

The Urban Impacts Toolbox: An initial assessment of climate change flood adaptation options for Westport

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Abstract

This paper presents a simplified or rapid process for evaluating adaptation responses to projected climate change impacts as part of community planning, using flooding scenarios in Westport as a case study. The paper draws upon many of the tools found in "Impacts of Climate Change on Urban Infrastructure and the Built Environment *Toolbox*", and builds on the results presented in the second paper of this special issue.

A key finding from the flood adaptation options case study for Westport was a demonstration of the process of an initial options assessment. This was in the context of constraints on resources and information, which is likely to be starting point for many climate change adaptation processes. For Westport, a preferred adaptation option was developed from a list of four options by varying the climate change parameters and running sensitivity tests. This was achieved using a rapid benefit-cost ratio approach with the proviso that the results provide a strategic direction on where more detailed planning and investigation would be beneficial.

The Westport case study showed that more stopbanks is the best option for flood protection for further study. In some circumstances, raising houses above the flood level is also an option deserving further investigation. In this context a long term plan to renew/rebuild structures at higher foundation levels could progressively reduce flood risks. On the other hand, options requiring extensive earthworks to widen the river and provide extra overflow capacity were shown to be poor options, even under a range of inputs conditions, and could be removed from further consideration.

1. Introduction

The impacts of global climate change are only beginning to be detected and felt in New Zealand with projections of increased impacts in the future (Ministry for the Environment, MfE, 2008a&b). Given that a large part of New Zealand's important infrastructure is located near to the coast or near a river (or both), the impacts will manifest at the same period of time over a widespread area of the country, as well as around the world (NASA, 2012). Such a situation will place a demand on resources and technical expertise (NCCARF, 2012).

The proposed climate change adaptation decision-making process for flood risk, as developed in the case study described in this paper, makes a few key assumptions:

- In New Zealand, adaptation assessments are to engage the

community and stakeholders, and assess options that arise from consultation in a transparent manner and demonstrate a means of ranking or prioritising the initial assessments. (Allan, 2012)

- Industry-standard flood assessment tools and readily-available information are applied over a wide range of adaptation options to get a first, initial assessment of the relative merits of options.
- Assessment of the relative costs and benefits of the different options is considered to be high-level. Costs and benefits are estimated using subjective judgement and relatively simple modelling with an explicit treatment of uncertainty through the use of a sensitivity analysis (Oldfield, 2012 [Tool 4.3]).

- The most favourable adaptation options from this process are to be given further assessment in subsequent studies to refine costs and benefits, and to reduce uncertainty, so that a preferred option and long-term future strategy can be determined.

1.1 Preamble

This Paper is the third in a special combined series prepared for Water and Climate. The three papers are:

The Urban Impacts *Toolbox*: An overview

The Urban Impacts *Toolbox*: An example of modelling the effect of climate change and sea level rise on future flooding

The Urban Impacts *Toolbox*: An initial assessment of climate change flood adaptation options for Westport

A *Toolbox* of information, procedures and assessment tools "Impacts of Climate Change on Urban Infrastructure & the Built Environment *Toolbox*" has been developed (see the first paper in this special issue; and National Institute of Water and Atmosphere, New Zealand (NIWA), MWH Global Inc (MWH), Institute of Geological and Nuclear Sciences Limited (GNS) and Building Research Association New Zealand Limited (BRANZ), 2012). The intention of the *Toolbox* is to assist New Zealand councils and others in taking account of long term climate change effects using current guidance methods and tools with the broad aim of planning to make urban infrastructure more resilient to climate change.

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. The *Toolbox* contains case studies to illustrate how a number of the tools can be used in practice.

This paper gives details of one of these case studies and describes an initial assessment of climate change induced flood impacts for

Westport. It uses climate change-impacted rainfall and runoff assessments and flood inundation modelling (McMillan et al., 2012; MfE, 2010) to generate likely flood predictions for the Buller River, then applies rapid cost/benefit evaluation to four adaptation options previously identified by a group of Westport council and stakeholder representatives as being of interest in a workshop session in 2010.

1.2 Background

Westport is typical of many communities around New Zealand and faces increased flooding risks from the sea and/or local river catchments due to projected climate change. Most communities have limited resources to commit to a wide-ranging assessment of adaptation options. Ultimately the implementation of a flood adaptation strategy has to be accepted and paid for by the community. The challenge is to provide simple, but robust, analysis methods to shortlist viable adaptation options and engage with the community early in a decision-making process.

At two day-long meetings in Westport with a group of officers and representatives from the Buller District Council (BDC) and West Coast Regional Council (WCRC), a number of climate change impacts and mitigation strategies were discussed with respect to Westport in the long term. Ultimately, it was agreed that the principal climate change impact facing Westport was from increased flood risk and four ideas were included into the case study as adaptation options for initial assessment and comparison in terms of their benefits and costs (Figure 1). Three of the four adaptations had no previous formal assessment but the fourth option was subject to an ongoing detailed assessment.

The aim of this study is to investigate the potential for undertaking a high-level assessment of real life 'strategic' flood mitigation options. The focus here is to demonstrate a process using relatively low investigation and analysis costs, simple and readily available models and high-level cost

information for evaluation, comparison and ranking of adaptation options ahead of a more detailed assessment of the most promising ones.

An explicit treatment of uncertainty has been included to account for uncertainties in long-term climate change impacts and the

simplified modelling and cost assumptions made in the analysis. It would be expected that this type of analysis would be a precursor to more detailed evaluation of the most promising option(s) and consultation with the community.

