CHRISTCHURCH CITY COUNCIL

STUDY OF THE EFFECTS OF SEA LEVEL RISE FOR CHRISTCHURCH

REFERENCE NUMBER: 50275

AUGUST 1999

REPORT PREPARED FOR:

CHRISTCHURCH CITY COUNCIL

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EXECUTIVE SUMMARY

The debate on sea level rise (SLR) as a result of climate change has been ongoing for nearly 20 years. The prime questions asked are those dealing with how can we be sure it is happening, how much will it rise and when, what will be the impact on the shorelines, and what can we do about it. In spite of the best scientific efforts many of these uncertainties remain today.

Globally the quest for answers is being led by the Inter-governmental Panel on Climate Change (IPCC), which is charged with assessing the most up to date scientific, technical and socio-economic research on climate change. Major IPCC assessments have been released in 1990 and 1995, with the next one due in the year 2000. While these assessments represent a consensus of international thinking on the causes, magnitude, effects and best responses to climate change, there are a number of scientists who do not support the IPCC views.

In relation to SLR, the most recent IPCC (1995) assessment makes the following key points:

- In the last 100 years , global mean sea level has risen at an average rate of 1-2 mm/yr. (0.1 to 0.2 m)
- Projected future SLR relative to the 1990 levels are:

2030:	0.11 m (2.75mm/yr)	Range 0.05-0.21 m (1.4-6.5mm/yr)
2070:	0.29 m (4.5mm/yr)	Range 0.11-0.55 m (1.5-8.5mm/yr)
2100:	0.49 m (6.7mm/yr)	Range 0.20-0.86 m (3-10.3mm/yr)

- These estimates are approximately 25% lower than the “best estimate” in 1990 due to better modelling capabilities resulting in a reduction in the predicted increases in global temperature.
- Most of the contribution to SLR is estimated to derive from thermal expansion of the oceans and increased melting of mountain glaciers and small ice caps. A rapid disintegration of the West Antarctica Ice Sheet is considered unlikely in the next century.

- All SLR projections are similar to 2050, indicating that sea level only becomes sensitive to changes in human greenhouse gas emissions rates after 50 years.
- SLR will continue at a similar rate in future centuries beyond 2100, even if concentrations of greenhouse gases were stabilised by that time, and would continue to do so even beyond the time of stabilisation of global mean temperature.
- Regional SLR changes may differ from global mean values owing to localised land movements and ocean current changes.
- Differences from past SLR include the rapid rate of rise and the impact of humans blocking the natural response to rise (e.g. erosion and migration of ecosystems).

None of the preliminary scenarios for the IPCC 2000 assessments appear to predict a reduction in SLR from the 1995 projections.

In New Zealand, initial concern about the effects of SLR in the 1980's were based on northern hemisphere predictions and assumptions that there had been an acceleration of SLR since the 1950's. However, subsequent comprehensive reviews of past sea level trends (Hannah 1988,1989) found no evidence of any acceleration in rise, and resulted in much lower predictions of SLR of 0.07-0.17 m by 2025 and 0.17-0.35 m by 2050. These predictions are similar to the latter IPCC 1995 projections. More recent studies by NIWA suggest that the suppression of a SLR signal in NZ over the last 20 years is due to persistent El Nino conditions. The following conclusions regarding NZ sea level changes are made:

- There is a long-term linear trend of SLR of 1.8 mm/year over the past 100 years, with no evidence of acceleration.
- Until IPCC estimates are updated in 2000, continued use should be made of the IPCC 1995 estimates for SLR of 0.2±0.15 m for 2050 and 0.5±0.3 m for 2100.
- SLR will not stop at 2100, and will continue well after the temperature

has stabilised due to lags in the response of oceans.

- More important than the rise in sea level will be the potential increased inter-annual variability in sea level (El Nino- La Nina) and the potential changes in storm frequencies, tropical cyclone occurrence, and sediment supply to coastal regions.

For other coastal processes, the most recent climate change scenarios for New Zealand, are those from modelling Australasian impacts in 1997, which take account of New Zealand's topography and vast expanse of surrounding ocean. The key projections from these models for coastal processes include:

- Temperature increase of 0.5-1.5°C by 2030, and 1-3°C increase by 2070.
- An increase in the strength of the mid latitude westerly winds.
- An increase in water vapour and deep convection activity resulting in increased intensity and frequency of heavy rainfall events on both east and west coasts. The resulting predictions of change in the average return period of point-based heavy rainfall events are for up to a halving of the return period by 2030, and up to a four-fold reduction in the return period by 2070.
- Suggestion that the frequency of low-pressure troughs and depressions passing over NZ might increase slightly.

While there are many uncertainties and gaps in the scientific knowledge regarding the effect of human influence on climate change, the global magnitude and timing of SLR, regional variations, and process-response interactions for local coastal conditions, we can make the following "best estimate" projections of possible impacts for the Christchurch coastal environment based on SLR of 0.2 m by 2050, and 0.5 by 2100:

1. Waimakariri River and Brooklands Lagoon

- In the lower Waimakariri River there is unlikely to be any significant difference to flood risk due a large river channel capacity and considerable free-board on the lower river stopbanks.
- Within Brooklands Lagoon, water level changes will most likely mirror those at the open coast, hence are projected to rise 0.2 m by 2050, and 0.5 m by 2100. As a result the lagoon area will increase, and sand dunes around the margins of the lagoon will retreat in the order of 2.5 m by 2050 and 6.5 m by 2100. This will be significant at Brooklands township, where the narrow dunes provide natural protection for up to 50 houses that have floor levels below 11.00 (CDB datum).
- The risk of inundation at Brooklands township will also be increased due to greater frequency of extreme lagoon levels. The current minimum floor level will be approximately equivalent to the 1:100 year tide level with 50 years, and within 100 years the current minimum lot level for new developments will be approximately the mean level of monthly maximum tide.
- The Styx tidal gate will only offer 1:100 year protection from tidal flooding by 2050, and less than 1:50 year protection by 2100.
- The area at risk from a 1:100 year tidal event will increase by approximately 420 hectares by 2100 with a 0.5 m increase in water levels. The value of assets at risk from this size event will be approximately $32 million, an increase of 220% on the current value at risk in this size event.
- There will be retreat of tidal flats and saltmarshs around the margins of the lagoon with similar migrations of fish and bird habitats. Any attempts to protect existing pastoral lands in these areas will reduce the ability of this ecological migration and result in a loss of habitats of intertidal species and wading birds.

2. Christchurch Dunes

- 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 depths is likely to slightly reduce the net southerly sediment transport due to more frequent southerly wave events, and less wave refraction from this approach direction.
- The effects of SLR on equilibrium beach profile position were calculated to be in 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 that the status quo shoreline advance, 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 in the order 8-9 m for sites with low flat dunes. At North Brighton is will result in 15-20% volume and width losses from the 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 beach water tables will further increase storm erosion losses.
- A decrease in the frequency of easterly winds will decrease dune growth rates 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.

3. Avon-Heathcote Estuary

- Increases in mouth channel width by up to 10 m by 2050 and up to 25 m by 2100 to accommodate an increased tidal compartment, resulting in possible erosion on the Brighton spit side of the channel.

- Increased sedimentation on the ebb and flood tide deltas with increased tidal bypassing. For the flood tide delta this is likely to further restrict the

  channel at Moncks Bay.

- Continuation of current low rates of deposition on the estuary floor from possible increased river sediment supply.

- Projected Estuary water level increases of 0.2 m by 2050, and 0.5 m by 2100. These increases will by 2050 reduce the probability of a 1:500 year water level event to that of less than a 1:50 year event, and by 2100 monthly perigean tides without any storm surge or wind set-up would be approximately the level of a current 1:50 year event.

- These changes in water levels imply that the minimum ground levels for building around the estuary of 11.30 (CDB datum) will be exceeded by a 1:100 year water level without any allowance for run-up effects by 2050 and the minimum floor level of 11.45 m will be exceeded by a 1:50 year water level without run-up effects by 2100.

- The area at risk from a 1:100 year tidal event will increase by approximately 80 hectares by 2100 with a 0.5 m increase in water levels. The value of assets at risk from this size event will be approximately $208 million, an increase of 750% on the current value at risk in this size event.

- Increased bank erosion on the estuary side of Brighton Spit from equilibrium profile adjustments. The recession is calculated to be up to 3.6 m for SLR of 0.2 m, and 9.6 m for SLR of 0.5 m.

- Migration and “squeezing” of eelgrasses, saltmarsh, and marsh ribbon wood environments resulting in potential loss of feeding grounds for flounder, eels, and inanga.

4. Lower Avon & Heathcote Rivers

- By 2050 the tidal influence in the Heathcote River extending an additional 1.5 km further upstream to approximately Bowenvale Rd, and in the Avon river approximately 1 km to Barbodoes St. Due to the river gradients steepening beyond these points significant further upstream migration by 2100 is not considered likely.
- The area at risk from a 1:100 year tidal event in the Lower Heathcote
- River will increase by approximately 55 hectares by 2100 with a 0.5 m increase in water levels. The value of assets at risk from this size event will be approximately $95 million, an increase of 600% on the current value at risk in this size event. For the lower Avon River, the corresponding additional area at risk is 180 hectares with an additional asset value of approximately $550 million, also an increase of 600% on the current value at risk in this size event.
- The Heathcote tidal barrage and the lower Avon stopbanks will continue to provide protection in 1:500 year tidal events up to 2050, but by 2100, the protection from the tidal barrage will be less than a 1:100 year event and the protection from the Avon stopbanks less than a 1:50 year event.
- The saline water boundary will extend further upstream, potentially resulting in up to 10 m of bank collapse from a break down in soil structure, vegetation die back, and the migration of mud crabs. In the Heathcote River it is considered that this effect will extend further upstream than occurred following the construction of the Woolston Cut, In the Avon River this effect could extend to beyond Porritt Park.

5. Clifton, Sumner & Taylors Mistake Beaches

- Less sediment being available at Clifton due to increased trapping in the estuary tidal deltas and a less predominant southerly littoral drift. Shoreline recession due to equilibrium beach profile adjustments of up to 5 m by 2050, and 13.5 m by 2100, which affect the stability of existing rock protection works along the edge of the road to Sumner.

- Likely increased sediment scour from in front of the Sumner sea wall.
- Increased erosion at Taylors Mistake due to equilibrium beach profile adjustments of up to 5 m by 2050, and 14 m by 2100. This could affect the Taylors Mistake Surf Lifesaving building.

Many of these effects will not become noticeable for several years. However, it should not preclude a continuation of the current efforts into scientific investigations and planning responses, as a failure to begin to adapt to SLR may result in opportunities to avoid adverse impacts being lost if the process is delayed. For Christchurch, it is recommended that a combination of both planning and protection options be investigated and pursued at the current time, which allows for flexibility if projected rates of SLR or impacts change in the future.

For planning responses it is recommended that the Council adopt the following two-tier approach to new land-use developments in areas at risk.

1. Restrict new land-use developments in areas that within 50 years would be below 2% AEP tide level with a 0.2 m SLR and a 0.1 m safety factor for wind set-up. This equates to a ground level 11.2 (CDB datum). The implementation of this planning control would allow the water bodies to naturally expand with SLR into undeveloped areas to accommodate ecological migration and retain bio-diversity.

2. Control new land-use developments in areas that within 100 years would be below 1% AEP tide level with SLR of 0.5 m. This equates to a ground level of 11.5 (CDB datum). Control below this level is considered appropriate as it would allow for low cost or temporary developments while retaining flexibility of either retreat or more substantial development once some of the existing uncertainties are clarified.

For existing development areas it is recommended that the following standardised minimum levels be implemented:

- Lot levels at 11.20 m (CDB datum) based on 2% AEP tide level with a 0.2 m SLR within 50 years and a 0.1 m safety factor for wind set-up.
- Floor levels at 11.50 m (CDB datum) based on 1% AEP tide level with 0.2 m sea level rise (e.g. 2050) and existing 0.3 m safety for wind set-up and run-up effects.

The use of these minimum levels should restrict the need for protection works in existing development areas to after 2050, when a clearer picture of the total range of potential impacts and their costs should be available.

There are two types of protection options that need to be considered. The first is the maintenance of existing natural protection systems such as sand dunes, beaches and vegetation. It is recommended that ongoing maintenance programmes such as dune restoration, vegetation control and beach renourishment should be enhanced or implemented now, before costly or irreversible losses occur.

The second type of protection option is longer term physical engineering works to upgrade existing structures or construct new ones in high risk areas. Existing structures which will require upgrading at some time after 2050 in order to maintain the current level of protection include the Heathcote and Styx tidal gates, the Lower Avon Stopbanks, and protection walls around the Estuary. Possible new protection works that will need to be considered in the future include tidal gates on the Avon and stopbanks on the Lower Heathcote. However, before any of the longer-term protection options are considered, it is recommended that the Council undertake a cost-benefit analysis of implementing these options against the alternative options of do nothing and planned retreat. As well as economics, this analysis should also consider the environmental and social implications of the different options.

PART ONE: INTRODUCTION

1.0 Introduction

1.1 Objectives

Tonkin & Taylor Ltd (T&T) were commissioned by the Christchurch City Council (CCC) Environmental Policy and Planning Unit and Water Services Unit to undertake a study on the effects of sea level rise. The stated objectives of this study were:

1. To gain a comprehensive overview, based on current knowledge, of potential effects of sea level rise on the city of Christchurch, including an understanding of the likelihood and severity of these effects and their probable timing.

2. To establish where gaps in the knowledge exist and to gain an understanding of the significance of these gaps.

3. To provide a "best guess" of potential effects, their probability and significance, and suggestions for mitigation.

1.2 Additional Considerations

The study will also assist the Council in decisions pertaining to the City Plan Policy 2.5.4 – Sea Level Rise i.e. "To avoid higher intensity forms of built development in areas that could be subject to anticipated sea level rise."

The direct effects of sea level rise are commonly manifested as:

- increased beach erosion

- greater risk of flooding from both the sea and higher coastal water tables
- changes in tidal flushing and salinity
- alterations in habitats
- possible contamination of shallow ground water aquifers.

The effect of sea level rise on the coastal environments needs to also be considered in conjunction with the other potential effects of climate change. These associated effects include;

- changes in rainfall patterns and intensities that may alter sediment supply
- shifts in the predominant wind directions which may alter wave climates and hence longshore sediment transport
- changes in storm frequencies
- the effect of raising of coastal water tables and salinity on coastal landforms.

These factors are addressed in the current study to gain a more accurate understanding of the potential vulnerability of a Christchurch coastal environment to climate change and sea level change.

1.3 Report Layout

The following report is presented in three parts:

Part Two: The Global Perspective
Part Three: The New Zealand Scene
Part Four: Assessment Of Impacts For Christchurch

Within parts two and three of the report, there are sections on

- Background to climate change scenarios
- Estimates of global sea level rise

- Predictions of impacts and effects of sea level rise
- Responses and options to these impacts
- Uncertainties and gaps in the knowledge.

Further information on the IPCC and global climate change scenarios are included in Appendix B, and on New Zealand Scenarios in Appendix C. The Assessment of Impacts for Christchurch in Part Three are divided into the following areas:

- Waimakariri River & Brooklands Lagoon.
- The Christchurch Dune System
- The Avon-Heathcote Estuary
- The Lower Avon & Heathcote Rivers
- The Beaches South of the Estuary

A list of the author, date and title of all references is included at the end of the report along with a list of useful web sites. The actual ACCESS database of information in the references is provided separately.

Methodology

The methodology undertaken for this study involved three components:

- a detailed literature review
- the identification of gaps and uncertainties in the knowledge, and
- assessment of potential impacts for Christchurch.

2.1 Literature Review

The literature review involved the following four parts:

1. Review of global assessments of climate change effects on coastal geomorphology, ecology and management.
2. Review of New Zealand assessment of climate change effects and impacts on coastal geomorphology, ecology and management.

3. Review of literature relevant for assessing the impacts of climate change and sea level rise on the Christchurch coastal environment.
4. Review of literature, reports, and plans from other New Zealand territorial authorities that contained relevant information on mitigating the effects of sea level rise.

The review involved covering the following relevant climate change topics that were considered important for assessing the effects on coastal and estuarine environments:

- Magnitudes of Sea Level Rise (SLR)
- Changes in wind patterns and wave climates
- Changes in rainfall patterns and sediment transport
- Changes in storm frequencies and intensities.
- Modifications to surface water quality and ecosystems
- Models for assessing shore line retreat as a result of sea level rise
- Salt water contamination of ground water aquifers
- Mitigation measures

The following Library and databases were searched as part of this review:

- The Christchurch Public Library Catalogue
- The University of Canterbury Library Catalogue
- The University of Auckland Library Catalogue
- The University of Waikato Library Catalogue
- Massey University Library Catalogue
- The Aquatic Sciences & Fisheries abstract database
- The National Bibliographic Database
- The Index New Zealand Database.

An internet web site search of sites containing relevant information on sea level rise from the following organisations:

- Intergovernmental Panel on Climate Change (IPCC)
- Climatic Impacts Centre (CIC), Macquarie University, Sydney
- International Global Change Institute (IGCI), University of Waikato
- National Institute of Water and Atmospheric Research (NIWA), New Zealand
- Ministry for the Environment,(MfE), New Zealand
- Royal Society of New Zealand
- CSIRO Atmospheric Research, Australia
- National Oceanic and Atmospheric Administration (NOAA), USA
- United States Environmental Protection Agency (EPA)
- Natural Environment Research Council (NERC), United Kingdom
- United Nations Environmental Programme (UNEP)
- Environmental Defence Fund, USA
- American Geophysical Union (AGU)
- Goddard Institute for Space Studies, NASA, USA
- American Petroleum Institute, (API) USA
- Science and Environmental Policy Project (SEPP), USA
- The Heartland Institute, USA

The web site addresses for these organisations are given at the end of the Reference List.

