Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

TECHNICAL REPORT Science Group

Timaru District recreational hut communities, overview assessment of flooding hazards

Report No. R20/57

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Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

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Summary

Background

The Timaru District is home to several hut settlements. Each of these settlements is located near the coast or a major river or stream and is vulnerable to various natural hazard risks including flooding, coastal erosion, and seawater inundation.

As part of a full review of their District Plan, Timaru District Council asked the Canterbury Regional Council (Environment Canterbury) to provide a summary of expected natural hazards and their potential impacts on each of these communities. This will inform planning decisions within the review process.

The settlements included in this assessment are the South Rangitata Huts, the Waipopo Huts (and adjacent land), and the Grassy Banks, Mill Road, Butlers Road, Stratheona Road, and Collett Road hut settlements along the Opihi River. Also included is part of the Blandswood settlement that is zoned as recreational land.

What we did

We collated and summarised existing flooding & coastal hazard information for each of the hut communities. We also provide context on the expected impact the hazards would have on development as well as general information on flood warning and evacuation. High level comment on the potential impacts of climate change is also provided. The report is intended as an information source and does not include recommendations or advice on planning responses to the hazard risks described.

For the Waipopo Huts, Timaru District Council informed Environment Canterbury that Ngāi Tahu and local Arowhenua rūnanga have expressed interest in the potential for future development on adjacent land under their ownership. For this reason, we carried out new modelling of a series of river flooding scenarios specific to that area. We also expanded the study area, beyond the main hut's settlement, to include a wider area of adjacent land. At South Rangitata Huts a concurrent coastal hazard investigation carried out by Jacobs Engineering Consultants (and briefly summarised here) provides new coastal hazard information.

This report does not include the Milford Huts which was the subject of a 2019 Environment Canterbury Report, 'Milford Huts natural hazards overview', March 2019 (Report R19/12).

What we found

The hut settlements have been recognised as vulnerable to natural hazards since before the first-generation Timaru District Plan and this report generally supports that. Most of the settlements are prone to severe flooding. The exceptions are some limited areas within the Waipopo Huts study area and at South Rangitata Huts where the river flooding poses significantly lower risk to life and property damage than typical of the other hut settlements. South Rangitata is also prone to coastal hazards.

The report also confirmed that each community faces varying challenges regarding safety of people, and evacuation, warning and education initiatives are critical for the continued viability of the established hut settlements. Lastly, we assess that climate change has the potential to further increase hazard risk in these communities.

What does this mean?

This report is a comprehensive summary of our understanding of the natural hazard risks facing hut settlements in the Timaru District. It has been written as a reference document to help inform the current review of the Timaru District Plan. The report provides an information base that could also help to inform future public awareness, civil defence, and emergency and planning initiatives in these hut settlements.

How we have considered climate change

Climate change is discussed throughout this report. The report uses Ministry for the Environment (MfE) guidance and Climate Change Projections for the Canterbury Region (NIWA 2020) to discuss future climate change scenarios and the possible impacts they may have on each of the hut communities. The expected challenges posed by climate change will vary a little across the South Rangitata, Opihi River and Blandswood settlements as each unique setting creates different vulnerabilities.

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1 Introduction

This report provides a summary of the flood hazard risks that affect the recreational hut communities located in the Timaru District. This report does not recommend mitigation or planning responses. The report is intended to be used as an information source for the Timaru District Plan review, but it may also be used to assist other future education, planning and civil defence initiatives. Comment is made regarding flood warning and evacuation considerations, and property impacts. Climate change is discussed with the intention of acknowledging high level trends and the general impact that climate change may have on the natural hazard risk profile of each settlement.

This report regularly refers to expected 'high hazard' flooding. In this context 'high hazard' areas mean areas that are expected to meet the Canterbury Regional Policy Statement definition given below.

"High hazard areas" are:

1. *Flood hazard areas subject to inundation events where the water depth (metres) x velocity (metres per second) is greater than or equal to 1, or where depths are greater than 1 metre, in a 500-year average recurrence interval flood event;*
2. *Land outside of greater Christchurch subject to erosion over the next 100 years; and*
3. *(relevant only to Christchurch so not listed here)*
4. *Land subject to sea water inundation (excluding tsunami) over the next 100 years. This includes (but is not limited to) the land located within the sea water inundation zone boundary shown on Maps in Appendix 5 of this Regional Policy Statement.*

When determining high hazard areas, projections of the effects of climate change will be taken into account.

Regarding the river flooding risk described in this report, high hazard criteria could be triggered by either river overflows or a stopbank breach. The setback distances referred to in this report are the distances that we have assessed high hazard flooding could extend to as per the Regional Policy Statement definition given above.

In the 'principal reasons and explanation' for high hazard policy 11.3.1, the Canterbury Regional Policy Statement discusses that the combination of depth and velocity, or excessive depth (greater than 1 metre) can pose significant risk to life and can damage property.

For the remainder of the report, flooding assessed as meeting the above definition will simply be referred to as 'high hazard' without further explanation of meaning. Also, where high hazard flooding is referenced the reader can assume (if not directly referenced) the potential for risk to life and of serious property damage as per the Regional Policy Statement policies and discussion.

2 South Rangitata hut settlement

2.1 Location and key features

The South Rangitata hut settlement is located on the south bank at the mouth of the Rangitata River (Figure 2-1 and Figure 2-2). The South and Middle Branches of the Rangitata River, which act as flood overflow channels in major floods, re-enter the main branch just upstream of the hut settlement. The river mouth is an extremely dynamic area where coastal and riverine processes constantly interact to affect the environment around the hut settlement. The closest huts to the coast are just 20 m from the mixed sand/gravel beach and the main access road through the huts is only about 50 m from the beach.

The land is owned by the Timaru District Council and sites are leased to individual hut holders who own their buildings. A residents committee operates within the community. It is unclear from Environment Canterbury information exactly when the huts were first established, however aerial photographs from the early 1930s shows there was roughly 20-25 buildings located there at this time (Figure 2-3).

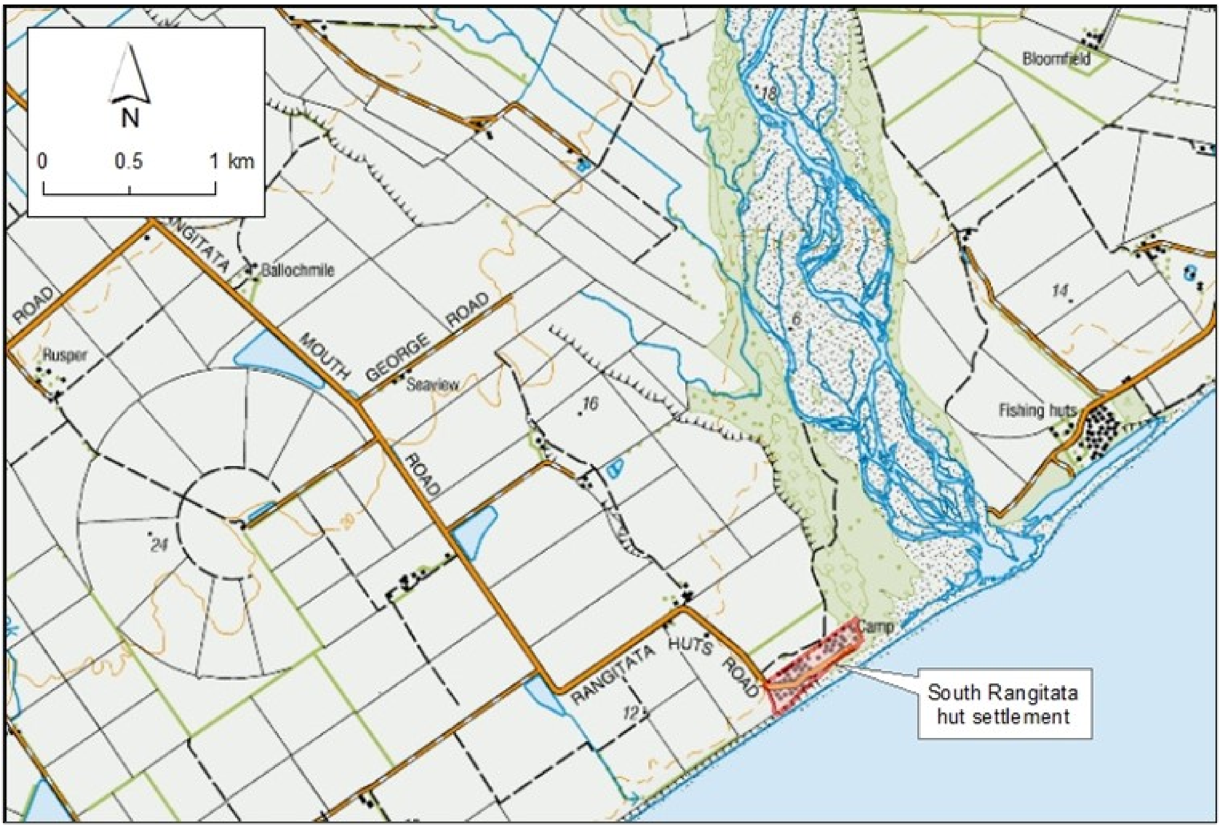


Figure 2-1: Location of South Rangitata hut settlement

Figure 2-2: Recent aerial photograph showing South Rangitata hut settlement

Figure 2-3: 1935-1939 aerial photograph showing South Rangitata hut settlement

The huts developed for use as recreational and holiday baches and as bases for fishing. A small number of residents now live there permanently under restrictions managed by the Timaru District Council (refer South Rangitata Huts Policy 14 October 2014). The area contains approximately 120 individual huts and a campground (leased to a private operator). Additional visitors are common (particularly during summer) which can lead to a large daytime population during holiday periods.

Part of the huts area is prone to river flooding from two distinct scenarios: backing-up of river water unable to escape efficiently to the sea; or upstream overflows from the Rangitata River flowing into the huts area from the northwest. In the future, part of the hut settlements is also likely to be threatened by coastal erosion and inundation.

2.2 Brief summary of historic flooding

The most common form of flooding in the huts area is from floodwater backing up against the coastal barrier beach when the mouth of the river is either closed to the sea or located a long way to the north (Figure 2-4).

This flooding most frequently affects some of the dwellings on the two roads closest to the river (and at right angles to the coast) as well as the lone dwelling on the coastal side of the main huts access road. In larger flood events, water has backed up across about half of the huts area and inundated the campground out to the low terrace.

Table 2-1 notes some of the recent occurrences of this type of flooding. There are likely to be other occasions of flooding for which Environment Canterbury has no record, especially prior to the last 20-30 years when records were not so comprehensive.

South Rangitata hut settlement during flood event

South Rangitata hut settlement after flood event ("FL" written on fence indicates flood level)

Figure 2-4: Flooding at South Rangitata hut settlement - 9 January 2004

Table 2-1: Summary of known recent occasions where flooding has been caused by "backing-up" of floodwater from the river mouth area

Date	Peak flow in Rangitata River at Gorge (cumecs)	Estimated No. of baches flooded	Additional comments
9 January 2004	1525	10	No other flooding issues on the river
14 November 2006	1570	30-40	Flooding was approximately 600 mm deep through the campground
28 May 2012	64	2-3	Mouth was north of the north huts
23 June 2012	290	2	
11 September 2013	500	1	5 other huts were close to being flooded

The part of the hut settlement between the west boundary of the campground and the river may also be susceptible to flooding from upstream breakouts from the Rangitata River. This flooding may originate from South Branch overflows, or overflows from the main river channel, between the huts and where the South Branch re-enters the Main Branch (approximately 1.5 km upstream). Environment Canterbury has no record of this occurring in recent history - including the floods of December 1957, December 1995, and December 2019 when large flows went down the South Branch channel.

Environment Canterbury has few records of seawater inundation in the South Rangitata hut settlement area despite many events being photographed elsewhere. This suggests such inundation has not been a major issue for this area over recent history. In one coastal storm event in 30 June 1992, which had widespread impact in South Canterbury, some beach overtopping appears to have occurred with seawater around the lowest parts of the settlement (Figure 2-5).

Figure 2-5: South Rangitata hut settlement during 30 June 1992 coastal storm event

We are aware that seawater overtopped the beach very recently (April 2020) via a low point in the beach crest used as a four-wheel motorbike track. This flooding did not extend into the established huts area but got onto the access road. This low point in the beach crest has since been filled in.

There may be other occasions of minor flooding from coastal inundation of which Environment Canterbury has no record. When considering the beach position and height above sea level of the lowest parts of the South Rangitata Huts, future seawater inundation is possible during extreme coastal storm events particularly for areas east of and including the campground.

2.3 River flooding – backwater flooding

The Rangitata River mouth is constantly in competition with the sea. During periods of lower flows in the river, the mouth is often pushed northwards by the prevailing swell and beach sediment transport conditions (Figure 2-6). Under certain conditions the mouth can be blocked completely. During sustained periods without a fresh in the river, the mouth may move as far as 1.4 km north of a central river position to sit opposite the North Rangitata hut settlement. A river mouth to the north of a central river position is hydraulically less efficient and this can result in river flows backing up against the barrier beach and into the South Rangitata hut settlement.

Figure 2-6: Rangitata River mouth on 26 June 2012. Mouth has migrated to north of the north bank huts which are visible in photograph. This was a few days after two huts were inundated at the South Rangitata hut settlement as a result of backwater flooding

Backwater flooding can occur at a wide range of flows. Moderate freshes in the river (400 – 600 cumecs) can cause serious flooding in the hut settlement if the mouth is a long way north. Water has backed up and entered a hut at a flow in the river of 200 cumecs, and 30 – 40 huts were flooded in November 2006 when the river flow at the mouth was only 750 cumecs (prior to a peak flow of 1570 cumecs). Much larger flows have the potential to cause more severe backwater flooding into the huts if the mouth is a long way north. The location of the mouth and the height and width of the barrier beach are key factors in determining how high the river backs up before it breaches the barrier beach. If there is a wide straight mouth at the time the river begins to rise, there is only a small chance of backwater flooding occurring at the South Huts, even at very high flows.

Backwater flooding only represents a threat to development located between the western boundary of the campground and the river. The remaining huts are located on higher ground and backed up water would likely overtop the beach crest before it reached this level. The flooding tends to be low velocity, with water entering dwellings and other buildings but not causing serious structural damage. It is also likely to pose less risk to people’s safety.

The threat to the settlement from backwater flooding can be significantly reduced by mechanically opening the river mouth or weakening the beach ahead of a high river flow. There have been many floods in the Rangitata River when the mouth has blown out at a location where the beach has been either mechanically weakened (lowered) or opened in advance of the high flow. This has substantially reduced the number of times that the South Rangitata hut settlement would have otherwise been flooded. Mechanically opening the river mouth is a highly effective means of mitigating against river flooding at the South Rangitata hut settlement, but a mouth opening cannot always be guaranteed for the following reasons:

- Large swells or high tides can prevent an opening or can close the mouth shortly after an opening has been made;
- It is most effective to open the mouth on the falling tide when a greater hydraulic head assists in scouring a deep channel to the sea. If favourable tides do not coincide with daylight hours and availability of machinery, an opening may be difficult or impossible;
- Strong onshore winds can cause the mouth to close quickly after an opening;
- River or sea conditions can make it unsafe for machine operators to attempt an opening;
- Low river flows make it more difficult to open the river mouth and reduce the length of time the mouth stays open;

The mouth openings are funded by a special rate paid by the South Rangitata Huts Residents Committee to Timaru District Council to enable Environment Canterbury to carry out mouth openings. In addition to the primary focus of protecting property from damage by flooding, Environment Canterbury must always consider several other factors before attempting a mouth opening:

- the financial cost to ratepayers,
- the effect openings have on the river environment and wildlife;
- the potential flooding problems at the hut settlement.

The likelihood of flooding at the huts depends on many factors relating to river flow, flood flow travel times, sea conditions, location of the mouth and the width and height of the beach at the mouth. Environment Canterbury staff members consider all the above factors, and consult with contacts in the hut community, rūnanga, Fish and Game, and Department of Conservation when making a mouth opening decision. In recent times the mouth has been mechanically opened 2–4 times each year. There are other times when machinery is on standby to open the mouth but either the mouth opens naturally, or the flood situation doesn't develop as forecast.

River flows that often result in backwater flooding in the hut settlement are considered only a 'fresh' in the Rangitata River. Problems can develop at the huts at flows between 200 and 600 cumecs. For other parts of the river system these flows are not a problem. A mean annual flood in the Rangitata River is currently assessed at about 1100 cumecs.

2.4 River flooding – upstream river breakouts

The Rangitata River is a large, braided, and gravel bearing river that occupies a wide riverbed. The river has a wide floodplain, but it is difficult to predict where the river will breakout and, therefore, which parts of the floodplain will be impacted by any given flood event. The extent and location of out of river flooding depends on many factors within the river besides the size of the flow. These factors include gravel distribution within the river and the location and angle of the main flow channels during a flood.

Environment Canterbury holds no information to indicate that upstream breakouts have entered the South Rangitata hut settlement in recent history. Breakouts from upstream have re-entered the main branch where the South and Middle Branch channels return to the river (Figure 2-7).

In historic events, floodwaters that overtop the South Branch tend to head further to the southwest and miss the huts but can cut road access. Significant overflows to the southwest occurred in recent floods in 2019, 1995 and 1957, but none of these affected the huts.

Given the unpredictability of the Rangitata River, upstream river breakouts reaching the huts cannot be discounted. For this to happen, an overflow from the main channel would have to occur in the reach between the South Branch re-entry point (1.5 km upstream of the huts) and the hut settlement. Alternatively, upstream breakouts into the South and Middle Branches could overwhelm those channels near the re-entry point to the Main Branch (1.5–2 km upstream) and continue downstream to the huts. While not considered impossible, in the largest instances of South Branch flooding on record this has not happened.

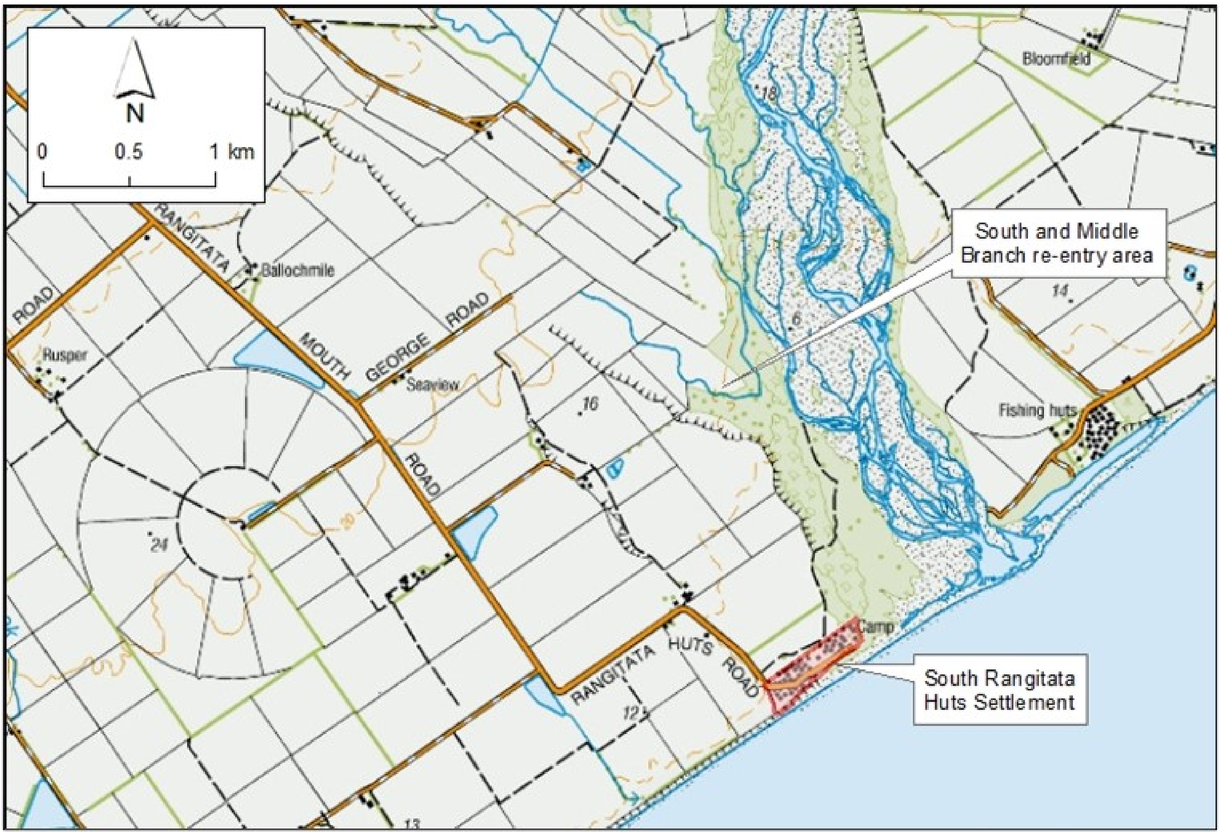


Figure 2-7: Location where South and Middle Branches of the Rangitata River re-enter the main river channel. The natural terrace downstream of this point has historically prevented floodwater continuing down toward the huts

Environment Canterbury (Wild, 2016) modelled a range of breakout flows into the South and Middle Branches at several different locations. The modelling shows floodwaters would not overtop these channels and reach the South Rangitata hut settlement area. A scenario of 800 cumecs, entering the South Branch upstream of State Highway One, was modelled and did not show floodwaters reaching the South Rangitata hut settlement (Figure 2-8). Note that the 2016 report did not model potential overflows from the main river between the huts and South Branch re-entry point.

If upstream river flooding occurred, it would impact the same part of the settlement below the low terrace adjacent to the campground. This is a low probability scenario limited to very extreme flood events and certain in-river issues developing. However, a major breakout from the river does have the potential to cause significantly greater impacts on the lower part of the huts settlement than is caused by backwater flooding.

For residents in a situation where flooding was threatening, either evacuation from the area, or evacuation to the higher part of the South Rangitata hut settlement (west of the campground) will provide safety.

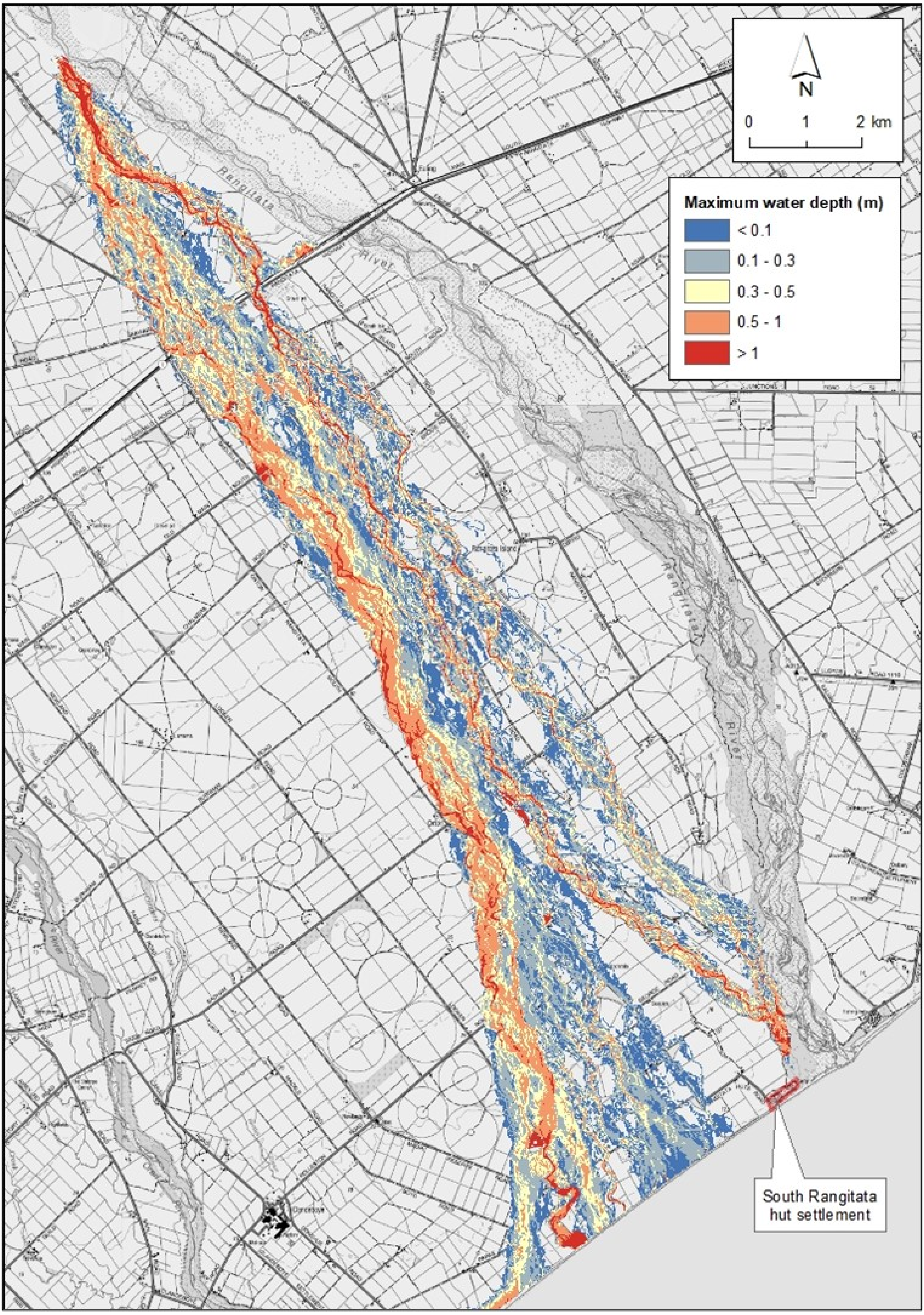


Figure 2-8: Flood extent and depth from a modelled 800 cumecs breakout into the South Branch Rangitata River Channel upstream of State Highway One (Wild, 2016)

2.5 Existing river flooding hazard zones

River flooding at the South Rangitata hut settlement has previously been divided by Environment Canterbury into four zones (Figure 2-9). These zones were defined by Hall (1996) and have been used by Environment Canterbury and the community to help understand the hazard present. The zone boundaries relate to rises in ground level in a southwest direction away from the river. The lowest of these four zones, Zone 1, was close to the river with Zone 4 on the highest ground at the southwest end of the settlement. The definition of four zones in previous investigations assisted Environment Canterbury (in providing advice) and the community (in understanding risk) and will remain a source of information in future.

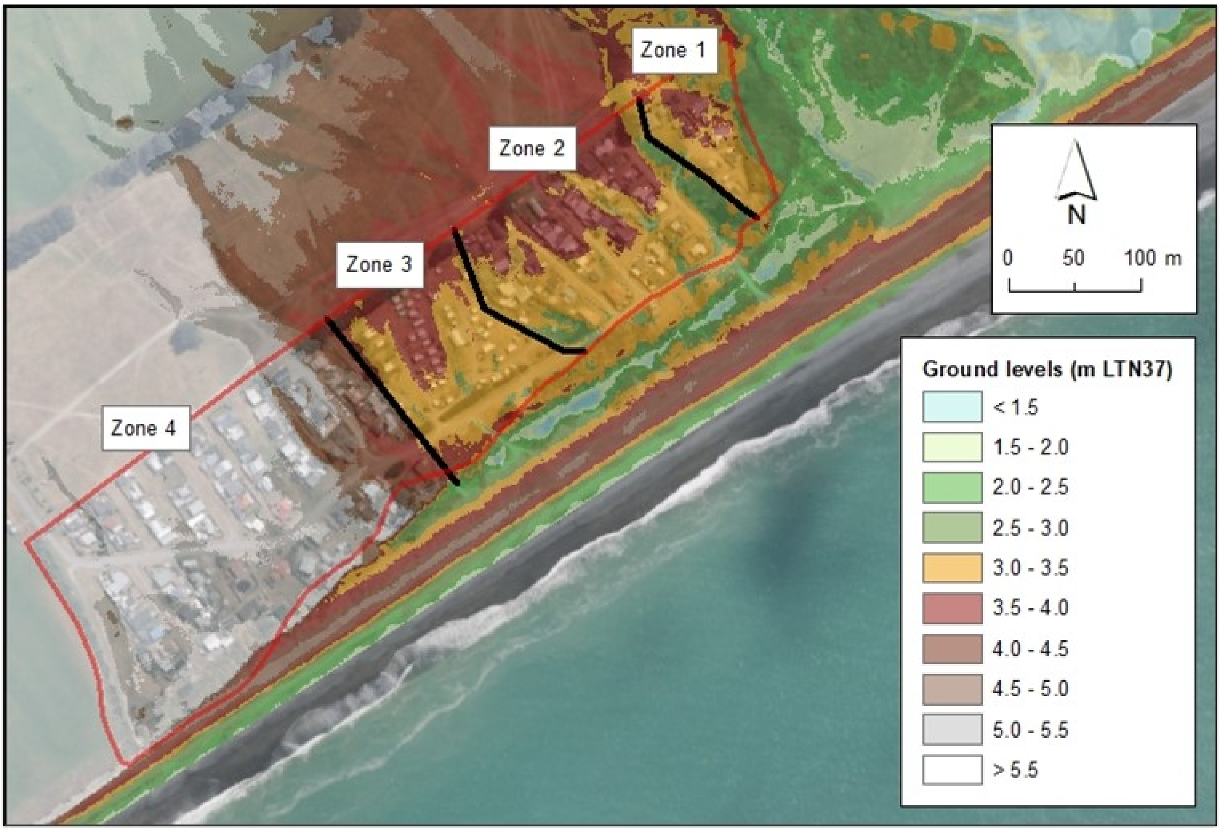


Figure 2-9: 2010 LiDAR (ground level) data, and the four river flooding zones

Improved topographical information suggests Zones 1, 2 and 3 have very similar ground profiles. This area is floodable from floodwater backing up from the mouth or from upstream breakouts. The only difference being the frequency at which a dwelling could be affected, with topographic data suggesting this is not necessarily linked to distance from the river. The impacts of flooding will be similar for all dwellings and there is considered little benefit to presenting the risk across Zones 1 to 3 as different when all this area has potential to receive river flooding.

Zone 4 is at least one metre higher than all other land in the hut settlement area and is not traversed by any significant swales or depressions. This area is very unlikely to be affected by river flooding and there is no record of river flooding threatening this area in the past.

In order to simplify the information around river flooding hazard at the South Rangitata hut settlement we show all land north east of the west boundary of the campground as floodable (Figure 2-10). All land south west of the campground can be considered very unlikely to be subject to river flooding. This simpler distinction is in keeping with how floodable areas have been mapped in the rest of the district. Rather than trying to define the severity of flooding at a mapping level, the area is broadly defined by potential susceptibility to future flooding. Site specific investigation can be used to refine the flood hazard as required.

Figure 2-10: Proposed simplified Rangitata River flooding zones

2.6 Coastal (seawater) inundation and coastal erosion

Concurrent investigations are being carried out by Jacobs Engineering Consultants on coastal hazards within the Timaru District. These are due to become available to Timaru District Council at the same time as this report. The Jacobs investigation is considerably more technical and detailed than this summary of natural hazards and will provide further detail on coastal (seawater) inundation and coastal erosion at the South Rangitata hut settlement. exceeded within that 50- or 100-year timeframe. A 50% probability of exceedance could be interpreted as being likely. A 5% probability of exceedance is possible but unlikely.

2.7 Flood warning and evacuation

The most frequent flooding scenario for the hut settlement area is from backwater flooding. While this has significant impact on property, floodwater levels tend to rise slowly, and flow velocities are low.

Flood travel times on the Rangitata River are long, with a river flow peak at the Rangitata Gorge taking about 10 to 12 hours to travel to the river mouth in a flood. At the mouth, the South Rangitata hut settlement residents benefit from this extended flood warning time, and communication with the residents occurs well in advance of any issues occurring.

Although the likelihood of flooding at the huts from river overflows is low, Environment Canterbury still monitors this closely and communicates with emergency authorities during flood events, especially as. upstream breakouts can cut road access to and from the area. In extreme flood events, like the recent 2019 event, access could be cut or impeded for several days. Environment Canterbury maintains close contact with a local hut holder (permanent resident) and the campground managers. Those community members pass on information to the rest of the community. This communication is often about river mouth issues and potential backwater flooding. The same contacts are also used to warn of potentially dangerous swell forecasts, and residents can avoid any inundation by moving to higher ground at the southwest end of the huts area. In larger river flooding events, the Timaru District Council Civil Defence staff are responsible for communicating with the South Rangitata hut settlement community. During the

December 2019 flood event they were in constant communication with the hut residents. Discussions included voluntary evacuation and egress from the area.

The long flood travel times, and good egress options, mean that effective flood warning and potential evacuation occurs under current emergency procedures. Flood events occurring at night can be managed due to the long travel times and the ability to pre-warn the community of rainfall in the upper catchment well in advance of the arrival of potential flooding.

2.8 Climate change

2.8.1 Rangitata River

The impacts of future climate change on the Rangitata River catchment are complex and, at present, not fully known. A report into climate change projections was completed in 2020 by NIWA for Environment Canterbury. The following points relevant to climate change impacts for the Rangitata River are taken from this report.

- Seasonal mean air temperature is expected to increase most in the western areas of Canterbury with projected increases of 3-4 degrees by 2090 in RCP 8.5 scenarios.
- Predicted rainfall changes will vary across the region, and seasonally. For western catchments, like the Rangitata, average winter rainfall is projected to increase by 15-40% by 2090 using RCP8.5 scenarios. In spring, mean rainfall may increase by 5-15% by 2090. In summer, rainfall averages may decrease by 5-15% over the same time period. This points toward more extremes in weather patterns.
- Mean annual flood flows are expected to increase, but mean annual discharge is expected to decrease, by 2090. This again signalling greater weather extremes are likely.

The above general trends - particularly the expected increase in temperature - will have a significant impact on the Rangitata Catchment.

Snowfall in the upper catchment of the Rangitata can reduce peak flood flows in the river. With anticipated warmer temperatures more precipitation will fall as rain, not snow. This will result in more rapid runoff and higher peak river flows. It may also impact the seasonality of major floods which have tended to be more common in spring and summer (when the freezing level is higher).

Increases in air temperature are likely to increase the intensity of rainfall events given that warmer air contains around 8% more moisture for each 1 degree increase in temperature (Mullan *et al.,* 2008).

More intense rainfall events may increase the frequency of floods of a certain size. For example, what was previously considered a 50 year Average Recurrence Interval (ARI) flood may in future be a 20 or 10 year ARI flood.

In the Rangitata River it is difficult to predict what impact climate change will have on out of river flooding. Flooding out of the river depends not just on flow, but also on gravel distribution and the position and angle of the main flow channels within the river at any given time. However, an increase in the frequency of high flood flows is likely to increase out of river impacts.

Sequences of high flood flows over a relatively short space of time causes problems in this river. The December 2019 flood is a typical example, where the damaging flood flow occurred after two flows at or above 1000 cumecs had been recorded earlier the same week. Prior to those three high flows the river had recorded a series of smaller flows (around 500 cumecs) over the preceding month. Also, one year prior the river had recorded another very large flow of 1900 cumecs.

Successive floods mobilise the gravel, and saturate and weaken riverbanks, setting the river up for damage in the next flood. Any increase in the frequency and intensity of rainfall may result in an increase in the occurrence of successive (closely spaced) floods.

2.8.2 Coastal elements

New Zealand sea-level has risen at a rate of ~1.8 mm/year over the 20th century. The recent trend in global-average mean sea level from 1993 is 3.4 mm/year. This is nearly double the global average rate over the 20th century.

According to the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, global sea-level rise will likely be in the range 0.28-0.98 m by 2100 (lower bound for RCP 2.6 (immediate and drastic greenhouse gas emissions reduction), upper bound for RCP 8.5 (continuing high emissions). However, the onset of the collapse of the polar ice sheets could cause global mean sea level to rise substantially above the likely range towards the end of this century and early next, possibly producing sea level rise of 1.4-1.5 m by 2120.

Higher base mean sea levels will contribute to increased vulnerability of low-lying coastal areas such as the South Rangitata hut settlement to coastal storm events. There is likely to be an escalation in the frequency of nuisance and damaging coastal inundation events as sea levels rise and increases in erosion rates may occur in areas already experiencing coastal erosion.

Climate induced changes in storminess could affect the frequency and magnitude of storm effects that may influence the drivers of coastal hazards such as storm surges, wave heights and wave direction. Subtle changes in wave direction and storm frequency may influence the longshore transport of coastal sediments both onto and away from parts of the coast. Climate change effects in river catchments such as the Rangitata also have the potential to affect the amount of sediment delivery to the coastline and ultimately affect future shoreline patterns of retreat (or advancement).

However, current national coastal hazards guidance considers weather related coastal hazard drivers such as storm surge, waves and winds and the frequency and intensity of storms, as secondary to ongoing sea level rise as the principal effects of climate change on coastal hazards. The current understanding of trends and projections of future changes in weather induced coastal and ocean drivers is not as clear or consistent as for sea level rise.

3 River and stopbank information relevant to all Opihi River hut settlements

3.1 Opihi River capacity

The objective of the Opihi Catchment Control Scheme, managed by Environment Canterbury on behalf of the special river rating district, is *to maintain the Opihi Catchment Control Scheme to minimise flooding, erosion and degradation/aggradation in the lower river and the contribution of upper catchment detritus to the lower catchment.*

As part of the flood protection component of the scheme, the following relevant service levels exist. Design capacity from Pleasant Point to the Temuka River confluence is 2410 cumecs and from the Temuka confluence to the river mouth is 3130 cumecs. These flows are currently estimated to have an Average Recurrence Interval (ARI) in the range of 40–50 years. In flood events greater than the design capacity of the river, flood overflows can be expected from the river system.

The Opihi River is a mobile, gravel bearing, braided river and its margins are prone to erosion during floods. Gravel movement in the riverbed can lead to localised changes in flow patterns, which can redirect flood flows towards the river stopbanks. Due to the legacy of development close to the river, the riverbed has been constrained to a far narrower width than is natural. As a result, lateral erosion of the berm areas and stopbanks is a very real threat. Records from the 1986 flood show many stopbank breaches on the Opihi River as a result of overtopping or lateral erosion.

Climate change may reduce the relative level of flood protection provided by the Opihi River scheme. The location of stopbanks along the river is often dictated by the presence of legacy development on the floodplain; widening the river in future to increase capacity is a difficult prospect. The other way to increase capacity is to raise the height of the stopbanks. While that may reduce the probability of stopbanks being overtopped, it does not lessen the likelihood of a breach caused by lateral erosion since higher stopbanks have the potential for more water pressure to build up on the river side of a stopbank - potentially increasing the likelihood of lateral breach. Rock protection could be used to strengthen stopbanks, but this is expensive and may not be affordable for the rating district.

Consequently, the likelihood of flooding, and of lateral erosion stopbank breaches, for the Opihi River hut settlements is unlikely to reduce significantly in the foreseeable future.

3.2 Stopbank breach description and setback rules in current District Plan

Rule 6.16.2.3 (1) of the current Timaru District Plan states that the following is a discretionary activity: *"Other than for non-habitable accessory buildings, public utilities and utility services the erection of a building or structure on the landward side of a Regional Council stopbank or within 100 m of a stopbank identified on the District Plan Maps."*

Stopbank setback distances are used to avoid the area where deep, high velocity, and debris laden floodwaters will occur in the event of a stopbank breach during a flood event. The 100 m distance used in the District Plan is a catch all measure which triggers closer scrutiny for specific development proposals via a discretionary resource consent. The actual distance over which flooding, that meets the Canterbury Regional Policy Statement definition of high hazard, may extend from a stopbank depends on factors such as the stopbank height, the ground level on the river and landward side of the stopbank, and the expected water level at the time of a stopbank breach. This last factor acknowledges that breaches often result from lateral erosion rather than overtopping.

The high hazard definition includes a probability component, and severe flooding must be expected to occur in events with a 500-year ARI in order to meet the definition. The Opihi River flood protection scheme is designed to contain flows with a much lower ARI, and it is likely multiple overtopping or erosion breaches of the stopbank will occur in a 500-year ARI event. For example, in the 1986 flood (less than 500-year ARI flow) at least 13 breaches of the Opihi River stopbank occurred between Pleasant Point and the sea (Scarf *et.al,* 1987).

The likelihood of a breach in any given location cannot be accurately determined, however it is a realistic possibility for stopbank breach to occur adjacent to any hut settlement during a 500-year ARI flood. For this report we have assumed stopbank overtopping or erosion breach will occur adjacent to the hut settlements in a 500-year ARI event, and have assessed high hazard setback areas on this basis.

Using the parameters discussed above, the setback distance can be estimated from the results of breach modelling analysis produced in Connell (1998). Connell (1998) includes a graph displaying setback distances for a range of water level and ground level/riverbed level scenarios (Figure 3-1). Once these parameters are known for a given site, the setback distance can be taken from this graph.

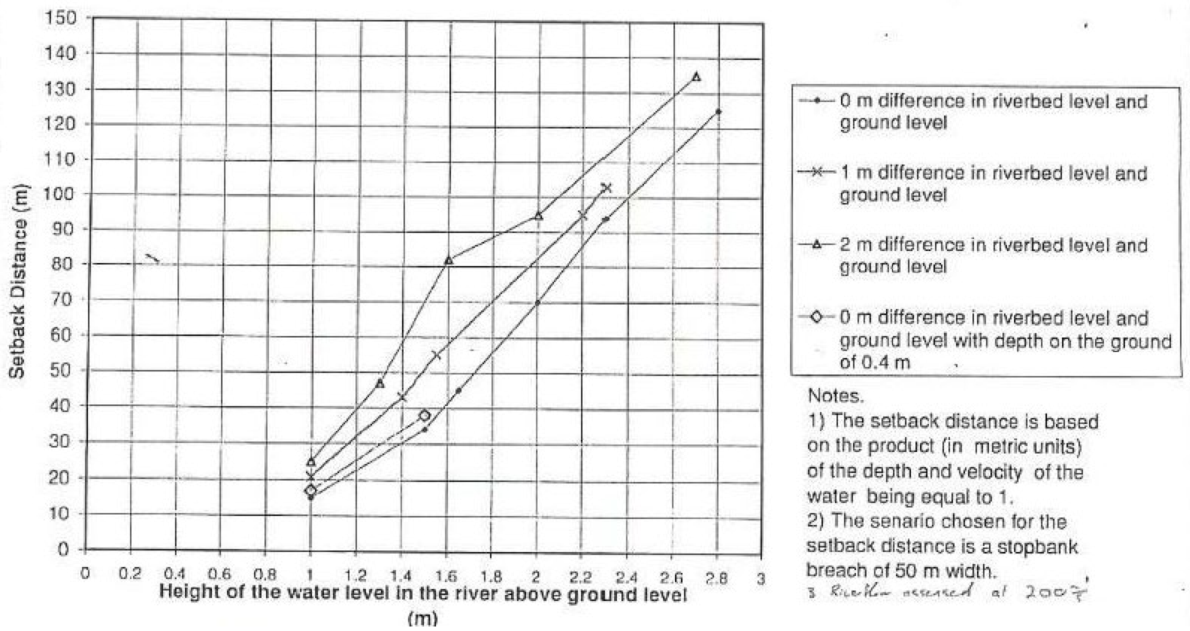


Figure 3-1: Setback distance from stopbanks for dwellings graph (summarising breach modelling results). This graph output from breach modelling is used to obtain final setback in all areas

Limitations of the breach modelling include:

- It uses a standard breach width of 50 m and doesn't allow for wider breaches.
- It does not allow for debris entrainment in the water and the impact that would have on buildings.
- Other potential factors such as ground scour through the breach point, or the slope of the land away from the breach point, are not customised in the modelling.

For these reasons an uncertainty factor is added to the stopbank setback distance. The additional distance is calculated as 15% of the total estimated setback in order to allow for uncertainty proportional to the size of the expected high hazard area.

For each of the Opihi River hut settlements assessed, a high hazard setback area has been calculated based on a stopbank breach analysis. This has been mapped alongside the current catch-all distance over which discretionary activity status applies in the current District Plan (100 m from stopbank). This is less than 100 m in some locations, but closer analysis suggests 100 m is not adequately covering all the expected high hazard flooding extent in some locations. The parameters used to determine high hazard stopbank setback distances for each community has been included as appendices.

The likelihood of a stopbank breach occurring somewhere along a river system in a major flood is often relatively high, but the likelihood of this occurring at any specific location is generally low. However, given the very high potential consequences, Environment Canterbury recommends against building in areas that may experience severe flooding from an adjacent stopbank breach. Environment Canterbury information and observations show that stopbank breaches are quite common in Canterbury's gravel bearing, braided rivers during major events. The Opihi and Te Ana a Wai Rivers have certain design flood capacities and when flood flows exceed that capacity, overtopping of stopbanks is likely.

4 Waipopo hut settlement

4.1 Location and key features

The Waipopo hut settlement is situated off the end of Waipopo Road, on the south side of the Opihi River approximately 1.4 km inland from the coast (Figure 4-1).

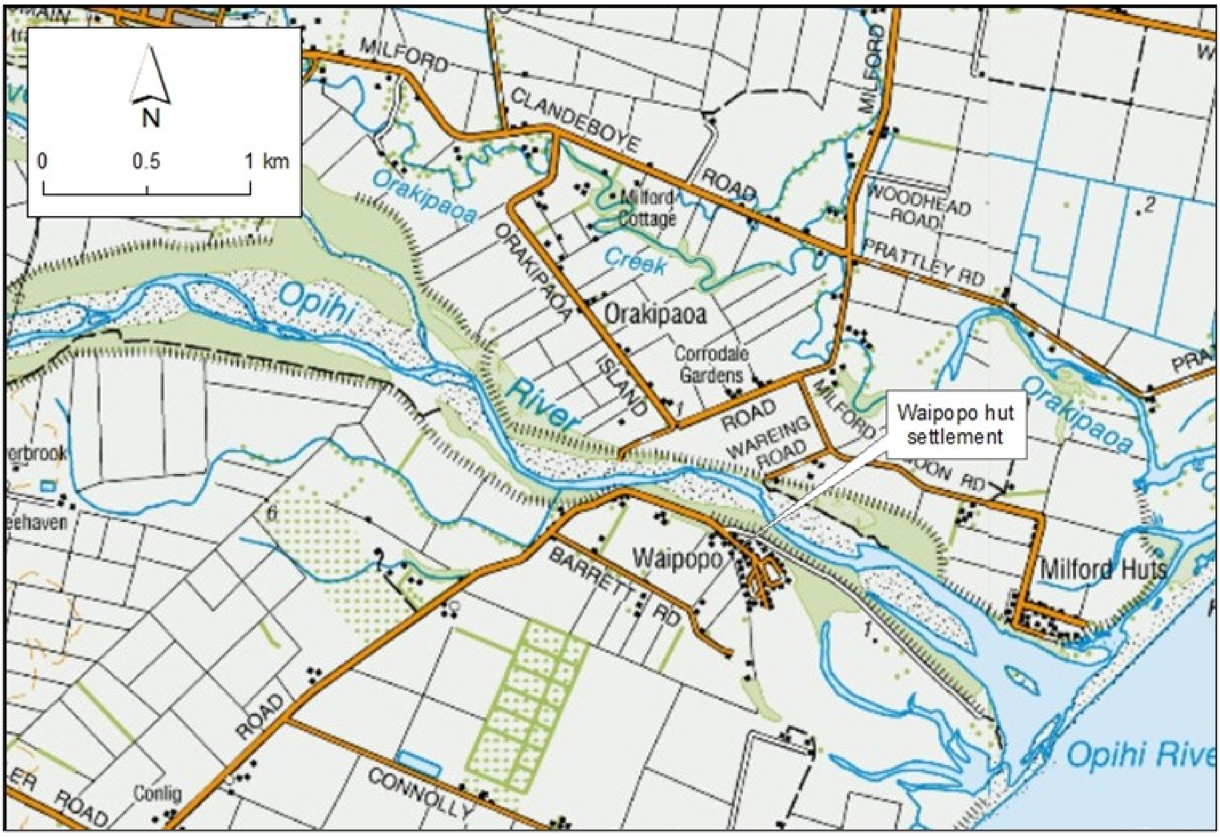


Figure 4-1: Location map for the Waipopo hut settlement

The Opihi River stopbank forms the north boundary of the settlement which has dwellings separated into fragmented areas. There are 90 to 100 dwellings in the Waipopo hut settlement area with most of the those located at the eastern (downstream) end of the settlement off the end of Waipopo Road. This area will be referred to as the 'main huts' area in this report (Figure 4-2). The remaining two areas are on the south side of Waipopo Road where it runs parallel to the river and to the west of Waipopo Road before it reaches the river stopbank and bends around toward the coast. Those huts upstream of Waipopo Road will be referred to as the 'top huts' in this report (Figure 4-2). The dwellings are a mixture of permanently occupied and holiday residences. The ownership of land and established development of land parcels also varies:

- Single land parcels under private ownership with one dwelling
- Individual Māori owned land parcels containing multiple dwellings
- Māori owned land containing one dwelling or that is currently vacant
- Two single but large land parcel areas owned by two separate home or hut holder associations and containing 20-30 dwellings in each.

Figure 4-2: Location map for the Waipopo hut settlement dwellings

As well as considering the established development at Waipopo, the Timaru District Council is interested in the flood hazard risk to Māori owned land in the Waipopo hut settlement area as Arowhenua Rūnanga have queried if the land is suitable for papakāinga provision. Figure 4-3 shows Māori freehold land in the vicinity of the Waipopo hut settlement that has been used to draw the boundary of the study area for this report. This information was obtained using the Māori Land-Māori court layer supplied in the Canterbury Maps online database. We understand there may be other land of interest in this area that is owned by tangata whenua but may not be represented in this database/map. We believe this land is covered within the Waipopo study area shown in Figure 4-4 (referred to in this report as the study area).

Figure 4-3: Māori freehold land as shown in Māori Land-Māori Court layer in Canterbury Maps

Figure 4-4: Waipopo study area

Ground levels vary significantly across the study area (Figure 4-5), with most of the established dwellings in the main huts area located below a significant terrace immediately to the southwest.

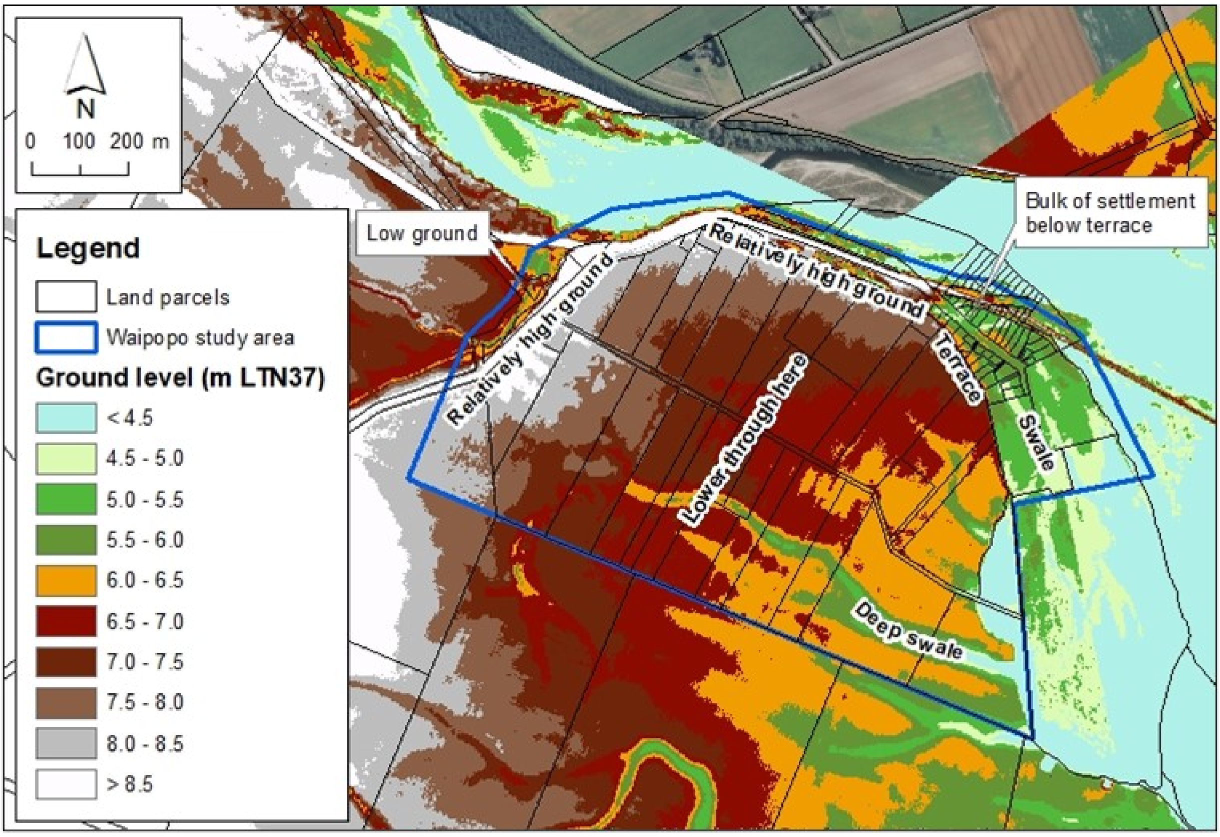


Figure 4-5: 2010 LiDAR (ground level) data for the Waipopo hut settlement area

A 150 to 200 m wide strip of higher land exists adjacent to Waipopo Road where it runs parallel to the river and extends from the main huts area to where the road bends toward the coast. Further south the land falls away significantly and is relatively low all the way out to the southern boundary of the study area. This part of the study area is traversed by several deep channels (historic flood flow paths) as is the area around the main huts. The dwellings at the top huts are on a thin strip of higher ground but ground levels fall away immediately to the west.

