Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

TECHNICAL REPORT Science Group

Selwyn River/ Waikirikiri floodplain investigation

Report No. R19/41
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Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

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Executive summary

Background
Flooding of the Selwyn River floodplain typically occurs during prolonged periods of persistent rainfall, generated by depressions off the east coast of the country. During these events, the spring-fed Irwell River (located to the south of the Selwyn River), receives overbank flows from the Selwyn River. This can rapidly increase flows in the Irwell River. With both the Selwyn River and Irwell River being slightly perched above the mainly flat adjacent farmland, flooding of the floodplain is inevitable when significant Selwyn River overflows occur.

What we did
This study of the Selwyn River floodplain used a combined 1-dimensional (1D) and 2-dimensional (2D) hydraulic computer model (MIKE Flood) to estimate flood extent, depths, and flood levels for the 50, 200, and 500 year Average Recurrence Interval (ARI) flood events. The model was calibrated using the mainly in-bank July/August 2008 high flow event (Qpeak ~250 m^3/s, ~5 year ARI) and the larger July 2017 flood event (Qpeak ~470 m^3/s, ~40 year ARI). The August 2000 flood event (Qpeak ~480 m^3/s, ~40 year ARI) was also used to validate the model. For the design flood events, stopbank overtopping has been considered, but not inundation from stopbank failures.

What we found
Overflows to the Irwelll River are calculated to occur at flows around 250 m^3/s (e.g. 2008 flood event). These overflows occur along the Selwyn River south bank, between Westenras Road and Old South Road (opposite the Greendale Golf Course). At the same time, floodwater also flows through the Greendale Golf Course.

The current capacity of the Selwyn River Control Scheme is estimated to be equivalent to a 10 to 20 year ARI flood event, with a maximum channel capacity upstream of the Upper Selwyn Huts of ~320 to 330 m^3/s. Assuming no stopbank failures (i.e. only overtopping of stopbanks but no scouring or collapsing of stopbanks), approximately 57 km^2 of floodplain will be inundated for a 50 year ARI flood event, and 88 km^2 for a 500 year ARI flood event. However, structural failure of stopbanks should not be discounted for flood events of this magnitude, or even more frequent flood events.

What does this mean?
The results of this modelling will be used to inform land use planning decisions. The results identify high hazard flood areas and will ensure appropriate floor levels can be determined for new buildings constructed on the Selwyn River floodplain. The model developed as part of this study could also be used in the future to analyse proposed flood protection works, and for emergency management purposes.

How we have considered climate change

To allow for climate change to 2120, current design peak flow estimates have been increased by 25%. This 25% flow increase is in line with upper-range RCP projected increases for relevant extreme rainfall events. 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 lake openings. Modelling of a 200 year ARI design flood event, with Te Waihora/Lake Ellesmere levels raised by 0.5 m, also showed any significant increases in maximum water level were limited to the lake shoreline. It is recommended that these climate change assumptions are updated as better information becomes available.

Note: During the July 2017 flood event, high flows were measured around the flood peak. This investigation uses the revised Coes Ford flow information.

February 1945 Flood
Looking south across the Selwyn River at Main South Road and Rail Bridge. Overflow from the Selwyn River passes into the Irwell River (which can be seen in the background).

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1 Introduction

The Selwyn River catchment and floodplain area lies to the south-west of Christchurch in the Selwyn District. Large flood events (including the floods of 1945, 1951, 2000 and 2017) often occur in this area when a slow-moving depression develops to the north of the South Island, moving warm moist air from the north into the Central Canterbury area. This can produce prolonged periods of persistent rainfall over the catchment, resulting in flooding within the Selwyn and Irwell River systems. During such flood events, State Highway 1 (SH1) can be inundated, causing major disruptions to traffic. Large rural areas of farmland also become inundated, restricting farming operations.

While Environment Canterbury has some information on the approximate extent and magnitude of several large historic flood events, there is limited information on more extreme flood events. The computational modelling described in this report has been undertaken to simulate the extent of flooding likely to occur for large flood events – in particular, 200 and 500 year average recurrence interval (ARI) flood events. This is achieved by using very detailed topographic data obtained from a LiDAR (aerial laser) survey, and a combined 1D and 2D hydraulic computer model of the Selwyn River and floodplain (which includes the Irwell River).

Potential inundation areas, including depths of flooding, are required for land use planning purposes, and the provision of minimum floor levels. At present, this is limited to approximate inundation areas based on historic flooding. This modelling investigation provides accurate inundation maps for more extreme events.

2 Background

2.1 Selwyn catchment and floodplain

The Selwyn River catchment has an area of approximately 770 km^2, with the headwaters of the river and main tributaries originating in the Big Ben and Russell Ranges in the Canterbury foothills (Figure 2-1). An additional 300 km^2 of plains contributes a negligible amount to flood flows and has not been included in this study.

Average annual rainfall within the catchment varies from ~2000 mm in the headwaters, to ~700 mm on the plains (Topélen, 2007). The upper catchment bedrock is predominantly composed of volcanic rock formations and greywacke (i.e. quartz and feldspar), while the basin floor in the upper catchment consists of soft sandstones and gravel sediments covered by loess (Topélen, 2007). Some of the upper catchment is planted with exotic trees, with the higher areas of the sub-catchments used for forestry. The remainder of the land is used predominantly for pastoral farming.

When the Selwyn River exits the Canterbury foothills, it flows in a south-easterly direction along a depression formed between the merged Waimakariri and Rakaia river outwash fans (CRC, 1996). As the plains are mainly free-draining gravels, the mid-plains reach of the Selwyn River is ephemeral. Surface flow often only passes along the full length of the river for a few months of the year (Vincent, 2005). For large periods of the year, the main tributaries of the Selwyn River (i.e. the Hororata, Waianiwaniwa, and Hawkins Rivers), also tend to have dry riverbeds in their upper plains reaches (Vincent, 2005).

The catchment characteristics for the Selwyn River, upstream of the Hawkins River confluence (~35 km upstream of Te Waihora/Lake Ellesmere), are summarised in Table 2-1 (NCCB, 1953).

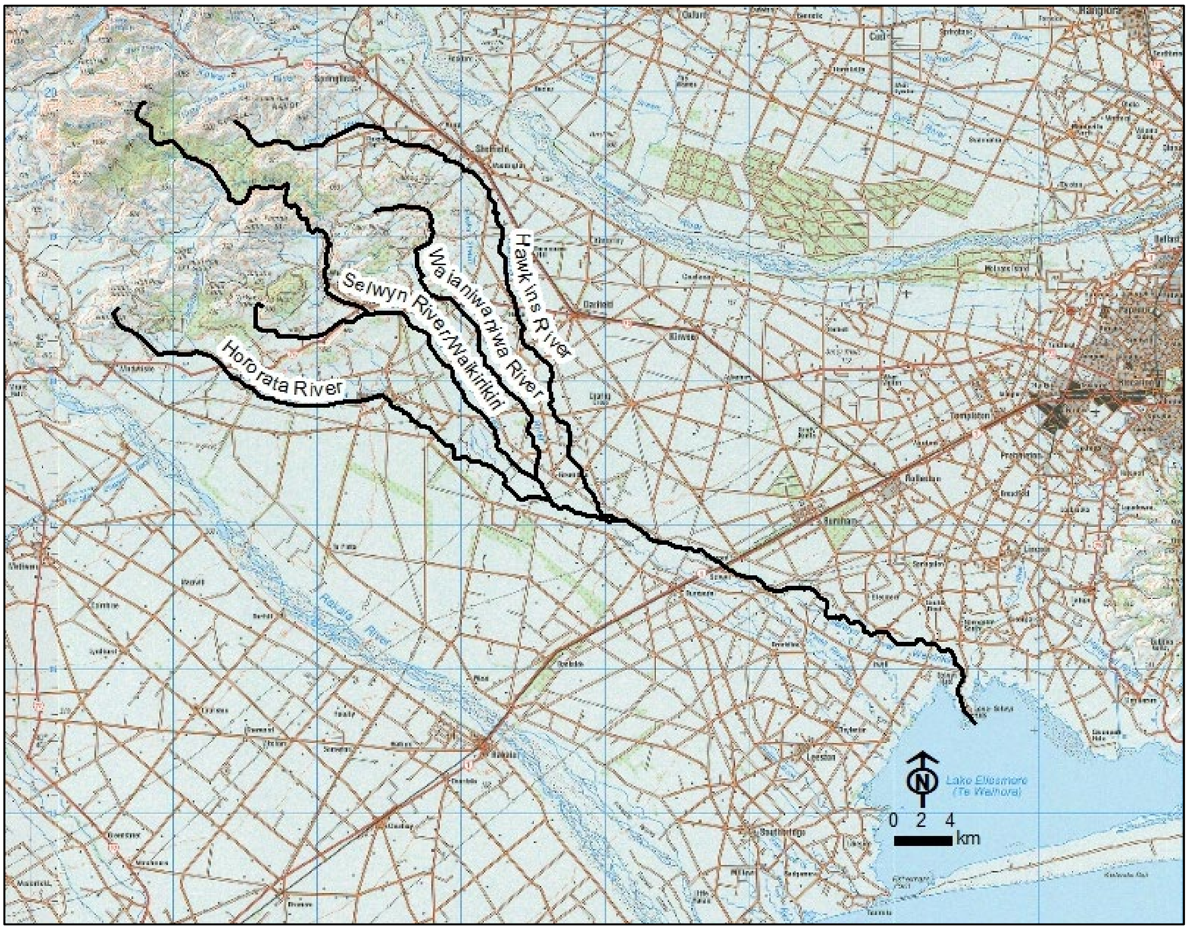


Figure 2-1: Selwyn River and main tributaries

Table 2-1: Upper Selwyn River catchment characteristics [source: NCCB (1953)]

Subcatchment	Area (km^2)	% of catchment area		
		High elevation, mainly steep slopes	Medium elevation, more gentle slopes	Low elevation, flat slopes
Upper Selwyn	278	73	10	17
Hawkins	146	37	30	33
Waianiwaniwa (formerly Waireka)	119	31	26	43
Hororata	135	22	26	52
TOTAL	678	48	20	32

Downstream of the Hawkins River confluence, the catchment and greater floodplain area (which includes the Irwell River), has a gentle gradient. The lower reaches of the Selwyn River and Irwell River pass through predominantly rural farmland, before discharging into Te Waihora/Lake Ellesmere. The soils in the lower floodplain area (i.e. downstream of SH1) tend to be heavy and relatively impermeable, impeding drainage. A network of drains in the lower floodplain are designed to reduce the, otherwise high, water table and make the land more suitable for farming activities. These drains will also convey some Selwyn River overflows toward Te Waihora/Lake Ellesmere in large flood events.

The Selwyn River, and the spring-fed Irwell River, are slightly perched above adjacent land, resulting in flooding of surrounding farmland whenever significant overflows occur from either river (CRC, 1996). Although the Irwell River is spring-fed, during significant flood events the river flows can rapidly increase when the Irwell River receives overbank flows from the Selwyn River (Figure 2-2).

Figure 2-2: Selwyn River (left) overflows to the Irwell River on 11 August 1986 (looking east)

Low-lying land adjacent to Te Waihora/Lake Ellesmere is also susceptible to flooding from the lake (Figure 2-3).

Figure 2-3: Selwyn River mouth and Lower Selwyn Huts (middle of photo) on 17 July 1963

Although the catchment area downstream of the Hawkins River confluence is large (about 300 km^2), it is assumed that this area produces a negligible flow contribution to Selwyn River flood flows. It is criss-crossed with minor drains and water races but produces little runoff, even in heavy rain. As the land is predominantly rural, the total impervious area is also negligible.

2.2 Historic flooding

Floods in the Selwyn River typically occur when south-easterly weather systems produce long duration rainfall over the catchment. Many of the larger flood events (including the floods of 1945, 1951, 2000 and 2017) occur when a slow-moving depression occurs over the ocean to the north of the South Island. This tends to move warm moist air from the north into the South Canterbury area, producing prolonged periods of high intensity rainfall in the foothills. For example, in the April 1951 flood, 210 mm was recorded over 48 hours at the Selwyn River at Gorge gauge, and in the August 2000 flood, 209 mm was recorded over 48 hours at the Selwyn at Whitecliffs gauge.

Depending on the size of the flood event, the flood peak takes ~ 8 to 20 hours to travel from Whitecliffs downstream to Coes Ford. The estimated peak flows for historic floods are summarised in Table 2-2.

For large flood events, it can be difficult to measure the total flood flow precisely. Some flood flow usually ‘escapes’ from the Selwyn River system, passing onto the floodplain and/or into the Irwell River. Flood peaks can also occur at night, when it is dangerous to make observations or measurements. Even during daytime, large flood events are often unable to be gauged at their peak flow for logistical reasons, resulting in rating curves (that convert water level to flow) having to be extrapolated for higher water levels. For example, prior to the July 2017 flood event, the Coes Ford water level recorder had maximum measured flows of 169 m^3/s (28 July 1994), and 165 m^3/s (14 January 2002). During the July 2017 flood event, higher flows of 346 and 397 m^3/s were measured at Coes Ford (Figure 2-4). This enabled high flows for this event, and previous flood events, to be better estimated.

Figure 2-4: July 2017 - Selwyn River at Coes Ford on the true left bank (looking south)

Although high flows have now been measured, ratings still change during flood events and over time (e.g. if there is significant vegetation or aggradation in the river channel). Historically, there have been periods of time when significant vegetation in the Selwyn riverbed has reduced the flood carrying capacity. For example, in 1986, four relatively small flood flows overtopped the Selwyn River banks in the Westenras Road area. This led to water flowing over SH1, disrupting traffic. Other larger flood flows have been carried by the river channel, with much smaller overflows to the Irwell River. Various stopbank configurations have also been in place since the Selwyn River Control Scheme was implemented in the 1940s (see Section 2.3), and some flow measurement methods are less reliable than others (e.g. slope-area calculations). In general, larger flood flow measurements, and older unrated estimates, should be used with caution.

Table 2-2: Summary of estimated peak flows at various locations along the Selwyn River

Year	Estimated peak flow (m^3/s)	Description	Source
22-23 Feb 1945	290 to 315	Approximately 230 m^3/s at Selwyn Huts plus another 60 to 85 m^3/s from the large body of water that overflowed upstream (e.g. Westenras, Coes (south), and north above & below Ellesmere Bridge). River bed overgrown with willows, broom and gorse.	NCCB Chief Engineer report (28 March 1946)
18-19 Apr 1951	615	Approximately 473 m^3/s at Selwyn Huts + ~142 m^3/s overflow upstream	Ex-Chief Engineer Report

Year	Estimated peak flow (m^3/s)	Description	Source
25-26 Jan 1953	580	Estimated peak at Ellesmere Bridge. Some overflow upstream of bridge, returning by Coes Ford. Slope-area calcs ~500 m^3/s between Ryan's Cut and Rennie's.	NCCB Chief Engineer report (9 February 1953)
	620	Current meter gauging at Ellesmere Br; 520 m^3/s, river rose further approx. 6" before peak. Note: excludes the one overflow upstream of Ellesmere Bridge – this would increase peak flow to ~620 m^3/s.	Memo: Chief Engineer (13 February 1953)
April 1959	400	400 m^3/s (assume referring to estimated flow at Ellesmere Bridge)	NCCB Chief Engineer report (26 August 1963)
May 1959	310	310 m^3/s (assume referring to estimated flow at Ellesmere Bridge)	NCCB Chief Engineer report (26 August 1963)
18-19 Jul 1961	650	620 m^3/s; estimated flow at Selwyn Bridge excluding overflows. Pegged flood marks estimate a peak flow of ~650 m^3/s for the McBeans to Rennies reach.	NCCB Chief Engineer report
14-17 Jul 1963	>620	17th July peak was bigger than 15th July (~620 m^3/s, gauged at 570 m^3/s on 15th at 9:15am). Gaugings were measured before peaks at Ellesmere Bridge (peak occurred at night). Overflows at Westenras, upstream of Main South Rd, etc, are not included in gauged flows. Lower Huts were flooded.	NCCB Chief Engineer report
	570	Ellesmere Traffic Bridge peak level; 60.35 ft. Overflows at several sites.	Special report – Selwyn works rating area, F.J. McGuigan, Nov 1987
13-14 Mar 1986		Peak water level; 58.5 ft on Ellesmere Bridge (rated flow; 400 m^3/s). Overflow from Westenras closed SH1.	
		235 m^3/s at Coes Ford	Coes Ford (Site 68002)
11-13 Aug 1986		288 m^3/s (gauged) at Ellesmere Bridge plus 75 m^3/s overflow on TRB immediately d/s of Hororata River to end of Hunters Rd – opposite golf course. Channel was restricted and elevated with willow growth/well vegetated islands. ** Four floods in 1986 – all overflowed SH1. 11-13 August event recorded highest river level and overflow since 1963.	Special report – Selwyn works rating area, F.J. McGuigan, Nov 1987

Year	Estimated peak flow (m^3/s)	Description	Source
	302	7.6 m recorded level (227 + 75 m^3/s; 302 m^3/s)	Coes Ford (Site 68002)
24 Dec 1993	216		Coes Ford (Site 68002)
27 Jul 1994		Low lake level as lake remained open to sea during event (0.6 m to 0.8 m).	Flood summary – Ross Vesey
	352	8.034 m recorded level.	Coes Ford (Site 68002)
20 Aug 2000	478	Coes Ford; 428 m^3/s (8.334 m recorded level). Overflows to Irwell estimated to be ~50 m^3/s.	
13 Jan 2002	256	7.917 m recorded level.	Coes Ford (Site 68002)
1 Aug 2008	246	Not aware of any significant overflows observed for this event.	Coes Ford (Site 68002)
14 Aug 2012	164		Coes Ford (Site 68002)
18 June 2013	163		Coes Ford (Site 68002)
19 April 2014	158		Coes Ford (Site 68002)
22 July 2017	471	Coes Ford; 421 m^3/s. Overflows to Irwell estimated to be ~50 m^3/s.	Coes Ford (Site 68002)

2.3 Selwyn River Control Scheme

The existing Selwyn River Control Scheme has 23.2 km of stopbanks located along both sides of the Selwyn River (Figure 2-5). These continuous stopbanks extend from the river mouth at Te Waihora/Lake Ellesmere upstream to:

- Ellesmere Bridge on the Christchurch/Leeston Road (southern bank)
- Coes Ford (northern bank)

There are also smaller sections of isolated stopbanks further upstream.

Other Selwyn River Control Scheme assets include over 70 km of erosion control works (i.e. tree planting) and several small culvert/floodgate structures. Additionally, annual maintenance programs control vegetation and shingle movement (including commercial shingle extraction), as well as managing the alignment of the active channels.

The original flood protection scheme for the Selwyn River was designed in the 1940s to contain a 425 m^3/s design flow. The Scheme works commenced at the mouth of Lake Ellesmere in November

1947, with Central Government subsidy at the rate of 3:1 on an estimated capital cost of $70,000 (c.1947).

Figure 2-5: Selwyn River Control Scheme downstream of Coes Ford on 20 August 2000

During 1951, the Scheme ran into difficulties with over expenditure. A large flood that exceeded the Scheme design discharge caused considerable damage to the flood protection works that were under construction. By 1952, the Scheme works had progressed upstream as far as Ellesmere Bridge with expenditure of $135,000.

In 1953, amendments were made to the Scheme design, and, although the improved scheme (849 m^3/s design flow) was approved by government in 1956, the cost of implementing the scheme was not supported by the ratepayers. A revised proposal, aimed at providing flood protection for all but the major floods, was requested by ratepayers in 1961. The objectives of this modified 1962 scheme were to:

1. Provide for a 560 m^3/s design flood flow.
2. Provide stopbanks, where necessary, to carry this flow with 0.8 m freeboard.
3. Provide a clear fairway of 160 m.
4. Undertake works within limits of available local funding.

However, flooding in 1963 exceeded the 560 m^3/s design standard. This resulted in little ratepayer enthusiasm to proceed. Although a 1965 report to the Board endorsed the objectives of the 1962 modified scheme, the issue of anomalies in the classification were never addressed. The recommendations contained in that report, and adopted by the Board, were to:

1. Maintain assets created by Scheme works (and light protection works at isolated points upstream as far as Westenras), up to a 560 m^3/s design standard, whether by public, or private, construction
2. Undertake no new works out of rating monies.
3. Abandon further investigations, Schemes and reports.
4. Establish a flood reserve fund.

The Selwyn River Scheme was generally managed according to these objectives until 1990. At this time, the Canterbury Regional Council confirmed a special order to adopt a system of rating, on a differential basis, for the protection from flood or erosion in the whole of the Selwyn River Rating District. The current objectives of the scheme are, therefore:

1. To prevent overflows from the Selwyn River in floods up to a discharge of 560 m^3/s.
2. To maintain the riverbed downstream from the Hororata River confluence. This involves keeping the riverbed clear of vegetation and obstructions (trees and brushweeds), which would have the effect of impeding or diverting flows.
3. Maintain fairway edge erosion control works, and berm planting, to provide protection for the stopbank system, and to control or reduce flood overflows onto the floodplain.

Although objectives 2 and 3 are being met, between cross section surveys in 1946/52 and 2009 there has been ~1.1 million m^3 of gravel deposited in the Selwyn River river bed and berm areas. This has reduced the flow capacity in some reaches (Surman, 2013). This aggradation is likely to be exacerbated by the loss of some river flow to groundwater, as well as reduced conveyance downstream of overflow locations (where water exits the Selwyn River and flows towards the lake via other flow paths).

Based on a 1999 survey of the river channel, the stopbank capacity was approximately 400 to 500 m^3/s with no freeboard (Surman, 2013).

2.4 Te Waihora/Lake Ellesmere levels

Although Te Waihora/Lake Ellesmere is adjacent to the ocean, it is not tidal. This is because the outflow to the ocean is usually blocked by Kaitorete Spit, a 25 km long by 5 m high gravel beach barrier.

When there are high flows into the lake, the combination of the closed lake outlet and flat land surrounding the lake can lead to the lake surface area increasing dramatically with relatively modest water level increases. For example, if the lake level rises from 1.0 to 1.5 m Lyttelton Vertical Datum 1937 (LVD37), the lake surface area increases by 3,900 hectares. The lake level and opening are governed by requirements of a National Water Conservation Order and the opening is managed for multiple values (e.g. drainage, birdlife, fishery, vegetation). When certain water levels are reached the outlet is excavated, connecting the lake to the ocean (Figure 2-6).

According to historic records, the lake has been manually opened between 1 to 7 times per year since 1901, with an average opening level of 1.27 m LVD37 (1901 to 2019). The current resource consents allow Te Waihora/Lake Ellesmere to be artificially opened when its level is no less than:

- 1.05 m LVD37 from 1 August to 31 March; or
- 1.13 m LVD37 from 1 April to 31 July; or
- At any level from 1 April to 15 June, primarily for fish migration from the lake to the sea; or
- At any level from 15 September to 15 October, primarily for fish migration from the sea to the lake and/or for the purposes of enhancing outstanding wildlife values by minimising the occurrence of low lake levels over the summer period.

Although the winter opening level for the lake is 1.13 m LVD37, lake levels regularly rise above this if unfavourable sea conditions delay works to open the outlet. In 2010 the lake reached 1.41 m LVD37 when the lake opening was delayed by 6 weeks, and on 29 June 2013 (after a period of high rainfall in the catchment) the lake reached 1.81 m LVD37 before being successfully opened. During flood events in 1923 and 1945, records indicate that the lake was not open, and water levels rose 2 feet (0.6 m) in 3 days.

Lake levels of 1.20 m LVD37 and 1.13 m LVD37 have been used in previous studies (i.e. 1962 design work and Aurecon modelling, respectively). Boyle (2011) demonstrated that backwater effects from Te Waihora/Lake Ellesmere extend upstream to just below Coes Ford, while the backwater effect during flood flows only affect the river system as far upstream as the Upper Selwyn huts (Surman, 2013).

As Te Waihora/Lake Ellesmere is relatively shallow (average depth of ~2.1 m), with a large surface area, it is susceptible to wind setup. This occurs when strong, persistent, winds ‘push’ the water towards the downwind (leeward) end of the lake, elevating the water surface in that area. During several periods of south-westerly winds, Dalmer (1970) recorded the rise in lake level at the Kaituna water level recorder (Table 2-3). It was also noted that a much more significant south-westerly storm event, occurring on 10/11 August 1968 (Wahine storm event), raised the lake levels at Kaituna by 1.2 to 1.5 m (Dalmer, 1970). Changes in lake level at the Selwyn River exit to the lake are likely to be less than at Kaituna due to the shorter fetch length.

Figure 2-6: Te Waihora/Lake Ellesmere opening at Taumutu (29 July 2009)

Table 2-3: Measured wind setup at Kaituna during south-westerly winds (Dalmer, 1970)

Date	Maximum hourly wind speed (m/s)	Recorded rise in water level above still lake level at Kaituna (m)
19/2/1953	Unknown	0.90
11/4/1953	27.3	0.89
10/7/1954	24.7	0.64
16/4/1962	21.6	0.91

2.5 Climate change

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

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.

Rainfall
In general, rainfall varies more significantly spatially and temporally 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 can contain up to ~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 very 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 the more significant increases in rainfall. In the Selwyn catchment, a mid-range increase in rainfall intensity would approximately double the frequency of the rainfall event. This means that, in 100 years from now, what is currently considered to be a 100 year ARI flood event may become a 50 year ARI flood event.

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).

To maintain the existing lake levels, small increases in sea level will require more frequent openings of the Te Waihora/Lake Ellesmere outlet to the sea. These more frequent openings will be required as the outlet to the sea will tend to close earlier (i.e. at higher lake levels). Once sea level rise increases by more than approximately 0.3 m, it may become more difficult, and potentially less economic, to maintain the opening (Surman, 2013). It is therefore likely that the threshold levels, that currently trigger lake openings, will need to be modified in the future as higher sea levels will make it more difficult to achieve successful lake openings (Renwick *et al.,* 2010).

Previous modelling has shown that if Te Waihora/Lake Ellesmere levels increased by 0.8 m, water levels in the Selwyn River at distances of 2 km and 4 km upstream of the lake would increase by 0.3 m and 0.1 m, respectively (Surman, 2013). The main area affected by increased lake levels would therefore be the Lower Selwyn Huts, which would be inundated directly by the lake, rather than from backwater effects along the Selwyn River.

Other
In conjunction with sea level rise, it is expected that the Kaitorete Spit (barrier) beach system will also rise at a similar rate, and the shoreline may retreat (Renwick *et al.,* 2010). Future irrigation developments on the Canterbury Plains may also change Te Waihora/Lake Ellesmere inflows (including Selwyn River flows) as well as lake levels.

3 Methodology

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

This floodplain investigation uses a combined 1-dimensional (1D) and 2-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 historic flood event information (Section 2.2)
- 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 (Section 3.5)
- Modelling of the Selwyn River Control Scheme capacity (Section 3.6)
- A sensitivity analysis (Section 3.7)

3.1 Flood hydrology

Determining flood estimates for the upstream limit of the hydraulic model (i.e. the Selwyn River at Gillanders Road, near the Hororata River confluence) is complicated by several factors. Firstly, the existing Selwyn River water level recorders do not properly represent the flows passing Gillanders Road because the Whitecliffs recorder only measures the main river channel (excluding other tributaries), and the Coes Ford recorder can be bypassed by floodplain overflows. An additional water level recorder is located at Ridgens Road (above the Hawkins confluence), but this is not rated for flow. These three permanent recorder sites on the Selwyn River are shown in Figure 3-1.

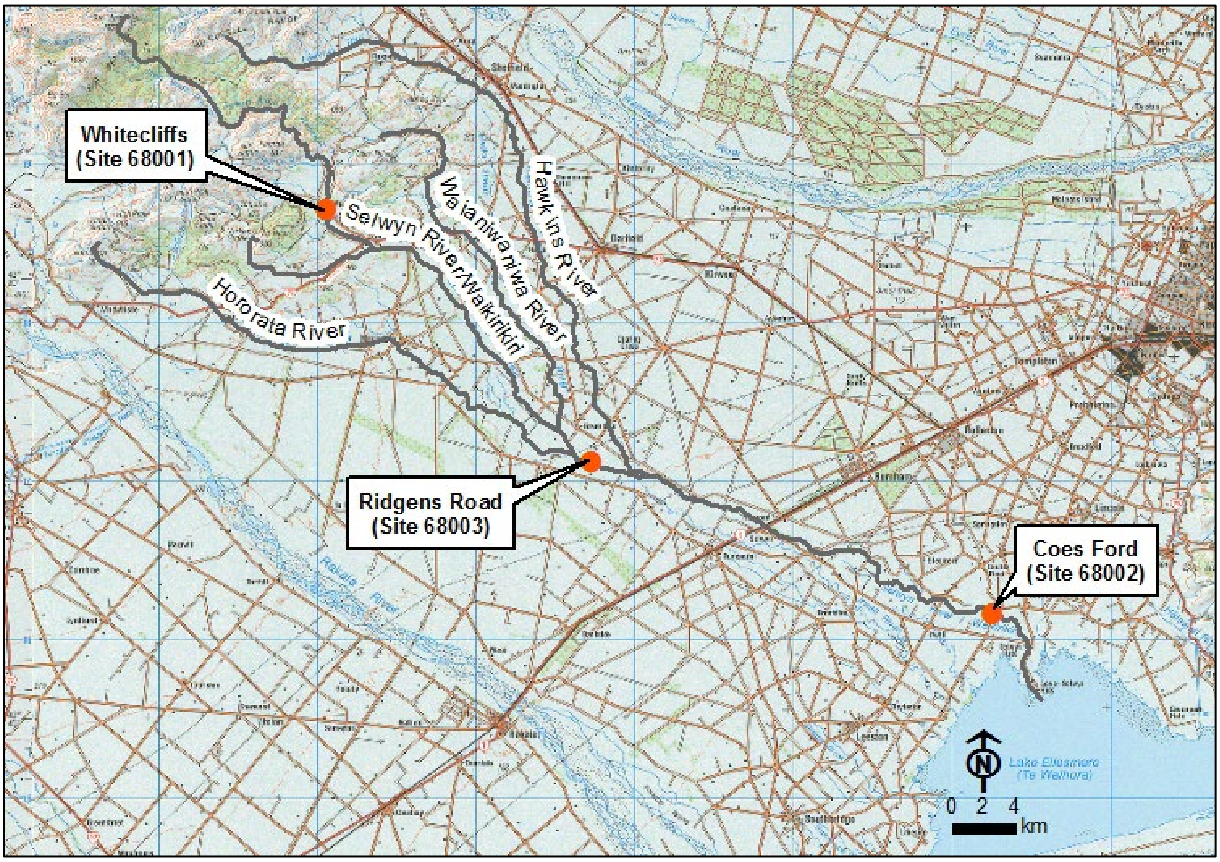


Figure 3-1: Selwyn River water level recorder sites

The details for these sites are described below:

- Selwyn at Whitecliffs, Site 68001 (July 1963 to present) - located ~23 km upstream of Gillanders Road, above the Hororata, Waianiwaniwa, and Hawkins River confluences.
- Selwyn River at Ridgens Road, Site 68003 (May 1990 to present) – located ~2 km upstream of Westenras Road, above the Hawkins River confluence.
- Selwyn at Coes Ford, Site 68002 (February 1984 to present) - located ~35 km downstream of Gillanders Road, and 7 km upstream of Te Waihora/Lake Ellesmere. This recorder captures flow from all main tributaries, excluding major flood overflows to the Irwell River and Selwyn floodplain.

For flood events prior to the installation of the continuous water level recorders, flood flow estimates are less reliable. This is due to both the methodology used to estimate flows within the river, and potential errors in judgement when estimating overbank flows. The continual changes in both bank protection and channel aggradation over time have also meant it is inadvisable to compare two similar magnitude flood events, when they have occurred several years apart. For example, in the early 1960s, the Ellesmere Road Bridge could pass flood flows of ~600 m^3/s, without significant overflows to the Irwell River. By 1986, extensive overflow flooding occurred for flows approximately half this magnitude. This was attributed to the vegetation that had encroached onto the fairway near the Greendale/Westenras Road overflow area.

Despite the limitations of the recorder sites, the Selwyn River at Coes Ford record was chosen to best represent the Gillanders Road flows. If there were any overflows to the Irwell River during the flood event, an estimate of the overflow was added to the recorded Coes Ford flood flow. For example, the Coes Ford flow record was modified to include an estimated 50 m^3/s of outflow for the August 2000 and July 2017 flood events.

Assumptions must also be made regarding the probability distribution that defines the annual maximum flow series. For this investigation, the Gringorten plotting position was used to plot the Selwyn at Coes Ford annual maximum flow series. Ten different distributions were fitted to the annual maximum flow series, and the goodness of fit was determined using the Andersen-Darling test. The distribution with the best fit to the recorded (1984 to present) annual maximum flow series was the two-component extreme value (TCEV) distribution which had an A^2 of 0.23. Three other distributions were also considered: TCFG ($A^2 = 0.35$), Generalised Pareto ($A^2 = 0.40$), and GEV PWM ($A^2 = 0.48$). All four distributions are plotted in Figure 3-2.

Using the two-component extreme value (TCEV) distribution, the Selwyn River design flows were determined. These flows are summarised in Table 3-1, and shown in Figure 3-3. To allow for climate change to 2120, an additional 25% was added to the current design peak flows. This 25% flow increase is in line with upper-range RCP projected increases for relevant extreme rainfall events. This climate change adjustment should be updated as better estimates becomes available.

A previous study (Connell and Pearson, 2001) concluded that Canterbury East Coast rivers do not necessarily fit an EV1 distribution, as larger magnitude flood events can be infrequent 'outliers'. This was more so for South Canterbury rivers where a two-component extreme value (TCEV) distribution was found to be more appropriate. This was hypothesised as being due to the alignment of the upper catchment and greater orographic effects during moisture-laden north-easterly storm events. The Selwyn catchment also experiences moisture-laden storm events with depressions centred to the north of Canterbury. These depressions can produce large north-easterly to south-easterly flood events in the Selwyn catchment (e.g. April 1951 and July 1961), and provide some assurance that the TCEV distribution is appropriate for the Selwyn River at Coes Ford.

Table 3-1: Selwyn River design flood flows for upper limit of model

Average Recurrence Interval (ARI)	Current Peak Flow m^3/s	Peak flow with climate change (to 2120) m^3/s
5	220	280
10	310	390
20	390	490
50	500	630
100	580	730
200	660	830
500	770	1000

Griffiths *et al.* (2011) also provides data and a methodology to enable design flood peak estimates to be calculated specifically for the Canterbury region. This regional flood estimation study updated the previous work of McKerchar and Pearson (1989). Both analyses used the superseded Coes Ford flow record, so are likely to over-estimate the Selwyn River at Coes Ford flows.

