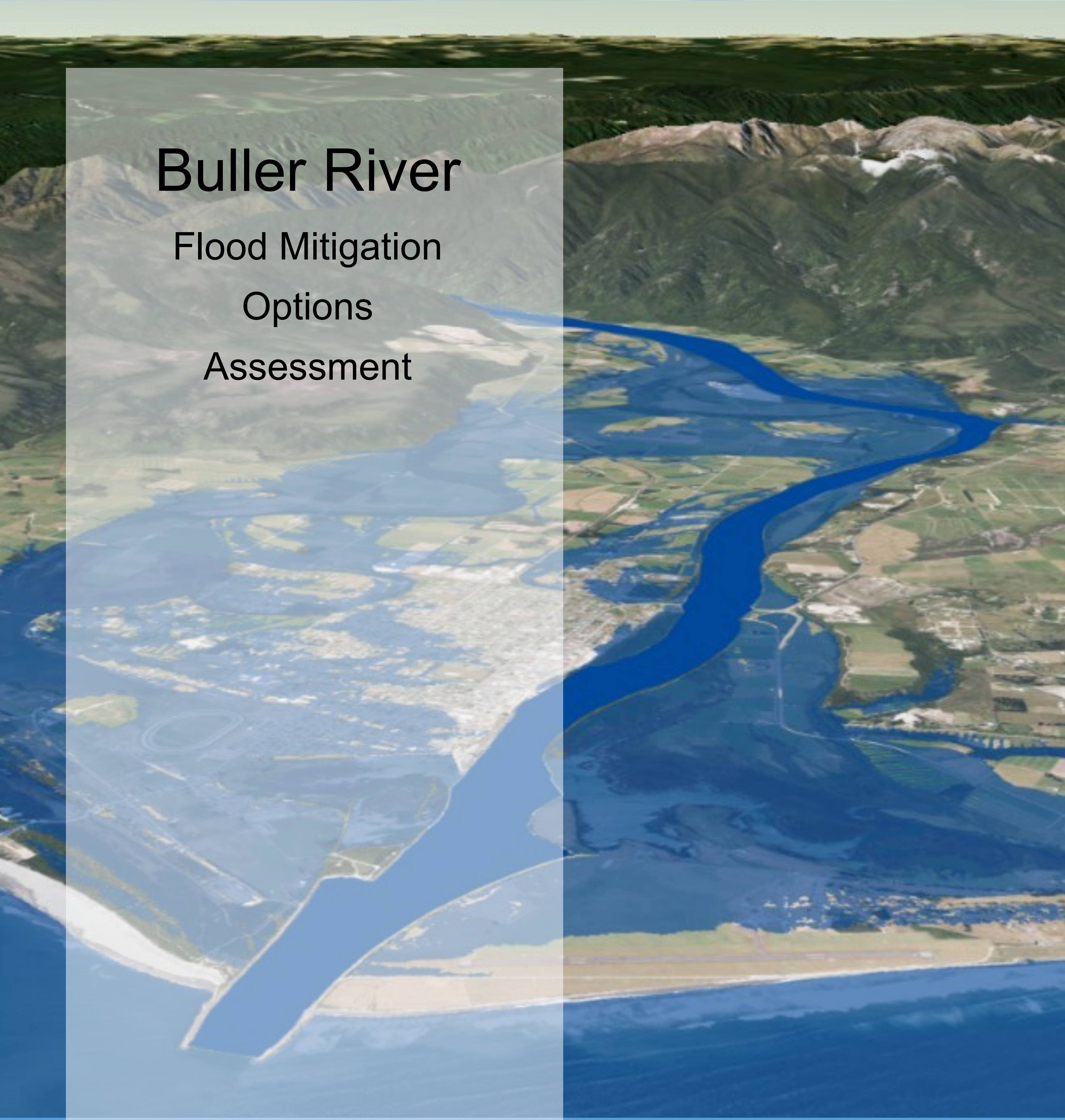

Buller River

Flood Mitigation Options Assessment

June 23, 2022
Client: West Coast Regional Council
Report by: Matthew Gardner
Land River Sea Consulting Ltd
www.landriversea.com

BULLER RIVER

REVISION HISTORY

Author:	Matthew Gardner Water Resources Engineer, CMEngNZ, CPEng
Signature:	
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Authorised by:	Rachel Vaughan
Signature:	
Organisation:	West Coast Regional Council
Date:	

Land River Sea Consulting Limited
PO Box 27121, Shirley
Christchurch

M: +64 27 318 9527
E: matthew@landriversea.com
W: landriversea.com

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1. INTRODUCTION

1.1 SCOPE / BACKGROUND

The Technical Advisory Group (TAG) for the Buller River Protection scheme project has been tasked with assessing potential options to mitigate the flood risk for Westport.

The group has selected seven options for further investigation / detailed modelling which are summarised below. More detail for each option is provided in the following section.

OPTION 1 — COMPREHENSIVE SCHEME (AS PROPOSED BY WCRC IN THE LTP)

Extensive ring bank, including Carters Beach and Snodgrass area

OPTION 2 — COMPREHENSIVE SCHEME WITH SNODGRASS AREA EXCLUDED

Extensive ring bank, including Carters Beach, but excluding Snodgrass area

OPTION 3 — INLAND EMBANKMENT

Reduced scale ring bank, excluding the southern area farm land, but including Carters Beach and Snodgrass area

OPTION 4 — REMOVE STATE HIGHWAY CAUSEWAY CROSSING OROWAITI

Extensive ring bank, including Carters Beach and Snodgrass area, with the State Highway causeway at the bridge crossing of the Orowaiti Estuary removed.

OPTION 5 — EXTEND RAILWAY OPENING

Extensive ring bank, including Carters Beach and Snodgrass area, with an extended opening (100m) in the Railway embankment at Stephens Rd.

OPTION 6 — EXCLUDE SNODGRASS WITH FLOODWAY

Extensive ring bank, including Carters Beach, but excluding Snodgrass area and including a Snodgrass floodway

OPTION 7 — REVEGETATE OVERFLOW AREA

Extensive ring bank, including Carters Beach and Snodgrass area, with revegetation of the Organ's Island overflow area.

Each option has been run through the existing MIKE Flood hydraulic model of the river and has been assessed for the following return period events

- 20-year ARI river flow (historic climate)
- 50-year ARI river flow (historic climate)
- 100-year ARI river flow (historic climate)
- 100-year ARI river flow (future climate, RCP6.0)

In addition, where relevant the options have also been assessed

- 100-year ARI coastal event (historic climate)
- 100-year ARI coastal event (future climate, RCP6.0)

Outputs for each simulation have included the following:

- Peak water surface elevation
- Peak depth
- Peak velocity
- Difference in depth (compared to base scenario)
- Difference in speed (compared to base scenario)

Results have been presented as a series of A3 maps, animated videos, as well as plots of stopbank crest level profiles.

A preferred alignment has been suggested as a result of this hydraulic study and is presented in Section 4 of this report. In addition to the scenario used to assess the preliminary options the scheme has also been assessed for future climate, RCP8.5 flows as well as overdesign events (i.e. assuming the banks overtop).

1.2 GEOGRAPHIC AREAS

This report refers to several geographic areas such as Carters Beach, Snodgrass, Organs Island and Westport Urban area. To assist the reader a map of these general areas is presented below.

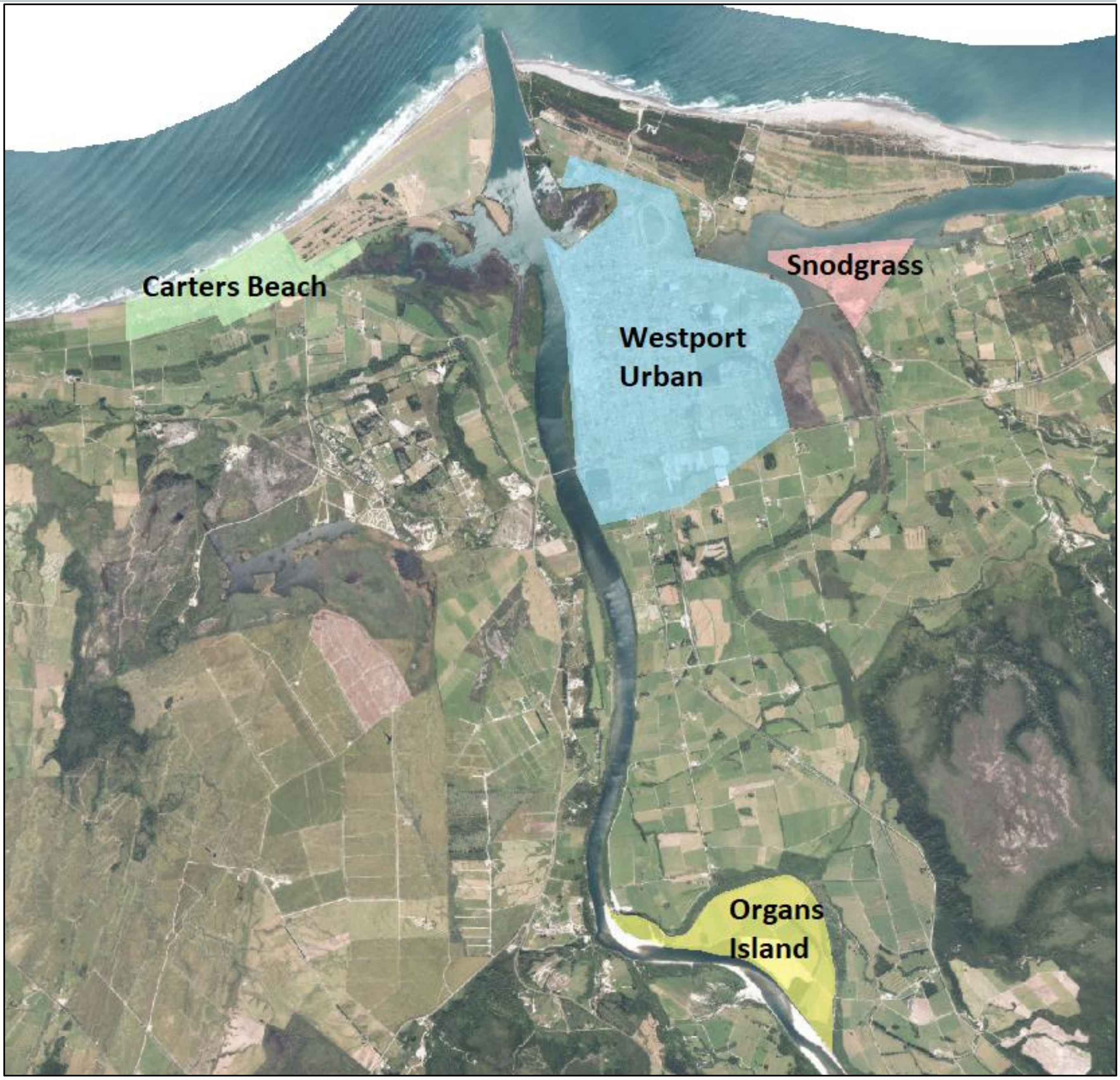


Figure 1-1 – Geographic Areas

1.3 GLOSSARY OF KEY TERMS

RCP - Representative Concentration Pathway - a greenhouse gas concentration trajectory adopted by the IPCC. Four pathways were used for climate modeling and research for the IPCC fifth Assessment Report (AR5) in 2014. The pathways describe different climate futures, all of which are considered possible depending on the volume of greenhouse gases emitted in the years to come (Wikipedia)

AEP - Annual Exceedance Probability – the likelihood of a given flow being exceeded in any 1-year period.

ARI - Average Return Interval - is the average time period between floods of a certain size. For example, a 100-year ARI flow will occur on average once every 100-years

2. DETAILED OPTIONS INVESTIGATIONS

The assessment of each option has been carried out using the existing detailed hydraulic model of the area (Gardner, 2022). This model has been calibrated to the July 2021 flood event and was able to provide a very good representation of both the flood extent and depth. The model has been peer reviewed and found to be fit for the purposes used in this investigation.

The model has been used to assess a wide range of potential flood scenarios including both riverine and coastal flooding. Base maps showing peak flood depth for a range of return period scenarios are included in Appendix A. A comparison with these maps is used as the basis for assessing the efficacy of each potential option.

The default scenario is to carry on as existing which is essentially a do-nothing scenario. Hydraulic modelling results are presented in Appendix B which highlight the flood risk for Westport should the do-nothing scenario be adopted. In essence, the entire town is at significant risk as was witnessed in July 2021.

INFLOW BOUNDARY CONDITIONS

All river inflows in the model are based on the NIWA hydrology (McKerchar, 2021) detailed in the model build report (Gardner, 2022). Climate change impacts are based on the NIWA assessment (Zammit, 2022).

Peak inflows for each modelled scenario are presented in Table 2-1.

Table 2-1 – Summary of modelled flow inputs used in this assessment

ARI	Climate Scenario	Flow (m^3/s)	Percentage change in duration
20yr	Historic Climate	7,640	0
50yr	Historic Climate	8,730	0
100yr	Historic Climate	9,540	0
100yr	Future Climate RCP6.0 (2080-2100)	11,009	10.2
100yr	Future Climate RCP8.5 (2080-2100)	11,877	14.3

COASTAL BOUNDARY CONDITIONS

Base sea levels used in the modelling are based on the same assumptions used in the base modelling report (Gardner, 2022) and have been determined in conjunction with NIWA as well as Land Information New Zealand (LINZ). We have adopted the NIWA value of Mean High Water Spring 7 (MHWS7) for this study which is defined as the high-tide elevation exceeded by only 7% of high tides. The adopted values of mean sea level and MHWS for the historic climate are as follows:

Location	**MSL (m) NZVD2016**	**MHWS-7 (m NZVD2016)**
Westport	-0.107	1.49

The base design tide magnitude is therefore based on;

- Mean High Water Spring (MHWS)
- Additional Storm Surge Component of 0.4m

For the design runs, the tide has been timed so that the peak of the flood coincides with the main flood peak in the Buller River. A visualisation of the 100-year ARI design flow / tide is presented in Figure 2-1 below. Due to the fact that the duration of the storm increases for each future climate scenario, the timing of the flood peak has also been adjusted for each scenario to correspond with the flood peak arriving to coincide with high tide.

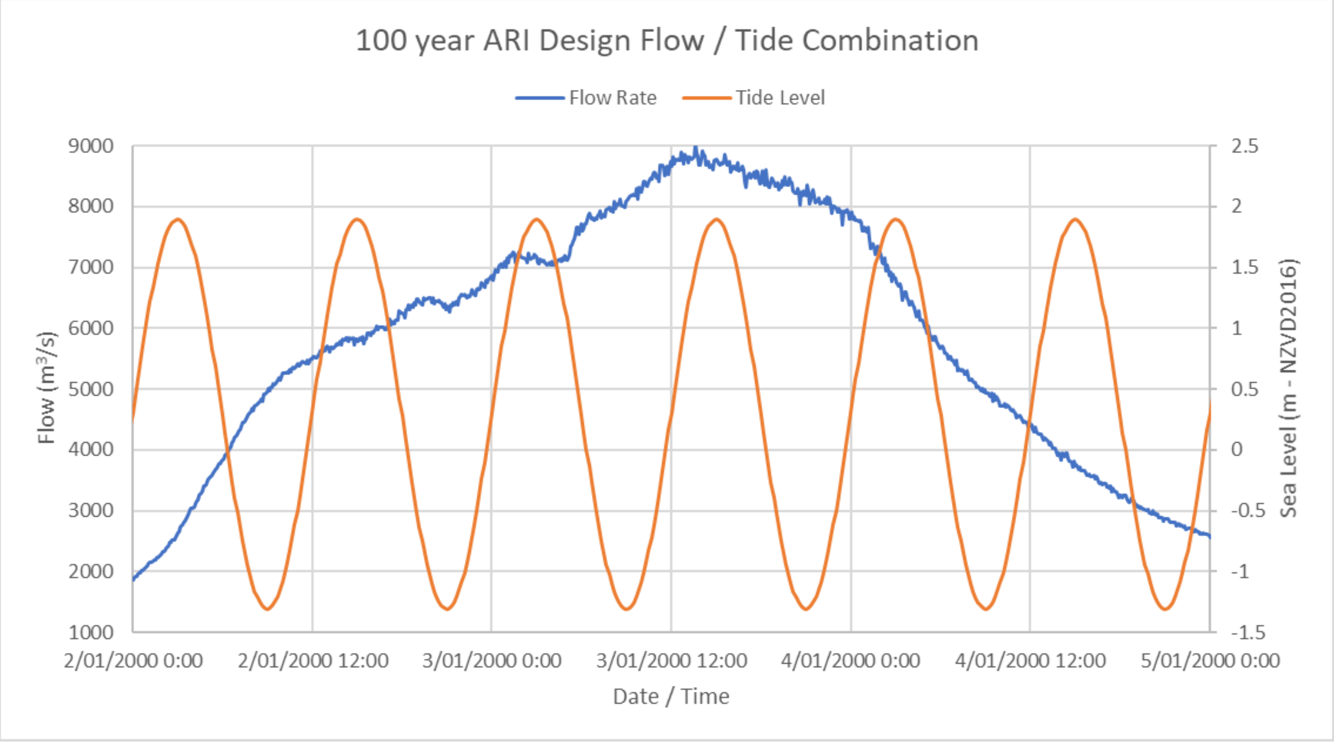


Figure 2-1 – Visualisation of design flow and tide boundary conditions for 100yr ARI scenario (Historic Climate)

SEA LEVEL RISE

As per the requirements under the New Zealand Coastal Policy Statement 2010, the cumulative effects of sea level rise, storm surge and wave height have been considered over a period of 100-years, for this case we have assessed sea level rise to 2120.

In order to assess potential sea level rise scenarios, we have adopted the predictions detailed in the latest IPCC assessment (IPCC et al., 2021). Historically the IPCC used the terminology of RCP to define future climate scenarios, however in the IPCC6 report, the terminology has change to Shared Socioeconomic Pathways (SSP). We have used the Shared Socioeconomic Pathways to define potential levels of sea level rise. A brief summary of each pathway is as follows:

SSP2-4.5 is approximately in line with the upper end of aggregate Nationally Determined Contribution emission levels by 2030. SR1.5 assessed temperature projections for NDCs to be between 2.7 and 3.4°C by 2100, corresponding to the upper half of projected warming under SSP2-4.5. New or updated NDCs by the end of 2020 did not significantly change the emissions projections up to 2030, although more countries adopted 2050 net zero targets in line with SSP1-1.9 or SSP1-2.6. The SSP2-4.5 scenario deviates mildly from a 'no-additional- climate-policy' reference scenario, resulting in a best-estimate warming around 2.7°C by the end of the 21st century relative to 1850-1900.

SSP3-7.0 is a medium to high reference scenario resulting from no additional climate policy under the SSP3 socioeconomic development narrative. SSP3-7.0 has particularly high non-CO2 emissions, including high aerosols emissions.

SSP5-8.5 is a high reference scenario with no additional climate policy. Emission levels as high as SSP5-8.5 are not obtained by Integrated Assessment Models (IAMs) under any of the SSPs other than the fossil fueled SSP5 socioeconomic development pathway.

To assess the appropriate level of sea level rise for each SSP scenario, we have utilised the NASA sea level rise portal (https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool). Table 2-2 summaries the adopted sea level rise scenarios. It should be noted that these sea level rise projections are based on the 1995-2014 baseline and compare relatively closer to the forecasts on the national sea level rise website (https://www.searise.nz/) which was released after this project had started.

Due to the recent release of the IPCC6 reports, NIWA are still reporting flow information in relation to the RCP terminology, we have therefore continued the use of that terminology and used the most appropriate scenario as summarised in Table 2-2.

