Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

TECHNICAL REPORT Science Group

Little River/Wairewa floodplain investigation

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Environment Canterbury
Regional Council
Kaunihera Taiao ki Waitaha

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Summary

Background
The Little River catchment, with an area of 85 km^2, is located approximately 30 km south-east of Christchurch on Banks Peninsula. In recent years, rainfall events have caused extensive flooding within the Little River township. This flooding has inundated businesses, dwellings, and the main roads. The largest of these flood events was on 5 March 2014 and produced flooding in some areas previously perceived to have little or no chance of flooding.

What we did
In this study we used a combined one-dimensional and two-dimensional hydraulic computer model to estimate flood extent and water depths for 5 to 500 year Average Recurrence Interval (ARI) flood events. Additional model runs were completed to address model uncertainty, the effects of Te Roto o Wairewa/Lake Forsyth on flood levels in the township, and the impact that various improvements to the river system (e.g. vegetation clearance) are likely to have on flooding.

What we found
There is good agreement between the modelled and observed flooding for the March 2014 flood event.

To reduce flooding in the Little River catchment, vegetation clearance and/or engineering options can alleviate flooding, while reductions in Te Roto o Wairewa/Lake Forsyth levels will not have a significant impact on flooding – except in the area immediately adjacent to the lake.

What does this mean?
Modelled 5 to 500 year ARI flood depths and flow velocities will assist land use planning, emergency planning and identification of ‘high hazard’ areas. This will allow appropriate floor levels for new buildings and extensions to be determined.

The model developed as part of this study can also be used to analyse existing or proposed flood protection works and other scheme improvements.

How we have considered climate change

To allow for climate change to 2120, current design peak flow estimates have been increased by 25%. No specific allowances have been made for sea level rise as, in the short-term, it is assumed that this will be managed by more frequent Te Roto o Wairewa/Lake Forsyth openings. Modelling also showed that, with existing Te Roto o Wairewa/Lake Forsyth levels raised by 1.0 m, increases in maximum water levels were limited to the lake shoreline and the land immediately adjacent to the lake. We recommend that these climate change assumptions are updated as better information becomes available.

The Okana River in flood on 19 October 2011. The petrol station is in Little River on SH75.
[Photo: Shona Mackintosh, CC BY-SA 2.0]

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1 Introduction

The Little River township is located on State Highway 75, between Christchurch and Akaroa (Figure 1-1). The Okana River flows to the east of the township, draining the upstream streams and hill slopes into the Takiritawai River and Te Roto o Wairewa/Lake Forsyth.

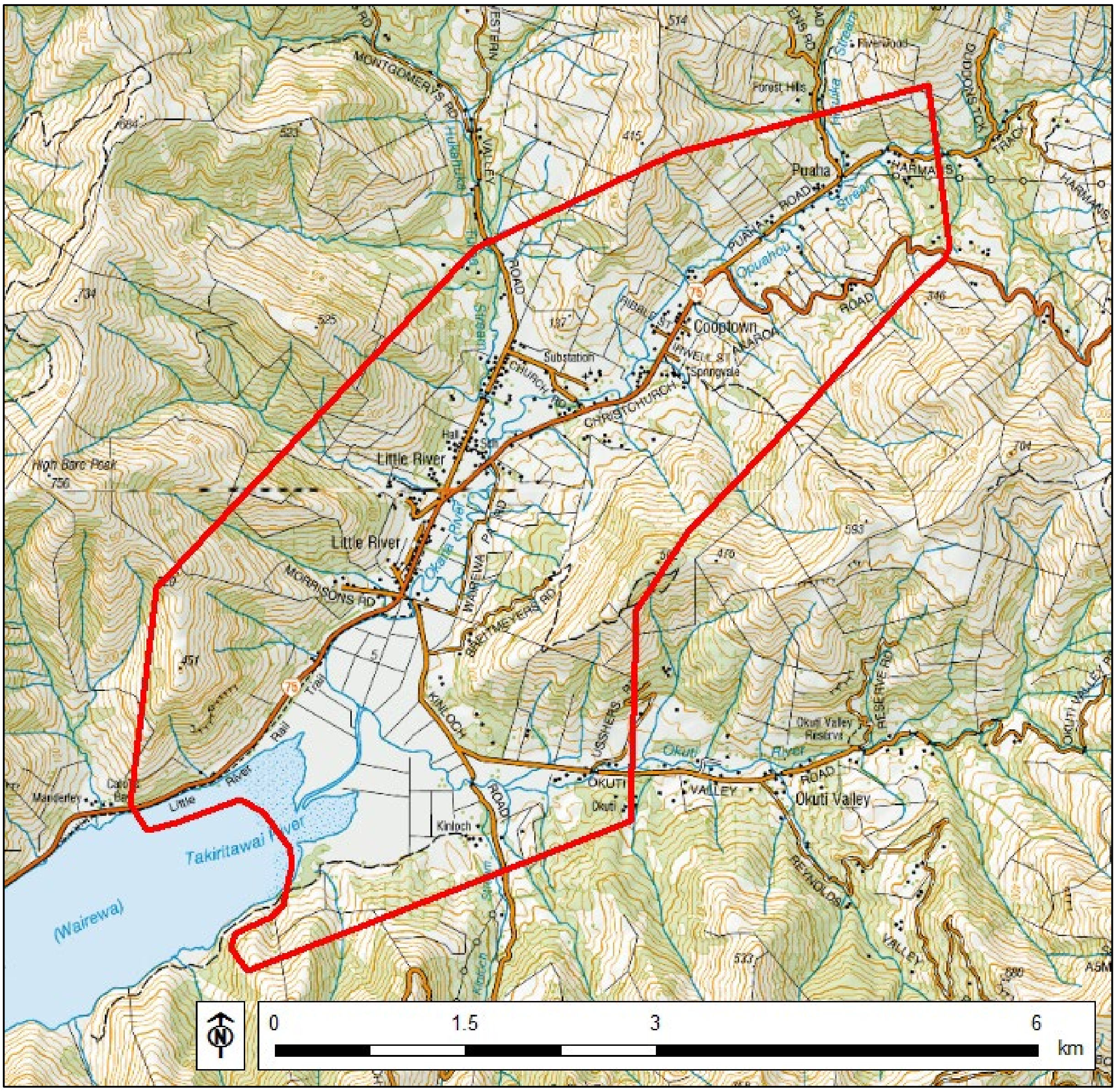


Figure 1-1: Location map showing the study area

In recent years, rainfall events have caused extensive flooding within the township, inundating businesses, residential dwellings, and the main roads. The largest of the recent flood events occurred on 5 March 2014, flooding some areas previously perceived to have little or no chance of flooding.

This report describes the detailed topographic data, and the combined one and two-dimensional hydraulic computer model used to simulate the behaviour of the river system during flood events. The hydraulic computer model is partially validated using observations from the 5 March 2014 flood. Impacts of vegetation clearance, and three options to alleviate flooding, are modelled as well as the 5, 10, 20, 50, 100, 200, and 500 year Average Recurrence Interval (ARI) flood events. Areas identified as 'high hazard' in the Canterbury Regional Policy Statement (RPS) are also identified for the 500 year ARI flood event.

2 Background

2.1 Study area

The Little River township is located on the floodplain of the Okana River. The Okana River drains the surrounding hills and streams, flowing into Te Roto o Wairewa/Lake Forsyth via the Takiritawai River.

2.1.1 Little River catchment

The Takiritawai River catchment has an area of 85 km^2 and consists predominantly of steep hill slopes that are subject to heavy rain during storm events.

The location of the main rainfall recorders in the catchment are shown on Figure 2-1, with information relating to the rainfall recorders summarised in Table 2-1. The catchment has been divided into the 7 subcatchments identified on Figure 2-2. These subcatchments have been used to determine the inflows to the model for this investigation.

Table 2-1: Summary of rainfall data for the Little River area

Site	Site Number	River basin	Elevation (m)	Start date	End date	Mean annual rainfall (mm)
Kaituna Valley	327701[a]	Banks Peninsula		1/1/1951	1/1/2008	1437
Okuti	327801[a]	Okuti	61	9/1915	-	1190[c]
4960 ChCh Akaroa Hwy	327804		270	12/11/2012	-	-
Okuti Valley	327810	Okuti Valley	152	26/8/1958	6/1965	-
Summit	327811	Hukahuka	610	18/8/1989	7/7/1999	1052
Kaituna Valley Rd	328711	Kaituna	70	1/6/1990	-	820
Brankins Br	328816	Reynolds	152	20/12/1967	30/6/1976	-
Lathams Rd	328820[b]	Hukahuka	70	19/2/1988	8/1/1992	810
Hilltop	328914	Barrys Bay	487	17/5/1989	7/7/1999	1159

[a] Daily record
[b] Replaced by Site 327811
[c] Only record from 1980 onwards is used in mean annual rainfall calculation

2.1.2 Little River streams and rivers

The Hukahuka Turoa Stream and Opuahou Stream converge upstream of the Little River township to form the Okana River. The Okana River flows downstream towards Te Roto o Wairewa/Lake Forsyth, converging with Police Creek (at the township) and the Okuti River (downstream of the township). Downstream of the Okana River/Okuti stream confluence, the watercourse becomes the Takiritawai River before entering the lake.

Water level/flow data is collected for the Hukahuka Turoa Stream at Lathams Bridge (Site 67602) by the National Institute of Water and Atmospheric Research (NIWA). This is currently the only continuous (and rated) water level recorder in the catchment. The location of this site is shown on Figure 2-1 and Table 2-2 summarises available flow data.

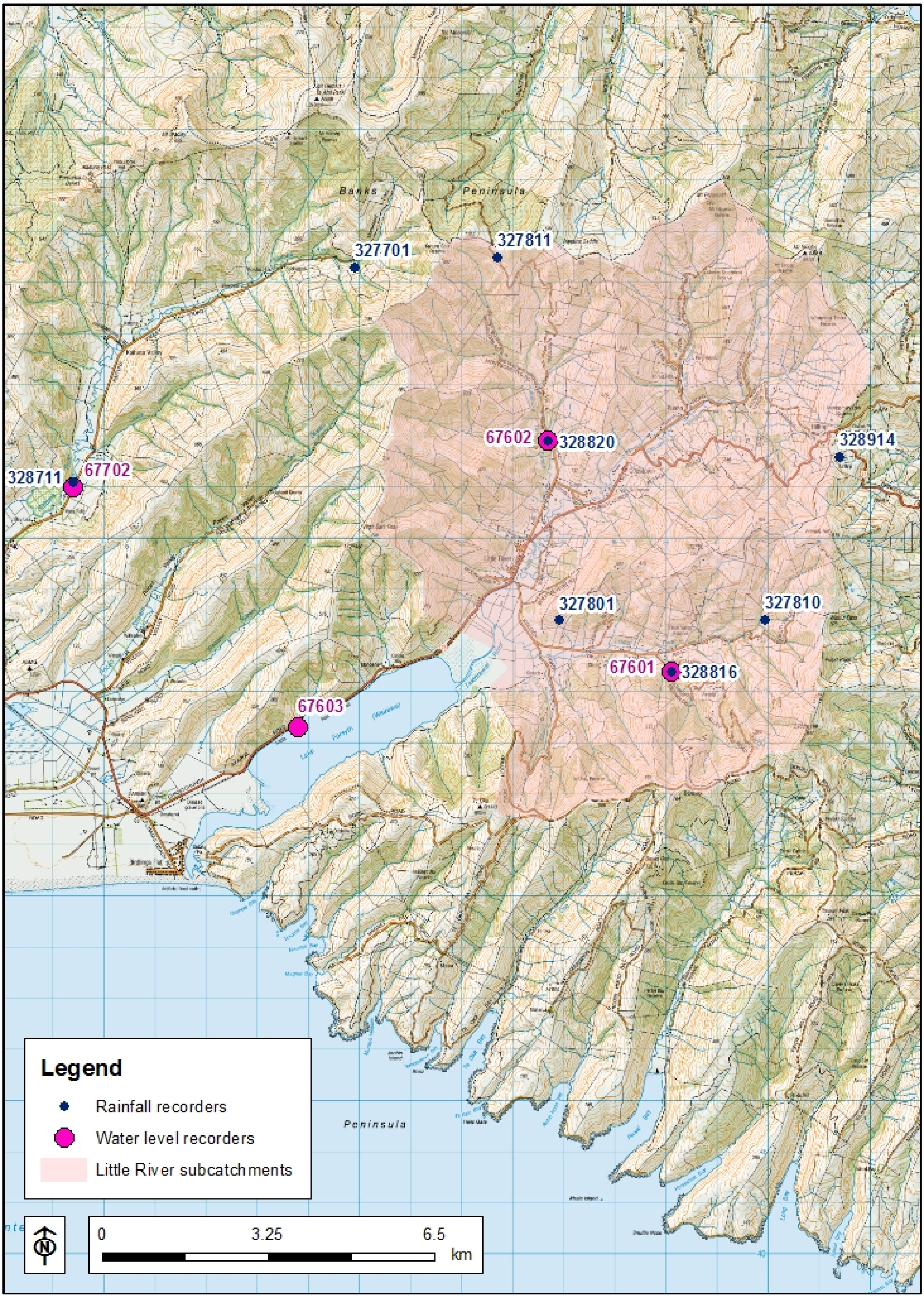


Figure 2-1: Location of rainfall and water level/flow recorders

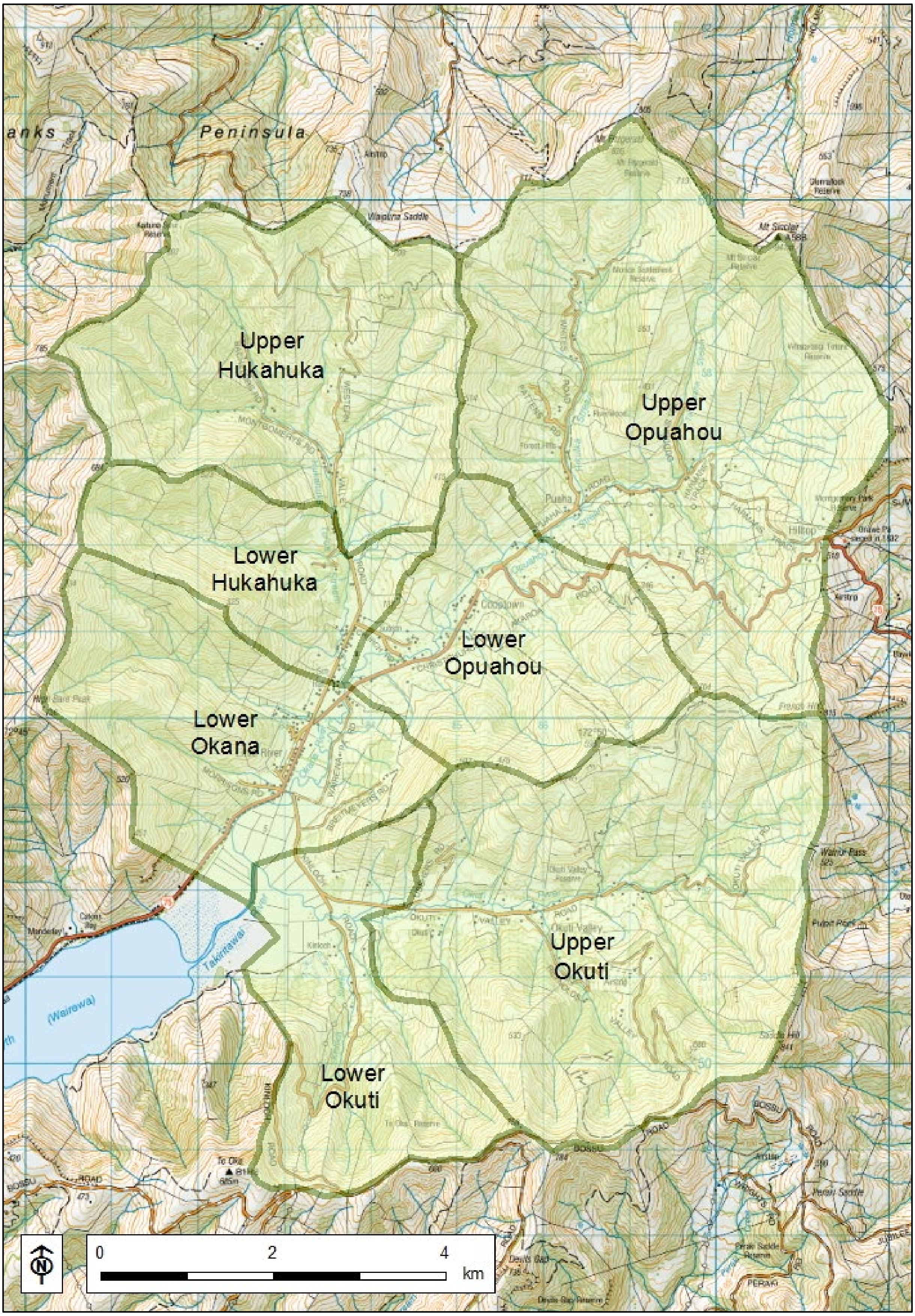


Figure 2-2: Little River (Takiritawai River) subcatchments

Table 2-2: Flow data for the Little River area

Site	Site Number	Catchment area (km²)	Start date	End date	Mean flow (m³/s)	Maximum flow
Reynolds at Brankins Br	67601	3.2	21/12/1967	30/6/1976	0.08	13.0 m³/s (11/4/1968)
Hukahuka at Lathams Br	67602	13.0	14/12/1987	-	0.2	30.5 m³/s (18/4/2014)
Kaituna at Kaituna Valley Road	67702	39.5	9/6/1986	-	0.6	92.3 m³/s (17/5/1993)

Recent reports (e.g. Vallance, 2014) indicated that there were significant restrictions to flood flows, such as trees, between the Kinloch Bridge (over the Okana River) and Te Roto o Wairewa/Lake Forsyth). This is a direct consequence of limited clearance work being undertaken in the past 30 years, and is understood from previous modelling work (Blakely, 2014) to have exacerbated flooding in the Little River township area. Since the Wairewa Rating District was established in 2015/16, work has been undertaken to remove these restrictions from the watercourse. This work is ongoing.

2.1.3 Te Roto o Wairewa/Lake Forsyth

Te Roto o Wairewa/Lake Forsyth is a shallow lake located ~1.5 to 2 km downstream of Kinloch Road and the Little River township. The lake is over 4 km long and ~1 km wide, with the outlet to the sea located at the south-western end.

Prior to the 19th century, the area that the lake occupies was an estuary/coastal inlet. However, by the 1840s, a gravel beach barrier (Kaitorete Spit) had formed across the inlet creating the current lake (Schallenberg & Schallenberg, 2013). Since the early 1900s, the lake has been reported as being eutrophic; algal blooms and fish deaths were reported as early as 1907 (Schallenberg & Schallenberg, 2013 from Pyle, 1992). At present, there is no permanent lake outlet to the sea through the gravel beach barrier. Instead, the outlet is mechanically opened as required.

Water level data is collected for Te Roto o Wairewa/Lake Forsyth at the Christchurch Akaroa Road (Site 67603). The location of this water level site is shown on Figure 2-1 and Table 2-3 summarises the water level site data.

Table 2-3: Summary of Te Roto o Wairewa/Lake Forsyth water level data

Site	Site Number	Lake area (km²)	Start of record	Mean lake level	Maximum lake level
Te Roto o Wairewa/Lake Forsyth at ChCh Akaroa Rd (SH75)	67603	-	April 1995	~1.6 m	3.07 m (28 June 2010)

2.2 Historic flooding

The Little River township has a long history of flooding due to prolonged, high-intensity rainfall in the Okana River catchment. Table A-1 (Appendix A) summarises historic flooding in the Little River area.

Post-flood analyses of the August 2012 flood event concluded that flooding in the Little River township area would have occurred for this flood event (and, therefore, other previous flood events) regardless of Te Roto o Wairewa/Lake Forsyth levels. The reason for this is the relatively confined Okana River (and tributaries) and floodplain width where the township is located (Harrington, 2013).

2.3 Wairewa Rivers Rating District

The Wairewa Rivers Rating District area is shown on Figure 2-3. The main objective of the Rating District is to reduce the frequency and severity of flooding to Little River, Cooptown, and the Okana, Okuti, and Takiritawai River floodplain areas by managing riverbank tree growth and removing tree and debris channel obstructions (i.e. by optimising the capacity of the Lower Hukahuka and Opuahou Streams, Police Stream, Okana, Okuti, and Takiritawai Rivers).

Figure 2-3: Wairewa Rivers Rating District

This work must either complement, or not conflict with, other catchment management objectives such as river erosion control, reduced stream sedimentation, and enhancement of Te Roto o Wairewa/Lake Forsyth water quality. The investigation of other flood risk reduction methods, such as development of secondary flow paths and floodways, stopbank or bund construction, flood proofing of buildings, and flood warning and evacuation planning, is to progress as a lower priority as funding allows.

Background information on the formation of the Wairewa Rivers Rating District, and historic maintenance work within the Little River catchment, is described further in the Wairewa Rivers Rating District Asset Management Plan.

2.4 Climate change

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

2.4.1 Air temperature

MfE (2016) presents projected changes in annual mean temperature for four scenarios of future radiative forcings, known as 'Representative Concentration Pathways (RCPs). These represent different pathways of human development and greenhouse gas emissions. For Canterbury, the projected increases in annual mean temperature from a 1986-2005 baseline out to 2101-2120 range from 0.7-3.6 ºC.

2.4.2 Rainfall

In general, rainfall has greater spatial and temporal variation than temperature. For the east coast of the South Island, summer is likely to become wetter, and winter and spring drier (MfE, 2016).

Rising air temperatures will also 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). On this basis, the projected increases to design rainfall events from a 1986-2005 baseline out to 2101-2120 under the four RCP scenarios range from 5.6 – 28.8%. A 2018 update (MfE, 2018) incorporates extreme rainfall results from the "HIRDS" report (Carey-Smith *et al.,* 2018). This shows extreme rainfall increasing with climate change in all areas, with shorter duration events likely to have more significant increases in rainfall.

Rainfall in the upper Little River catchment is currently around 100 mm of rainfall, for a 6 hour 100 year ARI storm event. Using HIRDS version 4, by 2081 to 2100 this is predicted to increase to between 107 and 130 mm based on the four RCP scenarios. Over the same time period a 6 hour 50 year ARI storm event is predicted to increase rainfall from 87 mm to between 93 and 112 mm for the same four RCP scenarios. This means that a 100 year ARI storm event will potentially become a 50 year ARI storm event by 2100.

Current climate change estimates for the Little River area show climate change (to 2120) may increase peak rainfall by the order of 22 to 35%, for the RCP 8.5 scenario (for storm durations of 24 hours to 1 hour, respectively). However, the relationship between increased peak rainfall, and the resulting increase in peak flood flows, is not likely to be linear – with peak flood flows tending to increase by a greater percentage than peak rainfall. For example, a recent modelling study by Gardner and Henderson (2019) showed that, in the Wairarapa, a 17% increase in peak rainfall increased peak flows by 17 to 27% (depending on catchment characteristics). Steel and Martin (2019) estimated a 22% increase in rainfall intensity would translate to a 32% increase in peak flow for high recurrence interval (extreme) floods in the Ashley River. Further work, in the form of a detailed hydrologic model, would be required to better define this relationship for the Little River watercourses.