In addition, pertinent internal reports of the Christchurch City Council were reviewed and interviews conducted with relevant staff. Relevant staff from other local authorities were also surveyed by e-mail and telephone to determine what response their council was making to the threat of sea level rise .

In total, 131 references were reviewed, summarised and stored in an ACCESS database. Within the database the references are categorised into relevant subject areas and into whether they contain global (52 references), New Zealand (61 references), or Christchurch local information

(18 references). A list of the author, date and title of all references is included at the end of the report, and a disk of the full database is supplied separately. Instructions on how to run this database are included in Appendix A of this report.

2.2 Identification of Gaps and Uncertainties in Knowledge

From the above technical literature reviews, the relevant gaps and uncertainties in knowledge on the impacts of climate change that are pertinent to the Christchurch coastal environment were identified. These included:

- Gaps or uncertainties in the international literature on the likely effects of climate change which mean that local effects can not be assessed with any confidence.
- Gaps or uncertainties in the local knowledge of coastal processes; coastal ecology, groundwater salinity and water tables, which means local effects of climate change can not be accurately assessed.
- Areas where sufficient understanding on the general effects of sea level rise are known and sufficient local data exists, but assessments of effects have not been undertaken.

Where possible, the report highlights how these gaps or uncertainties are being addressed, and whether the Christchurch City Council has a local role.

2.3 Potential Impacts for Christchurch

Where possible, depending on the gaps in the knowledge, the "best guess" of potential impacts for Christchurch has been evaluated. These impacts are presented in scenario form for each of the following coastal or estuarine areas:

- The coastal sand dunes and beaches from the Waimakariri River mouth to the mouth of the Avon –Heathcote Estuary. This involved applying the Brunn Rule (to calculate the horizontal rate of beach retreat due to sea level rise, and applying the SBEACH dune development model to assess the impacts of different sea level rise scenarios on extreme storm event run-up elevations and dune erosion
- The sand beaches of Sumner, Scarborough and Taylor's Mistake, also using the Brunn rule and SBEACH modelling.
- The Avon – Heathcote Estuary. This involved estimates of changes in the tidal compartment, water levels and sedimentation.
- The lower Avon and Heathcote Rivers. This involved estimate of changes in water level and salinity.
- The lower Waimakariri River, Brooklands Lagoon. This involved estimates of changes in water level and sedimentation.

PART TWO: THE GLOBAL PERSPECTIVE

3.0 Background

In this report, information on the causes of climate change are only given where relevant for the predictions of associated Sea Level Rise (SLR) and where the changes have an influence on coastal processes (e.g. changes in wind direction, storm frequencies and rainfall).

If required, a good brief summary of the "Greenhouse Effect and Climate Change" can be found on the NIWA web site (http://katipo.niwa.cri.nz./ClimateFuture/Greenhouse.htm).

Much of the scientific research and assessment on the magnitude and impacts of climate change, including SLR, has been undertaken by the Intergovernmental Panel on Climate Change (IPCC). This organisation was established in 1988, and released major assessments in 1990 and 1995. Appendix B includes a summary of the workings of the IPCC and parts of the various global climate change predictions which are relevant to SLR and coastal processes.

The most significant difference between the IPCC assessments in 1990 and 1995 was a one third reduction in the climate warming by the year 2100 in the 1995 assessment, with the mid-range estimate being for a 2^{o}C increase by 2100.

The next IPCC assessment is due in the year 2000. Preliminary versions of the four scenarios to be used in this assessment are available on IPCC Data Distribution Centre assessment and can be found at website (http//ipcc-ddc.cru.uea.ac.uk)

These are reproduced in Appendix B. The differences in these scenarios relate primarily to greenhouse gases emission rates, with two producing higher temperatures than the 1995 assessment and two producing lower temperatures.

While the IPCC assessments represent a consensus of the international thinking on the causes, there are a number of scientists who do not support the IPCC views. Some scientists believe that the estimates of Global Warming are too high, hence the sea level predictions are also too high. Others believe that the Western Antarctic Ice Sheet is on the point of melting, hence SLR will be greater than predicted. Another group suggests that Climate Warming is due to increased sun activity over the last century rather than human emissions of greenhouse gases. A summary of the criticisms of the IPCC assessments is also included in Appendix B.

4.0 Global Sea Level Rise

4.1 Historical Sea Level Changes Over the Past 1000 Years

Warrick et al (1993) suggests that over the last 1000 years sea level has risen in the order of 0.1 – 0.2 mm/year due to lingering isostatic adjustments from the last major glaciation some 15-20,000 years Before Present (BP). Based on data from the Pacific Islands, including New Zealand, Nunn (1998) provides some more detail of sea level movements over the last 1000 years, suggesting that it was close to present level approximately 1000 years BP before rising to 0.9m above around 700 BP during a period of warming named the Little Climatic Optimum. Then followed a transition to the Little Ice Age, when ground temperatures fell rapidly resulting in sea level being as much as –0.9m below present some 200 BP. Since this time it is widely reported that global mean sea level has increased in response to increasing global mean air temperature.

Based on the results of 13 independent studies, IPCC (1990) concluded that the average rate of SLR in the last 100 years to be 1-2 mm/yr., hence an order of magnitude greater that reported for the previous 10 centuries. However, as pointed out in Bird (1998) there is only a limited number of reliable tide gauge records which extend more than 30 years, the majority of which are located in Western Europe and North America, with only 2.6% in the southern hemisphere. These gauges show a wide distribution of results including a significant number which show a fall in relative sea-level. Both the IPCC 1990 and 1995 assessments reported that there was no firm evidence of acceleration in SLR during this century.

4.2 Future Projections

Titus (1989) attributes the initial concern about a substantial rise in sea level, as a result of projected global warming to Mercer (1968), who suggested that the Ross & Filchner-Ronne ice shelves might disintegrate, causing a deglacialisation of the West Antarctic, which are the best scientific consensus, sheet and resulting SLR of 6-7 m, possibly in 40 years. Subsequent investigations concluded that such a rapid rise is unlikely, and such a disintegration would more likely take 200-500 years.
(However, there is still scientific debate on this point, see Appendix B-5)

During the 1980's researchers turned their attention to calculating the relative contributions of thermal expansion of ocean water, melting of alpine glaciers, Greenland and the West Antarctica ice sheets to the magnitude of SLR in the next 100 years. Titus (1989) lists five estimates of predicted SLR by the year 2100, which range from 0.5-0.6 m for low rise scenarios to 3.4-4.7m for high rise scenarios. The major difference between these scenarios was the contribution of the West Antarctic ice sheet to SLR, with estimates from this contribution varying between 0.1 m and 2.2 m.

The findings of the 1985 Villach Conference included a predicted SLR of 0.2-1.4 m by 2030 from thermal expansion with further rise beyond this from the effects of melting of polar ice.

The SLR predictions from the IPCC 1990 assessments are presented in the following Table:

Table 1: IPCC 1990 Scientific Assessment of SLR from the "Business as Usual Scenario"		
Time	**SLR**	**Low- High scenario range**
2030	0.18 m	Range 0.08 – 0.29 m
2070	0.44 m	Range 01 – 0.71 m
2100	0.66 m	Range 0.31 – 1.1 m

Other major findings Post LR from IPCC 1990 include:

- Key points tribution is estimated to derive from thermal expansion (50% of total) and increased melting of mountain glaciers and small ice caps (30%).
- Antarctica is expected to contribute negatively to SLR due to increased snow accumulation with warming, and a rapid disintegration of the West Antarctica Ice Sheet is considered unlikely in the next century. Melting of this ice sheet is not considered likely to occur until the temperature increases by 4°C.
- Even with substantial decreases in the emission of the major greenhouse gases, future rises in sea level are unavoidable due to lags in the climate system.

IPCC 1995 Assessment:

These sea level predictions from the 1995 Assessments are presented in the following table.

Table 2: IPCC 1995 Assessment of SLR			
Time	**SLR**	**Average Rate of Rise**	**Low –High Scenario Range**
2030	0.11 m	1990-2030: 2.75 mm / yr.	Range 0.05 – 0.21 m
2070	0.29 m	2030-2070: 4.75 mm / yr.	Range 0.11 – 0.55 m
2100	0.49 m	2070-2100: 6.7 mm / yr.	Range 0.20 – 0.86 m

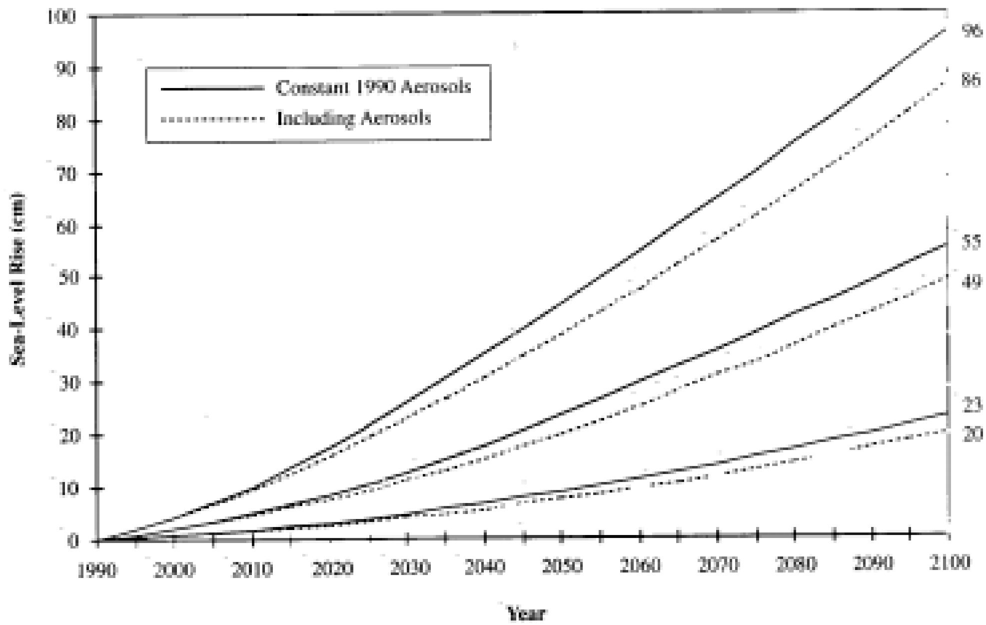


Figure 1: IPCC 1995 projections of Sea Level Rise 1990-2100 for "Best Estimate" Scenario IS92a.

- These estimates are approximately 25% lower than the "best estimate" in 1990 due to greater use of full AOGCM and cooling effect of aerosols resulting in reductions in predictions for temperature.
- All of the scenario projections are similar to the year 2050, indicating that sea level only become sensitive to changes in emissions rates of greenhouse gases after 50 years.
- Sea Level will continue to rise at a similar rate in future centuries beyond 2100, even if concentrations of greenhouse gases were stabilised by that time, and would continue to do so even beyond the time of stabilisation of global mean temperature.
- Differences from historical SLR include the rapid rate of rise, and the impact of human activity blocking the natural responses (e.g. erosion and migration of ecosystems).
- Regional Sea Level changes may differ from global mean values owing to land movements and ocean current changes.

Two of the preliminary scenarios developed for use in the IPCC 2000 Assessment suggest similar SLR to the year 2100 as given above in the 1995 assessment. However, the other two preliminary scenarios result in higher SLR, with the mean estimate up to approximately 0.6 m and the high range estimate up to approximately 1.05m by 2100.

Importantly, none of the preliminary scenarios appear to suggest a future reduction in estimates of SLR over the next century.

5.0 Global Impacts

5.1 Sea Level Impacts

It is well recognised that the general effects of SLR would be felt in the following ways:

- Erosion of shorelines as they attempt to gain a new equilibrium profile position with nearshore water depths
- Exacerbation of coastal storm flooding due to higher water levels
- Inundation and displacement of wetlands and lowlands
- Increases in tidal prisms and salinity in estuaries
- Alter tidal ranges in rivers and bays
- Impair coastal drainage
- Threaten freshwater aquifers and impair water quality
- Alter sediment deposition patterns.

It is noted in the IPCC 1995 Impacts, Adaptation, & Mitigation Report (Watson *at el, p299*) that there has been considerable progress since 1990 in the understanding of the effects of SLR and climate change on coastal geomorphological and ecological systems. Studies have shifted from the use of simple, monothematic approaches to more complex methods that generally fall into three broard categories:

- Retrospective studies concerned with reconstructing past geomorphological and ecological responses to sea level change in the Holocene Age
- Contemporary studies of geomorphological and ecological trends over the past several decades
- Mathematical and simulation modelling of coastal geomorphological and ecological systems using simplified SLR scenarios and process assumptions.

It is also recognised that the impacts will not be uniformly felt, and there will be considerable variation between different regions and different coastal morphologies. An important consideration is that the higher SLR merely creates potential for erosion. The speed of responses of beaches to SLR will depend on the frequency of storms. Actual erosion may lag SLR by several years or decades, hence will considerably lag behind climate change.

However, in spite of the increased research effort there are still gaps in the knowledge of the impacts due to the following factors:

- The emphasis of the recent studies being unevenly spread across the different coastal morphologies
- The limitations of the models being used
- The lack of long term trend data
- The complications of human impact overriding geomorphological and ecological responses.

Of particular interest to the Christchurch situation are the impacts on sandy beaches, dunes, and estuaries, and lagoons. The following two sub-sections briefly summarise the assessment of SLR impacts for these coastal environments.

5.1.1 Impacts on Sandy Beaches, Barriers and Dunes

Due to unconsolidated sand coasts being common on a world scale, and a large percentage of them being in an erosional state, there have been many attempts to correlate beach retreat with SLR over the past century. However, the results are not conclusive due to difficulties in excluding other factors, including human impacts.

The existing studies of sandy-barrier responses to rises in sea-level in the Holocene Age can be used as a historical analogue for future SLR impacts. However, the shoreline responses were not consistent, including not only the expected land ward migration as a result of erosion and wash-over, but also *in situ* growth and seaward advance. Rates of sediment supply and coastal configuration were identified as two important factors that influence how the shoreline responds to SLR.

There has also been widespread use of models to predict beach-profile changes as a result of a rise in water level. The best known of these is Bruun (1962), who formulated a two-dimensional relationship between SLR and the rate of shoreline retreat based on the concept of a equilibrium profile. The Bruun rules state that :

1. There is a shoreward displacement of the beach profile as the upper beach is eroded.
2. The material eroded from the upper beach is equal in volume to the material deposited on the nearshore bottom.

3. The rise in the nearshore bottom as a result of this deposition is equal to the rise in sea level, thus maintaining a constant water depth at a constant distance from the receding shoreline.

This model has been subject to much evaluation by laboratory and field studies. However, the verification has been hampered by significant lag times of beach change and the influence of other elements of the sediment budget that produce shoreline erosion. One solution to these uncertainties has been to determine a range of beach recession scenarios rather than a single estimate. A new generation of shoreface profile models are presently being developed which improve the predictions by better modelling of the coastal process interactions.

In conclusion, the IPCC 1995 Impacts, Adaptation, & Mitigation Report (p300) suggests that with future SLR there will be tendencies for currently eroding shorelines to erode further, stable shorelines to begin to erode, and accreting shorelines to wane or stabilise. However, locally, changes in coastal conditions and particularly sediment supply may modify these general tendencies.

5.1.2 Estuaries and Lagoons

Burns *et al* (1990) notes that "*estuaries are by their very nature complex and dynamic systems of which we have a good conceptual but poor quantitative understanding. It is therefore difficult to predict with any certainty what the full consequences of climate change might be.*" Burns also noted that the effects observed will depend largely on the topography of the land surrounding the estuary, hence the effects are to a large degree specific to each estuary, and therefore only general guidelines can be given.

Studies on the physical aspects of tidal rivers and estuaries to predicted SLR have covered two main areas; geomorphic responses and saltwater penetration. Generally accepted geomorphic responses include:

- Increase in the tidal prisms (tidal volume of water moving in and out of opening each cycle),
- Increase in size of the mouth opening to accompany changes in the tidal prisms.
- Increase in sedimentation on the ebb and flood tide deltas
- Enhance their role as sediment sinks for river sediment, but with deposition regions shifting upstream.

However, there is some debate in the literature about other geomorphic responses, including:

- Increased tidal oscillations and wave lengths (through the increase in speed of wave propagation)
- Increased tidal currents in bays and estuaries
- Changes in water depths. Some authors believe estuaries will become wider and deeper, while others suggest they will be wider and shallower by the local redistribution of sediment as the inter-tidal profile shifts both upwards and shore-wards.

The magnitude of any changes depends upon the hydrography, tidal period and range, and freshwater inflows of each water body. Hydrodynamic models can be used to study these effects. However, since the modelled conditions represent extrapolation beyond the calibrated conditions, there are uncertainties with the model results.

For saltwater penetration it is accepted that saline water will gradually extend further upstream and will also move laterally into the riverbanks. As a result, there can be a decrease in the soil cohesion of the riverbanks due the calcium ions in the soil being replaced by sodium ions which have less "binding" capacity, hence a resultant increase in bank erosion. The degree to which this happens depends on the effectiveness of clay and organic matter in the soil continuing to hold it together.

There will be ecological effects from both the increases in water level and the increased salinity. Ecological communities will have to undergo vertical and horizontal migration to remain in their tolerance limits for salinity and water level. However, if the ability to migrate has been compromised, (e.g. by "hard edges" such as sea walls, flood banks, revetments, roads, etc), some of the lower intertidal plant species will be "squeezed" and lost. Fish species and birdlife that live and feed in these habitats will also be affected.

