Climate Change Case Study:

Assessment of the impacts of sea level rise on floodplain management planning for the Avon river

Prepared for the NZ Climate Change Office (Ministry for the Environment) by Harris Consulting in conjunction with Christchurch City Council

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LIST OF ABBREVIATIONS

AAD	Annual Average Damages
AEP	Annual Exceedance Probability
BSM	Bexley Special Management [Area]
CCC	Christchurch City Council
ECan	Environment Canterbury
ENSO	El Nino Southern Oscillation
FD	Future Development
IPCC	Intergovernmental Panel on Climate Change
NZCCO	New Zealand Climate Change Office
MFE	Ministry for the Environment
MHWS	Mean High Water Spring
MSL	Mean Sea Level
NPV	Net Present Value
PV	Present Value
RL	Reduced Level – level relative to a datum
RMA	Resource Management Act
SLR	Sea Level Rise

SUMMARY AND CONCLUSIONS

1. As part of its portfolio of climate change work, the New Zealand Climate Change Office (NZCCO) within the Ministry for the Environment (MfE) has begun a programme to assist regional councils and territorial authorities to better understand and take into account climate change effects when carrying out their day-to-day operations. In particular, the programme aims to develop guidance materials for local authorities to assist them in assessing and managing the risks of climate change in their planning processes. This report was commissioned as a case study on the impact of climate change on risk management planning for the Avon catchment and associated coastal areas. The study focuses primarily on an economic analysis of likely damages, and the response options available to local government to mitigate these. While this report is geographically specific in its scope, it is expected that many of the issues, challenges, and methodologies relating to coastal hazard planning within a climate change framework presented here will also be applicable in other regions and catchments.

2. The trend in sea-level rise for the past 100-150 years is small, with a global mean of +1.8 mm/yr (range 1-2 mm/year). Predictions of future sea-level rise, within the context of climate change in response to human-induced changes in atmospheric composition (e.g. "greenhouse gases"), are regularly addressed by the Intergovernmental Panel on Climate Change (IPCC). Bell (2001) includes the following predictions for the most likely range of relative sea-level rise in Canterbury (in terms of the CCC Datum), based on IPCC (2001) predictions for the years 2050 and 2100. A mean level of the sea of 9.114 m in 1990 was taken as the starting point.
    - Level in 2050: 9.25 – 9.29 m (increase 0.14 – 0.18 m : 0.15m assumed)
    - Level in 2100: 9.42 – 9.60 m (increase 0.31 – 0.49 m : 0.4m assumed)

3. In the short to medium term, it seems likely that damage will occur around coastal margins in concert with changing storm patterns and, in the longer term, rising sea-levels will increase the potential for such damage to occur.

4. Investigation of the lower Avon and associated coastal area is particularly pertinent because the current stopbank system in that area provides adequate protection for most properties under current sea level, but with sea level rise (SLR) the stopbanks are likely to be overtopped with increasing frequency. It is also timely because CCC is currently working through a proposed variation to the City Plan on flooding issues. This proposed variation would change the minimum floor level in the floodplain to a level which will accommodate predicted SLR, and would restrict the minimum section size in a very low lying area in Bexley to 650m^2 to reduce intensity of asset build up in the area and to assist with recession plane problems associated with the minimum floor level.

5. The total cost of flooding from the Avon River with the current structural and institutional measures in place is shown in Table 1. This assumes an 11.4 m

minimum floor level, full development of vacant land in the area over 50 years and redevelopment of housing in the area at a rate of 30% every 50 years.

Table 1 : Total damages from flooding of the Avon River ($millions) with current protection measures

Land Use		**Present**	**Future Development (vacant land taken up over 50 years, 30% redevelopment every 50 years)**	
Sea Level		**Status Quo**	**0.15 m Rise (in 50 years)**	**0.4 m Rise (in 100 years)**
Storm Event	**20 year event**	$0.02	$1.70	$58.19
	100 year event	$0.21	$2.48	$163.51
	500 year event	$1.45	$127.57	$373.19
Earthquake (with stopbank liquefaction)	**Mean HWS (0.83% AEP)**	$0.23	$0.48	$1.28
	Perigean (0.28% AEP)	$0.85	$1.35	$2.72

6. The PV[1] of flood damages over the 100 year period of sea level rise projection is estimated at $3.9 million at a discount rate of 8% and for current levels of protection. The damage figures are only moderately sensitive to the uncertainty of future sea-level rise. Within the "most likely" band of 30 to 50cm sea-level rise by 2100, the flood damage estimates vary from $3.6 to $4.7 million. This figure is however very sensitive to the discount rate used, and ranges between $18.6 million at a 4% discount rate, and $2.4 million at a 10% discount rate. Because damages to residential housing comprise 95% of the total damages, the results are also very sensitive to variation in damage estimates at different depths.

7. A range of different minimum floor levels was considered for the area which would impact on damages to new and redeveloped housing in the area. When considering the area as a whole, none of the minimum floor level provisions showed a net benefit when compared with the 11.4 m RL[2] current policy. This conclusion is however very sensitive to discount rate, damage estimates and timing and does not include a number of unquantified and intangible damages.

8. If a higher minimum floor level than 11.4 m were to be chosen, 11.85 m may be a more appropriate level to target than 11.7 m, because under most alternate assumptions modelled 11.7 m produces a lower net benefit than the 11.85 m floor level. With a 50% increase in damages, which would not be out of the order to account for intangible damages, or a 6% discount rate, the 11.85 m floor level is the most appropriate option. Analysis of individual ponding areas suggests that the 11.7 m level is most appropriate where there are no or minimal stopbanks. Because of the complex interaction between sea level,

[1] Present value at an 8% discount rate.
[2] Reduced level – relative to the Christchurch Drainage Board datum.

ponding level and the minimum floor levels, setting the minimum floor level will be an exercise in judgement rather than a simple answer. Further modelling of ponding area levels with different overtopping events is recommended.

9. The Bexley Special Management Area subdivision restrictions as proposed by the Christchurch City Council do not appear to produce a net economic benefit in terms of preventing flood damages over the next 100 years. The primary justification appears to be as a means to allow the minimum floor levels to be achieved without impacting on amenity and the bulk and location requirements. As with the option of raised floor levels, wider considerations that account for social impacts and other economic issues not modelled in this study are expected to influence relevant council decisions.

10. Tidal barrages and stopbanks were considered as mitigation measures. Neither of these structural measures are recommended for immediate action. There are major environmental and technical constraints on the potential for tidal barrages. There are also significant technical barriers to raising stopbanks, and there is no gain from immediately undertaking upgrading for most of the stopbank system. The Hulverstone area has minimal stopbanking, and is the most promising area for stopbank improvement. Upgrade of stopbanks in this area produces a net economic benefit and should be considered for immediate action. However given the large residual damages and frequency of flooding in 50 to 100 years time even with the highest minimum floor level, it is very likely that some form of upgrade to the entire stopbank system for the area will be required. Planning for the area should be based on the inevitability of this occurring under current sea level rise projections at some stage over the next 100 years.

11. The council should note that the analysis has not included all economic and social costs, and management decisions need to consider social impacts, distribution of economic costs and benefits, and issues such as risk aversion and irreversibility. In particular, the zoning decisions in Bexley will create use rights which are essentially irreversible, leading to a build up of assets in a hazardous area. The council also needs to consider the relationship between minimum floor levels and stopbanks and ensure that the mitigation measures enacted now do not prevent the development of a comprehensive solution to flooding in the area in the future. This will involve some combination of increased stopbanks and a minimum floor level, which will provide protection related to likely flood levels with the stopbanks in place.

12. Damage costs from sea-level rise for the Avon estuary area were found to increase significantly in the period 2050-2100 compared to the period 2000-2050. Due to the effect of discounting, only a few specific damage control measures seem justified on a purely economic basis at present, but their economic efficiency will increase over the next few decades. Based on the conclusions from this study, it is therefore recommended that one key element of council planning decisions should be to ensure that future inevitable mitigation measures are not precluded by current development choices and

remain technically, socially and environmentally feasible at manageable costs to the community.

REPORT

1. Introduction

As part of its portfolio of climate change work, the New Zealand Climate Change Office (CCO) within the Ministry for the Environment (MfE) has begun a programme to assist regional councils and territorial authorities to better understand and take into account climate change effects when carrying out their day to day operations. In particular, the programme aims to develop guidance materials for local authorities to assist them in assessing and managing the risks of climate change in their planning processes. This report was commissioned to investigate the impact of climate change induced sea level rise on risk management planning for the Avon catchment and associated coastal areas. While this report is geographically specific in its scope, it is expected that many of the issues, challenges, and methodologies relating to coastal hazard planning within a climate change framework presented here will also be applicable in other regions and catchments.

Investigation of the lower Avon and associated coastal area is particularly pertinent because the current stopbank system in that area provides adequate protection for most properties under current sea level, but with seal level rise (SLR) the stopbanks are likely to be overtopped with increasing frequency. It is also timely because CCC is currently working through a proposed variation to the City Plan on flooding issues. This proposed variation would change the minimum floor level in the floodplain to a level which will accommodate predicted SLR, and would restrict the minimum section size in a very low lying area in Bexley to 650 m^2 to reduce intensity of asset build up in the area and to assist with recession plane problems associated with the minimum floor level.

2. Climate change impacts on the Avon River, the estuary and its surrounds including the ocean beach along Brighton Spit

2.1 Sea Levels

Whenever the subject of climate change is raised in relation to the ocean (and the waters connected to it), people's minds most often think of the issues in terms of sea-level rise and whatever consequential effects may arise from it. Unlike other potential effects of climate change, such as changes in storm patterns, wind directions, etc., which as far as the coastal margin is concerned, are arguably more important, sea-level rise seems a somewhat more straightforward concept to grasp. This, however, is not necessarily the case. The meaning of the term 'sea-level' is quite complex and is not always well understood. Even 'Mean Sea Level', which is often referred to as a datum implying that it is a constant, is subject to variations according to inter-annual (year to year) and decadal time-scales, as well as seasonal changes. These variations have an important role in determining the "background" sea-level, or vulnerability to storm activity, present at any given time. If the background sea-level is elevated, it will exacerbate the effects of storm surges and tides.

Although recent research has raised the level of understanding of seasonal, inter-annual and decadal variability in sea-level around New Zealand (e.g. Bell and Goring, 1997; Bell et al., 2000), there remains a serious lack of long-term, open coast, sea-level data, and the reasons for such variations in sea-level are not always clear. For example, in the report by Bell (2001) it was noted that sea-level in Pegasus Bay (after allowing for annual cycles) is elevated above normal during a La Niña event such as occurred between 1998 and 2001, but is normally depressed during an El Niño. However, during the 1995-96 La Niña episode the pattern went against this trend and sea-levels dropped. At Sumner Head, measurements of the monthly mean sea-level between 1995 and 2001 varied between 8.9 m and 9.3 m relative to the Christchurch City Council Datum for MSL of 9.114 m. Bell (2001) recommends further investigation to establish why and when such anomalies occur. This view is strongly supported.

When considering the potential effects of climate change on coastal land, assets, etc., the essential point to consider in most cases is extreme water (sea) level and this is affected by a range of factors, including climate change effects such as sea-level rise and storminess. Apart from day-to-day tides, and ENSO (El Niño-Southern Oscillation) and other effects referred to above, there are other climate-related factors that affect extreme sea-levels and also need to be considered. These are principally storm surge, wave set-up and wave run-up, the latter being of greater concern on an open-sea coast. All these may be affected to some degree by climate change.

- Storm surge is normally defined as the temporary elevation of sea-level above the predicted tide caused by a varying combination of low barometric pressure that results in a regional rise in sea-level; and adverse winds that cause seawater to “pile up” against the coast. Storm surges around the New Zealand coast typically range up to about 0.7 m

- Wave set-up, which is effectively caused by the “piling up” effect as waves shoal along the shoreline, is dependent on the breaking wave height, wave period, and also the slope of the beach and nearshore zone, and will generally be 8-15% of the incident breaking wave height. Wave set-up in extreme storm conditions can range up to around 1.0 m.

- Wave run-up, which is simply the level to which waves run up the beach, is more difficult to generalise as it is strongly dependent on the site-specific beach and foredune profiles, and the associated substrate (e.g. walls, rocks, gravel, sand) at each site. Therefore, a site-by-site appraisal is usually needed for each different section of the coastline. Wave run-ups of a metre or more are not unusual in severe storms.

2.2 Trends in Sea Level Rise

The trend in sea-level rise for the past 100-150 years is small, with an accepted global mean of +1.8 mm/yr (range of 1 – 2 mm/year). Over the last century, this equates to an increase in sea-level of 0.18 m. This on-going rise gradually increases the probability of exceedance of any specified hazard datum (relative to the landmass) from coastal inundation events. Sea-level rise should be factored into any long-term plans for the coast.

An analysis by Hannah (1990) of sea-level trends from 1900-1988 based on tide-gauge data at New Zealand's four main ports produced a national average rise in sea-level of +1.7 mm/yr This is similar to the global average and, so far, there has been no apparent acceleration in the rate of rise (Bell et al., 2000). More recent work by Hannah, as yet unpublished but reported at the NZ Geographical Conference, Auckland, 9 July 2003, suggests that the mean rise in sea level over the same period remains approximately 1.7 mm/yr but now averaged over the three northern main ports. The Dunedin record is no longer considered because the results are not reliable. More specifically, the latest values are:

- Auckland 1.30 ±0.1 mm/yr
- Wellington 1.78 ±0.2 mm/yr
- Lyttelton 2.08 ±0.1 mm/yr

Projections of future sea-level rise, within the context of climate change in response to human-induced changes in atmospheric composition (e.g. "greenhouse gases"), are regularly addressed by the Intergovernmental Panel on Climate Change (IPCC). Bell (2001) includes the following projections for the most likely range of relative sea-level rise in Canterbury (in terms of the CCC Datum), based on IPCC (2001) projections for the years 2050 and 2100. A mean level of the sea of 9.114 m in 1990 was taken as the starting point.

