Impacts of Climate Change on Urban Infrastructure & the Built Environment

A Toolbox

Westport Case Study: Initial Assessment of Climate Change Flood Adaptation Options

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1. Introduction

1.1 Preamble

The Toolbox has been developed to assist Councils, and others, in taking account of long-term climate change effects in their on-going asset development and management, with the broad aim of making urban infrastructure more resilient to climate change.

The Toolbox contains case studies which are intended to illustrate how a number of the tools can be used in practice to evaluate a specific aspect of climate change in a given location or study area. The case studies are also intended to assist decision-makers in developing strategies on how best to adapt to these identified effects.

This case study provides an initial assessment of flood impacts and selected adaptation options for Westport. It uses flood modelling to generate likely flood predictions for the Buller River, then applies rapid cost/benefit evaluation [Tool 4.3] to four options previously selected in workshop sessions with council representatives.

The Toolbox is specifically concerned with the risks that will arise from climate change effects and uncertainties, and not the risks and uncertainties associated with the drivers of climate change.

1.1.1 Background

Westport faces flooding issues from the sea and the Buller River. Like many communities around New Zealand affected by flooding, Westport has limited resources that can be committed to a wide-ranging assessment of response options. Any flood adaptation option that is chosen has to be affordable and acceptable to the local community. The challenge, therefore, is to provide relatively simple, but robust, methods for short-listing viable adaptation options.

The Westport community is well aware that climate change projections mean that the existing flooding risks are likely to be intensified and the long-term flood mitigation strategies that are currently underway may need to be revised or expanded in the future.

The aim of this study was to demonstrate an assessment process for adaptation options for a climate change flood risk scenario using off-the-shelf tools and normal engineering practices, together with selected tools from the Toolbox. The primary focus is in gaining an initial understanding of which types of adaptation are feasible using relatively simple models and high-level cost information. It is therefore seen as a precursor to more detailed evaluation of the preferred option(s).

The selected scenario is a strategic evaluation of a number of adaptation options applied to Westport based on discussion with the local authorities. At a meeting with representatives from Buller District and West Coast Regional councils, a number of ideas were presented for consideration as flood mitigation strategies in response to climate change. Most of these have had little or no formal assessment to date but were included in the case study for initial assessment and comparison in terms of their benefits and costs.

The case study illustrates how broad options for flood adaptation can be evaluated at a relatively high level, taking account of long-term climate change, so as to shortlist viable options for more detailed analysis and discussion with the affected community. The study represents a high-level assessment of strategic options. Relatively simple flood and cost models have been used with an explicit treatment of uncertainty to account for uncertainties in long-term climate change impacts and the simplifying modelling assumptions made in the analysis.

1.2 Objectives

The objective of this case study is to illustrate the use of selected Toolbox tools in a real situation to provide insight to decision-makers and affected communities on the relative merits of broad options for flood mitigation in response to climate change. The study seeks to show how fundamentally different flood adaptation options for Westport can be compared and their economic viability evaluated at a strategic level, and in a robust way, to help inform future policy directions and flood mitigation planning.

2. Case Study Overview

2.1 Location and Scope of Study

Westport is a township that is positioned next to the Buller River and near to the coast on the historic Buller River floodplain fan (Figure A1, Appendix A). The population during the 2006 Census was 3,783, and comprises 1,725 dwellings.

The three main access roads into town cross the Buller River or the Orowaiti River. The port facilities are on the right bank of the river, with the main commercial road through Westport set back by one or two blocks from the river. The river is intermittently dredged at the mouth to allow cement ships to load from a wharf along the river edge. A railway from the coal mines to the north-east of the town passes through Westport and carries coal inland to Reefton and further afield towards Christchurch.

The Buller River catchment covers 6,350 km^2 and flows are monitored by the flow recorder at Te Kuha some 16km upstream from the river mouth. The river carries a large amount of water from the West Coast Buller Region which is one of the wettest places in New Zealand, contributing an annual average flow of approximately 430m^3/s.

The river mouth into the Tasman Sea is stabilised by sea walls and regular bed dredging is carried out to maintain throughput of the river bed load where the river gradient flattens. The lower reach of the river has a mid-channel constraining wall to constrict low flows and keep sediments moving in a higher velocity current.

The township itself does not have a large or extensive stopbank system because the river bed geology, neighbouring topography, mid-channel wall and other maintenance structures serve to constrain the main channel alignment in place, and keep the river mouth capacity high.

The right bank Orowaiti River now only provides an overflow channel during large rainfall events. At such times, the Buller River flow spills through culverts and bridges under the railway line embankment that leads to Reefton. When both the Buller River and Orowaiti River are in flood, the Westport township is effectively surrounded by floodwater and the sea coast.

2.2 Climate Change Concerns

The main effects of climate change on Westport are expected to be increased rainfall and runoff from the Buller River catchment, along with an increase in bed load volume due to more landslip materials entering the river. By the year 2090, the mean sea level is expected to rise by 0.4 – 0.8m, and the coincidence of peak tides and large river flows is expected to increase. These effects all combine to imply that today's 0.01 AEP magnitude storm event will become more frequent. Gravel bed load movements from the catchment will also increase due to more intense rainfall and greater flood flows. Natural deposition rates at the river outlet will increase due to the rise in average sea level.

The main objectives of current river harbour management and flood protection are to maintain the commercial viability of the harbour, to prevent flooding in Westport and to keep road and rail linkages intact. Climate change effects will require increased river maintenance effort and more flood protection measures to keep the flood risk at current levels.

