Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

TECHNICAL REPORT Science Group

Ote Makura (Goose Bay) floodplain investigation

Report No. R18/37
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Michelle Wild

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Environment Canterbury
Regional Council
Kaunihera Taiao ki Waitaha

	Name	**Date**
Prepared by:	*Michelle Wild* *Hazards Analyst (Flooding)*	*23 November 2018*
Reviewed by:	*Brodie Young* *Environmental Science & Hazards Manager*	*20 December 2018*
Model externally reviewed by:	*Matthew Gardner* *Land River Sea Consulting Ltd*	*6 November 2018*
Approved by:	*Tim Davie* *Chief Scientist*	*23 January 2019*

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

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

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

Summary

Background

Ote Makura Stream is located ~15 km south-west of Kaikōura township, in an area where considerable ground movement occurred during the November 2016 Kaikōura earthquake sequence. As part of the Kaikōura District Plan review, a better understanding of flooding from local rivers was required. This modelling investigation has therefore been undertaken, as part of a series of investigations, to quantify the extent and depth of flooding for land adjacent to Ote Makura Stream.

The modelling simulated flooding from large, high-intensity rainfall events, rather than failure of any of the recent earthquake-induced landslide dams in the Ote Makura Stream catchment.

What we did

This study used a combined 1-dimensional and 2-dimensional hydraulic computer model to estimate flood extent, depths, and levels for 50 and 500 year Average Recurrence Interval (ARI) flood events. Sensitivity runs were also completed to address the considerable uncertainty contained within the modelling. Sources of uncertainty include, but are not limited to, inadequate hydrological data, no calibration data and the dynamic landscape.

What we found

For the Ote Makura Stream floodplain, inundation in a 500 year ARI flood event is likely to be confined to the stream margins and the ponding areas upstream of the railway bridge.

What does this mean?

Maps showing predicted 500 year ARI flood levels, depths, and high hazard areas, will assist land use planning within the area. The model results will allow appropriate floor levels for new buildings and extensions to be determined. The model developed as part of this study could also be used in the future to analyse existing or proposed flood protection works, and for emergency planning purposes.

Goose Bay settlement and the Ote Makura Stream mouth (15 November 2016)

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1 Introduction

Ote Makura Stream and floodplain are located ~15 km southwest of Kaikōura township. Figure 1-1 shows the Ote Makura floodplain, and Figure 1-2 shows Ote Makura Stream and the Goose Bay settlement, which is mainly located on the Ote Makura floodplain.

As part of the Kaikōura District Plan review, a better understanding of flooding from local rivers was required. This modelling investigation has been undertaken to quantify the extent and depth of flooding for land adjacent to Ote Makura Stream.

Detailed topographic data, and a combined 1-dimensional (1D) and 2-dimensional (2D) hydraulic computer model, were used to determine the likely extent and depth of flooding on the Ote Makura floodplain for 50 and 500 year ARI flood events. High hazard areas (see Glossary) are also derived.

This information will assist with land use planning (e.g. defining minimum floor levels and high hazard areas) and emergency management planning (e.g. evacuation).

Chapter 11 of the Canterbury Regional Policy Statement (CRPS) includes policy which requires new buildings in areas subject to inundation to have floor levels above the 200 year ARI flood level. However, the current Kaikōura District Plan requires floors in certain areas to be above a 500 year ARI flood level. The CRPS also requires new development to be avoided in high hazard areas.

Figure 1-1: Location of Ote Makura Stream floodplain study area

Figure 1-2: The Ote Makura Stream floodplain and Goose Bay settlement, 13 December 2016

2 Background

The primary focus of this investigation is to quantify the post-November 2016 Kaikōura earthquake sequence flood risk on the Ote Makura floodplain.

2.1 Study area

Ote Makura Stream flows into the sea at the coastal settlement of Goose Bay. The stream has a catchment area of ~21 km^2, which extends in a northwest direction for ~6 km from the coast (Figure 2-1). Most of the length of Ote Makura Stream is very well confined by the steep, coastal, range that rapidly increases in elevation from sea level to almost 1000 m. As the stream approaches the Goose Bay settlement, it becomes less confined and flood flows spread out over the small Ote Makura floodplain area adjacent to the coast.

Prior to the 2016 Kaikōura earthquake sequence, the mouth of Ote Makura Stream closed when stream flows were low and sea conditions were favourable for moving sediment across the opening. When the mouth was closed, water would back up behind the gravel barrier, causing flooding in the campground.

2.2 14 November 2016 Kaikōura earthquake sequence

Soon after the 7.8 magnitude Kaikōura earthquake sequence (and subsequent aftershocks), a landslide dam was discovered on Ote Makura Stream (Figure 2-1 to Figure 2-3). This small, narrow, landslide dam (known as ‘Ote Makura 100’) formed when a landslide from the western side of the valley blocked the narrow stream channel.

More than 30 homes and holiday houses in Goose Bay were evacuated, as a precaution, since it was not known when the dam might breach, potentially causing sudden and substantial increases in flows and water levels.

Because of the potential impact of the landslide dam breach on the downstream infrastructure, the New Zealand Transport Agency (NZTA) set up a water level and rainfall monitoring site. This continuously monitored the landslide dam for sudden changes in water level until April 2017.

Between 4 and 6 April 2017, rainfall associated with ex-Tropical Cyclone Debbie caused the Ote Makura landslide dam to overtop, scouring a significant channel through the toe of the landslide (Figure 2-4). There were no reports of damage, and so it is assumed that any flood wave dissipated quickly. This minimised the flood hazard and consequently the monitoring site was discontinued.

Ground levels in the area around the Goose Bay settlement have risen by ~1.4 to 1.8 m due to the earthquake activity (Figure 2-5).

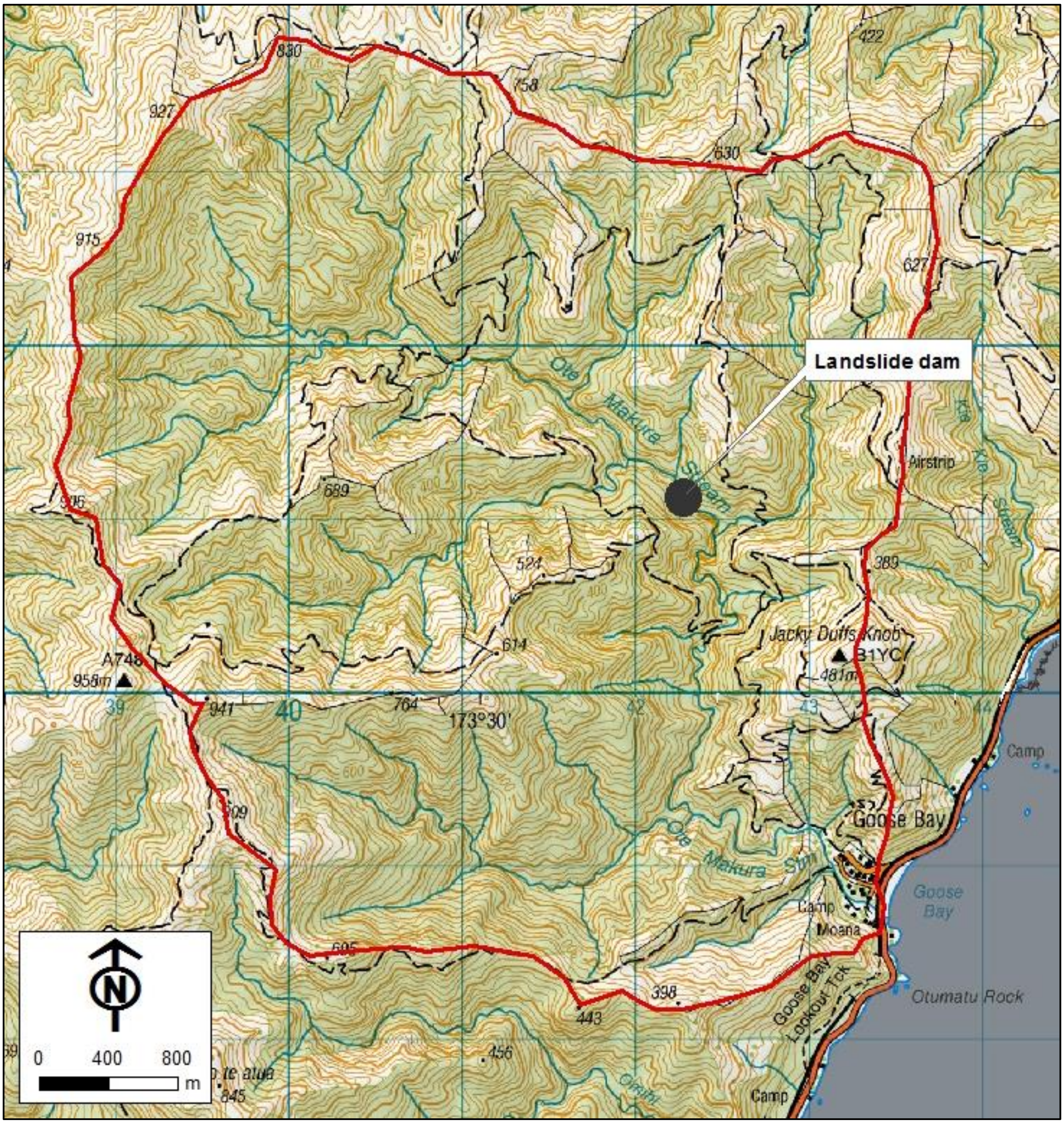

Figure 2-1: Ote Makura catchment area and landslide dam location

Figure 2-2: Ote Makura landslide dam on 19 November 2016 – looking upstream from above landslide dam

Figure 2-3: Ote Makura landslide dam on 28 December 2016 – looking downstream from above landslide dam

Figure 2-4: Ote Makura landslide dam on 7 April 2017 – looking downstream, from the lake area, at the channel cut through the landslide