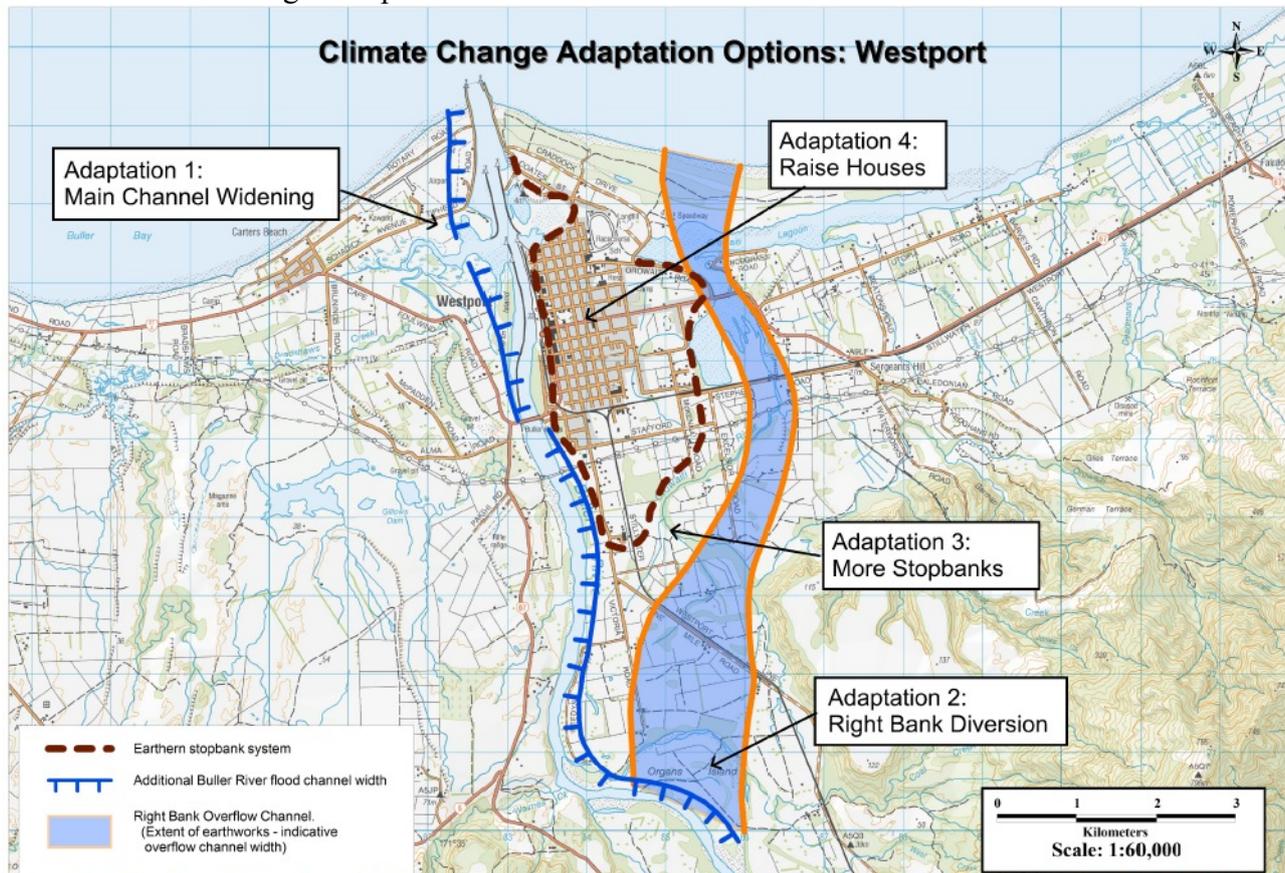


Figure 1: Schematic showing the four flood adaptation options assessed in the Westport case study

2 Case-Study Overview

2.1 Location and Scope of Study

Westport township has a population of 3,783, and comprises 1,725 dwellings (2006 Census, Statistics New Zealand) located on the West Coast of New Zealand and next to the Buller River (Figure 1). The Buller River drains over 6,350 km² of the Southern Alps and is situated in one of the highest rainfall catchments in New Zealand. The Buller River has the third highest mean discharge rate in New Zealand (454m³/s) and the largest estimated flood peak in New Zealand of 12,700 m³/s in 1926 (Cowie and Attwood, 1957). Flows are measured by NIWA at the Te Kuha Gorge some 16km upstream from the river mouth. The three main access roads

into Westport cross the Buller River or the nearby 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 regularly dredged at the mouth to allow cement ships to enter and load from a wharf along the river edge (Westport Harbour Limited, 2012). A railway from the coal mines to the north-east of the town passes through Westport and carries coal inland through Reefton towards Christchurch.

Since 1870 the river mouth into the Tasman Sea has been progressively constrained by sea walls. Opposite the township, a mid-channel constraining wall is in place to constrict low

flows and increase sediment mobilisation through the main harbour channel. Sea walls have pushed the beach out seawards by up to a kilometre or more (West Coast Marine Protection Forum, 2012).

The township itself does not have a large or extensive stopbank system because the topography, dredging efforts, mid-channel wall and other maintenance efforts presumably serve to hold the main channel alignment in place, and keep the river mouth capacity high. Detailed 2D modelling of Westport indicates that short, selected reaches of new stopbank will reduce flood risk to a large amount of township (Duncan, M. and Smart, G., NIWA, pers comm).

The right bank Orowaiti River becomes an overflow channel during large flood flow events. At such times, the Buller River flow spills through railway bridges and the Westport township is effectively surrounded by floodwater and the sea coast (Duncan, M. Smart, G., NIWA, pers comm).

2.2 Climate Change Concerns

Climate change concerns for Westport include increased rainfall and runoff from the Buller River catchment, rising tidal levels and increased bed load volume due to more erosion materials entering and pulsing down the river. These effects all combine to imply that today's 0.01 Annual Exceedance Probability (AEP) magnitude inundation event will become more frequent. Furthermore, natural deposition rates at the river mouth will increase due to the rise in average sea level and a flattening hydraulic river gradient.

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 itself and to keep road and rail linkages intact. Climate change effects will demand an increasing river maintenance effort to keep port serviceability and flood protection at current levels.

Secondary climate change impacts may include an increase in flood insurance premiums for vulnerable properties and business as a response to projected flood risk, and reducing land and property values. The viability of industry and potential for disruption to business is further affected by the increased risk to community infrastructure and supply lines such as road and rail bridges (Agricultural Engineering Institute, 1992).