4.2 Brief summary of historic flooding events

The Levels Plains and Seadown area, where the Waipopo hut settlement is located, have a long history of flooding, with some records dating back to floods in the 1860s. Records include a very large flood in 1868 which inundated this area and much of the coastal areas of Canterbury and North Otago.

In more recent times, flood events in February 1945 and April 1951 caused severe flooding around the Opihi River, and likely in the Waipopo hut settlement area. While the 1868, 1945 and 1951 floods were large events there were several smaller flood events that occurred over this period. The 1951 flood prompted the earliest flood protection scheme works for the Opihi River. Figure 4-6 shows flooding during the 1951 flood.

Photograph taken at SH1

Looking to land immediately upstream of the Waipopo hut settlement from opposite side of the river

Figure 4-6: Flood event on 18 April 1951

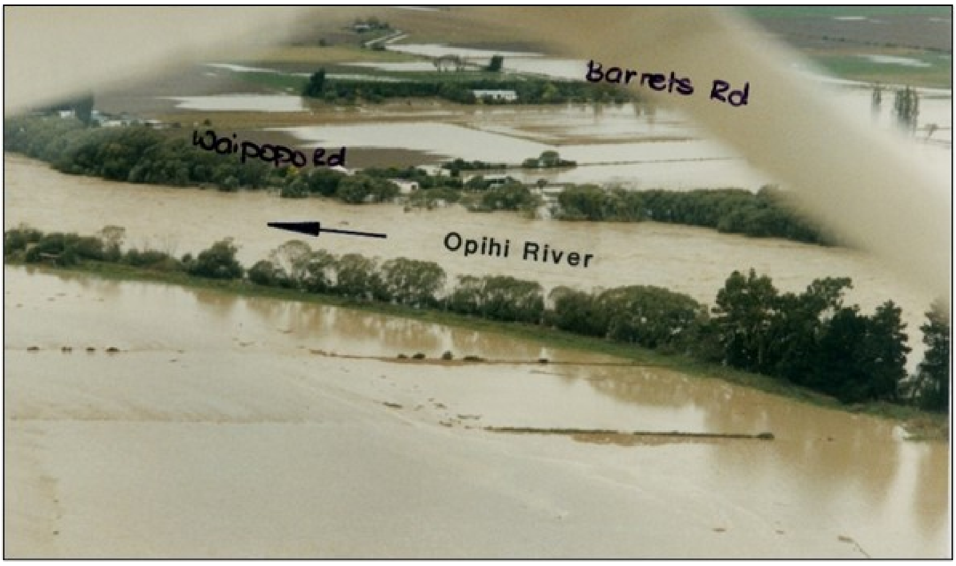
At least four floods occurred through the 1950s and 1960s which overtopped the newly constructed stopbanks, resulting in some flooding on the south side of the river. It is unclear from Environment Canterbury's records what happened in the Waipopo study area in these floods but a photograph from 1957 indicates some flooding (Figure 4-7). While some flooding occurred, the extent of flooding was less than in 1951 and less than what would have been anticipated without the early scheme protection works. The scheme was therefore deemed a valuable investment and further improvements were made in 1968 which held up well until the March 1986 flood

The 1986 event is the largest on record for the Opihi River and it caused severe flooding of the Levels Plains and Seadown areas including to several of the Opihi River hut settlements. There was significant flooding in the Waipopo study area, particularly on the upstream side of Waipopo Road before it bends toward the coast and around Barrett Road toward the western end of the study area. The stopbank was overtopped at the bend in Waipopo Road before it turns toward the coast near the 'top huts'. This stopbank was subsequently raised to bring it up to the standard of the rest of the river scheme but it remains susceptible to lateral erosion breach.

Figure 4-7: May 1957 flood – upstream breakouts flowing towards the Waipopo study area

Figure 4-8 shows flood overflows from this location combining with upstream overflows near Barrett Road. Most of the main huts area remained clear of flooding, which travelled more to the southeast from the breakout location. The dwellings along the straight section of Waipopo Road (between top and main hut areas) were flooded by shallow water on the fringes of the breakout flows. The straight stretch of river stopbank itself was not overtopped as per the accounts of works staff who witnessed the flood.

View from opposite side of river at overtopping at bend in Waipopo Road



View from opposite side of river to Barrett Road

View northwest across Barrett Road toward river

Figure 4-8: 13 March 1986 flooding in Waipopo study area

There are several reasons why the impacts of the 1986 flood were limited across the full study area, and the main huts were largely unaffected:

- The stopbank did not breach adjacent to or immediately upstream of the main huts.
- Major flood breakouts occurred on the north side of the Opihi River which caused extensive flooding at Milford Huts. Those breakouts relieved pressure on the stopbanks at Waipopo Huts and reduced the flooding in the Waipopo Study area.
- The railway line near State Highway One let some floodwater through via partial washouts but did not suffer a major breach. Had the railway line breached, larger flows would have entered the Waipopo study area especially near the top huts and rural area.

In March 1994 another major breakout on the north bank of the Opihi River likely relieved pressure on the stopbanks protecting Waipopo. The Waipopo study area received minor flooding in this event from runoff and minor upstream overflows but was mostly unaffected.

After the 1994 flood it was recognised by the Canterbury Regional Council that a section of the flood protection scheme on the north side of the river was not up to the scheme standard as laid out in the Opihi River Rating District Asset Management Plan. Works were undertaken to bring the flood protection works on the north side of the river up to the same standard as all other parts of the river. The flood protection scheme, in theory, is now equal for both sides of the Lower Opihi River and breakouts are no more or less likely to occur in any one place. Since those works there has not been a flood large enough to threaten major river breakouts.

4.3 Flood hazard summary (prior to current modelling investigation)

Given the history of flooding in the Opihi River, and the comments above, the impacts of historic flooding on the Waipopo hut settlement (especially since the formation of the flood protection scheme) needs to be treated with caution. While parts of the Waipopo study area were largely unaffected by the 1994 and 1986 floods, there is still a significant possibility of flooding from the river in future floods.

The flood hazard at Waipopo has been known for a long time, including at the time of writing the first generation of the Timaru District Plan. Connell and Miller (1992) recognised the possibility of stopbank breaches and overtopping into the Waipopo hut settlement. Specific modelling of the 100-year ARI flood in Waipopo was included in that study and indicated depths of up to 0.5 m over higher parts of the study area and depths between 0.5 to 1 m in swales and depressions. The modelling of the whole Levels Plains area indicated depths up to 1 m over much of the Waipopo study area in the 500 year ARI with depths in some lower areas exceeding 1 metre (Figure 4-9).

4.4 Stopbank breach and setback provision

Ground levels vary significantly in the Waipopo hut settlement area. This means the height of the stopbank changes a lot relative to the adjacent ground level, which impacts on stopbank breach high hazard setback estimates. Stopbank setback determination (refer Appendix 3) for this area shows that in some places the high hazard area can be a lot closer to the river, while in other areas the current District Plan 100 m catch-all setback may not cover the full extent of the expected high hazard area.

Using the methodology set out in Connell (1991) and parameters identified in Appendix 3, we determined high hazard setback at nine locations along the stopbank adjacent to Waipopo. We then drew a smoothed line between these points to depict a specific high hazard setback distance for the Waipopo study area. The setback line and other key features are presented in Figure 4-10.

There are limitations to determining the high hazard stopbank setback distance using this methodology, but it is considered to represent a conservative yet realistic approach.

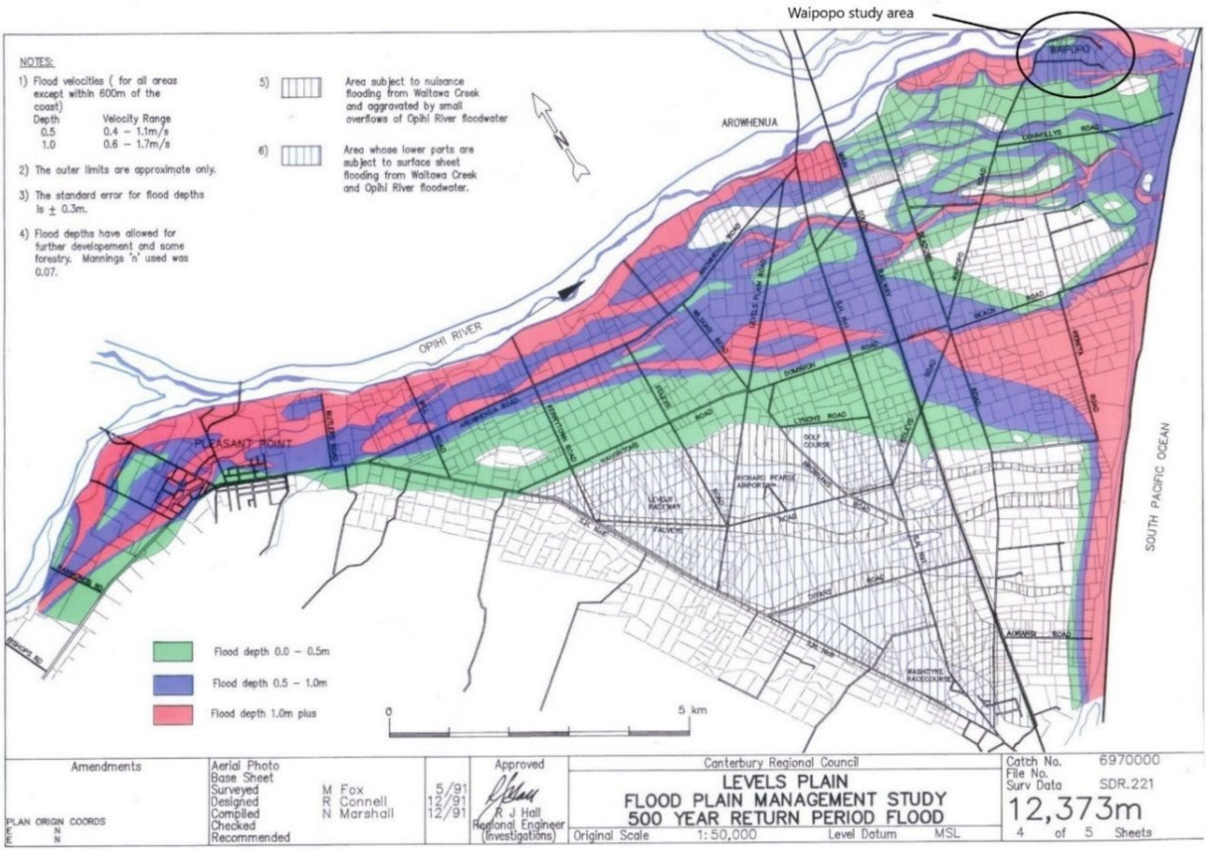


Figure 4-9: 500 year ARI flood showing Waipopo Study Area [Source: Connell & Miller, 1992]

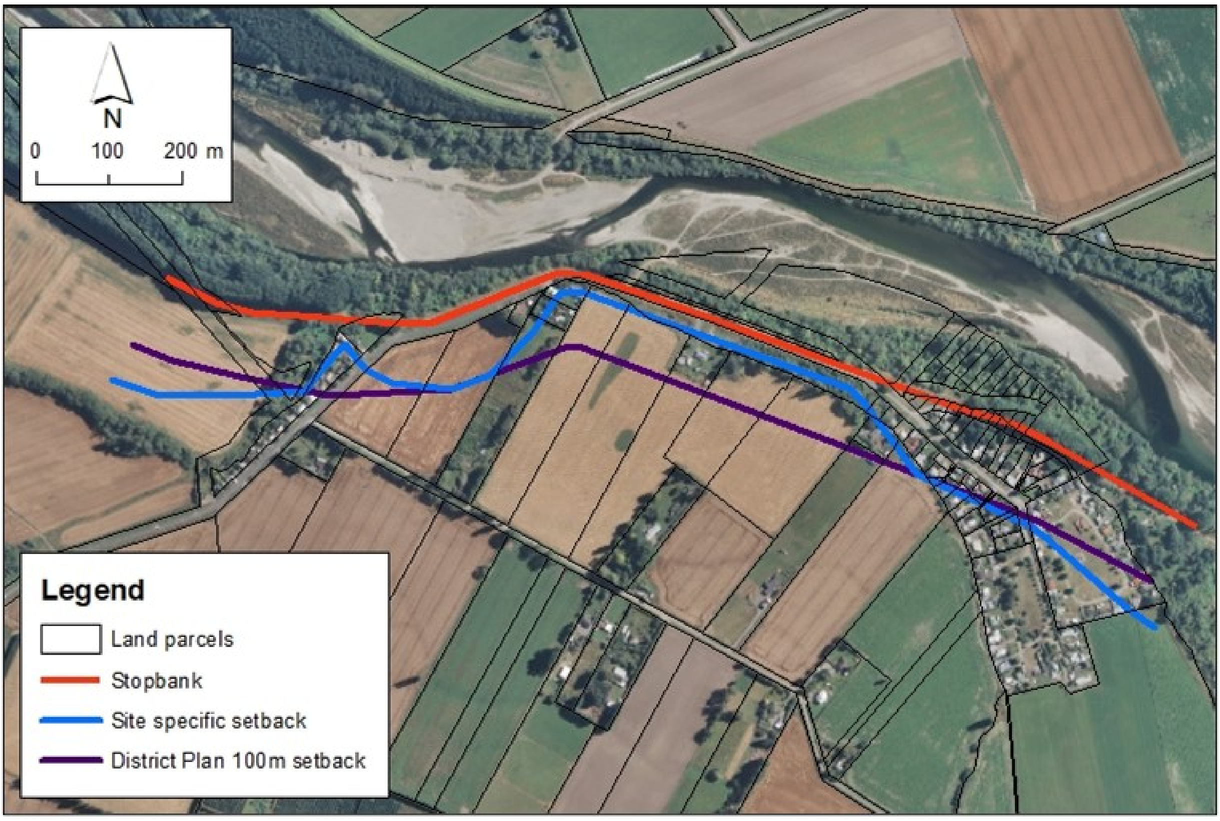


Figure 4-10: Waipopo hut settlement setback distances

The Waipopo hut settlement modelling investigation carried out as part of this report looked at breakout flows into the hut settlement area from the Opihi River. Figure 4-11 shows that the results from the modelling support the stopbank setback analysis. Greater depths of inundation relate closely to where setback distances are greater, and shallow modelled flooding to where the stopbank setback distances are less. While the modelling was not produced for the purpose of calculating stopbank setback, its general agreement with the stopbank breach analysis adds confidence to the methodology used.

Note that the high hazard area defined by the blue line in Figure 4-10 and Figure 4-11 relates only to stopbank breach and does not account for overland flooding from breakouts originating further upstream.

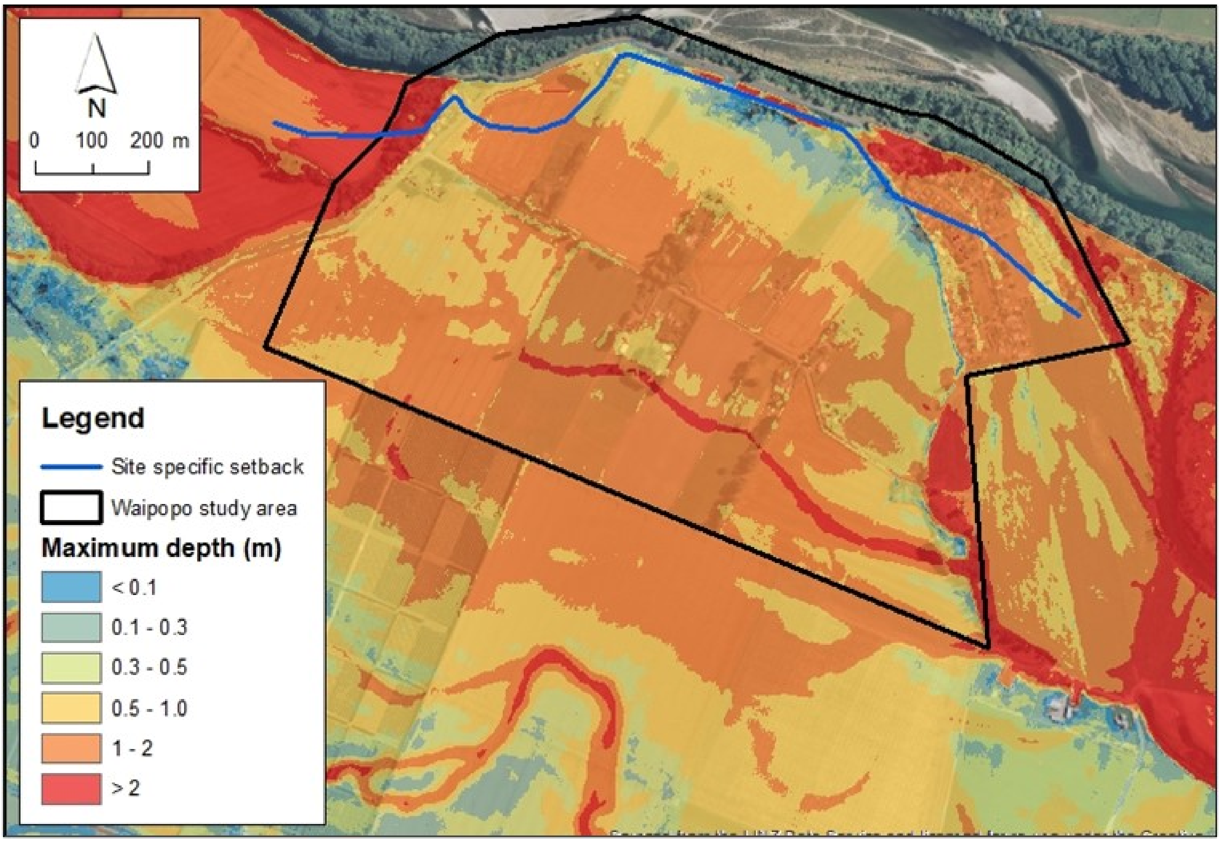


Figure 4-11: Waipopo hut settlement stopbank setback distances and modelled maximum flood depths (elevated scenario with all breakouts occurring)

4.5 Description of flood modelling investigation

The Timaru District Council indicated that Arowhenua rūnanga has interest in future development possibilities in this area. For most of the Levels Plains and Seadown area, we have comprehensive photographic records of the 1986 flood which helps us to quantify the flood hazard in this area. Because most of the Waipopo study area was not seriously flooded in 1986, less historic information exists. This makes quantification of the flood hazard more difficult.

To add confidence to the existing understanding of flood hazard we carried out Opihi River flood modelling for the Waipopo hut settlement study area. The modelling uses detailed topographic (LiDAR) data and a combined 1-dimensional (1D) and 2-dimensional (2D) hydraulic model to simulate breakout flows and determine flood depths, flood extent, flow patterns, and flood velocity on the floodplain. Breakout flows from the river were estimated using a combination of:

- 1986 Opihi River flood levels,
- stopbank breach location and geometry from South Canterbury Catchment Board records,
- topographic and survey data of stopbank parameters.

Allowances for uncertainty were also considered. The specific locations used as breakout points were based on historic information and the knowledge of Environment Canterbury staff. A site visit was carried out with Paul Eddy (Environment Canterbury southern works overseer), and several conversations with him provided a better understanding of how the river has performed in this area over many years. Paul has worked in his role for 45 years and has extensive knowledge of the area, flood protection works and historic flooding.

For each breakout location two scenarios were modelled:

- 'Base' breakout flows - determined using data from the 1986 flood event to estimate a water level at the breach location.
- 'Elevated' breakout flows - outflow through each breach was increased by 30%. The elevated scenarios are used to estimate flooding outcomes for floods bigger than in 1986, or if the river behaves differently to the way it did in 1986.

The model development, hydrology, model assumptions and methodology are detailed in Appendix 1. Breakout locations and determination of outflows is detailed further in Appendix 2.

4.6 Flood scenarios

Opihi River breakout flows can pass into the Waipopo study area from a distant source (e.g. a stopbank breach upstream of the study area in the vicinity of State Highway One (SH1)) and/or a near source (i.e. a stopbank breach in close proximity or adjacent to the study area). These sources are described below.

4.6.1 Distant breakout source

Opihi River breakouts can flow overland into the Waipopo study area from a range of upstream stopbank locations. A breakout near State Highway One (SH1) was modelled to confirm the likely flow path of floodwater coming from this 'general direction'. The modelling confirmed that, while some floodwater travels to the southeast (away from the river), a percentage of floodwater from the vicinity of SH1 will continue parallel to the river and flow into the Waipopo study area. The modelling demonstrates that breakouts that reach SH1 from upstream, or that occur between the highway and the upstream end of the study area, will flow into the Waipopo hut settlement in this way. There are several potential breakout locations along this upstream reach of the river that would flood Waipopo (the breakout doesn't have to be right at the highway).

Breakouts upstream of the main trunk railway line would need to at least partially breach the railway embankment to reach the huts. As the railway line is not a flood protection structure that is designed to stand up to deep flowing water, a breach of the line is something that is likely to happen. Although it may not breach in every extreme flood, it is considered the best floodplain management practice to assume a worst-case scenario when a breach is realistic. This investigation therefore assumes the railway line will partially breach during an extreme flood.

4.6.2 Near breakout source

Flooding can affect the Waipopo hut settlement from a stopbank breach just upstream of, or adjacent to, the study area. Three locations in the vicinity of the study area have been identified as potential breakout points based on topographical and stopbank characteristics, history of breakouts, and the experience of river engineering and natural hazards staff (including staff site visits). Once realistic breakout points were selected the final locations were refined based on where they would result in the most flooding in the study area.

4.7 Flood modelling results

The technical modelling summary in Appendix 1 sets out the full range of results from the flood modelling and the different scenarios modelled. A summary of the expected flood impacts across key parts of the study area is provided here. The key areas at the Waipopo hut settlement are:

- The main huts area in the northeast of the Study Area (Section 4.7.2)
- The top huts to the west of Waipopo Road (Section 4.7.3)

- The land for 150 m south of the part of Waipopo Road that runs parallel to the river (between the top and main huts) (Section 4.7.4)
- The remainder of the study area made up of rural land and lifestyle blocks with some housing and farm accessory buildings (Section 4.7.5)

These four areas are shown in Figure 4-12.

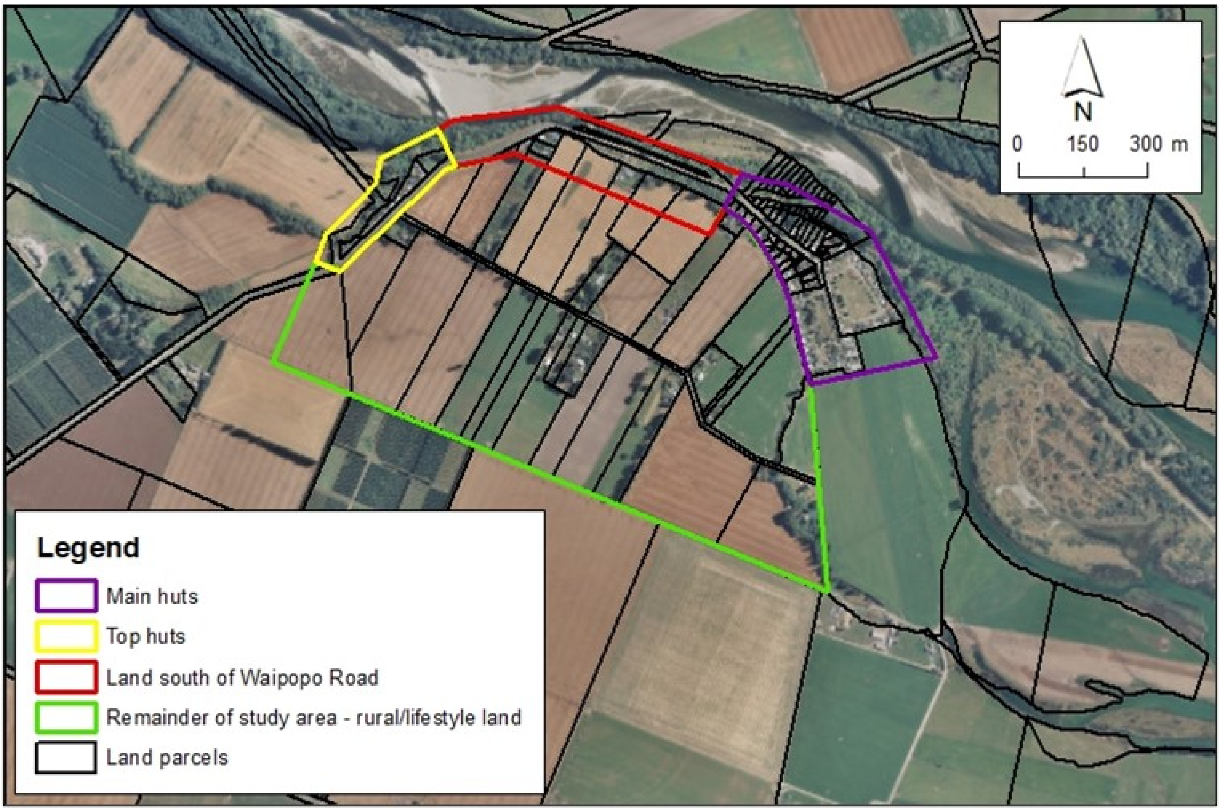


Figure 4-12: The key areas at the Waipopo hut settlement

4.7.1 General comment on flood modelling results

Most of the Waipopo study area is susceptible to overland flood flows entering the area from further upstream (SH1 breach in modelling report). However, the impacts of this flooding are relatively low in comparison to an adjacent stopbank breach scenario. In the upstream SH1 breach scenario (Figure 4-13), a 150 m wide strip of land adjacent to the river would remain flood free. This includes most of the main huts (excluding some at the eastern end of the study area) and those on the western side of Waipopo Road, before it bends toward the coast. The top huts and the remaining farmland within the study area will be affected by moderate flooding, except for some isolated channels where flooding will meet the threshold required to be deemed high hazard. Modelled flood depths, for an upstream SH1 breakout flow, are shown on Figure 4-13 to inundate a large portion of the study area. Figure 4-14 confirms that upstream flood flows have previously crossed SH1, and headed towards the Waipopo study area, in 1951.

Upstream floodwaters flowing into the Waipopo study area is therefore a likely outcome during an extreme flood event. The flood protection scheme on the Opihi River is designed to contain floods up to the 50-year ARI flood so, in floods larger than this, breaches and overtopping of the scheme is likely upstream of Waipopo. The modelling shows that some of those flood breakouts will travel parallel to the river and into the Waipopo study area.

A less likely, but higher consequence, flooding outcome would be for a stopbank breach to occur closer to the study area as modelled in scenarios A, B and C. As upstream overflows are considered a likely outcome in extreme floods, if the stopbank does breach nearby it is assumed the resultant flooding will combine with upstream overflows.

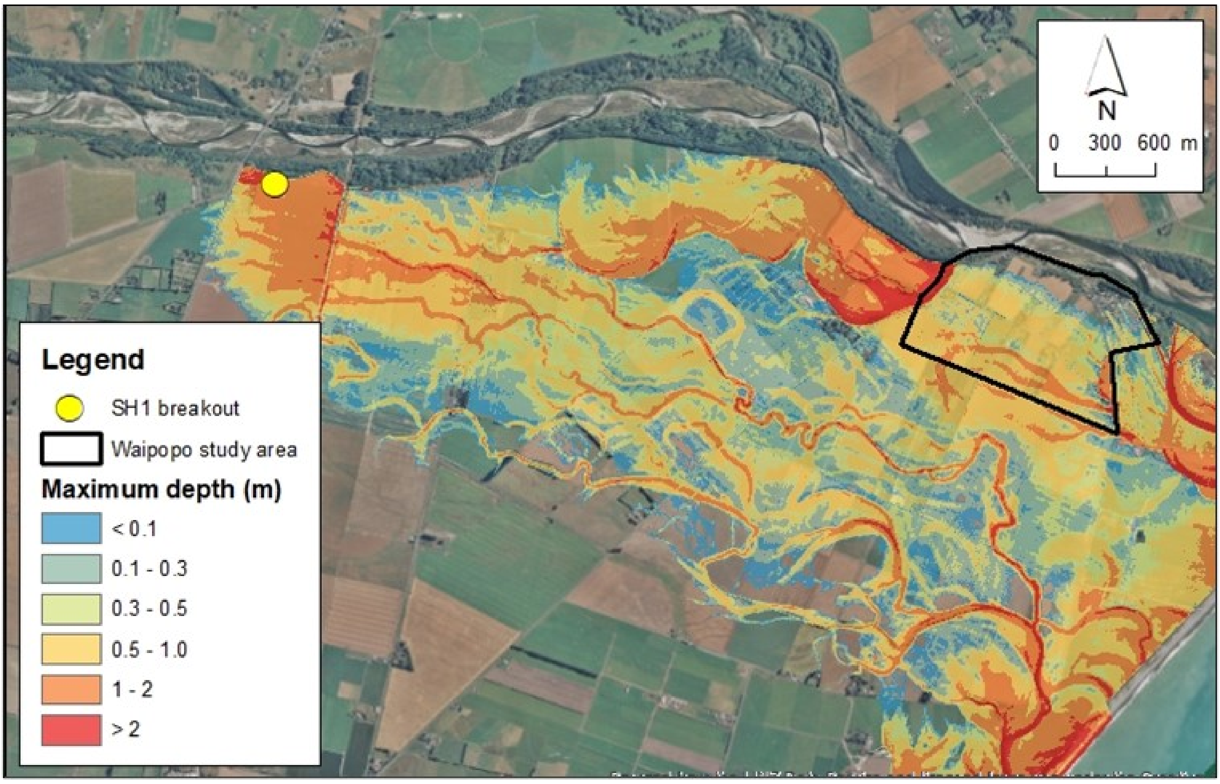


Figure 4-13: Modelled maximum flood depths for elevated SH1 breakout flow scenario

Figure 4-14: 18 April 1951 – flood water flowing across SH1 towards the Waipopo study area

Evidence from the 1986 flood indicates that downstream stopbank breaches (including near location B used in the modelling investigation) occurred despite major overflows out onto the floodplain further upstream. For these reasons all of breakout A, B and C scenarios are combined with the upstream SH1 breakout. Breakout locations are identified on Figure 4-15.

Figure 4-15: Waipopo study area breakout flow locations

It is feasible that a stopbank breach could occur from lateral erosion at lower flows, without upstream breakouts having occurred, but this is considered less likely than a breach during a flood that exceeds scheme capacity. A breach during a smaller flood would result in less flooding in the huts area and therefore was not included in this investigation.

4.7.2 Main huts area

The main huts area is on land situated between a 2 to 2.5 m high terrace (to the south) and the river stopbank (which is at least 3m high). Although low relative to the surrounding land, this area is protected by the natural topography upstream, which deflects flows from further upstream (SH1 breakout and Breakout A), to the southeast. In a SH1 breakout, combined with a breakout A scenario, some flooding may impact on the most downstream part of the main huts area, but depths are moderate when clear of well-defined swales.

In a SH1 breakout, combined with a breakout B scenario, flooding increases in the main huts area but there are still wide areas that are clear of flooding or where flooding is shallow.

If the adjacent stopbank breached at location C, the confined nature of this area would result in severe flooding and high flood depths. In the breakout C scenario (Figure 4-16), most of this area is subject to high hazard flooding and, in those areas that are not high hazard, depths are likely to be high (600 to 900 mm).

The potential frequency of severe flooding within the main huts area is lower than for much of the rest of the study area due to the limited number of breakout locations that will affect the area. While a low probability outcome, there would be very high consequences if the adjacent stopbank were to breach at or near breakout location C. The high hazard stopbank setback area goes someway to defining this hazard but flooding impacts will be significant to the terrace bounding the main huts to the southwest.

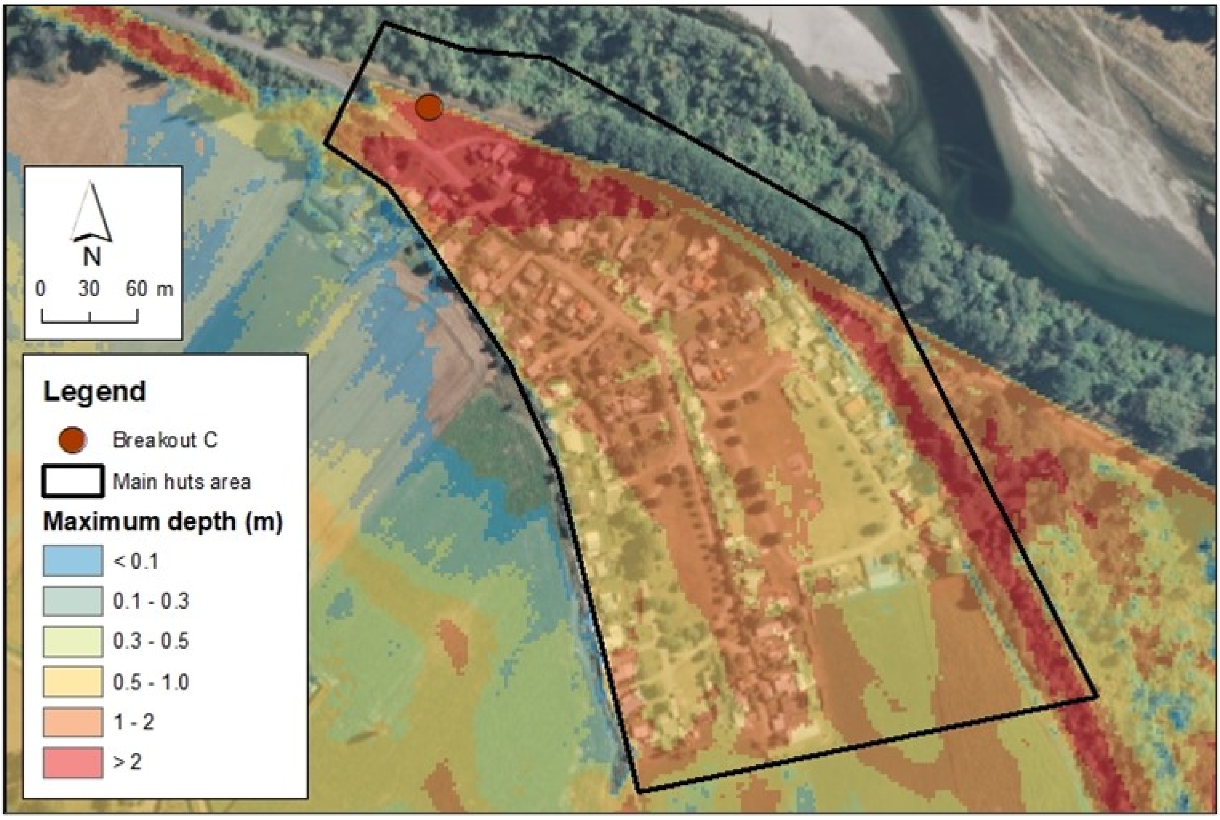


Figure 4-16: Modelled maximum flood depths for elevated SH1 and C breakouts at main huts

4.7.3 The top huts area

Breakouts at locations B and C are downstream of the top huts and will not affect these dwellings. However, upstream overflows from the river, and breakouts at location A, would cause flooding to these dwellings (Figure 4-17).

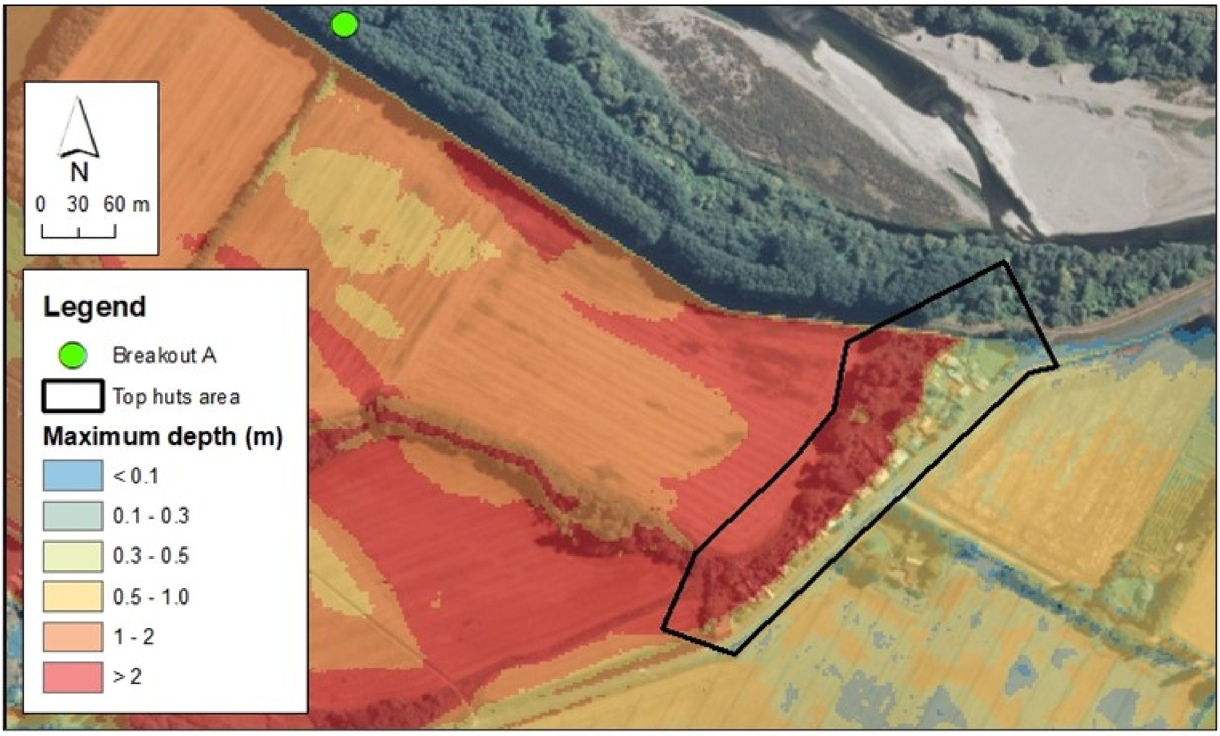


Figure 4-17: Modelled maximum flood depths for elevated SH1 and A breakouts at top huts

The dwellings are located on a ridge of higher ground, between the road and very low ground, which prevents flooding reaching high hazard depths. However, in the worst-case scenario of both breakouts combining (and using elevated outflows), the flooding at these dwellings will still be significant (~600 to 800 mm deep).

4.7.4 First 150 m of land south of where Waipopo Road runs parallel to the river

This strip of land is relatively high and is not considered as prone to the impacts of stopbank breach. Stopbank breach is considered less likely in this reach and, if it were to occur, the extent of high hazard flooding would be small. The topography of the area directs most flooding from upstream to the south and southeast, although with a breakout at location B (Figure 4-18) some, mostly shallow, water can affect the area. There are isolated depressions where deep flooding could occur. This area stays clear, or receives only moderate flooding, in all scenarios and is the least susceptible part of the whole Waipopo study area.

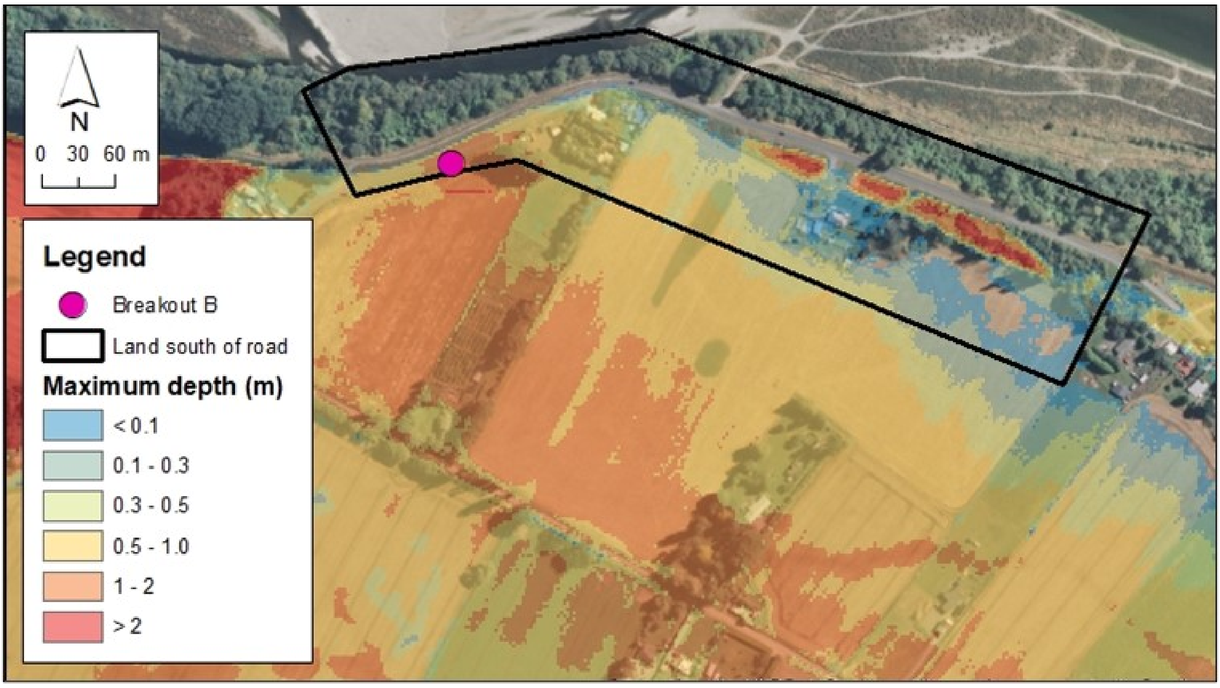


Figure 4-18: Modelled maximum flood depths for elevated SH1 and B breakouts south of road

4.7.5 Remainder of study area (rural land and lifestyle blocks)

The remaining part of the Waipopo study area is large parcels of farmland with some dwellings and farm accessory buildings. The area is susceptible to flooding from multiple sources including upstream overflows from the river around SH1 (Figure 4-19) and stopbank breaches at locations A and B.

Ground levels vary considerably but there are some dominant topographic features that influence the severity of flooding. The area is traversed by a deep, well defined swale visible in Figure 4-5. Either side of this swale are two wider and shallower depressions. Barrett Road runs through the centre of one of these depressions and the second depression is located close to the south boundary of the study area. The swale and wider depressions are major overflow paths for the Opihi River and are likely to carry 'high hazard' flooding in a range of flooding scenarios.

When considering the worst case scenario of a breakout at SH1 combining with breakouts at locations A and B, flooding over much of this undeveloped part of the study area is 700 mm to almost 1 m deep (Figure 4-20). The depths do not reach high hazard criteria for areas clear of the main channel and depressions, but they are still significant. In lesser flooding scenarios, where only one breakout (either A or B) coincides with the SH1 breakout, the depths are slightly less.

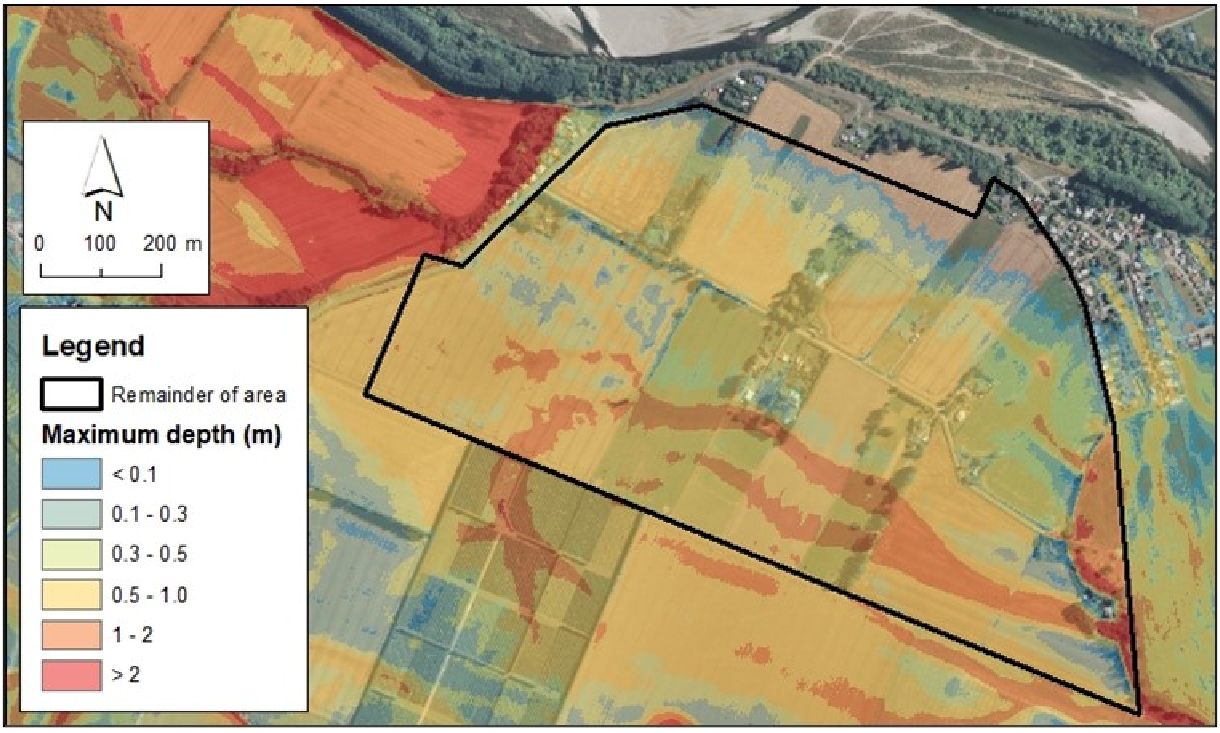


Figure 4-19: Modelled maximum flood depths for elevated SH1 breakout over remainder of area

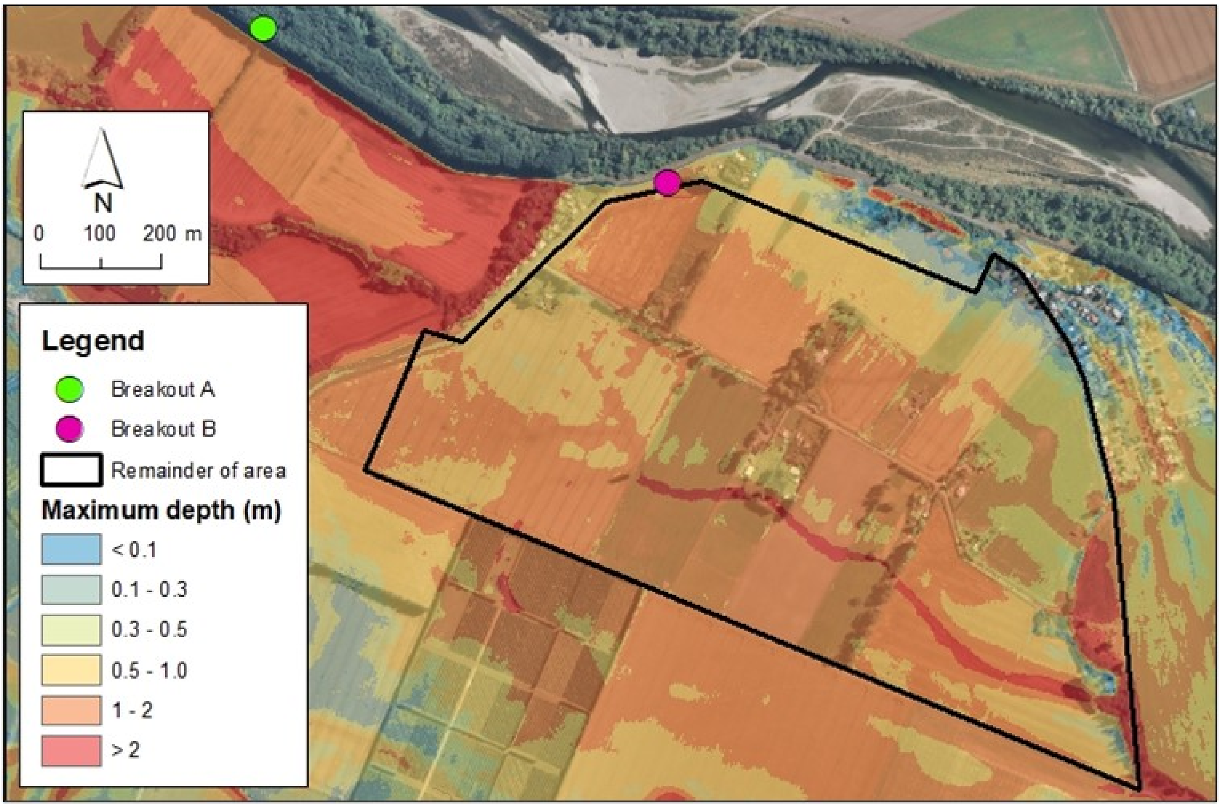


Figure 4-20: Modelled maximum flood depths for elevated SH1, A and B breakouts over remainder of area

The modelling shows flooding is substantial over all the area for several flooding scenarios. Depths are high but wide areas of isolated ground, clear of the major swale and depressions, do not trigger high hazard criteria.

4.8 Summary and conclusions – Waipopo hut settlement

The severity of flooding in the Waipopo hut settlement study area varies but most of the area is likely to be subject to flooding in major events.

The main huts area avoids serious flooding in a range of modelled scenarios when flooding originates from upstream, however there is potential of severe flooding if the adjacent stopbank breaches. This is a low probability scenario but would have high consequences for the dwellings, and for the safety of any resident present during a flood. Any future increase in development at the main huts area would increase the flood risk in a local stopbank breach scenario.

The top huts are likely to be subject to serious flooding in a wide range of scenarios, including from upstream river overflows and stopbank breaches immediately upstream. In the scenarios modelled as part of this investigation, deep flooding occurs at these dwellings but in no scenario does it trigger high hazard flooding criteria (apart from a small area within the high hazard stopbank setback area). Flooding is still significant and property damage may still occur. While not triggering high hazard criteria the flooding at these dwellings is significant in some scenarios and property damage may still result.

The remainder of the study area is prone to significant but variable flooding. Large tracts of farmed or relatively undeveloped land will be prone to severe (likely high hazard) flooding in major flood events. Between channels and depressions are higher areas where flooding is not expected to meet the definition of high hazard, but it will still be significant in extreme floods. Areas of slightly shallower flooding are scattered throughout the full study area but are limited in size.

The modelling indicates there are no large blocks of land that are entirely clear of expected high hazard flooding. However smaller, isolated pockets of higher ground, where flooding will be slightly less (and likely below high hazard criteria), do exist throughout the study area.

There is considerable uncertainty contained within in flood modelling and assumptions. The modelling should not be used in isolation but in combination with historic records, topographic information and site visits to fully determine flood hazard at a site-specific level. The uncertainty and limitations in the modelling approach are recognised but do not create doubt around the overall nature and patterns of flooding expected over the study area. Where deep flooding is shown, we expect deep flooding, and where flow paths are indicated, we expect the worst flooding in major floods. The pattern of flooding provided here is the best quantification of the flood hazard that we can produce at this time.

In future it is possible that the whole of the Opihi River will be remodelled as part of a wider investigation. While this may refine our understanding of the flood hazard in more detail, we do not anticipate future investigations to significantly change the patterns and severity of flooding expected in this area.

5 Grassy Banks hut settlement

5.1 Location and key features

Grassy Banks is a small holiday hut settlement situated at the end of Seadown Road on the south side of the Opihi River (Figure 5-1).

Figure 5-1: Location of Grassy Banks hut settlement

Figure 5-2 shows that the hut settlement contains three dwellings which are located on privately owned lots subdivided off from the adjacent farmland. Two of the lots are ~800 m^2 and the third is ~1600 m^2. Part of the larger property extends over the river stopbank. There are no other lots available in the area as the three existing land parcels border onto large farm blocks. The dwellings are between 10 m and 75 m from the river stopbank.

Figure 5-2: Location of Grassy Banks hut settlement dwellings

Environment Canterbury cannot confirm the occupation of these dwellings but assume they are only used for holiday and recreational use. The settlement is on an area of slightly higher ground, when compared with land to the south, and the stopbank immediately adjacent to the huts area is about two metres higher than ground level in the settlement.

5.2 Brief summary of historic flooding events

The Grassy Banks settlement was not flooded in the 13 March 1986 flood event, which had a peak flow in this area of about 3600 cumecs, and nominal average recurrence interval (ARI) in excess of 100 years. In 1986 the adjacent stopbank held up to the flooding in the vicinity of Grassy Banks, and the flood overflows that occurred upstream flowed to the south of the huts area. Figure 5-3 shows the 13 March 1986 flood extent in the Grassy Banks hut settlement area.