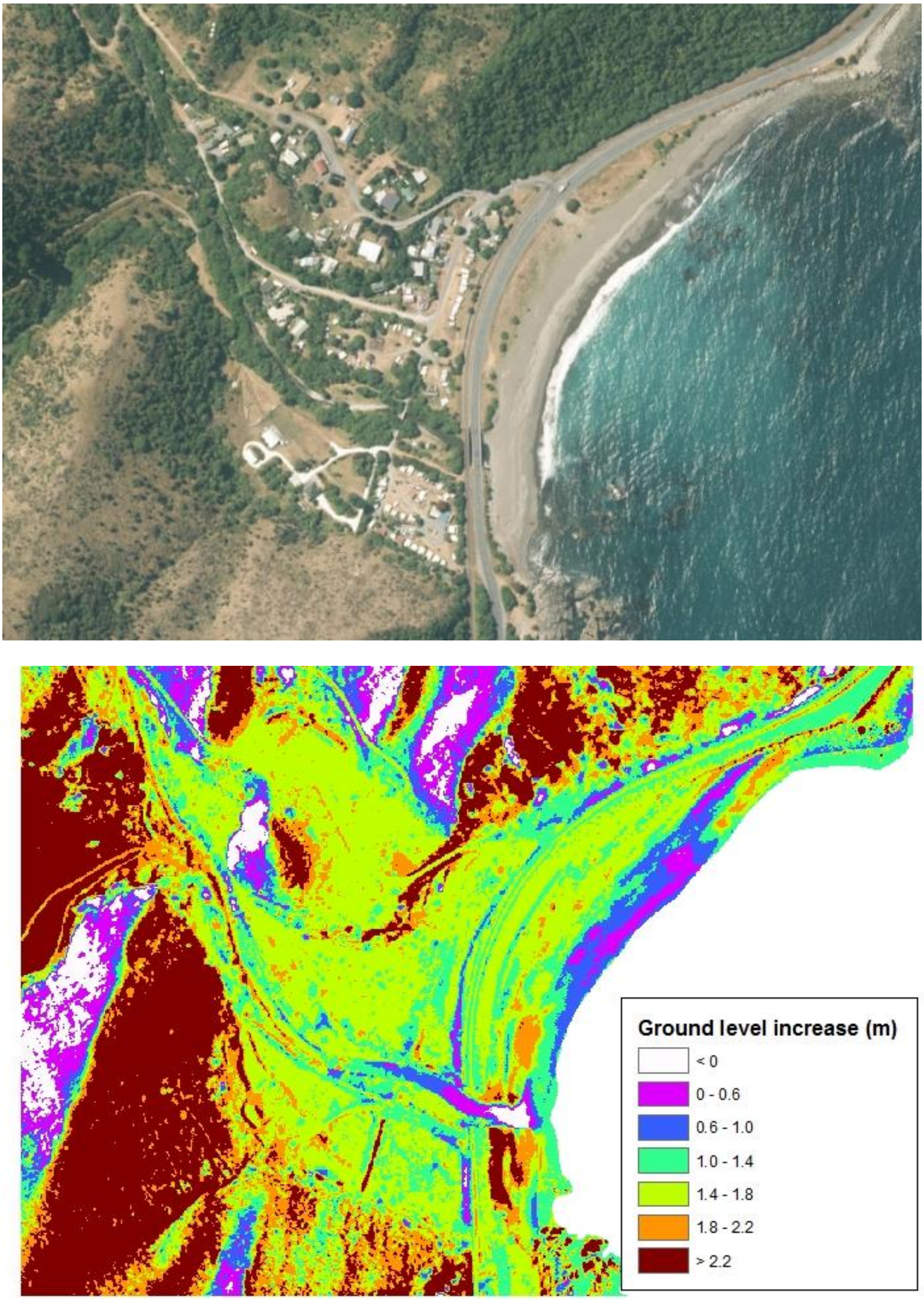

Figure 2-5: Indicative changes in ground level after the 2016 Kaikōura earthquake sequence

<u>Note:</u> Horizontal ground movement exaggerates changes, especially where land slopes steeply

2.3 Historic flooding

High flows in Ote Makura Stream tend to occur during widespread, high-intensity, southerly or easterly rainfall events. Depressions, formed from tropical cyclones, can also produce extremely high-intensity rainfall along the Kaikōura coast. High flows can cause flooding (and sediment and landslide issues) for smaller streams and creeks, such as Ote Makura Stream, which drain the steep coastal ranges adjacent to the coastline.

Information regarding notable flood events in the Ote Makura catchment, and surrounding area, are summarised below. A more detailed account of flooding in the Kaikōura area is provided in McPherson (1997). There are no quantified flood flow estimates for Ote Makura Stream.

2.3.1 February 1868

This was the first documented flood event after European settlement in the area. It was described as '*the greatest flood ever recorded on the Marlborough coast'* by Sherrard (1966) in McPherson (1997, p 7). Mrs V Boyd described the flood event as several days of rain, followed by a cold southerly (with rain, hail and snow). On the 6th day a north-westerly rainfall event occurred. The snow and hail disappeared and extensive flooding occurred.

2.3.2 May 1923

The May 1923 flood was a southerly rainfall event. Heavy rainfall also fell throughout the rest of Canterbury. At the time, this was described as the worst flood since 1868. At Hāpuku, approximately 610 mm of rain fell over 48 hours, and 690 mm over 5 days (SCRCC, 1957). Nearly every bridge in the County was damaged (McPherson, 1997).

2.3.3 November 1952

This was described as the worst southerly storm to hit the Kaikōura coast and Marlborough for many years. The Kowhai River broke its banks, and flowed into Lyell Creek, flooding properties and part of the town (SCRCC, 1957).

2.3.4 January 1953

Prolonged, heavy rainfall along the east coast caused widespread flooding and closed the road along the Kaikōura coast. There was over 254 mm of rainfall recorded at Grange Road over 72 hours (McPherson, 1997).

2.3.5 March 1975

High-intensity rainfall occurred along the Kaikōura coastal area due to the passage of Cyclone Alison. The Meteorological Office recorded 284 mm of rain and, in the Puhi Valley, a resident recorded 450 mm of rainfall (McPherson, 1997). The 6-hourly rainfall intensities also exceeded 30 mm/hr in several locations (Bell, 1976). This caused widespread flooding and landslides – particularly along the Hāpuku River to Clarence River portion of the coastline (north of the Ote Makura catchment).

2.3.6 March 1980

Like the Cyclone Alison storm, this event was caused by a depression that had formed from a tropical cyclone. Heavy rainfall was mainly confined to the coastal area with 245 and 340 mm of rain recorded in Kaikōura and Luke Creek, respectively, over 24 hours (McPherson, 1997).

2.3.7 December 1993

This was an easterly rainfall event. A total of 147 mm of rain fell at Luke Creek in 10 hours, with hourly rainfall intensities of up to 20 mm/hour. In the Puhi Puhi catchment, further north, 300 mm of rainfall was recorded for this event (McPherson, 1997).

2.3.8 February 2018

The remnants of Tropical Cyclone Gita passed across the Kaikōura area causing significant rainfall along parts of the Kaikōura coast. Rainfall for this event varied spatially with nearby Rosy Morn recording 269 mm of rainfall in 12 hours, while only 156 mm of rainfall fell at Luke Creek over 12 hours. For the more extreme rainfall at Rosy Morn, the 12 hour rainfall total was estimated to have a 100 to 200 year ARI. Although no flows were recorded, both Rosy Morn Stream and Kie Kie Stream carried significant volumes of gravel, which accumulated upstream of the railway line, blocking the railway culverts and filling the stream channels. Excess water and gravel flowed over the small, confined, floodplain areas adjacent to the streams, entering dwellings beside each stream (https://www.stuff.co.nz/national/101645608/extropical-cyclone-gita-causes-landslips-destroys-two-homes-near-kaikura, accessed 7 January 2019).

2.4 Flood protection works

Ote Makura Stream and floodplain are not part of the Kaikōura Rivers Rating District nor the Kaikōura Drainage District. At present there are no managed river protection works in this area. Raised stopbanks, located along Ote Makura Stream, are not likely to have been properly compacted when placed many years ago, and nothing is known about any work undertaken to protect the rail and road.

2.5 Climate change

The impacts of future climate change on the Ote Makura Stream and floodplain are complex and, at present, not fully known. Some of the likely changes that are relevant to this flood modelling investigation include:

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

Rainfall
In general, rainfall varies more significantly spatially and temporally than temperature. For the east coast of the South Island, summer is likely to become wetter, and winter and spring drier (MfE, 2016).

Rising air temperatures will also produce an increase in the intensity of extreme rainfalls since warmer air can contain up to ~8% more moisture for each 1ºC increase in temperature (Mullan *et al.,* 2008). On this basis, the projected increases to design rainfall events from a 1986-2005 baseline out to 2101-2120 under the four RCP scenarios range from 5.6 – 28.8%. A 2018 update (MfE, 2018) incorporates very extreme rainfall results from the "HIRDS" report (Carey-Smith *et al.,* 2018). This shows extreme rainfall increasing with climate change in all areas, with shorter duration events likely to have the more significant increases in rainfall.

In the Ote Makura catchment, a mid-range increase in rainfall intensity would approximately double the frequency of the rainfall event. This means that, in 100 years from now, what is currently considered to be a 100 year ARI flood event may become a 50 year ARI flood event.

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

As Ote Makura Stream has a relatively steep gradient, predicted increases in sea level of the order of 1m will not have any impact on flood water levels, except in the vicinity of the coast. Section 3.6.4 also shows that sea level rise of up to 1 m is likely to have a negligible impact on the Goose Bay Settlement adjacent to the river mouth. Any sea level rise impacts on flooding have decreased since the November 2016 Kaikōura earthquake sequence as ground levels on the Ote Makura floodplain have risen by ~1.4 to 1.8 m relative to sea level.

3 Methodology

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

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

- Compilation of historic flood event information (Section 2.3)
- Estimation of flood hydrology/design flows (Section 3.1)
- Construction of a computational hydraulic model (Section 3.2)
- Calibration of the hydraulic model (Section 3.4)
- Modelling of design flood events (Section 3.5)
- A sensitivity analysis (Section 3.6)

3.1 Flood hydrology

The primary focus of this part of the investigation was to determine the likely extent and depth of flooding on the Ote Makura floodplain for a 500 year ARI flood event.

Although there are no water level recorders in Ote Makura Stream, there is a water level/flow record in the adjacent Rosy Morn catchment (Figure 3-1). This record extends back to February 1978.

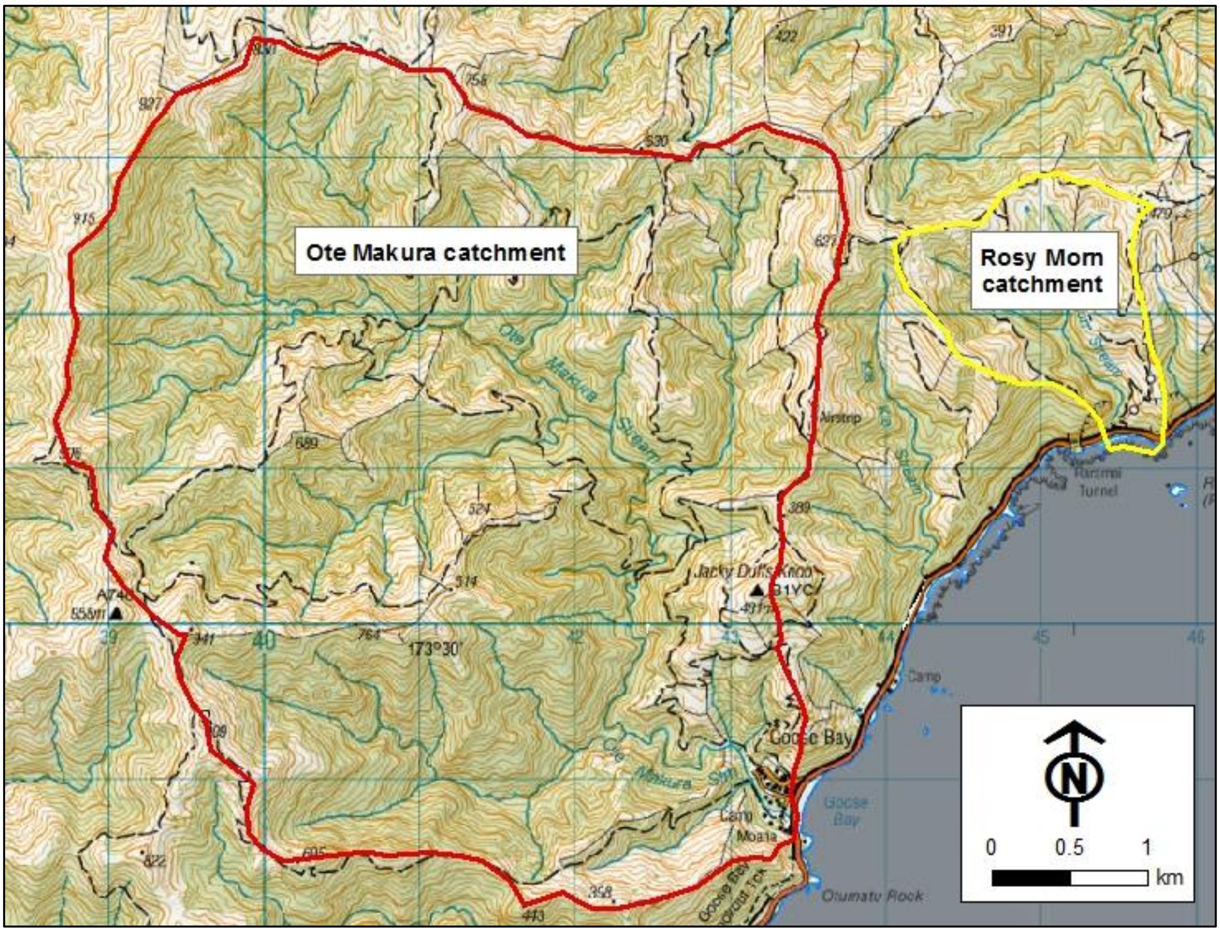

Figure 3-1: Ote Makura and Rosy Morn catchment locations

Griffiths *et al.* (2011) provides a methodology to enable design flood peak estimates to be calculated for rivers in the Canterbury region that do not have flow records. This regional flood estimation study updated the previous work of McKerchar and Pearson (1989), and included the Rosy Morn data which produced the following factors from the flow record:

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

$$Flood\ frequency\ factor \quad q_{100} = \frac{Q_{100}}{Q_{MAF}} = 5.1$$

where: Q_{MAF} = mean annual flow (m^3/s)
Q_{100} = 100 year ARI flow (m^3/s)
A = catchment area (km^2)

Using these factors, and the 21.3 km^2 Ote Makura catchment area, the mean annual flow is calculated to be ~19.8 m^3/s, and the 100 year ARI flow is ~101 m^3/s (Table 3-1). As the flood frequency factor is based on an EV1 distribution, flood events greater than a 100 year ARI may be underestimated for streams that have an EV2 distribution (Griffiths *et al.,* 2011). Therefore, if Ote Makura Stream has an EV2 distribution, this method may underestimate larger (less frequent) flood events.