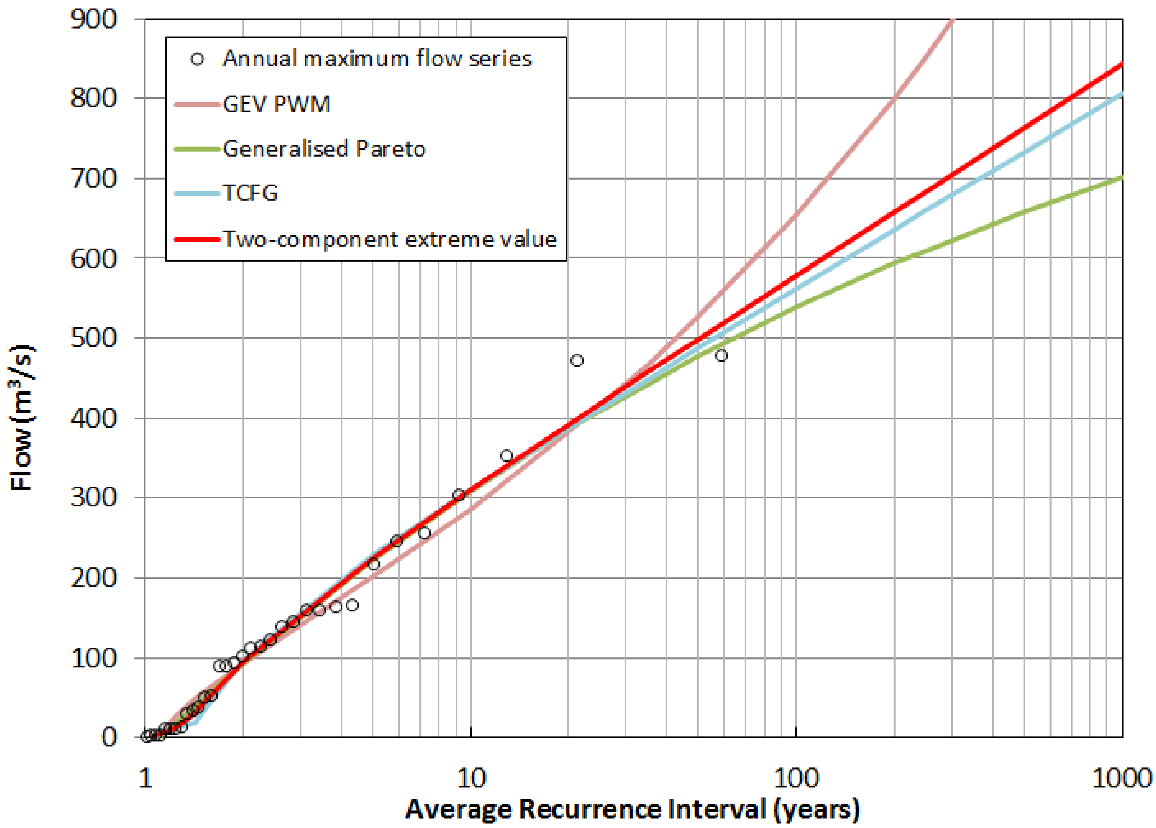


Figure 3-2: Selwyn River at Coes Ford annual maximum flow series with 'best-fit' frequency distributions (flow includes overflows upstream of recorder)

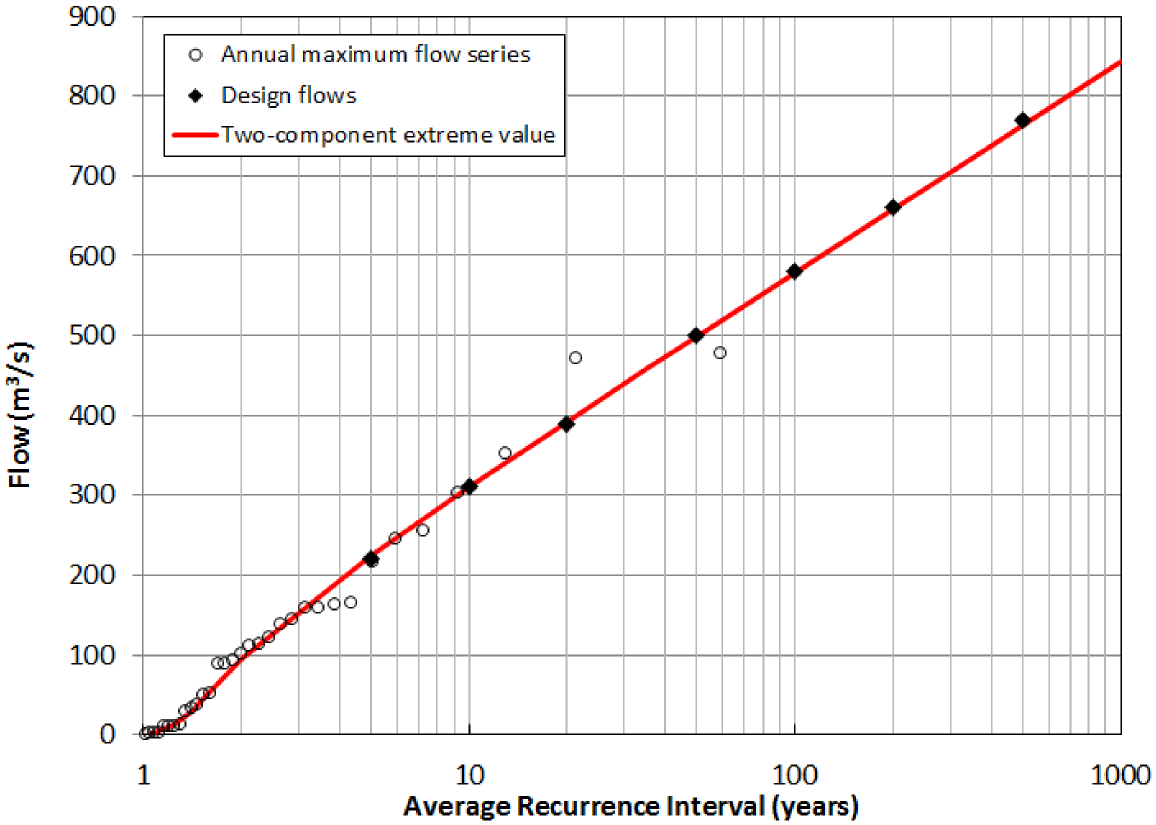


Figure 3-3: Selwyn River at Coes Ford design flows (includes overflows upstream of recorder)

3.2 Hydraulic model construction

The MIKE Flood modelling package combines 1-dimensional (1D) modelling for the main rivers with 2-dimensional (2D) modelling for the floodplain. The 1D and 2D models are linked along the entire length of the Selwyn River (i.e. from Gillanders Road to Te Waihora/Lake Ellesmere) to allow flood waters to move between the river channel and the floodplain (for example when a stopbank is overtopped). Other links between the lake and the floodplain allow overland flood flows to drain into the lake. A schematic of the model, including links, is shown in Appendix A (Figure A-1).

3.2.1 1D river channel model

The 1D model contains the Selwyn River channel and Te Waihora/Lake Ellesmere (which has also been modelled as a wide channel).

Selwyn River model channel extent
The 1D model of the Selwyn River extends ~42 km upstream from Te Waihora/Lake Ellesmere to Gillanders Road, at Greendale. The upstream limit of the model is approximately 1 km downstream of the Waianiwaniwa confluence, immediately upstream of the Hororata River confluence. The only other tributary with significant flood flows is the Hawkins River, which enters the Selwyn River approximately 5 km downstream of Gillanders Road.

Cross section data
As the Selwyn riverbed is often dry for extended periods of time during summer, cross-sections for the model have been generated using a combination of 2008 and 2010 LiDAR data, and 2012 cross-section survey data.

The 2008 LiDAR data were captured along the Selwyn River channel, while the 2010 LiDAR data covered not only the Selwyn River channel, but also the full extent of the Selwyn River floodplain. When the 2010 LiDAR data were compared to 5 points of known location and elevation (located on clear open ground) there was a standard deviation of 0.07 m for vertical accuracy.

Comparisons between Selwyn River 2008 and 2010 LiDAR demonstrated that, upstream of the SH1 road bridge, there were only minor differences in bed levels. Since most changes were due to reworking of the gravel-bed/movement of the main channel location, it was considered appropriate to use the Aurecon (2009) cross-section data that was extracted from the 2008 LiDAR upstream of SH1. Downstream of SH1, the 2010 LiDAR data revealed that, since 2008, there had been some degradation of the riverbed (and some bank erosion), as well as movement of the main channel. This difference is likely to be due to the August 2008 flood, and/or gravel extraction. New cross-sections were therefore extracted from the 2010 LiDAR data between the SH1 Bridge and Chamberlain’s Ford.

Despite the upper reaches of the Selwyn River being dry at the time of the 2010 LiDAR survey, approximately 4 km upstream of Chamberlain’s Ford the river was flowing due to water surfacing from under the gravel-bed. Cross-section survey data was used to capture submerged bed levels downstream of Chamberlain’s Ford. The latest survey, between 24 May and 21 June 2012, provided data from Chamberlains Ford downstream to approximately 2.5 km upstream of Te Waihora/Lake Ellesmere.

For the 2.5 km of channel immediately upstream of the lake, cross sections were measured in 2015. Measurements were in the form of soundings, taken from a small boat. These submerged cross-section profiles were combined with 2010 LiDAR data (for the river banks), to complete cross section profiles. Cross sections from the Lower Selwyn Huts (chainage 100000 m) downstream to the lake were also ‘partially excavated’ to represent some removal (or scouring) of accumulated material in the channel, over the course of flood events. Sediment is likely to be re-deposited in this area as flood flows recede.

A summary of the data used for each cross section is provided in Table 3-2. The location of cross sections is shown in Appendix A, along with a table summarising cross section information (Table A-1).

Table 3-2: Summary of data source for Selwyn River cross sections

Chainage (m)	Cross-section data source
60672 to 75095	February 2008 LiDAR
75223 to 89649	March/April 2010 LiDAR
89791 to 97715	2012 cross-section survey (with interpolated cross sections using 2010 LiDAR)
98440 to 99190	2015 soundings (with 2010 LiDAR for river banks)
100000 to 100750	2015 soundings (with 2010 LiDAR for river banks) + some excavation of bed

<u>*Channel roughness (bed resistance)*</u>
Upstream of the SH1 road bridge, a Manning’s n of 0.045 has been used for the channel bed resistance. This was increased to 0.050 from the SH1 bridge downstream to below the Upper Selwyn Huts. Downstream of the Upper Selwyn Huts, a lower Manning’s n of 0.022 has been used for the channel bed resistance. Variations in resistance, due to vegetation, have been accounted for by using a relative resistance across each cross-section. Manning’s n values of around 0.10 to 0.11 were mainly used for the more densely vegetated berm areas, while the more lightly vegetated active channel area was assumed to be the same as the bare channel. The reason for this is that, during a large flood, vegetation is stripped from the river bed. Manning’s n values are summarised in Table 3-3.

Table 3-3: Summary of Manning's n values used in the 1D Selwyn River model

Vegetation	Manning's n upstream of SH1 (chainage 75223 m)	Manning's n from SH1 (chainage 75224 m) to chainage 97714 m	Manning's n from chainage 97715 m to the lake (chainage 101000 m)
River channel & light scrub in active channel	0.045	0.050	0.022
More dense scrub or trees on berm areas	0.10	0.11	0.05

Modelled structures

Two road bridges (Ellesmere Bridge/Chamberlain's Ford and SH1), and one railway bridge (SH1), have been included in the model to account for head losses due to channel cross-section changes, submerged soffits, and pier losses. Head losses across the Coes Ford culvert crossing have also been represented by incorporating 14 small culverts, and a broad-crested weir, into the model.

Te Waihora/Lake Ellesmere

As discussed in Section 2.4, the Selwyn River flows into Te Waihora/Lake Ellesmere, which is generally separated from the sea by Kaitorete Spit. In the model, Te Waihora/Lake Ellesmere has been included as a wide 1D river channel, with the same water level boundaries at the upstream and downstream limits of the 'reach'. The lake 'channel' is connected to the downstream limit of the 1D Selwyn River channel (see Appendix A for cross section information).

3.2.2 2D floodplain model

The 2D floodplain model includes the Selwyn River floodplain between the upstream limit of the 1D Selwyn River model and Te Waihora/Lake Ellesmere.

Floodplain topography

To realistically model floodplain flows, good topographic data (including features such as banks, terraces, overland flow channels, roads, and railway embankments) is necessary. For the Selwyn floodplain, these high-resolution topographic data were obtained from a LiDAR survey (aerial laser scanning) flown in March/April 2010. The detail provided by LiDAR data, including historic flow paths, is illustrated in the grey scale image of the floodplain (Appendix B, Figure B-1). The extent of the additional LiDAR that was added later (to cover all areas of inundation for the larger design events), is shown in Figure B-4. This included both 2010 LiDAR, as well as earlier 2008 LiDAR.

The specified accuracy of the 2010 LiDAR is a standard deviation of ±0.07 m on clear open ground. However, uncertainties are likely to increase in some areas (e.g. where there are steeply sloping riverbanks). In some areas, data points that represent the surface elevation of crops have been incorrectly classified as ground, creating false high ground in the model grid. Where additional LiDAR data sets are available, areas of cropping can often be easily identified as entire paddocks which have been raised or lowered (Appendix B, Figure B-2).

The impact of cropping related data errors has been checked in areas where there is overlapping LiDAR from 2008 – and the model results have been examined for any obvious anomalies. When using the model results, care should be taken to ensure that flow paths, flood depths, and water levels are not being affected by erroneous ground level data. Figure B-2 illustrates that the 2010 LiDAR was flown after crops had been harvested (i.e. it has fewer artificially raised ground levels compared to the 2008 LiDAR). However, the 2008 LiDAR extent is mainly adjacent to the Selwyn River, and does not include most of the Irwell River overflow area.

Water levels and flows on the floodplain are resolved on a rectangular grid. The size of the grid is a function of the level of detail required, model stability, and computational efficiency (i.e. computer capacity and speed). A 10 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 ~4 to 5 days.

The 10 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 large and infrequent storm events.

As the Selwyn floodplain contains many elevated topographic features capable of impeding flows (e.g. roads and stopbanks), the 10 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. Irwell River), to ensure correct conveyance of flow. Because of the intensive drainage networks on the Selwyn floodplain, there are also many bridges/culverts at the road crossings. To ensure flood water flows were not constricted, 51 culvert structures were included on the main waterways of the modelled floodplain. The location of these culverts is shown in Figure B-3.

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 10 m grid, and that historic flow paths were correctly simulated.

Floodplain roughness (surface resistance)

Floodplain flow and depth are influenced by the hydraulic resistance of the ground cover and other obstructions, such as buildings and trees, on the floodplain. Normal practice is to assign a range of resistance values to the various surfaces of the floodplain - either by interpretation of aerial photographs or by ground survey.

For this investigation, the raw LiDAR points were converted from ‘xyz and intensity’ to ‘xyz and Strickler Number’. This was based on an interpretation of both differences in z-values, and intensity values. The conversion was calibrated for a range of ground surfaces, based on aerial photos taken concurrently with the LiDAR survey. The scattered LiDAR points were then interpolated into a regular 5 m raster, using the average value for each cell. For the 2D model, this raster was then down-sampled to a 10 m raster using the ‘nearest neighbour’ interpolation, which retains the original values (see Appendix B, Figure B-4).

Typically, Strickler Number varies from 50 (roads) to 6.7 (dense vegetation). That is, Manning’s n values varied from 0.02 (roads) to over 0.15 (dense vegetation). Where additional LiDAR data were added to extend the floodplain, a Strickler Number of 17 (n=0.059) was used to represent the generally shallow overland flow (Appendix B, Figure B-4).

3.3 Model calibration

To provide confidence in the model predictions, it is important to calibrate with historic flood events where possible. Despite limited flow and water level information, the Selwyn River MIKE Flood model was initially calibrated using the August 2008 and August 2000 flood events. On 22 July 2017, whilst undertaking this investigation, another large flood event occurred in the Selwyn River. During this event Coes Ford flows were gauged, resulting in a significant change to the rating curve for this site. Debris marks were also used to estimate maximum flood levels in some areas. The Selwyn River model was therefore re-calibrated using the August 2008, and July 2017 flood events.

Inflows at the upstream limit of the model have been derived using the Coes Ford flow records. The derived total inflow hydrographs for the Selwyn River and main tributaries have been proportioned based on the NCCB (1953) study, so that:

- 63% of the flow, representing the Upper Selwyn and Waianiwaniwa, is input at the upstream limit of the 1D model.
- 21% of the flow, representing the Hawkins River, is input evenly over 15 grid cells in the 2D model.
- 16% of the flow, representing the Hororata River, is input evenly over 10 grid cells in the 2D model.

During southerly wind conditions, the lake level at the north-eastern (Kaituna) end of Te Waihora/Lake Ellesmere can be elevated by wind setup across the lake, as described in Section 2.4. However, wind setup at the Selwyn River outlet to the lake is likely to be less than at Kaituna for easterly winds - although it will still be elevated relative to the Lake Ellesmere at Taumutu (Site 68302) water level recorder. A modified Lake Ellesmere at Taumutu (Site 68302) water level has therefore been used to simulate the lake levels.

A summary of the calibration flood events, and the derivation of the boundary conditions, is presented in Sections 3.3.1 and 3.3.2, respectively.

3.3.1 August 2008

On 31 July 2008, the east coast of the South Island, particularly North Canterbury, experienced a large rainfall event. During this event, the Selwyn catchment received a reasonably large amount of rain, producing a flood event with an average recurrence interval (ARI) of ~ 5 years.

A 24 hour rainfall of 102 mm fell at the Selwyn at High Peak (Site 314701) rainfall gauge during this event. Although this was significant, it was considerably less than the 24 hour rainfalls of 197 and 136 mm during the August 2000 and July 2017 flood events, respectively.

Aerial photographs taken around the same time as the river gaugings (e.g. Figure 3-4), and other photographs taken after the flood peak (e.g. Figure 3-5), show some of the flooding and enable peak flood levels to be identified from debris marks. Unfortunately, no aerial photographs were taken at the time of the flood peak, and no river gaugings were undertaken at Coes Ford until the flood peak had passed, and flows were considerably less (Table 3-4 and Figure 3-6). This was partly due to health and safety reasons (i.e. peak occurring during night, flow gaugings only able to be undertaken using a jet boat, etc), and partly due to available resources.

Figure 3-4: Aerial photograph of Coes Ford area – looking southeast (downstream) across road inundated during flood (1 August 2008)

Figure 3-5: Flood/debris marks on stopbank downstream of Coes Ford (4 August 2008)

Table 3-4: Gauging information from Coes Ford for August 2008 flood event

Date	Time	Water level (m LVD37)	Flow (m^3/s)
1/8/2008	2:30 pm	7.63	156.2
1/8/2008	2:45 pm	7.63	153.2

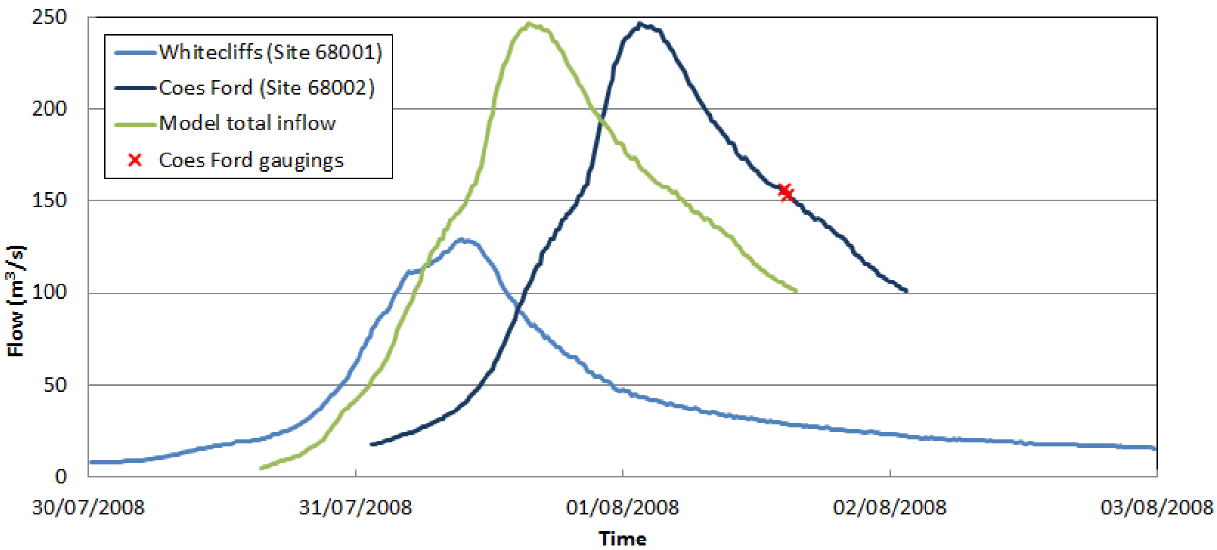


Figure 3-6: August 2008 flow hydrographs for the Selwyn River at Whitecliffs (light blue), Coes Ford (dark blue) and total model inflow in vicinity of Gillanders Road (green)

Despite limited information, this flood was a relatively recent event. As such, the river cross sections should be representative. Aggradation/degradation within the river system 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 overflows observed for this event, it was considered a suitable flood event to calibrate the 1D component of the MIKE Flood model. The MIKE Flood model inputs, and modelling results for the August 2008 flood event, are presented below.

<u>Model inputs</u>
For the August 2008 flood event, the Coes Ford flow record was simply moved 10 hours back in time to account for the travel time along the Selwyn River (Figure 3-6). No allowances were made for changes in hydrograph shape, or flood water entering or leaving the river system, as no significant overflows were identified.

During storm events, wind setup generally occurs on Te Waihora/Lake Ellesmere, as described in Section 2.4. As there is only a staff gauge near the Selwyn River exit to the lake, 'calm' lake level data have been used to produce a downstream boundary water level. These 'calm' lake levels, shown in Figure 3-7, have been derived by Graeme Horrell (NIWA) by extracting recorded lake levels at times when wind velocities were less than 1.6 m/s (5.8 km/h) for 3 hours (Graeme Horrell, PSIM program). These calm lake levels were originally derived for a Te Waihora/Lake Ellesmere water balance model (Horrell, 2009).

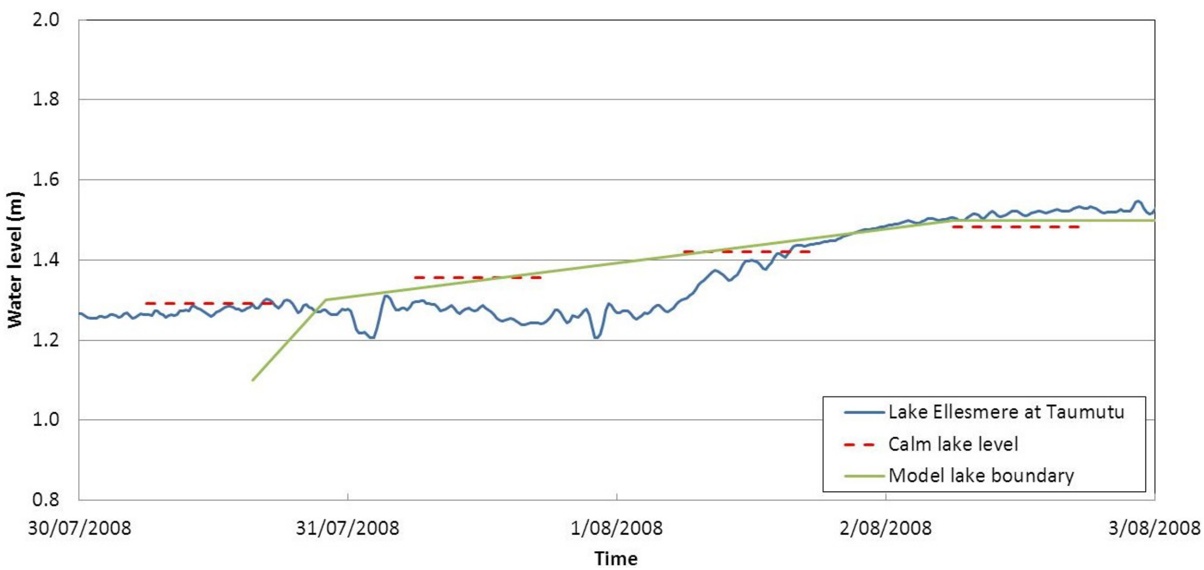


Figure 3-7: Lake Ellesmere water levels – 30 July to 2 August 2008

Figure 3-7 sets out the Lake Ellesmere at Taumutu (Site 68302) water levels, 'calm' lake levels, and the lake level used in the model. Figure 3-8 details the corresponding wind velocity and direction with south-easterly winds peaking at around 18 m/s (65 km/h) in the early hours of 31st July. Around the time of the peak wind velocities, water levels temporarily dropped by ~0.1 m at the Taumutu water level recorder. This water level disturbance appears to last only a short period of time - as do the high wind speeds. Given that only small water level disturbances were observed, and 'calm' periods also occurred each day, wind setup has not been accounted for in the model lake level. Although wind setup may temporarily raise lake levels near the Selwyn River mouth, it has been previously shown that the backwater effect upstream of elevated lake levels is relatively small, and only extends a short distance upstream during flood events (Surman, 2013).

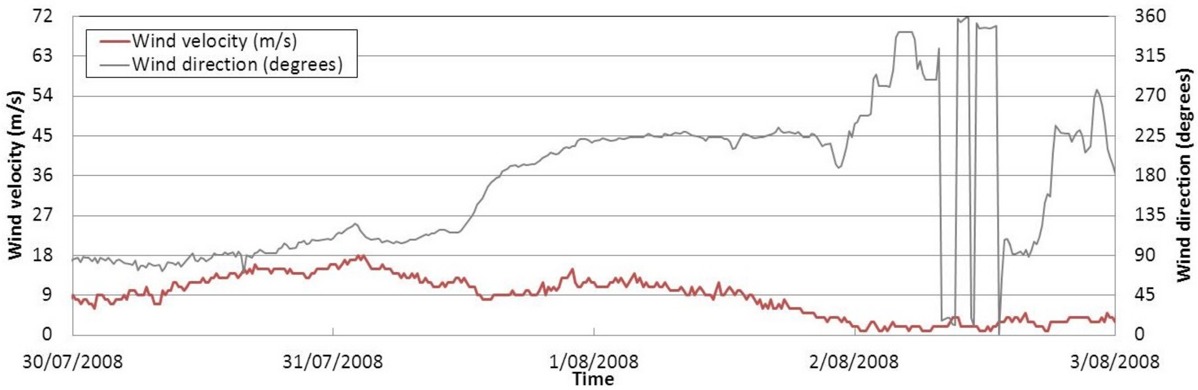


Figure 3-8: Lake Ellesmere wind velocity and direction – 30 July to 3 August 2008

<u>Results</u>
Using the model inputs described above, the MIKE FLOOD model was run for 2 days over the August 2008 flood event (commencing 30 July 2008 at 3:30pm).

Only limited observations of flooding were available for this storm event. Figure 3-10 compares modelled and recorded water levels at the Coes Ford recorder (cross section 93452) and Figure 3-11 compares modelled water levels to flood/debris marks downstream of Coes Ford (cross section 96440, Figure 3-5). At Coes Ford (cross section 93452), there was excellent agreement between the modelled and recorded maximum water levels. The maximum modelled water level downstream of Coes Ford (cross section 96440) also agreed very closely with the observed debris mark. A comparison of maximum modelled water levels (Figure 3-9) and aerial photographs (Figure 3-4) also illustrate a very similar extent of flooding around Coes Ford.

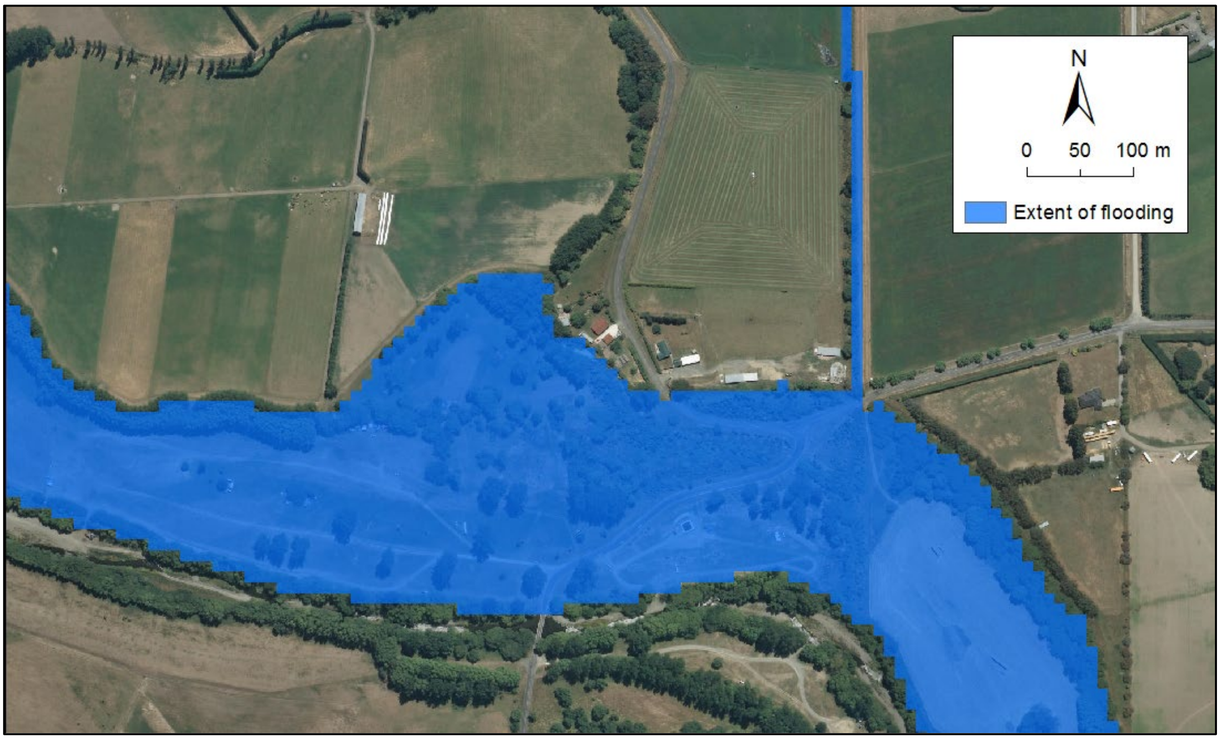


Figure 3-9: Modelled extent of flooding around Coes Ford for the August 2008 flood

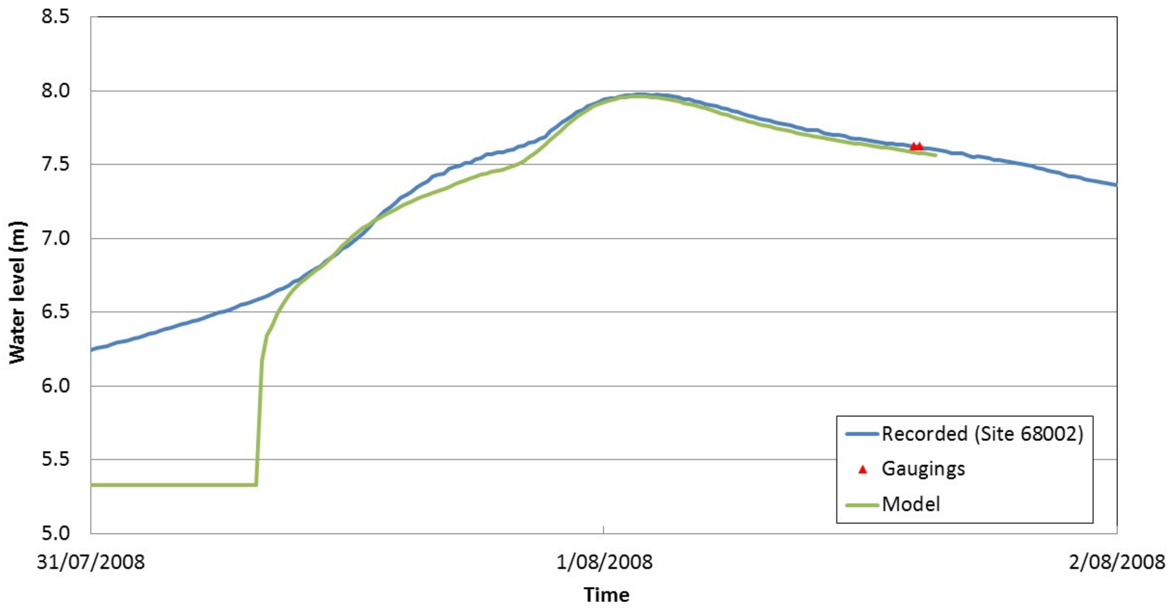


Figure 3-10: Water level comparison at Coes Ford (Cross section 93452)

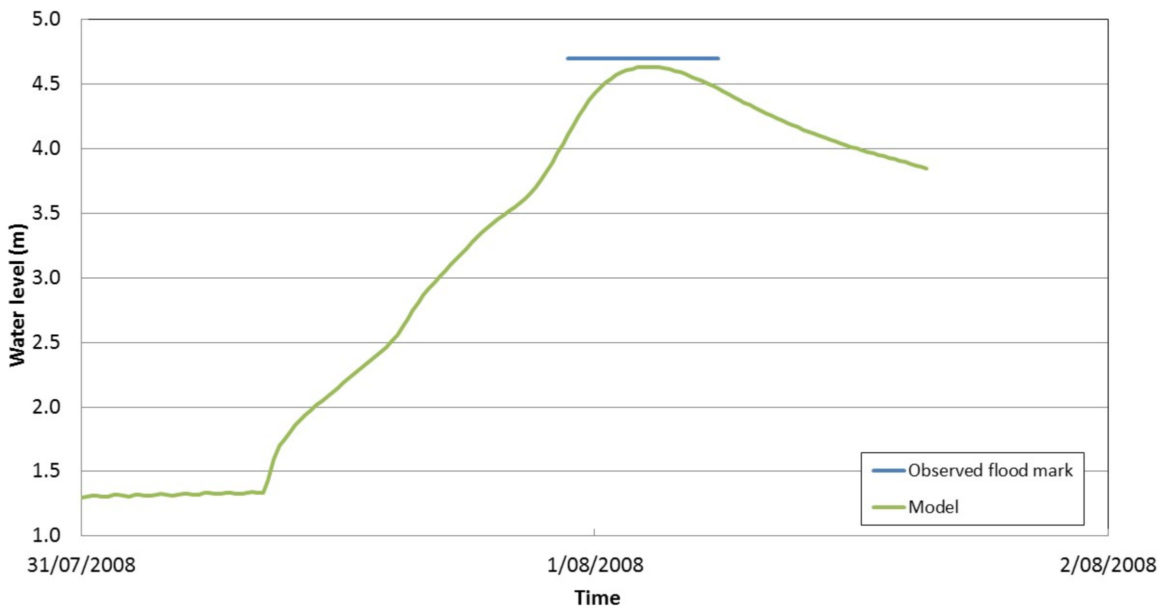


Figure 3-11: Water level and observed flood mark comparison at cross section 96440

Figure 3-12 details the modelled maximum water depths, and floodplain inundation (including some berm areas), for the August 2008 event. Although most of the Selwyn River flood flows are contained within the existing river system, some flood water does pass over the true right bank, flowing onto the floodplain and into the Irwell River. These overflows to the Irwell River occur between Westenras Road and Old South Road. Other overflows onto the floodplain tend to be relatively insignificant. Although no specific records exist of floodplain flows occurring during this storm event, it does not necessarily mean they did not occur. The flood peaked, during the hours of darkness in most areas, and some flows may have gone undetected.

Figure 3-12: Modelled August 2008 Selwyn floodplain extent of inundation

3.3.2 July 2017

A large and complex low-pressure system moved over New Zealand on Thursday 20 July. By Friday 21 July, the system was positioned off the coast of Marlborough and North Canterbury, producing a strong and moist south-easterly flow across the South Island. During Saturday 22 July, the system moved slowly off to the east.

This flood event occurred when the Canterbury Plains were already saturated from previous rainfall. During autumn, the Selwyn catchment received rainfall ranging from 1.3 to 2.5 times monthly averages. Then, as this flood event progressed, the forecasted snow level of 400 m ended up rising to over 1100 m, producing more rain in the catchment rather than snow.

At the Selwyn High Peak site, over 165 mm of rain fell during the event, with 136 mm falling in a 24 hour period. Three other rain gauges in the Selwyn catchment recorded rainfall totals of around 100 mm over the same 24 hour period, indicating that this rainfall was around a 10 year ARI event, with the 24 hour rainfall total around a 25 year ARI event.

During this flood, two gaugings were completed around the flood peak (Table 3-5). Aerial photographs were also taken during the afternoon on 22 July, while water was still overtopping the stopbanks (Figure 3-13). This was followed up with a site visit on 28 July, to measure debris marks observed around the lower reaches of the Selwyn River and floodplain (Figure 3-14).

Table 3-5: Gauging information from Coes Ford for July 2017 flood event

Date	Time	Water level (m LVD37)	Flow (m^3/s)
22/7/2017	8:40 am	8.446	345.5
22/7/2017	3:01 pm	8.545	397.1
24/7/2017	10:13 am	7.109	59.6
24/7/2017	12:05 pm	7.07	57.0

Figure 3-13: Looking upstream towards the Selwyn River overflows upstream of the Upper Selwyn Huts, 22 July 2017 at 4:47pm

Figure 3-14: Flood debris on farm gate near Upper Selwyn Huts, 28 July 2017

Model inputs
For the July 2017 flood event, the Coes Ford flow record was multiplied by 471/421 to increase the 421 m^3/s peak flow to the 'best estimate' 471 m^3/s peak flow. This enables the water passing out of the Selwyn River (e.g. into the Irwell River system) to be included. The derived total flow was also moved 9 hours backwards in time, to account for the travel time along the Selwyn River (Figure 3-15).

Figure 3-16 depicts the Lake Ellesmere at Taumutu (Site 68302) water levels, and the lake level used in the model. Figure 3-17 shows the corresponding wind velocity and direction. Southerly winds peaked at around 20 m/s (72 km/h) on 22 July, resulting in water levels temporarily dropping by around 0.3 m at the Taumutu water level recorder. This water level disturbance appears to reduce throughout the day, as the wind eases. The lake levels used in the model are a 'best-guess' for levels at the Selwyn River outlet to Lake Ellesmere.

Results
Using the model inputs described above, the MIKE FLOOD model was run for 2 days over the July 2017 flood event (starting 21 July 2017 at 12:00pm).

Figure 3-18 compares modelled and recorded water levels at the Coes Ford recorder (cross section 93452). Figure 3-19 compares modelled water levels to flood/debris marks measured on 28 July. Figure 3-20 also shows the modelled flood depths at the time that the aerial photograph in Figure 3-13 was taken. All figures demonstrate excellent agreement between the modelled and recorded/observed maximum water levels between Coes Ford and the Lower Selwyn Huts.

