doubling the frequency of the rainfall event. This means that by 2090 a 100 year flood event may potentially become a 50 year flood event.

Sea level

As this river system has a relatively steep gradient, any predicted increases in sea level will not have any impact on river water levels in this study area.

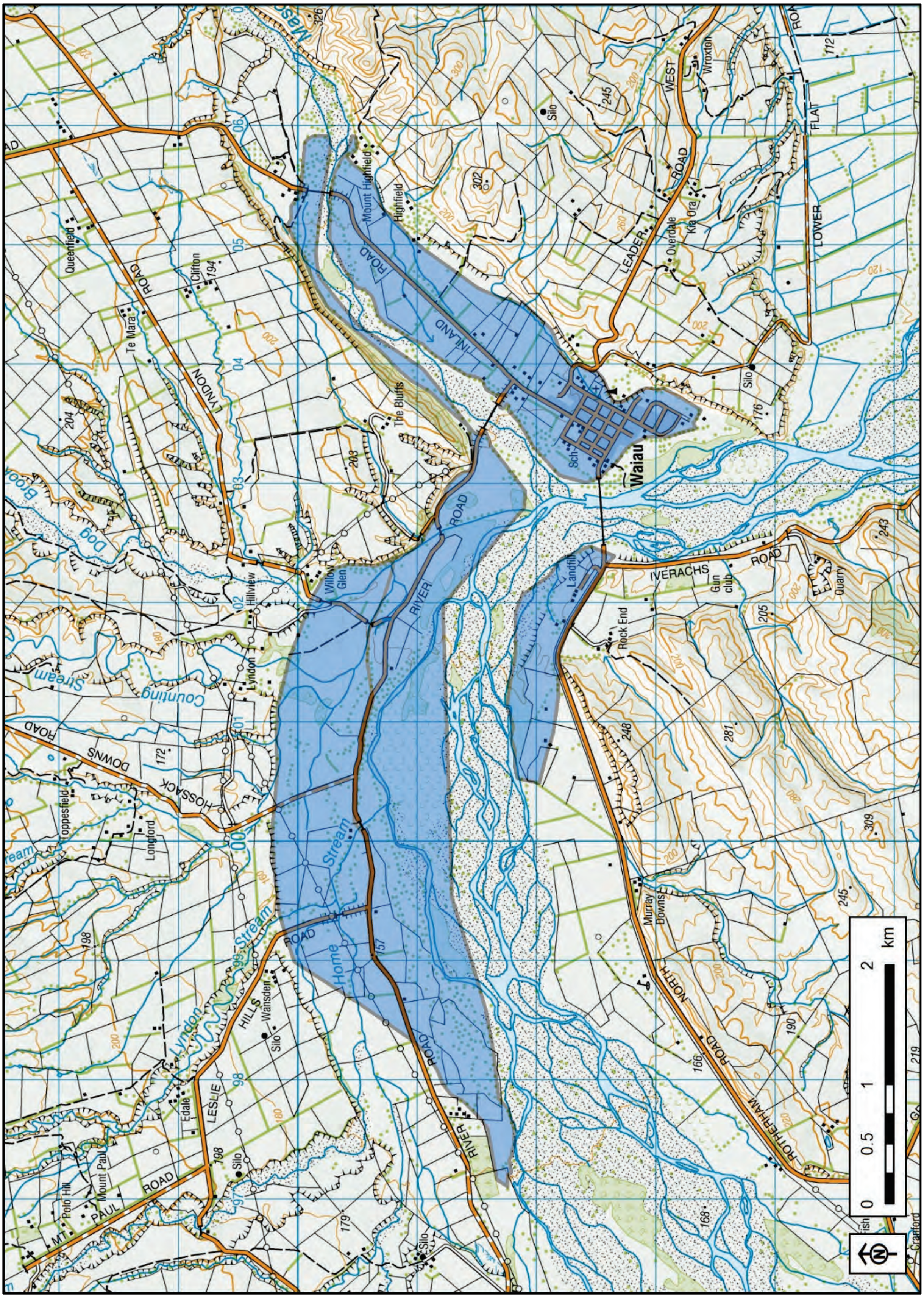


Figure 2-8: Waiau Township Rating District area

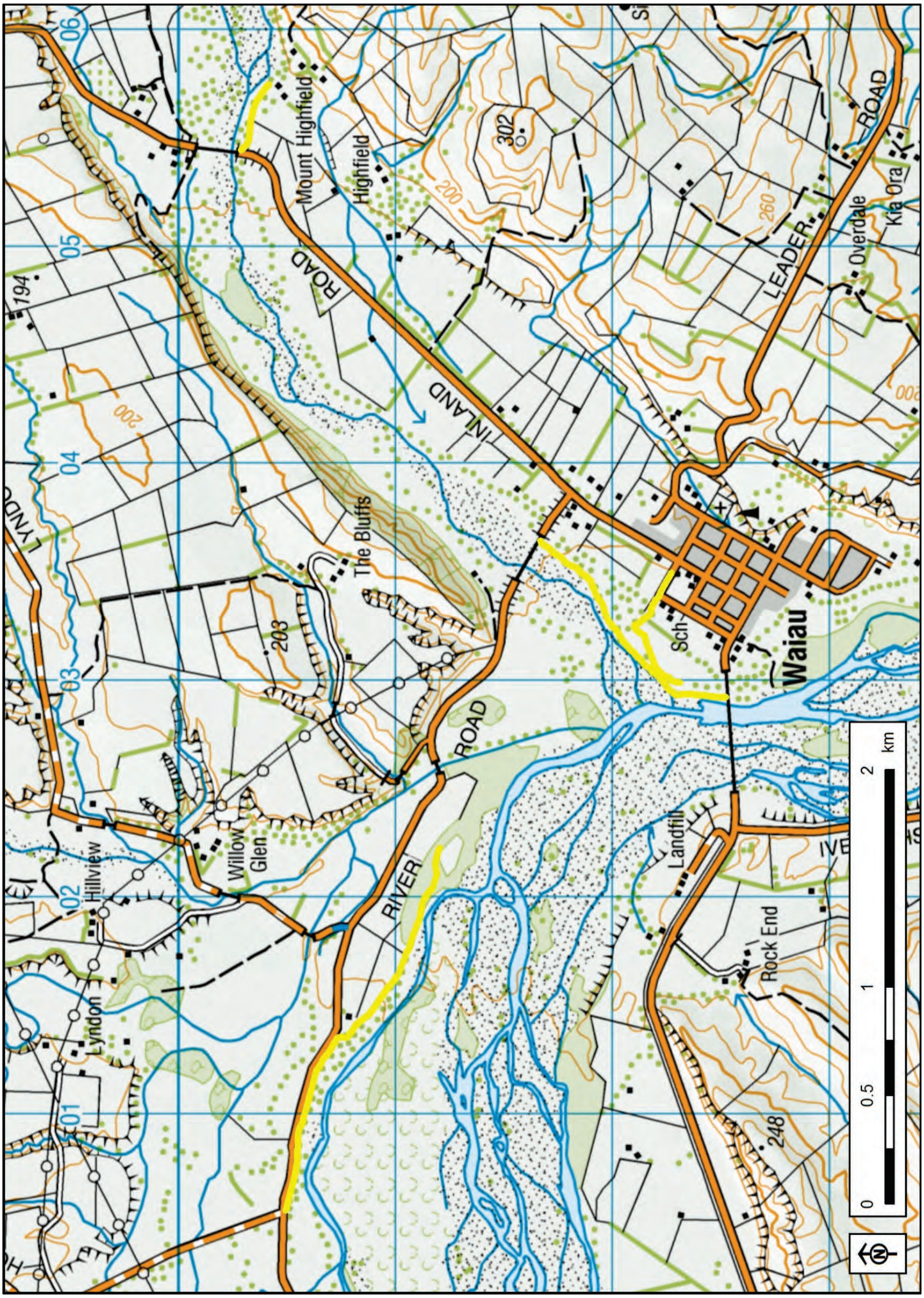


Figure 2-9: Main stopbanks in the study area

3 Methodology

Floodplain flows are often difficult to predict due to the multi-directional nature of the flows, the interaction between main river channel flows passing out of and then returning to the river, and also the difficulty in identifying flow paths where ground levels vary more gradually.

This floodplain investigation used a combined one-dimensional/two-dimensional hydrodynamic computer model (Mike Flood) to simulate flood events and determine river and floodplain water levels, floodplain extent, floodplain flow patterns and flow velocities. The methodology included:

- Compilation of historical flood event information (Section 2.2 and Section 2.3)
- Estimation of flood hydrology/design flows (Section 3.1)
- Construction of a computational hydraulic model (Section 3.2)
- Calibration of the hydraulic model (Section 3.3)
- Modelling of design flood events using the calibrated hydraulic model (Section3.4)
- A sensitivity analysis (Section 3.5)

3.1 Flood hydrology

The primary focus of this investigation was to determine the likely extent and depth of flooding in and around Waiau township, for 50, 200 and 500 year ARI flood events. This required 50, 200 and 500 year ARI flood flows to be calculated for both the Waiau and Mason Rivers, and several of the more significant streams in the floodplain area.

Immediately upstream of the hydraulic model inflow locations, for both the Waiau and Mason Rivers, there are permanent water level recorder sites (Figure 3-1). The sites are:

- Waiau River at Marble Point (Site 64602). This recorder has been operating since October 1967. The highest gauged flow was 1112 m^3/s on 3 June 1976.
- Mason River at downstream of Lottery River confluence (Site 64622). This recorder has been operating since April 2008 with flows available from November 2008. The highest gauged flow was 11 m^3/s on 9 June 2010.

These sites provide some of the information for estimating 50, 200 and 500 year ARI flood flows for the Waiau and Mason Rivers, as well as other streams. For flood events prior to the installation of continuous water level/flow recorders, the methodology used to estimate flows within the rivers was generally less reliable. Even when there are good water level records available, the ratings (i.e. conversion of water level to flow) may contain considerable uncertainty, especially when only low flows have been measured. Several assumptions are also required when determining the probability distribution that best defines large flood events. Overall, there is a considerable degree of uncertainty when determining the magnitude of large design flood events. The derivation of the design flows used in this study is given below.

3.1.1 Waiau River flows

The upstream limit of the model of the Waiau River is located 2.7 km downstream of the permanent recorder site (i.e. Site 64602, Waiau River at Marble Point). As the river reach between the two locations is a confined gorge, with relatively small inflows from tributaries, the recorder flows have been used to determine the calibration and design flows for the Waiau River.

The historic flow record can be analysed using various statistical methods in order to estimate peak flows for given average recurrence interval (or annual exceedance probability) events. For this investigation we used the Gringorten plotting position (α=0.44) to plot the Marble Point 1968 to 2013 annual maximum flow series. The GEV distribution was fitted to the annual series (Figure 3-2) and the design flows were estimated using the GEV distribution (Table 3-1).

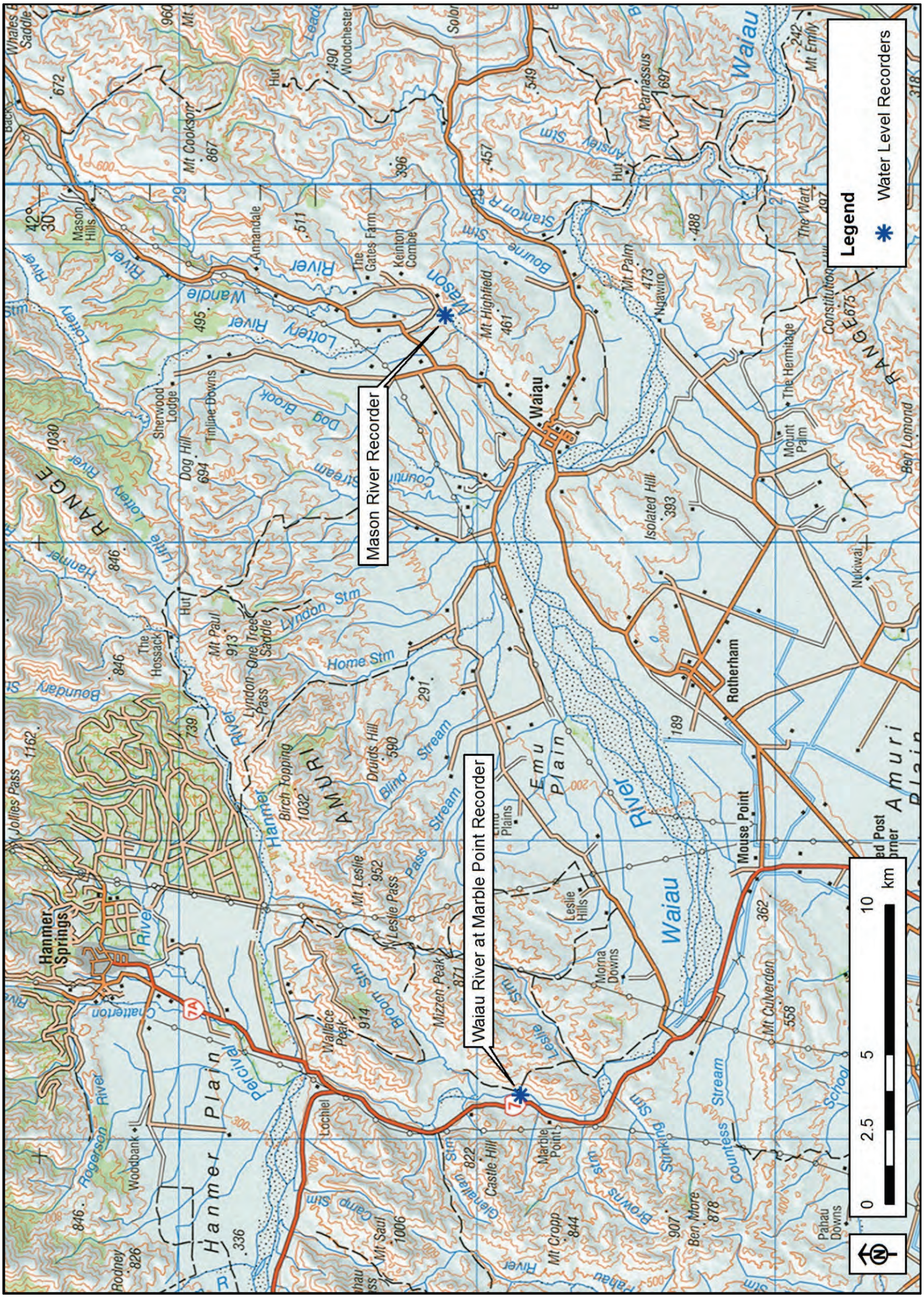


Figure 3-1: Waiau and Mason River water level recorder sites

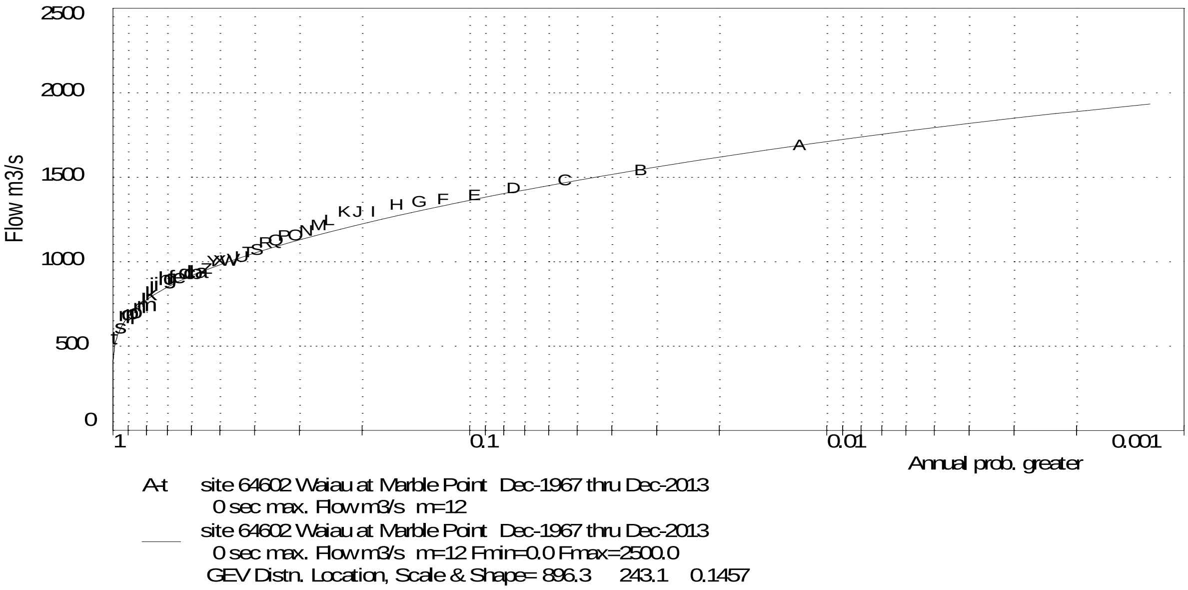


Figure 3-2: Annual exceedence probability (AEP) for Waiau River at Marble Point with GEV distribution

Griffiths *et al.* (2011) also provides a methodology to enable design flood peak estimates to be calculated specifically for the Canterbury region. This regional flood estimation study updates the previous work of McKerchar and Pearson (1989). Estimated design flood flows are shown on Figure 3-3, along with dashed lines representing the standard error for the calculated peak flows. These estimated peak flows, calculated for the Waiau River at Marble Point recorder site (1980 km^2 catchment area), are 'pooled' design flows based on a combination of (1) flows derived assuming no at-site data and (2) flows derived from an at-site flood frequency analysis. The mean annual flood and design flows derived assuming no at-site data are based on:

$$Mean\ annual\ flood\ (MAF)\ factor \quad \frac{Q_{MAF}}{A^{0.866}} = 1.4$$

$$Flood\ frequency\ factor \quad q_{100} = \frac{Q_{100}}{Q_{MAF}} = 1.9$$

The Waiau River design peak flood flows derived using this methodology are shown in Table 3-1 and on Figure 3-3. Although the GEV distribution fits the annual maximum flow series well, there are relatively few gaugings at high flows, and the flow record covers a time period considerably less than 500 years. This means there is a high level of uncertainty in the derived design flows for large floods. The higher design flows, derived using the Griffiths *et al.* (2011) method, have therefore been used for the Waiau River.

Table 3-1: Waiau River design flood flows

Event Probability	Peak Flow m^3/s	
	GEV method	**Griffiths *et al.* (2011)**
10 year ARI (0.1 or 10% AEP)	1360	1300
20 year ARI (0.05 or 5% AEP)	1480	1460
50 year ARI (0.02 or 2% AEP)	1600	1700
200 year ARI (0.005 or 5% AEP)	1800	2000
500 year ARI (0.002 or 0.2% AEP)	1900	2300

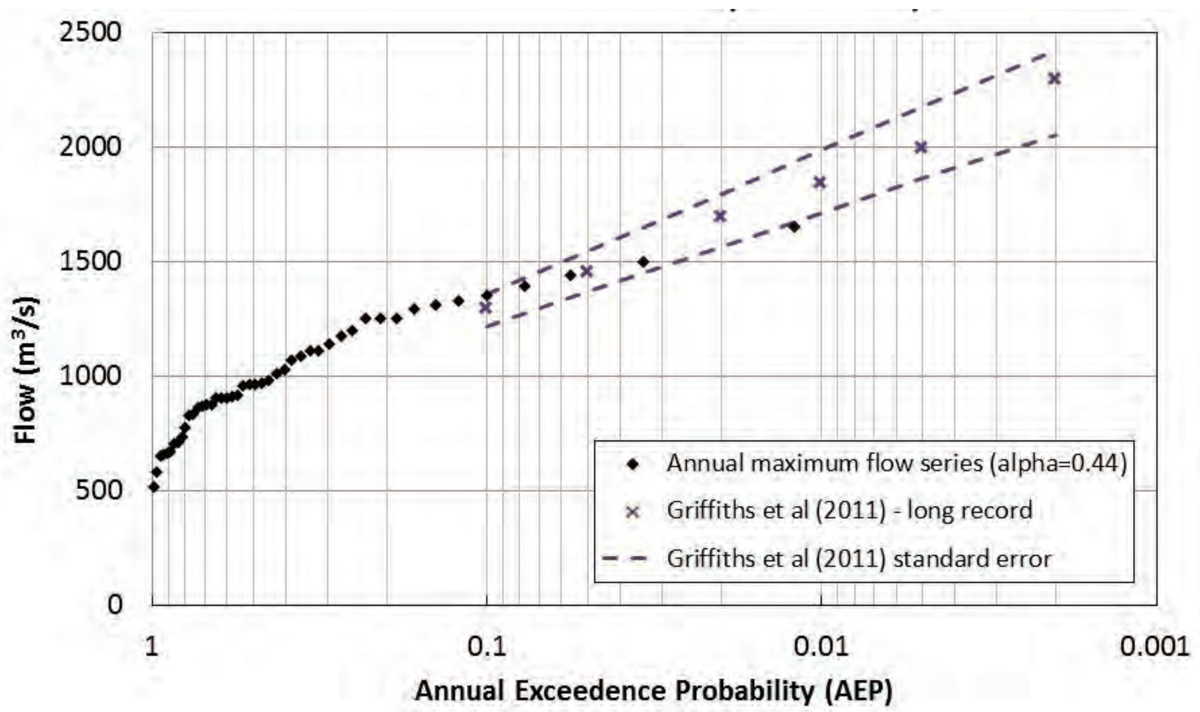


Figure 3-3: Annual exceedence probability (AEP) for Waiau River at Marble Point with design flows derived using Griffiths *et al.* (2011)

3.1.2 Mason River flows

The upstream limit of the model of the Mason River is located 0.7 km downstream of the permanent recorder site (i.e. Site 64622, Mason River at downstream Lottery River confluence). As the river reach between the two locations is relatively confined, with only small inflows from tributaries, the recorder flows have been used to determine the calibration and design flows for the Mason River.

Using the Gringorten plotting position (α=0.44), the Mason River November 2008 to October 2014 annual maximum flow series was generated (Figure 3-4). An additional maximum annual flow of 320 m^3/s was also added to the time series as a 'best estimate' of the flow for the highest recorded water level of 2482 mm measured on 31 July 2008. The earliest rating for the site (4 November 2008) was used to convert this water level to a flow.

Unfortunately this flow site only has approximately 7 years of water level data, with flows only gauged up to a maximum of 11 m^3/s. It is, therefore, not possible to confidently extrapolate to a 50, 200 or 500 year ARI flood event using this data alone.

However, as with the Waiau River, Griffiths *et al.* (2011) provides a methodology to enable design flood peak estimates to be calculated for the Mason River. The mean annual flood and design flow, for each tributary contributing to the Mason River, was therefore derived assuming no 'at-site' data and the following factors:

$$Mean\ annual\ flood\ (MAF)\ factor \quad \frac{Q_{MAF}}{A^{0.866}} = 1.3$$

$$Flood\ frequency\ factor \quad q_{100} = \frac{Q_{100}}{Q_{MAF}} = 3.3$$

To determine the overall Mason River design flows at the upstream limit of the hydraulic model, the tributary design flows were added together (Table 3-2). This is based on the assumption that, during a large flood event with widespread high intensity rainfall occurring over a relatively long time period, the Lottery, Mason and Wandle rivers would all peak simultaneously at the upstream limit of the model. The derived design flows are also shown on Figure 3-4, with dashed lines representing the standard error for the peak flows.