2.4.3 Sea level

MfE (2017) presents current sea level rise projections. For Canterbury, the projected increases in sea level from a 1986-2005 baseline out to 2120 range from 0.55–1.06 m (under the same RCP scenarios used for the temperature increase projections).

Sea level rise will have an impact on Te Roto o Wairewa/Lake Forsyth water levels and the lake outlet opening regime. An increase in lake levels is likely but will be complicated by sea conditions and a changing outlet barrier configuration; both of which will affect the success of any lake outlet openings.

3 Methodology

Floodplain flows are difficult to predict due to the multi-directional nature of the flows, the interaction between main river channel and floodplain flows, and the difficulty in identifying flow paths where ground levels vary gradually.

This floodplain investigation used a combined one-dimensional (1D) and two-dimensional (2D) hydrodynamic computer model (Mike Flood) to simulate flood events and determine river and floodplain water levels, depths, flood extent, flow patterns, and flow velocities. The methodology included:

- Compilation of historical flood event information (Section 2.2)
- Estimation of flood hydrology/design flows (Section 3.1)
- Construction of a computational hydraulic model (Section 3.2)
- Validation of the hydraulic model and sensitivity analyses (Section 3.3)
- Modelling of design flood events (Section 3.4)

3.1 Flood hydrology

To determine peak flows and flood hydrographs in the various water courses, flow data from the three flow sites in Table 2-2 have been used. These water level/flow time series provide some flow information for historic flood events and, together with the Regional Flood Estimation (RFE) method, can be used to estimate design flows in the various water courses. The derivation of the modelled flood hydrographs is given below.

3.1.1 Hukahuka at Lathams Bridge (Site 67602) flow data

The Hukahuka at Lathams Bridge (Site 67602) recorder is currently the only site continuously recording water level/flow in the Little River catchment. Although there are some historic sites, they only recorded for shorter time periods of less than ~10 years. Therefore, the Hukahuka at Lathams Road flow record is the only site available to derive flow hydrographs and design flows for the water courses in the Little River catchment.

Annual maximum flow series
From 1988 to 2018, the Hukahuka at Lathams Bridge record had a mean annual flood flow (Q_M) of 10.4 m^3/s. This excludes the 1998 year as it did not have a complete flow record. Figure 3-1 plots the Hukahuka at Lathams Bridge annual maximum flow series using the Gringorten plotting position (α=0.44).

Regional Flood Estimation (RFE) Method
Griffiths *et al.* (2011) provides a regional flood estimation methodology to enable design flood peak estimates to be calculated specifically for the Canterbury region. This method updates the previous work of McKerchar and Pearson (1989) and uses the following relationships:

$$q_{MF} = \frac{Q_M}{A^{0.866}} \qquad or \qquad Q_M = q_{MF} \times A^{0.866}$$

$$Q_{100} = Q_M \times q_{100}$$

where
q_{MF} = Mean annual flood factor
Q_M = Mean annual flood (m^3/s)
A = catchment area (km^2)
q_{100} = 100 year ARI flood factor
Q_{100} = 100 year ARI flow (m^3/s)

The mean annual flood and flood frequency factors derived for the Banks Peninsula area were only based on 3 sites:

1. Opara (Okains) at Friesian Stud Farm (Site 67001, *13 year record*).
2. Reynolds at Brankins Road (Site 67601, *8 year record*).
3. Kaituna at Kaituna Valley Road (Site 67702, *25 year record*).

Of these sites, only the Kaituna site has a relatively long record, and the Hukahuka at Lathams Bridge site was not included. Table 3-1 summarises the mean annual flood and flood frequency factors derived from both the Hukahuka at Lathams Bridge record and Griffiths *et al.* (2011).

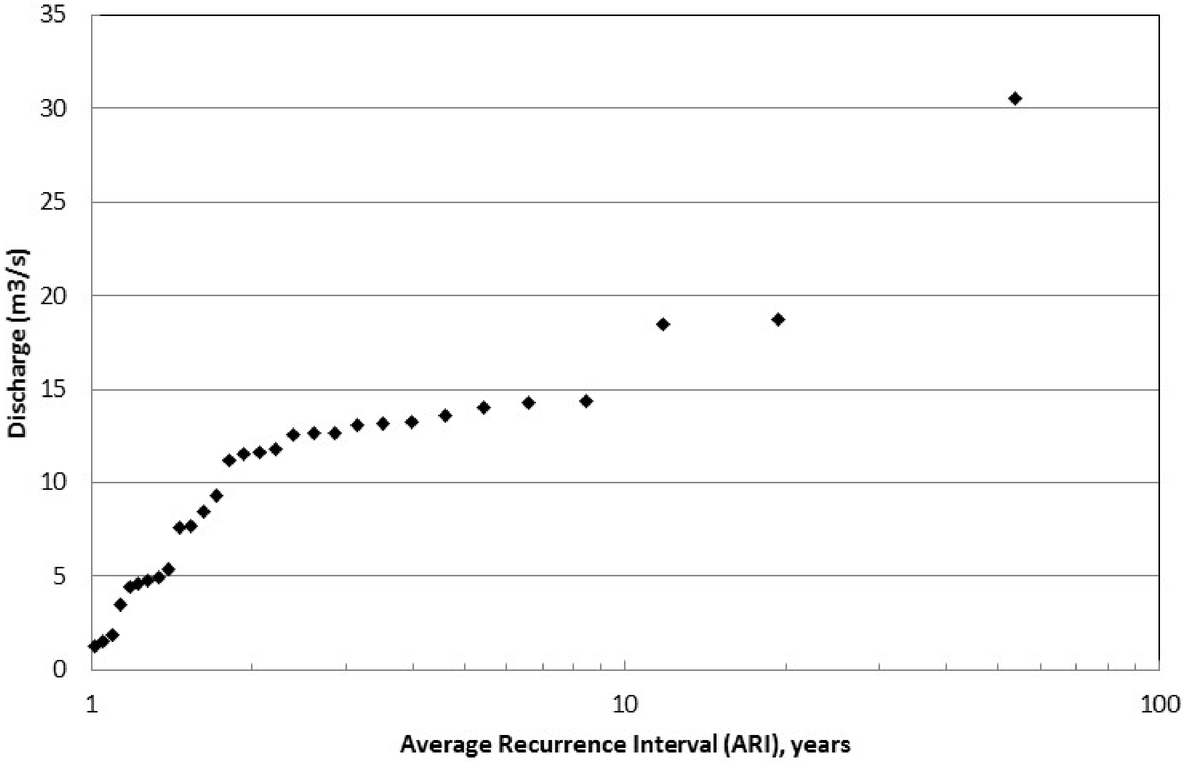


Figure 3-1: Hukahuka at Lathams Bridge (Site 67602) annual maximum flow series (plotted using the Gringorten plotting position)

Table 3-1: Comparison of catchment factors

Parameter	**Source** **Hukahuka at Lathams Bridge (Site 67602)**	 **Kaituna (Site 67702) (Griffiths *et al.*, 2011, Table 2-1)**	 **Little River catchment (Griffiths *et al.*, 2011, Figures 2-1 and 3-1)**
Record length	30	25	-
Catchment area (A, km^2)	13.0	39.5	-
Mean annual flood (Q_M, m^3/s)	10.4	34.9	-
Mean annual flood factor (q_{MF})	1.13	1.4	1.5
100 year ARI flood (Q_{100}, m^3/s)	-	113	-
Flood frequency factor (q_{100})	-	3.2	3.25

Figure 3-2 compares the annual maximum flow series to distributions derived using the RFE method in Table 3-1, including an assumed q_{100} factor of 3.25 for Hukahuka at Lathams Bridge based on Griffiths *et al.* (2011). Of the distributions plotted, the best fit to the Hukahuka at Lathams Bridge flow data is the q_{MF} factor of 1.13 (derived from the recorded site data), combined with the q_{100} factor of 3.25 (derived from Griffiths *et al.* (2011)).

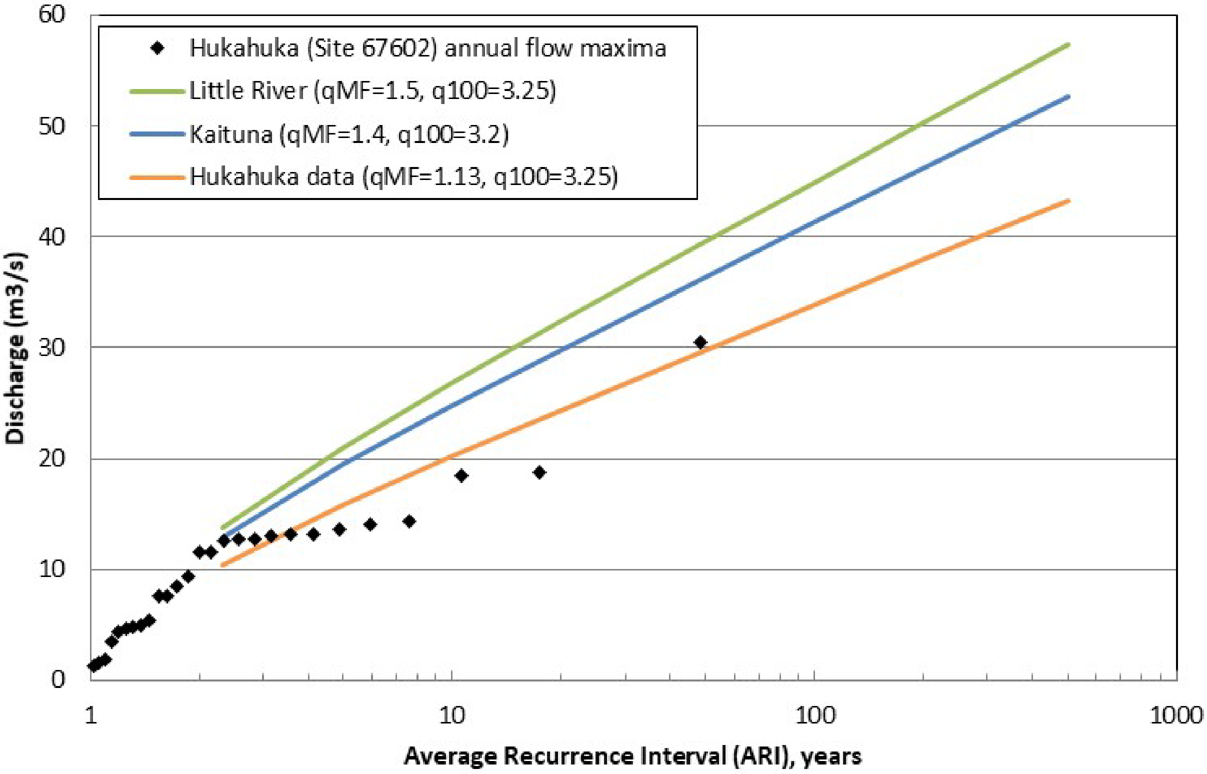


Figure 3-2: Comparison of various flood frequency estimates for Hukahuka at Lathams Bridge (Site 67602)

3.1.2 Subcatchment peak flows for validation and design events

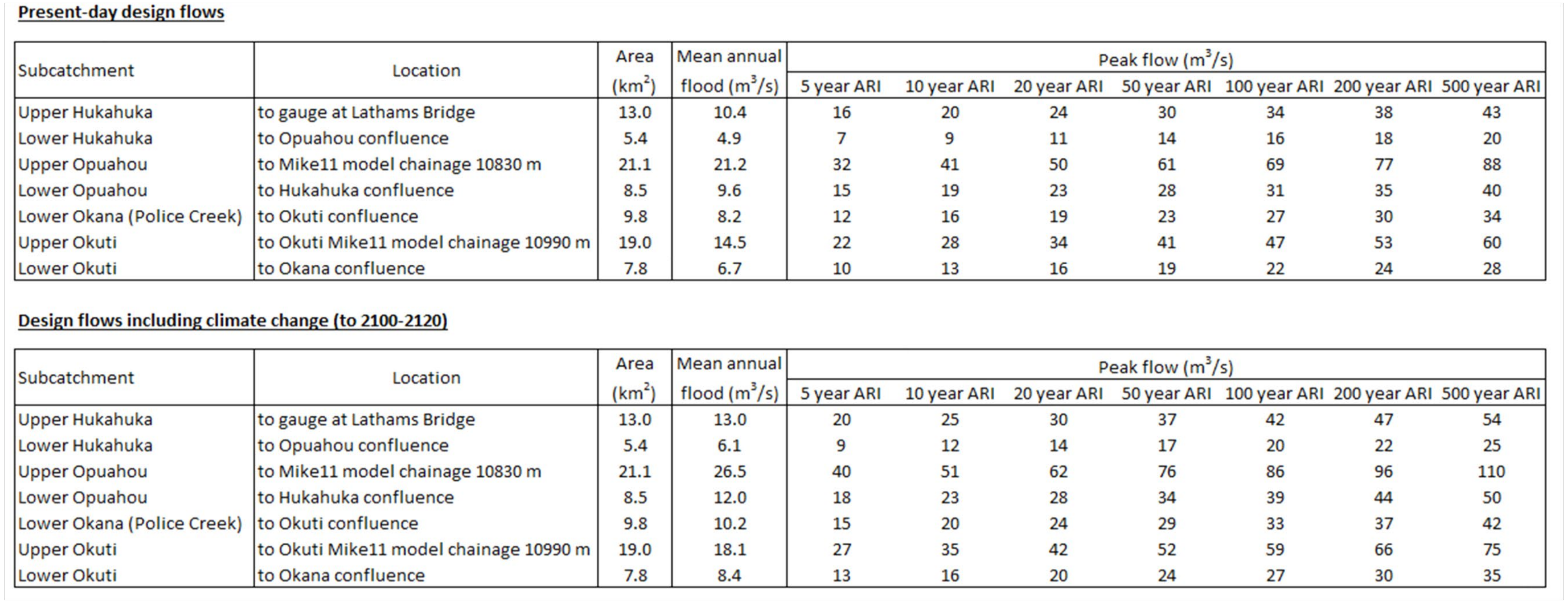
In Section 3.1.1, q_{MF} and q_{100} factors of 1.13 and 3.25, respectively, produced the best fit to the Hukahuka at Lathams Bridge annual maximum flow series. These factors have been used to generate the present-day design flows for the Hukahuka Turoa Stream, Police Creek, and Okuti River subcatchments.

For the March 2014 flood event, the 30 hour storm accumulation gauge corrected radar plot showed that a greater depth of rain fell in the Okana/Opuahou subcatchment (and to a lesser extent in the Okuti River catchment) compared with the western subcatchments of Hukahuka Turoa Stream and Police Creek. These western subcatchments are predominantly in a 'rain shadow' for typical southerly rainfall events. Therefore, to represent the likely increase in rainfall/flow for the Okana/Opuahou River, Griffiths *et al.* (2011) derived Little River factors of $q_{MF} = 1.5$ and $q_{100} = 3.25$ were used to produce a present-day mean annual flood flow (Q_M) for the entire Little River catchment. This was calculated to be 70 m^3/s.

The sum of the present-day mean annual flood flows for Hukahuka Turoa Stream, Police Creek and Okuti River is estimated to be 41.7 m^3/s (using $q_{MF} = 1.13$ and $q_{100} = 3.25$). Assuming the Opuahou River has a present-day mean annual flow of 28.3 m^3/s, and an area of 29.6 km^2, this produces a higher q_{MF} of 1.5 for the Opuahou subcatchment. This higher mean annual flood factor has been used to produce all present-day design flows for the Opuahou River.

Table 3-2 summarises the present-day (2020) design peak flow estimates for the Little River subcatchments. Design flows, incorporating climate change to 2100-2120, are also provided.

Table 3-2: Little River subcatchment design peak flood flows



Present-day design flows

Subcatchment	Location	Area (km^2)	Mean annual flood (m^3/s)	Peak flow (m^3/s)						
				5 year ARI	10 year ARI	20 year ARI	50 year ARI	100 year ARI	200 year ARI	500 year ARI
Upper Hukahuka	to gauge at Lathams Bridge	13.0	10.4	16	20	24	30	34	38	43
Lower Hukahuka	to Opuahou confluence	5.4	4.9	7	9	11	14	16	18	20
Upper Opuahou	to Mike11 model chainage 10830 m	21.1	21.2	32	41	50	61	69	77	88
Lower Opuahou	to Hukahuka confluence	8.5	9.6	15	19	23	28	31	35	40
Lower Okana (Police Creek)	to Okuti confluence	9.8	8.2	12	16	19	23	27	30	34
Upper Okuti	to Okuti Mike11 model chainage 10990 m	19.0	14.5	22	28	34	41	47	53	60
Lower Okuti	to Okana confluence	7.8	6.7	10	13	16	19	22	24	28

Design flows including climate change (to 2100-2120)

Subcatchment	Location	Area (km^2)	Mean annual flood (m^3/s)	Peak flow (m^3/s)						
				5 year ARI	10 year ARI	20 year ARI	50 year ARI	100 year ARI	200 year ARI	500 year ARI
Upper Hukahuka	to gauge at Lathams Bridge	13.0	13.0	20	25	30	37	42	47	54
Lower Hukahuka	to Opuahou confluence	5.4	6.1	9	12	14	17	20	22	25
Upper Opuahou	to Mike11 model chainage 10830 m	21.1	26.5	40	51	62	76	86	96	110
Lower Opuahou	to Hukahuka confluence	8.5	12.0	18	23	28	34	39	44	50
Lower Okana (Police Creek)	to Okuti confluence	9.8	10.2	15	20	24	29	33	37	42
Upper Okuti	to Okuti Mike11 model chainage 10990 m	19.0	18.1	27	35	42	52	59	66	75
Lower Okuti	to Okana confluence	7.8	8.4	13	16	20	24	27	30	35

These flows have been estimated by increasing the present-day design flows by 25% and can be updated as more flow and climate change data become available.

The 5 March 2014 flood event had a peak flow of ~30 m^3/s (at Hukahuka at Lathams Bridge) and was used to validate the model. Figure 3-2 and Table 3-2 indicate that this is equivalent to a present-day 50 year ARI flood event at the recorder site. Table 3-2 indicates that this flood event is more likely to be equivalent to a 20 year ARI flood event by 2100-2120.

3.2 Hydraulic model construction

The Mike Flood modelling package combined 1D modelling for the main rivers with 2D modelling for the floodplain. The 1D and 2D models were linked along the river channels to allow flood water to move between the river channels and the floodplain. Figures showing river cross section locations and lateral links (linking the river channels to the floodplain) are provided in Appendix B. A more detailed description of the model is given below.

The model does not include the local stormwater network for the developed area of the Little River township. For the smaller flood events, less than the capacity of the stormwater network, flood depths in the vicinity of the township may be conservative.

3.2.1 1D river channel model

The 1D model includes the lower reaches of the Hukahuka Turoa, Opuahou, and Okuti streams, together with the Okana and Takiritawai rivers (Appendix B).

Model boundaries

Flood flow hydrographs for the combined upper and lower subcatchments for each river channel were input into the 1D model at the upper limit of each 1D river channel, while the downstream boundary at Te Roto o Wairewa/Lake Forsyth has a water level boundary. The locations where the flows enter the 1D river channels are shown on Figure B-5. As the largest contributing tributary flows into the lower Hukahuka, Opuahou and Okuti subcatchment areas tend to be near the upstream limit of each 1D river channel, it was considered appropriate (although conservative) to add the combined upper and lower subcatchment flows at these locations.

Channel cross sections

Where the channel reaches were dry (i.e. for cross sections in the middle and upper catchment areas), cross sections were extracted from the 2008 LiDAR data described in Section 3.2.2. Additional submerged channel cross sections and long sections, bridge profiles, banks, and road levels were surveyed in May 2016 and November 2018 by the Environment Canterbury survey team. Due to significant water depths, a small boat was required to measure channel profiles downstream of the Kinloch Road bridge. Cross section locations are shown in Appendix B (Figure B-1 to B-4), and the data source for each cross section is summarised in Tables B-1 to B-6.

Channel roughness (bed resistance)

Channel roughness values used in the 1D model are summarised in Appendix B (Table B-1 to B-6). In the lower river reaches, a Manning's n number of 0.030 has been used for the channel roughness. This assumes that there are no, or few trees on the banks to obstruct flow, and no abrupt transitions within the channel. For the steeper upper river reaches with boulders and variable cross section profiles, a higher channel roughness of Manning's n equal to 0.045 was used. These roughness values have been assumed to represent the channels once the Wairewa Rivers Rating District maintenance program has removed the main trees and other channel constrictions. A model run was also completed for the March 2014 storm event, assuming a channel roughness around 25% higher (i.e. 0.030 was increased to 0.040 and 0.045 was increased to 0.055). This is discussed in Section 3.3.

Bridge structures

There are several road bridges located within the 1D model. The bridges included are:

- Opuahou Stream (Okana River) at Church Road (chainage 13634)
- Okana River at SH75 (chainage 15074)

- Police Creek at Western Valley Road (chainage 11279)
- Police Creek at SH75 (chainage 11326)
- Okana River at Kinloch Road (chainage 17272)

3.2.2 2D floodplain model

The 2D component of the model includes the floodplain surrounding the Little River township, and downstream to Te Roto o Wairewa/Lake Forsyth (see Appendix B, Figure B-1). The floodplain topography and roughness used in the model are described below.

Floodplain topography

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) are essential. For the Little River floodplain area, this high-resolution topographic data was obtained from a LiDAR (Light Detection and Ranging) survey referenced to the Lyttelton 1937 (LTN37) vertical datum. LiDAR data was obtained using a fixed wing aircraft between 6 and 11 February 2008. Height differences between the LiDAR data and surveyed checkpoints on the ground had a standard deviation statistic of ±0.07m.

During the LiDAR surveys, most of the river system was relatively dry and the lake level low. This allowed an optimal amount of ground coverage, since LiDAR surveys do not show bed levels obscured by water. As flows were low, most of the riverbed was exposed and the data could also be used to generate channel cross-sections for the 1D model. The detail provided by LiDAR data is shown in Figure 3-3 for the Little River floodplain area.

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 m x 5 m cells to represent the floodplain topography. A 5 m grid was chosen to allow for a reasonable degree of topographic detail, while keeping the model run time to under 1 day. However, 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. This is usually a reasonable assumption - especially for the larger and less frequent storm events.

Checks were made with the detailed LiDAR data to ensure important topographic features (e.g. banks, terraces, roads and railways), and historic flow paths, were correctly simulated in the 5 m grid.

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's 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 dense, or there were significant restrictions to the flow path (e.g. hedges, houses), the Manning's n value was increased to 0.12 to increase the surface resistance. Where there were smoother road surfaces Manning's n was decreased to 0.02. For the rest of the floodplain, Manning's n was set at 0.05. Figure 3-4 identifies the areas where Manning's n has been assigned values of 0.12 and 0.02.

Te Roto o Wairewa/Lake Forsyth model boundary

At the 2D model boundary at Te Roto o Wairewa/Lake Forsyth, the model was set up so that water could flow out of the 2D grid into the lake and vice versa.