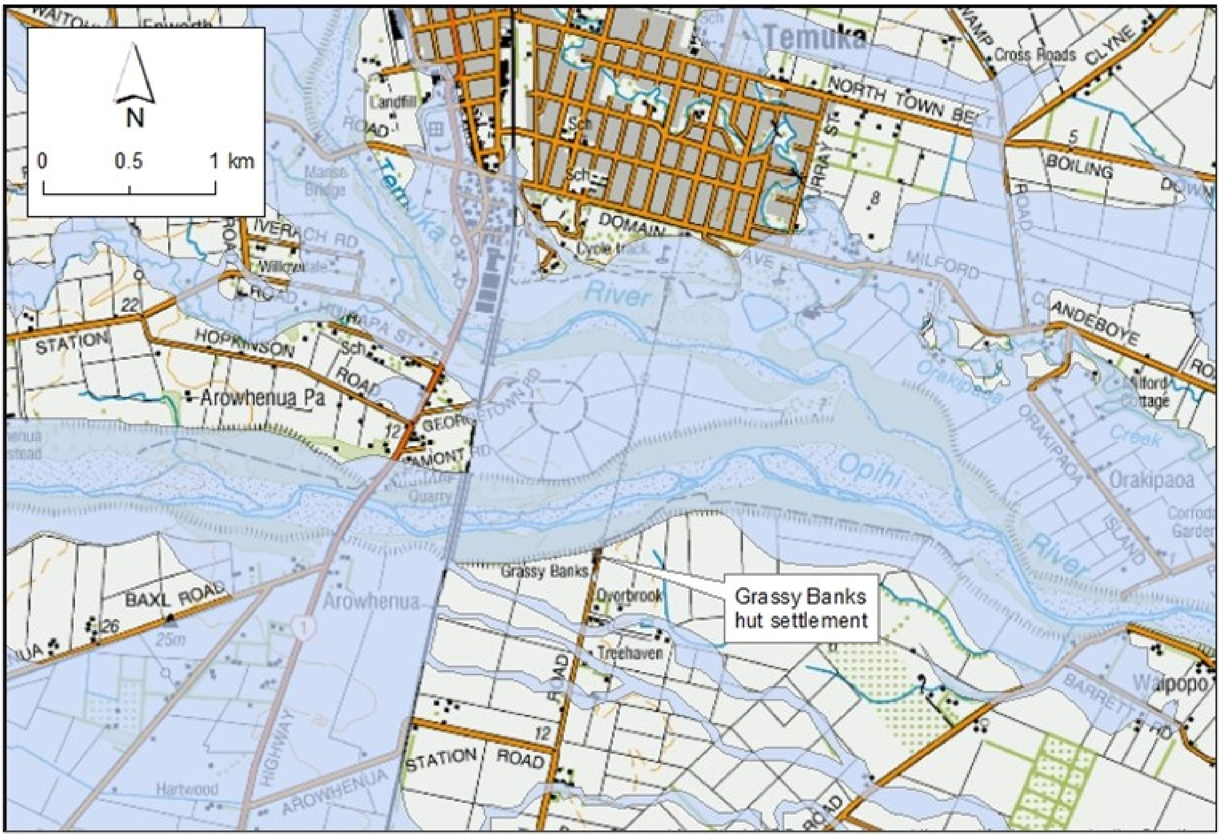


Figure 5-3: 13 March 1986 flood extent in Grassy Banks hut settlement area

On 18 April 1951 the Grassy Banks hut settlement area experienced severe flooding from the Opihi River. Multiple buildings suffered damage with anecdotal evidence from the event suggesting as many as 6 huts may have been washed away. Figure 5-4 shows the aftermath of that flood. Given there are only 3 dwellings present now, it is my assumption that after the 1951 flood the community reduced in size, but this cannot be confirmed. The records are unclear as to whether all affected buildings were in this specific location or spread along the riverbank.

5.3 Stopbank breach and setback provision

All three dwellings are within 75 m of the stopbank, with the stopbank ~2.2 metres above the hut settlement ground level. The 1986 maximum flood level at Grassy Banks hut settlement was about 770 mm below the top of the stopbank and similar freeboard was recorded for several hundred metres upstream and downstream. Flood levels in this reach would in part have been lower due to large river breakouts further upstream. The 1994 flood (~50-year ARI) also recorded similar freeboard levels in this area.

Figure 5-4: Aftermath of 18 April 1951 flood event in the Grassy Banks hut settlement area

It is likely that some form of river breakout would occur upstream of this location in a major flood although a breakout may not always be as large as 1986. The freeboard in this reach, in both the 1994 and 1986 floods, suggests a stopbank breach from overtopping is unlikely. The stopbank breach scenario here is more likely to be from lateral erosion. Appendix 3 sets out the parameters used for determining the high hazard stopbank setback area.

The determined distance over which high hazard flooding may spread at Grassy Banks, in the event of a stopbank breach, is 75 m. This means the high hazard setback line would be at the third dwelling away from the river (Figure 5-5). The stopbank setback distance relates only to the determination of high hazard flooding. While we have determined stopbank breach flooding is right on the cusp of high hazard criteria for the third dwelling, the flooding at the site would still be severe. For comparison, the 100 m setback distance, over which discretionary activity status currently applies in the District Plan, is also shown on Figure 5-5.

5.4 Flood hazard summary

In recent history, when the flood protection scheme of the Opihi River has been at a similar standard to what it is today, the Grassy Banks hut settlement appears to have avoided serious damage during major floods. Both the 1994 and 1986 floods had little impact on the settlement. Despite its very close proximity to the river, the settlement is on relatively high ground devoid of any of the major swales that are common across the Seadown and Levels Plains areas (Figure 5-6).

Connell and Miller (1992) indicates the Grassy Banks hut settlement is not expected to flood in the 100-year ARI flood event. The huts may be affected by some minor flooding from upstream break outs from the Opihi River in the 200-year ARI flood event and larger. Flood depths of 300 mm or less are expected even in the 500-year ARI flood.

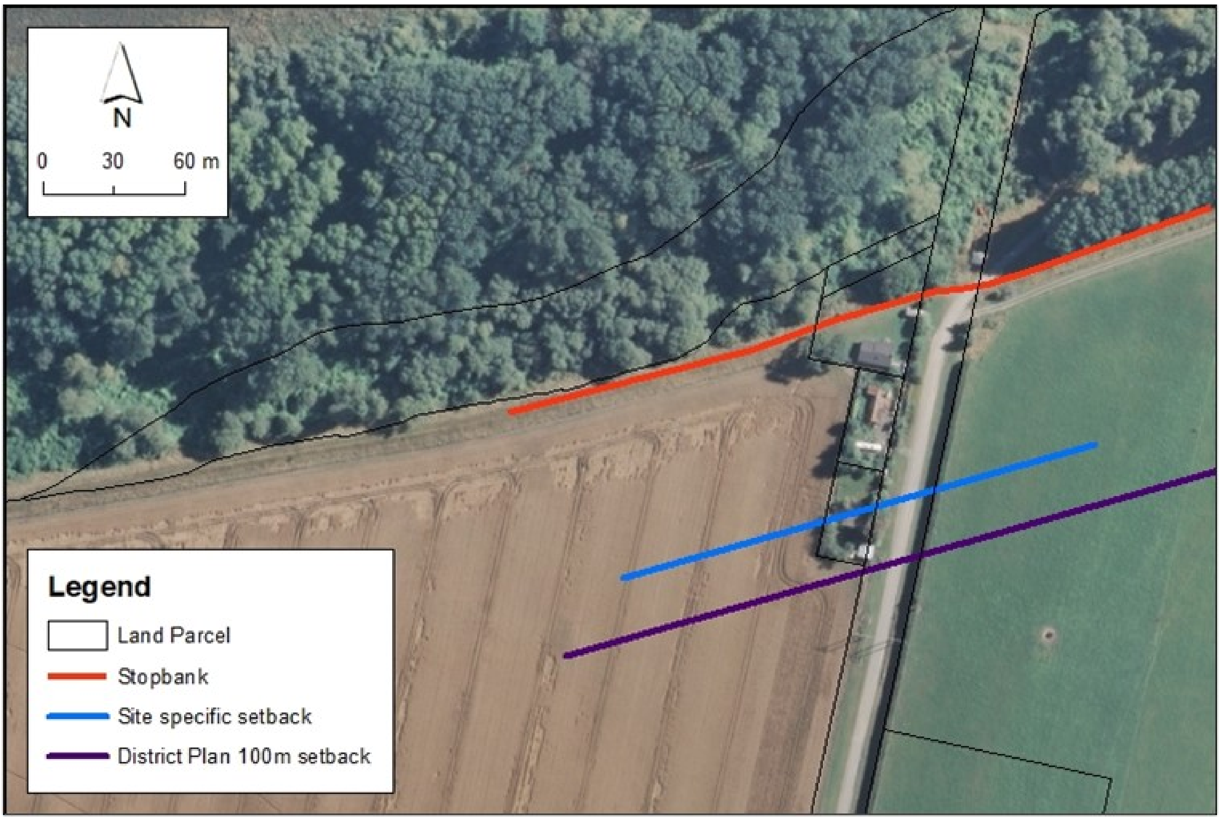


Figure 5-5: Grassy Banks hut settlement setback distances

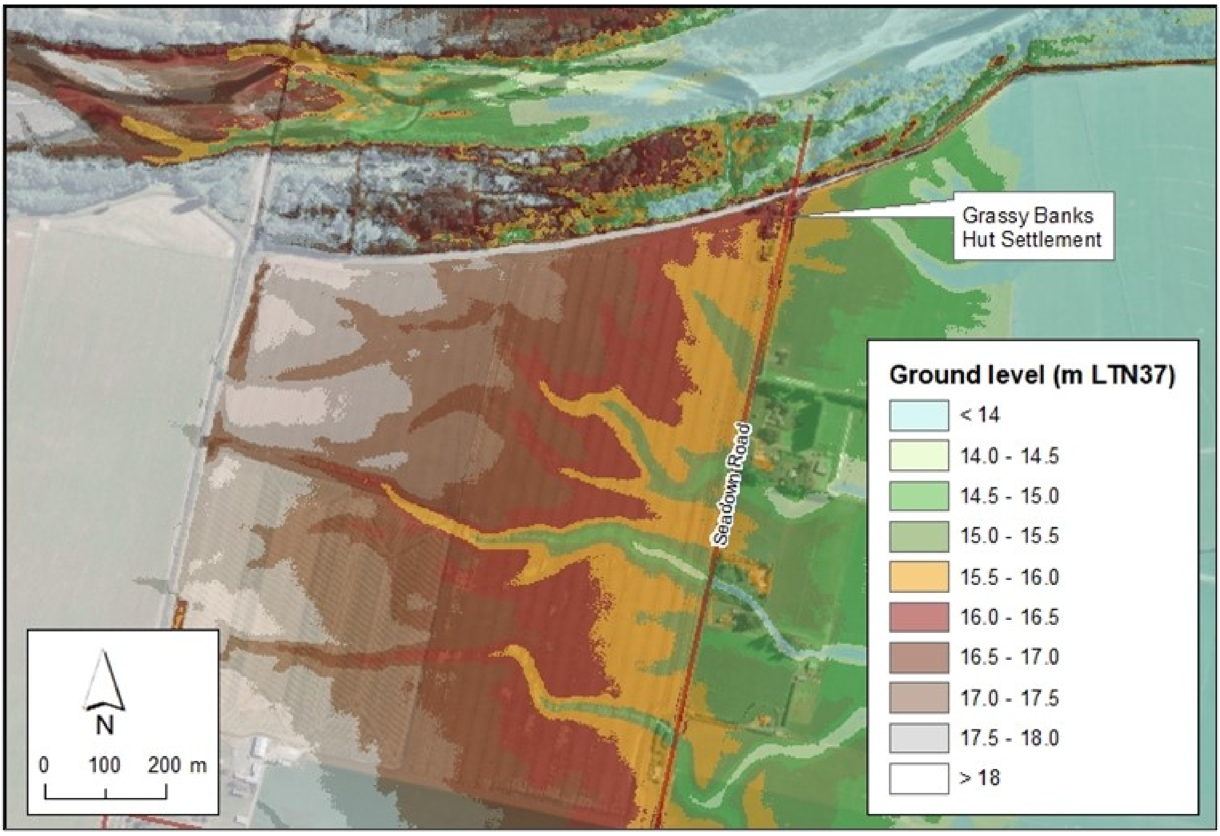


Figure 5-6: 2010 LiDAR (ground level) data for the Grassy Banks hut settlement area

Deeper flooding is expected to the south of the Grassy Banks area in large flood events if upstream breakouts occur. The deep swales that traverse the area to the south will cut road access to the settlement during major flooding.

5.5 Summary and conclusions – Grassy Banks hut settlement

Grassy Banks hut settlement can be flooded from upstream breakouts from the Opihi River. These breakouts could be described as the most expected flooding situation in the Opihi River. This flooding is likely to be shallow at the settlement itself but is likely to cut road access to the south preventing safe egress.

A low probability but high consequence source of flooding at the settlement is the adjacent stopbank breaching during a major flood. A lateral erosion breach of the stopbank is impossible to predict and could occur at a flow well below stopbank capacity. While a breach immediately adjacent to the settlement has a low probability of occurring the resultant high hazard flooding has the potential to be devastating for the three existing dwellings.

6 Mill Road hut settlement

6.1 Location and key features

The Mill Road hut settlement is located at the north end of Mill Road on the south bank of the Opihi River (Figure 6-2). This location is ~2.5 km east of Pleasant Point, around 3.2 km downstream of the Te Ana a Wai and Opihi River confluence. The Pleasant Point Stream flows west to east ~110 metres south of the settlement.

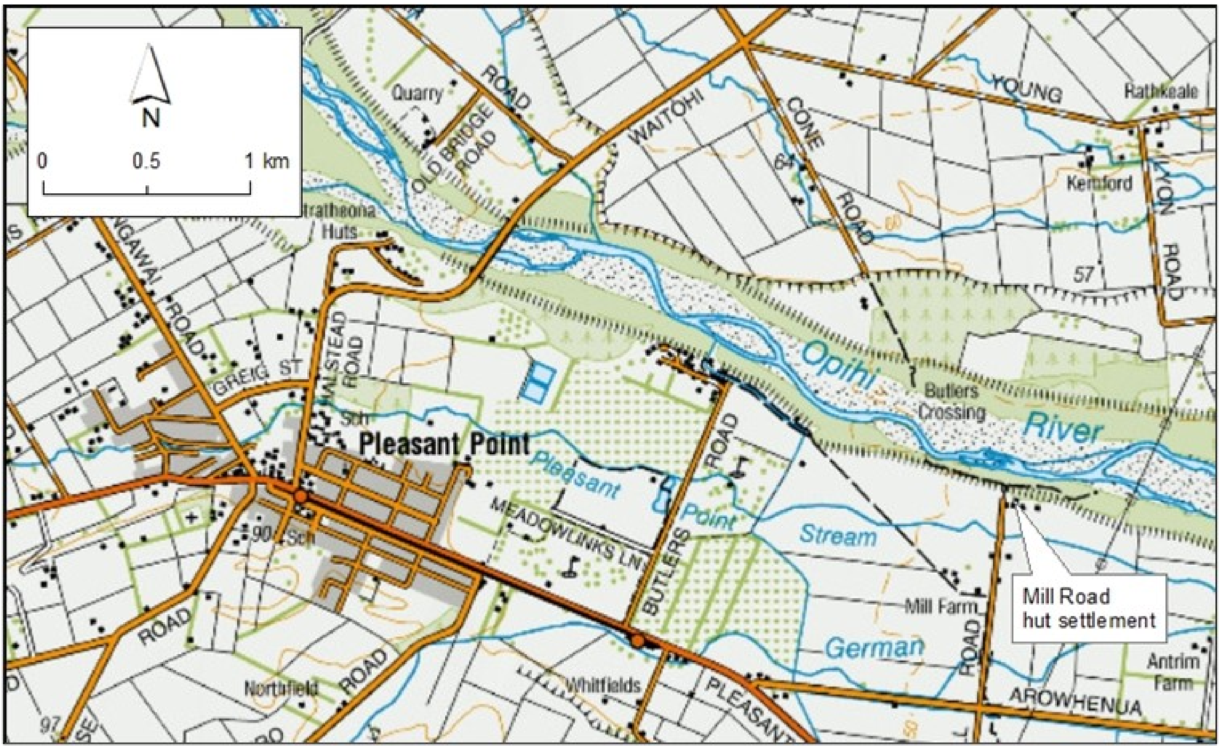


Figure 6-1: Location of Mill Road hut settlement

Figure 6-2 indicates there are 9 dwellings, and other accessory buildings, situated on a single privately-owned land parcel. Some garden areas and accessory buildings extend onto public land, around the Opihi riverbed, and it is unclear whether any of the dwellings are permanently occupied.

Figure 6-2: Location of Mill Road hut settlement dwellings

The centre of the river stopbank is ~60 metres north of the dwellings, which are all in a single row running parallel to the river - except for one small dwelling located closer to the stopbank. The stopbank in this reach is about 2.5 metres high and a deep swale traverses the area between the dwellings and stopbank (Figure 6-3). The main row of dwellings is situated on a narrow ridge of slightly higher ground between the deep swale and low ground to the south. The dwelling closer to the stopbank is also on a slight rise between two arms of the deep swale but it is slightly lower than the other dwellings.

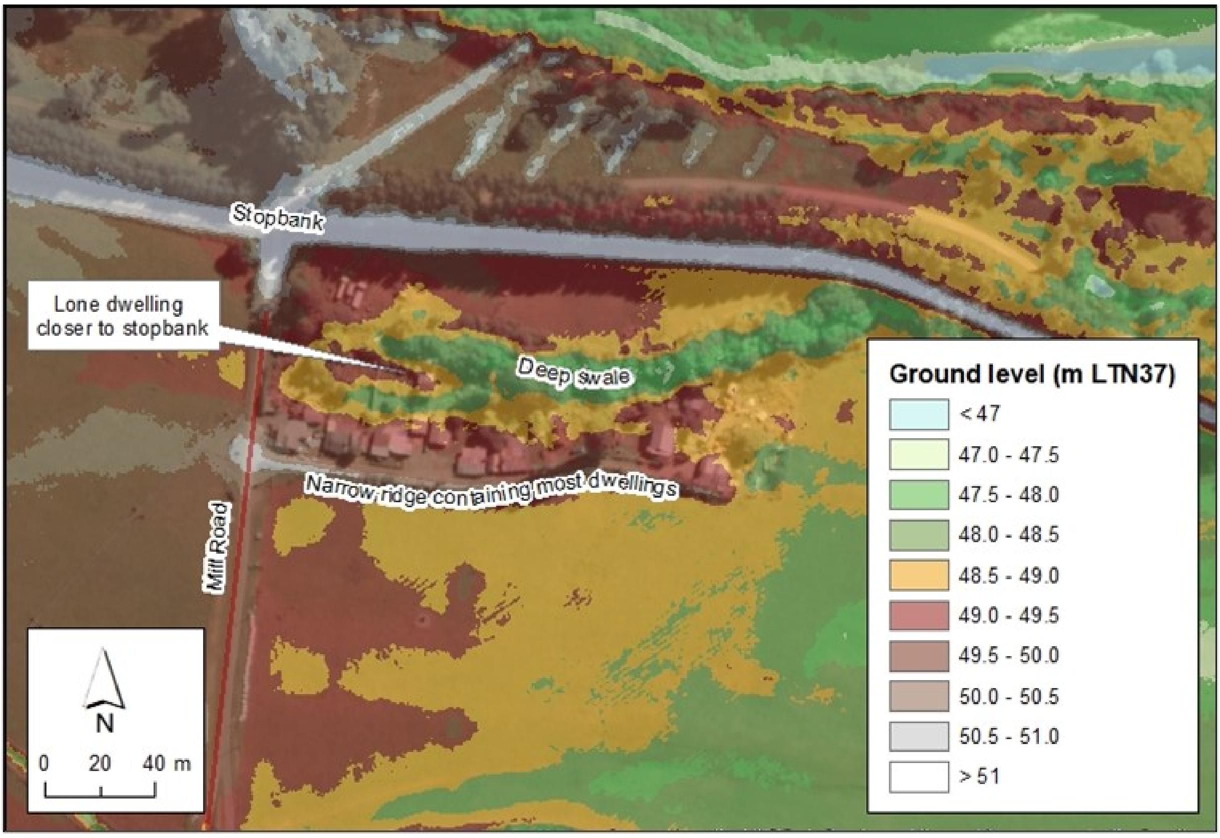


Figure 6-3: 2010 LiDAR (ground level) data for the Mill Road hut settlement area

6.2 Brief summary of historic flooding events

The Mill Road hut settlement has the same early history of flooding as experienced on the rest of the Levels Plains, with major recorded floods dating back into the 1860s. Between 1868 and 1961 there were at least 10 major floods in the Opihi River that would likely have impacted on this area (plus numerous other smaller floods). Major floods include February 1868, February 1945 and April 1951. These would all have caused serious flooding at this site.

An extract from a Timaru Herald Newspaper Article after the 1868 flood reads: "*We have since our report on Wednesday visited the scene of desolation at Parr's mill, from whence, at a distance of about a quarter of a mile, are the remains of the houses of the Parrs and Salter. The houses stood close together, and within a very few yards of the mill, when on that stormy Monday night, the flood swept over them, first carrying away the Parr's house, and almost immediately afterwards that of Salter's".* the Parrs Mill and houses referenced were situated along Mill Road. As well as the damage referenced here the flood took the lives of five members of the Salter family.

In April 1951 the flooding of this area was again severe (Figure 6-4) and, as indicated elsewhere, this was the impetus for the first flood protection scheme works. Works were improved in the late 1960s and early 1970s but the 13 March 1986 flood (largest flow on record) overwhelmed the flood protection scheme in this area causing devastating flooding.

Figure 6-4: April 1951 flood event. Floodwaters from Opihi River pouring over Butlers Road and toward Mill Road

In the 1986 flood the stopbank adjacent to the huts was overtopped and breached (Figure 6-7). Civil Defence records of the 1986 flood do not appear to have covered this settlement and it is unclear what damage the buildings suffered. However, Figure 6-6 and Figure 6-7 indicate the extent of flooding in this area. The 1986 flood had a peak flow at Saleyards Bridge of 3600 cumecs and the scheme capacity is 2410 cumecs for this reach of the Opihi River. The 1986 flood had an average recurrence interval well in excess of 100 years.

Since the 1986 flood event, the Mill Road hut settlement appears to have remained clear of any serious river flooding. This includes during the March 1994 flood which had an estimated average recurrence interval of 50 years.

Figure 6-5: 13 March 1986 - breach through stopbank (40 m wide) looking from Mill Road downstream

Figure 6-6: 13 March 1986 - Mill Road hut settlement during flood

Figure 6-7: 13 March 1986 - Opihi River floodplain below Mill Road. Hut settlement is just to the left of this photograph

6.3 Stopbank breach and setback provision

Records indicate a 40 m wide stopbank breach adjacent to this settlement during the 13 March 1986 flood (Figure 6-5). The breach occurred as a result of overtopping and subsequent scouring of the stopbank from the landward side. Overtopping of the stopbanks at this location is a realistic scenario in a super design flood so the top of the stopbank has been used as the water level for determining stopbank setback distance.

To calculate setback, three cross sections from the 2010 LiDAR were used: one upstream, one through the dwellings, and one downstream. At each cross-section line, the height of the stopbank, typical ground level at the dwellings, and typical ground level on the riverside of the stopbank were used to determine high hazard stopbank setback. The parameters used are given in Appendix 3.

The determined high hazard stopbank setback distance at Mill Road extends beyond the 100 m catch all distance referenced in the District Plan, although all current dwellings fall within both. The determined high hazard setback distance and other key features are shown in Figure 6-8. The analysis indicates that all the dwellings in this settlement are prone to high hazard flooding from a stopbank breach.

6.4 Flood hazard summary

The Mill Road hut settlement has a long history of being flooded from the Opihi and Te Ana a Wai Rivers and is likely to be subject to serious flooding from both of those sources in extreme flood events. The floodplain on the south side of the Opihi River, extending from near the Saleyards Bridge (Waitohi

Pleasant Point Road) and across Butlers and Mill Roads, is an area where major river flooding is likely in floods that exceed scheme capacity. Reasons for this include:

- The area is just downstream of the confluence of the Te Ana a Wai and Opihi Rivers. Historic flood evidence indicates these rivers can peak at a similar time during major flood events.
- A high terrace on the north side of the river at Butlers Huts (just upstream of Mill Road) prevents the Opihi River from breaking out to the north.
- Breakouts from the Te Ana a Wai River, upstream of Pleasant Point, are likely to flow into the Mill Road hut settlement area. This occurred in 1986, combining with the Opihi River flooding. If the Te Ana a Wai does not breakout upstream of Pleasant Point it would result in higher flood levels in the Opihi River below the confluence. This means a higher likelihood of stopbank overtopping in the Mill Road hut settlement area.

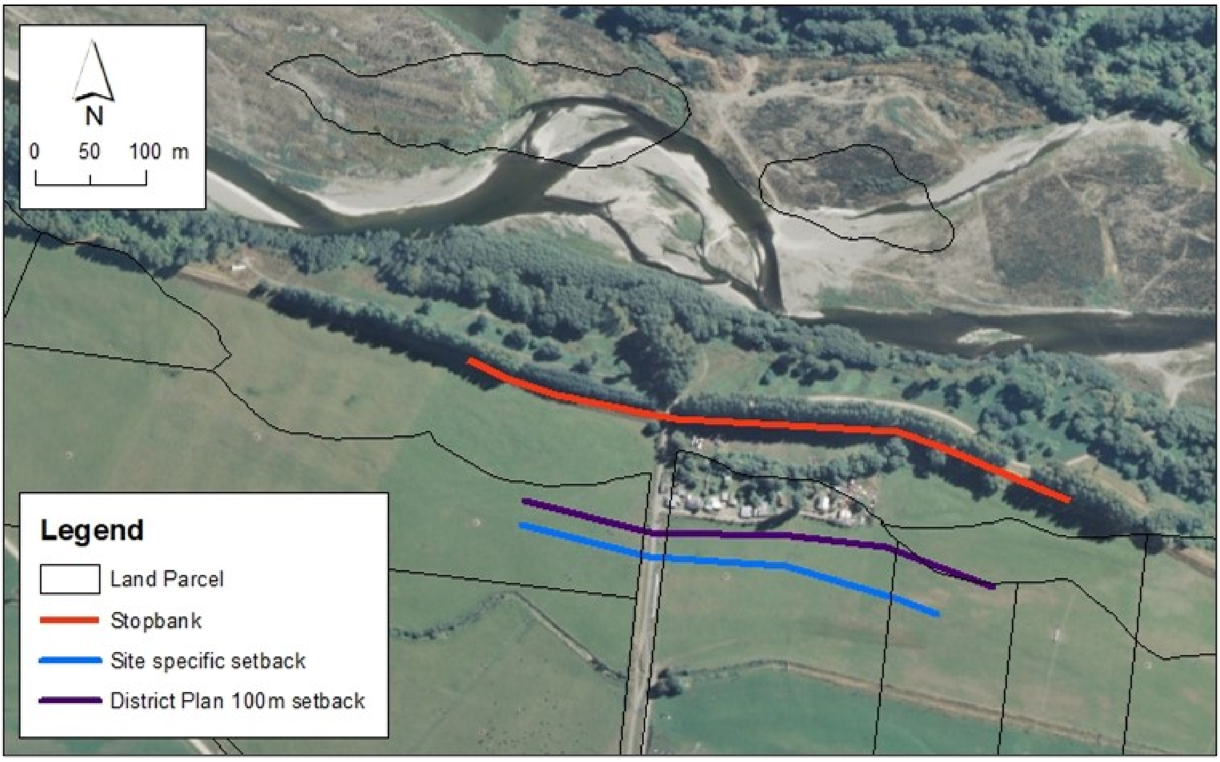


Figure 6-8: Mill Road hut settlement setback distances

Connell and Miller (1992) indicates the Mill Road hut settlement area is likely to be flooded to depths of up to one metre from upstream breakouts from the Te Ana a Wai and Opihi Rivers in the 100-year and 200-year ARI floods. In the 500-year ARI flood Connell and Miller (1992) indicates depths in excess of one metre in the settlement. Given the depths of floodwater expected at the settlement in the 500-year ARI flood, all of the dwellings can be described as being subject to high hazard flooding from upstream river breakouts.

6.5 Summary and conclusions – Mill Road hut settlement

The Mill Road hut settlement is prone to a serious flooding hazard from upstream overflows from the Te Ana a Wai and Opihi Rivers. The area has flooded several times in the past and is highly vulnerable to flooding in floods larger than scheme capacity. The settlement can be described as prone to high hazard flooding from either an adjacent stopbank breach or from upstream river breakouts. Serious property damage from extreme flood events is likely and, if the adjacent stopbank breached, dwellings could be structurally damaged or destroyed.

7 Butlers Road hut settlement

7.1 Location and key features

The Butlers Road hut settlement is located at the north end of Butlers Road, on the south side of the Opihi River (Figure 7-1). The settlement is located 800 m downstream of Saleyards Bridge (Waitohi Pleasant Point Road) and 1300 m below the Te Ana a Wai and Opihi River confluence.

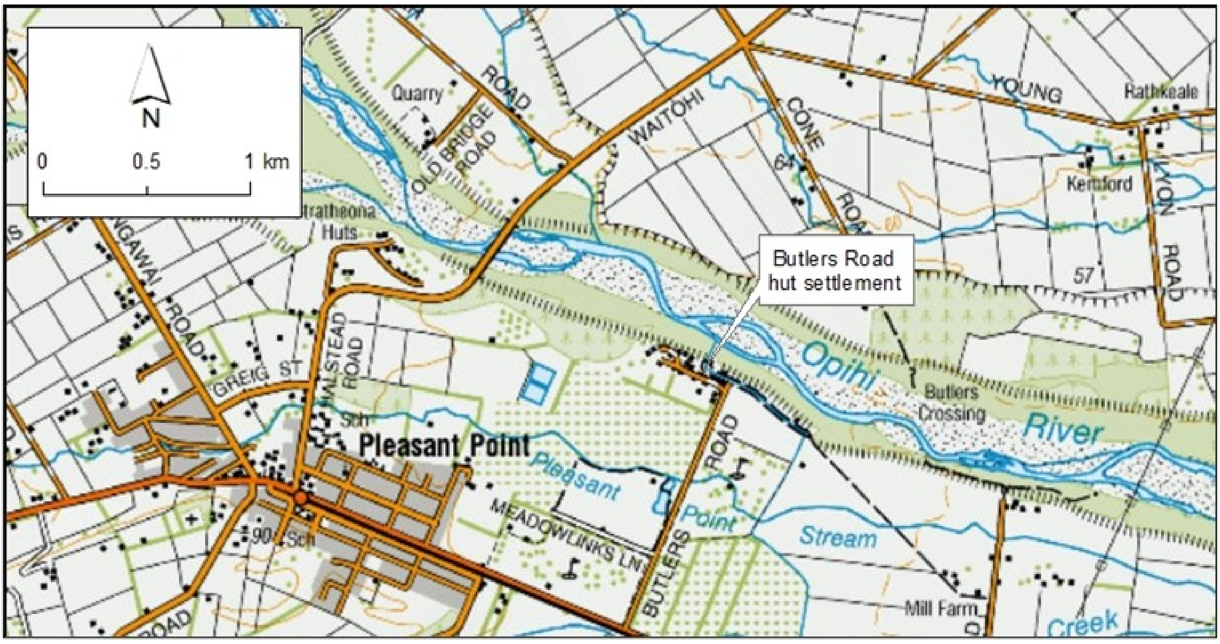


Figure 7-1: Location of Butlers Road hut settlement

Figure 7-2 indicates there are ~30 dwellings, as well as other accessory buildings in the settlement, most of which are located on a single land parcel owned by the Butlers Rd Hut Holders Society Inc. Sites are sub-leased to individual hut holders. Two dwellings extend onto public land near the river and we understand the dwellings are a mixture of permanently occupied and holiday homes.

Figure 7-2: Location of Butlers Road hut settlement dwellings

The nearest dwellings are just a few metres from the stopbank and furthest ~120 m. At least two dwellings on the river side of the stopbank. There is also a kink in the stopbank near Butlers Road, where a major irrigation intake diverts water into a canal which then flows parallel to the stopbank near the southeast corner of the huts.

There are small variations in ground level within the settlement, however there are no deep historic flow channels or areas of high ground. A narrow strip of lower land between the stopbank and the first row of houses is the only exception. There are several historic flood channels just upstream and to the south of the huts area with one deep channel running south to north immediately upstream of the huts area. This channel meets the river stopbank near the upstream end of the huts area. LiDAR (ground level) data shows this channel extends to and originates from near Te Ngawai Road approximately 2.5 km upstream (Figure 7-3). These historic flood flow channels on the floodplain will convey upstream flood flows into the Butlers Road hut settlement area (Figure 7-4).

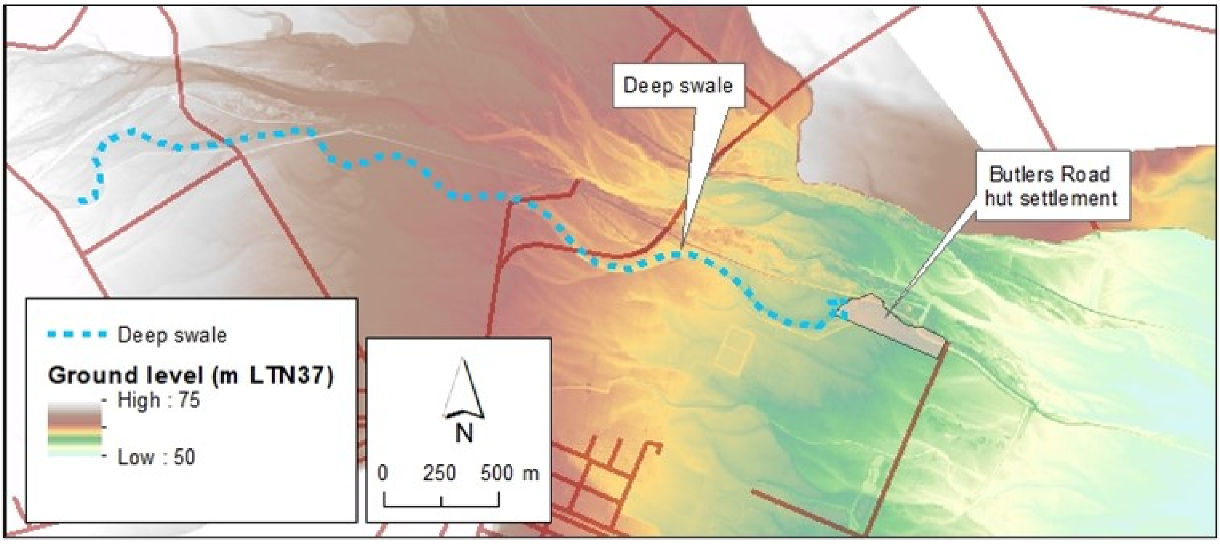


Figure 7-3: 2010 LiDAR (ground level) data for upstream of the Butlers Road hut settlement

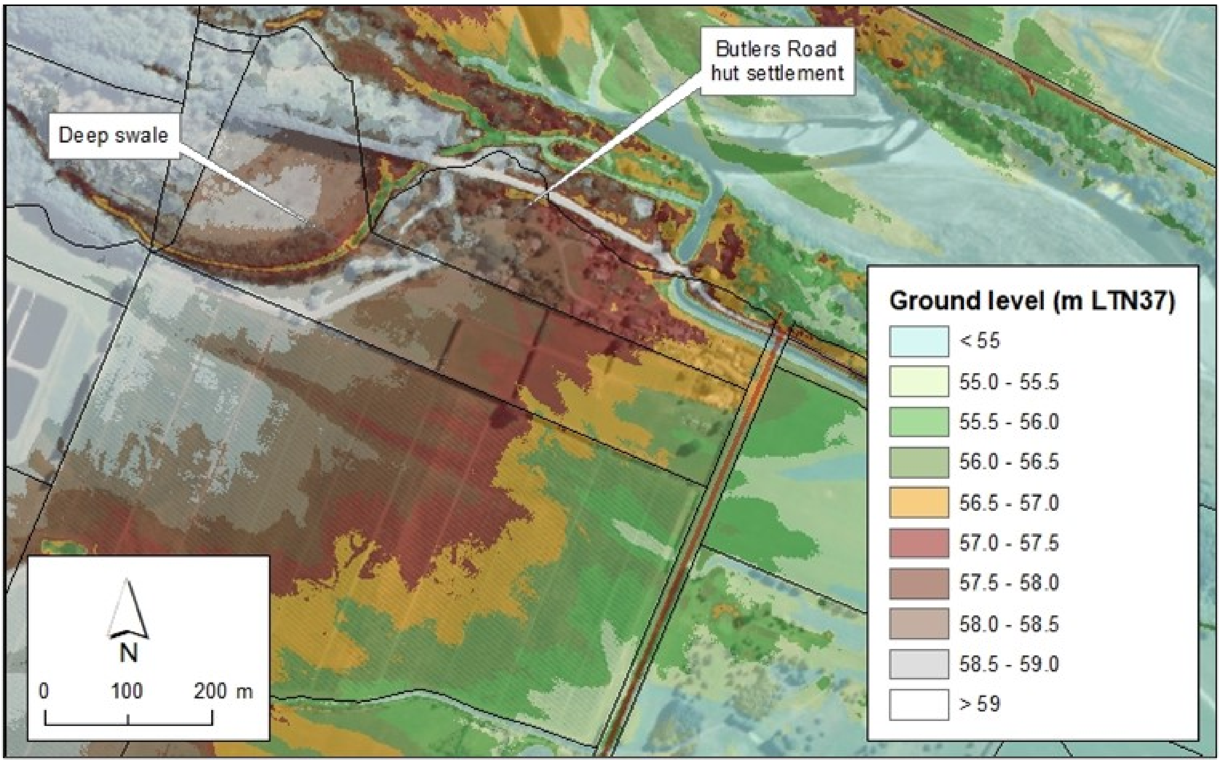


Figure 7-4: 2010 LiDAR (ground level) data for the Butlers Road hut settlement area

7.2 Brief summary of historic flooding events

The Butlers Road hut settlement has a similar history of flooding as the rest of the Levels Plains, with major recorded floods dating back into the 1860s. Between 1868 and 1961 there were at least 10 major floods in the Opihi River that impacted on this area (and numerous other smaller flooding events). These floods include February 1868, February 1945 and April 1951 - which all would have caused significant flooding at the huts. Previous investigations in this area also refer to significant flooding in 1961 and 1972. As with other areas, the stopbanks were upgraded in the late 1960s and early 1970s after being constructed in the early 1950s (Figure 7-5).

Figure 7-5: November 1952 - First Opihi River stopbank at Butlers Road hut settlement

There was a redundant stopbank on the upstream side of the Butlers Road hut settlement in 1986 which directed upstream flood flows toward the huts making flooding in the area worse. This stopbank has since been removed. The construction of the Opuha Dam in 1998 may have slightly improved flood protection at the Butlers Road hut settlement by attenuating peak flood flows in the Opihi River. Other minor improvements have been made in the flood protection scheme since 1986. These factors have improved flood protection and may reduce the frequency of expected flooding a little, but serious flooding will still occur at the Butlers Road hut settlement in an extreme flood. The area is on the floodplain of both the Te Ana a Wai and Opihi Rivers which have limited flood protection capacity, and when that capacity is exceeded serious flooding is likely in the Butlers Road hut settlement.

7.3 Stopbank breach and setback provision

To determine stopbank setback, five cross sections from the 2010 LiDAR, covering the area just upstream, through and just downstream of the hut settlement were used. As for other areas the parameters used are set out in Appendix 3.

The stopbank setback distance determined is similar to the 100 m setback used in the current District Plan to trigger discretionary consent. In parts of the hut settlement the expected high hazard setback distance is slightly more than 100 m, and in other areas slightly less. When considering the uncertainty in determining stopbank setback these differences are minimal. The 100 m setback from the centre of the stopbank appears appropriate to indicate the high hazard flooding area from a stopbank breach at the Butlers Road hut settlement.

Figure 7-6 presents both high hazard setback lines. The analysis shows most of the dwellings located at the Butlers Road hut settlement are within the expected high hazard area for a stopbank breach scenario. It is expected that dwellings that fall just outside the high hazard area will still be prone to serious flooding (albeit slightly below high hazard criteria) should the adjacent stopbank breach.

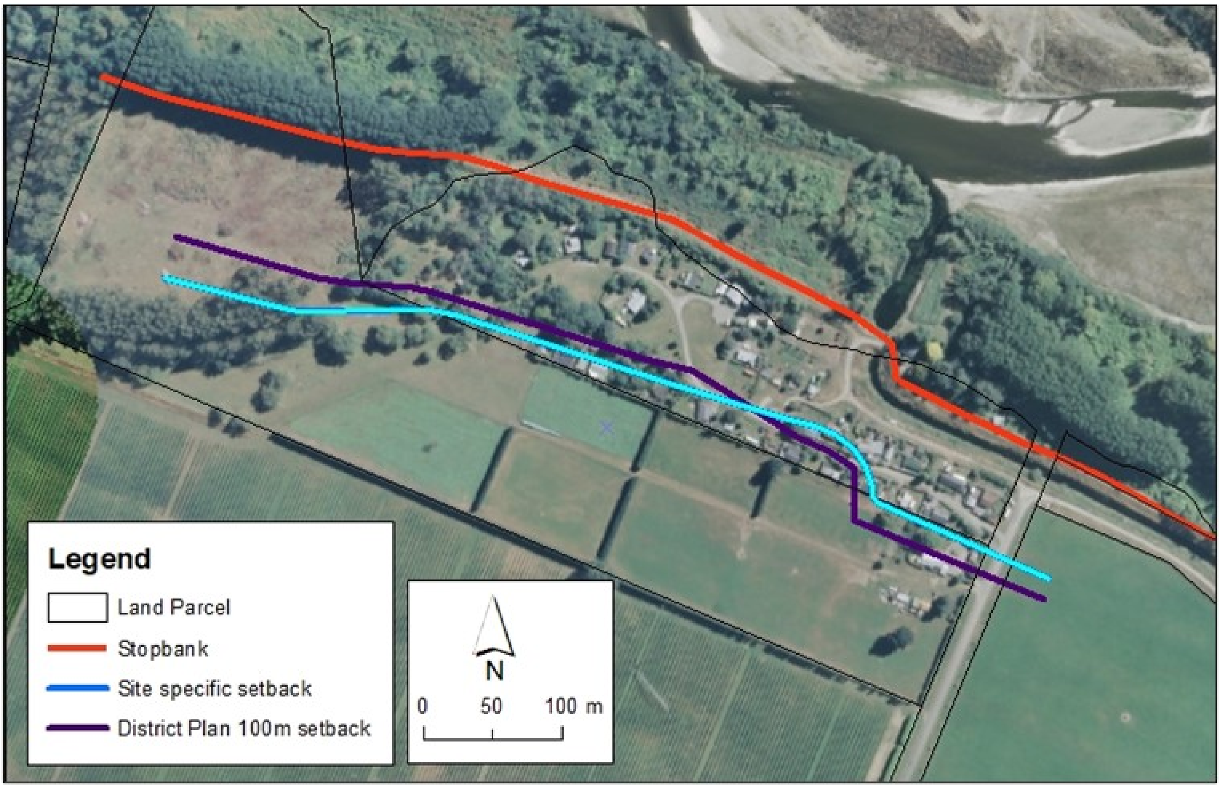


Figure 7-6: Butlers Road hut settlement setback distances

7.4 Flood hazard summary

The Butlers Road hut settlement has a long history of being flooded from the Opihi and Te Ana a Wai Rivers, and is susceptible to serious flooding from both those rivers in a major flood. The southern Opihi River floodplain from the Saleyards Bridge (Waitohi Pleasant Point Road) and past Butlers Road and Mill Road hut settlements is an area where major river flooding is likely to occur in floods that exceed scheme capacity. Some of the reasons include:

- The area is just downstream of the confluence of the Te Ana a Wai and Opihi Rivers. Historic floods indicate these rivers can peak at the same time in a major flood.
- A high terrace on the north bank of the river prevents Opihi River floodwater from breaking out to the north.
- The topography of the area indicates breakouts from the Te Ana a Wai River upstream of Pleasant Point are likely to also flow into the Butlers Road hut settlement area.
- If the Te Ana a Wai does not breakout upstream, it will result in higher flood levels in the Opihi River at Butlers Road hut settlement and therefore a higher likelihood of overtopping or stopbank breach.

Connell and Miller (1992) indicates the area will experience severe flooding from the Opihi and Te Ana a Wai Rivers in the 100 and 200 year ARI flood events with nearly all the Butlers Road hut settlement area potentially affected by flooding depths greater than one metre (Figure 7-7). In the 500-year ARI flood, all the hut settlement is expected to be flooded to depths of greater than one metre. Given the depths of floodwaters expected at the settlement in extreme flood events, all the dwellings can be described as susceptible to high hazard flooding.

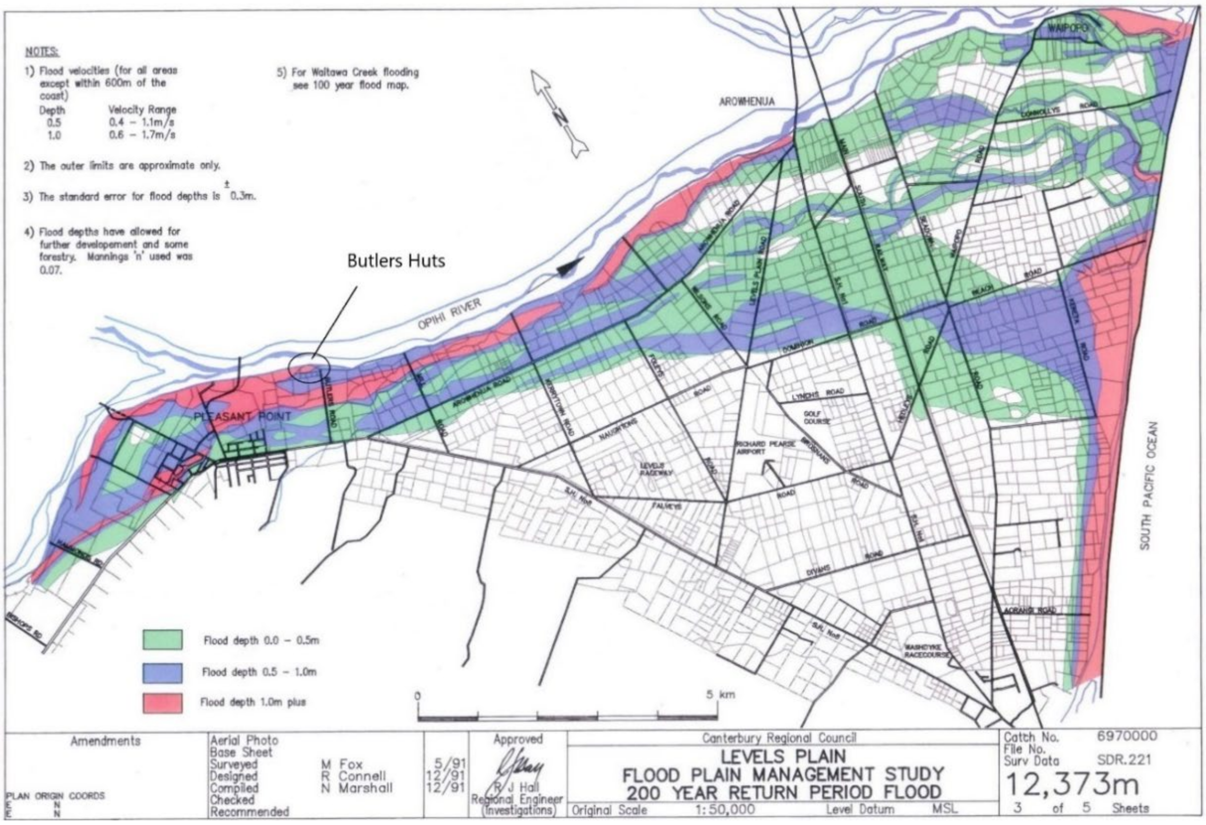


Figure 7-7: 200 year ARI modelled flood event with Butlers Road hut settlement circled [Source: Connell and Miller, 1992]

7.5 Summary and conclusions – Butlers Road hut settlement

The Butlers Road huts settlement is subject to severe flooding from upstream overflows from the Te Ana a Wai and Opihi Rivers in major floods. Historically the area has flooded several times and is vulnerable to serious flooding in events that exceed flood protection scheme capacity. The hut settlement is mostly within the expected high hazard flooding area should the adjacent stopbank breach during a flood. In major flood events high hazard flooding from upstream breakouts is expected across the whole Butlers Road hut settlement area.

Serious property damage may occur in major flood events and if the adjacent stopbank breached, dwellings could be structurally damaged or destroyed.

8 Stratheona hut settlement

8.1 Location and key features

The Stratheona hut settlement is located between the Waitohi Pleasant Point Road (Saleyards Bridge Approach) to the south and southeast, and the Opihi River stopbank to the north (Figure 8-1). Stratheona Road bisects the hut settlement, with three dwellings to the west and the remainder to the east.

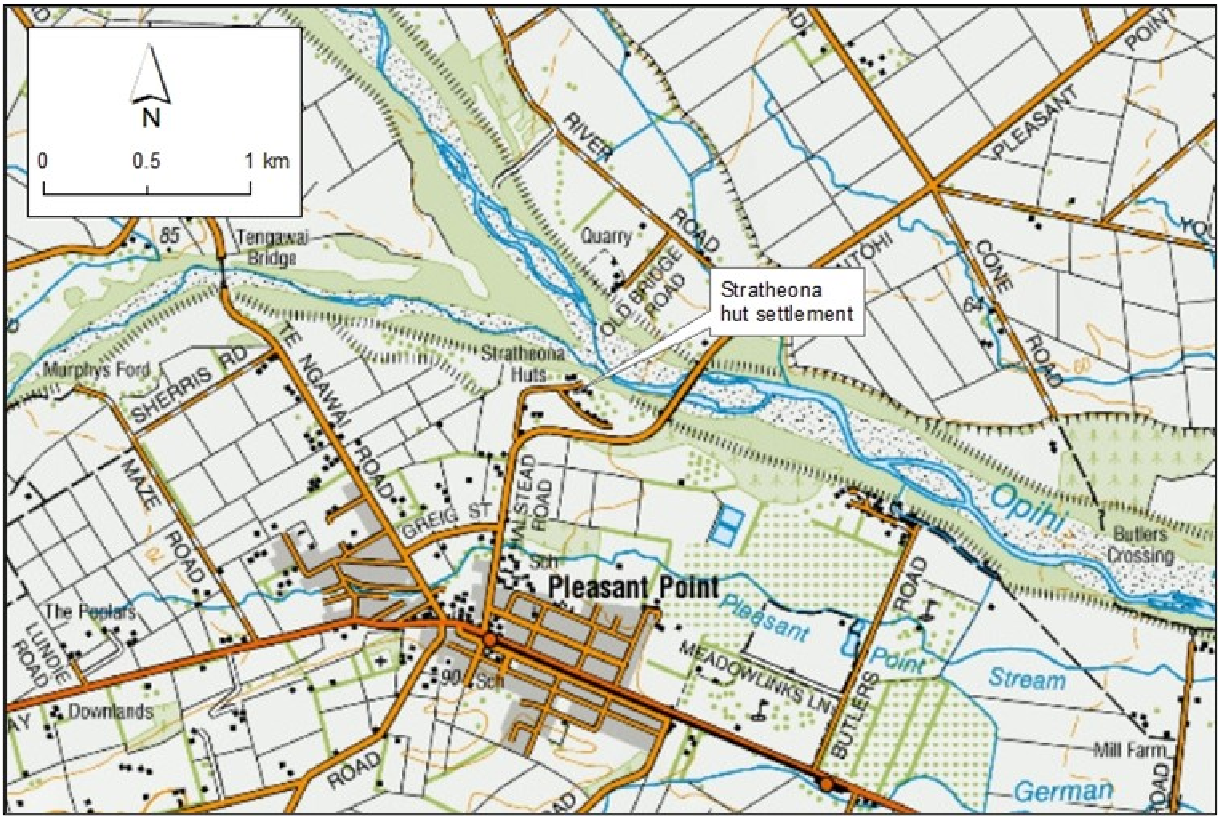


Figure 8-1: Location of the Stratheona hut settlement

There are 19 dwellings at the hut settlement, 16 of which are located on one land parcel between Waitohi Pleasant Point Road and Stratheona Road, and three on a land parcel west of Stratheona Road (Figure 8-2). Both land parcels are owned by the Timaru District Council with sites leased to the occupiers. It is unclear whether dwellings are used permanently or as holiday homes, but Canterbury Regional Council reports from the 1990s refer to some dwellings being permanently occupied.

Two stopbanks in this area are not managed by Environment Canterbury. The first runs roughly at right angles to the river, just upstream of the settlement. It is about 2 m high near the Opihi River stopbank and lower to the south where it tapers into natural ground level. The other stopbank runs southeast from the Opihi River stopbank just downstream of Stratheona Road at an angle from the river to Waitohi Pleasant Point Road. These stopbanks are shown on Figure 8-2.