Table 2-2 – Future Sea Level Scenarios

Shared Socioeconomic Pathway	**Assumed RCP**	**Increase in sea level (m)**
SSP2-4.5	4.5	0.76
SSP3-7.0	6.0	0.97
SSP5-8.5	8.5	1.12
SSP5-8.5 (low confidence)	8.5	1.37

2.1 OPTION 1 - COMPREHENSIVE SCHEME

2.1.1 DESCRIPTION OF PROPOSAL

This is the most comprehensive mitigation proposal. It is based on the proposals drawn up in 2014, but with modifications based on the present investigations and consideration of alternatives. These modifications include changes in the lengths of stopbanks and walls, and in the wall design, as well as location and access refinements. Crossings of streets, main roads and railway lines have been identified (Williams, 2022)along with private access ways, as well as outlets for open drains and the position of stormwater pipes under the stopbanks or walls.

In the Carters Beach area, the stopbank has to be extended west to accommodate the climate change scenario but could also be extended along Schadick Avenue to include houses along this road and the airport. Including this additional area has been assessed as part of Option 6 (Williams, 2022).

This proposal includes all the urban area of Westport, with a ring bank along the Buller River and around the Orowaiti river, plus a separate bank/wall around the low-lying Snodgrass area, and a bank around Carters Beach. Under the climate change scenario, the Carters beach area would remain vulnerable to sea flooding and wave-generated erosion, unless other measures were implemented along the coastline (Williams, 2022).

The farmland to the south of the main urban area was included within the ring bank, by following the higher ground of a low terrace formation of old alluvial floodplain channels. At the time of the original drafting of the ring bank location, this area was being considered for urban expansion. (Williams, 2022)

A schematic of the proposal is presented in Appendix A.

2.1.2 ASSESSMENT OF EFFECTS

FLOOD DEPTH / EXTENT

This option has been shown to be effective at preventing inundation for all of the protected areas up to a 100-year ARI (historic climate), however under a future climate scenario the Snodgrass Road area is shown to receive a degree of inundation in the 100-year ARI, future climate (RCP6) scenario. Close analysis of the results shows that this is caused by water overtopping the embankment on the true right bank of the Orowaiti River immediately upstream of the cemetery and spilling into the protected area. Due to the presence of the floodwalls, this water will be unable to drain out of this area and would require a portion of the banks to be sacrificed to allow this water to freely drain back into the estuary.

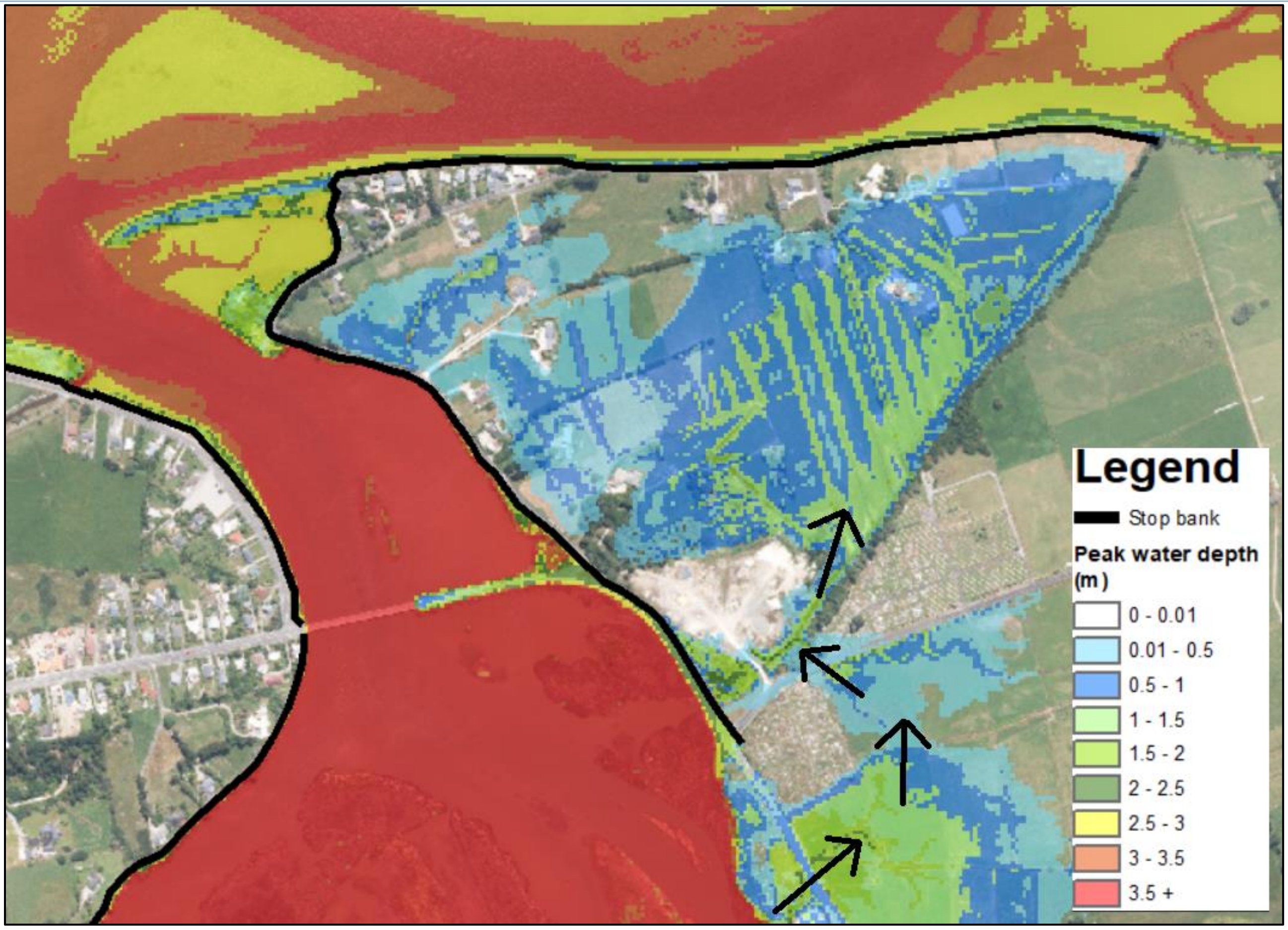


Figure 2-2 – Flood extent

DIFFERENCE IN FLOOD DEPTH

Analysis of the results shows the most significant impact for this option is in relation to increases in peak flood depth in areas not receiving protection.

OROWAITI RIVER

Comparison of peak water levels with the base scenario simulations show that the most consistent impact on peak depths is in the Orowaiti overflow area upstream of the Snodgrass Road banks, with the stopbanks on both sides of the Orowaiti River creating a significant constriction, causing the water to back up in this location for several kilometres.

Increases in water level are most significant in the area upstream of the Orowaiti Bridge (SH6) with increases in peak water depth ranging from about 0.08 m (8cm) for a 20-year ARI event to approximately 0.4m for a 100-year ARI event (historic climate), however once a future climate scenario is considered, then the increase in flood depth increases to almost 0.8m. These increases propagate for approximately 6km upstream of the Orowaiti State Highway Bridge as shown in the following figures.

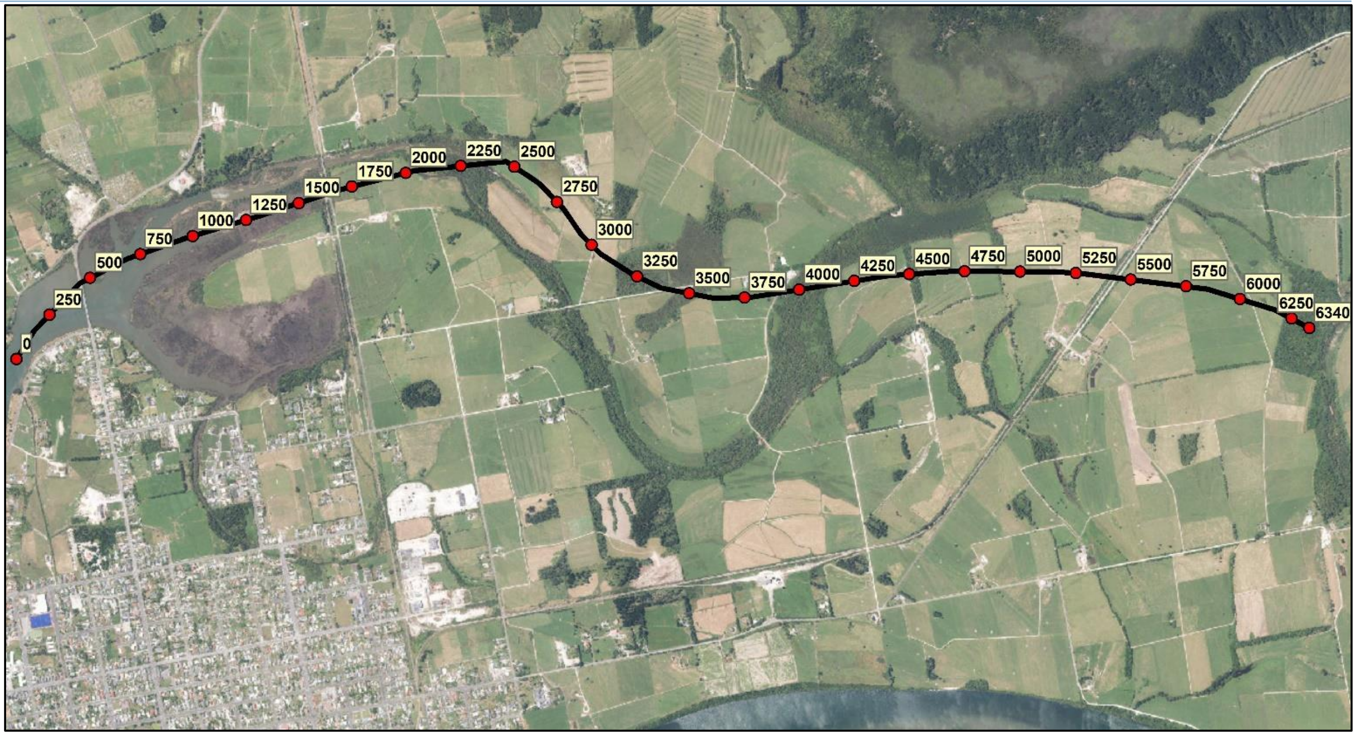


Figure 2-3 – Distance markers for longsection profile

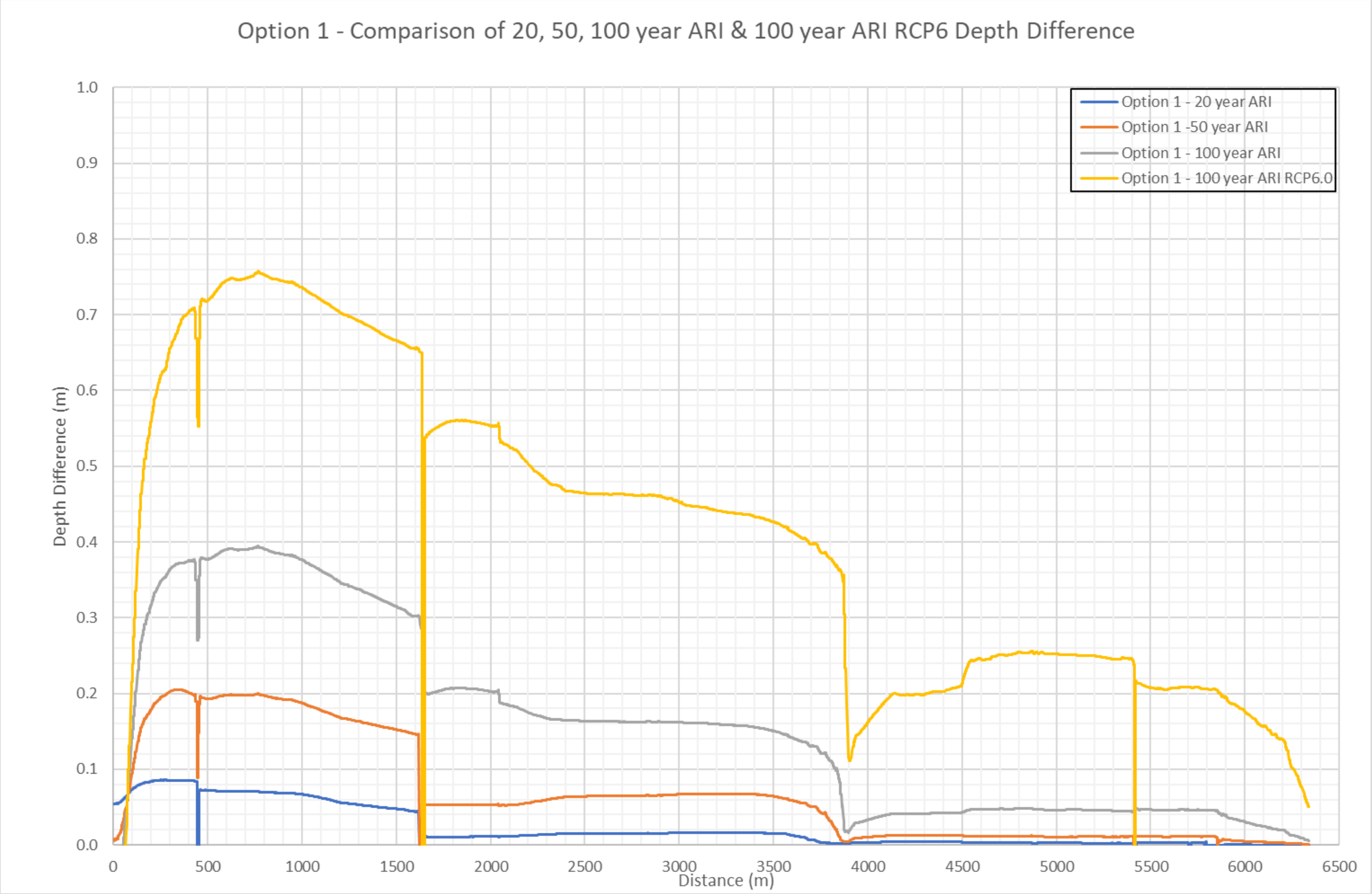


Figure 2-4 – Longsection profile showing peak water depth difference due to extensive stopbanks (Option 1)

BULLER RIVER – LEFT BANK

The second area where water levels are shown to increase is on the true left bank of the Buller River. Results show a relatively uniform increase in flood depths over this entire area, with increases in levels summarised in Table 2-3.

Table 2-3 – Summary of increases in peak water levels on left bank of Buller River with Option 1 flood banks

Scenario	Increase in peak depth (m)
20-year ARI (Historic Climate)	0.03
50-year ARI (Historic Climate)	0.07
100-year ARI (Historic Climate)	0.1
100-year ARI (RCP6)	0.2

These depths are significantly less than those present in the Orowaiti overflow area, however the effects will may still be felt by landowners, particularly building owners as the flood waters may be pushed closer to their floor levels than would otherwise be the case.

IMPACT ON BRIDGES

The impact of the stopbanks on peak water levels at each of the bridges has been assessed in the model.

Buller River SH6 Bridge

Results show the peak water level is increased by up to 0.16m as a result of the stopbanks. A summary of peak water levels is presented in Table 2-4.

Table 2-4 – Summary of modelled peak water levels at Buller River SH6 Bridge (no allowance for potential debris blockage)

Scenario	Base Scenario Peak Level (m)	Option 1 Peak Level (m)	Increase (m)
20-year	4.69	4.70	0.01
50-year	4.96	4.98	0.02
100-year	5.12	5.28	0.16
100yrRCP6	5.44	5.59	0.15

Table 2-5 – Impact on bridge freeboard (no allowance for potential debris blockage)

Scenario	Base Scenario Available Freeboard (m)	Option 1 Available Freeboard (m)
100-year	1.04	0.88
100yrRCP6	0.72	0.57

Buller River

Results show that there is a lack of available capacity under the main Buller River bridge which will be exacerbated by the proposed scheme. The Waka Kotahi bridge design manual specifies a desired minimum freeboard for new bridge structures to be 1.2m above the 100-year ARI flood level. Whilst this is an ideal standard for new bridge builds, it is not currently being met by the existing bridge, and the level of freeboard will be reduced by construction of the scheme.

Orowaiti River SH6 Bridge

Results show the peak water level is increased by up to 0.69m as a result of the stopbanks constricting the flow at the location of the bridge. A summary of peak water levels is presented in Table 2-6 below.

Table 2-6 - Summary of modelled peak water levels at Orowaiti River SH6 Bridge (no allowance for potential debris blockage)

	Base Scenario	Option 1	Increase
20-year	2.45	2.54	0.09
50-year	2.98	3.18	0.20
100-year	3.30	3.67	0.37
100yrRCP6	3.92	4.61	0.69

IMPACT ON FLOW SPLIT

Results show that one of the reasons for the significant increase in peak depths in the Orowaiti overflow channel is that the scheme prevents water from re-entering the Buller River in the larger events therefore increasing the proportion of flow going down the Orowaiti River. This effect is most pronounced in events larger than a 1 in 100-year ARI (historic climate).

Orowaiti Flow Rate (m^3/s)

	20-year ARI	50-year ARI	100-year ARI	100-year RCP6 ARI
Base Scenario	583	951	1231	1620
Option 1	583	950	1261	1921

CARTERS BEACH

Model results show that the main Carter's Beach urban community will be protected from river flooding for the full range of events, however, will remain unprotected in a 100-year ARI, future climate (RCP6) scenario. Depth difference results show that whilst coastal flooding will be no worse for a 100-year ARI event (historic climate), there will be an increase in flood risk for a future climate scenario on some properties between 0.1 and 0.3m as shown in Figure 2-5.

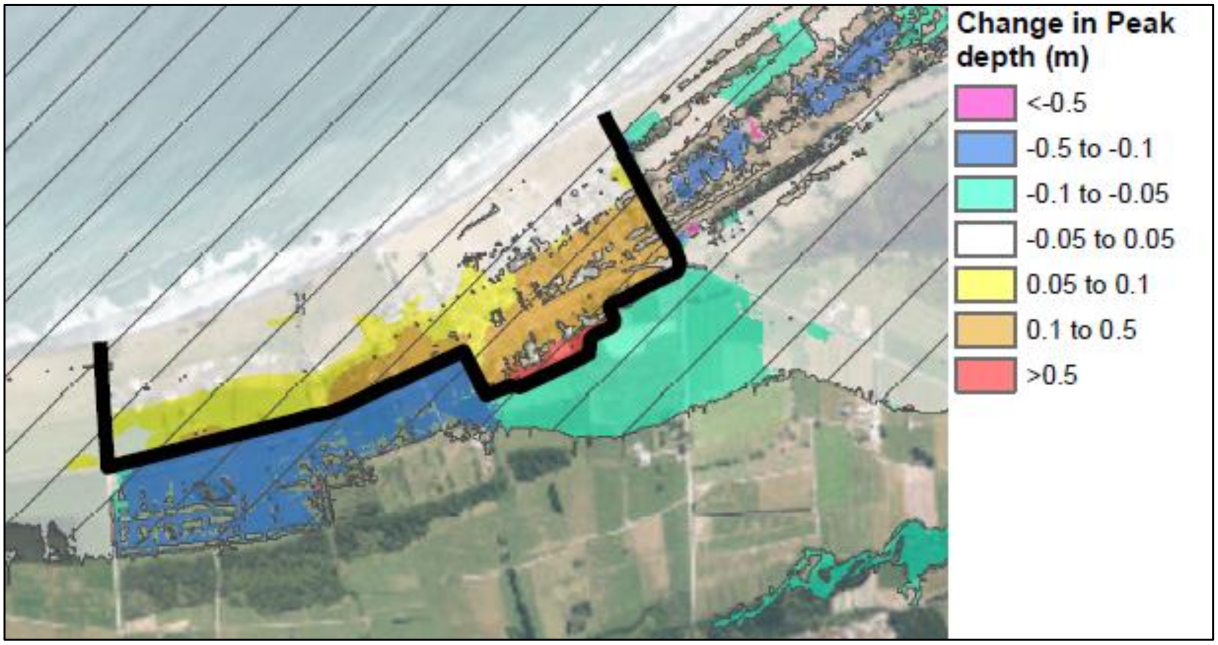


Figure 2-5 – Increase in flood depths for coastal scenario – 100-year ARI RCP6

There are several residential dwellings which remain outside of the area of the protected zone, mainly to the east between the airport and the river. Option 6 investigates the practicalities of extending the protection.