Figure 3-3: **Aerial photography and LiDAR data (m LTN37) around the State Highway/Kinloch Road intersection to the south of the Little River township**

Figure 3-4: **Manning's n values of 0.12 (green) and 0.02 (pink)**

3.3 Model validation

To provide confidence in the model predictions, it is important to calibrate and/or validate the model with historical flood events (where possible). As there was only limited flow and flood level information for the flood events at Little River, the Mike Flood model has been partially validated using the 5 March 2014 flood event.

During this storm event, a tropical depression was located to the east of the Canterbury coast, moving slowly north between 3 to 5 March. The 992 hPa low pressure system generated heavy and prolonged rainfall in the Little River catchment, with 341 mm of rainfall recorded at the Christchurch-Akaroa Highway (Site 327804) from 3 to 6 March. The depression also produced a 0.3 to 0.4 m storm surge along the coast. This coincided with a high king tide with a 20 to 50% annual exceedance probability level (Allen *et al.,* 2014).

The Mike Flood model inputs and modelling results for the March 2014 flood event are described below.

3.3.1 Flows

For the March 2014 validation model, 50 year ARI peak flows are assumed for all Little River subcatchments. This is based on the assumptions made in Section 3.1.2. Subcatchment peak flows are summarised in Table 3-2. The Hukahuka at Lathams Bridge flow hydrograph, measured during this event, is scaled to match these peak flows.

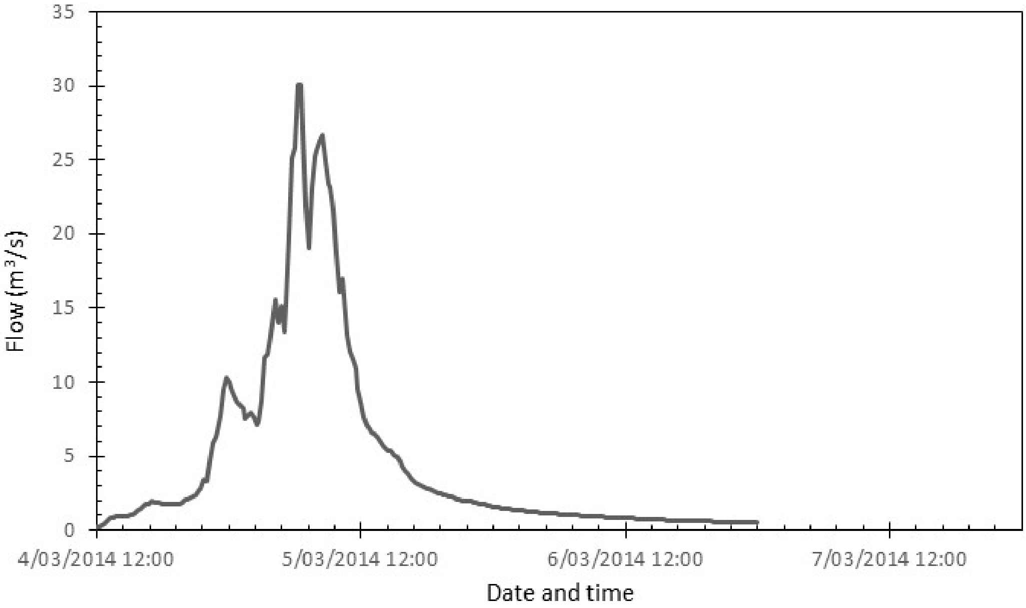


Figure 3-5: **Hukahuka at Lathams Bridge (Site 67602) flow hydrograph for the March 2014 flood event**

3.3.2 Te Roto o Wairewa / Lake Forsyth levels

The Te Roto o Wairewa/Lake Forsyth recorded water levels at the Christchurch Akaroa Road (Site 67603) were used in the March 2014 validation model. Around 9am on 5 March, the recorder float was caught in the sensor rope. The water level record for the rest of the flood event was synthesised using surveyed flood marks and the shape of the flood peak recorded for the following flood event. The synthesised water level record for this flood event is shown in Figure 3-6. This shows that the lake was opened on 7 March 2014, allowing the lake level to fall.

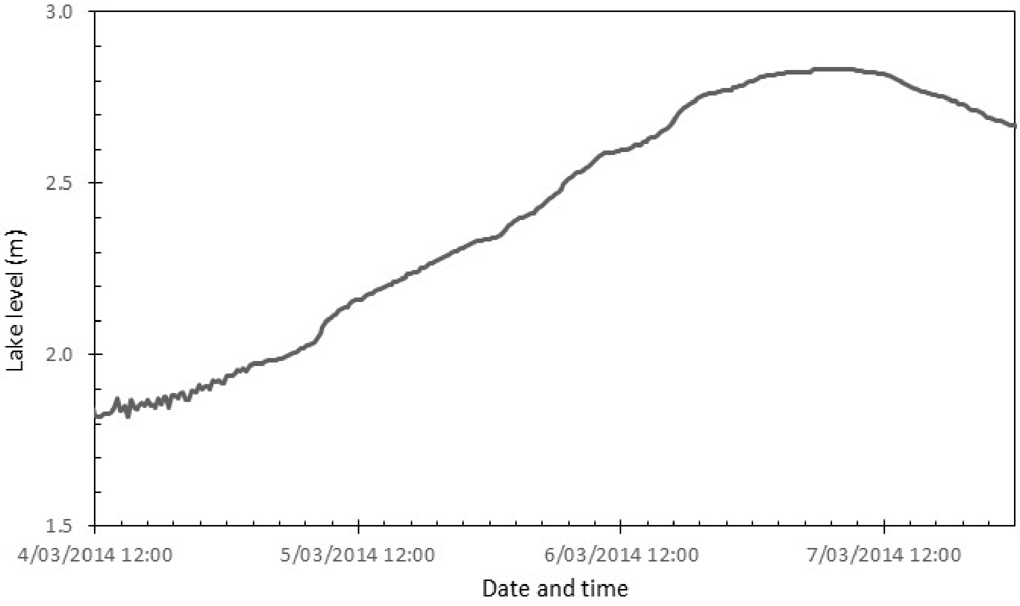


Figure 3-6: **Te Roto o Wairewa/Lake Forsyth water levels during the 5 March 2014 flood event**

3.3.3 Model run details

The Mike Flood model was run for a 25 hour time period over the March 2014 flood event (i.e. from midnight on 5 March 2014 until 1am on 6 March 2014). The model has a 0.5 second time step and took less than a day for each model simulation.

3.3.4 Results

Maximum modelled water depths for the March 2014 flood event are shown on Figure 3-7 and Table 3-3 compares the modelled flood levels to observed flood levels. Given all the uncertainties and assumptions made for the modelling, the modelled floodplain extent and flood levels are a good fit to the observed flooding.

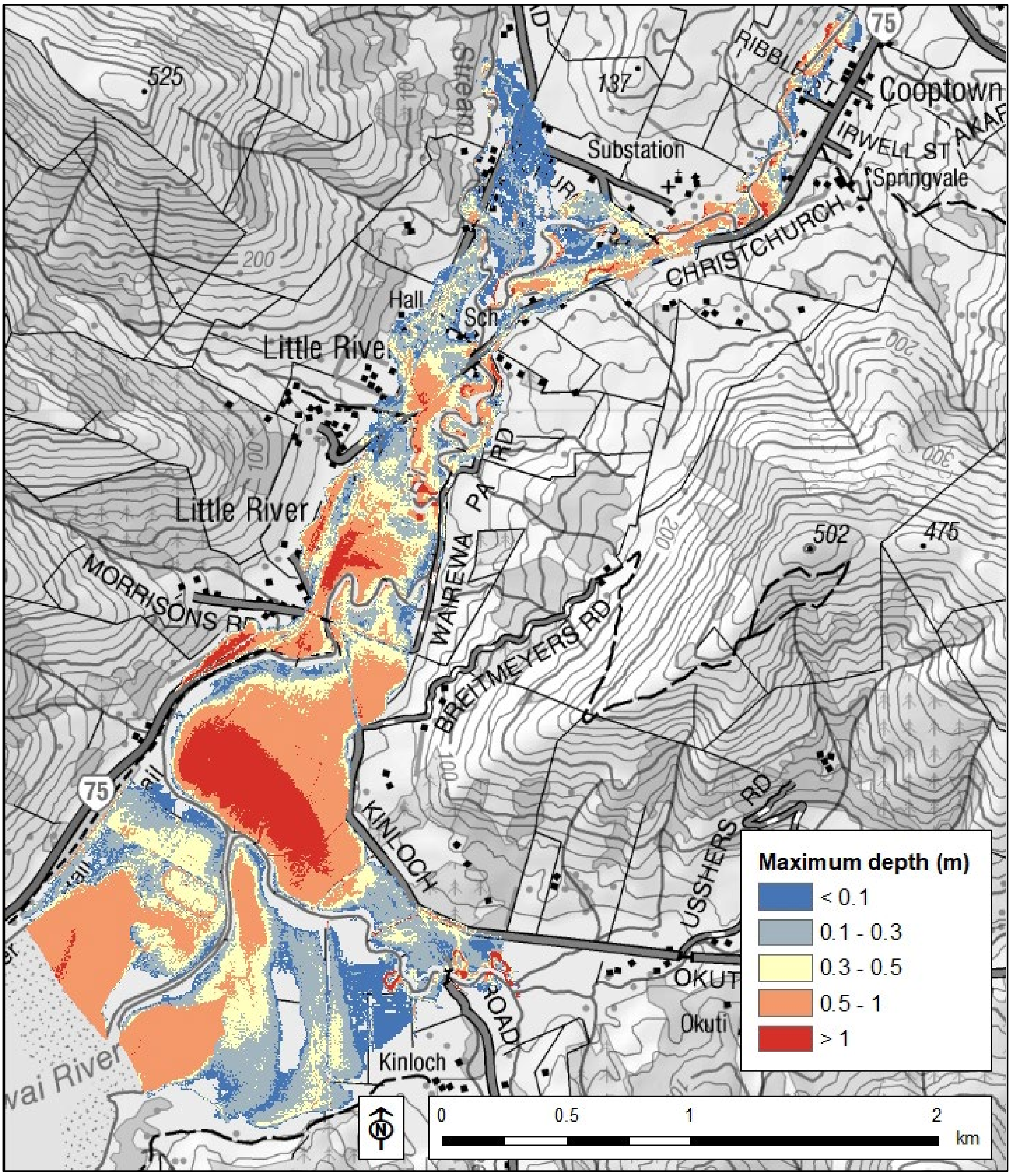


Figure 3-7: Modelled maximum water depths for March 2014 flood extent

Table 3-3: Comparison of measured and modelled flood elevations (m LTN37) for March 2014 flood event

Location	Measured level	Modelled level	Difference (m)
Wairewa Garage	23.06	23.16	0.10
Church Road	18.86	18.91	0.05
Rugby Clubrooms	9.53	9.40	-0.13
Western Valley Road	7.76	7.88	0.12
Little River Garage	5.45	5.49	0.04
Kinloch Road	5.04	5.01	-0.03
Near hotel	3.56	3.78	0.22
Okuti Bridge	5.4	5.5 - 5.6	0.1 - 0.2

3.3.5 Sensitivity tests

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

River channel roughness

The watercourses have modelled channel roughness values as specified in Appendix B (Table B-1 to B-6). Since floodplain flow only occurs when water flows out of the river channel (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 increase if Manning’s n roughness increases). As a sensitivity test, Manning’s n roughness values along the Mike 11 river channels were increased by ~25%. The increased channel roughness values are specified in Table 3-4.

Table 3-4: Manning’s n channel roughness adjustments for sensitivity test

Manning’s n	Sensitivity test - increased Manning’s n
0.030	0.040
0.045	0.055
0.060	0.075
0.080	0.100

Figure 3-8 illustrates the change in maximum water depths when channel roughness is increased. Water depths tend to increase by up to 0.1 m, suggesting the model is not particularly sensitive to a 25% change in channel roughness.

Floodplain roughness

As most of the Little River floodplain is pastureland, a Manning’s n of 0.05 has been used to represent most of the floodplain roughness. Higher and lower roughness values have been used for houses/dense vegetation (0.12) and roads (0.02), respectively. Should the floodplain become more vegetated, or populated, Manning’s n could increase. A model run was completed with floodplain roughness increased: pastureland 0.05 to 0.07, houses/dense vegetation 0.12 to 0.15, and roads 0.020 to 0.025.

Figure 3-9 illustrates that, when floodplain roughness is increased, maximum flood depths increase by up to 0.1 m. This is a similar increase to that observed for increased channel roughness and is regarded as minor.

Te Roto o Wairewa/Lake Forsyth levels raised and lowered

To get a better understanding of the influence of lake levels, the March 2014 lake levels (1.94 to 2.35 m during the model run time) were increased, and decreased, by 1 m. The increase of 1 m is relatively conservative as the lake levels fall between 2.95 to 3.35 m, which is above the highest level of 3.07 m recorded on 28 June 2010.

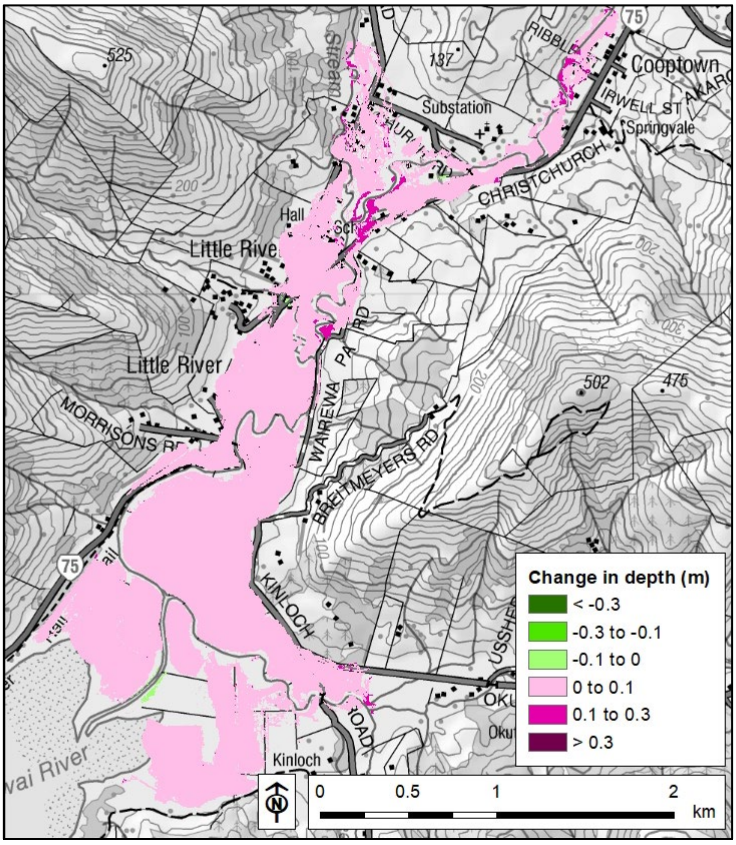


Figure 3-8: Change in modelled maximum water depths - channel roughness increased

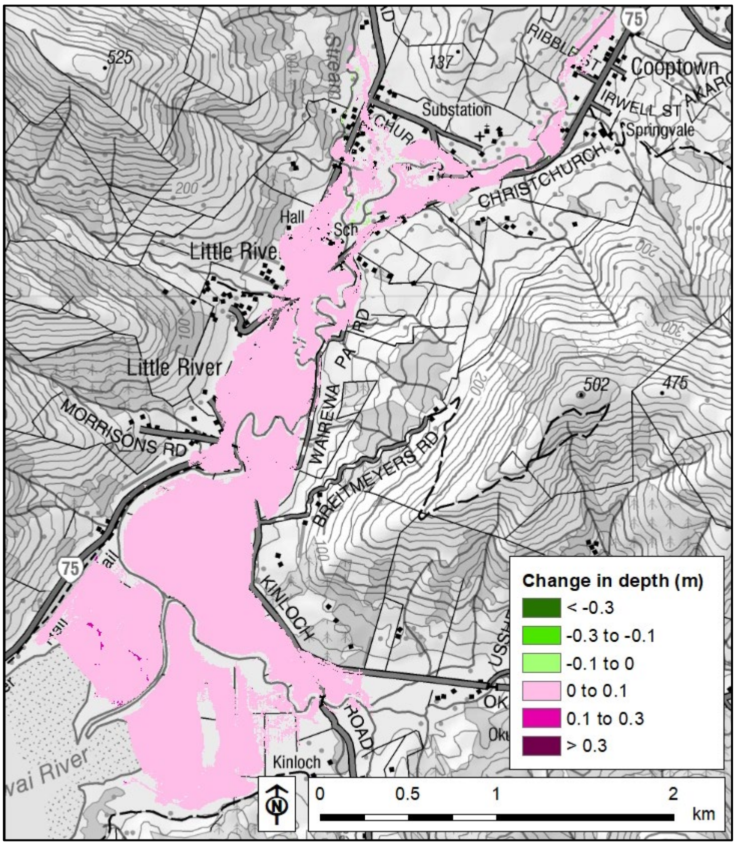


Figure 3-9: Change in modelled maximum water depths - floodplain roughness increased

Figure 3-10 and Figure 3-11 show changes in maximum flood levels for lake levels decreased and increased by 1 m, respectively.

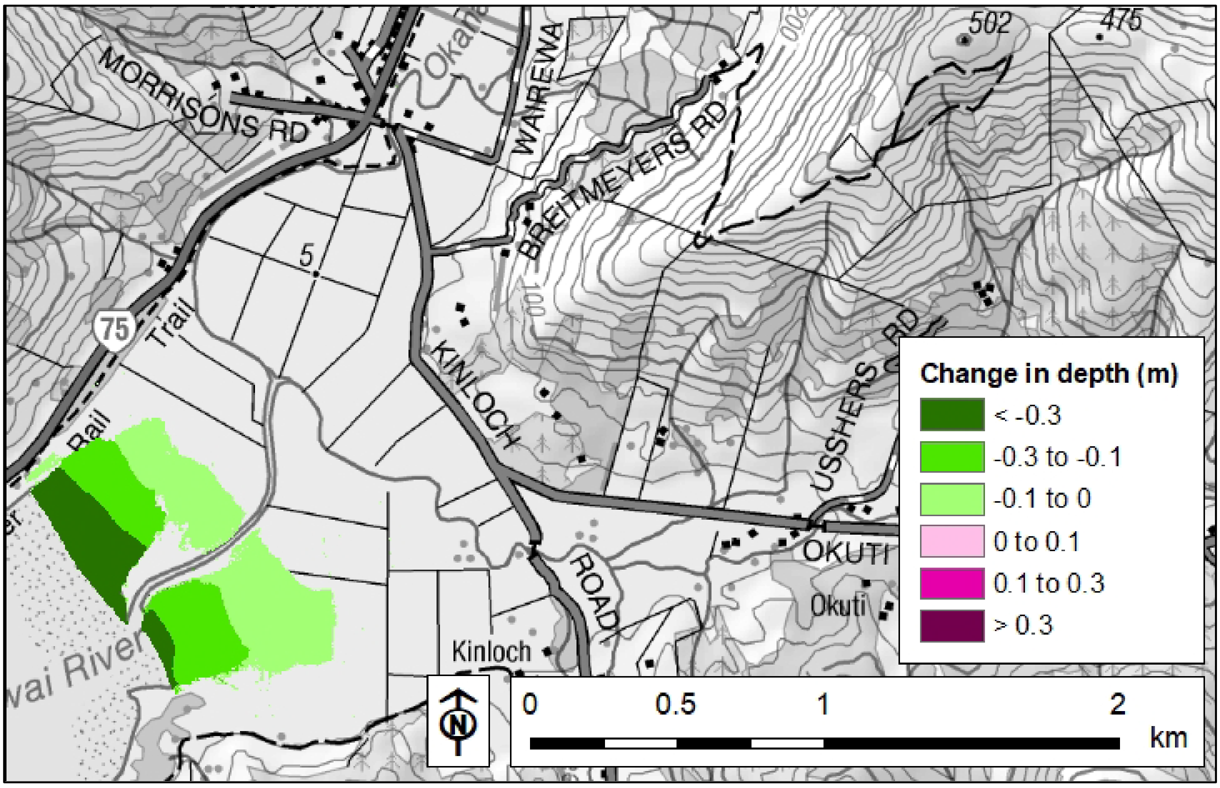


Figure 3-10: **Change in modelled maximum water depths – Te Roto o Wairewa/Lake Forsyth levels lowered by 1 m**

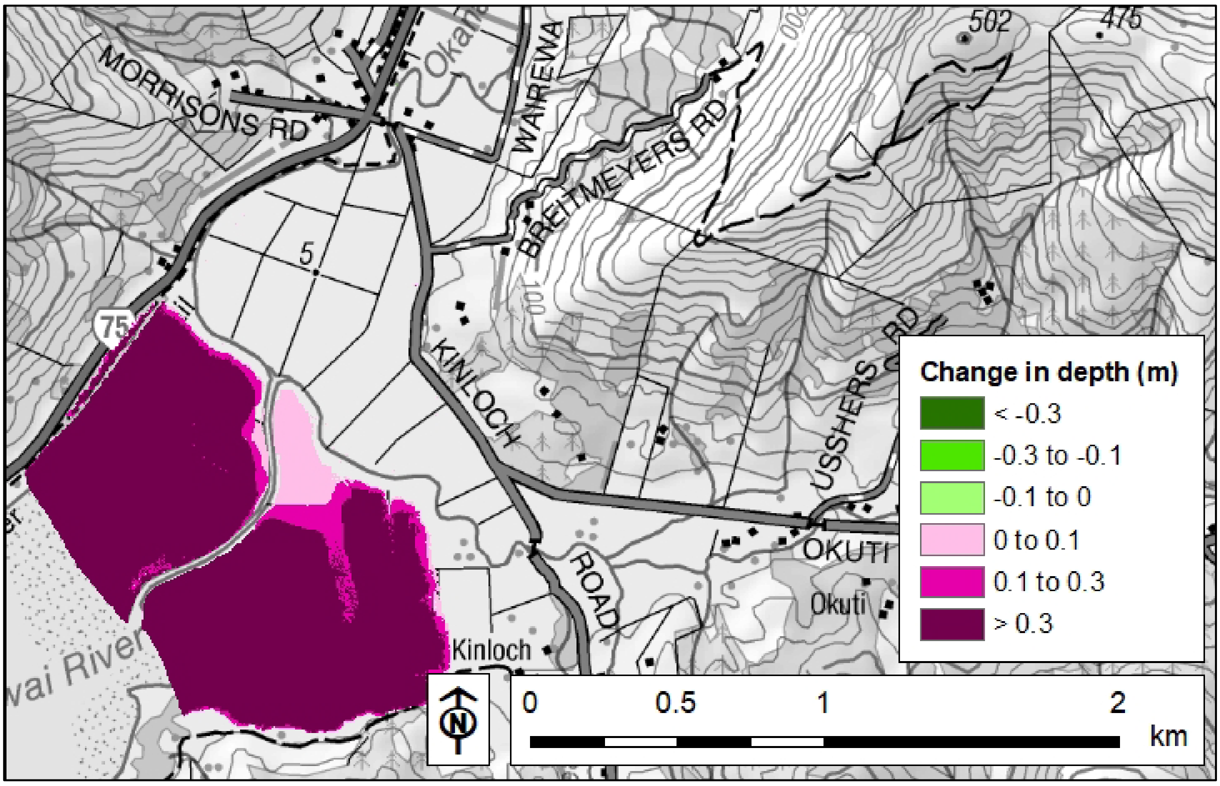


Figure 3-11: **Change in modelled maximum water depths – Te Roto o Wairewa/Lake Forsyth levels increased by 1 m**

The modelling demonstrates that neither an increase, nor decrease, in lake level is likely to have had a significant impact on flood levels in the Little River township for any of the recent flood events.