2.3 Adapting to Climate Change

The engineering response to climate change flood risk could be to increase the design standard for flood protection options. The New Zealand Building Code (Department of Building and Housing, 2011) requires housing to be clear of the 0.02 AEP flood level and this will be progressively more difficult to meet as climate change impacts intensify. The 0.01AEP design standard plus freeboard allowance is now seen as a minimum acceptable level for flood protection under new land development planning (New Zealand Standard publication NZS4404:2010).

The anticipation of future climate change is today putting additional cost on engineering works through the imposition of higher design standards for infrastructure with a design life of 50 to 100 years. An accepted approach to decision-making now includes a robust community engagement on a wide range of options in order to determine a preferred flood risk adaptation option (NZS9401:2008). This includes options that may prove to be superior under long-term design horizons even though they are less palatable in the short term.

To assist councils that are beginning to consider a wide range of climate change adaptation options and strategies on behalf of their communities, we propose a process that takes advantage of inexpensive public domain data and analysis tools in a high-level options assessment. This technical process seeks to provide users with the tools to work within the flood risk management framework and its principles and outcomes set out in NZS9401. The framework requires a method of

community consultation, integration of risk factors and an iterative process that seeks to minimise the economic, social, environmental and cultural costs of a flood risk adaptation option on the community. The technical process is applied to Westport as an illustrative case study.

3 Data Needs and Methodology

3.1 Data Needs

Many data sets are readily available in total or in part from electronic records held by councils. The data sources that were used in this study are identified below and comments on nationwide data sets are provided as further guidance.

Tidal data is well known at Westport from harbour records. All coastal locations will have tidal data from nearby Port Authorities or a tidal model (e.g., NIWA tide forecaster, 2012).

Rainfall records are held by councils and NIWA have developed a rainfall design tool, HIRDS (High Intensity Rainfall Design System) that summarises the design rainfall distribution over the whole of New Zealand, based on location coordinates (NIWA HIRDS, 2012).

River flow data in New Zealand can be assessed using empirical procedures based on a nationwide flow gauge network, or from using the Regional Flood Frequency estimation process (McKerchar and Pearson, 1990).

Climate change projections are published as guidance material by the MfE including Westport. The guidance materials give data and a simple algorithm to determine anticipated changes in rainfall intensity and sea level rise for all parts of New Zealand up to the year 2090 (MfE, 2008).

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

(LINZ data, QV, Statistics NZ). This information assists in developing flood depth to damage relationships.

GIS data and other information such as contours and ground survey data are held by councils over many places in New Zealand. The whole country is covered by a 20m contour data set that can be converted into a ground model but the accuracy may not be suitable for flat areas where levels are important (LINZ, Free GIS Data).

Aerial photography is available from Google Maps for the whole country and councils also hold detailed datasets (Google Maps New Zealand).

Cost estimations of construction rates and labour can be obtained from council knowledge or from quantity surveyor commercial publications (Rawlinsons New Zealand Construction Handbook, 2009). This information assists in developing the costs of adaptation options.

3.2 Information Overlay

Spatial datasets were loaded into a GIS-based model for visualisation and estimation of the flood damage to land and property. Modelled flood depths that were calculated during the case study were superimposed onto a grid cell layout representing land use zone and value. The damage costs were then calculated at each grid cell in the GIS model using relationships between the depth of flood water and the damage cost of the inundated landuse zone (Agricultural Engineering Institute, 1992).

Flood damage costs include both direct and indirect costs, and both are difficult and expensive to quantify accurately. Direct cost principally arises from damage to buildings, infrastructure and businesses based on flood depth, and is estimated in part by using reported historical information of past New Zealand floods as a guide. Indirect cost arises from recovery costs, health and social costs derived on the basis of lost productive time and earnings, and injuries and fatalities likely

to be caused by the flood. (Agricultural Engineering Institute, 1992). The process of decision making in this case study relies on a less-detailed, but broadly representative, flood damage assessment that can be treated in a sensitivity analysis to test outcomes. Property parcels were grouped into residential, commercial/industrial, agricultural and green field zones, and each property zone was given a depth-to-damage relationship to calculate direct costs. For simplicity, indirect costs were calculated as a fixed, additional proportion of the direct costs.

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 in the *Toolbox* (Oldfield, 2012).

3.3 Software Modelling Tools Used

This case study attempts to illustrate how commonly available software and datasets could be used to assess and determine a range of climate change adaptation options at a strategic level, with the assumption that further targeted work would subsequently be carried out to refine data inputs and improve the accuracy of the assessment to confirm options. . In this case study the following tools, information and processes were used:

- An earlier background study by NIWA which developed a runoff model of the Buller River catchment to estimate peak river discharges under climate change scenarios. Many rainfall-runoff model packages could be used to convert rainfall information into a flood hydrograph (for example software Hydrological Engineering Centre – Hydrologic Modelling System - HEC-HMS, 2012).
- BDC holds LiDAR data for the township and surface area around Westport and the WCRC holds river cross-sections for the Buller River. NIWA combined the LiDAR data with river cross-sections into a digital elevation model (DEM) that could be used for cross-sections in the 1-dimensional (1-D) model and in the GIS to calculate summed flood damages.
- A 1-D hydraulic flood modelling software was used to model the lower Buller River flood levels. The 1-D software 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 (for example Hydrological Engineering Centre – River Analysis System (HEC-RAS), 2012) and many commercial products are available on the market. The 1-D model was “calibrated” to results from a detailed 2-D flood inundation model of Westport for the 0.02AEP event, developed by NIWA (pers. comm Duncan, Smart 2010-11) and which in turn had been calibrated to the 1970 flood event (see the second paper in this special issue). 2-D software is recommended to be used for options that require more detailed assessment, typically after the initial options assessment has refined the options to a small number of feasible alternatives. For this case study, the existing and proposed stopbanks were assumed to remain intact for the event. Further work would be needed to run stopbank failure scenarios, and this was beyond the scope of this initial options assessment.
- The conversion of a water level profile along a 1-D channel into a flood surface over a floodplain can be drawn by hand using contour maps or more accurately derived using GIS software and digital terrain models. Commercial software examples are Vertical Mapper (Vertical Mapper, 2012) and WaterRide (WaterRIDE,

2012) software. In the Westport case study, WaterRIDE software was used with MIKE11 hydraulics software (MIKE11, 2012) to calculate and map the aerial extent of the peak flood surface.