Figure 3-21 compares observed and modelled flooding around Westenras Road. At this location, the model does not show the stopbank on the downstream side of the road overtopping. Overflows are only small, but this may indicate that Selwyn River water levels are under-estimated in this area – or that the stopbank levels are high. At Selwyn Lake Road, around 2 to 2.4 km downstream of SH1, overflows across the road are also slightly less than expected.

Overall, there is very good agreement between the model results and observations.

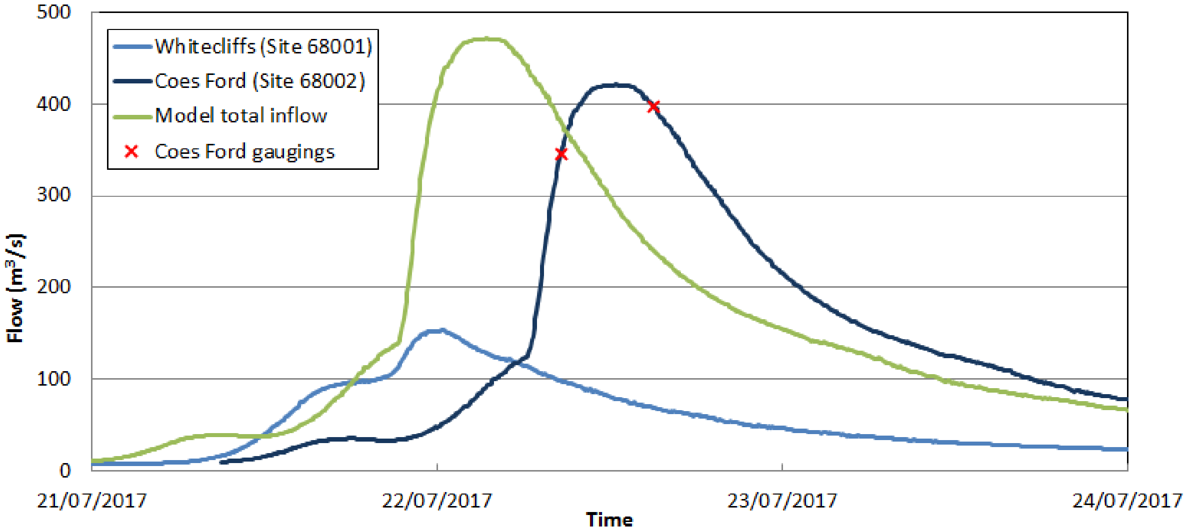


Figure 3-15: July 2017 flow hydrographs for the Selwyn River at Whitecliffs (light blue), Coes Ford (dark blue) and total model inflow in vicinity of Gillanders Road (green)

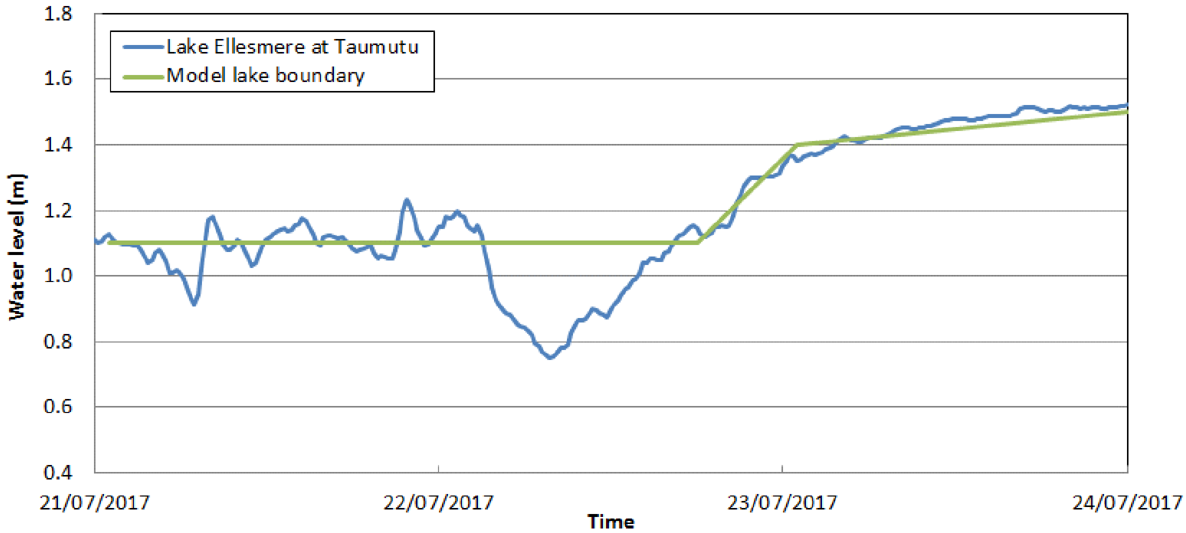


Figure 3-16: Lake Ellesmere water levels – 21 to 23 July 2017

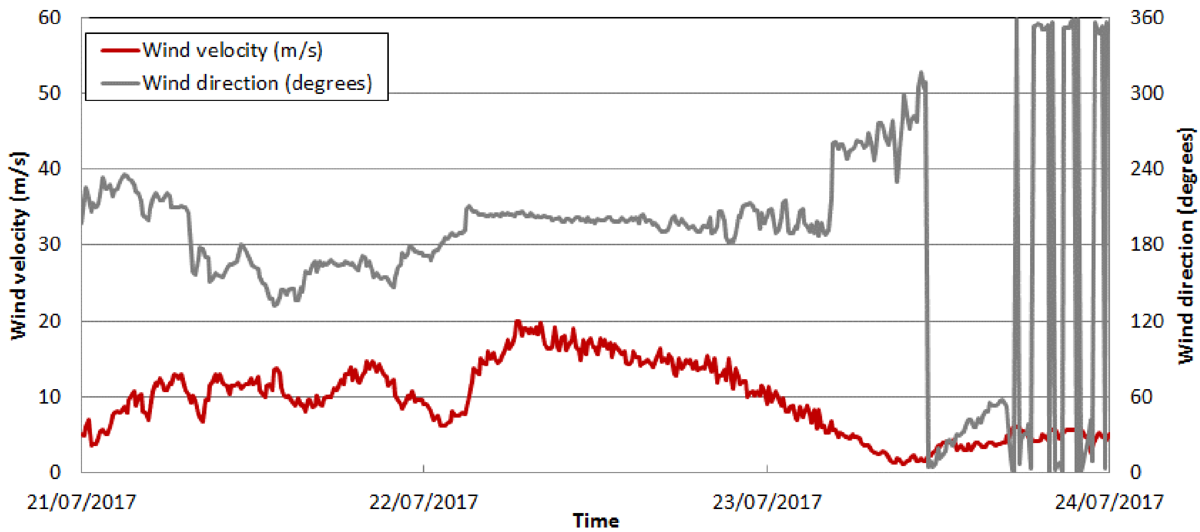


Figure 3-17: Lake Ellesmere wind velocity and direction – 21 to 23 July 2017

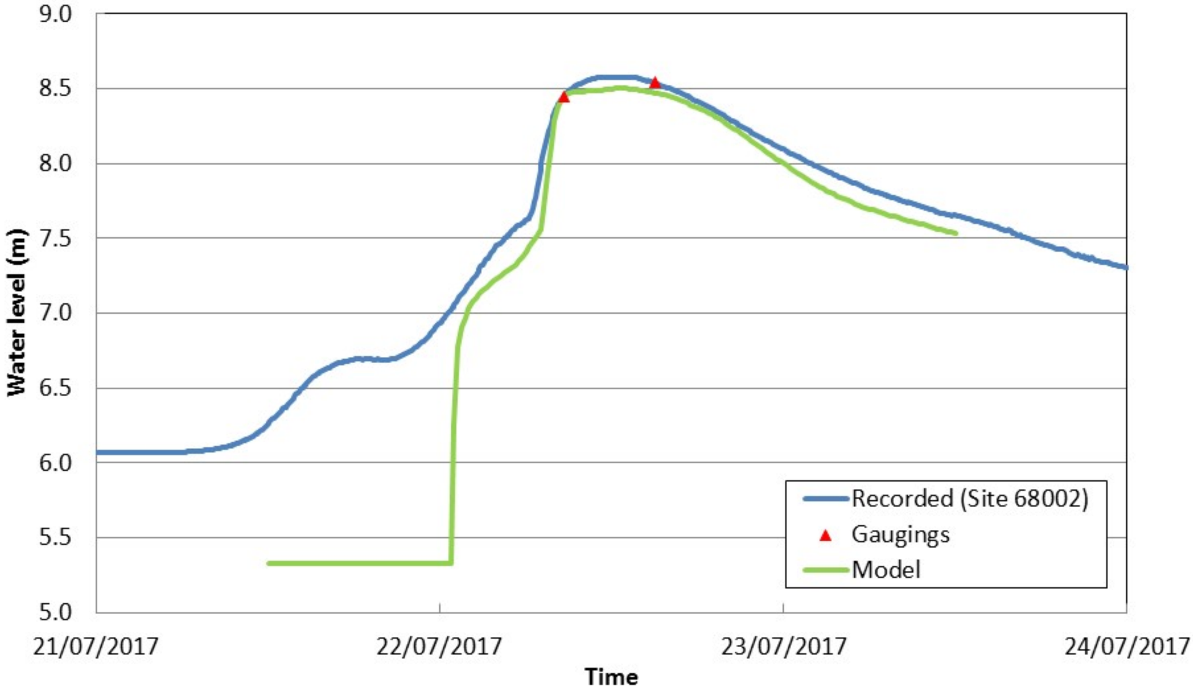


Figure 3-18: Comparison of Coes Ford (cross section 93452) recorded and modelled water levels during the July 2017 event

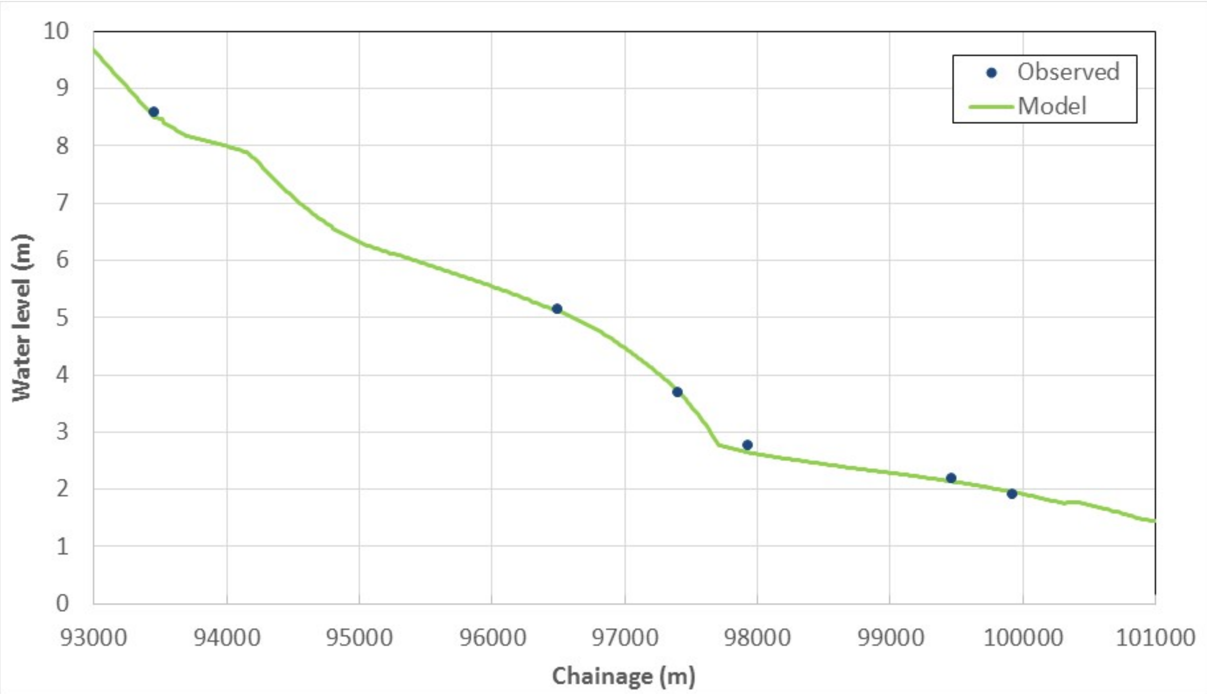


Figure 3-19: Comparison of modelled water levels and observed post-flood debris marks for the July 2017 event

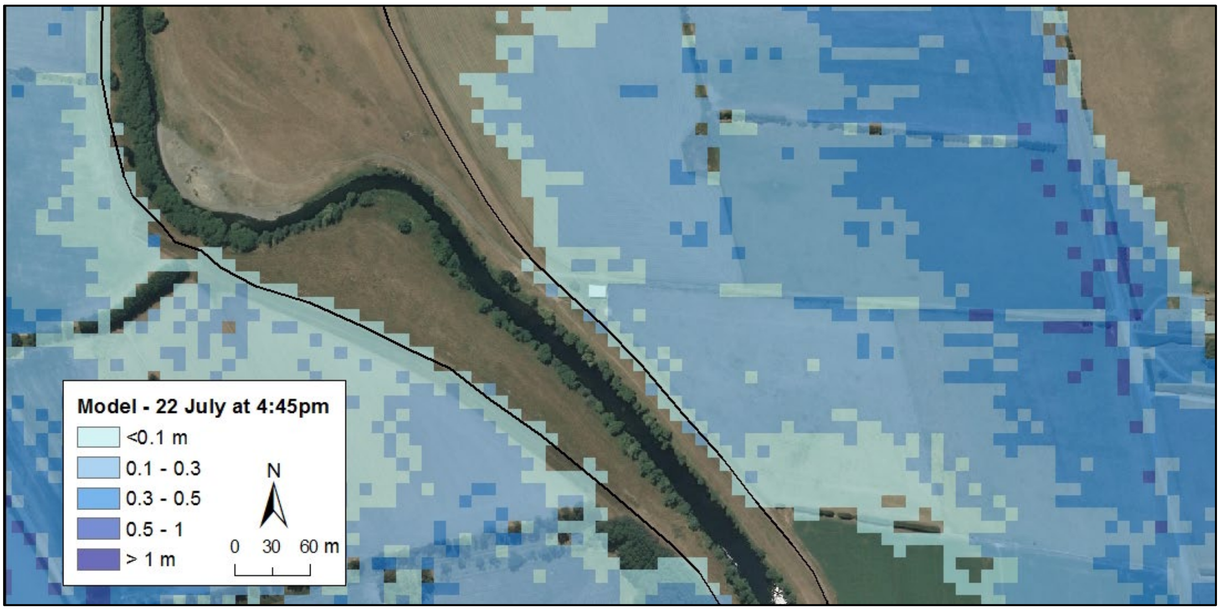


Figure 3-20: Modelled maximum water depths for the Selwyn River, upstream of the Upper Selwyn Huts on 22 July 2017 at 4:45pm

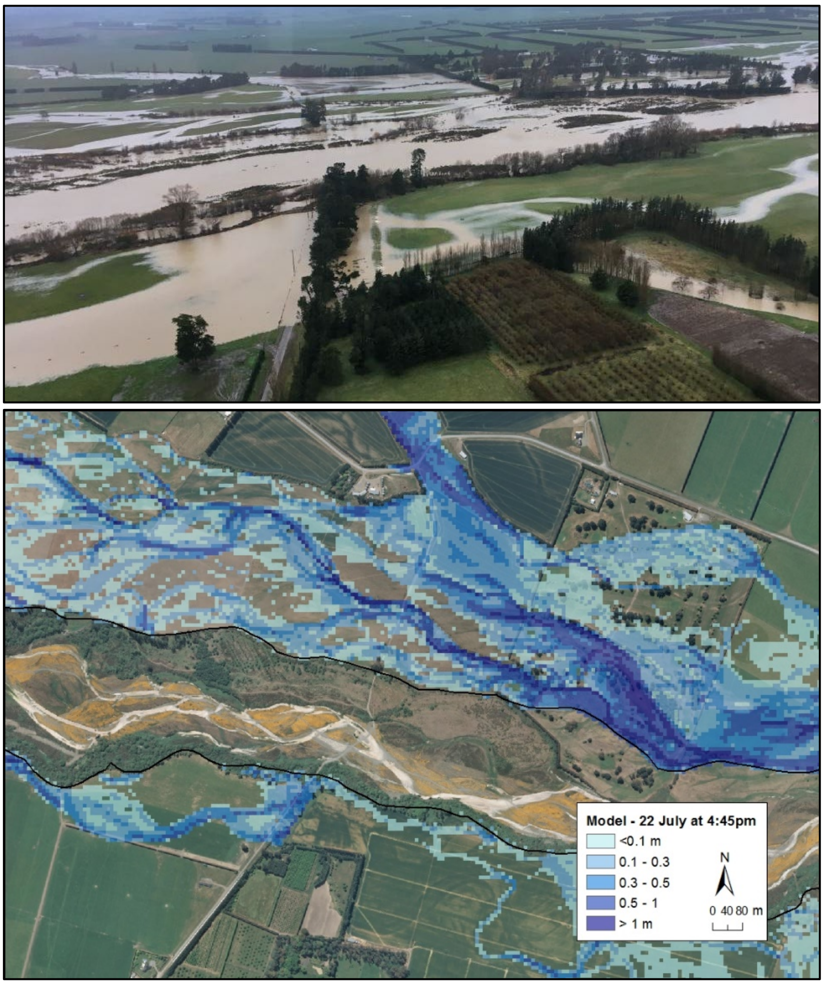


Figure 3-21: Comparison of observed and modelled flooding at Westenras Road (lower left corner of images) around 4:45pm on 22 July 2017. Note: model does not show as much overflow onto the floodplain at the Westenras Road stopbank

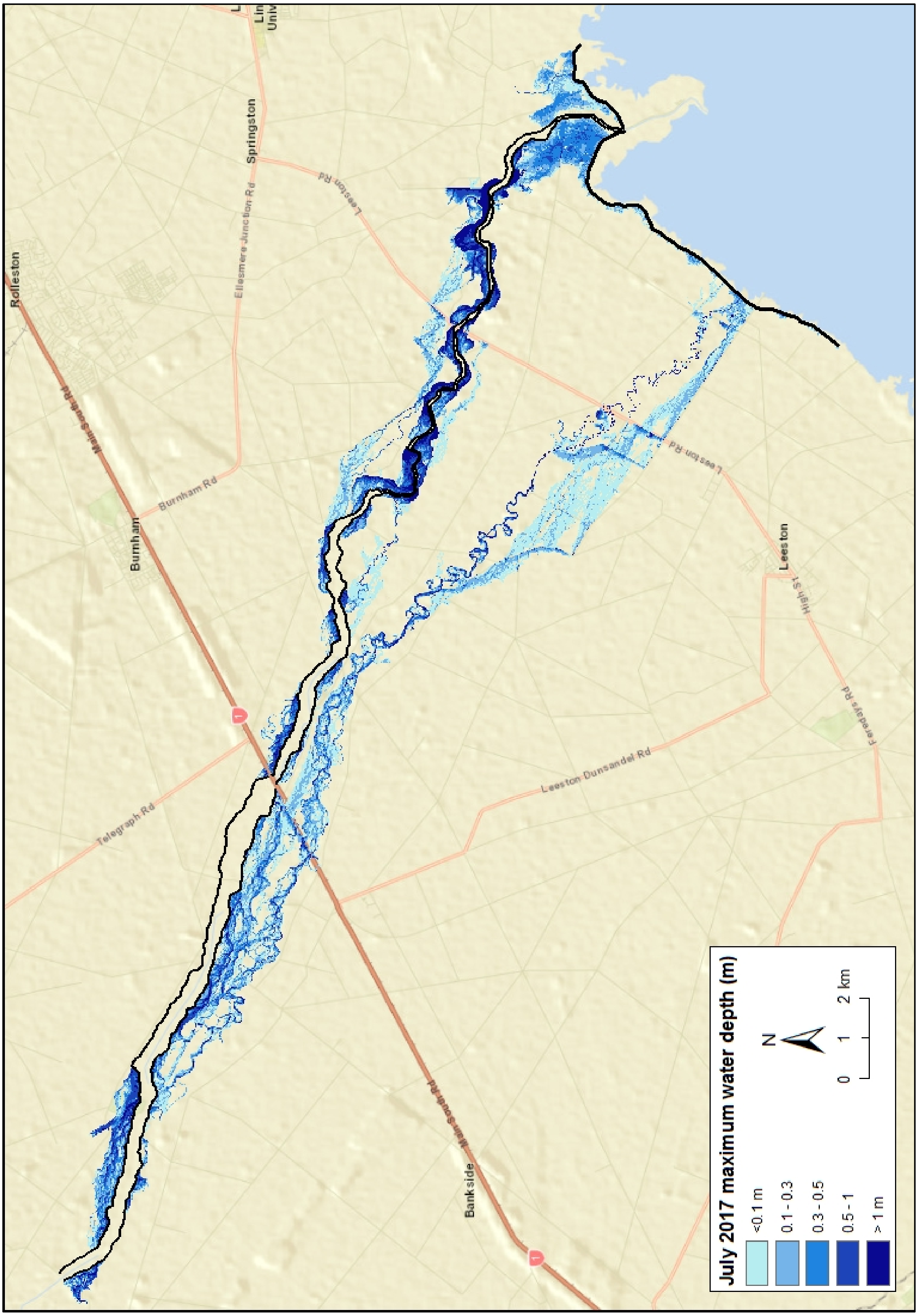


Figure 3-22: Modelled July 2017 Selwyn floodplain extent of inundation

3.4 Model validation

To confirm the model was calibrated correctly, the August 2000 flood event was used to validate the model.

3.4.1 August 2000

Between 17 and 19 August 2000, a depression moved slowly from west to east across central New Zealand, blocked by two high pressure systems located to the south-west (in the Tasman), and to the north-east. This led to widespread high-intensity rainfall in the Canterbury region over 18-19 August 2000. For example, the Selwyn River at Whitecliffs site recorded a maximum 24 hour rainfall of 163 mm, and a total rainfall of 212 mm for the 17-19 August time period (McKerchar and Smith, 2004).

Both the Selwyn River at Whitecliffs (Site 68001), and Selwyn River at Coes Ford (Site 68002), recorded their largest flows since the sites were installed in 1964, and 1984, respectively. Stopbanks were overtopped in the lower reaches, and a 30 m breach also occurred in the true right (south) bank. SH1 was closed due to flooding, and high flows in the Irwell River closed the main trunk railway line. A summary of the Flood Control log, detailing observations made during the August 2000 flood, is given in Appendix D. This event was estimated to have an average recurrence interval of ~ 20 to 50 years.

No river gaugings were undertaken at Coes Ford until the flood peak had passed, and flows were considerably less (Table 3-6). As noted previously, this was partly due to health and safety reasons (i.e. peak occurring during night and flow gaugings only able to be undertaken using a jet boat), and partly due to available resources.

Table 3-6: Gauging information from Coes Ford for August 2000 flood event

Date	Time	Water level (m LVD37)	Flow (m^3/s)
21/8/2000	12:20 pm	7.09	73.4
25/8/2000	11:00 am	6.15	16.6

Aerial photographs taken on 20 August illustrate that significant flooding was still occurring in the Irwell area (Figure 3-23). As the Canterbury region had relatively dry antecedent conditions (i.e. lower than normal soil moisture levels) prior to this flood event, flooding was less severe than if the soil moisture levels were at field capacity (McKerchar and Smith, 2004).

Figure 3-23: 20 August 2000 around 1:30pm. Irwell River downstream of Stephens Road (Heslops Corner is centre left)

This was a large flood event for the Selwyn River and flood observations were made during the event. However, most of these observations were not at the flood peak, which occurred during the night at most locations. Despite limited available information, this flood was a relatively recent event and therefore current river cross sections are likely representative of actual conditions at the time. For instance, aggradation/degradation within the river system 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.

With significant overflows from the Selwyn River onto the floodplain (and into the Irwell River), it was considered an excellent flood event to validate the MIKE Flood model. The MIKE Flood model inputs and results for the August 2000 flood event are set out below.

Model inputs

For the August 2000 flood event, the Coes Ford flow record was multiplied by 478/428 to increase the 428 m^3/s peak flow to the 'best estimate' 478 m^3/s peak flow. This enabled the water passing out of the Selwyn River (e.g. into the Irwell River system) to be accounted for. The derived total flow was also moved 9 hours backwards in time to account for the travel time along the Selwyn River (Figure 3-24).

On 19 August 2000 at 5:37pm, the Lower Selwyn Huts boat ramp gauge recorded a water level of 1.62 m LVD37 (which is reported as being approximately the lake level), while the Taumutu water level recorder measured a water level of 1.13 m LVD37, which is approximately 0.5 m lower. This suggests wind setup, or that river levels at the ramp are elevated (relative to lake level) for higher flows. Unlike the August 2008 flood event, no 'calm' lake level readings were able to be derived between 18 and 21 August (inclusive), due to consistently high wind velocities greater than 1.6 m/s (5.8 km/h) (Graeme Horrell, PSIM program).

Figure 3-25 sets out the Lake Ellesmere at Taumutu (Site 68302) water levels, 'calm' lake levels (where available), measured river levels at the Lower Selwyn Huts boat ramp, and the lake level used in the model. Figure 3-26 sets out the corresponding wind velocity and direction. South-easterly winds peaked at around 18 m/s (65 km/h) on 18 August, resulting in water levels temporarily dropping by 0.2 m at the Taumutu water level recorder. This water level disturbance appears to last a short period of time, as wind speeds reduce significantly by midday on19 August.

The lake levels used in the model are a 'best-guess' for levels at the Selwyn River outlet to Lake Ellesmere. These levels suggest that raised water levels at the Lower Selwyn Huts boat ramp are due to the hydraulic gradient between the boat ramp and the lake more so than wind setup.

No information was found regarding the timing of the 30 m breach along the Selwyn River south bank. In the model this 30 m breach has been simulated, as occurring between cross section 95203 and 95293 (about 1.7 km downstream of Coes Ford) between 10:00pm and 10:30pm on 19 August.

Results

Using the model inputs described above, the MIKE Flood model was run for 4 days over the August 2000 flood event (starting 19 August 2000 at 2:15am). Comparisons between measured, and modelled, water levels at the Coes Ford water level recorder (cross section 93452) indicate that the modelled peak water level was 0.19 m higher than the recorded peak water level (Figure 3-27).

In the Flood Control Log it was also noted at 3:04 am on 20 August " … *level @ Ellesmere Bridge 18.23. Seems to be no change since he had seen it @ 10.51*". Figure 3-28 shows that modelled water levels immediately downstream of the Leeston Road Bridge (model cross section 89638) give a similar constant peak water level over this period. Figure 3-29 compares modelled and observed floodplain inundation, and Figure 3-30 sets out the modelled maximum water depths, and extent of modelled floodplain inundation, during the August 2000 event.

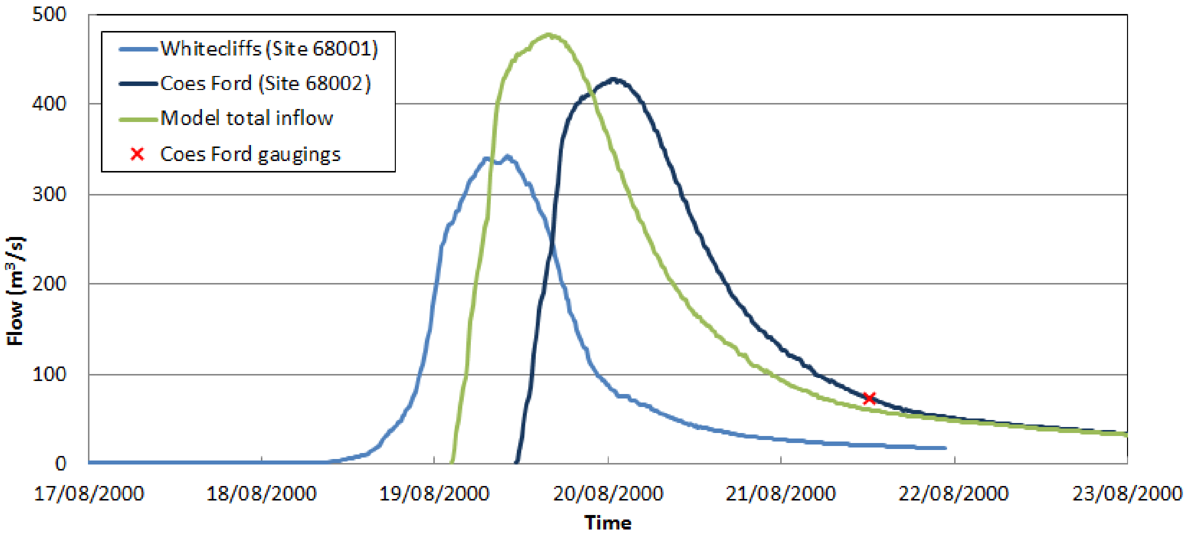


Figure 3-24: August 2000 flow hydrographs for the Selwyn River at Whitecliffs (light blue), Coes Ford (dark blue) and total model inflow in vicinity of Gillanders Road (green)

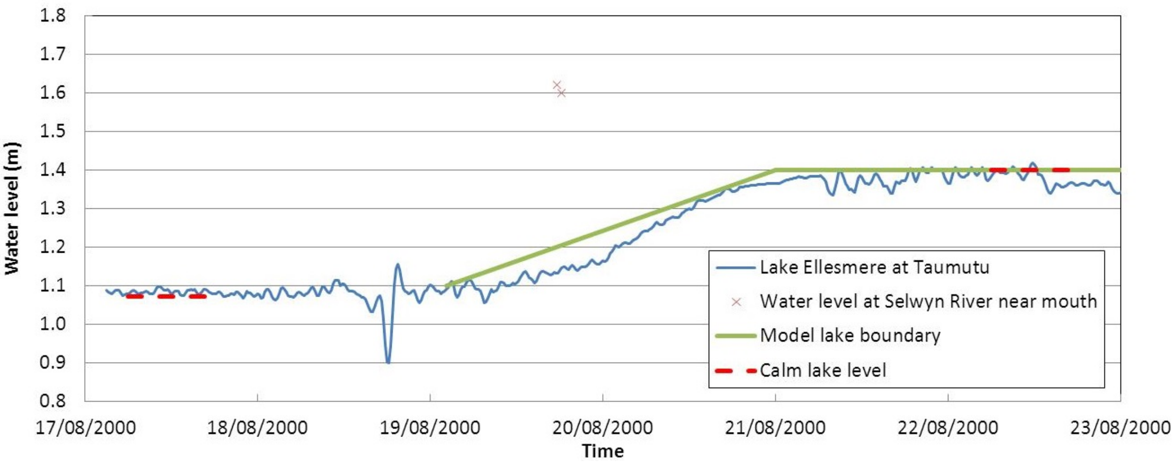


Figure 3-25: Lake Ellesmere water levels – 17 to 22 August 2000

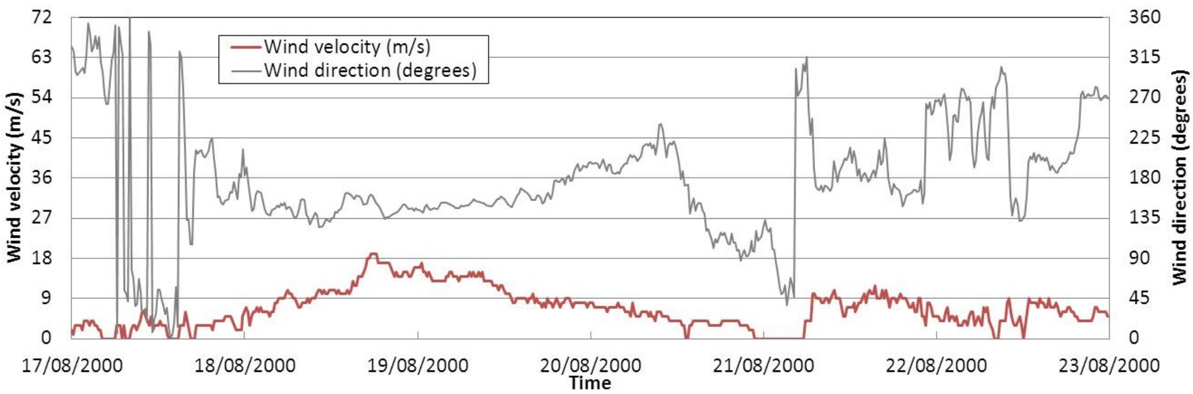


Figure 3-26: Lake Ellesmere wind velocity and direction – 17 to 22 August 2000

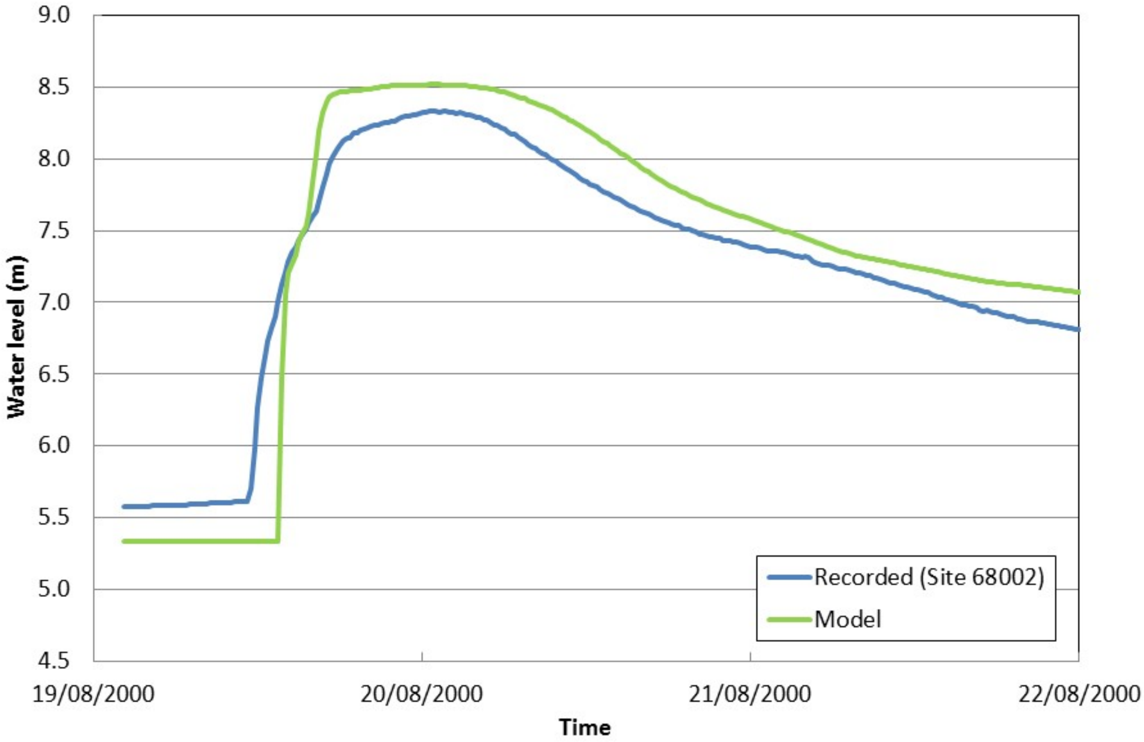


Figure 3-27: Comparison of Coes Ford (cross section 93452) recorded and modelled water levels during the August 2000 event