Secondary climate change impacts may, for example, include an increase in flood insurance premiums in the face of perceived flood risk, and concerns on diminished land and property value for residential and commercial owners. The viability of industry regarding flood-prone locations and potential for disruption to business is further affected by the increased risk to infrastructure such as road and rail bridges that services these premises.

2.3 Adapting to Climate Change

Current engineering response to climate change flood risk is principally through increasing the design standard for flood protection schemes. The New Zealand Building Code requires housing to be clear of the 50 Year ARI flood level (i.e. 0.02 AEP design) and this will be progressively more difficult to meet as climate change impacts intensify. Increasingly, a 0.01 AEP design standard is now seen as a minimum acceptable level of protection for buildings.

Climate change is therefore already putting additional cost on today's capital works through the provision of more robust design. The process of option evaluation is now considered to include a range of strategies that include traditional approaches that have worked well in the past, new approaches that may prove to be beneficial under long-term design horizons, and more 'unpalatable' options that communities are increasingly being required to consider in open discussion.

This case study uses a simplified process for the initial evaluation of adaptation options to demonstrate to the local community the potential viability of as wide a range of options as possible. Each selected option is then broadly defined to a comparable level and assessed on an 'order of magnitude' cost versus benefits basis. The methodology and data needs of this study are described in the following section.

3. Data Needs and Methodology

3.1 Data Needs

A number of data sets are needed to conduct this type of assessment. For this flood risk case study the data needed included: tidal levels, river flow data, rainfall records, climate change projections, topographical and river bed data, and GIS data including land use and land values. Most of these data sets are readily available in total or in part from electronic records held by councils. Data sources used in this study, and potential other sources, are briefly outlined below.

For *tidal data*, the top water level is important, and in the case study this was well known at Westport from harbour records. Other coastal locations will have tidal records; alternatively NIWA and the Port Authorities publish such records for around the country.

River flow data is used for estimating peak discharge and hydrographs. All river flows in New Zealand can be assessed using an empirical procedure, based on a nationwide flow gauge network, using the Regional Flood Estimation process.

Rainfall records were used for input into a runoff model of Buller River. NIWA have developed a rainfall design tool, HIRDS (High Intensity Rainfall Design System), to give an intensity-frequency-duration table for all parts of the country, based on location coordinates.

Climate change projections for sea-level rise and river flow were calculated by NIWA specifically for the Buller River as part of this case study. Climate change guidance documents published by the Ministry for the Environment (MfE) give data on anticipated changes in rainfall intensity and sea level rise for all parts of New Zealand up to the year 2090. The MfE guidelines also give ranges of effects due to different climate change model scenarios.

Aerial survey data was available in Westport to describe the topography, and river cross-sections were added into the digital ground model. Many places in New Zealand have aerial mapping as well as field survey data held at councils. The whole country is covered by a 20m contour data set that can be converted into a ground model but the accuracy is not suitable for flat areas where levels are important. In some areas, a ground survey using GPS (global positioning survey) equipment may be required to define the ground shape for use in modelled calculations.

Aerial photography is now available from Google Maps for the whole country.

Land and property information can be obtained from the council rates database, Quotable Value property data, LINZ (Land Information New Zealand) and other governmental and local authority databases.

In this case study, various spatial data sets were incorporated into a GIS model for ease of visualisation, and to automate the estimation of the flood damage to land and property. The GIS was used to superimpose modelled flood depths on a grid cell layout representing land use zone and value. The damage costs were then calculated in the GIS model using simplified spatial relationships between the depth of flood water and the damage cost of the landuse zone inundated at each grid cell.

Flood damage costs included both direct and indirect costs. Direct costs principally arise from damage to buildings, infrastructure and businesses, estimated using historical information of past New Zealand floods as a guide. Indirect costs arise from clean-up costs, and health and social costs derived on the basis of the lost time and injuries likely to be caused by the predicted flood extent and depths. The attempt is to derive costs to the region, which are likely to be considerably higher than the direct damage costs alone.

As an alternative, maps of flood extent may be produced and broad estimates made of the damage caused through a process of expert elicitation, as described in [Tool 3.5].

3.2 Overview of Software Modelling Tools Used

The non-Toolbox tools used in this case study include: a rainfall-runoff model, a 1-dimensional hydraulic flood model, surface water definition software, GIS and spreadsheets. This information and software is commonly available and often used by consultant engineers and council staff.

A brief description of the above tools used in this Westport case study is given below:

- A rainfall-runoff model was used to convert rainfall from NIWA HIRDS information into a flood hydrograph.. Rainfall runoff software such as HEC-HMS (developed by the Hydrologic Engineering Centre of the US Army Corps of Engineers) is available from freeware websites. NIWA has developed a national model called TopNet.

- A 1-dimensional (1-D) hydraulic flood modelling programme was used as a simple alternative to more complex 2-D models. The 1-D programme calculates flood levels based on flow inputs, cross-sectional areas and tidal conditions, and can be run quickly with different hydrology or boundary conditions. 1-D hydraulics software is freely available on websites (e.g. HEC-RAS) and commercially available products include MIKE11 by DHI. (A 2-D model is more accurate for floodplains and situations where the effects of flooding are not obvious but will be slower to run scenarios and more complex to assemble. 2-D software should be used for options that require more detailed assessment, typically after an initial options assessment has refined the options to a small number of feasible alternatives).