SNODGRASS

Model results show that providing protection to the Snodgrass area would require stopbanks to be built into the estuary with heights in excess of 3m. With 2 to 1 batter slopes and a top width of 3m there would be a base width close to 30m and this is likely to extend into the estuary unless some form a wall structure was adopted. Stopbank heights for a 100-year ARI RCP scenario are presented in Figure 2-6.

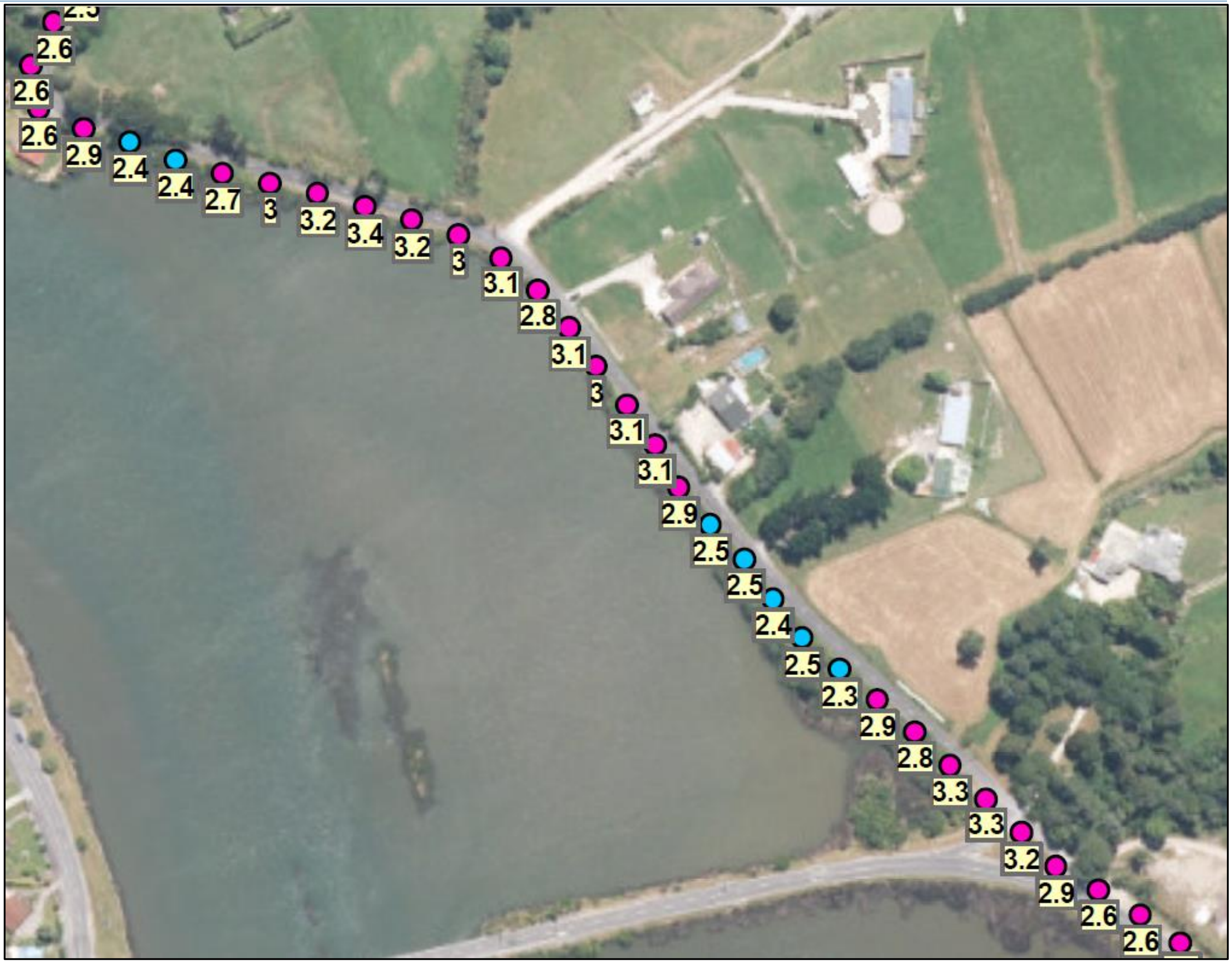


Figure 2-6 – Estimated stopbank heights for a 100-year ARI – Future Climate RCP6 event

2.2 OPTION 2 - COMPREHENSIVE SCHEME WITH SNODGRASS AREA EXCLUDED

This scenario is identical to Option 1 however it doesn't include any protection for the Snodgrass area and results for the Buller River area are identical to the Option 1 results and have therefore not been addressed here.

A schematic of the proposal is presented in Appendix A. Detailed maps showing peak flood depth as well as depth difference maps are included in Appendix B.

2.1.2 ASSESSMENT OF EFFECTS

FLOOD DEPTH / EXTENT

SNODGRASS ROAD AREA

Results show that whilst the entire Snodgrass Road area will be flooded in all scenarios, there are no noticeable increases in peak water levels in the Snodgrass area itself due to a lack of protection. This indicates that residents would be no worse off than they currently are by not providing protection to this area.

OROWAITI RIVER

As was the case with Option 1, comparison of peak water levels with the base scenario simulations shows that the most consistent impact on peak depths is in the Orowaiti overflow area upstream of the Snodgrass Road area. However, with the removal of the Snodgrass Road stopbanks, peak water levels are significantly reduced with the difference in peak water level from the base scenario having a maximum increase of 0.14m for the 100-year ARI (historic climate) event and 0.36m for the 100-year ARI, future climate (RCP6) scenario. A long section of the depth difference results in the same location as shown for option 1 is presented in Figure 2-7 (see Figure 2-3 for distance markers).

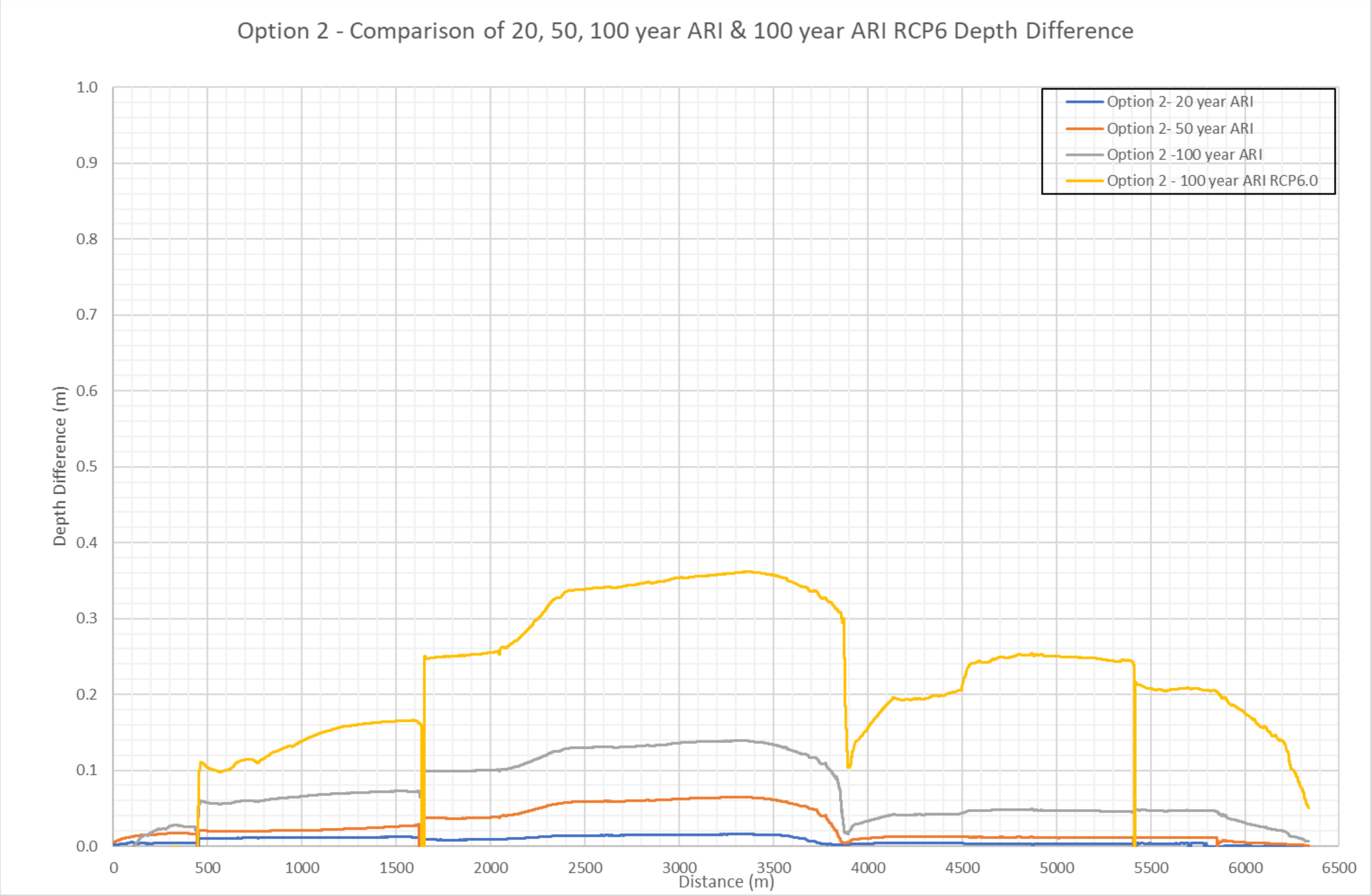


Figure 2-7 - Long section profile showing peak water depth difference due to extensive stopbanks with Snodgrass banks excluded (Option 2)

COMPARISON OF STOPBANK LEVELS WITH OPTION 1

Stopbank levels are significantly reduced (~0.6m) down the length of the true left bank of the Orowaiti River for a distance of approximately 2 km and then tapering off as highlighted in Figure 2-8 on the following page.

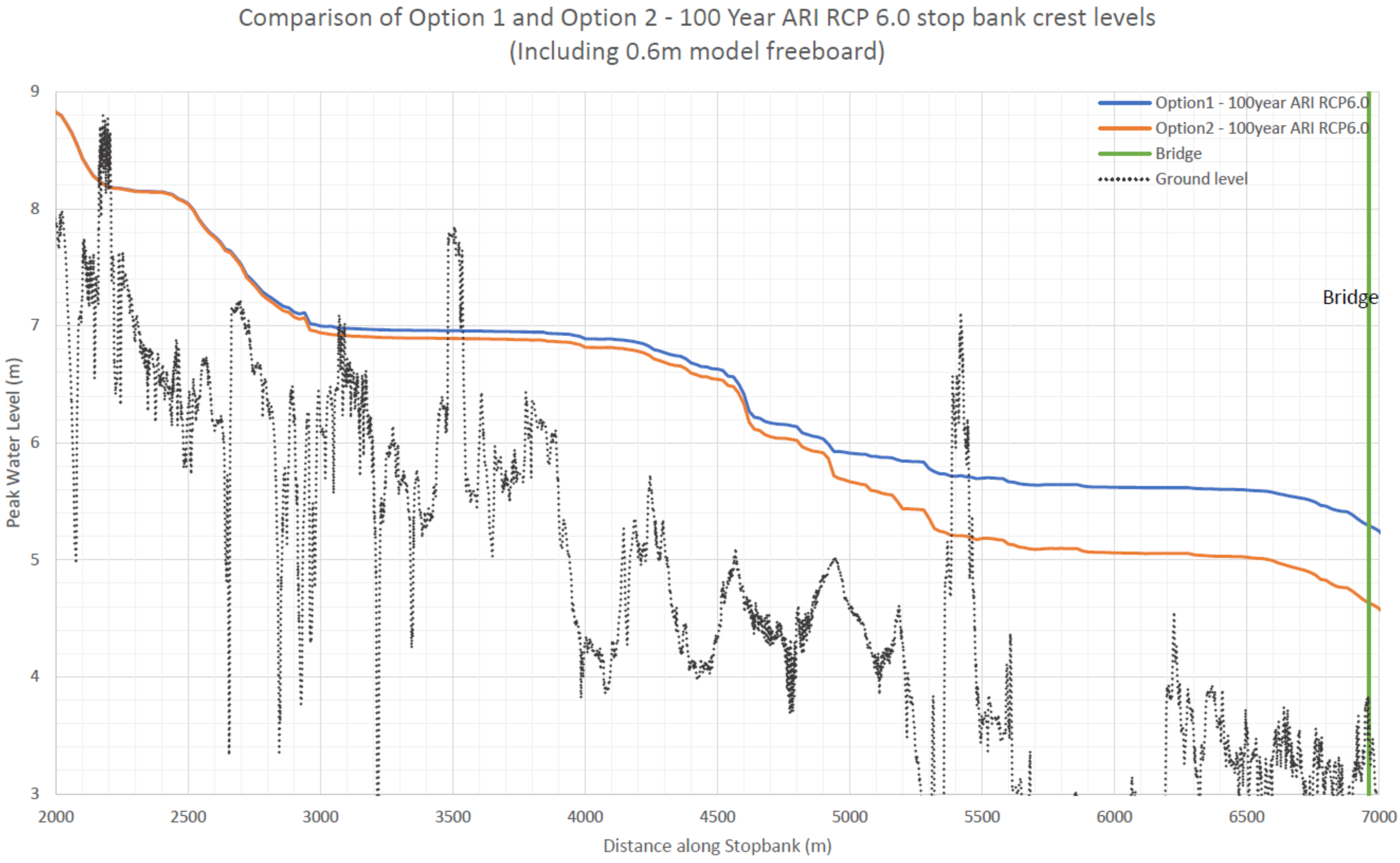


Figure 2-8 – Comparison of stopbank levels upstream of the Orowaiti Bridge for Option 1 and Option 2

BULLER RIVER AND CARTERS BEACH

The impacts on levels in the Buller River and to Carters Beach for Option 2 are unchanged from Option 1.

2.3 OPTION 3 — INLAND BANKS (EXCLUDING SOUTHERN FARM LAND)

Options 3 excludes the southern farmland, which was originally included for urban expansion.

This farmland is outside the main overflow area and channels to the Orowaiti estuary, and thus less prone to flooding, but is floodable from the Buller River, with old overflow channels alongside the existing Buller River. (Williams, 2022)

Flooding of this land is a rare occurrence, and the full extent stopbank would be relatively expensive to protect farmland that is only rarely flooded. It may not be worthwhile to do the full stopbank if planning restrictions are then applied to prevent its conversion to urban use. (Williams, 2022)

The bank around the southern end is not high, but there are many drains and swale depressions going down to the main overflow area, which would all have to be piped with outlet flap gates. There are at least 12 such outlets. One advantage of this alignment is it minimises the number of drainage outlets required. (Williams, 2022).

A schematic of the proposal is presented in Appendix A. Detailed maps showing peak flood depth as well as depth difference maps are included in Appendix B.

FLOOD DEPTH / EXTENT

This option has been shown to be effective at preventing inundation for all of the protected areas up to a 100-year ARI (historic climate), however under a future climate scenario, as was the case in Option 1, the Snodgrass Road area is shown to receive a degree of inundation in the 100-year ARI, RCP6 scenario.

It should be noted that in a 50-year ARI event, most of the farmland at the upper end of the bank receives no floodwaters, despite the lack of flood banks (Figure 2-9).

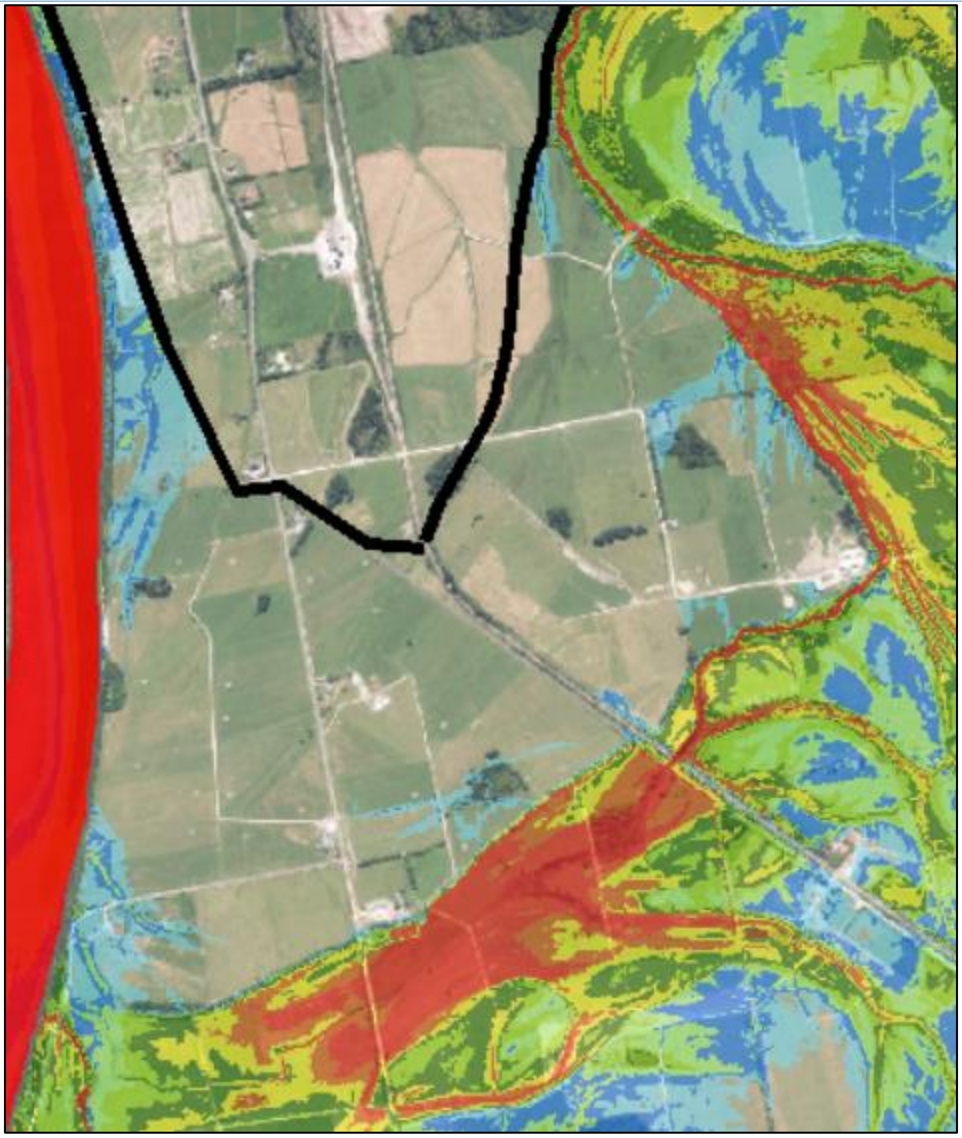


Figure 2-9 – Inundation extent for Option 3 of southern farmland - 50-year ARI event

DIFFERENCE IN FLOOD DEPTH

OROWAITI RIVER

Results show a less pronounced increase in flood levels than in Option 1 and 2, due to the fact that less flow is diverted down the Orowaiti River. However, the increase is still significant due to the presence of the Snodgrass Banks.

Comparison with Option 1 shows a decrease in flood levels in the order of 0.2 m in the Orowaiti Channel. This would provide both a saving in cost, as well as improve the amenity value for the properties on the true left bank of the Orowaiti River.

BULLER RIVER LEFT BANK

Results indicate a flood level increase on the true left bank in the order of 0.23m (23cm) in comparison to the base scenario, and 0.03 (3cm) higher than for option 1 for a 100-year ARI, future climate (RCP6) scenario (Table 2-7). This extra increase in flood level in comparison with Option 1 is due to more flow being diverted down the Orowaiti Channel in option 1, and therefore a slightly lower amount is diverted down the Buller.