- A GIS-based model (developed by MWH New Zealand) was used to calculate flood damage against flood depth over a grid of cells covering the Westport area. A spreadsheet and manual process could be used for smaller areas of interest. Note, the RiskScape tool (RiskScape, 2012) can also be used for the purpose of converting flood levels within an area of interest into flood damage if more detailed data is available, but was not used in this study as the objective was to illustrate the use of less data-demanding processes.
- Spreadsheets were set up to document and summarise results, and present the information for all scenarios. 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 (New Zealand Asset Managers Support organisation NAMS, 2004). Spreadsheets are of particular value due to their universal availability, adaptability and the ease with which sensitivity analysis and presentation outputs can be produced.

3.4 Overall Case Study Methodology

The process of evaluating flood adaptation options for Westport started with a site visit and was followed by two separate workshops with 11 officers and 2 council representatives from the BDC and the WCRC. The roles and functions of the council officers included water supply, flood protection, solid waste, land development, port facilities, traffic engineering, rates and commercial functions. One Councillor and one ex-mayor were also involved. This group was able to provide to

the study a broad cross section of the issues and constraints that are currently facing Westport.

At the first workshop NIWA scientists gave a presentation on the predicted climate change effects for Westport, including: the effects of increased rainfall and flood risk on existing flood defences; rising temperatures and the effects on diseases and farming practice; the effects of rising mean sea levels including saline groundwater interface movement and water supply extraction from bores; increases in maintenance efforts for underground utilities, above ground infrastructure and transportation networks. The workshop participants were then encouraged to describe the current infrastructure and built environment within Westport that is potentially vulnerable to climate change effects based on their local, practical, knowledge. The facilitated discussions about vulnerabilities were recorded using a Sensitivity Matrix, which was a simple tabular form for recording the views of the participants (Oldfield and Allan, 2012). The sensitivity matrix, and the following discussions, identified that one of the principal climate change impacts to Westport was the increased flood inundation risk from the Buller River.

The second workshop involved a discussion of a range of flood mitigation measures that could be considered for Westport including dams in the upper catchment, channel diversions, stopbanks, managed retreat, relocation of the town, planning controls and education, widespread raising of house floor levels, maintenance of the river bed and catchment modifications, as well as other suggestions. During the workshop, the representatives of Westport agreed by consensus that four adaptation options would be considered to illustrate the options evaluation and decision process used in this case study. The options are shown in Figure 1: widening of the Buller River channel to increase flow capacity; formalising and widening an overflow path to allow spillover into the right bank channel; extend and

upgrade a stopbank system surrounding the township; and raising floor levels on existing foundations throughout Westport. This study focussed on harder engineering solutions

because of the concern over the high flood risk to existing infrastructure. The process methodology used in this case study is illustrated in Figure 2.