- Level in 2050: 9.25 – 9.29 m (increase 0.14 – 0.18 m)
- Level in 2100: 9.42 – 9.60 m (increase 0.31 – 0.49 m)

While the projected increases in MSL due to climate change may not appear to be large when compared to normal variations, particularly under storm conditions, they clearly must be taken into account. On the open coast, extreme water levels can be calculated providing appropriate wave and climate information is available, and beach management practices organised accordingly. Within the Avon-Heathcote Estuary, the matter is rather more complex. Barometric and storm-related extreme water levels, based on historical wind records measured over a period of 34 years (1960-1993) at Christchurch Airport, and tide data from a recorder at the Ferrymead Bridge, have been analysed (McKercher and Kirk, 1994) to gauge wind effects (wave set-up and run-up) on the estuary at the mouth of the Avon River. The study suggested that while water levels were largely dependent on sea levels in the estuary rather than stormwater run-off in the river, there were anomalies present that indicated the need for further work.

CCC estimates are based on projected sea level rise and it associated impacts in the estuary. The best estimates for current sea levels in the estuary are:

Table 2: Storm event probability and current sea levels

Event	Sea level (RL)[3]
2% AEP[4]	10.92
1% AEP	10.98
0.5% AEP	11.03
0.2% AEP	11.07

These levels are based on storm surge only. While there is likely to be cross correlation between storm surge events and heavy rainfall and associated river flooding, the CCC modelling has determined that the levels in the lower Avon are dependent on storm surge, while those in the upper Avon are largely dependent on rainfall events[5].

The sea levels for 50 and 100 years from now were estimated by adding the projected SLR onto the storm events. For the purposes of modelling future water levels CCC adopts a figure of 0.15 m for SLR to 50 years, and 0.4 m to 100 years. The estimated sea levels in the estuary may also be modified by changes to the hydrology of the estuary, but to make a more accurate estimate would require a sophistication of modelling beyond the scope of this project.

Sea-level rise, and the effects of climate-related changes on the estuary and its surrounds, have been canvassed in a number of reports including, more recently, in Tonkin and Taylor (1999) and Bell (2001). Bell, in particular, noted that higher mean sea-levels will change coastal and estuary systems by two mechanisms. Firstly by increasing water depth, which creates a number of problems if sedimentation from the catchment doesn't keep pace with sea-level rise and, secondly, by higher tide and storm sea levels relative to land datum.

Within the estuary, it can be anticipated that increasing water depths will change the way waves, tides and storm surges behave and any decrease in light levels will impact on aquatic ecosystems. Where the boundaries of the estuary are constrained by stopbanks and landward migration of the coastal margin is prevented, higher water levels will cause greater inundation of coastal wetlands and some loss of inter-tidal habitat may be expected. There are already some changes occurring around the river mouths and inside the spit, but it is difficult to determine whether this is associated with SLR or other factors. The risk of coastal flooding will increase during extreme high tides and storm surges, posing a hazard for adjacent low lying land such as the lower Avon and Heathcote areas.

Increasing intrusion of salt water into ground water and further up river reaches may also impact on water resources, infrastructure and lowland river ecosystems. Existing drainage networks in low-lying areas may require new or additional pumping.

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[3] RL – Reduced Level – a surveying term indicating a level relative to a datum – in this case the Christchurch Drainage Board Datum.
[4] Note: "AEP" is a term used to describe return periods as Annual Exceedance Probability – the risk of an event being equalled or exceeded in any one year. Thus, 0.5% AEP can be said to refer to a "200 year flood" and 0.2% AEP a "500 year return period flood"
[5] Tony Oliver, ECan, 2003 pers.comm.

Outside estuarine areas, on the open coast, the coastal processes tend to be much more aggressive and the shoreline and coastal margin has to cope with a greater range of sea levels as well as a more hostile marine (wave and current) environment on a day-to-day basis. Here, the risks are more associated with physical hazards such as erosion and over-topping than with ecological and habitat issues.

Generally, on the open coast, sandy shorelines that have been dynamically stable (no long-term evidence of erosion or accretion) will retreat landward when sea levels rise if additional supplies of sand from rivers or from off-shore cannot keep pace with the sediment demands created by higher sea levels and any accompanying changes in wave climate. Accreting sandy coasts may continue to accumulate material but at a slower rate (Bell, 2001). Eroding shorelines, on the other hand are likely to suffer increasing risk.

In the short to medium term it seems likely that damage will occur around coastal margins in concert with changing storm patterns and, in the longer term, rising sea-levels will increase the potential for such damage to occur.

This report is intended to assist CCC to integrate the effects of climate change and SLR into its planning for the floodplain. The report assesses the current, 50 and 100 year scenarios, and assess damages to the floodplain under current conditions and with SLR of 0.15 m (50 years) and 0.4 m (100 years). The level of damages and various mitigation options are analysed and implications for planning discussed. The report also discusses implications for the coastal side of the New Brighton beach and spit.

3. Approach and focus of study

The impacts of climate change and SLR for Christchurch are primarily of concern in the lower Avon and the Brooklands area, with the latter being less developed. The lower Avon floodplain has large areas of residential housing which are currently protected by stopbanks or are above the 500 year flood event level, and so are considered relatively unaffected by flooding. However, with sea level rise, less severe events will overtop the existing protection measures and inundate new areas, so it is pertinent that climate change be taken into account when planning for the area.

The report undertakes an investigation of damages to the lower Avon under different mitigation measures. As a first step, it estimates the risk arising from sea-level rise and storm surge events and consequent damages to property and infrastructure in the study area. As a second step, a number of risk management/flood mitigation options were considered. These options were determined in conjunction with CCC and Environment Canterbury staff. The mitigation options comprise two non structural measures – minimum floor heights and subdivision control, and two structural measures – tidal barrages, and stopbanks.

Some consideration was also given to the impacts on the New Brighton Beach and spit, on the coastal side of the estuary, which will be subject to higher water levels, and potentially greater erosive forces. However because of the uncertain nature of effects in this area, Section 10 discusses the impacts of climate change on beach management as the fifth mitigation measure, but does not make estimates of damages nor recommendations for action.

3.1 Areas Flooded

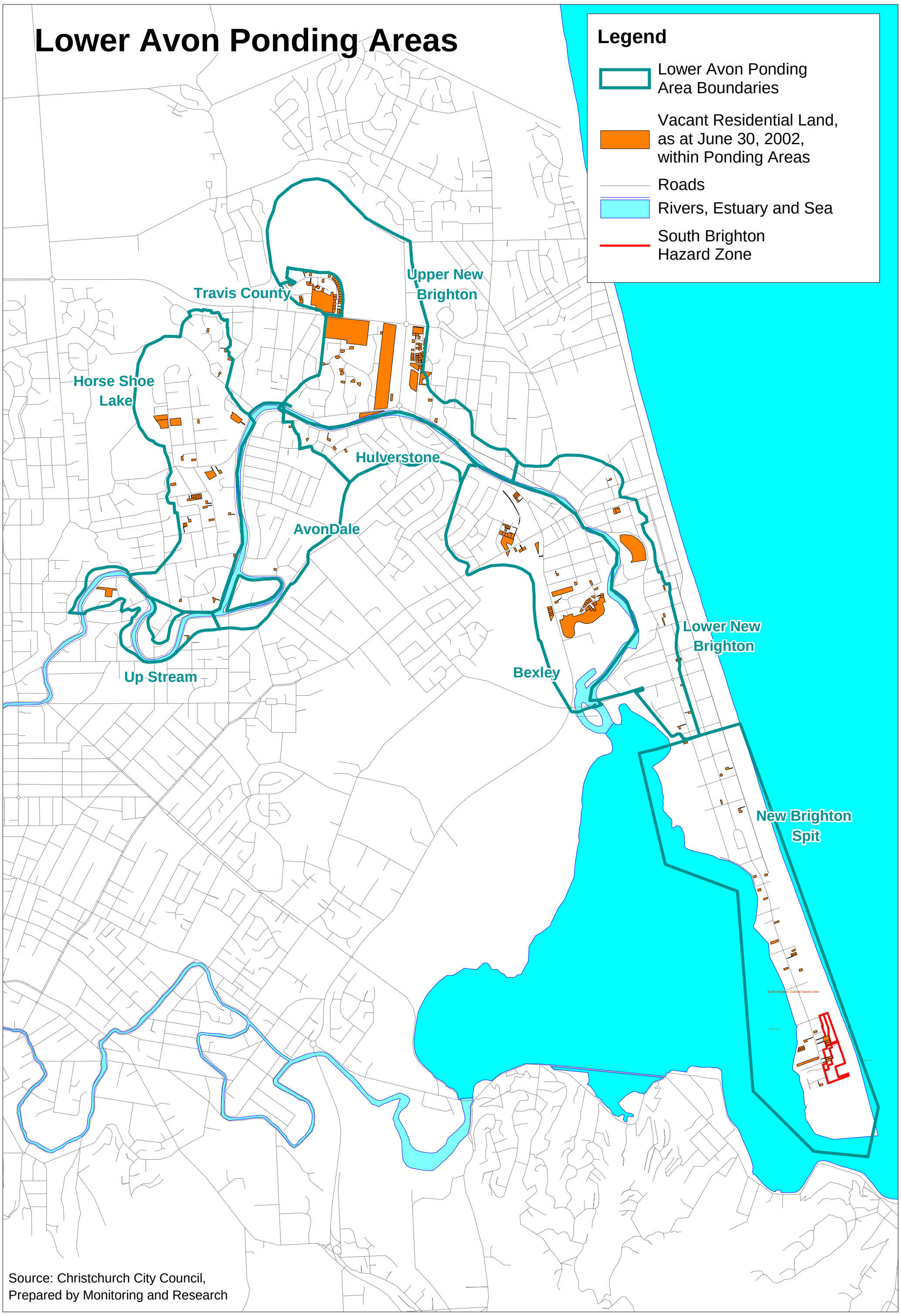
In 1993-94 the Christchurch City Council undertook hydraulic modelling of the catchment and flood flows together with street surveys of section and house elevation which indicated the physical extent and number of properties likely to be flooded by the Avon. The physical extent of the floodplain has been defined for this study as downstream of and including Horseshoe Lake. Although there will be some flooding in an extreme event in Fendalton and the central city, the main flooding in the Avon river is in five "ponding areas" - New Brighton, Avondale, Horseshoe Lake, Hulverstone and Bexley. In addition, flooding is expected in an area between the New Brighton and Horseshoe Lake ponding areas in sea level rise scenarios. This additional area is labelled Upper New Brighton for the purposes of this study. Areas of flooding are shown in Figure 1 on page 7.

The flood height in these ponding areas is determined primarily by sea level. There is a small area upstream of these ponding areas which is affected by both tidal events and river events, but the differences in damages at this location from changes in sea level rise are not significant and it was not included in the study. Modelling was undertaken in 1993 of the likely levels in the ponding areas under current, +0.1 m and +0.3 m SLR. Where stopbank overtopping occurs, the stopbanks were modelled as weirs, with the height of water in the ponding areas determined by the length of the stopbank where overtopping occurs, the sea level height, and the area of the ponding basin[6]. These levels were updated to current estimates of SLR by interpolation and extrapolation from the earlier modelling data, rather than remodelled for each ponding area. Nine scenarios of storm related inundation have been assessed - three mean sea levels (current sea levels, 0.15 m and 0.4 m sea level rise) and three storm surge events (20, 50 and 100 year events).

Other flooding events are possible in this area. The Avon river stopbank system is considered to be at considerable risk of liquefaction during an earthquake. McCahon and Woods (1999) predict lateral spreading during a strong earthquake of about 1 m displacement at the river bank. The most likely earthquake event which causes this level of damage is a major Alpine fault event, predicted to have a 65% probability of occurrence in the next 50 years[7].

[6] Tony Oliver, flood model designer, pers. comm.
[7] A major Alpine Fault event with prolonged (>one min) shaking duration.

Figure 1: Map of Ponding Basins for Lower Avon



Based on this data, it is assumed that in such an earthquake the stopbanks will have sufficient failures to create a “banks down” situation. In the event of an earthquake of this magnitude, it is considered unlikely that the banks would be repaired within two to three days, so it is assumed that the surrounding areas will be exposed to 4 high tides. The mean high tides at the estuary have been used to estimate the probability of water inundating housing in the area. The figures for present day events are 10.04 m for mean high water, 10.14 for 12% high water exceedance, and 10.35 m for the perigean high water (once every 28 days)[8]. Using these estimates, even with sea level rise of 0.4 m, only the Bexley ponding area[9] is likely to be affected in a typical high tide. Obviously if the earthquake were to coincide with storm conditions, the sea level and therefore impacts would be considerably higher. However because the co-probabilities of storm events and earthquakes become very small[10], these events were not considered.

Damages for these further six scenarios of sea inundation based on failure of the stopbanks in an earthquake were estimated[11]. The fifteen scenarios considered are shown in Table 3.

Table 3 : Flood scenarios used for damage assessment

Land use		**Present**	**Future development[12]**	
Mean sea level		**Status quo**	**0.15 m rise**	**0.4 m rise**
Flood event	**20 year event**	X	X	X
	100 year event	X	X	X
	500 year event	X	X	X
Earthquake leading to stopbank failure	**MHWS (12%)**	X	X	X
	Perigean (one in 28)	X	X	X

In addition to these flood event scenarios, a threat to these areas arises from tsunamis. The threat from tsunamis is thought to arise from earthquakes around the Pacific. However:

- The impact of sea level rise on tsunami risk will be small, since the 100 year difference of 0.4 m is minor in the context of a predicted 10 m variation in water level from a tsunami.