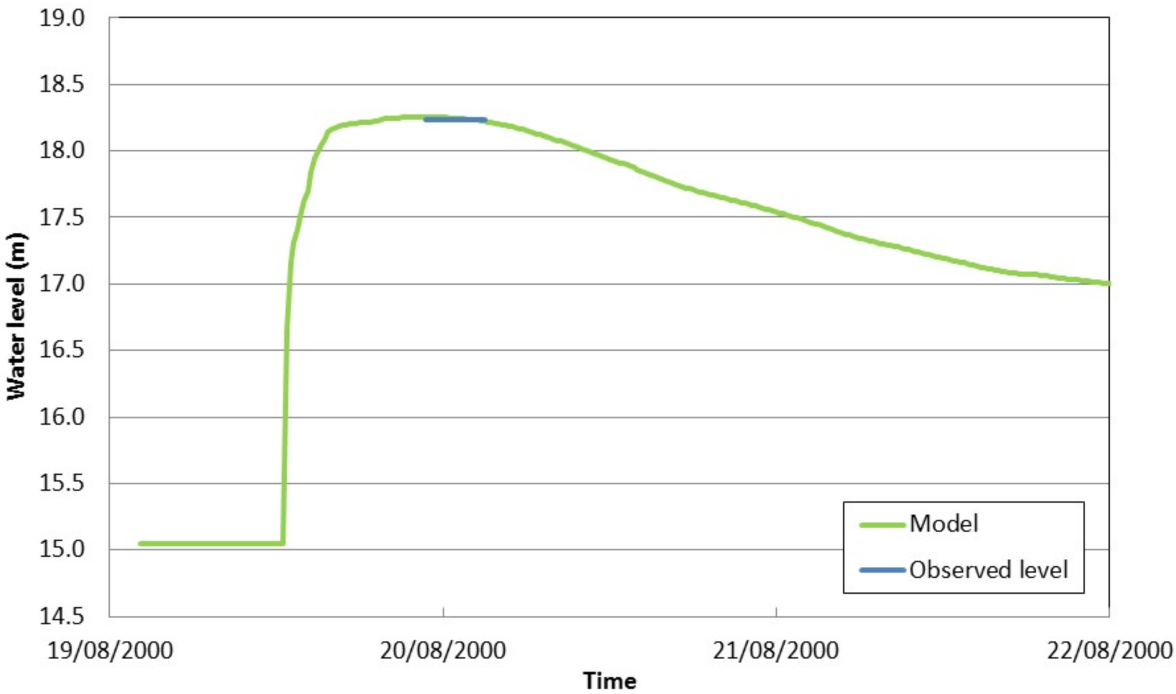
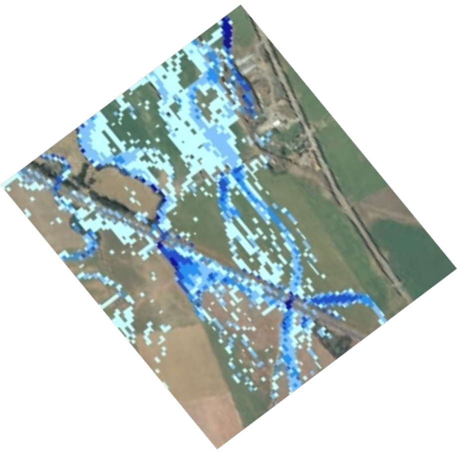
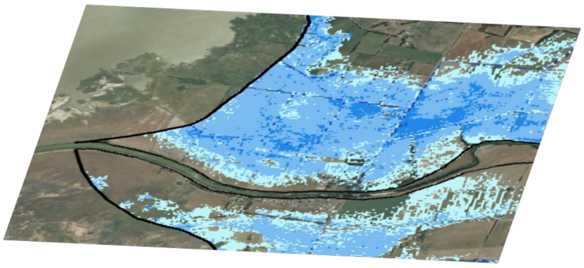


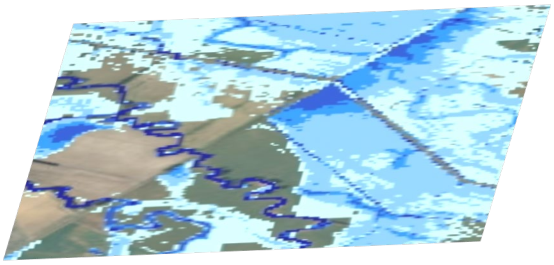
Figure 3-28: Comparison of Ellesmere Road Bridge (cross section 89638) observed and modelled water levels during the August 2000 event

Irwell River, Boundary Creek Road on right, SH1 in centre

Upper Selwyn Huts with overflow in background (looking west)

Irwell River from downstream Stephens Road. Brookside and Irwell Road in centre (south)

Figure 3-29: Comparison of 2D model and aerial photographs (at approximately same time on 20 August 2000, in the afternoon after the peak flow had passed along the Selwyn River)

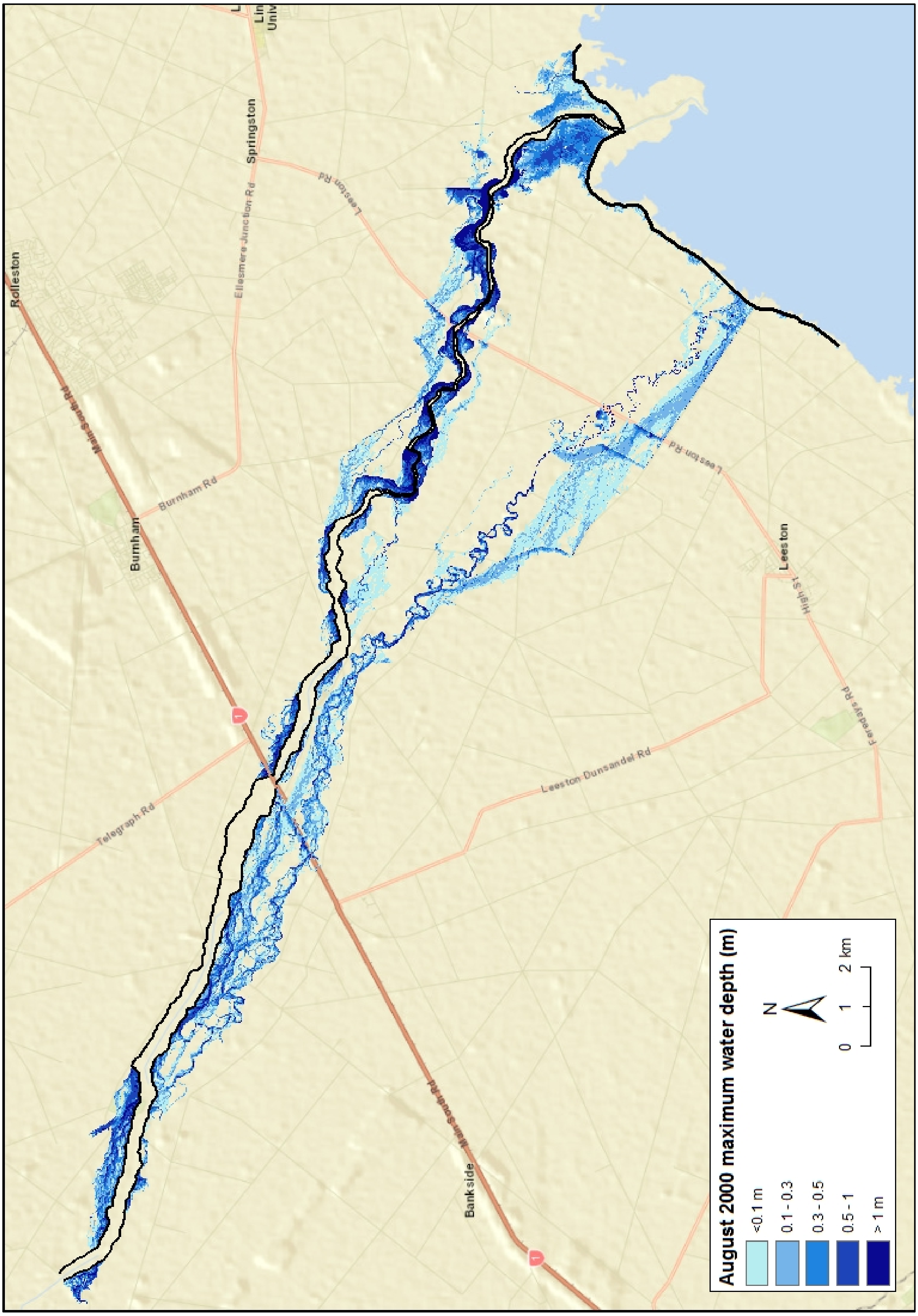


Figure 3-30: Modelled August 2000 Selwyn floodplain extent of inundation

Initial model runs, during the model calibration phase, showed that reducing the peak inflow by around 10%, reducing channel roughness by 20%, reducing the floodplain roughness by 20%, or adjusting the model eddy viscosity, gave only small incremental changes in maximum water levels at Coes Ford, and made very little difference to Ellesmere Road Bridge water levels. The lower measured levels at Coes Ford may therefore be due to localised lower bed levels in this area in August 2000 (compared to August 2008 and July 2017). Given that the July 2017 and August 2000 flood peak flows were estimated to be very similar in magnitude, it is interesting that the August 2000 maximum recorded water level at Coes Ford is 0.24 m lower than in July 2017. As the model uses the same 'fixed' cross section profiles for both flood events, it will not account for any channel aggradation, degradation, or other changes, in channel configuration.

Comparisons with observations from the Flood Log (Appendix D) reveal that the modelled extent of flooding, and timing, are generally excellent. Some of the modelled flooding occurs at a slightly earlier, or later, time than observed. However, this could be due to the timing and shape of the estimated inflow hydrographs.

With the limited number of recorded water levels along the river system, along with most observations around the flood peak occurring during the hours of darkness, it is not possible to fully validate the model. Instead, sensitivity tests are undertaken in Section 3.7, to address uncertainty.

3.4.2 Summary

Given the large number of assumptions and uncertainties, there is very good agreement between modelled and observed flooding for the calibration and validation events. This is particularly pleasing, given that the modelling is based on Coes Ford flows transferred to the upstream limit of the model (and scaled for August 2000 and July 2017 to account for overflows). The model does not include localised surface runoff, nor changes in the shape of the hydrograph, between the upstream limit of the model and Coes Ford.

As the August 2008 event was largely contained within the main Selwyn River channel, and immediately adjacent floodplain areas, it was used to determine the initial 1D channel Manning n values (Table 3-3). These Manning n values also provided good agreement with measured and observed water levels and flood/debris marks for the August 2000 and July 2017 flood events - where there was significantly more flood overflow onto the floodplain.

The hydraulic modelling indicates that approximately 35 and 38 km^2 of floodplain (including some berm areas) were inundated for the July 2017 and August 2000 flood events, respectively – with the greater extent of flooding for the August 2000 flood event being largely due to the longer duration peak.

3.5 Modelling of design flood events

The 50, 200, and 500 year Average Recurrence Interval (ARI) design flood events have been modelled for land use planning and flood mitigation purposes. These are equivalent to 2%, 0.5%, and 0.2% Annual Exceedance Probability (AEP) events, respectively.

The design storm events were simulated over a 3.25-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 ~5 days).

The design flows and lake levels used in the model are described in Sections 3.5.1 and 3.5.2. Modelling results, including maps of floodplain extent and maximum water depths, are shown in Section 3.5.3. For the design flood events, no stopbank breaches were simulated – just overtopping of stopbanks.

3.5.1 Selwyn River design flows

Some of the recent high flow events recorded at Coes Ford (Site 68002) are shown in Figure 3-31. Dimensionless hydrographs were also compared in Figure 3-32, for the same events. These dimensionless hydrographs plot instantaneous flow divided by the peak flow, where peak flow includes any additional flow that leaves the river system upstream of Coes Ford.

Figure 3-31 and Figure 3-32 demonstrate that, for the larger flood events, flows can increase much more rapidly on the rising limb. Also, although the 2000 and 2017 flood events have similar peak flows at Coes Ford, the duration of the 2000 flood event was longer.

The July 1994 recorded flow hydrograph at Coes Ford had a relatively high peak flow (352 m^3/s), but no significant overflows (i.e. the hydrograph shape was not truncated by additional flows leaving the river system upstream of Coes Ford). The hydrograph also retained higher flows for longer, compared to the smaller 1993 and 2008 flow events. The July 1994 hydrograph was therefore considered to be slightly more conservative (i.e. not likely to underestimate a large flood event), but representative of a large flood event on the Selwyn River. The July 1994 hydrograph was scaled to produce the 50, 200, and 500 year ARI flow hydrographs (Figure 3-33). These design hydrographs use the peak flows from Table 3-1.

The design inflow hydrographs for the model, shown in Figure 3-33, have been proportioned the same way as the calibration event inflows (Section 3.3) so that:

- 63% of the flow, representing the Upper Selwyn and Waianiwaniwa, is input at the upstream limit of the 1D model.
- 21% of the flow, representing the Hawkins River, is input evenly over 15 grid cells in the 2D model.
- 16% of the flow, representing the Hororata River, is input evenly over 10 grid cells in the 2D model.

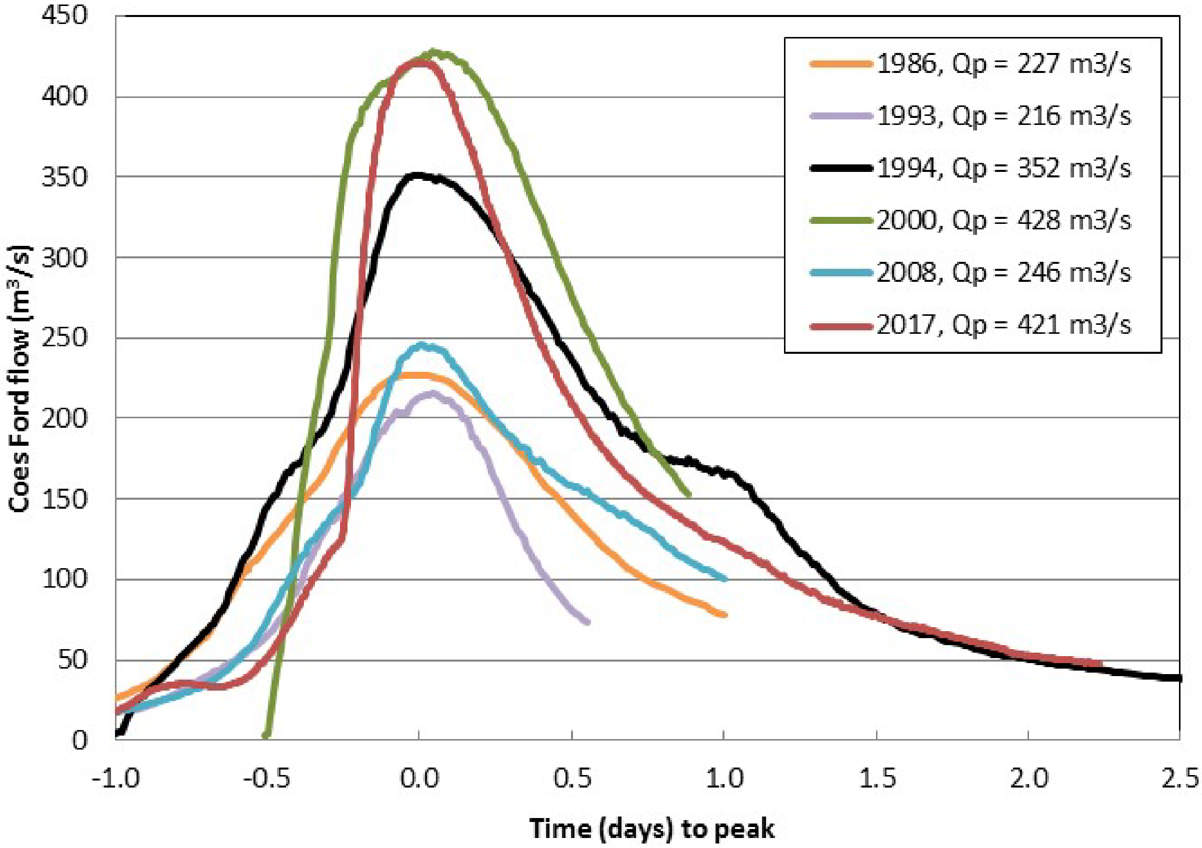


Figure 3-31: Hydrographs for various 'high flow events' recorded at Coes Ford (Site 68002)

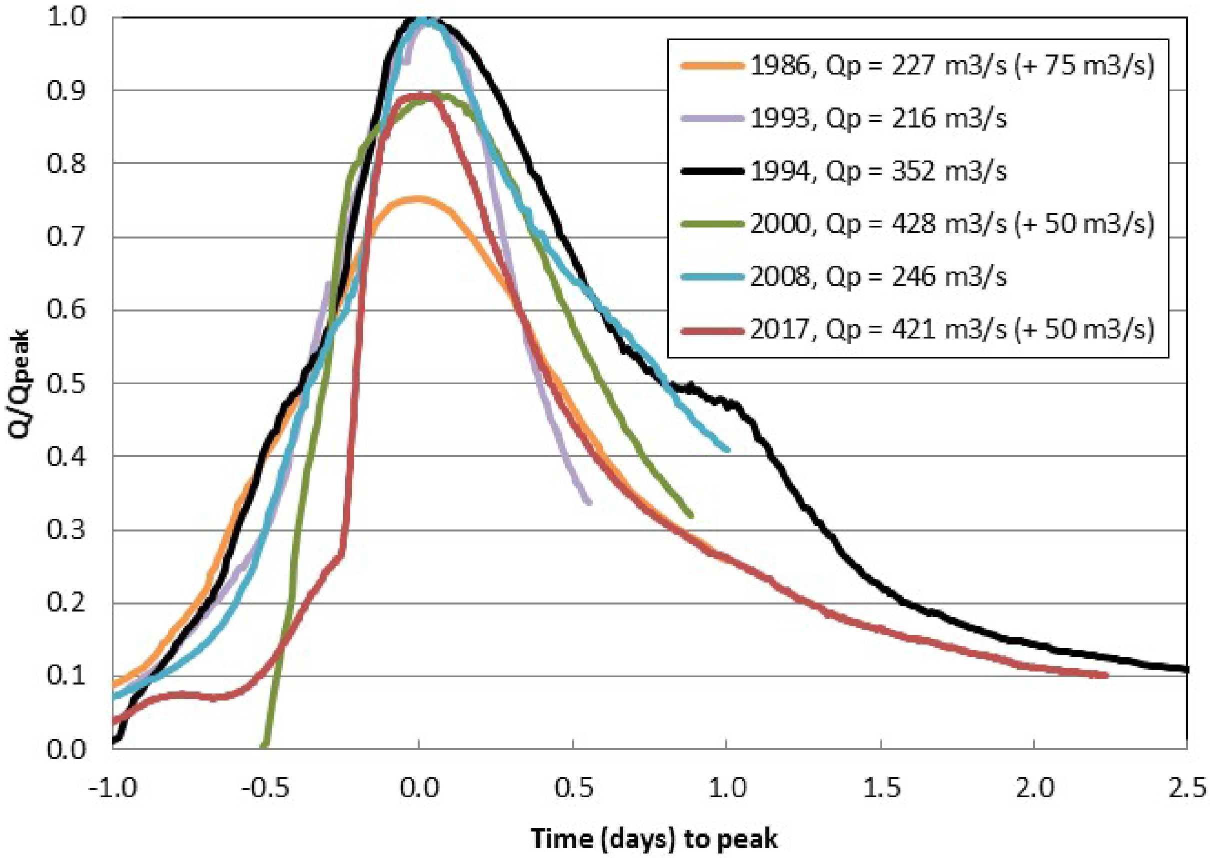


Figure 3-32: Dimensionless hydrographs for various 'high flow events' recorded at Coes Ford (Site 68002). Note: Peak flow (Qpeak) includes estimated flows exiting the river upstream of the recorder site

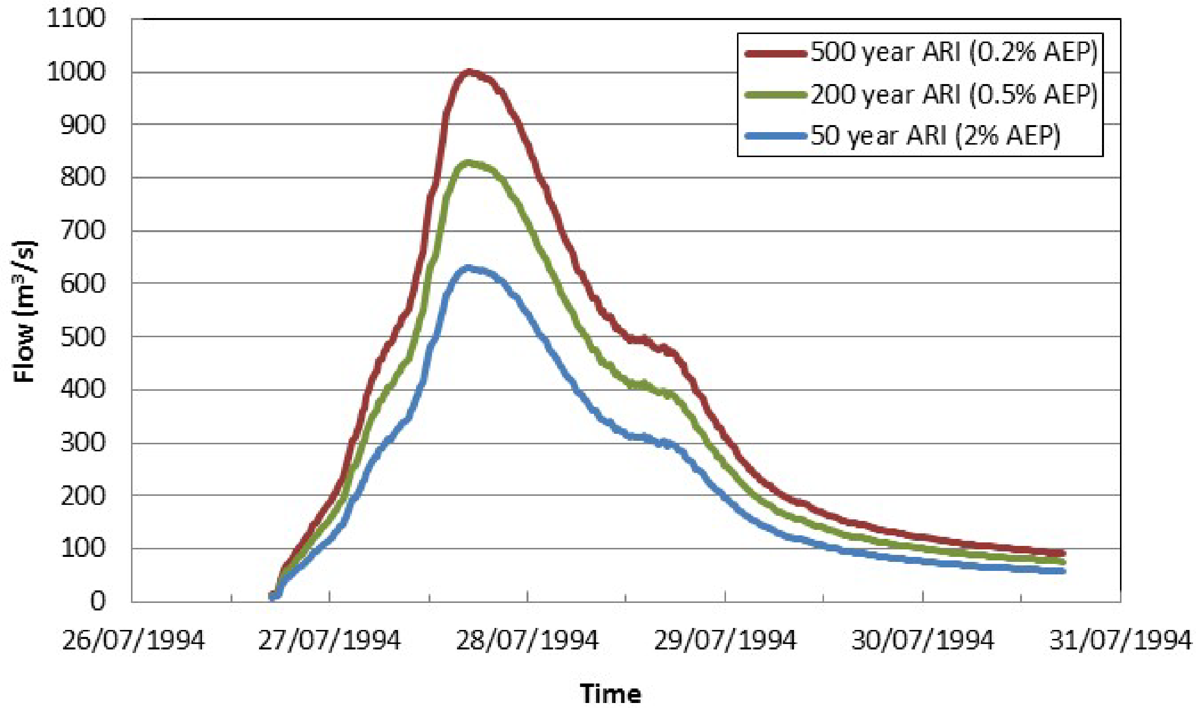


Figure 3-33: Design flood hydrographs showing the total flows entering the Selwyn River model

3.5.2 Te Waihora/Lake Ellesmere design lake levels

For the 50, 200, and 500 year ARI flood events, a maximum lake level of 1.8 m LVD37 was assumed. This level is considered realistic given that a water level of 1.81 m LVD37 was recorded in 2013. The post-1947 record represents the time over which the current opening method (i.e. mechanical opening) for the outlet has been in place. Analysis of lake levels, recorded over this time, suggests that this level represents a 50 to 100 year ARI lake level (Figure 3-34).

Should a higher lake level be used, it is likely that the combined probability of, for example, a 200 year ARI Selwyn River flow and a 200 year ARI lake level, will combine to produce a flood event with an ARI significantly greater than 200 years. Figure 3-35 shows the design lake level time series. It is assumed that the lake takes 2 days to rise from 1.1 m to 1.8 m, reaching the maximum water level 40 hours after the Selwyn River flow peaks at the upstream limit of the model. A sensitivity test, using an increased water level, is discussed in Section 3.6.

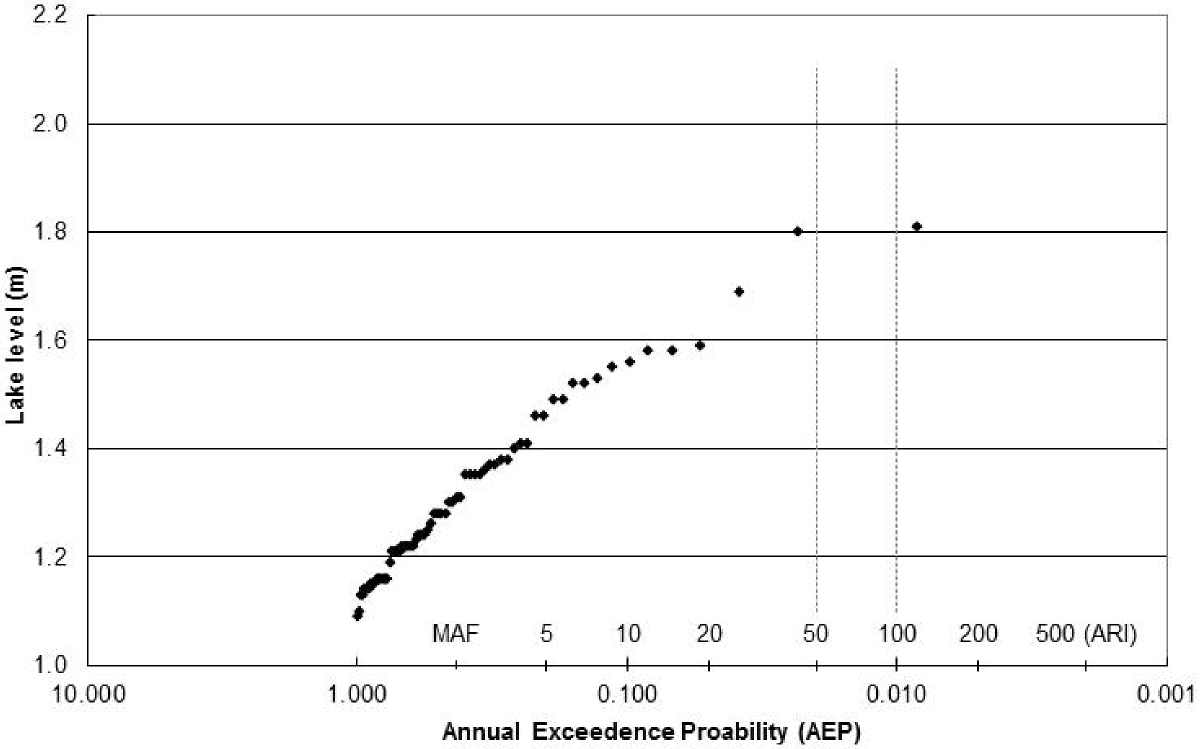


Figure 3-34: Annual exceedence probability for Te Waihora/Lake Ellesmere levels (1947 and 2013)

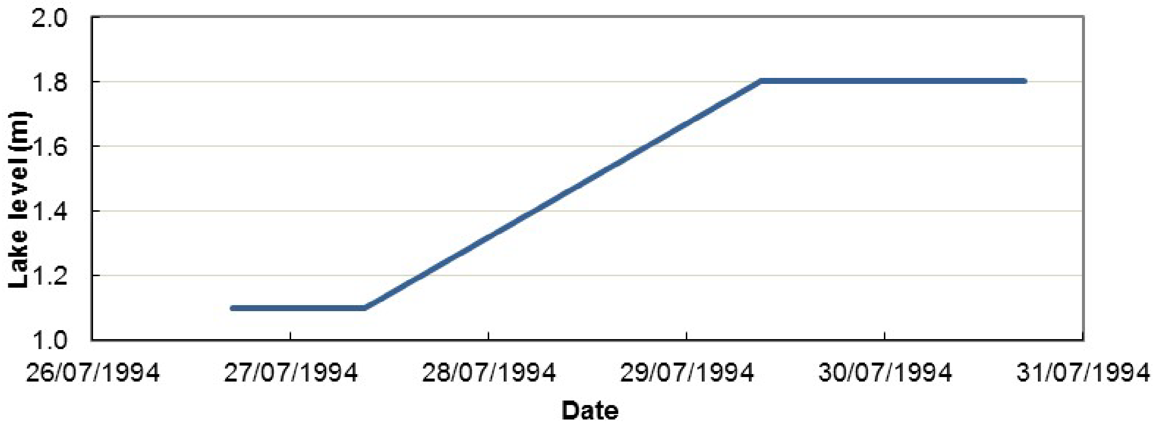


Figure 3-35: Design Te Waihora/Lake Ellesmere water level for the 50, 200, and 500 year ARI

3.5.3 Model results for design flood events

The 50 year ARI design event model predicts 57 km^2 of floodplain (including some river berm areas included in the 2D model) will be inundated to an average depth of 0.35 m (Figure 3-36). This represents an increase of 50 to 63% of the floodplain area inundated, when compared with the July 2017 and August 2000 flood events.

The predicted flooding for 50, 200, and 500 year ARI events are shown in Figure 3-36, Figure 3-37 and Figure 3-38, respectively. The estimated flood extent in the 200 year ARI event is approximately 74 km^2, increasing to around 88 km^2 for the 500 year ARI event. Floodplain flows tended to spread out and stay relatively shallow for all flood events modelled. Average flow velocities were also usually less than 1 m/s on the floodplain – except in river berm areas and more defined floodplain channels, where deeper floodwater produced velocities up to ~3 m/s.

For all three design flood events, the maximum flow in the Selwyn River, where it passes the Upper Selwyn Huts, is ~326 m^3/s. In the Selwyn River, immediately downstream of Coes Ford, the maximum river flows are ~394 m^3/s (50 year ARI flood), 402 m^3/s (200 year ARI flood) and 407 m^3/s (500 year ARI flood).

Note that:

- Flood mapping does not include localised runoff from rainfall. In some areas rainfall runoff is likely to exacerbate Selwyn River flooding and produce greater flood depths than shown by the model results.

- Averaging of the topography to produce the 10 m grid for the floodplain removes many of the smaller drains. This is comparable to having them in the model, running at full capacity transporting local runoff downstream to the lake.

- Flooding around the Te Waihora/Lake Ellesmere shoreline is mainly due to the elevated level of the lake. This assumed lake level may be partly due to wind setup (typically occurring during storms), but more importantly due to delays in being able to excavate the lake opening due to inclement weather and sea conditions. During larger flood events, especially when there is significant rainfall falling on (and around) the lake, the lake level can rise quickly.

- No structural failures of stopbanks are included in these models; only overtopping of stopbanks. If a stopbank breach were to occur, it would likely result in relatively minor increases in flooding away from the main Selwyn River channel due to water spreading out. However, the model results show some areas near the stopbanks to be clear of flooding (or affected by only minor flooding), but in the event of a stopbank breach flooding could be significant (for example at the Upper Selwyn Huts).

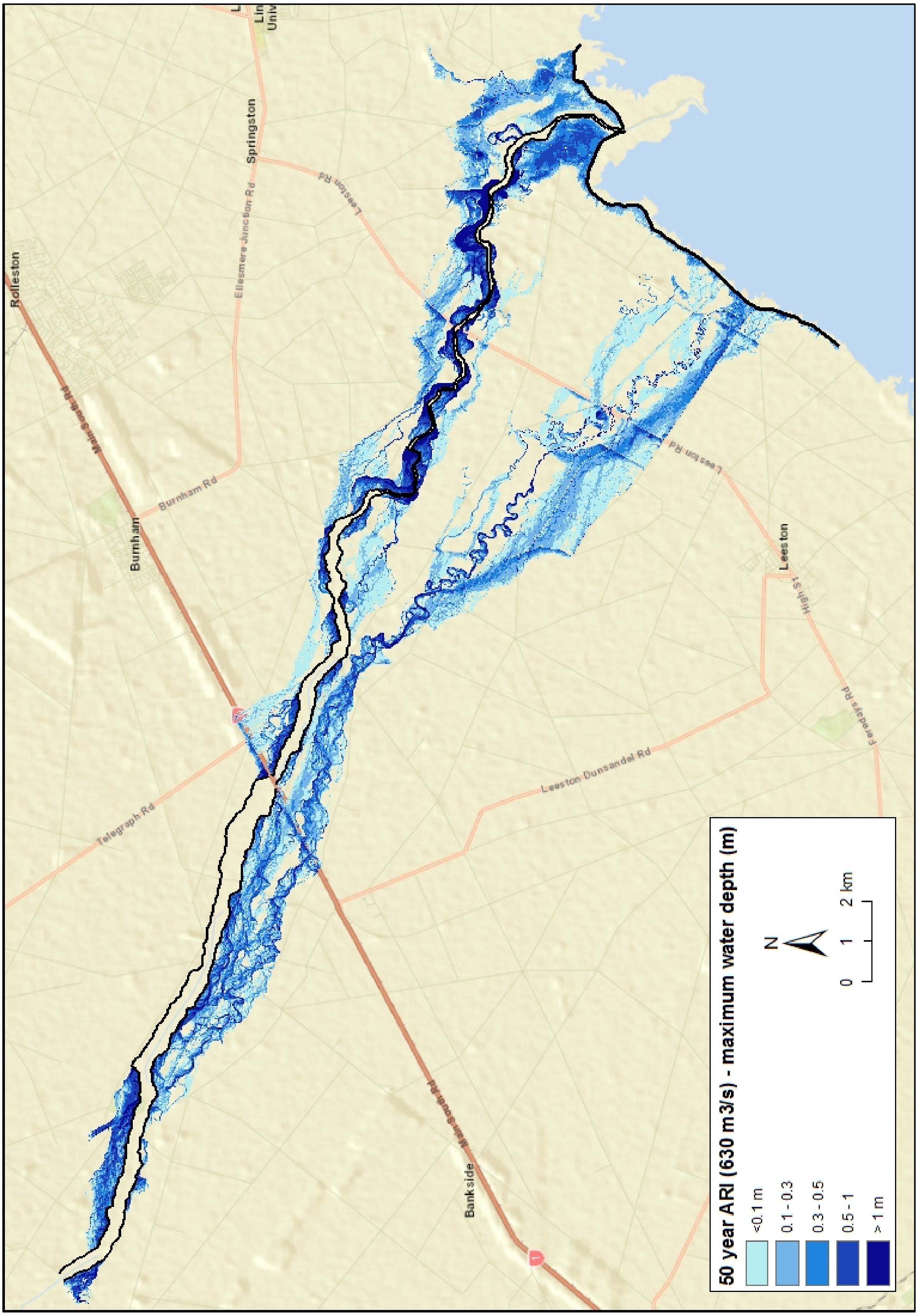


Figure 3-36: Maximum modelled water depths for a 50 year ARI flood event

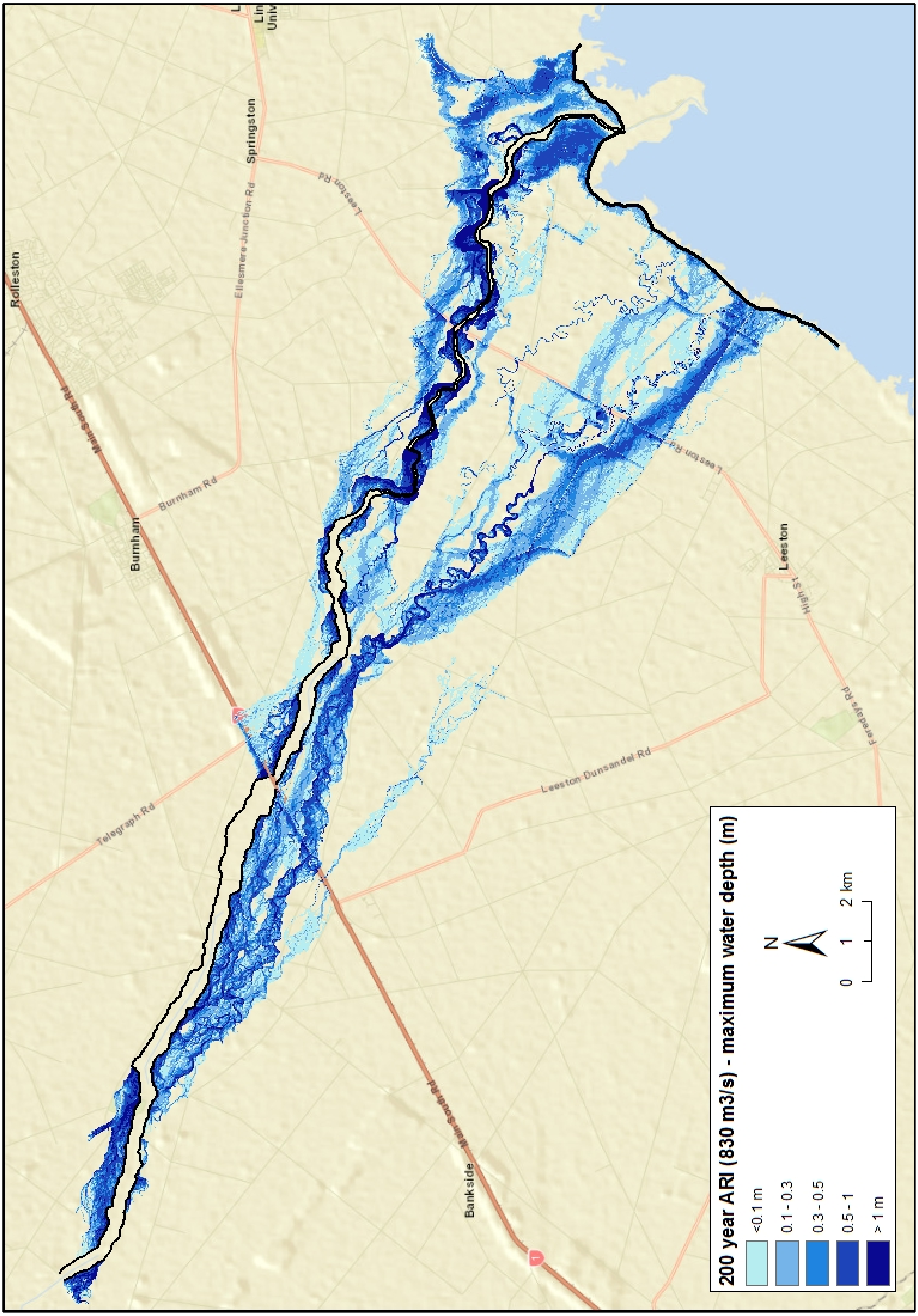


Figure 3-37: Maximum modelled water depths for a 200 year ARI flood event

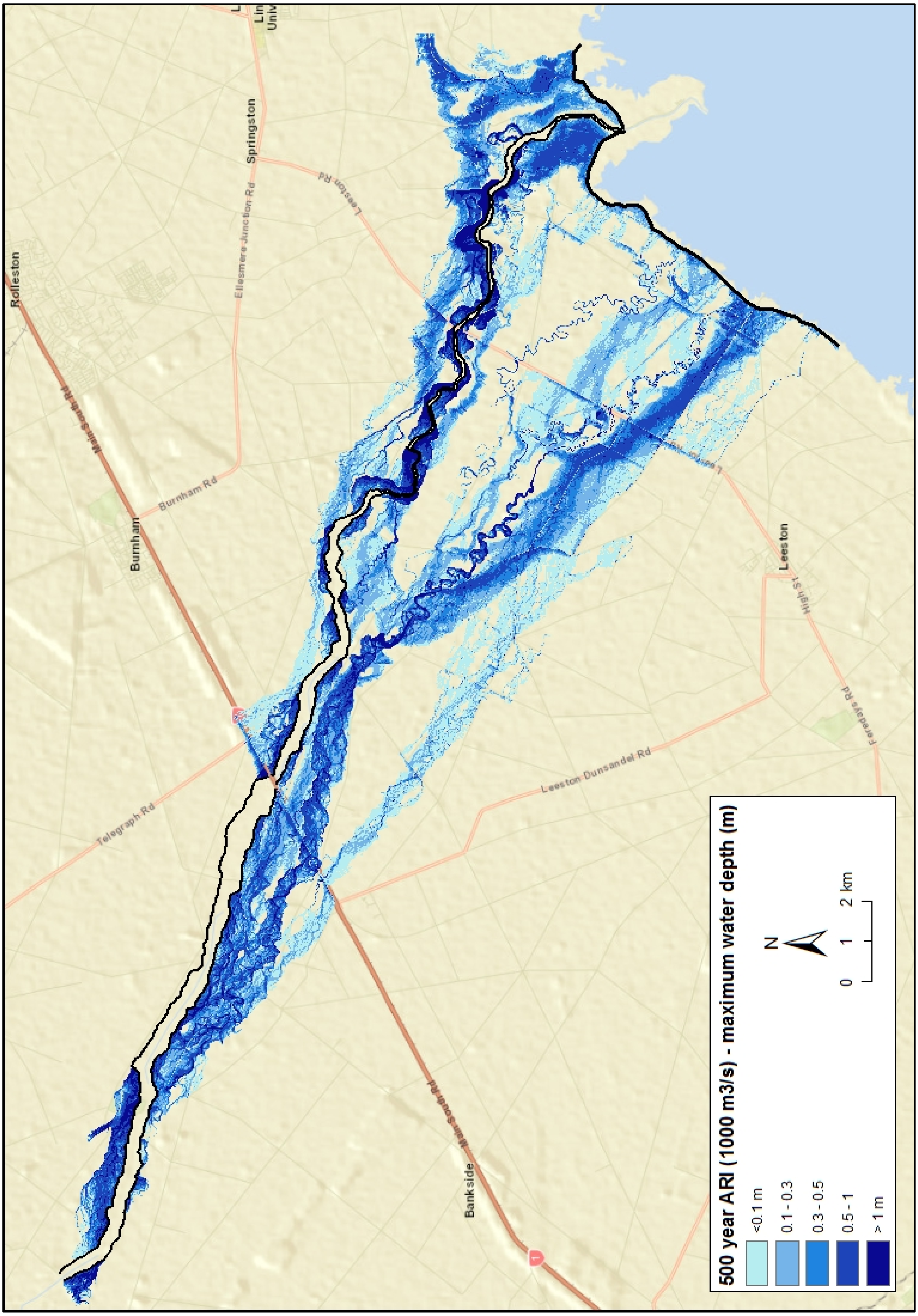


Figure 3-38: Maximum modelled water depths for a 500 year ARI flood event

3.6 Modelling of Selwyn River Control Scheme capacity

One of the objectives of the Selwyn River Control Scheme is to prevent overflows from the Selwyn River for up to 560 m^3/s peak flood flows. To determine whether the Scheme has this capacity, a model was run with a peak flood flow equivalent to the 560 m^3/s scheme capacity. The model simulation was based on a 1 second time step to ensure stability, and results were saved every 15 minutes over the full storm event. No stopbank breaches were simulated – only overtopping of stopbanks.