3.3.6 Improvements to the river system since the March 2014 flood event

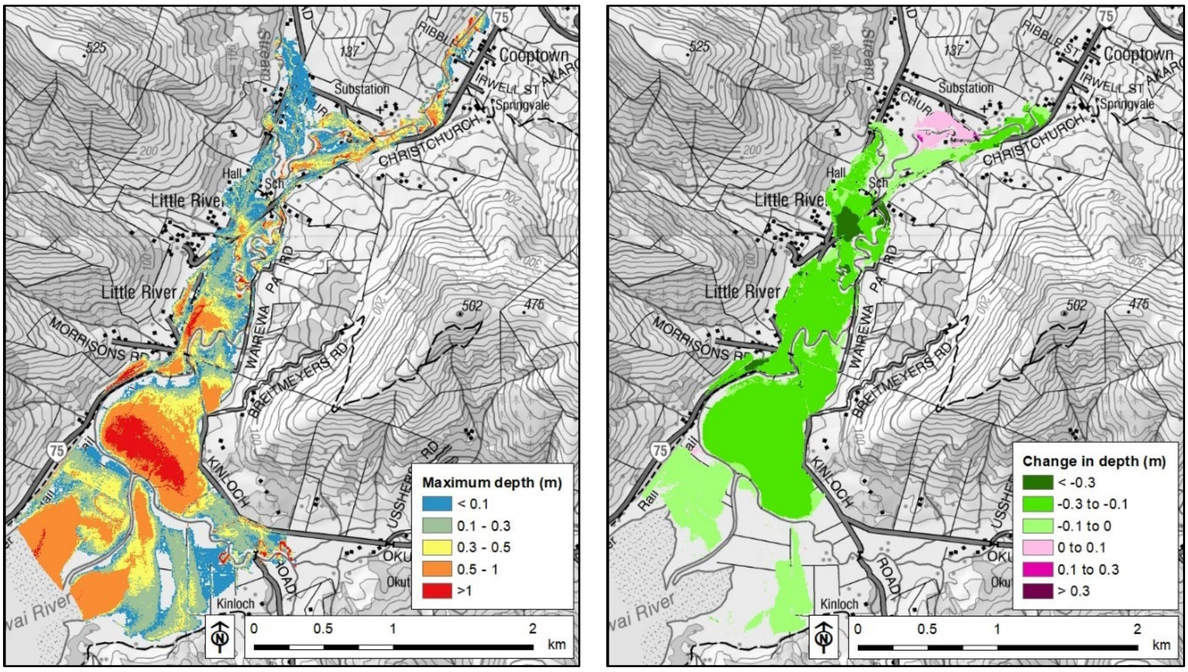
The Wairewa Rivers Rating District was established in the 2015/2016 financial year to reduce flooding in the Little River area (see Section 2.3). Since the March 2014 flood, funding from the rating district has been used to alleviate flooding by removing constrictions in the existing river channel network. This has mainly involved the removal of established willow trees and other vegetation located within the river channels.

By the end of 2019, willow tree clearance had been largely completed for the Okana River, lower Hukahuka Turoa Stream, and Opuahou Stream (downstream of Wairewa Motors but excluding the area immediately downstream of Church Road). A small portion of Lower Police Stream was also cleared, but no additional work had been undertaken in Okuti Stream or Takiritawai River. This work is likely to be completed by 2022.

To gain an understanding of the impact of the current and future improvements to the river system that have resulted from vegetation clearance, the model was re-run using adjusted channel roughness values. Manning's n values for each river are provided in Appendix B for the following three scenarios:

1. Pre-clearance = river system during March 2014 flood event.
2. Current = river system with river works completed up until the end of 2019.
3. Post-clearance = river system once all proposed vegetation clearance is completed.

Figure 3-7 displays the pre-clearance maximum water depths. Modelling indicates that vegetation clearance up to December 2019 is likely to have resulted in widespread reductions in flood levels in most areas, with the possibility of minor increases immediately downstream of Church Road (Figure 3-12).

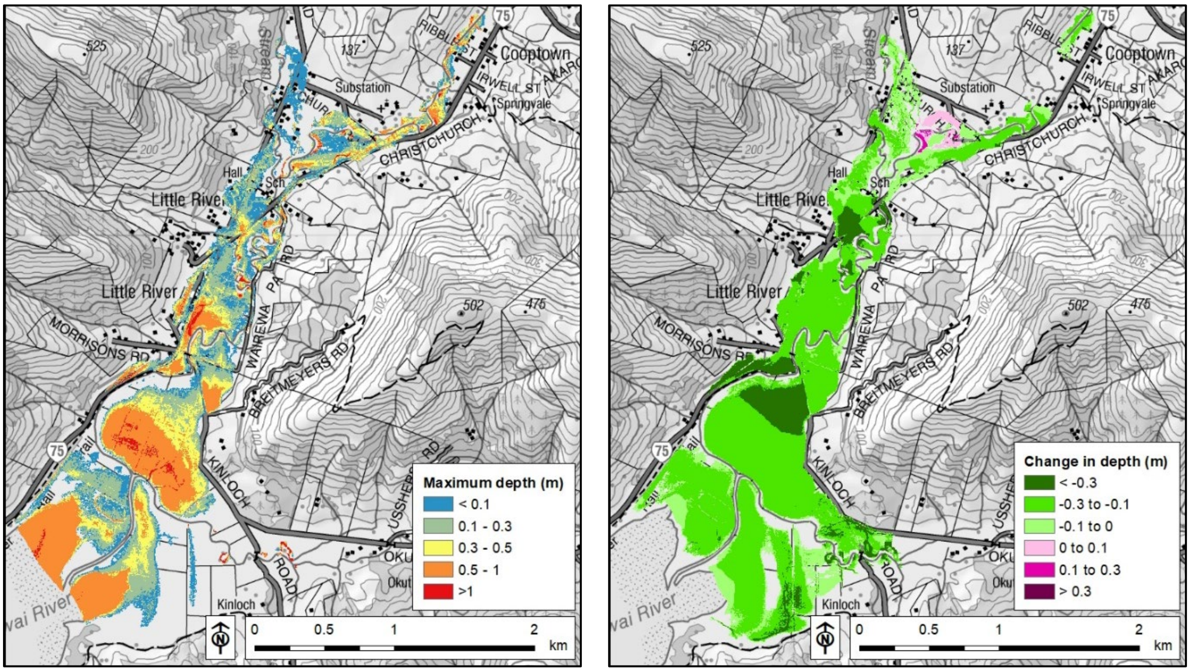


a) Maximum water depths

b) Change in flood depths with current vegetation clearance

Figure 3-12: 'Current' model scenario results for March 2014 flood event

Additional vegetation clearance, yet to be completed, is likely to further decrease the maximum water levels for flood events comparable to March 2014. Figure 3-13 shows the accumulated decrease in maximum water depths likely with all the planned vegetation clearance complete, while Figure 3-14 only includes the decrease in maximum levels able to be achieved from the current situation.



a) Maximum water depths

b) Change in flood depths with all vegetation clearance complete

Figure 3-13: 'Post-clearance' model scenario results for March 2014 flood event

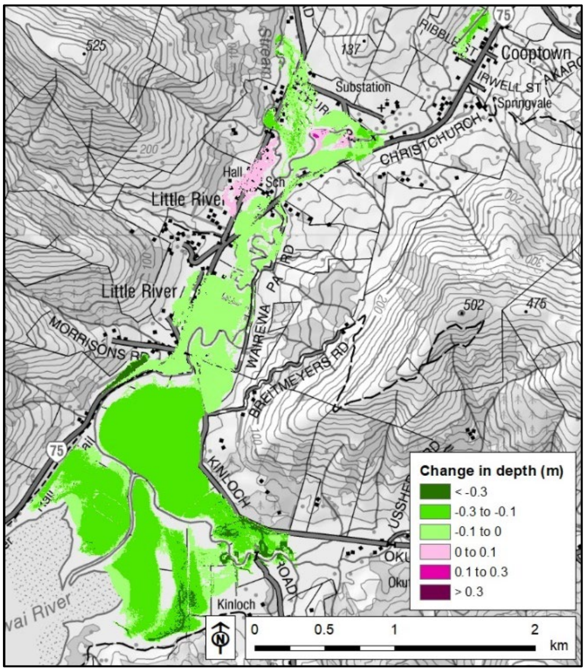


Figure 3-14: Change in flood depths likely between current and 'Post-clearance' model scenarios for March 2014 flood event

Interestingly, the additional vegetation clearance, that is planned to be completed by 2022, might only decrease (or increase) water levels by negligible amounts, with reductions in depth of more than 0.1 m mainly limited to the area downstream of Kinloch Road. Township water levels may only reduce by

~0.04 m (Figure 3-14). The additional vegetation clearance might also allow more water to be conveyed along the river system, potentially slightly increasing inundation in areas downstream of the vegetation clearance areas.

3.3.7 Engineering solutions to alleviate flooding

As well as providing indicative information regarding the likely benefits of vegetation clearance, the hydraulic model of the Little River area can also be used to assess potential engineering solutions that may further alleviate flooding in the Little River area. Although not the focus of this report, the following engineering options have been modelled:

1. Five ‘cuts’ in the sinuous river channels to more effectively convey flood waters downstream to the lake.
2. A bund to divert Police Creek and Hukahuka Turoa overflows towards the Okana River.
3. Option 2 with levees and stopbanks upstream and downstream of Kinloch Road removed.

These options illustrate how the model could be used to assess the effectiveness of various changes to the river system. More detailed modelling, and further analysis of other impacts (e.g. a geomorphological analysis of erosion potential for any cuts), should be considered before any options are implemented. Details of the three potential engineering solutions outlined above are given below.

Option 1:
This engineering solution considered placing 5 ‘cuts’ in the sinuous river network to allow water to be conveyed more efficiently downstream. Grade and erosion control have not been considered as part of this study. If this option was deemed feasible, further geomorphological investigations would be required as the cuts are likely to generate additional sediment as the channels adjust to a new equilibrium.

The location of the 5 cuts is shown on Figure 3-15, and the modelled maximum depths (and possible reductions in maximum water depths) are provided on Figure 3-16.

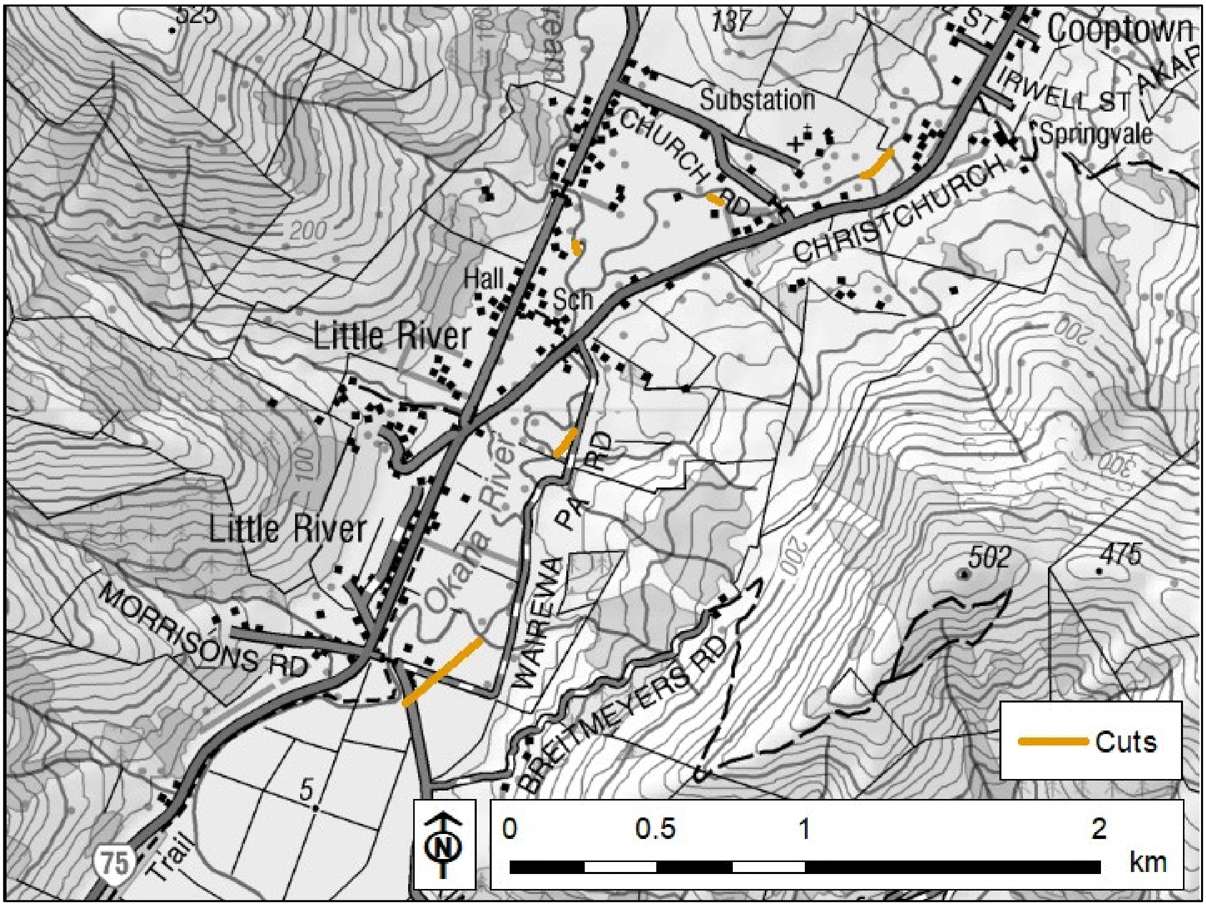
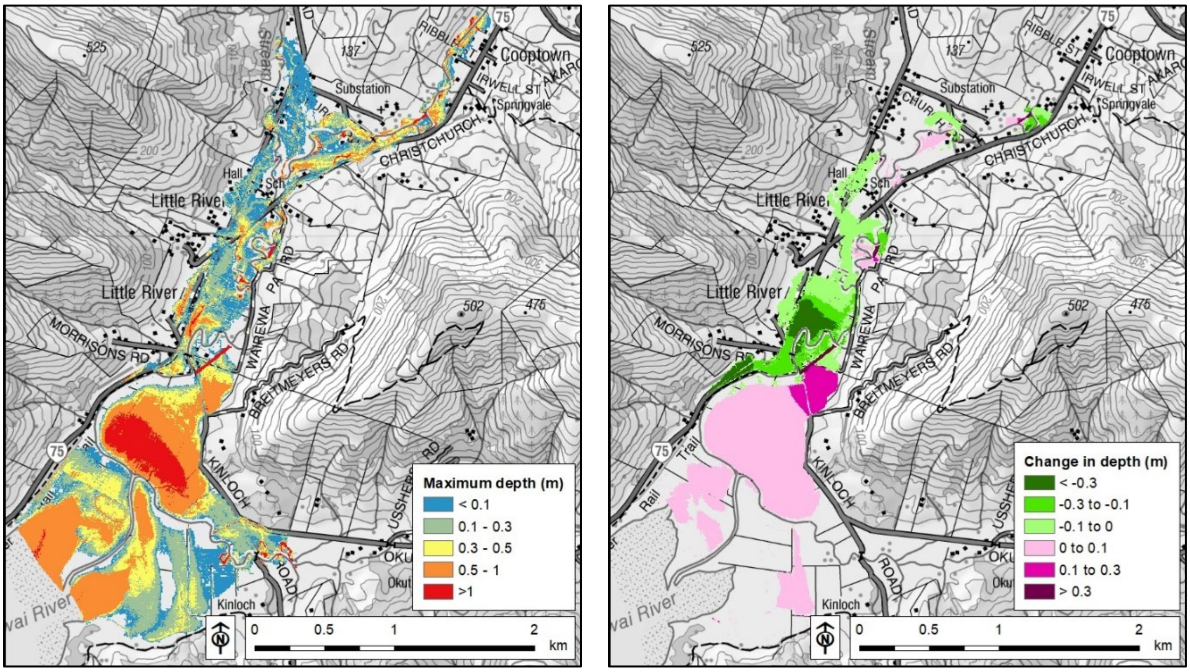


Figure 3-15: Location of 5 'cuts' for Option 1



a) Maximum water depths

b) Change in flood depths with 5 'cuts' in river system

Figure 3-16: Model results for Option 1 - Five 'cuts' in river system

With each of the minor cuts, there is an area upstream of the cut where maximum flood levels decrease, and an area downstream of the cut where water levels increase. The most significant reductions in maximum flood levels occur for the largest cut that bypasses the Kinloch Road bridge; a known constriction for flood flows. Incorporating a cut in this area could potentially decrease flood levels through Little River (along SH75) by ~0.3 m, for a flood comparable to the March 2014 event.

Option 2:
The modelling indicated that some flood water from Police Creek, along with overflows from Hukahuka Turoa Stream and Okana River, can flow over SH75 around the Western Valley Road/SH75 intersection. This floodwater flows along the eastern side of SH75, towards the Little River township, before flowing back over SH75 and into the Township. One possible solution to alleviate flooding could be to construct a flood diversion bund to divert this water back towards Okana River (Figure 3-17).

Figure 3-18 (b) shows that the construction of the bund could decrease maximum water levels in the northern and western areas of the Township, with minor increases in levels between the bund and Wairewa Pa Road.

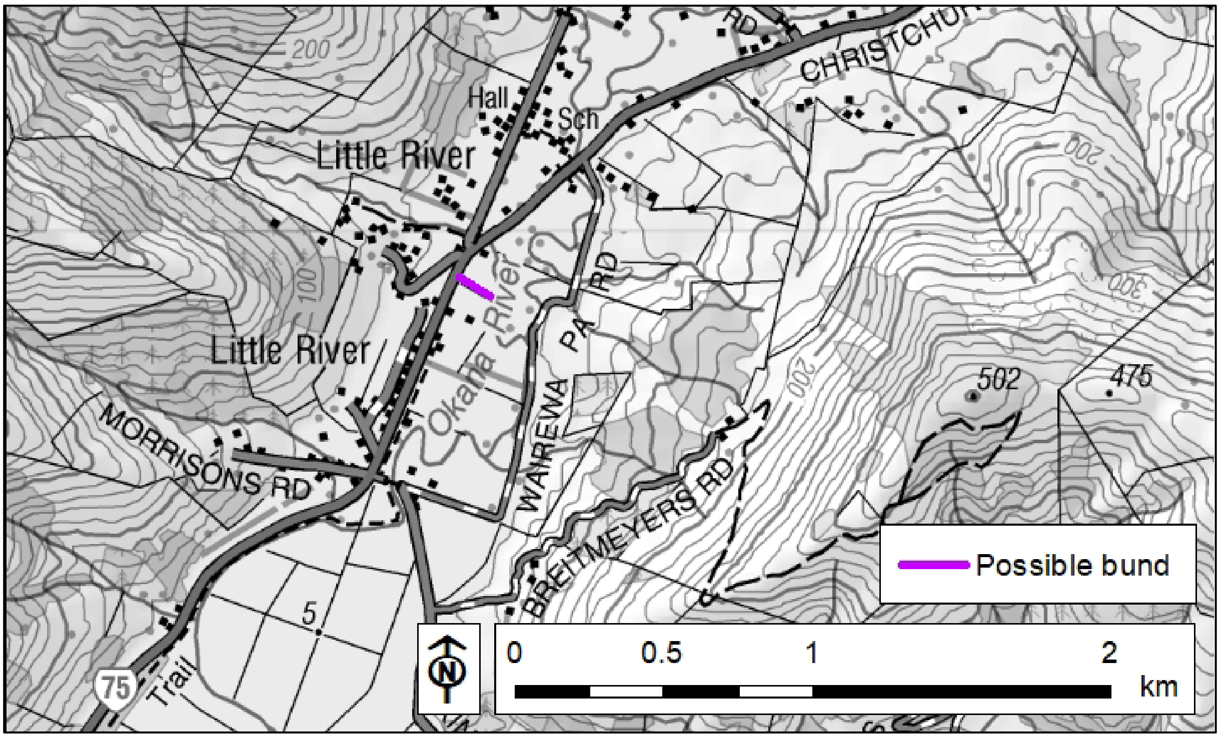
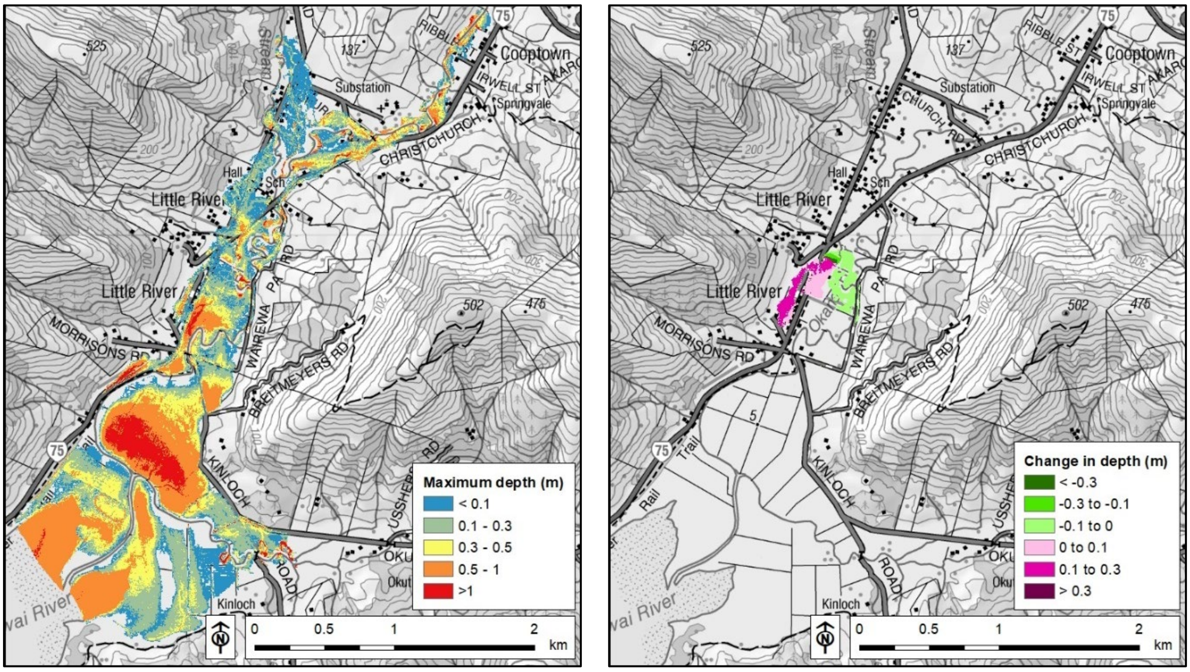


Figure 3-17: Possible bund location to divert overflows towards Okana River



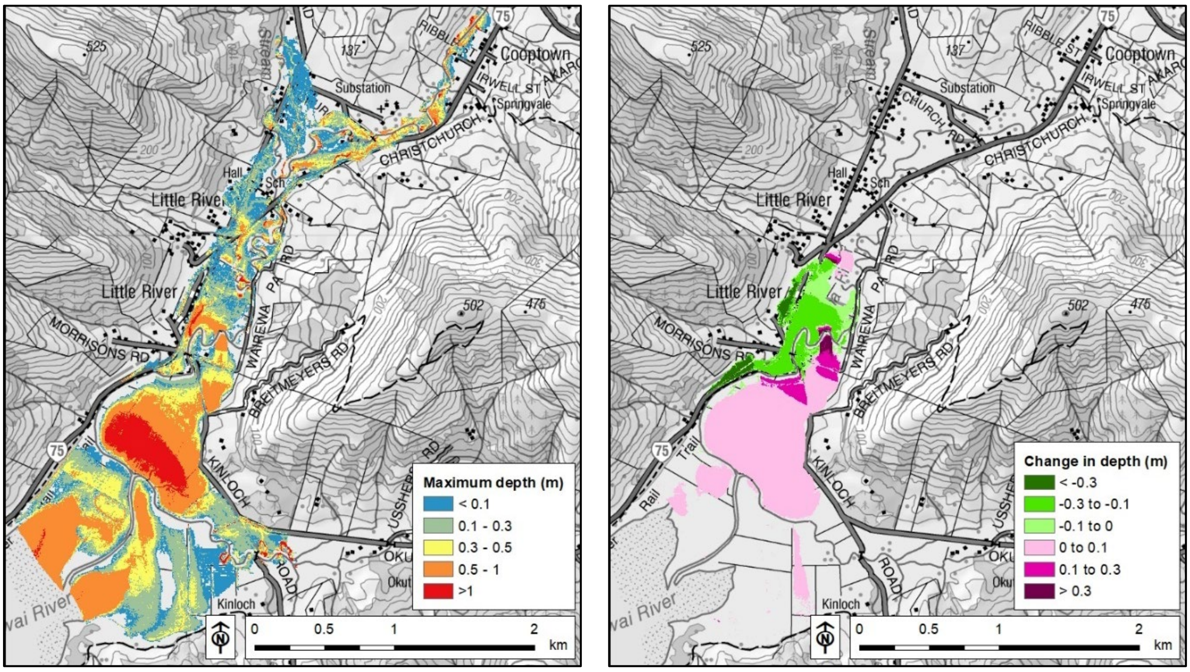
a) Maximum water depths

b) Change in flood depths with bund diverting water in river system

Figure 3-18: Model results for Option 2 – Bund to divert flows towards Okana River

Option 3:
Option 2 (i.e. construction of a bund) reduced maximum water levels in some parts of the Little River township, but not in other areas. Option 3 included the Option 2 bund, along with lowering of the Okana River levees/stopbanks (both banks for 410 to 540 m upstream of Kinloch Bridge, and the true left bank 150 to 420 m downstream of Kinloch Bridge).