- Conversion of water level to flood surface – a means of converting a top water level at a river branch cross-section into a flood surface over a flooded area beside the river is required. This can be roughly estimated by hand using contour maps or more accurately derived using GIS software and digital terrain models (e.g.

derived from LiDAR data). An example commercial GIS product is Vertical Mapper by MapInfo; an example non-GIS mapper is WaterRide flood management software by Worley Parsons. In the Westport case, WaterRide software was used with MIKE11 hydraulics software to calculate the extent of the flood surface.

- A GIS model of the flood extent was superimposed upon a number of data layers to calculate a summed flood damage cost based on a flood-damage relationship. This model calculated the flood depth and damage at each grid cell in Westport. A spreadsheet and manual process could be used for smaller areas of interest. (Note: the RiskScape tool [see Tools 3.2 and 3.3] can also be used for this purpose).

- Spreadsheets were set up to document and summarise results, and present the information in a clear manner. Spreadsheets were also used to perform the discounted cost and benefit calculations for the comparison of alternative options on the basis of a Benefit-Cost Ratio (BCR). Spreadsheets are of value due to their universal availability, adaptability and the ease with which sensitivity analysis and presentation outputs can be produced.

3.3 Overall Case Study Methodology

The process of evaluating flood adaptation options for Westport started with a site visit and was followed by two workshops with key representatives from the local authorities.

The first workshop comprised a facilitated discussion of a wide range of climate change effects and potential impacts on the built environment in Westport (for example, effects of increased rainfall and flood risk, rising temperatures and sea-level rise on water supply, utilities and transport infrastructure). These discussions were facilitated and recorded using the Sensitivity Matrix [Tool 1.6]. The key climate change threat from this asset/infrastructure sensitivity review was determined to be flooding from the Buller River.

The second workshop involved a discussion of a range of flood mitigation measures that could be considered for Westport. Examples included dams in the upper catchment, channel diversions, earthen stopbanks, managed retreat or relocation of the town, as well as widespread raising of house floor levels. Following the workshop, four very different adaptation options were selected to demonstrate the decision process used in this case study (see Section 4.2).

The overall process methodology used in this case study is illustrated in the process diagram depicted in Figure 3.1.

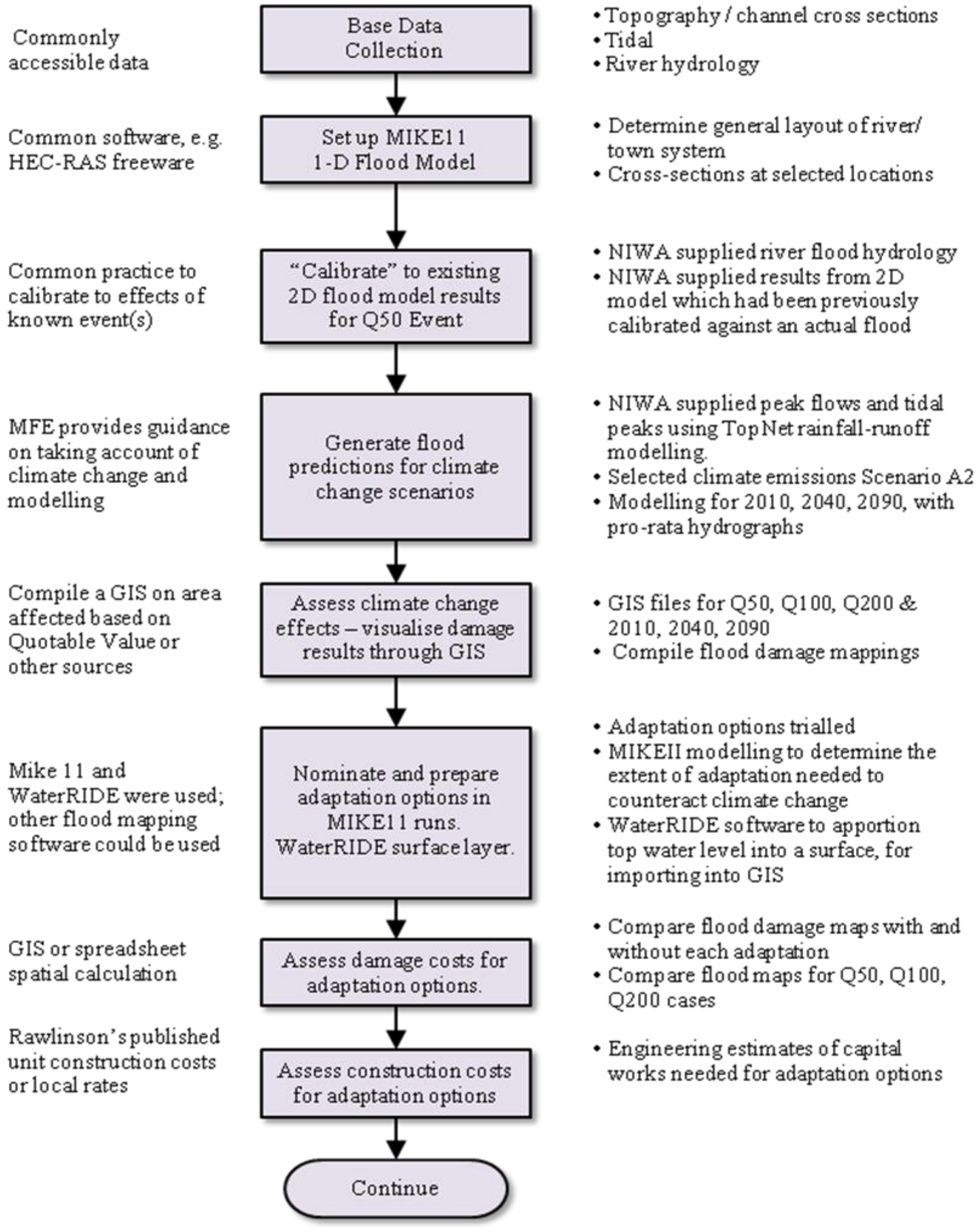

Figure 3.1: Methodology Process Diagram (continued overleaf)