5.2 Other Impacts of Climate Change to Coastal Processes

As well as SLR, there are a number of other climate change induced responses which could impact on coastal processes. These include:

- Changes in rainfall patterns and intensities that may alter sediment supply to the coast
- Shifts in the predominant wind directions which may alter wave climates and hence longshore sediment transport
- Changes in storm frequencies and the tracking of tropical cyclones
- The effect of raising of coastal water tables and salinity on the stability of coastal and estuarine landforms

Unfortunately, there is little guidance in the IPCC assessments for the magnitude and impacts of these changes, as many will be felt on a regional scale. As pointed out in the IPCC 1995 assessment, although globally climate change may result in a wetter world with global mean precipitation increasing by 3-15% for a temperature increase of 1.5-4.5°C, projections of regional changes in precipitation are less certain than projections for regional changes in temperature. The predicted changes in precipitation and wind climate from the regional model for Australasia are presented in Section 11.2. The IPCC 1995 assessment also notes that there is little confidence, and essentially no change from the IPCC 1990 position, in how the intensity of mid-latitude storms and tropical cyclones might change under a warmer climate.

6.0 Global Responses

The IPCC 1990 Strategies for Adaption to Sea Level Rise Report states that *"it is urgent for coastal nations to begin the process of adapting to SLR not because there is an impending catastrophe, but because* ***there are opportunities to avoid adverse impacts by acting now****, opportunities that may be lost if the process is delayed."*

The Report identifies three groups of response strategies for dealing with SLR.

1. Planned Retreat:

Involves no effort to protect the land from the sea. The coastal zone is abandoned and ecosystems shift landward. Methods include:

- preventing new developments
- planned phasing out of existing developments
- withdrawal of government and council services

2. Accommodate:

Implies that people continue to use the land at risk but do not attempt to prevent the land from being flooded. Methods include:

- advanced planning to avoid the worst impacts
- erecting emergency flood shelters
- modification of landuse (e.g. converting to fish farming, growing flood or salt tolerant crops)
- modification of building (e.g. putting on piles)
- protection of threatened ecosystems

- strict regulation of hazard zones
- hazard insurance

3. Protection:

Emphasis on defence of vulnerable areas, population centres, economic activities and natural resources. Methods include:

- Hard structural solutions (e.g. seawalls, groynes, detached breakwaters, floodgates and tidal barriers, saltwater intrusion barriers)
- Soft structural options (e.g. beach renourishment, wetland creation, littoral drift replenishment)

As pointed out in the IPCC 1995 Impacts, Adaptation, & Mitigation Report (Watson *at el*, p311) The first two strategies are based on the premise that increases in land loss and coastal flooding will be allowed to occur and that some coastal functions and values will be lost. However, these strategies also help to maintain the dynamic nature of coastal ecosystems and thus allow them to adapt naturally. The protection strategy seeks to maintain the shoreline in its present position, which could also result in the loss of natural functions and values.

The IPCC Assessments in both 1990 and 1995 point out that each strategy has environmental, economic, cultural, and legal implications that need to be assessed by integrated coastal zone management techniques. For example, case studies presented in the IPCC Assessment (Watson *at el*, p308), shows that for the potentially most affected developed countries, Japan and the Netherlands, the capital value at loss from a 1 m rise in SL without any protection measures will be approximately 70% of GNP ($849 & $186 billion respectively), while adaptation/protection costs are under 1% of GNP ($156 & $123 billion respectively). However, it is also pointed out that there are a number of constraining factors that can determine how successfully an option can be implemented. The applicability of any option must be evaluated against a background of a country’s technology and human resource capability, financial resources, cultural and social acceptability, and the political and legal framework.

Dalziell (1989) presented a model for determining when a climate change problem will be addressed based on the following relationship: $f(s, p^+) > f(u,\$,p^-)$

Where: s = seriousness of the problem (combination of urgency for action and size of potential harm)

u = uncertainty

$ = Cost of action

p^+, p^- = political factors.

Hence, action will only be taken when the seriousness of the problem and the positive political factors for action outweigh the uncertainty of the problem, the cost of the solution and the negative political factors of not taking action. For potential climate change issues, the major hold up to action is the high level on uncertainties regarding the magnitude of the problem.

7.0 Uncertainties and Gaps in the Knowledge

Clearly there is still work to be done on improving the scientific and public understanding of sea level rise before any of the response options are implemented. In particular there is a need for removing the uncertainties in the magnitude and timing of future SLR.

Unfortunately, several more decades of sea level data are required before we can remove these uncertainties and confirm the predictions based on facts. By the time this information is available, it is likely to be too late to consider and implement the full range of response options. Therefore, at a global level the gaps in the knowledge which produce the uncertainties can only be addressed by improved modelling. Some of the relevant gaps in the knowledge required to remove these uncertainties relate to climatic processes, some to climate-ocean interactions, some climate-sedimentation processes, and others relate to coastal and estuarine processes.

On a global scale, the major uncertainties for determining future sea level include:

- Distinguishing the role of anthropogenic influences on climate change
- Determining the time frame for stabilisation of greenhouse gas emission
- Confirming the time lags between changes in global temperature and global sea level
- Determining the critical temperature rise required for the disintegration of the West Antarctic ice sheet.

It appears that preliminary scenarios to be used in the IPCC 2000 assessment focus on the first two points, but indicate little progress on the second two points.

On a hemisphere scale, the most relevant uncertainties for coastal effects in New Zealand include:

- Determining the change in frequency and track of tropical cyclones associated with warming of the South Pacific ocean. While the impacts of those potential changes are more likely to be felt on the East Coast of the North Island, Christchurch may also be affected by the remnants of these weather systems.
- Confirming the magnitude of change in the wind climate and the significant of these to the wave climate, particularly the passage of southerly depressions that have a major influence on the generation of large southerly swell events.
- Determining the influence of El Nino-Southern Oscillation signal on future variations in sea level. Recent research suggests that during periods of El Nino conditions in New Zealand, long term SLR is suppressed, and is enhanced during periods of La Nina conditions. Since we are projected to be heading in to a prolonged period of La Nina conditions, it is possible the SLR over the next few decades may be greater than predicted by the global estimates.

While uncertainties related to climate-sedimentation processes and coastal/estuarine processes are uniform across the globe, the effects of these processes are site specific and will be addressed with in Part Three.

PART THREE: THE NEW ZEALAND SCENE

8.0 Climate Change

New Zealand scientists have been actively involved in the climate change debate for the last fifteen years.

In 1988 the Ministry for the Environment launched the New Zealand Climate Change Programme with a Workshop in Wellington (Ministry for the Environment, 1988b), which was attended by representatives of Government research agencies, universities, local authorities and Government departments. Out of this programme came 8 reports between 1988 and 1994 on the likely impacts of and possible responses to climate change in New Zealand. Two climate change scenarios for New Zealand to the year 2050 were presented by Salinger and Hicks (1990). Summaries of these scenarios are presented in Appendix C.

Also as part of the programme, New Zealand scientists participated in international conferences and workshops, and helped develop climate change impact models for Australasia in partnership with CSIRO (Australia), (Whetton, Mallon & Pittock, 1986). A summary of these impacts which are relevant for coastal processes is also presented in Appendix C. Notable points from these more recent projections were on increase in the strength of westerly winds over New Zealand, and an increase in intensity and frequency of heavy rainfall events. However, they are silent on changes in the frequency and tracking of tropical cyclones.

9.0 New Zealand Sea Level Rise Estimates

The first reported concern at SLR for New Zealand was Gibb (1986) based on northern hemisphere predictions. An initial analysis of New Zealand tide gauge records (Gibb & Aburn 1986) suggested that the rate of SLR had been accelerating since 1944.

A more comprehensive review of SLR trends in New Zealand by Hannah (1988 and 1989) indicated SLR had been occurring at a mean linear rate of

1.7 ± 0.23 mm/year since 1900 (Lyttelton – slightly higher at 2.3 ± 0.17 mm/year), and that there was no evidence of an acceleration in rate since 1950. Hannah extrapolated the existing trends and included components for ocean thermal expansion and glacier and Greenland ice melt, to project SL in New Zealand could rise by 0.07-0.17 m by 2025 and 0.17-0.35 m by 2050.
A summary of these projections of SLR are presented in Appendix C.

9.1 Advancements in the Estimates and Data in the 1990's

Up until 1995, the estimates of the magnitude of SLR incorporated into coastal management and planning reflected the IPCC 1990 assessments rather than the work of Hannah. However, following the release of the IPCC 1995 assessment, there has been an increasing expectance of a lower rate of rise as recommended by Hannah.

NIWA (Bell & Goring 1999) have undertaken a recent analysis of Hannah's long-term sea level trends for New Zealand, which confirms has over the past 100 years, SLR has averaged 1.8 mm/yr. with a range of uncertainty of 1-2.5 mm/year.

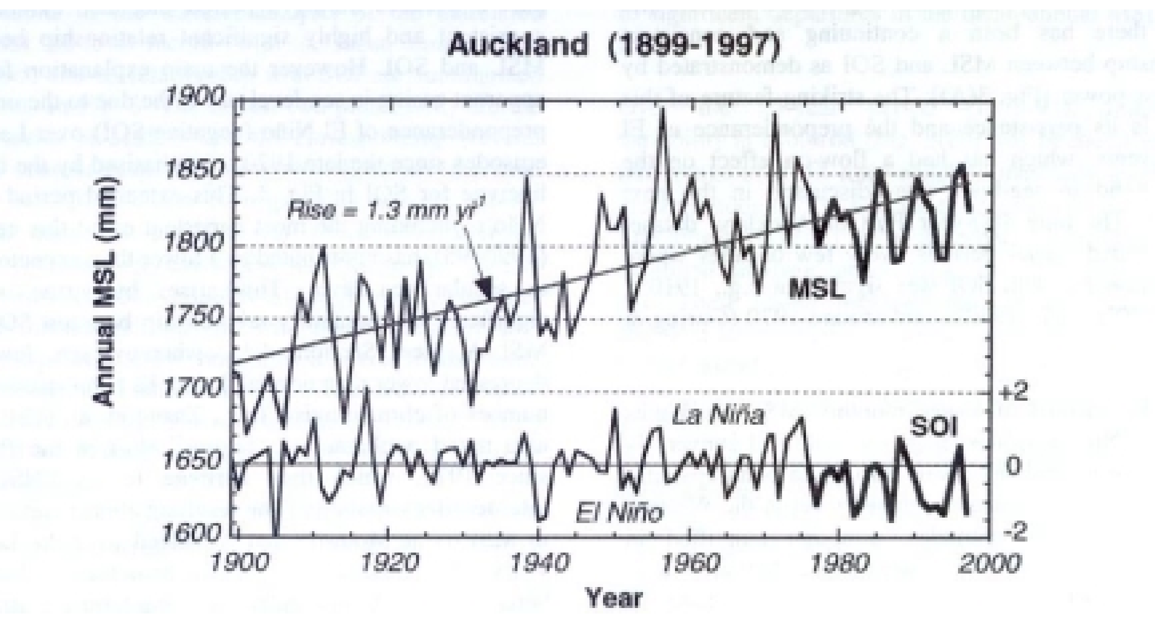


Figure 2: From Bell & Goring, 1999

This analysis also examined the role of El Nino and La Nina events to sea level fluctuations and long-term SLR trends at Auckland. The results showed that long-term SLR trends are suppressed during persistent El Nino conditions and accentuated in persistent La Nina events. The results also indicated that the presence of interdecadal oscillations (termed the Pacific Decadal Oscillation, PDO), in the climate regime which had previously been identified for the North Pacific. The PDO seems to accentuate or curtail the effects of El Nino and La Nina events depending on its phase. The last phase change in the PDO occurred in the mid 1970's coinciding with the start of persistent El Nino episodes. Since this time, the long-term SLR signal had been suppressed over the last 25 years as shown in Figure 2 (from Bell & Goring 1999). Hence, any data on SLR collected only during this period will
show lower rates of SLR than the longer-term trends. This is the situation with all New Zealand open coast sea level records, the longest of which is 26 years at Motariki Island in the Bay of Plenty .

Bell & Goring also noted that the other striking feature of the long-term SL record shown in Figure 2, was the large decodal oscillations between 1930 and 1970's. These fluctuations were interpreted by some authors (e.g. Gibb & Aburn, 1986) as indications of acceleration of SLR. However, the recent analysis indicated that prior to the mid 1970's, the previous switch in phase of the PDO occurred in 1947/48 accentuating the affects attributed to La Nina on SLR and hence, resulting in a period of relatively rapid rise in SL at Auckland. Bell, Goring and de Lange (in Press) point out that the extent of these effects in the South Island await collection of larger open-coast sea level records, but early results from Canterbury recorders at Sumner and Kaikoura (5 and 3 years of records respectively) indicate similar inter annual response of SL to El Nino and La Nina events. They go on to suggest that the next decade should see another change in the PDO phase which could cause regional SL to rise more rapidly, similar to the 1950's.

9.2 Conclusions on New Zealand Sea Level Changes

The following conclusions about New Zealand seal level changes can be made.

- NIWA's recent analysis confirms Hannah's long-term trend of 1.8 mm/year SLR over the past 100 years. Within this trend there are periods of more rapid SLR (e.g. 1940-1970) due to persistent La Nina conditions and periods of slower SLR (1970-1980) due to persistent El Nino conditions.
- It is possible that rates of SLR will increase over the next decade due to persistent La Nina events and the phase of the PDO.
- Until IPCC estimates are updated in 2000, should continue to use IPCC 1995 estimates for SLR of 0.2±0.15 m for 2050 and 0.5±0.3 m for 2100.
- SLR will not stop at 2100, and will continue well after temperature has stabilised due to lags in the response of oceans.
- More important than the rise in sea level will be the potential increased inter-annual variability in sea level (El Nino- La Nina) and the potential changes in storm frequencies, tropical cyclone occurrence, and sediment supply to coastal regions.

10.0 New Zealand Coastal Impacts

In general terms the impact of SLR and associated changes in coastal processes should be similar for New Zealand to those presented in Section 6.0 for global impacts. As summarised by Hicks (1990), currently eroding shores should erode faster, stable shores could begin to erode, and advancing or accreting shores will wane or stabilise. Changes in the existing spatial variations in the behaviour of the coast will be dependent on the changes in the supply of sediment, local tectonic uplift or subsidence, local engineering coastal structures, and if there is a shift in predominant wave direction, the orientation of the shoreline. The speed of response of beaches will depend on the frequency of storm events, rather than the rate of SLR.

Hicks (1990) suggests that under the general assumptions of the Bruun Rule, previously stable sand beaches will retreat in the order 20 –80 m in response to SLR of 20 – 40 cm. However, gravel beaches are liable to behave differently with their crests building higher and land ward retreat by recurring sediment roll-over rather than by offshore losses. Since gravel beaches have steeper slopes than sand beaches, their rate of retreat is liable to be considerably less than sand beaches.

Hicks (1988) also notes that a wind climate of less westerly wind could result in a subtle rotation in the direction of the dominant wave approach away from the southerly quarter, possible resulting in a reversal of the net littoral drift direction, hence, causing beaches to re-orientate their planform shapes. However, more recent wind projections indicate that there will be more frequent rather than fewer westerlies, hence a beach re-orientation response is now considered unlikely.

Hicks (1990) assessed the main coastal impacts for each region of New Zealand. The key points from the assessment for Canterbury are summarised in Appendix C.

Most of these effects are still applicable, except for the impacts of a change to a stronger north-east wind-wave regime. An attempt to quantify these effects is made in Part Four.

11.0 New Zealand Responses

The national response to SLR in New Zealand has been for the inclusion of the following policies in the New Zealand Coastal Policy Statement (1994):

Policy: 3.4.2: Policy plans should recognise the possibility of a rise in sea level, and should identify areas which would as a consequence be subject to erosion or inundation. Natural systems which are a natural defence to erosion and/or inundation should be identified and their integrity protected.

Policy 3.4.4: In relation to future subdivision, use and development, policy statements and plans should recognise that some natural features may migrate inland as the result of dynamic coastal processes including sea level rise.

It is notable that policy 3.4.2 mentions sea level rise, and not the other coastal process responses to climate change that could result in erosion and/or inundation.

11.1 Christchurch Responses

Dalziell (1989) suggested that the threats to Christchurch of SLR could be countered in two ways:

1. Prevent or reduce physical impacts by stopbanking, etc. However, this action should be delayed until the threat is apparent rather than be undertaken at present.

2. Retreat from the hazard. However, this is considered too costly at present, but authorities should prevent any increase in costs of such a shift by restricting developments in risk areas.

Watts (1993) suggested that the City Plan should adopt similar policies including:

1. No new urban land-use zones be created in areas threatened by rising sea levels.
2. Further subdivision and development only be permitted within exiting zones at appropriate levels.

3. Control activities that would diminish the functioning of the coastal dune system as a natural storm buffer.
4. Options for long term strategies be investigated for possible sea level rises beyond the next 100 years in order to ensure that actions taken now do not unduly compromise future strategies.

The City Council and the former Christchurch Drainage Board (CDB) have advocated minimum landfill areas for land along the coast, estuaries, and lower rivers for the last 10 years. In August 1989, the Drainage Board adopted a minimum land fill level of 11.00 m (CDB Datum, i.e. 0.86 m above MHWS) in these areas. In September 1989, a report to the Board recommended that these be raised to 11.25 m and a minimum house floor level of 11.5 m be established (Carver 1992). However, the events of local government reorganisation overtook the adoption of these recommendations.

The current minimum floor level being applied is 11.45 m (CD Datum), being a combination of the 2% AEP water level in the Estuary (10.9 m), 0.1 m SLR, 0.3 m safety for wave/wind run-up, and 0.15 m above ground level.