Table 3-2: Mason River design flood flows derived using Griffiths *et al.* (2011)

Water course	Mason River below Lottery River confluence ($215\ km^2$)	Mason River tributaries		
		Mason River ($79\ km^2$)	Lottery River ($103\ km^2$)	Wandle River ($33\ km^2$)
Mean Annual Flood (m^3/s)	160	60	70	30
5 yr ARI (m^3/s)	240	90	110	40
10 yr ARI (m^3/s)	310	110	140	50
20 yr ARI (m^3/s)	370	140	170	60
50 yr ARI (m^3/s)	460	170	210	80
100 yr ARI (m^3/s)	520	190	240	90
200 yr ARI (m^3/s)	580	210	270	100
500 yr ARI (m^3/s)	660	240	310	110

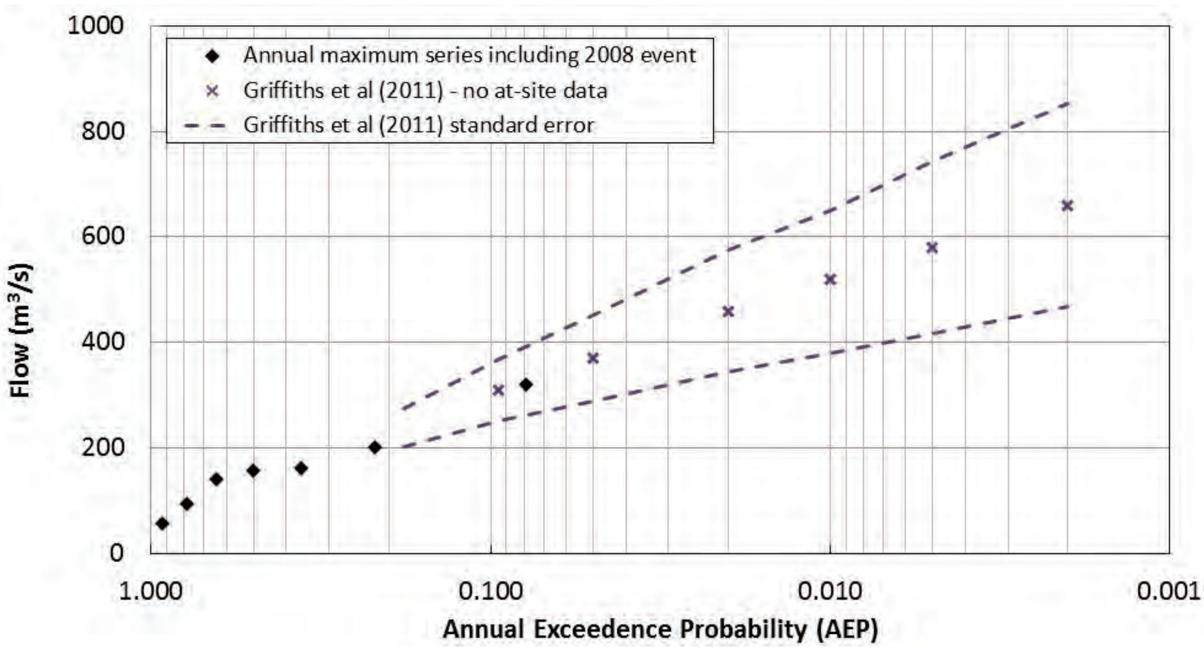


Figure 3-4: Annual exceedence probability (AEP) for Mason River downstream of Lottery River

3.1.3 Other stream flows

Several other streams in the vicinity of Waiau township contribute a substantial volume of water to the Waiau floodplain area. The stream catchments incorporated into the model are shown in green on Figure 2-3.

As no data is available to quantify flood flows from the Waiau tributary streams and Parnassus Street drain, the design flows for each watercourse have been derived using the Griffiths *et al.* (2011) methodology that was used to derive the Mason River peak flows. The mean annual flood and design flows for each stream was derived assuming 'no at-site data' and the following factors:

$$Mean\ annual\ flood\ (MAF)\ factor \quad \frac{Q_{MAF}}{A^{0.866}} = 1.3$$

$$Flood\ frequency\ factor \quad q_{100} = \frac{Q_{100}}{Q_{MAF}} = 3.3$$

The design peak flows for the Waiau tributary streams and Parnassus Street drain are shown in Table 3-3.

Table 3-3: Design flood flows for the Lyndon area streams and Parnassus Street drain

Water course	Area (km^2)	Mean Annual Flood (m^3/s)	Peak Flow m^3/s		
			50 year ARI	200 yr ARI	500 yr ARI
Blind Stream	27.5	23	67	85	97
Home Stream	19.8	17	50	64	73
Lyndon Stream	12.9	12	35	44	50
Longford Stm	16.9	15	44	56	64
Counting Stm	26.5	22	64	82	94
Dog Brook	28.7	24	69	88	100
Parnassus Street Drain	2.1	2.5	7	9	10

3.2 Hydraulic model construction

The Mike Flood (DHI software) modelling package, combining one-dimensional (Mike 11) modelling for the main rivers, with two-dimensional (Mike 21) modelling for the floodplain, was used in this study. The Mike 11 and Mike 21 models were linked along the Waiau River and Mason River in the vicinity of Waiau township to allow flood waters to move between the river channels and the floodplain. This occurs, for example, when a stopbank is overtopped allowing water to flow onto the floodplain. These lateral links are also required where floodplain flows are returned to the main river. A schematic of the model, including lateral links, is shown in Appendix B (Figure B-1). A more detailed description of the model is given below.

3.2.1 One-dimensional river channel model (Mike 11)

The one-dimensional (Mike 11) model of the Waiau River extends from 4.4 km upstream of the Leslie Hills Road bridge to 13 km downstream of Waiau township (Appendix B, Figure B-1 to Figure B-4). The one-dimensional (Mike 11) model of the Mason River extends from 2 km upstream of the Inland Road bridge downstream to the Waiau River confluence (Appendix B, Figure B-1 and Figure B-5).

Flood flow hydrographs are input at the upper limits of the Waiau and Mason Rivers, while the downstream boundary of the Waiau River has a constant water level. The downstream boundary for the Waiau River is located over 11 km downstream of the area of interest and, as the river is a relatively steep watercourse, localised ponding and drawdown of water levels only occurs in the immediate vicinity of this boundary (i.e. no backwater effects occur in the study area).

High resolution topographic data (LiDAR - Light Detection and Ranging) for the study area was obtained on 29 May 2013 using a fixed wing aircraft. At this time the flows in the Waiau and Mason Rivers were approximately 55 m^3/s and 2 m^3/s, respectively. The LiDAR survey does not show the bed levels obscured by this water, however the flows are only around 2 - 3% of the maximum design flows used in the modelling. As these flows are low, most of the riverbed is exposed, and the data can be used to generate cross-sections for the model, with minimal loss of capacity. Waiau River cross sections were extracted with an average spacing of 700 m, and Mason River cross sections were extracted with an average spacing of 200 m. The cross section locations are shown in Appendix B (Figure B-1 to Figure B-5), along with Tables B-1 and B-2, which summarise the cross section information.

The 2013 LiDAR data also covers the full extent of Waiau township and the surrounding floodplain, enabling the data to also be used in the two-dimensional Mike 21 floodplain model. Further information on the accuracy of the LiDAR data is given in Section 3.2.2.

A Mannings ‘n’ number of 0.04 has been used for the open channel bed resistance. Variations in resistance due to vegetation have been accounted for by using relative resistances for each cross-section, based on 2013 aerial photographs. Mannings ‘n’ values of up to 0.12 have been used for heavily vegetated berm areas (Table 3-4).

Table 3-4: Summary of Mannings ‘n’ values used in the Waiau River Mike 11 model

Vegetation	Relative resistance	Mannings ‘n’
Gravel-bed channel	1.0	0.04
Light scrub	1.5	0.06
Scrub	2.0	0.08
Dense scrub or trees	3.0	0.12

On the Mason River, there are two road bridges within the model extent (Inland Road and River Road). Both of these bridges have been included in the model to take into account head losses due to channel cross-section changes, submerged soffits, and pier losses. Within the model extent for the Waiau River there are also two road bridges (Leslie Hills Road and Waiau township). However, only the bridge at Waiau township has been incorporated into the model as the Leslie Hills Road bridge is near the upper limit of the model and any energy losses due to the bridge would not have an impact on the study area.

3.2.2 Two-dimensional floodplain model (Mike 21)

The two-dimensional (Mike 21) component of the model covers the Waiau River true left bank floodplain in the Lyndon area, and the Mason River floodplain (including the true left bank floodplain which extends downstream to Waiau township and the Waiau River (Appendix B, Figure B-6). The floodplain topography and roughness used in the model are described below.

<u>Floodplain topography</u>

To realistically model floodplain flows with any degree of accuracy, good topographic data (including features such as banks, terraces, overland flow channels, roads and railway embankments) is essential. For the Waiau floodplain this high resolution topographic data was obtained from a LiDAR survey (aerial laser scanning) flown on 29 May 2013 by Aerial Surveys. The detail provided by LiDAR data, including historic flow paths, can be seen in the floodplain image (Appendix C, Figure C-1).

The Aerial Surveys Project summary of the LiDAR data states:

‘*The height accuracy of the ground classified LiDAR points was checked using open land-cover survey check site data collected by C & R Surveyors . This was done by calculating height differences statistics between the checkpoints and a TIN of the LiDAR ground points. The standard deviation statistic is 0.03 m, a RMS of 0.03m and Average of 0.01m for Middle Waiau’*. However, this level of accuracy is likely to decrease where there are rapidly changing levels (e.g. steeply sloping riverbanks). In some areas of the floodplain, dense crop cover has resulted in inaccurate ground levels being recorded by the LiDAR survey. It is also likely that ground levels recorded in some of the heavily vegetated areas of the floodplain may be less accurate.

Water levels and flows on the floodplain are resolved on a rectangular grid. The size of the grid is based on the level of detail required, model stability, and computational efficiency (i.e. computer capacity and speed). For this model, the LiDAR data has been used to generate a grid of 5 x 5 m cells to represent the floodplain topography. A 5 m grid was chosen for this study to allow for a reasonable degree of topographic detail while keeping the model run time to a maximum of 2 days. Unfortunately the 5 m grid does have some limitations pertaining to representation of some features such as smaller drains. Where these drains are not able to be represented it is generally assumed that this is equivalent to the drain being either blocked or at full capacity due to local rainfall runoff, which is usually a reasonable assumption – especially for the larger and less frequent storm events.

As the Waiau and Mason floodplains contain elevated topographic features capable of impeding flows (e.g. roads and stopbanks), the 5 m model grid was modified using ArcGIS software. Modifications included using maximum elevations - rather than average elevations - to represent roads and stopbanks, and manually connecting the lower elevation grid cells (representing some of the more significant smaller waterways, e.g. Parnassus Street Drain) to ensure correct conveyance of flow. Because of the intensive drainage networks on the Waiau floodplain, there are also bridges/culverts at many road crossings. To ensure flood water flows were not incorrectly constricted, 15 culvert structures and a weir were included on the main waterways of the model floodplain. The location of these culverts and the weir are shown in Appendix C (Figure C-2).

Checks were made with the detailed LiDAR data to ensure important topographic features (e.g. banks, terraces, roads and railways) were correctly represented in the 5 m grid, and that historic flow paths were correctly simulated. The grid cells have also been corrected as best as is possible where there are obvious inaccuracies due to crop effects.

Floodplain roughness (surface resistance*)*

Floodplain flows and depths are influenced by the hydraulic resistance of the ground cover and other obstructions, such as buildings and trees on the floodplain. Resistance values (i.e. Manning ‘n’ values) were assigned to the various surfaces of the floodplain by interpretation of aerial photographs and ground survey.

Initial model runs identified areas most likely to flood. Where vegetation was thick, or there were significant restrictions to the flow path (e.g. hedges, houses, etc.), the Manning ‘n’ value was increased to 0.12 to increase the surface resistance. Likewise, where there were smoother surfaces (e.g. roads) the Manning ‘n’ value was decreased to 0.03 to reduce surface resistance. For the rest of the floodplain, Manning ‘n’ was equal to 0.05 (Appendix C, Figure C-3). Typically Manning ‘n’ values vary from 0.02 (roads) to over 0.15 (dense vegetation).

3.3 Model calibration

To provide confidence in the model predictions, it is important to calibrate with historical flood events where possible. Despite limited flow and water level information, the Waiau River Mike Flood model has been partially calibrated using the September 1988 flood event.

As there have been no observed flood events (i.e. no aerial photography or measured flood levels) on the Mason River since the flow recorder was installed in 2008, it has not been possible to calibrate the model for this river reach.

A summary of the September 1988 calibration flood event, and the boundary conditions, is given below.

September 1988 flood event

During this north-west rainfall event, a peak flow of 1460 m^3/s was recorded in the Waiau River at Marble Point on 13 September at 5:30pm. Substantial overflows from the Waiau River occurred adjacent to River Road, while the Mason River appeared to be carrying only a relatively normal flow (Figure 2-4). The Waiau River flow had an average recurrence interval (ARI) of approximately 20 years.

Aerial photographs were taken in the Waiau township area at approximately 5:15 pm (estimated to be approximately 3 hours prior to the flood peak at this location), but no gaugings were undertaken in either river during this event.

As this flood was a relatively recent event, it is assumed that aggradation/degradation within the river system since this time should be relatively minimal, vegetation changes should be limited to the main water course (i.e. main changes are due to avulsion of the active braided channels), and stopbank profiles should be similar.

As there were no significant flow contributions from the Mason River and the nearby Waiau River tributaries observed during this event, it was considered a good flood event to calibrate the Waiau River reach of the model. The Mike Flood model inputs and modelling results for the September 1988 flood event are given below.

Model inputs
For the September 1988 flood event, inflows at the upstream limit of the Waiau River model were assumed to be equal to the recorded Waiau River at Marble Point (Site 64602) flow hydrograph (Figure 3-5). No allowances were made for changes in hydrograph shape or flood water entering or leaving the river system, as no significant inflows were identified between the recorder and the upstream limit of the model.

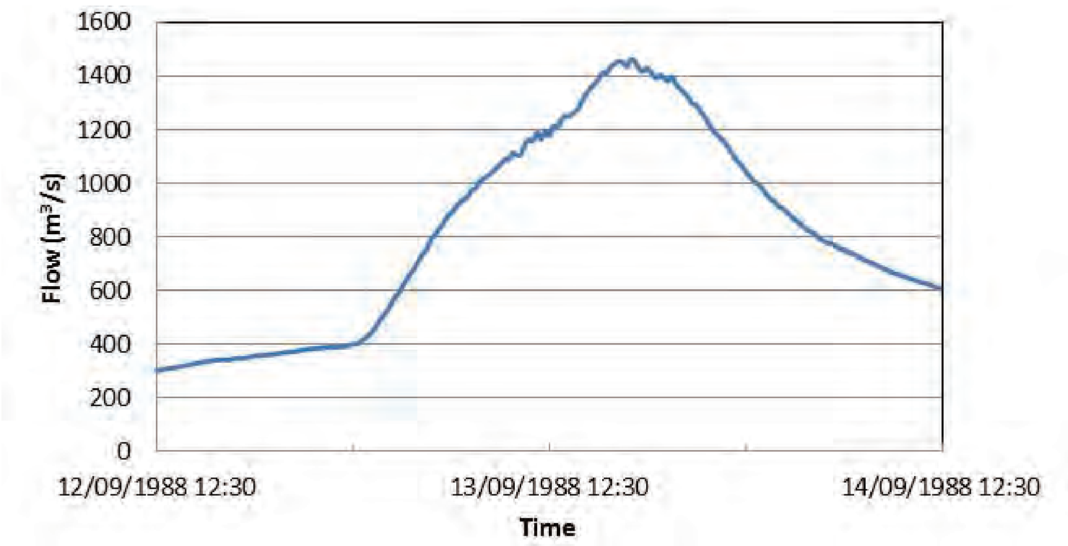
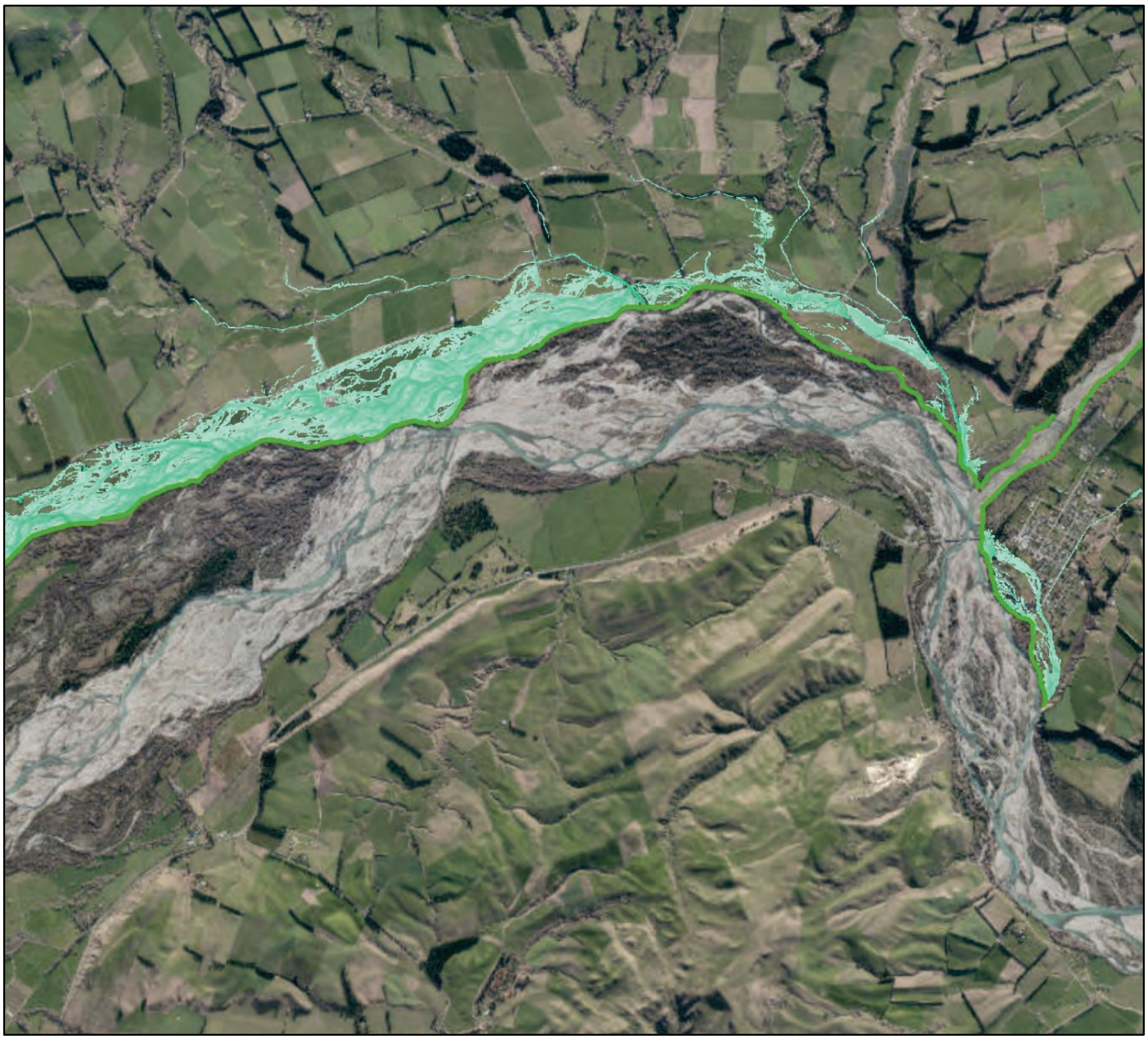


Figure 3-5: September 1988 flow hydrograph for the Waiau River at Marble Point (Site 64602)

As the Mason River and local streams were not observed (e.g. in aerial photography) to be particularly high, the Mason River flow was set to a constant flow of 5 m^3/s and other local inflows to 0.1 to 0.5 m^3/s for the duration of this event. The downstream modelled water level also remained at a constant value of 91 m above mean sea level.

Results
Using the model inputs described above, the Mike Flood model was run for a 2 day time period over the September 1988 flood event (i.e. from 12 September 1988 at 12:30pm until 14 September 1988 at 12:30pm).

Unfortunately, only limited information on observed flooding was available for this event. Figure 3-6 shows the modelled water depths and extent of modelled floodplain inundation at 5:15 pm on September 1988 (i.e. at time aerial photographs were taken).



Modelled water depths around Waiau Township

Waiau River between Rotherham and Waiau

Waiau River at Waiau Township

13 September 1988

Figure 3-6: Comparison of Mike 21 model and aerial photographs at approximately 5:15pm on 13 September 1988

Model results show that most of the Waiau River flood flows are contained within the existing river system and adjacent floodplain (i.e. some water does pass over the true left bank and flow onto the floodplain). The model estimates that during the September 1988 flood event approximately 4.5 km^2 of floodplain was inundated.

Summary
Taking into account all of the assumptions and uncertainties, there is good agreement between modelled and observed flooding for the calibration event. However, it should be remembered that the modelling does not include all localised surface runoff and relies on several assumptions regarding the Mason River and other local stream inflows. It has also not been possible to calibrate the model for a Mason River flood event with the currently available flow data and aerial photography.

As the September 1988 event was observed to be contained within the main Waiau River channel and immediately adjacent floodplain areas, it provided a good check of the Mike 11 channel roughness.

Although no floodplain water level elevations were measured during the flood event, the flood photographs were able to provide some information (regarding the location, extent and timing of flooding prior to the peak).

3.4 Modelling of design flood events

50, 200, and 500 year average recurrence interval (ARI) events have been modelled for land use planning and flood mitigation purposes.

The design storm events were simulated over a 2-day period. All model simulations were based on a 1 second time step, to ensure stability, and results were saved every 15 minutes over the full storm event. Computer run times for each simulation were quite long (i.e. up to 2 days).

3.4.1 Waiau River, Mason River and local stream design flow hydrographs

The derivation of the design flow hydrographs used in the computer model is outlined below for the various water courses.

Waiau River
Several of the ‘high flow events’ recorded by the Waiau River (Site 64602) water level/flow recorder were compared by plotting instantaneous flow divided by the peak flow (Figure 3-7). Figure 3-7 shows that, despite some variations in hydrograph shapes, for flows greater than 60% of the maximum flow (i.e. $Q/Q_{peak} > 0.6$), there was generally good agreement – even between the different weather events (i.e. northwest versus southerly/easterly); an exception being the September 1988 flood event which was longer. It was therefore considered appropriate to scale a ‘typical’ flood hydrograph by the design peak flows to produce the design flow hydrographs used in the Mike Flood model.

As the May 1988 flood hydrograph had the highest peak flow (1650 m^3/s), it was scaled by the Waiau River design peak flows to produce the 50, 200, and 500 year ARI flow hydrographs (Figure 3-8).

Mason River
Several of the more recent ‘high flow events’ recorded by the Mason River (Site 64622) water level/flow recorder were compared by plotting instantaneous flow divided by the peak flow (Figure 3-9). Figure 3-9 shows that, despite some variations in hydrograph shapes, there was generally good agreement – even between the different weather events (i.e. northwest versus southerly/easterly events).

As the May 2013 flood hydrograph had the highest peak flow (200 m^3/s), and was similar to the other dimensionless hydrographs, it was scaled to produce the 50, 200, and 500 year average recurrence interval (ARI) flow hydrographs with the previously derived peak flows of 460, 580 and 660 m^3/s, respectively (Figure 3-10).