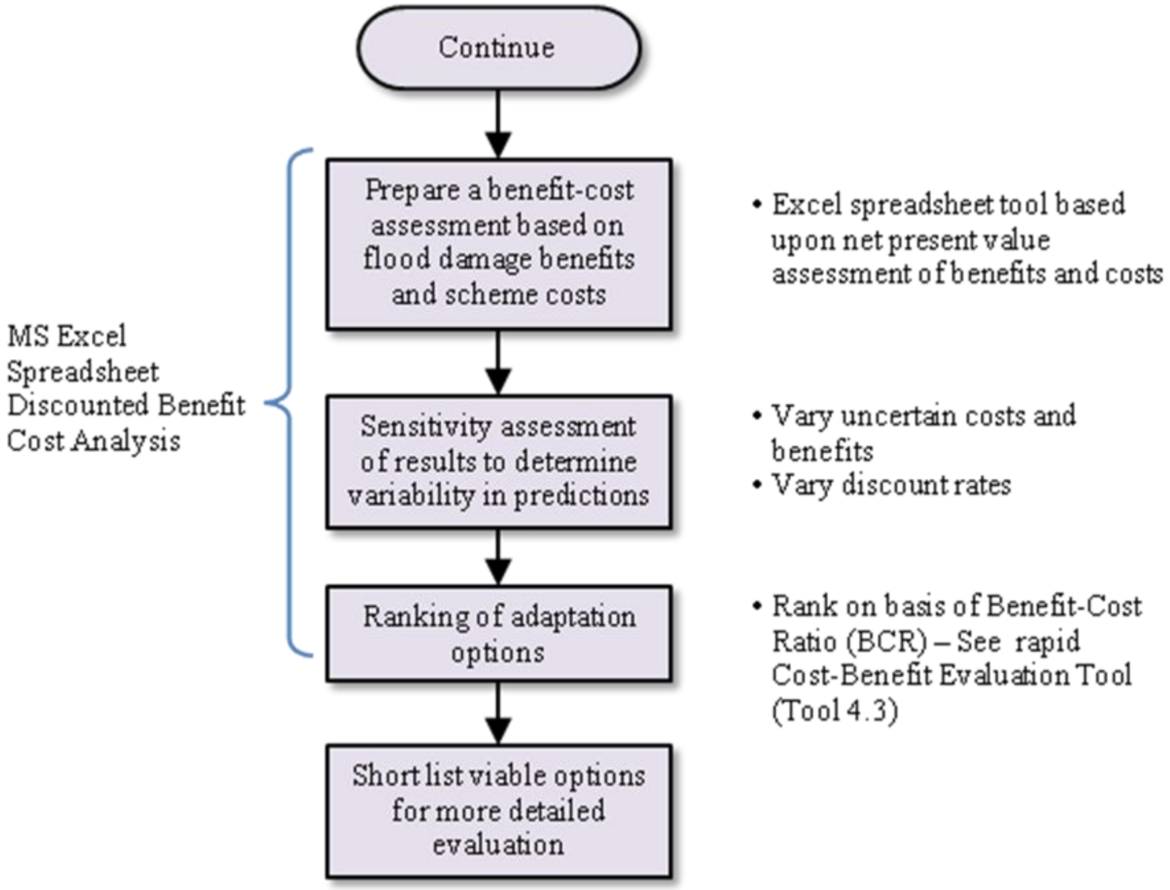

Figure 3.1: Methodology Process Diagram (continued from previous page)

4. Adaptations to Climate Change Flood Impacts

4.1 Projected Climate Change Impacts

Analysis of climate change impacts at Westport by NIWA gave a projected sea level rise at the Buller River mouth of 0.4m by 2050 and 0.8m by 2100. The peak flows in the Buller River under the chosen emissions scenario (Scenario A2) are shown in Table 4.1.

Table 4.1: Expected Peak Buller River Flood Flow (m^3/s) for the Chosen Scenarios

	2010	2050	2100
Q50	8,500	9,083	9,512
Q100	9,400	10,045	10,519
Q200	10,400	11,113	11,638

The median increase in top water levels along the Buller River due to increased flood flow, including climate change impacts (but excluding sea level rise effects at the river mouth) is shown in Table 4.2.

Table 4.2: Approximate Median Increase in Top Water Levels (m) Along the Buller River Due to Climate Change

	2010	2040	2090
Q50	0	+0.1	+0.2
Q100	0	+0.1	+0.3
Q200	0	+0.2	+0.4

The flood effects of climate change at Westport will be to increase river flood depth, send more flow into the Orowaiti River and raise the high tide level at the outlet, thereby potentially increasing flood depths for houses and possibly flooding a larger number of houses. Other impacts will include increased damage to man-made structures and river banks due to higher flood velocities than would otherwise be the case.