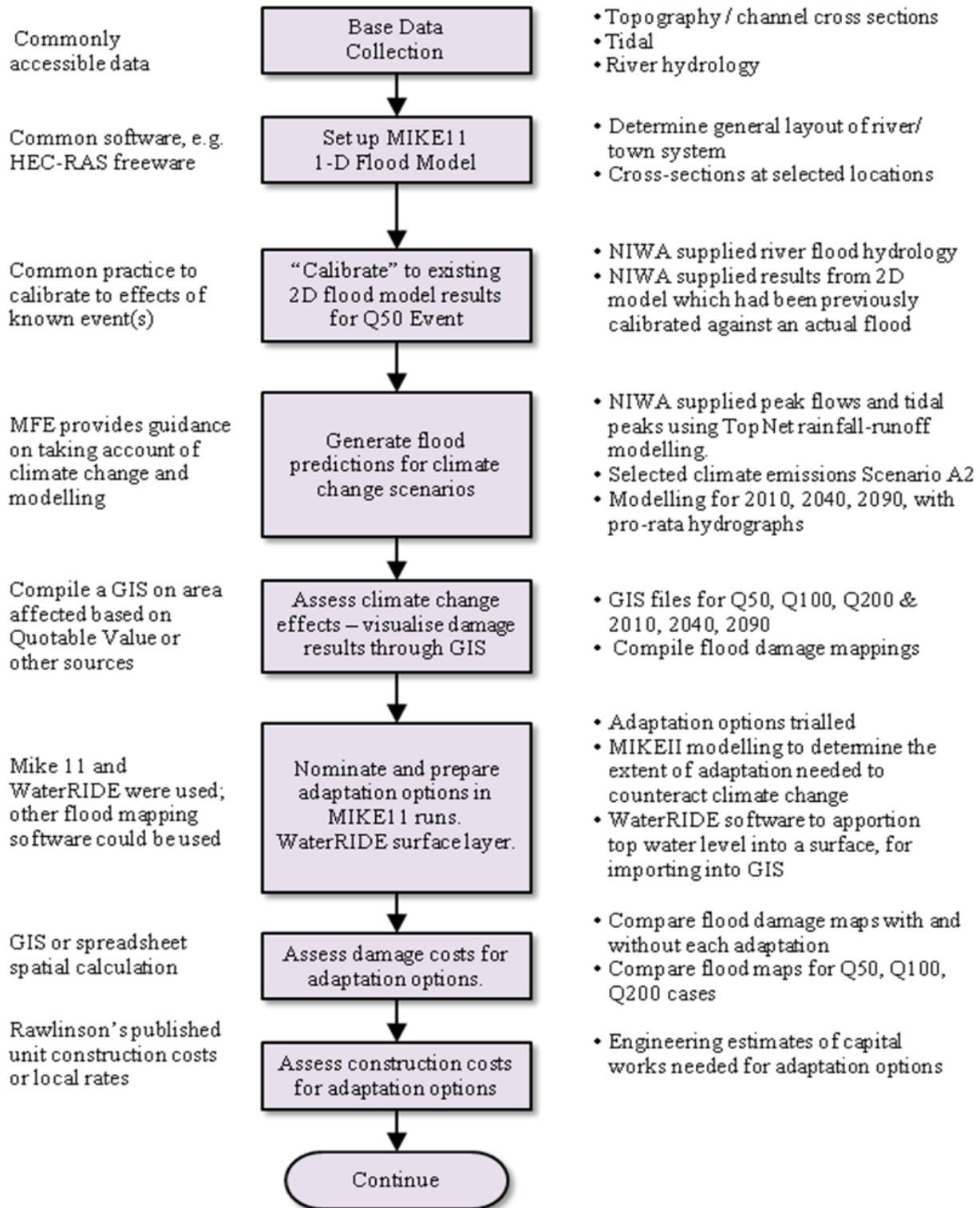


Figure 2 Methodology Process Diagram (continued on next page)

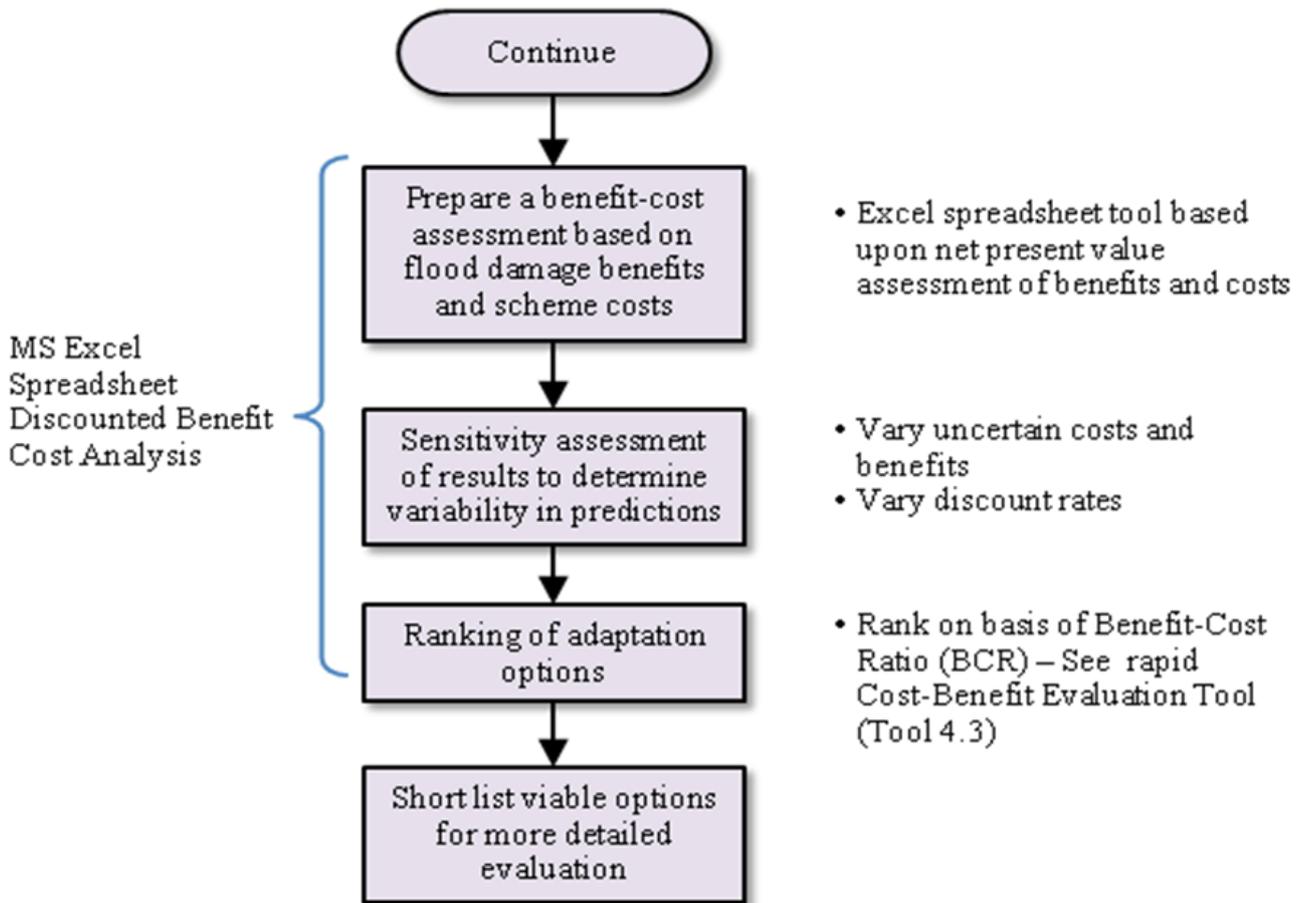


Figure 2: Methodology Process Diagram (continued from previous page)

4 Results

4.1 Projected Climate Change Impacts

For the Westport case study, future sea-level rise projections (compared with 1990 levels) were 0.4m by 2040 and 0.8m by 2090 and peak flows in the Buller River under climate change emissions scenario A2 were calculated by NIWA (Table 1; see the second paper in this special issue for details). The hydrograph shape recorded at Te Kuha Gorge gauge in August 1970 was used for the modelled flood inflow and scaled up to the peak. The median increase in top water levels due to increased flood flow from climate change impacts on rainfall is shown in Table 2. Table 2 excludes sea level rise effects which are local to the river mouth and only includes the Lower Buller River within the study area.