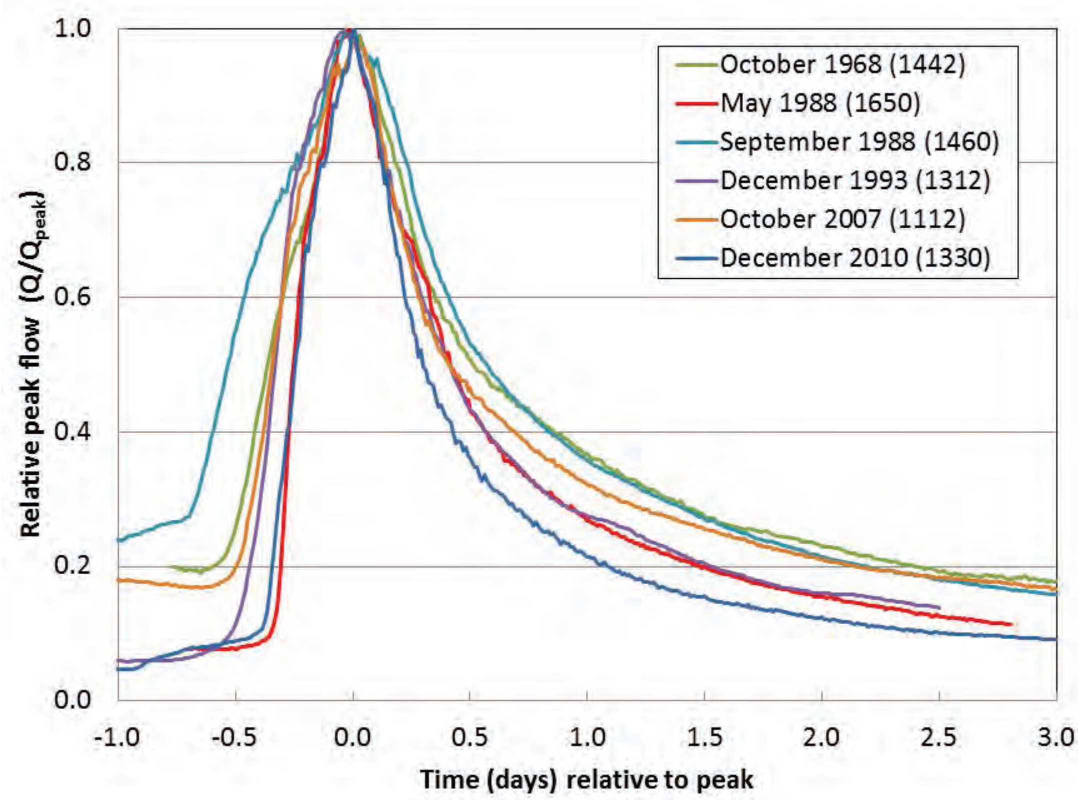


Figure 3-7: Dimensionless hydrographs for various 'high flow events' recorded at Waiau River at Marble Point (Site 64602). Number in brackets is peak flow in m^3/s

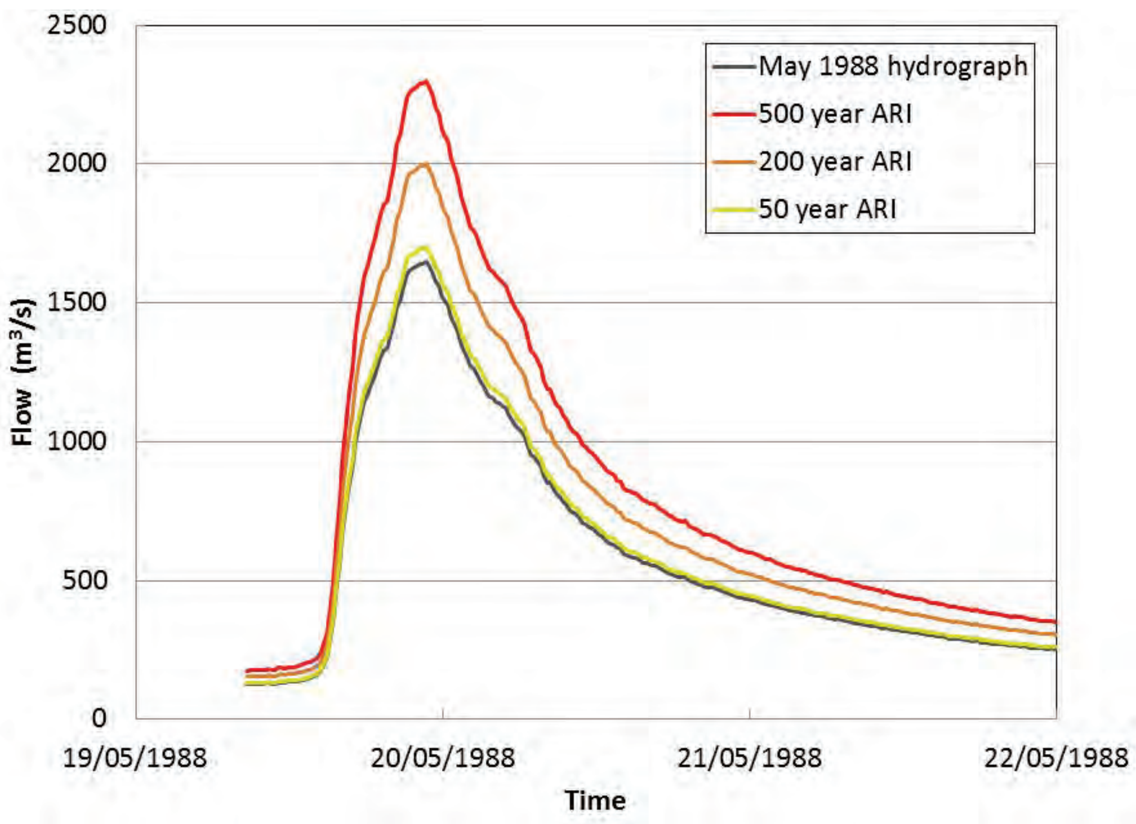


Figure 3-8: Flow hydrographs for the May 1988 flood and the 50, 200 and 500 year ARI design flows entering the Waiau River

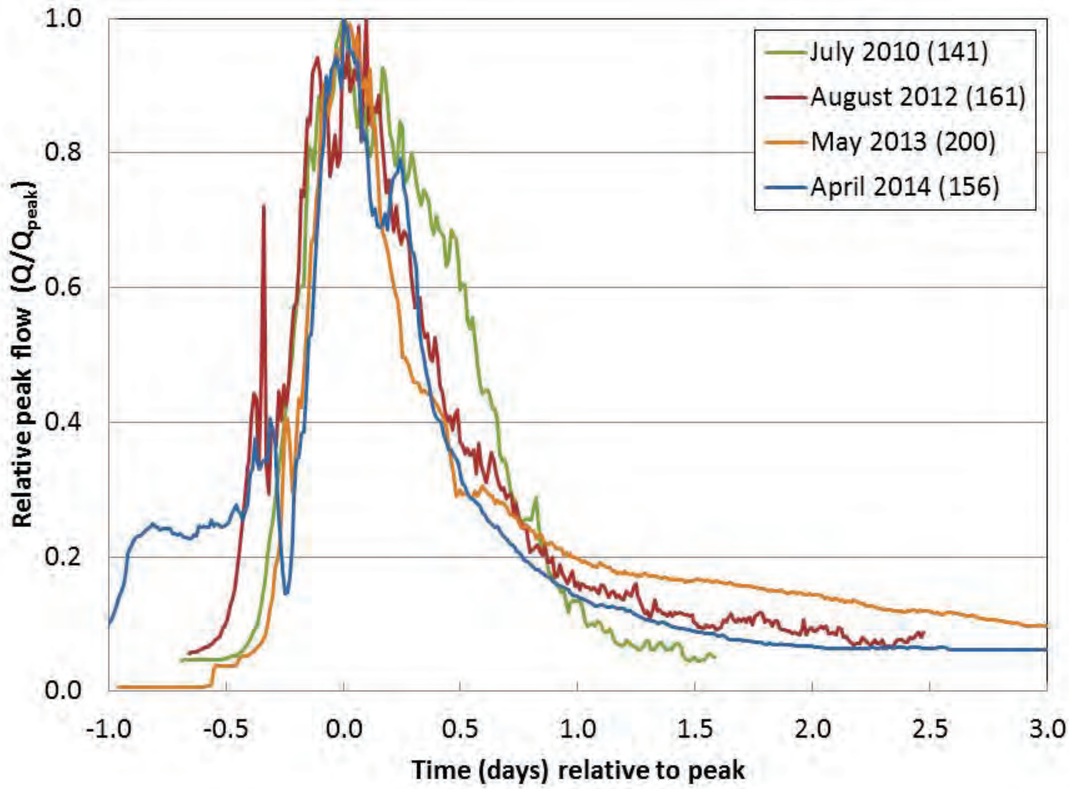


Figure 3-9: Dimensionless hydrographs for various 'high flow events' recorded at Mason River (Site 64622). Number in brackets is peak flow in m^3/s

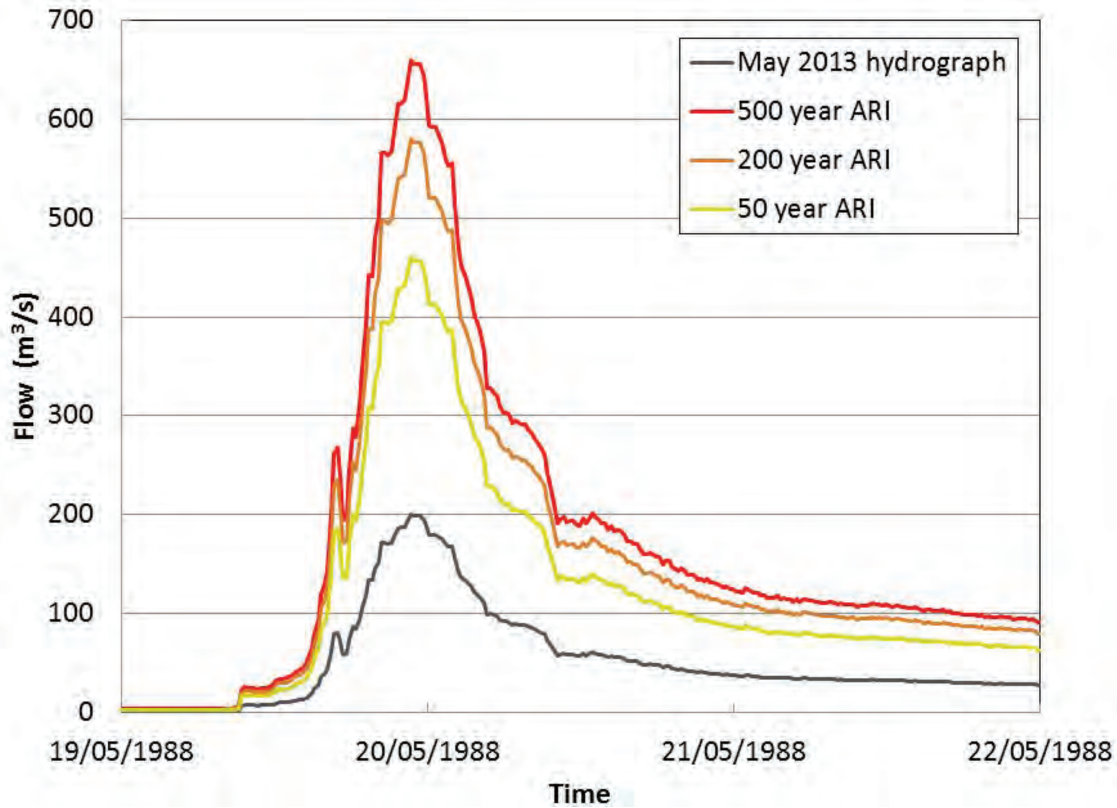


Figure 3-10: Flow hydrographs for the May 2013 flood and the 50, 200 and 500 year ARI design flows entering the Mason River design flood events

<u>Other local stream inflows</u>
For the streams in the Lyndon area, and the Parnassus Street Drain, the May 2013 Mason River hydrograph (Figure 3-10) has been scaled to generate flow hydrographs for the peak flows specified in Table 3-3.

3.4.2 Stopbank breaches during design flood events

When modelling the large design flood events, a judgement must be made as to whether the existing flood protection works are likely to effectively contain the river flows or if they are likely to fail.

Breach flows (also known as stopbank breaches or breakouts) are very difficult to predict, as they result from a complex interaction between water in the river and the bank structure. In Canterbury, most river stopbank breaches are due to overtopping, high lateral flow velocities or large water level differences across the stopbank. When a breach does occur, the downstream flood extent is determined by the rate at which the breach flow is released, the total volume of the breach flow and the topography of the floodplain.

The results from the one-dimensional component of the model suggest that the main stopbanks along the Waiau and Mason Rivers are unlikely to be overtopped during the design flood events, however the risk of these banks failing through lateral erosion is considered to be relatively high.

Historic information suggests that the most likely location for stopbank breaches to occur in the vicinity of Waiau township are:

1. The Mason River true left bank upstream of the Inland Road Bridge
2. The Waiau River true left bank at River Road

These breach locations are shown on Figure 3-11.

Figure 3-11: Stopbank breach locations modelled for the Mason and Waiau Rivers

To enable breach flows to be determined, the 'levee breach' module was used to generate a stopbank breach (defined as a time series of varying stopbank breach profiles). The MikeFlood model was then run, simulating the stopbank breach forming and water flowing out of the river onto the floodplain. Once the model run is complete, the breach flow time series at the breach location can also be extracted.

The unpredictable nature of stopbank breaches has required several estimates and assumptions to be made in deriving these breach flows. These have been based on records and experience of stopbank breaches in similar Canterbury rivers and include:

- Downstream and upstream of the breach location, the existing flood protection works provide adequate protection (i.e. only one breach flow occurs). This assumption is made because a significant proportion of the flood flow leaves the river system.
- The stopbank breach occurs as the peak flood flow in the Mason or Waiau River passes the breach location.
- The main river channel with the fastest flowing water (i.e. thalweg) is assumed to be flowing against the stopbank creating high velocities and lateral erosion. When the breach occurs up to 1 m of scour is assumed at the breach location.
- For the Mason River, it is assumed that a 40 m wide breach will form over 5 minutes in the 200 year and 500 year ARI design events, with the bank assumed to hold in a 50 year ARI design event. For the Waiau River, a 100 m wide breach is assumed to form at River Road over 5 minutes in each of the design events.

The stopbank profiles for the Mason River and Waiau River stopbank breaches are shown in Figure 3-12 and Figure 3-13, respectively.

3.4.3 Combining design flows for the Waiau River, Mason River and Lyndon area streams to produce design flood events

As Waiau township is located at the confluence of the Waiau and Mason Rivers, consideration must be given to the likely combination and timing of peak flows for each river in order to realistically assess the flood risk in this area. As described in Section 2.1, the Waiau River catchment extends back to the Main Divide, whereas the Mason River and Lyndon area streams are primarily fed from the south-eastern slopes of the Amuri Range and lower foothills. Due to their different catchment characteristics, high flows in the Waiau River will not necessarily coincide with high flows in the Mason River or Lyndon area streams, and vice versa. Depending on the type of storm event, flows in the two rivers may also peak at different times.

Design flood scenarios for the Waiau and Mason Rivers

Design flood scenarios have been considered separately for both Waiau River and Mason River 50, 200 and 500 year ARI design flows, to determine which flood event has the greater impact on the Waiau township area. A description of the design flood events modelled is summarised below:

- ***Waiau River design flood events***

  High flows in the Waiau River typically occur when north-westerly weather systems bring spill-over rainfall to the upper part of the catchment. Unfortunately, as the water level recorder on the Mason River has only been operating since 2008, there is some difficulty in determining what a typical flow would be in the Mason River during these high flow events in the Waiau River.

  In the absence of flow data for the Mason River, recorded rainfall data in the Mason catchment has been compared to the eight highest flows recorded in the Waiau River at Marble Point since records began in 1967 (Appendix A, Table A-1). With the exception of December 1993, all of these flows occurred as a result of north-westerly weather systems, confirming that these weather systems tend to produce the highest Waiau River flood flows. In each of these north-west events, the Mason catchment generally received relatively modest or low rainfall, suggesting that no significant flood flows tend to occur in the Mason River during these events.

- ***Mason River design flood events***

  High rainfalls in the Mason River and Lyndon area stream catchments generally occur as a result of southerly or easterly weather systems (or combinations thereof), which is typical of Canterbury foothill catchments. Although the Waiau River catchment extends back to the Main Divide, it also has a substantial foothills catchment capable of generating reasonably high flows during these events.

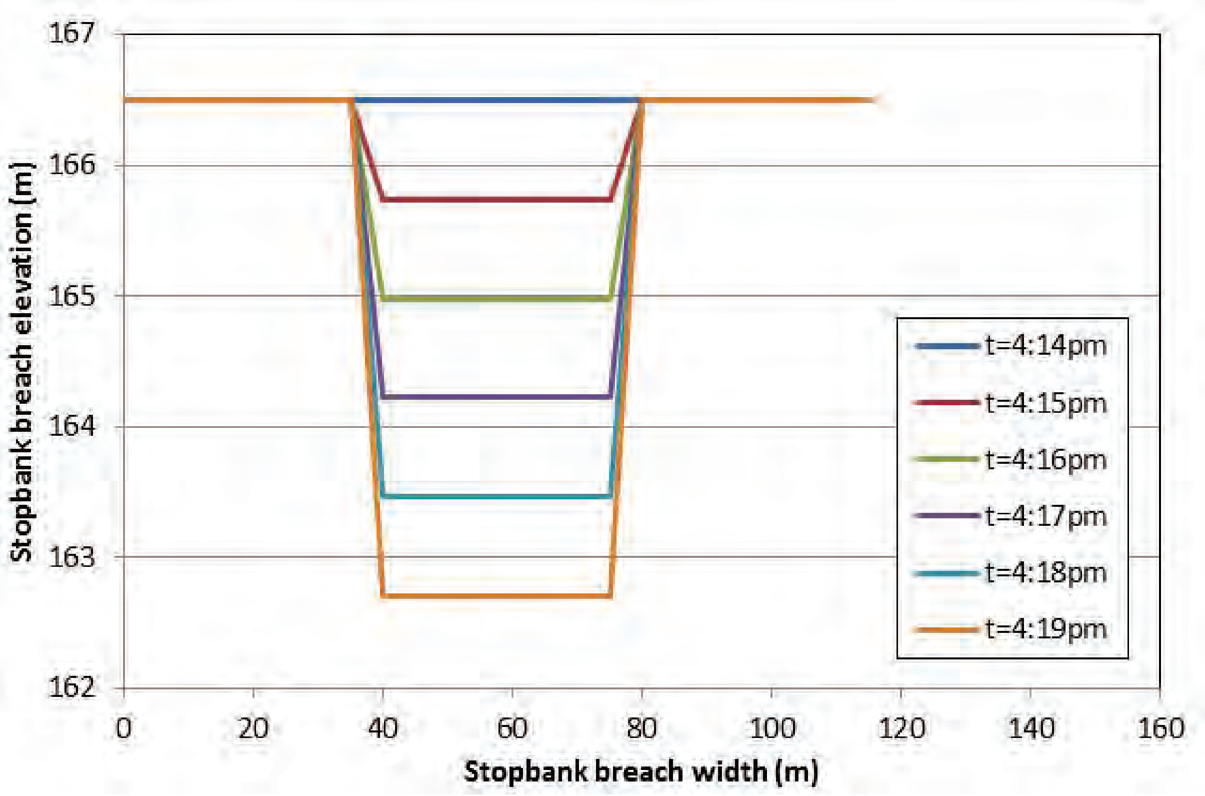


Figure 3-12: Mason River stopbank breach profile

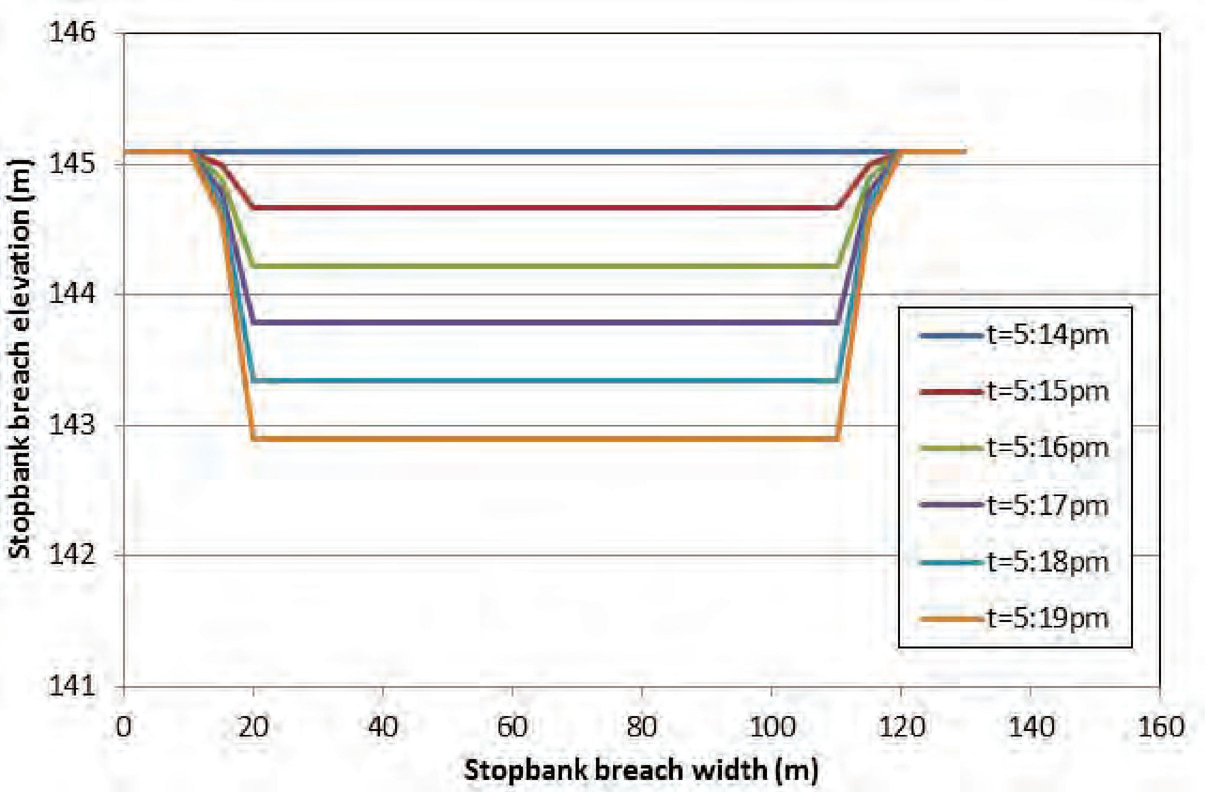


Figure 3-13: Waiau River stopbank breach profile

Post-2008 Mason River recorded peak flood flows, and corresponding peak flows recorded in the Waiau at Marble Point, are shown in Appendix A (Table A-2). Of the historic Mason River flood events referred to in Section 2.2, Waiau River flow records are only available for June 1982, December 1993 and August 2000.

- In June 1982, 202 mm of rainfall was recorded over 48 hours at Whales Back in the Mason catchment (~30 year ARI rainfall – Refer to Table 2-1 and Table 2-2), and the Waiau River reached a peak flow of 601 m^3/s at Marble Point (less than a mean annual flood).
- In December 1993, an easterly storm produced 253 mm of rainfall over 72 hours at Whales Back in the Mason catchment (a 40 – 50 year ARI rainfall – Refer to Table 2-1 and Table 2-2), and the Waiau River reached a peak flow of 1,312 m^3/s at Marble Point (~10 year ARI flow).
- The rainfall in August 2000 was very similar to that of June 1982 (i.e. ~30 year ARI), and the Waiau reached a peak flow of 962 m^3/s at Marble Point (less than a mean annual flood).

Based on this information, it is considered likely that the Waiau would be in relatively high flood during a 200 year ARI flood flow in the Mason River.

A summary of the Waiau and Mason River peak design flows, for 50, 200 and 500 year ARI Waiau River and Mason River flood is shown in Figure 3-14, together with peak flows for recent flood events. Table 3-5 provides the details of the Waiau River, Mason River and Lyndon area stream flows that are combined to produce the 50, 200 and 500 year ARI design flood events.