11.2 Responses of Other Local Territorial Authorities to SLR

As part of the current study, other LTA's were canvassed to determine their responses to SLR in planning documents, consent issues and research. A summary of the responses is presented in the Table 3. Notes from each of the responses and extracts from the relevant plans are included in Appendix D. From the responses it can be seen that there is no uniform approach to SLR, in either regional or district/city planning.

The most common approach is to have regard for SLR in policies about natural hazards, but few councils have carried this forward in rules on floor levels or set backs or policies about other response options.

For the four respondents who have set floor levels, three used the 100 year estimate of 0.49 m SLR from IPCC 1995 best estimate (IS929) scenario, and the other (Nelson) uses a 0.3 m by 2050. While all of these are higher components of SLR that currently adopted by CCC, as shown in Table 4 direct comparisons beyond this are difficult due to the use of different tide elevations, surge levels and safety margins.

Table 4: Minimum Floor Levels in Response to SLR

Council	Christchurch City Council	Environment Bay of Plenty	Wellington Regional Council	Gisborne District Council	Nelson City Council
Tide Level	2% AEP Water Level in Estuary	2% AEP	1% AEP in river		SpringTide
Storm Surge	Included in Water Level	Included in Water Level	Included in Water Level		0.6m
SLR (m)	0.1	0.49	0.5	0.5	0.3
Wave / Wind Runup (m)	0.3				0.2
Floor Level Above Ground (m)	0.15				0.2 Concrete 0.35 Timber
Additional Factors (m)		0.5	0.4		

Some of the councils with flood level controls indicated that they would adjust those controls as new IPCC assessments became available.

While several councils have adopted coastal hazard zones, few have included a component for SLR. For those that have included SLR, their planning documents are not clear how this is to be assessed, particularly equilibrium shoreline retreat and storm erosion under SLR scenarios. Most councils appear to leave the choice of assessment method to the developers applying for the required resource consents, and allow acceptable methods to be evolved from the Hearing discussions. For example, Auckland Regional Council have four different options for assessment in their coastal hazard strategy, which range from no consideration of SLR, to use of the Bruun Rule for shoreline retreat.

Environment Bay of Plenty appears to be more pro-active to incorporating SLR in its planning consideration that other councils, including a 50 year SLR component in the design of stopbanks and flood walls, and 100 years on lower river bridge approvals. Some districts in the Bay of Plenty have included a component for global warming in their stormwater designs.

In terms of developing policy on response options to SLR, other than limiting new developments in hazard zones, no councils appear of be prepared to take a stance at this time. Nor do there appear to be any programmes of assessing the costs of the different options in different communities. Councils are generally taking a “wait and see” attitude due to the high level of uncertainty in the estimates and impacts. In this regard, CCC is neither ahead nor behind other councils in their planning for SLR. However, this current study is seen as an important first step. Many other councils are awaiting the outcome of the study, and how CCC responds to it.

12.0 Uncertainties And Gaps In The Knowledge

There are a number of uncertainties and gaps in the knowledge on a hemisphere, national and regional level that reduce the confidence in projections of coastal impacts for New Zealand and Canterbury.

On a hemisphere scale, the most relevant uncertainties for coastal effects in New Zealand include:

- Determining the change in frequency and track of tropical cyclones associated with warming of the South Pacific ocean
- Confirming the magnitude of change in the wind climate and the significance of this to the wave climate, particularly the passage of southerly depressions
- Determining the influence of the El Nino-La Nina events on future variations in sea level

At this stage, it is unknown whether some of those uncertainties will be clarified in the IPCC 2000 Assessment or not. On a national and regional scale the most relevant uncertainties include:

- Regional rates of SLR
- Changes in rainfall patterns and the frequency of high intensity events, which will influence sediment supply to the coastal sediment budget.
- Changes in the frequency and intensity of coastal storms events, and the significant of these storms on the magnitude of storm surge
- Changes in beach orientation and sediment transport as a result of changes in the wind climate
- Changes in wave refraction and coastal sediment transport as a result of SLR
- The relationship between changes in sea level on the open coast to changes in estuaries and lagoons

In New Zealand, many of these gaps are currently being addressed by either crown research institute, regional council or university data collection and investigation programmes. However, as there is no co-ordinated programme or national direction to these investigations it will be several years before all the gaps are filled, and we have a conclusive picture of the coastal process changes due to climate change.

Adding to the uncertainty of the impacts of climate change and SLR are the gaps in our existing knowledge on quantifying coastal zone processes and relationships in the Canterbury coastal zone. These include:

- Sea level trends and variations for Canterbury
- The effect of historical sea level rise on coastal stability in Canterbury
- The effect of storm surge on coastline erosion and stability in Canterbury
- The relationship between rainfall and catchment erosion in the Waimakariri River
- The relationship between sediment transport rates and yields with flow in the Waimakariri River
- The sediment supply of the Waimakariri River to the coastal sediment budget, particularly for the Christchurch foreshore
- Relationships between discharge and sedimentation in the Christchurch Estuary
- The role of ebb and flood tide bars on sediment volumes at Clifton and Sumner
- The wave climate of Canterbury
- Salt water intrusion up the Avon, Heathcote and Waimakariri River systems and the effects of this on river ecology.

Until we are able to quantify these parameters and relationships, we will not accurately be able to quantify the impacts of climate change and SLR, even with accurate estimates of future climates and sea level.

Some of the gaps are being addressed by CRC investigations and state of environmental monitoring, such as sea level monitoring and the Waimakariri river sediment transport studies. Others will require specific investigations which use existing understandings of the physical processes to address the specific issues. Most of these investigations lend themselves to joint initiatives between CCC, CRC and for some, possibly the Waimakariri District Council. What is required is a co-ordinated approach under the leadership and direction of one council to ensure that investigations programmes are adequately planned, appropriately financed, effectively implemented and the results widely disseminated. It would not be inappropriate for CCC to take a pro-active role and initiate discussions with the relevant councils on how to prioritise and implement the required investigations.

Another gap in knowledge that is specific to CCC requirements, is the relative cost of implementing the various response options given in Section 6. While there has been some costing of assets at risk from SLR (Watts 1993, CRC/CCC 1997) this does not include looking at the economic cost of physical protection, or the environmental, legal or social implications of following any particular option.
By the time accurate information on SLR, coastal processes and the potential impacts is available, it is likely to be too late to consider the full range of possible response options.

It is therefore considered that to allow more informed decision-making on the best response options to follow, each option should be indicative cost based on the assessment of impacts given in Part Four under agreed development scenarios.

PART FOUR: ASSESSMENTS OF IMPACTS FOR CHRISTCHURCH

13.0 Assessment of Impacts on the lower Waimakariri River and Brooklands Lagoon

The mouth of the Waimakariri River and Brookland Lagoon (Right)

13.1 Past Assessments

The only reference to past assessments of the impacts of SLR on the lower Waimakariri River was in Hicks (1990), who suggested that the flood protection scheme would be less effective.

At Brooklands Lagoon, Wilkinson & Smith (1995) present maps of likely inundation as a result of SLR of 0.3 m by 2050 and 0.65 m by 2100 (IPCC 1990) which show that the areas between Brooklands Lagoon and the Styx River, to the west of Styx River towards Kainga, and south of Brooklands Lagoon to Spencerville could be affected.

Crossland (pers com, 1999) noted that the total number of wading birds at Brooklands Lagoon is dropping due to a decrease in the size of the salt marsh. However, it is unknown whether this is a result of SLR. For the more endangered swamp birds, numbers appear to have been retained, including the “Australasian Bittern” which is globally endangered.

13.2 Lower Waimakariri River

13.2.1 Sedimentation

The most recent climate model scenarios for Australasia (Whetton, Mullan & Pittock, 1996) suggest there will be an increase in westerly rain in the upper Waimakariri catchment and also an increase in the frequency of high intensity rainfall events. As a result, sediment supply to the river from erosion in the catchment should increase and in-river sediment transport will be enhanced. It is beyond the scope of this study to attempt to quantify these potential increases in sediment supply. However, there is no reason to suggest that the current situation of bedload transport of gravels on the Waimakariri River terminating 2.5 km upstream from the river mouth due to major change in river gradient, will alter significantly under the climate change scenarios. If anything the gravel deposition zone may migrate slightly upstream.

Downstream of the gravel deposition zone, there will be a reduction in river gradient with SLR, resulting in potential increased deposition of sand and silt sized material in the lower river channel due to reduced flow velocities. However, as is currently the situation, high flow events will regularly flush this material out the river mouth, hence the net impact of climate change on lower river sedimentation is considered to be negligible.

13.2.2 Water Levels

The mouth of the Waimakariri River is approximately 200 m wide at mid tide, and is conservatively estimated to have a cross-section area of approximately 480 m^2 area. From increases in sea level of 0.2 m by 2050 and 0.5 m by 2100 the resulting increases to the cross-sectional are estimated be in the order of 10% and 25% respectively. Currently the tidal backwater effects on the Waimakariri River extend approximately 6 km up the river channel to the position of the SH1 bridge. With the larger cross-sectional area, it is estimated that this influence would extend a maximum of 0.5 km further by 2050, and 1.5 km further by 2100.

Maximum water level changes in the vicinity of the mouth can be conservatively estimated to be the same as the magnitude of SLR, and reducing with distance upstream. Flood levels on the lower river are more influenced by tide that river flow, and stopbanks have a freeboard of approximately 1 m above extreme tide level (Tony Boyle, CRC, pers com). Hence it is considered that the resulting changes in water level from SLR will not make significant differences to flood risk in the lower channel within the next century.

13.2.3 Salinity Effects

Under low flow conditions, evidence of saline water has been found approximately 3 km upstream from the river mouth (Ken Taylor, CRC, pers com). With SLR of 0.5 m, it is considered that the salt water will possibility mitigate upstream for a further kilometre. However, the effects of this migration will be restricted to subtle changes in river berm vegetation with changes in salt concentrations. Since the stopbanks are some distance back from the river fairway, it is not anticipated that there will be any effect on stopbank stability from increased salinity.

13.3 Brooklands Lagoon and Styx River

13.3.1 Sedimentation

There is some debate about the past sedimentation rates in Brooklands Lagoon. Kirk (1979) estimated 30% of the rivers suspended sediment load was trapped in the lagoon, which equates to 390,000 m^3/yr . However, Hicks & Duncan (1992), who computed deposition rates from cross-sections, found that the average deposition rate was 38,000 m^3/yr, with the majority occurring between 1940 and 1969 in association with a change in the river mouth location. Hicks & Duncan concluded that the lagoon had changed little since 1969, and hence it acted only as a temporary trap.

Although it is considered that Waimakariri suspended sediment supply will increase with climate change (see Section 13.2.1), based on the findings of

Hicks & Duncan, it is considered unlikely that the net sedimentation rate in Brooklands Lagoon will increase significantly. However, there could be a change in sedimentation patterns with enhanced channel formation to drain the additional water.

13.3.2 Water Level Changes

The current wide and shallow mouth of Brooklands Lagoon has a cross-sectional area approximately 20% of that of the Waimakariri mouth. Correspondingly, Tony Boyle, hazards analyst for the CRC (1999 pers com) estimates that 20% of the flood tide volume entering the Waimakariri mouth goes into Brooklands Lagoon. With SLR there are three scenarios for how these relationships may change, which will affect water levels in the lagoon. Assuming SLR from IPCC 1995 of 0.2 m by 2050, and 0.5 m by 2100, these scenarios are:

1. The relationship will remain the same, hence, over the current lagoon area ($2.05x10^6$ m^2), the mean rise in lagoon water level will be 0.09-0.13 m by 2050, and 0.21-0.3 m by 2100. This scenario implies that the current tidal dampening in the lagoon will progressively increase.
2. That water level changes in the lagoon will mirror those on the open coast, with the resulting rise being 0.2 m by 2050, and 0.5 m by 2100. This is a reasonable assumption given that the mouth of the lagoon is close to the open coast, and mouth widths are sufficient to allow the required volume of water to enter the lagoon during the flood tide. Under this scenario, 30-45% of the increase in the tidal compartment of the Waimakariri due to SLR will flow into Brooklands Lagoon. However, the percentage increase of the total tidal compartment of the river entering the lagoon is very small.
3. Due to the wide shallow shape of the lagoon mouth, the cross-section area of the lagoon will be increased by 40% due to SLR by 2050, and by 100% by 2100. The corresponding water level

increases over the current area of the lagoon would be 0.35-0.5 m by 2050 and 0.87-1.24 m by 2100.

Due to the different ratio of width to depth of the two mouths it is considered that they will respond differently to SLR, hence the relationship between them is considered likely to change and hence scenario 1 can be rejected. While it is considered possible that the magnitude of SLR may be attenuated in the lagoon due to the wide mouth opening in relation to the depth, it can not be to the extremes given in scenario 3 as this would result in water levels in the lagoon being greater than at the coast. Hence, it is considered that scenario 2, is the most likely. A small attenuation equivalent to the current dampening of approximately 100 mm in high tide levels could be expected at the mouth of the lagoon, but due to estuary effects, this is not expected to extend over the whole of the lagoon.

Water level changes in the Styx River should be limited to downstream of the existing tide gates at the Harbour Road Bridge. However, the higher lagoon levels will inhibit land drainage from the low-lying areas within the lower Styx catchment, particularly the area between the river and Brooklands Lagoon. In the long term, the higher water table may have some adverse effects on the stability of river stopbanks, and Lower Styx Road.

13.3.3 Erosion and Inundation

At high tides, due to the low-lying nature of the undeveloped surrounding land, the area of the lagoon will be enlarged with resulting erosion and vegetation changes at the current lagoon margins. On unconsolidated sand dunes, recession distances have been conservatively estimated by the Bruun Rule at approximately 2.5 m by the year 2050, and 6.5 m by the year 2100. This recession will have the greatest potential impact at Brooklands township, where it is likely to erode the narrow band of sand dunes that provide a degree of protection for the township from inundation in extreme tide events in the lagoon.

For Brooklands Township, there is also increased risk of inundation associated with the greater frequency of extreme lagoon levels. For example, the estimated rise in lagoon levels by 2050 would reduce the probability of a 1:500 year event to that of a 1:50 year event, and by 2100 monthly perigean tides would be approximately the level of a current 1:50 year event. The current minimum lot level for new developments applied by CCC in this area of 10.85 (CDB datum) will approximately be the mean level of the monthly perigean high tide within 100 years. The current minimum floor level in this area of 11.25 (CDB datum) will be approximately equivalent to the 1:100 year tide level within 50 years, and within 100 years will be approximately 0.25 m below the 1:50 year return period tide level. There are estimated to be approximately 50 houses within the township which pre-date these building level controls, and have floor levels below 11.00 (CDB datum). These properties are protected by the narrow band of sand dunes along the lagoon margins that have a minimum elevation of approximately 11.05 (CDB datum). Even without erosion of these dunes as referred to above, their protection capacity will be reduced to less than a 1:50 year return period event by 2050, and only a little above monthly perigean high tide within 100 years.

The Styx tidal gate has an elevation of 11.20 (CDB datum), therefore will still be an effective barrier against 1% AEP tidal events in the next 50 years, but will be under greater risk of being overtopped in the latter half of the 21st century. The stopbanks downstream of the tidal gates have elevations of approximately 12.00 (CDB datum), hence are likely to continue to provide protection in even extreme events (0.2% AEP) over the next century.

By reworking the indicative inundation maps in Wilkinson & Smith (1995), it is calculated that the area of land around Brooklands Lagoon with elevations below the estimated water levels in a current 1:100 year return period (1% AEP) tide event with 0.1 m allowance for wind set-up is approximately 900 hectares. With a 0.5 m SLR by 2100, the area of land below the corresponding 1% AEP water level is increased by approximately 420 hectares, to a total area of 1,320 hectares potentially at risk from inundation in this magnitude event. This assumes a worst case scenario of failure of the Styx tidal gate, and removal of the sand dunes protecting Brooklands township. The areas included in these inundation risk areas are shown in Figure 3 (Section 19).

Watts (1992) estimated that the value of the additional assets in the above areas which would potentially be at risk from a 0.5 m rise in water level was approximately $3.35 million for public assets and $28.8 million for private assets. This is equivalent to a 220% increase in the value of assets presently at risk from the same return period event.

13.3.4 Salinity changes

It is considered that salinity levels in Brooklands Lagoon are unlikely to change, and it is assumed that salinity in the Styx River will continue to be controlled by the existing tide gates at the Harbour Road Bridge.

13.3.5 Ecological Effects

Water level increases will occur at all phases of the tide. Hence at low tide, existing tidal mud flats will be permanently drowned resulting in a change in some bird feeding and invertebrate habitats. These environments will be re-established on existing salt marsh areas, which will be displaced to higher elevations where possible, particularly at the upper reaches of the lagoon which are undeveloped. Salt rush environments will similarly migrate to higher undeveloped elevations at the expense of pasture and salt meadow vegetation. As long as there is the ability of these ecological migrations to occur, and they are not compromised by human constraints, fish and bird species should not be adversely affected, as their habitats will also migrate. However, further residential development or action to protect current pastoral areas around the margins of the lagoon, would significantly reduce the ability for ecological migration with progressive water level increases, resulting in the loss of vegetation, fish, invertebrates, and bird habitats.

14.0 Assessment of Impacts on Christchurch Dunes

New Brighton Foreshore looking South

14.1 Past Assessments

Hicks (1993) undertook a model study of the long-term effects of SLR and climate change on the shoreline position of Pegasus Bay. The model used was a '1-line" shoreline evolution model (GENESIS), which required input data on deep-water wave climate (synthetic record used), wave refraction, sea level changes, sediment supplies, and beach profiles. The model was calibrated against historical shoreline changes in the 100 years from 1880 to 1980 with results being the best in the centre of the bay and least reliable at either end. The model was then run to predict future shoreline positions in 2030 (50 years from 1980) for five scenarios. The results of the model runs were as follows:

- Status quo sand supply wave climate and SLR (1.8 mm/year): General shoreline advance of 40 m (0.8 m/year).