Tonkin and Taylor (2017) produced an updated flood frequency analysis for some of the Kaikōura Rivers. For the near-by Kowhai River site, the derived factors were:

$$Mean\ annual\ flood\ (MAF)\ factor \quad \frac{Q_{MAF}}{A^{0.866}} = 1.9$$

$$Flood\ frequency\ factor \quad q_{100} = \frac{Q_{100}}{Q_{MAF}} = 4.0$$

Design flood flows produced using these factors, and the Ote Makura catchment area of 21.3 km^2, are shown in Table 3-1. This table illustrates that design flows are similar for both sets of flood frequency factors. Design flows of 90 and 130 m^3/s were therefore chosen for the 50 and 500 year ARI flows, respectively. To understand the sensitivity to climate change (to 2120), design flows were increased by 25% (Table 3-1). This percentage increase is consistent with the higher range RCP air temperature projections presented in MfE (2016). A 2018 update (MfE, 2018) incorporates very extreme rainfall results from the "HIRDS" report (Carey-Smith *et al.,* 2018). This shows extreme rainfall increasing with climate change in all areas, with shorter duration events likely to have the more significant increases in rainfall. The 25% flow increase used in this study, to account for climate change to 2120, may therefore be more representative of a mid to lower range RCP air temperature projection for Ote Makura Stream.

Table 3-1: Ote Makura Stream design flows

Event Probability	Flow (m^3/s)			
	Griffiths *et al.* (2011)	**Tonkin & Taylor (2017)**	**Design**	**Design (with climate change)**
10 year ARI (10% AEP)	54	58		
20 year ARI (5% AEP)	68	71		
50 year ARI (2% AEP)	87	87	90	110
100 year ARI (1% AEP)	101	98		
200 year ARI (0.5% AEP)	115	110		
500 year ARI (0.2% AEP)	134	126	130	160

3.2 Kaikōura sea level and storm tides

Storm tides are a combination of tide, storm surge, seasonal cycles, and long-term fluctuations. These are outlined below.

3.2.1 Tide

Kaikōura sea level data are available on the Land Information New Zealand (LINZ) website (http://www.linz.govt.nz/sea/tides/sea-level-data/sea-level-data-downloads, accessed 14 February 2017). The 'data zero' value is approximately -2.95 m NZVD2016. From the LINZ website data, a relatively high perigean tide at Kaikōura (e.g. 11 January 2016) would be around +1.26 m NZVD2016.

3.2.2 Storm surge

Storm surge occurs when low barometric pressure (from low atmospheric weather systems) and strong winds temporarily elevate sea levels. Storm surge is limited to increases in sea level of less than 1 m for the New Zealand open coast (Bell, 2010). This does not include short-lived localised wave run-up effects.

3.2.3 Seasonal to long term fluctuations

Sea level can also fluctuate over longer periods of time due to seasonal cycles and El Niño-Southern Oscillation (ENSO) fluctuations, which can increase sea level by a further 0.1 to 0.2 m (Bell *et al.,* 2000).

3.2.4 Storm tide

Analyses of existing sea level records around New Zealand has demonstrated that the higher storm tides tend to occur during a perigean tide combined with relatively small storm surges of 0.1 to 0.3 m (Bell, 2010).

For Kaikōura, a 500 year ARI flood event is likely to occur during a low pressure weather system. The high tide level of 1.26 m NZVD2016 is therefore likely to be combined with a storm surge. For this study, a storm surge of 0.4 m and a 0.1 m seasonal/ENSO water level fluctuation has been adopted to produce a maximum sea level of ~1.75 m NZVD2016. This level has not been derived using a joint probability analysis of stream flows and sea level. However, it is considered appropriate for this study since overly conservative values have not been chosen for any of the components of the storm tide.

For all model runs, the sea level is set to a constant level to simulate high tide occurring at the same time as the peak stream flow reaches the river mouth. Section 3.6.4 addresses the effect of sea level rise.

3.3 Hydraulic model construction

The Mike Flood modelling package combined 1-dimensional (1D) modelling, for the Ote Makura Stream channel and coastal boundary, with 2-dimensional (2D) modelling, for the Ote Makura floodplain. The 1D and 2D models were linked along the stream channel boundary and coastal boundary to the floodplain, to allow flood water to move freely between the stream, floodplain and sea. A schematic of the model is shown in Figure 3-2. A more detailed description of the model is given below.

3.3.1 1D river model

Ote Makura Stream, and the coastal boundary, are included as 1D river channels in the Mike Flood model.

Ote Makura Stream cross sections extend 1.1 km upstream from the coast. These cross sections were extracted from high resolution topographic data obtained from a 2016 airborne LiDAR survey (see Section 3.3.2). Although the cross sections include the water surface as the bed level, flows in the stream during the survey were low making the reduction in cross section area insignificant.

The coastal boundary extends along the seaward side of SH1, across the width of the bay (Figure 3-2). The northern end of the coastal 'channel' is closed and the southern end has the sea level boundary.

Figure 3-2: **Ote Makura Stream model schematic**

Channel roughness

A Manning's n value of 0.040 has been used for the bed resistance (channel roughness) along Ote Makura Stream. Figure 3-3 shows Ote Makura Stream, looking upstream from near the campground road bridge.

Structures

The 1D model includes bridge structures to represent the campground road bridge (Figure 3-4) and the railway bridge (Figure 3-5). These bridges could potentially be blocked, overtopped, and/or destroyed during a large flood event.

The SH1 road bridge, located immediately downstream of the railway bridge, has not been included in the model as it provides less of a constriction than the railway bridge.

Figure 3-3: Ote Makura Stream looking upstream from near the campground road bridge

Figure 3-4: Ote Makura Stream looking downstream towards the campground road bridge

Figure 3-5: Ote Makura Stream looking downstream towards the railway and SH1 bridges

3.3.2 2D floodplain model

The 2D model covers the Ote Makura floodplain, on both sides of the stream. The model floodplain topography and roughness are described below.

<u>Floodplain topography</u>

To realistically model floodplain flows with any degree of accuracy, good topographic data (including features such as banks, terraces, overland flow channels, roads and railway embankments) are essential. For the Ote Makura Stream and floodplain, the high resolution topographic data were obtained from an airborne LiDAR survey (aerial laser scanning) flown between 19 and 21 November 2016 by AAM NZ Limited. This work was commissioned by NZ Transport Agency, immediately after the 14 November Kaikōura earthquake. The detail provided by LiDAR data can be seen in Figure 3-6.

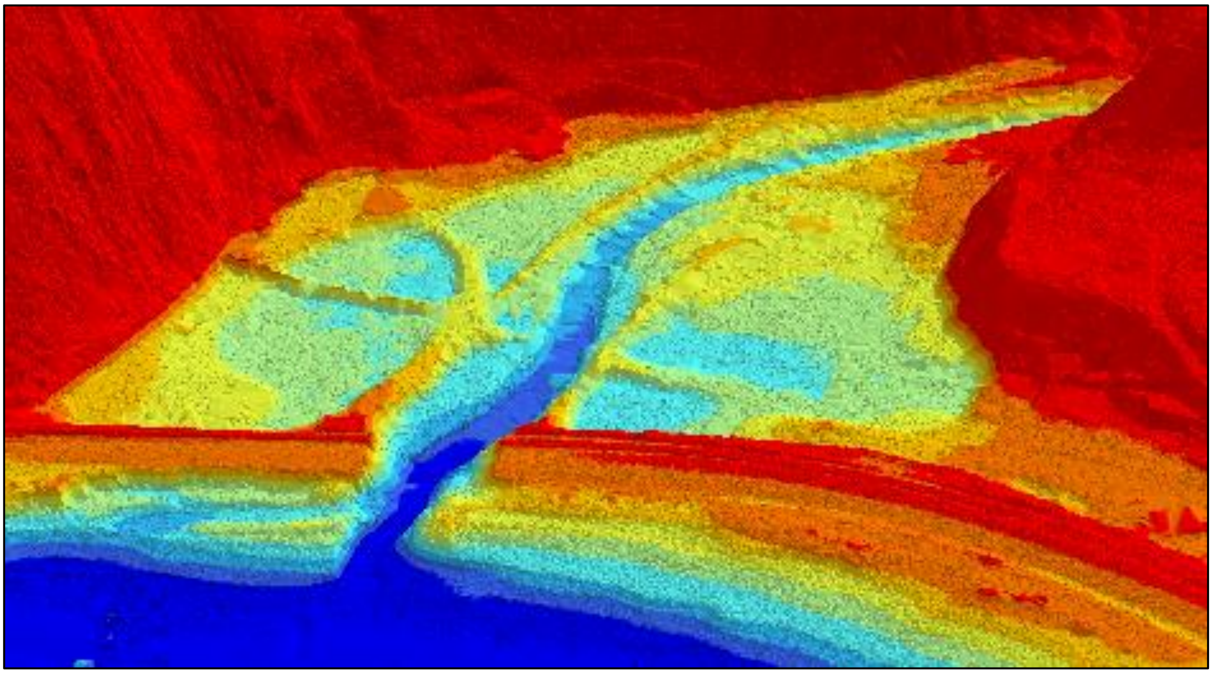

Figure 3-6: 3D image of Ote Makura floodplain LiDAR data (with vertical scale exaggerated by a factor of 2)

Water levels, and flows, on the floodplain are resolved on a rectangular grid. The size of the grid is based on the level of detail required, model stability, and computational efficiency (i.e. computer capacity and speed). For this model the 1 m digital elevation model (DEM), generated using the 2016 LiDAR data, has been used to produce a grid of 2 x 2 m cells to represent the floodplain topography.

A 2 m grid was chosen for this study to allow for a reasonable degree of topographic detail while keeping the model run time as short as possible. Elevated topographic features capable of impeding flows (e.g. roads and stopbanks) were represented well, with no significant modifications to the model grid required to compensate for averaging (as is often required with larger girds).

The LiDAR data were provided using the NZVD2016 vertical datum.