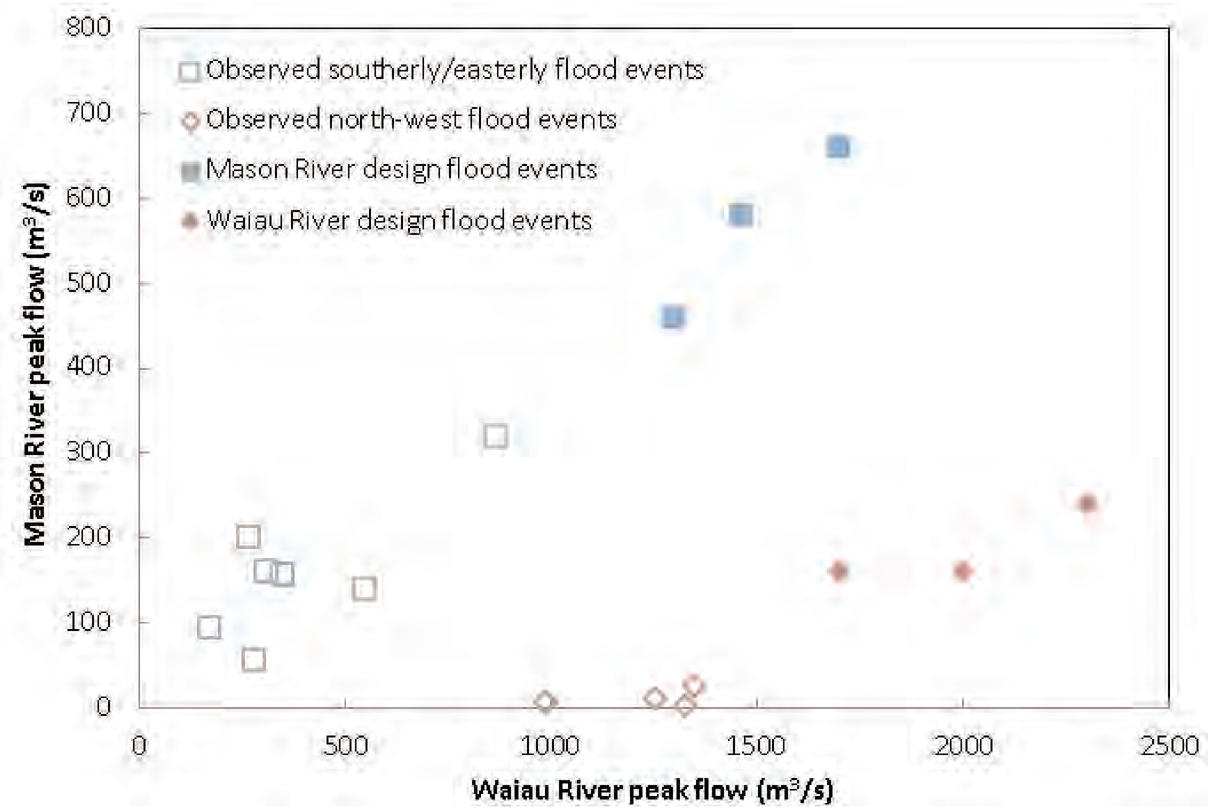


Figure 3-14: Waiau and Mason River peak flows for recent flood events (2008 to 2014) and design flood

Table 3-5: Summary of Waiau River and Mason River/Lyndon area flood events combined to produce the 50, 200 and 500 year ARI design flood events

	Waiau River ARI (peak flow)	Mason River[1] ARI (peak flow)	Stopbank breach
Waiau River flood event			
50 year ARI	50 year (1700 m^3/s)	Mean annual flood (160 m^3/s)	100m (Waiau River)
200 year ARI	200 year (2000 m^3/s)	Mean annual flood (160 m^3/s)	100m (Waiau River)
500 year ARI	500 year (2300 m^3/s)	5 year (240 m^3/s)	100m (Waiau River)
Mason River flood event			
50 year ARI	10 year (1300 m^3/s)	50 year (460 m^3/s)	-
200 year ARI	20 year (1460 m^3/s)	200 year (580 m^3/s)	40m (Mason River)
500 year ARI	50 year (1700 m^3/s)	500 year (660 m^3/s)	40m (Mason River) & 100m (Waiau River)

[1] Lyndon area streams and Parnassus Street Drain use the same ARI as used for the Mason River

<u>Timing of peak flows on the Waiau and Mason Rivers</u>
For the post 2008 events (where flow data for both rivers is available), peak flows on the Waiau River at Marble Point occurred several hours after flood flows reached their peak at the Mason River recorder. Allowing for travel times to the confluence at Waiau township, peak flows in the Mason River would have passed prior to the peak Waiau flows arriving. However, as data from both gauges is only available for a short period, it cannot be assumed that this is a typical occurrence, or that equivalent timing would occur during larger scale events.

Given the short record of flow data for the Mason River, it has not been possible to establish any correlation between the timing of flood peaks in the two rivers during both northwest and southerly/easterly flood events. It has therefore been assumed that, for all design flood events, both the Waiau River and Mason River will peak simultaneously at the Waiau River/Mason River confluence. Based on the information outlined above, this is considered to be a conservative but realistic approach.

3.4.4 Waiau River downstream boundary water level

For the 50, 200 and 500 year ARI flood events a constant water level of 91 m above mean sea level was assumed. This level was somewhat arbitrary as the relatively steep river channel only has a small impact on water levels in the river reach immediately upstream of the boundary. This boundary was intentionally placed over 11 km downstream of the study area to avoid backwater effects.

3.4.5 Model results for design flood events

Modelled flood depths for the 50 and 200 year ARI Waiau River and Mason River flood events are shown in Figures 3-15 to 3-20. Key observations from the modelling are summarised below.

<u>Waiau township</u>
In a Waiau River flood event, 50 year ARI flows in the Waiau River are not likely to cause flooding in Waiau township as the maximum water levels are lower than the elevated terrace on which Waiau township is located.

For higher 200 year ARI flows on the Waiau River, maximum water levels in the Waiau River are still predicted to be lower than the elevated terrace upstream of Parnassus Street Drain. However, on the river side of St Helens Street and Mendip Street the peak Waiau River flood levels are likely to cause some water to back up and inundate this area with relatively shallow water depths. The input to Parnassus Street Drain is only a mean annual flow for this scenario, however some overflows are shown to occur. The model has been optimised to predict the extent and depth of flooding across the wider river floodplains, and is less suited to accurately conveying flow through small defined channels such as Parnassus Street Drain. The results for this area should, therefore, be treated with caution in this scenario. The results are expected to be more accurate for the higher flow scenarios, as the amount of flow able to be conveyed within the drain becomes less critical.

In a Mason River flood event, 50 year ARI flows in the Mason River are expected to be mainly contained, with some overflows along the true left bank upstream of the River Road bridge (Figure 3-18). This water backs up on the upstream side of the bridge as far east as the River Road/Inland Road intersection. Additional flooding to Waiau township is also likely from Parnassus Drain, with any overflows passing out of the drain tending to be shallow and flowing towards Fernihurst Street, and out into the Waiau River.

In a larger 200 year ARI Mason River flood event, it is expected 200 year ARI flows in the Mason River will compromise stopbanks causing a breach – with the most likely location being upstream of the Inland Road Bridge. If this occurs, the breach flows are predicted to flow in a westerly direction over the Inland Road, with most of the water flowing down the floodplain adjacent to the true left bank of the Mason River (Figure 3-20). A small amount of shallow overland flow also passes back over the Inland Road and into Parnassus Street Drain, but this is relatively minor. Water on the Mason River floodplain also flows over River Road near the Inland Road intersection, causing shallow overland flows downstream of River Road. As with all scenarios, the Parnassus Street Drain is likely to overflow and cause relatively shallow flooding around Fernihurst Street. Downstream of the Mason River/Waiau River confluence, maximum water levels are expected to be lower than the elevated terrace on which Waiau township is located. However, downstream of Parnassus Street Drain water is likely to back up and inundate the area between the river and St Helens Street\Mendip Street as the peak Waiau River flow passes.

<u>Lyndon area</u>
For both the 50 year ARI Waiau River and Mason River design flood events, the Lyndon area tends to become inundated as far inland as the elevated terrace situated ~600 to 800 m from River Road. Water levels on the floodplain adjacent to River Road tend to be up to 0.2 m higher for Waiau River flood events, and up to 0.4 m in the area affected by the 100 m long Waiau River stopbank breach (Figure 3-21).

Along River Road, near Dog Stream, the 50 year ARI Waiau River flood event produces maximum water levels over River Road that are up to 0.2 m higher than during a 50 year ARI Mason River flood event. During both events maximum water depths over River Road are likely to be 0.8 to 1.0 m deep.

For the 200 year ARI Waiau River and Mason River flood events, maximum water levels in the area from the Mason confluence upstream to the Lyndon Road/River Road junction, are within ±0.1 m of each other. Modelled maximum water levels for both 200 year ARI storm events show River Road inundated with water depths up to ~1.1 m, and surrounding land with maximum water depths greater than 1.1 m (i.e. adjacent to Dog Stream, adjacent to River Road and between Hossack Downs Road and Lyndon Road).

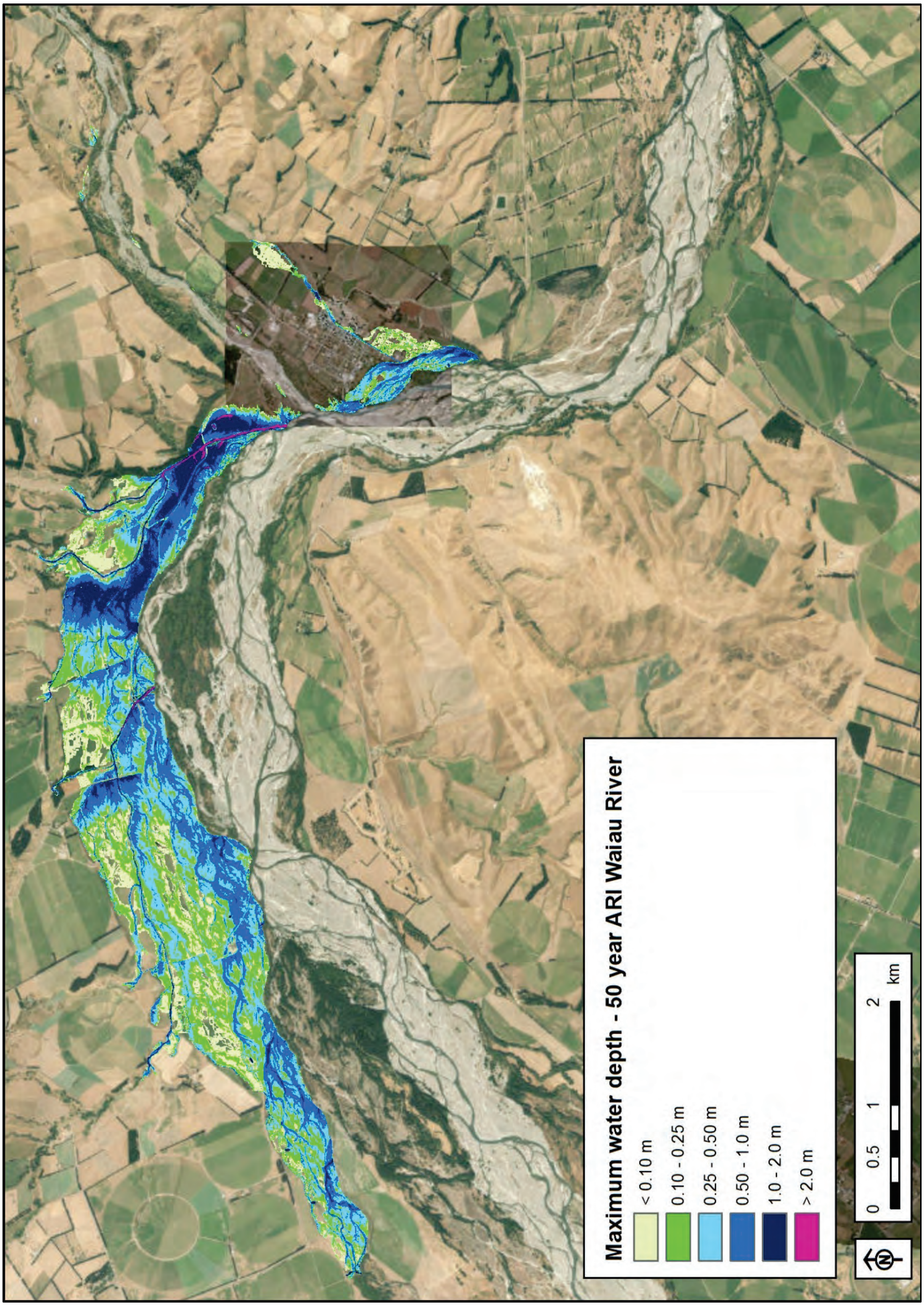


Figure 3-15: 50 year ARI Waiau River flood event - maximum water depths

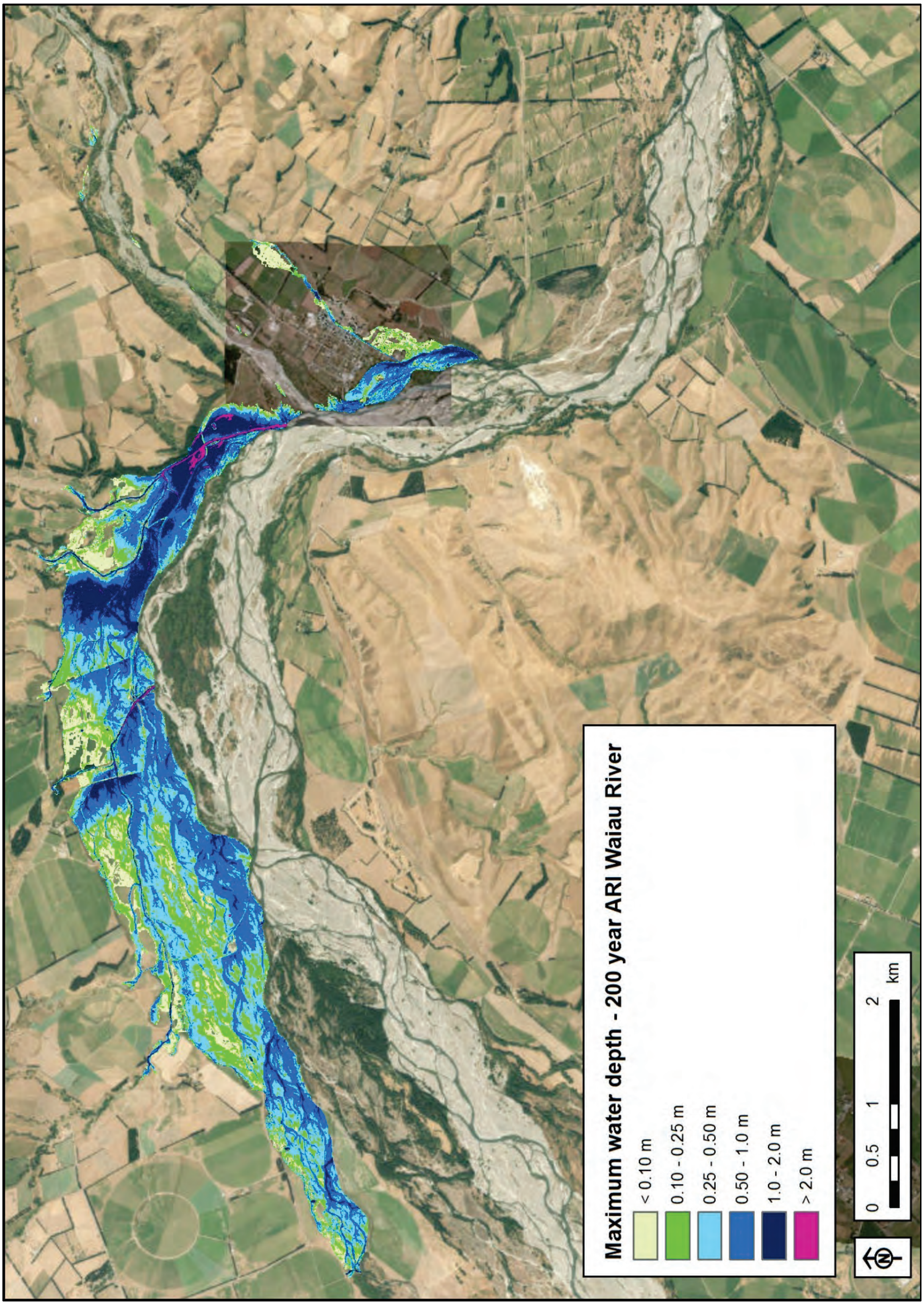


Figure 3-16: 200 year ARI Waiau River flood event - maximum water depths

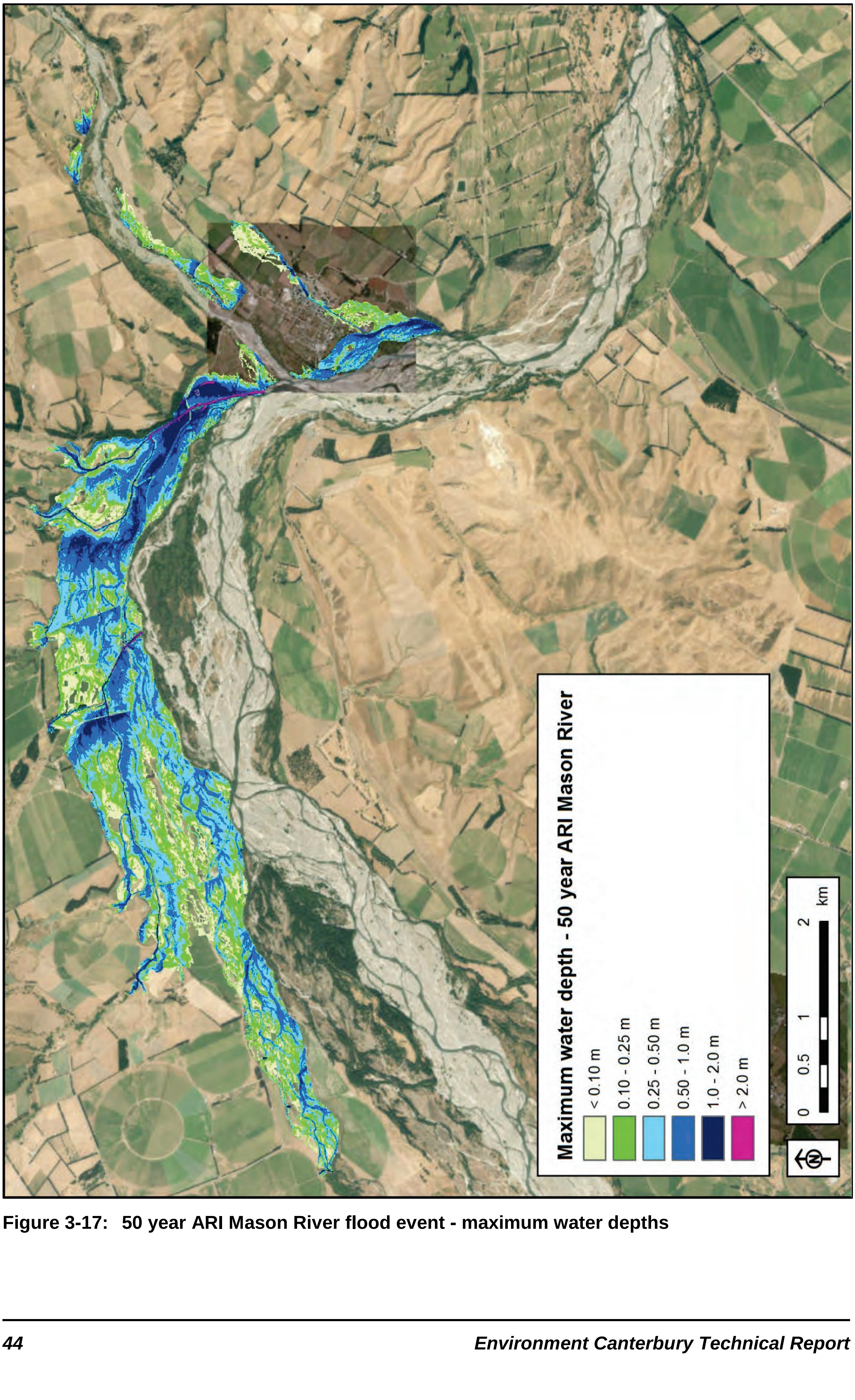


Figure 3-17: 50 year ARI Mason River flood event - maximum water depths

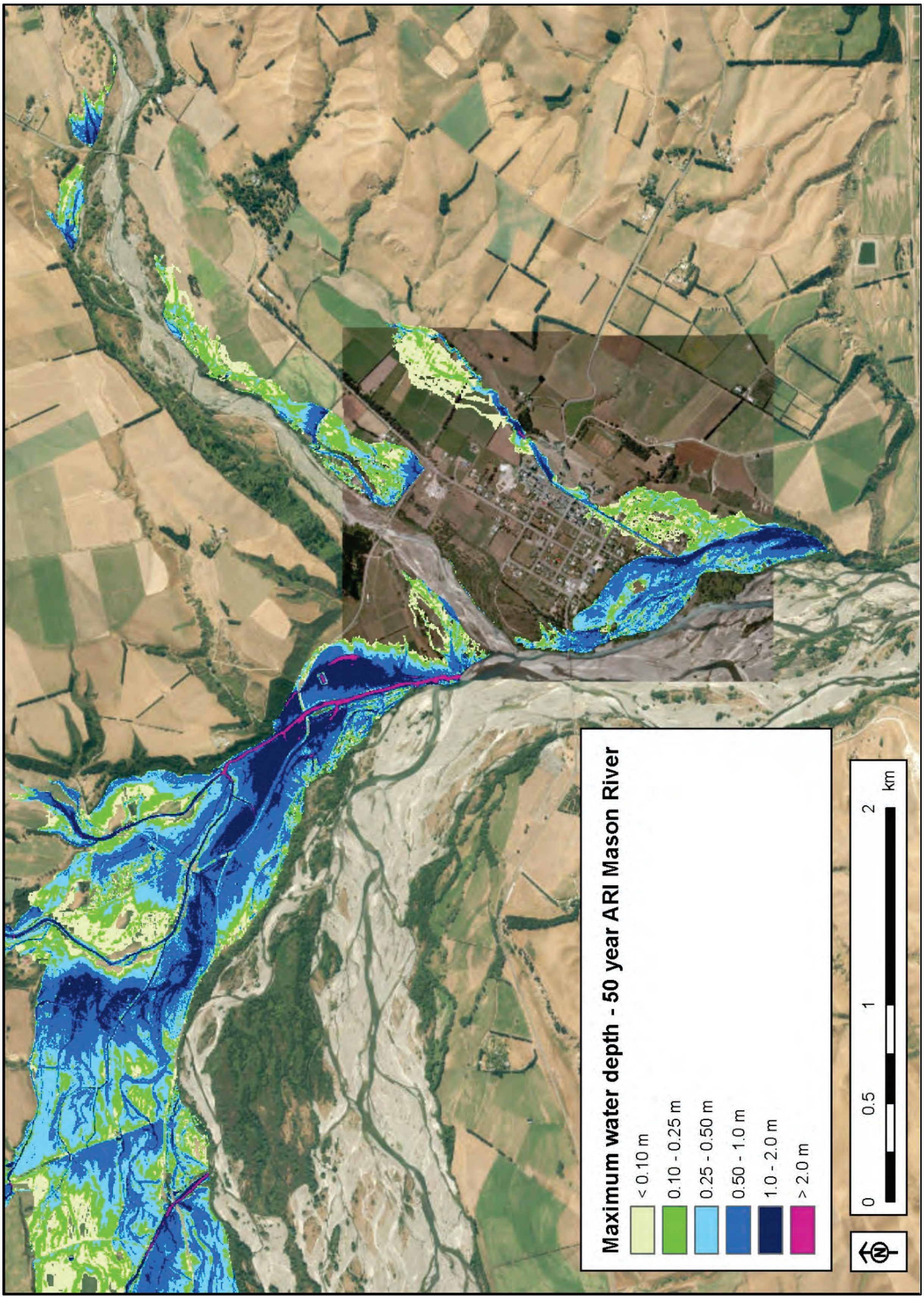


Figure 3-18: Waiau township 50 year ARI Mason River flood event - maximum water depths