From a river engineering point of view, the impacts of climate change at Westport are expected to be: an increased river flood depth for a given return period magnitude; more flood flows entering the Orowaiti River; increased mean sea level and coastal storm surge; and higher coincidence of high tide level and peak flows at the outlet. Secondary impacts from climate change are expected to include: increased wear and tear damage to man-made structures and river banks due to higher flood velocities and more frequent events; increased maintenance effort to manage the river bed and banks; and increased bed load movements and gravel source volumes from erosion in the upper catchments which could exacerbate floating debris loads on bridge piers and increase bed levels at the river mouth.

		Climate Change Date		
		2010	2040	2090
ARI (AEP)	50 year (0.02)	8,500	9,083	9,512
	100 year (0.01)	9,400	10,045	10,519
	200 year (0.005)	10,400	11,113	11,638

Note: ARI = average recurrence interval, AEP = annual exceedence probability.

Table 1: Expected Peak Buller River Flood Flow (m³/s) for the Chosen Scenarios

		Climate Change Date		
		2010	2040	2090
ARI (AEP)	50 year (0.02)	0	+0.1	+0.2
	100 year (0.01)	0	+0.1	+0.3
	200 year (0.005)	0	+0.2	+0.4

Note: ARI = average recurrence interval, AEP = annual exceedence probability.

Table 1: Approximate Median Increase in Top Water Levels (m) Along the Lower Buller River Due to Climate Change

4.2 Development of Flood Adaptation Options

In general, flood mitigation options can be grouped into four Types as described 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. This could include providing wider flood plains to increase the hydraulic capacity and efficiency in channels, or creating additional overland flood paths. This Type of flood mitigation provides an efficient means of passing flood flows through critical locations and with minimal damage;

Type B – Methods for containing flood flows using dams, stopbanks, rockwall protection of river banks etc. This Type of flood mitigation provides the means to contain flood volumes

and flood levels in order to resist flood effects such as flood level and flow erosion;

Type C – Methods of increasing the resilience of existing properties and infrastructure when flood waters occur. This Type includes raising or moving critical infrastructure out of flood range or, if movement is not possible, reducing the negative impacts that floods have on infrastructure by providing the means of quick or inexpensive post-flood recovery of an asset or service;

Type D – Planning instruments to rationalise the development of new property or infrastructure within flood-prone areas over long, urban planning time frames. This Type includes re-zoning of land, urban retreat strategies, education and investigation, incremental stages of adjustment of assets and infrastructure over time in order to reduce flood damage risk.

Based on discussions with council representatives, the four adaptation options identified as being of particular interest for this study (Figure 1), at a strategic level, are described below. Other options and variants have not been included for reasons of brevity and because the study was only intended to be illustrative of the processes used.

a) **Main Channel Widening** – enlarge the existing river channel (Type A adaptation).

b) **Right Bank Diversion** – widen old river channels on the right hand side of the existing river channel (Type A adaptation).

c) **More Stopbanks** – construct a larger and more extensive stopbank system to improve flood protection for Westport (Type B adaptation).

d) **Raise Houses** – raise buildings above the level of flood waters (Type C adaptation).

Planning adaptations (Type D), while important for managing future risk, were considered by the workshop group but were not included into the options analysis. The cost of relocating a township is not well understood in New Zealand or easily considered from first principles as there are many underlying assumptions that have to be known such as the distance to the new site, constructability and population. An example situation could be the Cromwell township part-relocation that occurred to accommodate the hydropower lake, Lake Dunstan, in 1984-1992. For the purposes of this case study, the options chosen were based on protecting the existing township of Westport on its current, historical location.

The *Toolbox* includes an Option Screening Tool (Keenan and Oldfield, 2012) to assist in an initial consideration and screening of different flood mitigation measures. The tool is based on simple location-specific

contextual parameters such as topography, value of assets, budget affordability and adaptability to change, and can be used in a workshop environment to encourage community discussion before a list of adaptation options is selected for assessment.

4.3 Development of Option Costs

Each option requires a cost estimate to compare against the benefits of the option and to contrast with a “do nothing” case. The comparison of the costs and benefits is the basis of decision-making using cost benefit analysis. With all analyses of this sort, the quality of the data has a strong relationship to the confidence in the outcomes, and where the quality of data is low, a sensitivity analysis of parameters may be sufficient to improve the confidence of the outcomes, and lead to a decision.

Broad costs were developed for each adaptation option. In this case study, where the options involve a dominant construction component, costs were based on quantities and published unit construction costs (Rawlinsons New Zealand Construction Handbook, 2009). Additional sources of cost information would include local authority records or institutional knowledge, developers and contractors’ tender submissions, and planning procedures costs possibly obtained from experienced council officers. Overall cost estimates were based on quantities and rates using industry-standard methods, with factors added to allow for engineering design, resource consents, land purchase, and contingency.

A best estimate overall option cost, and lower 5th percentile and upper 95th percentile cost ranges, are given in Table 3 for each adaptation option. These construction costs were assumed to be incurred as a linear spend rate over a specified number of years depending on the Option. Construction timescales assumed for each adaptation option are also included in Table 3.

Adaptation Option	5th %ile Option Cost (\$m)	Best Option Cost (\$m)	95th %ile Option 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

Table 3: Indicative Option Costs and Build Times for Adaptation Options

4.4 Flood Damage Cost Estimates

Flood damage cost estimates were calculated by overlaying flood extent maps onto a GIS database of property types and damage relationships. Flood damage cost estimates were developed for the Do Nothing option and each of the four adaptation options, for the time horizons of 2010, 2040 and 2090 and for 0.02, 0.01 and 0.005 AEP flows, and are summarised in Table 4 (a) to (e), respectively.

The results are presented in terms of a percentage with respect to the overall damage predicted by the 2010 0.005 AEP flood prediction (the base case damage scenario).

All of the flood damage scenarios were calculated using the same consistent process. It would therefore be expected that the relative magnitude of costs would be more accurate than the absolute predicted cost in any particular instance. Uncertainty ranges applied to the flood damage costs reflect the lack of benchmarking. These uncertainties could be reduced by undertaking 'ground truthing' surveys of the properties that are predicted to be flooded.