Floodplain roughness (surface resistance)

Floodplain flows, and depths, are influenced by the hydraulic resistance of the ground cover and other obstructions, such as buildings and trees on the floodplain. Resistance values (i.e. Manning's n values) were assigned to the various surfaces of the floodplain mainly by interpretation of aerial photographs. Where there are significant restrictions to the flow path (e.g. buildings), the Manning's n value was increased to 0.12 to increase the surface resistance. Likewise, where there were smoother surfaces (e.g. roads) the Manning's n value was decreased to 0.03 to reduce surface resistance. For the rest of the floodplain, Manning's n was set at 0.07 to represent a combination of grass, vegetation, fences and caravans (Figure 3-7).

3.4 Model calibration

To provide confidence in model predictions, it is important to calibrate models with historical flood events, where possible. This ensures that the models are realistic. Unfortunately, there are no measured or observed flood water levels available for Ote Makura Stream. Changes to the stream and floodplain ground level, due to the recent 2016 earthquakes, also mean any previous flood observations will be less helpful. As it has not been possible to calibrate this model, sensitivity model runs have been completed to quantify the sensitivity of the model to the various model parameters.

3.5 Modelling of design flood events

Flood events with an average recurrence interval (ARI) of 50 and 500 years have been modelled for land use planning, and flood mitigation purposes. The design storm events were simulated over a 36 hour time period. Model simulations were based on a 0.5 second time step, to ensure stability, and results were saved every 5 minutes. Computer run times for each simulation were relatively short (i.e. less than an hour).

3.5.1 Design flow hydrographs

To determine a design hydrograph profile for Ote Makura Stream, the flow records for Rosy Morn (Site 63501), Kowhai River at below Orange Grove (Site 63201) and Charwell at Gorge (Site 64305) were analysed. Flow hydrographs for each site were divided by the peak flow (for each specific flood event) to produce a non-dimensional hydrograph profile for each site for periods of high flow. An 'average' hydrograph shape was then produced, by fitting a hydrograph through the hydrographs (Figure 3-8). The non-dimensional hydrograph was then scaled by the peak flows for the 50 and 500 year ARI flood events to produce the design flow hydrographs (Figure 3-9).

3.5.2 Downstream sea boundary water level

Initial design and sensitivity model runs were completed using a constant water level of 1.75 m NZVD2016. This level represents a relatively high tide combined with storm surge, and seasonal/ENSO fluctuations (see Section 3.2). For the final design model runs, and derivation of the high hazard areas, the water level was increased to 2.75 m NZVD2016 to account for climate change effects (to 2120).

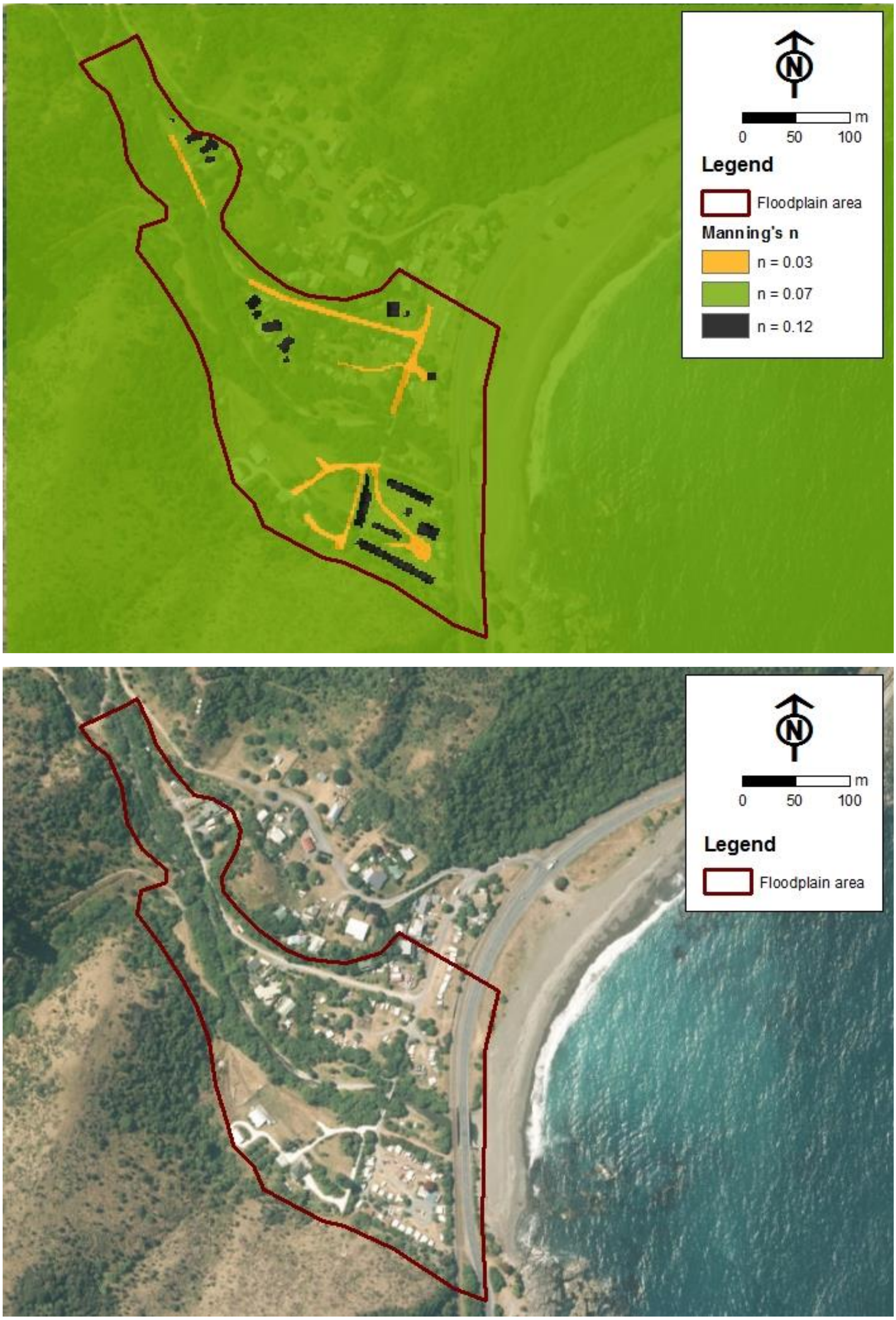

Figure 3-7: **Ote Makura floodplain Manning's n roughness**

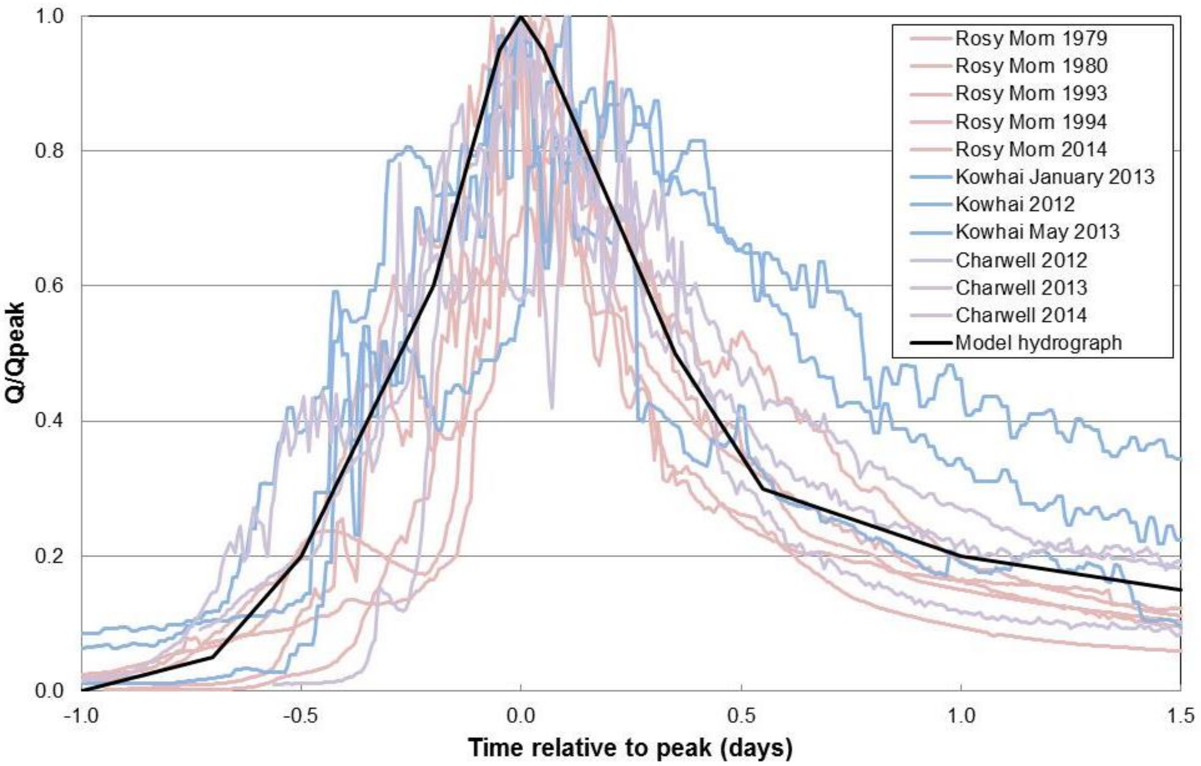

Figure 3-8: **Non-dimensional hydrographs**

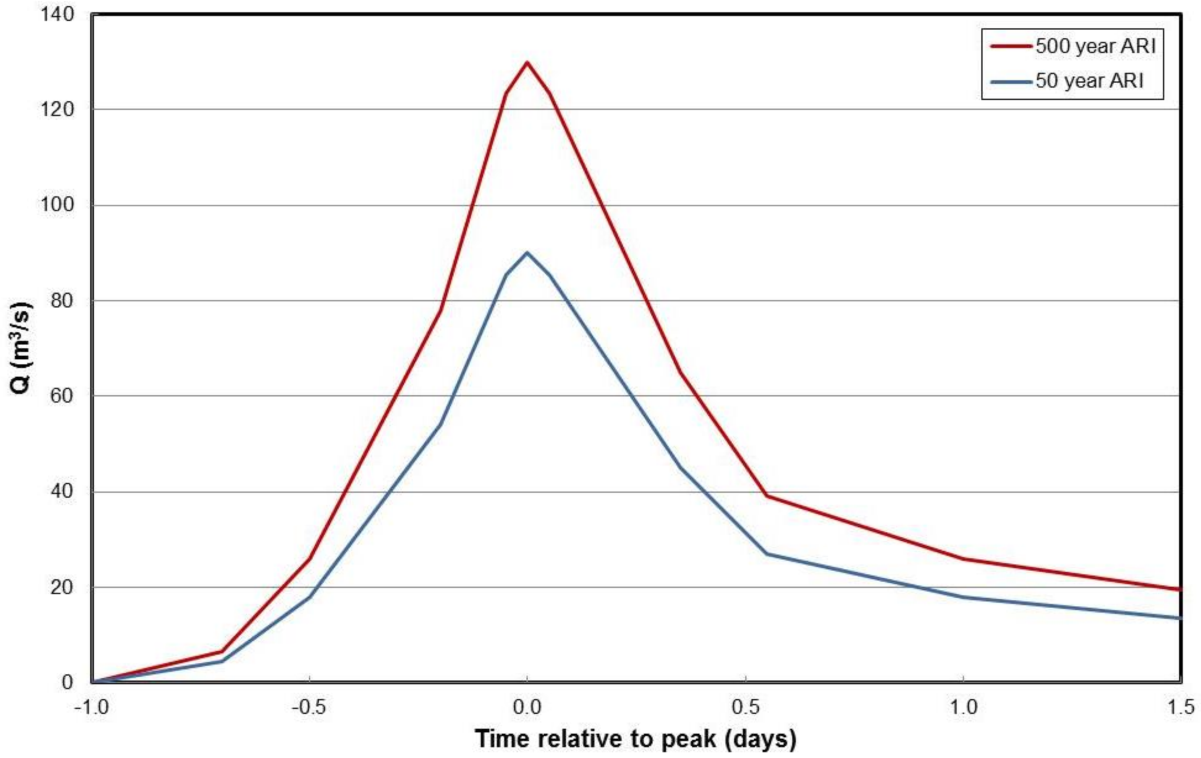

Figure 3-9: **Design flow hydrographs for the 50 and 500 year ARI floods**

3.5.3 Model results for design flood events

Design flood models have been calculated both with and without climate change (i.e. a 25% increase in flow and 1 m increase in sea level). Both models assume existing bed levels and no stopbank breaches or bridge blockages. The maximum modelled flood depths for the 50 and 500 year ARI flood events are shown on Figure 3-10 (no climate change) and Figure 3-11 (with climate change).