[8] Waterways, Wetlands and Drainage Guide, Christchurch City Council, 1997.

[9] There are a small number of houses in the Brighton area which are also likely to be affected, but the magnitude of damages was not sufficiently large in relation to the total damages to make the additional analysis of earthquake events for this ponding basin worthwhile.

[10] For example a one in 20 year event, coinciding with a one in 500 year earthquake event for two days of the year has a probability of 0.05*0.002*2/365 = one in 1.8 million

[11] In an earthquake event, damage to residential property only is calculated. The earthquake itself is likely to cause significant damage to infrastructure, evacuation etc, and the flood induced damage will be important but not significant in the context of this study.

[12] Future development is considered only in conjunction with SLR because there is no damage in storm surge events without SLR apart from the Hulverstone ponding area, and this has very limited potential for future development.

- Much of the inundation is expected to occur from the seaward side rather than the estuary side of the spit (although some overtopping of stopbanks is expected with the tsunami bore moving up the river as far as Fitzgerald Ave). There is thought to be some additional risk however of the spit being inundated with backwash from the estuary side which is not protected by dunes.
- There has been little detailed modelling of the potential behaviour of a tsunami in the estuary environment, and without this it is difficult to predict or include sea level rise impacts.

For these reasons, the impact of tsunamis has not been included in this study.

Section heights were surveyed and garage and house floor elevations were either surveyed or estimated[13] for each of the five ponding areas. The number of properties flooded in the SLR scenarios was estimated directly from flood maps in the upper New Brighton area and interpolations made for the number of houses affected in different SLR scenarios. Adjacent known levels were used for estimates of section and house flooding upstream of the main ponding areas. The extent of flooding does not allow for blocked outfalls and drains which cause water to back up and flood surrounding areas, and as such the structural damage estimates are likely to be lower-bound.

The levels estimated for the ponding basins are shown in Table 4 below.

Table 4: Estimated flood event levels in lower Avon ponding areas

Storm surge event	Ponding basin	Flood height (RL)		
		Current	50 years (+0.15 m)	100 years (+0.4 m)
20 year event (5% AEP)	Avondale	-	-	11.31
	Bexley	-	-	10.82
	Horseshoe Lake	-	-	10.99
	Hulverstone	10.98	11.18	11.25
	New Brighton	-	-	11.09
100 year event (1% AEP)	Avondale	-	-	11.43
	Bexley	-	-	11.08
	Horseshoe Lake	-	-	11.04
	Hulverstone	11.09	11.23	11.46
	New Brighton	-	-	11.16
500 year event (0.2% AEP)	Avondale	-	11.38	11.58
	Bexley	-	10.72	11.53
	Horseshoe Lake	-	11.40	11.59
	Hulverstone	11.23	11.28	11.56
	New Brighton	-	11.11	11.52

[13] Based on adjacent known levels.

Under present day land use scenarios only the Hulverstone ponding area, where stopbanks are low, receives extensive flooding. However in the one in 500 year events with 0.15 and 0.4 m SLR where more stopbanks are overtopped, over 380 ha of urban residential land is flooded. In addition, it is understood that up to 260 ha associated with Travis Swamp in the rural area north-west of the Barkers Road/New Brighton Road intersection will also be flooded in one in 500 year events, but that this will involve minimal damage in that the area will be either be in low lying pasture with low productivity or in reserve.

3.2 Damage Assessment

Earlier data from an insurance assessor experienced in flood damage assessment (The Assessing Agency) was used to estimate damages to urban dwellings and the few commercial properties in the flood plain. This data was based on a 25% sample taken of houses experiencing flooding in the ponding areas[14]. The assessor conducted a drive-past survey of these sample houses, and identified likely flood damage to the section, the garage, and the house (at <0.05 m, 0.05 – 1 m, > 1 m entry into the house)[15]. These figures were updated using the Capital Goods Price residential housing index as a reasonable basis for costs of repairing damage to houses. This sample data was used to generate an average flood damage for each of the scenarios, and a total damage for each ponding area. For upper New Brighton, damages were interpolated from counts of flood maps under a 0.3 m SLR scenario undertaken previously.

It has been assumed that any flooding in the lower reaches of the catchment where flood height is affected by sea levels will have a saltwater content, with the proportion of salt increasing toward the estuary. In addition surcharging of sewers and damage to sewer pumping stations is likely to mean that the flood will also contain sewage, increasing the damage and costs of cleanup.

Costs associated with other infrastructure were estimated in discussion with the organisations involved (Christchurch City Council, Southpower (now Orion), Telecom). Indirect damages from traffic diversion were estimated from road counts on arterial roads and average length of time where > 150 mm of water covered the road.

The direct damages (from contact with floodwaters) and indirect damage (associated damages such as traffic diversion) have been estimated. However indirect damages from loss of income and disruption, loss of memorabilia, damages to ecosystems, as well as intangible damages, such as psychological trauma and stress, have not been quantified.

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14 The few commercial properties affected in each flooding scenario were included in the sample.

15 The house depth estimates of <0.05 m, 0.05 – 1 m, and >1 m correspond to major flood damage intervals - below skirting board, above skirting board but some damage preventable (e.g. by stacking chattels on benches etc), and extensive damage.

4. The Costs of Flooding

4.1 Damage to Urban Properties

The average damage for properties affected in each of the ponding areas at different depths is shown in Table 5[16].

Table 5 : Average damage per property to affected residential and retail properties in the major ponding areas ($) updated to 2002

Depth	0 - 0.1 m	<0.4 m	< 0.45 m		<1 m		>1 m	
Damage to :	Section	Garage	House at less than 0.05 m		House at 0.05 - 1.0 m		House at more than 1 m	
			Dwelling	Chattels	Dwelling	Chattels	Dwelling	Chattels
Avondale	$900	$900	$25,000	$30,900	$34,500	$40,400	$44,000	$49,900
Bexley	$700	$1,000	$25,000	$29,700	$30,900	$36,800	$36,800	$41,600
Horseshoe Lake	$1,200	$1,200	$27,300	$35,600	$36,800	$44,000	$44,000	$49,900
Hulverstone	$1,400	$1,400	$34,500	$39,200	$44,000	$48,700	$52,300	$58,200
New Brighton	$700	$500	$29,700	$35,600	$38,000	$45,200	$42,800	$47,500
Weighted Average Damage	$900	$900	$27,300	$33,300	$35,600	$41,600	$41,600	$47,500

[16] Updated to 2003 using Capital Goods Price Index Residential housing component.

Table 6 shows the damage to properties by ponding area under the storm event flood scenarios.

Table 6 : Damage to properties ($000s) for different storm events

Land Use / Sea Level	Flood area	Present Status quo sea level	Future Development 0.15 m rise	Future Development 0.4 m rise
20 year event	Avondale	$0	$0	$23,590
	Bexley	$0	$0	$4,921
	Horseshoe Lake	$0	$0	$830
	Hulverstone	$19	$1,695	$3,736
	New Brighton	$0	$0	$25,102
	Upper New Brighton	$0	$0	$0
	Total	$19	$1,695	$58,179
100 year event	Avondale	$0	$0	$28,573
	Bexley	$0	$0	$56,639
	Horseshoe Lake	$0	$0	$6,765
	Hulverstone	$206	$2,466	$21,920
	New Brighton	$0	$0	$35,296
	Upper New Brighton	$0	$0	$14,230
	Total	$206	$2,466	$163,423
500 year event	Avondale	$0	$25,324	$43,493
	Bexley	$0	$5,409	$88,667
	Horseshoe Lake	$0	$43,417	$58,427
	Hulverstone	$1,409	$9,098	$29,066
	New Brighton	$0	$25,653	$58,057
	Upper New Brighton	$0	$18,608	$95,290
	Total	$1,409	$127,510	$373,000

Under present land use and sea levels, the major sites of damage are in Hulverstone (where the stopbanks are low). As sea levels rise and the potential for the stopbanks to be overtopped increases, the potentially larger ponding areas of Bexley and Horseshoe Lake become proportionately greater contributors to the total damage. There is some question about damages at upper New Brighton, for which damages have not been included for the 5% AEP (20 year) event with +0.4 m SLR because of indications from the previous modelling which suggested that damage would not occur. This may need to be revisited with further modelling of the area.

It should be noted that the results are very sensitive to the entry of water into houses. When water reaches floor level, the amount of damage rises from an average of $1,800 to $60,000 per house including chattels. This means that sea level rise of only 0.15 m can have a major increase in damages for some properties which are currently just below a critical margin.

Damages for inundation due to stopbank failure resulting from an earthquake and consequent flooding in the Bexley area are shown in Table 7 below.

Table 7: Damage with flooding following earthquake damage to stopbanks

Event	Probability of combined event	Damage ($000s, residential property only)		
		Current	50 years (+0.15 m)	100 years (+0.4 m)
Stopbanks failure due to earthquake MHWS (12% exceedance)	**0.83%**	$16	$213	$1,590
Earthquake perigean tide (one in 28 days)	**0.28%**	$496	$981	$5,529

4.2 Damage to council infrastructure (roads, drains, sewers, pumping stations)

Damage to roads is likely to be insignificant because of low water velocities, and a high normal water table causing relatively saturated ground conditions even without a flood event. No figure for damage to roads has been included.

Damage to drains and sewers is also likely to be limited because of the low water velocity and minimal silt content. However surcharging of sewers and damage to pumping stations is likely to cause a spillover of sewage into the streets. A general allowance of $20,000 rising to $100,000 for the 0.4 m sea level rise scenarios and extreme rainfall events has been included to allow for cleanup of affected sites. No allowance has been made for the environmental damage associated with the discharge of raw sewage into the estuary.

Pumping stations are likely to be damaged in a number of scenarios. In significant levels of water, their switching boards are vulnerable to water damage. It is estimated that each pumping station flooded would sustain $10,000 worth of damage. Table 8 details the likely costs to the Council from damage to pumpstations (including sewer pumpstations) and cleanup of affected sites.

Table 8 : Costs to council (pumpstations and cleanup Costs)

Land use		**Present**	**Future development**	
Sea level		**Status quo**	**0.15 m rise**	**0.4 m rise**
Storm surge	20 year event	$20,000	$20,000	$100,000
	100 year event	$20,000	$20,000	$120,000
	500 year event	$50,000	$130,000	$180,000

4.3 Telephone

The major items of potential damage to the telephone system in the flooded areas are to exchange sites and cabinets. There is an exchange site on the border of the flooded area in Collingwood Road (No 11), but it is considered unlikely to be flooded. The cabling system is not considered vulnerable since in the major flood areas they are normally in water because of the high water table. Telephone cabinets are vulnerable to circuit breakdown in the event of flooding, but because of the low voltages no significant damage is expected to these. $200 per cabinet has been allowed for labour for cleaning and drying. One cabinet is assumed to require this treatment for every 200 houses which are flooded. Damage to telephone infrastructure is shown in Table 10 on page 18.

4.4 Power

Major sources of potential damage to electricity infrastructure are substations and cables of which substations are most significant. Damage to these is largely dependent on the warning received of the flood event. If sufficient warning is received to turn the power off, then little damage will be sustained to the substations and only cleaning and drying will be required. If power remains on when the substations are flooded then substantial damages are possible. It is assumed that sufficient warning will be available to allow power to be disconnected and prevent significant damage to the substations.[17] The number of the smallest kiosk requiring cleanup is estimated at one for every 30 houses flooded to greater than 0.6 m, and cleanup costs are $200 per kiosk. The mid level substations are housed in separate buildings, and are identified separately in the descriptions of flooded areas. Cleanup costs for these sized substations are estimated at $800/substation where these are flooded to greater than 0.6 m. The major substation in Pages Rd is likely to be flooded in each of the future sea level rise scenarios in a 500 year event. $100,000 allowance is made for cleanup of this major substation in the two scenarios concerned.

Some additional damage is also likely for cables, although this is difficult to quantify since they are normally in water because of the high water table. An additional 10 - 20% in jointing faults is expected, costing $5,000 per 11,000 kV line and $1000 per 400 kV line. $10,000 is allowed for each of the 500 year events under future land development to cover cabling faults. Damage to electricity infrastructure is provided in Table 10.

4.5 Traffic Diversion Costs

Traffic diversion costs are estimated from the traffic flows on the major arterial routes covered by floodwaters greater than 150 mm. Estimates of traffic flows are obtained from the nearest available road counts. Diversion costs are estimated to take place at 30 km/hr at $0.186/km running costs and $24.35/hr for travel time of occupants (1.5 passengers/vehicle). This amounts to $1 per km of diversion (2002 dollars[18]).

The major arterial roads and the costs associated with their disruption under different scenarios is shown in Table 11. It will be noted in some instances the costs of traffic diversion decrease in higher damage events. This is because the road serves an area which is predominantly flooded in the scenario, and it is considered that the traffic is stopped rather than diverted.

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[17] In the event that power was still on when the substations were flooded, then the damage would be approximately $13,000 per small kiosk, $160,000 per building sized substation, and $1 million plus for the major substation on Pages Rd.

[18] TransFund Project Evaluation Manual, 2003.

4.6 Excluded costs

The following costs were excluded:

Damage from disruption – some of these costs are included in the traffic diversion costs, but in the event of widespread flooding, houses affected will need to be evacuated and may not be re-occupied for some considerable time. It should be noted that in the ponding basins sewage may mix into the floodwaters as the wastewater system is inundated, and extensive renovation may be required for those houses which these contaminated floodwaters have entered. Delays of months may occur before repairs can be completed, with considerable costs associated with seeking alternate accommodation, disruption and stress.

Loss of income – the study area is largely residential, and significant losses in terms of commercial enterprises are not expected. However householders should be expected to require some time off work to deal with the event and its aftermath, which will result in a loss of income and productivity.