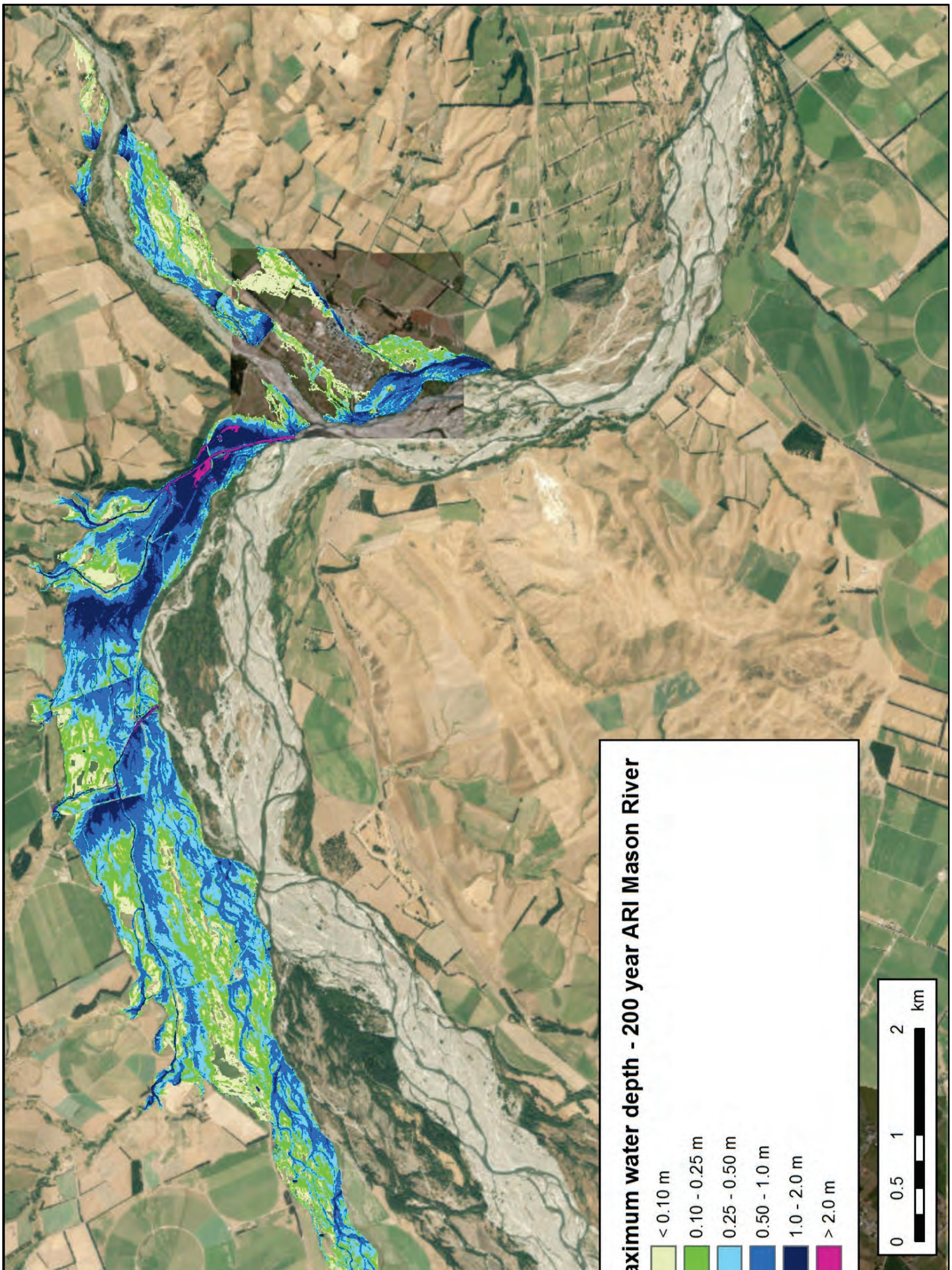


Figure 3-19: 200 year ARI Mason River flood event - maximum water depths

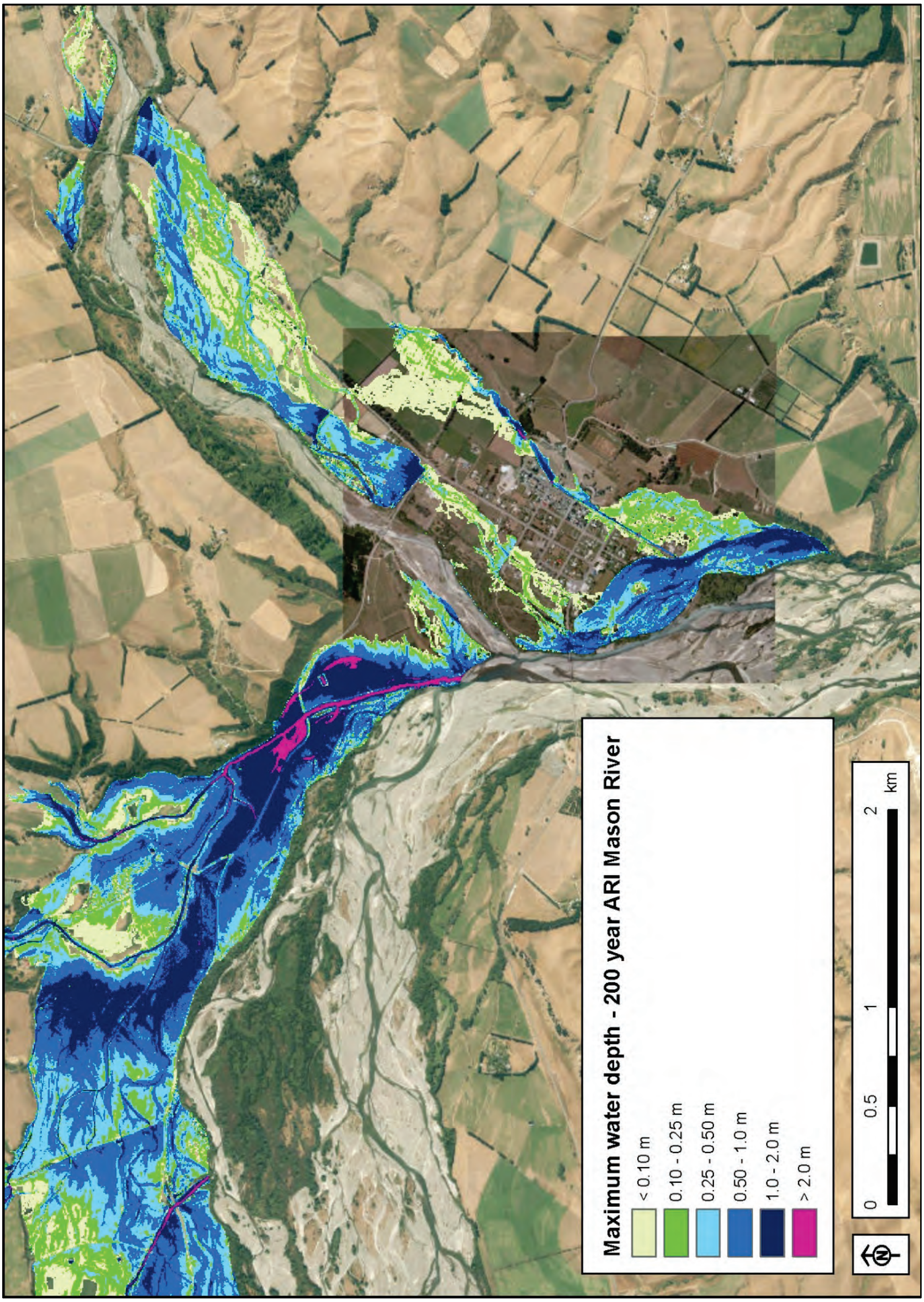


Figure 3-20: Waiau township 200 year ARI Mason River flood event - maximum water depths

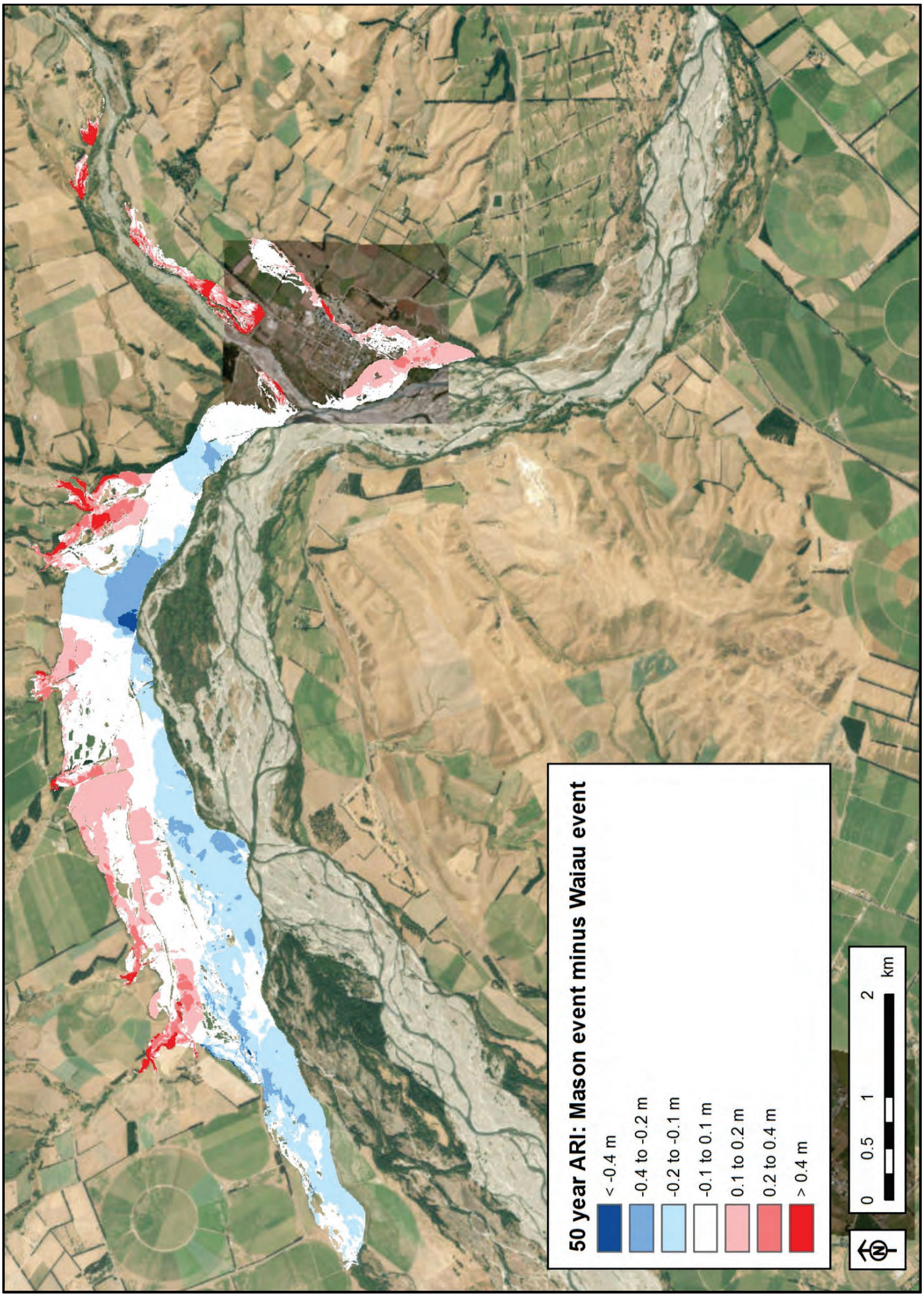


Figure 3-21: 50 year ARI comparison of maximum modelled water depths for a Mason River flood event compared to a Waiau River flood event

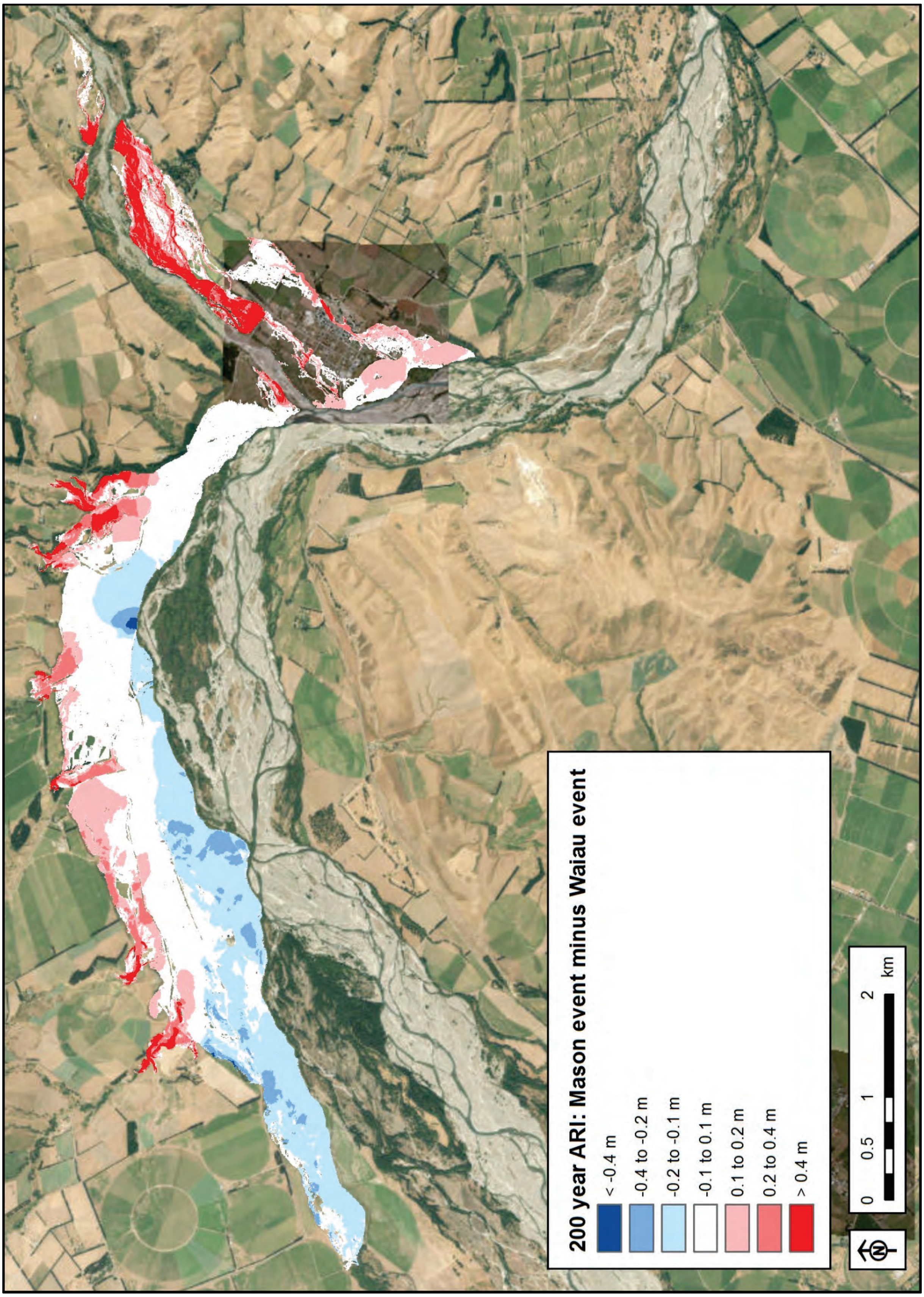


Figure 3-22: 200 year ARI comparison of maximum modelled water depths for a Mason River flood event compared to a Waiau River flood event

3.5 Model sensitivity analysis

Several scenarios were modelled to determine the sensitivity of flood inundation to various model parameters and assumptions. These are described below.

3.5.1 River channel roughness

The Waiau and Mason River Mike 11 model cross sections have channel roughness values as specified in Table 3-4. Since floodplain flow only occurs when water overtops the Mike 11/Mike 21 cross section banks (or a breach occurs), the volume of flood water entering the floodplain is somewhat reliant on the correct roughness values being used to represent the river system (i.e. water levels in the river will increase if Manning 'n' roughness increases).

Manning 'n' roughness values along the Mike 11 river channels were increased by 25% (i.e. the 'base' roughness was increased from 'n' = 0.040 to 0.05) for the 200 year ARI Mason River flood event. This enabled the impact of roughness on maximum floodplain water depths and extent to be examined (Figure 3-23).

For the increased river channel roughness, the total flooded area increased from 9.3 km^2 to 9.9 km^2. Although average maximum water depths on the floodplain only increased by approximately 0.05 m, significant areas of the Waiau/Lyndon and Mason River floodplains had water level increases of over 0.1 m (for example, areas of Waiau township that are downstream of the River Road bridge, and to the west of Cheviot Street and Leslie Street).

Maximum water depths adjacent to the true left bank of the Waiau River, at the Mason confluence and downstream of Waiau township, also increase by up to ~0.4 m with the increased channel roughness. This allows additional water to back up around Parnassus Street Drain in the St Helens Street\Mendip Street area, increasing water depths by up to 0.2 m. Here the Waiau River fairway is relatively confined, compared to upstream of the Mason River confluence where the fairway and the adjacent floodplain are wider.

3.5.2 Floodplain roughness

Floodplain roughness values used to represent the Waiau floodplain are described in Section 3.2.2 and areas where the roughness is not equal to 'n'=0.050 (M=20) are shown in Appendix C (Figure C-3). The Manning 'n' floodplain roughness value was increased by 25% for the 200 year ARI southerly/ easterly storm event. This enabled the impact of floodplain roughness on maximum floodplain water depths and extent to be examined (Figure 3-24).

For the increased floodplain roughness, the total flooded area only increased from 9.3 km^2 to 9.4 km^2. Average maximum water depths on the floodplain increased by 0.03 m, with the only increases in maximum water depths of greater than 0.1 m located in the Lyndon area between Hossack Downs Road and the Mason River confluence.

3.5.3 Stopbank breach size

Stopbank breaches assumed for this study are described in Section 3.4.2. For the 200 year ARI Mason River flood event, the 40 m long Mason River stopbank breach was increased in length to 80 m to determine the sensitivity of the model to breach size. Figure 3-25 shows that the increased Mason River breach length has a relatively minor impact on maximum water levels. The main areas where maximum water levels increased by greater than 0.1 m were near the initial breach location and along the edge of the terrace confining the breach flow.

For the increased breach size, the total flooded area only increased from 9.3 km^2 to 9.4 km^2. Average maximum water depths on the floodplain did not increase significantly.

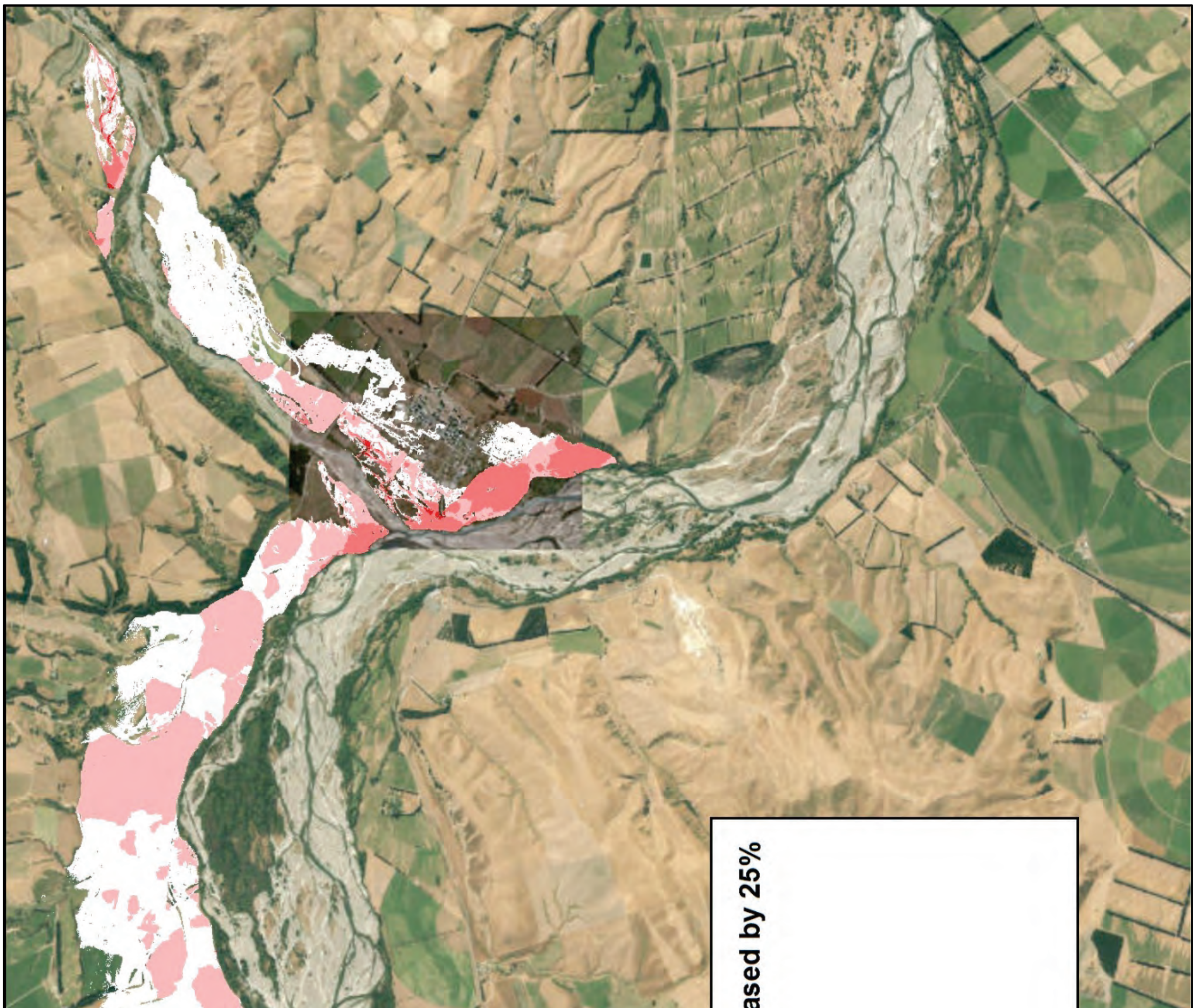


Figure 3-23: Change in maximum floodplain water depths when river channel roughness is increased by 25% for the 200 year ARI Mason River flood event

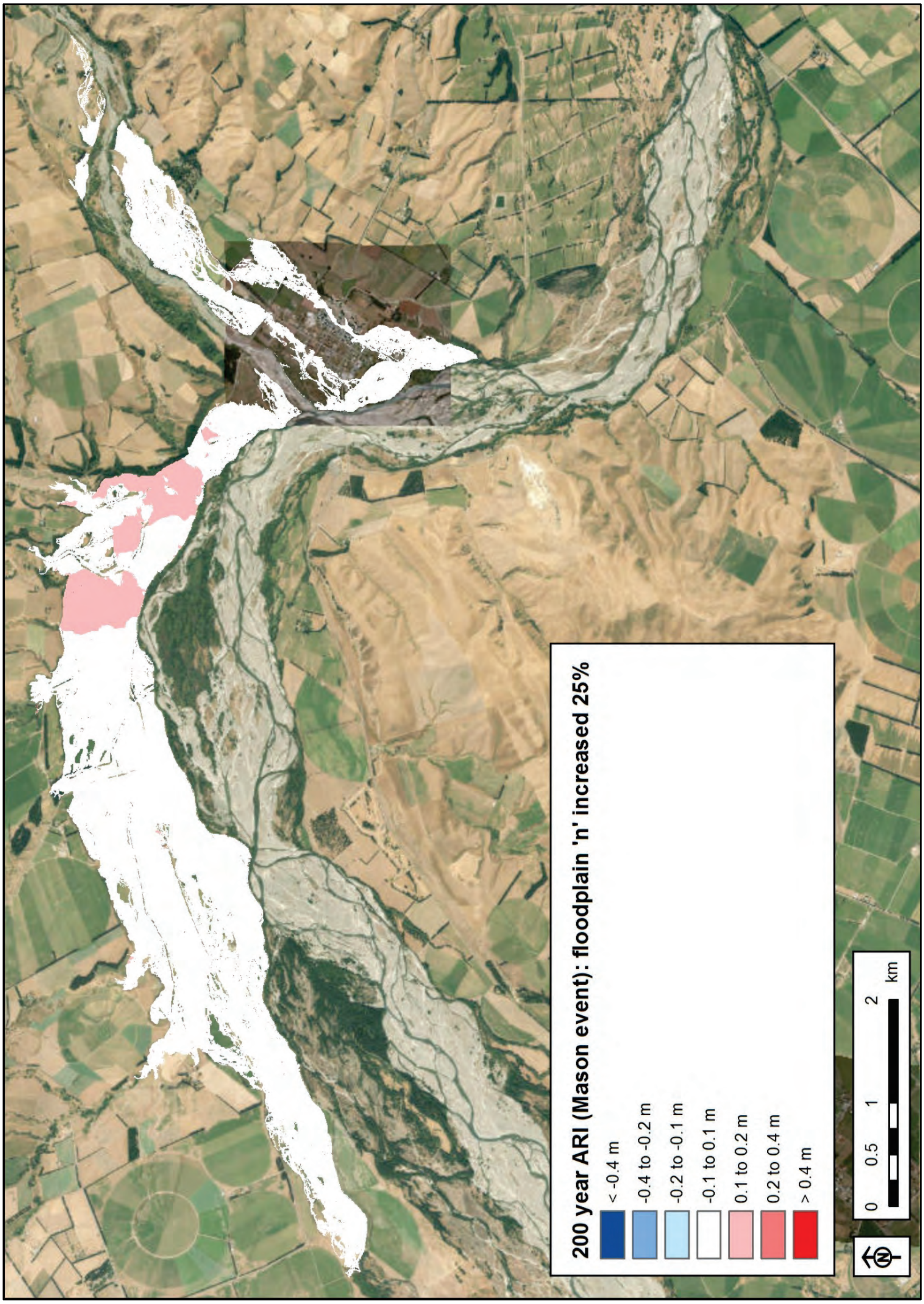


Figure 3-24: Change in maximum floodplain water depths when floodplain roughness is increased by 25% for the 200 year ARI Mason River flood event

Figure 3-25: Change in maximum floodplain water depths when the Mason River stopbank breach length is increased from 40 m to 80 m for the 200 year ARI Mason River flood event

3.5.4 Climate change – increased flow

Climate change is generally expected to increase peak runoff and elevate sea levels. Section 2.5 briefly summarises the likely impacts we can expect by 2090. Should peak flows increase by the order of 16-20%, the 200 year ARI Mason River peak flow of 580 m^3/s could increase to ~670-700 m^3/s (slightly larger than the present 500 year ARI flow). Likewise, the 200 year ARI Waiau River peak flow of 2000 m^3/s could increase to ~2300 to 2400 m^3/s (equivalent to the present 500 year ARI flow).