The hut settlement is on land only marginally higher than the adjacent Opihi riverbed. The Opihi River stopbank, the road approach to the bridge, the upstream small bank and the bank to the northeast of the dwellings are all features elevated several metres above the floodplain. The land also starts to rise around 100 to 120 m to the south of the dwellings.

Ground levels at Stratheona vary significantly (Figure 8-3). The dwellings are positioned on a slight ridge between two wide channels that run in a northwest to southeast direction. The channels are at similar level to the Opihi riverbed and the land on which the dwellings are located is generally about 1 to 1.5 m higher. The land further south of the hut settlement is higher again.

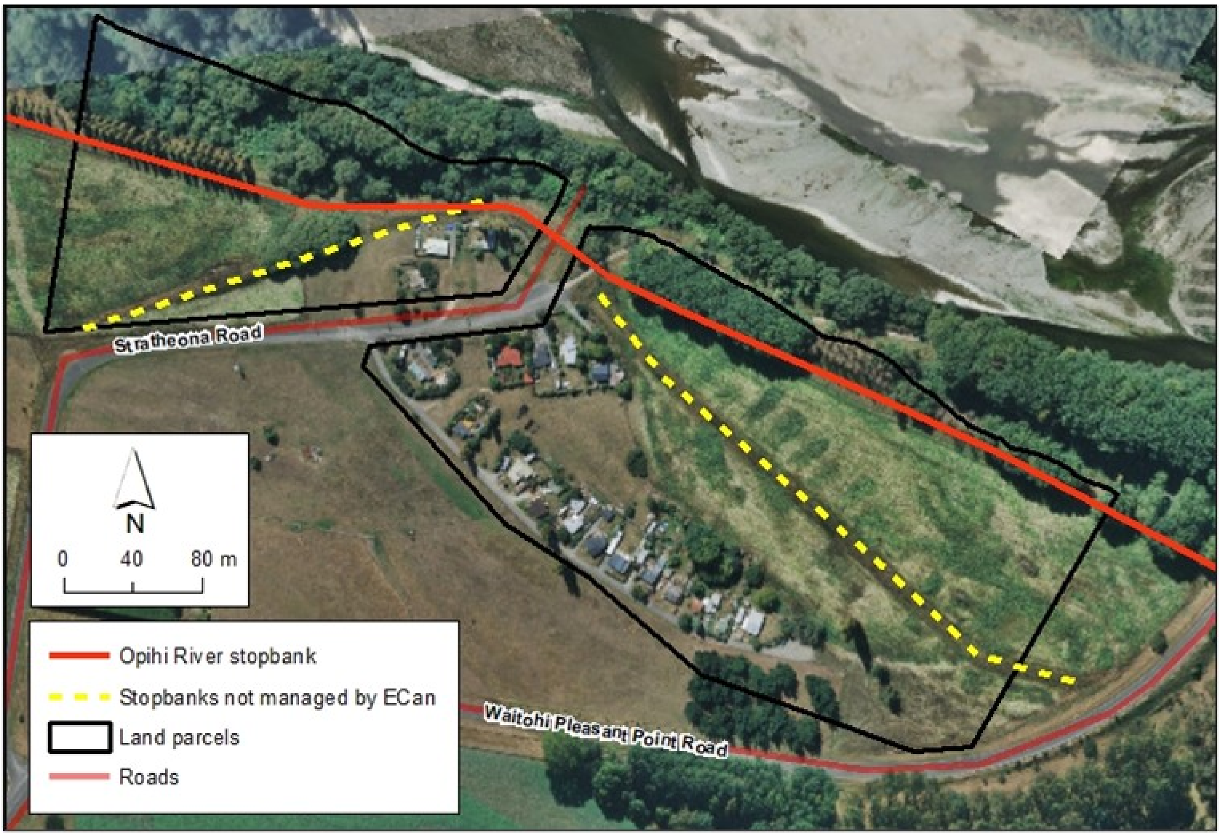


Figure 8-2: Location of the Stratheona hut settlement dwellings and stopbanks

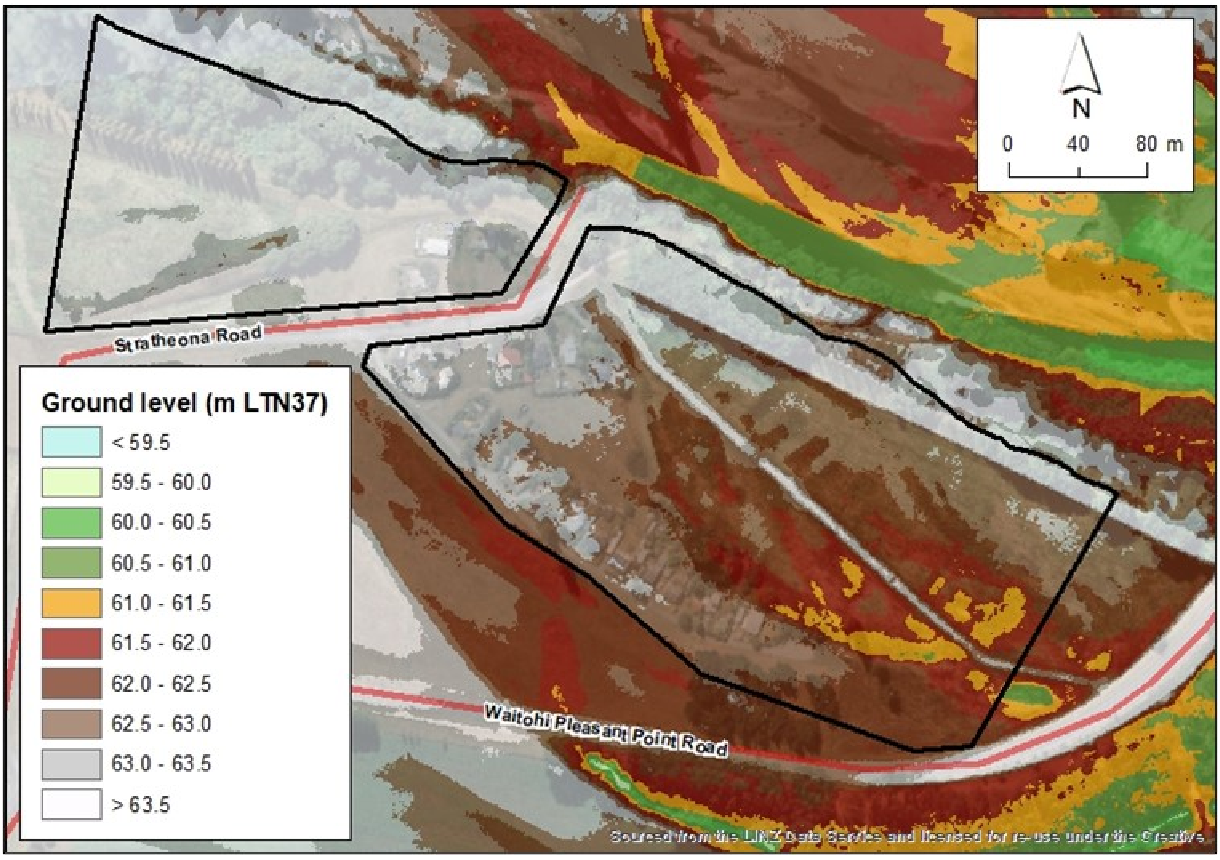


Figure 8-3: 2010 LiDAR (ground level) data for the Stratheona hut settlement area

8.2 Brief summary of historic flooding events

The Stratheona hut settlement has a similar history of flooding as the rest of the Levels Plains with major recorded floods dating back into the 1860s. Between 1868 and 1961 there were at least 10 major floods in the Opihi River that would likely have impacted on this area (and numerous other smaller floods). Major floods include February 1868, February 1945 and April 1951 which all would have caused flooding at the settlement. The 1951 flood appears to have been serious, with the Stratheona hut settlement area flooded, gravel deposited on the adjacent floodplain, and the Saleyards Bridge southern approach washed out (Figure 8-4).

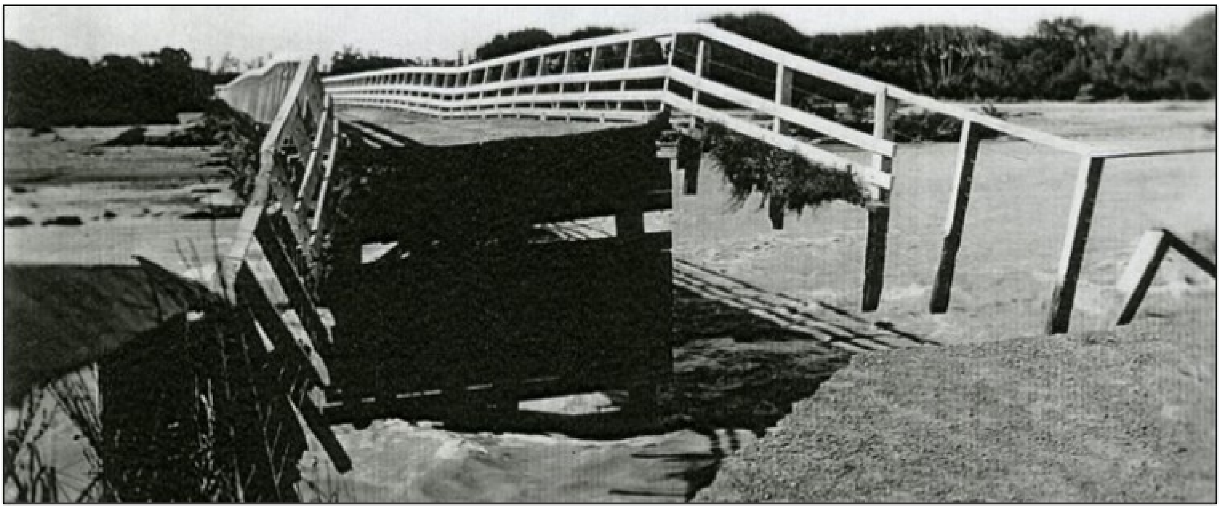


Figure 8-4: 18 April 1951 - Saleyards Bridge washout on south bank immediately downstream of the Stratheona hut settlement

The Opihi River stopbanks were upgraded in the late 1960s and early 1970s after being first constructed in the early 1950s. The 1986 flood event overwhelmed the flood protection scheme causing devastating flooding at the Stratheona hut settlement. Civil Defence records of the 13 March 1986 flood indicate 30 dwellings at the settlement were flooded. Many suffered structural damage and others were washed off foundations and destroyed. Flood depths inside dwellings ranged from 0.2 to 1.5 m with most flooded to 0.6 to 1 m above floor level. In 1986 there were more dwellings at the Stratheona hut settlement than currently (Figure 8-5) and the reduction is at least partly due to dwellings demolished by the flood not being replaced.

The stopbank at the Stratheona hut settlement did not breach in 1986 but was overtopped and partially eroded from the landward side. Most of the flooding originated from two 100 m wide breaches of the Te Ana a Wai River stopbank 700 - 900 m upstream (Figure 8-6).

Two more flood events had minor impact on the Stratheona hut settlement area. In August 1986 and March 1994 some shallow flooding affected the huts area but appears to not have had significant impact on dwellings (Figure 8-7). The August 1986 flood was likely in part because of the weakened flood protection works so soon after the devastating March flooding. The 1994 flood had an average recurrence interval in the Te Ana a Wai River of ~50 years.

Since the 1986 flood there have been improvements to the flood protection scheme that will slightly improve the situation at the Stratheona hut settlement. These include:

- Increasing the design flood protection scheme capacity of the Te Ana a Wai River from 900 cumecs (~30 year ARI flow) to 1200 cumecs (~60 to 70 year ARI flow).
- In-river improvements to both rivers including widening of river fairways, improved fairway vegetation control and stopbank strengthening.

While these works will reduce the frequency of flooding in the settlement, the area will still be seriously inundated in floods that exceed the scheme capacities of the two rivers.

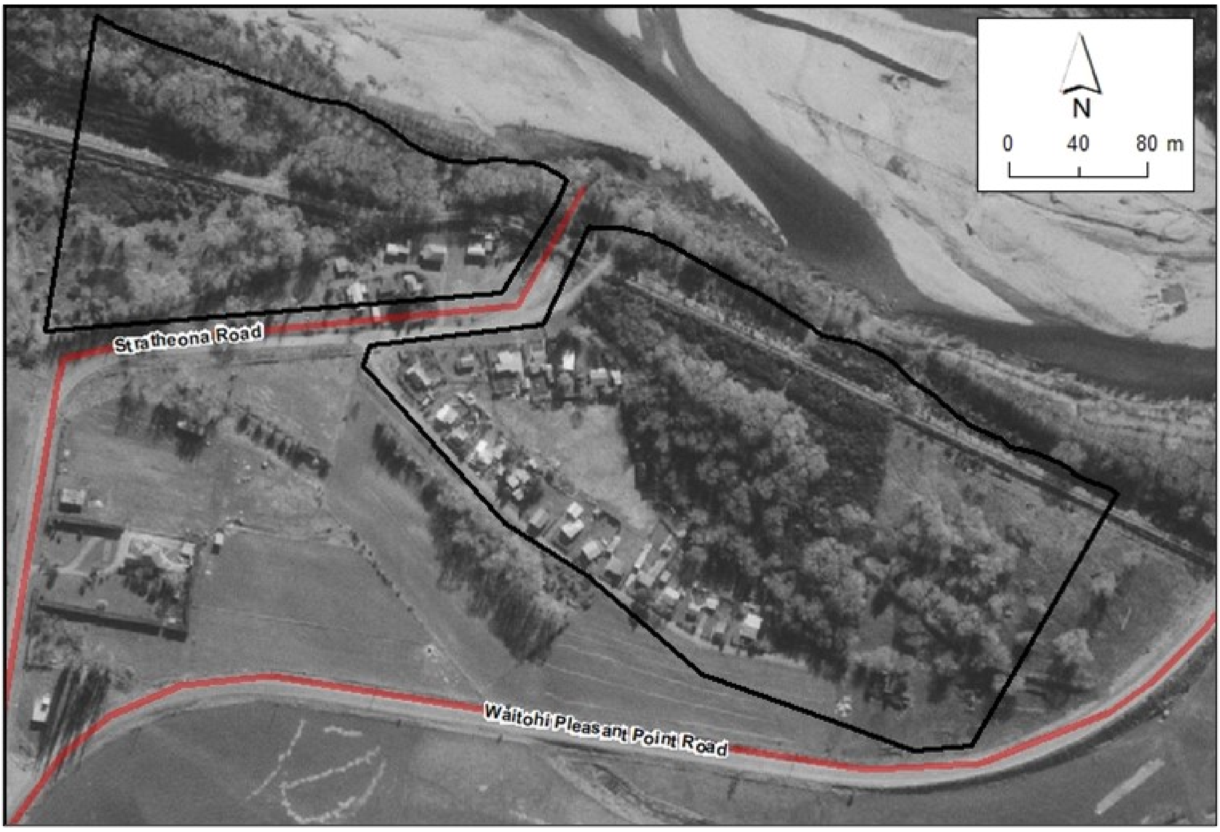


Figure 8-5: Aerial photograph of the Stratheona hut settlement around 1980 to 1984 when there were ~30 dwellings at Stratheona (prior to 1986 flood)

Figure 8-6: 13 March 1986 Flood view downstream at Te Ana Awai River Floodplain toward the Stratheona hut settlement (centre left of shot) and Saleyards Bridge

11 August 1986

19 March 1994

Figure 8-7: Stratheona hut settlement flood photographs

8.3 Stopbank breach and setback provision

The stopbank at the Stratheona hut settlement was overtopped in the 1986 flood, and suffered damage, but did not breach. While river engineering staff at Environment Canterbury have indicated some minor improvements to the scheme in this reach since 1986, there is no evidence to indicate the stopbank could not be overtopped during a major flood in future.

Increased flood water levels may occur in the Opihi River in the future if:

- the Te Ana a Wai River does not breakout upstream to the extent it did in 1986
- floods larger than the 1986 flood occur
- climate change impacts result in higher flows for the same frequency event

For these reasons it has been assumed that the top of the stopbank is the flood water level for high hazard stopbank setback distance determination.

The presence of the additional banks within the huts area complicates the high hazard setback determination. It is difficult to estimate what would happen if floodwaters breached the adjacent Opihi River stopbank and flowed into these secondary stopbanks. We have not attempted to determine setback for the area between the Opihi River stopbank and additional bank that runs at an angle form Stratheona Road to the Waitohi Pleasant Point Road. If floodwaters breached the Opihi Stopbank it is possible the secondary bank would hold them up or it may breach. This is very difficult to predict. A breach of this angled bank would not impact on the full huts area and would be a less damaging outcome than other breach scenarios.

The second bank on the floodplain is almost at right angles to the river and major upstream overflows from the river could build up on this bank and breach it. An estimated high hazard stopbank setback distance has been determined, using the parameters of that bank, for an Opihi River stopbank breach at a single location just upstream of Stratheona Road (between the two other floodplain stopbanks). If the Opihi River stopbank breached here it would outflank both other banks and their impacts would be negligible. A breach at this location is also right at the top end of the settlement and would impact on all dwellings. The determined high hazard stopbank setback distance for the area is 155 m. This is well beyond the stopbank setback distance of 100 m used in the current District Plan to trigger discretionary status. While this is a significant increase, at this location there are two relevant factors to consider:

- The stopbank breach location chosen is a worst case scenario and is a low probability outcome given the specific location the stopbank would need to breach. A stopbank breach upstream or downstream of that point would be affected by the additional banks on the floodplain and in both cases the resulting impacts on the hut settlement are likely to be less. A downstream breach would miss some of the existing dwellings.
- All the settlement is considered susceptible to high hazard flooding from floodwaters originating from further upstream, making the specifics of a stopbank setback distance less critical.

The setback distance from the bank on the floodplain upstream of the huts is shown in Figure 8-8. All dwellings within this area are already covered by the Opihi River setback distance and this setback distance can be considered general information only. It is possible for none, one, or both of the stopbanks to breach during the same flood.

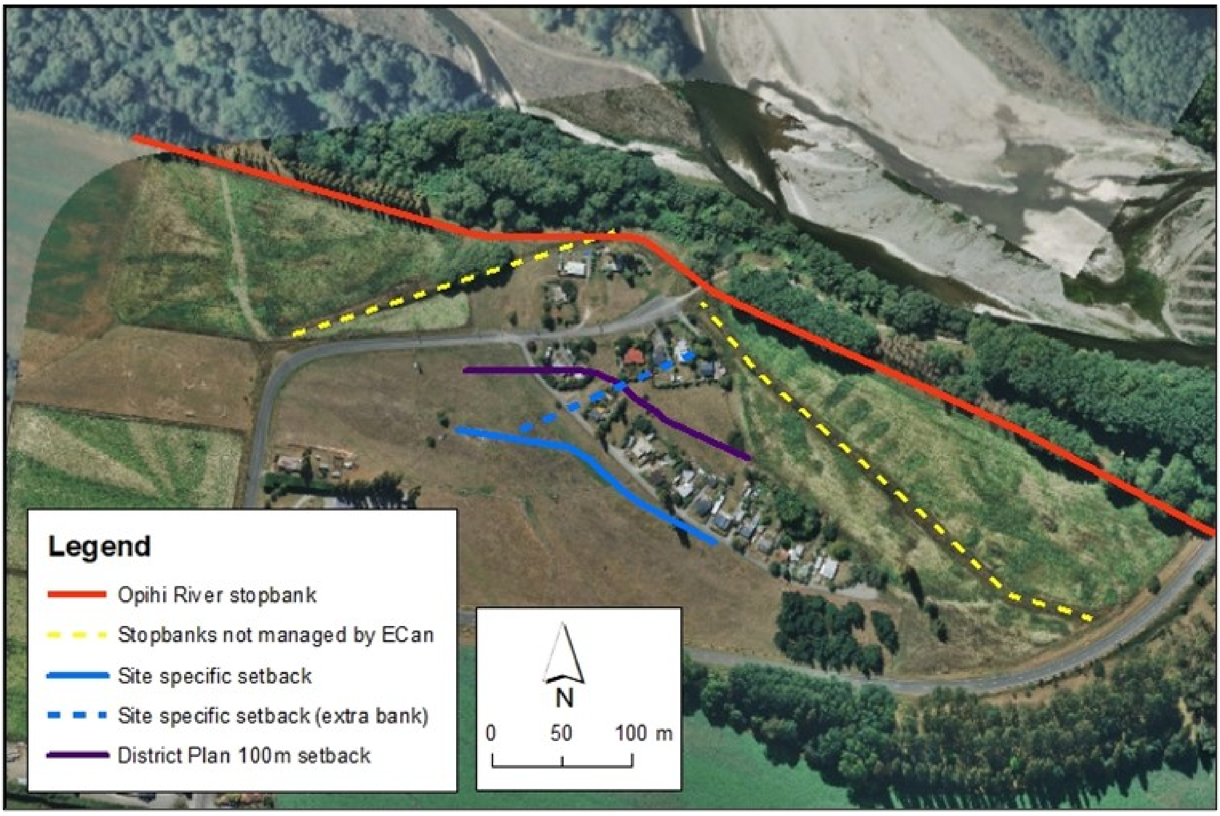


Figure 8-8: Stratheona hut settlement setback distances and stopbank locations

8.4 Flood hazard summary

Some improvements to the river protection works that protect the Stratheona hut settlement may reduce the frequency of flooding at the settlement. However, when extreme floods occur that exceed the scheme capacity, serious flooding of the settlement is likely.

The stopbanks surrounding the settlement, and the raised bridge approach, will keep some floodwater away from the dwellings. However, once floodwaters overwhelm these features, they may confine flood flows and increase the flooding. Floodwater could build-up to a higher level before overflowing into the settlement or, with the road approach, hinder the passage of floodwater away from the area.

Three floodplain investigations have been carried out by Environment Canterbury and its predecessor organisations that indicate severe flooding could occur at the Stratheona hut settlement in future events. The investigations are the Butlers and Stratheona Huts Draft Floodplain Management Study (Connell, 1991), the Levels Plains Floodplain Study (Connell and Miller, 1992) and the Te Ana a Wai River stopbank capacity investigation (Wild, 2016). The latter study was not focussed on flooding at the huts, but it still demonstrates the potential for large flood overflows into the Stratheona hut settlement area. The flood risk at this settlement is high and expected flood depths and velocities are likely to meet high hazard criteria.

8.5 Summary and conclusions – Stratheona hut settlement

The Stratheona hut settlement is prone to severe flooding from upstream overflows from the Te Ana a Wai River. The area has flooded from this source several times historically and is vulnerable to deep flooding in extreme floods. The settlement is also likely to experience high hazard flooding if the adjacent Opihi River stopbank breached. This is a lower probability situation that would have high consequences. Serious property damage from extreme flood events is likely and dwellings could be structurally damaged or destroyed.

9 Collett Road hut settlement

9.1 Location and key features

The Collett Road hut settlement is located at the end of Collet Road on the west (true right) bank of the Opihi River about 3 km upstream of the confluence with the Te Ana a Wai River (Figure 9-2).

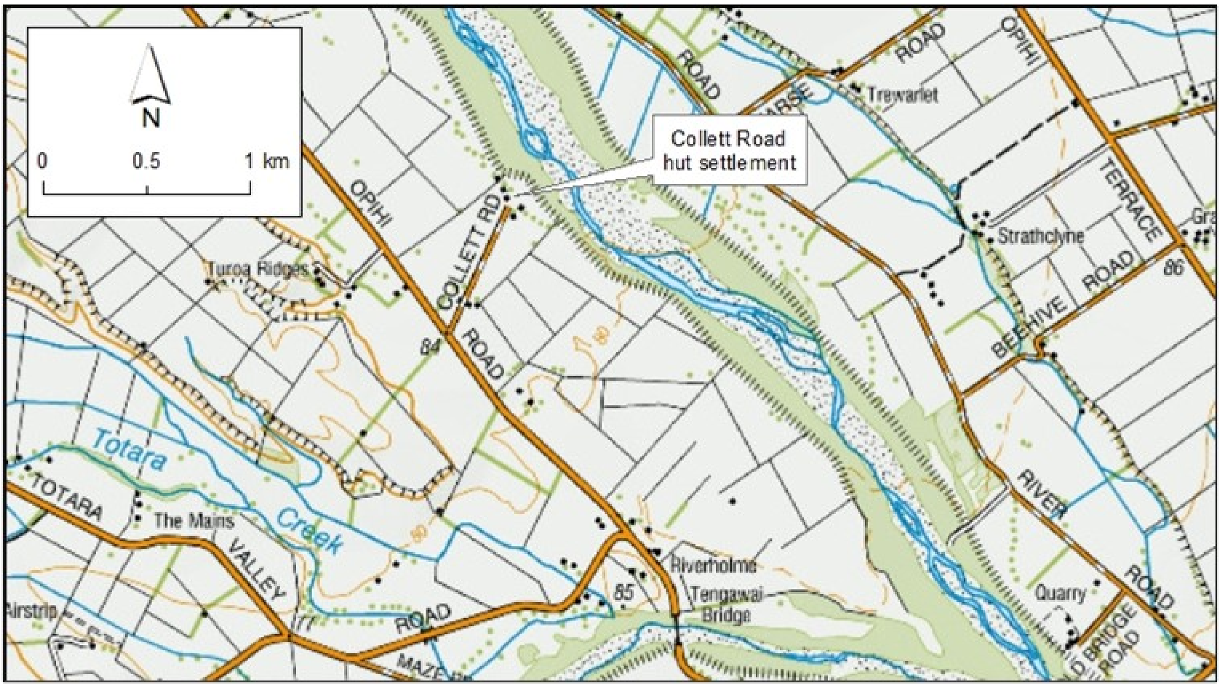


Figure 9-1: Location of the Collett Road hut settlement

There are 6 to 8 dwellings in the hut settlement that are located on two separate land parcels that are privately owned by the same person (Figure 9-2). This settlement does not appear to have been previously recognised as a recreational hut settlement and is therefore zoned as rural, not recreational, land. The dwellings range from 40 to 150 m from the river stopbank and the flood hazard is comparable to other communities along the Opihi River.

Figure 9-2: Location of the Collett Road hut settlement dwellings and stopbank

9.2 Brief summary of historic flooding events

Historic aerial photographs indicate that in the 1930s much of the Collett Road hut settlement area was located on active riverbed or berm of the Opihi River. By the early 1970s, when major flood protection scheme upgrades were undertaken, the land where the settlement is located appears to have been "reclaimed" from the river (Figure 9-3). Prior to the scheme upgrade in the 1970s the hut settlement area would have been flooded frequently, and at times severely.

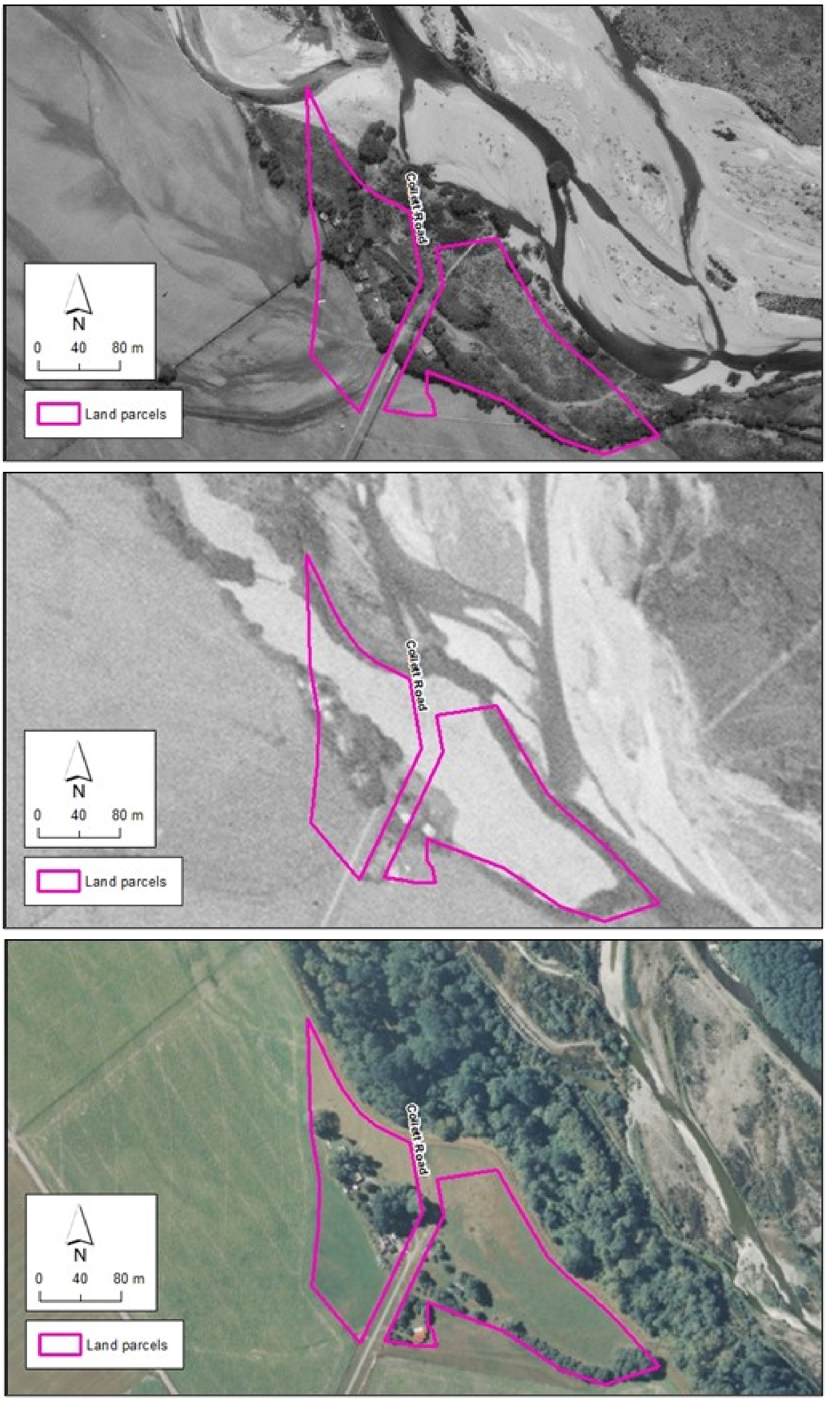


Figure 9-3: Aerial photographs of the Collett Road hut settlement area

Opihi River flood protection works held up well from the early 1970s until the 13 March 1986 flood, when stopbanks were overwhelmed and serious flooding again occurred on this property (Figure 9-4). The 1986 flood in this reach of the river had an estimated peak flow of 1800 cumecs and an ARI of about

100 years. The Opihi River flood protection scheme has a design flood capacity in this reach of around 1500 – 1600 cumecs and nominal ARI of around 50 years.

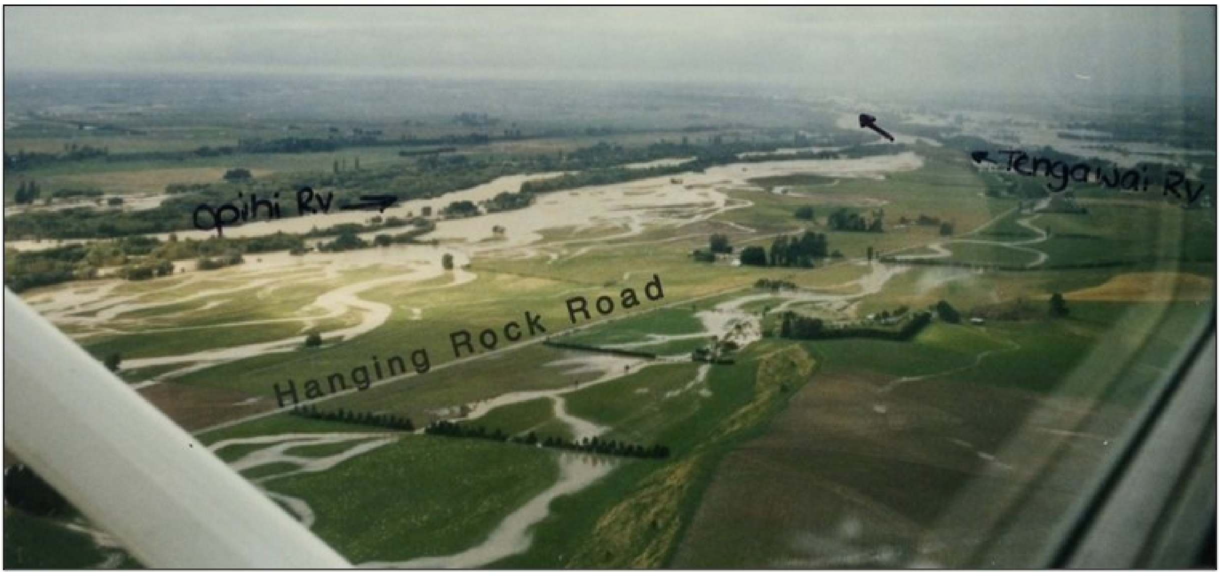


Figure 9-4: 13 March 1986 - view southeast (downstream) across Opihi Road (referred to as Hanging Rock Road then) and Collet Road. Huts are within the semi-circle of trees adjacent to the "Opihi River" text on the riverbank

In 1986 the stopbank was overtopped over a long distance extending from about 300 m to 700 m upstream of the Collett Road settlement. The stopbank suffered some damage but was not breached. Had the stopbank breached upstream of the property, the flooding at the dwellings could have been worse than experienced.

Civil defence records from 1986 indicate all eight dwellings in the settlement had floodwaters inside them. The records weren't detailed but stated the names of the eight owners and the depth of inundation for each dwelling. Flood depths ranged from 0.15 to 0.6 m above floor level. While the flooding was significant, flood velocities appear to have been relatively low and no structural damage was reported. A resident of the area spoken with in 2013 referred to the flooding as "backwater" flooding and confirmed that flow velocities were low.

Environment Canterbury has no record of flooding since the 1986 flood and this includes during the 19 March 1994 flood (50-year ARI flood) and the 1997 breach of the partially constructed Opuha Dam.

9.3 Stopbank breach and setback provision

The 1986 flood showed the river stopbank in this reach can be overtopped in an extreme flood (Figure 9-5). To determine stopbank setback, the top of the stopbank was adopted as the flood level. The parameters used to calculate high hazard stopbank setback area are given in Appendix 3.

The high hazard stopbank breach zone determined for the settlement is less than the 100 m distance referenced in the District Plan (Figure 9-6). At the upstream end of the settlement the setback distance is 90 m and includes some of the dwellings. Further downstream the dwellings are further from the stopbank and the high hazard stopbank setback distance is less. Most of the dwellings in the hut settlement are therefore not considered susceptible to high hazard flooding from stopbank breach. Some of these dwellings would also have fallen outside the 100 m distance used as a trigger in the District Plan.

Figure 9-5: Opihi River stopbank on true right bank ~300 m upstream of Collett Road following overtopping during the 13 March 1986 flood

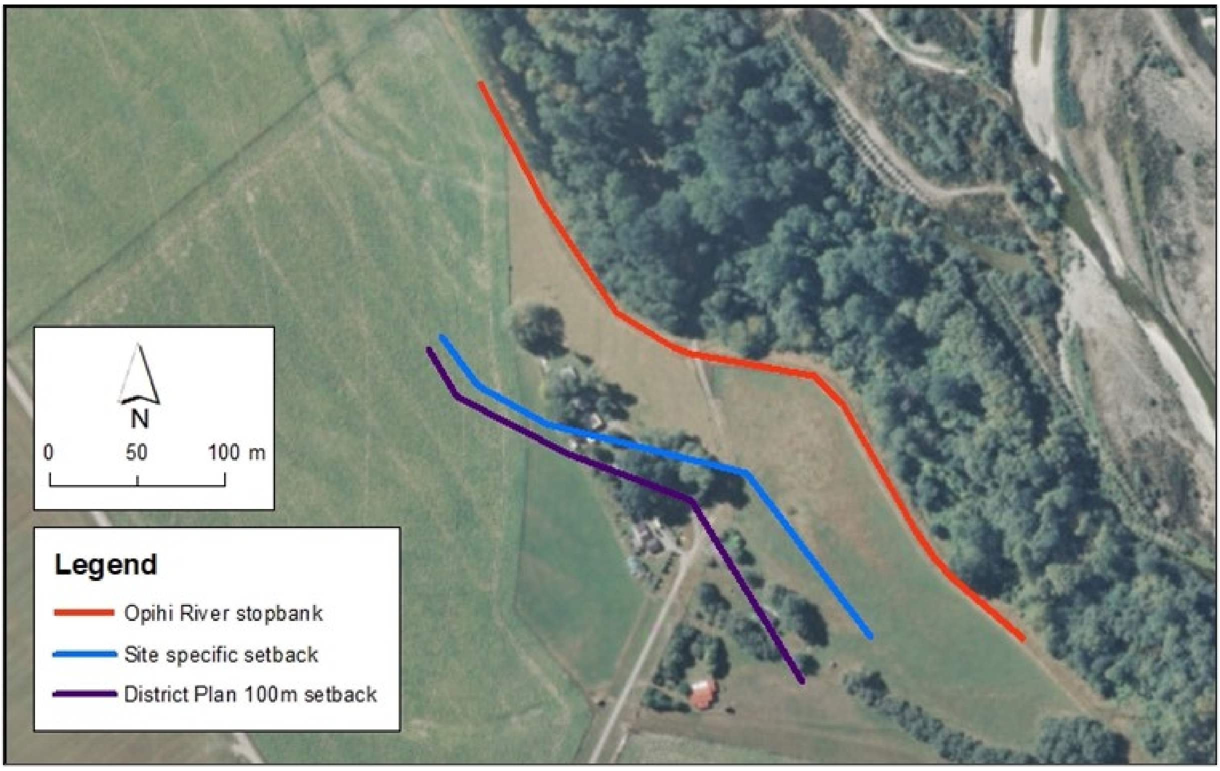


Figure 9-6: Collett Road hut settlement setback distances and stopbank location

9.4 Flood hazard summary

The topography, LiDAR data and historic flood information all indicate this settlement is situated on the floodplain of the Opihi River and may have formerly been part of the Opihi riverbed or berm. On a smaller scale, the topography indicates the settlement is part of a wide area of floodplain extending out from the river to the toe of high ridges located to the west of Opihi Road. Many historic flow channels traverse the area upstream of the property and will carry floodwaters into the general hut settlement area.

The Opihi River flood protection scheme is designed to contain flood flows up to and including the 50-year ARI flood. Breakouts are therefore expected in larger floods. Any breakout that occurs within the long reach of the river upstream of this property will cause flooding within the hut settlement.

The 1986 flood event showed the potential for flooding of the dwellings. While this flood was an extreme event, the flooding could have been worse had the stopbank fully breached upstream. Flooding at the settlement has the potential to be more damaging if the stopbank upstream is breached, or if flood flows are larger than 1986.

Environment Canterbury does not hold enough information to determine whether each individual dwelling in the settlement is prone to high hazard flooding. A site visit would be required to make this determination, and this was not possible at the time of writing this report. However, in any flood that exceeds the Opihi River scheme capacity, serious flooding will occur in this settlement and most dwellings will be affected. One dwelling located to the west of the other dwellings has a higher ground level and will be subject to less severe flooding.

9.5 Summary and conclusions – Collett Road hut settlement

The Collett Road hut settlement is prone to severe flooding from upstream Opihi River overflows in floods that exceed the scheme capacity. Serious flooding in and around dwellings is likely in major flooding events and if the adjacent stopbank breaches, some dwellings will be impacted by high hazard flooding.

Environment Canterbury is unaware of any existing evacuation or warning procedures for the settlement. It is not currently possible to determine if flooding would meet the definition of high hazard for all dwellings at the settlement, but (excluding the dwelling furthest to the west on higher ground) the flooding will be significant.

10 Considerations applicable to all Opihi River settlements (Sections 4 to 9)

10.1 Flood warning and evacuation

The water level recorder for the Opihi River is located at Rockwood (gorge). The estimated travel time for peak flood flows from the recorder to Saleyards Bridge is 5 to 7 hours, depending on the size of the flood. The Te Ana a Wai water level recorder is located at Manahune. The estimated travel time from the recorder to the confluence with the Opihi River is around 4 to 5 hours. It takes about another 2 hours for the flow peak to travel from the Te Ana a Wai River confluence to SH1. This means that a peak flow from the relevant recorders may reach Stratheona, Butlers Huts and Mill Road Huts after about 4 to 7 hours, Grassy Banks after 7 to 9 hours, and Waipopo Huts after 8 to 10 hours. Note: travel times are from the peak flows at the water level recorders. Heavy rainfall would have been occurring and river flows would be rising for several hours before peak flows are reached.

Given the vulnerability of the Opihi River hut settlements, warning would be provided to Civil Defence and Emergency Services by Environment Canterbury on impending high flood flows well before river flows were peaking at the upstream recorders. Flood warning lead times of 6 to 12 hours, at least, should be provided to emergency services, but these early warnings would indicate the potential for threatening river flows not specific outcomes along the river floodplains. This is important, as most of the hut communities along the river are highly vulnerable to not just floods larger than the design capacity, but also to stopbank breaches as a result of lateral erosion – which can occur at lower flows.

Floods that occur at night create a more complicated and potentially dangerous situation for the hut communities. A conservative approach may be needed to evacuate in daylight hours well ahead of peak river flow being known. To enable this, emergency authorities need to be prepared to make decisions on forecast river flows or rainfall information, and not wait for the river to peak. Emergency authorities and residents cannot watch and wait for floodwaters to reach the top of stopbanks before evacuating (given the potential for lateral erosion breach), and evacuation must be pre-emptive of problems developing to best mitigate risk.

Effective evacuation procedures that are sustainable through time are an effective way to reduce the consequences posed by high hazard flooding. Ongoing education of occupants living in these hut settlements is another useful tool. If residents understand the risks, and are fully aware of evacuation procedures, they are more likely to take the right actions in times of flood.

10.2 Climate change

The impacts of future climate change on the Opihi and Te Ana a Wai River catchments are complex and not fully understood. A report on climate change projections was completed in 2020 by NIWA for Environment Canterbury. The following points relevant to climate change impacts on the Opihi River settlements are taken from this report:

- Seasonal mean air temperature in Canterbury is projected to increase by 1.5 to 3 °C over much of Canterbury by 2090 under RCP 8.5 scenarios.
- Predicted rainfall changes vary across the region and seasonally. But for eastern catchments average winter rainfall is projected to increase by 15-40% by 2090 using RCP8.5 scenarios. Summer rainfall averages may decrease by lesser percentages over the same time period pointing to greater weather extremes in future.
- The hydrological impact of climate change is that mean discharge is expected to increase in eastern areas such as the catchments of the Opihi and Te Ana a Wai Rivers (particularly under RCP8.5 scenarios). Floods (characterised by occurrence of the Mean Annual Flood) are expected to become larger for many parts of Canterbury especially the foothill river catchments which appear to show the greatest percentage increase in mean discharge out to 2090. Most of these increases are projected for the period from 2040-2090 not for the first part of the century.

- Increases in air temperature are likely to increase the intensity of rainfall events given that warmer air contains around 8% more moisture for each 1 degree increase in temperature (Mullan *et al.,* 2008).

The Te Ana a Wai stopbank capacity investigation (Wild, 2016) also considered climate change. As part of that report HIRDS version 3 was used to demonstrate that a 2°C increase in air temperature would be consistent with approximately doubling the frequency of a rainfall event in the Te Ana a Wai River catchment. By 2090 the flow that is now characterised as a 100-year ARI flood flow may become a 50-year ARI flood. A similar effect is likely in the Opihi River catchment. The implications of climate change are that the level of flood protection provided by current schemes on eastern foothill rivers in Canterbury may reduce through time.

The Opihi River scheme is designed to contain floods up to the 50-year ARI flow while the Te Ana a Wai Scheme at Pleasant Point is designed to contain floods with a 60-70-year ARI. Interventions that increase the capacity of the river scheme are expensive and future decisions around protection scheme standards will need to be made between Environment Canterbury and other relevant authorities but mostly with the ratepayers within the rating districts funding these schemes. Decisions will inevitably be made on a cost benefit basis with the economic or social and cultural return on investment in flood protection needing to justify the cost.

Legacy development (including hut settlements) along these rivers restricts future ability to widen river fairways as a scheme improvement initiative. Improvements to scheme works in upstream areas of these river catchments would then have the potential to increase downstream flooding impacts making localised flooding improvements difficult. The alternative of raising the standard of the entire scheme at once would be very expensive.

The key message relating to climate change is that it is likely to increase the flood risk to these hut settlements and potentially the costs of remaining in place. These are communities already considered among the most vulnerable to natural hazards in South Canterbury.

11 Blandswood hut settlement

Much of the information in this section is summarised from Hall (1993) which provides extensive information about flooding in the area.

11.1 Location and key features

The Blandswood hut settlement is located at the Lookout Road and Blandswood Road intersection, approximately 2 km northwest of Peel Forest township. Kowhai Stream traverses this area in a northwest to southeast direction and passes by the community at the Blandswood Road and Lookout Road intersection where there is ford. The hut settlement is located at the toe of the foothills with land rising steeply to the north and southwest (Figure 11-1).

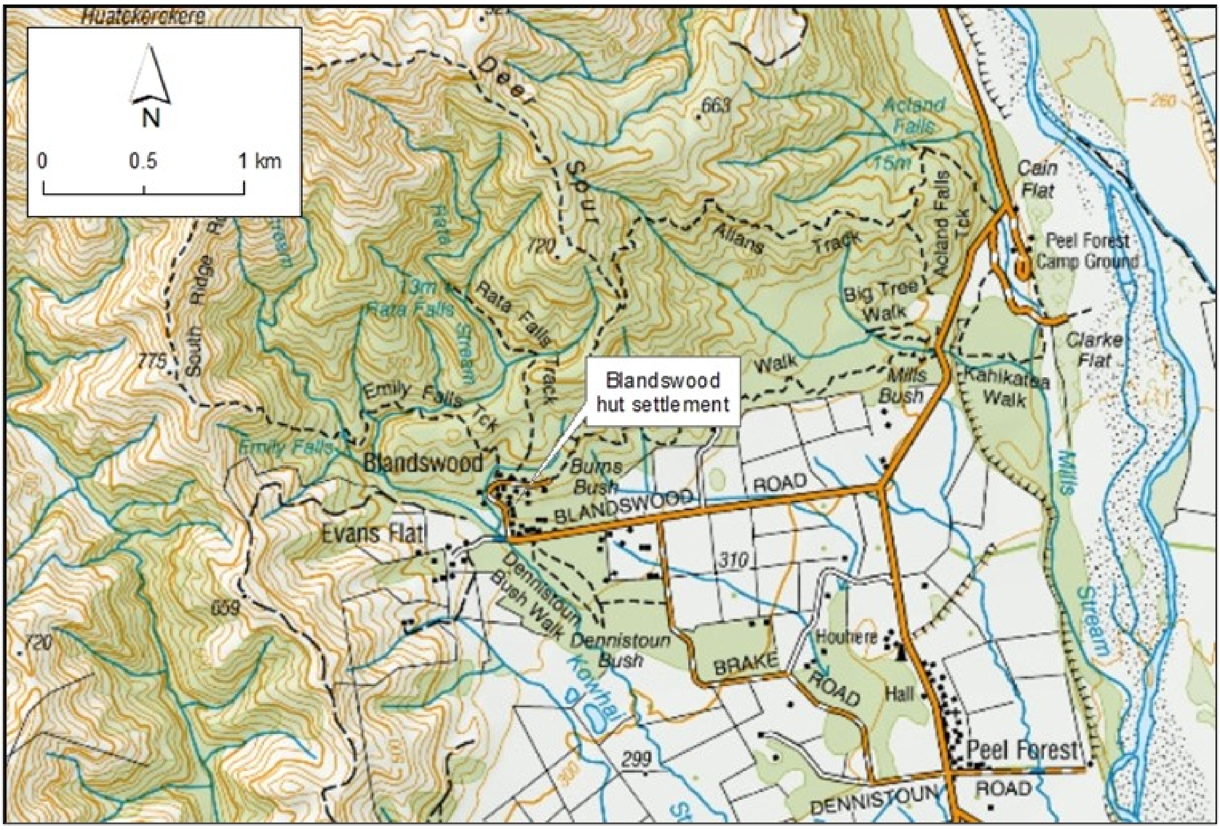


Figure 11-1: Location of Blandswood hut settlement

The Blandswood hut settlement includes about 25 dwellings which are a mixture of permanently occupied and holiday homes. A number of these dwellings are located on hill slopes rising to the north away from Blandswood Road. The area of interest for this study includes about 10 dwellings situated on the lower active alluvial fan of the stream that are zoned Recreational 1 land in the current District Plan (Figure 11-2).

The catchment of Kowhai Stream, and its tributaries above Blandswood, is about 4.3 km^2. Whilst not particularly large, this is a steep, sub-alpine, catchment that carries a very high gravel bed load during times of flood. The bed of Kowhai Stream is aggrading (building-up) over time as floods bring gravel down from the upper parts of the catchment. This aggradation reduces stream capacity and requires frequent works at the ford to keep it operable.

Kowhai Stream is frequently at very low flow or dry at the ford and the flows that occur in the stream are often short rises in response to heavy rain. When floods occur, it is generally due to antecedent rain conditions saturating the catchment over a period, followed by a more intense burst of rainfall and rapid rise in stream flow.

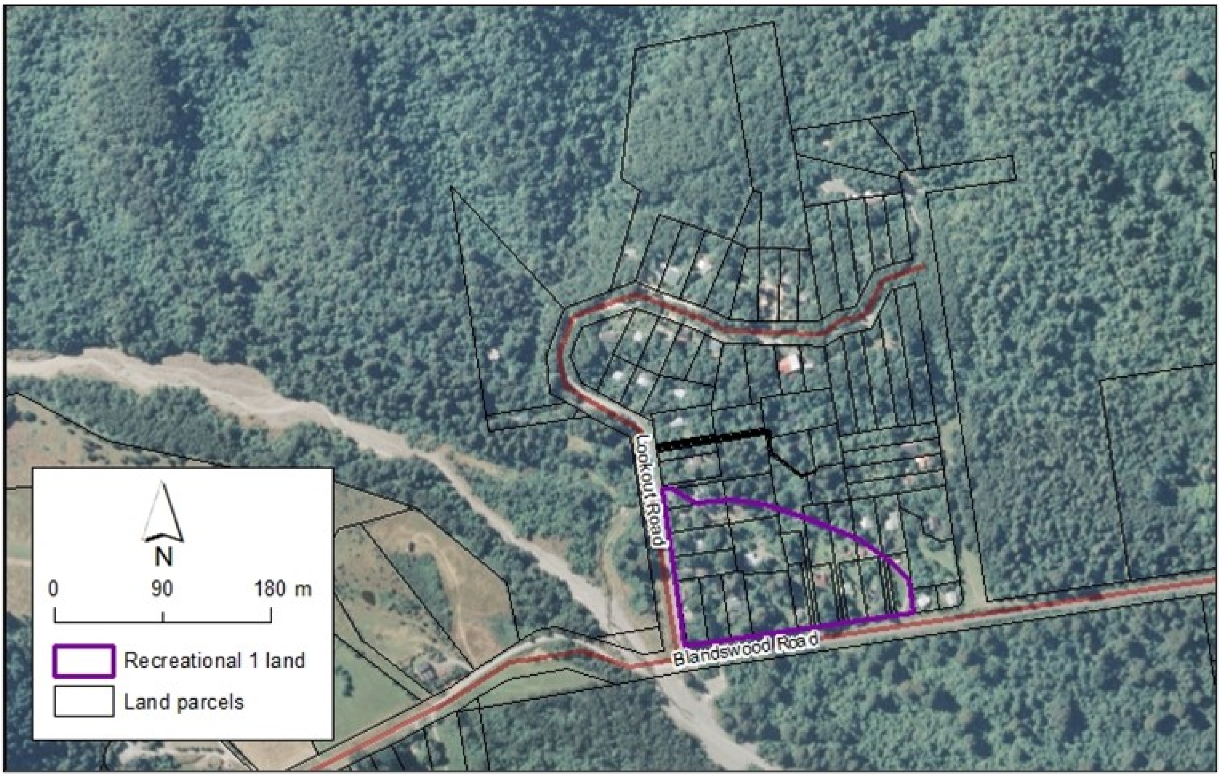


Figure 11-2: Location of Blandswood hut settlement dwellings situated on the active fan of Kowhai Stream and zoned recreational under the current Timaru District Plan

The steep sided Kowhai Stream catchment (including tributaries) are prone to land slippage and potential debris dams forming in the creek. If these occur, and then give way during flood times, this can lead to devastating flash flooding downstream.

A small stopbank runs north to south on the upstream side of the lower part of Lookout Road and affords minimal protection to the lower Blandswood settlement.

11.2 Brief summary of historic flooding events

At least four flash floods are thought to have occurred at Blandswood in the past 250 years, including an extreme flooding event in January 1975. The three other flash floods, of a similar size, occurred prior to development on the fan.