In terms of commercial premises, indirect damages can easily exceed direct damages, particularly where the disruption to business is significant, but these costs have not been included in the analysis.

Loss of land value and insurance associated with frequent flooding – it is possible that the level of flooding in the area will increase to the point where additional losses are incurred as a result of very frequent flooding. Exposure to risk in the order of 100 or 500 year events is not likely to cause such a loss, but it is possible that exposure to 20 year events may do so. Experience suggests that frequency of recent flooding is most important with respect to perceptions of land value and of potential for insurance loss. For example, flooding in Queenstown occurred several times in only a few years before insurance companies introduced higher excesses on claims for at risk properties. In some cases, flooding can actually lead to an increase in land value, with repairs resulting in a higher value house than prior to the flood, and no significant discount applied for flood risk. However if no mitigation measures were introduced for the area with SLR, particularly in the 100 year SLR scenario, relatively frequent flooding would be expected and some costs in respect of land values and insurance could occur.

In welfare terms, changes in insurance cover have both a transfer element and a welfare loss element. The transfer element arises because insurance is a means of spreading risk which transfers some of the cost of an adverse event from those affected to the wider community. In general, insurance premiums do not reflect the actual flood risk from particular locations, but across a wider range of the community, and so an inability to obtain insurance merely transfers the risk from the wider pool of insurance payers back onto the individual, but does not change the actual losses incurred by society as a whole. However there is also an element of welfare cost which arises because of risk aversion on the part of the property holder. The element of risk aversion typically arises because people are willing to pay more than the risk neutral cost to avoid low probability events which would cause them a very high loss – one which is not within their financial means to withstand. If the increase in sea levels were to cause an increase in flooding such that they were not able to obtain insurance, this would cause a welfare loss to society. The size of this loss is not able to be determined but may be significant. It should be noted that this would only arise because of an *inability* to obtain insurance. Typically insurers impose high premiums and excesses rather than refuse insurance, and these situations, where insurance is regarded as expensive or unaffordable, do not represent an additional welfare loss to those losses already calculated. This is because expensive insurance merely reflects the true cost of future damage to the property rather than the subsidized cost, and this true cost of damage has already been calculated.

Similarly a loss in land value as a result of additional flooding is really only a recognition of the costs of flooding incurred in an area, and these costs are already reflected in the calculated damages. Some loss in land value may also occur if insurance were unavailable, since this would affect the market perception of the property[19]. This loss can be represented either as a loss of land value, or the loss of welfare associated with not being able to offset risk as noted in the discussion of insurance above. Again, it is only valid to include this loss if insurance is unobtainable, not if the insurance is available but is considered expensive.

In social terms however a loss in land value and inability to obtain reasonably priced insurance can have significant consequences and the council may wish to take these consequences into account. This issue has not been included in the analysis.

Intangible damages including such factors as physical injury, fear, anxiety, ill health (physical and psychiatric problems) inconvenience, loss of memorabilia
Few studies have addressed the issue of intangible damages, with one concluding that the psychological trauma costs to affected households was substantially larger than structural damage costs[20], and another noting that over half the households interviewed said that they had still not fully recovered from a severe flood event five years earlier[21]. In the latter survey, the relative severity of impact, greatest to least, was: "disruption of the flood; loss of memorabilia; leaving home; stress of the flood; worry about future flooding; damage to contents; health effects; and damage to the house." There have been a number of studies which have identified health consequences of flooding, with these studies showing a general increase in visits to medical facilities following flooding, and some showing significant increases in mortality, hospital referrals for males, and serious illness[22]. It is apparent that in some cases therefore the direct damages to the house may be only a small part of the total damage costs when floodwaters enter a dwelling. On the basis of the evidence which is available, typically the intangible damages are valued at equal to the structural and contents damages associated with floodwaters entering the house. They have however not been included in the analysis.

Emergency response to flooding such as civil defense mobilisation, and fire and police response can also be significant costs in major events and the wider community also experiences intangible costs associated with others in the community being in

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[19] Because for example mortgages may not be obtainable.
[20]See Human Costs Assessment - The Impacts of Flooding and Non-Structural Solutions. Tug Fort Valley. pp 159 - 184 in George, A.L. (ed) 1983. Proceeding of Economic and Social Analysis Workshop, St Louis Miss 25 - 29 Oct., 1982. IWR Proceedings. US Army Corps of Engineers.
[21] Penning Rowsell, E.C. et al 1986. Floods and Drainage. The Risks and Hazards Series #2. Allen and Unwin. p. 102
[22] Studies cited in Penning-Rowsell et al 1986.

distress. No costs have been included from this source, although they are not expected to be significant in the context of the other damages.

Table 9: Costs not included in the study

Category	Item
Tangible but not quantified	Disruption
	Loss of income
	Emergency response
	Possible loss of land value
Intangible	Stress, fear, anxiety, etc
	Injury
	Ill health
	Loss of memorabilia
	Community tensions

Table 10 : Damage to telephone and electricity infrastructure

Land use		**Present**						**Future development**											
Sea level		**Status quo**						**0.15 m**						**0.4 m**					
		No Houses Flooded	No Houses Flooded > 0.6m	No flooded substations	Telephone damage	Electricity damage	Total cost of damage	No Houses Flooded	No Houses Flooded > 0.6m	No flooded substations	Telephone damage	Electricity damage	Total cost of damage	No Houses Flooded	No Houses Flooded > 0.6m	No flooded substations	Telephone damage	Electricity damage	Total cost of damage
Rainfall	20 year	$0	$0	$0	$0	$0	$0	$7	$0	$0	$0	$0	$0	$232	$0	$0	$300	$0	$300
	100 year	$2	$0	$0	$0	$0	$0	$15	$0	$0	$0	$0	$0	$1,496	$0	$0	$1,500	$0	$1,500
	500 year	$72	$0	$0	$100	$0	$100	$1,338	$0	$0	$1,500	$0	$1,500	$2,848	$251	$5	$2,900	$5,600	$8,500

Table 11 : Traffic diversion costs

Road	Avonside Dr	Cambridge Tce	Carlton Mill Rd	Fendalton Rd	Hulverstone Drive	Locksley Ave	Montreal St	New Brighton Rd	Oxford Tce	Pages Rd	Retreat Rd	River Rd	Travis Rd
Present day 5% AEP	$0	$0	$0	$0	$275	$0	$0	$0	$0	$0	$0	$0	$0
Present day 1% AEP	$1,217	$83	$1,372	$0	$550	$751	$0	$0	$565	$0	$0	$513	$0
Present day 0.1% AEP	$2,738	$500	$2,744	$3,375	$0	$1,689	$0	$14,346	$1,507	$0	$1,574	$1,091	$4,023
0.15 m SLR 5% AEP	$608	$0	$0	$0	$275	$375	$0	$0	$0	$0	$0	$0	$0
0.15 m SLR 1% AEP	$1,521	$625	$1,372	$0	$1,375	$751	$0	$0	$2,120	$0	$0	$642	$0
0.15 m SLR 0.1% AEP	$2,738	$667	$2,744	$3,375	$0	$1,689	$5,517	$14,346	$6,029	$0	$1,574	$1,091	$6,034
0.4 m SLR 5% AEP	$608	$0	$0	$0	$0	$1,173	$0	$0	$0	$0	$0	$0	$10,056
0.4 m SLR 1% AEP	$1,521	$625	$1,372	$0	$0	$1,173	$0	$0	$2,120	$50,415	$0	$642	$10,056
0.4 m SLR 0.1% AEP	$4,563	$667	$2,744	$3,375	$0	$5,630	$5,517	$28,693	$6,029	$67,220	$1,574	$1,091	$24,135

5. Total Costs of Flooding

The total damages from flooding of the lower Avon River with the current structural and institutional measures in place is shown in Table 12 for each of the scenarios considered. This assumes an 11.4 m minimum floor level, and full development of vacant land in the area over 50 years[23].

Table 12 : Total Damages from Flood Events of the Avon River ($million)

Land Use		**Present**	**Future Development**	
Sea Level		**Status Quo**	**0.15 m Rise**	**0.4 m Rise**
Storm Surge Event	**20 year event**	$0.02	$1.70	$58.19
	100 year event	$0.21	$2.48	$163.51
	500 year event	$1.45	$127.57	$373.19
Earthquake (stopbank liquefaction failure)	**Mean HWS (0.83% AEP)**	$0.23	$0.48	$1.28
	Perigean (0.28% AEP)	$0.85	$1.35	$2.72

5.1 Estimating a Present Value (PV) of costs

Damage estimates in themselves are of little use, since each event occurs with different timing in the future, and with a different probability. These are converted into a more useful figure, known as the Present Value (PV) of damages, through two processes. The damage estimates for each scenario are converted to equivalent average annual damages (AAD), and then these AADs are converted into a PV of damages.

The conversion to AAD occurs by estimating the average damage for each probability interval[24]. Thus for example events between the 20 year and 100 year event have a probability of 4% of occurring (5% AEP - 1% AEP), and their average damage will be the mean of the 20 and 100 year damage scenarios. Thus the total AAD for that interval is 4% of the mean of the 20 and 100 year scenarios. This process is repeated for each probability interval, and the average annual damages for each interval summed to give the AAD. This can be conceptualised as integrating the area under a probability-damage curve, where the curve is estimated as linear between each quantified data point. The total damages for each scenario shown in Table 12 are converted into AAD as shown in Table 14.

[23] Note that the future development scenario without SLR will not differ significantly from the current damages, because most of the ponding areas are protected from storm surge events with the current sea level. In Hulverstone, which is not currently protected by stopbanks, there is little vacant land available for development.

[24] e.g. see Cairns, I.J. 1973. "*Techniques for Evaluating Flood Benefits*." Ministry of Agriculture and Fisheries, Economics Division.

Once the AAD have been calculated they need to be converted to a value which will allow comparison with other costs. This is needed because costs or damages in the future have different values depending on when they occur. A sum in the near future has greater value than one in the distant future, because of uncertainty and other uses to which the money could be put in the intervening period. The difference in values is known as the time value of money. To assist in comparing values at different times in the future they are converted to present day values (PV), through a process known as discounting. In this all values are discounted by an annual proportion known as the discount rate, which represents the time value of money.

This approach allows us to compare the damages from flooding with the costs of various mitigation approaches analysed in later sections of the report. In particular, the council may wish to take decisions whether it is economically justified to take mitigation measures in the immediate future, and so the immediate cost of mitigation must be compared with the accumulated and time discounted cost of damages occurring in the future.

Typically, the outcome of this process is very dependent on the discount rate. The choice of this value is therefore critical to the analysis. Typically rates are chosen to reflect either:

- the opportunity cost of capital adjusted for risk, or
- the time preference of the society the agency is supposed to represent.

There is no simple answer as to the appropriate means of choosing a discount rate. In the case of this analysis where the impacts are beyond the time horizons of individuals there is a stronger rationale for using time preference of society, which when considering intergenerational issues may be quite low. In practical terms, choosing such a rate is difficult, and so some form of opportunity cost of capital is used.

The opportunity cost of capital is typically calculated using a risk free rate (say government bonds) with a risk premium added to this for the appropriate industry. This is more difficult for flood analysis, because there is no specific industry beta which could be applied to generate a risk premium. Comparable costs of capital are usually used in this case. Mortgage rates for homeowners would be in the order of 7% at present, which represents a cost of capital of 5.5% allowing for 1.5% inflation. CCC’s Annual Plan projects interest earnings of 5.5%, and its projected cost of debt capital is 6.75%. Treasury continues to use 10% as its discount rate on the basis of preventing government investment displacing private sector investment. The Treasury rate of 10% for project analysis is considered too high under these circumstances, and a value of 8% is used for this study since it is close to the cost of capital, allows some additional margin for risk, and is sufficiently high to prevent displacement of private sector investment. As noted earlier there is no strong single reason why 8% has been chosen over 6%, and the final choice is an informed judgement call. For this reason, sensitivity analysis has been undertaken using other discount rates for comparison.

In converting to a PV of damages, the annual average damages are treated as a stream of damages into the future. The damages are increased in a linear fashion between each scenario – i.e. between the current and 50 year, and between the 50 and 100 as SLR occurs. In practice, this linear increase in damages won't necessarily occur, because damage often increases in thresholds – as water overtops the stopbanks, and as it reaches levels which enter houses. However because of uncertainties in many of the factors modelled, such as variability in heights of stopbanks, uncertainty in flood height and rate of SLR, and inaccuracies in definition of section and floor heights, it is an appropriate approach to use for a study such as this.

The PV[25] of flood damages accumulated over the 100 year period of sea level rise projection is estimated at $3.9 million at a discount rate of 8%. This figure is very sensitive to the discount rate used, and ranges between $18.6 million at a 4% discount rate, and $2.4 million at a 10% discount rate. It ranges between $3.6 million and $4.7 million for the low and high ends of the most likely SLR range (30-50 cm by 2100) at an 8% discount rate. The range of damages is shown in table 13 below.

Table 13: Total damages under different assumptions

Assumption	Total damages (PV, $million)
Base (8% discount rate)	$3.9
4% discount rate	$18.6
10% discount rate	$2.4
Minimum SLR	$3.6
Maximum SLR	$4.7
Full redevelopment in 50 years[26]	$5.7

It should be noted that:

- The estimates assume that sufficient warning will be available to ensure that electricity supply is turned off, thus limiting the damage to the supply infrastructure. In the event that this is not possible, damage will be in the order of $100,000 - $1,000,000 greater in the more extreme events.

- Estimates have not been included for much of the aftermath costs of a severe flood. The results do not include the unquantified indirect damages, such as disruption and loss of income. Nor do they include the unquantifiable costs of damage, including stress and trauma associated with flooding. Given the likelihood of raw sewage flooding the streets, further investigation may be warranted on the intangible costs associated with this type of flooding (distress, disease etc). In addition, environmental costs to the estuary and surrounds may need to be considered.