- 50% reduction in sand supply from rivers: Significant erosion around the mouth of the Waimakariri River and smaller erosion at the mouth of the
- Ashley river. Retreat extends 8 km from Woodend to Spencerville, with maximum retreat up to 80 m at the Waimakariri mouth. Running the model for a 100 year period showed that erosion would not occur much further alongshore but the erosion would intensify.
- Beach profile adjustment from SLR of 0.25 m (5 mm/yr.): Produced a profile retreat rate of 0.6 m/year (30 m in 50 years) which would partially offset the "status quo" shoreline advance.
- Adjustment in wave refraction associated with SLR of 0.5 m: This scenario was used as the effect of 0.25m SLR on wave refraction was not distinguishable. The changes from status quo were relatively minor, the most significant being a reduction in the rate of shoreline advance between Leithfield and Woodend.
- 50% reduction in the incidence of southerly waves associated with a reduction in westerly winds: Shoreline becomes pivoted around to north-east resulting in accretion south of Spencerville, diminishing to the north with erosion at Amberley.

A cumulative worst case scenario from combining all the effects produces shoreline erosion retreat (relative to its current position) from Amberley to the Waimakariri at rates of 0.6 –1.4 m/year, and continued shoreline advance south of Spencerville. These results suggest there is little reason for concern along the Christchurch dunes.

However, of the scenarios used by Hicks, more recent climate projections indicate that a 50% reduction in river sediment supply and southerly waves is unlikely, hence these scenarios may not now be relevant. Also, the effect of possibly more frequent coastal storm events and storm surge conditions have not been taken into account.

14.2 Sediment Supply

As established by several authors and summarised in Hicks (1998), the supply of sand material to the southern Pegasus Bay (e.g. Christchurch dunes) is almost
exclusively from the suspended sediment load of the Waimakariri River. As established in Section 13.2.1 coarse bedload transport of gravels in the Waimakariri River will continue to terminate upstream from the river mouth, and will not contribute any material to the coastal sediment budget of Pegasus Bay. Hence, sediment supply to the coast of Southern Pegasus Bay will most likely continue to be sand.
Hicks (1998) estimated that approximately 20% of the suspended load of the Waimakariri River is of the same sand size as found on the Christchurch beaches (> 0.125 mm). Hicks estimated the net supply of this sized material to be approximately 360,000 m^3/year of which 50% is estimated to be transported south to the Christchurch beaches, the remainder being transported to northern Pegasus Bay beaches. Finer sands and silts are predominantly transported offshore and are not significantly represented in the beach sediments.

The above sand volume calculated to be transporting south to feed the Christchurch beaches (180,000 m^3/yr) is consistent with the 176,000 m^3/yr calculated by Hicks (1998) to have accumulated on these beaches in the last 100 years. This deposition calculation is based on a spatially averaged progradation rate of 0.55m/yr (from Worthington 1991) over the 16 km length of beach, and an average beach profile height of 20 m from the top of the dune field to the nearshore closure depth for sediment transport. As noted by Hicks, the confirmation that this historical rate of sediment accretion is still occurring is significant, as it suggests that there would need to be a significant reduction in river sand supply input (as a result of climate change or other reasons) to result in a sand deficit leading to the shoreline switching to an erosional state.

Section 13.2.1 established that the current climate change scenarios indicate that the increased frequency of high intensity rainfall events will increase upper catchment erosion and that the resulting more frequent high river flows will increase sediment transport including the regular flushing of sand and silt material out of the river mouth. Hence it is concluded that a long term reduction in the sand supply to the coastal sediment budget is extremely unlikely. In fact there is the possibility that the sediment supply rate could increase with climate change. However, it is considered that the best conservative estimate is a continuation of the status quo rate of supply. Hence, shoreline retreat from sediment starvation is also considered to be extremely unlikely. It should also be noted that if, as a worst case scenario, there are reductions in supply rate, the findings of Hicks (1993) suggests that the resulting erosion areas will be localised at the river mouth, with little effect on historical accretion rates south of Spencerville.

14.3 Wave Effects

More recent scenarios (Whetton, Mullon & Pittock, 1996), have superseded those of Salinger & Hicks (1990) which suggests a reduction in the incidence of southerly wave approach directions due to a decrease in the strength of westerly winds. The more recent scenarios, which project that the dominance of westerly weather will actually increase. Therefore, the frequency of southerly swell events which result from the westerly winds driving depressions across the southern Pacific Ocean below the South Island is more likely to increase rather than decrease. As a consequence of this, the current net southerly sediment transport in southern Pegasus Bay as a result of northerly winds is likely to be reduced (but not reversed). Hence the percentage of Waimakariri River sediment being transported south to the Christchurch beaches would also be likely to be reduced. However, the total volume being transported south may not be significantly reduced, due to potential for the increased total river contribution.

Hicks (1993) also considered the effect of SLR on wave refraction. His findings were that for a rise of 0.25 m, the effects were not distinguishable, and that for a rise of 0.5 m, there are only slight changes in the refraction of southerly swell events with less re-orientation of the swell crests due to an increase in water depth. As a consequence of this re-orientation, northerly longshore sediment transport would be increased and a corresponding reduction in southerly transport. For the Christchurch dunes this could result in a small reduction in the transport south of material from the Waimakariri River, but again this could be compensated for by the potential increased total river contribution, resulting in no net effect on shoreline position.

14.4 Effect of Sea Level Rise on Beach Profiles

From the above assessments, we can now use the Bruun rule to calculate the horizontal shift in the equilibrium beach profile associated with SLR, confident in the knowledge that there are unlikely to be other significant factors that could influence the resulting profile shift.

For this assessment the key indicator of effect of SLR on beach profiles was considered to be dune recession. This was calculated using the following three different formulas, all of which are based on the Bruun rule:

- Deans 1976
- Kriebel, Kraus, & Larsen 1991
- Kraus 1993

The resulting dune recession was calculated for SLR of 0.2 m, 0.5 m, & 1 m, which correspond to IPCC 1995 projections for “best-estimate” SLR in 2050 & 2100, and “worst case” for 2100 respectively. The formulae were also run for two mean wave heights (used to calculate water depth at breaking) of 1 m and 2 m. A range of dune recession distances were obtained for each value of SLR depending on the formula and wave height applied. The full range of these results is displayed in Table 4.

Table 4: Effect of Long-Term Sea Level Rise on Beach Profiles

		Dune Recession Distances for SLR of:		
Site	**CRC site code**	**0.2 m**	**0.5 m**	**1.0m**
Spencer Park	(c1755)	0-4.4 m	0.1-11.2 m	0.15-23.0 m

Bottle Lake	(c1400)	0-2.9 m	0.1-7.4 m	0.1-15.0 m
Effingham Street	(c1065)	0-4.3 m	0.1-11.0 m	0.2-22.8 m
Rawiti Road	(c0952)	0-3.1 m	0.1-7.8 m	0.1-16.0 m
Rodney Street	(c0815)	0-3.0 m	0.1-7.6 m	0.1-15.6 m
Jellicoe Street	(c0600)	0-3.0 m	0.1-7.5 m	0.1-15.4 m
Heron Street	(c0471)	0-3.5 m	0.1-9.0 m	0.1-18.5 m
Dune Contour Profile to 8m height		0-3.2 m	0.1-8.0 m	0.1-16.5 m

As can be seen from the above Table, using IPCC "best estimate" projections (scenario 92 IS92a) dune recession associated with long-term adjustment in
beach profile is generally predicted not to exceed 5 m by 2050, and not to exceed 10 m by 2100. The rates of retreat associated with this recession are in the order of 0.1 m/yr. This is a considerably lower recession rate for equilibrium profile adjustment than the 0.6 m/yr. for a 0.25 m SLR calculated by Hicks (1993).

Since the formulae are for equilibrium beach profiles, and it is known that the southern Pegasus Bay shoreline is still advancing (even with historical linear SLR rise in the last 100 years), this recession needs to be offset against the status quo advance. Hence the net effect of sea level rise is likely to be a reduction in the long-term rate of advance by 0.1 m/yr. Based on the rate of shoreline advance from Worthington (1991) over the last 100 years, this implies that the resulting advance rates will be in the order of 0.15 m/yr. at South Brighton, 0.3 m/yr. at New Brighton, 0.5 m/yr. at North Brighton, and 0.7 m/yr. at Spencerville.

It should also be considered that equilibrium beach profile adjustments involve the whole beach profile, hence they involved a landward horizontal shift of the whole foredune. At South Brighton, where there is generally sufficient width within the dune field to accommodate this, it should not present problem. However, at North and New Brighton, where beach widths are already restricted to just the foredune by Marine Parade, any degree of landward migration can only be accommodated by burial of the road, or by loss of dune volume, as this material is artificially removed.

14.5 Storm Effects Associated with Sea Level Rise

There are two components to climate change induced storm effects on sand beaches, one being the influence of increased water depth with SLR on dune erosion during storm events, and the second being changes in the frequency and intensity of the storm events.

14.5.1 Influence of Sea Level Rise on Dune Erosion during Storm Events

This was assessed by using the same SBEACH dune development model as used in the 1998 Christchurch Dune Study (Tonkin & Taylor 1998) for the 100 year return period storm waves and storm surge. The assessment assumes that sediment supply has been able to match long-term equilibrium beach profile retreat, therefore the foredune is in the same position as it is at the present. Hence, the full component of SLR will be felt as additional water depth during extreme storm events. To simulate SLR, 0.2 m and 0.5 m (as per IPCC "best estimate" projections for 2050 & 2100 respectively) were added to the sea levels in the model runs. The resulting dune erosion was then compared to the storm event erosion from the earlier study to get an estimate of the impact of SLR. From the model calibration in the earlier dune study, the results are considered to have a ∀30% error band. The results presented in the following Table show the increase in dune erosion on the upper foredune face (5 m contour) and the seaward dune toe (3 m contour) which would occur during a 100 year storm as a result of SLR. The comparison of modelled profile plots for this magnitude storm event at current water levels and with SLR of 0.5 m is displayed in Appendix E.

Table 5: Effect of Sea Level Rise on Increasing Dune Erosion Due to 100 Year Storm Events on Christchurch Beaches

	Increases in dune Erosion with SLR of :			
	0.2 m (IPCC 2050)		0.5 m (IPCC 2100)	
	5m contour	3m contour	5m contour	3m contour
Sites: North Beach				
Spencer Park (C1754)	0	2.1	0.1	1.9
Bottle Lake (C1400)	1.6	3.1	2	4
Effingham Street (C1065)	2.2	0	6.1	0.2
Design Profile (8m Height)	2	2	5.1	0.5
Sites: New Brighton				
Rawiti Road (C0952)	0.4	1.1	2.8	4.4
Rodney Street (C0815)	0.2	3.6	3.4	5.3

Design Profile	(8m Height)	0.4	1.4	3.5	0.4
Sites: South Brighton					
Beatty Street	(C0650)	0	4.3	0	6.3
Jellicoe Road	(C0600)	0	6.7	0.1	8.3
Heron Street	(C0471)	0.1	3.6	0.4	2.8
Design Profile	(8m Height)	1.4	1.8	4.4	2

As can be seen from Table 5, the impact of SLR on dune erosion during storms is dependent on the site conditions of dune slope and height. The results show that dune erosion during extreme storm events would be greater with SLR.

In the next 50 years, the greatest impact would predominately be felt at the dune toe, where erosion distances could be increased by up to 7 m. Increases in upper foreshore retreat due to SLR would be less, being modelled at approximately 2m. This would result in considerably steeper and consequently unstable foredune slopes than would occur during the same magnitude storm under current sea level conditions. However, within a 100 year time frame, more significant increases in erosion would occur on the upper foreshore face, with the most significant impact at New Brighton & North Beach, where increased erosion could be in the order of 2-6 m except at Spencer Park. Under this scenario, maximum dune face erosion would occur at lower, flatter dunes such as Effingham Street and the dune re-contour sites.

Total storm retreat of the 5 m contour would be in the order of 8-9 m, involving 15-20% losses of the dune width and volume at North Brighton.

While these erosion figures may be over-estimates due to the influence of equilibrium profile adjustments on nearshore water not being taken into account in the model runs, they never the less provide a good conservative indication of the additional storm demands which may be associated with SLR.

14.5.2 Changes In The Frequency And Intensity Of The Storm Events.

The most recent climate change scenarios for New Zealand suggest that the frequency of low-pressure troughs and depressions passing over NZ might increase slightly. This, coupled with the likely (but un-proved) more southerly track of tropical cyclones, could result in a higher frequency of coastal storms from both the southeast and northeast directions. There could also be an associated increase in the intensity of the storm events due to increased wind strengths and pressure gradients resulting in larger waves and larger storm surge in water levels.

Unfortunately, it is not possible at this stage to quantify these changes, and hence the impacts on shoreline stability. However, it can be assumed that the likely changes will all result in greater losses from the beach to nearshore bars than at present, and that dune recovery is less likely to be complete before the next damaging storm arrives. As a result, the status quo advance rates may be further reduced.

14.6 Beach Water Tables

The elevation of the water table within a beach profile has an influence on erosion. Higher water tables result in a super-saturated foreshore to a higher elevation, reducing swash percolation losses, increasing run-up and backwash velocities, therefore increasing both run-up elevations and sediment losses to the nearshore from backwash.

As a consequence of SLR, it is assumed that coastal water tables will be higher, hence increasing the potential for beach erosion. These effects can not be quantified at this time, but it can be assumed that they only become important in storm events, when they are likely to increase foreshore erosion, hence indirectly resulting in increased dune erosion above the modelled results given in the previous section.

14.7 Wind Effects

The current scenario of increased westerly winds suggest that there will be a corresponding reduction in the frequency of easterly wind events. It is these winds that are responsible for the development of the extreme dune system along the Christchurch coast by transporting dry sand from the upper foreshore to the dune environment where it is trapped by salt binder vegetation (predominately Marram Grass). Hence a reduction in the frequency of these winds should result in a reduction in the rate of dune growth, and the development of larger foreshore berms.

14.8 Combined Net Impact

From the above discussion the following points can be concluded:

- Waimakariri River sediment supply will continue to be sand. While it is possible that the supply rate could increase rather than decrease, due to more frequent, higher rainfall events, the status quo supply rate is considered to be a conservative estimate of future supply.
- Net southerly sediment transport from the Waimakariri River is more likely to be slightly reduced due to more frequent southerly wave events, and less wave refraction from this approach direction.
- The effects of SLR on equilibrium beach profile position were calculated to be in 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 that the status quo shoreline advance, 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 in the order 8-9 m for sites with low flat dunes. At north Brighton it will result in 15-20 % volume and width losses from the 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 beach water tables will further increase storm erosion losses.

- A decrease in the frequency of easterly winds will decrease dune growth rates from aeolian processes.

It is concluded from these points that the combined net impact will most likely be a reduced rate of shoreline advance and dune growth than in the past 100 years. Storm events will be more damaging to the dune system, but whether the effects of this are sufficient to tip the long-term advancement and dune growth into erosion will depend on the magnitude of changes in the frequency and intensity of these damaging events.

15.0 Assessment of Possible Impacts on the Avon Heathcote Estuary

Avon - Heathcote Estuary with the Sewerage Oxidation Ponds in the background

15.1 Past Assessments

The reports of The Heathcote River Task Force Tidal Control Study Team (1991b) noted that high tide levels in the estuary were typically 100 mm below Lyttelton Harbour levels, but that with future SLR the difference would reduce. The reasons for this reduction are not given.

Oliver & Kirk (1992) present calculations of possible changes in the Estuary tidal compartment associated with various estimates of SLR. The following Table summarises their results.

Table 6: Effect of SLR on Estuary Tidal Compartment

Period	Sea Level Rise	Increase in Tidal Compartment	% Increase
1854-1977	0.21 m (Hannah, 1989)	4.12 million m^3	61% of which 42.5% due to SLR
1977-2050	0.4 m (IPCC 1990)	3.2 million m^3	29 % from 1977
1977-2100	0.65 (IPCC 1995)	5.2 million m^3	47.6 % from 1977

Oliver & Kirk note these projections have substantial implications for sedimentation, erosion, and water levels in the estuary, but also note that they are difficult to evaluate further.

Hicks (1993), estimated from detailed cross-section surveys since 1962 that changes in the average bed level of the Estuary have been very small, with a net deflation (erosion) of 2-3 mm/year from 1962 to 1975, and net deposition of 1 mm/year since 1975. Hicks does not speculate the role of continued SLR in these sedimentation trends.

Wilkinson & Smith (1995) use IPCC 1990 SLR projections of 0.3 m by 2050 and 0.65 m by 2100 in association with 95% and 5% percentile spring tide levels in the Estuary to map likely inundation areas. The corresponding Estuary water levels were 10.77 & 11.07 (CDB datum) for 2050, and 10.95 & 11.70 for 2100. The predicted inundation areas are similar for both magnitudes of rise, being:

- an extensive area in Lower Linwood bounded by Ferry Road, Dyers Road and the Oxidation Ponds
- smaller areas around McCormacks Bay, Redcliffs and along South Brighton Spit.

Additional potential inundation areas are mapped on the lower Heathcote and Avon Rivers. The report notes that outfalls around the Estuary that are either gravity or pumped will require re-designing to prevent sea water intrusion.