The flood flow and lake hydrographs used to model the Scheme capacity are shown in Figure 3-39 and Figure 3-40. Modelled floodplain maximum depths of inundation are shown in Figure 3-41. This indicates that some overtopping of river banks and stopbanks is likely, as well as overflows to the Irwell River. The Irwell River is also likely to spill onto the floodplain, with overflows passing overland towards Hanmer Drain.

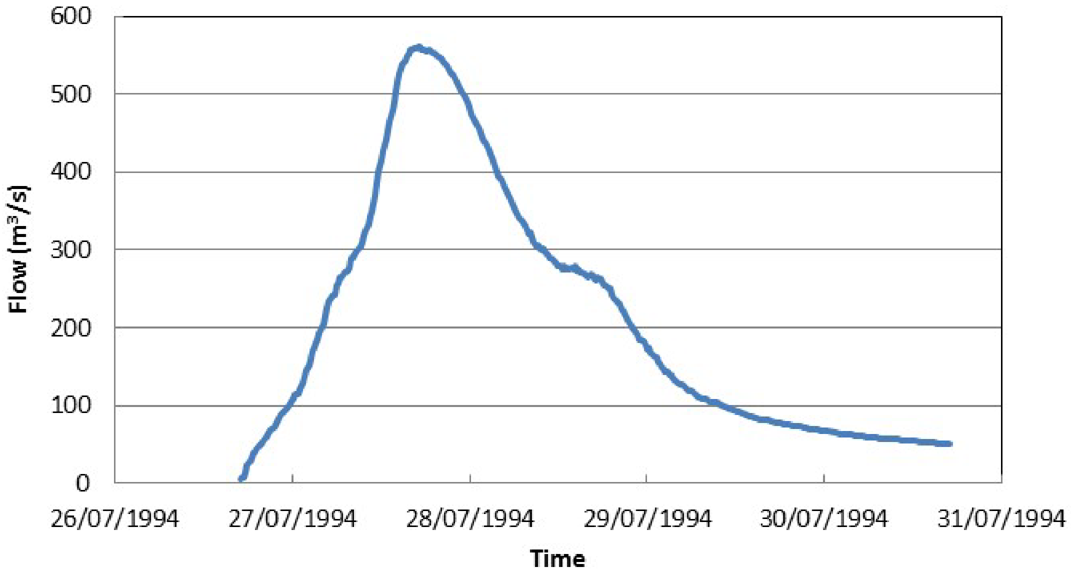


Figure 3-39: Scheme design flood hydrograph showing the 560 m^3/s total design flow entering the Selwyn River model

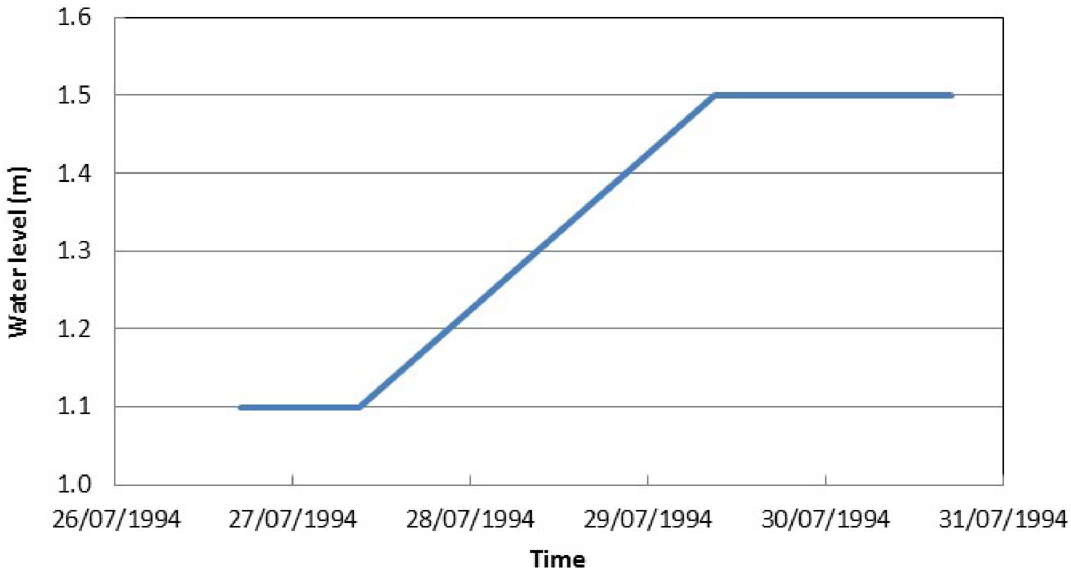


Figure 3-40: Downstream Te Waihora/Lake Ellesmere water level used for the scheme design model

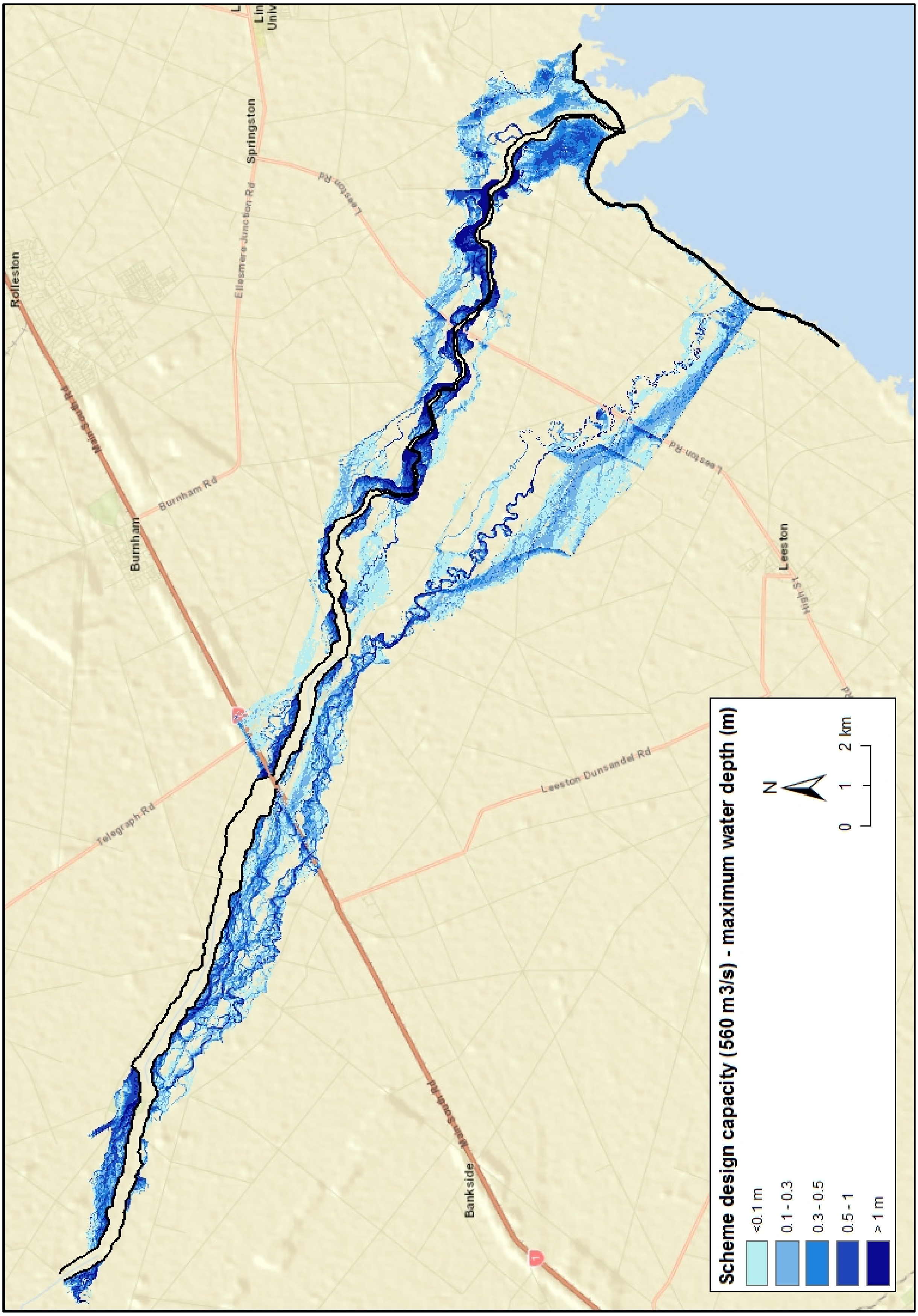


Figure 3-41: Inundation for a 560 m^3/s (Selwyn River Control Scheme capacity) flood event

3.7 Model sensitivity analysis

Additional scenarios were modelled to determine the sensitivity of the model to several parameters and assumptions. These are described below. For this modelling investigation, no stopbank breach scenarios have been modelled for the design flow scenarios. Stopbank breaches have only been included in the August 2000 calibration flood event, and as a sensitivity test (Section 3.7.6). Should a stopbank breach occur, this would increase maximum water depths downstream of the breach (on the floodplain), decreasing flows down river.

3.7.1 River channel roughness

The Selwyn River MIKE Flood model has channel roughness values as specified in Table 3-3. Since floodplain flow only occurs when water overtops the 1D/2D river channel boundary, the volume of flood water entering the floodplain is somewhat reliant on the correct roughness values being used to represent the Selwyn River channel (i.e. water levels along the river will increase if Manning's n roughness increases).

Manning's 'n' roughness values along the 1D Selwyn River channel were increased by 20%, to determine the impact of roughness on floodplain water depths and extent. Figure 3-42 shows the modelled increase in maximum water depth for a 20% increase in river channel roughness. Maximum water depths on the floodplain generally increase by less than 0.15 m, and an additional 620 hectares of floodplain is inundated.

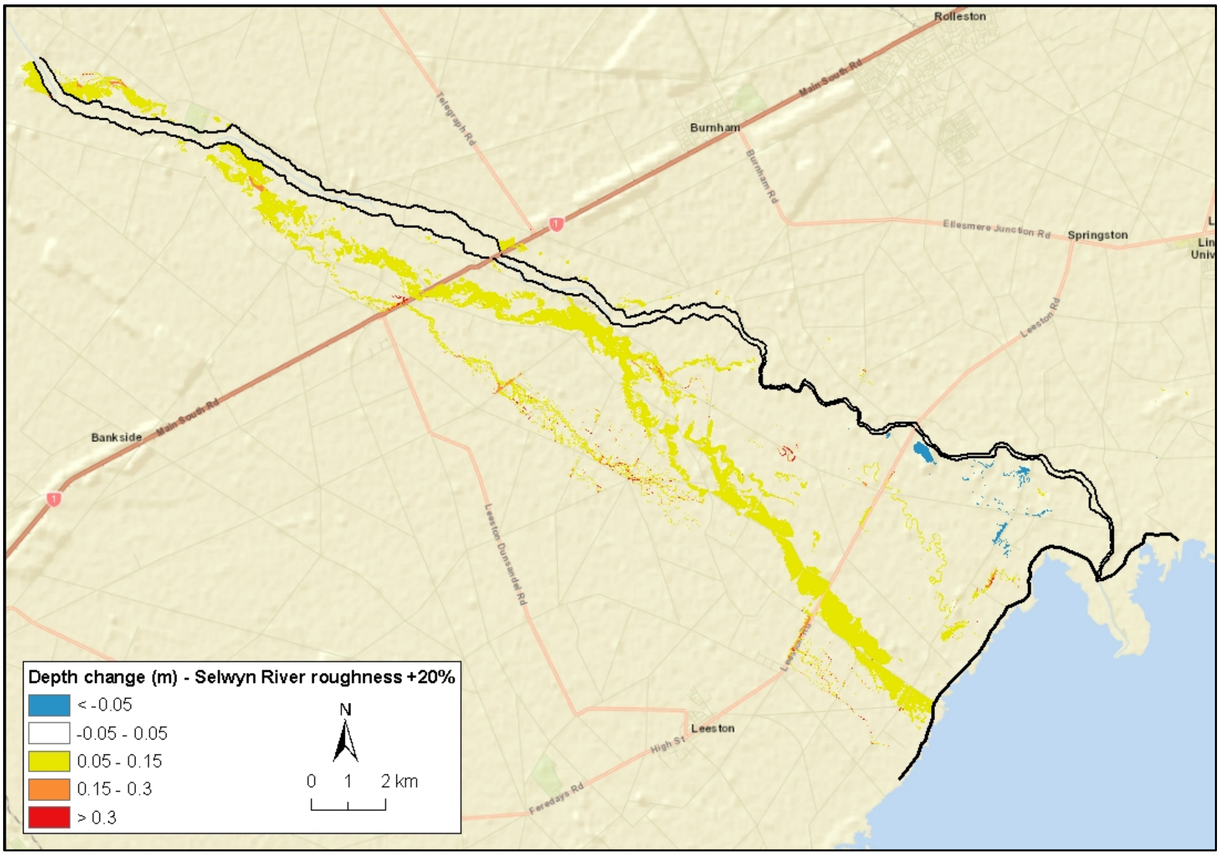


Figure 3-42: Change in maximum floodplain water depths when the Selwyn River channel roughness is increased by 20% for the 200 year ARI flood event

3.7.2 Floodplain roughness

Floodplain roughness values used to represent the Selwyn floodplain are described in Section 3.2.2 and shown in Figure B-4. Sensitivity analysis, using a Manning M (=1/n) roughness value decreased by 20% (i.e. an increase in Manning's 'n' roughness) showed a 460 hectare increase in inundated floodplain area. Figure 3-43 shows that increases in maximum water depths were generally less than 0.15 m.

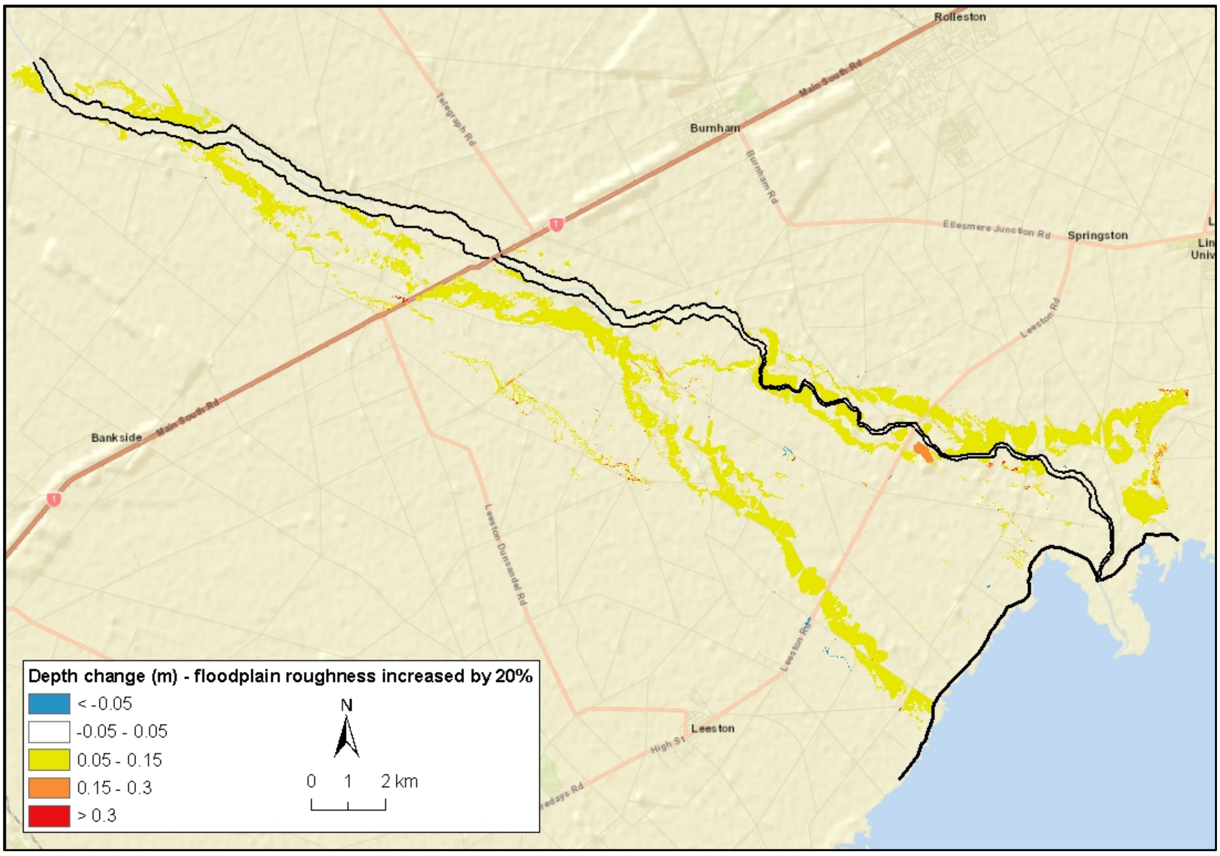


Figure 3-43: Change in maximum floodplain water depths when floodplain roughness is increased by 20% for the 200 year ARI flood event

3.7.3 No climate change – excluding likely increase in 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 2120. Should peak flows not increase, the 830 m^3/s peak flow for the 200 year ARI flood event would remain around 660 m^3/s (i.e. have a magnitude similar to the modelled 630 m^3/s peak flow for the 50 year ARI event).

Modelled maximum water depths for the 50 year and 200 year ARI flood events are shown in Figure 3-36 and Figure 3-37. The difference between the maximum water depths for the 50 and 200 year ARI flood events is shown in Figure 3-44. The modelling indicates that a decrease in peak flow, from 830 m^3/s to 630 m^3/s, reduces the extent of floodplain inundation by 17 km^2. In general, maximum water level decreases of more than 0.2 m tended to occur along the Irwell River overland flow path, in drains, and in ponding areas. Greater decreases in maximum flood levels also occur around the LII River floodplain. Although it is important to recognise that Selwyn River flows are likely to contribute to flooding on this area of the floodplain, this model does not include the LII River. Maximum water depths in this area may therefore vary due to LII River inflows also contributing to the flooding (i.e. for large storm events, all rivers in the area are likely to be flooding).

3.7.4 Additional climate change – Te Waihora/Lake Ellesmere level increase of 0.5 m

It is not currently known how increasing sea level will directly impact on Te Waihora/Lake Ellesmere, due to the reasons discussed in Section 2.5. For these sensitivity analyses, it has been assumed that the lake will rise by an additional 0.5 m during the flood event. Modelling indicates that, for the 200 year ARI design flood, the increased extent of flooding due to a 0.5 m rise in Lake Ellesmere level will be confined to the area adjacent to Lake Ellesmere (Figure 3-45). Increases in floodplain inundation upstream will be relatively insignificant. Note that this assumption is based on river cross sections in the lower reaches of the Selwyn River remaining the same – channel aggradation is not considered here, but this may impact river levels further upstream.

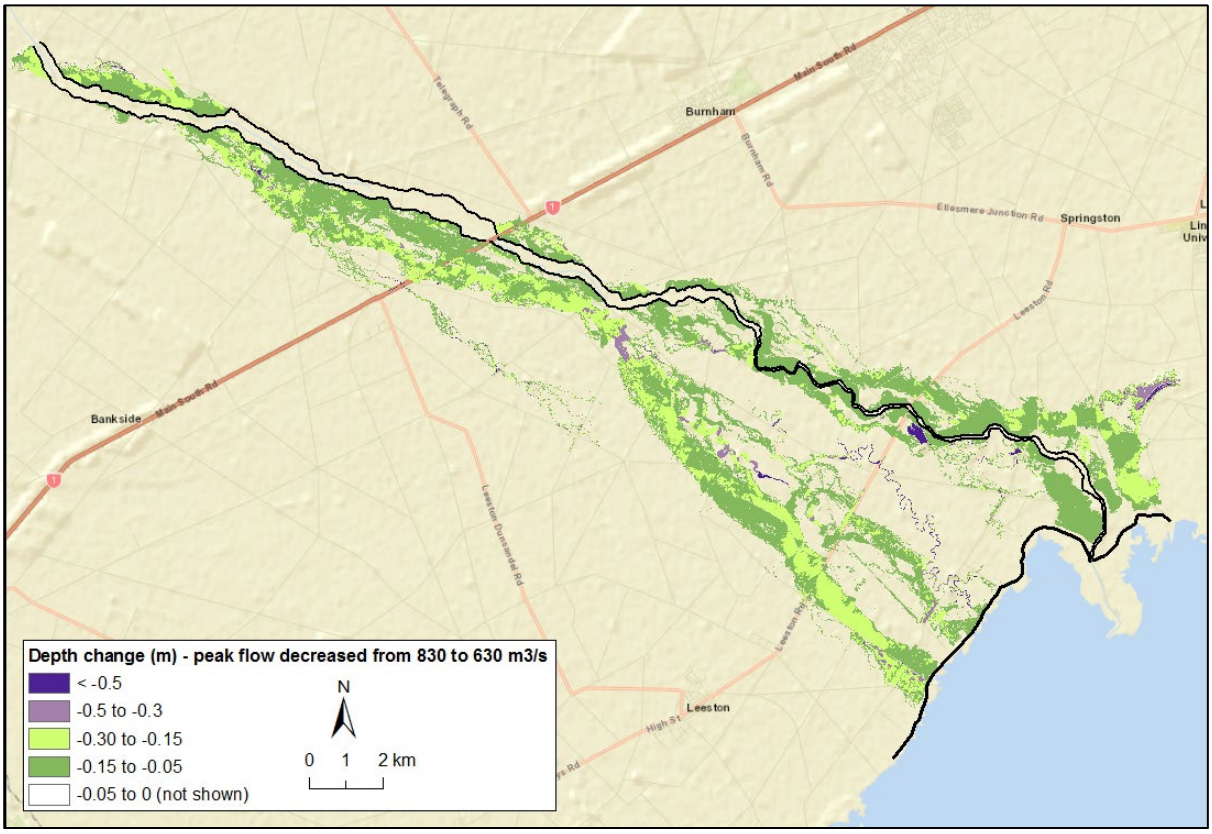


Figure 3-44: Change in maximum floodplain water depths when peak flow is reduced from 830 to 630 m^3/s for the 200 year ARI flood event

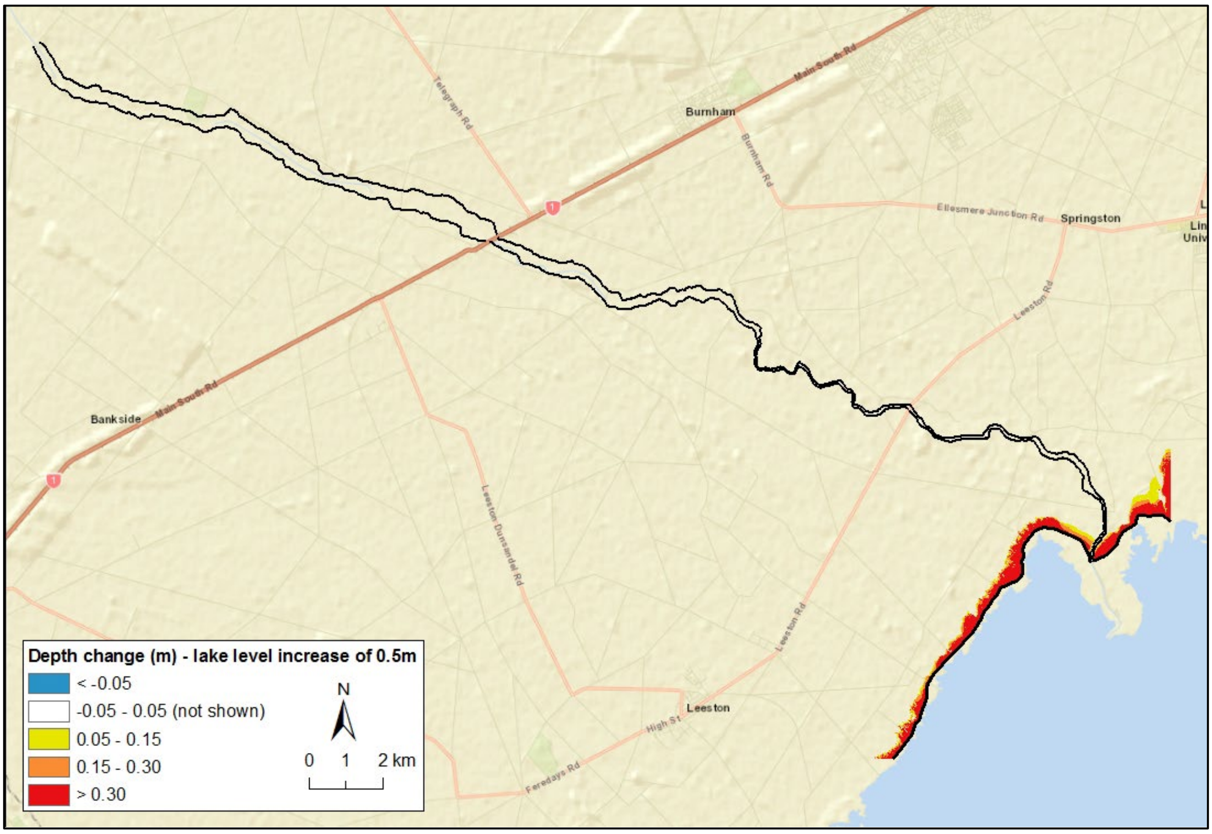


Figure 3-45: Change in maximum floodplain water depths when Lake Ellesmere levels are increased by 0.5 m for the 200 year ARI flood event

3.7.5 Selwyn River cross sections aggraded by 0.2 m

The Selwyn River is continuously aggrading, and degrading, due to both scour and deposition of sediment, as well as gravel extraction. The river has been modelled with all 1D Selwyn River cross sections, upstream of cross section chainage 83723 (located 1.2 km downstream of Withells Ford), raised by 0.2 m. This increased floodplain water depths on both the upstream floodplain adjacent to the raised channel, and along the Irwell River overflow path. It also decreased water depths downstream of the raised channel (Figure 3-46).

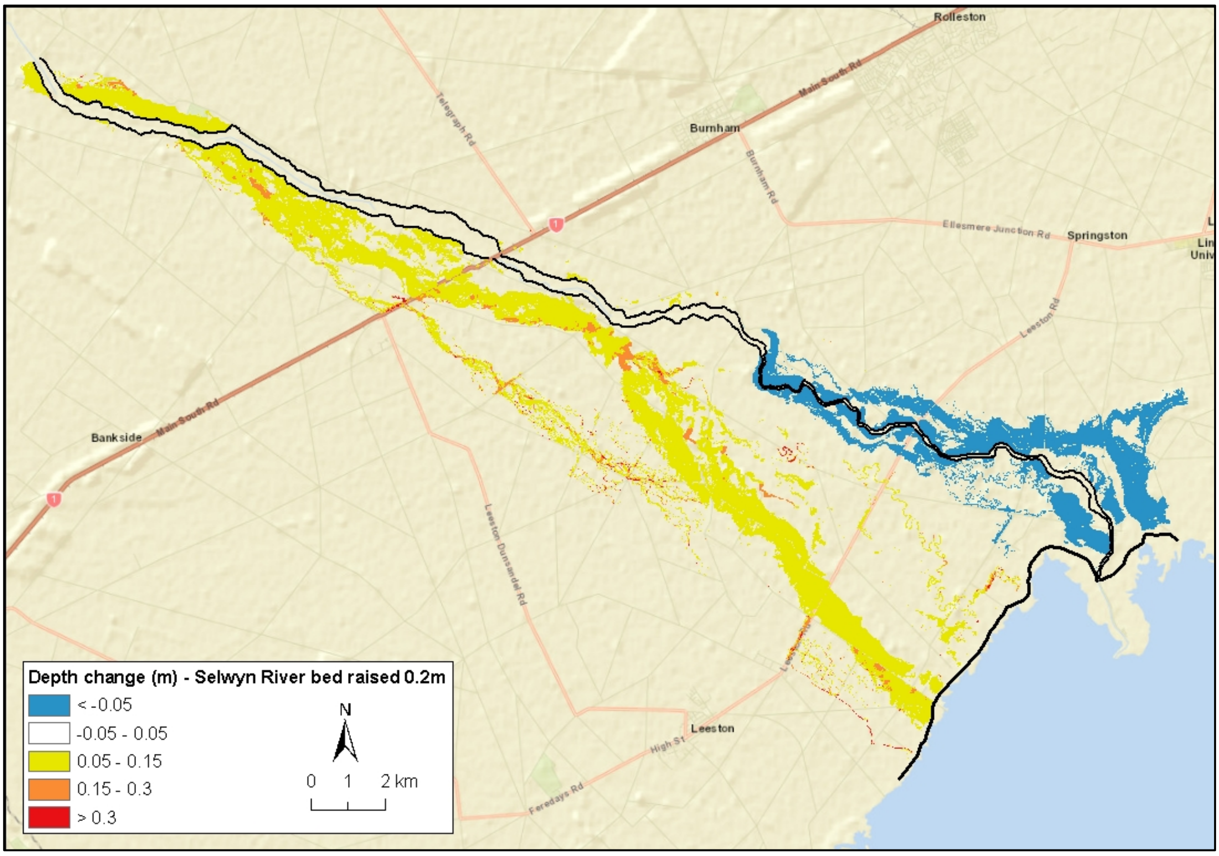


Figure 3-46: Change in maximum floodplain water depths for upstream Selwyn River bed levels raised by 0.2 m for the 200 year ARI flood event

3.7.6 Stopbank breach

Stopbank breaches are difficult to simulate due to the unpredictable nature of such failures (i.e. in terms of both location and breach size). To illustrate the potential increases in maximum water depths due to a stopbank being removed, the stopbank parallel to Westenras Road was removed for the 200 year ARI flood event. Figure 3-47 indicates increases in water depths of up to ~50 mm on the floodplain downstream of the stopbank, with greater increases immediately below the stopbank. Decreases in maximum water depths were generally up to 50 mm along the Selwyn River (and adjacent floodplain) downstream of the Westenras Road stopbank. Should a sudden breach/stopbank collapse occur, the increase in water depth immediately downstream of the breach would be higher. Water levels downstream of a breach are also dependent on various factors including the size of the breach, stopbank height, whether the floodplain is already inundated, and floodplain topography (e.g. whether there are any ponding areas or restrictions to flow).

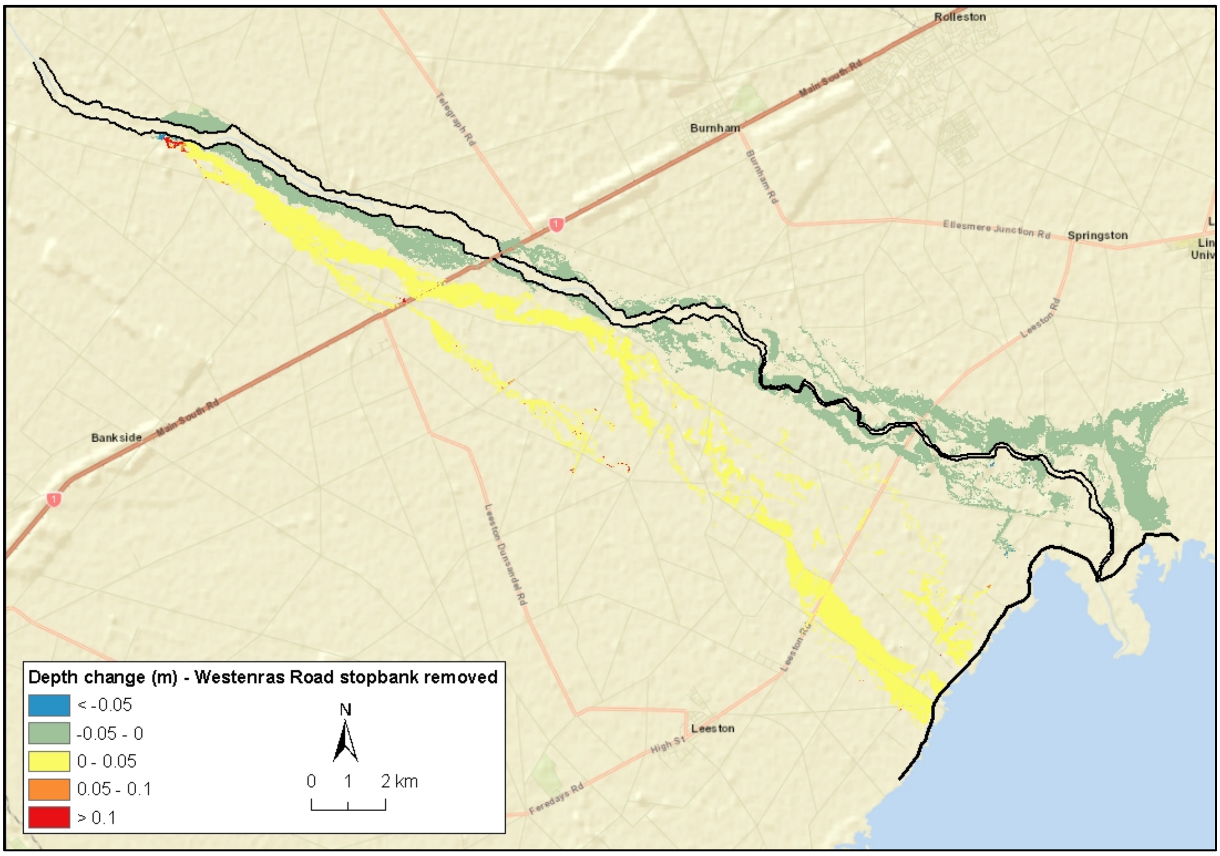


Figure 3-47: Change in maximum floodplain water depths when the stopbank parallel to Westenras Road is removed for the 200 year ARI flood event

3.7.7 Eddy viscosity

The eddy viscosity value of 0.5, used in the 2D model, was lower than the 'rule of thumb' value calculated using the following formula

$$0.02\,\frac{\Delta x\,\Delta y}{\Delta t}$$

A 10 m grid and 1 second time step would give an eddy viscosity of 2. To determine the impact of eddy viscosity, the July 2017 calibration model was re-run with a 1.5 second time step, and an eddy viscosity of 1.3. The revised model increased maximum water depths by an average of ~0.02 m with a standard deviation of 0.03 m. It was therefore considered valid to leave the eddy viscosity at 0.5, and the time step at 1 second.