Figure 3-19 (b) illustrates that combining the bund with a reduction in the levee/stopbank heights, produces greater reductions in maximum water levels around the Little River township, but also additional increases in maximum flood levels where the water is diverted onto the floodplain.



a) Maximum water depths

b) Change in flood depths with bund diverting water in river system and levees removed

Figure 3-19: Model results for Option 3 – Option 2 with levees and banks removed along parts of Okana River upstream and downstream of Kinloch Road

3.4 Design flood events

The design flows were based on the current model configuration (i.e. with vegetation clearance up until the end of 2019 and lake level rising from 1.94 to 2.35 m over the duration of the model run). Simulations covered a 25 hour time period, based on a 0.5 second time step, to ensure stability. Results were saved every 15 minutes, with computer run times around half a day for each simulation.

3.4.1 Design flows

Peak flows for all Little River watercourses, were based on the assumptions made in Section 3.1.2. Peak flows are summarised in Table 3-2. The Hukahuka at Lathams Bridge flow hydrograph, measured during the March 2014 flood event, is scaled to match these peak flows.

3.4.2 Design Te Roto o Wairewa / Lake Forsyth levels

The downstream water level at Te Roto o Wairewa/Lake Forsyth was shown in Section 3.3.5 to not have a significant impact on maximum water levels in and around the Little River township for the March 2014 lake levels – even when they were increased, or decreased, by 1 m. The March 2014 lake level has therefore been used for all design flood events.

3.4.3 Results

The 50 and 500 year ARI modelled maximum flood depths are shown on Figure 3-20 and Figure 3-21, respectively. The 5, 10, 20, 50, 100, 200, and 500 year ARI maximum flood depths are also shown in Appendix C (Figures C-1 to C-7).

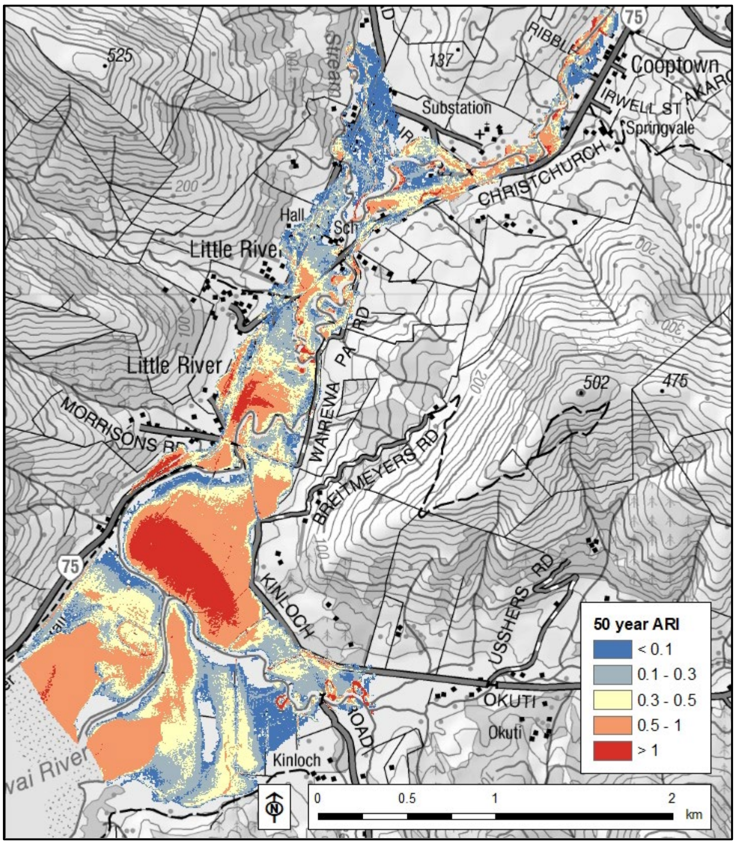


Figure 3-20: Floodplain maximum modelled water depths for a 50 year ARI design flood event

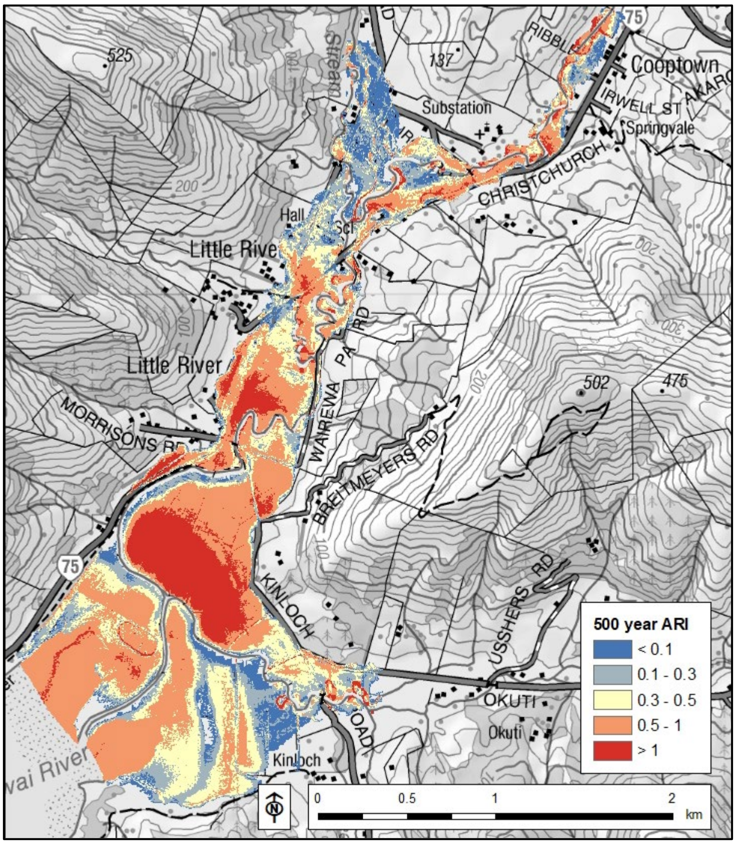


Figure 3-21: Floodplain maximum modelled water depths for a 500 year ARI design flood event

3.5 High hazard areas

High hazard areas are defined in the Canterbury Regional Policy Statement (RPS) 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***'.

Figure 3-22 identifies areas on the Little River floodplain that meet the RPS definition of high hazard, based on flood modelling for a 500 year ARI flood event generated by 500 year ARI inflows into the catchment watercourses (with vegetation clearance to the end of 2019).

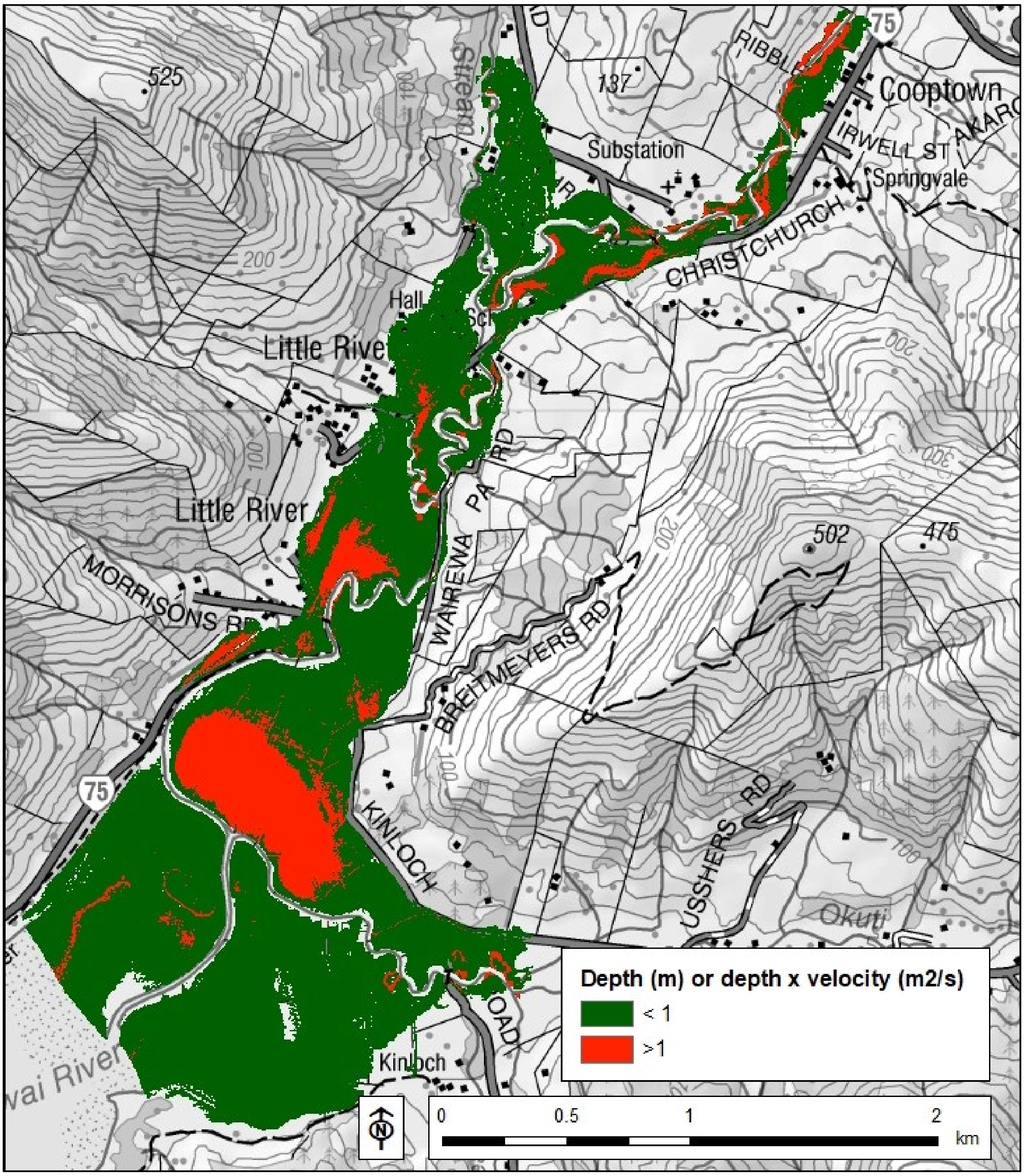


Figure 3-22: Little River floodplain high hazard areas (500 year ARI)

High hazard areas are mainly adjacent to waterways, as well as in depressions located on the floodplain. The original Little River Coronation Library (in Awa-iti Domain) is also in an area considered high hazard.

Figure 3-11 shows that, should Te Roto o Wairewa/Lake Forsyth levels be 1 m higher than the March 2014 levels (i.e. greater than the highest recorded level measured in 2010), maximum flood levels in the vicinity of the lake will increase to greater depths than those used to produce Figure 3-22. This means there are likely to be additional high hazard areas between the Okana and Okuti watercourses and the lake. A more detailed joint analysis of lake levels and design flows would be required to determine the high hazard extent at this location. Given the nature of the land use in this area, it has not been investigated as part of this study.

4 Discussion

During high-intensity rainfall events, the small and flashy nature of the Little River streams means there will be little warning time before inundation occurs. One of the advantages of computational hydraulic modelling is the ability to simulate various river configurations (e.g. vegetation scenarios, engineering options, flood magnitudes) in a timely manner. This enables the flood hazard in the Little River catchment to be better understood.

The modelling undertaken for this flood investigation has examined the March 2014 flood event, and considered the impact of channel vegetation, as well as various engineering options, Te Roto o Wairewa/Lake Forsyth levels and river flow magnitudes. The modelling provides the extent and depth of flood inundation for the various model simulations but does not consider any geomorphological impacts.

The uncertainty contained within the model results, and the data that would be required to calibrate the model more confidently, are summarised below.

4.1 Model uncertainty

Bales and Wagner (2009) outline some of the uncertainties associated with 1D 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 magnitude and hydrograph shape, roughness values, energy loss parameters, and climate change predictions).
- Topographic data (e.g. LiDAR data and estimated submerged riverbed levels). The model uses a fixed bed level which cannot account for scour and aggradation due to high-energy flood flows.
- 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).

Most stopbank levels have been extracted from LiDAR. In heavily vegetated areas the heights may be interpolated and therefore may not be accurate. This could have an impact on when, and where, overflows to the floodplain occur.

4.2 Data required to better calibrate the model

Model results could be improved by obtaining detailed survey levels of all the stopbanks/levees along the watercourses – particularly where dense vegetation has potentially distorted the measured LiDAR ground levels. Additional monitored water level/flow recorders and/or rainfall gauges in the Little River (Takiritawai River) catchment would also enable the rainfall distribution and/or flood flows to be estimated more accurately.

Flood information also needs to be gathered during and/or immediately after large flood events. This information would ideally include:

- Photographs of flood inundation, along with the time that the photographs were taken.

- Pegging, or marking the peak water levels.
- Cross section profiles or topographical data (e.g. LiDAR data).

Gathering this information may be problematic, as flood events can occur during the hours of darkness. Access to some areas may also be compromised during a large flood event. It would therefore be advantageous for local residents, who know the area well, to document as much as is practically possible (e.g. taking photos and/or videos and marking flood levels and times that they occurred).

5 Conclusions

The models used in this study have a fixed bed level and do not simulate changes in bed levels due to scour, erosion, or aggradation - all processes that will occur during large flood events. The model has also been based on limited recorded flow data and was only partially validated against the March 2014 flood event. Consequently, considerable uncertainties exist in the predicted extent and depth of flood water for all modelled scenarios.

Despite all model uncertainties, the modelling:

- Indicates there is good agreement between the modelled and observed flooding for the March 2014 validation event.
- Provides good insight into how flood waters are likely to behave for a range of flood magnitudes, vegetation clearance scenarios and engineering options. For example, vegetation clearance up to December 2019 is likely to have resulted in widespread reductions in flood levels in most areas, with the possibility of minor increases immediately downstream of Church Road.
- Identifies high hazard areas and preferential flow paths for flood events of varying magnitudes.

To reduce flooding in the Little River catchment, both vegetation clearance and/or engineering options are likely to alleviate flooding. Reductions in Te Roto o Wairewa/Lake Forsyth levels are unlikely to have a significant impact on flooding – except in the area immediately adjacent to the lake.

This investigation has not considered localised rainfall runoff on the floodplain (i.e. rainfall runoff is only included as part of the tributary inflows). Although localised rainfall runoff may produce additional flooding, it is assumed to be relatively minor compared to the stream overflows. Christchurch City Council is separately investigating the adequacy of the stormwater network within the Little River township.

Sensitivity tests show that the model is not particularly sensitive to increases in river channel or floodplain roughness (of the order of 25%). Increasing or decreasing Te Roto o Wairewa/Lake Forsyth levels by 1 m also only affects flood levels adjacent to the lake. These sensitivity tests help address model uncertainties but, in general, model results should only be interpreted and used by those who are familiar with all aspects of the modelling.

6 Recommendations

Due to the limitations of the modelling, the results should be used in conjunction with historic flood information and practical, scientific judgement. Should any of the engineering options be considered, a more refined version of the model (e.g. with more accurate stopbank elevations) would be required, along with consideration of scour, erosion and aggradation.

Possible future improvements to the model, that could increase the accuracy of the modelling, include:

- Reassessing model results produced in this study at such time as additional flow and water level data becomes available for other large flood events (as well as further climate change information). This would provide confidence in the design flows, and better calibration of the hydraulic model. Measured water level/flow data for the tributaries (i.e. Opuahou Stream, Police Creek and Okuti River) would also enable a better calibration of the model, and more confidence in the flows used for design flood events.

- Improving the Te Roto o Wairewa/Lake Forsyth downstream boundary levels by extending the model to include the whole lake and all sub-catchment flows entering the lake (as currently the lake boundary is based on the March 2014 synthesised levels). Including a mass-balance component for the lake could better represent lake levels for each of the design flood events (if enough hydrological data was available).
- Survey all stopbanks to better define the overflows.
- More detailed modelling of any flood alleviation engineering options, including analyses of likely changes to scour and aggradation in the river channels, before implementing any significant changes to the river system.
- Developing a rain on grid (rainfall runoff) model of the Little River catchments. This could better simulate the timing of peak flows from the various watercourses during flood events, and examine the relationship between climate change-induced increases in peak rainfall and the resulting increases in peak flows.

Flood reduction considerations should be examined in conjunction with other values. For example, the sediment reduction options explored in Painter (2014).

7 Acknowledgments

Kathy Walter at the National Institute of Water and Atmospheric Research (NIWA) provided flow data for this investigation.

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

- Tony Boyle (Principal Science Advisor)
- Shaun McCracken (Regional Lead River Engineering)
- Matthew Surman (Senior River Engineer)
- Su Young Ko (River Engineer)
- Nick Griffiths (Science Team Leader – Natural Hazards)

8 External peer review

An external peer review of the computational hydraulic model was completed by Matthew Gardner of Land River Sea Consulting Ltd (LRSC, 2020). This desktop review examined the model setup, results and documentation.

The review concluded that … *"Overall the model is well built and once the MIKE11 'dx' value is lowered to 5m and rerun, the model will be considered to be fit for the purpose outlined in the modelling report. Consideration should also be given to including more detail in the 2D roughness representation."*

As a result of the peer review:

- Mike11 model channels have been adjusted so the 'dx' values along the channels are 5 m.
- more detail has been included in the Mike21 roughness grid (additional areas of dense vegetation have been included).

All models have been rerun with these modifications.

9 Glossary

Aggradation: Deposition of shingle or other sediment in a river, raising the riverbed 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.

Eutrophic: When a lake rich in nutrients produces a dense plant population which, when it decomposes, kills animal life by depriving it of oxygen.

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).

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Appendix A: Historic flood information

Table A-1: Summary of historic flooding in the Little River area

Date	Rainfall	Flood observations
16-17 Apr 1925	193 mm in 24 hrs, 127mm in 12 hours at Okuti Valley (SCRCC, 1957)	On the 16th and 17th there was heavy rain throughout the province. (http://hwe.niwa.co.nz/event/April_1925_Canterbury_Flooding, accessed 8 January 2016). Severe flooding occurred at Little River where the road was under water for a depth of 1.2 m and the floodwaters stretched for 2.4 km. Many people abandoned their homes and slips blocked many roads (SCRCC, 1957).
5-7 Aug 1930		There was three days and two nights of continuous rain in and around Christchurch from the 5th to the 7th. The railway line and the road to Little River were blocked. (http://hwe.niwa.co.nz/event/August_1930_Canterbury_Flooding, accessed 8 January 2016). At Little River water invaded the township to a depth of 0.9 m, and 5 families had to abandon their homes (SCRCC, 1957).
4-5 May 1934	At Prices Valley, near Kaituna, ~360 mm fell in just over 12 hours	Steady rain fell in Canterbury, especially Banks Peninsula, over two days on the 4th and 5th. Heavy, squally rain from the south-west fell over the whole province. (http://hwe.niwa.co.nz/event/May_1934_New_Zealand_Storm, accessed 8 January 2016) At Little River the main street was converted into a subsidiary stream with water feet deep in places. Many people were forced to abandon their homes and personal losses were high (SCRCC, 1957).
25 Sep 1934		Part of Little River was under water for a short period, but the water receded quickly (SCRCC, 1957).
8-9 Feb 1936		A south-west storm, with heavy and persistent rain, caused rivers and creeks in many districts to flood. At Little River there was heavy surface flooding, the main road of the township being covered with water for 400 m with a depth of 0.9 to 1.2 m in some places (SCRCC, 1957).
8-9 Mar 1936		There was heavy rain on the 7th and 8th. Rain was still pouring down on the night of the 9th and wind reached gale force. Late on the night of the 8th Te Roto o Wairewa/Lake Forsyth was within 0.30 m of the road and was rising rapidly. Streets were filled with nearly 1.2 m of water. Most stores and the post office were flooded. On the floor of the post office water was 50 mm deep and there was similar flooding on the floor of the town hall. Roads to Kinloch and Okuti were blocked with 1.2 m of water blocking the way to Kinloch. Water was still nearly 1.2 m deep about the township on the night of the 9th. (http://hwe.niwa.co.nz/event/March_1936_Canterbury_Flooding, accessed 8 January 2016) At Little River small streams swelled quickly and brought a huge volume of water into the township. Several houses were evacuated when water invaded them, and the rising level of Te Roto o Wairewa/Lake Forsyth caused much anxiety. The main road north,

Date	Rainfall	Flood observations
		the Akaroa road, and other routes were blocked by floods and slips (SCRCC, 1957).
29 Jul 1936		Continuous rain raised the level of Te Roto o Wairewa/Lake Forsyth, and the road between Little River and Birdlings Flat became badly flooded (SCRCC, 1957).
16 Dec 1937		Heavy flooding occurred at Little River where 0.9 m of water covered the main road and Te Roto o Wairewa/Lake Forsyth rose 0.3 m in one hour (SCRCC, 1957).
12-14 Jun 1938		At Little River some minor flooding occurred in the township and farmlands in the vicinity were extensively inundated, but no serious damage was reported (SCRCC, 1957).
19 Aug 1938		At Little River some flooding occurred and water covered the ground to a depth of 0.9 m in parts, and slips blocked the road to Christchurch (SCRCC, 1957).
26 Dec 1939	164 mm at Little River, 130 mm at Okuti Valley, in 48 hours (SCRCC, 1957).	A long dry spell of dry weather was broken by heavy rain. No documented flooding in SCRCC (1957)
20-21 May 1945		Heavy rains throughout Canterbury caused extensive flooding on the 20th. (http://hwe.niwa.co.nz/event/May_1945_Canterbury_and_Otago_Flooding, accessed 8 January 2016). Considerable damage was caused by flood waters at Little River, and a number of residents had to evacuate their houses when 1.2 m of water covered some areas. A layer of silt 0.15 m deep covered the main road. All road and rail transport between Christchurch and Little River was suspended because of slips and flood waters, and stock losses were serious on the peninsula (SCRCC, 1957).
26-27 May 1946	82 mm at Little River in 24 hrs (SCRCC, 1957)	Flood damage from a south-west storm which swept the province was of only a minor nature, except at Little River, where creeks were swollen and slips and washouts blocked some roads (SCRCC, 1957).
1-3 Apr 1951		On Banks Peninsula practically all the eastern bays were isolated by slips, and serious flooding occurred at Little River. In the main street of the town the water was 0.5 – 0.6 m deep (SCRCC, 1957).
14 Aug 1952		At Little River 0.5 m of water was over the highway (SCRCC, 1957).
17-19 Jul 1961		There were several days of high intensity rain from the 17 - 19 July in South Canterbury. Flooding was reported with water 0.5 m deep over the road in the Little River township. (http://hwe.niwa.co.nz/event/July_1961_New_Zealand_Flooding, accessed 8 January 2016).