- Damage to housing and sections is the major item of damage. This contributes 95% of the PV of flooding in both scenarios (incorporating all damage events). The results are therefore very sensitive to the estimates of

[25] 8% discount rate.
[26] All houses in the area redeveloped to the new minimum floor level within 50 years. Base estimates are 30% per each 50 year period.

house flooding and resulting damages, and the total damage figure changes almost linearly with a change in estimates of housing damage.

- Other potential costs, such as losses from reduced land value associated with frequent flooding and problems with obtaining insurance have not been addressed. Nor have social, intangible and a number of unquantified costs been included.

Table 14 : Annual average damages in Lower Avon ($000s)

Event	Annual exceedance probability	Damage estimate			Change in probability	Mid point estimate of damages			Annual average damages (AAD)		
		2003	Future damages 0.15m	Future damages 0.4m		2003	FD 0.15 m	FD 0.4 m	2003	FD 0.15 m	FD 0.4 m
1 year	1										
					0.933	$0	$0	$0	$0	$0	$0
15 year[27]	0.067	0	0	0							
					0.0167	$10	$848	$29,097	$0	$14	$485
20 year	0.05	$20	$1,696	$58,194							
					0.04	$116	$2,086	$110,850	$5	$83	$4,434
100 year	0.01	$212	$2,476	$163,506							
					0.005	$831	$65,021	$268,348	$4	$325	$1,342
500 year	0.005	$1,449	$127,566	$373,190							
					0.005	$1,449	$127,566	$373,190	$7	$638	$1,866
Earthquake MHWS	0.0083	$235	$479	$1,284							
					0.006	$545	$915	$2,004	$3	$5	$11
Earthquake perigean tide	0.0028	$855	$1,350	$2,723							
					0.0028	$855	$1,350	$2,723	$2	$4	$8
						Annual Average Damage			$22	$1,069	$8,145

[27] The 15 year event was chosen as the initiation point because it was known that some damage will occur in events less than 20 year return interval, but the exact point at which damage will initiate is not known. The 15 year return period starting point is not based on any data.

6. Impact of Minimum floor levels

Minimum floor levels are regarded as an effective means of minimising flood risk to housing. Floor levels are required by the Building Act to be above the 1 in 50 year flood event, but potential exists in the RMA to set minimum floor levels above this. CCC is proposing a change to the minimum floor level requirements for the lower Avon area. Currently an 11.4 m minimum floor level requirement is imposed for new dwellings, and it is proposed that this will increase to 11.7 m with the floodplain variation. CCC considers that the 11.7 m represents protection against a 1 in 50 year flood with the 0.4 m sea level rise, and includes 0.3 m freeboard for wind and wave set up and a further 0.1 m safety margin. The impacts of a range of different floor levels on flooding were assessed, and these are shown in Table 15, Table 16 and Table 17 for minimum floor levels of 11.55, 11.7, and 11.85 m respectively. Hydraulic floor levels (without freeboard) were used in the calculation of damages for houses built in the future[28].

The tables show no differences in damages in the status quo scenario, because the minimum floor levels affect only future development of vacant land in the area and redevelopment of existing houses. The redevelopment assumed for this scenario is 30% in the first 50 years and a further 30% in the following 50 years. All development of vacant land area is assumed to take place within the first 50 years. All developed and redeveloped houses area assumed to be built to the specified minimum floor level.

[28] This compares with the approach adopted for existing houses, where actual floor levels were compared with hydraulic flood levels for estimates of damage. This was considered appropriate because the freeboard is designed to cope with matters not included in the hydraulic level, but does mean that damages for properties which exist currently are likely to be underestimated.

Table 15: Flood damage with 11.55 m minimum floor level ($000s)

Event	Damage item	Status quo	50 years	100 years
20 year event	Avondale	$0	$0	$23,534
	Bexley	$0	$0	$4,921
	Horseshoe Lake	$0	$0	$788
	Hulverstone	$19	$1,600	$3,736
	New Brighton	$0	$0	$2,496
	Upper New Brighton	$0	$0	$0
	Traffic	$0	$1	$14
	Power and other	$0	$0	$0
	Total	$20	$1,601	$35,489
100 year event	Avondale	$0	$0	$28,479
	Bexley	$0	$0	$10,233
	Horseshoe Lake	$0	$0	$1,182
	Hulverstone	$206	$2,466	$21,920
	New Brighton	$0	$0	$31,027
	Upper New Brighton	$0	$0	$14,230
	Traffic	$6	$10	$81
	Power and other	$0	$0	$1
	Total	$212	$2,476	$107,152
500 year event	Avondale	$0	$25,296	$43,022
	Bexley	$0	$5,409	$88,295
	Horseshoe Lake	$0	$43,392	$57,958
	Hulverstone	$1,409	$9,098	$27,542
	New Brighton	$0	$8,352	$57,818
	Upper New Brighton	$0	$18,608	$95,290
	Traffic	$40	$54	$180
	Power and other	$0	$2	$10
	Total	$1,450	$110,211	$370,115

Table 16: Flood damage with 11.7 m minimum floor level ($000s)

Event	Damage item	Status quo	50 years	100 years
20 year event	Avondale	$0	$0	$19,088
	Bexley	$0	$0	$4,921
	Horseshoe Lake	$0	$0	$788
	Hulverstone	$19	$738	$864
	New Brighton	$0	$0	$2,451
	Upper New Brighton	$0	$0	$0
	Traffic	$0	$1	$14
	Power and other	$0	$0	$0
	Total	$20	$740	$28,126
100 year event	Avondale	$0	$0	$28,469
	Bexley	$0	$0	$9,996
	Horseshoe Lake	$0	$0	$1,116
	Hulverstone	$206	$995	$21,920
	New Brighton	$0	$0	$3,910
	Upper New Brighton	$0	$0	$14,230
	Traffic	$6	$10	$81
	Power and other	$0	$0	$1
	Total	$212	$1,005	$79,722
500 year event	Avondale	$0	$25,293	$42,975
	Bexley	$0	$5,409	$88,248
	Horseshoe Lake	$0	$43,389	$57,900
	Hulverstone	$1,409	$4,505	$27,420
	New Brighton	$0	$8,300	$57,767
	Upper New Brighton	$0	$18,608	$95,290
	Traffic	$40	$54	$180
	Power and other	$0	$2	$10
	Total	$1,449	$105,560	$369,790

Table 17: Flood damages with 11.85 m minimum floor level ($000s)

Event	Damage item	Status quo	50 years	100 years
20 year event	Avondale	$0	$0	$2,803
	Bexley	$0	$0	$4,921
	Horseshoe Lake	$0	$0	$788
	Hulverstone	$19	$735	$859
	New Brighton	$0	$0	$2,451
	Upper New Brighton	$0	$0	$0
	Traffic	$0	$1	$14
	Power and other	$0	$0	$0
	Total	$20	$736	$11,836
100 year event	Avondale	$0	$0	$4,267
	Bexley	$0	$0	$9,996
	Horseshoe Lake	$0	$0	$1,116
	Hulverstone	$206	$990	$18,464
	New Brighton	$0	$0	$3,858
	Upper New Brighton	$0	$0	$14,230
	Traffic	$6	$10	$81
	Power and other	$0	$0	$1
	Total	$212	$1,000	$52,012
500 year event	Avondale	$0	$9,173	$42,952
	Bexley	$0	$5,409	$88,202
	Horseshoe Lake	$0	$19,807	$57,841
	Hulverstone	$1,409	$4,499	$27,420
	New Brighton	$0	$8,300	$57,750
	Upper New Brighton	$0	$18,608	$95,290
	Traffic	$40	$54	$180
	Power and other	$0	$2	$10
	Total	$1,449	$65,852	$369,644

The cost of achieving a higher minimum floor level was estimated by taking surveyed section levels in each of the ponding basins, and calculating the additional height required to achieve each specified minimum floor level. Surveyed section heights were not available in the Upper New Brighton area, and so existing heights were estimated from the areas occupied during each flood event.

Costs of achieving a given floor level were estimated by quantity surveyors[29] for a variety of different floor heights, construction methods and building size. Using an average of these estimates, a regression equation was developed for the cost of achieving the minimum floor level[30]. This was used to develop a weighted average cost of achieving the minimum floor level for each ponding basin, and this was then converted into an average cost for each year in the periods 1-50 years and 50-100 years. These costs were then discounted to the current day at 8%, and this PV of cost of achieving the minimum floor level is compared with the saved benefits in Table 18 below. This shows that none of the elevated minimum floor levels demonstrate a

[29] QS Cost Management Limited, 2003 pers. comm.

[30] Cost = 10.096*height-91.46; the r2 = 0.997. E.g. if height = +150mm, cost = 10.096*150-91.46 = $1,552

positive net benefit relative to the current 11.4 m minimum floor level. The 11.55 m floor level shows the least negative outcome relative to the 11.4 m floor level, while the 11.75 m floor level shows the most negative outcome.

Table 19 gives a full range of outcomes under different assumptions regarding development, discount rate and SLR. It shows that most of the assumptions do not change the overall conclusions regarding the minimum floor level provisions, but that the results are very sensitive to discount rate. At a 6% discount rate the 11.85 m minimum floor level is positive, and at a 4% discount rate, which is not out the question for a social time preference for money, the values of all minimum floor provisions are positive, with the 11.85 m minimum floor level giving the highest net benefit.

The results are also sensitive to the estimates of damages. With damages 50% higher the 11.85 m level gives a positive net benefit, and at 100% higher, which for example might be included to allow for the intangible damages, both the 11.55 and 11.85 m floor levels show a positive net benefit with 11.85 m showing the highest net benefit (PV of $1 m). These changes do not make the 11.7 m minimum floor level positive however.

Table 18 : Damages and costs of minimum floor levels (PV, $000)

Minimum floor level (RL)	Damages ($000, PV)	Cost ($000, PV)	Net benefit relative to 11.4 m floor level ($000, NPV[31])
11.4	$3,893	$1,992	
11.55	$3,379	$2,851	-$345
11.7	$3,053	$3,717	-$885
11.85	$2,096	$4,587	-$798

6.1.1 Impact of timing

The minimum floor levels are set in place to allow for rises in sea level over the next 100 years. There is greater sea level rise over the second 50 years than the first 50 years, and so the impact of the higher floor levels will be greater in the second period. An analysis was undertaken comparing the costs and benefits over the two periods as shown in Table 19 on page 30. The analysis shows that while the minimum floor levels show a negative outcome for the first period of the analysis, they are strongly positive for the second period. Regardless of the minimum floor level chosen now, it is likely to be worth at some time in the next 50 years revisiting the need to increase it to 11.85 m or higher.

[31] Net Present Value

Table 19: Sensitivity Analysis of Minimum Floor levels (PV, $000s)

60% redevelopment	Damages			Costs			Net Benefit (relative to 11.4 m)		
	Total	1st 50 years	2nd 50 years	Total	1st 50 years	2nd 50 years	Total	1st 50 years	2nd 50 years
11.4	$3,893	$3,189	$32,998	$1,992	$1,969	$1,091			
11.55	$3,379	$2,818	$26,305	$2,851	$2,818	$1,553	-$345	-$478	$6,231
11.7	$3,053	$2,561	$23,104	$3,717	$3,674	$2,019	-$885	-$1,076	$8,966
11.85	$2,096	$1,728	$17,236	$4,587	$4,534	$2,489	-$798	-$1,104	$14,363
30% redevelopment									
11.4	$3,441	$2,842	$28,082	$1,435	$1,423	$546			
11.55	$3,118	$2,609	$23,902	$2,058	$2,042	$777	-$301	-$385	$3,949
11.7	$2,945	$2,474	$22,123	$2,686	$2,664	$1,010	-$755	-$872	$5,495
11.85	$2,377	$1,974	$18,892	$3,316	$3,289	$1,245	-$817	-$998	$8,491
100% redevelopment									
11.4	$4,496	$3,653	$39,552	$2,736	$2,697	$1,819			
11.55	$3,727	$3,098	$29,508	$3,909	$3,854	$2,589	-$405	-$603	$9,274
11.7	$3,197	$2,676	$24,412	$5,091	$5,020	$3,365	-$1,057	-$1,347	$13,594
11.85	$1,722	$1,402	$15,029	$6,282	$6,194	$4,149	-$773	-$1,246	$22,193
0% redevelopment									
11.4	$2,988	$2,494	$23,166	$878	$878	$0			
11.55	$2,857	$2,399	$21,499	$1,265	$1,265	$0	-$256	-$292	$1,666
11.7	$2,838	$2,387	$21,142	$1,654	$1,654	$0	-$626	-$669	$2,023
11.85	$2,657	$2,219	$20,547	$2,045	$2,045	$0	-$835	-$891	$2,618
60% redevelopment, 6% discount rate									
11.4	$7,506	$4,897	$48,046	$2,613	$2,537	$1,406			
11.55	$6,383	$4,319	$38,018	$3,740	$3,631	$2,002	-$4	-$516	$9,433
11.7	$5,727	$3,918	$33,320	$4,874	$4,733	$2,602	-$482	-$1,217	$13,531
11.85	$3,986	$2,621	$25,139	$6,016	$5,842	$3,207	$117	-$1,029	$21,106