The increase in maximum water depths for the 500 year ARI Mason River and Waiau River flood events (compared to the 200 year ARI storm events) are shown on Figure 3-26 and Figure 3-27, respectively.

For the Mason River flood event, the relatively large increases in maximum depths in the area between Hossack Downs Road and the Mason River confluence are largely due to the fact that in a 500 year ARI Mason River flood event, the stopbanks on the Waiau River are assumed to breach, while for the 200 year ARI Mason River flood event it is assumed that there will be no breach.

For the Waiau River flood event, the increased maximum water depths in the Lyndon area (and around Parnassus Street drain) are likely due to increased local flows.

3.6 Model summary

Several observations can be made from the modelling.

Firstly, it appears that a Mason River flood event is likely to have the biggest impact on Waiau township for a 200 year ARI design flood event. This is because:

- There is a greater chance of the Mason River stopbanks being breached during this storm event, allowing water to flow across the floodplain towards the township – potentially passing additional flow into Parnassus Street Drain or over River Road (near the Inland Road junction).

- Parnassus Street Drain will have higher flows in a Mason River flood event and will therefore be more likely to pass shallow flows out of the channel, draining towards Fernihurst Street, and out into the Waiau River.

- The peak flood flows in the Waiau River, downstream of the Mason River confluence, are likely to be higher for the Mason River design event than the Waiau River design event. This is because the combined peak flows for the 20 year ARI flows on the Waiau River and the 200 year ARI flows on the Mason River, Lyndon area streams and Parnassus Street Drain are greater than the combined peak flows of a 200 year ARI flow on the Waiau River combined with a mean annual flood on the other water courses. Higher flows in the river channel will lead to higher maximum water levels in this area, and may cause water to back up in Parnassus Street Drain.

For both the 200 year ARI Mason River and 200 year ARI Waiau River flood events there will be extensive flooding in the Lyndon area – in particular downstream of Hossack Downs Road. River Road is likely to be impassable with water depths ~1 m deep.

The Mason River flood event is likely to produce higher maximum water depths further away from the Waiau River (i.e. where the Lyndon area streams enter the floodplain area), while the area adjacent to the Waiau River is likely to have greater maximum water depths during the Waiau River flood event.

Sensitivity tests show that stopbank breaches, increased river channel roughness and increased flows can all increase maximum water depths on the floodplain significantly, while increased floodplain roughness and doubling the length of a stopbank breach seem to have a much less significant overall impact.

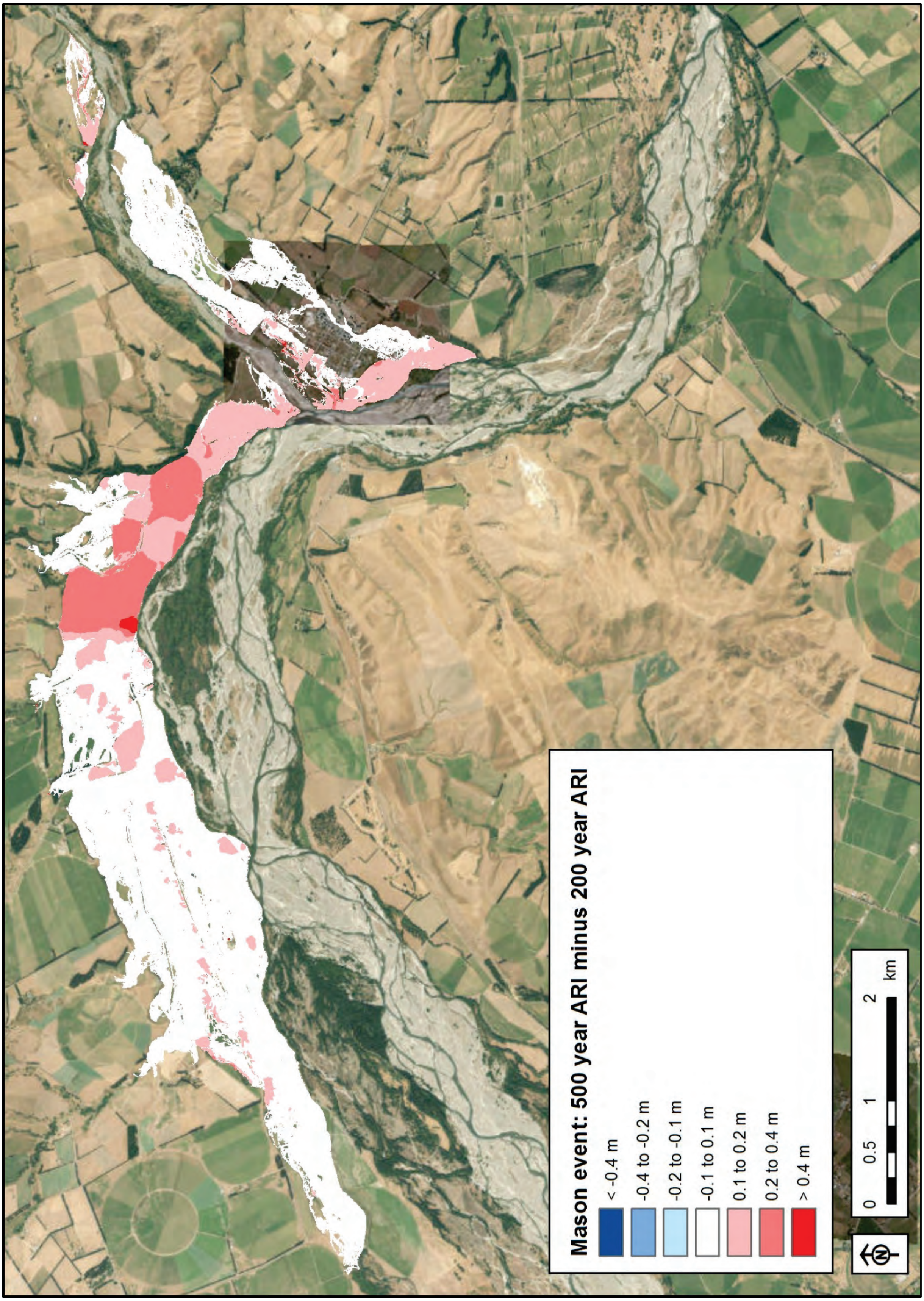


Figure 3-26: Change in maximum floodplain water depths between a 200 year ARI and 500 year ARI Mason River flood event

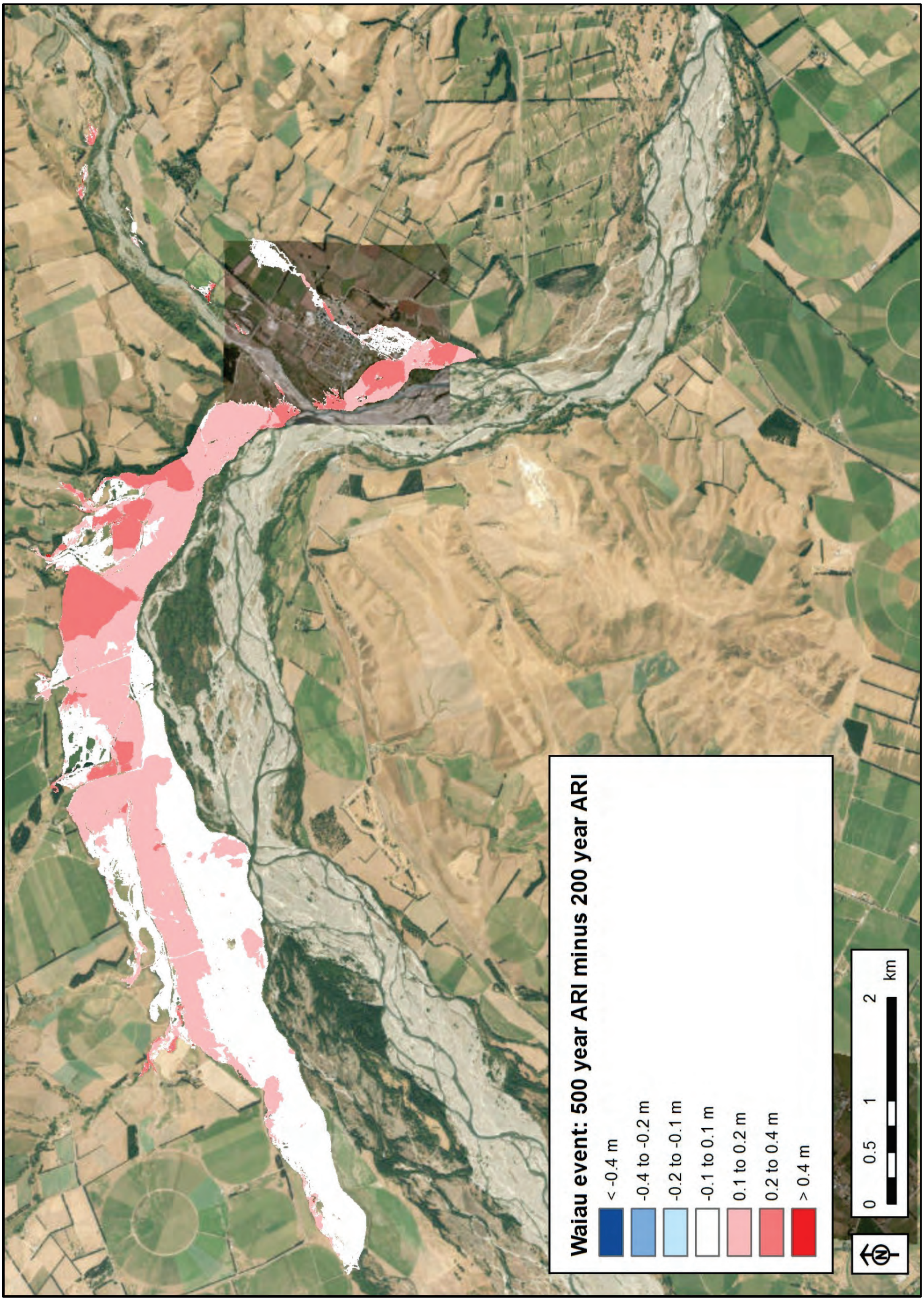


Figure 3-27: Change in maximum floodplain water depths between a 200 year ARI and 500 year ARI Waiau River flood event

Note that this floodplain modelling does not include localised runoff from rainfall as this is considered to be relatively insignificant compared to the larger flood flows in the Waiau and Mason rivers, Lyndon area streams and Parnassus Street Drain.

3.7 Derivation of 'high hazard' areas

'High hazard' areas are defined in the Canterbury Regional Policy Statement as '***flood hazard areas subject to inundation events where the water depth (m) x velocity (m/s) is greater than or equal to 1, or where depths are greater than 1 metre, in a 500 year ARI flood event***'. Although a 500 year ARI flood event seems extremely large and infrequent, over a 70 year period it is estimated that there is a 12% chance of an event of this magnitude occurring (Table D-1, Appendix D).

For the floodplain modelled in this study, some areas are more adversely affected by the Waiau River design event, while other areas are more adversely affected by the Mason River design event. Both the 500 year ARI Waiau River and Mason River flood events have therefore been used to define the 'high hazard' areas. Maximum water depths and velocities for each event were compared, and the maximum value out of 'depths greater than 1m' or the product of 'water depth x velocity' was selected for all inundated areas. Figure 3-28 identifies the combined high hazard areas on the Waiau floodplain, assuming breach flows occur on the Waiau River (at River Road) and Mason River (upstream of the Inland Road bridge).

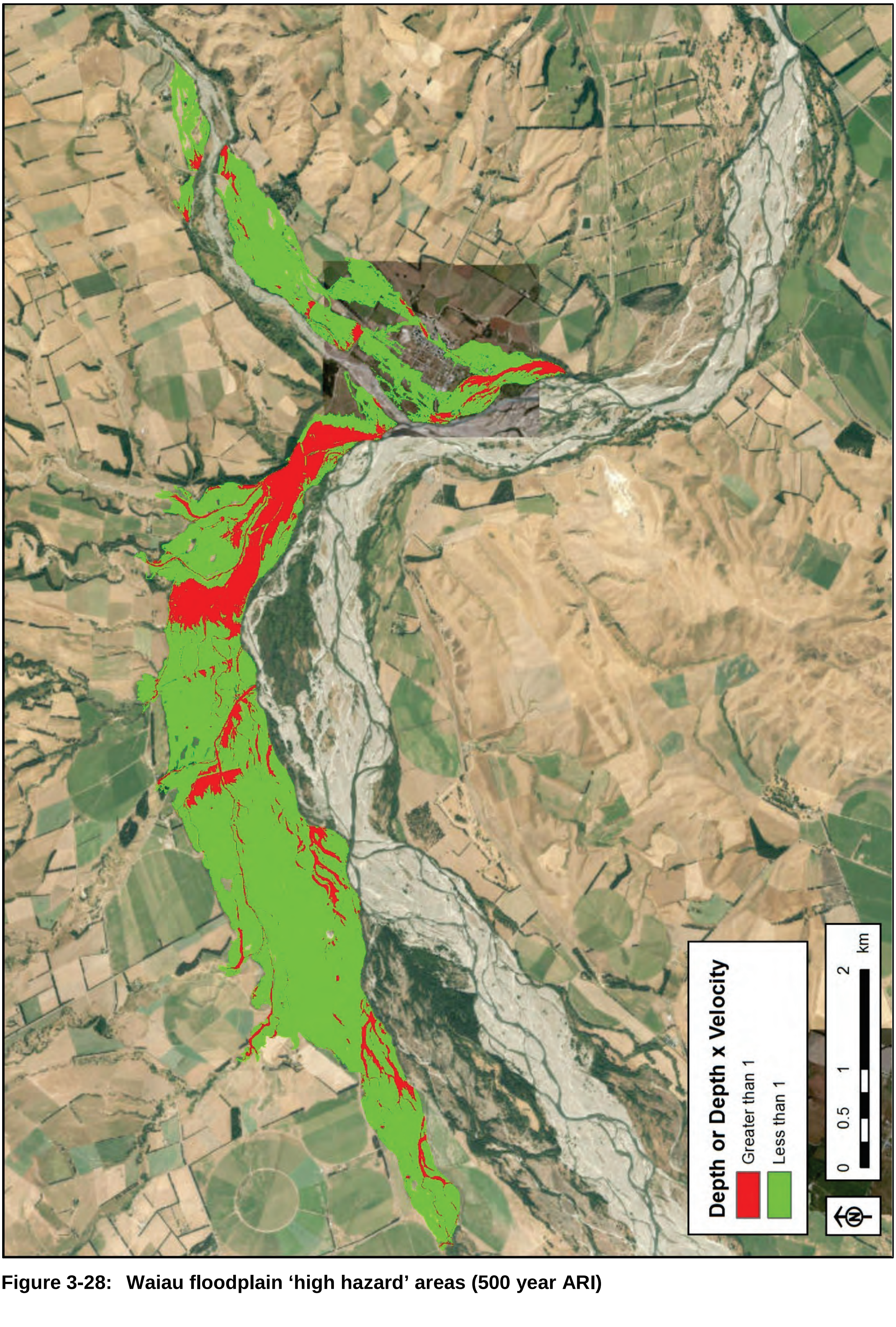


Figure 3-28: Waiau floodplain 'high hazard' areas (500 year ARI)

4 Conclusions

Waiau Township

A 50 year ARI Waiau River flood event is unlikely to cause flooding to Waiau township, while a 50 year ARI Mason River flood event is likely to produce some flooding along the Mason River true left bank upstream of the River Road bridge. During a 50 year ARI Mason River flood event shallow overflows from Parnassus Street Drain are also likely to flow towards Fernihurst Street, and out into the Waiau River.

During a 200 year ARI Waiau River flood event maximum water levels in the Waiau River are expected to be lower than the elevated terrace as far downstream as the area around the Parnassus Street Drain outlet. However, downstream of this outlet, some water may back up into the area between the river and St Helens Street/Mendip Street during peak flows in the Waiau River. There may also be some shallow overflows from Parnassus Street Drain flowing towards Fernihurst Street, and out into the Waiau River.

During a 200 year ARI Mason River flood event it is expected that the Mason River stopbanks will be breached, with the most likely location being upstream of the Inland Road Bridge. Should this occur, floodwaters are likely to flow in a westerly direction over Inland Road, with most of the water flowing down the floodplain adjacent to the true left bank of the Mason River. A small amount of shallow overland flow may also pass back over Inland Road and into Parnassus Street Drain but this would likely be relatively minor. Water on the Mason River floodplain, upstream of River Road, may also flow over River Road near the Inland Road intersection. This would cause shallow overland flows downstream of River Road. As with all scenarios, the Parnassus Street Drain is also likely to overflow and cause relatively shallow flooding around Fernihurst Street. Downstream of the Mason River/Waiau River confluence, maximum water levels are expected to be lower than the elevated terrace on which Waiau township is located. However, downstream of Parnassus Street Drain water is likely to back up and inundate the area between the river and St Helens Street\Mendip Street as the peak Waiau River flows pass.

Lyndon area

The Lyndon area is likely to be flooded for 50 year and 200 year ARI Waiau River and Mason River design events due to a combination of Waiau River breach flows and/or overflows from the local streams. During the design events, most of the area becomes inundated and the main evacuation route via River Road is likely to be impassable.

'High hazard' areas

Although some flood inundation is likely to occur in Waiau township during a 500 year ARI Mason River flood event, this is not likely to produce any 'high hazard' areas.

The Lyndon area is prone to flood inundation with significant 'high hazard' areas. Stopbank breaches at other locations (e.g. upstream of River Road) are likely to produce additional 'high hazard' areas. These scenarios have not been modelled in this study.

Uncertainty

The flood inundation maps produced in this study have numerous sources of uncertainty that need to be considered when using the results. Bales and Wagner (2009) outline some of the uncertainties associated with 1-d hydraulic modelling using LiDAR data. These uncertainties are also relevant for this modelling study where uncertainties include model inputs (e.g. stopbank breach locations and sizes, flow hydrographs, roughness values and energy loss parameters), topographic data (e.g. LiDAR data, cross section data) and hydraulic model assumptions (e.g. simplification of equations by depth-averaging, as well as averaging topography and flow behaviour over a 5 m grid cell for computational efficiency). Sensitivity tests can help address these uncertainties but modelling results should generally only be interpreted and used by those who are familiar with all aspects of the modelling.

It is recommended that the design flood levels and 'high hazard' areas produced in this study are reassessed at a future date when additional flow data and stopbank information becomes available. Measured water levels, collected during or immediately after a large flood event, would also enable the computational hydraulic model to be calibrated properly.

5 Acknowledgments

The following Environment Canterbury staff have reviewed this report and provided valuable input to this study:

- Tony Oliver (Principal Hazards Analyst) - reviewed modelling report.
- Richard Holmes (Hazards Analyst) - reviewed modelling results.
- Tony Boyle (Principal Hazards Analyst) - reviewed modelling report and provided technical advice regarding potential breakouts.
- Ian Heslop (Principal River Engineer) - reviewed modelling report and provided technical advice regarding potential breakouts.

6 Glossary

Aggradation: Deposition of shingle in a river, raising the river bed level.

Annual exceedance probability (AEP): The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means there is a 5% chance (i.e. a chance of one-in-twenty) of a peak flood discharge of 500 m^3/s or larger occurring in any one year. AEP is the inverse of average recurrence interval (ARI), expressed as a percentage.

Average recurrence interval (ARI): The average time period between floods, equivalent to or exceeding a given magnitude. For example, a 100 year ARI flood has a magnitude expected to be equalled or exceeded an average of once every 100 years. Such a flood has a 1% chance of being equalled or exceeded in any given year, i.e. 1% AEP. ARI is often used interchangeably with 'return period' or 'flood frequency'.

Catchment: The land area draining through the main stream and tributaries to a particular site.

Discharge: The rate of flow of water measured in terms of volume per unit time, e.g. cubic metres per second.

Fairway: The open (ideally vegetation-free) area of the riverbed that carries the majority of any flood flow. There is often a maintenance program in place for clearance of vegetation such as willows, gorse and broom from the fairways.

Floodplain: The area of relatively flat land, which is inundated by floodwaters from the upper catchment up to the probable maximum flood event.

Floor level*:* The top surface of the ground floor of a building (prior to the installation of any covering).

High hazard areas: 'High hazard' areas for this study are defined as '*flood hazard areas subject to inundation events where the water depth (m) x velocity (m/s) is greater than or equal to 1, or where depths are greater than 1 metre, in a 500 year ARI or 0.2% annual exceedance probability event*'.

LiDAR (Light Detection and Ranging) data: Data acquired using a laser scanner mounted on an aircraft. The scanner measures the ground level at approximately one point every square metre. This point data is used to generate very accurate and high resolution digital elevation maps which enable subtle topographic features to be identified.

Stopbank breach flow: Flow from the river onto the floodplain resulting from a stopbank failure (usually due to overtopping or lateral erosion/scour).

Thalweg: Line defining the lowest elevations along a length of a riverbed. This represents the channel with the fastest flowing water.

7 References

Bales, J.D. and Wagner, C.R. (2009). Sources of uncertainty in flood inundation maps. Journal of Flood Risk Management, Volume 2, Issue 2, p 139-147.

Connell, R.J. and Pearson, C.P. (2001). Two-component extreme value distribution applied to Canterbury annual maximum flood peaks. Journal of Hydrology (NZ), 40(2): 105-127.

Griffiths, G.; McKerchar, A.; Pearson, C. (2011). Review of flood frequency in the Canterbury region. Environment Canterbury Technical Report R11/50. August 2011.

McKerchar, A.I.; Pearson, C.P. (1989). Flood frequency in New Zealand. Hydrology Centre Publication 20, Christchurch, New Zealand. 87p.

McKerchar, A.; Smith, E. (2004). Canterbury Region Flood: 18-19 August 2000. Environment Canterbury Technical Report U04/94. August 2004.

Ministry for the Environment. (2008). Coastal hazards and climate change. A guidance manual for local government. 2nd edition. Revised by Ramsay, D, and Bell, R. (NIWA). Prepared for Ministry for the Environment.

Mullan, B.; Wratt, D.; Dean, S.; Hollis, M.; Allan, S.; Williams, T.; Kenny, G.; MfE. (2008). Climate change effects and impacts assessment: A guidance manual for local government in New Zealand. Report prepared for Ministry for the Environment, 2nd Edition, xviii + 149 p.

Scarf, F.; Keys, R.S.; Connell, R.J.; Cuff, J.R.I.; Waugh, J.R. (1987). Report on flood: 13th March 1986. South Canterbury Catchment Board Publication No. 47.

Surman, M. (2013). Selwyn River/Waikirikiri capacity – Issues and options. Environment Canterbury Technical Report U13/2. November 2013.