For the 50 year ARI flood event, the flooded area increases by approximately 3300 m^2 for the ‘with climate change’ scenario. By comparison, the flooded area for the 500 year ARI flood event only increases by approximately 370 m^2 when climate change is incorporated into the model - even though the water level in the ponding areas around the campground increases from around 4.8 - 5.05 m NZVD2016 to around 5.3 m NZVD2016. Note: a water level of 5.3 m NZVD2016 will produce water depths of up to 2 m deep on the northern floodplain area, and up to 1.7 m deep on the southern floodplain.

3.6 Model sensitivity analyses

As the model was not able to be calibrated, a range of sensitivity tests were undertaken to determine the effects of various model parameters, and assumptions, on the extent and depth of flooding. These are described below and are compared to the 500 year ARI ‘no climate change’ scenario.

3.6.1 River channel roughness

The Ote Makura Stream cross sections had channel roughness values as specified in Section 3.3.1. Since floodplain flow only occurs when water flows out of the river channel (or a breach occurs), the volume of flood water entering the floodplain is somewhat reliant on the correct roughness values being used to represent the river system (i.e. water levels in the river will increase if Manning’s n roughness increases). Manning’s n roughness values along the 1D Ote Makura Stream channel were increased by 25% (i.e. the ‘base’ roughness was increased from n = 0.040 to 0.050) for the 500 year ARI flood event (Figure 3-12).

For increased channel roughness, maximum water depths increased by 0.25 - 0.30 m on the floodplain to the south of the Ote Makura Stream, and by ~0.2 m further upstream where the channel is more confined.

3.6.2 Floodplain roughness

Floodplain roughness values used to represent the Ote Makura Stream floodplain are described in Section 3.3.2. Areas where the roughness is not equal to n=0.07 are shown in Figure 3-7.

The Manning’s n floodplain roughness value was increased by 25%. Figure 3-13 demonstrates that the increased floodplain roughness had a minimal effect on maximum water depths, which remained within 0.1 m of the original modelled floodplain water depths.

3.6.3 Climate change – increased flow

Figure 3-14 shows that, if the flows for a 500 year ARI flood event increased by 25%, it would increase maximum flood depths by over 0.1 m for most of the floodplain, with depth increases of over 0.3 m for a large portion of the southern floodplain area.

3.6.4 Climate change – sea level rise

Should sea levels rise by 1 m, there is likely to be minimal effects on the Ote Makura floodplain due to the elevated sea level (i.e. modelling showed negligible changes in floodplain water depths). However, this modelling does not take into consideration aggradation or degradation of cross section profiles, which is likely to occur with permanent changes in sea level.

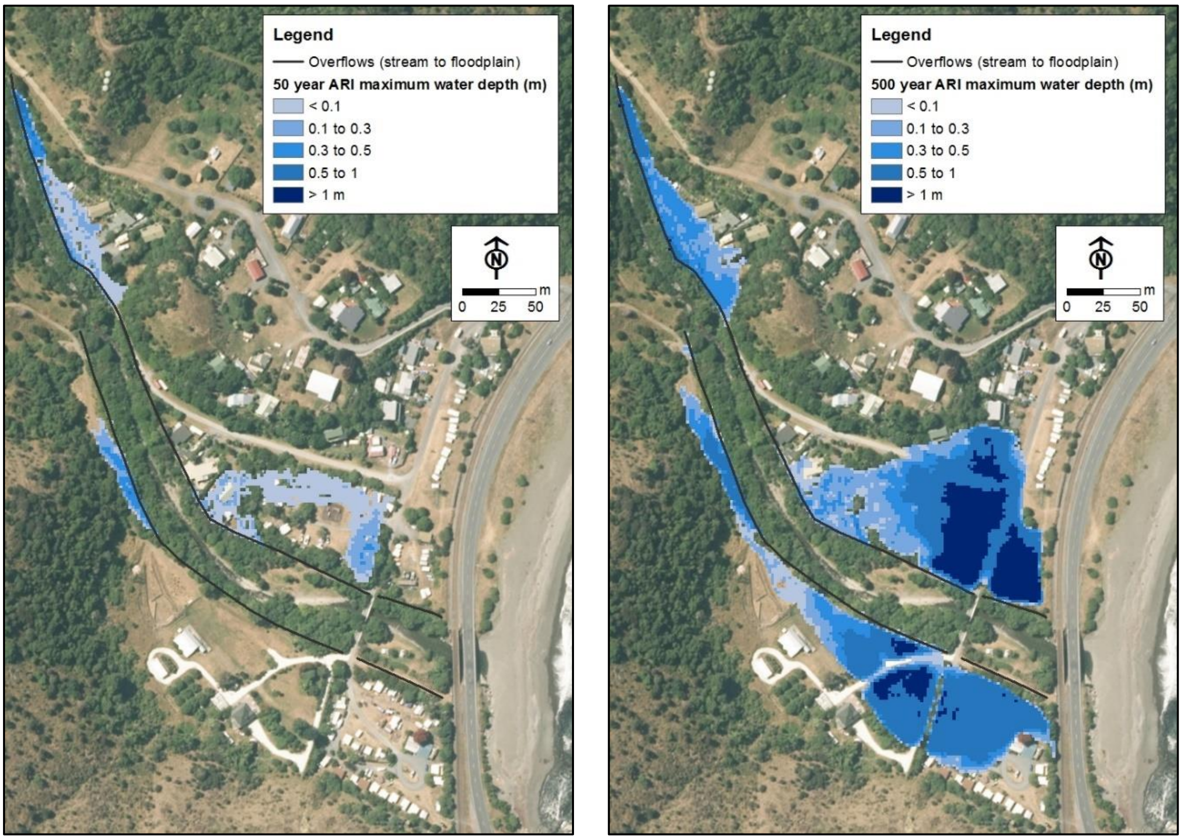

Figure 3-10: Maximum modelled water depths (no climate change)

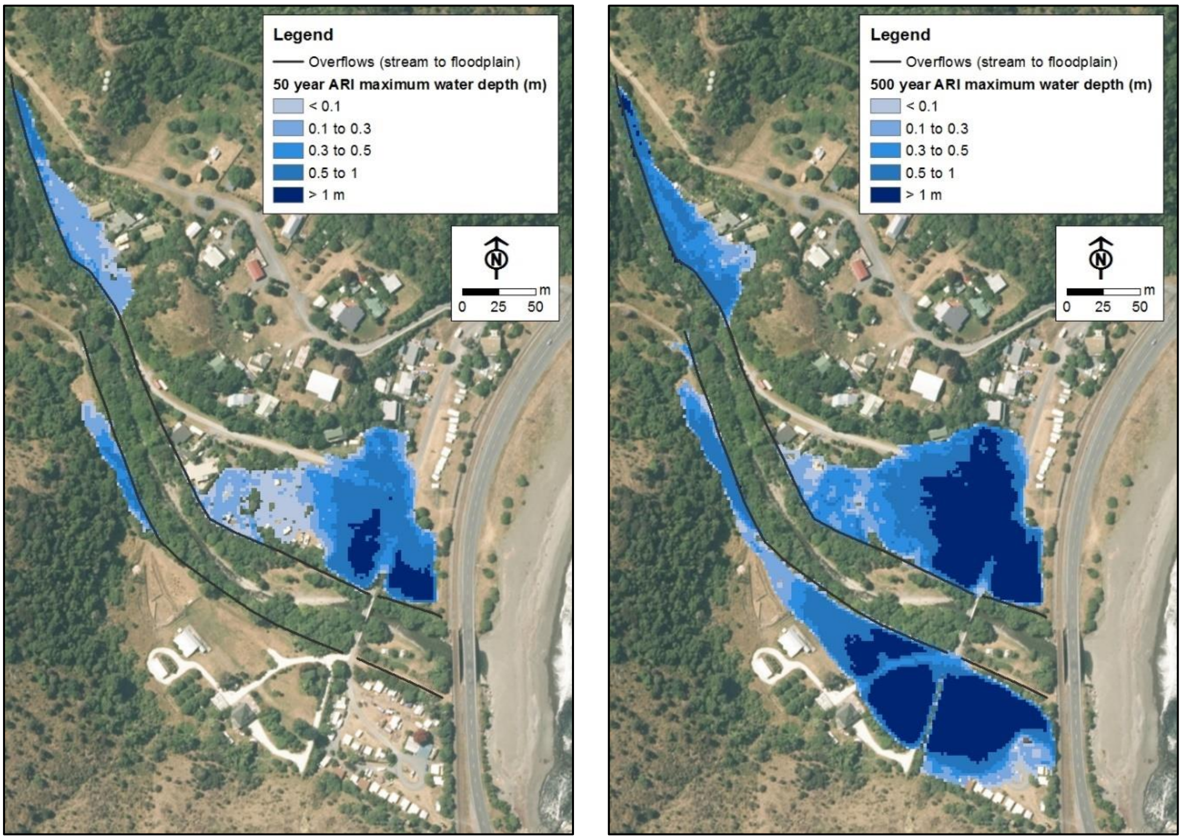

Figure 3-11: Maximum modelled water depths (climate change included)

3.6.5 Stopbank breach

During large flood events, stopbanks can breach due to either overtopping or lateral erosion. However, the location and size of such breaches is difficult to predict.

For the 500 year ARI flood event, it is considered very likely that the stopbanks along Ote Makura Stream would fail. A 30 m long stopbank breach was, therefore, simulated to occur on the bend in Ote Makura Stream - upstream of the campground bridge along the true right bank. The breach was assumed to occur at the flood peak (i.e. 24 hours after the start of the model run). Figure 3-15 illustrates that the breach caused maximum water levels downstream of the breach to increase by over 0.3 m.

3.6.6 Bridge blockages

Landslide dam material, together with dense vegetation adjacent to Ote Makura Stream, means there is the potential for the campground and/or railway bridges to become partially blocked during a large flood event.

The increase in maximum water depth, for the 500 year ARI flood event with 50% of the campground bridge blocked by debris (and the bridge underside also lowered by 0.5 m to account for debris), is shown in Figure 3-16. Floodplain water levels increase on the northern floodplain by 0.6 m, while southern floodplain water levels increase by 0.8 to 0.9 m.

If both the campground and railway bridges become 50% blocked by debris, and the bridge undersides are lowered by 0.5 m to account for debris, water level increases of 1.1 m could occur on the northern floodplain, while southern floodplain water levels could increase by 1.3 to 1.4 m (Figure 3-17). For both bridge blockage scenarios, there are only small increases in water levels upstream of the main floodplain area.

3.6.7 Ote Makura bed level changes

The existing Ote Makura Stream bed level is likely to incise into the existing bed after the recent uplifting of the land relative to the sea level. However, the large volume of landslide debris in the upper catchment could also lead to aggradation of the bed level as the material travels along the watercourse and is deposited on the less steeply sloping stream bed near the mouth.