3.8 High hazard areas and floodplain extent

High hazard areas are defined in the Canterbury Regional Policy Statement (CRPS) 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 3-48 identifies the hazard categories for the Selwyn River floodplain. High hazard areas are present along the existing Selwyn River channel (mainly in areas largely contained by stopbanks), as well as along other watercourses (e.g. Irwell River and various drains). Areas around the Greendale Golf Course/Hawkins River confluence and Hororata River confluence are also classified as high hazard.

The Selwyn River floodplain extent is also shown in Figure 3-49. This is based on the area of inundation expected for a 500 year ARI flood event. This does not include stopbank breach scenarios.

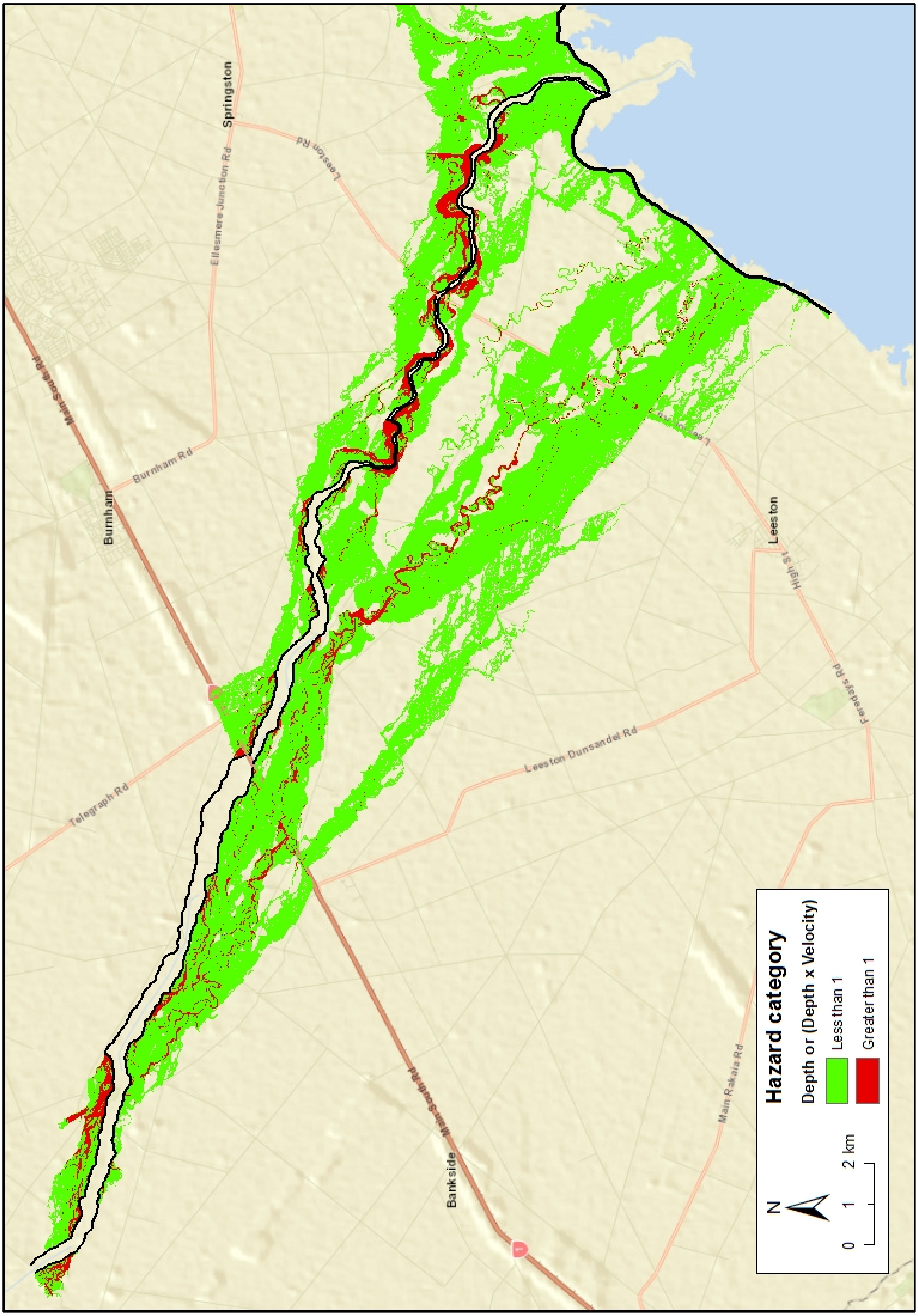


Figure 3-48: Selwyn River floodplain hazard categories (500 year ARI flood event)

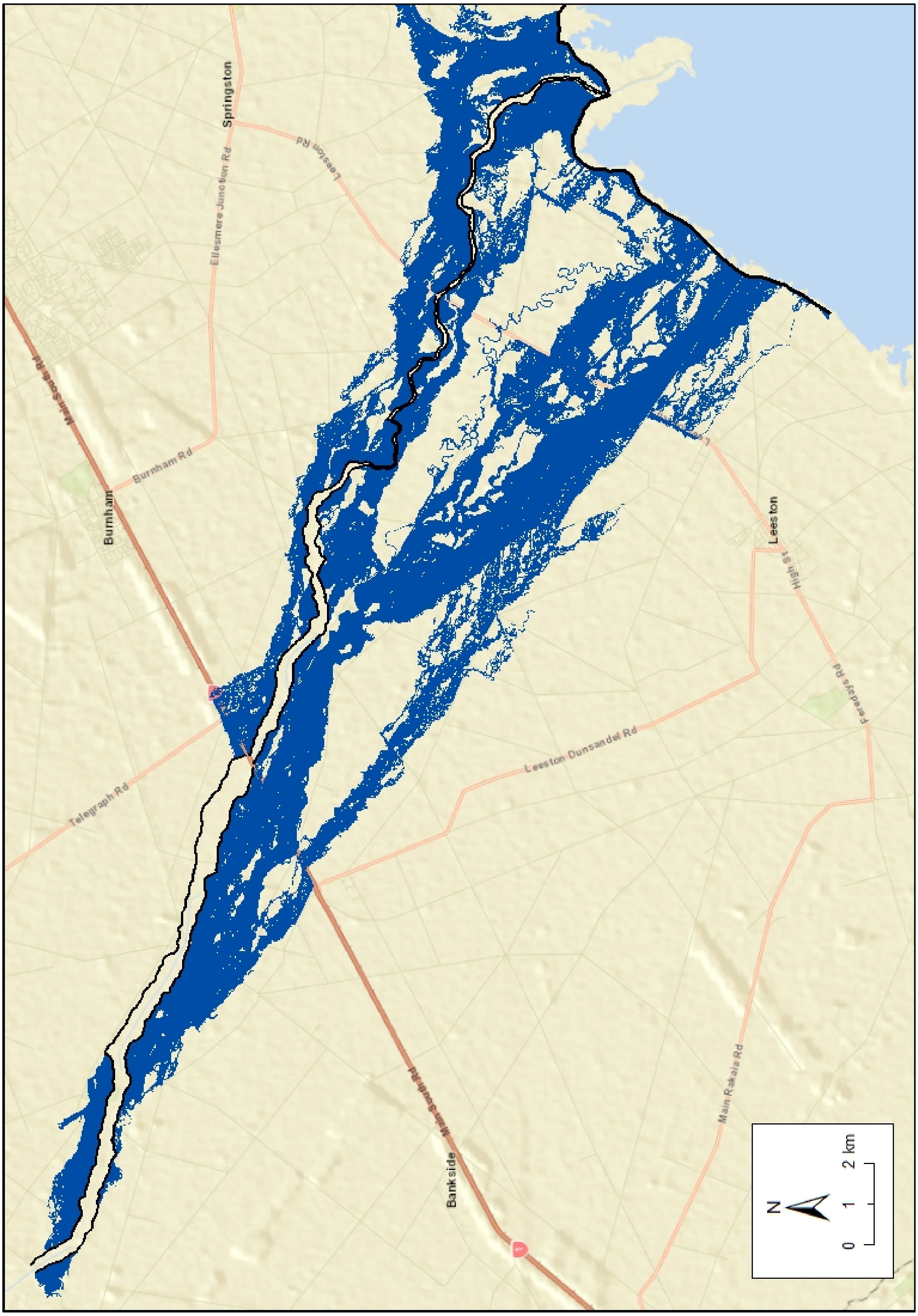


Figure 3-49: Selwyn floodplain potentially inundated area (500 year ARI flood event)

4 Discussion

The information from this modelling investigation will assist with floodplain mapping, identification of high hazard areas, and the prediction of flood levels for land use planning (e.g. providing minimum floor levels for proposed buildings). A summary of the model results, and modelling uncertainty, is given below.

4.1 Summary of model results

Overflows to the Irwell River are shown to occur at flows as low as 250 m^3/s (e.g. 2008 flood event). These overflows initially occur along the Selwyn River south bank, between Westenras Road and Old South Road (opposite the Greendale Golf course). At the same time, floodwater also flows through the Greendale Golf Course.

The current capacity of the Selwyn River Control Scheme is estimated to be equivalent to a 10 to 20 year ARI flood event. The reason for this is that the maximum channel capacity in the reach immediately upstream of the Upper Selwyn Huts is estimated to be ~320 to 330 m^3/s, with no freeboard. As mentioned above, upstream of the Scheme there are already outflows onto the floodplain (and into the Irwell River) at flows as low as 250 m^3/s. Additional flooding from stopbank breaches is also possible during the design flood events, as well as during more frequent events.

Sensitivity tests show that maximum water depths along the main overland flow paths (i.e. areas on the floodplain where depths are already greatest) are most sensitive to changes in model parameters such as river channel and floodplain roughness, river channel aggradation, and other main river overflows. This is most likely because these areas of the floodplain tend to be natural depressions, where additional flow will be directed.

4.2 Uncertainty in modelling

Flood inundation maps have several sources of uncertainty that need to be considered when interpreting them. Bales and Wagner (2009) outline some of the uncertainties associated with hydraulic modelling using LiDAR data. These uncertainties are also relevant for this modelling study where uncertainties include:

- Model inputs (e.g. flow hydrographs, roughness values and energy loss parameters).
- Topographic data (e.g. LiDAR data, cross section data).
- Hydraulic model assumptions (e.g. simplification of equations by depth-averaging, as well as averaging topography and flow behaviour over a 10 m grid cell for computational efficiency).
- Potential stopbank breaches, which are difficult to predict in terms of both location and size.

Another uncertainty, more specific to this model, is that of the division of flood flows between the Selwyn River and overflows to the Irwell River. In the area around Westenras Road, changes in river channel vegetation, and modifications to any stopbanks (in terms of height or extent), may change the proportion of the flow passing on to the floodplain. Sensitivity tests can help address uncertainty, but modelling results should only be interpreted and used by those who are familiar with all aspects of the modelling.

Maximum depths of inundation around Days Road (particularly the area east of Days Road) are also not likely to be precise for larger modelled flood events. This is because additional flood waters from the LII River needs to be taken into consideration to correctly simulate flood inundation in this area. This was outside the scope of this investigation. Flood water may also be confined in places by the model boundary.

As the 10 m grid does not represent flow along the Irwell River particularly well (given the river is only one 10 m cell grid wide in most places), the flexible mesh version of the 2D software may better represent the Irwell River should any future floodplain modelling investigations be undertaken for this area. This is because the flexible mesh can use higher resolution triangular or rectangular mesh to represent this watercourse.

4.3 Recommendations

It is recommended that this modelling study be updated once additional flow and calibration data are available. Additional calibration data should ideally include measured water levels along the Selwyn River, Irwell River and on the floodplain, during a significant flood event that causes floodplain inundation. Any breaches during flood events should also be documented. The Coes Ford flow record, used to generate average recurrence intervals for flood flows, could also be extended by considering historic flood events.

Advances in 2D modelling mean it may be advantageous for future models to simulate the wide, braided, upper reaches of the Selwyn River in 2D rather than using the 1D model for the active channel. This would allow the model to better represent the variations in flood levels across the width of the river (e.g. super-elevation on bends).

The less substantial stopbanks at Westenras Road and Coes Ford, running perpendicular to the main river system, provide flood protection to land on the floodplain. There may be some benefit to undertaking a structural assessment of these stopbanks, as well as more accurately measuring the crest levels to ensure they meet the required standard of protection.

When using these model results for planning purposes, all sources of model uncertainty should be taken into consideration.

5 External peer review

An external peer review of the initial model was completed by GHD Limited (Appendix F). Along with minor recommendations, the review concluded that '*the model is considered suitable, but it is recommended that the following improvements be carried out:*

1. *Improve conveyance characteristics of the six M11 cross-sections identified.*
2. *Include a right bank marker at section chainage 100310 associated with the Selwyn River M11 branch.*
3. *Modify the level-width relationship of the seven M21 structures identified above which currently appear to be included as a depth-width relationship.*
4. *Change the 'structure source type' lateral link parameter from M21 to HGH.'*

All minor recommendations for improvements to the model have been completed, along with items 1 and 2 above. Item 3 was also completed for consistency – although the initial relationship for the culverts (assuming an invert level with an elevation of 0 m) produced the same model results.

Item 4 has not been adopted. The reason for this is that the ground levels along the stopbanks (i.e. overflows) do not necessarily vary evenly between the cross sections. In this case it is considered more likely that the LiDAR data will provide a better estimate of the stopbank elevations.

After the peer review was completed, the July 2017 flood event occurred. Following this event, the rated flows for Coes Ford were significantly modified, meaning the model needed to be re-calibrated. This re-calibration was completed, incorporating the new data collected during the July 2017 flood event.

The main modifications to the model were: changes to the flow hydrographs (flows are now significantly reduced), an increase in Manning's n for the 1D Selwyn River channel, and some minor 'excavation' of cross sections near the river mouth to represent scour/flushing of sediment (to enable the model to better represent the flood levels observed in July 2017 around the river mouth). The time step and eddy viscosity were also modified.

Given the minor nature of the modifications, and the successful calibration of the model, it was not considered necessary to have the model externally peered reviewed a second time.

6 Acknowledgments

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

- Kate Steel (Scientist) – analysed the Coes Ford flow record and produced design flows.
- Tony Oliver (Principal Hazards Analyst) - reviewed original modelling report.
- Nick Griffiths (Science Team Leader – Natural Hazards) - reviewed modelling results and provided archived images and background information about historic flooding on the Selwyn River floodplain.
- Tony Boyle (Principal Science Advisor) - reviewed modelling report and provided historic information on Selwyn River Control Scheme.
- Matt Surman (Senior River Engineer) – undertook an analysis of Te Waihora/Lake Ellesmere levels, provided information on the Selwyn River Control Scheme, and reviewed the modelling report.
- Ian Heslop (Senior River Engineer) - reviewed modelling report.

External assistance was provided by:

- Graeme Horrell (NIWA) - Te Waihora/Lake Ellesmere 'calm' lake level data for the flood events.

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Appendix A: Model cross section locations

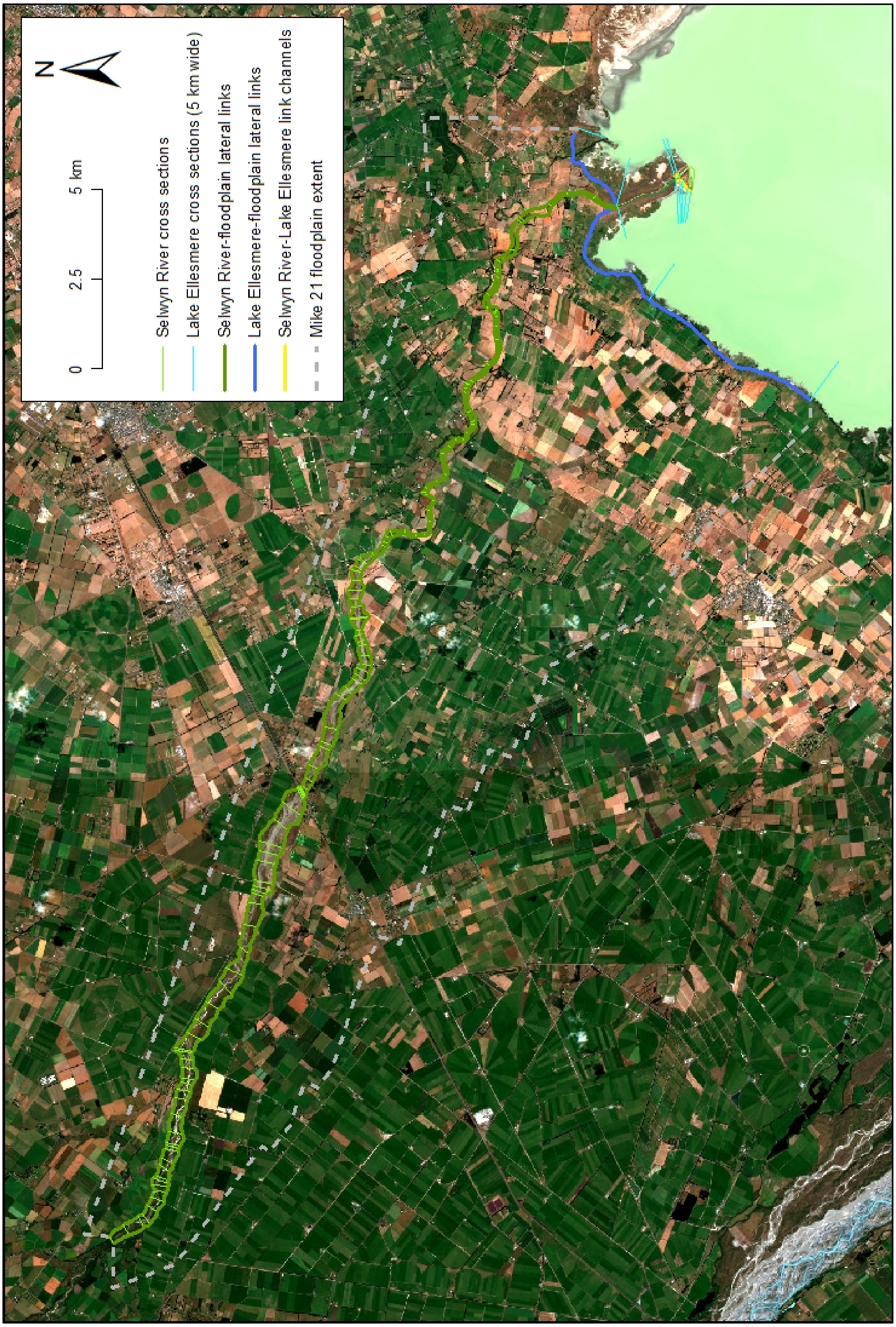


Figure A-1: Location of 1D Selwyn River cross sections and overflows

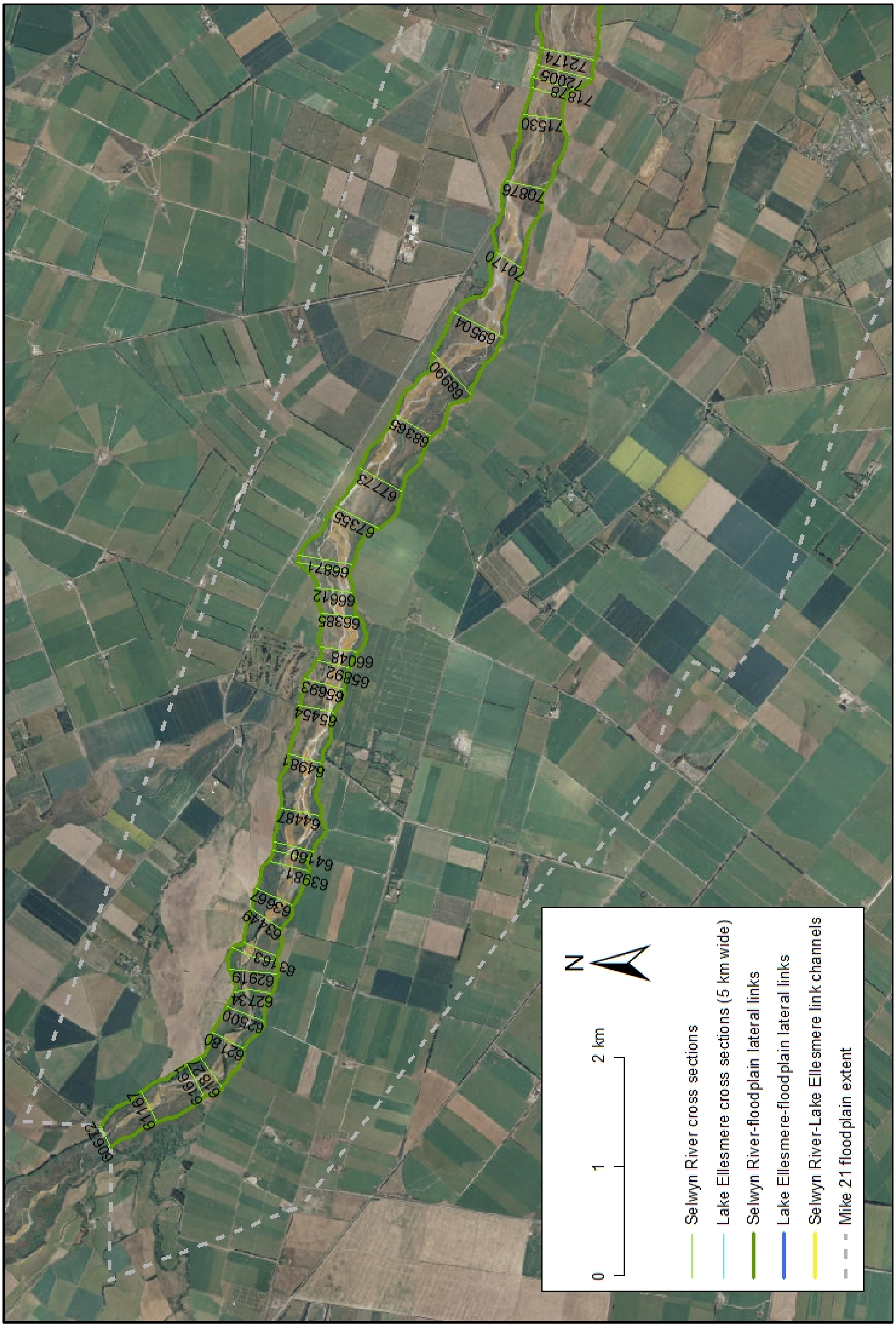


Figure A-2: Location of 1D Selwyn River cross sections and overflows (1 of 3)

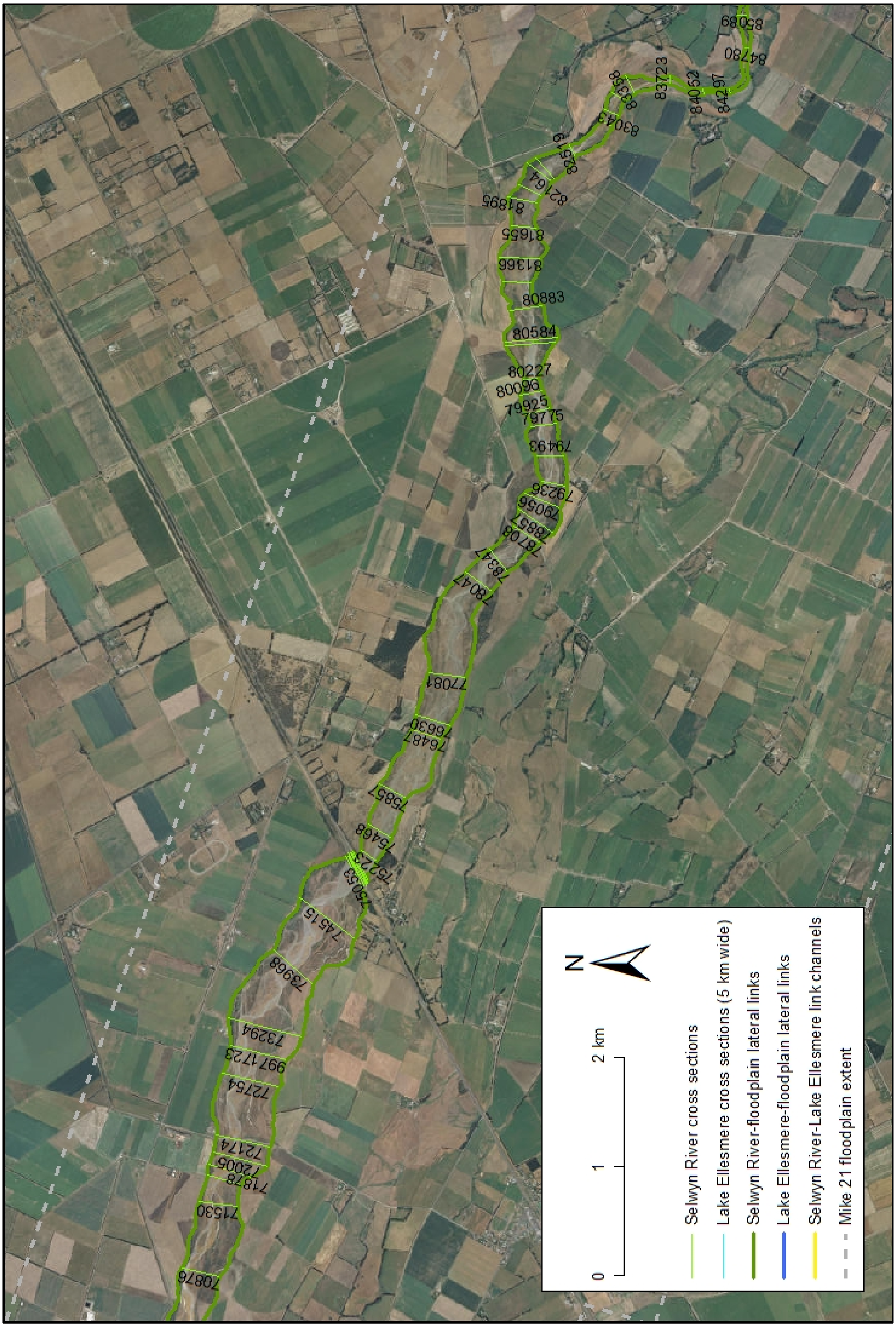


Figure A-3: Location of 1D Selwyn River cross sections and overflows (2 of 3)

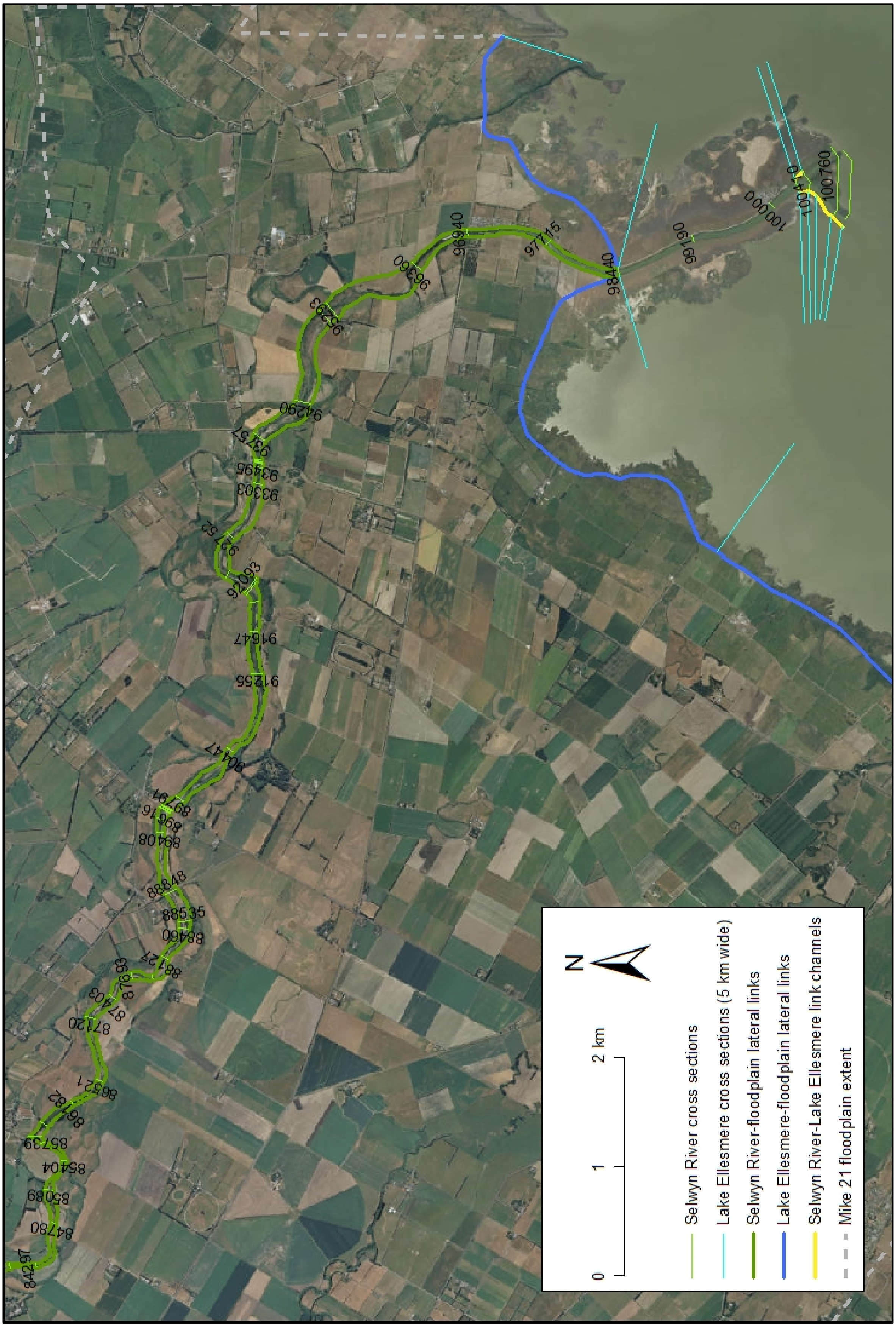


Figure A-4: Location of 1D Selwyn River cross sections and overflows (3 of 3)

Figure A-5: Location of 1D Lake Ellesmere cross sections and overflows

Table A-1: Summary of 1D cross section information

1D model chainage	Data source	Survey date	Reference	Location/Description
60672	LiDAR	Feb 08	Aurecon (XS41295)	Gillanders Road/Ford
61167	LiDAR	Feb 08	Aurecon (XS40770)	
61661	LiDAR	Feb 08	Aurecon (XS40240)	
61816	LiDAR	Feb 08		
61827	LiDAR	Feb 08		
62180	LiDAR	Feb 08	Aurecon (XS39660)	
62500	LiDAR	Feb 08		
62734	LiDAR	Feb 08		
62919	LiDAR	Feb 08	Aurecon (XS38900)	Ridgens Stream gauge
63076	LiDAR	Feb 08		
63163	LiDAR	Feb 08		
63449	LiDAR	Feb 08	Aurecon (XS38380)	
63667	LiDAR	Feb 08		
63981	LiDAR	Feb 08	Aurecon (XS37810)	
64084	LiDAR	Feb 08		
64160	LiDAR	Feb 08		
64487	LiDAR	Feb 08	Aurecon (XS37280)	
64981	LiDAR	Feb 08	Aurecon (XS36780)	Upstream of Westenras Road
65454	LiDAR	Feb 08	Aurecon (XS36300)	Upstream of Greendale Golf Course
65693	LiDAR	Feb 08		
65892	LiDAR	Feb 08		
66048	LiDAR	Feb 08	Aurecon (XS35680)	
66385	LiDAR	Feb 08	Aurecon (XS35330)	
66612	LiDAR	Feb 08	Aurecon (XS35110)	
66800	LiDAR	Feb 08		
66871	LiDAR	Feb 08	Aurecon (XS34840)	
67255	67355			67355 with width reduced
67355	LiDAR	Feb 08	Aurecon (XS34330)	
67773	LiDAR	Feb 08	Aurecon (XS33900)	
68365	LiDAR	Feb 08	Aurecon (XS33305)	
68990	LiDAR	Feb 08	Aurecon (XS32620)	
69504	LiDAR	Feb 08	Aurecon (XS32045)	
70170	LiDAR	Feb 08	Aurecon (XS31295)	Old South Rd (crosses to Coaltrack Rd)
70876	LiDAR	Feb 08	Aurecon (XS30540)	
71530	LiDAR	Feb 08	Aurecon (XS29885)	
71773	LiDAR	Feb 08		
71878	LiDAR	Feb 08		
72005	LiDAR	Feb 08		
72174	LiDAR	Feb 08	Aurecon (XS29245)	Highfield Ave (crosses to Coaltrack Road)
72754	LiDAR	Feb 08	Aurecon (XS28670)	
73294	LiDAR	Feb 08	Aurecon (XS28155)	
73968	LiDAR	Feb 08	Aurecon (XS27480)	
74515	LiDAR	Feb 08	Aurecon (XS26920)	
75013	LiDAR	Feb 08	Aurecon (XS26400)	Upstream of SH1 rail bridge
75033	LiDAR	Feb 08		
75043	LiDAR	Feb 08		
75053	LiDAR	Feb 08	Aurecon (XS26360)	Downstream of SH1 rail bridge, upstream of SH1 road bridge
75065	LiDAR	Feb 08		
75075	LiDAR	Feb 08		
75095	LiDAR	Feb 08	Aurecon (XS26320)	Downstream of SH1 road bridge
75223	LiDAR	Mar/Apr 10		
75468	LiDAR	Mar/Apr 10		

1D model chainage	Data source	Survey date	Reference	Location/Description
75857	LiDAR	Mar/Apr 10		
76487	LiDAR	Mar/Apr 10		
76630	LiDAR	Mar/Apr 10		
77081	LiDAR	Mar/Apr 10		
77606	LiDAR	Mar/Apr 10		
78047	LiDAR	Mar/Apr 10		
78347	LiDAR	Mar/Apr 10		
78708	LiDAR	Mar/Apr 10		McGregors Ford (Selwyn Road)
78857	LiDAR	Mar/Apr 10		
79056	LiDAR	Mar/Apr 10		*** gravel aggrades between McGregors
79236	LiDAR	Mar/Apr 10		and Withells Ford – regular gravel
79493	LiDAR	Mar/Apr 10		extraction in this reach
79775	LiDAR	Mar/Apr 10		
79925	LiDAR	Mar/Apr 10		
80096	LiDAR	Mar/Apr 10		
80227	LiDAR	Mar/Apr 10		
80549	LiDAR	Mar/Apr 10		
80584	LiDAR	Mar/Apr 10		
80883	LiDAR	Mar/Apr 10		
81122	LiDAR	Mar/Apr 10		
81366	LiDAR	Mar/Apr 10		
81655	LiDAR	Mar/Apr 10		
81895	LiDAR	Mar/Apr 10		
81986	LiDAR	Mar/Apr 10		
82164	LiDAR	Mar/Apr 10		
82215	LiDAR	Mar/Apr 10		
82519	LiDAR	Mar/Apr 10		Withells Ford (Brookside & Burnham Road/Corbetts Road)
82930	LiDAR	Mar/Apr 10		
83043	LiDAR	Mar/Apr 10		
83201	LiDAR	Mar/Apr 10		
83358	LiDAR	Mar/Apr 10		
83723	LiDAR	Mar/Apr 10		
84052	LiDAR	Mar/Apr 10		
84297	LiDAR	Mar/Apr 10		
84780	LiDAR	Mar/Apr 10		
85089	LiDAR	Mar/Apr 10		
85404	LiDAR	Mar/Apr 10		
85675	LiDAR	Mar/Apr 10		
85739	LiDAR	Mar/Apr 10		Rivendell/Corbetts Road
85859	LiDAR	Mar/Apr 10		
86182	LiDAR	Mar/Apr 10		
86521	LiDAR	Mar/Apr 10		
87120	LiDAR	Mar/Apr 10		
87403	LiDAR	Mar/Apr 10		
87693	LiDAR	Mar/Apr 10		
87885	LiDAR	Mar/Apr 10		
88107	88127			
88127	LiDAR	Mar/Apr 10		
88147	88127			
88460	LiDAR	Mar/Apr 10		
88535	LiDAR	Mar/Apr 10		
88848	LiDAR	Mar/Apr 10		Old Bridge Road
89408	LiDAR	Mar/Apr 10		
89528	LiDAR	Mar/Apr 10		