From interviews undertaken with CCC staff as part of this study, John Walter suggested that the estuary does not appear to be draining as much now as in the past. He was not sure whether this is due to SLR or a change in the mouth shoal bars. Andrew Crossland estimated from aerial photographs that there had been up to 70% dieback on a specific saltmarsh at Sandy Point in the western Estuary, which could have been as a result of SLR. He also suggested that the continued loss of saltmarsh environments in the Estuary would not have a great effect on the birdlife, as the majority of the swamp birds have already gone from the Estuary.

15.2 Tidal Compartment

15.2.1 Current Tidal Compartment

Recent investigations (February 1999) for the Christchurch wastewater outfall indicated that the current cross-sectional area (mid tide) of the Estuary mouth is 625 m^2 with a channel width of 135 m. Using a mean discharge velocity of 0.8 m/s, based on previous direct measurements of the tidal compartment and cross-sectional area, gives a current tidal compartment of $11.25x10^6$ m^3. This estimate is $0.33x10^6$ m^3 larger that the previous direct tidal compartment measurement in 1975/77 (Findlay & Kirk, 1988), of which only 45% of the increase could be attributed to SLR at the historical rate of 2 mm/yr. The remainder of the increase in the tidal compartment must therefore due to increases mouth cross-sectional area from channel scour.

It is notable that the above percentage increase in the tidal compartment which can be directly contributed to a rise in sea level is constant with those estimated by Oliver & Kirk (1992) for the period 1854-1977. While there are many other factors that influence the mouth channel dimensions, the above result suggests that there could also be a relatively constant ratio of increase in mouth channel width with increases in sea level. This needs to be taken into account when calculating the size of future tidal compartments.

15.2.2 Future Increases in the Tidal Compartment

The above ratio of change in tidal compartment to magnitude of SLR has been used to estimate the size of the tidal compartment in 2050 and 2100.

- With a SLR of 0.2 m by 2050:
  The increase in mouth cross-sectional area from the greater water depth would be approximately 27 m^2 . Assuming this is 45% of the total change in the cross-sectional area and a mean velocity of 0.8 m/s, the

total increase in the tidal compartment is estimated to be the order of be 1.08×10^6 m^3.

- With a SLR of 0.5 m by 2100:
  The increase in mouth cross-sectional area from the greater water depth would be approximately 67.5 m^2 . Assuming this is 45% of the total change in the cross-sectional area and a mean velocity of 0.8 m/s, the total increase in the tidal compartment is estimated to be the order of be 2.7×10^6 m^3.

Both of these estimates are considerably less that those presented in Table 6 from Oliver & Kirk (1992) for the same time periods.

It should be emphasised that the tidal compartment will also respond to other processes (e.g. sedimentation, and run-off), hence the changes in volume given above are only the component which relates to SLR.

15.3 Mouth Dynamics

The existing estuary mouth and deltas are relatively dynamic but assumed to be generally stable.

The previous section indicates that there will be increases to the mouth channel width to accommodate increases in the tidal compartment. Based on the ratio that 55% of the increase in estuary mouth cross-section area could be due increases in channel width, it is estimated that 7-10 m of channel bank erosion is likely to occur by 2050 and 18-25 m by 2100. It is considered that this erosion will occur on the less confined Brighton Spit side of the channel. Although the movements involved will not directly threaten housing on the South Brighton Spit, it must be remembered that, as described by Findlay & Kirk (1988), "*the estuary mouth is a complex process-response environment involving several influences on the morphology and location of the mouth channels that could result in a similar range of changes that have occurred in the past.*" Hence existing land-use controls will still be relevant in the future.

SLR will also affect tidal bypassing and the size of the ebb and flood tide deltas. As noted in Section 5.1.2, one of the common responses of estuaries to SLR is increased sedimentation on the ebb and flood tide deltas due to increased dominance *of tidal bypassing* over *bar bypassing*. Findlay & Kirk (1988) describe tidal bypassing as sand being carried into the estuary by the flood tide (where some may be deposited), then jetted back out on the ebb to be re-distributed onto adjacent beaches or the ebb tide delta. It is suggested by Findlay & Kirk that based on the ratio of the tidal compartment to littoral drift, the Avon-Heathcote Estuary changed from a predominantly bar-bypassing regime to a mixed tidal and bar bypassing regime during the 1930's. This change has strongly influenced the development of the extensive flood tide delta and subsequent northward constriction on the Moncks Bay channel over the last 50 years.

The influence of SLR further increasing the volume of the tidal compartment should further increase the dominance of tidal bypassing, which will result in further sedimentation on the tidal deltas. This in-turn could result in either increased channelisation at Moncks Bay, or a possible choking of the channels. The location of the ebb tide delta will influence the position of the estuary discharge channel to sea and beach accretion/erosion cycles on Brighton Spit and Clifton beaches. It is not possible to quantify these changes at this time.

15.4 Estuary Sedimentation

As well as increased sedimentation on the tidal deltas, another estuary response to SLR is an increased role as a sediment sink for river material. This assumes that the Avon & Heathcote Rivers supply a source of material to the Estuary. Hicks (1993) noted that historical dredging in both the Avon and Heathcote rivers had more than contained deposition for much of the century and that recent sedimentation rates in the estuary were very low. From analysis of detailed cross-section surveys of the Estuary since 1962, Hicks, concluded that there had been net overall erosion of 2-3 mm/yr. up to 1975, and net deposition of 1 mm/yr. from 1975 to 1988.

Under the climate change scenario of increased frequency of high intensity rainfall events, it is considered likely that there will be increased sediment loading in both rivers, particularly in the Heathcote due to erosion of rural hill sub-catchments. However, it is not part of this study to quantify these increased sediment loadings or to determine what will happen with deposition or dredging in the river channels. As a conservative estimate it is assumed that Hicks,(1993) net deposition rate of 1 mm/yr. will continue under SLR scenarios. Under this assumption the mean bed cover of the estuary will rise approximately 0.05 m by 2050, and 0.1 m by 2100.

15.5 Estuary Water Levels

There are two approaches to estimating water levels inside the estuary. The first is the conservative approach of assuming that the estuary water levels will respond at the same magnitude as SLR at the open coast. Hence predicted changes are 0.2 m rise by 2050 and 0.5 m rise by 2100.

The second approach involves taking account of the changes in the tidal compartment and sedimentation within the estuary. In this approach the following equation is used to estimate water level increases in the estuary:

$$\frac{\text{Increase in tidal compartment (from Section 15.2.2)}}{\text{Area of the estuary } (6.80 \times 10^6\ m^2)} + \text{sedimentation rate (from Section 15.4)}$$

The resulting estuary water levels are:

- For a 0.2 m SLR by 2050

  $$\frac{(1.08 \times 10^6\ m^3)}{(6.80 \times 10^6\ m^2)} + 0.05 = 0.21\ m$$

- For a 0.5 m SLR by 2100

  $$\frac{(2.70 \times 10^6\ m^3)}{(6.80 \times 10^6\ m^2)} + 0.10 = 0.5\ m$$

As can be seen, the resulting water levels from this approach are very similar to the first approach. While this indicates that the estimates of the mouth channel erosion and increases in the tidal compartment in the previous section are reasonable approximations, it is considered that the figures used in the second approach are on the conservative side (e.g. none of the increase in tidal compartment going up the rivers). Hence, the results indicate that there is unlikely to be any significant attenuation of water level increases within the estuary. Based on these results, it is considered that the current "best guess estimate" is the conservative first approach of similar water level rises in the estuary as at the open coast, being 0.2 m by 2050 and 0.5 m by 2100.

These results imply that the current dampening of high tide water levels in the estuary of approximately 100 mm will continue in the future.

15.6 Inundation Risks

Inundation risks in the estuary relate to extreme tide and storm surge events rather than high river flows. Current design flood levels (CDB datum) for the estuary including a 0.1 m factor for wind set-up are:

2% AEP (50 year return period):	11.01
1% AEP (100 year return period):	11.08
0.2% AEP (500 year return period):	11.17

(Note: These levels were established in 1994 (McKerchar & Kirk, appendix) from a frequency analysis based on over 30 years of observed extreme estuary water levels and assumes a 1994 mean sea level of 9.15 (CDB datum) based on a 1.8 mm/yr. SLR from the 1937 MSL datum of 9.043).

As with Brooklands Lagoon, there is an increased risk of inundation around the margins of the estuary associated with the greater frequency of these extreme estuary water levels with SLR. For example, the estimated rise in estuary water levels by 2050 would reduce the probability of a 1:500 year event to that of less than a 1:50 year event, and by 2100 monthly perigean tides without any storm surge or wind set-up would be approximately the level of a current 1:50 year event. The resulting new design flood levels adjusted for a 0.2 m & 0.5 m rise in estuary water levels by 2050 & 2100 respectively are:

	2050	2100
2% AEP (50 year return period):	11.21	11.51
1% AEP (100 year return period):	11.28	11.58
0.2% AEP (500 year return period):	11.37	11.67

These changes in water levels imply that the minimum ground levels for building around the estuary of 11.30 (CDB datum) will be exceeded by a 1:100 year water level without any allowance for run-up effects by 2050 and the minimum floor level of 11.45 m will be exceeded by a 1:50 year water level without run-up effects by 2100.

It is noted that the climate change scenarios related to wind and storm frequency could also alter the magnitude of storm surge and wind/wave run-up experienced in the estuary, particular on the northeastern side. These changes can not be quantified at the present time. However, it is considered that the resulting water levels will not be less than currently experienced. It is therefore recommended that the current 0.3 m safety margin wind/wave run-up effects remain in use until more definitive data on these effects is available.

By reworking the indicative inundation maps in Wilkinson & Smith (1995), it is calculated that the area of land around the estuary with elevations below the estimated water levels in a current 1:100 year return period (1% AEP) tide event with 0.1 m allowance for wind set-up is approximately 410 hectares. With a 0.5 m SLR by 2100, the area of land below the corresponding 1% AEP water level is increased by approximately 80 hectares, to a total area of 490 hectares potentially at risk from inundation in this magnitude event. The areas included in these inundation risk areas are shown in Figure 3 (Section 19).

Watts (1992) estimated that the value of the additional assets in the above areas which would potentially be at risk from a 0.5 m rise in water level was approximately $8.73 million for public assets and $200 million for private assets. This is equivalent to a 750% increase in the value of assets presently at risk from the same return period event.

15.7 Estuary Bank Erosion

As well as possible inundation hazards, increased water depths will result in Estuary bank erosion, particularly on the northeastern side due to storm surge and wind/wave run-up effects. Using the same formulas as in Section 14.4, with a mean Estuary wave height of between 0.25 and 0.5 m, bank erosion along the estuary side of South Brighton spit was estimated to range between the following limits:

- Recession of 0.1- 3.6 m for 0.2 m rise in estuary water level
- Recession of 0.2- 9.6 m for 0.5 m rise in estuary water level

At the upper level of this range there will be failure of existing protection walls and erosion of private property. It is not known whether any dwellings are located this close to the estuary.

15.8 Estuary Vegetation and Ecological Effects

The above Section on water level suggests that increases in water depths from SLR will outpace sedimentation on the tidal mudflats by approximately 3mm/yr. As a result, there will be a progressive loss of these types of environments from the estuary, unless there is the ability for horizontal migration. However, this ability is restricted by the existing "hard edge" to the majority of the Estuary and by adjacent land-use developments.

The first plant species to be "squeezed out" will be eelgrasses which live between the low tide and mid-tide zones, followed by sea rushes (mid tide to high tide) and marsh ribbon woods (above HWL). Fish species will tend to move with the transition in salinity. However, eventually some species such as flounder, eels and inanga will lose their feeding grounds as water depths progressively increase. Wading birds will also be affected by a loss of habitat.

In the limited areas where there is the ability for ecological migration, there will be a progressive die off of non salt tolerant species with the rise in water levels and succession to more salt tolerant species with the same vertical zonation as is currently present. However, the net ecological impact is considered to be a loss of bio-diversity and natural character of the estuary edge.

16.0 Assessment Of The Effects On The Lower Heathcote And Avon Rivers

Mouth of the Heathcote River

16.1 Past Assessments:

As with the estuary, Wilkinson & Smith (1995) use IPCC 1990 SLR projections of 0.3 m by 2050 and 0.65 m by 2100 in association with 95% and 5% percentile spring tide levels to map likely inundation areas in the lower Avon and Heathcote Rivers. The predicted inundation areas are similar for both magnitudes of rise. For the lower Avon, potential inundation areas included:

- Bexley to the west of Bexley Road and south of Pages Road
- Travis Swamp almost to Beach Road
- Horseshoe Lake bounded by Horseshoe Lake and Terrace Lake Roads
- Avondale between the river and the golf course
- Dallington between the river and Gayhurst Road
- Wainoni between the river and Wainoni Road.

The CCC mapped similar areas in 1995 as being at risk from inundation in a

0.2% AEP flood event with a 0.1 m SLR.

For the lower Heathcote, potential inundation areas included;

- Lower Linwood from Ferry Road to Linwood Ave.
- Ferrymead from Ferry Road to the railway, on the east of Tunnel Road
- Woolston from Ferry Road to the Woolston Loop.

A similar area is shown on CCC plans for extreme flood areas on the Heathcote Floodplain with a 0.1 m SLR.

The reports of The Heathcote River Task Force Tidal Control Study Team (1990 &1991), while not mentioning SLR specifically, provide a clear indication of the types and possible magnitude of effects of future SLR based on observations of effects of the construction of the Woolston Cut in 1986. These effects included a greater tidal range in the river and an upstream migration of the salt water influence by approximately 2 km upstream. This resulted in bank erosion and collapse due to exposure to salt water intrusion damaging the soil structure, die back of vegetation on the banks, and the upstream migration of mud crabs tunnelling into the banks.

Crossland (1998) noted that saltmarsh die-back at the Heathcote Loop, Devils Elbow, and Stilts Island started in 1946 and continues to the present. Meurk & Crossland (1998) note there has been searush and toetoe die-back on the Ferrymead saltmarsh and a slight colonisation of higher ground that could be as a result of SLR.

16.2 Water Levels and Inundation

The increased water levels in the both the Heathcote and Avon Rivers as a result of SLR will be dependent on the increased water levels in the estuary. From the discussion in Section 15.5, these water levels are conservatively estimated to be 0.20 m higher than present in 2050, and 0.5 m higher in 2100 at both Ferrymead Bridge (Heathcote River) and Bridge Street (Avon River).

16.2.1 Heathcote River

The lower Heathcote River has been considerably modified, firstly by the construction of the Woolston Cut in 1986, which resulted in upstream intrusion of salinity, and secondly by the construction of a full tidal barrage in 1993 to prevent further upstream salinity effects. The design of the tidal barrage allowed for a SLR of 0.3 m within its full height of 11.3 m (CDB datum). In this assessment it is assumed that the tidal barrage will continue to operate as present at water levels below this elevation.

Under current normal river flow conditions (approximately 0.8 m^3/s), the tidal influence on water levels is felt for approximately 12 km up stream (Tennyson Ave) of the river mouth. Recent modelling by Tony Oliver (CCC) suggests that in these types of flow condition, the influence of a 0.2m rise at Ferrymead would extend this influence a further 1.5 km upstream, while a 0.5 m rise would extend the tidal effect approximately 2 kms.

Beyond this point (approximately Bowenvale Rd), the gradient of the river becomes considerably steeper, hence effectively limiting the tidal effect for even more extreme projections of SLR.

Extreme tide and storm surge events, rather than river floods, cause flooding in the Lower Heathcote, hence inundation areas can be mapped from the extreme water levels in the estuary. Reworking the indicative inundation maps in Wilkinson & Smith (1995) in the same way as was done for the estuary, indicates that for a 1:100 year return period (1% AEP) tide event the area at risk from a 0.5 m rise in water level in the lower Heathcote River would be approximately 430 hectares. This is 55 hectares more than currently at risk in the same size event. As shown in Figure 3 (Section 19), the majority of this area is to the south of the river towards the railway in Ferrymead.

Watts (1992) estimated that the value of assets in the above areas which would potentially be at risk from a 0.5 m rise in water level was approximately $2.5 million for public assets and $92.3 million for private assets. This is equivalent to a 600% increase in the value of assets presently at risk from the same return period event.

The tidal barrage on the Woolston Cut will still provide protection in a 1:500 year return period event with the projected rise in water levels by 2050. However, by 2100 the level of protection will have dropped to below a 1:100 year return period event.

16.2.2 Avon River

The tidal influence on the Avon extends also extends approximately 12 km upstream to a position around Fitzgerald Ave. For both a 0.2 m and a 0.5 m rise in water level in the estuary, it is expected that this position would migrate upstream through the Avon Loop to approximately Barbadoes Street. Above this the river gradient is steeper, restricting further migration.

As with the Heathcote, extreme tide and storm surge events rather than river floods cause flooding in the Lower Avon, hence inundation areas can be mapped from the extreme water levels in the estuary. Currently land adjacent to the lower Avon River is protected by stopbanks that have an elevation of 11.25 (CDB datum). These banks currently provide protection for events in excess of a 1:500 year return period (0.2% AEP). With the projected future water level increases, these banks will continue to be adequate in a similar return period event until 2050, but by 2100 they will be overtopped in 1:50 year return period events (2% AEP).

Again, reworking the indicative inundation maps in Wilkinson & Smith (1995) in the same way as was done for the estuary indicates that for a 1:100 year return period (1% AEP) tide event the area at risk from a 0.5 m rise in water level in the lower Avon River would be approximately 1000 hectares. As shown in Figure 3 (Section 19), this is approximately 180 hectares more than currently at risk in the same size event, with the addition areas being predominately in New Brighton, Aranui, Richmond and Avonside. In reality, the current area at risk is over stated as it assumes failure of the lower Avon stopbanks, hence the additional area at risk with SLR is likely to be greater than 180 hectares.