Appendix A: Rainfall and flow data

Table A-1: Waiau River peak flows and Mason River catchment rainfall (and flow) during significant historic Waiau River flood events (red = northwest storm event, blue = predominantly southerly/easterly)

Event	Waiau peak flow (m^3/s)	Mason peak flow (m^3/s)	Gauge	24 hr (mm)	48 hr (mm)	72 hr (mm)	Event total (mm)
May1988	1650	-	Whales Back	29	31	36	38
			Keinton Combe	12	13	19	19
			Highfield	19	20	24	25
			Waiau (Lyndon St.)	18	20	25	26
Nov 1984	1503	-	Whales Back	0	0	0	0
			Keinton Combe	0	0	0	0
			Highfield	0	0	0	0
			Waiau (Lyndon St.)	5	7	7	9
Sept 1988	1460	-	Whales Back	3	3	3	3
			Keinton Combe	0	0	0	0
			Highfield	1	1	1	1
			Waiau (Lyndon St.)	1	1	1	1
Oct 1968	1442	-	Whales Back	44	49	54	71
			Keinton Combe	17	21	21	37
			Highfield	18	21	23	37
			Waiau (Po)	24	24	36	36
Nov 1994	1395	-	Whales Back	45	69	74	76
			Keinton Combe	16	23	26	26
			Highfield	22	36	37	37
Oct 2013	1351	25	Whales Back	15	21	33	33
			Keinton Combe	13	17	17	28
			Waiau (School)	10	13	13	22
Dec 2010	1330	3	Whales Back	24	24	24	24
			Keinton Combe	8	14	14	14
			Highfield	14	14	14	14
			Waiau (School)	8	15	15	15
Dec 1993	1312	-	Whales Back	178	233	253	253
			Keinton Combe	116	160	163	192
			Highfield	99	99	120	120

Table A-2: Waiau and Mason River peak flows, and Mason catchment rainfall, during recent Mason River flood events (all events were predominantly southerly/easterly)

Event	Waiau peak flow (m^3/s)	Mason peak flow (m^3/s)	Gauge	24 hr (mm)	48 hr (mm)	72 hr (mm)	Event total (mm)
Jul 2008	868	~320	Whales Back	111	176	206	206
			Keinton Combe	135	167	189	189
			Highfield	129	143	156	156
Aug 2012	314	161	Whales Back	97	102	102	102
			Keinton Combe	75	79	79	79
			Waiau School	42	46	46	46
May 2013	270	200	Whales Back	87	191	191	191
			Keinton Combe	45	46	46	46
			Waiau (School)	15	17	17	17
Apr 2014	351	156	Whales Back	69	106	106	106
			Keinton Combe	69	95	96	96
			Waiau (School)	33	43	43	43

Appendix B: Model cross section locations

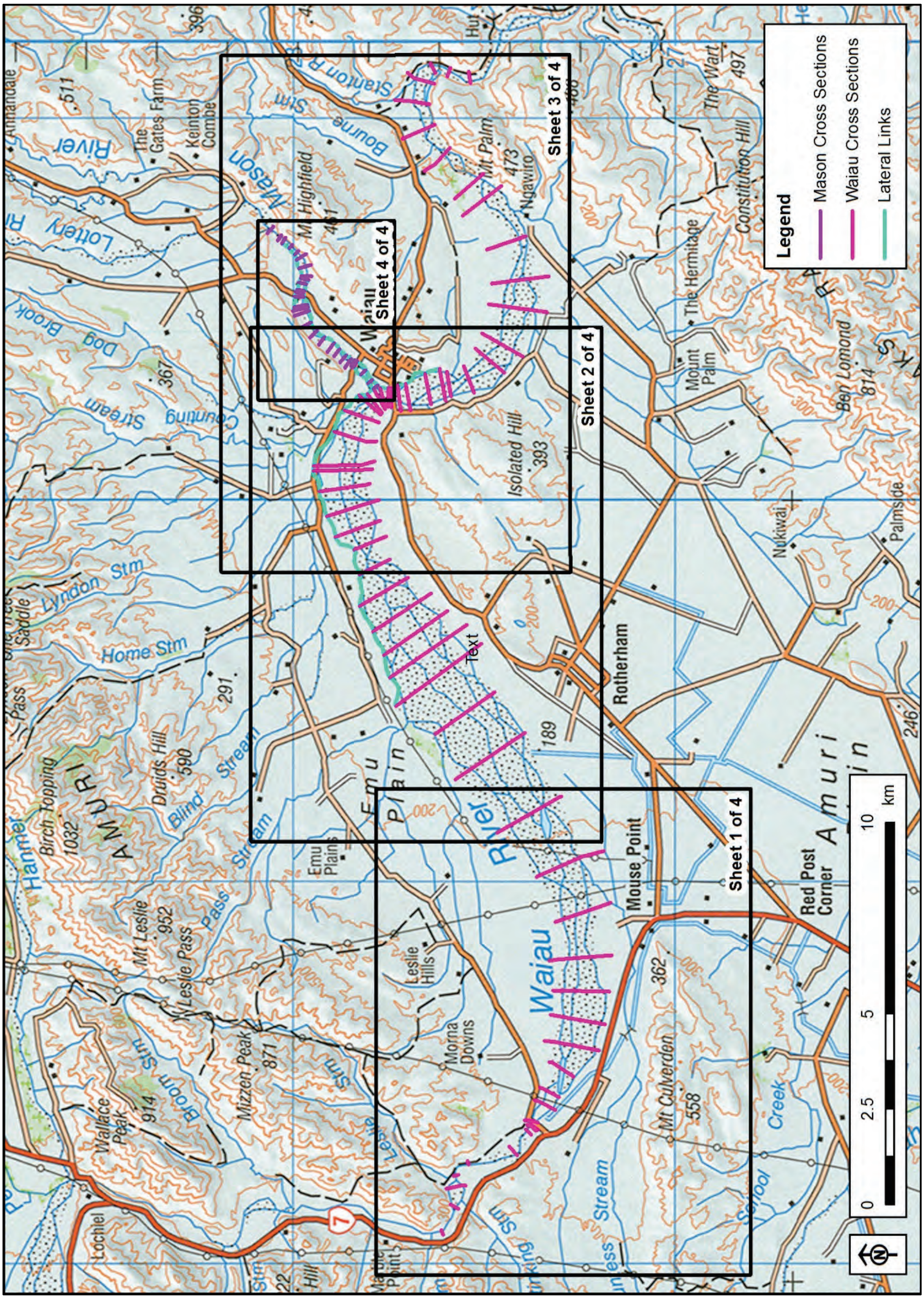


Figure B-1: Overview of Waiau and Mason River Mike 11 model cross sections and overflows (represented by 'lateral links')

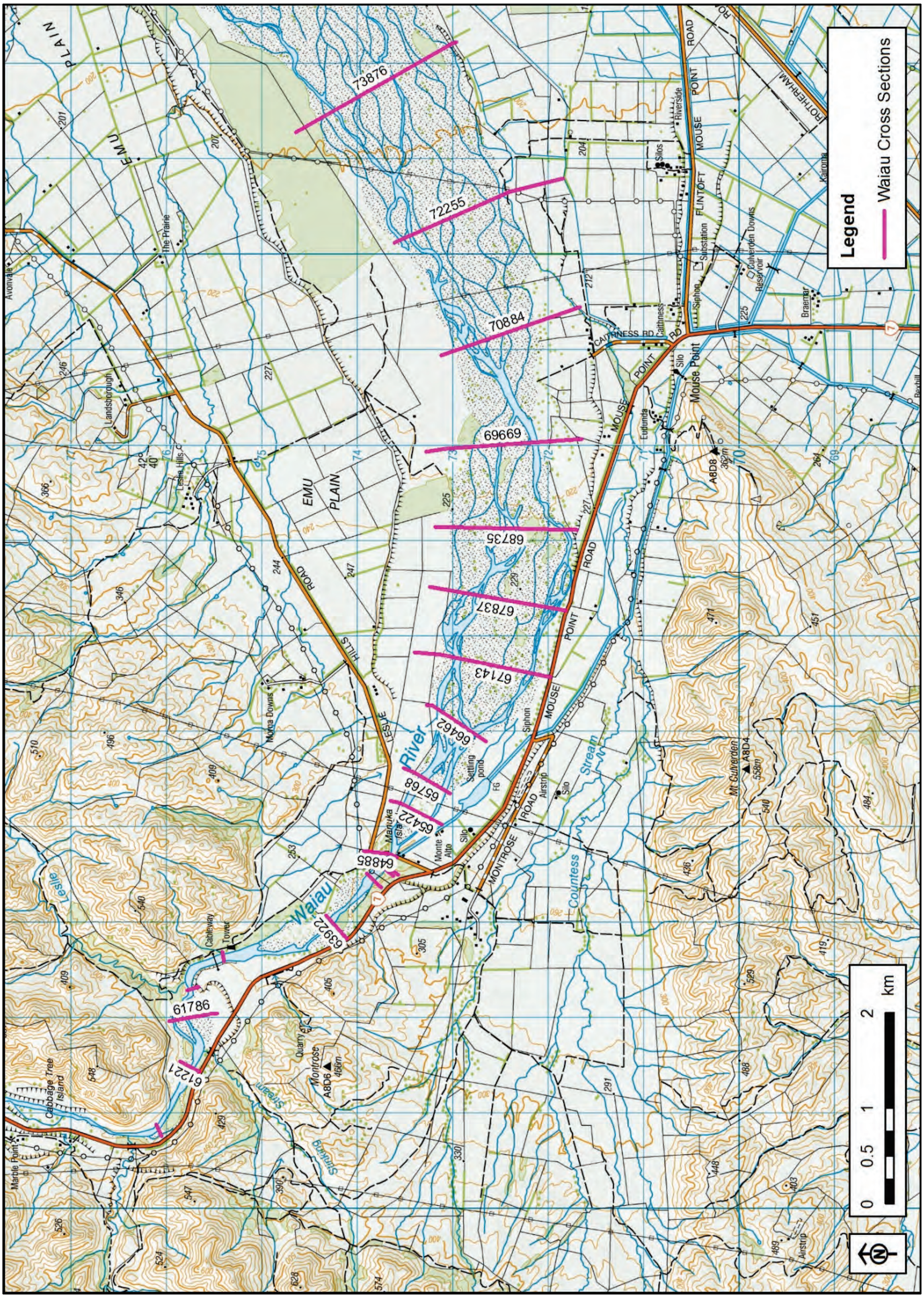


Figure B-2: Location of Waiau and Mason River Mike 11 model cross sections and overflows (1 of 4)

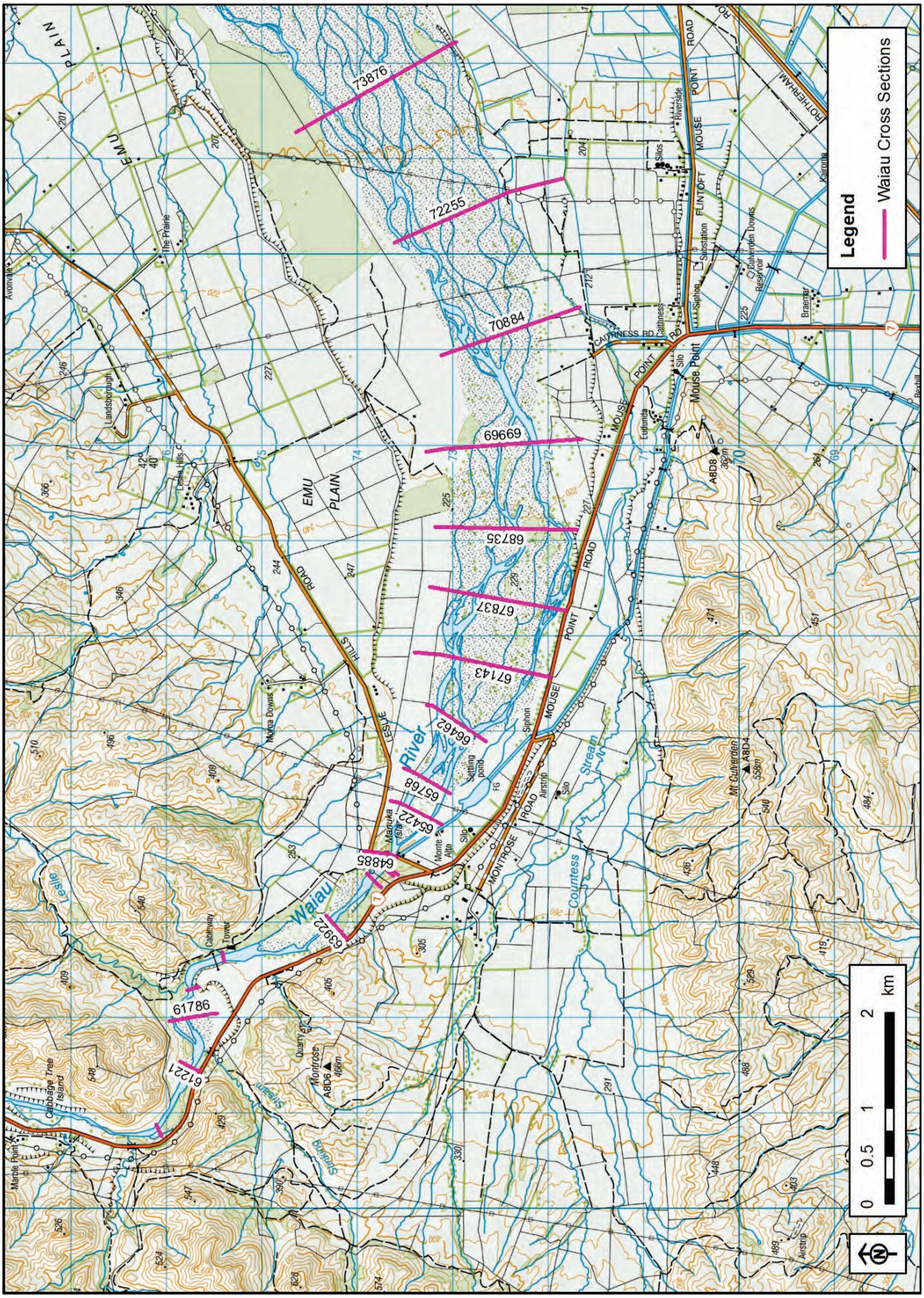


Figure B-3: Location of Waiau and Mason River Mike 11 model cross sections and overflows (2 of 4)

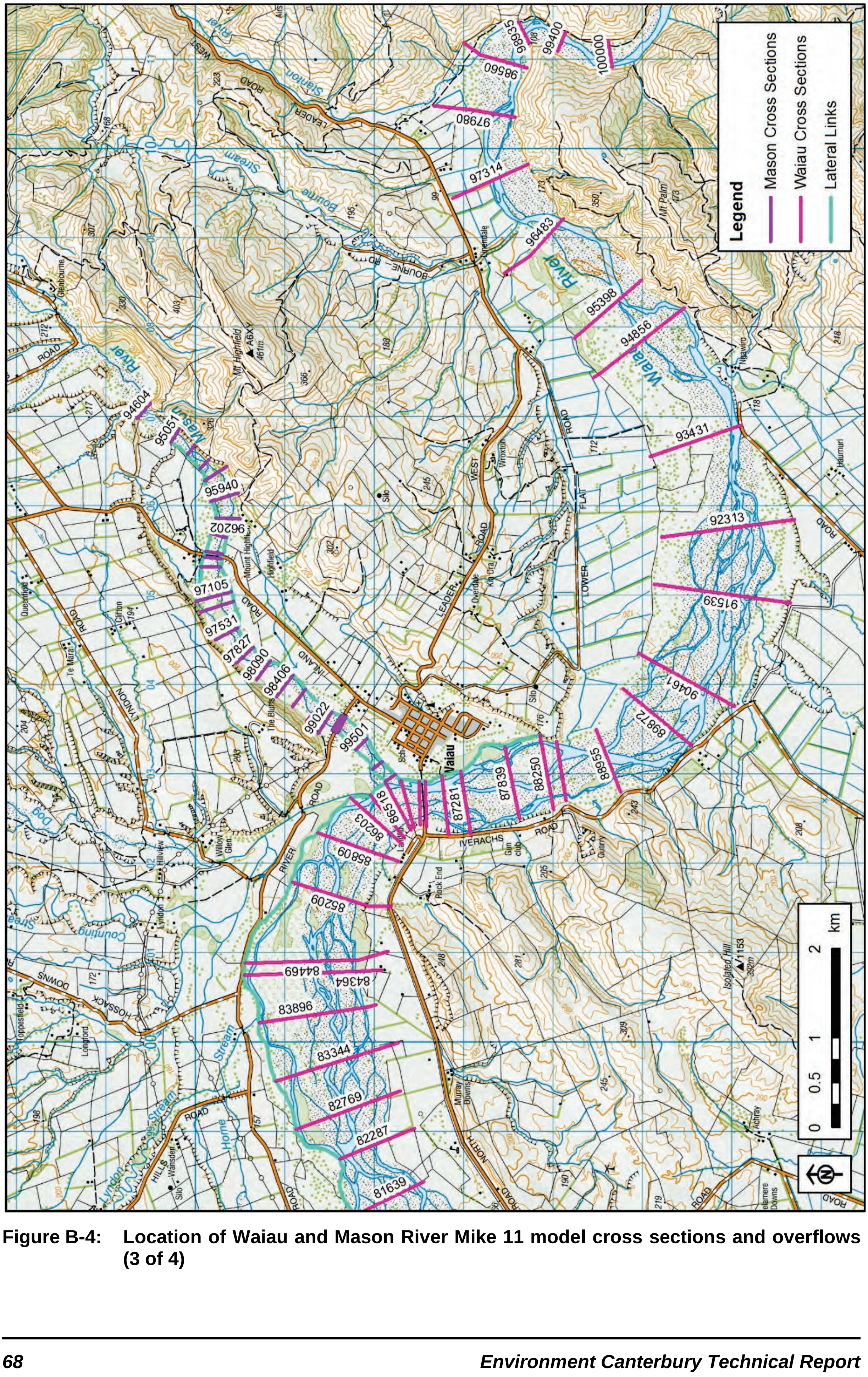


Figure B-4: Location of Waiau and Mason River Mike 11 model cross sections and overflows (3 of 4)

Figure B-5: Location of Waiau and Mason River Mike 11 model cross sections and overflows (4 of 4)

Table B-1: Summary of Mike 11 cross section information for the Waiau River

Mike 11 chainage	Data source	Location/Description
60478	LiDAR	
61221	LiDAR	
61786	LiDAR	
62104	LiDAR	
62668	LiDAR	
63922	LiDAR	
64557	LiDAR	
64722	LiDAR	
64755	LiDAR	
64885	LiDAR	
65422	LiDAR	
65768	LiDAR	
66462	LiDAR	
67143	LiDAR	
67837	LiDAR	
68735	LiDAR	
69669	LiDAR	
70884	LiDAR	
72255	LiDAR	
73876	LiDAR	
75746	LiDAR	
77079	LiDAR	
78300	LiDAR	
78955	LiDAR	
79536	LiDAR	
80179	LiDAR	
80871	LiDAR	
81639	LiDAR	
82287	LiDAR	
82769	LiDAR	
83344	LiDAR	
83896	LiDAR	
84469	LiDAR	
85209	LiDAR	
85809	LiDAR	
86203	LiDAR	
86339	LiDAR	
86518	LiDAR	
86628	LiDAR	Downstream of the Mason River confluence
86811	LiDAR (originally XS 86777)	Upstream of Waiau township bridge
86831	LiDAR (originally XS 86847)	Downstream of Waiau township bridge
87046	LiDAR	
87281	LiDAR	
87839	LiDAR	
88250	LiDAR	
88412	LiDAR	
88955	LiDAR	
89872	LiDAR	
90461	LiDAR	
91539	LiDAR	
92313	LiDAR	
93431	LiDAR	
94856	LiDAR	

Mike 11 chainage	Data source	Location/Description
95398	LiDAR	
96483	LiDAR	
97314	LiDAR	
97980	LiDAR	
98560	LiDAR	
98935	LiDAR	
99400	LiDAR	
100000	LiDAR	Downstream limit of model

Table B-2: Summary of Mike 11 cross section information for the Mason River

Mike 11 chainage	Data source	Location/Description
94604	LiDAR	
94918	LiDAR	
95051	LiDAR	
95292	LiDAR	
95509	LiDAR	
95663	LiDAR	
95940	LiDAR	
96202	LiDAR	
96430	LiDAR	
96640	LiDAR (originally XS 96627)	Upstream of Inland Road bridge
96660	LiDAR (originally XS 96686)	Downstream of Inland Road bridge
96787	LiDAR	
97026	LiDAR	
97105	LiDAR	
97223	LiDAR	
97531	LiDAR	
97827	LiDAR	
98090	LiDAR	
98406	LiDAR	
98623	LiDAR	
98858	LiDAR	
99022	LiDAR	
99153	LiDAR (originally XS 99132)	Upstream of River Road bridge
99173	LiDAR (originally XS 99198)	Downstream of River Road bridge
99501	LiDAR	
99800	LiDAR	
100000	LiDAR	Confluence with Waiau River