The increased frequency of flood events will increase bed load movements and gravel source volumes from upper catchments, exacerbate floating debris loads on bridge piers and increase bed load movement and settlement volumes at the river mouth. Over time, maintenance effort needed in managing the river bed and banks will increase as climate change impacts increasingly take effect.

4.2 Development of Flood Adaptation Options

A range of possible adaptation options were considered for the Buller River and Westport. The various options may be grouped generically by type, as outlined below:

> Type A – Methods for modifying or improving the hydraulics of flood flows to direct flood waters away from properties or reduce the peak flow depths and/or velocities. These could include providing flood plains in the upper catchment or increasing the hydraulic capacity and efficiency in channels or overland flood passages;
>
> Type B – Methods for containing flood flows using dams, stopbanks, rockwall protection of river banks etc;
>
> Type C – Methods of increasing the resilience of properties from flood waters. These could include raising buildings sufficiently above predicted flood levels;
>
> Type D – Planning instruments to control the development of new property or infrastructure within flood-prone areas.

In this case study, typical examples of flood adaptations that are relevant to Westport have been selected from each of the types A to C given above. Planning adaptations (Type D), while important for managing future risk, were not included because the study was limited to addressing the legacy flooding issues for Westport.

Many other options and variants to the ones selected in this case study have not been included for reasons of brevity and because the study was only intended to be illustrative of the processes used. The Toolbox includes an Option Screening Tool [Tool 4.2] to aid in identifying and selecting different flood mitigation measures based on simple location-specific contextual parameters.

Based on discussions with council representatives, the adaptations identified as being of particular interest for this study, at a strategic level, were as follows:

a) **Main Channel Widening** – enlarge the existing river channel (Type A adaptation). The Buller River flood channel was assessed to need widening by 100m over 10km at a depth of 4m to compensate for increased flood peak flows due to climate change. Earthworks were estimated at 9 million m^3.

b) **Right Bank Diversion** – open up the old river channels on the right hand side of the existing river channel (Type A adaptation). The volume of earth works for the Orowaiti River (9.3 million m^3) was similar to the Buller River channel widening option above, with additional bridge and road/rail modifications needed to allow for extra flow discharge capacity.

c) **More Stopbanks** – provide additional stopbanks to improve flood protection for Westport (Type B adaptation). The stopbank concept explored here includes 7.5 km of 2.5m high embankment (earthworks of approximately 180,000 m^3) plus amendments to infrastructure and roading. The stopbank system relies upon ongoing maintenance, and in the case of the Buller River mouth the maintenance of river bed levels in the face of expected increased bed load volumes and deposition from sea-level rise.

d) **Raise Houses** – raise homes above the level of flood waters (Type C adaptation). This option assumed an urban Westport population of 3,900 persons and the need to raise 1,800 dwellings (a rounded up figure based on 2006 census data). Costs were derived from the benefit/cost tool for individual house flood mitigation measures [Tool 4.4] and included sundry items for service connection, landscaping and access, and reinstatement to the interior and exterior of the house.

The options selected for study are illustrative of the type A, B and C categories. They represent a selection of quite different approaches, all of which are considered to be viable solutions worthy of at least a strategic consideration.

The potential to relocate the whole of Westport away from the river was also considered, but was excluded from the study because it was felt too difficult to develop meaningful relocation costs within the time available for the study.

All of the selected adaptation options were discussed at the workshop with council representatives in Westport and are presented here to show how very different solutions can be compared relatively rapidly in terms of their benefit/cost ratios (i.e. balancing the benefits of reduced flood damage costs versus the scheme costs).

4.3 Development of Scheme Costs

Broad scheme costs were developed for each adaptation based on published unit construction costs (Rawlinson)[1]. A best estimate overall scheme cost, and lower 5th percentile and upper 95th percentile cost ranges, are given in Table 4.2 for each adaptation

[1] Rawlinsons New Zealand Construction Handbook, 2009 Edition (revised annually)

option. These construction costs were assumed to be incurred as a linear spend rate over a specified number of years depending on the scheme. Construction timescales assumed for each adaptation option are also included in Table 4.2.

Table 4.2: Indicative Scheme Costs and Build Times for Adaptation Options

Adaptation Option	5th %-ile Scheme Cost ($m)	Best Scheme Cost ($m)	95th %-ile Scheme Cost ($m)	Assumed Build Duration (years)
Do Nothing	$0	$0	$0	0
Main Channel Widening	$139	$185	$231.8	5
Right Bank Diversion	$183.5	$236	$290	10
More Stopbanks	$19.5	$26	$48.2	10
Raise Houses	$97.5	$140	$195	20

4.4 Flood Damage Cost Estimates

The process quantified the effects of climate change in terms of increased flood damage if no adaptation strategies were taken. This can be considered to be the 'Do Nothing' case against which all adaptation options are compared.

Flood damage cost estimates developed for the Do Nothing option and each of the four adaptation options for the 2010, 2040 and 2090 scenarios and for Q50, Q100 and Q200 flows are summarised in Tables 4.3 (a) to (e), respectively.

Cost comparisons are made on the basis of a percentage with respect to the overall damage predicted by the 2010 Q200 flood prediction.