60% redevelopment, 4% discount rate	Damages			Costs			Net Benefit (relative to 11.4 m)		
	Total	1st 50 years	2nd 50 years	Total	1st 50 years	2nd 50 years	Total	1st 50 years	2nd 50 years
11.4	$18,612	$8,032	$75,186	$3,727	$3,458	$1,917			
11.55	$15,383	$7,072	$59,057	$5,333	$4,949	$2,728	$1,624	-$531	$15,317
11.7	$13,672	$6,405	$51,646	$6,950	$6,451	$3,546	$1,717	-$1,366	$21,911
11.85	$9,797	$4,252	$39,404	$8,577	$7,962	$4,372	$3,965	-$724	$33,327
Maximum SLR projections									
11.4	$4,710	$3,763	$44,431	$1,992	$1,969	$1,091			
11.55	$4,618	$3,701	$43,016	$2,851	$2,818	$1,553	-$766	-$787	$953
11.7	$3,545	$2,889	$30,792	$3,717	$3,674	$2,019	-$559	-$830	$12,711
11.85	$2,579	$2,034	$25,522	$4,587	$4,534	$2,489	-$463	-$836	$17,511
Minimum SLR Projections									
11.4	$3,630	$3,116	$24,112	$1,992	$1,969	$1,091			
11.55	$3,245	$2,788	$21,420	$2,851	$2,818	$1,553	-$474	-$522	$2,230
11.7	$2,937	$2,530	$19,073	$3,717	$3,674	$2,019	-$1,032	-$1,119	$4,111
11.85	$1,945	$1,698	$11,581	$4,587	$4,534	$2,489	-$910	-$1,148	$11,133
Damage 50% higher									
11.4	$5,839	$4,784	$49,497	$1,992	$1,969	$1,091			
11.55	$5,069	$4,228	$39,457	$2,851	$2,818	$1,553	-$89	-$293	$9,577
11.7	$4,580	$3,841	$34,656	$3,717	$3,674	$2,019	-$465	-$761	$13,913
11.85	$3,144	$2,593	$25,854	$4,587	$4,534	$2,489	$101	-$374	$22,244
Damage 100% higher									
11.4	$7,786	$6,379	$65,995	$1,992	$1,969	$1,091			
11.55	$6,759	$5,637	$52,610	$2,851	$2,818	$1,553	$168	-$107	$12,924
11.7	$6,106	$5,121	$46,208	$3,717	$3,674	$2,019	-$45	-$447	$18,860
11.85	$4,192	$3,457	$34,473	$4,587	$4,534	$2,489	$999	$357	$30,125

6.1.2 Impact by Ponding Area

The results shown above give aggregate results across the lower Avon floodplain. However these aggregate results differ for each ponding area, because the degree of protection and resulting flood levels for each event are distinct for each area considered. The results for each ponding area are given in Table 20 and are discussed below:

Hulverstone – in this ponding area there is a positive net benefit for all minimum floor levels considered, and the minimum floor level of 11.7 m shows the highest net benefit. This is primarily because of the low level of protection offered by the stopbanks in this area, and this level of protection can be considered to be an appropriate level for a "no banks" situation.

Horseshoe – the 11.55 and 11.7 m floor levels show negative benefit relative to 11.4 m, but the 11.85 m floor level shows a positive net benefit. Examination of flood levels in this area suggests that the reason for this is that the 11.85 m floor level offers protection against all events other than the 500 year event with 0.4 m SLR, while the other levels provide no significantly enhanced protection relative to 11.4 m.

Brighton – in this ponding area both the 11.55 and 11.7 m floor levels give a positive net benefit, and the 11.55 m floor level has the highest net benefit.

Bexley – none of the floor levels tested show a net benefit in this ponding area relative to 11.4 m. This area is less affected by flooding as analysis of the flood levels shows that only the 100 year and 500 year 0.4 m SLR events affect houses with a 11.4 m minimum floor level. There is no difference in the level of protection offered by the 11.55 m, 11.7 m or 11.85 m floor levels in terms of these two events, and so the analysis does not distinguish between them in terms of saved benefits. However it should be noted that in parts of the Bexley area, known as the Bexley Special Management area, ground levels are very low lying and even the 11.4 m minimum floor level is very difficult to achieve without having other impacts. This issue is discussed further in the next section.

Avondale – in this ponding area the 11.85 m floor level offers the greatest protection, because it is the only level which offers protection against any of the events which overtop the stopbank.

The analysis of individual ponding areas highlights the complexity of setting minimum floor levels in conjunction with stopbanks. With no or minimal stopbanks in place, the 11.7 m minimum floor level appears to offer the highest net benefit. However with stopbanks which protect against events with current sea levels, it appears that an ability to prevent damages in 500 year events with more immediate SLR (+0.15 m) is the distinguishing factor among the floor levels, since the benefit from protection against +0.4 m SLR events is heavily discounted because of the time in the future at which it occurs.

Table 20: Benefits and Costs of Minimum Floor Levels by Ponding Area

Ponding area and floor level (RL)	Benefits (PV, $000s)	Costs (PV, $000s)	Net benefit relative to 11.4 m (PV, $000s)
Hulverstone			
11.4 m floor level	$644	$2	
11.55 m floor level	$633	$7	$6
11.7 m floor level	$358	$22	$266
11.85 m floor level	$354	$41	$252
Horseshoe			
11.4 m floor level	$852	$167	
11.55 m floor level	$845	$276	-$102
11.7 m floor level	$845	$386	-$212
11.85 m floor level	$399	$496	$124
Brighton			
11.4 m floor level	$604	$301	
11.55 m floor level	$221	$447	$237
11.7 m floor level	$189	$594	$122
11.85 m floor level	$189	$740	-$24
Bexley			
11.4 m floor level	$290	$963	
11.55 m floor level	$237	$1,167	-$151
11.7 m floor level	$237	$1,366	-$350
11.85 m floor level	$237	$1,566	-$549
Avondale			
11.4 m floor level	$581	$91	
11.55 m floor level	$580	$173	-$81
11.7 m floor level	$570	$255	-$153
11.85 m floor level	$201	$338	$133

7. Impact of Zoning Measures

There are two areas within the Avon-Heathcote estuary which are currently subject to frequent flooding (estimated 2-3 years) when high sea levels occur and the tidal flapgates do not function properly. CCC is considering zoning measures for the Bexley area adjacent to the Avon where section levels are very low (<10.5 m RL). The proposed variation to the City Plan identifies this area as a Special Management Area, for which specific zoning requirements will be introduced[32]. Within this Bexley Special Management (BSM) Area, allowing for redevelopment of all sections capable of being subdivided into 450m^2 sections would provide for an additional 78 sections (not including the potential for amalgamating then subdividing sections). The options for zoning management are:

[32] There is also an area in Redcliffs which has the same designation as it is also very low lying.

- minimum floor levels
- larger minimum site areas
- prohibition on development
- engineering solutions.

The minimum floor level requirement creates some difficulties because the ground levels in the area are as low as 10.2-10.33 RL, and to raise the floor levels to 11.7 RL as for elsewhere in the floodplain could create adverse effects on residential amenity, problems with drainage between sites, and create difficulties in achieving the bulk and location standards for the zone at the minimum section size.

The prohibition on new buildings in the area would create difficulties in terms of existing use rights, and the limitation in use of the site may be seen as onerous. The CCC has therefore proposed a limitation on minimum site size of 650 m^2 which would limit the build up of assets in the area, and at the same time allow for the higher minimum floor level to be achieved without impacts on residential amenity or the bulk and location requirements.

The analysis of this measure considers the impact on an individual site capable of being redeveloped. The outcomes assume redevelopment occurs now, with damages occurring over the next 100 years. Damages for sites at different ground levels are shown in Table 21 below and summarised as a weighted average for the sections of less than 10.5 m RL.

Table 21: Weighted NPV of damages for subdivision site in Bexley Special Management Area

Ground level of section	**Proportion of BSM at this level**	**NPV of average damages per house, taking sea-level rise into account**
10.1 m ground level	5%	$3,488
10.2 m ground level	15%	$2,228
10.3 m ground level	36%	$2,159
10.4 m ground level	29%	$1,857
10.5 m ground level	15%	$1,853
Weighted average NPV of damage per house		**$2,103**

Thus a subdivision of a section into two 450 m^2 sections without a minimum floor level of more than 150 mm above the existing section height would increase the damages from the section by approximately $2,100. However offsetting this would be an increase in utility associated with each additional section of $10,000 - $15,000[33] after subdivision costs. This utility can be thought of as value to society from the subdivision, which should be set against the costs from increased damages.

[33] Based on an average vacant section value of $43,000 (Rating Valuation database), with $23,000 subdivision costs and a 10% discount on the original section value for the subdivided section. Subdivision costs based on evidence given by a registered valuer (Gary Sellars) at the Southshore Environment Court Hearing.

In aggregate therefore allowing the subdivision would maximise welfare if it takes place in the present or near future. This primarily arises because the major part of the damages from sea level rise are still 50 years hence, and the discounting of these costs means the benefit to be gained from undertaking the subdivision now offsets the damages in the future. If we were to look 50 years from now, with 0.15 m of sea level rise already occurred and be faced with an additional 0.25 m of sea level rise in the next 50 years, the NPV of damages would be $20,400. These damages would substantially outweigh the likely benefits from subdividing and so a control on subdivision would be more appropriate.

There are however a number of caveats to this conclusion. It assumes that the utility from creating the additional sections in the Bexley area cannot be satisfied elsewhere in the city at a lower flood risk. If this is the case the benefits of $10,000 - $15,000 per section are merely transferred from another section vendor, and do not represent a welfare gain, or increase in value for society. If the value from the additional sections can be satisfied elsewhere in the city, the subdivision will create additional costs without any benefits and the minimum lot size would be justified for preventing flood damages.

The analysis assumes the minimum floor levels to be applied elsewhere in the floodplain cannot be achieved with a 450 m^2 section. It is unlikely that building would be allowed without meeting the requirements of the Building Act, but if the minimum floor levels can be achieved with the 450 m^2 section, there would be less justification to prevent zoning because the additional damages arising from the subdivision would be substantially ameliorated by the minimum floor level.

The primary conclusion from this section is that the zoning provision does not appear justified at present as a flood management tool based on the value of subdivisions compared with expected damage costs over the next 100 years. Its primary justification appears to be as a means of allowing the minimum floor levels under the Building Act to be achieved.

However it is important to recognise that this analysis excludes a number of relevant other economic and social impacts discussed in Section 4.6, as well as a range of social considerations specific to subdivision which would be expected to influence council decisions. The analysis makes no distinction between individuals who receive benefits from subdivisions, and individuals who receive costs from flood damages. Social equity issues and community tensions which may arise as a result of additional flooding in the future in this area will be a relevant consideration in the decision, and they are not considered in this economic analysis. The council may also wish to clarify issues of long term liability and their own insurance cover in the area for allowing subdivision with a prior knowledge of future flood risk.

Furthermore it should be noted that that subdivisions are essentially “forever”, and the planning horizon of 50 or 100 years is only a convenient tool. It is expected that sea-levels will continue to rise for centuries even after global greenhouse gas concentrations have been stabilised. Build-up of assets in the BSM area creates a set of existing-use rights in a hazardous area. The council needs to satisfy itself that the establishment of these existing use rights would be consistent with Local Government Act 2002 considerations regarding the economic, social and environmental well-being of its communities.

While it is clearly difficult to quantify and weigh the relevance of these considerations against the economic analysis presented in this report, it is important to realise the limitations of the present analysis. It should therefore be considered as a tool to aid decision-making, rather than the only consideration in the decision.

8. Structural Options

8.1 Tidal Barrage

The idea of constructing a barrier to control flooding during times of very high tides is not new to Christchurch. The Woolston Tidal Barrage, completed in 1994, is a good example. A canal (Woolston Cut) had been built in the 1980s to enable flood waters from the Heathcote River to by-pass the constriction caused by a loop in the river. However, the adverse effects of this proved to be unacceptable and the situation was remedied by building the barrage across the canal. Now, the barrage is only opened when necessary to allow excess flood waters to escape.

Well-known international examples of tidal barrages include those that provide flood protection to the cities of Venice and London. The basic idea of a tidal barrage is to hold back extreme tides to prevent flooding of low lying land or flowing into a river system. When such tides coincide with flood run-off in a river there needs to be a sufficient receiving basin to hold the river run-off until it can be released to the sea at low tide. This may require a residence time of up to 12 hours, otherwise pumping to sea of the excess river water would be required. Although the necessary analysis does not appear to have been done it is expected that, in the case of the Avon-Heathcote Estuary, there would be sufficient capacity for temporary storage of flood run-off.

The notion that flood levels in the estuary may be controlled by building a barrage across the entrance is likely to raise many issues. Technically, such a structure is feasible but significant investigation will be required before a robust argument can be presented to prove that it is practical. Environmental effects and cost are likely to weigh heavily against the idea. Among other things, there seems little doubt that the delicate balance of estuarine habitat would be significantly affected by occasional flooding with sediment laden fresh water. Clearly, obtaining resource consent would be far from straightforward.

Even if environmental difficulties can be overcome, there will remain the need to justify or off-set the significant cost of construction. The prospect of using a barrage to provide a facility for the purpose of generating electricity is one possible means of off-setting the construction costs, and a feasibility study to examine this idea would demonstrate its practicality. If used for this purpose, the barrage would be required to direct tidal flows through turbines, which, apart from any other effects, would very likely limit the availability of the estuary entrance for other uses every time electricity generation was required. From a practical point of view, the construction of such works would constitute a major engineering project that would have significant permanent environmental and ecological impacts. Again, rigorous environmental impact assessments would be needed and the consents process under the Resource Management Act could severely limit the prospect of gaining consent at this site for the development of tidal power. The environmental and ecological effects of tidal barrages have largely halted progress with this technology and there are only a few commercially operating plants in the world. The best known of these is the La Rance barrage in France. Furthermore, neither the volume of water flowing into and out of the estuary, nor the tidal range in Pegasus Bay, is considered large enough for power generation to be economic. Normally, mean tidal ranges of at least 5 m are necessary and, here, new technologies, which will allow energy to be extracted from smaller tidal ranges, would be needed. The cost of electricity generated by tidal power is expected to be in the region of 6-10 times the cost of electricity generated by hydro or natural gas.