Table 2-7 – Summary of increases in depth on the Buller Left Bank

Scenario	Increase in peak depth (m)
20-year ARI (Historic Climate)	0.03
50-year ARI (Historic Climate)	0.07
100-year ARI (Historic Climate)	0.12
100-year ARI (Future Climate - RCP6)	0.23

IMPACT ON BRIDGES

The impact of the stopbanks on peak water levels at each of the bridges has been assessed in the model.

Buller River SH Bridge

Results show a more significant impact on peak water levels in the Buller River for Option 3 compared to Option 1 and 2, due to more flow in the main channel (Table 2-8). Results show that freeboard between the modelled peak water level and the bottom of the bridge is less than 0.5m for a 100-year ARI, future climate (RCP6) scenario.

Table 2-8 – Peak Flood Levels at Buller Bridge for Option 3 (excluding potential blockage)

Scenario	Base Scenario Peak Level (m)	Option 3 Peak Level (m)	Increase (m)
20-year	4.69	4.70	0.01
50-year	4.96	4.98	0.02
100-year	5.12	5.31	0.19
100yrRCP6	5.44	5.72	0.28

-

Table 2-9 – Summary of impact on bridge freeboard for option 3 (excluding potential blockage)

Scenario	Base Scenario Available Freeboard (m)	Option 3 Available Freeboard (m)
100-year	1.04	0.85
100yrRCP6	0.72	0.44

Orowaiti River SH6 Bridge

As was the case with option 1, model results show a significant increase at the Orowaiti Bridge (Table 2-10). This is primarily caused by the constriction in flow created by the Snodgrass and Orowaiti flood banks.

Table 2-10 - Summary of modelled peak water levels at Orowaiti River SH6 Bridge (no allowance for potential debris blockage)

	Base Scenario	Option 3	Increase
20-year	2.45	2.54	0.09
50-year	2.98	3.17	0.19
100-year	3.30		
100-year RCP6	3.92	4.43	0.51

IMPACT ON FLOW SPLIT

Option 1 and 2 showed a significant increase in flow down the Orowaiti River due to the fact that flow was prevented from re-entering the river at the top end by the banks. One advantage of Option 3 is that this flow is not blocked off, and the impact on the flow proportion down the Orowaiti is minimal as highlighted in Table 2-11.

Table 2-11 – Summary of impact of Option 3 on flow split down the Orowaiti Overflow

	Orowaiti Flow Rate (m^3/s)			
	20-year ARI	**50-year ARI**	**100-year ARI**	**100-year RCP6 ARI**
Base Scenario	583	951	1231	1620
Option 3	583	951	1237	1653

CARTERS BEACH

The impact on the Carters beach is greater than that shown in option 1 and 2 due to the fact that more water makes it down the Buller River. The stopbanks

2.4 OPTION 4 — REMOVE STATE HIGHWAY CAUSEWAY CROSSING OROWAITI

Options 4 assesses the effect of removing the causeway that links the S H 67 bridge across the Orowaiti estuary to the right bank of the estuary. It investigates the impacts of the short bridge and causeway as compared to a full-length bridge. An increase in the hydraulic capacity could be obtained by a series of box culverts (Williams, 2022).

A schematic of the proposal is presented in Appendix A. Detailed maps showing peak flood depth as well as depth difference maps are included in Appendix B.

DIFFERENCE IN FLOOD DEPTH

Overall the option shows a small benefit with a decrease in water levels at the Orowaiti Bridge in the order of 0.1m for the 100-year RCP6 event tapering off to 0.06m at the Stephens Road Railway embankment and 0.15 m for the 100-year (historic climate) scenario tapering of to 0.1m at the Stephens Road Railway embankment.

The decrease in flood depth between option 4 and option 1 is presented in Figure 2-10 below.

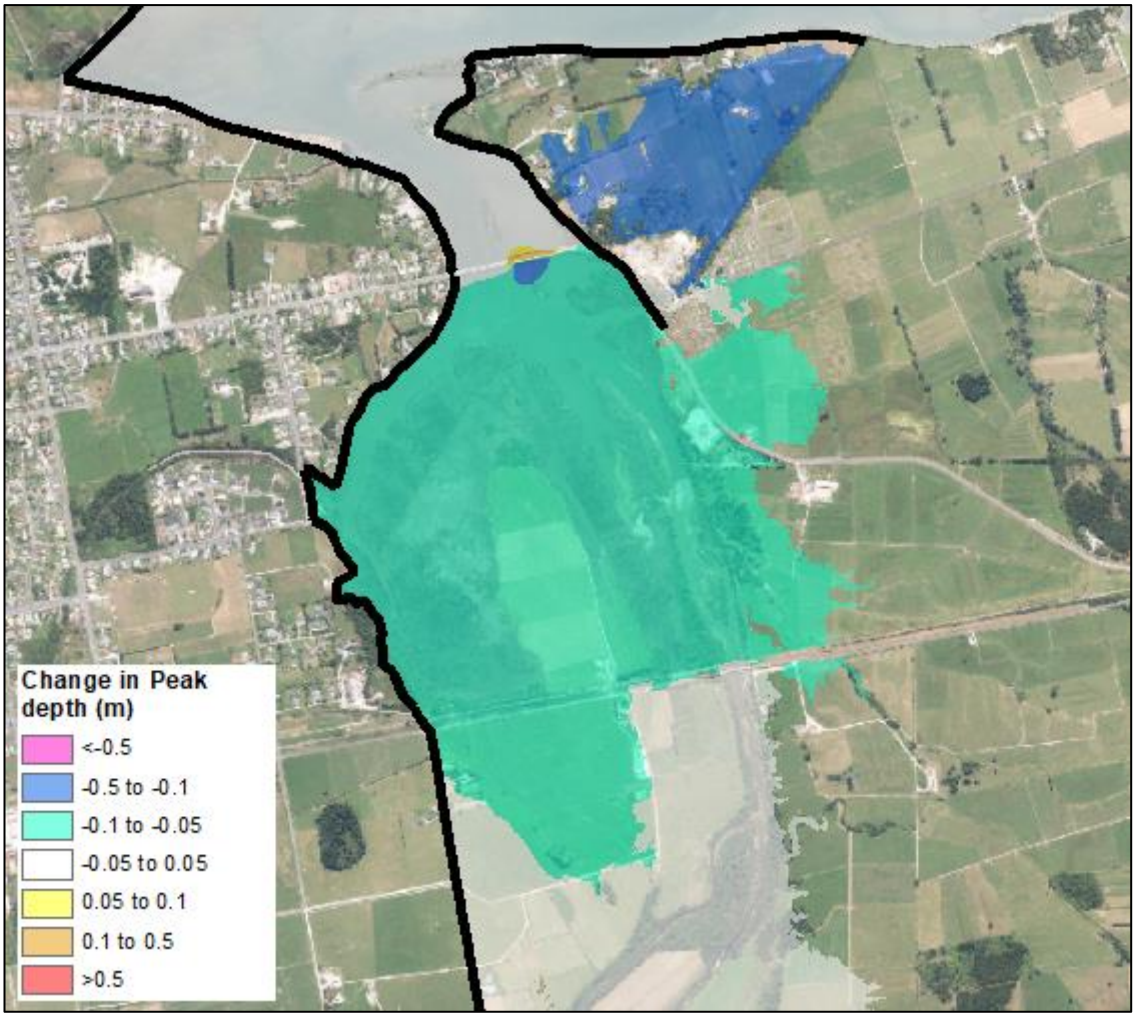


Figure 2-10 – Difference in flood depth between Option 4 and Option 1 (100-year ARI, Future Climate (RCP6) Scenario)

The decrease in flood depth is not sufficient to eliminate flooding from the Snodgrass Road area, with the main advantage being a slight reduction in flood depths and stopbank heights between the Orowaiti Bridge and the Stephens Road Railway Bridge.

Implementation of this option would likely be costly, with the most practical method being installing box culverts under the causeway. Alternatively, the entire estuary could be bridged.

This scenario has been modelled using a simplified approach and if this option was to be considered in greater detail, then more detailed modelling would be warranted.

The reason for the minimal impact however is likely to be due to the low level of the existing causeway already allowing significant overflow in large events. The causeway is essentially completely drowned during large flood events, and even more so once the floodwalls are included in the model.

BULLER RIVER AND CARTERS BEACH

The impacts on levels in the Buller River and to Carters Beach are the same as for Option 1.

2.5 OPTION 5 — EXTEND RAILWAY OPENING

The Railway embankment across the Orowaiti at Stephens Road acts as a weir control on the overland flood flows, and the existing bridge/culvert openings are small compared to the length of the embankment restriction (Williams, 2022).

A relatively short (100 m) extension of the waterway opening has been modelled to assess impacts both upstream and downstream of the railway embankment. This will reduce upstream flood levels from the backup effect but could increase downstream levels depending on the timing of the flood peak and downstream travel times to the Orowaiti estuary (Williams, 2022).

The Railway embankment was severely damaged by flood flows in the recent overflow flood events, and an enlarged waterway capacity could have significant long-term benefits for the Railway (Williams, 2022).

A schematic of the proposal is presented in Appendix A. Detailed maps showing peak flood depth as well as depth difference maps are included in Appendix B.

DIFFERENCE IN FLOOD DEPTH

Results show that the impact on flood depth is very localised with flood depths upstream of the culvert being reduced by up to 0.1m in the vicinity of the Stephens Road Railway embankment for large events with no noticeable impact downstream. This is largely due to the topography of the land restricting the flow in and out of the opening. The lower-level length of Stephens Road is offset to the Railway bridges and the lower downstream land.

Whilst there is only minor localised impact on the flood depths, there may be benefit to Kiwi Rail in increasing the resilience of the railway embankment which has been known to fail in this location, requiring the line to be closed and repaired in the following days.

BULLER RIVER AND CARTERS BEACH

The impacts on levels in the Buller River and to Carters Beach are the same as for Option 1.

2.6 OPTION 6 — EXCLUDE SNODGRASS WITH FLOODWAY – EXTENSIVE CARTERS BANK TO AIRPORT

Option 6 essentially investigates two separate options

1) Creating a cut through the Snodgrass area at the base of the cemetery, allowing the water to bypass the current estuary outlet to the sea. NB. This cut follows the historic alignment of the Orowaiti river prior to the 1870 flood event which is recorded as cutting a new path to the sea during a flood event and is the path that the water will naturally take anyway (as occurred in July 2021 with the river blowing out an exit at the downstream end of the Snodgrass area so that it could escape).
2) Extending the Carter's Beach stopbank all the way to the riverbank and therefore providing protection to the Airport, Golf Course and further residential properties down the length of Cape Foulwind Road.

A schematic of the proposal is presented in Appendix A. Detailed maps showing peak flood depth as well as depth difference maps are included in Appendix B.

The cut through the Snodgrass Road area has been designed to be approximately 250m wide with earth excavated down to an RL of 1m (NZVD2016). This level is below the typical high tide level and will likely become permanent marshland.

IMPACT OF THE CUT

The cut has the impact of reducing flood levels in the order of 0.15m for approximately 2km for the 100-year ARI event (Historic Climate), however the impact is slightly less pronounced for the 100-year ARI, future climate (RCP6) scenario.

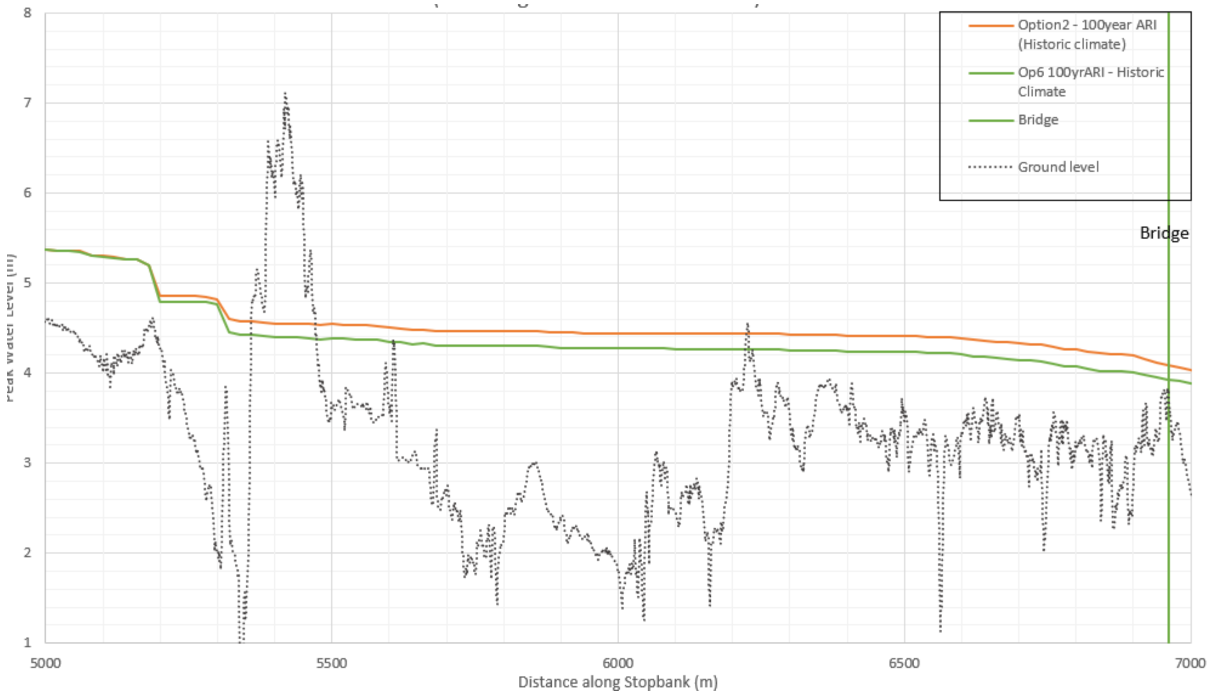


Figure 2-11 – Difference in stopbank crest levels upstream from the Orowaiti Bridge between Option 2 and Option 6 (100-year ARI – Historic Climate)

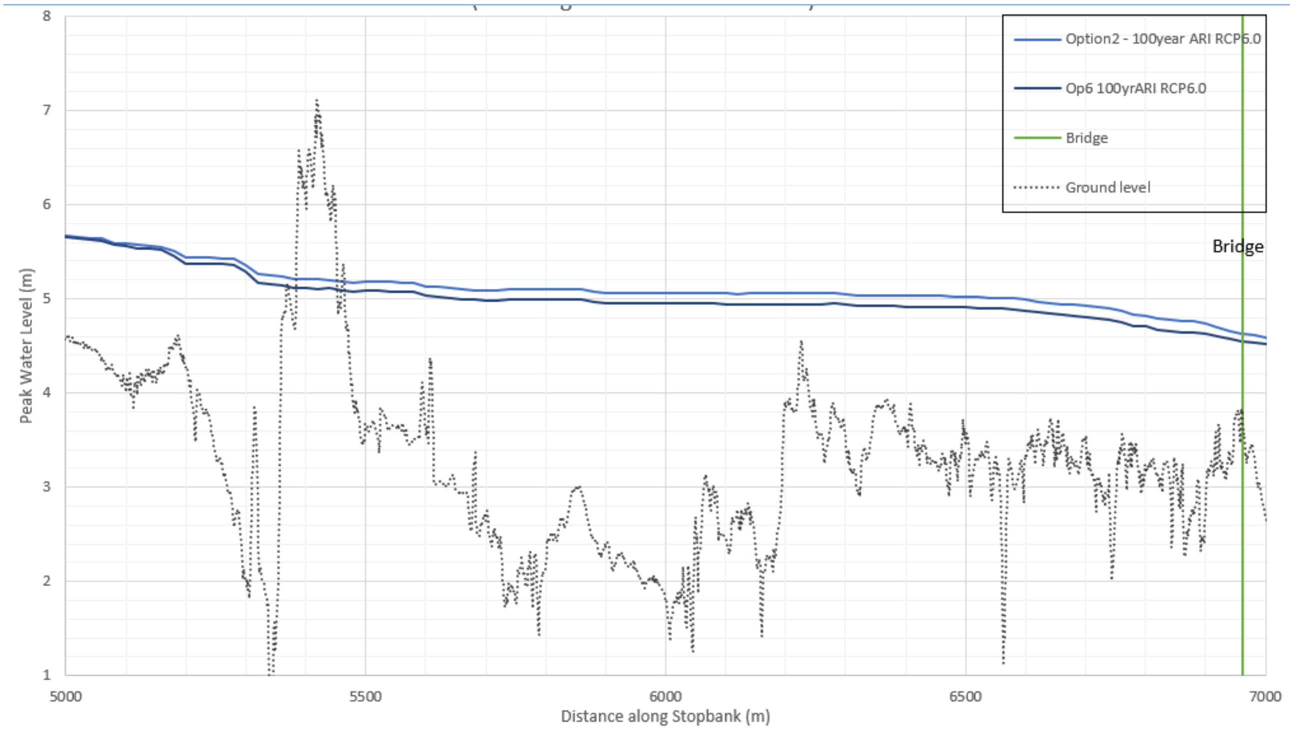


Figure 2-12 – Difference in stopbank crest levels upstream from the Orowaiti Bridge between Option 2 and Option 6 (100-year ARI – Future Climate RCP6)

CARTERS BEACH AREA

Extending the stopbank along Cape Foulwind Road to the Buller River provides protection to 10 more houses as well as preventing inundation of the golf course as well as the airport runway and facilities. There is a small amount of water spilling over the true left bank of the Buller River however in the 100-year ARI, future climate (RCP6) scenario, as highlighted in Figure 2-13 although it should be noted that spill over water is only minor and relatively shallow. In order to prevent this entirely, the true left stopbank would need to be further raised and potentially sealed.

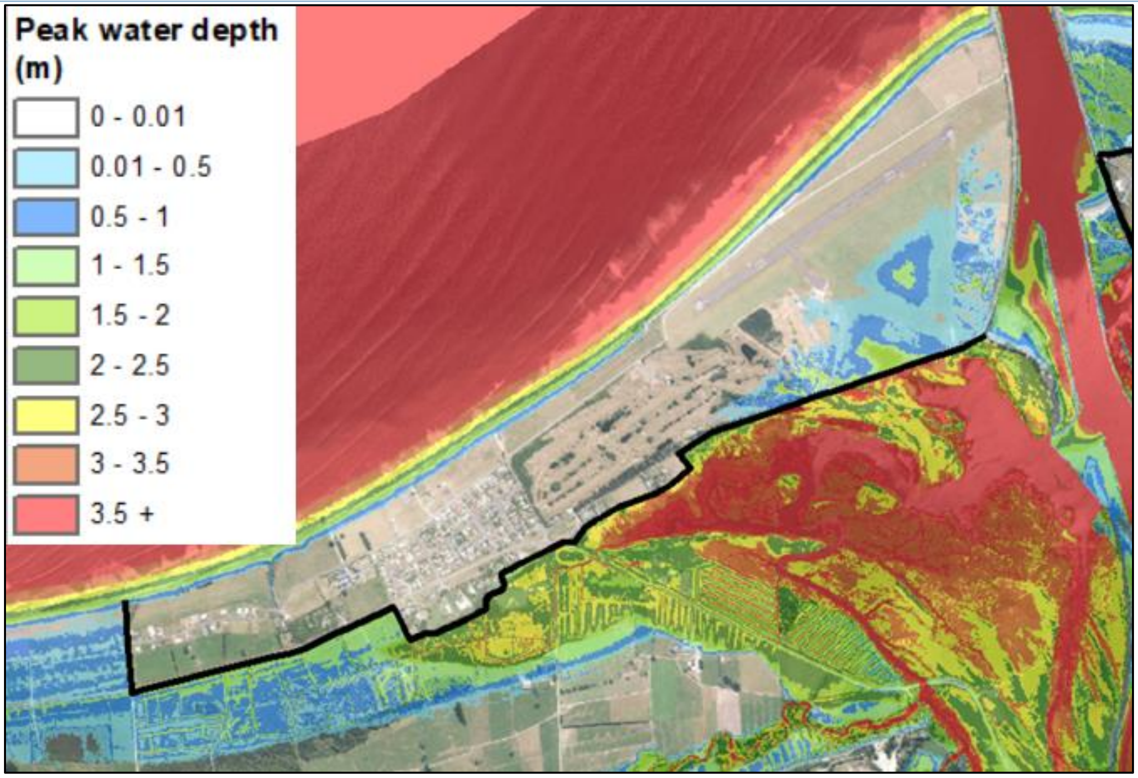


Figure 2-13 - Peak flood depth for a 100-year ARI – future climate RCP6 scenario highlighting inundation to the airport land

BULLER RIVER LEFT BANK

Results indicate a flood level increase on the true left bank in the order of 0.15m (15cm) in comparison to Option 1 immediately upstream of the stopbank tapering off to 0.1m by the Buller Bridge. There is no significant impact on water levels for the 100-year ARI event (historic climate) or below. The reason for the higher levels at this location is largely driven by sea level rise with the river spilling over the airport land to the sea in the base scenario. This flow path is blocked in this scenario and hence water in the main channel backs up increasing water levels on the surrounding land as well as upstream. Stopbank levels on the true right bank are also raised as a result.