Table 4.3(a): Flood Damage Cost Estimates – Do Nothing

Case	Flood Modelling Case	Integrated Damage Cost ($m)		
		2010	2040	2090
1	Q50 flows	86%	102%	105%
2	Q100 flows	95%	112%	121%
3	Q200 flows	**100%**	114%	152%

Table 4.3(b): Flood Damage Cost Estimates – Main Channel Widening

Case	Flood Modelling Case	Integrated Damage Cost ($m)		
		2010	2040	2090
4	Q50 flows	62%	74%	76%
5	Q100 flows	69%	82%	88%
6	Q200 flows	73%	83%	111%

Table 4.3(c): Flood Damage Cost Estimates – Right Bank Diversion

Case	Flood Modelling Case	Integrated Damage Cost ($m)		
		2010	2040	2090
7	Q50 flows	58%	68%	70%
8	Q100 flows	64%	75%	81%
9	Q200 flows	67%	77%	102%

Table 4.3(d): Flood Damage Cost Estimates – More Stopbanks

Case	Flood Modelling Case	Integrated Damage Cost ($m)		
		2010	2040	2090
10	Q50 flows	16%	18%	19%
11	Q100 flows	17%	20%	22%
12	Q200 flows	18%	21%	28%

Table 4.3(e): Flood Damage Cost Estimates – Raise Houses

Case	Flood Modelling Case	Integrated Damage Cost ($m)		
		2010	2040	2090
13	Q50 flows	27%	28%	30%
14	Q100 flows	28%	30%	32%
15	Q200 flows	33%	34%	37%

The effects of uncertainty in these flood damage costs were explicitly accounted for by defining upper 95th percentile damage costs that are 25% higher than the best estimate cost for each of the options. The exception was the Raise Houses option for which costs were increased by 50% as the uncertainties are higher.

Likewise, lower 5th percentile damage costs were defined as 10% below the best estimate costs given in Table 4.3 for maintaining the Do Nothing option, for the Main Channel Widening option and for the More Stopbanks option. The 5th percentile damage cost for the Right Bank Diversion option was set at 20% below the best estimate costs, while the lower 5th percentile for the Raise Houses option was set at 50% below the best estimate.

The expectation of increased frequency of storms as climate change effects develop over the long-term was represented by multiplying the storm event probability by an annually increasing factor ranging from 1.0 to 1.2, rising linearly over the next one hundred years.

4.5 Benefit / Cost Analysis Assumptions

Base case analysis conditions used in this study assumed the following:

a) The analysis was performed over the period 2010 to 2110 using river flood conditions predicted for 2010, 2040 and 2090, including the effects of climate change on the river flows.

b) A discount rate of 5% was applied to the annual damage costs and benefits, and to the scheme costs.

c) Best estimate (50^{th} percentile) flood damage costs and best estimate (50^{th} percentile) scheme costs were applied.

d) The greenhouse gas emissions scenario A2 was used to determine climate change impacts on rainfall intensity, with a mid-range projection within the scenario.

The Benefit / Cost Analysis spreadsheet allowed each of these assumptions to be varied to explore the sensitivity of the results to changes in these assumptions. However, for reasons of brevity only a limited amount of sensitivity testing is reported here (see Section 5.2).

5. Benefit / Cost Analysis Findings

5.1 BCRs of the Adaptation Options

The Benefit/Cost Ratios (BCR[2]) for each of the options considered (assuming a 100 year design life and 5% discount rate) are summarised in Table 5.1.

[2] BCR is used here because it is widely known and understood. Other economic measures are often used as well as or instead of BCR. These other measures should be used as well in a more detailed analysis.

Table 5.1: Benefit / Cost Analysis of Options – Base Case

	Case A	Case B	Case C
Time Horizon (yrs)	100	100	100
Discount Rate (%)	5	5	5
Flood Conditions for Year	2010	2040	2090
Percentile Damages	50%-ile	50%-ile	50%-ile
Percentile Costs	50%-ile	50%-ile	50%-ile
Benefit / Cost Ratios:			
Main Channel Widening	0.17	0.18	0.18
Right Bank Diversion	0.14	0.16	0.16
More Stopbanks	1.07	0.99	0.82
Raise Houses	0.77	0.85	0.88

It can be seen that the More Stopbanks option appears to be the most favourable on the basis of the BCR, except for 2090 conditions where the Raise Houses option has a slightly higher BCR.

A key reason why the Raise Properties option appears relatively favourable is that it is assumed in the analysis that raising properties at risk from flooding can begin immediately, so giving an early benefit compared to the other options which will take time to implement. Early benefits have a significant effect as later gains are increasingly discounted.

Uncertainty in the flood damages and scheme costs means that there is significant variability in the BCR results. This can be seen from the BCR plots given in Figure 5.1 which show for each option the upper (Optimistic) and lower (Pessimistic) bounds for the Best Estimate.