The benefit of each option is the flood damage cost reduction when compared with the do nothing scenario. Because engineering solutions will be designed to a particular magnitude of flood event (in this study 1% AEP) there will be a residual flood risk from more extreme flood events. The difference between the damage that occurs without flood

protection compared with the damage that would eventuate if a 1% AEP flood protection option was implemented provides the measure of the benefit from the flood protection.

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 subjectively increased by 50% as the uncertainties are considered to be higher, principally because there is little information available on the probable costs involved.

Likewise, lower 5th percentile damage costs were defined as 10% below the best estimate costs 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 a subjectively determined annually increasing prevalence factor ranging from 1.0 to 1.2, rising linearly over the next one hundred years.

Case	Flood Case	Modeling	Integrated Damage Cost (\$m)		
			2010	2040	2090
1	0.02AEP flows		86%	102%	105%
2	0.01AEP flows		95%	112%	121%
3	0.005AEP flows		100%	114%	152%

Table 4(a): Flood Damage Cost Estimates – Do Nothing

Case	Flood Case	Modeling	Integrated Damage Cost (\$m)		
			2010	2040	2090
4	0.02AEP flows		62%	74%	76%
5	0.01AEP flows		69%	82%	88%
6	0.005AEP flows		73%	83%	111%

Table 4(b): Flood Damage Cost Estimates – Main Channel Widening

Case	Flood Case	Modeling	Integrated Damage Cost (\$m)		
			2010	2040	2090
7	0.02AEP flows		58%	68%	70%
8	0.01AEP flows		64%	75%	81%
9	0.005AEP flows		67%	77%	102%

Table 4(c): Flood Damage Cost Estimates – Right Bank Diversion

Case	Flood Case	Modeling	Integrated Damage Cost (\$m)		
			2010	2040	2090
10	0.02AEP flows		16%	18%	19%
11	0.01AEP flows		17%	20%	22%
12	0.005AEP flows		18%	21%	28%

Table 4(d): Flood Damage Cost Estimates – More Stopbanks

Case	Flood Case	Modeling	Integrated Damage Cost (\$m)		
			2010	2040	2090
13	0.02AEP flows		27%	28%	30%
14	0.01AEP flows		28%	30%	32%
15	0.005AEP flows		33%	34%	37%

Table 4(e): Flood Damage Cost Estimates – Raise Houses

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 option costs.
- c) Best estimate (50th percentile) flood damage costs and best estimate (50th percentile) option 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 (MfE, 2008; Table 6).

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 (Section 0).

5 Benefit/Cost Analysis Findings

The objective of this study is to investigate the use of a simplified BCA methodology in strategic level option assessment studies. It is recognised that a number of other decision-making methodologies could be used and that there are limitations in the use of the BCA methodology when considering climate change effects. Nevertheless, the BCA

methodology is currently and widely used in making decisions about the economics of infrastructure investment. The *Toolbox* project (NIWA, MWH, GNS and BRANZ, 2012) includes information on the pitfalls of using the BCA methodology when climate change effects are included Oldfield (2012b). An explicit treatment of uncertainty and a sensitivity assessment are used in this case study to investigate whether, despite these pitfalls, a BCA methodology could be used to assist in making strategic level decisions that take account of climate change.

5.1 BCRs of the Adaptation Options

Three separate Benefit Cost Analyses were undertaken, one for each of the three different time horizons 2010, 2040 and 2090. In each case a “Do Nothing” option representing the continuance of current river management practices was used as a benchmark against which the benefits of the different adaptation options could be compared.

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 a subjectively determined annually increasing prevalence factor ranging from 1.0 to 1.2, rising linearly over the next one hundred years.

	Case A	Case B	Case C
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

Table 5: Benefit / Cost Analysis of Options – Best Estimate Case

The Benefit/Cost Ratios (BCR¹) for each of the options considered (assuming a 100 year design life and 5% discount rate) are summarised in Table 5. 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 Houses 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 option costs means that there is significant variability in the BCR results. This can be seen from the BCR plots given in Figure 3 which show for each option the upper (Optimistic) and lower (Pessimistic) bounds about the Best Estimate.

Taking account of the upper and lower bounds of uncertainty in the BCR estimates, Figure 3 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 3 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. Main Channel Widening or Right Bank Diversion).

It is also interesting to note that (for this illustration) there are a number of cases where the uncertainty bands for different options

overlap. This indicates that preferences amongst these options could be reversed from that indicated by considering the best estimate predictions alone.

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 best estimate case, using flood conditions for 2090.

Table 6 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 options to address long-term climate change impacts is given in Oldfield (2012b). In particular, low discount rates 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 (refer to Tol, 2006).

Table 7 shows the effect of increasing storminess and compares the best estimate 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. In this analysis only the prevalence for storms is increased, with predicted flood levels assumed to be unchanged.

¹ 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.