Watts (1992) estimated that the value of additional assets in the above areas which would potentially be at risk from a 0.5 m rise in water level was approximately $15 million for public assets and $535 million for private assets. This is equivalent to a 600 % increase in the value of assets presently at risk from the same return period event. More recently, CRC/CCC (1997), estimated the additional costs of damage associated with 1 % AEP water level in the Lower Avon from SLR of 0.1 m and a 0.3 m. Interpolating between these estimates suggests that the additional costs for a 0.2 m SLR in the Lower Avon would be in the order of $7 million. The majority of these costs (95%) were estimated to be direct damage to private houses and contents, and the remaining 5% were from direct damage to infrastructure.

16.3 Salinity Limits

Since the construction of the tidal barrage on the Woolston Cut in 1993, the location of the upstream influence of salinity has returned to its pre –cut position (Mackenize Ave), 8.25 km upstream from the river mouth. However, the changes in water level and salinity boundary that occurred as a result of the Cut can be used to estimate the possible effects of SLR. As stated in Section 16.1, a 2 km shift in the salt water boundary occurred in association with a 60 mm increase in high tide water levels at Catherine Street. Given that there is little change in river gradient until about Ensors Road, it is assumed from the above result that larger increases in water level associated with SLR of 0.2 m would result in a greater upstream migration of the saline boundary. Due to the complex interactions involved, it is not possible to predict the actual location of saline boundary under these scenarios without modelling.

In the Avon River saline water normally penetrates to above Avondale Road (Chch Drainage Board, 1980). If similar migration occurs as in the Heathcote, the boundary for this penetration could extend to beyond Porritt Park.

16.4 River Bank Erosion

The experience of the Woolston Cut showed that river bank erosion was associated with upstream migration of the salinty boundary due to a combination of factors. Hicks (1993) assessed that as a result of this bank collapse, increases in channel widths exceeded 10 m in places within a period of 10 years. A similar result could be expected to occur for further upstream reaches affected by salinity with SLR.

16.5 River Vegetation and Ecological Effects

As with the Estuary, there will be a progressive die-off of salt tolerant plant species at lower elevations as their habitats become flooded, and an progressive upstream migration with an associated die-off of non-salt tolerant species. This migration will be greatest on the Heathcote River where there is considerably more vegetation in the river channel and on the banks. In the Avon River, these effects will be limited to the extreme lower reaches of the rivers adjacent to the estuary due to the presence of stopbanks.

17.0 Assessment Of The Effects On Clifton, Sumner, Taylors Mistake Beaches

Sumner Foreshore looking South from Cave Rock

The impact of climate change and SLR on the beaches of Clifton, Sumner and Taylors Mistake will be due to potential changes in sand supply and littoral drift, and adjustments in equilibrium profile position.

17.1 Clifton Beach

Historically, this beach has undergone considerable fluctuations in position in association with changes in the location of the Estuary outflow channels and ebb tide delta. These fluctuations will continue in the future. However, the net combined effects of more sand being trapped in the estuary tidal deltas, and a less predominant southerly littoral drift is likely to be that less sediment will be available to feed the Clifton-Cave Rock beach cell. Hence, beach sand volumes are likely to be lower than at present when the ebb tide delta is in a northerly position off Brighton Spit.

Using the same formulas as in Section 14.4, for equilibrium beach profile adjustments at the Clifton Surf Club, the resulting dune recession is estimated to be within the following limits:

- Recession of 0.0- 5.3 m for 0.2m SLR (e.g. 2050)

- Recession of 0.1- 13.5 m for 0.5 m SLR (e.g. 2100).

In some locations along this section of beach, profile recession at these magnitudes would result in significant sand losses from in front of the rock work supporting the road to Sumner.

17.2 Sumner Beach

Due to there being only a low tide beach at Sumner, it is not possible to calculate dune recession with SLR. However, increasing water depths with SLR should result in increased scour of sand material from the base of the rock wall along the promenade and the further loss of a 'dry" recreational; beach at low tide.

There appears to be little littoral sand transport into Sumner due to trapping by the Cave Rock, therefore it is considered that changes in sand supply and littoral transport should have little effect.

17.3 Taylors Mistake

Historically, the shoreline at Taylors Mistake has been eroding at an average rate of 0.46 m/yr. since the 1940's (Worthington 1991). Sediment is supplied to this beach by northerly transport of sand material from the Canterbury Bight. The effect of climate change and SLR on this supply is beyond the scope of this study.

Using the same formulas as in Section 14.4, for equilibrium beach profile adjustments at central Taylors Mistake, the resulting dune recession is estimated to be within the following limits:

- Recession of 0.0- 5.4 m for 0.2m SLR (e.g. 2050)
- Recession of 0.1- 13.8 m for 0.5 m SLR (e.g. 2100).

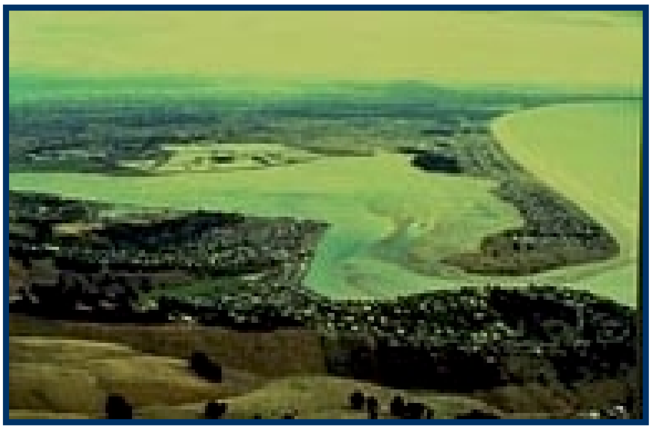
This recession rate should be added to the long-term erosion rate for planning purposes. This recession could create potential erosion problems at the Taylors Mistake Surf Life Saving Building.

18.0 Groundwater

It is commonly stated that SLR will result in contamination of groundwater by salt water intrusion into the surface aquifers. For Christchurch this is most likely to occur closer to Banks Peninsula, as groundwater pressures reduce away from the Waimakariri River, hence the first aquifer in this area is thought to surface onto the seabed only a few kilometres from the coast. Whether the projected SLR with the next 100 years is sufficient to contaminate the first aquifer is currently unknown. However ,to investigate this possibility, the CRC will be drilling a new coastal well at Plover Street on the South Brighton in the coming summer, which will be used to detect changes in salt water concentrations in both in the first and second aquifers.

In the Woolston area, the recent thesis of Hertel (1998) identified salt water intrusion in industrial water bores. However, the source of this intrusion was from over extraction resulting in the groundwater table being drawn down below the saline water level in the estuary and lower Heathcote river, hence the temporary recharge was with saline water. Under SLR, the groundwater pressure will also rise, so it is considered that the risk of this source of intrusion should remain relatively the same if the extraction rates and drawdown are well managed. However, there is increased potential for salt water intrusion from excessive drawdown in areas close to the estuary and the lower Avon and Heathcote Rivers.

19.0 Conclusions and Recommended Responses



Avon-Heathcote Estuary, with the mouth and South Brighton Spit in the foreground.

19.1 Conclusions

The greatest effect of SLR will be the increased risk of inundation around the estuary, the lower Avon & Heathcote Rivers, and Brooklands Lagoon associated with the greater frequency of extreme tidal water levels. For example, the estimated rise in estuary water levels by 2050 would reduce the probability of a 1:500 year event to that of less than a 1:50 year event, and by 2100 monthly perigean tides without any storm surge or wind set-up would be approximately the level of a current 1:50 year event. As a result of these
changes in water levels, the protection ability provided by such structures as the Heathcote and Styx tidal gates and the lower Avon stopbanks will be dramatically reduced after 2050. The existing protection provided by minimum ground and floor levels will also be progressively reduced. For example, around the estuary the minimum ground levels of 11.30 (CDB datum) will be exceeded by a 1:100 year water level without any allowance for run-up effects by 2050, and the minimum floor level of 11.45 m will be exceeded by a 1:50 year water level without run-up effects by 2100.

An alternative way of assessing the effects of SLR is to compare the areas at risk for inundation in similar sized events with and without SLR. The indicative inundation areas for a 1 % AEP (100 year return period) tidal event associated with 0.5 m SLR are shown in Figure 3 along with the current situation. It is estimated that an additional 735 hectares of land within the city could be potentially at risk by this magnitude event by 2100, which is an 30 % increase from the current situation. In monetary terms, the costs of the additional assets at risk are significant, being estimated at approximately $880 million. This represents approximately a 600 % increase from the current value of assets at risk in this size event. While private assets make up 97 % of the value of the addition assets at risk, the total includes approximately $30 million of public assets which the Christchurch City Council are responsible for. A summary of all the major inundation, geomorphogical and ecological effects are summarised in Table 7. Many of these effects will not become noticeable for several years. However, it should not preclude the current effort into scientific investigations and planning responses from continuing.

19.2 Recommended Planning and Protection Responses

Although there are still many uncertainties in the impacts of climate change and SLR on coastal processes, it is still appropriate for the Christchurch City Council to consider planning responses at this time. As stated in Section 5, failure to begin to adapt to SLR now may result in opportunities to avoid adverse impacts being lost.

The possible responses include both planning and protection options. For Christchurch, the recommended approach at this time is a combination of both, which allows for flexibility if projected rates of SLR or impacts change in the future. The recommended responses for each area of the Christchurch coastal environment are summarised in Table 7.

19.2.1 Planning Responses

In line with City Plan Policy 2.5.4: "To avoid higher intensity forms of built development in areas that could be subject to anticipated sea level rise" it is recommended that the Council adopt the following two tier approach to new land-use developments in areas of potential risk.

1. Restrict new land-use developments in areas that within 50 years would be below 2 % AEP tide level with a 0.2 m SLR and a 0.1 m safety factor for wind set-up. This equates to a ground level 11.2 (CDB datum). Restriction below this level is considered appropriate, as extrapolation of existing linear trends in SRL would result in the 2 % AEP level being only 0.1 m below this level in 50 years, and equivalent to it within 100 years. These restrictions may take the form of limiting development to open space and reserves, and prohibiting the placement of fill. The use of fill to raise ground levels in these areas is not considered appropriate, as with continuing SLR, the resulting developments would still require protection from inundation at some stage in the future. The implementation of this planning control would allow the water bodies to naturally expand with SLR into existing undeveloped areas to accommodate ecological migration.

2. Control new land-use developments in areas that within 100 years would be below 1 % AEP tide level with SLR of 0.5 m. This equates to a ground level of 11.5 (CDB datum). Control below this level is considered appropriate as it would allow for low cost or temporary developments while retaining flexibility of either retreat, or more substantial development once some of the uncertainties are clarified. Possible levels of control could involve "future proofing" building by setting minimum floor levels at 11.8 (CDB datum), (e.g. 2% AEP in 100 years plus existing 0.4 m safety), and only consenting relocatable buildings.

For existing development areas, City Plan Policy 2.5.4 can be met by increasing the minimum lot and floor levels to include appropriate levels of SLR. It is recommended that the following minimum levels be:

- Standardise minimum lot levels at 11.20 m (CDB datum) based on 2 % AEP tide level with a 0.2 m SLR within 50 years and a 0.1 m safety factor for wind set-up.
- Standardise minimum floor levels at 11.60 m (CDB datum) based on 1 % AEP tide level with 0.2 m sea level rise (e.g. 2050) and existing 0.4 m

safety for wind set-up and run-up effects. This level would also provide protection against 2 % AEP tide level with SLR of 0.5 m within 100 years and a 0.1 m safety factor for wind set-up.

The use of these minimum levels should restrict the need for protection works in existing development areas to after 2050, when a clearer picture of the total range of potential impacts and their costs should be available.

19.2.2 Protection Responses

There are two types of protection options that need to be considered. The first is the maintenance of existing natural protection systems such as sand dunes, beaches and vegetation. This form of protection is vital at Brooklands Lagoon, North and New Brighton, the estuary side of South Brighton spit, and south of the estuary mouth. It is recommended that ongoing maintenance programmes such as dune restoration, vegetation control and beach renourishment should be enhanced or implemented now in all of these areas before costly or irreversible losses occur.

The second type of protection option is longer term physical engineering works to upgrade existing structures or construct new ones in high risk areas. Existing structures which will require upgrading at some time after 2050 in order to maintain the current level of protection include the Heathcote and Styx tidal gates, the lower Avon Stopbanks, and protection walls around the Estuary. Possible new protection works that will need to be considered in the future include tidal gates on the Avon, and stopbanks on the lower Heathcote.

However, before any of the longer-term protection options are considered, as stated in Section 12.0, it is recommended that the Council undertake a cost-benefit analysis of implementing these options against the alternative options of do nothing and planned retreat. As well as economics, this

Table 7: Summary of Effects, Implications, Possible Responses, and Uncertainties of Sea Level Rise for Christchurch

	Inundation Effects	Morphological Effects	Ecological effects	Implications for Christchurch	Suggested Planning and Protection Measures	Areas & Degree of Uncertainty
Waimakariri River	• None due large river channel capacity and excessive freeboard on stopbanks.	• Increase in size of river mouth	• Some die-off of non salt tolerant plant species in lower river channel	• None	• None	• Tidal compartment and mouth changes (2)
Brooklands Lagoon	• Water level rise 0.2 m by 2050, & 0.5 m by 2100. • Additional 420 hectares at risk from inundation in 1%AEP event by 2100. • Styx Tidal Gate reduced to 1:100 year protection by 2050, and less than 1:50 year protection by 2100..	• Erosion of sand dunes by approximately 2.5 m by 2050 and 6.5 m by 2100	• Retreat of tidal flats and saltmarshs around the margins of the lagoon with similar migrations of fish and bird habitats..	• Increased frequency of inundation in Brooklands township, and lower Styx catchment. • Increase in value of assets at risk from inundation (eg estimated 220% increase for 1% AEP tidal event with SLR of 0.5 m). • Any attempts to protect existing pastoral lands around the margins of the lagoon will reduce the ability of this ecological migration and result in a loss of habitats of intertidal species and wading birds.	• Restrict new land-use developments around lagoon margins in areas which are below a level of 11.2 (CDB datum) (eg Within 50 years would be below 2%AEP tide level with a 0.2 m SLR and a 0.1 m safety factor for wind set-up). These restrictions may take the form of limiting developments to open space and reserves, and prohibiting the placement of fill. • Encourage natural expansion of lagoon area away from existing developed areas by restricting erosion and inundation protection measures. • Maintain sand dunes between the lagoon and Brooklands township to height of 11.6m • Increase minimum lot and floor levels for existing sub divisions to 11.2 & 11.5 (CDB datum). • Long-term; Rise the height of the Styx tidal gate.	• Magnitude of change in tidal compartment and water levels (5) • Erosion of dunes (3)
Dune System	• Increased coastal storm frequency and intensity may increase the risk of inundation in association with dune erosion and around sea wall such as New Brighton	• The effects of SLR on equilibrium beach profile retreat calculated to be in 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 that the status quo shoreline advance, 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 after 2050. For a 100 year return period storm with a 0.5 m SLR, maximum dune face retreat is predicted to be in the order 8-9 m for sites with low flat dunes. At North Brighton is will result in 15-20% volume and width losses from the single row of dunes. A decrease in the frequency of easterly winds will decrease dune growth rates from aeolian processes.	• No significant changes in dune vegetation.	• Continued sand beach • More dune erosion during storms than at present, hence greater costs in dune maintenance and vegetation costs. • Possible greater dune encroachment on to Marine Parade at North and New Brighton with equilibrium profile adjustments if maintainence and vegetation not maintained.	• Ensure adequate sand volume, height and vegetation cover maintained in all dunes environments, particularly north and New Brighton. • Allow buffer zone for dune recession in all new developments located behind the beach.	• Rise in sea level (3) • Waimakariri River sediment supply (2) • Changes in wave approach directions (3) • Equilibrium profile adjustments (3) • Storm effects (4) • Dune growth rates (2)

Note: Areas and Degrees of Uncertainty: The ranking is on a (1) to (5) scale with (1) being the least uncertainty and (5) the most. The ranking reflects both the level of uncertainty and the significant of it to the estimates of effects.