The initial development in this area did not recognise the characteristics of the Kowhai Stream and built on an area that is part of a steep and active alluvial fan. The 1975 flood resulted in the tragic loss of four lives at the Blandswood hut settlement, when a short period of very heavy rain fell on an already saturated catchment. The Kowhai stream became discoloured and began to overflow its natural banks below the foot of the hill on Lookout Road. Two major surges of floodwater occurred in the stream spaced only 2 to 3 minutes apart. The first surge was the smaller of the two but destroyed a footbridge and carried it 30 m downstream. The second surge was estimated at 3.7 m in depth over the top of Lookout Road. The deep surges, heavily laden with tree debris and sediment, swept into the hut settlement and destroyed one dwelling while seriously damaging another. The remaining dwellings were flooded to depths of up to 1.5 m. One building was swept off its foundations and deposited on the opposite side of Blandswood Road while a 550 to 650 mm wide boulder was ejected from the stream and deposited on Lookout Road near the breakout point.

This flooding was the result of debris dams forming in the upper catchment of the stream and subsequently breaching, releasing a sudden rush of floodwater like a wave. In a steep, sub-alpine catchment such as this, with narrow tributaries, such dam formation and breaching is not unexpected.

Aside from the four extreme flooding events identified, there is a lesser flood hazard at the hut settlement from heavy rainfall resulting in stream overflows without debris dam breach surges. While there would have been occurrences of such flooding throughout history, these types of events have had a less serious impact on the dwellings. Regular damage to the ford adjacent to the settlement occurs during such floods and these events also have the potential to erode stream banks and to deposit large volumes of gravel in the stream bed.

A recent minor flooding example was the July 2017 flood event, which caused erosion, gravel deposition around the ford, and damage to stream banks (Figure 11-3).

Figure 11-3: Looking towards the Ford at Blandswood from upstream (post July 2017 flooding)

11.3 Aggradation of Kowhai Stream Bed

The 1975 flood resulted in the stripping or damage of a significant amount of vegetation in the upper Kowhai Stream catchment, exposing land to slippage and erosion. Since the 1975 flood, several flooding events have bought down large amounts of gravel from the upper reaches of the catchment to the reach immediately upstream of and adjacent to the Blandswood hut settlement. At present the Kowhai Stream Bed is actually relatively degraded, likely as a result of long period with few significant floods. However, the volumes of gravel available upstream, and the ability of stream flows to transport large volumes of gravel in individual flood events, means that there remains a strong potential for future aggradation of the stream bed. Simply extracting gravel from this reach is ineffective as a long-term flood protection measure as large volumes of gravel can be shifted in single flood events causing significant bed level changes.

The potential future aggradation of the stream bed has serious implications. In a natural system (without development) the stream could migrate laterally across the full width of the fan, remaining in an area until gravel built up enough to deflect flow onto a lower part of the fan. A future build-up of gravel in the stream bed will increase the potential for the stream flows to deflect laterally from the current stream bed putting the Blandswood hut settlement at increased risk.

11.4 Flood protection history

There is currently no river rating scheme for Kowhai Stream meaning Environment Canterbury does not collect targeted rates for flood protection, nor maintain flood protection works. This has not always been the case, with a separate Blandswood Flood Protection Scheme in place in the 1980s. This scheme collected a targeted rate for works in Kowhai Stream and assets from the scheme include the stopbank running parallel to Lookout Road and some other rock protection works in the river. These rock protection works are now mostly buried beneath the gravel stream bed having been more than 2 metres above the bed when first installed 30 years ago.

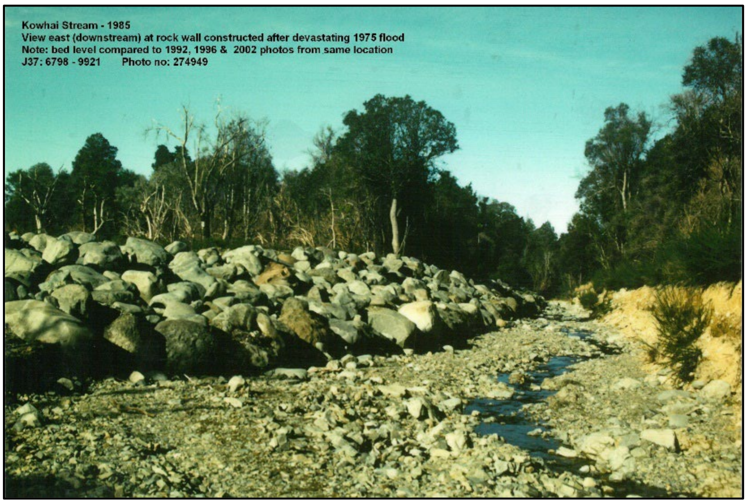
The rating district scheme members resolved not to continue funding this scheme in the 1990s and, while the stopbank and rock are still present, funding for maintenance does not exist. Since this time any maintenance or improvements have been carried out on a user pays basis by the local residents, with occasional and isolated assistance from various other agencies. In recent years there has been conversation between residents and other agencies around reviving works in the area and potentially revisiting a scheme or funding arrangement. Unless a rating scheme is in place, Environment Canterbury will not be able to substantively contribute to ongoing flood protection of the area.

11.5 Flood hazard summary

The Kowhai Stream has caused devastating flash flooding in the past, most tragically so in January 1975 (Figure 11-5). The limited flood protection works that are in place will provide some assistance in small to moderate flooding occurrences and particularly in floods that do not involve any large slippage or debris dam formation and breach in the upper catchment.

An event of similar scale to 1975, will overwhelm flood protection works that are in place and will have similar impact on the settlement. The ongoing aggradation of the stream bed will increase the impacts of large floods and the vulnerability of the stopbank to overflow. The higher stream bed also has the potential to cause an increase in nuisance issues such as erosion of stream banks during small to moderate floods, the operation of the ford, and the maintenance of the existing stopbank.

All dwellings in the identified lower fan settlement of Kowhai Stream are susceptible to high hazard flooding and significant damage during major floods Devastating flooding could occur with little to no warning.



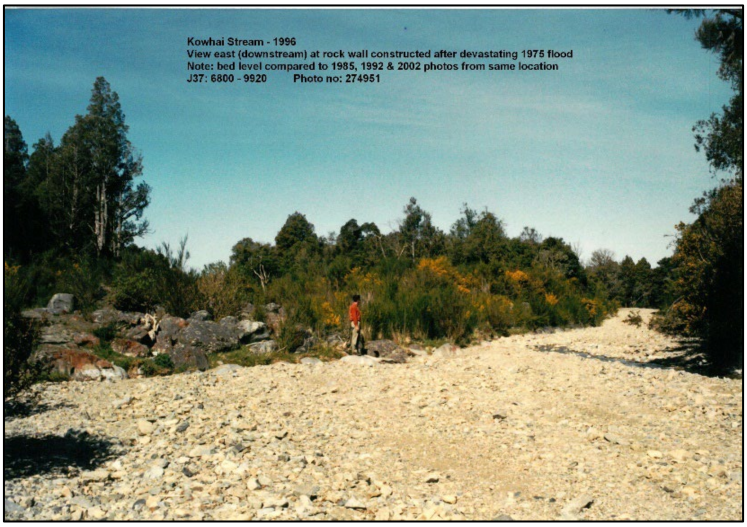


Figure 11-4: Series of photographs (Top: 1985, Middle: 1996 and Bottom: 2002) taken of rock protection put on true left stream bank upstream of ford following the devastating 1975 flood. Note photographs are all the same location and show the very rapid gravel bed aggradation occurring

Figure 11-5: Lookout Road, Blandswood following 1975 flood event [Source: Hall (1993), plate 4]. Note large boulder thrown onto road in centre bottom of shot and huge volume of debris on road

11.6 Flood warning and evacuation

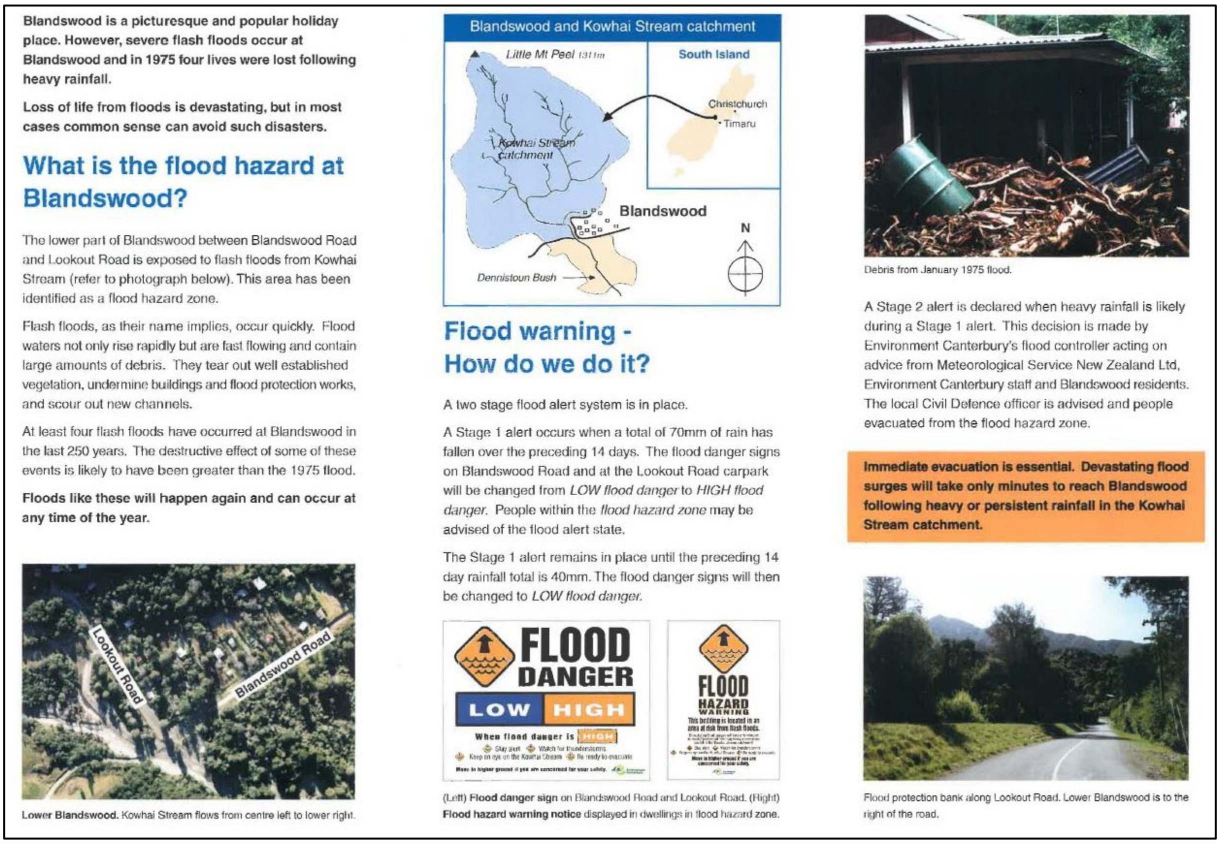
The lower Blandswood hut settlement area is unique in terms of its topography and flood hazard compared with the rest of Timaru District. The Kowhai Stream is a very short, steep, catchment and can rise to flood levels very quickly (1 to 2 hours) in response to heavy rain.

The most dangerous flooding scenario at the settlement is from debris dams forming and then breaching in the upper parts of the catchment, releasing surges of water into the settlement. This situation can develop out of sight and unknown to residents. Should heavy thunderstorms or debris dams form at night-time, the situation is even more dangerous.

Because of the extremely limited warning time residents cannot rely on emergency authorities to evacuate them in advance of dangerous flooding events. Environment Canterbury monitor Metservice weather warnings and rainfall in the catchment and contact emergency authorities and local resident contacts if high intensity rainfall was falling or was expected in the catchment. However, the rain gauges in the area do not always pick up very localised, but potentially dangerous, thunderstorms. Nor can Environment Canterbury ascertain if land slippages have occurred in the upper catchment. The best defence against the flooding is for residents to have a sound understanding of the flood risk they are exposed to and be prepared to self-evacuate in threatening weather - in advance of serious increases in stream flows. If the stream is already carrying major flood flows, or it is raining very heavily, the potential for land slips exists, and it may already be too late to evacuate safely.

Environment Canterbury and Timaru District Council has historically carried out education days with local residents, including a visit from staff members last year. Posters explaining the flood risk have been given to residents to be displayed in every dwelling on the active fan. Environment Canterbury also manages flood warning signs at both Blandswood Road and at Lookout Road which inform locals and visitors of whether risk is considered high or low. The high or low risk indication is based on antecedent rainfall amounts. High risk periods are when the catchment is expected to be fully saturated and therefore prone for rapid rises in stream levels should heavy rain occur. The signs also detail the general nature of the flood risk.

While the sign and education tools used have served a purpose, discussion between residents and Environment Canterbury suggest a review of warning procedures and future education initiatives may be of value. Environment Canterbury is currently discussing this with residents and is considering a full review of flood warning procedures.



Blandswood is a picturesque and popular holiday place. However, severe flash floods occur at Blandswood and in 1975 four lives were lost following heavy rainfall.

Loss of life from floods is devastating, but in most cases common sense can avoid such disasters.

What is the flood hazard at Blandswood?

The lower part of Blandswood between Blandswood Road and Lookout Road is exposed to flash floods from Kowhai Stream (refer to photograph below). This area has been identified as a flood hazard zone.

Flash floods, as their name implies, occur quickly. Flood waters not only rise rapidly but are fast flowing and contain large amounts of debris. They tear out well established vegetation, undermine buildings and flood protection works, and scour out new channels.

At least four flash floods have occurred at Blandswood in the last 250 years. The destructive effect of some of these events is likely to have been greater than the 1975 flood.

Floods like these will happen again and can occur at any time of the year.

Lower Blandswood. Kowhai Stream flows from centre left to lower right.

Flood warning - How do we do it?

A two stage flood alert system is in place.

A Stage 1 alert occurs when a total of 70mm of rain has fallen over the preceding 14 days. The flood danger signs on Blandswood Road and at the Lookout Road carpark will be changed from *LOW flood danger* to *HIGH flood danger*. People within the *flood hazard zone* may be advised of the flood alert state.

The Stage 1 alert remains in place until the preceding 14 day rainfall total is 40mm. The flood danger signs will then be changed to *LOW flood danger*.

(Left) **Flood danger sign** on Blandswood Road and Lookout Road. (Right) **Flood hazard warning notice** displayed in dwellings in flood hazard zone.

Debris from January 1975 flood.

A Stage 2 alert is declared when heavy rainfall is likely during a Stage 1 alert. This decision is made by Environment Canterbury's flood controller acting on advice from Meteorological Service New Zealand Ltd, Environment Canterbury staff and Blandswood residents. The local Civil Defence officer is advised and people evacuated from the flood hazard zone.

Immediate evacuation is essential. Devastating flood surges will take only minutes to reach Blandswood following heavy or persistent rainfall in the Kowhai Stream catchment.

Flood protection bank along Lookout Road. Lower Blandswood is to the right of the road.

Figure 11-6: Part of Blandswood Flood Information package put together for residents of the area explaining flood risk and the flood warning system. Flood Danger signage still in place at Blandswood shown in centre-bottom of page

One complicating factor to education and evacuation procedures is that dwellings in the area are often used by visitors who do not have knowledge of the area. This is something that will have to be carefully considered as part of any review. Safe evacuation from this area is the only way to reduce threat to life during floods. This relies on the ability of the community to understand threatening weather conditions. Currently Environment Canterbury have two very good contacts within the community who understand the risk and can assist the wider community in times of flood. Such contacts cannot be relied on in the long-term however, as communities change, and the area will always remain one of the most vulnerable in the district.

11.7 Climate change

The impacts of future climate change on Kowhai Stream catchment is complex and not fully understood. A report into climate change projections was completed in 2020 by NIWA for Environment Canterbury. The following points relevant to climate change impacts are taken from this report or from previous Ministry for the Environment (MfE) guidance on climate change:

- Seasonal mean air temperature in Canterbury is projected to increase by 1.5-3 °C over much of Canterbury by 2090.
- Increases in air temperature are likely to increase the intensity of rainfall events, with rainfall depths for short duration events expected to increase by more than 13% for each 1 degree

increase in temperature (MfE, 2018). This is particularly pertinent factor when considering the Blandswood hut settlement which is most vulnerable to intense short duration rainfall events.

- Any increase in rainfall intensity has the potential to increase the frequency of threatening rain events within the Kowhai Stream catchment. Not every high intensity rain event will cause catastrophic flooding of Blandswood, but the more frequently such storms occur, and the higher intensity these are, the greater chance there is of rapid rises in Kowhai Stream flooding and of slippage and debris dam formation in the upper catchment.
- Increased frequency and intensity of storms could also lead to a greater number of smaller land slippage and erosive events and smaller to moderate flood events downstream that bring increased volumes of gravel into the area.

Given the above comments, climate change is not expected to change the hazard present in this area but may increase the frequency of threatening weather events and therefore increase the flood risk to the Blandswood community through time.

11.8 Summary and conclusions – Blandswood hut settlement

The lower Blandswood hut settlement is subject to severe flooding during extreme rain events in Kowhai Stream. The area is clearly prone to high hazard flooding and debris deposition.

The safety of the community at this location relies on good education of residents and clear advice and evacuation procedures. The nature of the flooding hazard is such that self-evacuation will be necessary in many situations as external warning cannot be relied on.

12 Key findings and future considerations for all settlements

All eight recreational hut communities discussed in this investigation are susceptible to significant flooding in future flooding events. The Opihi River settlements are also susceptible to severe flooding in the event of stopbank breach.

For five of the settlements (Blandswood, Stratheona, Butlers & Mill Road Huts and Grassy Banks), the flooding has the potential to be high hazard for all the existing dwellings. At Collett Road the flooding is very significant, but a full assessment of whether all dwellings would be considered susceptible to high hazard flooding is not made. For Waipopo, most of the study area is expected to be susceptible to high hazard flooding but some smaller areas of land may be prone to lesser, but still significant, flooding in major floods.

The Canterbury Regional Policy Statement describes high hazard areas are those where the combination of depth and velocity, or excessive depth (greater than 1 metre) can pose significant risk to life and can damage property. The impacts of flooding will vary, but for a lot of these areas structural damage to dwellings (including potential to be washed off foundations), scouring of the ground surface, deposition of large debris amongst the dwellings and risk to life are all very real possibilities. Aside from the physical impacts, such flooding can be devastating to those residents who permanently occupy or regularly holiday in these areas.

Advanced warning of flooding events will be provided by Environment Canterbury to emergency authorities for all the communities - excluding Blandswood where the unique flooding hazard means that advanced warning of serious flooding cannot be guaranteed. Safe evacuation from each settlement is the only way to guarantee the safety of community members. For those settlements adjacent to river stopbanks, pre-emptive evacuation is necessary to alleviate the risk from lateral erosion breach.

At South Rangitata Huts the flooding hazard has significant impact - especially the potential for backwater flooding to enter some of the dwellings and campground. However, the variable river and coastal hazard expected across the settlement, very long warning times, and readily available egress options create a comparatively less dangerous situation than for the other communities discussed.

Ongoing education of these communities on flooding and coastal hazards is important as a community that has a high level of awareness of the hazard it is exposed to is more likely to react appropriately when future flood events occur.

13 Peer review

This report has been peer reviewed by Mr R J Hall (R J Hall & Associates Ltd). Bob is uniquely qualified to review this report having been a former Southern Area Engineer for the Canterbury Regional Council. While on the regional council staff Mr Hall was directly involved in the production of the Levels Plains Floodplain Study and South Rangitata Huts Draft Floodplain Study both of very high relevance to this report. Mr Hall also carried out a Master of Engineering Thesis “*An approach to Natural Hazard Assessments and Hazard Reduction”* of which one of the major case studies was on the Blandswood Hut Settlement.

Mr Hall provided the following comments on this report, as well as meeting in person with the authors to discuss:

> *I can confirm that I have reviewed the above report and make the following observations.*
>
> *The flood hazard mapping exercise has been undertaken expressly to cover those parts of the Timaru District Councils where Recreational Hut Communities exist both adjacent to the main rivers and along the coastline adjacent to river mouths.*
>
> *The intention of ECan’s review was to revisit the flood mapping work compiled at various times some years ago and which is currently used by the District Council to make determinations on*

the suitability or otherwise primarily of building work within its district; the current maps inform the relevant parts of the District Plan.

It is understood that the intention of ECan's river and coastal flood mapping review is to provide a more comprehensive coverage than presently in use and to improve the accuracy and reliability of the information reflected by the maps as it pertains to these recreational hut communities.

Whilst the principal aim of this study focusses on improving the accuracy of the maps that the TDC currently hold and use it is important to appreciate what they represent and what other implications relating to flood hazard and flood risk that they also provide so the full value of that information can be achieved.

The study area covers major river systems whose river margins have stopbanks which provide a measure of protection to the flood plains on which significant development has occurred over time. This study has made critical comment on the limit of the protection that these systems provide not only in terms of super design events but also importantly in the context of sub-design failure. By way of explanation sub-design failure refers to the failure of these structures at flood levels less than the values for which they have been designed. Typically, these failures arise from lateral bank erosion, piping failure and/or localised loss of flood capacity, arising from channel obstructions e.g. vegetation growth of washouts, localised aggradation. This situation is particularly pertinent to the recreational hut communities located adjacent to or within reasonable proximity to those rivers and the coastline where that is also appropriate.

The study has paid close attention to the potential for these situations to arise particularly with respect to their potential to significantly alter flood risk in and/or adjacent to areas where these small recreational settlements occur, of which there are a number in the TDC district. In particular attention has been drawn to the fact that when failures of this kind occur, they do so with little prior warning and whilst they may not necessarily occur immediately adjacent to a settlement, they can never the less significantly exacerbate risk by cutting off access and hence evacuation opportunity which in either case can readily put lives at risk.

Experience has shown that stopbank failures in times of flood, be it caused by overtopping or sub-design events, result in localised concentrated high velocity flows often carrying debris such as large branches and small trees etc. The outflow zones can be further divided into near field areas where these high velocities occur and far field where flows spread out and become slower and shallower often merging with other flood flows passing down the flood plain. This report has gone to some lengths to define the areas adjacent to the stopbanks where these effects could occur but does not distinguish between them. The study has used earlier work by R. Connell (1998) in conjunction with "at a site" hydraulic modelling to define areas at risk. It was noted that the latter was a technically demanding exercise such that only a limited amount of work could be undertaken in the context of this study. That said it does suggest, given the harm that can arise when these sudden failures occur, that further research using hydraulic modelling techniques to update the present methodology and provide more detail around the extent and form of near field and far field effects is warranted.

Whilst a detailed evaluation of the risk of injury and loss of life in and around these recreational hut settlements arising from the sudden failure of stopbanks and associated blocking of evacuation routes when most needed may lie beyond the reports brief it is never the less an important consideration when the contents of the ECan report is being considered by TDC in association with their planning functions. This approach was clearly demonstrated in the Christchurch City Council Sec 32 Natural Hazards Evaluation document which was publicly notified 27 August 2014. Appendix 7 of this report titled "Risk Modelling on the Port Hills and Banks Peninsular" addresses the matter of risk to human life associated with rock falls and associated geo-fluvial phenomena. It is opined that consideration should be given to undertaking a similar exercise here with respect to stopbank failure in order to give greater clarity of the true nature of the risks that these recreational settlements are presently exposed to as described herein.

The approach taken has been to identify flood extent boundaries which are based variously on known flood extents from historic flooding incidents, and incorporate the limiting or influencing effects of physical features such as alluvial terraces, swales, alluvial fan surfaces (active and/or senile). This methodology has adopted a definition of flood effects which recognizes not only the passage of flood waters per se. but also the movement, storage and erosion of sediment as a consequence of the presence and movement of flood waters, the effects associated with stopbank failure and the coastal retreat.

A critical aspect of the study is to establish flood extent boundaries in map form from which "at a site" assessments can be made on a property by property basis as circumstances require. This approach will assist the District Council to make determinations on the suitability or otherwise of land on which building works might be proposed as and when building consent applications are lodged. These maps also provide a basis or assisting staff (both TDC & ECan) during flood emergencies as to the extent to which flooding might occur during an event in order to assist the flood emergency management needs at such times.

It is concluded that the approach taken is both comprehensive and practical and the analytical approach balanced and soundly based indicating that it is founded on a combination of good research and local knowledge. It is clear that the intention has been to focus particularly on the various recreational hut communities that are dotted around the TDC district where specific flood and flood related risks prevail.

Further to that it provides updated information on those areas where such risk is anticipated and allow for "at a site" determinations to be made which would confirm and quantify that risk that could prevail, the circumstances under which it could occur and the consequential effects that can arise such as loss of safe egress.

It is opined that this work would benefit from more clarity around the consequences of the types of failure canvassed in human terms in and adjacent to the recreational hut settlements being considered (viz. risk to life and injury). By definition risk comprises two parts, the probability of its occurrence and the consequences of its occurrence, both aspects need to be addressed in order to provide a complete picture of the risks associated with flood hazard.

This report was also peer reviewed internally by Philip Lees (Senior Scientist – Natural Hazards) and Nick Griffiths (Science Team Leader - Natural Hazards).

14 Acknowledgments

The following staff provided valuable input into this report and its review.

- Phil Lees (Senior Scientist), review of the report. Information gathering and other information input.
- Justin Cope (Principal Science Advisor – Natural Hazards), coastal and climate change information inputs
- Nick Griffiths (Science Team Leader), review of the report.

Also, thanks to R J Hall for assisting with the external review of this report.

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Appendix 1: Waipopo Huts settlement modelling

A1.1 Introduction

A flood modelling study was undertaken to gain a better understanding of flood behaviour in the vicinity of the Waipopo hut settlement. This study used detailed topographic data and a combined 1-dimensional (1D) and 2-dimensional (2D) hydraulic modelling software package (Mike Flood) to simulate breakout flows and determine floodplain water levels, depths, flood extent, flow patterns, and flow velocities. The modelling included four potential breakout flow locations, based on historic breakouts and stopbank characteristics. These breakout locations are shown in Figure A1-1.

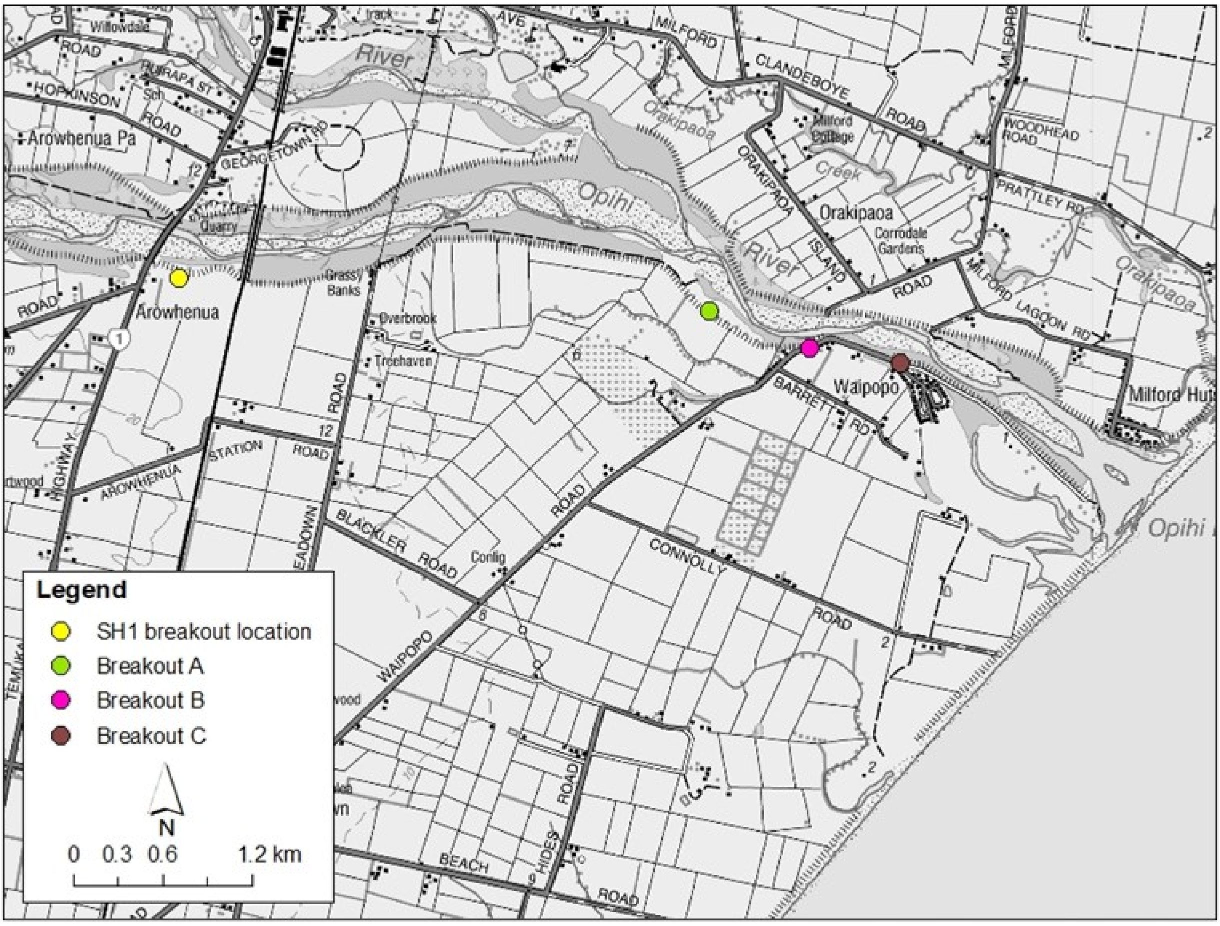

Figure A1-1: Map showing modelled breakout locations

A1.2 Flood hydrology

The derivation of the design flows is outlined below for the Opihi River and the various breakout scenarios. There is considerable uncertainty in these estimates due to the inherent difficulty in predicting both flow magnitudes and breakout locations.

Opihi River

Downstream of the Temuka River confluence, the Opihi catchment control scheme design capacity is 3460 m^3/s (Boyle and Surman, 2007). For this investigation, the modelled flow remaining in the Opihi River was assumed to be the difference between the scheme design capacity and the sum of the modelled breakout flows (i.e. breakout flows were subtracted from the scheme capacity to simulate Opihi River water levels where the floodplain flows return to the Opihi River near the river mouth). This assumption was considered appropriate given maximum floodplain water depths around the Opihi River mouth do not have an impact on maximum flood depths in the vicinity of the Waipopo Hut settlement.

Breakouts
Breakout flows were modelled for the 4 locations described in Table A1-1 and shown in Figure A1-1. These locations were specifically chosen to simulate the combination of breakout flows likely to travel into the Waipopo study area from both distant breakouts (e.g. State Highway One area), as well as local breakouts, closer to the hut settlement.

Between the Waipopo study area and some distance upstream of SH1, a portion of any breakout flow can run parallel to the river and enter the Waipopo study area. The distant breakout, located in the model at SH1, therefore represents a range of potential breakout locations both around SH1, as well as further upstream. The location of the 3 local breakouts was based on:

- known historic breakout information,
- characteristics of the stopbank and adjacent topography,
- experience/knowledge of Environment Canterbury staff, including a site visit by natural hazards staff and long-time river works overseer Paul Eddy.

Each breakout site is located along a reach of stopbank that is considered to have a very realistic chance of breaching, with the specific location based on where it would represent the worst-case scenario for all or part of the Waipopo study area. No other potential stopbank breach locations are likely to result in worse flooding within the study area.

Table A1-1: Breakout flow locations

Breakout scenario	Location
State Highway 1 (SH1)	Between SH1 and the main trunk railway line. As the railway embankment is not a flood protection structure, it has been lowered by 0.5m to simulate some breaching (i.e. good practice to assume it would breach)
A	650 m upstream of Waipopo Road
B	Immediately upstream of Waipopo Road, at bend beside first row of huts
C	Breach of high stopbank directly opposite Penny Lane/Waipopo Road intersection

Both ‘base’ and ‘elevated’ (worst-case) breakout flow scenarios have been modelled. Base breakout flows have been estimated using the following information and assumptions:

- 1986 stopbank breach width and ground level (based on historic information and detailed ground level (LiDAR) data).
- 1986 maximum measured river levels (i.e. maximum depth of breach flow)
- An assumed depth-averaged breach flow speed of 2 metres/second.

The 1986 flood was estimated to have a peak flow at Saleyards Bridge (Pleasant Point) of 3600 m^3/s and the 200-year Average Recurrence Interval (ARI) flood is estimated to be 3700 m^3/s at the same location. The base breakout flows are therefore considered a reasonable approximation to a 200-year ARI flood situation based on flow similarity with the recorded 1986 flood

To produce more extreme ‘elevated’ breakout flows, the base breakout flows were increased by 30%. This allows for:

- floods larger than the 1986 flood event,
- breach widths greater than what occurred in 1986,
- river levels higher than in 1986 (as a result of less water breaking out further upstream or water levels reaching higher levels on the stopbank prior to breach), and/or
- a mean flow speed greater than 2 m/s through a breach.

From the available information, a specific frequency cannot be determined for the elevated flood breakout scenario. However, a 30% increase in breakout flows this far downstream on the Opihi River is considered a conservative, extreme scenario. This is because larger flows in upstream reaches of the Opihi River are likely to result in larger upstream breakout flows onto the floodplain. It is unknown whether this would reduce or increase floodplain flows directed towards the study area (as it would be dependent on breakout location) – and how flood flows remaining in the Opihi River, near the study area, would be impacted. Environment Canterbury consider the elevated breakouts scenarios, especially when several breakouts are occurring simultaneously, to be a realistic 'present-day' approximation of worst-case flooding for the study area.

The dimensions for the breaches are summarised in Table A1-2. These dimensions are largely based on the South Canterbury Catchment Board recorded breach locations and widths following the 1986 flood event. The breakouts shown at SH1, and locations A and B, either directly mirror the documented breakouts or were approximated using nearby water level records, and nearby historic breaches (of stopbanks with similar characteristics). The breakout at location C was estimated using recorded 1986 water levels and accurate ground levels. However, the breach width needed to be estimated as no breach occurred in this area in 1986. The breach width chosen for location C was conservative, but comparable to those of the other recorded breaches.

Breakout flows (Q_{BO}, m^3/s) are calculated using the breach dimensions and the following equation

$$Q_{BO} = w\ d\ v$$

Where: w = breach width (m)
d = maximum depth of water (m)
v = depth-averaged breach flow speed (m/s)

Table A1-2: Breach dimensions and derivation of peak flows

Breakout scenario	Breach dimensions (m)		Breach mean flow speed (m/s)	Breach peak flow (m^3/s)
	Width	Depth		
SH1 breakout				540
SH1 Breakout 1	60	3.1	2	370
SH1 Breakout 2	40	2.1	2	170
Breakout A	50	3.0	2	300
Breakout B	60	2.1	2	250
Breakout C	60	2.7	2	320

Table A1-2 shows that the maximum depth of water for the Breakout B breach is almost 1 m less than at the other breach locations. This is due to the relative ground levels on the landward side of the stopbank being much higher at this location and breakout flows are therefore smaller at this location than at the other sites. Further details regarding the derivation of the breakout flows is given in Appendix 2.

Sea level
The study area is upstream from the Opihi River mouth, and not affected by sea level. A nominal sea level of 1.5 m Lyttelton Vertical Datum 1937 (LVD37) has been used for the model downstream sea boundary.

Climate change
The impacts of future climate change on the Opihi River and Waipopo hut settlement are complex and, at present, not fully understood. Some of the changes that need to be considered include:

Air temperature
Macara *et al.* (2020) presents projected changes in annual mean temperature for two scenarios of future radiative forcings, known as 'Representative Concentration Pathways (RCPs) for Canterbury. These represent different pathways of human development and greenhouse gas emissions with:

- RCP4.5 = realistic scenario if global action is taken to mitigate against climate change
- RCP8.5 = 'business as usual' scenario (i.e. greenhouse gas emissions continue at same rate)

For Canterbury, the projected increases in annual mean temperature from a 1986-2005 (1995) baseline out to 2081-2100 (2090) range from 0.5 – 3.5 ºC for these two scenarios.

Rainfall
Rising air temperatures will also produce an increase in the intensity of extreme rainfalls since warmer air contains ~8% more moisture for each 1ºC increase in temperature (Mullan *et al.,* 2008). On this basis, the projected increases to design rainfall events from a 1986-2005 (1995) baseline out to 2081-2100 (2090) under the two RCP scenarios range from 4 to 28%.

Under RCP8.5, by 2090 it is predicted that mean annual rainfall may increase by 20 to 25% in the eastern parts of south Canterbury near Timaru, with winter rainfall in many eastern, western and southern areas increasing by 15 to 40% (Macara *et al.,* 2020, p68).

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 more significant increases in rainfall. The online HIRDS tool (https://hirds.niwa.co.nz) produces design storm rainfall depths for a range of average recurrence intervals (ARIs), RCP scenarios and storm durations. Within the Opihi catchment, a 24-hour storm event that would currently have a 250-year ARI would be more like a 100-year ARI storm event (or less) in 2090 under RCP8.5.

Peak river flows
The relationship between increased rainfall, and the resulting increase in peak river flows, is not likely to be linear – with peak flood flows tending to increase by a greater percentage than peak rainfall. For example, a recent modelling study by Gardner and Henderson (2019) showed that, in the Wairarapa, a 17% increase in peak rainfall increased peak flows by 17 to 27% (depending on catchment characteristics). For the Ashley River/Rakahuri, Steel and Martin (2019) found that for a 250-year ARI 24-hour duration rainfall event, a 22% rainfall depth increase (to 2100) produced a 32% increase in peak flow. For a 48-hour duration rainfall event, a 19% rainfall depth increase (to 2100) produced a 25% increase in peak flow. Further work, in the form of a detailed hydrologic model, would be required to better define this relationship for the Opihi River.

Sea level
The Opihi River has a relatively steep gradient. Any increases in sea level, due to climate change, should not have a significant impact on flood levels at or adjacent to the Waipopo Huts settlement.

A1.3 Hydraulic model

The Mike Flood modelling package combined 1-dimensional (1D) modelling for the Opihi River with 2-dimensional (2D) modelling for the floodplain. The 1D and 2D models were joined using a lateral link to allow floodplain flow to pass back into the Opihi River immediately upstream of the river mouth. A schematic of the model, including the lateral link, is shown in Figure A1-2. A more detailed description of the model is given below.

1D Opihi River model
The 1D model of the Opihi River extends from 1.6 km upstream of the SH1 bridge to the coast. This 1D model has been extracted from an Opihi River model (Boyle and Surman, 2007) that has recently been updated using 2019 surveyed cross section information.

The cross-section locations are shown in Figure A1-2. Despite the 1D model crossing the SH1 bridge and the main trunk railway line bridge, no structures have been included in this model. This is because the river and floodplain are separated by stopbanks, and any localised increases in water levels due to the bridges have no significant impact on the model (i.e. the 1D model is only connected to the floodplain at the river mouth).

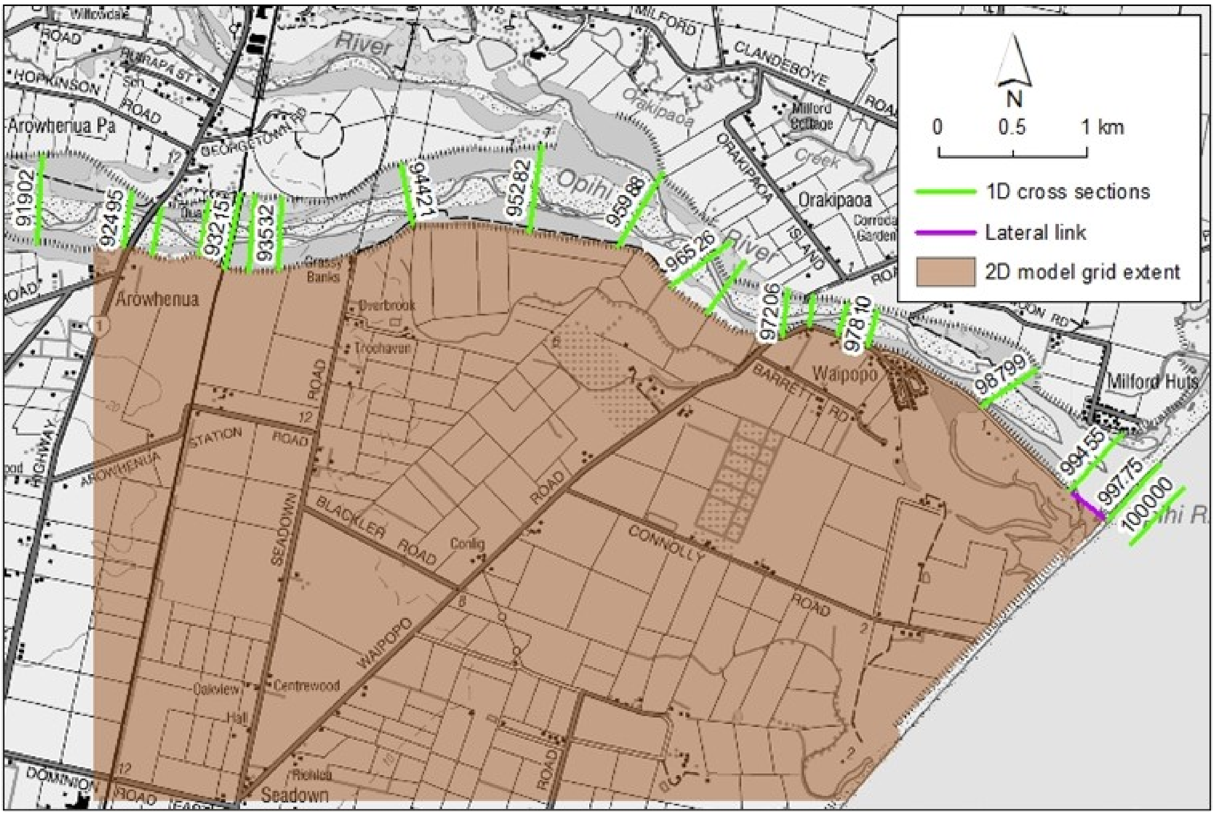

Figure A1-2: Waipopo Huts settlement model schematic

A Manning's n number of 0.040 has been used for the channel bed resistance and 0.125 for more heavily vegetated berm areas. Variations in resistance due to vegetation have been accounted for by using relative resistances for each cross-section.

2D model for alluvial fans and floodplains

The 2D component of the model covers the Opihi floodplain area shown in Figure A1-2. The topography and roughness used in the model are described below.

Topography

To realistically model alluvial fan and floodplain flows with any degree of accuracy, good topographic data (including features such as banks, terraces, overland flow channels, roads and railway embankments) are essential. For the Opihi floodplain, high resolution topographic data was obtained from a LiDAR (aerial laser scanning) survey. The survey was flown on 19 March 2010 by New Zealand Aerial Mapping (NZAM). An example of the detail provided by LiDAR data is shown in Figure A1-3.

Overland water levels and flows were resolved on a rectangular grid. The size of the grid was based on the level of detail required, model stability, and computational efficiency (i.e. computer capacity and speed). For this model, the 1 m digital elevation model (DEM) generated using the LiDAR data has been used to produce a grid of 2.5 x 2.5 m cells to represent the topography. This allows for a reasonable degree of topographic detail, while keeping the model run times to under a day. As the Opihi floodplain contains elevated topographic features capable of impeding flows (e.g. railway line), the 2.5 m model grid was checked against a finer resolution 1 m grid to make sure all barriers were properly represented by the 2.5 m grid.

The 2.5 m grid does have some limitations, pertaining to the 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 considered a reasonable assumption – especially for the larger and less frequent storm events.

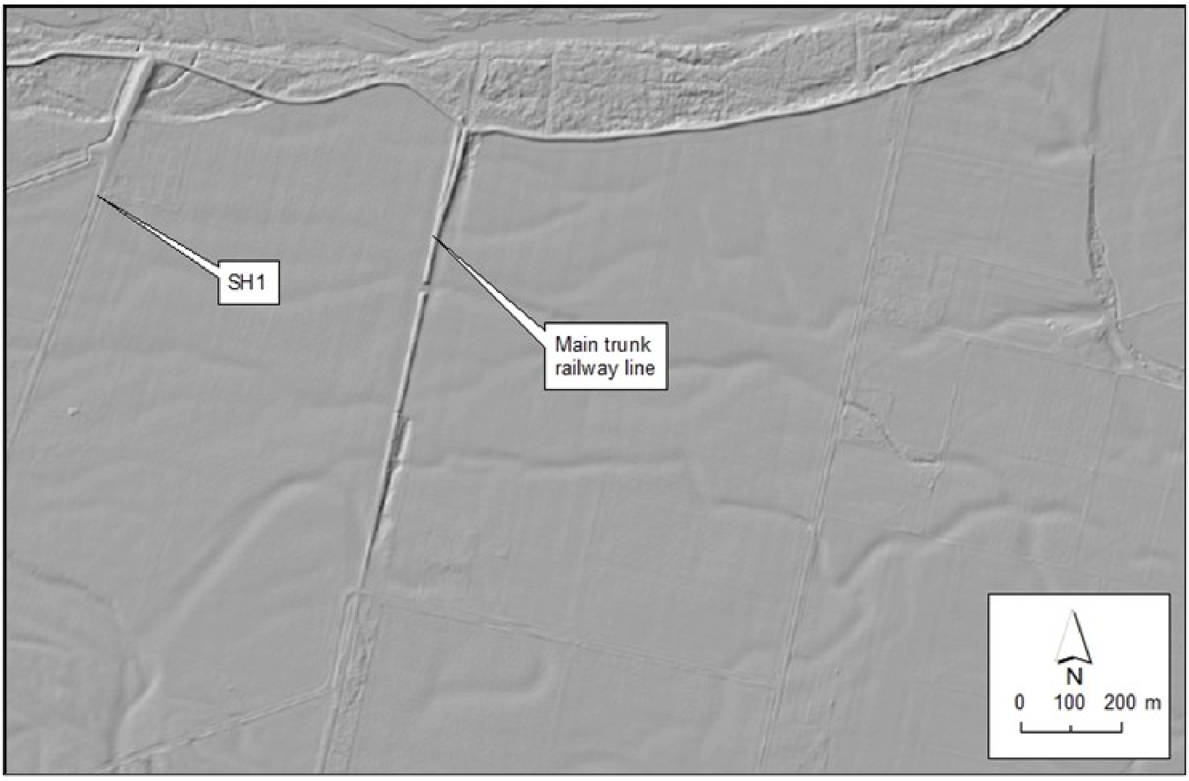

Figure A1-3: Comparison of aerial imagery and LiDAR (ground level) data (1m DEM)

Floodplain roughness (surface resistance)
For this study, a Manning's n value of 0.05 was used to represent the entire floodplain as it is predominantly land used for crops with small pockets of residential housing. Where there are dense hedges or groupings of trees, or more populated areas (with denser housing, fences, etc) localised water levels may be underestimated.

Model breakout flow inputs
Breakout flows were input as a flow source into the 2D model grid cells. Figure A1-1 indicates the location of the breakout flows.

Model validation and calibration
To provide confidence in model predictions, models should be calibrated using historical flood events to ensure they are realistic. Although the 1986 breach locations and peak Opihi River levels were measured after the flood event, floodplain water levels (and flows) were not well documented. The model was, therefore, not able to be calibrated or validated using flood observations. Instead, sensitivity tests have been completed to determine how model outputs vary for a range of model parameters (see *Model sensitivity analysis* section).

Model scenarios
Breakout flows were simulated over a 12-hour period with model simulations based on a 0.5 second time step to ensure stability. Model results were saved every 15 minutes over the full storm event. Computer run times for each simulation were around 20 hours.

Flow hydrographs
Several previous studies have derived breakout flows for Canterbury rivers. A recent study (Wild, 2015) produced breakout flows for the North Branch Ashburton River at Jessops Bend. Figure A1-4 shows a 500-year ARI breakout flow for Jessops Bend (generated from a computer model), along with the North Branch Ashburton River flow hydrograph – scaled to a comparable peak flow. A Waimakariri River breakout flow profile, used by Oliver *et al.* (2007) for breakout flows of 600 and 1000 m^3/s, has also been scaled to the Jessops Bend peak breakout flow (Figure A1-4).

This shows that both the river and breakout flows have a similar recession profile for several hours after the peak – should the breach occur around the flood peak. As time from the initial breach progresses, the larger Waimakariri River breakout flows reduce more rapidly. The profile of the rising limb of the breakout hydrograph is dependent on how rapidly the breach develops. Figure A1-4 shows that the Jessops Bend breakout simulates a very rapid failure of the stopbank compared to the Waimakariri stopbank breach.

For extreme flood events, the Opihi River flow hydrograph shape (at the modelled breakout locations along the river) is determined by various factors including the size and location of upstream breakouts, and the combined Opihi and Temuka River flow (for Breakouts A, B & C). For this study, no detailed examination of the Opihi and Temuka River flow records has been undertaken. Instead, another East Coast braided river flow hydrograph (North Branch Ashburton River) has been scaled to produce both Opihi River and breakout flow hydrographs. It has been assumed that the North Branch Ashburton River hydrograph shape (which is comparable to the North Branch Ashburton and Waimakariri River breakout profiles) would be a reasonable hydrograph to scale. The additional flow before the peak (for the breakout hydrographs) is not expected to have a significant impact on maximum modelled water depths or flow velocities in the Waipopo Huts Study Area as this area has no significant storage. A more detailed model (covering a greater floodplain and river extent and including breakouts), together with analyses of the flow data, would be required to better define these profiles. This has not been considered necessary for this study given the other uncertainties with regards to the stopbank breaches.

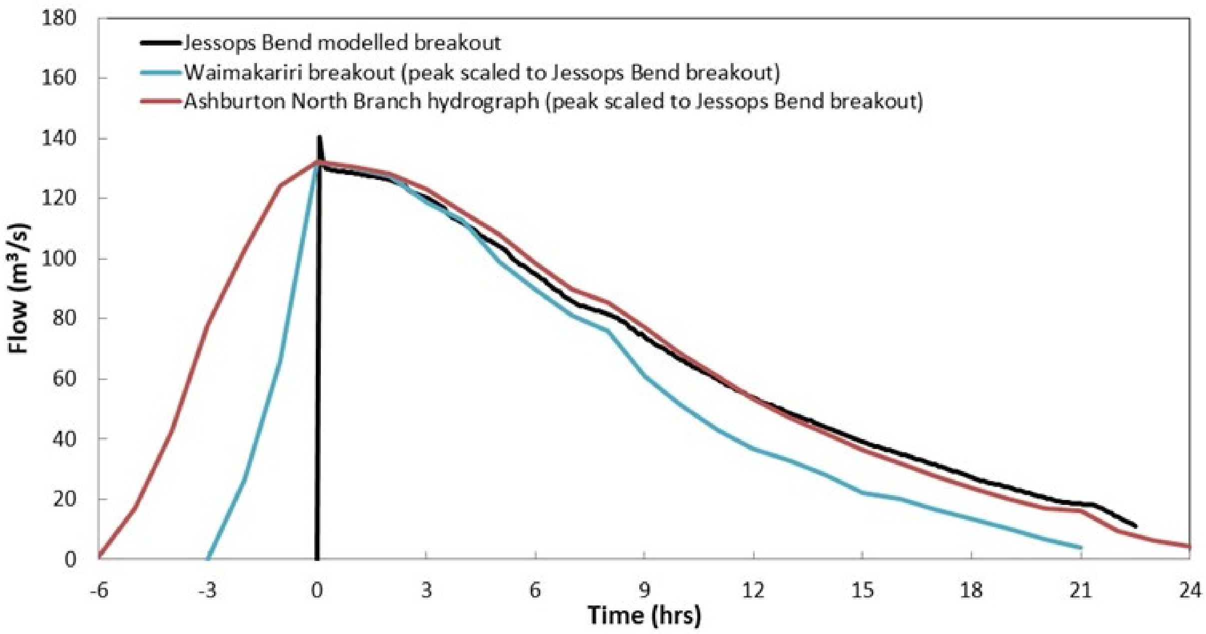

Figure A1-4: Comparison of breakout flows and Ashburton North Branch flood hydrograph (scaled to match Jessops Bend peak breakout flows)

Breakout flow scenarios

The breakout flows are provided in Table A1-3 for the scenarios modelled. Previous studies, such as Connell & Miller (1992), show that breakout flows in the vicinity of Waipopo Huts can be supplemented by flows from further upstream. A SH1 breakout flow has therefore been included in all breakout scenarios to allow for the additional flow contributions expected from upstream. In large flood events lateral erosion of stopbanks is likely to cause some, if not all, of the stopbank breaches along the Opihi River. It is therefore feasible that several breaches could occur around the same time. Simultaneous breakouts at SH1 and locations A and B – both with and without a breakout at location C – have also been modelled. Given that in 1986 there were multiple breakout flows along the Opihi River stopbank system, in an extreme flood event it is feasible that all breakouts (SH1, A, B and C) could occur.