A further justification, of course, might come from any benefits likely to arise from incorporating a road link across the estuary entrance into a barrage structure. Channel navigation issues would need to be resolved and a lock to allow the passage of small craft would very likely be required.

In the past, there has also been talk of building a barrage across the mouth of the Avon River. Again, unless there is a basin capable of holding flood run-off until it can be released, without causing backed-up waters to spill into the adjacent catchment the structure is not feasible. A barrage at the mouth of the Avon has little merit for this reason and is not considered further here.

Estimating the cost of constructing a tidal barrage at the mouth of the estuary with any degree of certainty is difficult. For the purpose of this exercise an allowance of $25 million is appropriate[34]. Depending on costs of capital, a further 10% allowance for annual costs is suggested.

Such a barrage would prevent all flood damages in the Avon – which would provide a net benefit of $3.9 million. Clearly therefore such a tidal barrage would not be economic to construct.

If the erection of the tidal barrage were delayed by 50 years, the PV of damages into the future from that point would be $33 million (11.4 m floor level), because of higher sea levels initially and greater rise predicted into the future. This would make a tidal barrage closer to being an economic means of managing sea level rise, but the problems associated with environmental damage and storage of in river flows would still need to be overcome. Tidal barrages are therefore not seen as a recommended strategy or likely option for mitigating the impacts of sea level rise.

8.2 Stopbanks

The purpose of the existing stopbanks around the estuary is to prevent inundation of low lying land during extreme tide and storm surge events.

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[34] This is higher than the estimate of $15 million in the Floodplain Variation discussion document, but is considered reasonable given the significant technical and environmental impediments.

There are two related issues to consider: flooding if stopbank coverage is inadequate or if levels are too low; and increased liquefaction risk during earthquake events. The latter has been discussed in a 1999 report prepared for Christchurch City Council by Soils and Foundations Ltd. This study reported that there was a high risk of liquefaction causing lateral spreading of stopbank foundations during strong earthquakes. Rising sea levels will raise water tables around estuary margins and, thus, increase the potential for significant stopbank damage to occur during such events. The report also found that, while mitigation measures are technically feasible, they are also likely to be very expensive. This is, perhaps, a serious but separate matter for CCC to address. For the time-being these events are rare enough for it being sufficient to rely on there being time to restore stopbank integrity before an inundation event occurs although some inundation is expected in Bexley and probably Brighton in MHWS or Perigean tide events without stopbanks. In this respect it will be appropriate for CCC to have contingency plans in place as part of earthquake recovery plans.

It is understood that most of the present stopbanks are at RL: 11.2 m and those along the Avon River (Hulverstone Drive), for which CCC is responsible, are at RL: 10.9.

In simple terms, in order to accommodate climate change predictions based on present-day scenarios, an increase in height of 0.2 m should be sufficient to accommodate the rise in sea level expected to occur by 2050, and an increase of 0.5 m to allow for the rise in sea level expected by 2100. This presumes, however, that adequate allowance has been made for storm surge and wind set-up in previous flood level estimates. It is recommended that these allowances be reviewed.

Subject to a review of storm surge and wave set-up conditions, completion of the stopbank system over a period of time and provision of protection up to a minimum level of 11.7 m (11.2 + 0.5 m) would allow for the rise in sea level expected by 2100. This may not be so straightforward, however, because of space and, sometimes, because the extra weight involved would exacerbate poor foundation conditions. In some cases, these constraints could be reduced by considering construction of a concrete wall (probably precast) to provide the necessary increase in height although this would possibly have negative ecological and amenity effects. Significant lengthening of the stopbank system would also be necessary along riverbanks. The stopbank system modifications would therefore have a number of technical, environmental and amenity impediments.

8.2.1 Stopbank Costs

To properly assess the costs of providing a robust stopbank system will require a detailed study of existing information and further investigation to fill any gaps in the knowledge. There are also issues relating to space limitations and access that would need to be resolved and which would impact on costing. By way of example, CCC has costed completing the stopbank system along Hulverstone Drive. This section, which is 650 m in length was estimated to cost $220,000, which is equivalent to around $350 per metre. In the absence of better information, this figure can be used to provide an indicative cost of raising the existing stopbanks 0.5 m. Note that the cost of only raising the banks 0.2 m will not be significantly less as it only reflects a small difference in quantity of material. The order of costs for upgrading all 9.9 km of existing stopbanks then can estimated as $3.5 million.

A further allowance needs to be made for the stopbank extensions that would be required up each side of the Avon River. For a 0.2 m sea level rise (2050) the increase length is assumed to be approximately 200 m on each side at a cost of $140,000 and a further 300 m extension of each side for a 0.5 m rise in sea level by 2100 would cost $210,000 (all in present day costs). In some cases, CCC may prefer to raise road levels for both practical and aesthetic reasons but this is a significantly more expensive option and has not been considered here. The total cost for achieving protection up to a 500 year event with 0.4m SLR would be a minimum of $3.85 million. In addition there may be amenity and ecological costs from the raised stopbanks which need to be considered.

8.2.2 Stopbank Benefits

If the stop banks along the Hulverstone ponding area were raised to a level of 11.25 m, this would prevent flooding to that area under present day sea levels, and for the 0.15 m SLR rise scenario in all events less than a 500 year event. Even where the raised stopbank were overtopped[35], there would be significant saved damages from reduced flow into the Hulverstone and Avondale ponding areas. Table 22 below shows the damages with and without the raised stopbank in this area and gives the NPV of benefits associated with the raising.

Table 22 : NPV of damages from Avon Flooding (all areas) with and without a raised stopbank at Hulverstone ($million) for gradual sea-level rise to 0.4 m by 2100

Item	Value
PV without stopbank	$3.9 m
PV with stopbanks	$3.3 m
Benefit associated with stopbank	$0.6 m
Stopbank Cost	$0.2 m
Net Benefit of Stopbank	$0.4 million

This is likely to be the most effective upgrade which could be undertaken by CCC since it prevents damages in near term events which are less affected by discounting of the damages. However, further design work is required to determine if this upgrade is feasible and meets community expectations for the area.

Upgrades to stopbanks in other parts of the Avon have a greater impact on damages. If the full stopbank system were implemented, the damages would be reduced to the impact of earthquake events on properties in the Bexley area, which represent damages of $78,000 (PV). This stopbanking system would therefore represent a net benefit of $3.8 million in present day terms, and at a cost of $3.85 million would

[35] In the 0.15 m extreme event and in all the 0.4 m sea level rise events. It is assumed that for the 20 and 100 year events where the stopbank is overtopped that 80% of damages are saved, and 20% of damages are saved in both of the extreme events. In all these scenarios where the bank is overtopped, it is assumed that 20% of the Avondale damages are also saved since the Hulverstone reach contributes to ponding in that area.

almost be worthwhile undertaking now assuming that they could be completed for that cost and were technically feasible.

However, upgrades to the remainder of the stopbank system will only begin to have an impact when some sea level rise has occurred. An alternate solution therefore would be to undertake the upgrades to the Hulverstone stopbanks now, then delay the implementation of upgrading the remainder by a minimum of 25 years. The damages under this scenario would be $1.7 million representing a saved benefit of $2.2 million. The costs of all stopbanks would be approximately $0.8 million in present day terms[36]. This approach would represent a positive net benefit to the council of $1.4 million as opposed to slight negative from implementation of a full upgrade now.

As with the tidal barrage it appears that implementation of a full stopbank upgrade is not appropriate for immediate action against sea level rise, or only where design considerations would prevent a later upgrade. Implementation of an upgrade at Hulverstone to 11.2 m does appear to be worthwhile, and implementation of a higher standard should be investigated to determine whether there are significant savings to be made from implementing a design level of 11.7 m at present.

9. Combined Options

The minimum floor levels and stopbanks are not necessarily mutually exclusive. The minimum floor levels do not remove all risk from the area. In the period 50 – 100 years out even an 11.85 m minimum floor level removes less than half the damages when compared with an 11.4 m minimum floor level, and residual PV of flood damages at that stage will be $23 million with the 11.7 m minimum floor level. Given that flooding will occur in the ponding areas in 20 year events with a 0.4 m SLR, such a frequency of flooding associated with a large concentration of assets is likely to require other mitigation measures. Indeed even if all houses were raised to a level where no damage occurred, there would be frequent flooding of streets and sections, and community pressure would be such that some action would be likely. The most probable course of action would be an increase in stopbank height, and the council should plan for SLR on the basis that increased stopbanks are inevitable at some stage in the future.

The usual problem with stopbanks is that they retain some residual risk of failure. However in the lower Avon situation this residual risk is not associated with flood events, because scouring and piping failures are not considered likely. The residual risk of failure, associated with earthquakes, is independent of flooding, and the associated damages are low and confined to the Bexley area even with 0.4 m SLR[37]. The usual arguments for a combined minimum floor level and stopbanks do not hold in the Avon situation.

The problem with raising stopbanks is that there are significant technical and amenity issues associated with the work. The costs here are very roughly based, and a much

[36] Including $0.2 million for the Hulverstone stopbank and a further $0.6 million in present day terms representing an expenditure of $3.85 million in 25 years time.
[37] There are some minor damages in the Brighton ponding area, but these were not included in the analysis.

more detailed analysis would be required before they could be considered feasible and cost effective. Some measure of caution should be taken therefore in an assumption that stopbanks will be the panacea, and is likely to be most prudent to proceed with a mixture of measures to combat the impacts of SLR.

Given that none of the SLR scenarios achieve a positive PV relative to the 11.4 m floor level, if the council wishes to proceed on the basis of risk aversion and unquantified and intangible damages it should choose a floor level which achieves some level of protection over the next 50 years with least cost. We consider that because of the complexity of the interaction between sea level, ponding basin level, and minimum floor levels, more detailed modelling of the ponding basins would be required to assist with this decision making and should be given serious consideration.

10. New Brighton Beach and Spit

10.1 Predicted behaviour

The New Brighton coastline comprises a sandy beach backed by a dune system that, while modified in places by reshaping and some land development, still retains high natural character values. Although serious erosion does occur from time to time, the plentiful supply of sediment to the coastline mainly means the New Brighton spit is generally considered to be a long-term accretional feature. Maintenance of amenity values and natural character are considered to rank highly in coastal management decision-making and this is likely to continue into the future. A map of the relevant area is provided in Figure 1.

The 1999 report “Study of the Effects of Sea level Rise for Christchurch” (Tonkin and Taylor, 1999) provides a useful assessment of climate change impacts on the beaches, estuaries and rivers in the Christchurch area. Among other things, the report includes an assessment of the impacts on the New Brighton Spit coastline. These are relevant and a summary of the main findings follows:

- Waimakariri River sediment supply will continue to be sand, and net supply to the coastal sediment budget is extremely unlikely to be reduced in volume.
- The combined effect of increased westerly winds and increased water depth is likely to slightly reduce the net southerly sediment transport.
- The effects of sea level rise (SLR) on equilibrium beach profile position were calculated to be of the order of 4 m for SLR of 0.2 m and 10 m for SLR of 0.5 m. The retreat associated with this adjustment is less than the status quo shoreline advance, (based on historical shoreline changes in the 100 years from 1880 to 1980), hence the net result is likely to be reduced advance rather than retreat.
- Dune erosion during storm events is likely to be more severe than at present, particularly for SLR predicted to occur after 2050. For a 100 year return period storm with a 0.5 m SLR, maximum dune face retreat is predicted to be of the order 8-9 m for individual storm events for sites with low flat dunes. At North Brighton this will result in 15-20% volume and width losses from a single row of dunes.

- If the frequency of coastal storms increases, beach volume losses in individual storms are likely to increase due to incomplete post storm recovery and, hence, long term net advance rates will be further reduced.
- Increases in water tables will further increase storm erosion losses.
- A decrease in the frequency of easterly winds will further decrease dune growth from aeolian processes.

The net result of all changes will be a reduced rate of shoreline advance and dune growth than in the past, with more damaging storms occurring more frequently. This long term change over the New Brighton beach and spit area should be distinguished from the rapid changes which can occur at the spit tip. The spit tip changes are associated with storm events and the morphology of the estuary mouth, and are likely to occur regardless of the longer term trends in the general area.

These findings, taken at face value, have important implications for any coastal management decisions concerning future climate change.

10.2 Management options

Managing climate change effects, particularly if there is the prospect of increased coastal erosion, implies human intervention of one sort or another in the dynamic processes of the beach system and its relationship with the hinterland. The findings from the study (Tonkin and Taylor, 1999) quoted above, suggest that Christchurch City Council may not need to take early preventative action in order to mitigate the predicted effects of climate change at least for its coastal dune system.

Such action as may be needed in the future, probably post-2050, is more likely to relate to increasing episodic erosion, which will become problematic if storm cycles are such that they occur over extended periods and the beach is unable to recover before further damage occurs. This sort of activity is not new on the New Zealand coastline. Year to year variations and storm patterns, for example, are intricately connected with the El Niño Southern Oscillation (ENSO) system, the behaviour of which can be modulated on a 20-30 year time scale by what has become known as the "Interdecadal Pacific Oscillation" (IPO), giving rise to a predominance of El Niño conditions and an increase in westerly winds over central and southern New Zealand. Such swings are likely to be followed by periods of more evenly balanced La Niña and El Niño events.