1D model chainage	Data source	Survey date	Reference	Location/Description
89616	LiDAR	Mar/Apr 10		Upstream of Ellesmere/Chamberlains Ford bridge
89628	LiDAR	Mar/Apr 10		
89638	LiDAR	Mar/Apr 10		
89649	LiDAR	Mar/Apr 10		Downstream of Ellesmere/Chamberlains Ford bridge
89761	89791		ECan XS 11070	
89791	Survey	15 Jun 12	ECan XS 11070	
90447	Survey	11 Jun 12	ECan XS 10525	
91255	Survey	11 Jun 12	ECan XS 9660	
91647	LiDAR	Mar/Apr 10		
91925	LiDAR	Mar/Apr 10		
92069	LiDAR	Mar/Apr 10		
92093	LiDAR	Mar/Apr 10		
92330	LiDAR	Mar/Apr 10		
92752	Survey	1 Jun 12	ECan XS 8050	
93303	Survey	1 Jun 12	ECan XS 7450	Upstream of Coes Ford
93452	Survey	29 May 12	ECan XS 7245	Approx 50m u/s Coes Ford
93495	LiDAR	Mar/Apr 10		
93500	LiDAR	Mar/Apr 10		
93511	LiDAR	Mar/Apr 10		
93528	LiDAR	Mar/Apr 10		
93757	Survey	29 May 12	ECan XS 7040	Downstream of Coes Ford
94290	Survey	24 May 12	ECan XS 6640	
95203	95293		ECan XS 5630	Datum + 0.15m
95233	95293		ECan XS 5630	Datum + 0.1 m
95293	Survey	28 May 12	ECan XS 5630	
96360	Survey	21 Jun 12	ECan XS 4630	
96940	Survey	21 Jun 12	ECan XS 4020	
97715	Survey	21 Jun 12	ECan XS 3220	
98440	Survey	21 Jun 12	ECan XS 2530	
99190	Survey	Sep 15 (soundings)	ECan XS1790	
100000	Survey	Sep 15 (soundings)	ECan XS1000	
100310	Survey	Sep 15 (soundings)	ECan XS 690	Immediately upstream of channel bifurcation near boat ramp.
100410	Survey	Sep 15 (soundings)	ECan XS 590 (west & east)	
100760	Survey	Sep 15 (soundings)	ECan XS 277 (west) & XS 240 (east)	
101000			Copy of XS100760	Te Waihora/Lake Ellesmere

Appendix B: Selwyn floodplain maps

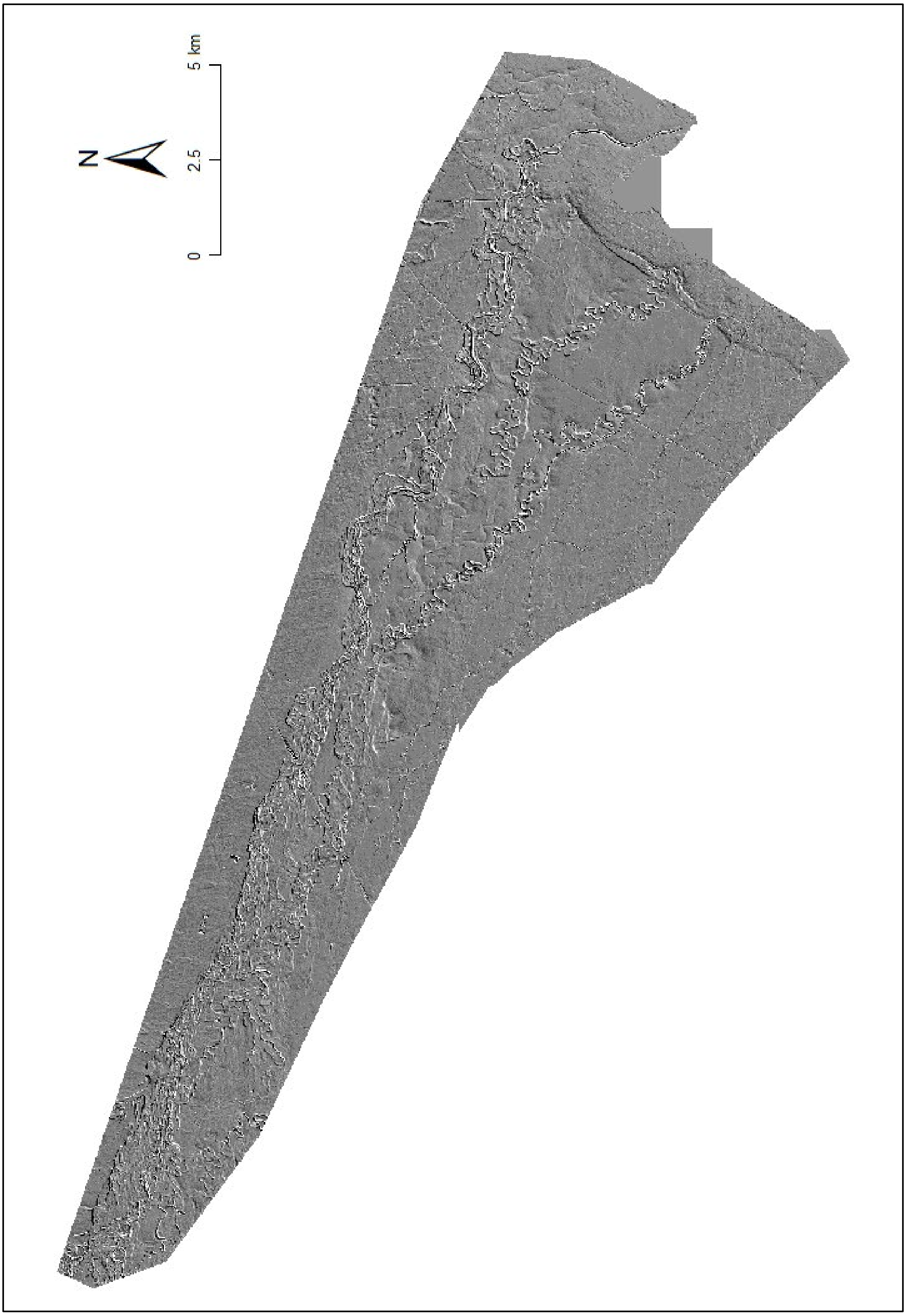


Figure B-1: Selwyn floodplain LiDAR grey scale map

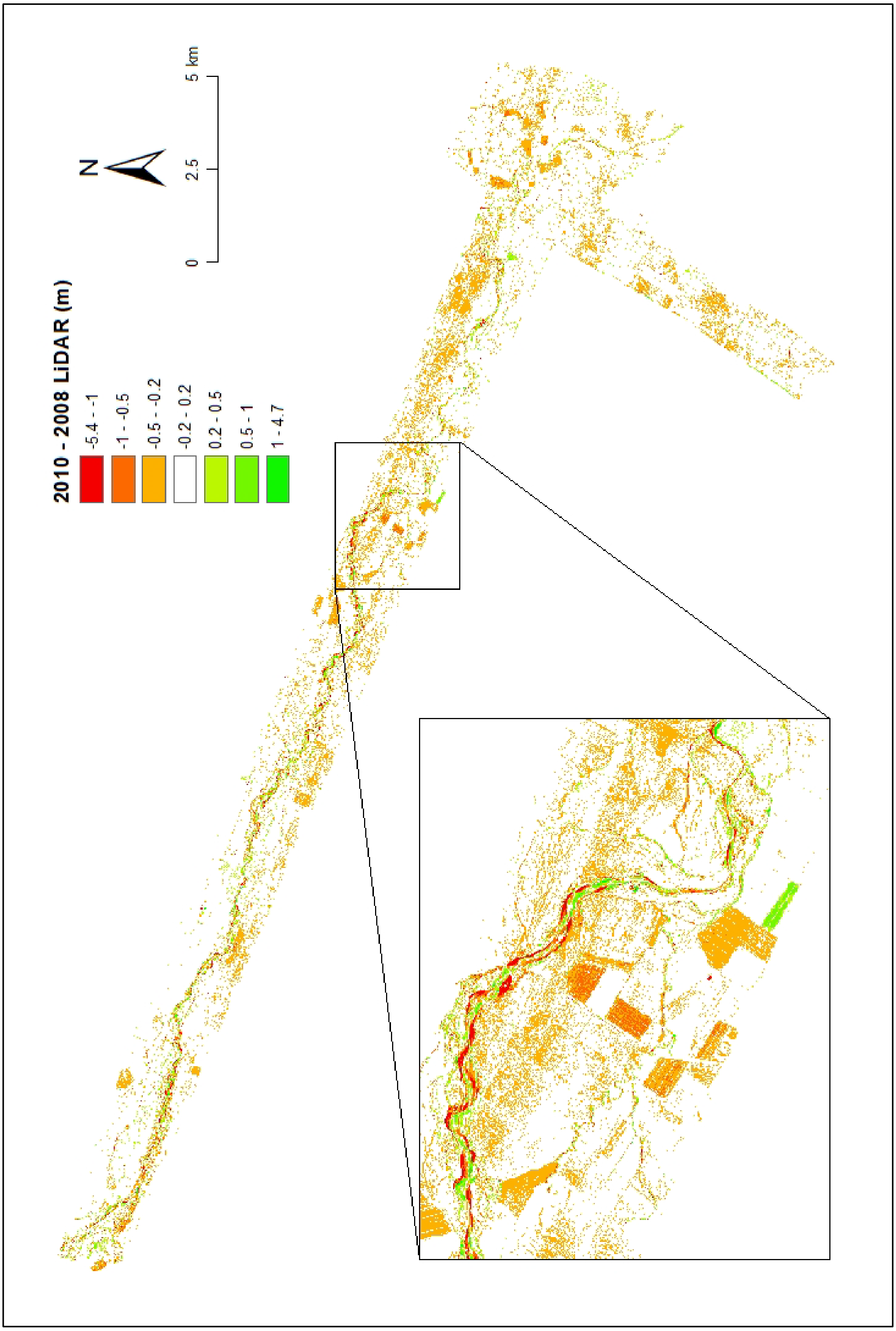


Figure B-2: Selwyn LiDAR captured in 2008 subtracted from LiDAR captured in 2010

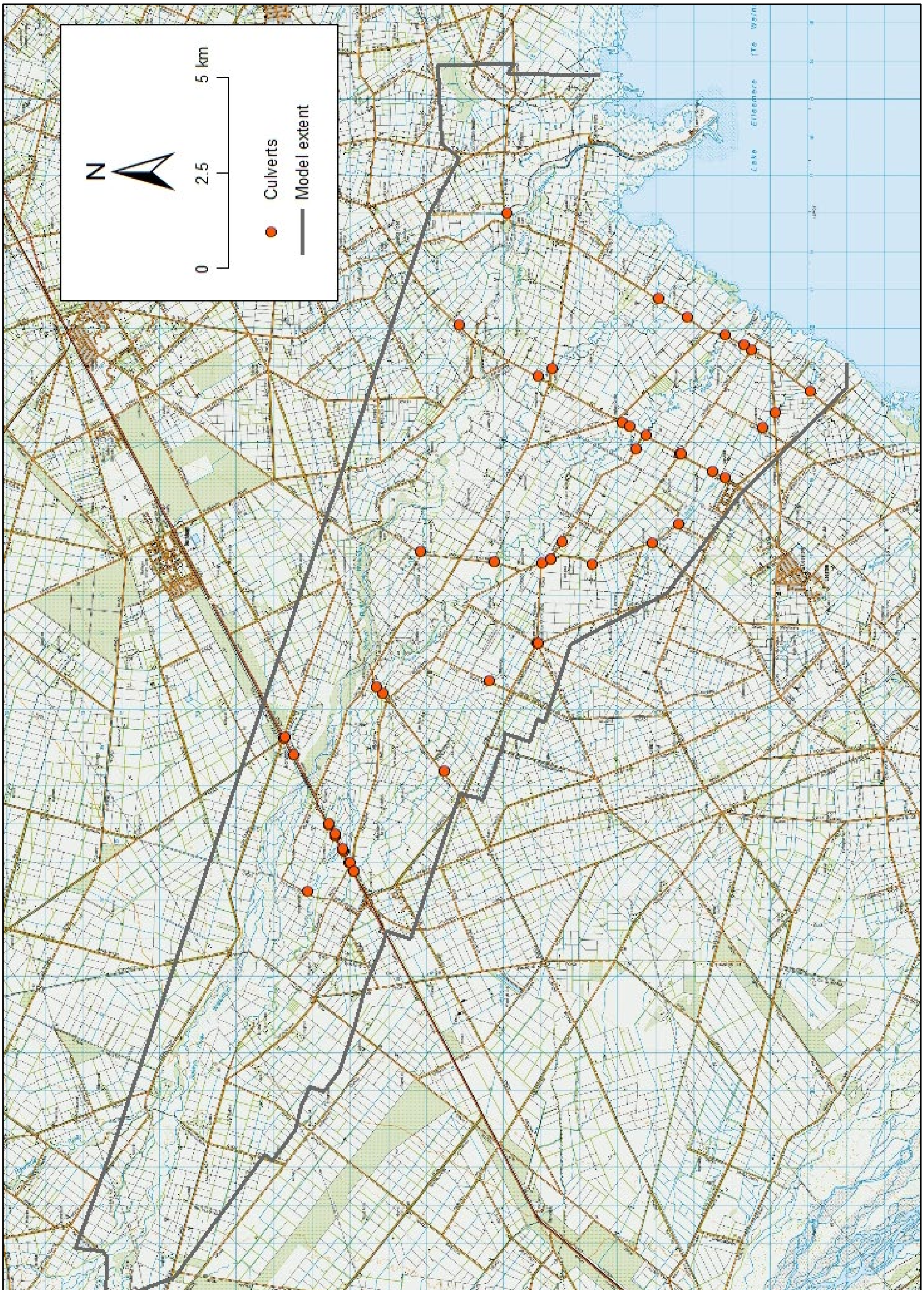


Figure B-3: Selwyn floodplain culvert location map

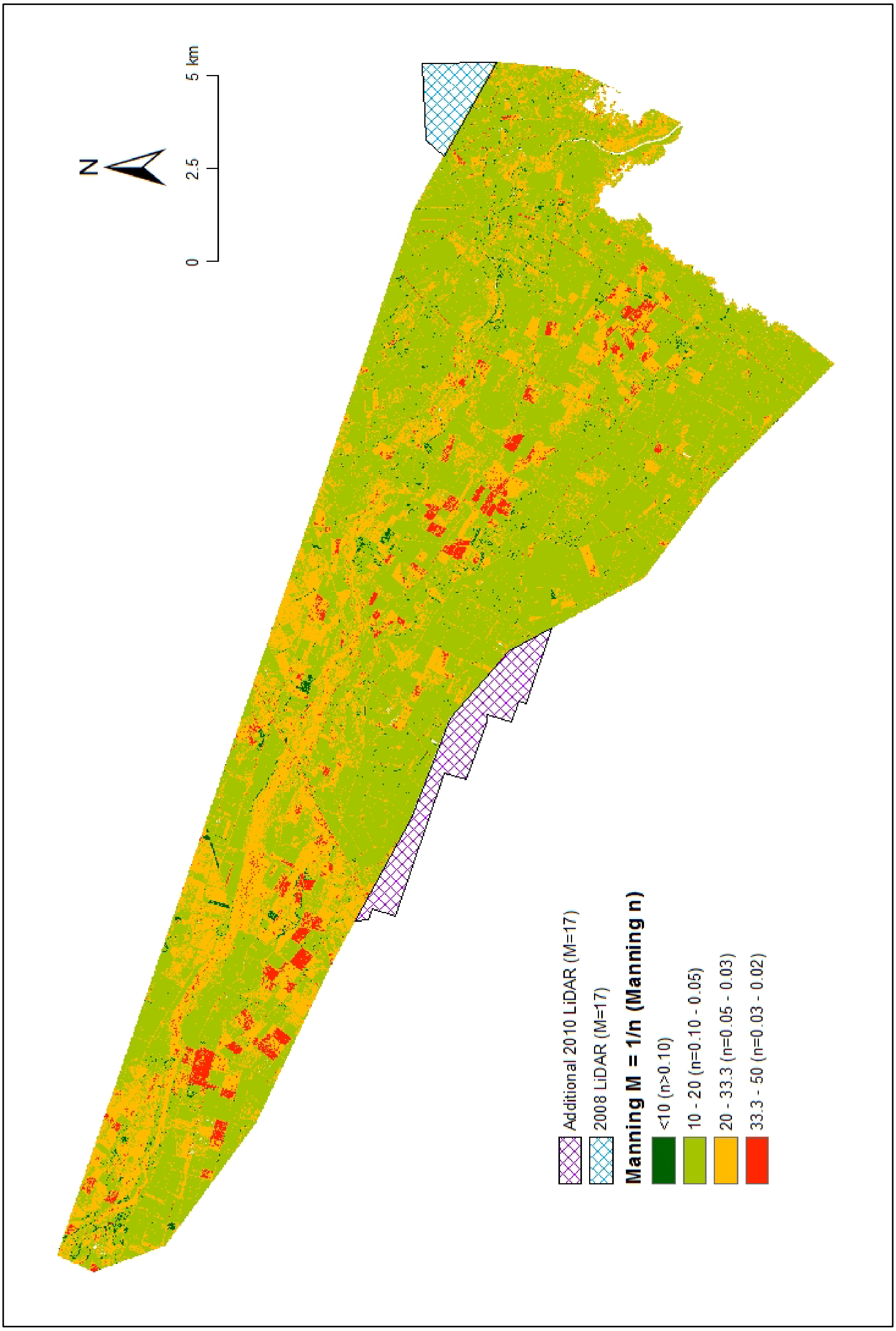
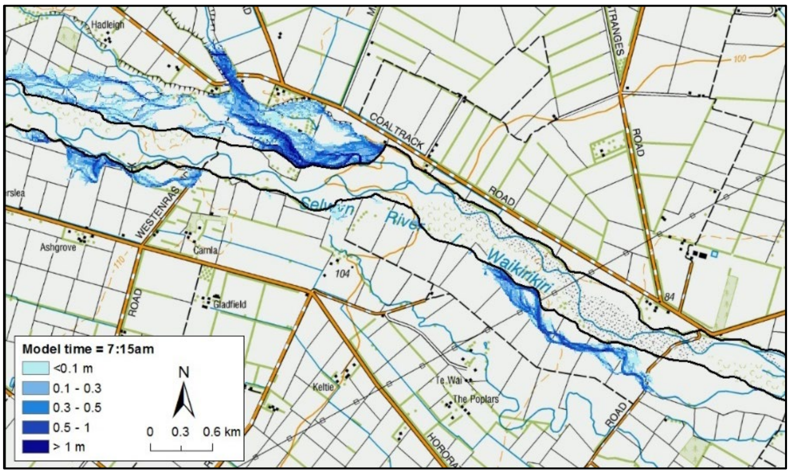


Figure B-4: Selwyn floodplain roughness map showing Manning M (= 1/n, $m^{1/3}/s$)

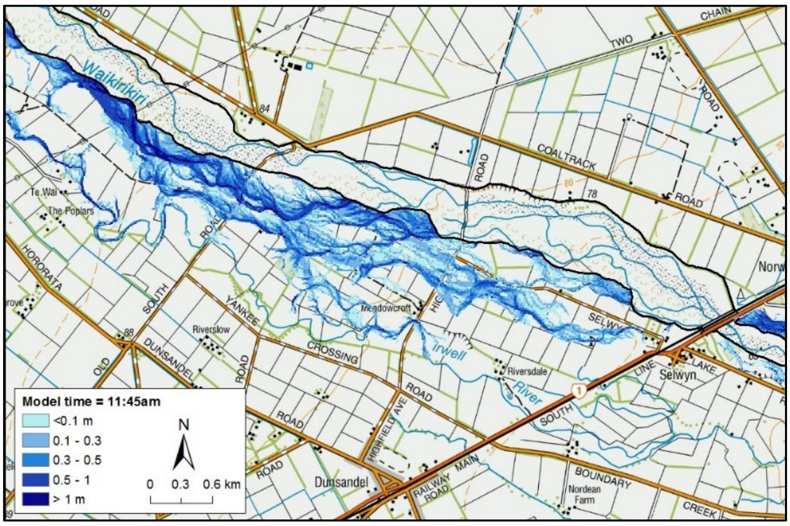
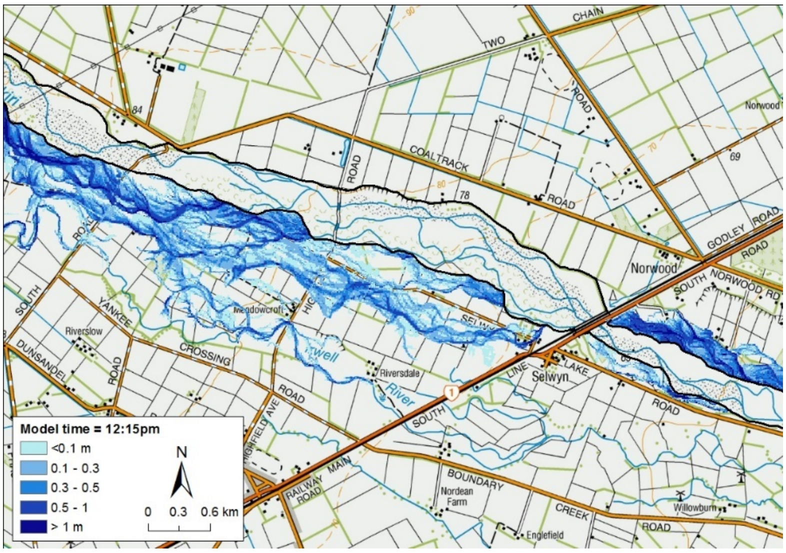
Appendix C: August 2000 flood control log

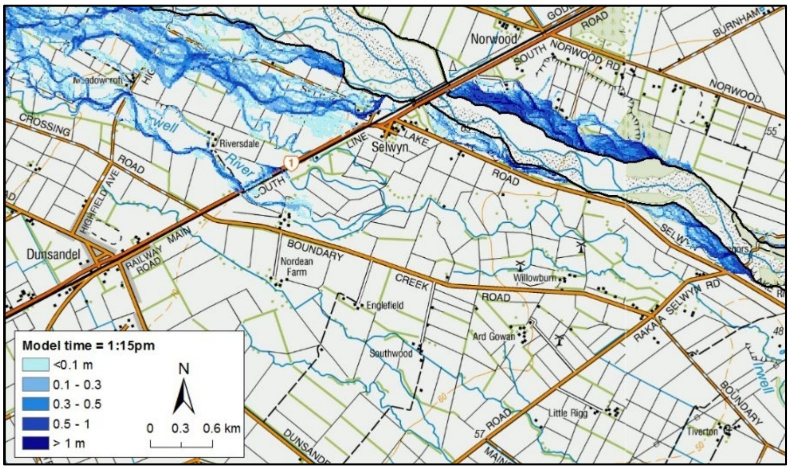
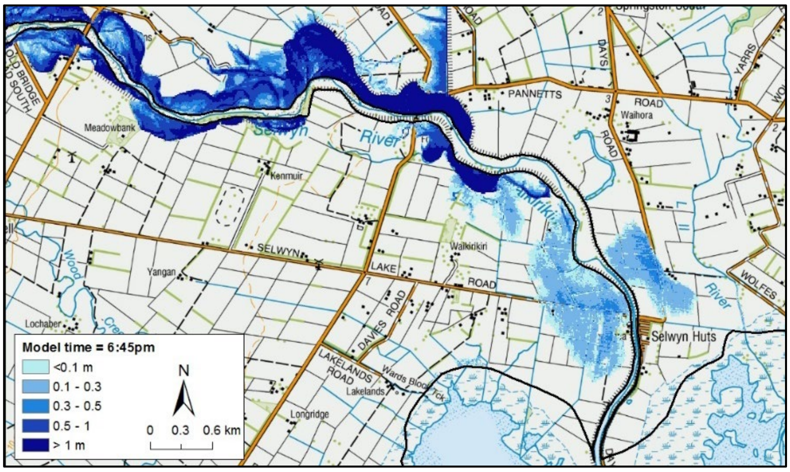
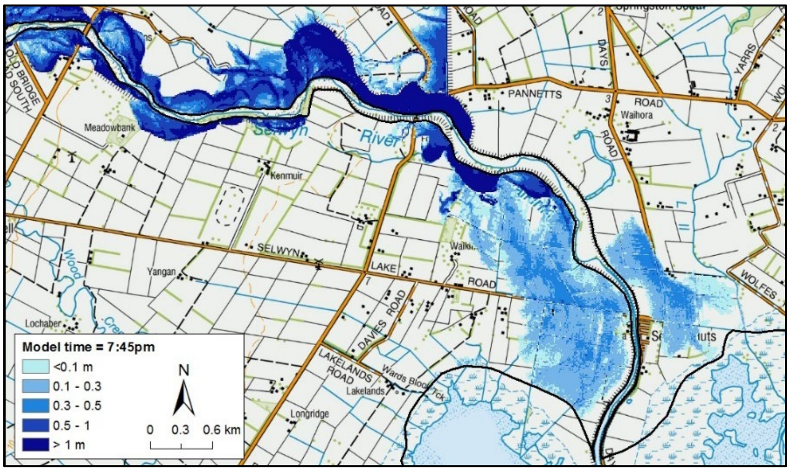
Excerpts from the Flood Control Log compared to model results:

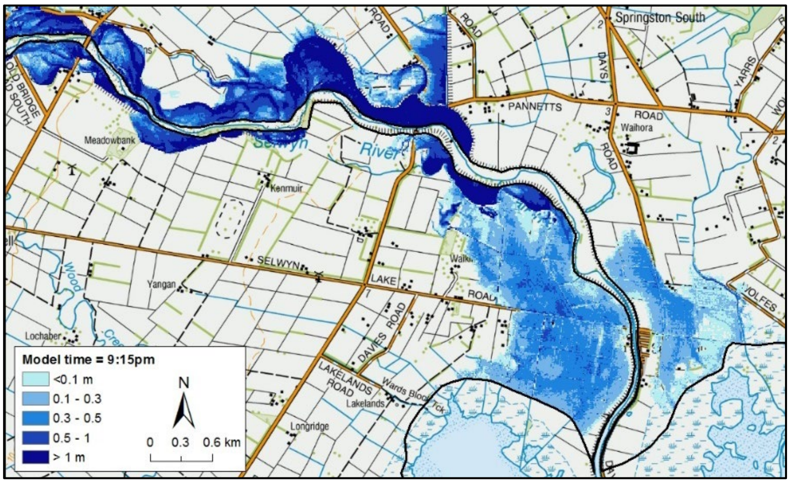
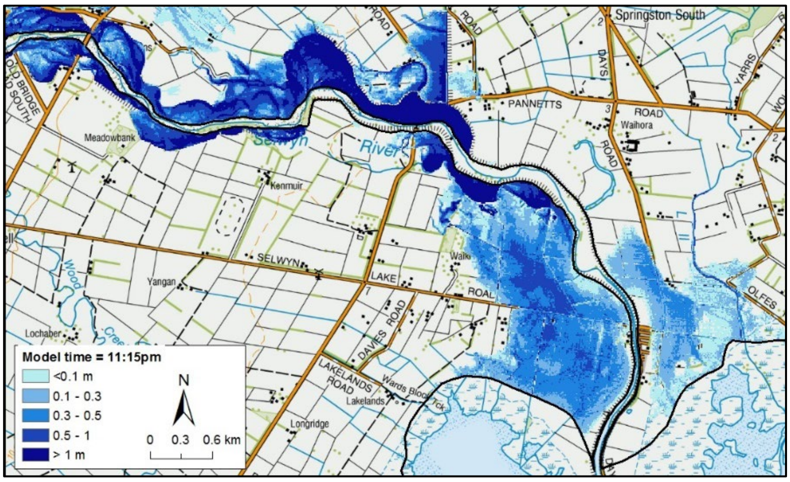
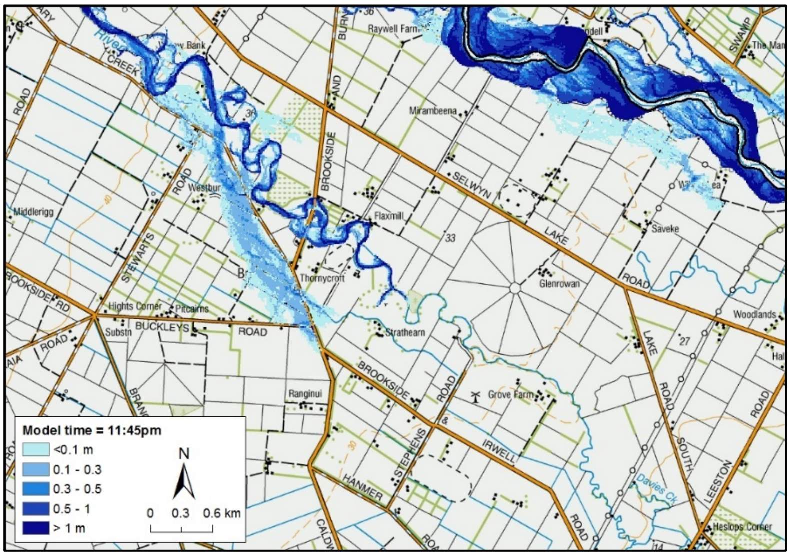
<u>Saturday 19 August 2000</u>

<table>
<tr><th>Time</th><th>Flood log</th><th>Model prediction</th></tr>
<tr><td>7:10am</td><td>Overflow at Westenras Road – 50-60 m^3/s</td><td>
</td></tr>
<tr><td>11:35am

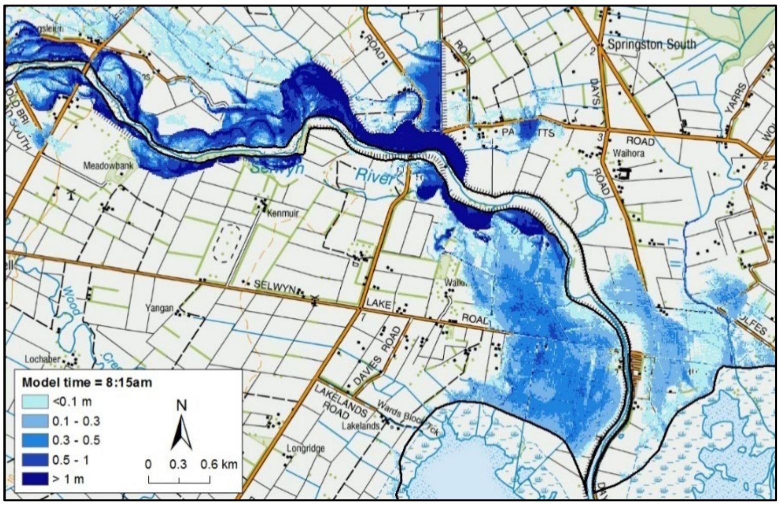
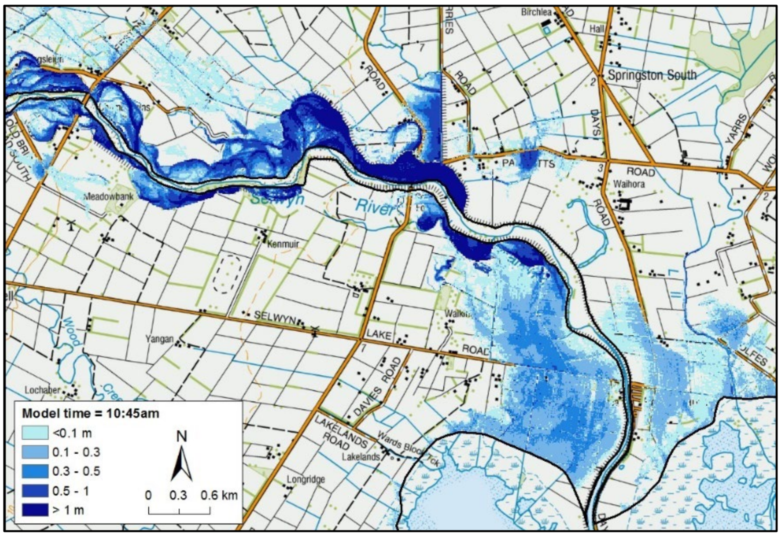
11:48am</td><td>No water from Irwell Creek crossing Highfield Road

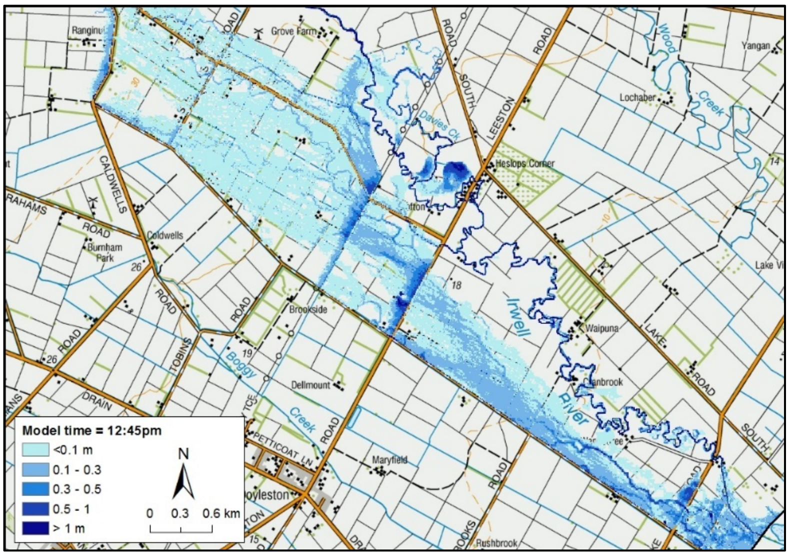
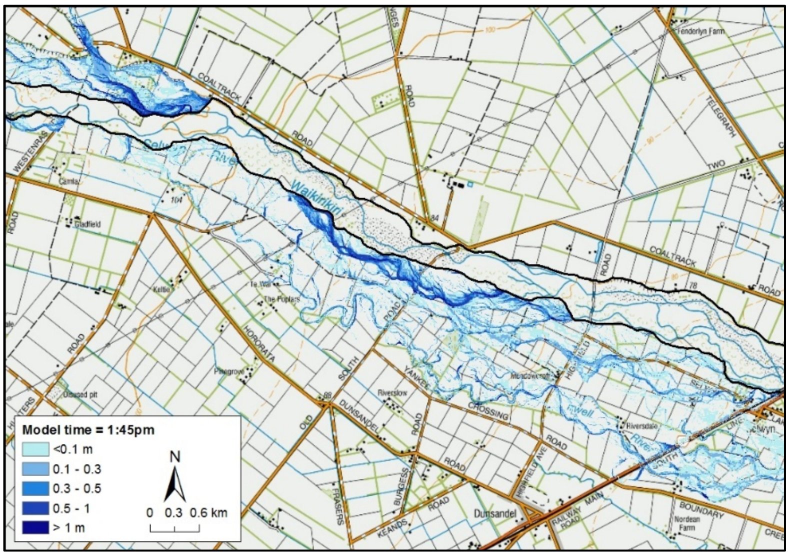
Irwell Creek across Old South Road – 20 to 30 m^3/s.</td><td>
</td></tr>
<tr><td>12:15pm</td><td>Selwyn overflowing d/s of the Whitehouse to the Irwell.</td><td>
</td></tr>
</table>

Time	Flood log	Model prediction
1:02pm	Selwyn rising at McGregors Road. Rakaia/Selwyn road being overtopped & will get into Irwell Creek. SH1 closed.	
5:22pm	Gauge reading at Coes Ford = 7.5 m, has risen 1 m in past couple of hours.	
5:37pm	1.5m freeboard at McBeans, 1.62m gauge at lower huts (effectively lake level).	
6:00pm	Left bank d/s McBeans estate hayshed = 0.5m freeboard.	
6:13pm	Lake level = 1.6m.	
6:30pm	70 m d/s McBeans hayshed = 200 mm freeboard.	
6:45pm	Water leaking through bank at huts and flowing across road.	
6:55pm	1 to 1.5 m freeboard on bank at entrance to huts.	
7:05pm	Stopbank overtopping 20 m d/s McBeans hayshed over at least 200 m.	
7:56pm	Overtopping now across road to huts departing site. Overtopping 200 m d/s McBeans hayshed. Still 1 m freeboard at huts.	

Time	Flood log	Model prediction
8:16pm	Coes Ford staff gauge = 7.84 m. Still rising.	
9:26pm	U/s of Selwyn huts water across road and roaring! Breakout rather than flow?	
10:20pm	Overflow below McBeans barn. Can't see any sign of breach but lots going over top of bank & noise due to water flow down outer batter (3m high).	
10:35pm	Gauge reading at Coes Ford = 7.92 m still rising.	
11:23pm	South side of Coes Ford, water about 100mm below low spot in bank, otherwise 750mm freeboard. Water up to tar seal on road into Rennies. By rate at which it's increasing there must have been bank overflow as no rain.	
11:45pm	Water too deep at Brookside Irwell Road.	
Midnight	Coes Ford telemetry = 8.322m.	