Table A1-3: Model scenarios

Breakout scenario		Peak flow (m3/s)				
		Opihi River	SH1	Breakout A	Breakout B	Breakout C
SH1 breakout	Base	2920	540			
	Elevated	2760	700			
SH1 + Breakout A	Base	2620	540	300		
	Elevated	2370	700	390		
SH1 + Breakout B	Base	2670	540		250	
	Elevated	2435	700		325	
SH1 + Breakout C	Base	2600	540			320
	Elevated	2345	700			415
SH1 + Breakouts A & B	Elevated	2045	700	390	325	
SH1 + Breakouts A, B & C	Elevated	1630	700	390	325	415

Model results

Maximum modelled flood depths for the various breakout scenarios are shown in Figure A1-5 to Figure A1-14. The model results show a large portion of the floodplain inundated, with maximum water depths exceeding 0.5 m is many areas. The Waipopo Huts settlement is particularly susceptible to Breakout C, where maximum water depths are likely to be over 1m deep for most of the settlement.

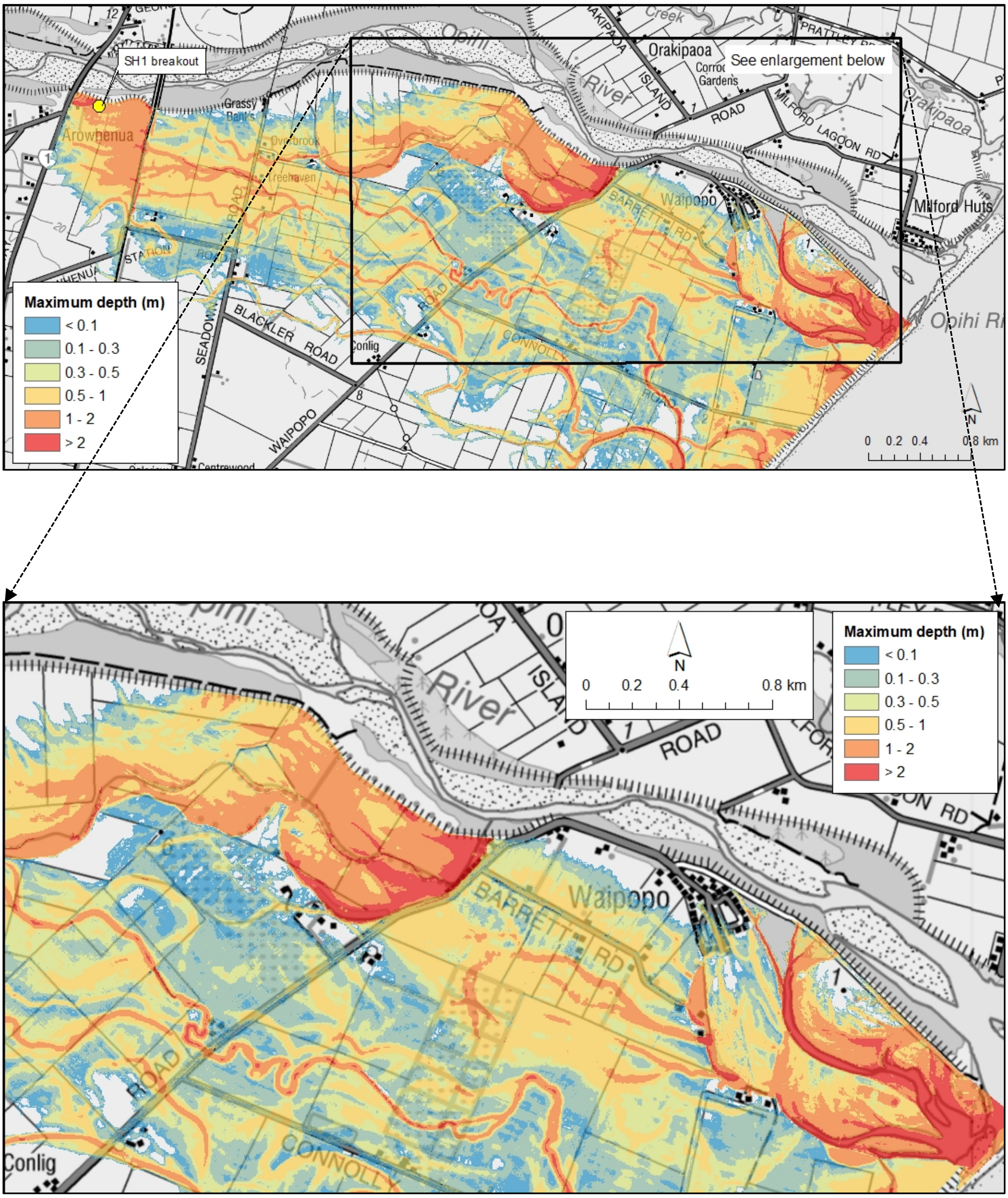

Figure A1-5: Maximum water depth for SH1 breakout flow of 540 m^3/s - base scenario

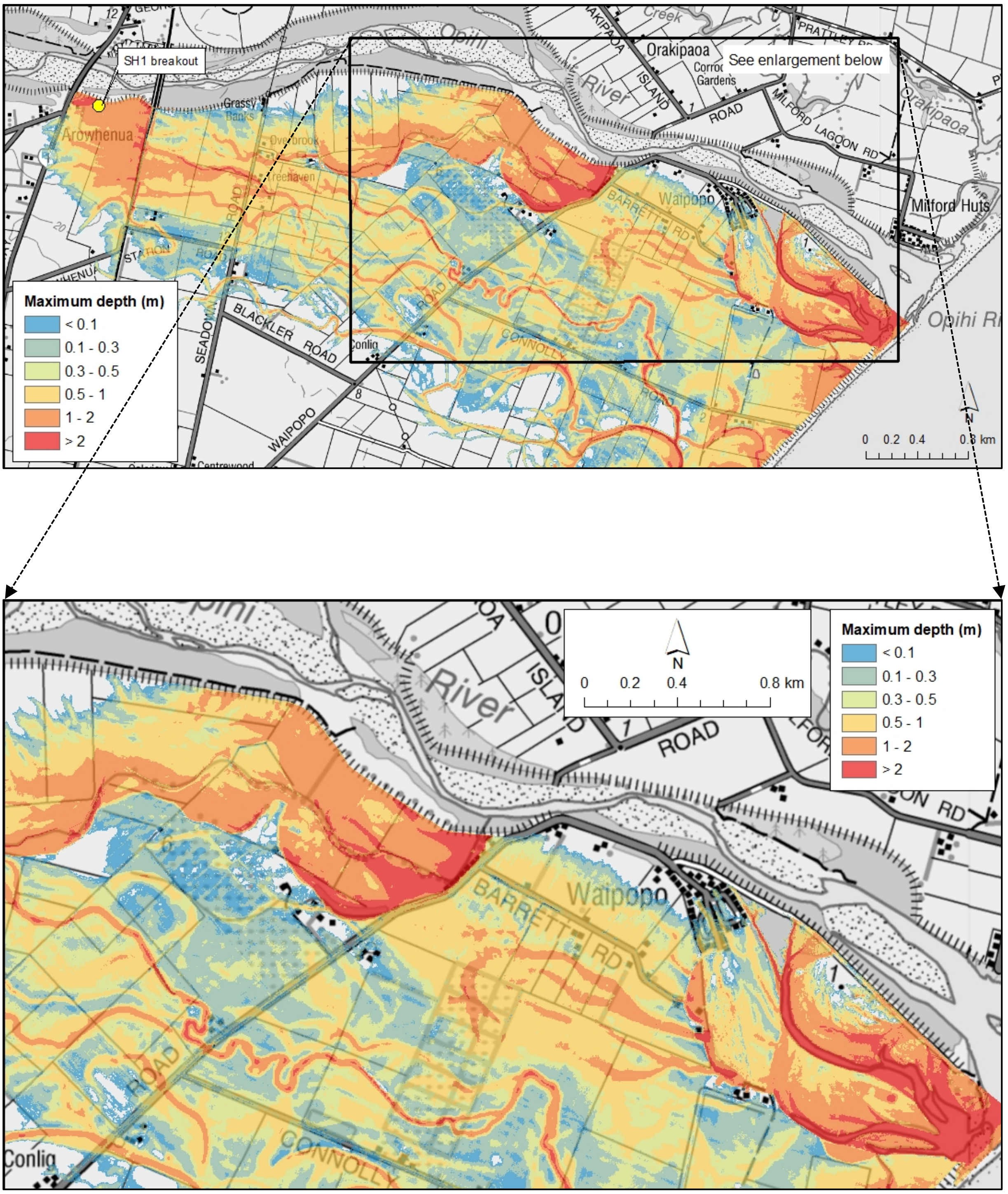

Figure A1-6: Maximum water depth for SH1 breakout flow of 700 m^3/s - elevated scenario

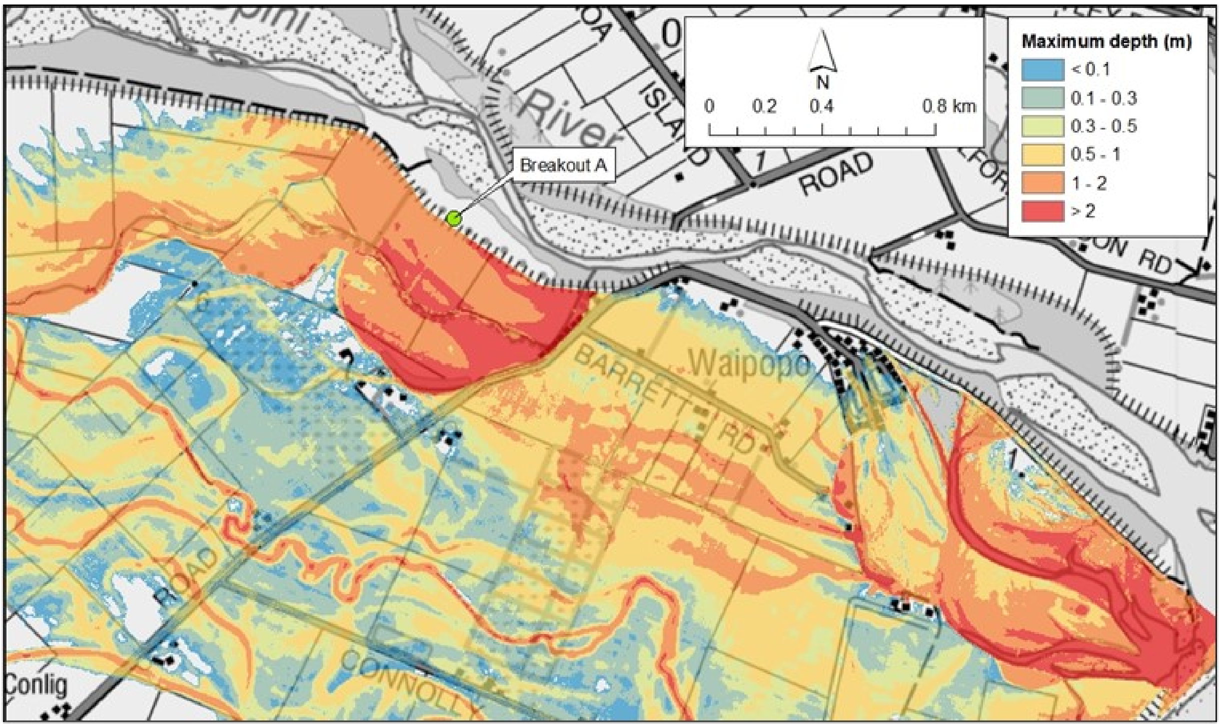

Figure A1-7: Maximum water depth for SH1 breakout flow (540 m^3/s) + Breakout A flow (300 m^3/s) - base scenario

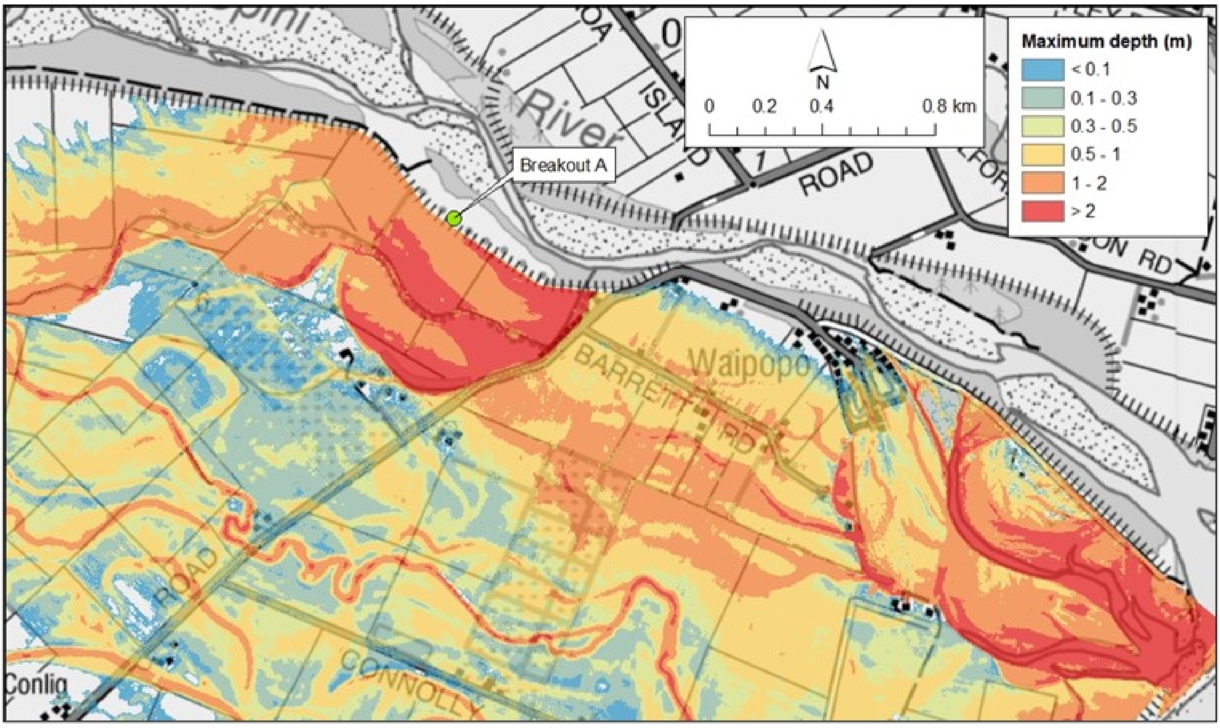

Figure A1-8: Maximum water depth for SH1 breakout flow (700 m^3/s) + Breakout A flow (390 m^3/s) - elevated scenario

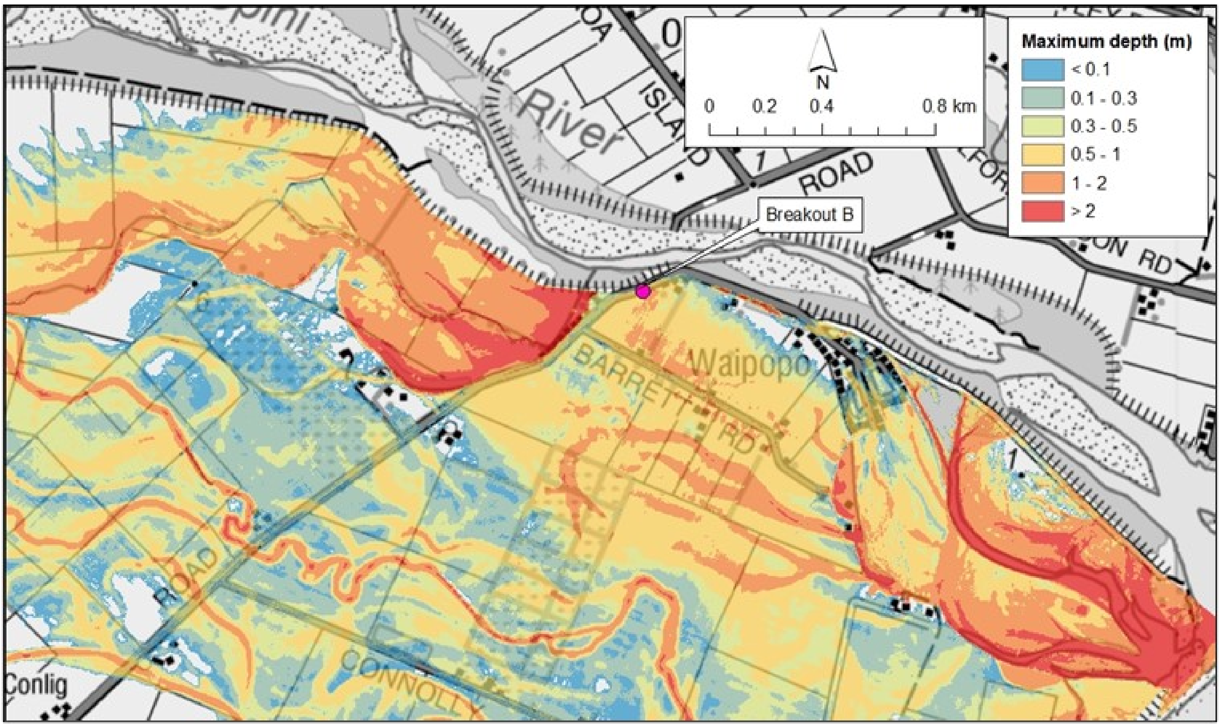

Figure A1-9: Maximum water depth for SH1 breakout flow (540 m^3/s) + Breakout B flow (250 m^3/s) - base scenario

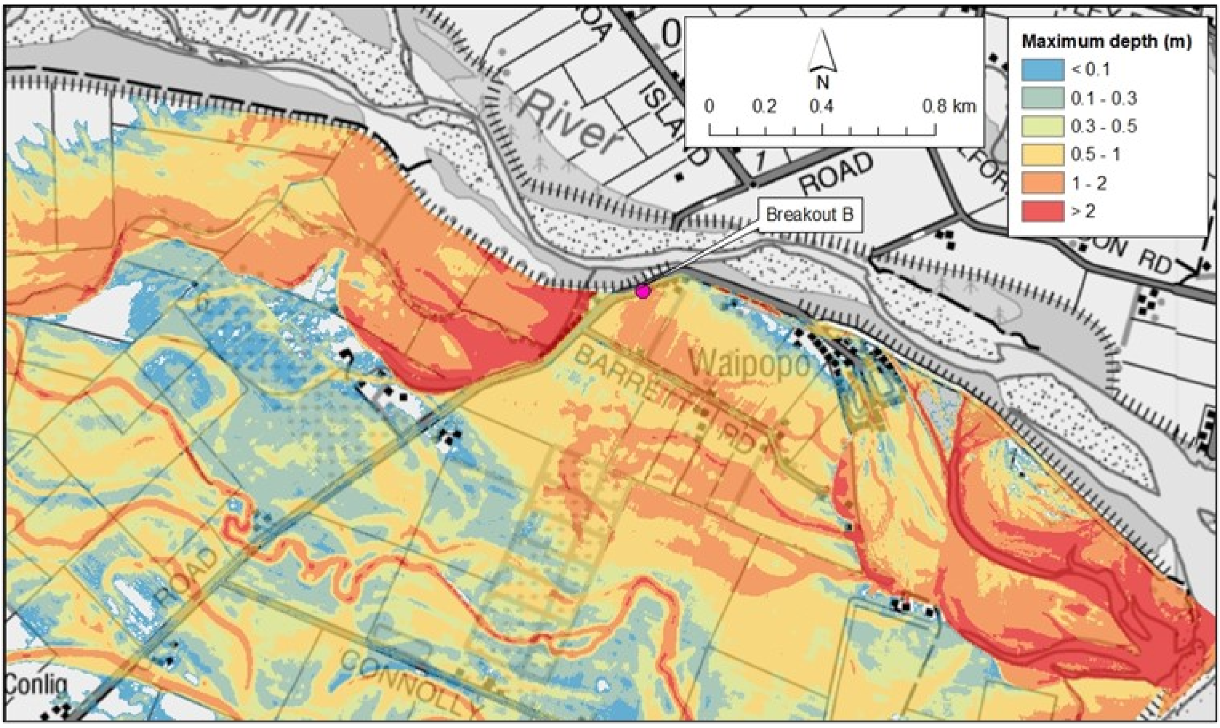

Figure A1-10: Maximum water depth for SH1 breakout flow (700 m^3/s) + Breakout B flow (325 m^3/s) - elevated scenario

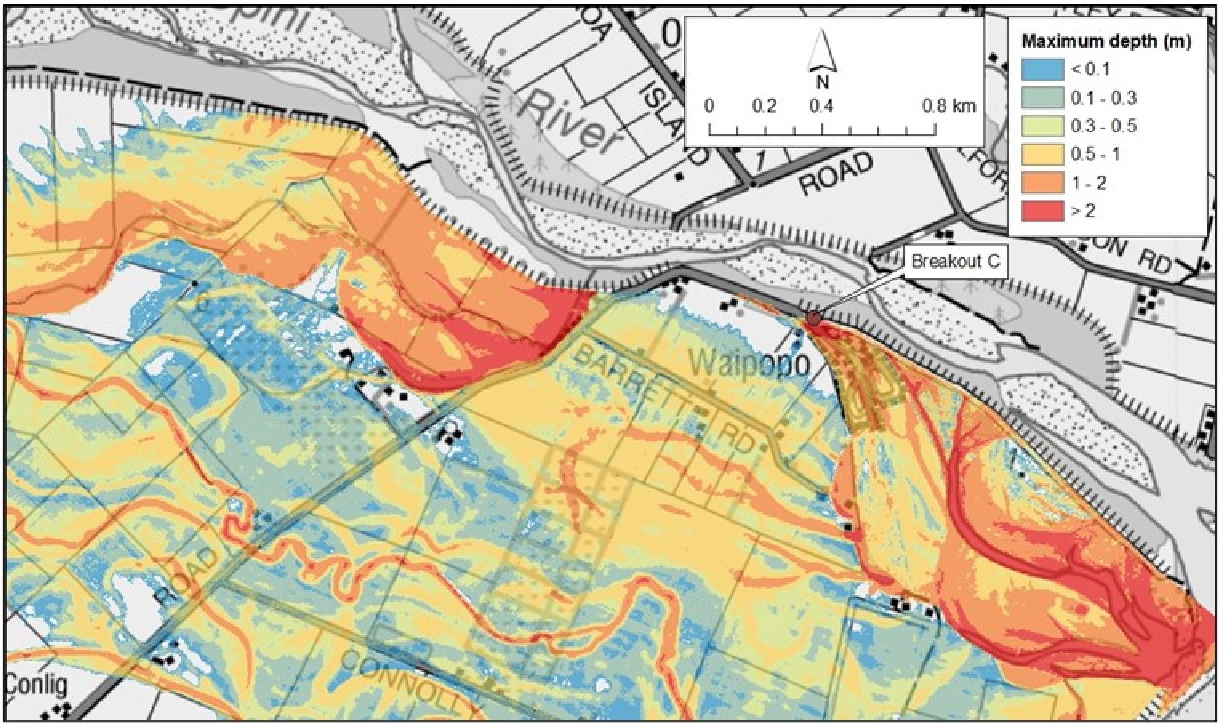

Figure A1-11: Maximum water depth for SH1 breakout flow (540 m^3/s) + Breakout C flow (320 m^3/s) - base scenario

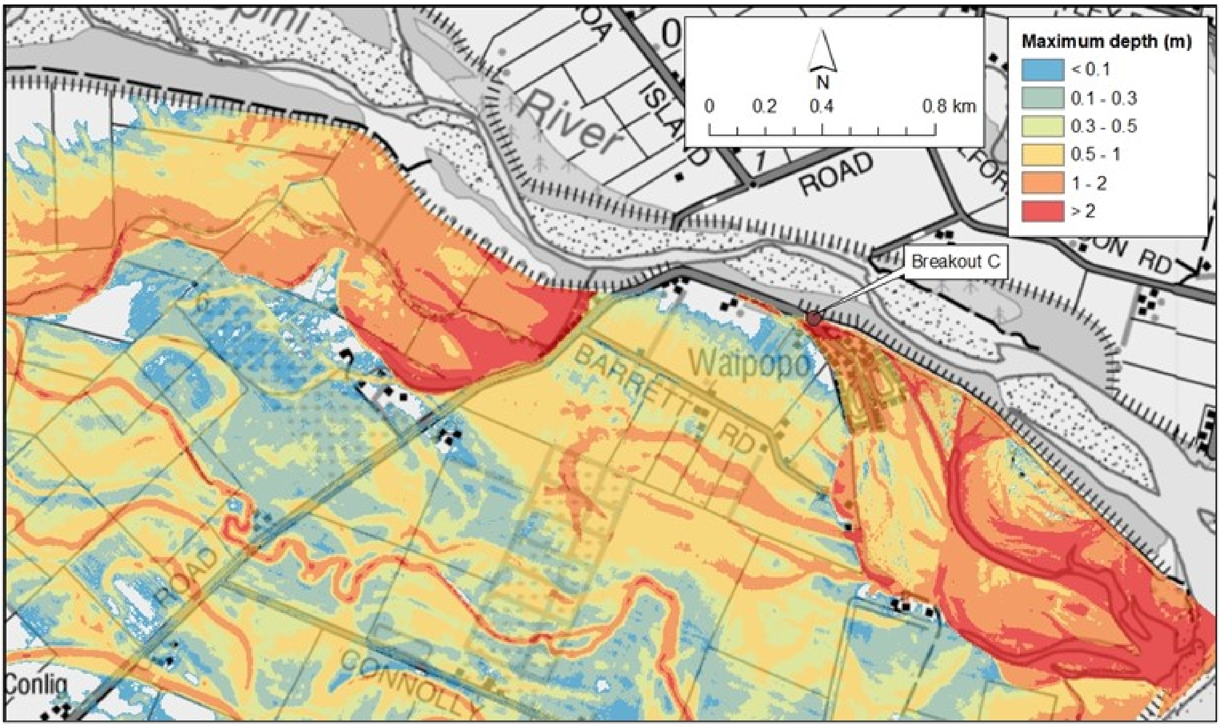

Figure A1-12: Maximum water depth for SH1 breakout flow (700 m^3/s) + Breakout C flow (415 m^3/s) - elevated scenario

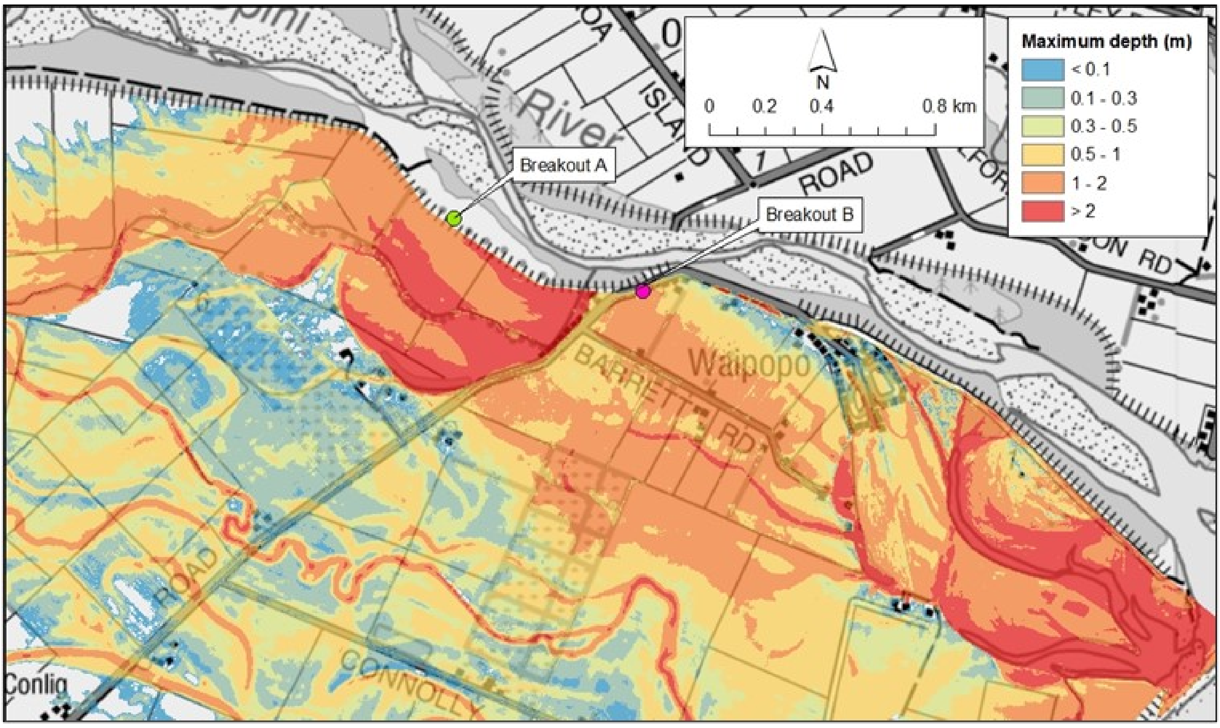

Figure A1-13: Maximum water depth for SH1 breakout flow (700 m^3/s) + Breakout A (390 m^3/s) + Breakout B (325 m^3/s) - elevated scenario

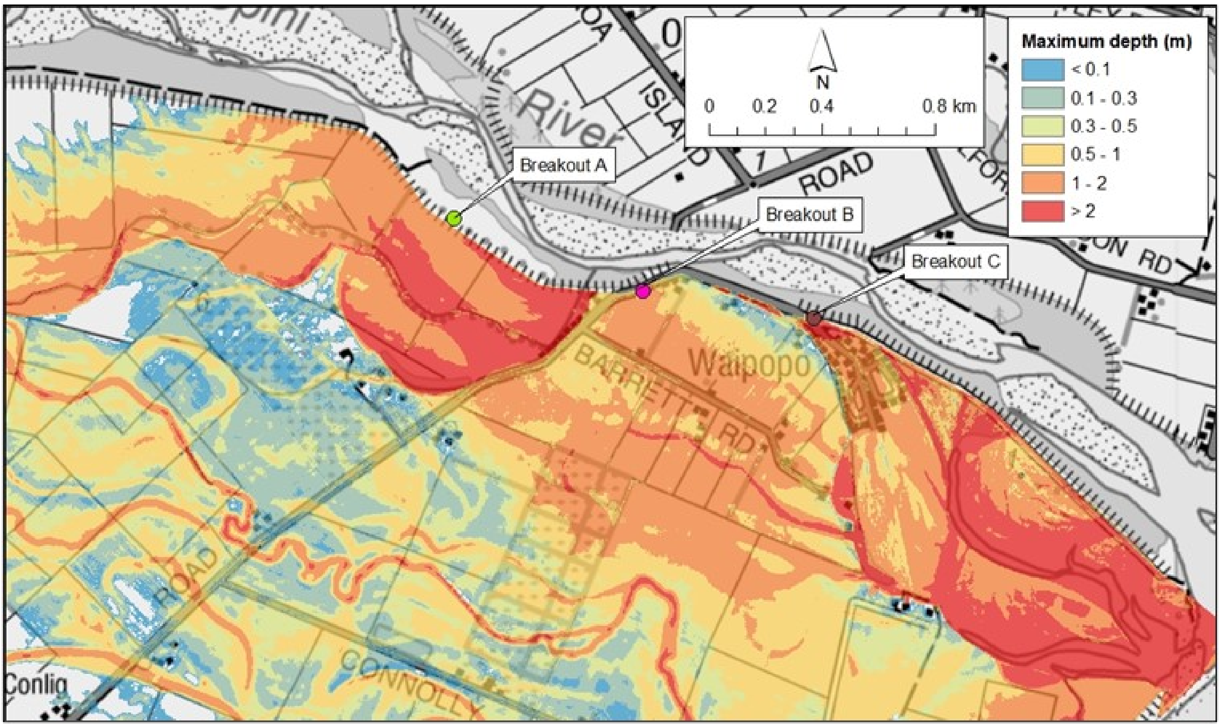

Figure A1-14: Maximum water depth for SH1 breakout flow (700 m^3/s) + Breakout A (390 m^3/s) + Breakout B (325 m^3/s) + Breakout C (415 m^3/s) - elevated scenario

Model sensitivity analysis
As the model was unable to be calibrated, additional scenarios were modelled to determine the sensitivity of flood inundation to various model parameters and assumptions. These are described below.

Increased floodplain roughness
The Opihi River floodplain Manning's n roughness value of 0.05 was increased to 0.07, to represent a scenario where, instead of mainly pasture, fields were covered in established crops. Figure A1-15 shows that increasing floodplain roughness from 0.05 to 0.07 may increase water depths by up to ~0.3 m in the Waipopo Hut Study Area.

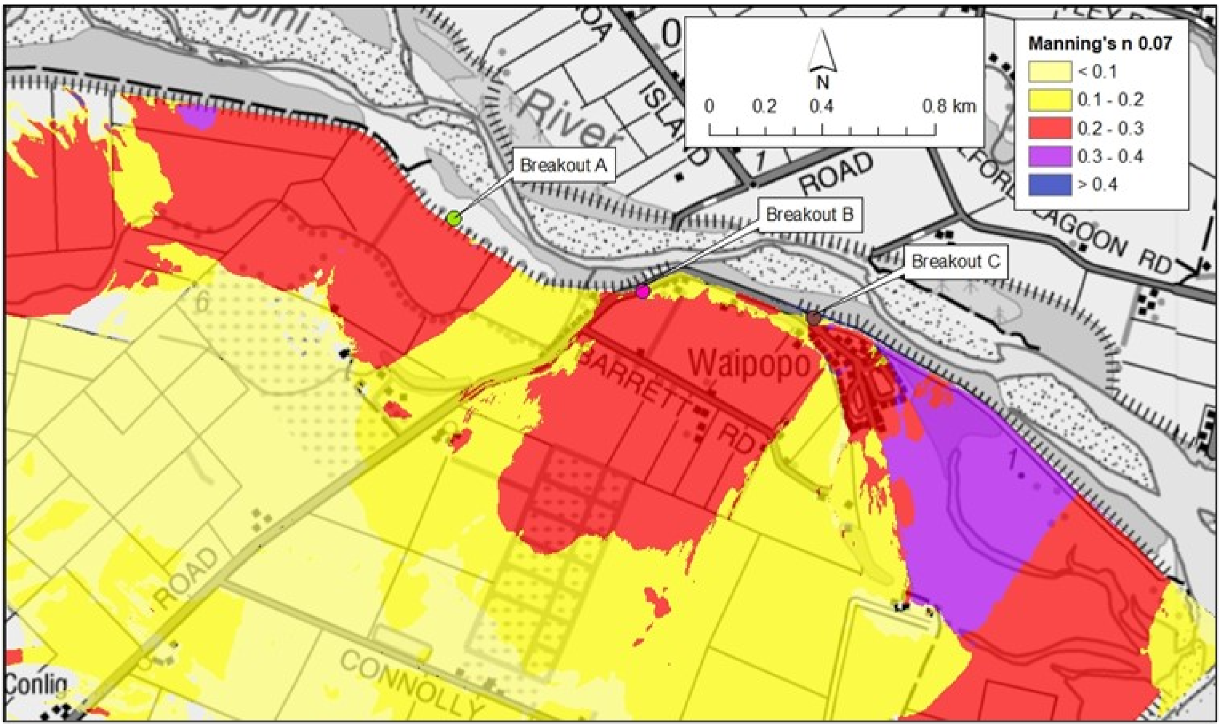

Figure A1-15: Increase in modelled water depths if floodplain Manning's n is increased from 0.05 to 0.07 [elevated scenario breakouts at SH1 and locations A, B and C]

Increased breakout flow
Should the elevated breakout flow scenarios prove to be more realistic for large events, such as a 200-year ARI flood event, then climate change impacts may exacerbate breach flow magnitudes further. For this sensitivity test, the elevated model (with all breakouts occurring) has 25% added to the breakout flows and the Opihi River flow.

Figure A1-16 indicates that increasing breakout flows by 25% increases floodplain flow depths by ~0.1 to 0.2 m in the Waipopo Huts Study Area. Greater increases in water depths occur on the floodplain area upstream of the river mouth and coastal stopbank system due to the larger volume of water on the floodplain trying to exit to the coast. At the Waipopo Huts settlement, this backing up of flood water does not have a significant impact on maximum water depths.

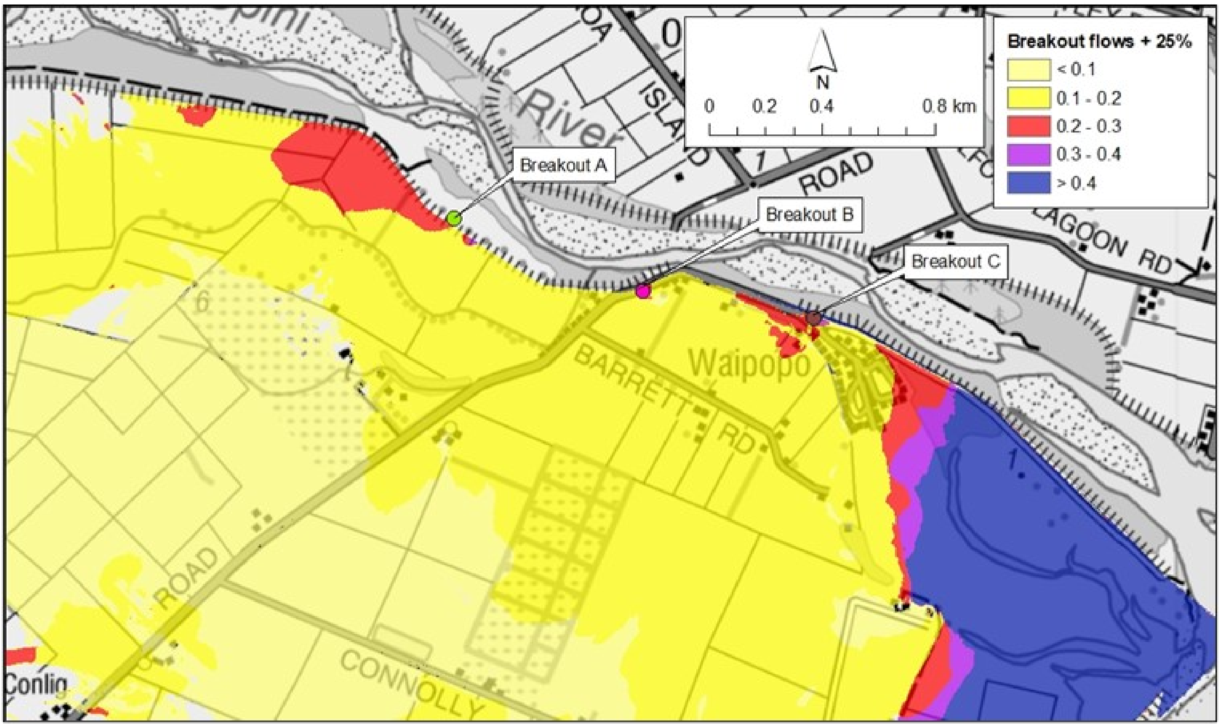

Figure A1-16: Increase in modelled water depths if breakout flows are increased by 25% [for elevated scenario breakouts at SH1 and locations A, B and C]

Derivation of high hazard areas
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***'.

During a 500-year ARI flood event, it is highly likely that the Opihi Riverbank protection works will fail. To allow for climate change to 2081-2100, and extreme flood conditions likely during a 500 year ARI flood event, the high hazard area for the Waipopo Huts settlement area has been determined by assuming simultaneous breakouts at SH1 and locations A, B & C (elevated scenario) together with either:

- 25% increase in the breakout flows or
- Increased Manning's n of 0.07 for the floodplain

Figure A1-17 identifies areas in the vicinity of the Waipopo Huts settlement that would potentially meet the CRPS definition of high hazard, based on the flood modelling and the above assumptions, for a 500-year ARI flood event.

As the computer model used in this investigation has a fixed bed, and only a limited number of breakout locations have been modelled (when scour/aggradation may force flood flows to breakout at other locations), not all possible high hazard areas will necessarily have been identified by this modelling investigation.

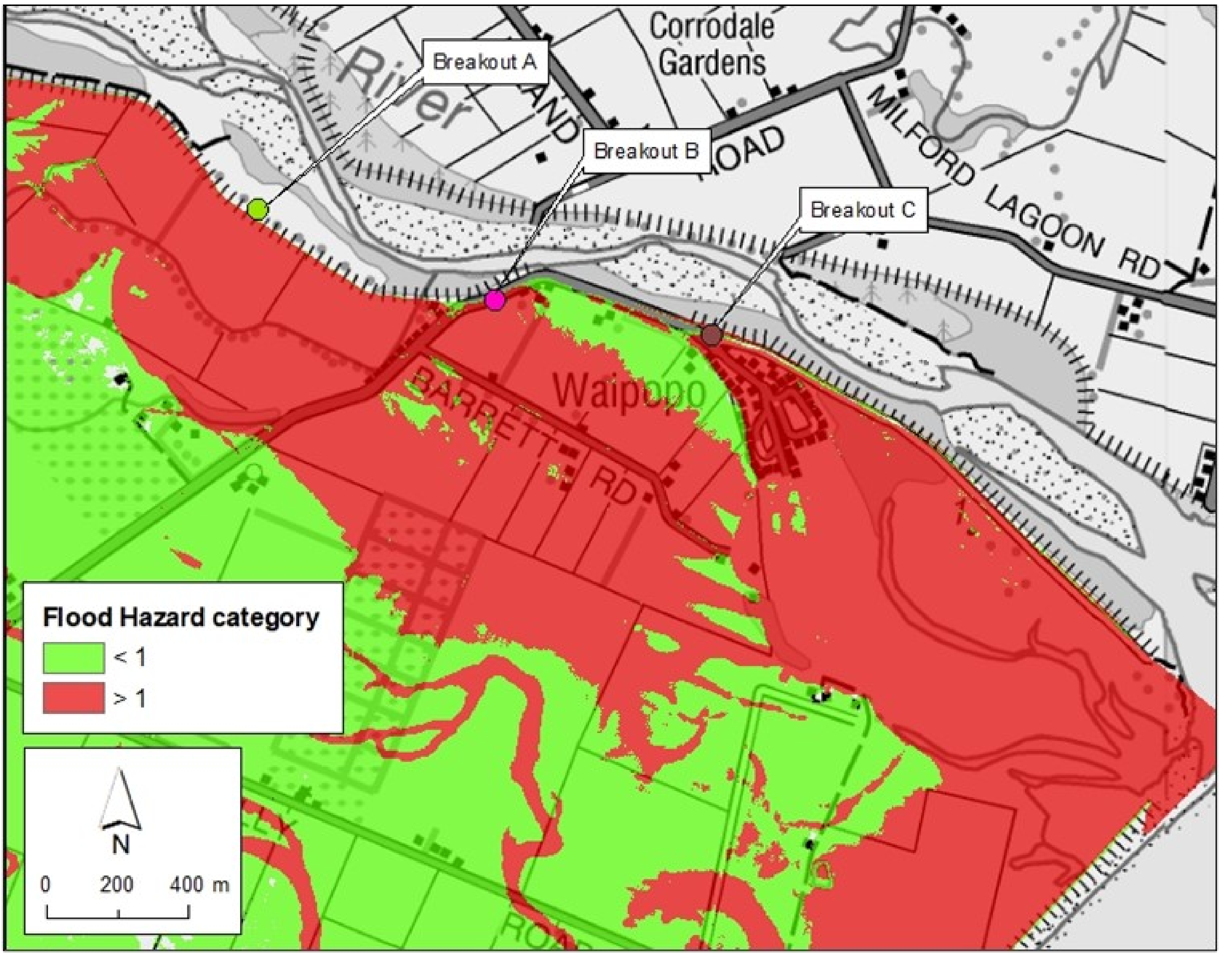

Figure A1-17: Flood hazard category [elevated scenario breakouts at SH1 and locations A, B and C with either flows increased by 25% or floodplain roughness increased to 0.07]

Model uncertainty

Bales and Wagner (2009) outline some of the uncertainties associated with 1-dimensional hydraulic modelling using LiDAR data. These uncertainties are also relevant for this modelling study, where uncertainties include:

- Model inputs (e.g. stopbank breach locations and sizes, flow magnitude and hydrograph shape, roughness values, energy loss parameters, and climate change predictions).
- Topographic data (e.g. LiDAR data). The model uses a fixed bed level so cannot account for scour and aggradation due to high-energy flood flows.
- Hydraulic model assumptions (e.g. simplification of equations by depth-averaging, as well as averaging topography and flow behaviour over a 5 m grid cell for computational efficiency).

The source of uncertainty that is particularly relevant for this study is the size and location of stopbank breaches, which are largely unpredictable. Not all feasible scenarios can be modelled so it is possible that, in a large flood event such as a 50 to 500 year ARI flood, other areas within the study area could be inundated with flood water (i.e. not all areas of possible inundation are necessarily covered by this study). Sensitivity tests can help address uncertainty, though modelling results should generally be interpreted and used by those who are familiar with all aspects of the modelling.

A1.4 Conclusions and recommendations

There is a large degree of uncertainty contained within the mapping and model results due to the unpredictable nature of stopbank breaches – particularly with the estimated magnitudes and locations of the modelled breakout flows (both present-day and with consideration for climate change). The model also has a fixed ground level and does not simulate changes in topography due to scour or aggradation.

Despite the uncertainty, the modelled breakout flows do show preferential flow paths, and significant depths of flood water over a considerable proportion of the Waipopo Huts Study Area. Although breakout flows from further up the floodplain (in the SH1 area) can inundate a large portion of the Waipopo Hut Study Area, most of the floodwaters pass to the south of the Waipopo Hut dwellings. The most significant impact on the Waipopo Hut dwellings is from the local breakouts. A breakout at location C is likely to produce the most significant flooding in the main hut area due to the confined nature of the topography that does not allow the floodwaters to spread out. The area least susceptible to flooding is located along Waipopo Road - to the west of the main hut settlement on elevated land parallel to the stopbank. Further discussions regarding flooding in the Waipopo Hut Study Area are provided in Section 4 of the main report.

Modelling indicates that significant portions of the Waipopo Huts Study Area may be considered high hazard and provides a good insight into how flood waters are likely to behave for a range of breakout scenarios. It also shows that self-evacuation during a flood event may not be possible.

Possible future improvements to the Waipopo Huts modelling include:

- Determining the breakout flows onto the floodplain, by modifying the model to connect the 1D model to the 2D model along the entire length of the stopbank system. Breaches could then be simulated based on:
    - Opihi River at SH1 bridge (Site 69607) flood hydrographs
    - Breach/failure dimensions (over time)

However, there would still be considerable uncertainty due to the unpredictable nature of breaches.

- Developing a rainfall runoff model of the entire Levels Plains area to better simulate the timing and magnitude of peak flows from both overland flows and the river using the wider floodplain extent. This could allow the river flood flows and breach magnitudes, nearer the river mouth, to be better understood. It would also allow the relationship between the latest predictions for climate change-induced increases in peak rainfall, and the resulting increases in river peak flows to be examined.

Due to the limitations of the mapping and modelling, it is recommended that the results of this study should be used in conjunction with historic flood information and practical, scientific judgement.

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Model run files

Model extent: (1461385 mE, 5093500 mN) to (1468400 mE, 5097490 mN)

Waipopo Huts model file summary

Mike11	
Network (*.nwk11)	Opihi_Waipopo
Cross section (*.xns11)	Opihi_90055_to_sea
Hydrodynamic file (*.hd11)	Opihi_HD
Mike21	
Drying depth (m)	0.01
Wetting depth (m)	0.03
Eddy viscosity	0.25
Number of structures	0
Simulation start time	1 January 1990 at 12:00pm
Simulation end time	2 January 1990 at 12:00am
Time step (s)	0.5
Length of run (steps)	86400

Scenario	Breakout Flow				MikeFlood	Mike11				Mike21				
	SH1	A	B	C	Couple (*.mf)	Simulation (*.sim11)	Boundary (*.bnd11)	HD Parameter (*.hd11)	Results (*.res11)	Simulation (*.21)	Bathymetry (*.dfs2)	Initial surface elevation (m)	Resistance (*.dfs2)	Results (*.dfs2)
SH1 breakout														
Base	540				Opihi_Q_2920_SH1_BO_540_cumecs_mf	Opihi_Q_2920_SH1_BO_540_cumecs	Opihi_Q_2920	Opihi_HD	Opihi_Q_2920_SH1_BO_540_cumecs	Opihi_Q_2920_SH1_BO_540_cumecs	waipopo_2_5m_rway_lowered	waipopo_2_5m_rway_lowered_initial_WL	0.05	Opihi_Q_2920_SH1_BO_540_cumecs
Elevated	700				Opihi_Q_2760_SH1_BO_700_cumecs_mf	Opihi_Q_2760_SH1_BO_700_cumecs	Opihi_Q_2760	Opihi_HD	Opihi_Q_2760_SH1_BO_700_cumecs	Opihi_Q_2760_SH1_BO_700_cumecs	waipopo_2_5m_rway_lowered	waipopo_2_5m_rway_lowered_initial_WL	0.05	Opihi_Q_2760_SH1_BO_700_cumecs
SH1 + location A breakouts														
Base	540	300			Opihi_Q_2620_SH1_BO_540_BO_A_300_mf	Opihi_Q_2620_SH1_BO_540_BO_A_300	Opihi_Q_2620	Opihi_HD	Opihi_Q_2620_SH1_BO_540_BO_A_300	Opihi_Q_2620_SH1_BO_540_BO_A_300	waipopo_2_5m_rway_lowered_BO_A	waipopo_2_5m_rway_lowered_initial_WL	0.05	Opihi_Q_2620_SH1_BO_540_BO_A_300
Elevated	700	390			Opihi_Q_2370_SH1_BO_700_BO_A_390_mf	Opihi_Q_2370_SH1_BO_700_BO_A_390	Opihi_Q_2370	Opihi_HD	Opihi_Q_2370_SH1_BO_700_BO_A_390	Opihi_Q_2370_SH1_BO_700_BO_A_390	waipopo_2_5m_rway_lowered_BO_A	waipopo_2_5m_rway_lowered_initial_WL	0.05	Opihi_Q_2370_SH1_BO_700_BO_A_390
SH1 + location B breakouts														
Base	540		250		Opihi_Q_2670_SH1_BO_540_BO_B_250_mf	Opihi_Q_2670_SH1_BO_540_BO_B_250	Opihi_Q_2670	Opihi_HD	Opihi_Q_2670_SH1_BO_540_BO_B_250	Opihi_Q_2670_SH1_BO_540_BO_B_250	waipopo_2_5m_rway_lowered_BO_B	waipopo_2_5m_rway_lowered_initial_WL	0.05	Opihi_Q_2670_SH1_BO_540_BO_B_250
Elevated	700		325		Opihi_Q_2670_SH1_BO_540_BO_B_250	Opihi_Q_2435_SH1_BO_700_BO_B_325	Opihi_Q_2435	Opihi_HD	Opihi_Q_2435_SH1_BO_700_BO_B_325	Opihi_Q_2435_SH1_BO_700_BO_B_325	waipopo_2_5m_rway_lowered_BO_B	waipopo_2_5m_rway_lowered_initial_WL	0.05	Opihi_Q_2435_SH1_BO_700_BO_B_325
SH1 + location C breakouts														
Base	540			320	Opihi_Q_2600_SH1_BO_540_BO_C_320_mf	Opihi_Q_2600_SH1_BO_540_BO_C_320	Opihi_Q_2600	Opihi_HD	Opihi_Q_2600_SH1_BO_540_BO_C_320	Opihi_Q_2345_SH1_BO_700_BO_C_415	waipopo_2_5m_rway_lowered_BO_C	waipopo_2_5m_rway_lowered_initial_WL	0.05	Opihi_Q_2345_SH1_BO_700_BO_C_415
Elevated	700			415	Opihi_Q_2345_SH1_BO_700_BO_C_415_mf	Opihi_Q_2345_SH1_BO_700_BO_C_415	Opihi_Q_2345	Opihi_HD	Opihi_Q_2345_SH1_BO_700_BO_C_415	Opihi_Q_2345_SH1_BO_700_BO_C_415	waipopo_2_5m_rway_lowered_BO_C	waipopo_2_5m_rway_lowered_initial_WL	0.05	Opihi_Q_2345_SH1_BO_700_BO_C_415
SH1 + location A & B breakouts														
Elevated	700	390	325		Opihi_Q_2045_SH1_BO_700_BO_A_390_BO_B_325_mf	Opihi_Q_2045_SH1_BO_700_BO_A_390_BO_B_325	Opihi_Q_2045	Opihi_HD	Opihi_Q_2045_SH1_BO_700_BO_A_390_BO_B_325	Opihi_Q_2045_SH1_BO_700_BO_A_390_BO_B_325	waipopo_2_5m_rway_lowered_BO_A_BO_B	waipopo_2_5m_rway_lowered_initial_WL	0.05	Opihi_Q_2045_SH1_BO_700_BO_A_390_BO_B_325
SH1 + location A, B & C breakouts														
Elevated	700	390	325	415	Opihi_Q_1630_SH1_BO_700_BO_A_390_BO_B_325_BO_C_415_mf	Opihi_Q_1630_SH1_BO_700_BO_A_390_BO_B_325_BO_C_415	Opihi_Q_1630	Opihi_HD	Opihi_Q_1630_SH1_BO_700_BO_A_390_BO_B_325_BO_C_415	Opihi_Q_1630_SH1_BO_700_BO_A_390_BO_B_325_BO_C_415	waipopo_2_5m_rway_lowered_BO_A_BO_B_BO_C	waipopo_2_5m_rway_lowered_initial_WL	0.05	Opihi_Q_1630_SH1_BO_700_BO_A_390_BO_B_325_BO_C_415
Sensitivity Tests:														
Manning's n roughness increased from 0.05 to 0.07 for the floodplain	700	390	325	415	Opihi_Q_1630_SH1_BO_700_BO_A_390_BO_B_325_BO_C_415_n_0_07_mf	Opihi_Q_1630_SH1_BO_700_BO_A_390_BO_B_325_BO_C_415_n_0_07	Opihi_Q_1630	Opihi_HD	Opihi_Q_1630_SH1_BO_700_BO_A_390_BO_B_325_BO_C_415_n_0_07	Opihi_Q_1630_SH1_BO_700_BO_A_390_BO_B_325_BO_C_415_n_0_07	waipopo_2_5m_rway_lowered_BO_A_BO_B_BO_C	waipopo_2_5m_rway_lowered_initial_WL	0.07	Opihi_Q_1630_SH1_BO_700_BO_A_390_BO_B_325_BO_C_415_n_0_07
All flows increased by 25%	875	490	410	520	Opihi_Q_1630_SH1_BO_700_BO_A_390_BO_B_325_BO_C_415_Q_plus_25perc_mf	Opihi_Q_1630_SH1_BO_700_BO_A_390_BO_B_325_BO_C_415_q_plus_25perc	Opihi_Q_2040	Opihi_HD	Opihi_Q_1630_SH1_BO_700_BO_A_390_BO_B_325_BO_C_415_q_plus_25perc	Opihi_Q_1630_SH1_BO_700_BO_A_390_BO_B_325_BO_C_415_q_plus_25perc	waipopo_2_5m_rway_lowered_BO_A_BO_B_BO_C	waipopo_2_5m_rway_lowered_initial_WL	0.05	Opihi_Q_1630_SH1_BO_700_BO_A_390_BO_B_325_BO_C_415_q_plus_25perc

Appendix 2: Methodology used to determine breakout flows for Waipopo modelling

Methodology and discussion regarding estimation of breakout flows for Waipopo Flood Modelling

A2.1 General Discussion

The Waipopo Huts Study Area is near the mouth of the Opihi River. This is a location where estimating breakout flows is complicated by:

- the flood protection scheme being designed to contain flows of around a 50-year Average Recurrence Interval (ARI), while this modelling investigation is looking at flooding impacts in more extreme flood events.
- the difficulty in determining the location and size of large breakouts that will also be occurring from the river upstream of Waipopo (and possibly opposite Waipopo) in floods that exceed the flood protection capacity. These breakouts are likely to be a combination of:
  - high flood water levels that overtop and subsequently breach the stopbank.
  - stopbank breaches that occur from lateral erosion from the riverside (when water level is below the top of the stopbank).