Changes in maximum flood depths for the 500 year ARI flood event, with bed levels increased or decreased by 0.5 m are shown in Figure 3-18 and Figure 3-19, respectively. As expected, maximum water depths increase for the raised bed level, and decrease for the lowered bed level. In the main floodplain areas, maximum water depths increase more substantially for the raised bed level, compared to the smaller decreases in water depths observed when the bed level was lowered.

3.7 Model summary

During larger flood events, water from Ote Makura Stream is likely to overflow into the ponding areas immediately upstream of the railway line and SH1 road bridge. Depending on the amount of overflow, water depths can be significant, but the extent of the flooding is generally well confined by the raised land surrounding the floodplain. Bridge blockages, and increases in bed level, tend to produce the largest increases in water depths in the main ponding areas on the floodplain. Increases in channel roughness, flow magnitude, and bed levels lead to greater increases in water levels in the upstream channel. Bridge blockages, stopbank breaches, and floodplain roughness have a lesser effect on water levels in the upstream channel.

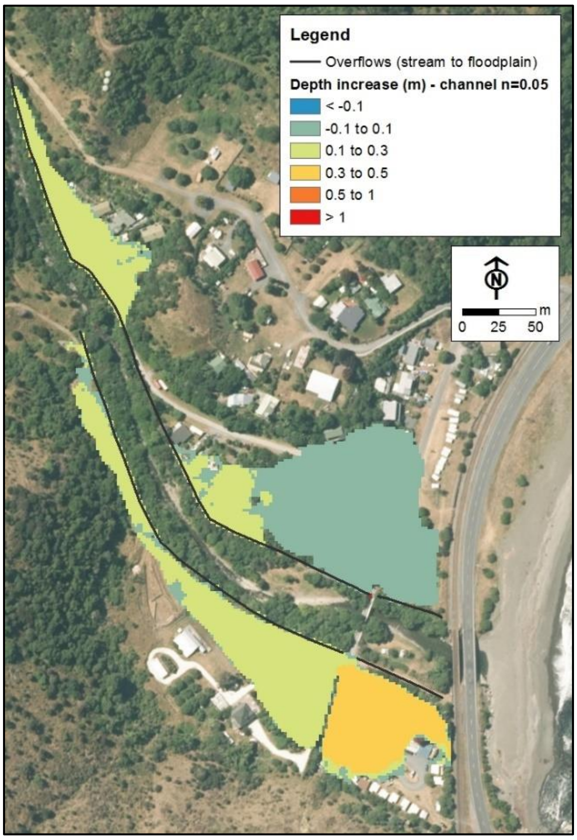

Figure 3-12: **Channel roughness +25%**

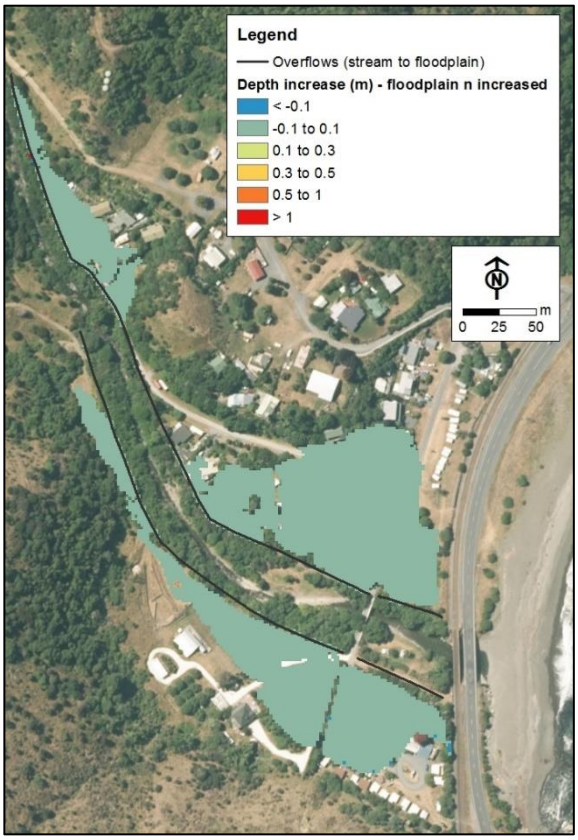

Figure 3-13: **Floodplain roughness +25%**

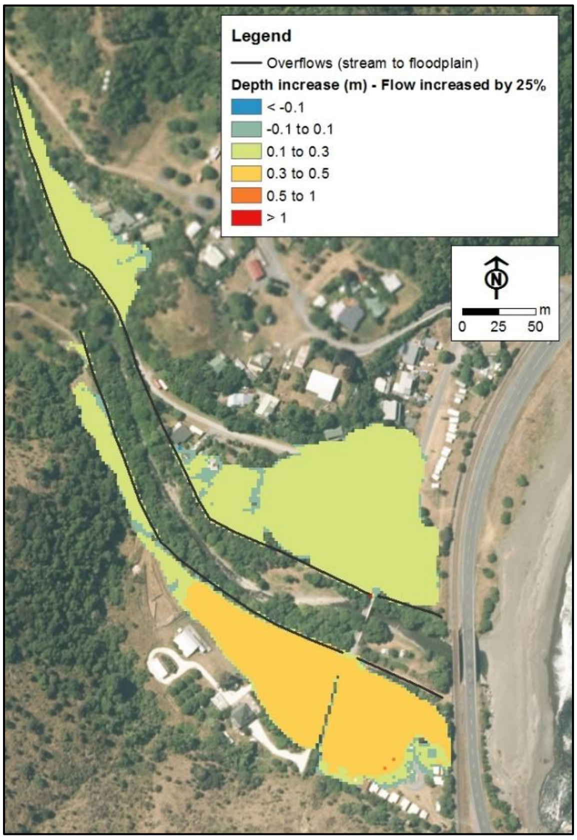

Figure 3-14: **Peak flow +25%**

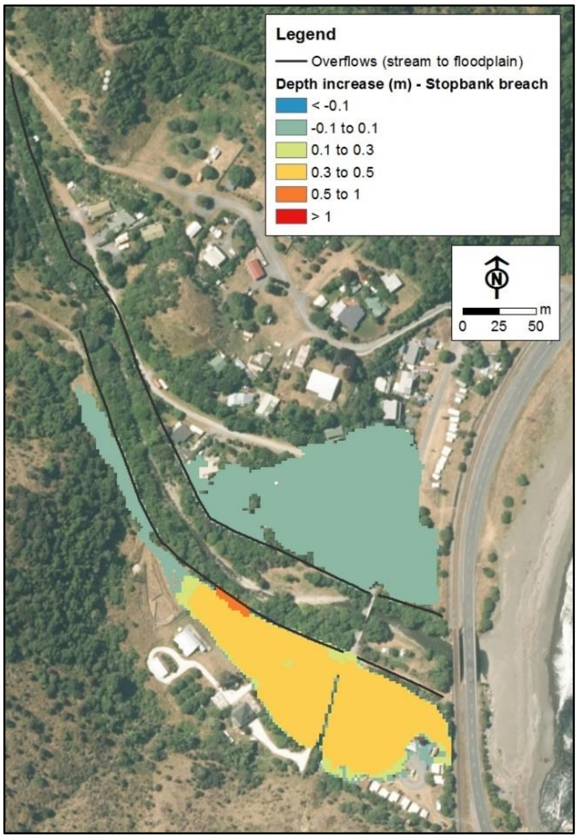

Figure 3-15: **30 m breach along the true right bank of Ote Makura Stream**

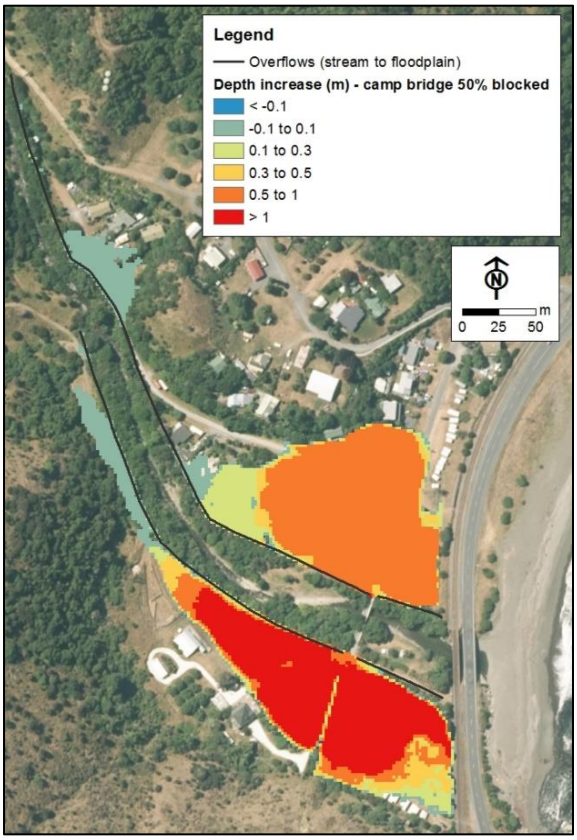

Figure 3-16: **Campground bridge 50% blocked**

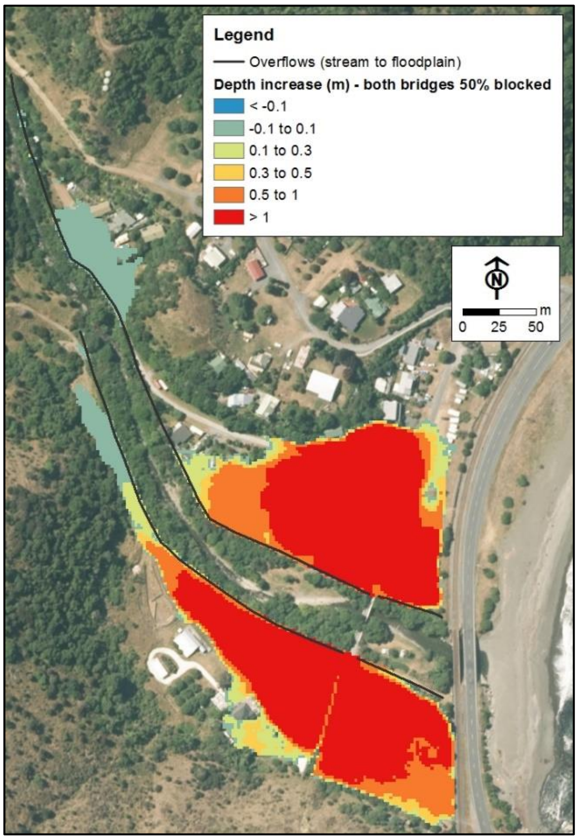

Figure 3-17: **Campground and railway bridges 50% blocked**

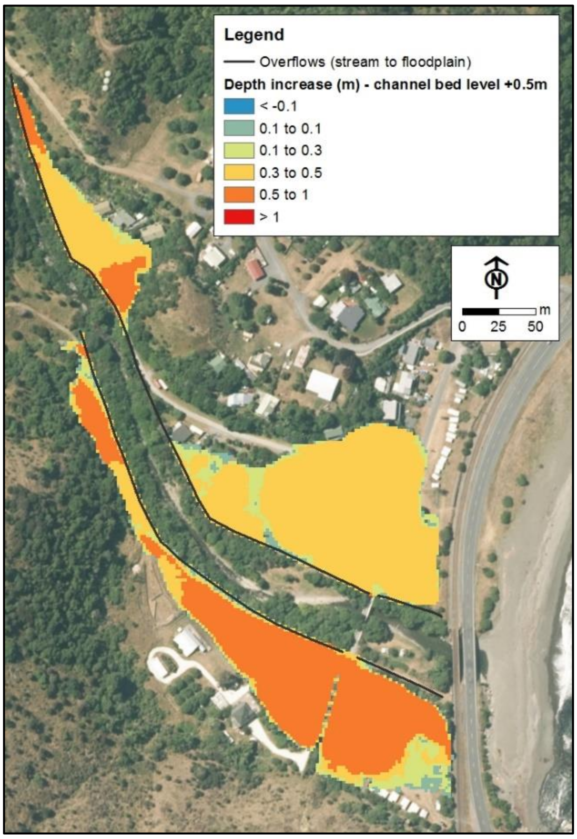

Figure 3-18: **Channel bed level +0.5 m**

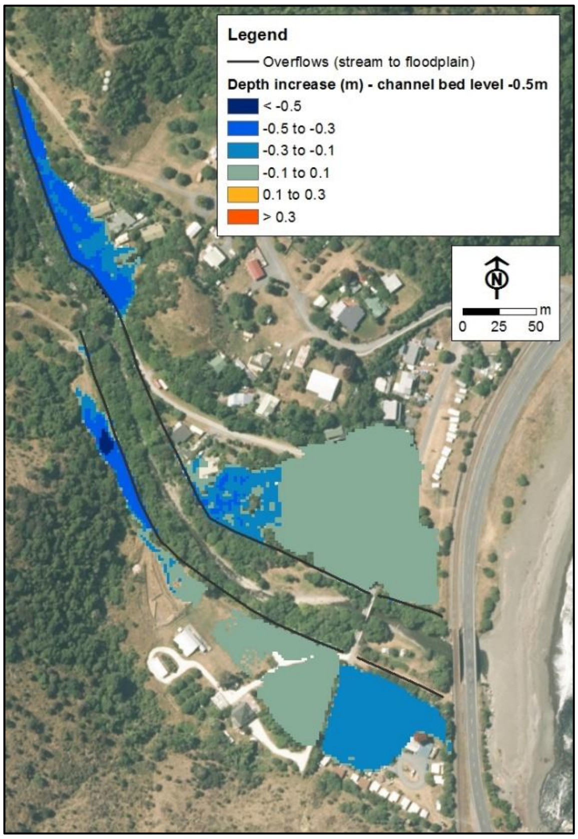

Figure 3-19: **Channel bed level -0.5 m**

3.8 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 in Ote Makura Stream, it is possible that:

- The campground bridge will be partially blocked and overtopped,
- Ote Makura Stream channel will aggrade, or scour – depending on the volume of sediment available within the stream. Should the campground bridge become partially blocked, sediment and debris are likely to accumulate in the channel upstream of the bridge.

To allow for climate change, and realistic extreme flood conditions, the modelled high hazard area for the Ote Makura floodplain includes:

- a 25% increase in the 500 year ARI flow,
- 1 m of sea level rise,
- the campground bridge being 50% blocked by debris.

For this scenario, Ote Makura Stream flows over the campground bridge, as well as the true left and right stream banks. Ponded water on the floodplain flows back into the stream over the stream banks downstream of the campground bridge, draining water into the sea under the railway line and the SH1 road bridge. The maximum ponded water level on the floodplain upstream of SH1 is 5.8 m NZVD2016.

Figure 3-20 shows the parts of the floodplain that meet the CRPS definition of high hazard areas.

A more extreme, and less likely, scenario would be a 50% blockage of both the campground bridge and the railway bridge (or SH1 road bridge). This would force flood water to back up behind the railway and SH1 bridges, to an elevation of around 7 m NZVD2016, before it would be able to pass over the railway line and SH1. Maximum water levels could be over a metre higher than the elevation of 5.8 m NZVD2016 modelled for climate change and a 50% blockage of the campground bridge.

A summary of modelled water levels, for a 500 year ARI flood event, is presented in Table 3-2. Note: these are levels relative to New Zealand Vertical Datum 2016 (NZVD2016) <u>not</u> water depths.

Table 3-2: Ote Makura modelled floodplain levels for a 500 year ARI flood

Model scenario	Northern floodplain (m NZVD2016)	Southern floodplain (m NZVD2016)
No climate change	5.05	4.8-4.85
Climate change	5.3	5.3
Climate change and campground bridge 50% blocked	5.8	5.8
Climate change and both campground and railway bridges 50% blocked	6.9	6.9

Figure 3-20: Modelled high hazard areas for the Ote Makura floodplain

4 Discussion

The modelling has shown that there is likely to be very little warning time before inundation occurs. This is due to the small and flashy nature of the stream during high-intensity rainfall events.

Bridge blockages, and increases in bed level, have been identified as the variables that tend to produce the largest increases in water depths in the main ponding areas on the floodplain. It is therefore important to keep the watercourse and bridges clear of debris and monitor any channel aggradation. It is particularly important for the railway bridge and the SH1 road bridge structures to remain open during flood events.

There is considerable uncertainty contained within the model results. The main model uncertainties, and the data that would be required to calibrate the model, are summarised below.

4.1 Model uncertainty

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

- Model inputs (e.g. stopbank breach locations and sizes, flow magnitude and hydrograph shape, roughness values, energy loss parameters and climate change predictions).
- Topographic data (e.g. LiDAR data and estimated submerged bed levels). Models also use a fixed bed level so don’t account for scour and aggradation.
- Hydraulic model assumptions (e.g. simplification of equations by depth-averaging, as well as averaging topography and flow behaviour over a 2 m grid cell for computational efficiency).

Sensitivity tests can help address these uncertainties but modelling results should generally be interpreted, and used, by those who are familiar with all aspects of the modelling.

4.2 Data required to enable the model to be better calibrated

To enable the model results to be used more confidently, a monitored water level/flow recorder would be required to more accurately determine flood flows, ideally over a long period of time. Flood information would also need to be gathered during and/or immediately after large flood events. This information would ideally include:

- Photographs of flood inundation, along with the time that the photographs were taken.
- Pegging, or marking with high-visibility paint, the peak water levels.
- Observations of any stopbank breaches (i.e. size, time).
- River cross section profiles (including beach shape).