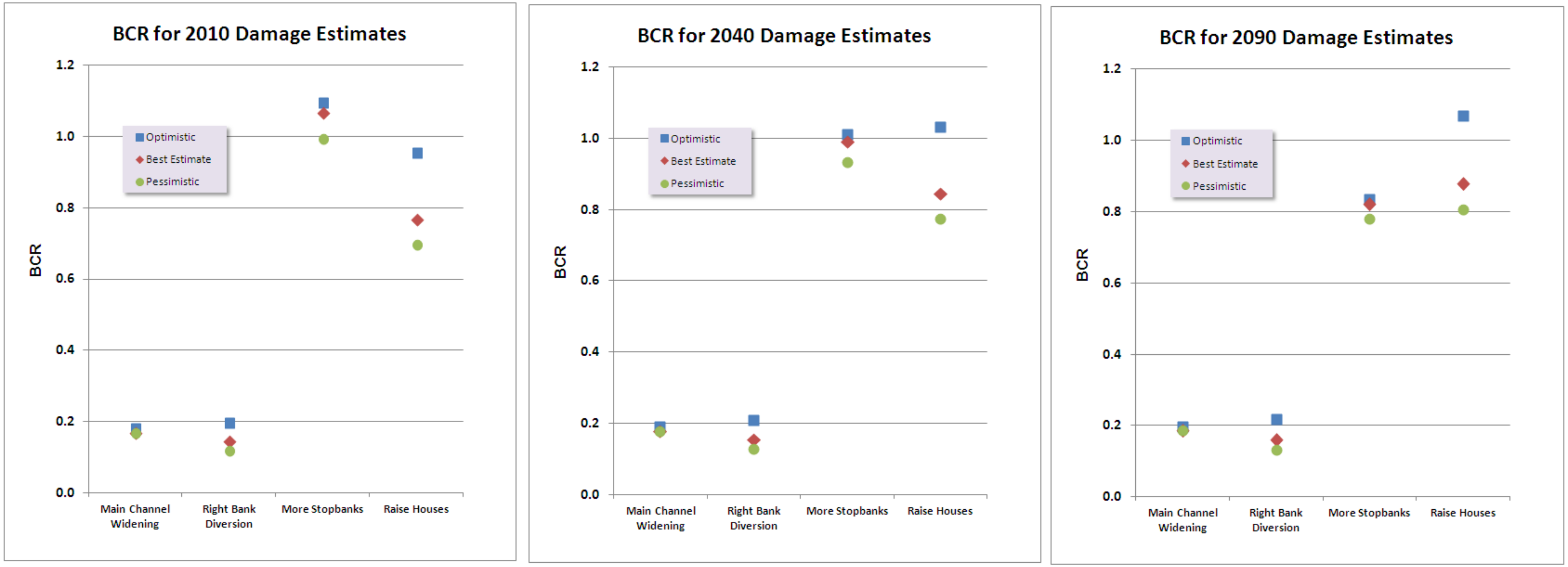

Figure 5.1: Benefit / Cost Ratio Comparisons of Options for Flood Damage Estimates in 2010, 2040 and 2090

Taking account of the upper and lower bounds of uncertainty in the BCR estimates, Figure 5.1 shows that there is no significant difference between BCRs for the Main Channel Widening and Right Bank Diversion options for all scenarios. Likewise, the more favourable BCR of More Stopbanks option compared with the Raise Houses option (in 2010) is no longer apparent in 2040 or 2090.

Also what is clear from Figure 5.1 is that the options of adding stopbanks or raising houses provide considerably better BCRs in all scenarios compared with the river excavation options (i.e. channel widening or right back diversion).

5.2 BCR Sensitivity Analysis

A limited number of parametric sensitivity tests are discussed here in which one parameter is adjusted at a time and the results for the BCRs are compared to the base case, using flood conditions for 2090.

Table 5.2 shows the effect of reducing the discount rate from 5% to 2%. The BCRs for all options have increased and for the More Stopbanks and Raise Houses options now exceed unity. This shows the benefit of using low discount rates to explore the longer term benefits of adaptation measures designed to provide increased resilience to climate change effects. In this case, it has not changed the relative ranking of options but has widened the gap in BCRs for the different options.

Guidance on the use and limitations of Benefit Cost Analysis for assessing schemes to address long-term climate change impacts is given in Tool 3.1. In particular low discount are used here since otherwise the benefits that will not be fully realised for many years to come will be masked by the discounting methodology.

Table 5.2: Effect of Discount Rate on Option BCR (2090 Conditions)

	Base Case - 5% Discount Rate	2% Discount Rate
Main Channel Widening	0.18	0.25
Right Bank Diversion	0.16	0.27
More Stopbanks	0.82	1.28
Raise Houses	0.88	1.73

Table 5.3 shows the effect of increasing storminess and compares the base case of 20% increase with a 100% increase in storminess over the next 100 years. Once again the BCRs have increased across all options and widened the gap.

Table 5.3: Effect of Increasing Storminess (2090 Conditions)

	Base Case - 20% Increase in 100 years	100% Increase in 100 years
Main Channel Widening	0.18	0.20
Right Bank Diversion	0.16	0.18
More Stopbanks	0.82	0.90
Raise Houses	0.88	1.02

Other sensitivity tests could and should be undertaken to further test the preferences between options. The results presented here should only be taken as indicative as the damages and scheme cost estimates are high level, not detailed estimates.

6. Summary of Findings

Key findings from the flood adaptation options case study for Westport are as follows:

a) Stopbank mitigation is clearly the best option for flood protection and is worthy of further detailed investigation and consultation.

b) The river channel widening options in the Buller River (Main Channel Widening) and the Orowaiti River (Right Bank Diversion) proved to be expensive due to the large earthworks volume needed to compensate for projected climate change impacts (approximately 9 million m^3 for each option).

c) The Raise Houses option that lifts dwellings above the flood level is feasible in many parts of Westport's residential areas but less feasible for large buildings and commercial areas. A long-term plan to renew/rebuild structures at higher foundation levels could progressively reduce flood risks. (Note that the Raise Houses option will still result in flood damage to properties and infrastructure, as well as secondary and indirect costs such as disruption to business, and emergency/safety issues to affected communities).