BULLER RIVER BRIDGE

Model results show that there is a very minor increase in water level for the 100-year ARI (historic climate) event, however there is a more significant increase in peak water level of 0.1m for a 100-year ARI, future climate (RCP6) scenario as summarised in Figure 2-11.

Table 2-12 – Comparison of peak water levels at the Buller Bridge for Option 1 and Option 6

Scenario	Option 1 Peak Level (m)	Option 6 Peak Level (m)	Increase (m)
20-year	4.70	4.70	0.0
50-year	4.98	4.98	0.0
100-year	5.28	5.29	0.01
100-year, Future Climate (RCP6)	5.59	5.70	0.11

2.7 OPTION 7 — REVEGETATE OVERFLOW AREA (ORGANS ISLAND)

There is a large area of contiguous public land at the Organ's Island overflow, which includes the old channel of the river. There is also a long rock lining that is constraining the river channel in its present course, and the lower length of this lining was severely damaged in the recent large flood event. The land is in various types of titles, with ownership currently being confirmed by the Regional Council (Williams, 2022).

This proposal involves revegetating a wide area of native riparian forest, which would provide a vegetative filter and moderator of flood overflows down the Orowaiti system. As this vegetation established the hard control of the rock lining could be relaxed, with the river able to move within this wider space, prior to its entry into the sharp bend downstream at the valley side bluff. This would reduce long-term rock maintenance costs of the flood mitigation scheme, while allowing a more natural river movement within a forested floodplain environment (Williams, 2022).

The risk of significant overflows occurring from the Orowaiti Overflow have been well recognised since the 1800's. This proposal is essentially very similar to what has been proposed since the late 1800's; in 1891, C. Napier Bell wrote the following:

"*OROWAITI OVERFLOW*

The Orawaiti (sic) Overflow is the skeleton in the cupboard to Westport. It is a danger that I think grows less every day, and can be perfectly controlled provided it is not neglected.

The most immediate necessity is the protection of the river bank from the wear and tear of floods, and there can be little doubt that if the Overflow had not been protected to the extent it has been, the Buller river would now be flowing out at the Orawaiti (sic)." (Bell, 1891).

He then went on to write;

"*PROTECTION BY PLANTING*

The foreshore of the Overflow being made quite secure by stone work, all other damage by floods can be checked by placing fascines loaded with stone in the holes and gullies which the floods cut out of the soil, and by planting every part of the Overflow with willows and blackberries. When the low ground is thus overgrown *with bushes, the sand and silt of floods will be arrested and again overgrown, and thus the land grows higher after each flood, instead of being cut away as it would be if neglected."* (Bell, 1891).

Option 7 therefore is simply a carrying out of the proposal put forward in 1891, however rather than using plantings of willows and blackberries, it is suggested that the area is used to generate dense native bush, appropriate to the location. This would not only provide significant flood benefits but would also allow for an increase in native biodiversity and provide natural ecosystem services, as well as acting as a dense carbon sink. It will also allow the relaxing of hard river edge protection over time, eventually reducing the long-term maintenance requirements and costs for the overall flood mitigation scheme.

The efficacy of the planting will increase over time as the forest becomes denser, it will slow the water down, and trap silts and sands from the river, thereby building up the ground levels overtime, which will encourage less water to go down the Orowaiti Overflow and more water to go down the Buller River.

Modelling of such a proposal is difficult and depends on roughness assumptions. However, the scenario has been simulated by allowing for a general increase in roughness of the land in the Organ's Island area.

A schematic of the proposal is presented in Appendix A. Detailed maps showing peak flood depth as well as depth difference maps are included in Appendix B.

FLOOD DEPTH / EXTENT

Option 7 has a similar flood extent / depth to Option 1, however there is a noticeable decrease in peak water levels down the entire Orowaiti when compared to Option 1 as shown in Figure 2-14.

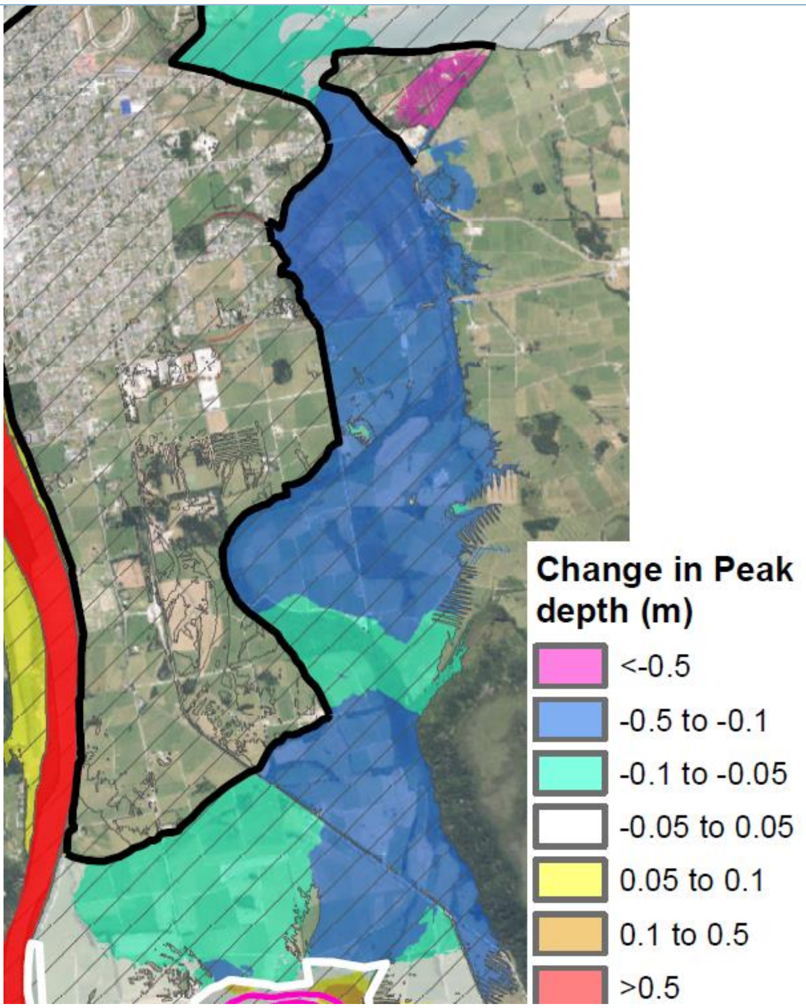


Figure 2-14 – Difference in depth map, comparing Option 7 with Option 1 results (100-year Ari RCP 6 Scenario)

DIFFERENCE IN FLOOD DEPTH

OROWAITI RIVER

Peak water levels are shown to be reduced by between 0.1 and 0.15m over a length of approximately 6km down the Orowaiti floodway for 100-year ARI, future climate (RCP6) scenario. In reality, stopbank crest levels would not be reduced due to the significant time required to allow the vegetation to generate, however the decrease in flood levels would be beneficial to landowners and would also provide for additional freeboard during a flood event thereby adding an additional layer of protection.

BULLER RIVER LEFT BANK

Due to the fact that there is a slight increase in flow going down the Buller River, flood levels on the true left bank area are increased.

Table 2-13 summarises the increase in peak water level downstream of the Buller Bridge.

Table 2-13 – Summary of increases in depth on the Buller Left Bank compared with Option 1

Scenario	Increase in peak depth (m)
20-year ARI (Historic Climate)	0.03
50-year ARI (Historic Climate)	0.04
100-year ARI (Historic Climate)	0.04
100-year ARI, Future Climate (RCP6)	0.03

IMPACT ON BRIDGES

The impact of the revegetation of Organs Island on peak water levels at each of the bridges has been assessed in the model.

Buller River SH6 Bridge

Results show that flood levels in the Buller River are increased by an addition 0.11m in the 100-year ARI, future climate (RCP6) scenario with an increase of only 0.04m for the historic climate event (Table 2-14).

Table 2-14 – Comparison of peak water levels at the Buller Bridge for Option 1 and Option 7

Scenario	Option 1 Peak Level (m)	Option 6 Peak Level (m)	Increase (m)
20-year	4.70	4.71	0.01
50-year	4.98	4.99	0.01
100-year	5.28	5.32	0.04
100yrRCP6	5.59	5.69	0.10

Orowaiti River SH6 Bridge

Results show a decrease in water levels of 0.16m for a 100-year ARI, future climate (RCP6) scenario and 0.13m for the 100-year ARI, historic climate event.

IMPACT ON FLOW SPLIT

Model results show that the vegetation buffer is likely to reduce the flow volume going down the Orowaiti Overflow with the impact increasing significantly as the flow increases. This is due to the fact that modelling shows that as the flow volume increases in the Buller River, the percentage flow split down the Orowaiti increases.

Because the volume going down the Buller River is almost an order of magnitude larger than the flows going down the Orowaiti overflow, the extra water being diverted down the Buller River is of minimal consequence and will only have a minor impact on the Buller River, however it will have a more significant impact on water levels in the Orowaiti overflow.

Table 2-15 - Summary of impact of Option 7 on flow split down the Orowaiti Overflow

	Orowaiti Flow Rate (m^3/s)			
	20-year ARI	**50-year ARI**	**100-year ARI**	**100-year RCP6 ARI**
Option 1	583	950	1261	1921
Option 7	524	864	1172	1773

3. CONCLUSIONS / DISCUSSIONS

Based on a detailed analysis of all of the modelling results and rigorous discussion and questioning among members of the TAG group, the group came to the following conclusions. These conclusions agree with the findings in this report.

3.1 PROTECTION OF SNODGRASS AREA

It is difficult to provide technical justification for providing protection to the Snodgrass area due to the following reasons;

- The banks significantly increase upstream water levels over several kilometres, therefore adversely impacting on water levels on private property within the floodway, as well as requiring the Orowaiti stopbanks to be approximately 0.6m higher over a length of 2km. This would add significant cost to the scheme and negatively impact on the amenity values of the Orowaiti residents who would have a more restricted view of the river-/-estuary.
- The banks do not provide full protection in a 100-year ARI future climate scenario (RCP6), with flood waters spilling into the area around the back of the cemetery.
- Land within the Snodgrass area is very low and was the historically the main Orowaiti River channel (prior to 1872). The land has been infilled over the years and developed, however much of the land is already below the current high tide levels. With future sea level rise it is likely that

groundwater will continue to rise along with the level of the sea, and as a result turn much of the area into saltwater marshlands — not ideal for residential dwellings. The relative height of a Mean High Water Spring (MHWS) tide in relation to the ground level is illustrated in Figure 3-1.

- The banks around the Snodgrass area would be difficult to construct, having amenity impacts on the residents as well as impacting on the estuary.

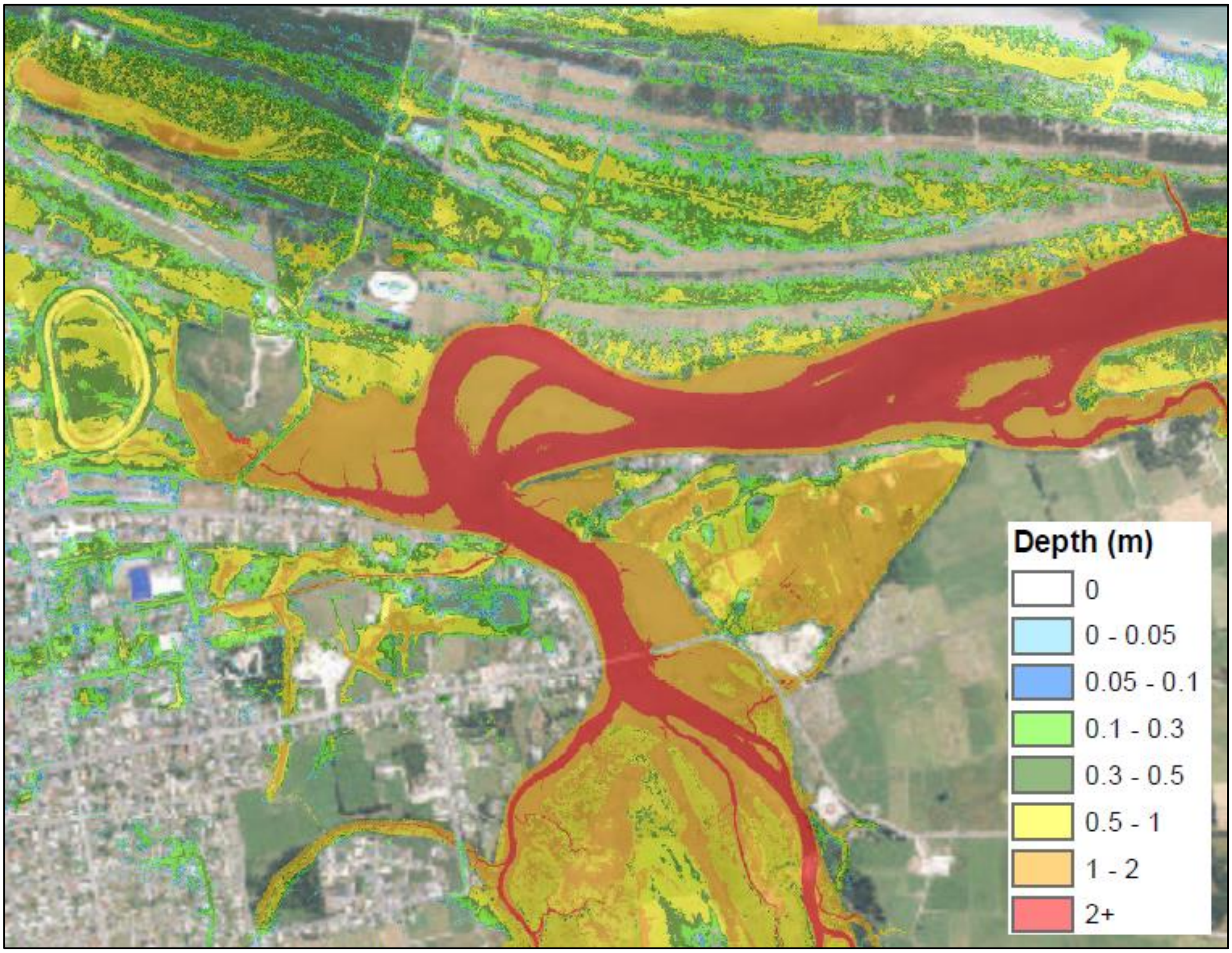


Figure 3-1 – Mean High Water Spring in relation to ground height with 1m Sea Level Rise

3.2 WESTPORT RING BANK

Model results show that providing full protection as per the ring bank presented in Option 1 and 2 has the downside of diverting a significant proportion of flood flows down the Orowaiti River, especially for the larger events in excess of a 100-year ARI (historic climate). This results in increased inundation for the properties in the floodway area and may pose issues for consenting. In addition, it results in higher stopbanks down the Orowaiti River, adding cost to the overall scheme and potentially having a negative impact on overall amenity values.

Buller River

In addition to the increase in flow, it is also evident that much of the rural land within the larger ring bank is not actually flooded in events less than a 50-year ARI event (historic climate). The saved flood damage benefits are~~,~~ therefore relatively low, while there is a significant cost of constructing banks to protect this infrequently inundated rural land. The cost benefit ratio is thus likely to be low or even negative.

3.3 CARTERS BEACH

Extending the stopbank all the way to the Buller River provides protection to a range of residential houses as well as to the golf course and the airport. Whilst extending the wall more than doubles the length and likely cost, the capital value of assets protected by the bank is significant. Results show that extending the bank does not have a significant adverse impact on the surrounding properties for events up to a 100-year ARI (historic climate) and provides a degree of protection on the vast majority of the residential units on the true left bank of the river. However, peak water levels on the true left bank are increased for a future climate scenario with peak water levels increasing at the Buller River Bridge in the order of 0.1m. As a result, consideration will need to be given to replacing the main bridge in the future to ensure there is adequate freeboard.

No banks have currently been allowed for to protect against coastal flooding, with the main risks to the Carters Beach community being from coastal erosion, however coastal inundation is likely to also become an issue with sea level rise as shown in the flood maps presented in Appendix B.

3.4 ORGANS ISLAND

Results of the hydraulic modelling indicate that revegetating the Organs Island area, as originally proposed in the 1890's, is likely to provide a degree of flood mitigation by reducing the proportion of flow down the Orowaiti which is currently the main cause of flooding to Westport for events of a similar magnitude to July 2021 event.

Aerial imagery from the 1940's shows this area to be heavily vegetated and has been progressively cleared since to make way for farming (Figure 3-2). Restoring the vegetation will likely result in an increase in flow down the Buller River, however in reality is just restoring the levels to what they would have been earlier.

Figure 3-2 – Comparison of Organs Island area in 1943 and 2022

Modelling shows that the Buller River is currently at capacity, and as flows in the Buller River increase, a greater percentage of the flow is diverted down the Orowaiti River. The revegetation of Organ's Island has the potential to offset this increase in flow percentage, and therefore mitigating the impacts of climate change to a degree.

3.5 BULLER RIVER STATEHIGHWAY BRIDGE

The Buller River Bridge was rebuilt in the 1970's due to damage to the piers in the 1970 flood event. It is reported that the bridge was rebuilt to a lower invert than the existing bridge.

REDUCTION IN FREEBOARD

Modelling shows that the level of freeboard for the bridge is less than specified in the NZTA bridge manual (Waka Kotahi, 2013) for new bridges with the current level of freeboard between the peak water level and the bottom of the bridge (soffit) being approximately 1m for a 100-year ARI event (historic climate) and 0.7m for a 100-year ARI, future climate (RCP6) scenario. The design freeboard for a new structure is 1.2m, however the design level for this bridge is unlikely to have incorporated any allowance for climate change.

Constructing stopbanks prevents the floodwaters from being able to spread over the floodplain and hence raises the water in the river channel further reducing the freeboard to the bridge. Freeboard is essential to allow for uncertainties within the flood model and also to account for potential debris blockage. Reducing the available freeboard will increase the likelihood of debris snagging on the underside of the bridge, which may have the effect of increasing peak water levels and as a result overtopping the stopbanks.

In order to avoid this scenario, consideration will need to be given to raising the bridge in the coming years as sea level and peak flow rates increase with climate change.

INCREASED RELIABILITY OF BRIDGE

Whilst the stopbanks do increase the likelihood of blockage at the bridge in an extreme event, the stopbanks do have the advantage that they will allow the bridge to remain open (because the approaches are not flooded) for evacuation purposes for a longer period of time, assisting with evacuation purposes if needed. In the existing scenario, the bridge approaches on the true right bank are shown to be flooded in a 100-year ARI event (historic climate) preventing access to the bridge. One significant advantage of the stopbanks is that the bridge may remain with the approaches remaining flood free in up to a 100-year ARI, future climate (RCP6) scenario.

4. RECOMMENDATION – PREFERRED SCHEME

Based on the hydraulic investigations in this report and the discussions and input of the TAG group, taking into account a wide range of factors, the following is recommended.