Sunday 20 August 2000

Time	Flood log	Model prediction
12:30am	Coes Ford telemetry = 8.332m.	
12:35am	Coes Ford staff gauge = 7.98 m.	
1:00am	Coes Ford telemetry = 8.334m.	
3:04am	Level at Ellesmere Bridge = 18.23m. Seems to be no change since he had seen it at 10:51pm.	
7:30am	Breach in bank near the hayshed. State Highway undermined.	
8:15am	Both upper and lower huts are not flooded. The water from the vicinity of the hayshed was overtopping but the level has dropped and the flow has ceased.	
9:45am	Coes Ford to Selwyn Huts banks intact; has been overtopping; flows towards LII. According to landowners, no significant stock losses. According to Lindsay McKenzie things aren't so good on the Rennie side	
10:00am	Leaving McBean area. No evidence of any bank failure	
10:11am	Coes Ford left bank. All looks reasonable from there. Talking to Mr Sparkes from d/s Coes Ford can see new house on right bank suggesting right bank gone	
10:35am	At Coes Ford right bank. Ok u/s of Coes Ford but can see water over the Lower Lake Road.	
11:00am	At Rennie house at end of Lower Lake Road. Forded water over about 1.5 km average depth 0.5m between Dillon and Rennies houses.	
11:30am	Selwyn at Coes Ford = 7.88m – 450 mm below peak	
11:40am	There has been general overtopping of right stopbank from Rennies house to his irrigation intake. About 1 km above house breach about 30m long, in order of 50 m^3/s flowing through into Hubbers house. Other signs of scour on bank but not right through.	

Time	Flood log	Model prediction
12:30pm	No water over road at Irwell but two areas 50m and 200m at Hanmer Drain and towards Doyelston. Flow appears to have spread out u/s of Irwell and into the Hanmer Drain catchment.	
12:35pm	About to take to air for photos.	
1:40pm	At Westernras, no flow from river. Still flow across SH1.	

Appendix D: Flood probability

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

[1]AEP = Annual Exceedance Probability i.e. the chance of a flood that size occurring in any one year
[2]ARI = Average Recurrence Interval i.e. the average time interval between floods of a certain magnitude

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

Appendix E: Model run files

(MIKE Flood, Release 2019)

Calibration models – August 2008 & July 2017 flood events

	July 2017	August 2008
	Model peak inflow of 471 m³/s (421 m³/s at Coes Ford + 50 m³/s overflows), Lake level rising to 1.5m	Model peak inflow of 246 m³/s with a downstream lake level rising to 1.5m.

MIKE Flood		
Couple file (*.mf)	FINAL_July_17_n_05_045_us_022_ds_ver_a_xs97715_orig_xs_rev_n	FINAL_August_08_n_05_045_us_022_ds_ver_a_xs97715_orig_xs_rev_n

MIKE 11		
Simulation file (*.sim11)	FINAL_July_17_n_05_045_us_022_ds_ver_a_xs97715_orig_mouth_rev_n	FINAL_August_08_n_05_045_us_022_ds_ver_a_xs97715_orig_mouth_rev_n
Network file (*.nwk11)	Selwyn_20160916_NWK	
Cross section file (*.xns11)	Sel20190422_XS_FINAL_orig_mouth_n_0_05_and_0_11_ver_a	
Boundary file (*.bnd11)	Q_Jul17	REVISED_Q_Aug08
HD parameter (*.hd11)	Q5_LL_1.1m_n_050_045_us_022ds_xs97715_rev	
Results file (*.res11)	FINAL_July_17_n_05_045_us_022_ds_ver_a_xs97715_orig_mouth_rev_n	FINAL_August_08_n_05_045_us_022_ds_ver_a_xs97715_orig_mouth_rev_n

MIKE 21		
Simulation file (*.21)	FINAL_July_17_n_05_045_us_022_ds_ver_a_xs97715_orig_mouth_rev_n	FINAL_August_08_n_05_045_us_022_ds_ver_a_xs97715_orig_mouth_rev_n
Bathymetry file (*.dfs2)	Selwyn_10m_20181126_adj_coes_sb	
Initial surface elevation (*.dfs2)	0	
Resistance (*.dfs2)	10m_NN_modori_xtra_lid2	
Results (*.dfs2)	FINAL_July_17_n_050_045_us_022_ds_ver_a_xs97715_orig_mouth_rev_n	FINAL_August_08_n_05_045_us_022_ds_ver_a_xs97715_orig_mouth_rev_n
Sources	(80,1944)→(80,1935) and (490,1894)→(504,1894)	
Sinks	-	
Drying depth (m)	0.01	
Wetting depth (m)	0.02	
Eddy viscosity	0.5	
Number of structures	50	
Simulation start time	21/7/2017 12:00pm	30/7/2008 3:30pm
Simulation end time	23/7/2017 12:00pm	1/8/2008 3:30pm
Time step (s)	1	1
Length of run (# time steps)	172800	172800

Validation model – August 2000 flood event

August 2000
Model peak inflow of 478 m³/s (428 m³/s at Coes Ford + 50 m³/s overflows), Lake level rising to 1.4m.

MIKE Flood	
Couple file (*.mf)	FINAL_August_00_n_05_045_us_022_ds_ver_a_xs97715_orig_mouth_rev_n_BO

MIKE 11	
Simulation file (*.sim11)	FINAL_August_00_n_05_045_us_022_ds_ver_a_xs97715_orig_mouth_rev_n_BO
Network file (*.nwk11)	Selwyn_20160916_NWK
Cross section file (*.xns11)	Sel20190422_XS_FINAL_orig_mouth_n_0_05_and_0_11_ver_a
Boundary file (*.bnd11)	REVISED_Q_Aug00
HD parameter (*.hd11)	Q5_LL_1.1m_n_050_045_us_022ds_xs97715_rev
Results file (*.res11)	FINAL_August_00_n_05_045_us_022_ds_ver_a_xs97715_orig_mouth_rev_n_BO

MIKE 21	
Simulation file (*.21)	FINAL_August_00_n_05_045_us_022_ds_ver_a_xs97715_orig_mouth_rev_n_BO
Bathymetry file (*.dfs2)	Selwyn_10m_20181126_adj_coes_sb_BO
Initial surface elevation (*.dfs2)	0
Resistance (*.dfs2)	10m_NN_modori_xtra_lid2
Results (*.dfs2)	FINAL_August_00_n_05_045_us_022_ds_ver_a_xs97715_orig_mouth_rev_n_BO
Sources	(80,1944)→(80,1935) and (490,1894)→(504,1894)
Sinks	-
Drying depth (m)	0.01
Wetting depth (m)	0.02
Eddy viscosity	0.5
Number of structures	50
Simulation start time	19/8/2000 2:15am
Simulation end time	22/8/2000 12:00am
Time step (s)	1
Length of run (# time steps)	251100

Design flood events

	50 yr ARI	200 yr ARI	500 yr ARI
	Model peak inflow of 630 m^3/s. Lake level rising to 1.8m.	Model peak inflow of 830 m^3/s. Lake level rising to 1.8m.	Model peak inflow of 1000 m^3/s. Lake level rising to 1.8m.

MIKE Flood			
Couple file (*.mf)	FINAL_50yr_ARI_ Q_630cumecs	FINAL_200yr_ARI_ Q_830cumecs	FINAL_500yr_ARI_ Q_1000cumecs

MIKE 11			
Simulation file (*.sim11)	FINAL_50yr_ARI_ Q_630cumecs	FINAL_200yr_ARI_ Q_830_cumecs	FINAL_500yr_ARI_ Q_1000cumecs
Network file (*.nwk11)	Selwyn_20160916_NWK		
Cross section file (*.xns11)	Sel20190422_XS_FINAL_orig_mouth_n_0_05_and_0_11_ver_a		
Boundary file (*.bnd11)	Q_50yr_ARI	Q_200yr_ARI	Q_500yr_ARI
HD parameter (*.hd11)	Q5_LL_1.1m_n_050_045_us_022ds_xs97715_rev		
Results file (*.res11)	FINAL_50yr_ARI_ Q_630cumecs	FINAL_200yr_ARI_ Q_830_cumecs	FINAL_500yr_ARI_ Q_1000cumecs

MIKE 21			
Simulation file (*.21)	FINAL_50yr_ARI_ Q_630cumecs	FINAL_200yr_ARI_ Q_830_cumecs	FINAL_500yr_ARI_ Q_1000cumecs
Bathymetry file (*.dfs2)	Selwyn_10m_20181126_adj_coes_sb		
Initial surface elevation (*.dfs2)	0		
Resistance (*.dfs2)	10m_NN_modori_xtra_lid2		
Results (*.dfs2)	FINAL_50yr_ARI_ Q_630cumecs	FINAL_200yr_ARI_ Q_830_cumecs	FINAL_500yr_ARI_ Q_1000cumecs
Sources	(80,1944)→(80,1935) and (490,1894)→(504,1894)		
Sinks	-		
Drying depth (m)	0.01		
Wetting depth (m)	0.02		
Eddy viscosity	0.5		
Number of structures	50		
Simulation start time	26/7/1994 5:00pm		
Simulation end time	29/7/1994 11:00pm		
Time step (s)	1		
Length of run (# time steps)	280800		

Selwyn River control scheme maximum capacity

560 m³/s peak flow
Scaled Coes Ford 1994 flood hydrograph (Q_{peak} = 560m³/s) with a downstream lake level rising to 1.5m.

MIKE Flood	
Couple file (*.mf)	FINAL_Q_560cumecs

MIKE 11	
Simulation file (*.sim11)	FINAL_Q_560cumecs
Network file (*.nwk11)	Selwyn_20160916_NWK
Cross section file (*.xns11)	Sel20190422_XS_FINAL_orig_mouth_n_0_05_and_0_11_ver_a
Boundary file (*.bnd11)	Q_560cumecs
HD parameter (*.hd11)	Q5_LL_1.1m_n_050_045_us_022ds_xs97715_rev
Results file (*.res11)	FINAL_Q_560cumecs

MIKE 21	
Simulation file (*.21)	FINAL_Q_560cumecs
Bathymetry file (*.dfs2)	Selwyn_10m_20181126_adj_coes_sb
Initial surface elevation (*.dfs2)	0
Resistance (*.dfs2)	10m_NN_modori_xtra_lid2
Results (*.dfs2)	FINAL_Q_560cumecs
Sources	(80,1944)→(80,1935) and (490,1894)→(504,1894)
Sinks	-
Drying depth (m)	0.01
Wetting depth (m)	0.02
Eddy viscosity	0.5
Number of structures	50
Simulation start time	26/7/1994 5:00pm
Simulation end time	29/7/1994 11:00pm
Time step (s)	1
Length of run (# time steps)	280800

Sensitivity run files (using 200 year ARI)

	Increased River Manning's n	Increased floodplain 'n'	Lake level rise of 0.5m
	Model peak inflow of 830 m^3/s. Lake level rising to 1.8m. River Manning's n increased (0.05 to 0.06, 0.045 to 0.054 & 0.022 to 0.026)	Model peak inflow of 830 m^3/s. Lake level rising to 1.8m. Roughness grid Manning M (=1/n) multiplied by 0.8.	Model peak inflow of 830 m^3/s. Maximum lake level increased from 1.8m to 2.3m.

MIKE Flood			
Couple file (*.mf)	FINAL_200yr_ARI_Q_830_cumecs_n_chan_plus_20perc	FINAL_200yr_ARI_Q_830cumecs_n_fp_plus_20perc	FINAL_200yr_ARI_Q_830cumecs_LL_plus_0_5m

MIKE 11			
Simulation file (*.sim11)	FINAL_200yr_ARI_Q_830_cumecs_n_chan_plus_20perc	FINAL_200yr_ARI_Q_830cumecs_n_fp_plus_20perc	FINAL_200yr_ARI_Q_830cumecs_LL_plus_0_5m
Network file (*.nwk11)	Selwyn_20160916_NWK		
Cross section file (*.xns11)	Sel20190422_XS_FINAL_orig_mouth_n_0_05_and_0_11_ver_a		
Boundary file (*.bnd11)	Q_200yr_ARI	Q_200yr_ARI	Q_200yr_ARI_LL_plus_0_5m
HD parameter (*.hd11)	Q5_LL_1.1m_n_060_054_us_026ds_xs97715_rev	Q5_LL_1.1m_n_050_045_us_022ds_xs97715_rev	Q5_LL_1.1m_n_050_045_us_022ds_xs97715_rev
Results file (*.res11)	FINAL_200yr_ARI_Q_830_cumecs_n_chan_plus_20perc	FINAL_200yr_ARI_Q_830cumecs_n_fp_plus_20perc	FINAL_200yr_ARI_Q_830cumecs_LL_plus_0_5m

MIKE 21			
Simulation file (*.21)	FINAL_200yr_ARI_Q_830_cumecs_n_chan_plus_20perc	FINAL_200yr_ARI_Q_830cumecs_n_fp_plus_20perc	FINAL_200yr_ARI_Q_830cumecs_LL_plus_0_5m
Bathymetry file (*.dfs2)	Selwyn_10m_20181126_adj_coes_sb		
Initial surface elevation (*.dfs2)	0		
Resistance (*.dfs2)	10m_NN_modori_xtra_lid2	10m_NN_modori_xtra_lid2_n_incr_20pc	10m_NN_modori_xtra_lid2
Results (*.dfs2)	FINAL_200yr_ARI_Q_830_cumecs_n_chan_plus_20perc	FINAL_200yr_ARI_Q_830cumecs_n_fp_plus_20perc	FINAL_200yr_ARI_Q_830cumecs_LL_plus_0_5m
Sources	(80,1944)→(80,1935) and (490,1894)→(504,1894)		
Sinks	-		
Drying depth (m)	0.01		
Wetting depth (m)	0.02		
Eddy viscosity	0.5		
Number of structures	50		
Simulation start time	26/7/1994 5:00pm		
Simulation end time	29/7/1994 11:00pm		
Time step (s)	1		
Length of run (# time steps)	280800		

Sensitivity run files (using 200 year ARI)

	Selwyn River bed level increased by 0.2m	Westenras Road stopbank removed
	Model peak inflow of 830 m^3/s. Lake level rising to 1.8m. Selwyn River bed level raised by 0.2m along entire length.	Model peak inflow of 830 m^3/s. Lake level rising to 1.8m. Westenras Road stopbank removed

MIKE Flood		
Couple file (*.mf)	FINAL_200yr_ARI_Q_830cumecs_bl_increase_0_2m	FINAL_200yr_ARI_Q_830cumecs_sb_breach

MIKE 11		
Simulation file (*.sim11)	FINAL_200yr_ARI_Q_830cumecs_bl_increase_0_2m	FINAL_200yr_ARI_Q_830cumecs_stopbank_breach
Network file (*.nwk11)	Selwyn_20160916_NWK	
Cross section file (*.xns11)	Sel20190422_XS_FINAL_orig_mouth_n_0_05_and_0_11_ver_a_bl_plus_0_2m	Sel20190422_XS_FINAL_orig_mouth_n_0_05_and_0_11_ver_a
Boundary file (*.bnd11)	Q_200yr_ARI	
HD parameter (*.hd11)	Q5_LL_1.1m_n_050_045_us_022ds_xs97715_rev	
Results file (*.res11)	FINAL_200yr_ARI_Q_830cumecs_bl_increase_0_2m	FINAL_200yr_ARI_Q_830cumecs_stopbank_breach

MIKE 21		
Simulation file (*.21)	FINAL_200yr_ARI_Q_830cumecs_bl_increase_0_2m	FINAL_200yr_ARI_Q_830_cumecs_stopbank_breach
Bathymetry file (*.dfs2)	Selwyn_10m_20181126_adj_coes_sb	Selwyn_10m_20181126_adj_coes_sb_breach
Initial surface elevation (*.dfs2)	0	
Resistance (*.dfs2)	10m_NN_modori_xtra_lid2	
Results (*.dfs2)	FINAL_200yr_ARI_Q_830cumecs_bl_increase_0_2m	FINAL_200yr_ARI_Q_830cumecs_stopbank_breach
Sources	(80,1944)→(80,1935) and (490,1894)→(504,1894)	
Sinks	-	
Drying depth (m)	0.01	
Wetting depth (m)	0.02	
Eddy viscosity	0.5	
Number of structures	50	
Simulation start time	26/7/1994 5:00pm	
Simulation end time	29/7/1994 11:00pm	
Time step (s)	1	
Length of run (# time steps)	280800	

Sensitivity run files (using 200 year ARI)

Eddy viscosity and time step adjusted
Model time step increased to 1.5 seconds, and eddy viscosity increased to 1.3

MIKE Flood	
Couple file (*.mf)	FINAL_200yr_ARI_Q_830_cumecs_t_1_5s_ed_vis_1_3

MIKE 11	
Simulation file (*.sim11)	FINAL_200yr_ARI_Q_830_cumecs_t_1_5s_ed_vis_1_3
Network file (*.nwk11)	Selwyn_20160916_NWK
Cross section file (*.xns11)	Sel20190422_XS_FINAL_orig_mouth_n_0_05_and_0_11_ver_a
Boundary file (*.bnd11)	Q_200yr_ARI
HD parameter (*.hd11)	Q5_LL_1.1m_n_050_045_us_022ds_xs97715_rev
Results file (*.res11)	FINAL_200yr_ARI_Q_830_cumecs_t_1_5s_ed_vis_1_3

MIKE 21	
Simulation file (*.21)	FINAL_200yr_ARI_Q_830_cumecs_t_1_5s_ed_vis_1_3
Bathymetry file (*.dfs2)	Selwyn_10m_20181126_adj_coes_sb
Initial surface elevation (*.dfs2)	0
Resistance (*.dfs2)	10m_NN_modori_xtra_lid2
Results (*.dfs2)	FINAL_200yr_ARI_Q_830_cumecs_t_1_5s_ed_vis_1_3
Sources	(80,1944)→(80,1935) and (490,1894)→(504,1894)
Sinks	-
Drying depth (m)	0.01
Wetting depth (m)	0.02
Eddy viscosity	1.3
Number of structures	50
Simulation start time	26/7/1994 5:00pm
Simulation end time	29/7/1994 11:00pm
Time step (s)	1.5
Length of run (# time steps)	187200

Appendix F: GHD model peer review

Memorandum

23 June 2017

To	Michelle Wild - Environment Canterbury		
Copy to			
From	John McArthur	Tel	03 378 0966
Subject	Peer Review - Selwyn Floodplain Model	Job no.	51/37219/

1 Introduction

Environment Canterbury (ECan) has built a Selwyn River/Waikirikiri Floodplain hydraulic model to establish floodplain inundation extents and areas of high flood hazard in large to extreme flood events. ECan engaged GHD to undertake a peer review of this model to confirm the suitability of the hydraulic model build for its intended purpose and if necessary provide recommendations with regard to model improvement.

The floodplain model has been built using the software package MIKE FLOOD. The software has a number of components and in this instance, one-dimensional (1D) elements, including the Selwyn River main channel, have been modelled using MIKE11 (M11) with the floodplain modelled using the two-dimensional (2D) component MIKE21 (M21). MIKE FLOOD provides the necessary two way coupling between the 1D and 2D elements. The reviewed model is described in ECan Report ***'Selwyn River/Waikirikiri floodplain investigation'*** dated January 2017.

ECan has provided design flood models for the peer review. The models have been checked for compatibility with information contained within the report, schematisation, parameter selection and result stability. The models have not been re-run and in accordance with ECan's request, the peer review has not included an assessment of the hydrology component of the modelling investigation.

2 Model Review

2.1 M11 Model Review

The projection used in the M11 model is NZTM.

There are two main branches in the M11 network (refer Figure 1) representing the Selwyn River channel (River name – Selwyn River) and Lake Ellesmere (River name – LAKE). Five link channels connect the Selwyn River branch to the Lake Ellesmere branch. A number of dummy cross-sections 5 km wide and up to a 100 m deep represent the Lake branch. The River branch is represented by cross-sections obtained from a number of sources including LiDAR, ground survey and soundings. The stop banks forming the existing Selwyn River Control Scheme are included in the River branch cross-section extents.

The M11 network includes 3 bridges, 1 weir and a set of 14 culverts in accordance with the Report. A review of the structure schematisation and parameters confirms the modelling approach is acceptable.

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In addition, a review of the 50 year model results provided by ECan shows no indication of any structure instability.

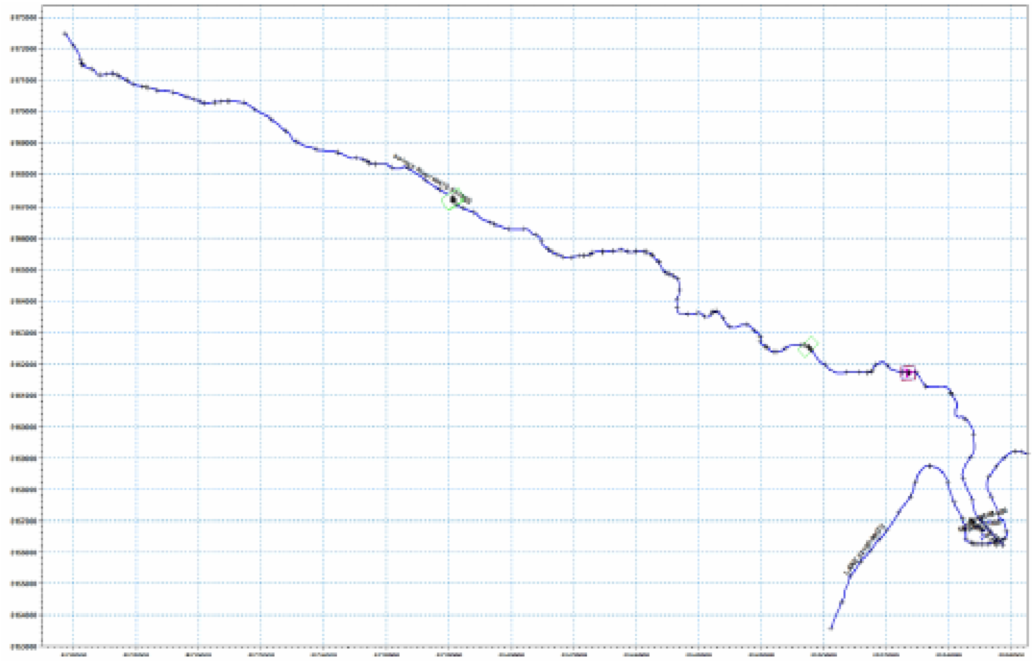

Figure 1 - M11 network

A check of the processed data in the cross-section (.xns11) file and in particular conveyance characteristics has been undertaken. Conveyance should monotonically increase with increasing water level as shown in Figure 2. However, at Selwyn River chainages 75223, 88460, 90447, 91255, 100760 and 101000, this is not the case with conveyance characteristics looking similar to Figure 3. As there is a risk of simulation instability when water levels are in the range where conveyance is not increasing, consideration should be given to modifying characteristics associated with these six cross-sections. This can include adjusting relative resistance in the raw data by a small amount (e.g. changing from 1.0 to 1.01) at the level contributing to the conveyance issue (e.g. a level where there is a sudden width increase).

Based on the 50 year model results, the link channels are performing appropriately, however it is noted that the Lake branch demonstrates flow instabilities. This does not affect flood levels, probably as a result of the relatively significant conveyance associated with the dummy Lake cross-sections. Although there is no evidence of flood level instability around the Lake Ellesmere boundary, consideration could be given to reducing the number and size of the Lake dummy cross-sections to better represent the Lake Ellesmere storage.

Other minor matters requiring attention either in the model or in the Report are as follows:

- Section 3.4 of the Report indicates the simulation period for the design storm events is 3 days and results are saved every 30 minutes. This should be amended to 4 days and 15 minutes respectively.
- Table 3.2 in the Report and Table A.1 in Appendix A summarise the cross-section data sources. Neither table references 2016 survey, which is included in the Cross section ID in the M11 .xns11 file for section chainages 98440 to 101000.
- Selwyn River branch Section chainage 100310 in the .xns11 file requires the inclusion of a right bank marker.

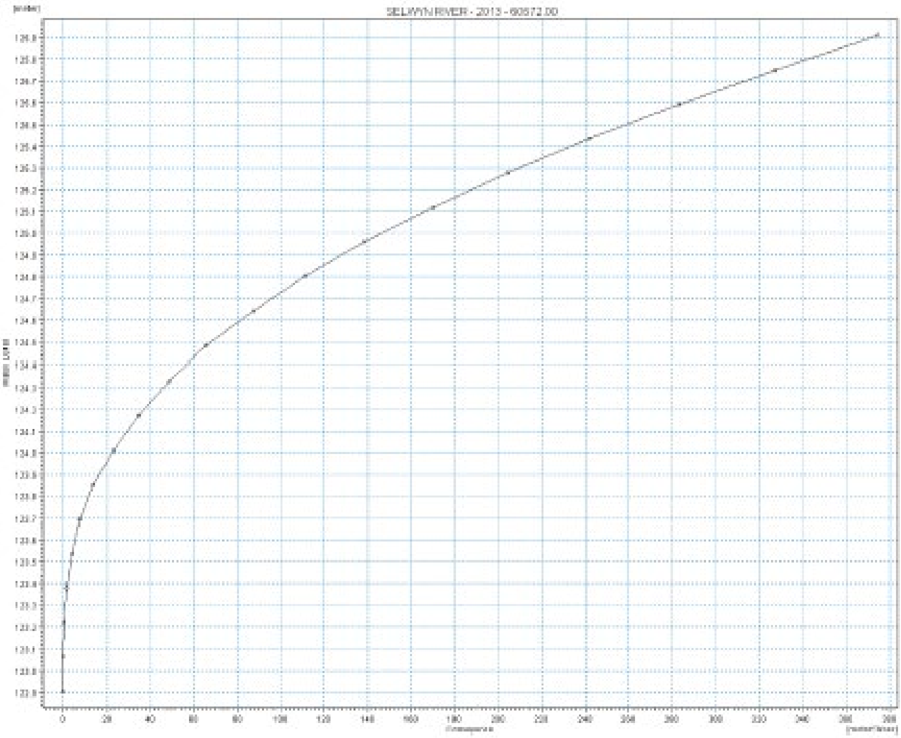

Figure 2 Conveyance vs water level at Selwyn river chainage 60672

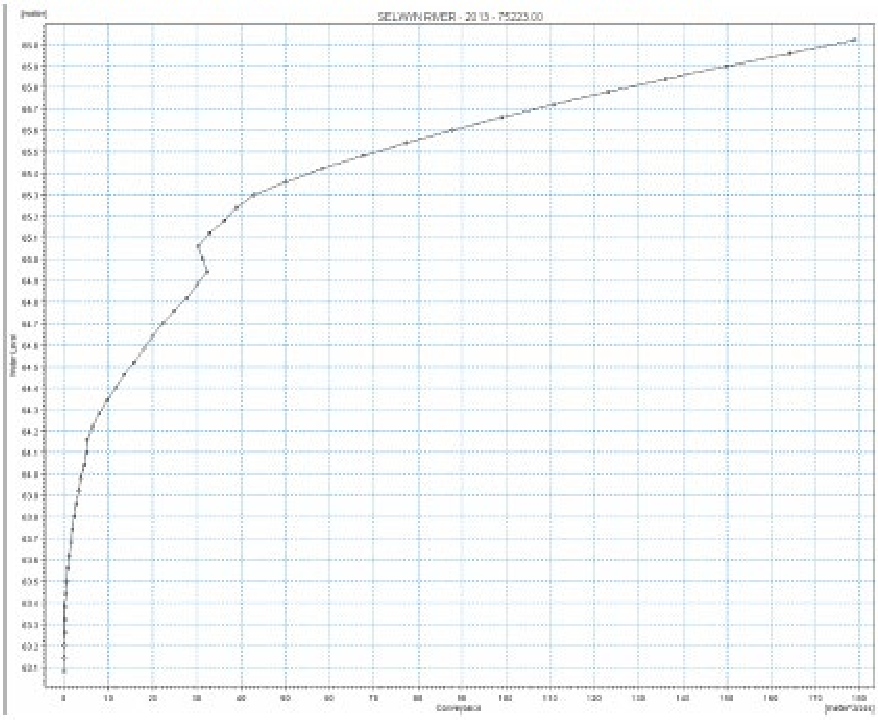

Figure 3 Conveyance vs water level at Selwyn river chainage 75223

Roughness values used in the model are appropriate with higher relative roughness values included to take account of bank vegetation.

A check of the upstream flow and downstream level boundary conditions in the M11 model, confirms they are in accordance with the Report details.

Model parameters included in the .hd11 file are in accordance with those generally recommended. In particular, the M11 model uses the 'high order fully dynamic' flow description and the computation scheme uses a Delta of 0.85 typically used for MIKE FLOOD model set ups of this nature.

2.2 Mike 21 Model Review

The coordinate system used in the model is NZTM, which accords with the coordinate system used in the M11 domain.

The 2D model has been set up with a 10 m rectilinear grid. Grid levels used to define the ground surface are based on a combination of 2008 and 2010 LiDAR. The grid is coarse relative to floodplain features such as road and railway embankments but it is noted the Report indicates modifications have been made to grid levels to ensure grid 'z' values generally reflect embankment crest levels.

Flows from the Hororata and Hawkins Rivers have been generated as a number of 'source' inflows at the upstream extent of the 2D domain. The Hororata River time varying design inflow has been distributed over ten (10) connected grids. Similarly, the Hawkins River inflow has been distributed over fifteen (15) connected grids. The review confirms the inclusion of the 50, 200 and 500 year ARI design flows (hydrograph shape and flow values) in the M21 model are appropriate and in accordance with the methodology outlined in the Report.

The range of floodplain roughness values outlined in the Report are consistent with standard practice. Review of the roughness map associated with the M21 extents confirms roughness values used in the model are acceptable. The roughness map has a maximum value of 48 (n = 0.021), a minimum value of 6.85 (n = 0.146) and a mean value of 19.81 (n = 0.050). Weighted values for the roads traversing the floodplain are generally within the range 35 – 48, which is satisfactory based on roughness grid size (10 m) and orientation.

The flooding and drying depth parameters used of 0.02 and 0.01 m respectively are acceptable. A flux based approach and a value 1 m^2/s has been used for eddy viscosity, which is also appropriate.

Matters requiring attention in either the Report or the model are as follows:

- Section 3.2.2 of the Report indicates there are 48 culvert structures included in the M21 model. A check of the model confirms there are 51 culvert structures. The Report therefore requires amendment.
- Of the 51 culvert structures, 16 have been schematised with a geometry type of 'Irregular, level width'. The level value associated with seven (7) of these structures, as tabulated below, appears to be a depth rather than a level and should be modified accordingly.

Structure Name
Boggy_Ck_2
ChCh Leeston Rd No5
Boggy_Ck_1
ChCh Leeston Rd No6
Bdy_Ck_Rd_2
Pannetts_Rd_Coes_Ford
ChCh Leeston Rd No9

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Review of the maximum velocity results provided indicates the cell with j,k coordinates ***'2377, 995'*** has a velocity in excess of 5 m/s. Inspection of this cell indicates it is immediately adjacent to the Selwyn River M11 branch and has a level more than 3 m lower than connecting cells. This anomaly is unlikely to be having an impact on model stability or flood level results but consideration could be given to increasing the level of this cell to match the surrounding terrain.

2.3 Mike Flood Model Review

The 1D M11 model has been connected to the 2D M21 model via lateral links. Figure 4 below shows the lateral link extents (purple lines).

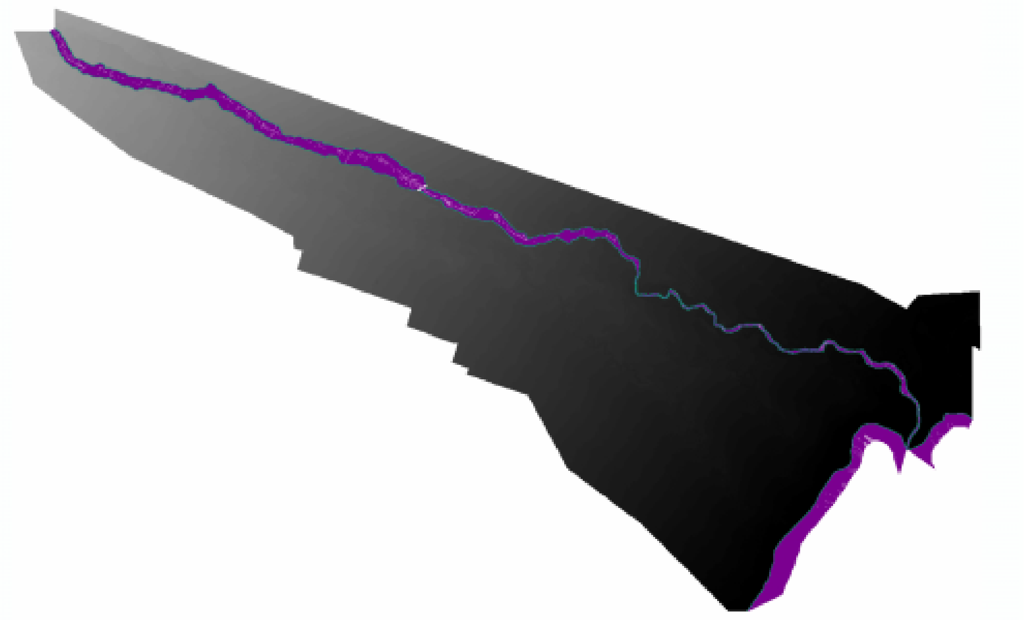

Figure 4 Lateral Link Extents

A review of the lateral link parameters used in the model confirm they are generally satisfactory. However, the 'structure source type' is set to **M21** and therefore the 'levee' level at which flow transfer occurs between the two models is based on the applicable M21 grid level (plus drying depth). As noted earlier in this correspondence, the Selwyn River Control Scheme stopbanks are included in the M11 schematisation. Comparison of the interpolation of M11 bank marker levels and M21 grid levels provided in the run generated MFLateral.xns11 file indicates typically between M11 chainages 96000 to 96900 and 97000 to 97300 the M21 level is lower than the M11 left bank marker level. Consequently, channel spilling could occur prematurely in these reaches. Similarly, between M11 chainages 97150 to 97300 and 97800 to 98400 the M21 level is lower than the M11 right bank marker level. It is therefore recommended that the 'structure source type' be set to **HGH**. This will ensure the 'levee' level is set to the higher of the M11 bank marker and M21 cell levels.

Link alignment has been checked and is acceptable. In particular there are no links crossing the M11 structures which can be a source of instability.

Appendix E of the Report provides a summary of the model run files. The names of the design MIKE FLOOD couple files need to be modified to reflect the files provided as outlined below:

- *Q_820_50yr* to *Q_820_50yr_n_035us_030ds.mf.couple*
- *Q_1200_200yr* to *Q_1200_200yr_n_035us_030ds.mf.couple*
- *Q_1400_500yr* to *Q_1400_500yr_n_035us_030ds.mf.couple*

3 Conclusion and recommendations

As outlined in the Report, the model has been set up specifically to model large to extreme flood events and establish inundation extents and areas of high flood hazard associated with events of this nature. Additional schematisation would be required if more frequent flood events needed to be assessed or site specific flood assessments needed to be carried out. On this basis, the model is considered to be suitable but it is recommended that the following improvements be carried out:

1. Improve conveyance characteristics of the six M11 cross-sections identified above.
2. Include a right bank marker at section chainage 100310 associated with the Selwyn River M11 branch.
3. Modify the level-width relationship of the seven M21 structures identified above which currently appear to be included as a depth-width relationship.
4. Change the 'structure source type' lateral link parameter from M21 to HGH.

In addition to these model improvements, there are some minor changes to the Report required to ensure consistency with the model.

Future model improvements that could be considered include:

- Updating the M21 component with more recent LiDAR once it becomes available.
- Inclusion of the larger drains (e.g. Irwell River) as MIKE11 branches particularly if it is intended to assess more frequent flood events.

4 Limitations

The following limitations apply to this peer review:

- This peer review is limited to the information contained within the Report and modelling files provided.
- This review has relied on the accuracy and completeness of information provided. Independent checks on source information have not been undertaken and no field verification has been conducted.
- This correspondence has been prepared by GHD for ECan and may only be used and relied on for the purpose agreed between GHD and ECan. GHD otherwise disclaims responsibility to any person other than ECan arising in connection with this correspondence.
- The opinions, conclusions and any recommendations in this correspondence are based on information reviewed at the date of preparation of the memorandum. GHD has no responsibility or obligation to update this memorandum to account for changes occurring subsequent to the date that this correspondence was prepared.

Please contact the undersigned should you require further detail or clarification.

Regards,

John McArthur

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

Facilitating sustainable development in the Canterbury region

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