Unfortunately, flood events often occur during the hours of darkness. For the Ote Makura Stream, access to the area may also be compromised during a large flood event. For example, road access may not be possible due to landslides or damage to bridge structures. Helicopters may not be available, or they may not be able to fly due to weather conditions. It would, therefore, be advantageous for local residents, who know the area well, to document as much as is practically possible (e.g. taking photos and marking flood levels and times that they occurred).

5 Conclusions

When using the modelling results from this study it is important to note that the model used in this study has a fixed bed level and does not simulate changes in bed levels due to scour, aggradation or channel avulsions – all processes that are likely to be occurring during a large flood event in a steep, gravel-bed river. The model has also not been based on recorded flow data, nor calibrated against any historical flood events. Consequently, there is considerable uncertainty in the flood water levels produced. The model results should, therefore. only be used to provide guidance, in conjunction with other available information, when determining 500 year ARI flood levels and high hazard areas.

For the Ote Makura Stream floodplain, inundation in a 500 year ARI flood event is likely to be confined to the stream margins, and the ponding areas upstream of the railway bridge.

Ote Makura Stream mouth is currently incising into the existing riverbed, as it attempts to adjust to the lower relative sea level caused by the land uplifting by ~1.4 to 1.8 m in the November 2016 earthquake sequence. To return to an 'equilibrium' riverbed slope, the channel is likely to continue lowering in the upstream direction as the mouth continues to incise (and the upstream riverbed tries to return to its pre-earthquake riverbed slope). This is advantageous as it will increase the flow at which water will begin to pass out of the riverbed and onto the floodplain.

However, there is also an increased supply of sediment entering the watercourse due to the landslides in the upper catchment. This will tend to increase bed levels near the stream mouth - where the riverbed slope decreases, and sediment is more likely to be deposited. Climate change and sea level rise may also lead to the beach barrier building up over time, which may eventually reverse the current downcutting. At this stage, it is not known over what timeframes degradation versus aggradation will dominate in the lower reaches of Ote Makura Stream.

6 Recommendations

It is recommended that:

1. Consideration be given to monitoring Ote Makura riverbed levels for aggradation/degradation, particularly after flood events.

2. The 500 year ARI maximum water levels and high hazard areas be used to inform land use planning (e.g. minimum floor levels) and emergency management (e.g. evacuation).

3. Design flood levels and high hazard areas produced in this study are reassessed at a future date when additional climate change, flood and riverbed information becomes available (see Section 4.2).

7 Acknowledgments

The 2016 LiDAR data for this study has been provided by the New Zealand Transport Authority.

The National Institute of Water and Atmospheric Research (NIWA) provided Environment Canterbury with permission to use the flow record at Rosy Morn (Site 63501).

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

- Tony Boyle (Principal Science Advisor)
- Nick Griffiths (Team Leader, Natural Hazards)
- Matthew Surman (Asset Management Engineer)

8 External peer review

An external peer review of the Ote Makura computational hydraulic model was completed by Matthew Gardner of Land River Sea Consulting Ltd (Gardner, 2018). This review concluded "*Overall the model is well built and is considered to be fit for the purpose outlined in the modelling report. No changes need to be made to the model.*"

After further discussions with Matthew Gardner, a minor adjustment was made for the bridge blockage scenarios so that the soffit level (i.e. underside of the bridge) was lowered by 0.5 m to account for debris.

9 Glossary

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

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

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

Avulsion: The rapid movement of a river channel to form a new channel. This usually occurs when the channel finds an ‘easier’ flow route with a steeper slope (shorter channel length) than the existing channel.

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

Degradation: Scouring of shingle or other sediment from a river bed, lowering the river bed level.

Discharge: The rate of flow of water measured in terms of volume per unit time, e.g. cubic metres per second (m^3/s).

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

Floodplain: The area of relatively flat land, adjacent to the fairway, that is inundated by floodwaters from the upper catchment.

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

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

Landslide dam: Occurs when a landslide blocks or ‘dams’ a river, forming a lake upstream of the landslide.

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

NZVD2016: New Zealand Vertical Datum 2016 is the official vertical datum for New Zealand and its offshore islands.

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

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Appendix A: Model run files

MikeFLOOD model: Release 2016, SP1

50 year ARI design flood event files

No climate change	With climate change
Peak Ote Makura Stream flow of 90 m^3/s, constant sea level of 1.75 m NZVD2016	Peak Ote Makura Stream flow of 110 m^3/s, constant sea level of 2.75 m NZVD2016

MikeFlood		
Couple file (*.mf)	Ote_50yr_Q90_SL_1_75m_mf	Ote_50yr_Q110_SL_2_75m_mf

Mike11		
Simulation file (*.sim11)	Ote_50yr_Q90_SL_1_75m	Ote_50yr_Q110_SL_2_75m
Network file (*.nwk11)	Ote_Makura	
Cross section file (*.xns11)	Ote_Makura_xsects	
Boundary file (*.bnd11)	Q50yr_Sea_1_75m	Q50yr_plus_20perc_Sea_2_75m
HD parameter (*.hd11)	Otemakura_SL_1_75m_HD	Otemakura_SL_2_75m_HD
Results file (*.res11)	Ote_50yr_Q90_SL_1_75m	Ote_50yr_Q110_SL_2_75m

Mike21		
Simulation file (*.21)	Ote_50yr_Q90_SL_1_75m	Ote_50yr_Q110_SL_2_75m
Bathymetry file (*.dfs2)	ote_2016_2m_mod	
Initial surface elevation (*.dfs2)	1.75	2.75
Resistance (*.dfs2)	ote_2016_2m_rough_M	
Results (*.dfs2)	Ote_50yr_Q90_SL_1_75m	Ote_50yr_Q110_SL_2_75m
Sources/Sinks	-	
Drying depth (m)	0.01	
Wetting depth (m)	0.03	
Eddy viscosity	0.2	
Number of structures	0	
Simulation start time	1/1/2000 12:00am	
Simulation end time	2/1/2000 12:00pm	
Time step (s)	0.5	
Length of run (# time steps)	259200	