4.1 RECOMMENDED LOCATION AND ALIGNMENT OF STOPBANKS

CARTERS BEACH

It is recommended to extend the Carters Beach Stopbank all the way to the Buller River along the alignment shown in Figure 4-1 (note this alignment has been slightly refined based on that presented in the options modelling).

Figure 4-1 – Proposed Carters Beach Stopbank Alignment

The primary justification for this is to provide protection to an addition 10 residential houses along Cape Foulwind Road. Once these houses are protected however, the bank would either need to cut through the golf course to the sea or continue along Cape Foulwind Road and tie into the existing bank on the true left of the river. Considering the significant capital value of the gold course and the airport, which would now be protected from the additional length of stopbank extending to the river, we consider that it is worthwhile following this alignment. It should be highlighted however this will raise water levels in the Buller River for a 100-year ARI, future climate (RCP6) scenario, and therefore reduce the available capacity at the State Highway Bridge. Consideration will need to be given to raising this bridge in the short to medium term, if not, the protection may need to only stick to the main Carters Beach residential area as originally proposed in the LTP consultation.

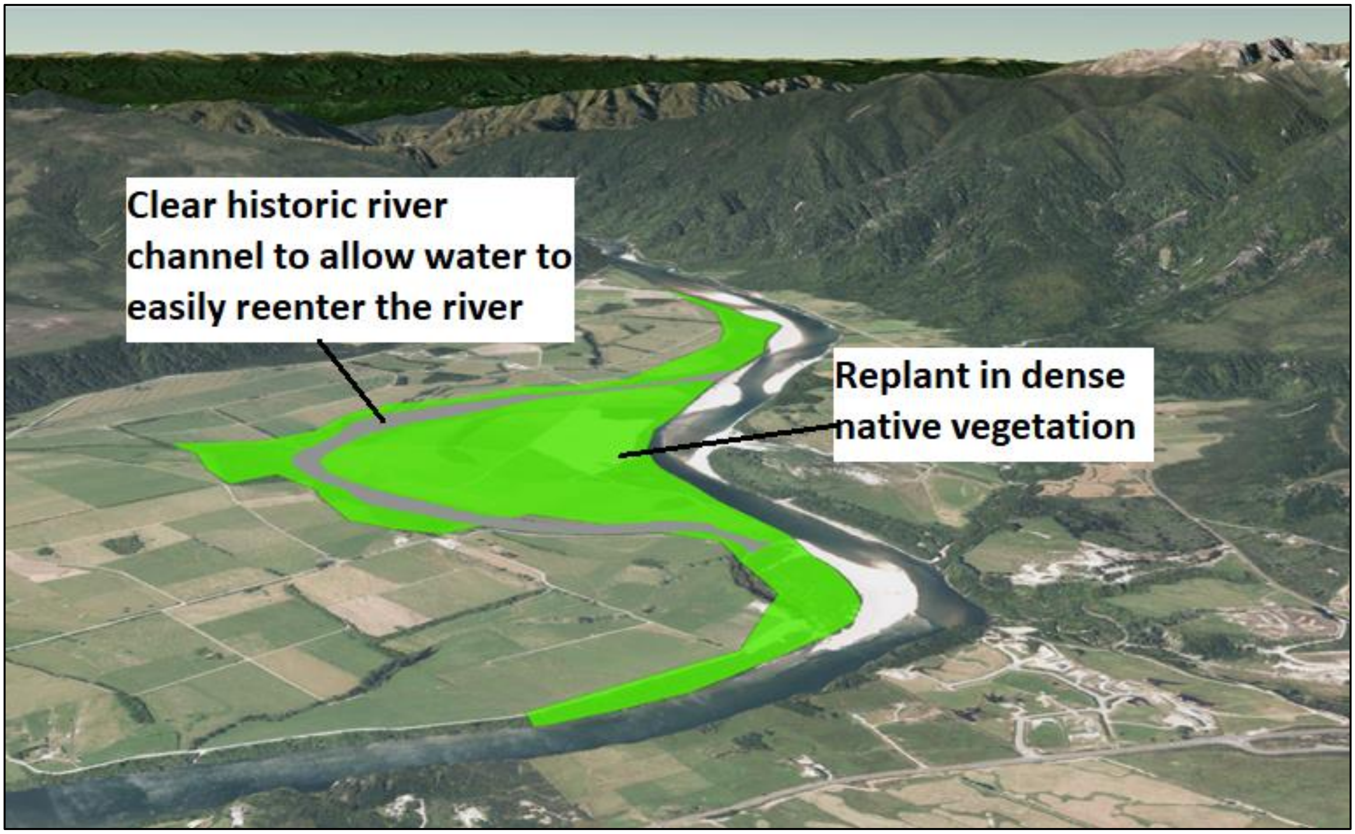
WESTPORT RING BANK

We recommend that a slightly altered version of the Option 3 ring bank is adopted as the preferred solution as shown in Figure 4-2. The alignment has been refined from that presented in Option 3 in order to improve the hydraulic performance, as well as to maximise the number of residential properties receiving protection. Several decisions regarding the alignment have been made without consultation with the affected community and it should be noted that this preferred alignment is what the TAG group have proposed. If this option is accepted in principle, there may still need to be refinements made during final consultations with the community and affected landowners, at the detailed design stage.

Figure 4-2 – Preferred Ringbank alignment

The alignment has been proposed based on a purely technical perspective and maximises land protected without sending more flow down the Orowaiti River. We also think however that consideration should be given to an alternative alignment which focuses the protection purely on the existing urban area, and does not encourage further expansion into flood prone areas. One potential alignment which achieves this with a sensible hydraulic design in presented in Figure 4-3. We would recommend making a final decision based on a combination of cost benefit / socio-economic factors.

Figure 4-3 – Alternative alignment (Townbank)



Revegetating the Organs Island as modelled in Option 7 appears to have largely positive impacts by limiting the volume heading down the Orowaiti River in very large events. This is largely expected to offset the increasing flow proportion which flows down the Orowaiti as the flow in the Buller River decreases.

4.2 DESIGN MATERIALS

The TAG group has made the following recommendation around type of construction:

Stopbanks: Standard earth stopbank with 2:1 batters and a top width of 4m. This may be reduced where there are space limitations. A concept sketch of a typical stopbank dimensions is presented in Figure 4-4 (drawing based on sketches provided by Gary Williams).

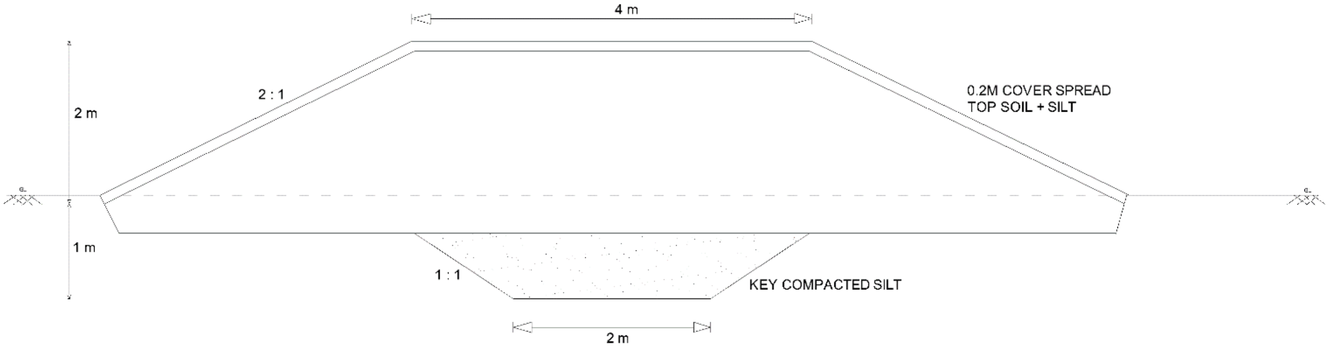


Figure 4-4 – Example of typical earth stopbank dimensions

Concrete Wall: A standard concrete panel wall has been specified for a shorty reach on the true right bank of the Buller River, downstream of the bridge due to space limitations.

Wooden Wall: Where floodwalls have been proposed along the Orowaiti Estuary it has proposed that the floodwall is made from a timber. The rationale for this is;

- Easy / cheap to construct
- Less disruptive to local residents
- No need for significant foundations
- Easily repairable, less susceptible to damage with liquefaction
- Fit for purpose based on design heights

Concept drawings have been provided below to aid the reader in visualising the potential structures and are based on sketches provided by engineer Gary Williams.

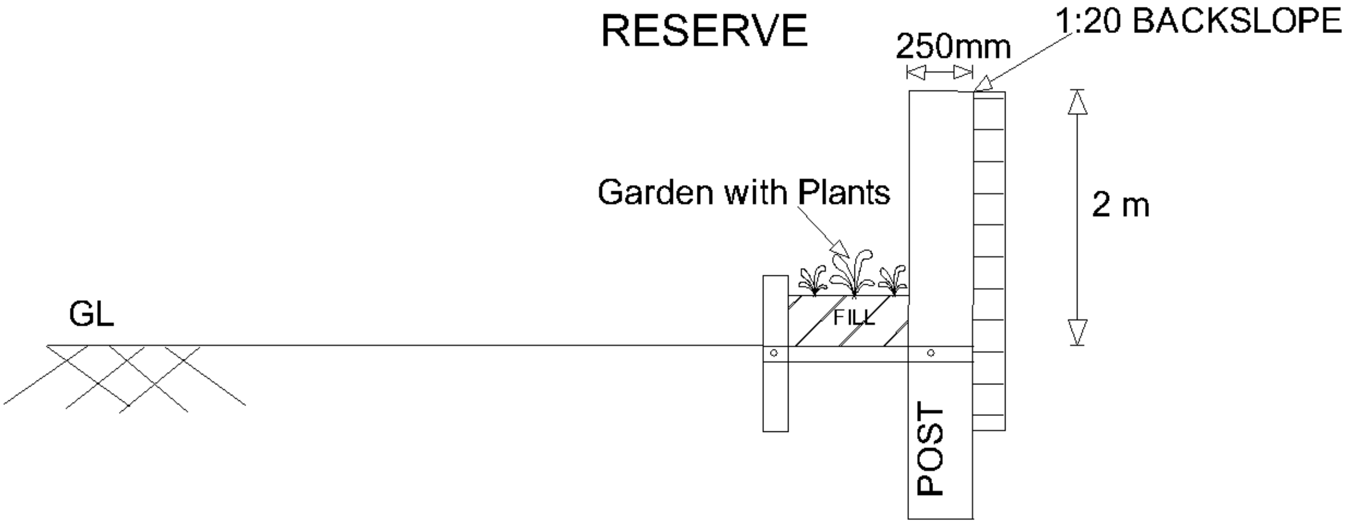


Figure 4-5 – Single wall concept sketch built on reserve land

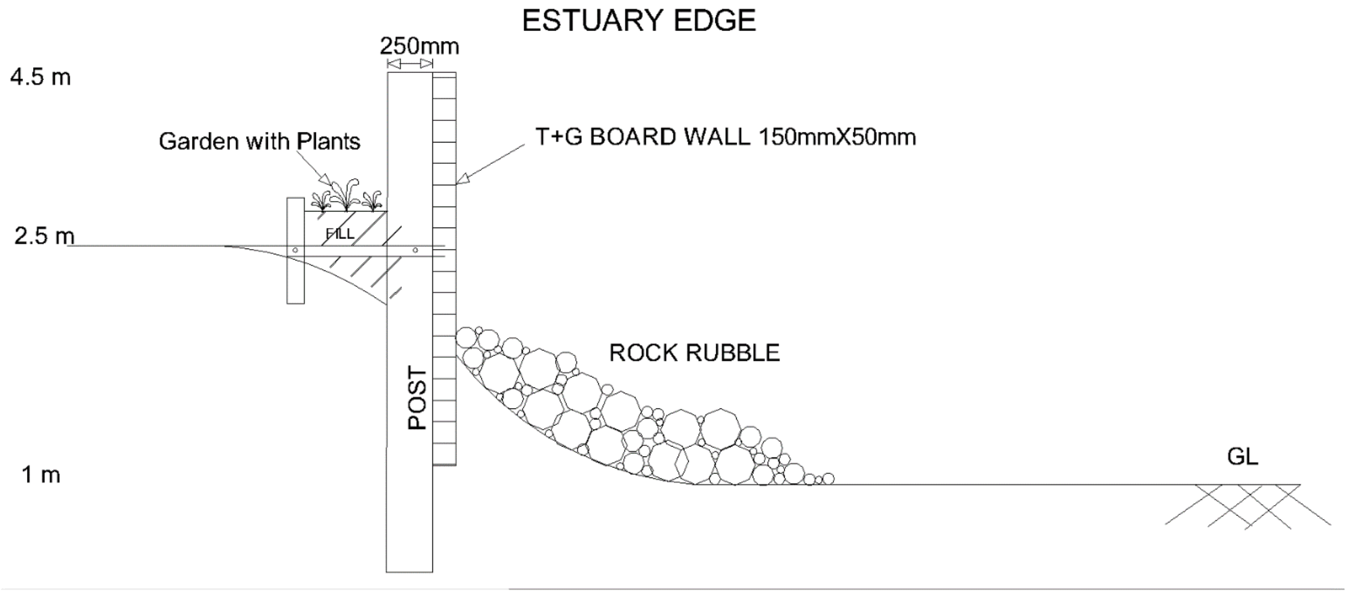


Figure 4-6 – Single wall concept sketch built on estuary edge

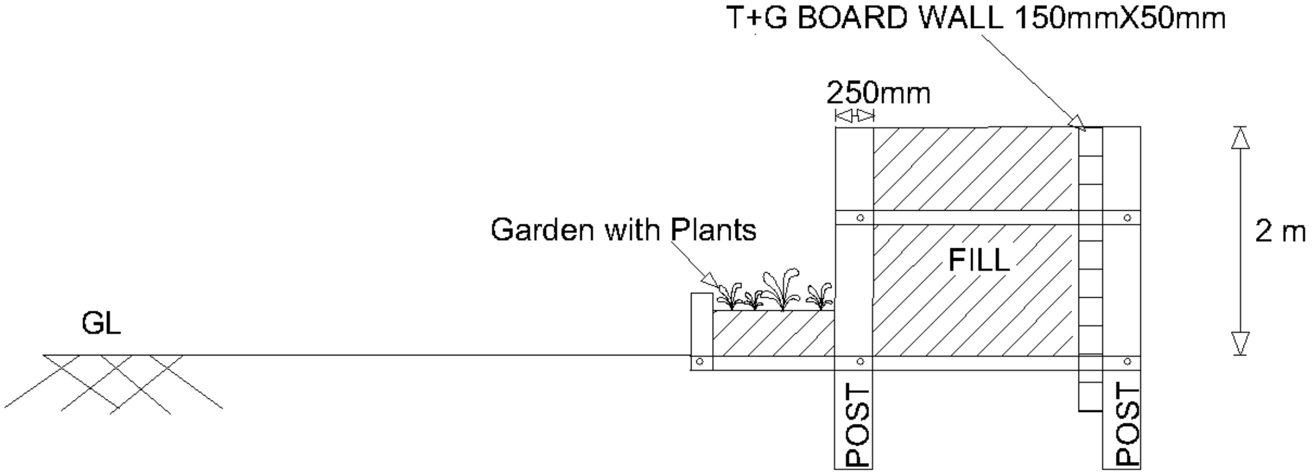


Figure 4-7 - Concept drawing for double timber wall

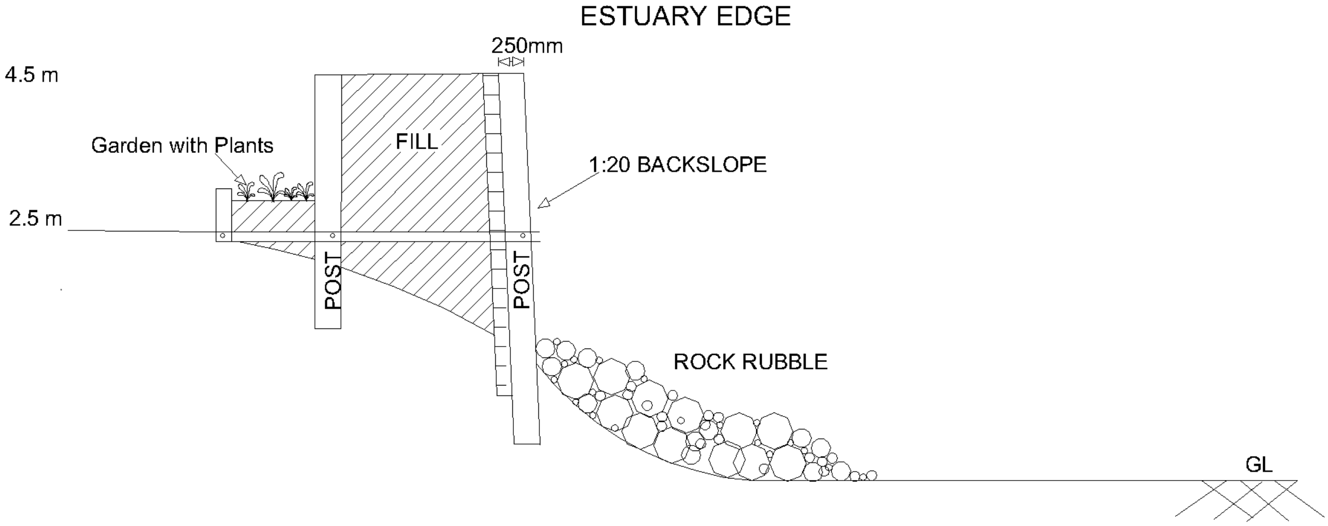


Figure 4-8 - Concept drawing for double timber wall

4.3 DESIGN PHILOSOPHY – LEVEL OF SERVICE / CLIMATE CHANGE ALLOWANCES

The original proposal presented to the community as part of the LTP process allowed for design to a 100-year ARI design level of service, based on a historic climate. This was an intentional decision made by the political leaders to allow some level of protection to be provided in the short term, which could potentially be raised further in the future as and when required / desired. It was intended that the stopbanks would have a crest width of at least 6m, allowing extra height to be added in the future.

Since then, it has been suggested that the stopbanks should be designed to a higher level of service and include an allowance for increased flows as well as higher sea levels to allow for a future climate scenario.

In order to provide an updated assessment into the likely impacts of sea level rise, NIWA were contracted to undertake an assessment into the potential impact on peak flow rates and duration for three separate future climate scenarios being RCP4.5, 6.0 and 8.5 (Zammit, 2022).

Discussions with NIWA scientists as well as internal discussions with the TAG group have come to the agreement that the RCP6 scenario is the most sensible to design for, with the consequences of an overdesign event being tested with an RCP8.5 event on the final preferred alignment.

However discussions within the TAG group have highlighted several issues around designing to the full 100-year ARI, Future Climate (RCP6) level of service in the Orowaiti Estuary area due to the following reasons:

- Design heights are significant with sea level rise projections adding on average 0.6m to the height of the wall along the estuary frontage. This will significantly impact on the aesthetic value of the area as well as increase the size of foundations required for the wall, and hence both the cost and amount of disturbance required to build the wall. In some locations the wall would be almost 3m high making it impossible to see the estuary from the road.

- Not allowing for climate change projections in the design sends a message that flood protection measures will not provide permanent protection and that long term strategies to move away from the hazard will need to be implemented in the short term. Serious thought may need to be given to trigger points which would initiate key objectives to move away from the flood hazard.
- Flood waters from the Orowaiti River and the coast have much lower velocities than Buller River flood waters and therefore a lower overall risk to loss of life. There is also a significant delay in arrival time in comparison with the Buller River and therefore more time to initiate evacuation in the case of an over design event.

A comparison of the design heights for a 100-year ARI (historic climate) event as well as for a 100-year ARI, Future Climate (RCP6) event is presented in Figure 4-9 and Figure 4-10.