Date	Rainfall	Flood observations
9-15 Apr 1968		*"Cyclone Giselle formed in the Coral Sea near the Soloman Islands, over 3000km north-west of New Zealand, on 5th April. The system moved in a south-southeast direction, passing north of New Zealand. On the 9th, it passed along the east coast of the North Island from North cape, and after crossing Cook Strait the system travelled down the east coast of the South Island to Banks Peninsula, remaining close to the South Island for some days longer. The combination of a complex frontal zone, which extended from Tasmania, and a depression 800 km south-west of Campbell Island brought heavy rain to places."* (http://hwe.niwa.co.nz/event/April_1968_New_Zealand_Ex-tropical_Cyclone_Giselle, accessed 8 January 2016). *"Little River families had to be rescued when the settlement was flooded"* (http://hwe.niwa.co.nz/event/April_1968_New_Zealand_Ex-tropical_Cyclone_Giselle, accessed 8 January 2016).
24 May 2010		A front carrying heavy rain moved down the North Island on the 24th and stalled over Canterbury - pinned in place by a low pressure system over the Tasman Sea. It was the wettest week in Canterbury for 36 years with some parts of Canterbury recording over 163 mm of rain in 7 days. Flooding caused the closure of Kinloch Road in Little River. (http://hwe.niwa.co.nz/event/May_2010_New_Zealand_Storm, accessed 8 January 2016).
19 Oct 2011		Flooding at Little River closed SH75 between Christchurch and Little River. "*Little River was turned into a big river by the downpour, with fast-running water up to knee-height streaming down the main road through the Banks Peninsula town yesterday afternoon*" (http://www.stuff.co.nz/the-press/news/5817788/Little-River-becomes-big-river, cited 2 December 2015). Caused the worst flooding in the area in recent memory with several shops flooded … "*I've been out here 18 years and I've never seen anything like this.*" By late afternoon the rain had stopped and the flooding eased.
13 Aug 2012	270 mm at Okuti Valley	Water on main road. Road to Akaroa near Little River closed at 3:30pm. (http://www.weatherwatch.co.nz/content/road-closed-akaroa, accessed 8 January 2016). River burst its banks and water flowing around Koa Cottage and into lower houses. Water was covering the white line on the road and in the Little River garage it started coming in around 9:30am and ended up ankle-deep (http://www.stuff.co.nz/the-press/news/your-weather/7467488/Flooding-chaos-across-Canterbury, accessed 5 September 2016).
5-6 Mar 2014	177 mm at Okuti Valley & 314 mm at Wairewa (341 mm at Okana Valley?)	10 houses and businesses flooded. 5 March at 8:20am there was ~400 mm of water on road and whole of main road was running like a tail-race (Mike Herlihy's comments). The road between Little River and Barrys Bay was closed and there was significant surface flooding in the Little River and Cooptown area (Davie, 2014). Flooding of one house occurred for the first time in 47 years of living in the house (Vallance, 2014).

Date	Rainfall	Flood observations
17-18 Apr 2014	146 mm at Wairewa	Ex-tropical cyclone Ita lay to the west of the North Island bringing heavy rain and strong winds. It moved southwards during the period 17-19 April. The main road to Akaroa from Little River was impassable due to slips. (http://hwe.niwa.co.nz/event/April_2014_New_Zealand_Storm, accessed 8 January 2016).
29 Apr 2014	170 mm (Site 327804)	100 mm of flooding in Little River garage.

Appendix B: Model configuration information

Figure B-1: Overview of 1D model extent

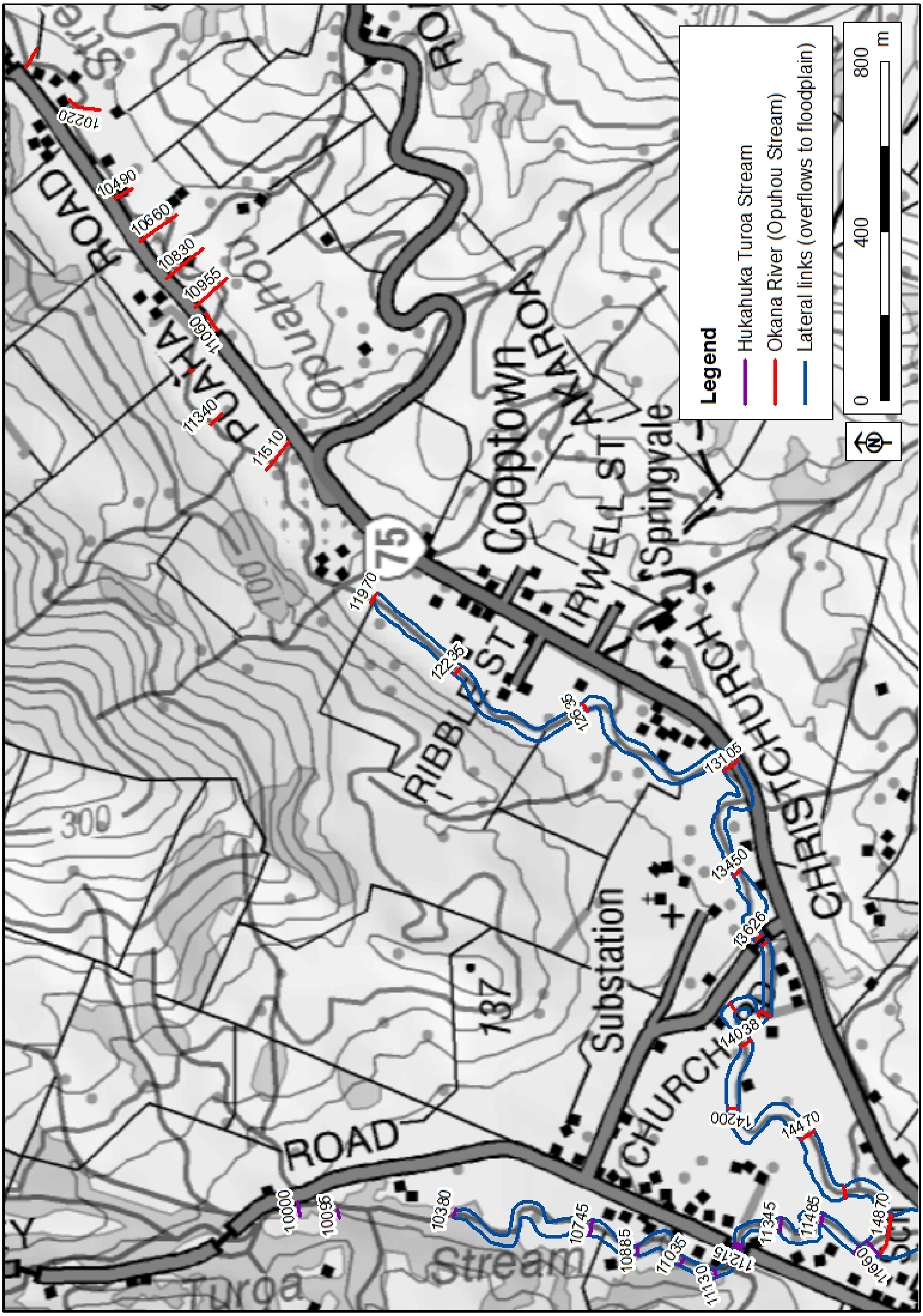

Figure B-2: Location of 1D cross sections and overflows (Sheet 1 of 3)

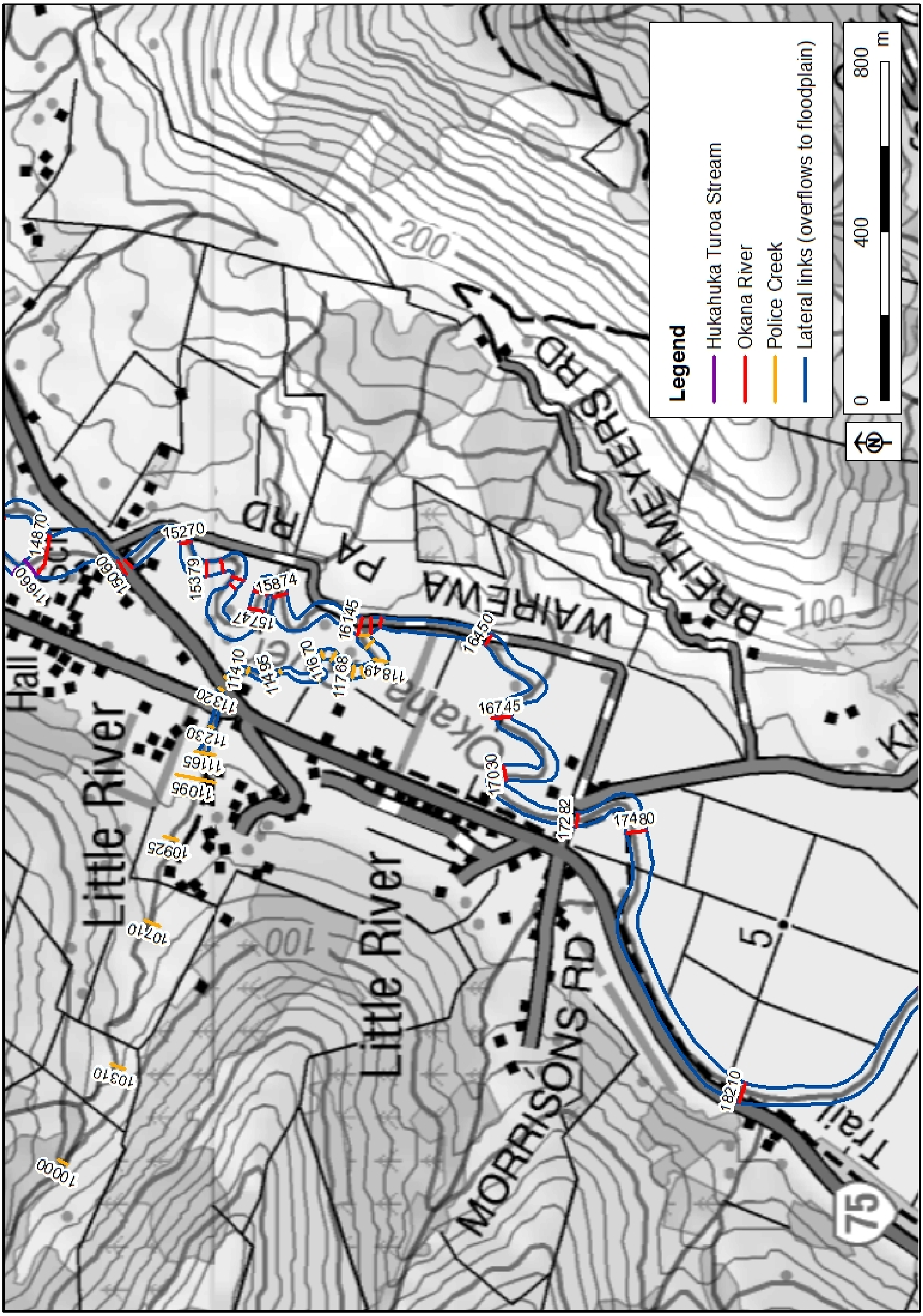

Figure B-3: Location of 1D cross sections and overflows (Sheet 2 of 3)

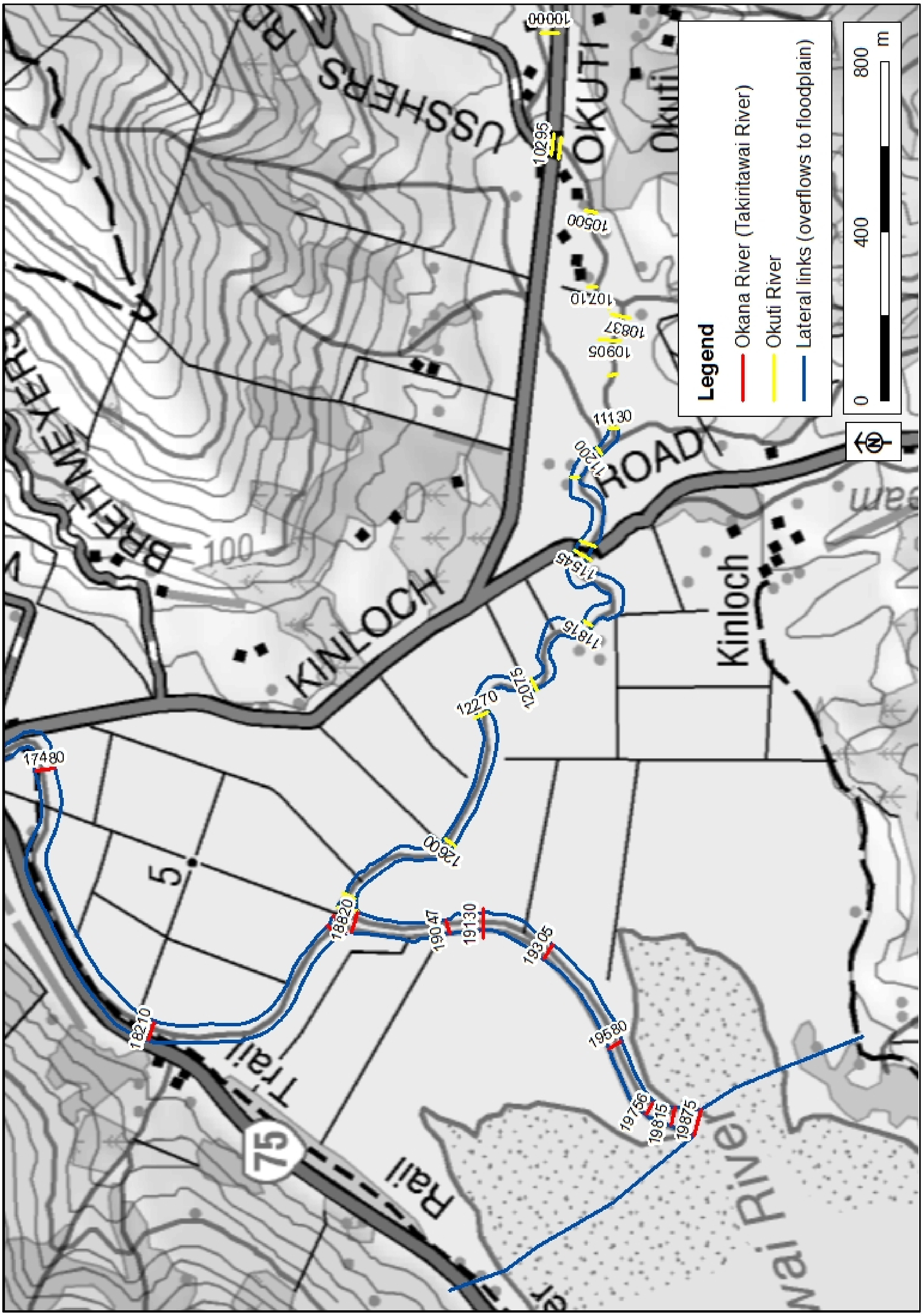

Figure B-4: Location of 1D cross sections and overflows (Sheet 3 of 3)

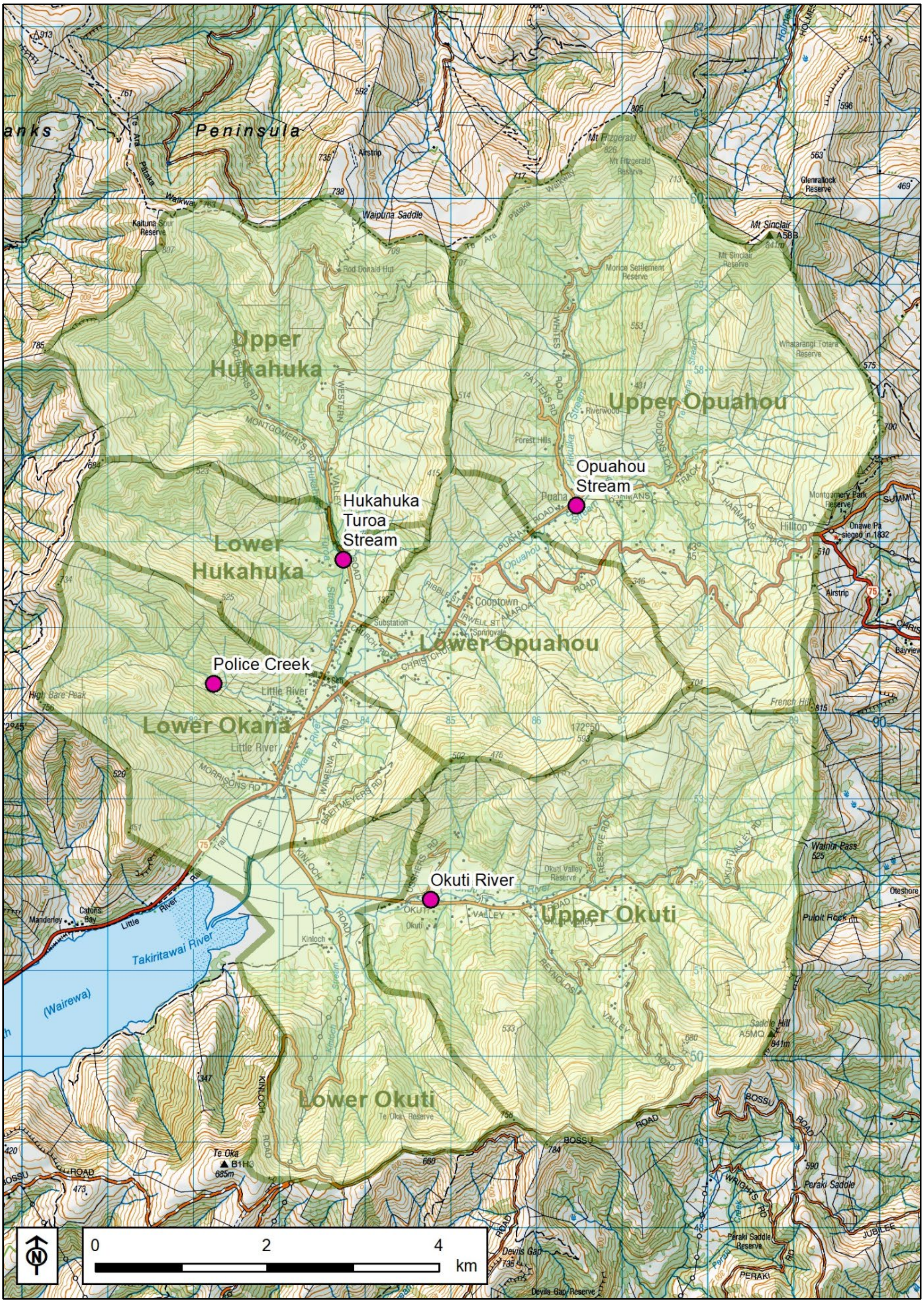

Figure B-5: Location of inflows

Table B-1: Summary of 1D cross section information for Hukahuka Turoa Stream

River	Mike 11 chainage (m)	Cross section source	Manning's n (pre-clearance)	Manning's n (current)	Manning's n (post-clearance)	Location/description
Hukahuka	10000	LiDAR				Upstream limit of model
Hukahuka	10095	LiDAR	0.080	0.080	0.045	
Hukahuka	10380	LiDAR	0.080	0.080	0.045	
Hukahuka	10745	LiDAR	0.080	0.080	0.045	
	(10885)		0.045	0.045	0.045	
Hukahuka	11035	LiDAR	0.060	0.060	0.060	
Hukahuka	11130	LiDAR	0.080	0.080	0.045	
Hukahuka	11215	LiDAR	0.080	0.080	0.045	Upstream of Western Valley Road bridge
Hukahuka	11225	LiDAR	0.080	0.045	0.045	Downstream of Western Valley Road bridge
Hukahuka	11345	LiDAR	0.080	0.045	0.045	
Hukahuka	11485	LiDAR	0.080	0.045	0.045	
Hukahuka	11600	LiDAR	0.080	0.045	0.045	
Hukahuka	11660	LiDAR	0.080	0.045	0.045	Confluence with Opuahou Stream (Okana River)

Table B-2: Summary of 1D cross section information for Opuahou Stream (Okana River)