A key finding from the Westport flood adaptation assessment is the clarity shown in the benefits of stopbanking compared with river widening options which are considerably more expensive.

The assumptions underpinning the stopbank option include a river bed level maintained in the face of expected increased bed load volumes and deposition due to higher sea level. A stopbank solution is likely to need integration with existing roads and infrastructure such as bridges to allow normal daily activities in the township.

The value of stopbanks and the marginal increase in value for extra height of stopbank is justification for looking further at this option. The risks of stopbank failure can be looked at in more detail and a stopbank design standard developed so that the risk of failure is lower and the adaptation potential is maximised.

House raising provides an option that could be looked at further to define the costs and benefits, but it does not prevent flooding, and a cost for cleaning and renewal of roads, property and infrastructure is expected after a flood event.

The options evaluation process illustrated in this case study has shown the value of varying inputs and running sensitivity tests to give an indication of the levels of confidence in the broad-brush data and assessment outcomes. The process may be completed and iterated relatively rapidly to provide a high level assessment of the BCRs for competing options and varying assumptions.

The community is then able to see those options which are sensitive to assumptions and can understand the rationale for further investigation or design of one option over another, taking account of budgetary constraints.

Local government and the insurance industry can also see an early demonstration of the viability of selected options and seek community feedback on their preferences in flood risk reduction measures to counter climate change.

Most forward planning for climate change will take many years to complete and community involvement is essential to coordinate adaptation activities and changing perception about flood risks.

Appendix A

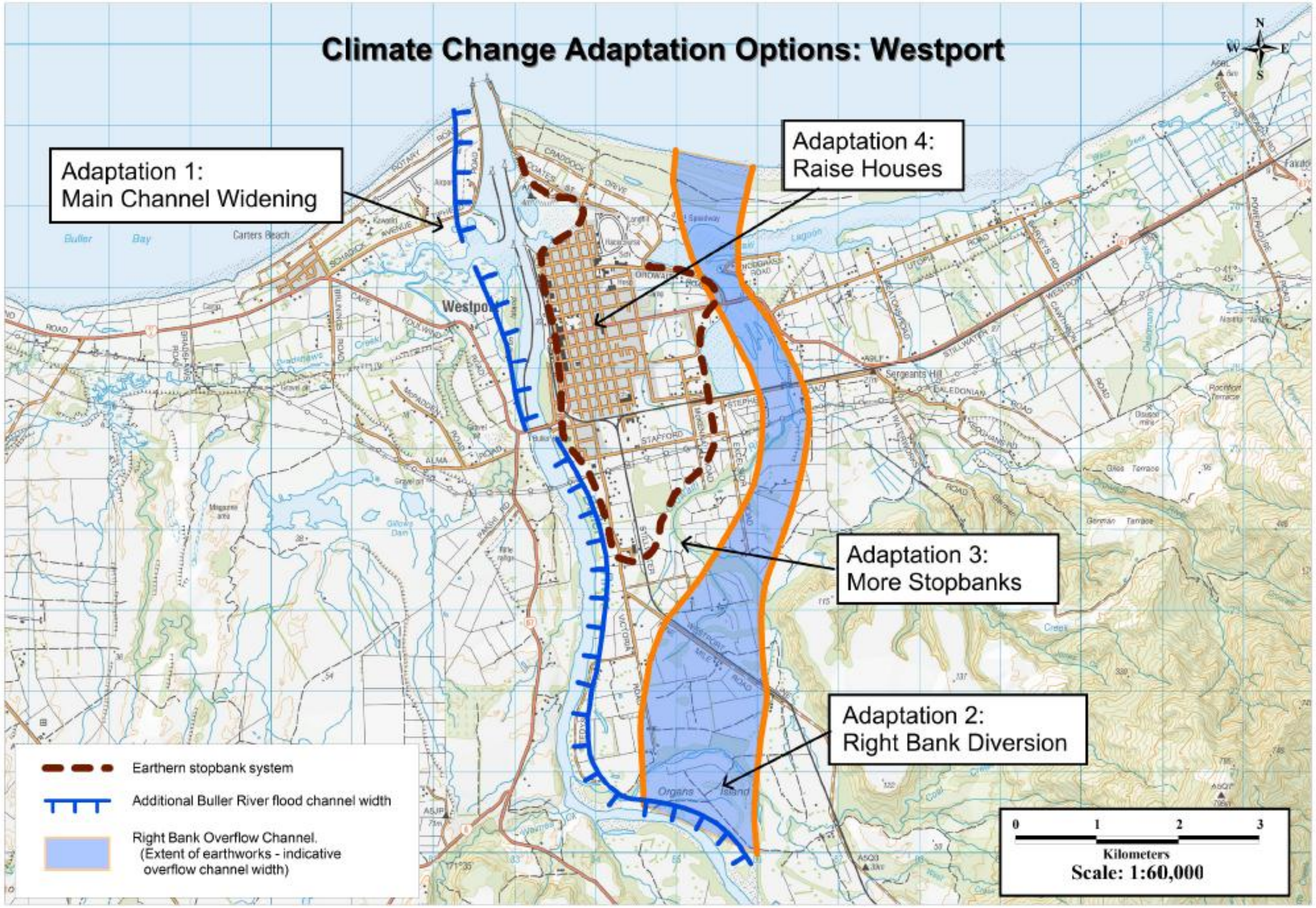

Figure A1: Schematic showing the four flood adaptation options assessed in the Westport case study