  The history of major floods in the Opihi indicate that both these outcomes can happen, and potentially at different locations in the same flood.
- not knowing the residual flows (and water levels) in the Opihi River at Waipopo in extreme flood events - due to the large degree of uncertainty in the location and size of the upstream breakouts mentioned above.

For these reasons we have had to estimate appropriate water levels in the river to use for each breakout scenario.

A2.2 General methodology for estimating "base" breakout flows

The best flood and stopbank breach information available for this area was records taken by the South Canterbury Catchment Board from the devastating 13 March 1986 flood. That flood had an estimated peak flow in the Opihi River at Saleyards Bridge of 3600 cumecs.

The present-day 200-year Average Recurrence Interval (ARI) flood in the Opihi River has an estimated peak flow at Saleyards Bridge of 3700 cumecs so very closely approximates the 1986 flow. When factoring in the amount of water that could potentially breakout of the river upstream and opposite Waipopo the difference of 100 cumecs is quite negligible. Furthermore, the fact that we have defined breakout locations in this modelling investigation based on realistic but worst-case scenarios for the Waipopo Area makes that small flow difference less significant. By applying the 1986 flood data to the specified breakout locations, and assuming that approximates the present-day 200-year ARI flood event, we established base breakout flows.

For each breach location identified in 1986 we used the following data:

- Breach widths and locations - taken from the report "*Report on Flood 13th March 1986" SCCB Publication No.47*
- Depth of water - estimated by relating nearby 1986 flood level estimates, river benchmark data (benchmarks on top of stopbanks) and 2010/2014 LiDAR information to obtain ground levels on landward side of stopbank. Flood level data was taken from Opihi River 6960000, Opihi Calculations Folder, Pages 198-213
- Breach flow velocity of 2 metres per second – estimated after discussions with senior hydrology staff at Environment Canterbury.

A2.3 Parameters used for determining "base" breakout flow at each identified location

State Highway One breakout
Although this State Highway One breakout flow location is a discrete point in the modelling, it represents a range of overflow flooding scenarios from upstream, to just downstream, of the highway. Overflows from this area all follow the same flow path towards the Waipopo Study Area.

In 1986 there were two breaches of the stopbanks in the State Highway One area:

- Breach 1 = a 60-metre-wide breach of the true right bank approximately 2.1 km upstream of State Highway One.
  - o Flood level is approximately 30.6 m,
  - o Stopbank height is 31.3 m,
  - o Ground level is 28.2 m; therefore depth of water is 3.1 meters.
  - o Width (W) x Depth (D) x Velocity (V) = 60 x 3.1 x 2 = <u>370 cumecs</u>

- Breach 2 = a 40-metre-wide breach of the true right bank approximately 650 m upstream of State Highway One.
  - o Flood level approximately 24.1 m
  - o Stopbank height is 25.0 m
  - o Ground level is 22.0 m, therefore depth of water is 2.1 meters
  - o Water velocity is 2 metres per second
  - o W x D x V = 40 x 2.1 x 2 = <u>170 cumecs</u>

The Levels Plains Floodplain Study (Report R92/7, Plan 12, 373 m, sheet 3) shows that breakouts in the vicinity of the above two locations will flow parallel to the river generally toward Waipopo. Combining the above two breakouts 370 + 170 = **<u>540 cumecs</u>.**

Breakout location A – upstream of Waipopo Road
In 1986 a breach of the stopbank occurred 650 m upstream of Waipopo Road. This was used to establish a base breakout flow for location A.

A 50 m wide breach of the true right bank occurred approximately 650 m upstream of Waipopo Road:

- o Flood level estimated by pro-rata between recorded levels at benchmarks 2,180 km and 3.485 km.
- o Flood level is approximately 11.25 m
- o Stopbank height is 11.65 m
- o Ground level is 8.2 m, therefore depth of water is 3.0 m
- o Water velocity is 2 metres per second
- o W x D x V = 50 x 3 x 2 = **<u>300 cumecs</u>**

Breakout Location B – bend in Waipopo Road (adjacent to Top Huts)
In 1986 a breakout occurred via overtopping and subsequent breach of the stopbank at this location. The breach width was recorded but there was no flood level recorded specifically for this site. The stopbank was lifted after 1986 as it was considered a weak point, not up to scheme standard. The repaired bank is less likely to be overtopped but it is still vulnerable to lateral erosion breach (conversation Chris F/Paul Eddy works overseer). Pro-rata estimates using flood levels upstream and downstream, as well as by comparing freeboards along adjacent areas, have been made.

For a 60 m breach immediately above Waipopo Road:

- o Comparison with known recorded levels upstream and downstream show 300 – 500 mm freeboard is typical between 1986 flood level and current stopbank height. Based on this information and Paul Eddy comments confirming repaired stopbank is

less likely to be overtopped we assume a flood level of stopbank height less 300 mm for this location.
- flood level is approximately 10.3 m,
- stopbank height is 10.6 m,
- ground level is 8.2 m, therefore depth of water is 2.1 m
- Water velocity is 2 metres per second.
- W x D x V = 60 x 2.1 x 2 = **250 cumecs**

Breakout Location C – Opposite Penny Lane at upstream end of main huts
This is the one location used in the modelling where a breakout did not occur in 1986. The stopbank upstream of this location has the Waipopo Huts access road built into it and is relatively strong. However, the road turns slightly to the southeast and drops down off the stopbank immediately upstream of breakout Location C. Downstream of where the road separates from the stopbank the stopbank returns to its usual shape, width and batter. The ground levels also fall away considerably from this point meaning the differential between top of stopbank and ground level on the landward side increases significantly. Discussion with Paul Eddy confirmed that while considered a low probability outcome there is no reason the stopbank could not breach at this location.

We do not have a historic breach width to use as a starting reference point at Location C. We opted to use a 60 m width which is both conservative but in keeping with the widths recorded elsewhere on the lower Opihi River.

For a 60-metre breach of the stopbank at true right bank opposite Penny Lane and Waipopo Road intersection:

- The flood level was estimated using a recorded flood level at benchmark 2,180 km approximately 80 m upstream of breakout location C.
- Flood level is approximately 8.1 m
- Stopbank level is 8.6 m
- Ground level 5.4 m, therefore depth of water is 2.7 m
- Water velocity is 2 metres per second
- W x D x V = 60 x 2.7 x 2 = **320 cumecs**

A2.4 Additional note regarding breakout locations not modelled

There is a reach of stopbank between the main and top huts where the differential between stopbank height and ground level on landward side is only around 1 metre or less. This reach of stopbank also has Waipopo Road built into it (straight stretch of road running parallel to river). Paul Eddy believes this stretch of bank is stronger than elsewhere, and possibly a little less likely to breach. The 1986 flood level was below the top of the stopbank and breach flow estimates indicate a breakout here would be significantly smaller than elsewhere. It was decided not to model a breach along this reach of the river because of the:

- additional width and strength of the stopbank (due to inbuilt road), which makes it slightly less likely to breach
- relatively small difference between stopbank crest and ground level, which makes it a little less likely to breach - and means if it does breach outflows would be less.
- smaller impact on the Waipopo Study Area compared to other scenarios modelled as part of this investigation – with a small exception being for the dwellings very close to the stopbank. However, these dwellings are addressed via the high hazard stopbank setback determination for this area.

A2.5 Discussion on elevated breakout flows used in modelling investigation

It is not possible to estimate specific flows and water levels at the bottom end of the Opihi River system as it is unknown how much floodwater would breakout upstream and opposite Waipopo Huts in an extreme flood.

We have taken 1986 flood level information and applied it to specific breakout locations to approximate a range of 200-year ARI flooding scenarios.

High hazard areas are determined on the basis of depth times velocity of floodwater, or depth of water in the 500-year ARI flood event. A 500-year ARI flood could result in larger breakouts upstream and/or breakouts in different locations, etc. It is not possible to determine any increase in flood outflows between our base scenarios and the 500-year ARI flood scenarios using flow estimates only. Instead, elevated scenarios for each of the four breakout locations were determined based on each breakout flow being increased by 30%. The 30% allows for factors such as:

- Water levels being higher due to a lesser percentage of the river flow breaking out of the river upstream or opposite the breakout locations
- Water levels rising higher up the stopbank (than occurred in 1986) before the stopbank breaches
- The breach width being greater than in 1986
- The flow velocity exceeding the 2 metres per second used

A present-day 500-year ARI flood will potentially result in significantly larger upstream breakouts. Waipopo is right at the downstream end of the river system, and the breakout locations chosen for this study area are considered “worst case”. We believe 30% represents a conservative increase in flooding outflows and the resulting flooding impacts should be viewed as a present-day extreme flooding outcome.

It is impossible to assign a frequency of flooding to our elevated flood scenarios. But we believe those scenarios are our best indication of an extreme flooding outcome such as could be expected in a flood as large as a present-day 500-year ARI flood.

To take into consideration climate change (to 2081-2100), an additional 25% has been added to the elevated breakout flows to estimate a 500-year ARI flood incorporating climate change to 2081-2100 – as has been done for other recent studies. It is reasonable to use these elevated scenarios to assist in the determination of high hazard flooding areas, but this information should not be used in isolation. Site specific investigation, employing a combination of all modelled flooding scenarios, historic information, topographical data and a site visit should occur when making specific development or land-use recommendations.

One other factor apparent from the modelling is that most of the land over which the deepest flooding tends to be is within wide depressions or deep swales. Flooding within these features triggers high hazard criteria in a number of flooding scenarios not just worst-case scenarios. There are some smaller parts of the Study Area that are not as obviously low lying where high hazard criteria may only be triggered in the worst-case, elevated flooding scenarios and it is in these relatively small areas where careful scrutiny of <u>all</u> available flooding information will be needed to make land-use decisions.

Appendix 3: Stopbank setback parameters and cross sections

A3.1 Waipopo Huts

Determining high hazard stopbank setback at Waipopo Huts.
Base Information

Series of cross sections from the 2010 LiDAR used to identify ground level (typical) on both sides of the stopbank and the height of the stopbank above ground (refer sections attached below).

Opihi River Calculations File Vol 1, 6960000, Pages 198-213 provided 1986 flood levels at riverbed survey cross section locations (not necessarily same locations as my cross sections from LiDAR). 1986 flood had Average Recurrence Interval in excess of 100 years. Pro rata estimates between benchmarks with recorded 1986 flood levels or slope estimates used to determine 1986 flood levels at LiDAR cross section locations where these don't already align.

300 mm added to all 1986 riverbed flood levels as a means to:

- allow for larger flood events than the 1986 flood;
- More water remaining in the river at this location due to lesser breakouts upstream of or opposite the property;
- Climate change impacts on the flood flow frequency (i.e. larger flows for the same given flood frequency in future).

Note the river has historically broken out on the opposite side of the river to this location (toward Milford Huts). Improvements since the 1994 flood have brought the opposite stopbanks up to the same flood protection standard as rest of the lower river. This means the river is in theory no more likely to breakout on the north side of the river in this reach then at any other location.

The LiDAR cross section locations used are shown on the aerial photograph below. The surveyed river cross section benchmark locations are shown as maroon dots.

Figure A3-1: Location of cross sections generated to from the 2010 LiDAR as well as river benchmark locations

These parameters were then used to read a setback distance of the graph from R J Connell's 1998 stopbank breach analysis.

A further 15% of the total estimated high hazard distance from the stopbank was then added on as a means for allowing for uncertainties and factors not covered in the breach analysis such as ground scour, wider breaches than 50 m and debris entrainment in the water.

Setback Calculations

LiDAR Cross Section 1 – upstream end of Study Area

Average ground level on riverside of stopbank and landward side are the same – assume 0 difference for setback graph.
Stopbank is at 11.28m which is roughly 3.3 – 3.4 m above ground level at this location.

Stopbank at surveyed river cross section location 460 m upstream (river distance 3.485 km) is 11.67 m. 400 mm difference in stopbank height between my LiDAR section and that section over 460 m. Flood level in 1986 there was 11.27. There was therefore just 400 mm freeboard at that location.
Applying same slope as the stopbank to river, 1986 flood level at LiDAR cross Section 1 would be 10.87m. Top of stopbank is 11.28 m.
Adding 300 mm onto the 1986 flood level gives 11.17 m so has the flood level just 100 mm below the top of the stopbank.
So – water level above ground 3.2 – 3.3 m
Difference in ground level on both sides of river is 0.
Using these parameters, the high hazard stopbank setback distance area easily extends out the full 100 m used in the District Plan. If the calculation was followed through and uncertainty factor of 15% applied, it would put the setback line out to about 160 m from stopbank.

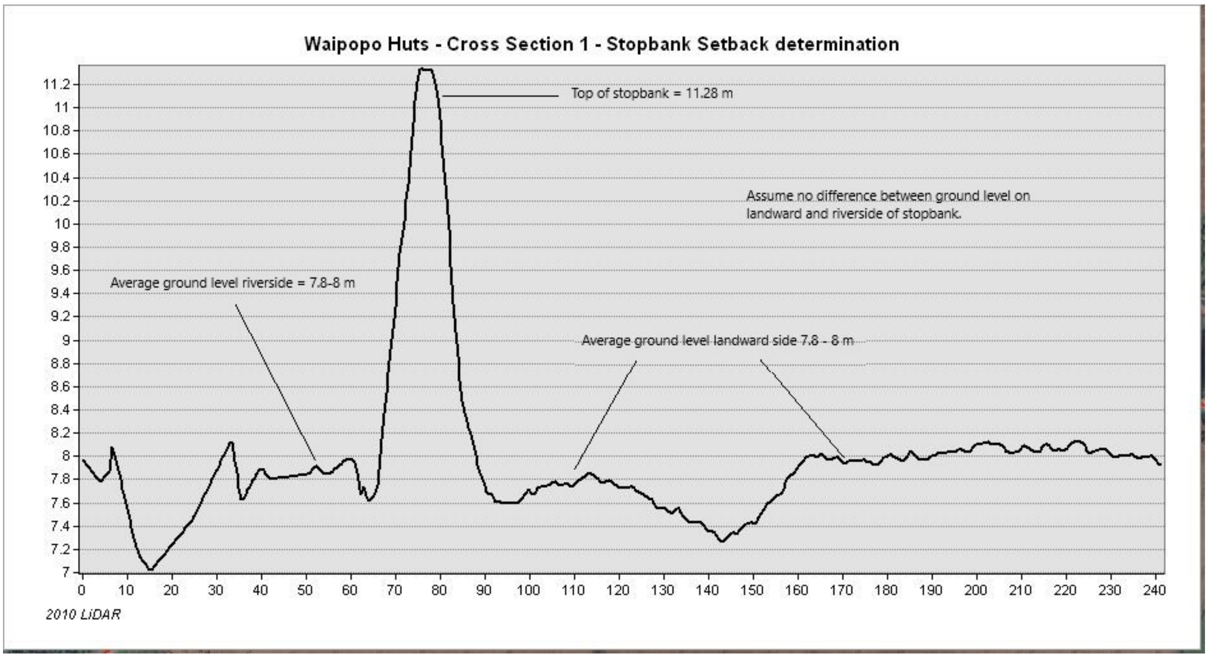


Figure A3-2: LiDAR cross section 1 Waipopo Huts Setback Distance Determination. LiDAR Cross Section 2

This is a more difficult setback distance to calculate. This cross section is really at two levels. The existing dwellings are located along a thin strip of high ground almost exactly 100 m from the stopbank (the catch all stopbank setback distance used in District Plan). Ground levels between this high strip and the river though are very low relative to height of stopbank.

Average ground level on riverside of stopbank and on landward side of stopbank is similar (until settlement reached which is 1 m higher) but assume 0 difference for setback determination.

Stopbank is at 11.0 m which is roughly 3.75 m above typical ground level between the stopbank and dwellings. The dwellings are on land that is 1 to 1.5 m higher.

1986 flood level at river distance 3.485 km is 11. 27m. The 1986 flood level at river distance 2.180 km is 8.13 m. The distance between the two is 1305 m and the difference in flood level is 3.14 m. The distance from river benchmark (3.485 km) and LiDAR cross section 2 is 660 m.
3.14/1305 x 660 m = 1.58 m. 11.27 m (level at 3.485 km benchmark) – 1.58 m = 9.69 m (estimated 1986 flood level at LiDAR cross section 2). Add on 300 mm gives 9.99 flood level for setback calculation (say 10.0 m).
The stopbank is at 11.0 m and flood level at 10.0 m meaning there is 1 metre freeboard at this location between estimated flood level and top of stopbank. The flood level is therefore 2.75 m above typical ground level between the stopbank and existing dwellings which are located at approx. 100 m from stopbank on this cross section.

Using 2.75 m water level and 0 difference between ground levels either side of the stopbank gives a setback distance of around 120 m. However, given the sudden ground level change at the dwellings (immediately upstream of Waipopo Road) we don't believe high hazard flooding would extend this far from the stopbank on that high ground. Therefore, we think it is appropriate to end the high hazard setback area at 100 m from stopbank (rise in ground level) at this cross section.

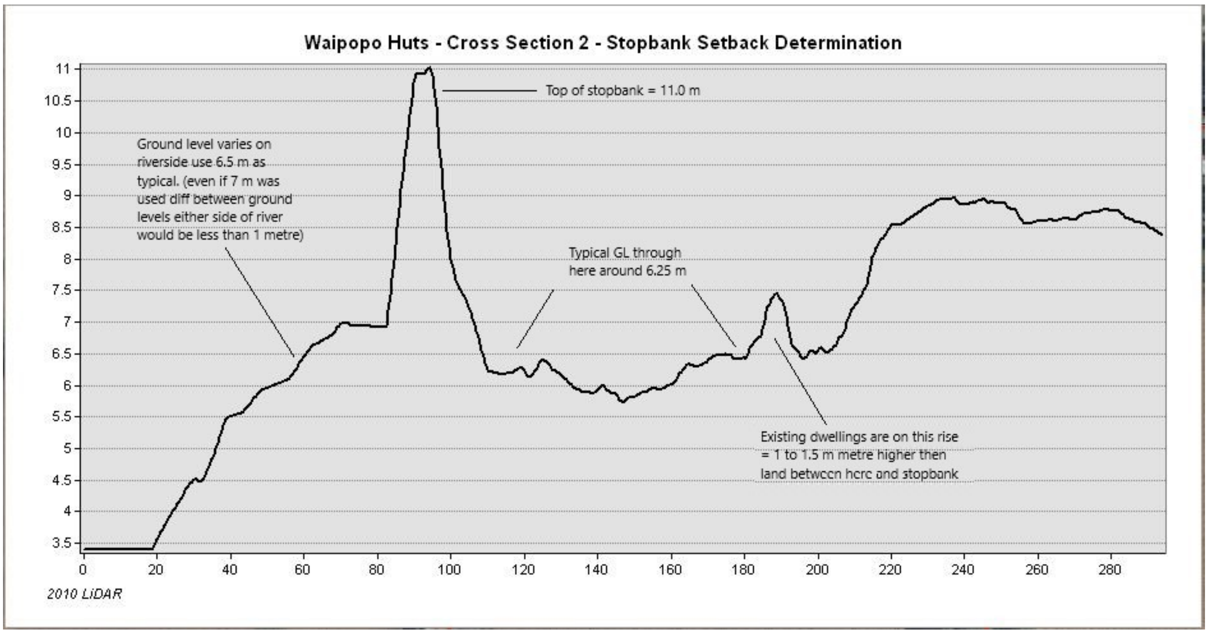


Figure A3-3: LiDAR cross section 2 Waipopo Huts Setback Distance Determination

LiDAR Cross Section 2A

Given the uncertainty around cross section 2 with the two varied ground levels existing between lower ground nearer to the stopbank and higher ground where dwellings were located along Waipopo Road we have added an extra cross section at this part of the settlement to better define setback distance.

Average ground level on the riverside of the stopbank is in excess of 2 metres lower than ground levels (typical) on the landward side.

The stopbank is at 10.9 m which is approx. 2.1 m above ground level on the landward side.

1986 flood level at river distance 3.485 km is 11. 27m. The 1986 flood level at river distance 2.180 km is 8.13 m. The distance between the two is 1305 m and the difference in flood level is 3.14 m. The distance from river benchmark (3.485 km) and LiDAR cross section 2 is 700 m.
3.14/1305 x 700 m = 1.68 m. 11.27 m (level at 3.485 km benchmark) – 1.68 m = 9.59 m (estimated 1986 flood level at LiDAR cross section 2). Add on 300 mm gives 9.89 flood level for setback calculation (say 9.9 m).

The stopbank is at 10.9 m and flood level at 9.9 m meaning there is 1 metre freeboard at this location between estimated flood level and top of stopbank. The flood level is therefore 1.1 m above typical ground level on the landward side of the stopbank.

Using 1.1 m water level and 2 m difference between ground levels either side of the stopbank gives a setback distance of around 32 m. Adding 15% on for uncertainty gives a distance of 37 m from stopbank for the high hazard setback distance reflecting the much higher ground levels through this area.

Note we avoided using the deep channel/swale adjacent to the stopbank in this analysis. If anything, that would help to carry floodwaters downstream faster if a breach should occur and may if anything reduce the setback distance. By not using it in the analysis we have included a little conservatism in the setback here.

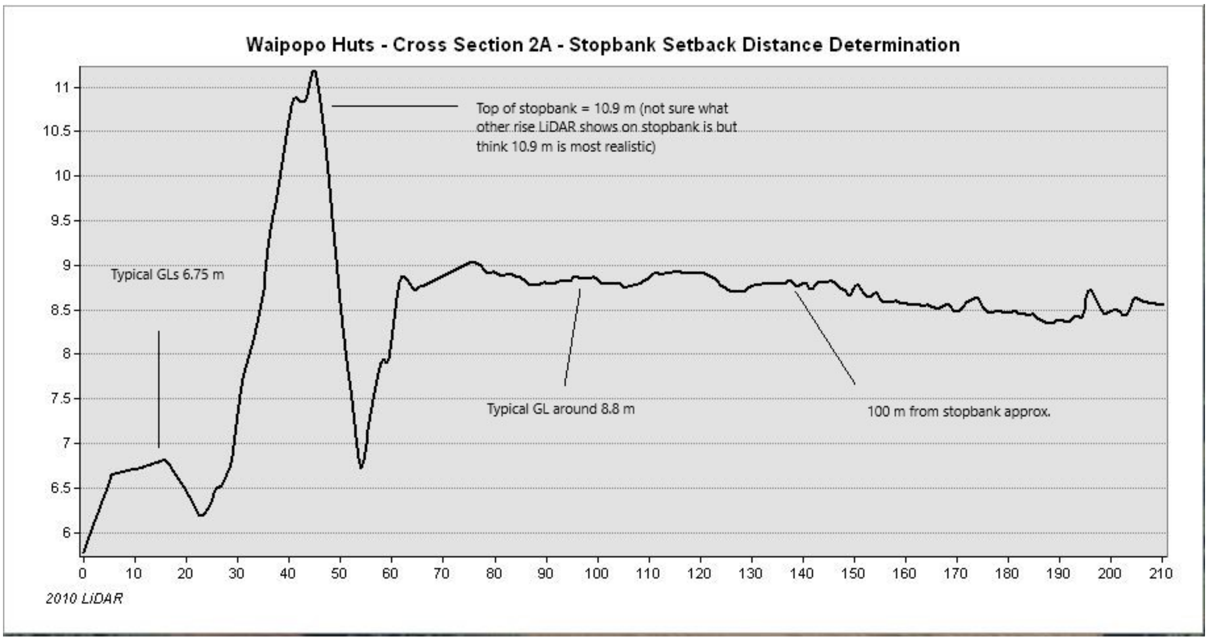


Figure A3-4: LiDAR cross section 2A Waipopo Huts Setback Distance Determination. LiDAR Cross Section 3

Average ground level on riverside of stopbank is 2 metres lower than on landward side.

The stopbank is at 10.5 m which is approx. 2.4 m above ground level.

There is a river benchmark at LiDAR cross section 3 but it does not have a 1986 flood level attached to it. The cross section is at river distance 2.835 km. 1986 flood level at river distance 3.485 km is 11.27 m. The 1986 flood level at river distance 2.180 km is 8.13 m. The distance between the two is 1305 m and the difference in flood level is 3.14 m. The distance from river benchmark (2.180 km) and LiDAR cross section 3 is 655 m.
3.14/1305 x 655 = 1.58 m. 8.13 m (level at 2.180 km benchmark) + 1.58 m = 9.71 m (estimated 1986 flood level at LiDAR cross section 3. Add on 300 mm gives 10.01 m flood level for setback calculation.

The stopbank is 10.6 m meaning there is 500 mm freeboard here between estimated water level and top of stopbank. The flood level is therefore 1.9 m above ground on the landward side of stopbank and there is a 2 m difference between ground level either side of stopbank.

Using setback graph this indicates a high hazard setback distance of 90 m. Adding on the additional uncertainty puts the high hazard setback distance out to the 104 m so essentially at the catch all distance from the District Plan at this location.

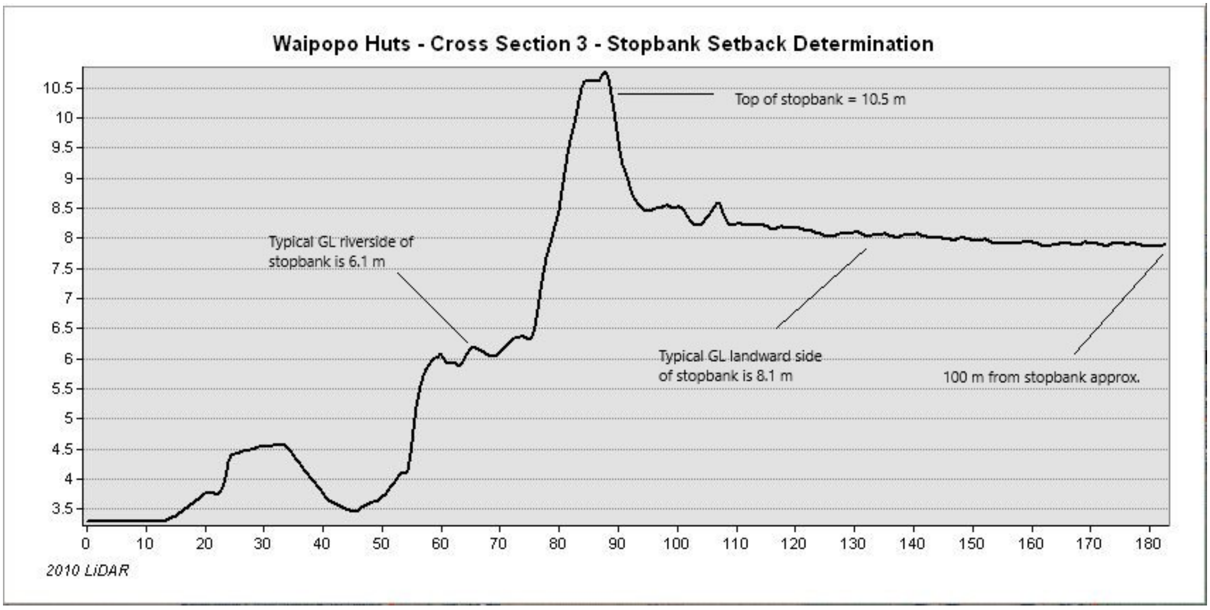


Figure A3-5: LiDAR cross section 3 Waipopo Huts Setback Distance Determination. LiDAR Cross Section 4

Average ground level on the riverside of stopbank is difficult to determine without site visit at LiDAR does not appear to have picked up berm area properly.

Stopbank is at 9.6 m which is just 1.1 m above typical ground level on the riverside of the stopbank. There is a river benchmark at LiDAR cross section 4 but it does not have a 1986 flood level attached to it. The cross section is at river distance 2.550 km. 1986 flood level at river distance 3.485 km is 11.27 m. The 1986 flood level at river distance 2.180 km is 8.13 m the distance between the two is 1305 m and the difference in flood level is 3.14 m. The distance from river benchmark (2.180 km) and LiDAR cross section 4 is 370 m.

3.14/1305 x 370 = 0.93 m. 8.13 m (level at 2.180 km benchmark) + 0.93 m = 9.06 (estimated 1986 flood level at LiDAR cross section 4). Add on 300 mm gives 9.36 m flood level for setback calculation.

The stopbank is at 9.6 m meaning there is 240 mm freeboard at this located between estimated water level and top of stopbank. The flood level is therefore just 850 mm above ground level (typical) on the landward side of the stopbank at this location.

Using the most conservative ground level differential between sides of the stopbank of 2 metres gives a setback distance of just 20 m at this location.

Adding 15% is just 3 metres – round to 25-metre-high hazard setback distance at cross section four. The small setback distance reflects the relatively high ground level through this area where Waipopo Road runs parallel to the river and incorporates the stopbank. Because the road has been built into the stopbank widening and strengthening it Paul Eddy (Works Overseer, Temuka Depot) believes it is a particularly strong reach of stopbank. The strength of the bank and low height of stopbank relative to ground level also makes this straight stretch of stopbank running parallel to the river considerably less likely to breach then other locations.

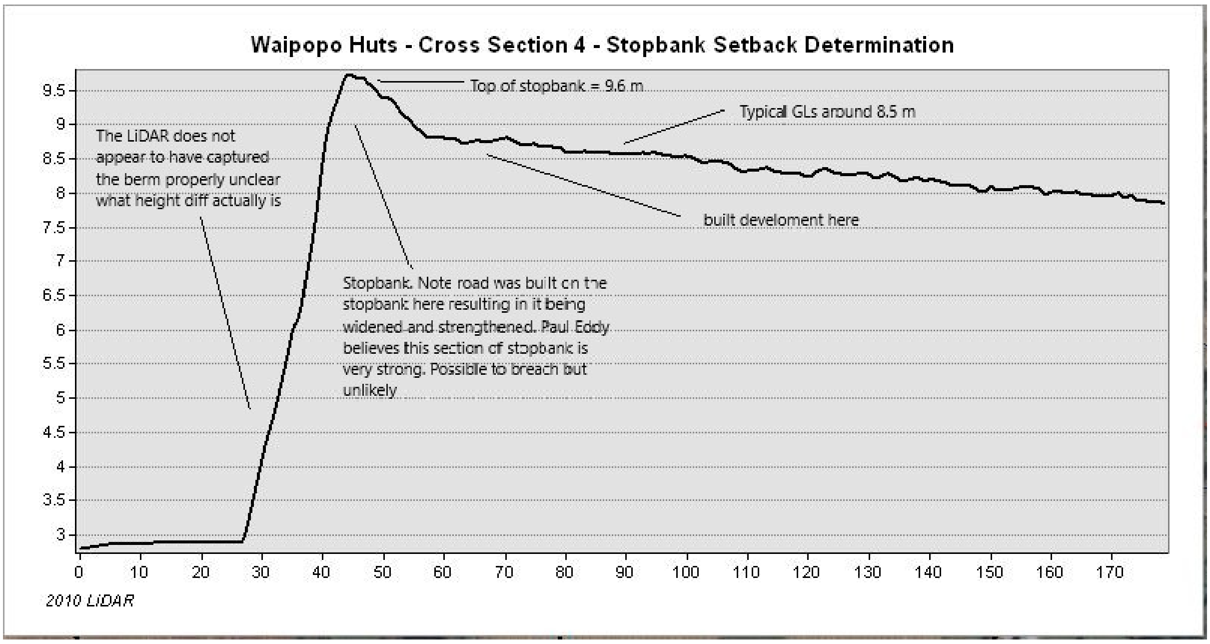


Figure A3-6: LiDAR cross section 4 Waipopo Huts Setback Distance Determination, LiDAR Cross Sections 5 & 6

These two sections replicate cross section 4 very closely. The ground level on the landward side of the stopbank is high relative to the stopbank crest. The road is built within the stopbank making wider, and in the opinion of river engineering staff, stronger than others in the area.

The stopbank is unlikely to breach at these cross-section locations and if it does the high hazard stopbank setback distance will be relatively low as with Cross Section 4.

At LiDAR cross section 6 the top of the stopbank is at 8.9 m which is approximately 1.2 m above ground level within the first 100 m from the stopbank.

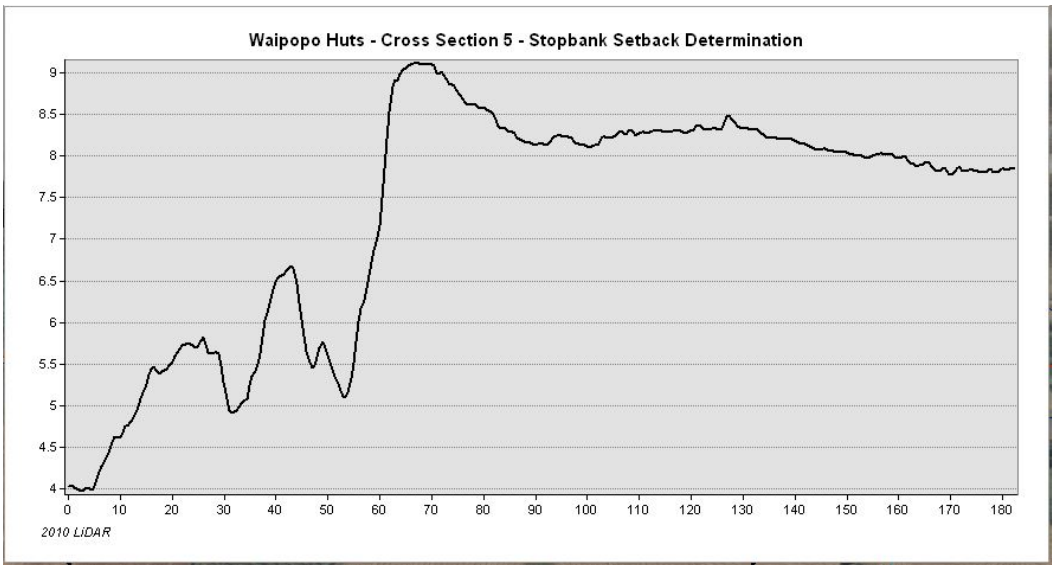
LiDAR cross section 6 is at the same location of surveyed cross section at river distance 2.180 km. The 1986 flood level recorded at this location was 8.13 m.

Adding 300 mm to the 1986 flood level gives a flood level to use for stopbank setback determination of 8.43 m at this location.

The stopbank is 8.9 m meaning there is 450 mm freeboard at this location between estimated water level and top of the stopbank. The flood level is therefore approximately 750 mm above ground level on the landward side of the stopbank.

This would translate to a very low setback distance in the vicinity of 15 m from the centre of the stopbank at this location.

We have not followed this methodology for cross section 5 given its similarity to LiDAR sections 4 & 6.



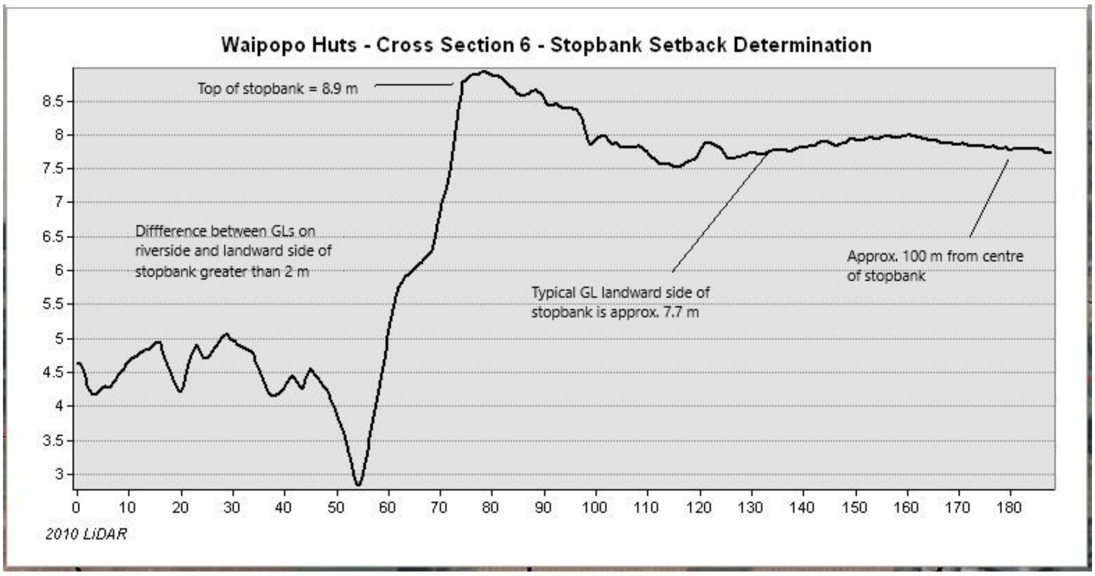


Figure A3-7: LiDAR cross sections 5 & 6 Waipopo Huts Setback Distance Determination

LiDAR Cross Sections 7

Main settlement here is located in a wide depression between the river stopbank and high ground to the south.

Average ground level is a little difficult to determine both sides of the stopbank as ground is up and down but definitely between 1 and 2 metres. Adopt 1 metre difference in ground level for graph.

Stopbank is at 8.5 m which is approximately 2.75 m above an average ground level within the first 100 m of the stopbank. About the first 60 m of the cross section landward of the stopbank is actually lower than this which would have increased setback distance further if used.

The 1986 flood level at river distance 2.180 km is 8.13 m. The 1986 flood level at river distance 1.205 km (not shown on maps here) is 5.86 m. The distance between the two is 975 m and the difference in flood level is 2.27 m. The distance from river benchmark (2.180 km) and LiDAR Cross Section 7 is approximately 133 m.

2.27/975 x 133 = 0.31 m. 8.13 m (level at 2.180 km benchmark) - 0.31 = 7.82 m (estimated 1986 flood level at LiDAR cross section 7). Add on 300 mm gives 8.12 m flood level for setback calculation.

The stopbank is at 8.5 m meaning there is 380 mm freeboard at this location between estimated water level and the top of the stopbank. The flood level is therefore 2.37 m above average ground level on the landward side of the stopbank (noting that we didn't use the lowest ground levels available).

Using the 2.37 m height differential and a 1 metre difference between ground level puts the high hazard setback area beyond the 100 m catch-all distance used in the current District Plan.

Ground levels varied in this area meaning slightly different inputs could have been used but no logical changes to ground level could result in the high hazard setback area coming within 100 m here and in fact in the example above we did not use the most conservative (lowest ground levels available) to determine stopbank height above ground. Furthermore, no uncertainty was added given the distance was already beyond 100 m.

If we followed the original calculation through as with other cross-sections, the distance from graph would be around 110 – 115 m. then 15% uncertainty would bring that distance to around 125-130 m from the centre of the stopbank. At that distance the cross section reaches the terrace on the south side of the huts settlement and that terrace is where the high hazard area should terminate for this location.

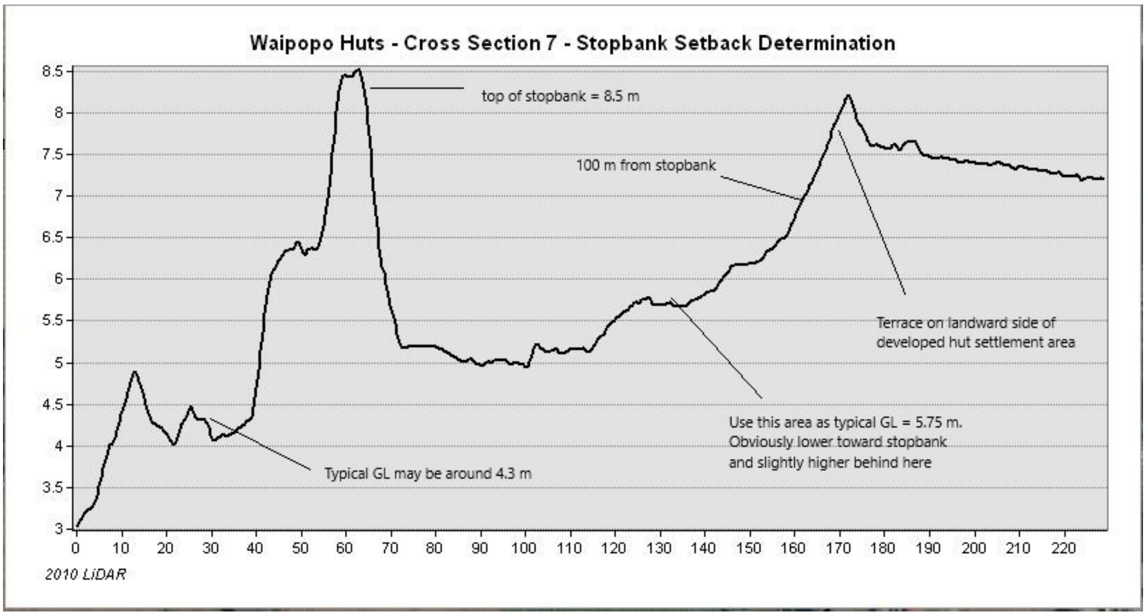


Figure A3-8: LiDAR cross section 7 Waipopo Huts Setback Distance Determination, LiDAR Cross Section 8

Average ground level is a little difficult to determine both sides of the stopbank as ground is up and down. Assume no difference between ground either side of stopbank as generally the difference between comparative GL both sides of stopbank appears less than 1 metre.

Stopbank is at 8.2 m which is approximately 2.8 m above an average ground level within the first 100 m of the stopbank (not overly conservative ground level used – there is lower ground further from stopbank).

The 1986 flood level at river distance 2.180 km is 8.13 m. The 1986 flood level at river distance 1.205 km (not shown on maps here) is 5.86 m. The distance between the two is 975 m and the difference in flood level is 2.27 m. The distance from river benchmark (2.180 km) and LiDAR Cross Section 8 is approximately 310 m.
2.27/975 x 310 = 0.72 m. 8.13 m (level at 2.180 km benchmark) - 0.72 = 7.41 m (estimated 1986 flood level at LiDAR cross section 8). Add on 300 mm gives 7.71 m flood level for setback calculation.

The stopbank is at 8.2 m meaning there is 490 mm freeboard at this location between estimated water level and the top of the stopbank. The flood level is therefore 2.31 m above average ground level on the landward side of the stopbank (noting that we didn't use the lowest ground levels available).

Using the 2.3 m height differential and a 0 m difference between ground level puts the high hazard setback area at around 95 m from the stopbank.

Adding 15% to this distance for uncertainty and factors not included in the modelling gives 110 m setback i.e. just beyond the catch all distance used to based discretionary status within the current District Plan.

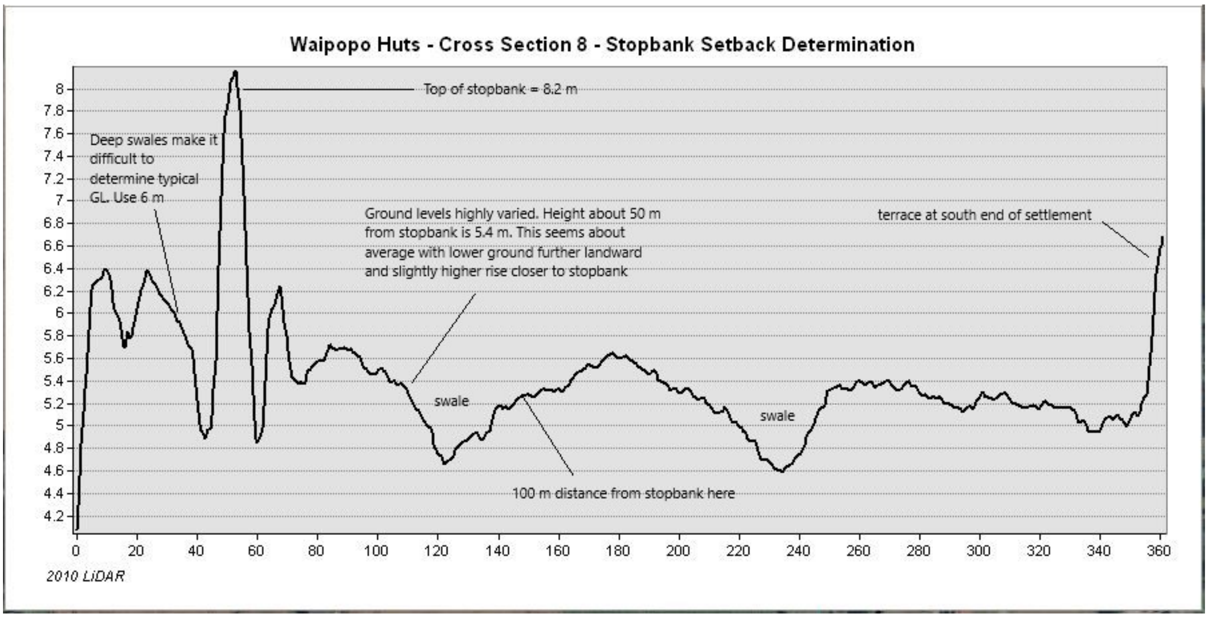


Figure A3-9: LiDAR cross section 8 Waipopo Huts Setback Distance Determination, LiDAR Cross Section 9

Average ground level is difficult to determine on riverside of stopbank but generally less than 1 metre lower than ground level on the landward side of the stopbank.

Stopbank is at 7.6 m which is approximately 3.6 m above typical ground level on landward side of the stopbank (not overly conservative ground level used.

The 1986 flood level at river distance 2.180 km is 8.13 m. The 1986 flood level at river distance 1.205 km (not shown on maps here) is 5.86 m. The distance between the two is 975 m and the difference in flood level is 2.27 m. The distance from river benchmark (1.205 km) and LiDAR Cross Section 9 is approximately 400 m.

2.27/975 x 400 = 0.93 m. 5.86m (level at 1.205 km benchmark) + 0.93 m = 6.8 m (estimated 1986 flood level at LiDAR cross section 9). Add on 300 mm gives 7.10 m flood level for setback calculation.
The stopbank is at 7.6 m meaning there is 500 mm freeboard at this location between estimated water level and the top of the stopbank. The flood level is therefore 3.1 m above average ground level on the landward side of the stopbank (noting that we didn't use the lowest ground levels available).

Using the 2.3 m height differential and a 0 m difference between ground level puts the high hazard setback area at around 135 m from the stopbank.

Adding 15% to this distance for uncertainty and factors not included in the modelling gives 155 m setback. This is a lot further than the catch all district of 100 m provided for in the District Plan and reflects the falling ground levels in this area and high river stopbank close to the mouth of the river.