Figure 4-9 – Design heights for a historic climate 100-year ARI event

Figure 4-10 - Design heights for a future climate 100-year ARI event RCP6 event

4.4 FREEBOARD ALLOWANCE

The following recommendations have been made in consultation with the TAG group in regards to stopbank sizing;

In addition to the peak water levels an additional freeboard of 0.6m should be added to all banks. This freeboard is to account for the inherent uncertainties within the hydraulic model as well to account for physical phenomena not represented in the modelling such as wave action, gravel mobilisation, turbulence, blockages etc. This level of freeboard is consistent with that adopted by the WCRC for other major rivers and is within the typical range adopted by other councils around the country.

Buller Bridge

In addition to a global freeboard of 0.6m, it is recommended that an additional 0.3m is added upstream of the Buller Bridge to allow for potential debris blockage (this has been based on sensitivity analysis) tapering of to 0m at the upstream end of the proposed stopbank.

It needs to be highlighted that the existing bridge does not have adequate clearance to pass the estimated 100-year future climate flow (RCP6) without having significant risk of debris blockage causing the waters to back up behind the bridge soffit which would cause the floodwaters to overtop the bank

Orowaiti State Highway Bridge

Buller River

An additional freeboard of 0.1m is currently proposed between the Orowaiti State Highway bridge and the Stephens Road Railway. The reason for the lower freeboard is that this bridge / causeway is already very low and is largely submerged during a design event.

It should be noted that the setup of this bridge has been largely simplified in the model on the advice of the Peer Reviewer (Wallace, 2022). It is recommended that in the detailed design phase, that more detailed headloss calculations are carried out on this structure, in order to confirm a suitable level of freeboard in this location before design heights are finalised.

4.3 CREST WIDTHS

Decisions around final design crest widths can be adjusted during the detailed design stage of the project, however for the sake of costing and visualising the potential stopbank footprints we have assumed the following.

BULLER RIVER

- 4m Crest Width upstream of the Buller River bridge
- 3m Crest width downstream (due to a lack of space)

OROWAITI RIVER

- 4m crest upstream of the Stephens Road Railway Bridge

In some areas which cross through farmland, the banks may be designed as gentle sloping mound which will have less impact on the farm operations than stopbanks with a 2:1 batter – it is expected that the exact alignment and footprint will be refined during the final detailed design stage in consultation with effected landowners.

4.3 BULLER RIVER SET BACK

Due to the ongoing lateral erosion on the true right bank of the Buller River upstream of the State Highway bridge and the likelihood of ongoing erosion due to the natural channel characteristics in this location, we have adopted a design philosophy that the stopbank base needs to be set back a minimum of 50m from the top of the existing bank. Setting the stopbank back from the bank provides significant advantages including;

- Reducing velocities along the riverside face of the stopbank and reducing the likelihood of scour.
- Providing room for access for maintenance of the stopbank as well as allowing access to the riverbank
- Providing a degree of buffer, allowing time to access the bank for repairs should significant bank erosion occur following a flood event.

In addition to providing a buffer width of at least 50m, planting significant riparian vegetation in this zone, would also have significant benefits by reducing the velocities of the water and therefore providing scour protection.

5. ANALYSIS OF PREFERRED ALIGNMENTS

A full set of depth as well as depth difference maps are presented in Appendix E and F.

In order to assess the impacts of the final scheme, we need to combine two sets of model results so that the worst-case scenario for both the Buller River, as well as the Orowaiti is considered. The worst-case scenario for the Orowaiti is when there is no vegetation at Organs Island and the worst case for the Buller is when the vegetation is in place, as this prevents some of the overflow down the Orowaiti and hence increases flood levels in the Buller River.

5.1 ASSESSMENT OF EFFECTS – PREFERRED ALIGNMENT

FLOOD DEPTH / EXTENT

Overall, the scheme is very effective at preventing inundation for the main urban Westport area as well as for the Carters Beach Community from river flooding. The Carters beach community along with the airport and golf course will still be exposed to coastal flooding however for a 100-year ARI return period coastal storm when combined with 1m sea level rise as shown in Figure 5-1.

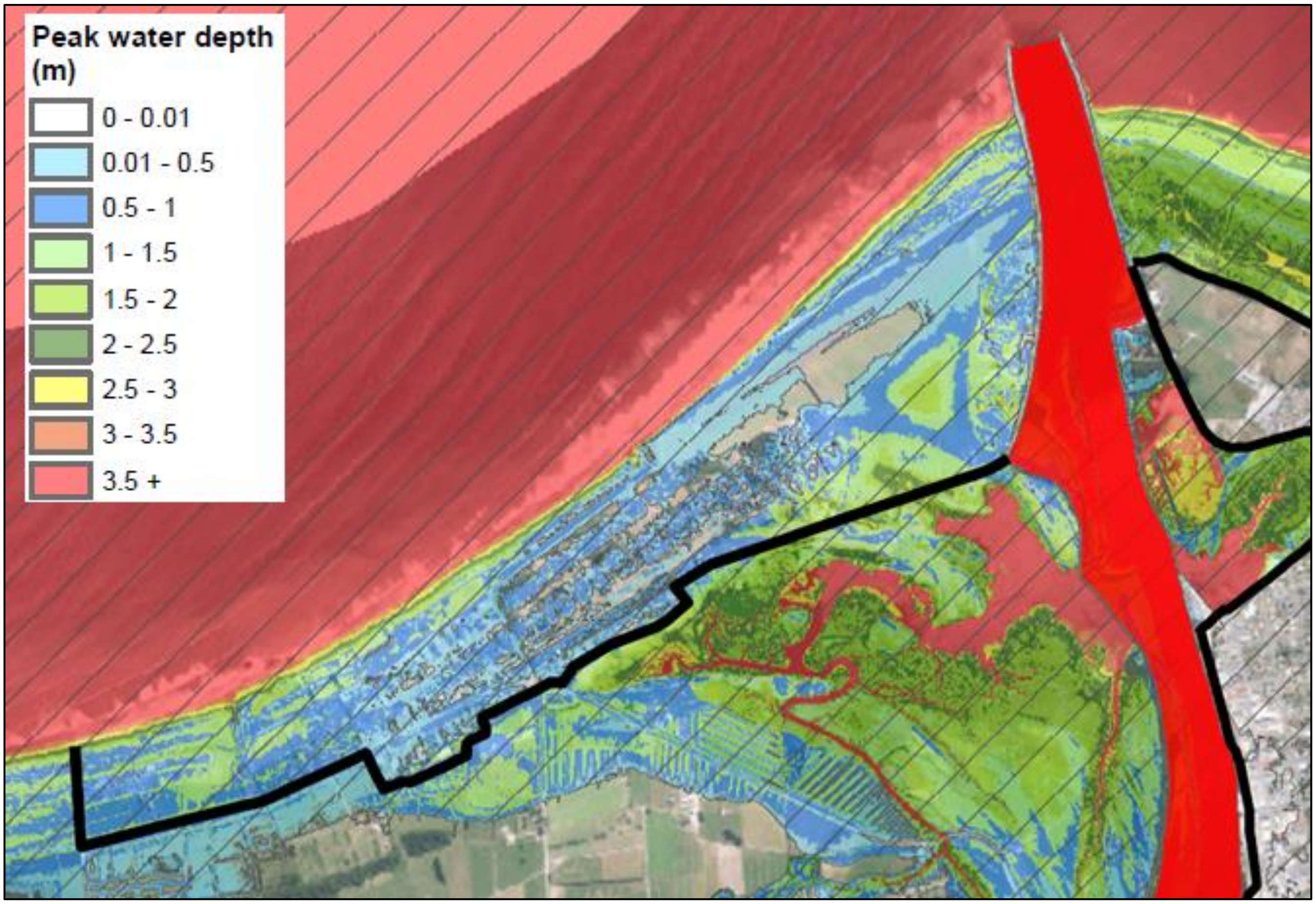


Figure 5-1 – Flood depth / extent for a 100-year ARI coastal storm with 1m sea level rise

Analysis of the results shows the most significant impact for this option is in relation to increases in peak flood depth in areas not receiving protection.

OROWAITI RIVER

Results show that water levels are decreased in the lower Orowaiti area / Snodgrass area due to the fact that flood waters are prevented from spilling out of the Buller River and entering the lower reaches of the Orowaiti, however results do show that flood levels upstream of Stephens Road will increase by between 0.1 and 0.25 m over a distance of approximately 2km (Figure 5-2) during a 100-year ARI, future climate (RCP6) event. This increase in levels does not take into account any upstream revegetation at Organs Island which is expected to reduce flows down the Orowaiti and hence mitigate some of this increase however may take decades before the full benefits can be realised.

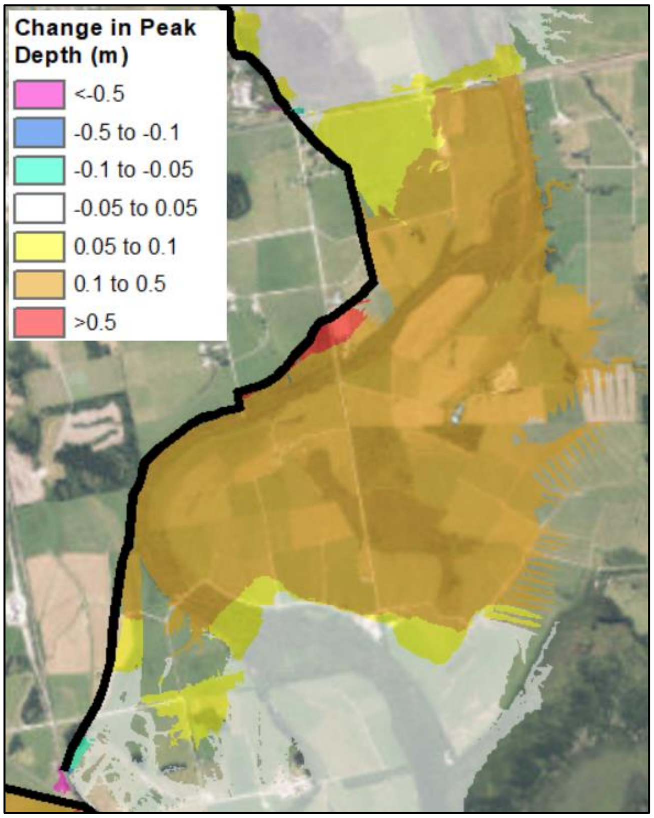


Figure 5-2 – Change in peak water levels for a 100-year ARI, future climate (RCP6) event (preferred alignment)

BULLER RIVER – LEFT BANK

Table 5-1 – Summary of increases in peak water levels on left bank of Buller River (downstream of bridge) for the proposed Alignment

Scenario	Increase in peak depth (m)
20-year ARI (Historic Climate)	0.05
50-year ARI (Historic Climate)	0.09
100-year ARI (Historic Climate)	0.13
100-year ARI, Future Climate (RCP6)	0.4

IMPACT ON BRIDGES

The impact of the stopbanks on peak water levels at each of the State Highway bridges has been assessed in the model.

Buller River SH6 Bridge

Results show the peak water level is increased by up to 0.16m as a result of the stopbanks. A summary of peak water levels is presented in Table 2-4.

Table 5-2 – Summary of modelled peak water levels at Buller River SH6 Bridge (no allowance for potential debris blockage)

Scenario	Base Scenario Peak Level (m)	Option A Peak Level (m)	Increase (m)
100-year	5.12	5.33	0.21
100yrRCP6	5.44	6.0	0.56

Table 5-3 – Impact on bridge freeboard (not allowance for potential debris blockage)

Scenario	Base Scenario Available Freeboard (m)	Option A Available Freeboard (m)
100-year	1.04	0.83
100yrRCP6	0.72	0.16

Results show that there is a lack of available capacity under the main Buller River bridge which will be exacerbated by the proposed scheme particularly for the future climate RCP6 scenario. The Waka Kotahi bridge design manual specifies a desired minimum freeboard for new bridge structures to be 1.2m above the 100-year ARI flood level. Extending protection to the airport is the primary cause for raising the levels in the Buller River with a significant overflow path blocked off by the bank. It is essential that the bridge is raised in the near future if this bank is built.

Orowaiti River SH6 Bridge

Results show the peak water level is increased by up to 0.21m as a result of the stopbanks constricting the flow at the location of the bridge. Of note is that water levels in the 100-year ARI, future climate (RCP6) scenario are reduced at the bridge, this is largely due to the fact that significant overflows from the Buller River are no longer reaching the Orowaiti Estuary due to the ringbank in place. A summary of peak water levels is presented in Table 2-6 below. These levels have been reported without any vegetation at Organs Island to present the worst case scenario.

Table 5-4 - Summary of modelled peak water levels at Orowaiti River SH6 Bridge (no allowance for potential debris blockage) for Option A (without vegetation at Organs Island).

	Base Scenario	Option A	Increase
20-year	2.45	2.63	0.18
50-year	2.98	3.19	0.21
100-year	3.30	3.51	0.21
100yrRCP6	3.92	3.87	-0.05

IMPACT ON FLOW SPLIT

The following table summarises the impact on the flow split down the Orowaiti River. The results show that the scheme has little impact on the flow split on events up to a 100-year ARI (historic climate), however reduces the volume of water going down the Orowaiti in a future climate scenario.

Table 5-5 – Impact on flow split

	Orowaiti Flow Rate (m^3/s)			
	20-year ARI	**50-year ARI**	**100-year ARI**	**100-year RCP6 ARI**
Base Scenario	583	951	1231	1620
Option A	NA*	NA*	1146	1572

**Not assessed to date however some reduction in flow is expected*

CARTERS BEACH

Model results show that the main Carter's Beach urban community will be protected from river flooding for the full range of events, however, will remain unprotected in a 100-year ARI, future climate (RCP6) scenario. Depth difference results show that whilst coastal flooding will be no worse for a 100-year ARI event (historic climate), there will be an increase in flood risk for a future climate scenario on some properties between 0.1 and 0.2m as shown in Figure 2-5.

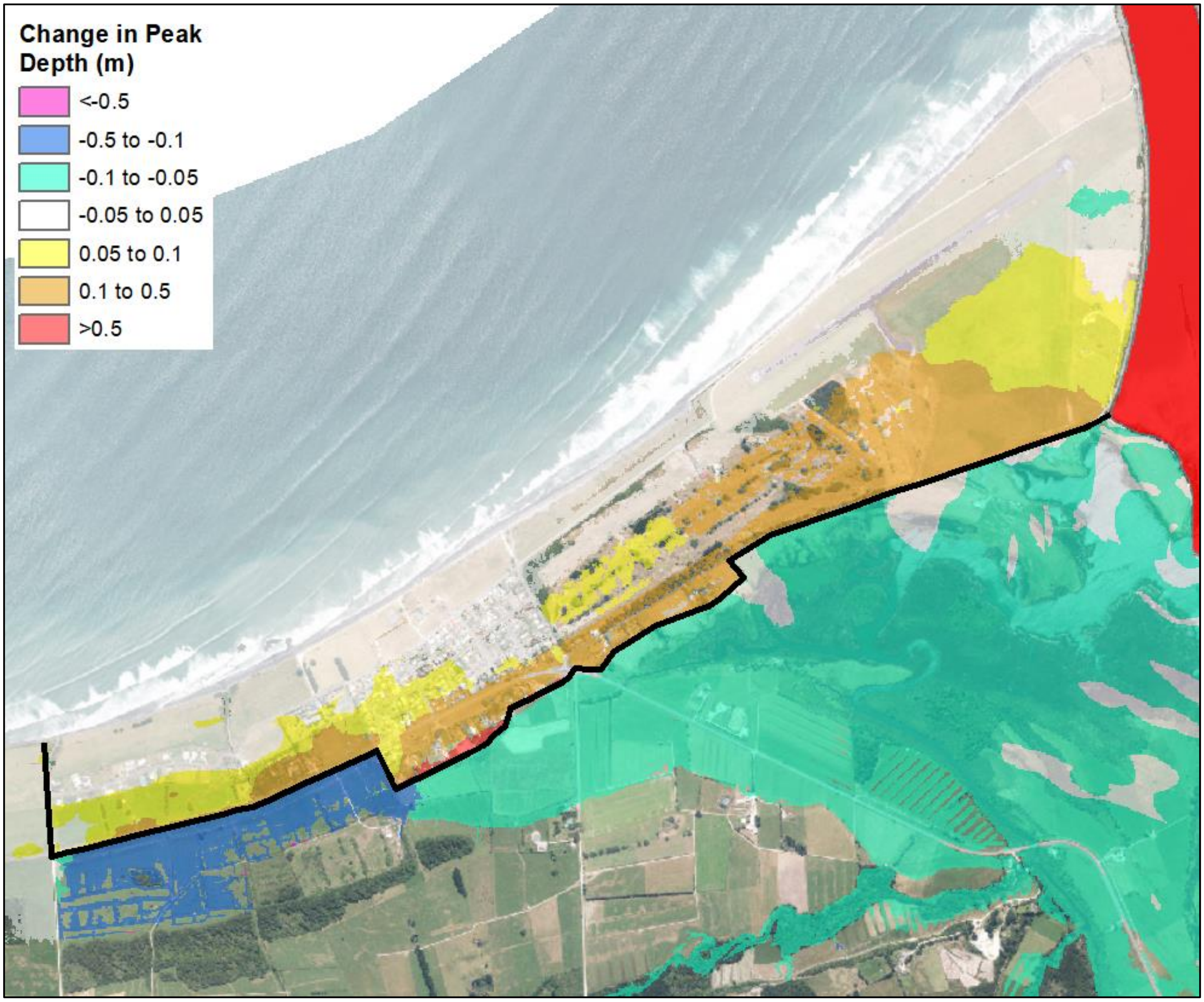


Figure 5-3 – Increase in peak depth for a 100-year ARI coastal storm with 1m sea level rise

SNODGRASS

Model results show that by not providing protection to Snodgrass, flooding will be no worse than it currently is. However, for a 100-year ARI, future climate (RCP6) scenario flood levels are actually reduced. This seems surprising at first, however the reason for this reduction in flood level is due to the prevention of additional water from the Buller River from crossing over Westport and into the Orowaiti due to the ring bank being in place.