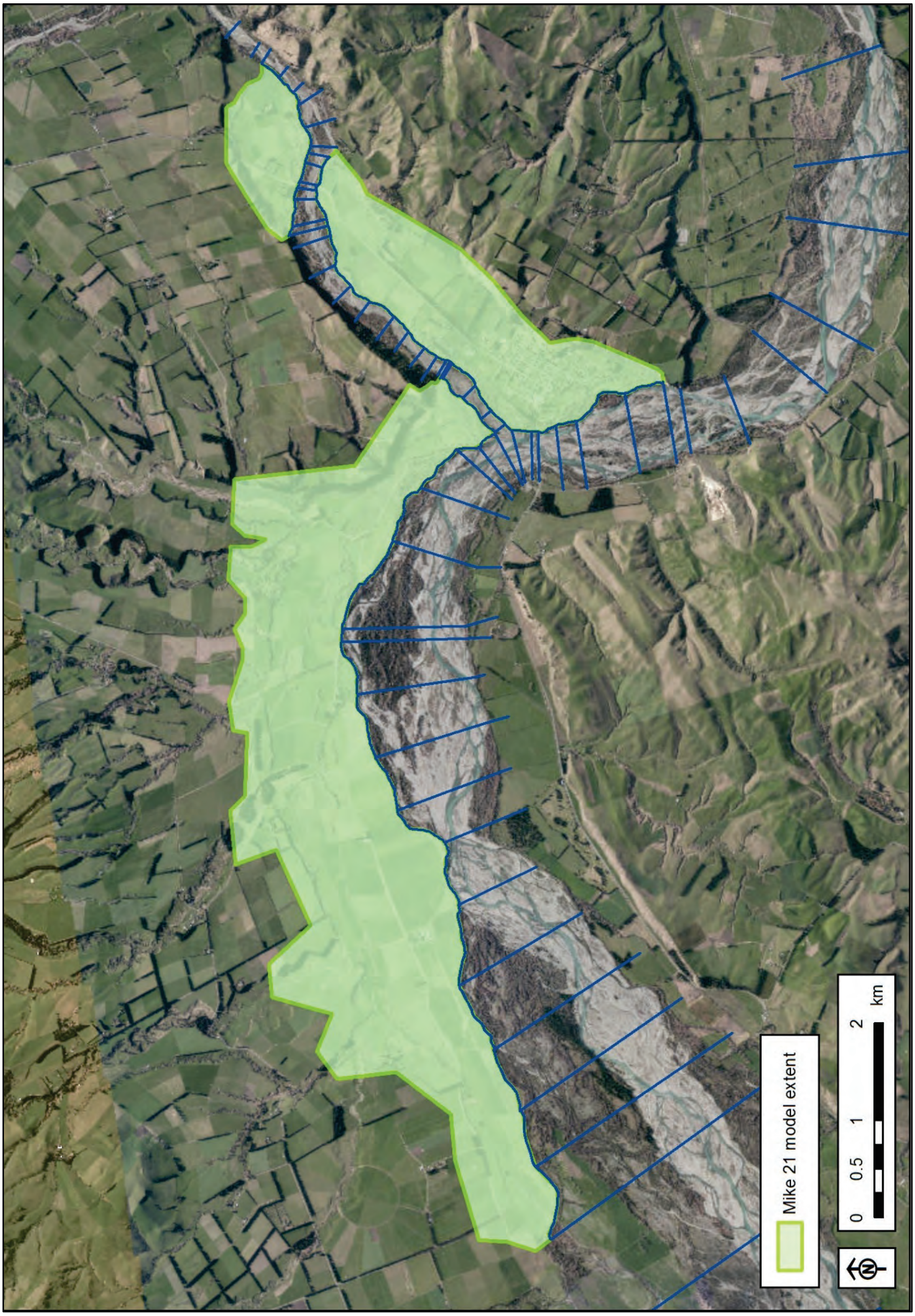


Figure B-6: Mike 21 model extent

Appendix C: Waiau floodplain maps

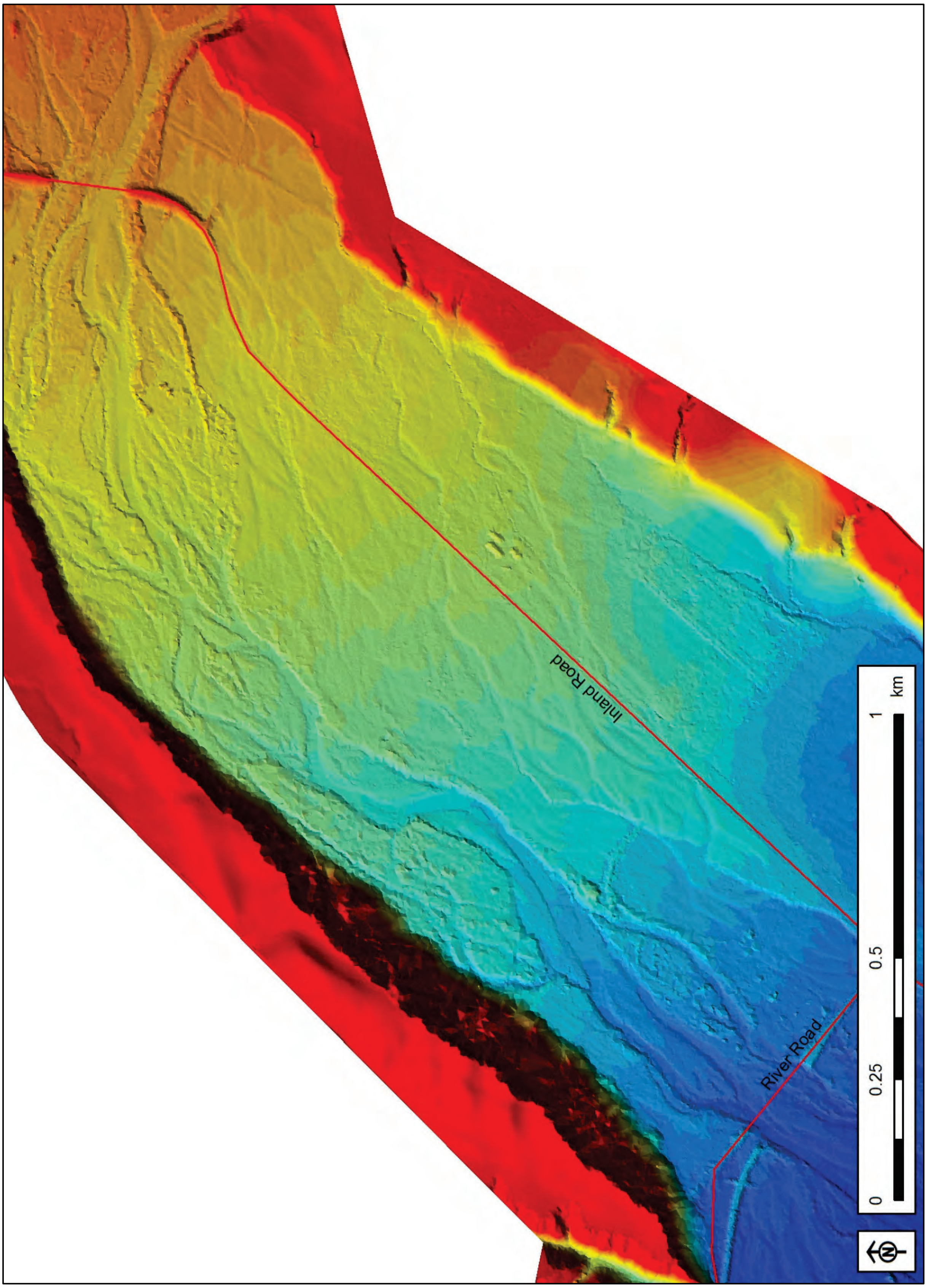


Figure C-1: Waiau floodplain LiDAR image

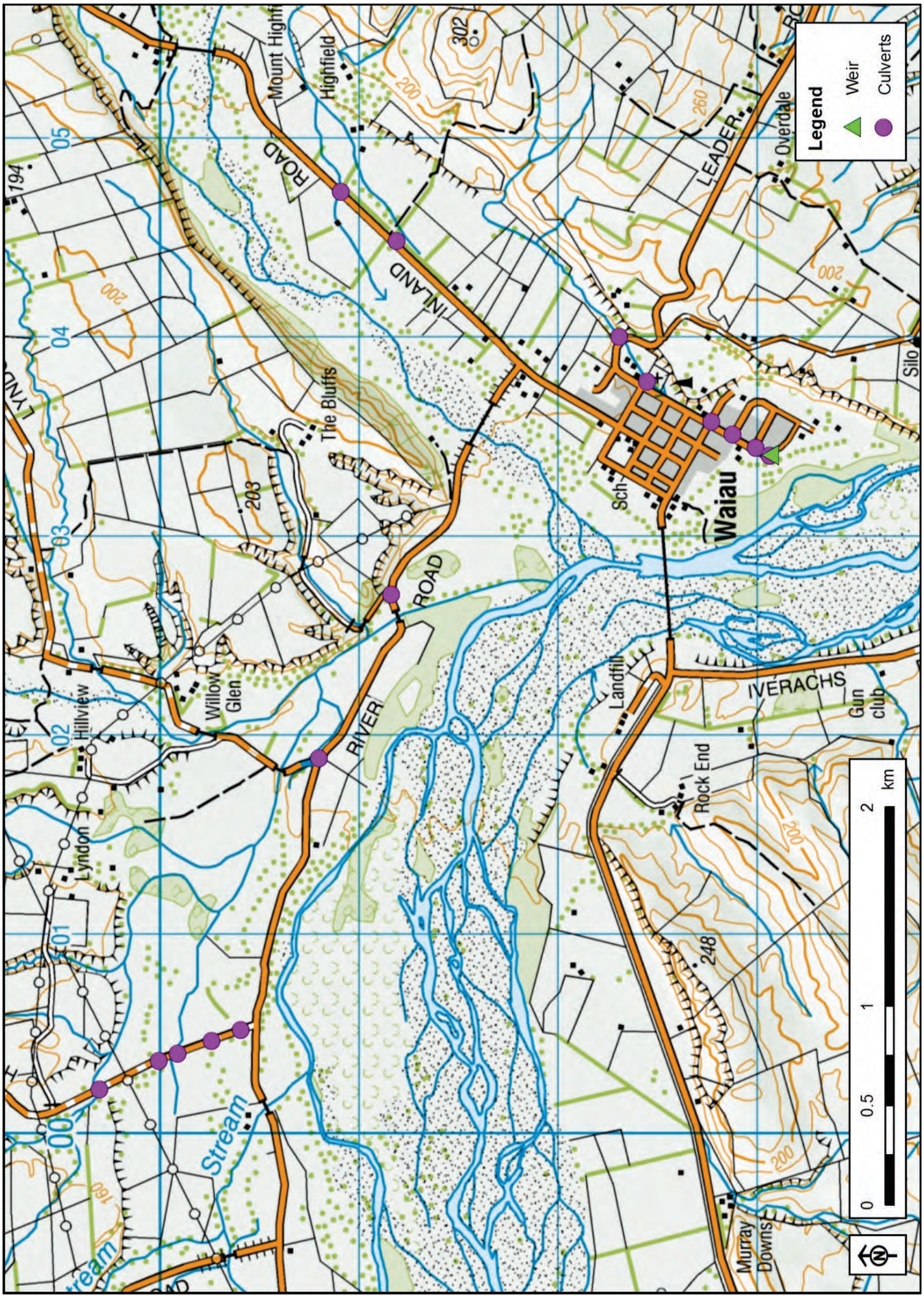


Figure C-2: Waiau floodplain culvert and weir location map

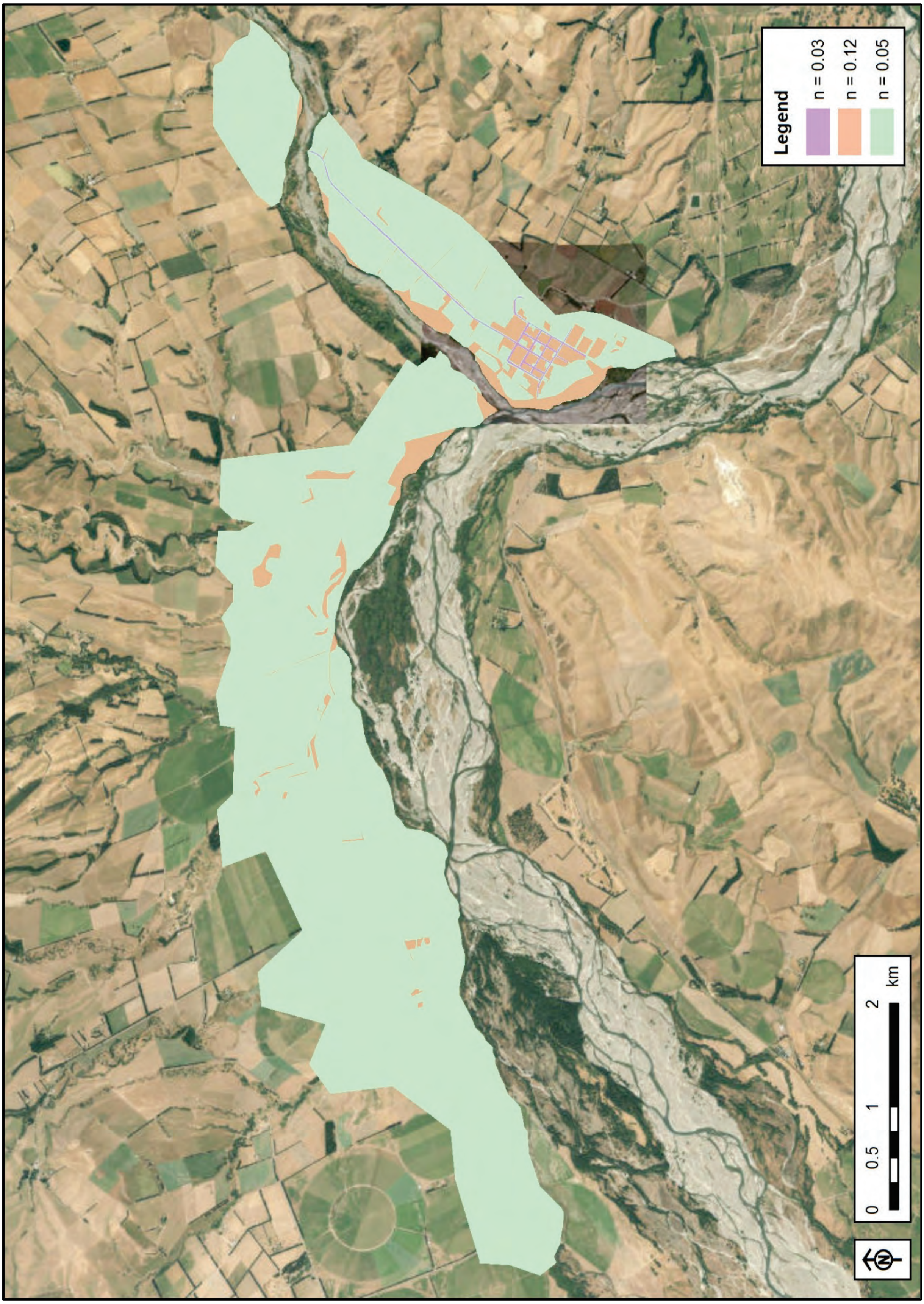


Figure C-3: Waiau floodplain roughness map showing Manning n (Manning M = 1/n)

Appendix D: Flood probability

Table D-1: Probability of design floods occurring over specified time intervals

Event	Probability of occurring in period		
ARI (% AEP[1])	**10 yr period**	**30 yr period**	**70 yr period**
20 year (5%)	40%	80%	97%
50 year (2%)	20%	50%	77%
100 year (1%)	10%	25%	50%
200 year (0.5%)	5%	15%	33%
500 year (0.2%)	2%	6%	12%

[1]AEP = Annual Exceedance Probability i.e. the chance of a flood that size occurring in any one year

For example there is 25% chance that a 100 year ARI (1% AEP) flood will occur within a 30 year period

Appendix E: Model run files

Calibration files

…\Model\Waiau*.*

September 1988
Recorded flow in Waiau River, low flows in other tributaries including Mason River

MikeFlood	***…\Model\Waiau\MikeFlood*.****
Couple file (*.mf)	Waiau_Sept_88_cal

Mike11	***…\Model\Waiau\1D*.****
Simulation file (*.sim11)	Waiau_Sept_88_cal
Network file (*.nwk11)	Waiau_NWK
Cross section file (*.xns11)	Waiau_River_2013_Lidar
Boundary file (*.bnd11)	Waiau_Sept_88_cal
HD parameter (*.hd11)	Waiau_HD
Results file (*.res11)	Waiau_Sept_88_cal

Mike21	***…\Model\Waiau\2D*.****
Simulation file (*.21)	Waiau_Sept_88_cal
Bathymetry file (*.dfs2)	waiau_5m_crop_20141223_v4
Initial surface elevation (*.dfs2)	0
Resistance (*.dfs2)	waiau_rough
Results (*.dfs2)	Waiau_Sept_88_cal_v2
Sources	(1569,932)→(1573,932), (1437,978)→(1440,978), (1171,989)→(1171,986), (999,979)→(999,975), (621,824)→(624,824), (471,793)→(471,790) and (2057, 587)
Sinks	-
Drying depth (m)	0.01
Wetting depth (m)	0.02
Eddy viscosity	0.5
Number of structures	15 culverts and 1 weir
Simulation start time	12/9/1988 12:30pm
Simulation end time	14/9/1988 12:30pm
Time step (s)	1
Length of run (# time steps)	172800

Waiau River flood event - design flood files

…\Model\Waiau*.*

50 yr ARI	200 yr ARI	500 yr ARI
50 year ARI Waiau, Mean Annual Flood Mason, 100m breach on Waiau at River Road	200 year ARI Waiau, Mean Annual Flood Mason, 100m breach on Waiau at River Road	500 year ARI Waiau, 5 year ARI Mason, 100m breach on Waiau at River Road

MikeFlood	**…\Model\Waiau\MikeFlood*.***		
Couple file (*.mf)	Waiau_50yr_100m_BO_IL_142_9m_Mason_MAF	Waiau_200yr_100m_BO_IL_142_9m_Mason_MAF_corr	Waiau_500yr_100m_BO_IL_142_9m_Mason_5yr
Waiau breakout file (*.dfs1)	Waiau_100m_BO_IL_142_9m		

Mike11	**…\Model\Waiau\1D*.***		
Simulation file (*.sim11)	Waiau_50yr_100m_BO_IL_142_9m_Mason_MAF	Waiau_200yr_100m_BO_IL_142_9m_Mason_MAF	Waiau_500yr_100m_BO_IL_142_9m_Mason_5yr
Network file (*.nwk11)	Waiau_NWK		
Cross section file (*.xns11)	Waiau_River_2013_Lidar		
Boundary file (*.bnd11)	Waiau_50yr_Mason_MAF_bnd	Waiau_200yr_Mason_MAF_bnd	Waiau_500yr_Mason_5yr_bnd
HD parameter (*.hd11)	Waiau_HD		
Results file (*.res11)	Waiau_50yr_100m_BO_IL_142_9m Mason_MAF	Waiau_200yr_100m_BO_IL_142_9m_Mason_MAF	Waiau_500yr_100m_BO_IL_142_9m_Mason_5yr

Mike21	**…\Model\Waiau\2D*.***		
Simulation file (*.21)	Waiau_50yr_100m_BO_IL_142_9m_Mason_MAF	Waiau_200yr_100m_BO_IL_142_9m_Mason_MAF	Waiau_500yr_100m_BO_IL_142_9m_Mason_5yr
Bathymetry file (*.dfs2)	waiau_5m_crop_20141223_v4_BO_Waiau_IL_142_9m		
Initial surface elevation (*.dfs2)	0		
Resistance (*.dfs2)	waiau_rough		
Results (*.dfs2)	Waiau_50yr_100m_BO_IL_142_9m_Mason_MAF	Waiau_200yr_100m_BO_IL_142_9m_Mason_MAF	Waiau_500yr_100m_BO_IL_142_9m_Mason_5yr
Sources	(1569,932)→(1573,932), (1437,978)→(1440,978), (1171,989)→(1171,986), (999,979)→(999,975), (621,824)→(624,824), (471,793)→(471,790) and (2057, 587)		
Sinks	-		
Drying depth (m)	0.01		
Wetting depth (m)	0.02		
Eddy viscosity	0.5		
Number of structures	15 culverts and 1 weir		
Simulation start time	19/5/1988 6:41am		
Simulation end time	20/5/1988 6:41am		
Time step (s)	1		
Length of run (# time steps)	86400		

Mason River flood event - design flood files

…\Model\Waiau*.*

	50 yr ARI	**200 yr ARI**	**500 yr ARI**
	50 year ARI Mason, 10 year ARI Waiau, no breaches	200 year ARI Mason, 20 year ARI Waiau, 40m breach on Mason	500 year ARI Mason, 50 year ARI Waiau, 40m breach on Mason/100 m breach on Waiau

MikeFlood	**…\Model\Waiau\MikeFlood*.***		
Couple file (*.mf)	Mason_50yr_Waiau_10yr	Mason_200yr_40m_BO_IL_162_7m_Waiau_20yr_rev	Mason_500yr_40m_BO_IL_162_7m_Waiau_50yr_100m_BO_IL_142_9m
Mason breakout file (*.dfs1)	-	Mason_40m_BO_IL_162_7m_rev	Mason_40m_BO_IL_162_7m_rev
Waiau breakout file (*.dfs1)	-	-	Waiau_100m_BO_IL_142_9m

Mike11	**…\Model\Waiau\1D*.***		
Simulation file (*.sim11)	Mason_50yr_Waiau_10yr	Mason_200yr_40m_BO_IL_162_7m_Waiau_20yr_rev	Mason_500yr_40m_BO_IL_162_7m_Waiau_50yr_100m_BO_IL_142_9m
Network file (*.nwk11)		Waiau_NWK	
Cross section file (*.xns11)		Waiau_River_2013_Lidar	
Boundary file (*.bnd11)	Mason_50yr_Waiau_10yr_bnd	Mason_200yr_Waiau_20yr_bnd	Mason_500yr_Waiau_50yr_bnd
HD parameter (*.hd11)		Waiau_HD	
Results file (*.res11)	Mason_50yr_Waiau_10yr_no_BO	Mason_200yr_40m_BO_IL_162_7m_Waiau_20yr_rev	Mason_500yr_40m_BO_IL_162_7m_Waiau_50yr_100m_BO_IL_142_9m

Mike21	**…\Model\Waiau\2D*.***		
Simulation file (*.21)	Mason_50yr_Waiau_10yr	\Mason_200yr_40m_BO_IL_162_7m_Waiau_20yr_rev	Mason_500yr_40m_BO__IL_162_7m_Waiau_50yr_100m_BO_IL_142_9m
Bathymetry file (*.dfs2)	waiau_5m_crop_20141223_v4	waiau_5m_crop_20141223_v4_BO_Mason_IL_162_7m	waiau_5m_crop_20141223_v4_BOs_Mason_IL_162_7m_Waiau_IL_142_9m
Initial surface elevation (*.dfs2)		0	
Resistance (*.dfs2)		waiau_rough	
Results (*.dfs2)	Mason_50yr_Waiau_10yr_no_BO	Mason_200yr_40m_BO_IL_162_7m_Waiau_20yr_rev	Mason_500yr_40m_BO_IL_162_7m_Waiau_50yr_100m_BO_IL_142_9m
Sources		(1569,932)→(1573,932), (1437,978)→(1440,978), (1171,989)→(1171,986), (999,979)→(999,975),	

	Continued … (621,824)→(624,824), (471,793)→(471,790) and (2057, 587)
Sinks	-
Drying depth (m)	0.01
Wetting depth (m)	0.02
Eddy viscosity	0.5
Number of structures	15 culverts and 1 weir
Simulation start time	19/5/1988 6:41am
Simulation end time	20/5/1988 6:41am
Time step (s)	1
Length of run (# time steps)	86400

Sensitivity test files (using 200 year ARI Mason River flood event)

…\Model\Waiau*.*

	Increased Manning 'n' in Waiau & Mason Rivers	Increased Manning 'n' on floodplain	Increased breach size
	Manning 'n' in Waiau & Mason Rivers increased from 0.040 to 0.050.	Manning 'n' increased by 25%	200 year ARI Mason, 20 year ARI Waiau, 80m breach on Mason

MikeFlood	**…\Model\Waiau\MikeFlood*.***		
Couple file (*.mf)	Mason_200yr_40m_BO_IL_162_7m_Waiau_20yr_rev_mason_n_plus_25perc	Mason_200yr_40m_BO_IL_162_7m_Waiau_20yr_rev_fp_n_plus_25perc	Mason_200yr_80m_BO_IL_162_7m_Waiau_20yr
Mason breakout file (*.dfs1)	Mason_40m_BO_IL_162_7m_rev	Mason_40m_BO_IL_162_7m_rev	Mason_80m_BO_IL_162_7m

Mike11	**…\Model\Waiau\1D*.***		
Simulation file (*.sim11)	Mason_200yr_40m_BO_IL_162_7m_Waiau_20yr_rev_mason_n_plus_25perc	Mason_200yr_40m_BO_IL_162_7m_Waiau_20yr_rev_fp_n_plus_25perc	Mason_200yr_80m_BO_IL_162_7m_Waiau_20yr
Network file (*.nwk11)	Waiau_NWK		
Cross section file (*.xns11)	Waiau_River_2013_Lidar		
Boundary file (*.bnd11)	Mason_200yr_Waiau_20yr_bnd		
HD parameter (*.hd11)	Waiau_HD_mason_n_plus_25perc	Waiau_HD	Waiau_HD
Results file (*.res11)	Mason_200yr_40m_BO_IL_162_7m_Waiau_20yr_rev_mason_n_plus_25perc	Mason_200yr_40m_BO_IL_162_7m_Waiau_20yr_rev_fp_n_plus_25perc	Mason_200yr_80m_BO_IL_162_7m_Waiau_20yr

Mike21	**…\Model\Waiau\2D*.***		
Simulation file (*.21)	Mason_200yr_40m_BO_IL_162_7m_Waiau_20yr_rev_mason_n_plus_25perc	Mason_200yr_40m_BO_IL_162_7m_Waiau_20yr_rev_fp_n_plus_25perc	Mason_200yr_80m_BO_IL_162_7m_Waiau_20yr
Bathymetry file (*.dfs2)	waiau_5m_crop_20141223_v4_BO_Mason_IL_162_7m		
Initial surface elevation (*.dfs2)	0		
Resistance (*.dfs2)	waiau_rough	waiau_rough_fp_n_plus_25perc	waiau_rough
Results (*.dfs2)	Mason_200yr_40m_BO_IL_162_7m_Waiau_20yr_rev_mason_n_plus_25perc	Mason_200yr_40m_BO_IL_162_7m_Waiau_20yr_rev_fp_n_plus_25perc	Mason_200yr_80m_BO_IL_162_7m_Waiau_20yr

	Continued …
Sources	(1569,932)→(1573,932), (1437,978)→(1440,978), (1171,989)→(1171,986), (999,979)→(999,975), (621,824)→(624,824), (471,793)→(471,790) and (2057, 587)
Sinks	-
Drying depth (m)	0.01
Wetting depth (m)	0.02
Eddy viscosity	0.5
Number of structures	15 culverts and 1 weir
Simulation start time	19/5/1988 6:41am
Simulation end time	20/5/1988 6:41am
Time step (s)	1
Length of run (# time steps)	86400

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

Everything is connected

Promoting quality of life through balanced resource management

www.ecan.govt.nz

Environment Canterbury offices

Christchurch
58 Kilmore Street
PO Box 345
Christchurch 8013
P: 03 365 3828
F: 03 365 3194

Timaru
75 Church Street
PO Box 550
Timaru 7940
P: 03 687 7800
F: 03 687 7808