500 year ARI design flood event files

	No climate change	With climate change
	Peak Ote Makura Stream flow of 130 m^3/s, constant sea level of 1.75 m NZVD2016	Peak Ote Makura Stream flow of 160 m^3/s, constant sea level of 2.75 m NZVD2016

MikeFlood		
Couple file (*.mf)	Ote_500yr_Q130_SL_1_75m_mf	Ote_500yr_Q160_SL_2_75m_mf

Mike11		
Simulation file (*.sim11)	Ote_500yr_Q130_SL_1_75m	Ote_500yr_Q160_SL_2_75m
Network file (*.nwk11)	Ote_Makura	
Cross section file (*.xns11)	Ote_Makura_xsects	
Boundary file (*.bnd11)	Q500yr_Sea_1_75m	Q500yr_plus_20perc_Sea_2_75m
HD parameter (*.hd11)	Otemakura_SL_1_75m_HD	Otemakura_SL_2_75m_HD
Results file (*.res11)	Ote_500yr_Q130_SL_1_75m	Ote_500yr_Q160_SL_2_75m

Mike21		
Simulation file (*.21)	Ote_500yr_Q130_SL_1_75m	Ote_500yr_Q160_SL_2_75m
Bathymetry file (*.dfs2)	ote_2016_2m_mod	
Initial surface elevation (*.dfs2)	1.75	2.75
Resistance (*.dfs2)	ote_2016_2m_rough_M	
Results (*.dfs2)	Ote_500yr_Q130_SL_1_75m	Ote_500yr_Q160_SL_2_75m
Sources/Sinks	-	
Drying depth (m)	0.01	
Wetting depth (m)	0.03	
Eddy viscosity	0.2	
Number of structures	0	
Simulation start time	1/1/2000 12:00am	
Simulation end time	2/1/2000 12:00pm	
Time step (s)	0.5	
Length of run (# time steps)	259200	

500 year ARI design flood event files *(continued)*

With climate change and campground bridge 50% blocked	With climate change and both bridges 50% blocked
Peak Ote Makura Stream flow of 160 m^3/s, constant sea level of 2.75 m NZVD2016, campground bridge 50% blocked & soffit level reduced 0.5m.	Peak Ote Makura Stream flow of 160 m^3/s, constant sea level of 2.75 m NZVD2016, campground and railway bridges 50% blocked with soffit levels reduced by 0.5m.

MikeFlood		
Couple file (*.mf)	Ote_500yr_Q160_SL_2_75m_campground_bridge_half_blocked_mf	Ote_500yr_Q160_SL_2_75m_bridges_half_blocked_mf

Mike11		
Simulation file (*.sim11)	Ote_500yr_Q160_SL_2_75m_campground_bridge_half_blocked	Ote_500yr_Q160_SL_2_75m_bridges_half_blocked
Network file (*.nwk11)	Ote_Makura_campground_bridge_half_blocked	Ote_Makura_bridges_half_blocked
Cross section file (*.xns11)	Ote_Makura_xsects	
Boundary file (*.bnd11)	Q500yr_plus_20perc_Sea_2_75m	
HD parameter (*.hd11)	Otemakura_SL_2_75m_HD	
Results file (*.res11)	Ote_500yr_Q160_SL_2_75m_campground_bridge_half_blocked	Ote_500yr_Q160_SL_2_75m_bridges_half_blocked

Mike21		
Simulation file (*.21)	Ote_500yr_Q160_SL_2_75m_campground_bridge_half_blocked	Ote_500yr_Q160_SL_2_75m_bridges_half_blocked
Bathymetry file (*.dfs2)	ote_2016_2m_mod	
Initial surface elevation (*.dfs2)	2.75	
Resistance (*.dfs2)	ote_2016_2m_rough_M	
Results (*.dfs2)	Ote_500yr_Q160_SL_2_75m_campground_bridge_half_blocked	Ote_500yr_Q160_SL_2_75m_bridges_half_blocked
Sources/Sinks	-	
Drying depth (m)	0.01	
Wetting depth (m)	0.03	
Eddy viscosity	0.2	
Number of structures	0	
Simulation start time	1/1/2000 12:00am	
Simulation end time	2/1/2000 12:00pm	
Time step (s)	0.5	
Length of run (# time steps)	259200	

Sensitivity run files for 500 year ARI flood event

	Channel roughness	Floodplain roughness	Climate change – increased flow
	Manning's n increased to 0.050	Manning's n increased by 25%	Flow peak increased from 130 m^3/s to 160 m^3/s

MikeFlood			
Couple file (*.mf)	Ote_500yr_Q130_SL_1_75m_n_chan_0_05_mf	Ote_500yr_Q130_SL_1_75m_n_fp_plus25perc	Ote_500yr_Q160_SL_1_75m_mf

Mike11			
Simulation file (*.sim11)	Ote_500yr_Q130_SL_1_75m_n_chan_0_05	Ote_500yr_Q130_SL_1_75m_n_fp_plus_25perc	Ote_500yr_Q160_SL_1_75m
Network file (*.nwk11)	Ote_Makura		
Cross section file (*.xns11)	Ote_Makura_xsects		
Boundary file (*.bnd11)	Q500yr_Sea_1_75m	Q500yr_Sea_1_75m	Q500yr_plus_20perc_Sea_1_75m
HD parameter (*.hd11)	Otemakura_n_chan_0_05_HD	Otemakura_SL_1_75m_HD	Otemakura_SL_1_75m_HD
Results file (*.res11)	Ote_500yr_Q130_SL_1_75m_n_chan_0_05	Ote_500yr_Q130_SL_1_75m_n_fp_plus_25perc	Ote_500yr_Q160_SL_1_75m

Mike21			
Simulation file (*.21)	Ote_500yr_Q130_SL_1_75m_n_chan_0_05	Ote_500yr_Q130_SL_1_75m_n_fp_plus_25perc	Ote_500yr_Q160_SL_1_75m
Bathymetry file (*.dfs2)	ote_2016_2m_mod		
Initial surface elevation (*.dfs2)	1.75		
Resistance (*.dfs2)	ote_2016_2m_rough_M	ote_2016_2m_rough_M_n_plus_25perc	ote_2016_2m_rough_M
Results (*.dfs2)	Ote_500yr_Q130_SL_1_75m_bridges_n_chan_0_05	Ote_500yr_Q130_SL_1_75m_bridges_n_fp_plus_25perc	Ote_500yr_Q160_SL_1_75m_bridges
Sources/Sinks	-		
Drying depth (m)	0.01		
Wetting depth (m)	0.03		
Eddy viscosity	0.2		
Number of structures	0		
Simulation start time	1/1/2000 12:00am		
Simulation end time	2/1/2000 12:00pm		
Time step (s)	0.5		
Length of run (# time steps)	259200		

	Climate change – sea level rise	**Stopbank breach**	**Bridge blockage No. 1**
	Sea level increased by 1m to 2.75m NZVD2016	30 m breach in TRB stopbank	Campground bridge is 50% blocked by debris
MikeFlood			
Couple file (*.mf)	Ote_500yr_Q130_SL_2_75m_mf	Ote_500yr_Q130_SL_1_75m_breach_mf	Ote_500yr_Q130_SL_1_75m_campground_bridge_half_blocked_mf
Mike11			
Simulation file (*.sim11)	Ote_500yr_Q130_SL_2_75m	Ote_500yr_Q130_SL_1_75m_breach	Ote_500yr_Q130_SL_1_75m_campground_bridge_half_blocked
Network file (*.nwk11)	Ote_Makura	Ote_Makura	Ote_Makura_campground_bridge_half_blocked
Cross section file (*.xns11)	Ote_Makura_xsects_SL_2_75m	Ote_Makura_xsects	Ote_Makura_xsects
Boundary file (*.bnd11)	Q500yr_Sea_2_75m	Q500yr_Sea_1_75m	Q500yr_Sea_1_75m
HD parameter (*.hd11)	Otemakura_SL_2_75m_HD	Otemakura_SL_1_75m_HD	Otemakura_SL_1_75m_HD
Results file (*.res11)	Ote_500yr_Q130_SL_2_75m	Ote_500yr_Q130_SL_1_75m_breach	Ote_500yr_Q130_SL_1_75m_campground_bridge_half_blocked
Mike21			
Simulation file (*.21)	Ote_500yr_Q130_SL_2_75m	Ote_500yr_Q130_SL_1_75m_breach	Ote_500yr_Q130_SL_1_75m_campground_bridge_half_blocked
Bathymetry file (*.dfs2)	ote_2016_2m_mod	ote_2016_2m_mod_breach	ote_2016_2m_mod
Initial surface elevation (*.dfs2)	2.75	1.75	1.75
Resistance (*.dfs2)	ote_2016_2m_rough_M		
Results (*.dfs2)	Ote_500yr_Q130_SL_2_75m	Ote_500yr_Q130_SL_1_75m_breach	Ote_500yr_Q130_SL_1_75m_campground_bridge_half_blocked
Sources/Sinks	-		
Drying depth (m)	0.01		
Wetting depth (m)	0.03		
Eddy viscosity	0.2		
Number of structures	0		
Simulation start time	1/1/2000 12:00am		
Simulation end time	2/1/2000 12:00pm		
Time step (s)	0.5		
Length of run (# time steps)	259200		

	Bridge blockage No. 2	**Stream bed level raised**	**Stream bed level lowered**
	Campground and railway bridges are 50% blocked by debris	Stream bed levels raised by 0.5 m	Stream bed levels lowered by 0.5 m
MikeFlood			
Couple file (*.mf)	Ote_500yr_Q130_SL_1_75m_bridges_half_blocked_mf	Ote_500yr_Q130_SL_1_75m_BL_incr_0_5m_mf	Ote_500yr_Q130_SL_1_75m_BL_decr_0_5m_mf
Mike11			
Simulation file (*.sim11)	Ote_500yr_Q130_SL_1_75m_bridges_half_blocked	Ote_500yr_Q130_SL_1_75m_BL_incr_0_5m	Ote_500yr_Q130_SL_1_75m_BL_decr_0_5m
Network file (*.nwk11)	Ote_Makura_bridges_half_blocked	Ote_Makura	Ote_Makura
Cross section file (*.xns11)	Ote_Makura_xsects	OteMakura_xsects_BL_incr_0_5m	OteMakura_xsects_BL_decr_0_5m
Boundary file (*.bnd11)	Q500yr_Sea_1_75m		
HD parameter (*.hd11)	Otemakura_SL_1_75m_HD		
Results file (*.res11)	Ote_500yr_Q130_SL_1_75m_bridges_half_blocked	Ote_500yr_Q130_SL_1_75m_BL_incr_0_5m	Ote_500yr_Q130_SL_1_75m_BL_decr_0_5m
Mike21			
Simulation file (*.21)	Ote_500yr_Q130_SL_1_75m_bridges_half_blocked	Ote_500yr_Q130_SL_1_75m_BL_incr_0_5m	Ote_500yr_Q130_SL_1_75m_BL_decr_0_5m
Bathymetry file (*.dfs2)	ote_2016_2m_mod		
Initial surface elevation (*.dfs2)	1.75		
Resistance (*.dfs2)	ote_2016_2m_rough_M		
Results (*.dfs2)	Ote_500yr_Q130_SL_1_75m_bridges_half_blocked	Ote_500yr_Q130_SL_1_75m_BL_incr_0_5m	Ote_500yr_Q130_SL_1_75m_BL_decr_0_5m
Sources/Sinks	-		
Drying depth (m)	0.01		
Wetting depth (m)	0.03		
Eddy viscosity	0.2		
Number of structures	0		
Simulation start time	1/1/2000 12:00am		
Simulation end time	2/1/2000 12:00pm		
Time step (s)	0.5		
Length of run (# time steps)	259200		

Environment Canterbury
Regional Council
Kaunihera Taiao ki Waitaha

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