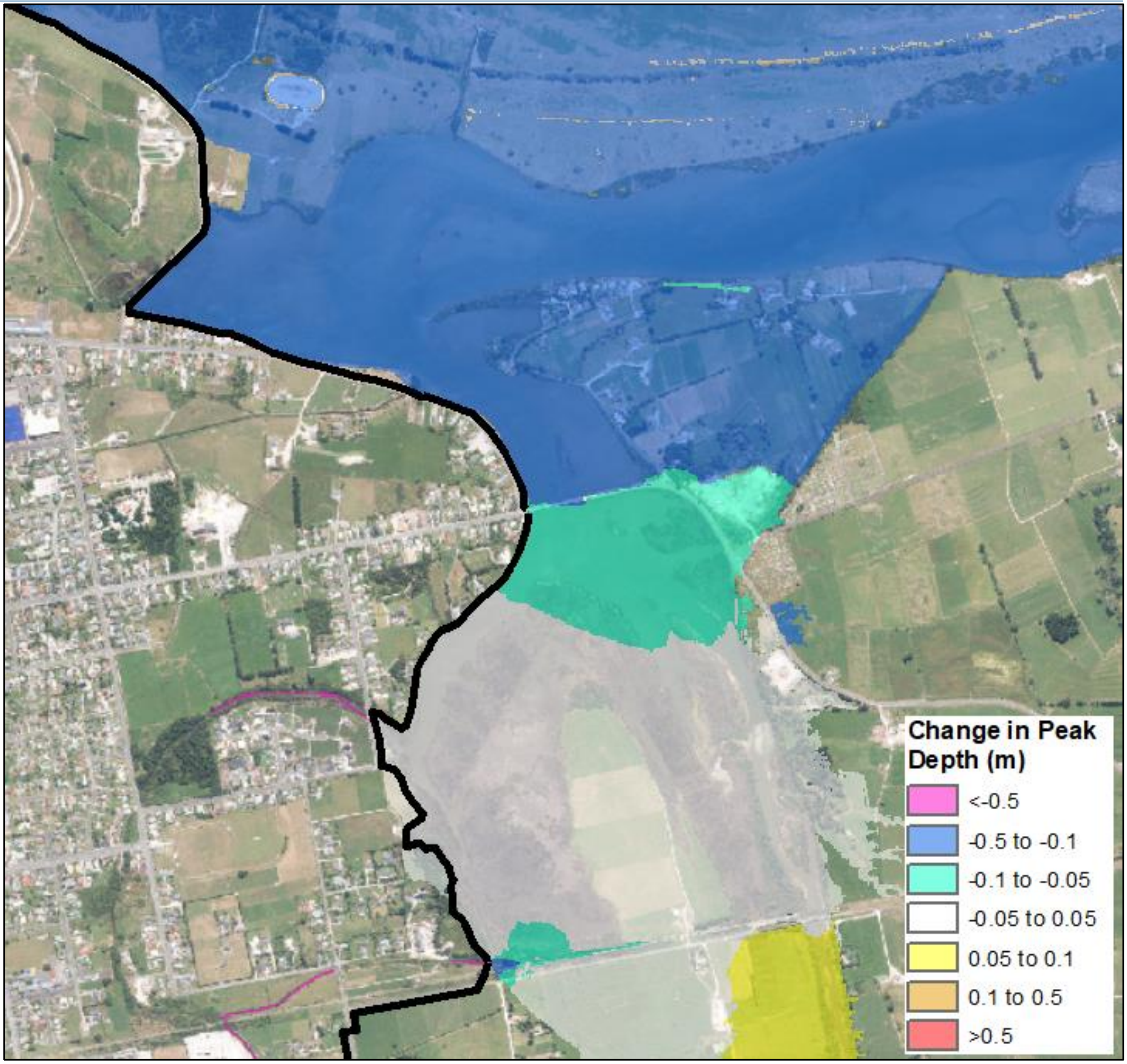


Figure 5-4 – Decrease in peak depth for a 100-year ARI future climate (RCP6) event

5.2 ASSESSMENT OF EFFECTS – ALTERNATIVE ALIGNMENT (TOWN BANK)

FLOOD DEPTH / EXTENT

Overall flood depths and extents are very similar to the preferred alignment with exception to the rural / semi urban areas which are not provided protection in this scheme.

Results show that much of the unprotected land on the Orowaiti Side remains relatively flood free in events up to a 100-year ARI event (historic climate).

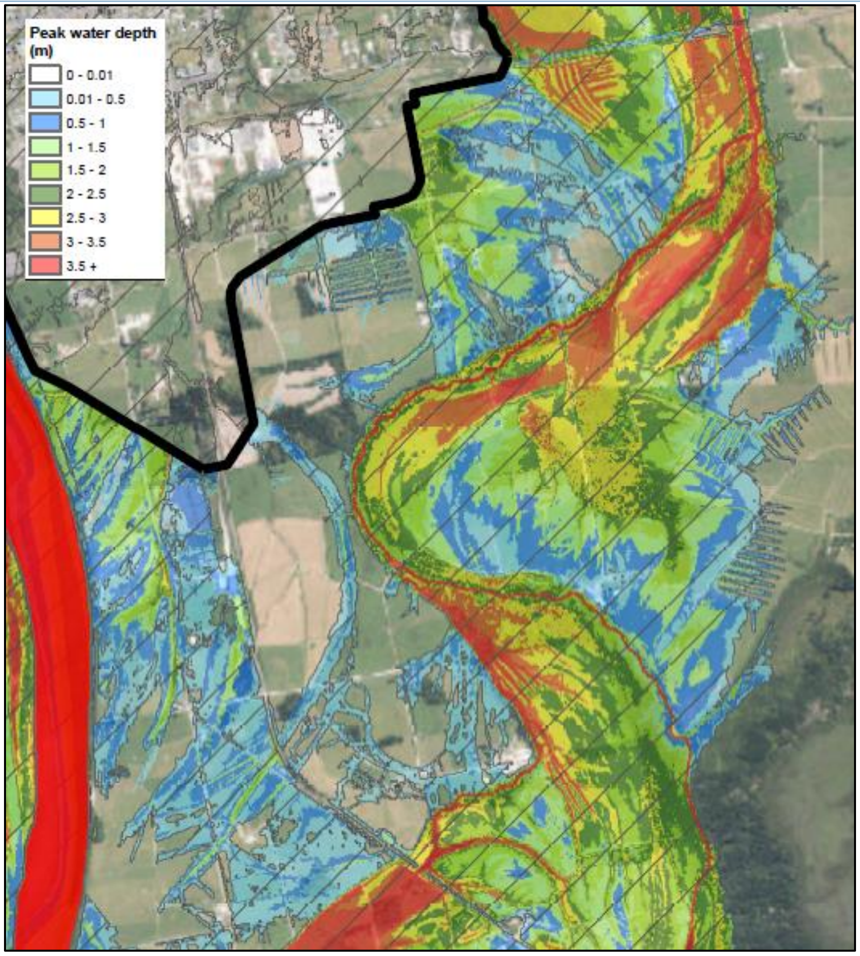


Figure 5-5 – Peak depth / extent for 100-year ARI event (Historic Climate)

DIFFERENCE IN FLOOD DEPTH

OROWAITI RIVER

The main difference between the two preferred alignments is around the area protected from flooding from the Orowaiti overflow with the main alignment protecting a greater number of properties.

Whilst there are additional properties flooded as a result, one advantage is that water levels upstream from Stephens Road are significantly less than with the previous alignment due to the fact that the flood waters can disperse over a wider area and as a result there is no significant increase in impact on existing road and rail infrastructure for events up to a 100-year ARI, future climate (RCP6) event.

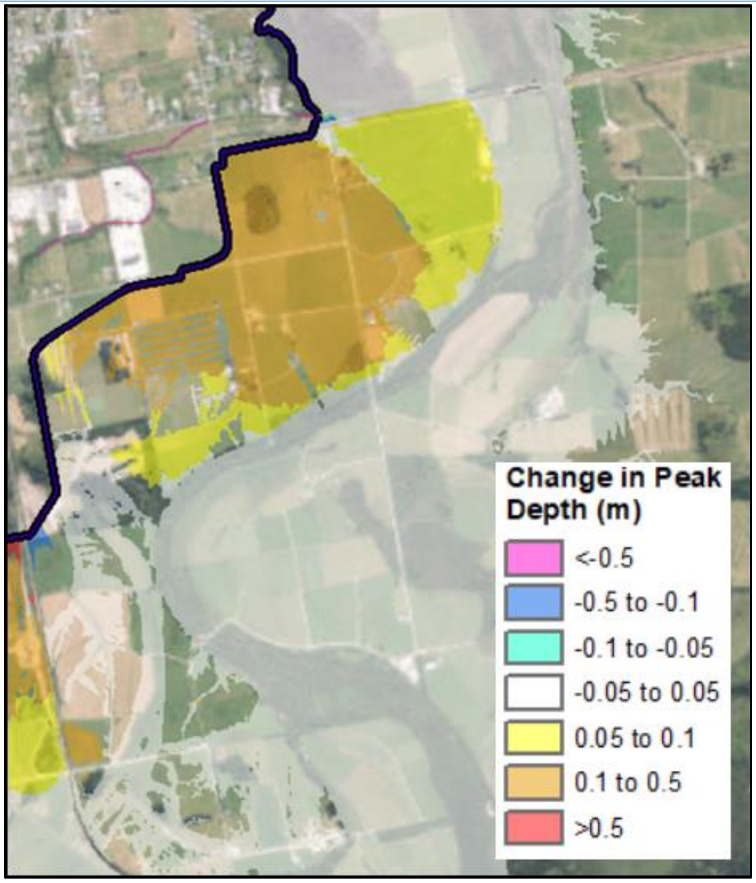


Figure 5-6 - Change in peak water levels upstream of Stephens Road for a 100-year ARI, future climate (RCP6) event (Alternative alignment)

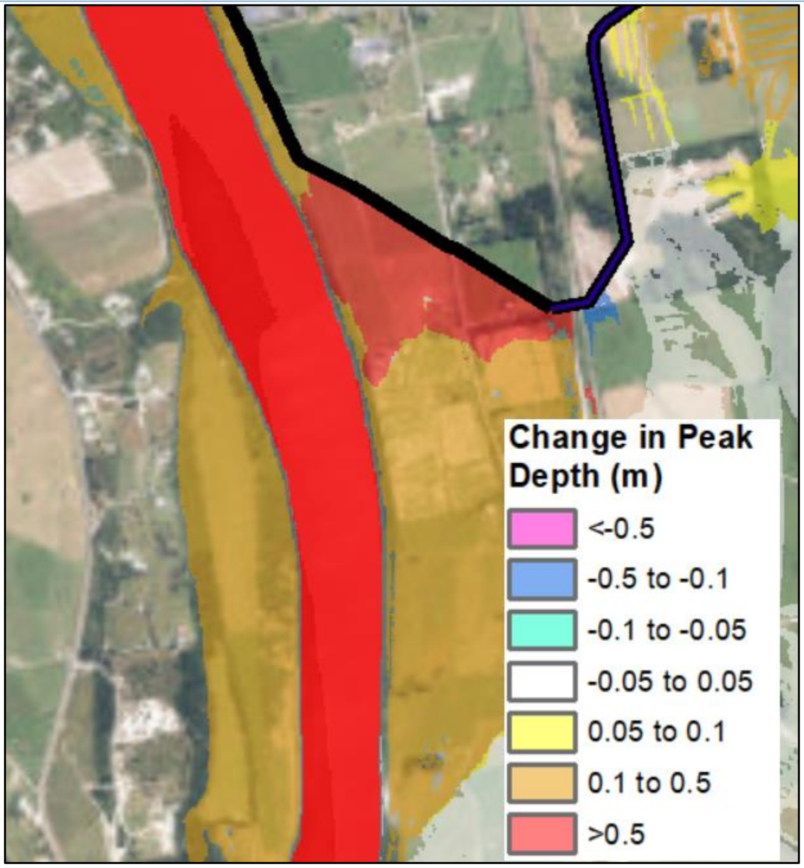


Figure 5-7 - Change in peak water levels on the Buller River right bank for a 100-year ARI, future climate (RCP6) event (Alternative alignment)

5.3 IMPACT OF OVERDESIGN EVENT

The current proposal only allows for banks being constructed to a 100-year historic level along the Orowaiti River downstream from the Stephens Road railway bridge. Buller River stopbanks and Orowaiti Banks upstream of the Stephens Road railway embankment however are designed to be constructed to a 100-year ARI – future climate RCP6 level of service.

Two overdesign events have been simulated. The first simulates the degree of flooding for a 100-year ARI future event (RCP6) against the proposed scheme. This event is expected to cause overtopping for the section of banks on the Orowaiti side, downstream from the Stephens Road railway embankment. The second scenario simulates the degree of flooding for a 100-year ARI, future event (RCP8.5) against the proposed scheme. This event is expected to cause overtopping from both the Buller River side as well as the Orowaiti.

Peak flood depth and difference in depth maps are presented in Appendix G, with a sample of the results presented in Figure 5-8 and Figure 5-9 below.

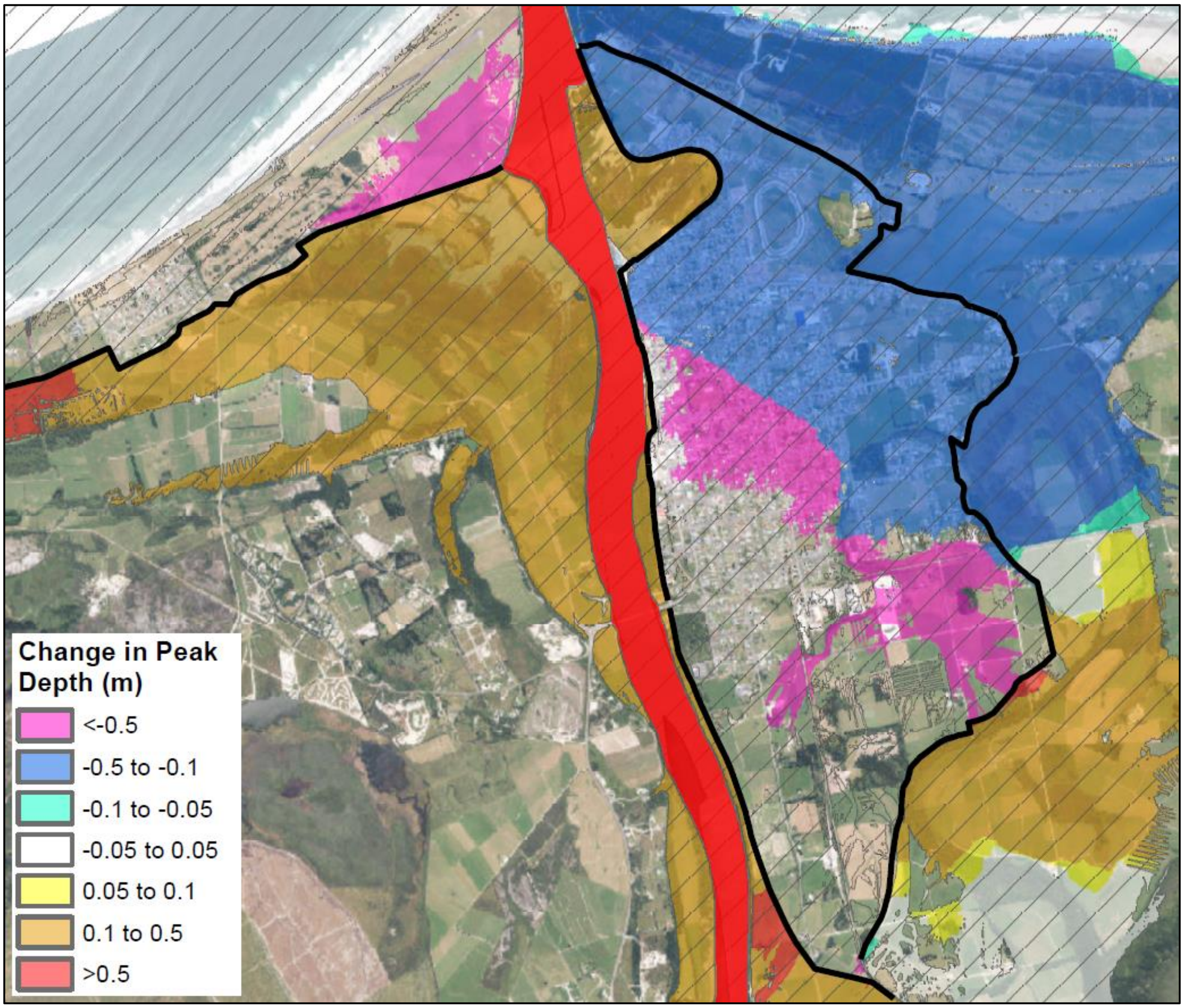


Figure 5-8 – Depth difference maps for an overdesign event with 100-year ARI - future climate (RCP6) flows

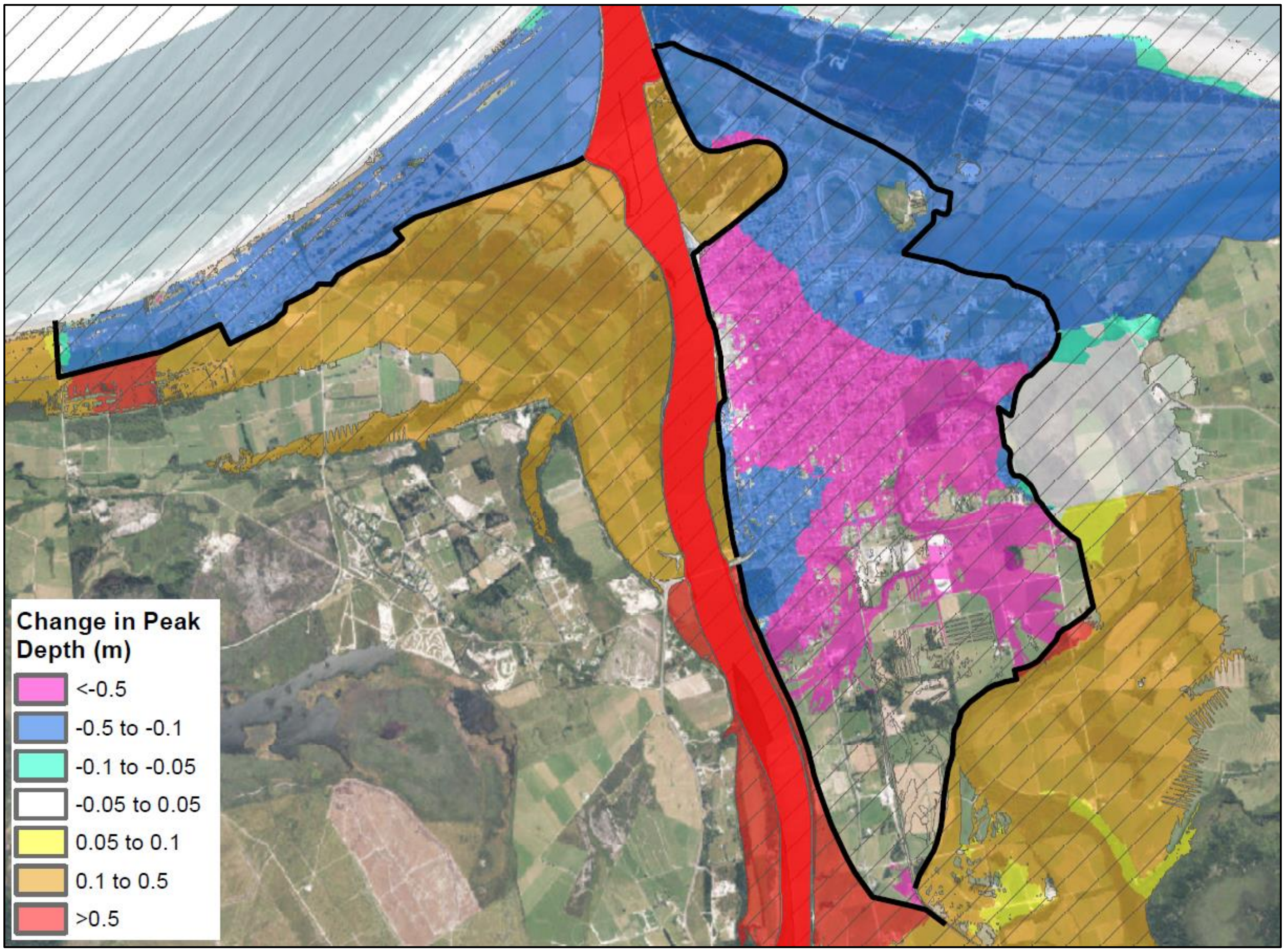


Figure 5-9 - Depth difference maps for an overdesign event with 100-year ARI - future climate (RCP8.5) flows

The key conclusion we can draw from the overdesign events, is that whilst there will still be significant flooding in town should an overdesign event occur – the depths are significantly less than would be the case should the stopbanks not be in place at all.

It must be acknowledged however that the banks will trap the water in the town should they overtop, and consideration will need to be given to having at least one sacrificial section of bank that can easily be demolished to allow the water to flow back into the Orowaiti should an overdesign event occur.

6. REFERENCES

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APPENDIX A – OPTIONS MAPS

APPENDIX B – PEAK DEPTH MAPS (OPTIONS 1 TO 7)

APPENDIX C –DEPTH DIFFERENCE MAPS (OPTIONS 1 TO 7)

APPENDIX D – PREFERRED OPTION STOPBANK DESIGN ALIGNMENT / FOOTPRINT

APPENDIX E – PROPOSED SCHEME – PEAK DEPTH MAPS (OPTION A & B)

APPENDIX F – PROPOSED SCHEME – DEPTH DIFFERENCE MAPS (OPTION A & B)

APPENDIX G – OVERDESIGN EVENT MAPS– DEPTH / DEPTH DIFFERENCE MAPS (OPTION A)