River	Mike 11 chainage (m)	Cross section source	Manning's n (pre-clearance)	Manning's n (current)	Manning's n (post-clearance)	Location/description
Okana	10000	LiDAR				Upstream limit of model
Okana	10220	LiDAR	0.045	0.045	0.045	
Okana	10490	LiDAR	0.045	0.045	0.045	
Okana	10660	LiDAR	0.045	0.045	0.045	
Okana	10830	LiDAR	0.045	0.045	0.045	
Okana	10955	LiDAR	0.045	0.045	0.045	
Okana	11060	LiDAR	0.045	0.045	0.045	Upstream of Puaha Road bridge
Okana	11080	LiDAR	0.045	0.045	0.045	Downstream of Puaha Road bridge
Okana	11190	LiDAR	0.045	0.045	0.045	
Okana	11340	LiDAR	0.045	0.045	0.045	
Okana	11510	LiDAR	0.045	0.045	0.045	
	(11830)		0.045	0.045	0.045	
Okana	11970	LiDAR	0.080	0.080	0.045	
Okana	12235	LiDAR	0.080	0.080	0.045	Cooptown
Okana	12635	LiDAR	0.045	0.045	0.045	
	(12950)		0.045	0.045	0.045	
Okana	13105	LiDAR	0.080	0.045	0.045	
Okana	13450	LiDAR	0.080	0.045	0.045	
Okana	13613	Survey	0.080	0.045	0.045	
Okana	13626	Survey	0.080	0.045	0.045	Upstream of Church Road bridge
Okana	13647	(13626)				Downstream of Church Rd bridge
Okana	13820	LiDAR	0.080	0.080	0.045	
Okana	13846	LiDAR	0.045	0.045	0.045	
Okana	13935	LiDAR	0.045	0.045	0.045	
Okana	14000	LiDAR	0.045	0.045	0.045	
Okana	14038	LiDAR	0.080	0.080	0.045	
	(14110)		0.080	0.080	0.045	
Okana	14200	LiDAR	0.045	0.045	0.045	
Okana	14470	LiDAR	0.045	0.045	0.045	
Okana	14670	LiDAR	0.045	0.045	0.045	
Okana	14810	LiDAR	0.045	0.045	0.045	Confluence of Hukahuka Turoa Stream

Table B-3: Summary of 1D cross section information for Okana River

River	Mike 11 chainage (m)	Cross section source	Manning's n (pre-clearance)	Manning's n (current)	Manning's n (post-clearance)	Location/description
Okana	14870	LiDAR				Confluence of Hukahuka Turoa St and Opuahou Stm (Okana River)
Okana	15060	LiDAR	0.045	0.045	0.030	Upstream of the SH75 bridge
Okana	15080	LiDAR				Downstream of the SH75 bridge
Okana	15270	LiDAR	0.080	0.030	0.030	
Okana	15379	LiDAR	0.080	0.030	0.030	
Okana	15427	LiDAR	0.080	0.030	0.030	
Okana	15477	LiDAR	0.080	0.030	0.030	
Okana	15500	LiDAR	0.080	0.030	0.030	
Okana	15747	LiDAR	0.080	0.030	0.030	
Okana	15787	LiDAR	0.080	0.030	0.030	
Okana	15874	LiDAR	0.080	0.030	0.030	
Okana	16120	LiDAR	0.030	0.030	0.030	
Okana	16145	LiDAR	0.080	0.030	0.030	Upstream of the Police Creek confluence
Okana	16165	LiDAR	0.080	0.030	0.030	Downstream of the Police Creek confluence
Okana	16190	LiDAR	0.080	0.030	0.030	
	(16300)		0.080	0.030	0.030	
Okana	16450	LiDAR	0.030	0.030	0.030	
Okana	16745	LiDAR	0.030	0.030	0.030	
	(16980)			0.030		
Okana	17030	LiDAR	0.080	0.045	0.030	
Okana	17262	Survey	0.030	0.045	0.030	Upstream of the Kinloch Road bridge
Okana	17282	Survey				Downstream of the Kinloch Road bridge
	(17350)		0.030	0.030	0.030	
Okana	17480	Survey	0.080	0.080	0.030	
Okana	18210	Survey	0.080	0.080	0.030	
	(18310)		0.080	0.080	0.030	
Okana	18765	Survey	0.030	0.030	0.030	
Okana	18780	(18790)	0.030	0.030	0.030	
Okana	18790	LiDAR + survey bed level	0.030	0.030	0.030	Confluence with Okuti River

Table B-4: Summary of 1D cross section information for Police Creek

River	Mike 11 chainage (m)	Cross section source	Manning's n (pre-clearance)	Manning's n (current)	Manning's n (post-clearance)	Location/description
Police Ck	10000	LiDAR				Upstream limit of model
Police Ck	10310	LiDAR	0.080	0.080	0.080	
Police Ck	10710	LiDAR	0.080	0.080	0.080	
Police Ck	10925	LiDAR	0.045	0.045	0.045	
Police Ck	11095	LiDAR	0.045	0.045	0.045	
Police Ck	11165	LiDAR	0.045	0.045	0.045	
Police Ck	11230	LiDAR	0.060	0.060	0.060	
Police Ck	11275	Survey	0.080	0.080	0.080	Upstream of Western Valley Road bridge
Police Ck	11290	(11275)				Downstream of Western Valley Road bridge
Police Ck	11320	Survey	0.080	0.080	0.080	Upstream of SH75 bridge
Police Ck	11340	(11320)				Downstream of SH75 bridge
Police Ck	11410	LiDAR	0.080	0.080	0.080	
Police Ck	11495	LiDAR	0.030	0.030	0.030	
Police Ck	11590	LiDAR	0.030	0.030	0.030	
	(11640)		0.030	0.030	0.030	
Police Ck	11670	LiDAR	0.080	0.030	0.030	
Police Ck	11697	LiDAR	0.080	0.030	0.030	
Police Ck	11768	LiDAR	0.080	0.030	0.030	
Police Ck	11790	LiDAR	0.080	0.030	0.030	
Police Ck	11849	LiDAR	0.080	0.030	0.030	
Police Ck	11900	LiDAR	0.080	0.030	0.030	
Police Ck	11925	LiDAR	0.080	0.030	0.030	Confluence with Okana River

Table B-5: Summary of 1D cross section information for Okuti River

River	Mike 11 chainage (m)	Cross section source	Manning's n (pre-clearance)	Manning's n (current)	Manning's n (post-clearance)	Location/description
Okuti	10000	LiDAR				Upstream limit of model
Okuti	10295	LiDAR	0.080	0.080	0.045	Upstream of Okuti Valley Road bridge
Okuti	10315	LiDAR	0.080	0.080	0.045	Downstream of Okuti Valley Road bridge
Okuti	10500	LiDAR	0.080	0.080	0.045	
Okuti	10710	LiDAR	0.080	0.080	0.045	
Okuti	10775	LiDAR	0.045	0.045	0.045	
Okuti	10837	LiDAR	0.045	0.045	0.045	
Okuti	10905	LiDAR	0.045	0.045	0.045	
Okuti	10990	LiDAR	0.045	0.045	0.045	
Okuti	11130	LiDAR	0.045	0.045	0.045	
Okuti	11200	LiDAR	0.045	0.045	0.045	
Okuti	11290	LiDAR	0.045	0.045	0.045	
Okuti	11515	LiDAR	0.080	0.080	0.030	Upstream of Wairewa Pa Road bridge
Okuti	11545	LiDAR	0.080	0.080	0.030	Downstream of Wairewa Pa Road bridge
Okuti	11815	LiDAR	0.080	0.080	0.030	
Okuti	12075	LiDAR	0.080	0.080	0.030	
Okuti	12270	LiDAR	0.045	0.045	0.030	
Okuti	12600	LiDAR	0.045	0.045	0.030	
Okuti	12893	Survey	0.030	0.030	0.030	
Okuti	12900	(12893)	0.030	0.030	0.030	
Okuti	12910	(12920)	0.030	0.030	0.030	
Okuti	12920	LiDAR + survey bed level	0.030	0.030	0.030	Confluence with Takiritawai River (Okana River)

Table B-6: Summary of 1D cross section information for Takiritawai River (modelled as part of Okana River)

River	Mike 11 chainage (m)	Cross section source	Manning's n (pre-clearance)	Manning's n (current)	Manning's n (post-clearance)	Location/description
Okana	18820	Survey				Confluence of Okuti River and Takiritawai River (Okana River)
Okana	18830	(18820)	0.030	0.030	0.030	
Okana	19047	LiDAR + survey bed level	0.030	0.030	0.030	
Okana	19130	LiDAR + survey bed level	0.080	0.080	0.030	
Okana	19305	LiDAR + survey bed level	0.080	0.080	0.030	
Okana	19580	LiDAR + survey bed level	0.080	0.080	0.030	
Okana	19756	Survey	0.080	0.080	0.030	
Okana	19815	Survey	0.030	0.030	0.030	
Okana	19875	LiDAR + survey bed level	0.030	0.030	0.030	Te Roto o Wairewa / Lake Forsyth

Appendix C: Design flood maps

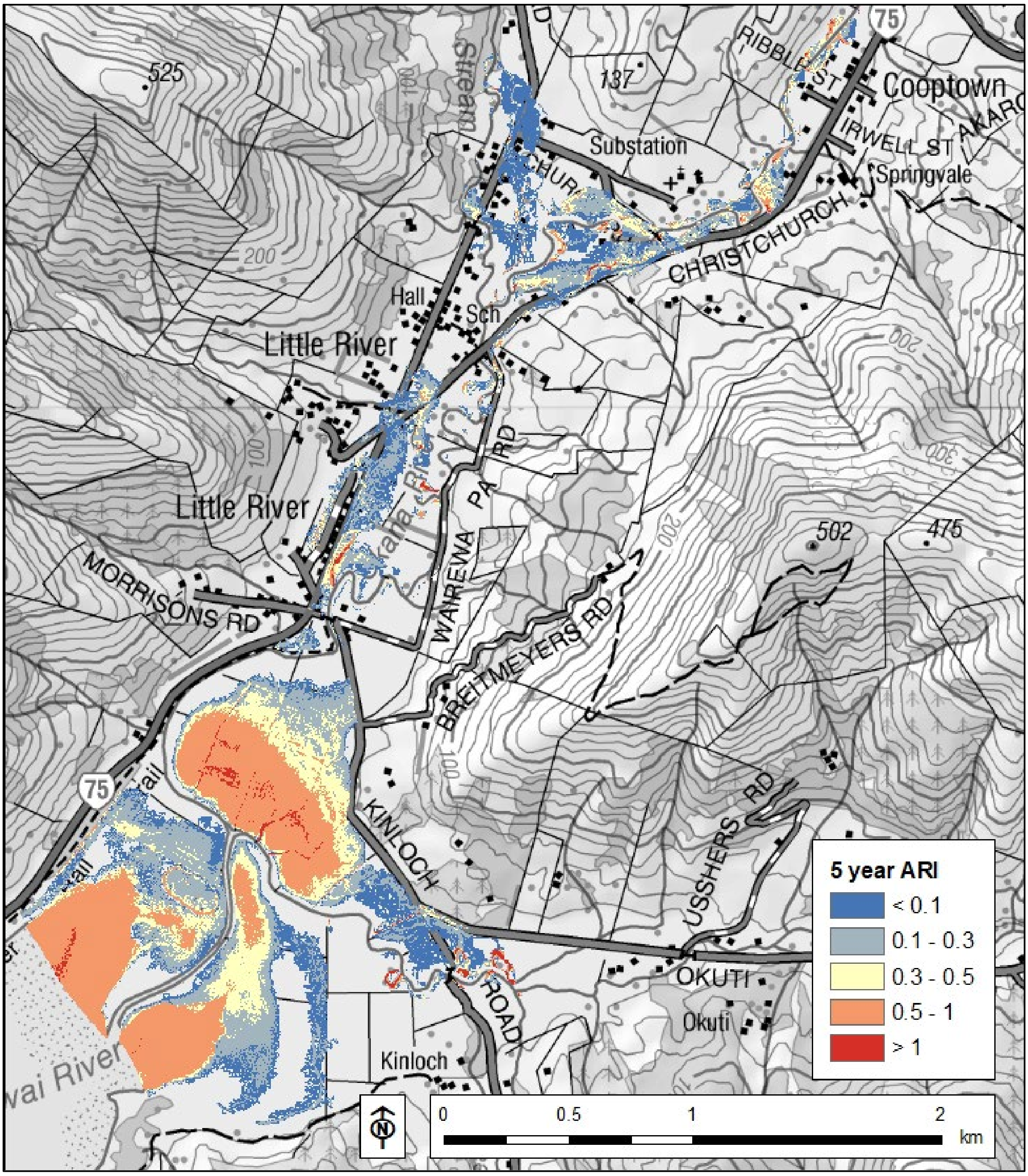

Figure C-1: Floodplain maximum modelled water depths for a 5 year ARI design flood event

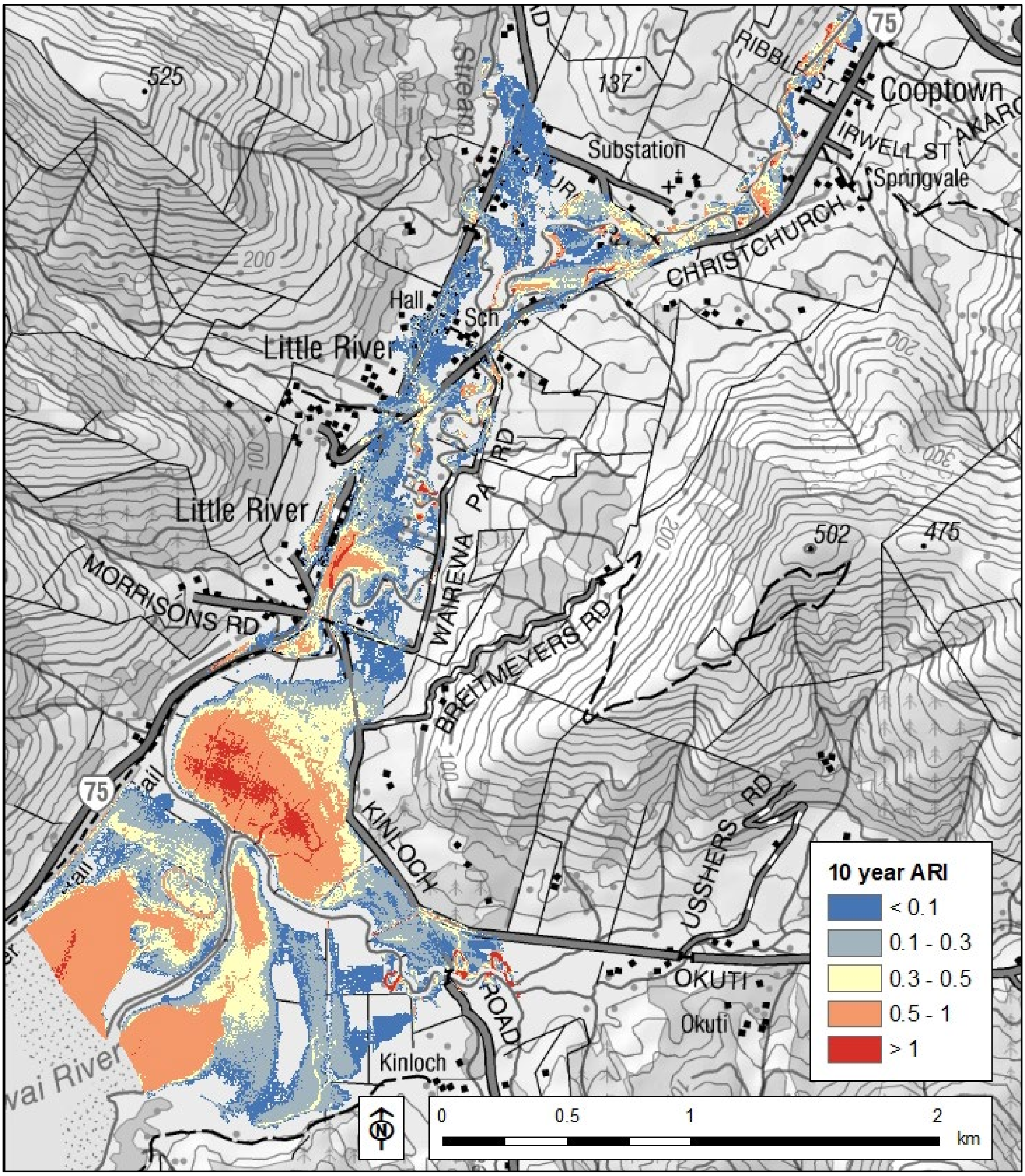

Figure C-2: Floodplain maximum modelled water depths for a 10 year ARI design flood event

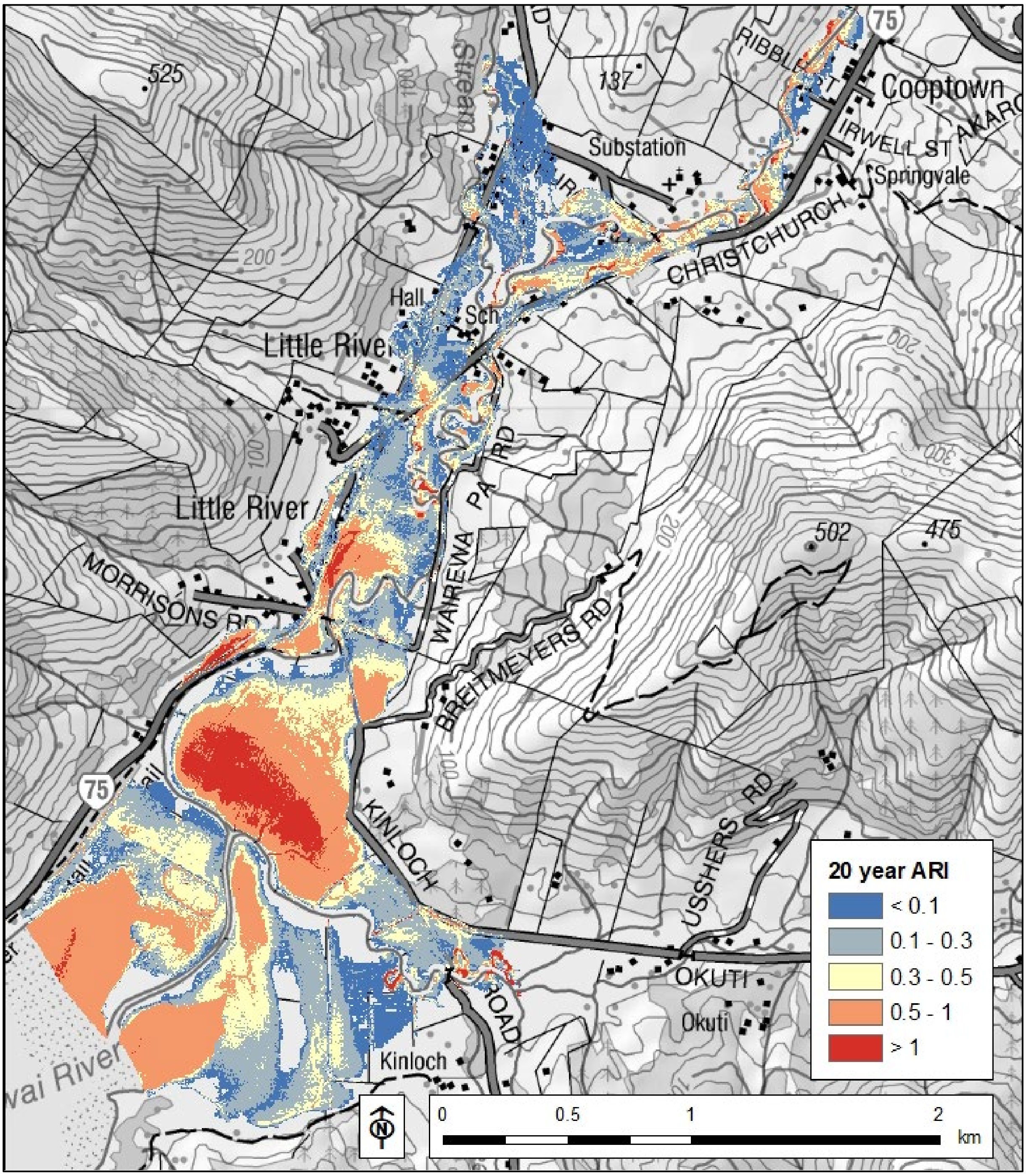

Figure C-3: Floodplain maximum modelled water depths for a 20 year ARI design flood event

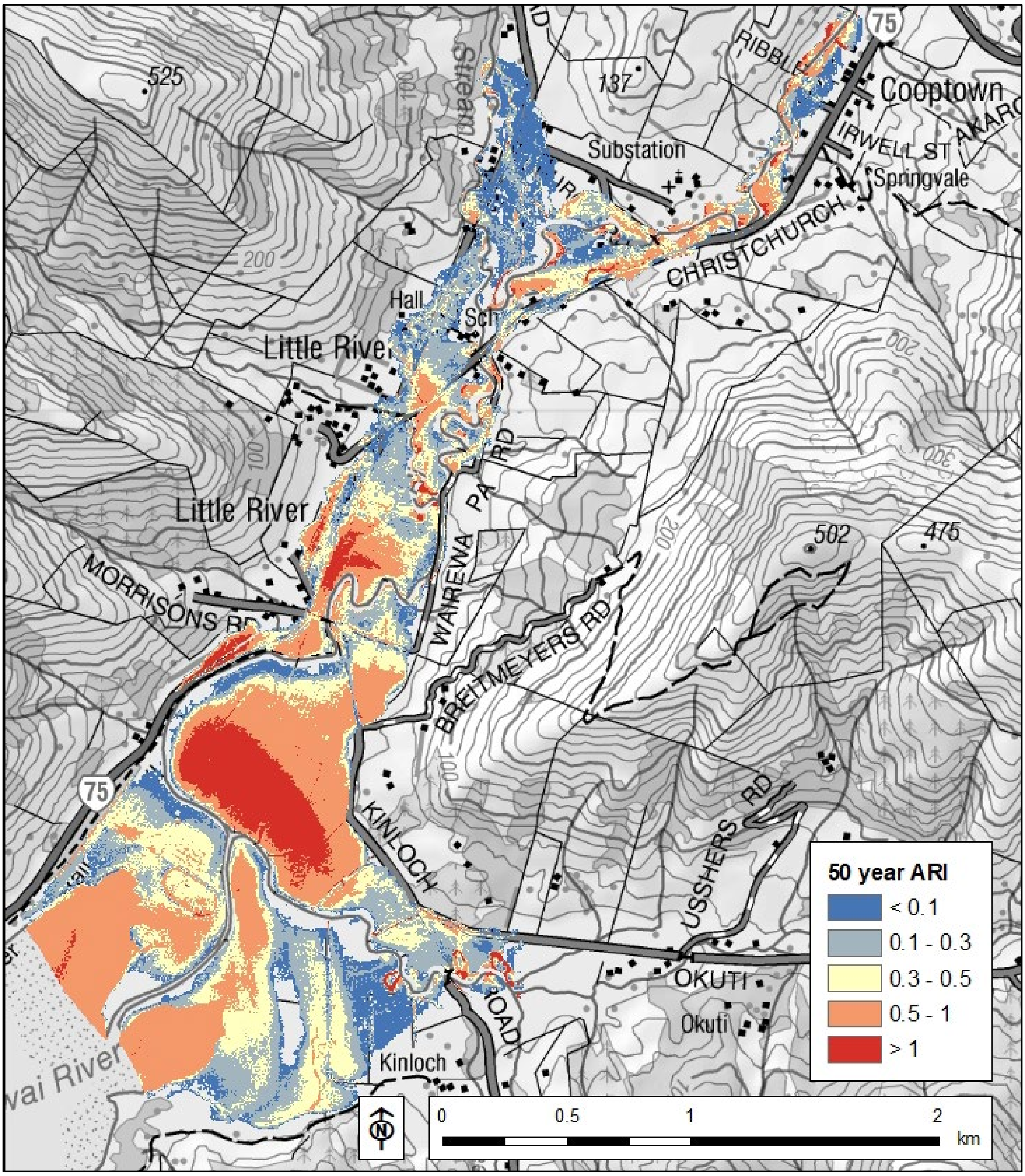

Figure C-4: Floodplain maximum modelled water depths for a 50 year ARI design flood event