The point is that, despite predictions (Tonkin and Taylor, 1999) that shoreline advance along New Brighton Spit will still occur on average, albeit at a slower rate, increased storminess, combined with SLR, may still require intervention to prevent property loss associated with storm events. Clearly, an appropriate coastal monitoring regime is necessary as has been established by Environment Canterbury, and existing planning requirements relating to development activities and construction setbacks will need to be kept under review. Fortunately these are relatively low cost actions that probably do not require a budget of more than $20,000 per year. However, the prospect that remedial action may be required to mitigate erosion in the future will need to be kept in mind, and contingency plans should be in place early enough to enable the use of options that will be compatible with maintenance of natural character wherever possible. Erosion management options are discussed in the next section.

10.3 Erosion Management

In the past, when dealing with coastal erosion, the usual practice was to build a seawall of one sort or another. These were often poorly conceived and failure was common. Now, in somewhat more enlightened times, the choice normally will lie within one of the following categories:

- do nothing, which may involve having to remove or relocate assets at risk
- so called 'soft' options such as beach replenishment and dune conservation
- structural solutions such seawalls, groynes and breakwaters, otherwise known as 'hard' options.

The decision has commonly been made on economic grounds although, more often now, environmental and social considerations may become an important issue. This is consistent with and required by the new Local Government Act 2002, which requires a balanced consideration of economic, social and environmental criteria. A critical issue is the value of the assets at risk and this may include cultural and amenity values or natural character, as well as infrastructural assets. The decision will, or should, also be based on an adequate understanding of the coastal processes and any underlying characteristics that are causing problems. Generally, the greater the degree of intervention the greater the level of understanding needed. Quite apart from the need to avoid making wrong and, perhaps, irreversible decisions, proper information is also necessary in order to keep costs down.

10.3.1 The 'do nothing' option

Erosion of rural or undeveloped land in Pegasus Bay may be inconvenient but the cost of remedial work, if required, is unlikely to be justifiable. Here, the 'do nothing' option will probably be the most sensible course of action. And, there may also be sound environmental reasons for choosing not to interfere, as well. However, on the New Brighton coastline, where coastal land development has occurred along the coastal margin and there are growth pressures, the value of assets at risk increases. In this case, the decision to allow nature to take its course becomes increasingly more difficult and demands to deal with the erosion start to be heard.

10.3.2 Soft options

The categories referred to above form a logical hierarchy. If the 'do nothing' option is unacceptable, sensible coastal management practice requires that the viability of a 'soft' solution, most often beach renourishment, be examined first. This, essentially, involves a process by which sand is 'imported' into the system from elsewhere. It may be dredged from off-shore and pumped on to the beach, or transported from another beach, or sometimes from inland sources. Because of high establishment costs, which may be upwards of $1 million, dredging options are normally only viable for large-scale projects (200,000 m^3 plus).

The object in a beach renourishment project is to compensate for the loss of sand and reduce or eliminate the negativity in the sediment budget. The capital costs of beach renourishment can be quite high but the downside is more likely to be the periodic maintenance, in the form of topping up the volume of sand on the beach, is usually required. Nevertheless, it is as close to a natural system as it is possible to get; it is working with, rather than trying to resist nature, and it maintains or enhances natural character.

A significant justification for adopting a renourishment option will often arise out of a need to maintain a beach, and sound reasons for doing so can usually be attached to the decision, particularly when it is realised that beaches can have a significant economic value in addition to any perceived amenity considerations. Not unrelated to this is the need to maintain natural character.

A potentially less resource intensive beach nourishment option is natural dune restoration and protection. It is considered good practice to establish dune conservation measures, often with council-coordinated programmes that involve community participation, whether or not additional beach renourishment is necessary. Christchurch City Council has such programmes in place. This approach by CCC includes re-contouring of dunes when blowouts occur, followed by rapid replanting with sand binding species. A comprehensive coastal management plan[38] has been developed for the full length of the city's coastline, including the dune system. This includes access management, planting programmes for both foredunes and back dunes, and creation of parking and picnic areas behind the dunes. Experience by some councils (for example, Environment Bay of Plenty) has shown that in some circumstances, dune care can be a highly effective way of naturally stabilising vulnerable coastal areas. The resource cost of dune care is difficult to estimate objectively since it often involves volunteer work and has a number of non-monetary co-benefits such as greater community participation and education, and preservation of natural coastal habitats and recreational areas.

10.3.3 Structural solutions

There are many instances where erosion has been allowed to proceed too far for soft options such as beach renourishment to remain viable, because of the quantities of sand required to restore a robust profile. Other times, protection of the properties at risk will take precedence over the need to maintain a beach, particularly when it is not a significant public asset and the costs of maintaining the beach cannot be justified. Here, a structural solution may be preferred and this is most likely to be some form of seawall, groynes or offshore breakwaters, with seawalls being the most likely option.

While seawalls, when properly designed, can adequately perform the intended function of stabilising the shoreline and protecting onshore assets, the potential for adverse effects must be recognised and either minimised in the design or otherwise mitigated against. They also have a significant impact on the "natural character" of the coast, on visual values and on recreational enjoyment of the beach. They are therefore considered a last resort, and ideally will not be required at the Brighton spit.

[38] "Christchurch Beaches and Coastal Parks Management Plant- Policy Document" Parks Unit, CCC, 1995.

Coastal Hazard Zoning

These days it is considered good practice to require development to be set back from the coast and there are presently planning rules in place that provide for this. The distance from the shoreline should reflect the coastal hazard risk including appropriate allowance for climate change effects, but other factors such as natural character, amenity, and/or cultural values may also be relevant considerations. This is fine for “greenfield” developments but, where infrastructure, commercial development, housing, etc., already exists, the establishment of setback lines becomes problematical, both in a practical sense as well as from a sociological perspective.

CCC and ECan have established coastal hazard zoning for the coastal area. There is also a Special Management Area for the South Brighton spit area which takes into account the particularly volatile nature of spit tips. It is understood that present setback distances on the new Brighton Spit have been mostly based on historic shoreline movements. It is uncertain whether or not these are sufficient to cope with potential climate change effects and further research may be justified, particularly if significant further development of the area were to occur that would create additional future existing-use rights. Setbacks beyond the established zones will have significant difficulties because of established housing and infrastructure assets (such as Marine Parade), and if erosion does occur, rather than accretion as projected, CCC may need to look to alternate options for managing the area.

10.4 Appropriate management options

Present information indicates that Christchurch City Council, at this stage, should continue with their Coast Care programme, and in conjunction with ECan ensure that continued monitoring of shoreline changes occurs. The council also should assess the capacity of the existing dune system to cope with potential storms on the basis of present climate change scenarios. Maintaining the minimum volume by beach renourishment on an as required basis is considered the most appropriate method of managing this shoreline.

As long as beach growth continues, there will be no need to resort to beach renourishment. However, if in the future, the reserve volume in the dunes is threatened because of prolonged storm action, sand will need to be imported into the system. Costs are difficult to predict with much confidence because it is not even certain that renourishment will be required and there will be issues to resolve including finding a suitable source of supply. Typical projects though, involve importing around 50 m^3 of sand per metre of shoreline at a probable cost in the region of $600 per metre. If this was done, say 1 km at a time, the cost would be of the order $600,000.

Seawalls or other ‘hard’ solutions are neither necessary nor appropriate in this case and no cost estimates have been derived.

11. Discussion

The report has estimated damages from inundation of the major ponding basins in the lower Avon. The damages are very sensitive to assumptions about the number and cost of damage to housing, since this is 95% of the total damages.

None of the minimum floor levels considered have shown a net benefit relative to the 11.4 m minimum floor level using the assumptions and matters included in the analysis. It should be noted however that the results are sensitive to timing and discount rates, and are more likely to be worthwhile at a low discount rate or with delayed implementation. As noted above they are also sensitive to the estimates of damages. It should be noted that 50% increase in damages, which would not be out of the order to account for intangible damages, or a 6% discount rate, both give a positive net benefit to the 11.85 m level. If a higher minimum floor level than 11.4 m were to be chosen, 11.85 m may be a more appropriate level to target than 11.7 m, because under most alternate assumptions modelled 11.7 m produces a lower net benefit than the 11.85 m floor level.

The benefits of minimum floor levels show considerable variability among the different ponding areas. This ranges from Hulverstone, with relatively low stopbanks, which shows a benefit for all levels and with 11.7 m as the highest benefit, to Bexley, which shows no net benefit for any floor level above 11.4 m. It appears from analysis of the event levels in each of the ponding areas that the level which protects against a 500 year event in a +0.15 m SLR scenario (50 years from now) is likely to provide the highest net benefit. Setting an appropriate universal floor level under these conditions is an exercise in judgement, and should take into account the unquantified and intangible damages not included in the study, and other matter discussed here. As noted below, a degree of risk aversion in setting the level may be appropriate. The sensitivity of the analysis to levels in the ponding basin points to a need for further hydrological modelling of stopbank overtopping events. It may be that the council looks to setting different minimum floor levels for each ponding basin based on that modelling.

The Bexley Special Management Area subdivision restrictions as proposed by the Christchurch City Council do not appear to represent a net aggregate economic benefit in terms of preventing flood damages over the next 100 years, although under certain conditions such as an assumption that the utility from the extra section could be met elsewhere in the city, it may do so. Given the size of the averaged damages to each property with no minimum floor level provision in place section level (NPV of approximately $2,000) and the potential surpluses from subdivision of sites in the area, it would not take a large deviation from this assumption however for the measure to be not worthwhile, and this measure cannot therefore be recommended as providing the highest net benefit. It should be noted however that, as discussed above, not all economic benefits have been included in the analysis, nor have a number of other planning considerations been considered and these would need to be included in the final decision. In terms of the measures considered here, the justification for such subdivision restrictions would appear to rest on the difficulties of achieving the Building Act minimum floor levels in the area, since houses would need to be 1 - 1.5 m above section level in this area. The damages from additional development in this area increase dramatically in the 50-100 year period, and this option is recommended for revisiting in the future.

The Hulverstone stopbank is the most promising area for stopbank improvement, because its current levels are RL 10.9 whereas in most of the rest of the lower Avon they are RL 11.2m to 11.25m. Analysis suggests an immediate net benefit from this upgrade.

The other stopbank upgrades are close to showing a net benefit, but do not do so under present circumstances. The analysis suggests that delaying this upgrade by 25 years would yield a net benefit, so it is recommended that the council revisit stopbank heights in the future when further SLR has occurred. It is likely that given the residual damages even with a 11.85 m minimum floor level that elevated stopbanks will be part of the mitigation options in the future. Further consideration of combinations of stopbank upgrades and minimum floor levels should proceed in conjunction with more detailed modelling of event levels in the ponding basin.

Tidal barrages have been considered, but are unlikely to be feasible, do not yield a net benefit, and they have significant environmental and amenity issues. They are not recommended for further consideration.

Despite studies indicating a likely continued advance of the coastline at Brighton, the council should ensure that ECan's monitoring programme of the New Brighton beach continues to determine what changes are occurring as a result of climate change. It should keep itself apprised of the results of this programme, and have contingency plans in place for beach renourishment should this be necessary.

11.1 Risk Aversion

Economists define different types of behaviour when faced with a risky situation as risk adverse, risk neutral and risk seeking. These are defined by the combination of cost or benefit of an event, and the probability of its occurrence.

- **Risk neutrality** is when the option will be taken when the combination of cost, probability and outcome is exactly equal to zero.

- **Risk Aversion** is most easily defined by the willingness to pay money to avoid a risk neutral situation.

- **Risk seeking** is most easily defined by a willingness to pay money to enter into a risk neutral contract.

Most people exhibit a range of risk seeking and risk adverse behaviour. Gambling is a risk seeking activity, since the combination of probability and potential gain are much less than the cost of purchasing say a lotto ticket, so on average we are paying money for the opportunity to take the risk. In taking insurance we are risk averse, since the cost of insurance is higher than the combination of probability and potential loss[39] and so on average we are paying money to avoid having to take the risk. In general where

[39] It has to be so; otherwise insurance companies would always lose money.

the potential losses for an individual are high, and the circumstances of the loss are beyond that individual's control, people will exhibit risk adverse behaviour. Although issue of societal risk aversion is extremely complex, and associated with the visibility and normality of events, it likely that society is risk averse to some degree in respect of flood events.

The analysis undertaken here is based on a risk neutral perspective. In choosing a floor level and other mitigation measures it is not inappropriate for decision makers to adopt a relatively risk averse position and choose a minimum floor level that provides additional protection against flooding into the future, even if this does not provide a net economic benefit as assessed in this analysis.

11.2 Irreversibility

In making decisions under uncertainty the issue of irreversibility should be considered. Some options will foreclose the use of other options in the future, and the council should take care that the decisions it makes preserve maximum flexibility for future decision makers. In respect of the zoning provisions irreversibility is most pronounced, because use rights are being created that will be impossible to extinguish. This may create a worse problem for councils in the future, and greater care should therefore be taken in approving such policies.

Minimum floor levels tend to be partially irreversible. In many cases the houses will be redeveloped over the period of consideration, and some more than once. The setting of the minimum floor level will be revisited therefore over the period of analysis and opportunities will exist to change some, but not all of the decisions which are made now. Setting a higher minimum floor level may also reduce the pressure on decision makers to move early to raise the stopbanks.

However it is also true that the past decisions made on development in this area are already irreversible, and it appears inevitable given current SLR projections that at some time in the future stopbank raising will be required. In this context the setting of a higher minimum floor level has some perverse consequences in terms of irreversibility. By expending money now on minimum floor levels it reduces damages in the ponding areas. However this expenditure may also reduce the capability of a later council to develop a comprehensive solution to the flooding[40] – because a significant portion of the damages has been ameliorated by minimum floor levels, the alternate comprehensive solutions may not be as attractive. In effect money which could have been spent on a comprehensive solution would be spent on a partial solution which only protects parts of the assets in the floodplain. The council should keep this consideration in mind in setting the minimum floor level for this area.

[40] Such a solution is likely to incorporate stopbanks and a minimum floor level set in relation to the risks of stopbank failure.

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