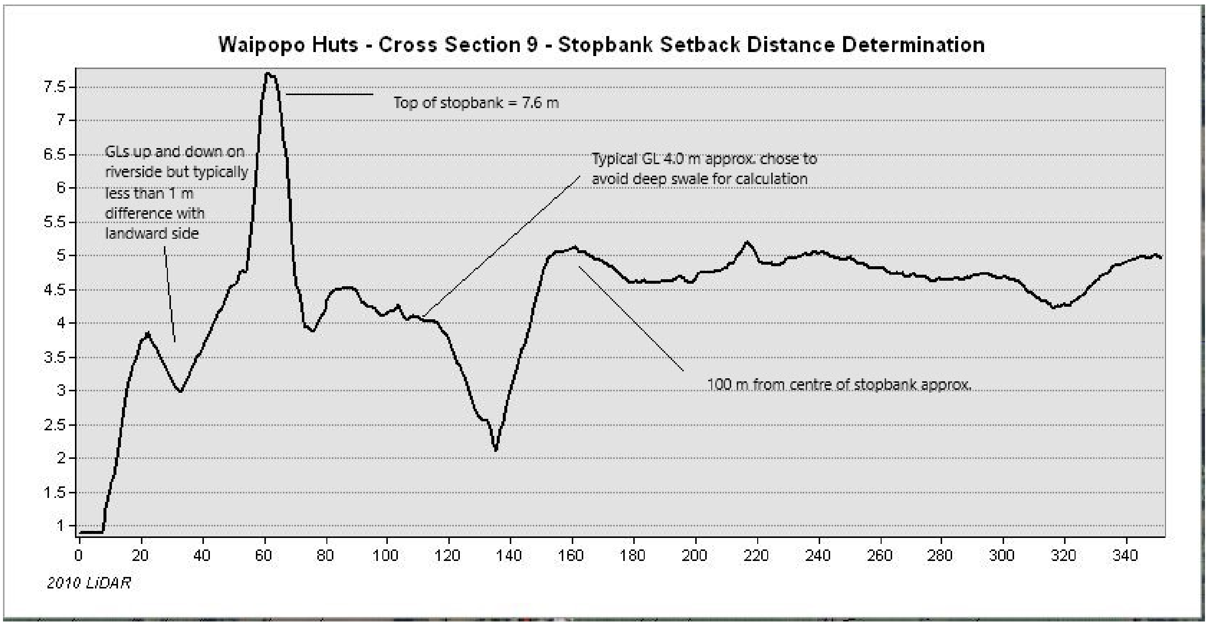


Figure A3-10: LiDAR cross section 9 Waipopo Huts Setback Distance Determination

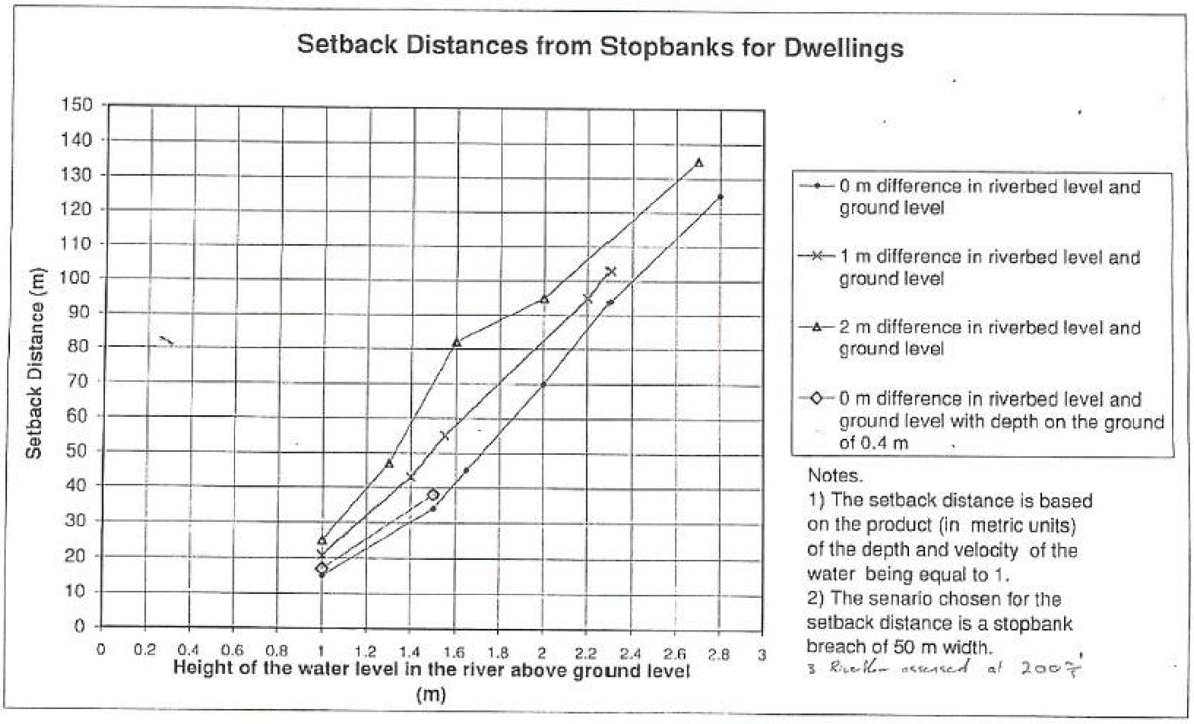


Figure A3-11: Stopbank setback breach analysis results graph. R J Connell 1998 – Setback Distances from Stopbanks for Dwellings

OPFLD_RL.XLS

OPIHI FLOOD LEVELS														
Data from Opihi Calcs Vol 4 6960000 Pages 571-579 For 19 March 1994														
Data from Opihi Calcs Vol 1 6960000 Page 198/13 For 13 March 1986 and 6960250 Page 172														
				Mar-86	Mar-94	Mar-86	Mar-94			Mar-86	Mar-94	Mar-86	Mar-94	
Section Name	Section No	Left BM	Left SB	Left FL	Left FL	Left FB	Left FB	Right BM	Right SB	Right FL	Right FL	Right FB	Right FB	Section No
00545	1	4.04	4.04	4.29	na	-0.25		2.59	2.59	3.04	na	-0.45		1
01205	2	6.77	6.77	5.67	5.51	1.10	1.26	6.77	6.77	5.86	5.61	0.91	1.16	2
02180	3	9.06	9.06	7.48	7.61	1.58	1.45	8.61	8.61	8.13	8.00	0.48	0.61	3
03485	4	11.32	11.32	11.62	10.66	-0.30	0.66	11.52	11.52	11.27	10.89	0.25	0.63	4
04665	5	11.09	na	13.69	12.95			14.20	14.20	13.67	13.29	0.53	0.92	5
05560	6	16.80	16.80	16.44	15.95	0.36	0.85	17.06	17.06	16.13	16.02	0.93	1.04	6
06410	7	19.71	19.71	19.26	18.98	0.45	0.73	19.46	19.46	18.83	18.70	0.63	0.76	7
06580	8	20.45	20.45	19.95	19.62	0.50	0.82	20.14	20.14	19.44	19.35	0.70	0.79	8
06695	9	21.70	21.70	21.20	20.65	0.50	1.06	20.21	20.21	19.36	19.55	0.85	0.67	9
06900	10	21.02	21.02	20.30	20.21	0.72	0.81	21.12	21.12	20.37	20.24	0.75	0.87	10
07205	11	22.45	22.45	21.65	na	0.80		22.31	22.31	22.17	21.18	0.14	1.13	11
07440	12	23.05	23.05	22.35	22.23	0.70	0.82	23.08	23.08	22.42	22.13	0.66	0.95	12
08015	13	25.14	25.14	24.15	23.77	0.99	1.37	24.99	24.99	24.06	23.72	0.93	1.27	13
08855	14	27.89	27.89	26.67	26.53	1.22	1.36	27.99	27.99	27.04	27.20	0.95	0.79	14
09780	15	31.66	31.66	30.69	29.39	0.97	2.27	31.36	31.36	30.57	30.24	0.79	1.12	15
11055	16	36.11	36.11	35.88	35.35	0.23	0.76	36.03	36.03	35.43	35.21	0.60	0.82	16
12645	17	42.97	42.97	42.95	42.40	0.02	0.57	42.82	42.82	43.02	42.14	-0.20	0.68	17
14115	18	49.97	49.97	48.89	48.49	1.08	1.48	49.92	49.92	49.92	48.86	0.00	1.06	18
15130	19	54.18	54.18	53.63	53.45	0.55	0.73	54.21	54.21	54.21	53.13	0.00	1.08	19
16485	20	59.23	59.23	na	na			60.51	60.51	59.96	59.39	0.55	1.12	20
17490	21	64.14	64.14	64.14	63.93	0.00	0.21	64.26	64.26	64.75	64.37	-0.49	-0.11	21
17720	22	65.36	65.36	65.46	64.88	-0.10	0.48	65.31	65.31	65.86	65.24	-0.55	0.07	22
17795	22A	65.48	65.48	na	65.07		0.41					0.00	0.00	22A
17885	23	65.85	65.85	65.95	65.89	-0.10	-0.04	65.91	65.91	66.01	65.62	-0.10	0.28	23
01840	24	66.64	66.64	66.89	66.71	-0.25	-0.07	66.61	66.61	66.71	66.17	-0.10	0.44	24
18565	T1	69.11	69.11	69.19	68.63	-0.08	0.48	68.25	68.25	68.47	67.80	-0.22	0.45	25

Figure A3-12: Opihi River flood levels summarised from 1994 and 1986 flood events. Opihi River Calculations File volume 4, Canterbury Regional Council

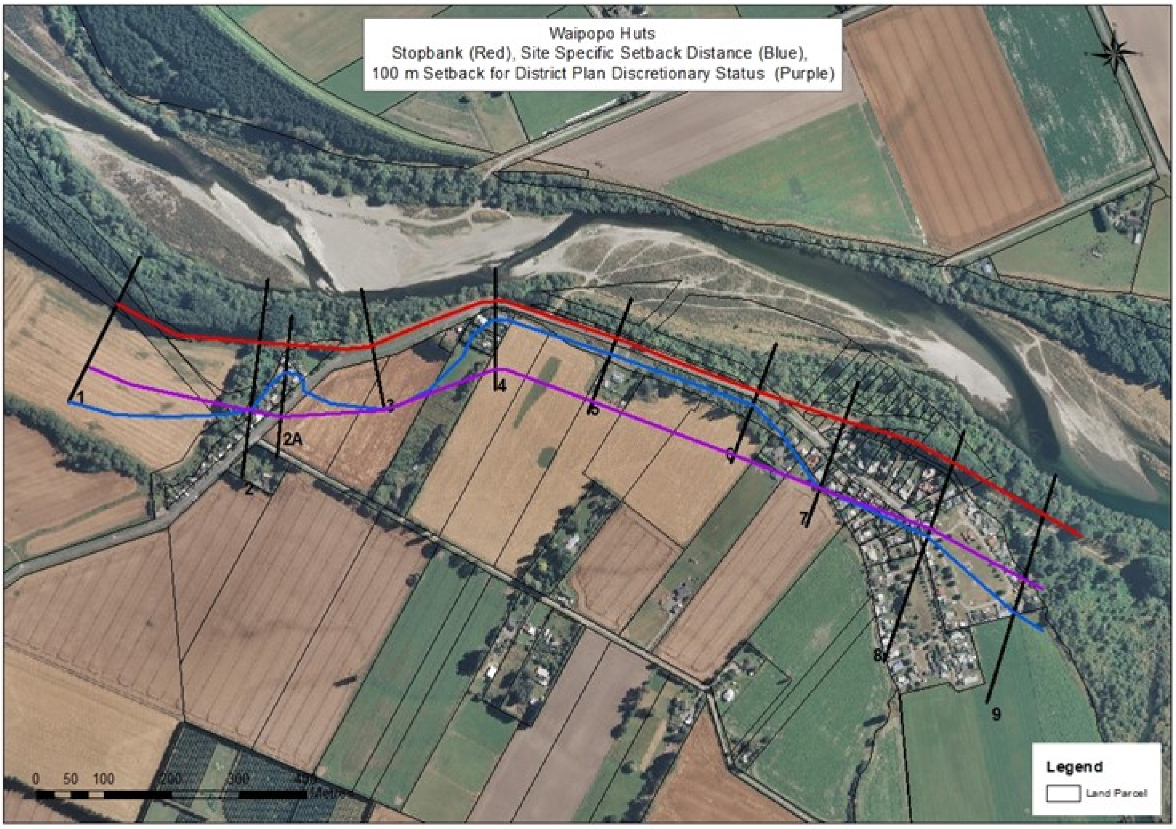


Figure A3-13: Waipopo Huts area specific stopbank setback (blue), stopbank (red) and 100 m line currently used in District Plan to defined discretionary activity status (purple)

A3.2 Grassy Banks

Notes on Stopbank Setback Consideration for Grassy banks Hut Settlement Area.
Opihi River Calculations File Volume 4 provides 1986 and 1994 flood levels at river cross section locations.
All heights given below are using Mean Sea Level Lyttleton (1937).
There are two river cross sections near grassy banks for which 1994 and 1986 flood levels were recorded. Cross Section 6 is at river distance 5.56 km and Section 7 is at river distance 6.41 km.
The two river cross sections are 850 m apart and Grassy Banks is roughly 410 m from cross section 6 and 440 m from cross section 7 (48% of the way from cross section 6 to 7 to use for pro-rata calculation). These distances are all measured in the centre of the river and given bends in the river and stopbank are subject to a margin of error.

At cross section 7 the top of the stopbank is 19.48 m and at cross section 6 downstream the height is 16.99 m. The difference between the two stopbank heights is therefore 2.49 m.

Applying 48% of the distance from cross section 6 to 7 to pro rata between these heights the stopbank height at Grassy Banks comes to 18.18 m i.e.

- 2.49 (diff in SB height) x 48% = 1.19 m
- 1.19 m + 16.99m (SB height at cross sect 6) = 18.18 m

This is very much in keeping with the LiDAR (2010) through the area which indicates the stopbank height at 18.2 m so we have strong confidence in this stopbank height estimate.

The calculations file says the 1986 flood level on the true right bank at cross section 6 in 1986 was 16.13 and at cross section 7 was 18.83 m. Applying same pro rata method the 1986 flood level at Grassy Banks is estimated to be:

- 18.83 m – 16.13 m = 2.7 m
- 2.7 x 48% = 1.296 (1.3 m)
- 16.13 m (cross section 6 flood level) + 1.3 m = 17.43 m 1986 flood level at Grassy banks

The top of the stopbank at Grassy Banks is 18.2 m – 17.43 m (flood level) means there was approximately 770 mm freeboard in 1986 on the stopbank. If the stopbank top is roughly 2.2 m above ground in the huts area that means the water level in 1986 was approximately 1.43 m above ground level.

Using 1.43 metre water level and 1 m difference in ground level between the landward and riverward side of the stopbank the setback distance for high hazard flooding in this area would be around 45 metres from the stopbank. This would result int the closest two dwellings to the river being defined as high hazard but not the third dwelling.
But there are several other factors to consider:

- The 1986 flood was an extreme flood event but not the worst-case scenario for the area. When considering high hazard flood areas, we look at all floods up to the 500 year ARI flood event. A flood larger than 1986.
- The flood levels at Grassy Banks would have been lower in part because of large upstream breakouts relieving downstream pressure. In future it is a possibility that less water may breakout upstream for some reason resulting in higher water levels in the Grassy Banks area.
- Climate change is expected to increase the severity of future flood events and may result in higher expected water levels at any given location for floods of the same Average Recurrence Interval.
- The stopbank breach modelling used to generate the setback distance does not allow for several uncertainties. These include debris entrainment within the outflow water, breach widths greater than 50 m and scouring of the ground surface at the breach point. For these reasons it is appropriate to apply an additional margin onto the calculated

The 1994 flood level at grassy banks was only around 100 mm less than the 1986 flood level when applying the same method as above. The 1994 flood had an ARI of slightly more than 50 years. The peak flow in this reach may have been around 2900 cumecs whereas the 1986 flood was around 3600 cumecs. The 1994 flood however did not involve major breakouts upstream which explains why the difference in flood level at Grassy Banks was so close and highlights that flood levels could be higher in this reach should future flood events not breakout so severely upstream.

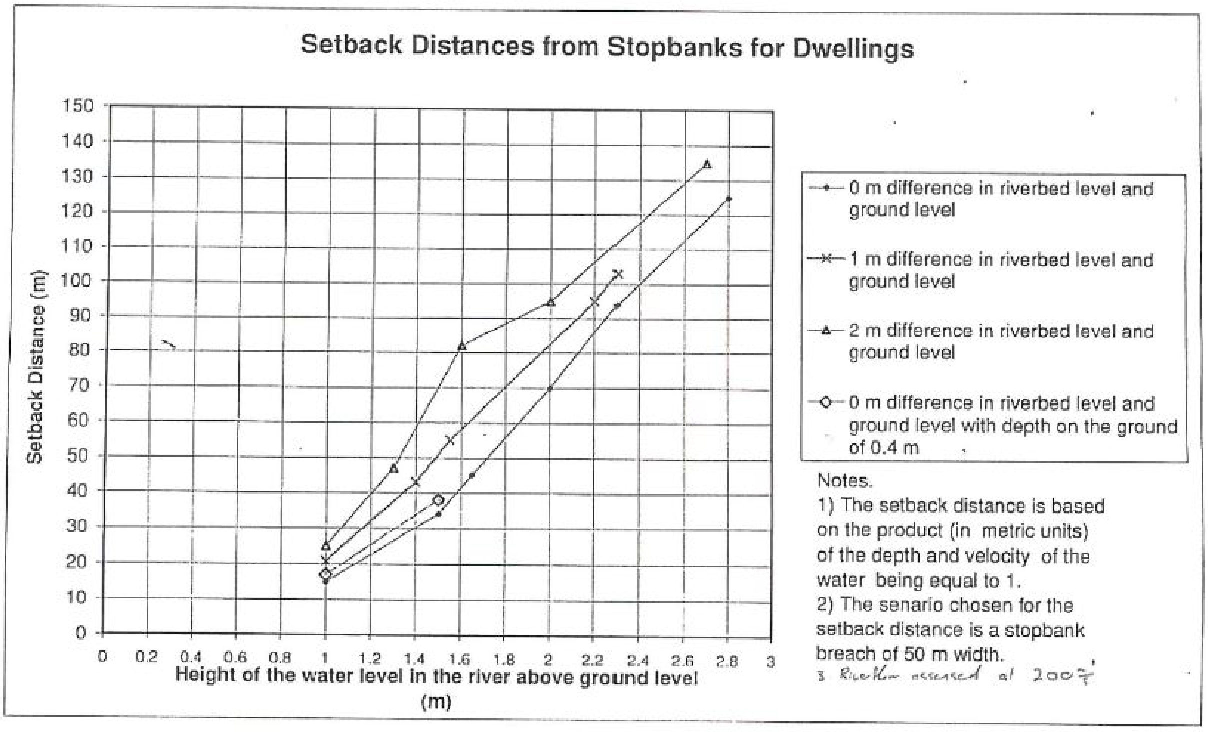
When considering all these additional matters it is appropriate to add both to the expected water level at Grassy Banks (above the 1986 water level) and to add a factor of uncertainty onto the distance calculated.

The 500-year ARI flood flow in the Opihi River is estimated at 4500 cumecs in this reach. If 1986 was 3600 cumecs this means the 500-year ARI flood flow is potentially 25% larger. Higher flood flows likely mean larger breakouts upstream of this area which may mean the full 25% increase in total flow is not felt at Grassy Banks. But given all the potential reasons flood levels could be higher we think it would be reasonable to increase the 1986 flood flow by a 20% in order to calculate a maximum expected setback distance.

Adding 20% to the 1.43 m difference between the water level and ground level in the huts area makes this difference now **1.7m**. By using this height and still applying the 1 metre difference between ground level on both sides of the stopbank, the setback distance measure becomes 65 m. If we then add 10 m for uncertainty (around 15% add on) gives 75 m high hazard distance from the stopbank.

The third dwelling from the river is located 75 m from the centre of the stopbank. Therefore, it is right on the cusp of the high hazard/low hazard boundary as calculated above.

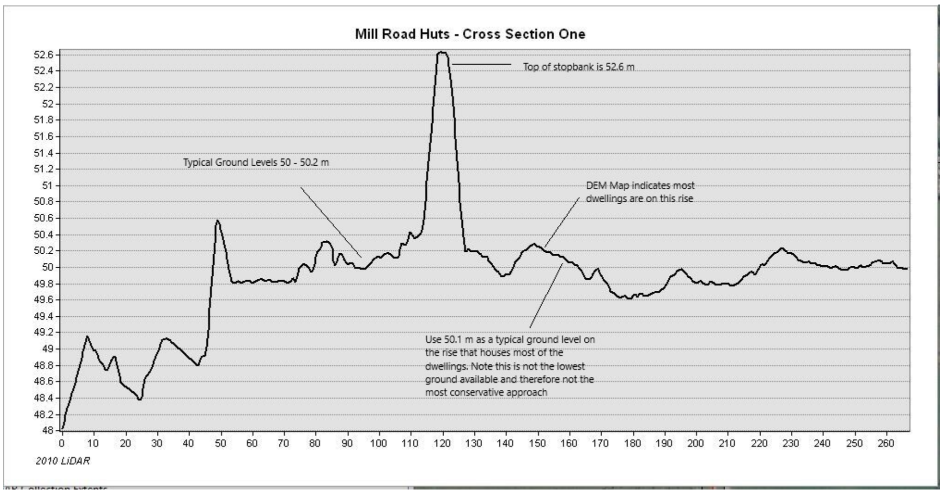
The final point to make in this regard is that the threat of flooding in a breach doesn't go away beyond this setback distance. The depth times velocity at the third dwelling from the river may not technically be high hazard but would only be very marginally lower.



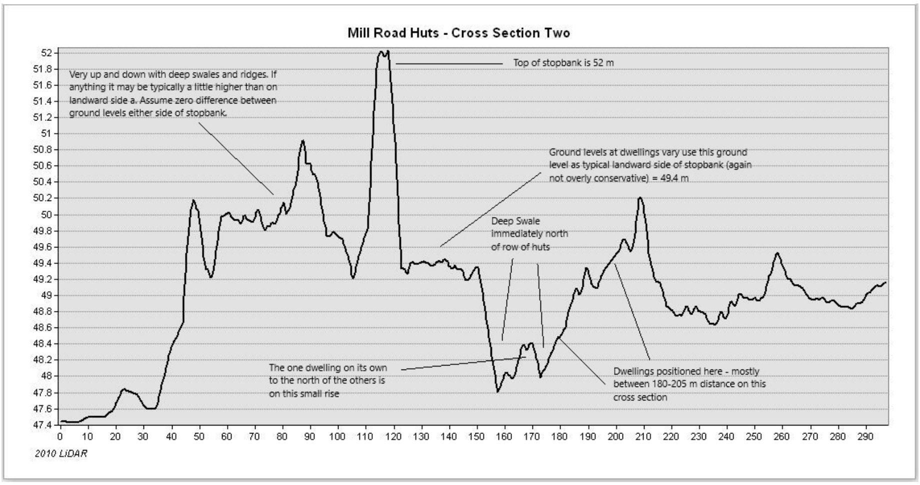
A3.3 Mill Road Huts

Mill Road Huts Stopbank Setback Parameters.
Cross Sections are from 2010 LiDAR.

Cross Section One
Top of stopbank is 52.6 m.
Typical ground level at location of dwellings 50.1 m
Typical ground level riverside of stopbank is 50 – 50.2 m.
Therefore: Relevant height of stopbank is 2.5 m and assume zero difference between ground level either side of the stopbank.
= 105 m setback
Adding on 15% for uncertainty and factors not covered in modelling gives: 120 m.



Cross Section Two
Top of stopbank is 52.0 m.
Typical ground level at location of dwellings 49.4 m
Typical ground level riverside of stopbank is hard to determine but overall is higher than on landward side.
Therefore, Relevant height of stopbank is 2.6 m and assume zero difference between ground level either side of the stopbank.
= 110 m setback
Adding on 15% for uncertainty and factors not covered in modelling gives: 126 m.



<u>Cross Section Two</u>
Top of stopbank is 51.5 m.
Typical ground level at location of dwellings 48.7 m
Typical ground level riverside of stopbank is hard to determine but overall is similar to the landward side. Therefore: Relevant height of stopbank is 2.8 m and assume zero difference between ground level either side of the stopbank.
= 125 m setback
Adding on 15% for uncertainty and factors not covered in modelling gives: <u>143 m.</u>

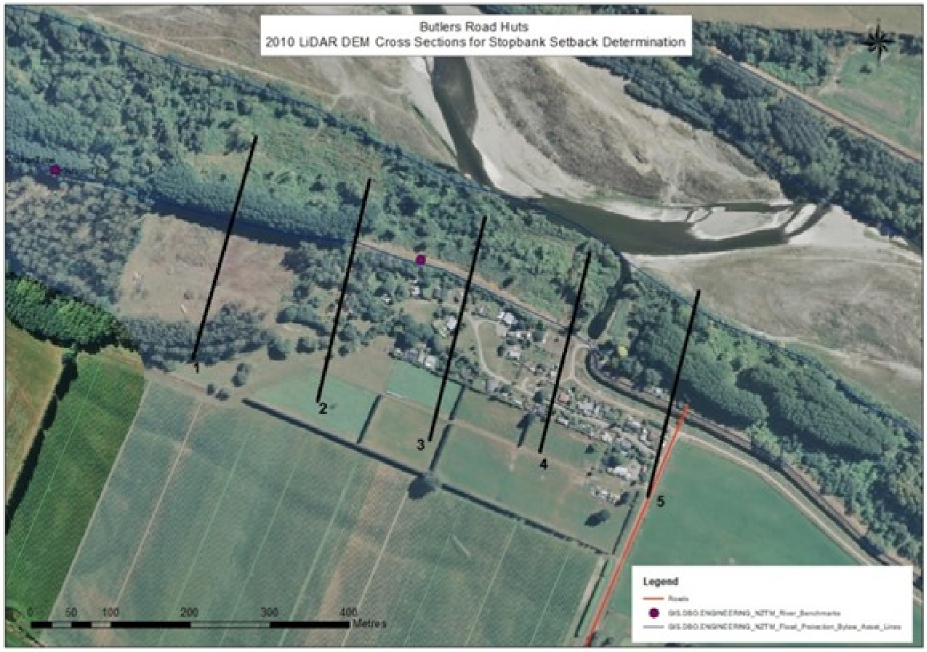
A3.4 Butlers Road Huts

<u>Butlers Road Huts Stopbank Setback Parameters.</u>
Estimation of an appropriate river water level to use for stopbank setback determination.
River survey benchmark at river distance 16.485 km is located on the stopbank in roughly the centre of the Butlers Huts Area. At this benchmark the stopbank height is 60.44 m. The South Canterbury Catchment Board (Opihi River Calculations File Vol 4 pages 198-213) recorded a flood level in the 1986 flood at this same location of 59.96 m. This means there was just 500 mm approx. of freeboard at the Butlers Huts in 1986.

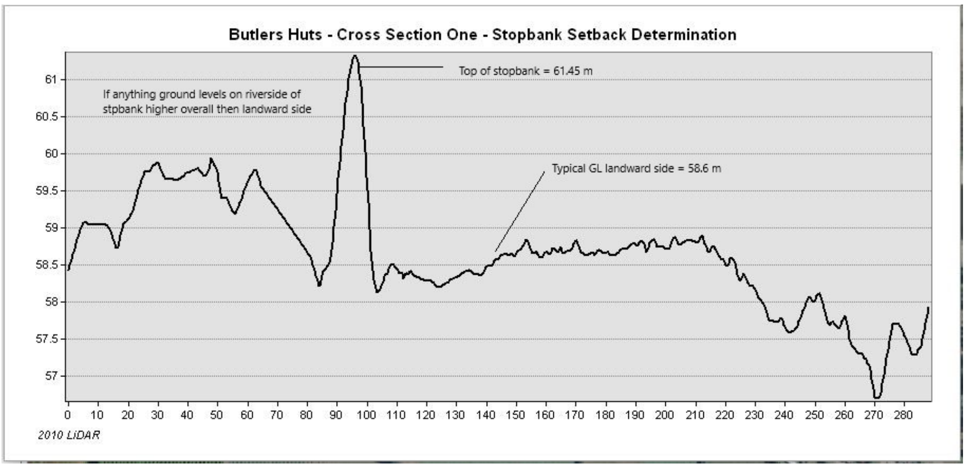
1986 accounts and the Butlers Huts Flood Plain Study Draft report (1991) refer to flooding in the huts are being as the result of Opihi River overflow upstream of the huts not immediately adjacent to the huts. This does not include any water in the irrigation intake race. So therefore, the water levels recorded, below the stopbank top, fit those accounts. There is also no record of a lateral erosion breach occurring right at the huts in 1986.

At Waipopo Huts and other areas we have taken the 1986 flood level and added 300 mm to obtain an estimated flood water level for stopbank breach scenarios and to be consistent we will do the same here and assume for all of my LiDAR cross sections below the water level is the top of the stopbank less 200 mm (i.e. 1986 flood level + 300 mm).

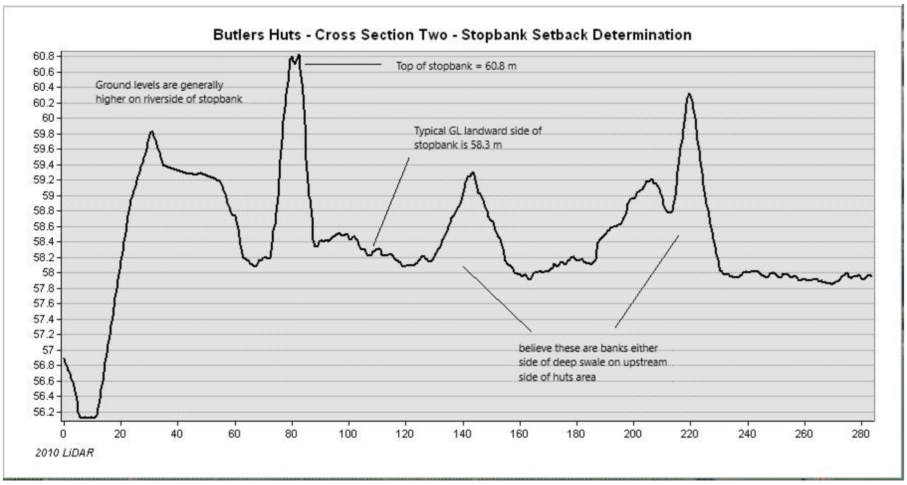
Not also the Butlers Huts Draft Flood Plain Study also refers to lateral erosion as the dominant stopbank breach threat at the huts which again fits in with using a water level a little below the top of the stopbank. The cross sections below are taken from the 2010 LiDAR. (Note benchmark 13.485 km shown between sections 2 and 3).



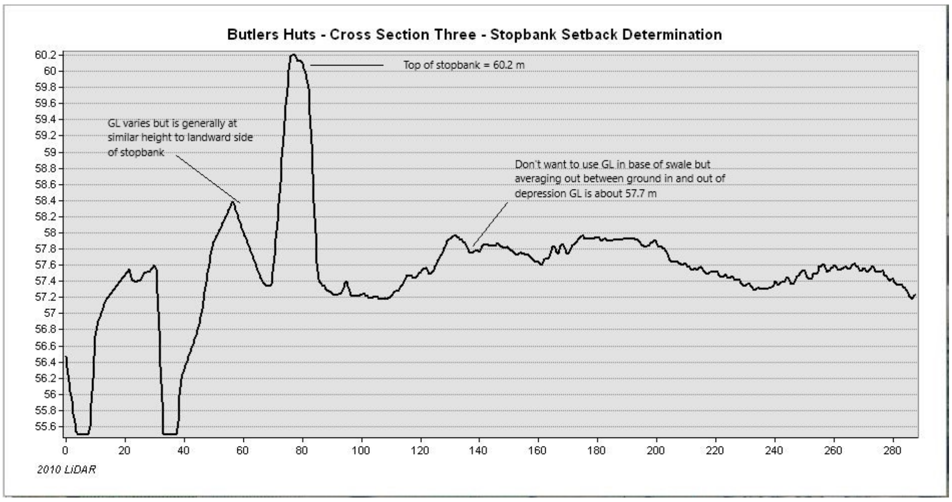
<u>Cross Section One</u>
Top of stopbank is 61.45 m. Less 200 mm for estimated water level is 61.25 m.
Typical ground level at location of dwellings 58.6 m
Typical ground level riverside of stopbank is generally higher than landward side.
Therefore: Relevant height of stopbank is 2.65 m and assume zero difference between ground level either side of the stopbank.
= 112 m setback approx.
Adding on 15% for uncertainty and factors not covered in modelling gives: <u>129 m.</u>



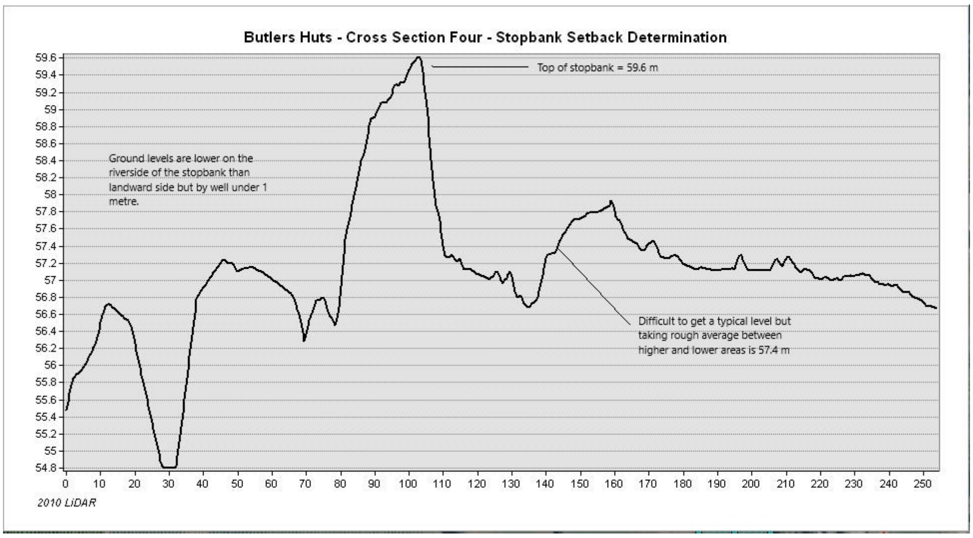
<u>Cross Section Two</u>
Top of stopbank is 60.8 m. Less 200 mm for estimated water level is 60.6 m.
Typical ground level at location of dwellings 58.3 m
Typical ground level riverside of stopbank is generally higher than landward side.
Therefore: Relevant height of stopbank is 2.3 m and assume zero difference between ground level either side of the stopbank.
= 95 m setback approx.
Adding on 15% for uncertainty and factors not covered in modelling gives: <u>110 m.</u>



Cross Section Three
Top of stopbank is 60.2 m. Less 200 mm for estimated water level is 60.0 m.
Typical ground level at location of dwellings 57.7 m.
Typical ground level riverside of stopbank is similar to the landward side.
Therefore: Relevant height of stopbank is 2.3 m and assume zero difference between ground level either side of the stopbank.
= 95 m setback approx.
Adding on 15% for uncertainty and factors not covered in modelling gives: 110 m.



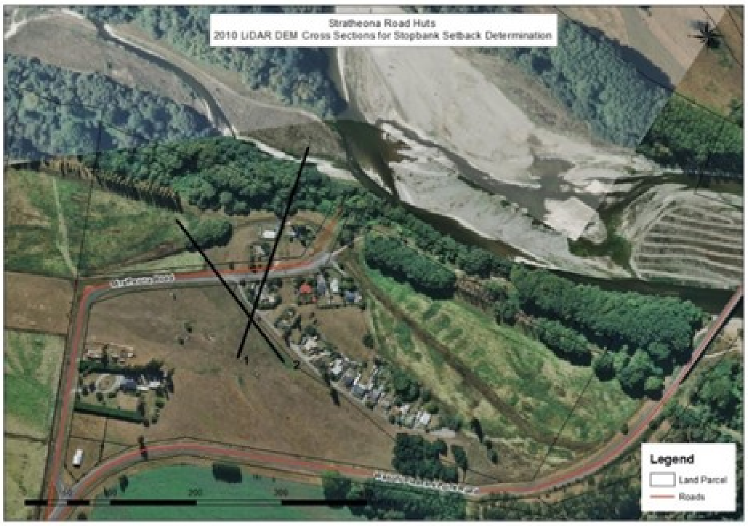
Cross Section Four
Top of stopbank is 59.6 m. Less 200 mm for estimated water level is 59.4 m.
Typical ground level at location of dwellings 57.4 m.
Typical ground level riverside of stopbank is less than one metre lower then landward side.
Therefore: Relevant height of stopbank is 2.0 m and assume halfway between zero and one metre difference between ground level either side of the stopbank.
= 75 m setback approx.
Adding on 15% for uncertainty and factors not covered in modelling gives: 86 m.



Cross Section Five
Top of stopbank is 58.8 m. Less 200 mm for estimated water level is 58.6 m.
Typical ground level at location of dwellings 56.6 m.
Typical ground level riverside of stopbank is less than one metre lower then landward side (around 0.5 m).
Therefore: Relevant height of stopbank is 2.0 m and assume halfway between zero and one metre difference between ground level either side of the stopbank.
= 75 m setback approx.
Adding on 15% for uncertainty and factors not covered in modelling gives: 86 m.
Note we have assumed irrigation channel would be full of water when stopbank breaches and therefore have not factored in that channel in terms of taking away breach flows.

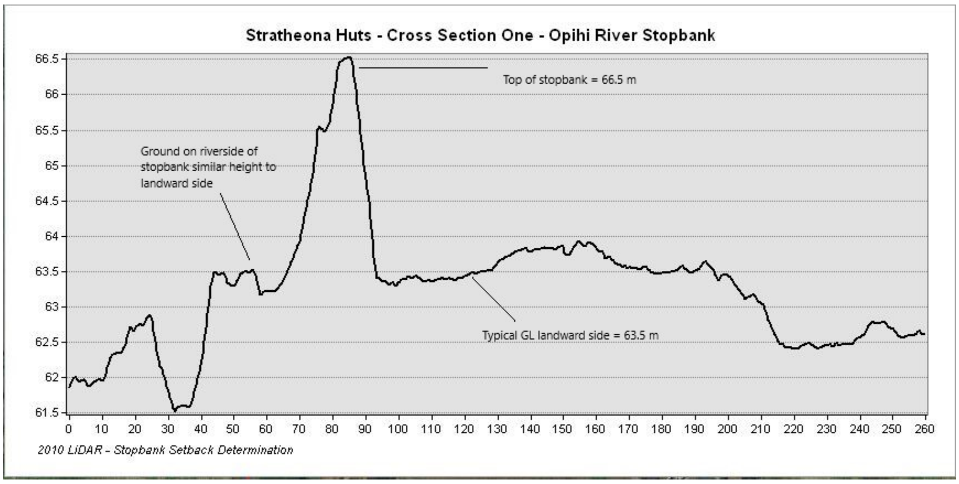
A3.5 Stratheona Huts

Stratheona Road Huts Stopbank Setback Parameters.
Cross Sections are from 2010 LiDAR. Top of stopbank is assumed to be water level.

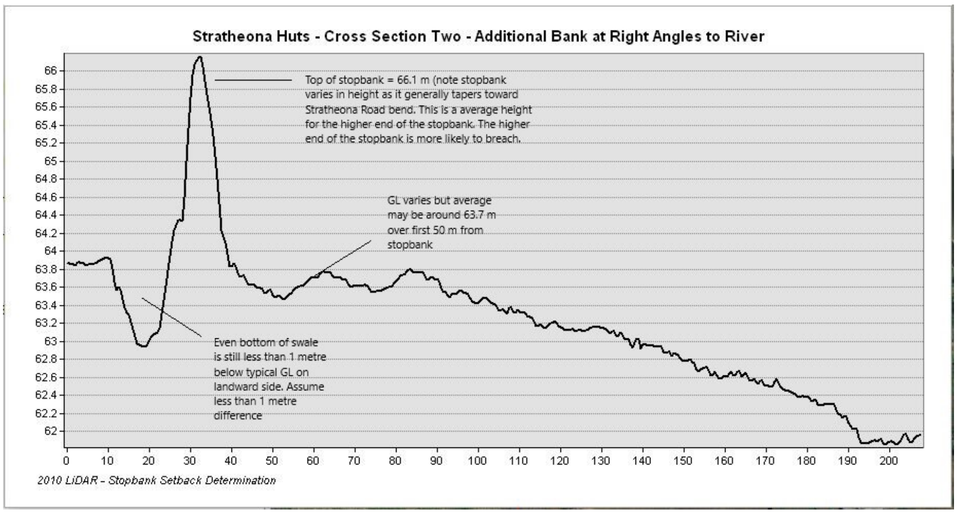


Cross Section One
Top of stopbank is 66.5 m.
Typical ground level at location of dwellings 63.5 m
Typical ground level riverside of stopbank is similar to landward side.

Therefore: Relevant height of stopbank is 3.0 m and assume zero difference between ground level either side of the stopbank.
= 135 m setback
Adding on 15% for uncertainty and factors not covered in modelling gives: 155 m.



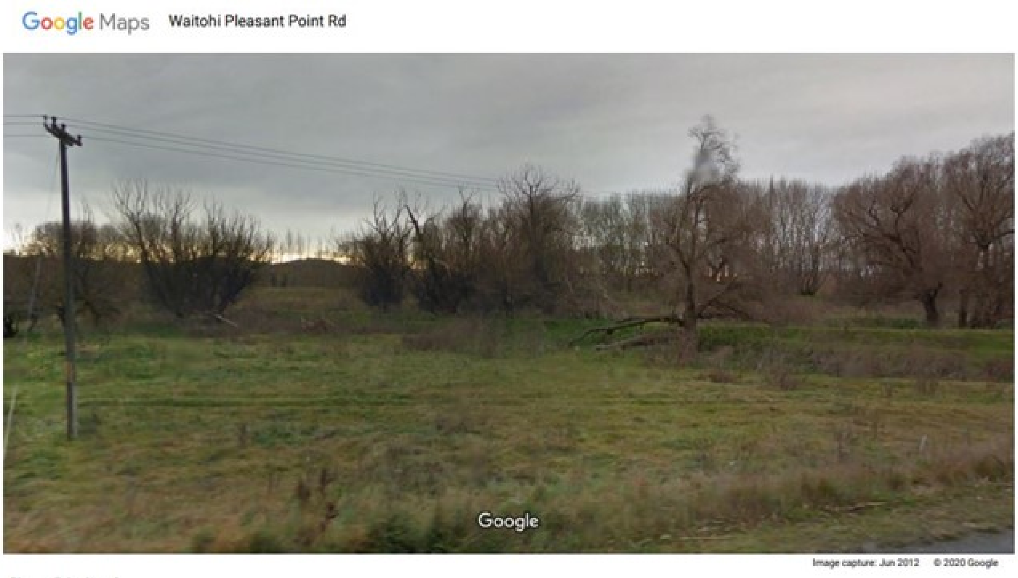
Cross Section Two
Top of stopbank is 66.1 m.
Typical ground level at location of dwellings 63.7 m
Typical ground level riverside of stopbank is slightly lower than landward side but by less than 1 metre.
Therefore: Relevant height of stopbank is 2.4 m and assume halfway between zero and 1 metre difference between ground level either side of the stopbank.
= 105 m setback
Adding on 15% for uncertainty and factors not covered in modelling gives: 120 m.
Note we also assumed floodwaters would reach the top of this stopbank before it would breach but it is unclear if the bank would hold up for that long. This makes the distance more conservative (a greater distance). Given the area is prone to high hazard flooding from both upstream river overflows and from an adjacent Opihi River stopbank breach this is somewhat a moot point.



We include the following photographs from google street view. The first shows the bank of the floodplain upstream of the huts area and at near right angle to flow (centre right). Note also Opihi River stopbank in background -view is off Stratheona Road near major bend.
Second photograph is the Opihi River stopbank between the two additional floodplain banks (where cross section one is roughly located).
Third street view photograph is off Waitohi Pleasant Point Road to the other additional bank angling across the floodplain between that road and Stratheona Road.


Google Maps
13 Stratheona Rd
Google
Image capture: May 2012 © 2020 Google
Pleasant Point, Canterbury

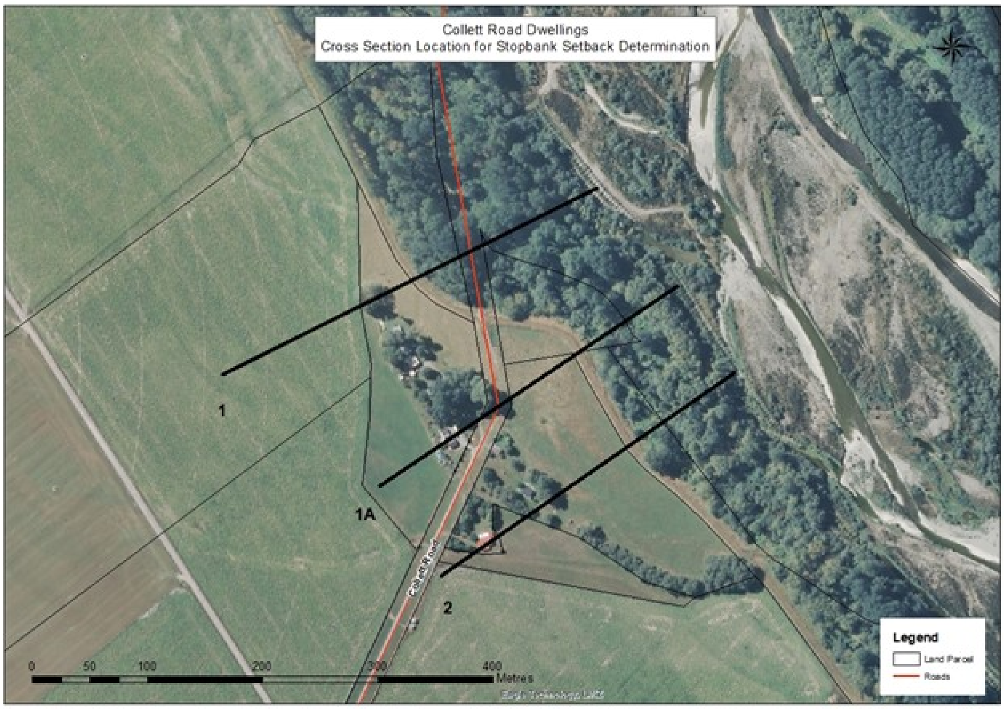

Google Maps
27 Stratheona Rd
Google
Image capture: May 2012 © 2020 Google


Google Maps
Waitohi Pleasant Point Rd
Google
Image capture: Jun 2012 © 2020 Google

A3.6 Collett Road Settlement

Collett Road Dwellings Stopbank Setback Parameters.

Cross Sections are from 2010 LiDAR. Assume water level is top of stopbank given overtopping threat demonstrated by 1986 flooding. Note high ground immediately to west of dwellings actually confines this area and will only increase water levels further.



Cross Section One

Top of stopbank is 86.1 m

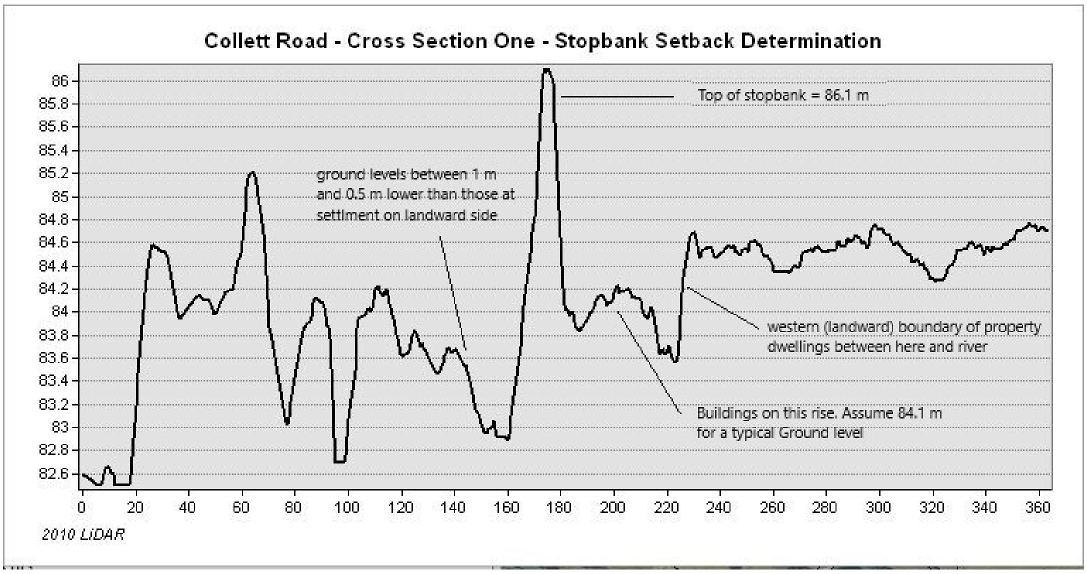
Typical ground level at location of dwellings 84.1 m

Typical ground level riverside of stopbank is 83 - 83.6 m.

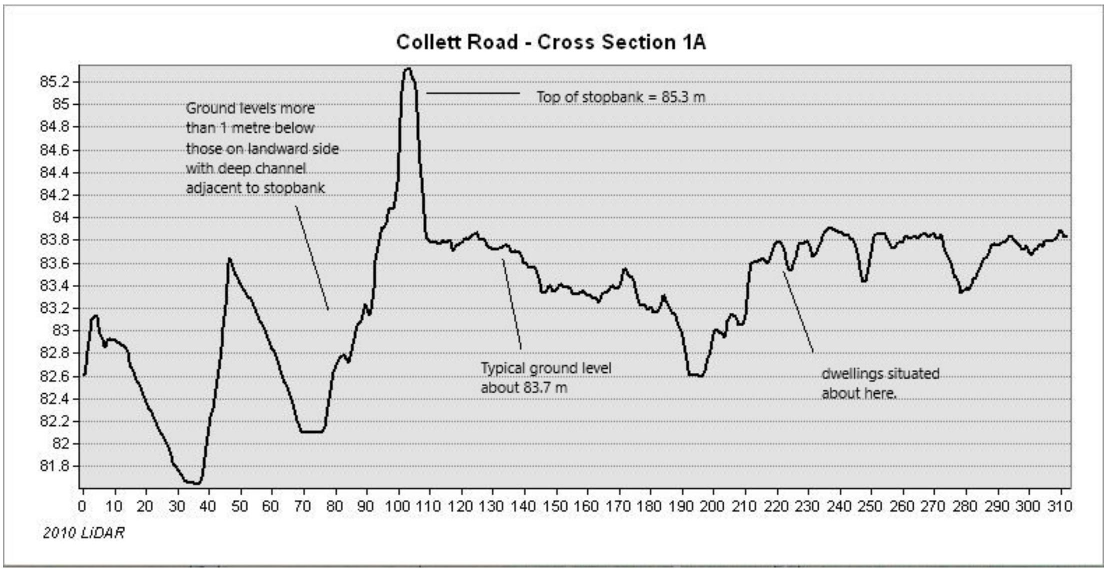
Therefore: Relevant height of stopbank is 2.0 m and assume difference between ground level either side of the stopbank is just below 1 metre (i.e. closer to 1 metre difference than zero.

= 77 m setback approx.

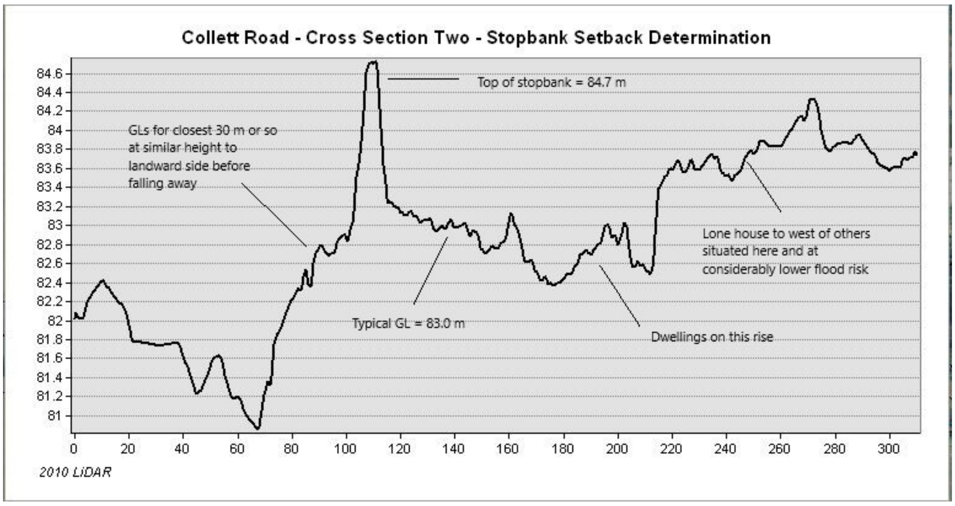
Adding on 15% for uncertainty and factors not covered in modelling gives: 89 say 90m.

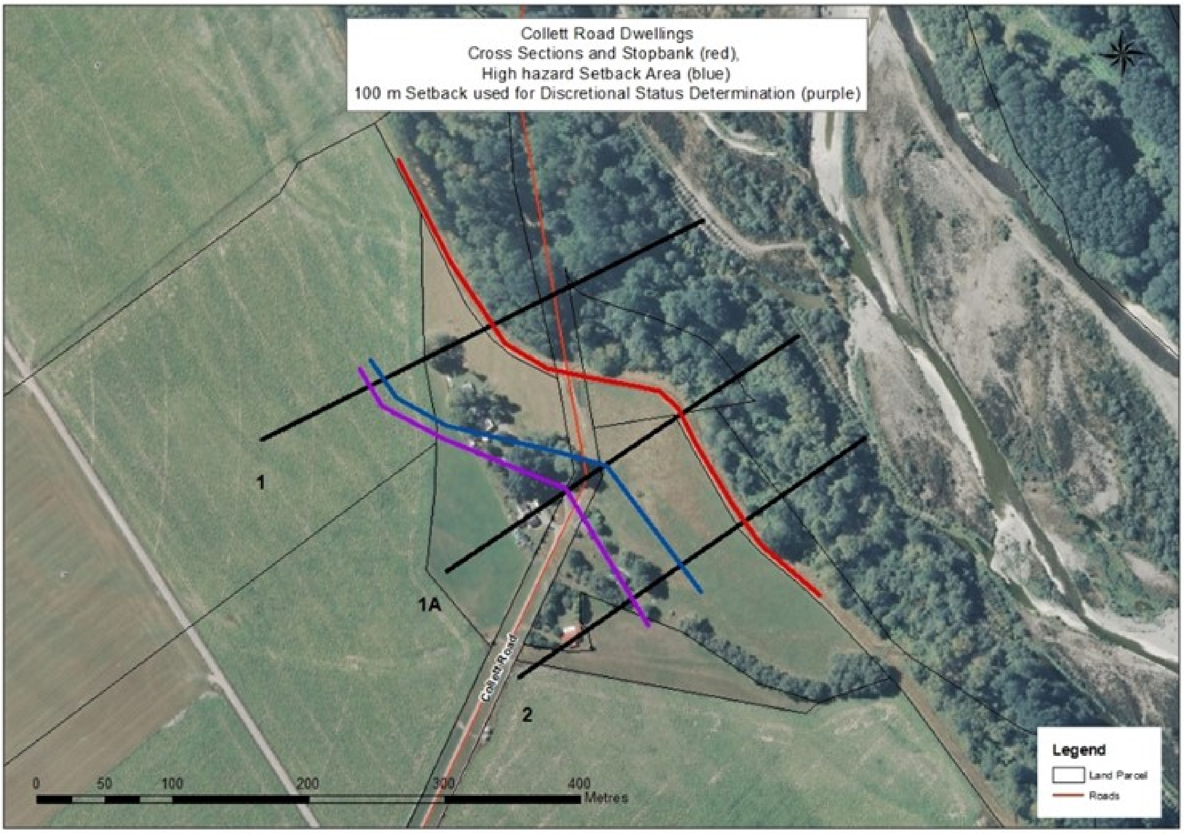


<u>Cross Section 1A</u>
After looking at cross sections 1 and 2 at the upstream and downstream ends of the settlement and seeing a significant difference in setback for each we decided to add a third cross section in between to define setback more accurately.
Top of stopbank is 85.3 m
Typical ground level at location of dwellings 83.7 m
Typical ground level riverside of stopbank is 83.2 – 82.2 m.
Therefore: Relevant height of stopbank is 1.6 m and assume difference between ground level either side of the stopbank is 1 metre.
= 58 m setback approx.
Adding on 15% for uncertainty and factors not covered in modelling gives: 67 m



<u>Cross Section Two</u>
Top of stopbank is 84.7 m
Typical ground level at location of dwellings 83.0 m
Typical ground level riverside of stopbank is 82.8 m close to stopbank but falls away further back.
Therefore: Relevant height of stopbank is 1.7 m and assume difference between ground level either side of the stopbank is zero.
= 50 m setback approx.
Adding on 15% for uncertainty and factors not covered in modelling gives: <u>58 m.</u>





Stopbank (red), high hazard setback area (blue), 100m discretionary status trigger (purple)

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