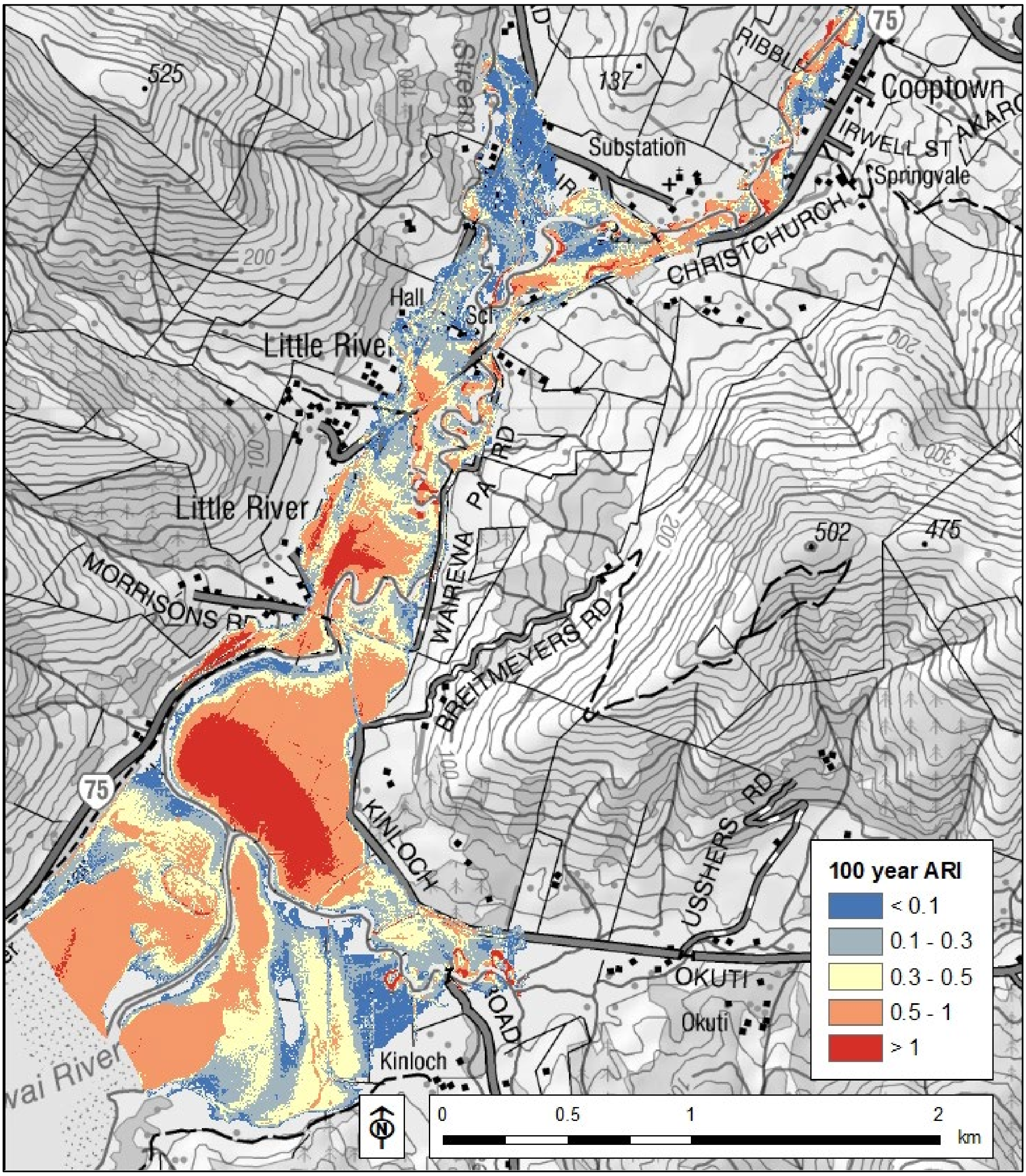

Figure C-5: Floodplain maximum modelled water depths for a 100 year ARI design flood event

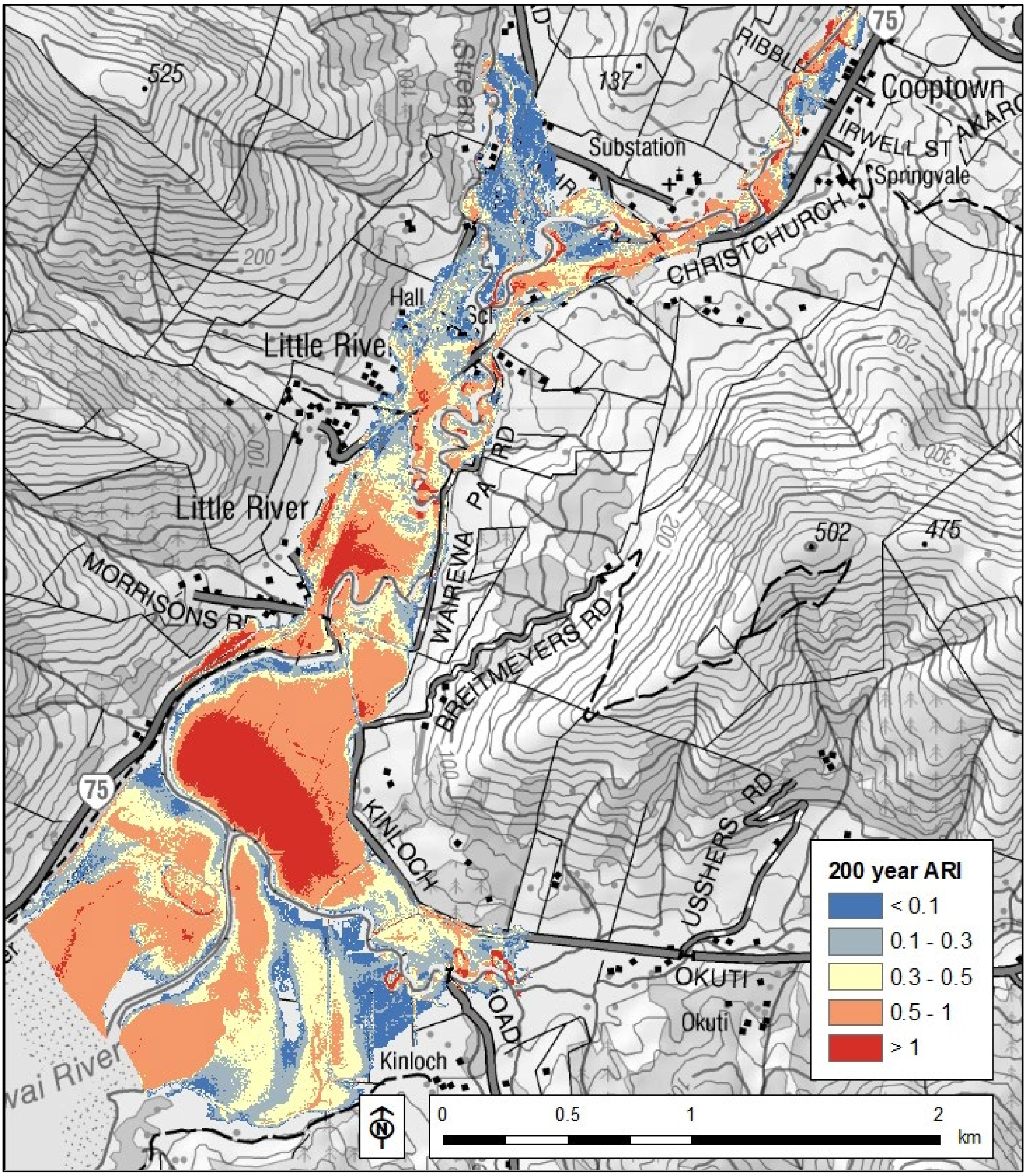

Figure C-6: Floodplain maximum modelled water depths for a 200 year ARI design flood event

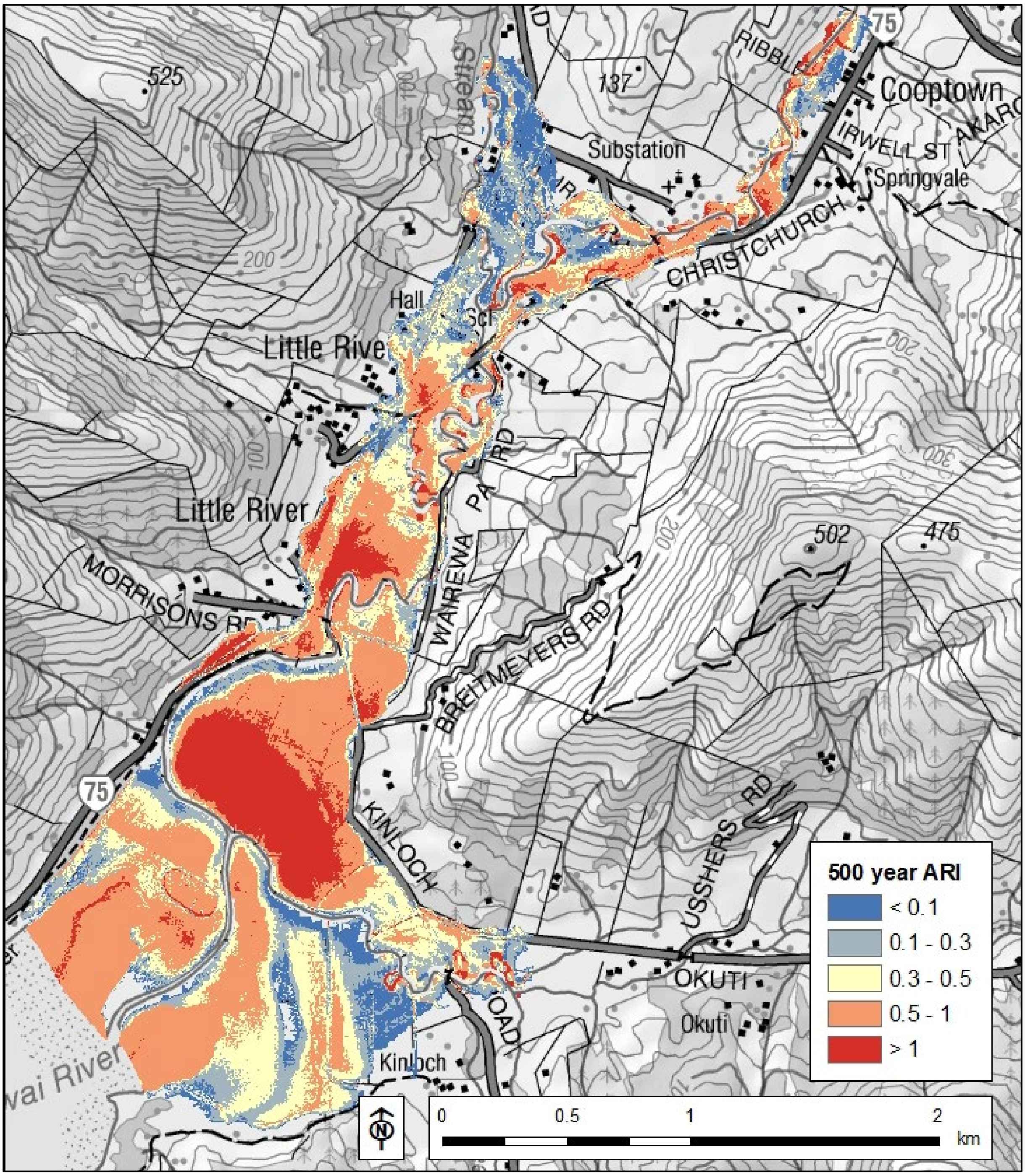

Figure C-7: Floodplain maximum modelled water depths for a 500 year ARI design flood event

Appendix D: Model run files

Little River model file summary

Mike11	
Network (*.nwk11)	Little_River_v6
Cross section (*.xns11)	Little_River_XS_v5
Mike21	
Drying depth (m)	0.01
Wetting depth (m)	0.03
Eddy viscosity	1
Number of structures	0
Simulation start time	5 March 2014 at 12:00am
Simulation end time	6 March 2014 at 1:00am
Time step (s)	0.5
Length of run (steps)	180000

Scenario	MikeFlood	Mike11				Mike21				
	Couple (*.mf)	Simulation (*.sim11)	Boundary (*.bnd11)	HD Parameter (*.hd11)	Results (*.res11)	Simulation (*.21)	Bathymetry (*.dfs2)	Initial surface elevation (m)	Resistance (*.dfs2)	Results (*.dfs2)
Validation: March 2014 (before channel clearance works)	Little_Riv_March2014_pre_work_rev_Okana_incr_mf	Little_Riv_March2014_pre_work_rev_okana_incr	Little_River_March2014_BCs_rev_okana_incr	Little_River_HD_n_pre_work	Little_Riv_March2014_pre_work_okana_rev_incr_final	Little_Riv_March2014_pre_work_rev_okana_incr	little_riv_5m_crop_v6_final	1.835	little_riv_5m_n_v6_final	Little_Riv_March2014_pre-work_rev_okana_incr_final
Sensitivity tests:										
Channel 'n' increased	Little_Riv_March2014_pre_work_rev_Okana_incr_chan_n_incr_mf	Little_Riv_March2014_pre_work_rev_okana_incr_chan_n_incr	Little_River_March2014_BCs_rev_okana_incr	Little_River_HD_n_pre_work_chan_n_incr	Little_Riv_March2014_pre_work_rev_okana_incr_chan_n_incr_final	Little_Riv_March2014_pre_work_rev_okana_incr_chan_n_incr	little_riv_5m_crop_v6_final	1.835	little_riv_5m_n_v6_final	Little_Riv_March2014_pre-work_rev_okana_incr_chan_n_incr_final
Floodplain 'n' increased	Little_Riv_March2014_pre_work_rev_Okana_incr_fp_n_incr_mf	Little_Riv_March2014_pre_work_rev_okana_incr_fp_n_incr	Little_River_March2014_BCs_rev_okana_incr	Little_River_HD_n_pre_work_chan_n_incr	Little_Riv_March2014_pre_work_rev_okana_incr_fp_n_incr_final	Little_Riv_March2014_pre_work_rev_okana_incr_fp_n_incr	little_riv_5m_crop_v6_final	1.835	little_riv_5m_n_incr_v6_final	Little_Riv_March2014_pre-work_rev_okana_incr_fp_n_incr
Lake level increased by 1m	Little_Riv_March2014_pre_work_rev_Okana_incr_LL_plus_1m_mf	Little_Riv_March2014_pre_work_rev_okana_incr_LL_plus_1m	Little_River_March2014_BCs_rev_okana_incr_LL_plus_1m	Little_River_HD_n_pre_work_LL_plus_1m	Little_Riv_March2014_pre_work_rev_okana_incr_LL_plus_1m_final	Little_Riv_March2014_pre_work_rev_okana_incr_LL_plus_1m	little_riv_5m_crop_v6_final	2.835	little_riv_5m_n_v6_final	Little_Riv_March2014_pre-work_rev_okana_incr_LL_plus_1m_final
Lake level decreased by 1m	Little_Riv_March2014_pre_work_rev_Okana_incr_LL_minus_1m_mf	Little_Riv_March2014_pre_work_rev_okana_incr_LL_minus_1m	Little_River_March2014_BCs_rev_okana_incr_LL_minus_1m	Little_River_HD_n_pre_work_LL_minus_1m	Little_Riv_March2014_pre_work_rev_okana_incr_LL_minus_1m_final	Little_Riv_March2014_pre_work_rev_okana_incr_LL_minus_1m	little_riv_5m_crop_v6_final	0.835	little_riv_5m_n_v6_final	Little_Riv_March2014_pre-work_rev_okana_incr_LL_minus_1m_final
Vegetation clearance runs:										
March 2014 with current vegetation clearance (to 2019)	Little_Riv_March2014_current_rev_Okana_incr_mf	Little_Riv_March2014_current_rev_Okana_incr	Little_River_March2014_BCs_rev_okana_incr	Little_River_HD_n_current	Little_Riv_March2014_current_rev_Okana_incr_final	Little_Riv_March2014_current_rev_Okana_incr	little_riv_5m_crop_v6_final	1.835	little_riv_5m_n_v6_final	Little_Riv_March2014_current_rev_Okana_incr_final
March 2014 with all vegetation clearance complete	Little_Riv_March2014_post_work_rev_Okana_incr_mf	Little_Riv_March2014_post_work_rev_Okana_incr	Little_River_March2014_BCs_rev_okana_inc	Little_River_HD_n_post_work	Little_Riv_March2014_post_work_rev_Okana_incr_final	Little_Riv_March2014_post_work_rev_Okana_incr	little_riv_5m_crop_v6_final	1.835	little_riv_5m_n_v6_final	Little_Riv_March2014_post-work_rev_Okana_incr_final
Engineering option runs:										
Five cuts - Sinuous channel straightened in 5 locations	Little_Riv_March2014_current_rev_Okana_incr_5_cuts_mf	Little_Riv_March2014_current_rev_Okana_incr_5_cuts	Little_River_March2014_BCs_rev_okana_incr	Little_River_HD_n_current	Little_Riv_March2014_current_rev_Okana_incr_5_cuts_final	Little_Riv_March2014_current_rev_Okana_incr_5_cuts	little_riv_5m_crop_v6_5_cuts_final	1.835	little_riv_5m_n_v6_final	Little_Riv_March2014_current_rev_Okana_incr_5_cuts_final
Bund - diverting overflows away from Little River Township	Little_Riv_March2014_current_rev_Okana_incr_with_bund_a_mf	Little_Riv_March2014_current_rev_Okana_incr_with_bund_a	Little_River_March2014_BCs_rev_okana_incr	Little_River_HD_n_current	Little_Riv_March2014_current_rev_Okana_incr_with_bund_a_final	Little_Riv_March2014_current_rev_Okana_incr_with_bund_a	little_riv_5m_crop_v6_with_bund_a_final	1.835	little_riv_5m_n_v6_final	Little_Riv_March2014_current_rev_Okana_incr_with_bund_a_final
Bund and removal of Okana River levees upstream and downstream of Kinloch Road	Little_Riv_March2014_current_rev_Okana_incr_with_bund_a_banks_rem_mf	Little_Riv_March2014_current_rev_Okana_incr_with_bund_a_banks_rem	Little_River_March2014_BCs_rev_okana_incr	Little_River_HD_n_current	Little_Riv_March2014_current_rev_Okana_incr_with_bund_a_banks_rem_final	Little_Riv_March2014_current_rev_Okana_incr_with_bund_a_banks_rem	little_riv_5m_crop_v6_with_bund_a_banks_rem_final	1.835	little_riv_5m_n_v6_final	Little_Riv_March2014_current_rev_Okana_incr_with_bund_a_banks_rem_final
Design flood runs:										
5 year ARI	Little_Riv_5yr_ARI_with_CC_current_Okana_incr_mf	Little_Riv_5yr_ARI_with_CC_current_Okana_incr	Little_River_5yr_ARI_with_CC_okana_incr	Little_River_HD_n_current	Little_Riv_5yr_ARI_with_CC_current_Okana_incr_final	Little_Riv_5yr_ARI_with_CC_current_Okana_incr	little_riv_5m_crop_v6_final	1.835	little_riv_5m_n_v6_final	Little_Riv_5yr_ARI_with_CC_current_Okana_incr_final
10 year ARI	Little_Riv_10yr_ARI_with_CC_current_Okana_incr_mf	Little_Riv_10yr_ARI_with_CC_current_Okana_incr	Little_River_10yr_ARI_with_CC_okana_incr	Little_River_HD_n_current	Little_Riv_10yr_ARI_with_CC_current_Okana_incr_final	Little_Riv_10yr_ARI_with_CC_current_Okana_incr	little_riv_5m_crop_v6_final	1.835	little_riv_5m_n_v6_final	Little_Riv_10yr_ARI_with_CC_current_Okana_incr_final
20 year ARI	Little_Riv_20yr_ARI_with_CC_current_Okana_incr_mf	Little_Riv_20yr_ARI_with_CC_current_Okana_incr	Little_River_20yr_ARI_with_CC_okana_incr	Little_River_HD_n_current	Little_Riv_20yr_ARI_with_CC_current_Okana_incr_final	Little_Riv_20yr_ARI_with_CC_current_Okana_incr	little_riv_5m_crop_v6_final	1.835	little_riv_5m_n_v6_final	Little_Riv_20yr_ARI_with_CC_current_Okana_incr_final
50 year ARI	Little_Riv_50yr_ARI_with_CC_current_Okana_incr_mf	Little_Riv_50yr_ARI_with_CC_current_Okana_incr	Little_River_50yr_ARI_with_CC_okana_incr	Little_River_HD_n_current	Little_Riv_50yr_ARI_with_CC_current_Okana_incr_final	Little_Riv_50yr_ARI_with_CC_current_Okana_incr	little_riv_5m_crop_v6_final	1.835	little_riv_5m_n_v6_final	Little_Riv_50yr_ARI_with_CC_current_Okana_incr_final
100 year ARI	Little_Riv_100yr_ARI_with_CC_current_Okana_incr_mf	Little_Riv_100yr_ARI_with_CC_current_Okana_incr	Little_River_100yr_ARI_with_CC_okana_incr	Little_River_HD_n_current	Little_Riv_100yr_ARI_with_CC_current_Okana_incr_final	Little_Riv_100yr_ARI_with_CC_current_Okana_incr	little_riv_5m_crop_v6_final	1.835	little_riv_5m_n_v6_final	Little_Riv_100yr_ARI_with_CC_current_Okana_incr_final
200 year ARI	Little_Riv_200yr_ARI_with_CC_current_Okana_incr_mf	Little_Riv_200yr_ARI_with_CC_current_Okana_incr	Little_River_200yr_ARI_with_CC_okana_incr	Little_River_HD_n_current	Little_Riv_200yr_ARI_with_CC_current_Okana_incr_final	Little_Riv_200yr_ARI_with_CC_current_Okana_incr	little_riv_5m_crop_v6_final	1.835	little_riv_5m_n_v6_final	Little_Riv_200yr_ARI_with_CC_current_Okana_incr_final
500 year ARI	Little_Riv_500yr_ARI_with_CC_current_Okana_incr_mf	Little_Riv_500yr_ARI_with_CC_current_Okana_incr	Little_River_500yr_ARI_with_CC_okana_incr	Little_River_HD_n_current	Little_Riv_500yr_ARI_with_CC_current_Okana_incr_final	Little_Riv_500yr_ARI_with_CC_current_Okana_incr	little_riv_5m_crop_v6_final	1.835	little_riv_5m_n_v6_final	Little_Riv_500yr_ARI_with_CC_current_Okana_incr_final

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