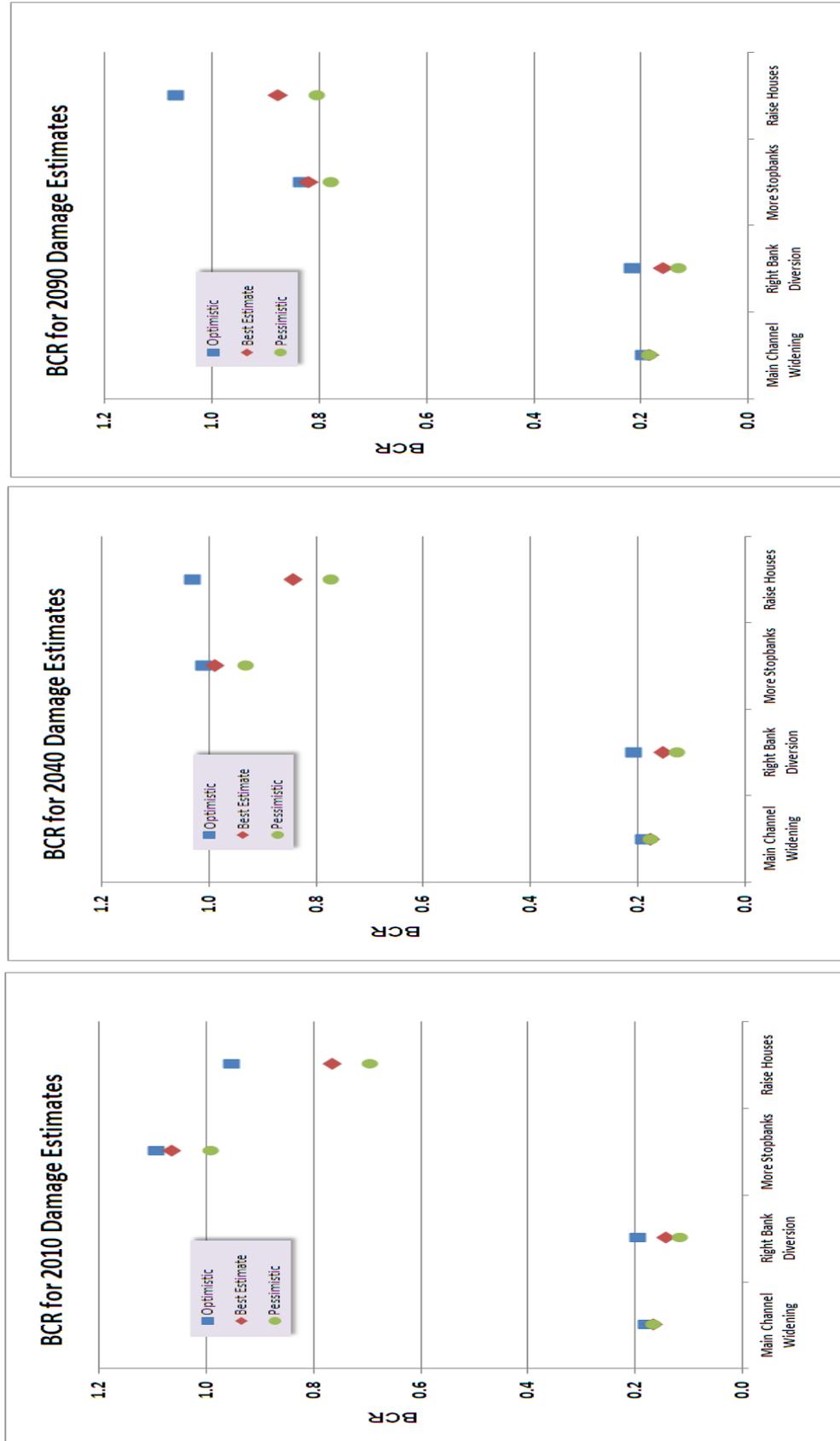


Figure 3: Benefit / Cost Ratio Comparisons of Options for Flood Damage Estimates in 2010, 2040 and 2090

Adaptation Option	Best Estimate Case: 5% Discount Rate	Best Estimate Case: 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 6: Effect of Discount Rate on Option BCR (2090 Conditions)

Adaptation Option	Best Estimate Case: 20% Increase in 100 years	Best Estimate Case: 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

Table 7: Effect of Increasing Storminess (2090 Conditions)

Other sensitivity tests could and should be undertaken to further test the preferences between options (for example, labour costs, construction costs, value of housing, effects of channel dredging, etc). As noted earlier, uncertainty bands in the BCR predictions could be reduced by further calibration of the damage costs. The results presented here should, therefore, be taken as illustrative only.

6 Model Assumptions and Uncertainty

It is important to realise when coupling a range of models (such as the climate, hydrological, hydrodynamic and risk models used here), that each link in the chain is subject to assumptions and uncertainty. While it is important that models should not introduce undue bias or uncertainty, there will always be a limit to what can be achieved, particularly in regards to climate change modelling, because the attempt is to predict many years into the future.

This case study did not attempt to examine all viable adaptation options but only to show a methodology that could be used to evaluate options. The options were selected by a workshop group of representatives of the Westport community who had been presented with climate change information and who had discussed the likely effects of climate change on their areas of expertise within council operations. With additional scope, further options could be assessed and the process of assessment on the four options could be refined. Given the limited scope of this study, results should be considered as illustrative only. The methodology, however, is considered to be an example of a robust, community-involved process of options analysis that could be repeated across a number of situations by a Council with a responsibility to make transparent decisions.

7 Summary of Findings

7.1 Flood Management Options

The methodology of using commonly available tools and datasets, along with an explicit of uncertainty, was illustrated in a case study of Westport. Given the assumptions and constraints in scope, the key findings from the flood adaptation options case study for Westport are as follows:

- a) Of the four options assessed within the scope of the case study, stopbank mitigation was shown to be the best of the options for flood protection and 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 m³ 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 some properties and to infrastructure. Secondary and indirect costs, such as disruption to business, and emergency/safety issues to affected communities, are

likely to reduce but some will remain.

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. The consequences of a stopbank failure also need to be carefully considered as development can be lulled into relying too heavily on flood protection in otherwise high-risk locations.

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

The economics of a retreat option has not been tested in this case study but it is an obvious direction of further assessment in any long term community planning.

7.2 Options Analysis

The study has shown that commonly-available software and data sources can be used to perform an economic assessment of 'strategic' options. An explicit treatment of uncertainty has shown that while preferences amongst options can be determined, a considerable amount of uncertainty remains. Some of these uncertainties could be reduced by more detailed modelling and analysis, using other methods and models presented in the *Toolbox*. Some uncertainties are irreducible because we face an uncertain future.

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 results of such studies can be used to inform the community, the insurance industry and others of the viability, or not, of a wide range of options and for ongoing community discussions of acceptable risk and as a rationale for further investigation or design of one option over another, taking account of budgetary constraints.

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. Such studies could also form the basis for seeking early community feedback on the preferences giving an overview of the broad costs and benefits associated with the options.

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