	Inundation Effects	Morphological Effects	Ecological effects	Implications for Christchurch	Suggested Planning and Protection Measures	Areas & Degree of Uncertainty
Avon-Heathcote Estuary	• Projected Estuary water levels increases of 0.2 m by 2050, and 0.5 m by 2100. These increases will by 2050 reduce the probability of a 1:500 year water level event to that of less than a 1:50 year event, and by 2100 monthly perigean tides without any storm surge or wind set-up would be approximately the level of a current 1:50 year event. • The area at risk from a 1:100 year tidal event will increase by approximately 80 hectares by 2100 with a 0.5 m increase in water levels. The value assets at risk from this size event will be approximately $208 million, an increase of 650% on the current value at risk in this size event.	• Increases in mouth channel width by up to 10 m by 2050 and up to 25 m by 2100 to accommodate an increased tidal compartment, resulting in possible erosion on the Brighton spit side of the channel. • Increased sedimentation on the ebb and flood tide deltas with increased tidal bypassing. For the flood tide delta this is likely to further restrict the channel at Moncks Bay. • Continuation of current low rates of deposition on the estuary floor from possible increased river sediment supply. • Increased bank erosion on the estuary side of Brighton Spit from equilibrium profile adjustments. The recession is calculated to be up to 3.6 m for SLR of 0.2 m, and 9.6 m for SLR of 0.5 m.	• Migration and “squeezing” of eelgrasses, saltmarsh, and marsh ribbon wood environments resulting in potential loss of feeding grounds for flounder, eels, and inanga.	• The minimum ground levels for building around the estuary of 11.30 (CDB datum) will be exceeded by a 1:100 year water level without any allowance for run-up effects by 2050 and the minimum floor level of 11.45 m will be exceeded by a 1:50 year water level without run-up effects by 2100. • Increase in value of assets at risk from inundation (eg estimated 750% increase for 1% AEP tidal event with SLR of 0.5 m). • Loss of bio-diversity and natural character of the estuary margins.	• Restrict new land-use developments around the estuary margins in areas which are below a level of 11.2 (CDB datum) (eg Within 50 years would be below 2%AEP tide level with a 0.2 m SLR and a 0.1 m safety factor for wind set-up). Some possible restrictions as for a Brooklands Lagoon. • Allow natural expansion of estuary into the above areas by restricting erosion and inundation protection measures. • Control new land-use developments in areas below 11.5 m which could be effected by SLR (eg within 100 years would be below 1%AEP tide level with SLR of 0.5 m). Levels of control could involve “future proofing” buildings, by setting minimum floor levels at 11.8 m (2% AEP in 100 years plus 0.4 m safety), and relocate able buildings. • Increase minimum floor levels for existing sub divisions to 11.6 m(CDB datum) based on 1% AEP tide level with 0.2 m sea level rise (eg 2050)and existing 0.4 m safety for wind set-up and run-up effects. • Co-ordinate erosion protection responses for properties on the estuary side of South Brighton Spit. • Longer-term: Rise the level of existing structures around the estuary which protect existing developments from extreme tide levels.	• Magnitude of change in tidal compartment and water levels (5) • Erosion of South Brighton spit (3) • Sedimentation in the estuary (4) • Changes to the tidal deltas (3) • Ecological responses (2)
Avon & Heathcote Rivers	• The area at risk from a 1:100 year tidal event in the Lower Heathcote River will increase by approximately 55 hectares by 2100 with a 0.5 m increase in water levels • For the lower Avon River, the corresponding additional area at risk is 180 hectares • By 2100 the Heathcote tidal barrage will only provide protection in less 1%AEP events and the lower Avon stopbanks, will only provide protection in less 2%AEP events.	• The saline water boundary will extend further upstream, potentially resulting in up to 10 m of bank collapse from a break down in soil structure, vegetation die back, and the migration of mud crabs. In the Heathcote River it is considered that this effect will extend further upstream that occurred following the construction of the Woolston Cut, In the Avon River this effect could extend to beyond Porritt Park.	• Upstream migration of eelgrasses, saltmarsh, and marsh ribbon wood environments in the Lower Heathcote with associated die-off on non-salt tolerant species. • “Squeezing” of the above environments on the Lower Avon due to stopbanking.	• Increase in value of assets at risk from inundation (eg estimated 600% increase in both the Heathcote and the Avon for 1% AEP tidal event with SLR of 0.5 m For the Lower Avon River this equates to approximately $550 million).	• Restrict new land-use developments around the lower rivers in areas which are below a level of 11.2 (CDB datum) (eg Within 50 years would be below 2%AEP tide level with a 0.2 m SLR and a 0.1 m safety factor for wind set-up). Same possible restrictions as from Brooklands and the estuary. • Control new land-use developments in areas below 11.5 m which could be effected by SLR (eg within 100 years would be below 1%AEP tide level with SLR of 0.5 m). Same possible controls as for the estury • Longer-term: Rise the level of the Heathcote Tidal Barrage • Longer term: Rise the level of the Lower Avon stopbanks or construct a Tidal barrage.	• Changes in water levels (4) • Migration of saline boundary and resulting bank erosion(4)

	Inundation Effects	Morphological Effects	Ecological effects	Implications for Christchurch	Suggested Planning and Protection Measures	Areas & Degree of Uncertainty
South of Estuary	• Possible increased risk of inundation at Cave rock and Taylors Mistake in coastal storm events.	• Less sediment being available at Clifton due to increased trapping in the estuary tidal deltas and a less predominant southerly littoral drift. Shoreline recession due to equilibrium beach profile adjustments of up to 5 m by 2050, and 13.5 m by 2100 • Likely increased sediment scour from in front of the Sumner sea wall. • Increased erosion at Taylors Mistake due to equilibrium beach profile adjustments of up to 5 m by 2050, and 14 m by 2100.	• None	• Clifton: Potential reduction in stability of existing rock protection works along the edge of the road to Sumner. • Potential undermining of rock revetment along Sumner Promenade. • Potential sediment losses around the Taylors Mistake Surf Life Saving club. • Loss of "dry" high tide recreational beach area at all three beaches.	• Beach renourishment as required	• Rise in sea level (3) • Sediment supply (2) • Equilibrium profile adjustments (3)
Groundwater	• Increased water tables and reduced drainage.	• None	• None	• Greatest risk of salt water intrusion into the first aquifer is close to Banks Peninsula. • Increased potential for salt water intrusion from excessive drawdown in areas close to the estuary and the lower Avon and Heathcote Rivers.	• Careful management of extraction rates in wells close to the estuary and lower rivers.	• Intrusion into the aquifer from the sea interface (3) • Intrusion rate from the Estuary (4)

analysis should also consider the environmental and social implications of the different options.

20.0 Applicability

This report has been prepared for the benefit of the Christchurch City Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

TONKIN & TAYLOR LTD
Environmental and Engineering Consultants

Report prepared by: Authorised for Tonkin & Taylor by:

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Derek Todd Bob Kingston

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15 December, 1999
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REFERENCES

SUMMARY OF REFERENCES UNDER CATEGORIES:GLOBAL/IPCC: LOCAL IMPACTS: NEW ZEALAND:			
ID	**AUTHOR**	**DATE**	**TITLE**
GLOBAL / IPCC:			
268	ASCE	1992	Effects of Sea Level Rise on Bays and Estuaries
249	Barth, M.C, Titus, J.G (ed)	1984	Greenhouse Effect and Sea Level Rise: A Challenge for this generation.
19	Begum, S. Fleming, G.	1997	Climate change and sea level rise in Bangladesh, Part 2: Effects
17	Berish, C.W.	1990	Global Climate Change and the Need for Planning
245	Bird, E.C.F	1988	Physiographic indications of a sea level rise.
262	Bird, E.C.F.	1993	Submerging coasts: the effects of a rising sea level on coastal environments.
247	Budd, W.F	1988	The Expected Sea-Level rise from Climatic Warming in the Antarctic.
28	Buddemeier, R.W.	1989	Sea-level rise in the coming century: Magnitude and mechanisms.
49	Calcott,-Dean	1998	No ocean rise from big thaw
267	Climatic Impacts Centre	1997	CIC Internet Site
15	Cubit, J.D.	1992	Global Climate Change and the Importance of Tidal Flat Ecosystems in the Caribbean and Gulf od Mexico
36	Deans, J.A.	1997	Coastal Flooding Hazard Assessment in South Australia
244	Gilbert, J; Vellinga, P	1991	Coastal Zone Management
248	Hoffman, J.S	1984	Estimates of Future Sea Level Rise.
141	Holbrook, N. J	1996	"Development of a statistical model for tropical cyclogenesis in the Southwest Pacific."
252	Houghton, J.T , Callander, B.A & Varney, S.K(ed)	1992	Climate Change 1992: Re Supplementary Report to the IPCC Scientific Assessment
234	IPCC	1990	Strategies for adaptation to sea level rise.
254	IPCC	1995	Summary for Policymakers: The Science of Climate Change-IPCC Working Group I.
251	IPCC: Response Strategies working group.	1990	Adoptive Responses to Climate Change: Coastal Zone Management Workshop. Re Proceedings, Perth 1990.
26	Kjerfve, B. Michener, W.K. Gardner, L.R.	1994	Impacts of climate change in estuary and delta environments
145	Kothavala, Z.	1996.	The Applicability of Equilibrium and Transient GCM Simulations to the Analysis of Extreme Events over Australia American Geophysical Union
144	Kothavala, Z. and Henderson-Sellers, A.	1995	"Extreme precipitation events and the applicability of GCMs to the analysis of floods and droughts."
43	Kumar,-Mahendra	1997	The greenhouse effect
12	Leatherman, S.P.	1996	Shoreline Stabilization Approaches in Response to Sea Level Rise: US Experience Implications for Pacific Island and Asian nations
27	Maul, G.A.	1993	Ecosystem and socio-economic response to future climatic conditions in the marine and coastal regions of the Caribbean Sea, Gulf of Mexico, Bahamas, and the north-east coast of South America.
229	McGlone, M, Clarkson, T, and Fitzharris, B.	1990	Unsettled-Outlook: New Zealand in a Greenhouse world.
235	Mimura, N and Nunn, P.D	1998	Trends of beach erosion and shoreline protection in rural Fiji.
236	Nunn, P. D	1998	Sea-level changes over the past 1,000 years in the Pacific.
7	Peer, R.L.	1990	Overview of Climatic Information Needs for Ecological Effects Models
13	Perez, R.T., Feir, R.B., Carandang, E., Gonzalez, E.B.	1996	Potentiall Impacts of Sea Level Rise on the Coastal Resources of Manila Bay: A preliminarty vulnerability assessment.
208	Peter Toynbee	1996	The Lost Vision of Global Warming
3	Platt, M.M. Rizzo, W.M. Neckles, H.A.	1994	Annotated Bibliography On The Potential Effects Of Global Climate Change On Submerged Aquatic Vegetation
178	Raper, S.C.B., Wigley, T.M.L. and Warrick, R.A.	1996	Global sea level rise: past and future.
263	Rintoul, S. (et al.)	1996	Ocean processes, climate and sea level.

ID = the number of the record in the data base that this piece of the literature refers to

ID	AUTHOR	DATE	TITLE
212	Maunder, W.J.	1987	Global Warming a hot time to come
35	Shalada, M. J.; Riley, M. J. ;Tosswell, P.	1995	Impacts Of Climate Change On Maritime Local Authorities-Drainage Aspects
228	Shrivastava, G.S.	1988	Impact of sea level rise on seawater intrusion into coastal aquifer.
250	Sorenson, A.M, Weisman, R.N, Lannon, C.P.	1984	Control of erosion, Inundation and Salinity intrusions caused by Sea Level Rise.
4	Sullivan, M	1990	The Impacts Of Projected Climate Change On Coastal Land Use In Papua New Guinea
30	Syvitski, J.P.M. Andrews, J.T	1994	Climate change: Numerical modelling of sedimentation and coastal processes, eastern Canadian Arctic
266	The Press	1999	Ice Sheet "on point of melting"
240	Titus, J.G	1987	Greenhouse Effect, Sea Level Rise, and coastal drainage systems.
243	Titus, J.G	1989	The Cause and Effects of Sea Level Rise.
22	Tolba, M.K	1991	Preparing for global and regional effects of climate change
255	Warrick, R, Oerlemans, J.	1990	Sea Level Rise
186	Warrick, R.A. and Speier, S.	1996	A standardised training package for climate change vulnerability and adaptation assessment: a preliminary framework.
259	Warrick, R.A.; Barrow, E.M & Wigley, T.M. (eds)	1993	Climate and Sea Level Change: Observations, Projections and Implications.
242	Watson, R T, Zinyowera, MC & Moss, R H (Ed)	1997	The Regional Impacts of Climate Change: An Assessment of Vulnerability
253	Watson, R.T, Zinyowera,M.C, Moss, R.H (ed)	1996	Climate Change 1995: Impacts, Adoptions, and Mitigation of Climate Change; Scientific-technical Analyses.
264	Wigley, T.M.L. and Raper, S.C.B.	1992	Implications for Climate and Sea Level of Revised IPCC Emissions Scenarios.
261	Wind, H.G. (ed).	1987	Impact of sea level rise on society.
11	Yohe, G, Neumann, J	1997	Planning for Sea Level Rise and Shore Protection Under Climate Uncertainty

LOCAL IMPACTS:			
42	Banks, G.A.	1991	Sea-level rise and beach response: a short note
206	Canterbury Regional Council / Christchurch City Council	1997	Issues and Options for Managing the Avon River Floodplain
37	Carver, D.M.	1992	Climate Change And Sealevel Rise Implications For Christchurch
46	Crean, M.	1994	Needed now: flood plan against greenhouse effect
292	Crossland, A	1998	Heathcoate Valley: Rezoning and Opportunities for Wildlife. Report 1 post and present wildlife
265	Dalziell, J.C.	1989	The Greenhouse Effect: An approach to a local response.
288	Findlay, R H	1984	The Mouth of the Avon-Heathcote Estuary: A review of historical development of the mouth of the Estuary of Avon and Heathcote Rivers
287	Findlay, R H & Kirk, R M	1988	Post 1847 Changes in Avon-Heathcote Estuary, Christchurch: a study of the effects of urban development around tidal estuary
289	Hicks, D M	1993	Sedimentation and Erosion in the Avon Heathcote Catchment and Estuary
2	McKerchar, A & Kirk, RM k	1994	Assessment of probabilities of high water levels for the lower Avon River
291	Meurk, C D and Crossland A	1998	Ferrymead Observations
1	Oliver, T. & Kirk, R. M.	1992	Extreme High Water Levels in the Avon-Heathcote Estuary
298	The Heathcote River Task Force Tidal Control Study Team	1991 (b)	Lower Heathcote Tidal Control Structure: Feasibility Technical Report 1: Ecological Studies
297	The Heathcote River Task Force Tidal Control Study Team	1991 (a)	Lower Heathcote Tidal Control Structure: Feasibility Technical Report 1: Ecological Studies
296	The Heathcote River Task Force Tidal Control Study Team	1991(c)	Lower Heathcote Tidal Control Structure: Feasibility Report

ID = the number of the record in the data base that this piece of the literature refers to

ID	AUTHOR	DATE	TITLE
299	The Heathcote River Task Force: Tidal Control Study Team	1990	Lower Heathcote Tidal Control Structure prefeasibility
290	Watts, R	1993	Sea Level Rise and Planning Responses
32	Wilkinson, L & Smith, I	1995	Implications of Climate Change for Christchurch

NEW ZEALAND:			
238	Allan, S.	1993	Information for the guidance of local authorities in addressing climate change.
282	Basher, RL	1990	Soils and Landscape Processes
284	Bell, R.G., Goring, D.G.	1999	Flow-on Effectrs of El Nino-Southern Oscillation Events on Sea Level Rise in Northern NZ
168	Braddock D. (ed)	1996	Climate Change IPCC'95 and Beyond
286	Burns, N (et al)	1990	Estuaries
213	de Freitas, C R	1987	Perspectives on the Impact of Short-Term Climatic Change in New Zealand
260	Erda, Lin	1996	Climate change vulnerability and adaptation in Asia and the Pacific: Manila, Philippines, 15-19 January 1996.
41	Gibb, J.G.	1992	Implications for coastal management of sea-level rise
226	Gibb, J.G.	1986	Report on an official visit by Dr J.G.Gibb to Ireland, United Kingdom and the Netherlands during 3/4 1986
230	Gibb, J.G.	1988	Impact of 'greeenhouse' induced sea level on the NZ coast.
241	Gibb, J.G.	1991	Implications of Greenhouse-Induced Sea Level Rise for Coastal Management.
273	Gibb, J.G.	1988	Impacts of Sea Level Rise in the Coastal Zone and Strategies to Reduce Impacts
274	Gibb, J.G.	1988	Past and Predicted Eustatic Sea Levels and their impacts on Coastal Advance and Retreat.
269	Gibb, J.G. & Aburn, J.H.	1986	Shoreline fluctuations and an assessment of a Coastal Hazard Zone along Pauanui Beach, Eastern Coromandel Peninsula, New Zealand.
39	Gillespie, A	1997	Burning Issues: The Failure Of The New Zealand Response To Climate Change
283	Griffiths, G.A.	1990	Water Resources
277	Hamilton, D.J.	1992	Sea Level Rise is for Real
227	Hannah, J.	1988	Analysis of Mean Sea Level Trends in New Zealand from Historical Tidal Data
278	Hannah, J.	1998	Sea Level Rise: Impacts upon the Surveying Profession
280	Hannah, J.	1989	Sea Levels - Post, Present and Future
271	Hicks, D.M.	1988	Effects of Sea Level Rise and Climate Change on Shoreline Plan Form.
285	Hicks, D.M.	1990	Coastal Impacts - Physical
252	Houghton, J.T , Callander, B.A & Varney, S.K(ed)	1992	Climate Change 1992: Re Supplementary Report to the IPCC Scientific Assessment
254	IPCC	1995	Summary for Policymakers: The Science of Climate Change-IPCC Working Group I.
251	IPCC: Response Strategies working group.	1990	Adoptive Responses to Climate Change: Coastal Zone Management Workshop. Re Proceedings, Perth 1990.
258	Kay, R.; Kirkland, A; Stewart, I.	1996	Planning for Future Climate Change and Sea Level Rise Induced Coastal Change in Australia and New Zealand.
175	Kenny, G.J., Warrick, R.A., Mitchell, N.D., Mullan, A.G. and Salinger, M.J.	1995	CLIMPACTS: an integrated model for assessment of the effects of climate change on the New Zealand environment.
33	Kirk, R.M.	1994	Sea Level Rise A Progress Report
214	Kirk, R.M.	1988	Monitoring Sea Level and Coastal Change
295	Kirk, R.M.	1996	Summary of Regional Coastal Impacts
38	Lumsden, J.L and Kirk, R.M.	1992	Sea Level Rise A Review Of The Issues

ID = the number of the record in the data base that this piece of the literature refers to

ID	AUTHOR	DATE	TITLE
8	McDowall, R.M.	1991	Global Climate Change and Fish and Fisheries: What Might Happen in a Temperate Oceanic Archipelago like NZ
229	McGlone, M, Clarkson, T, and Fitzharris, B.	1990	Unsettled-Outlook: New Zealand in a Greenhouse world.
218	Ministry for the Environment	1994	Climate Change - The New Zealand Response - NZs first National Communication under the Framework Convention on Climate Change
219	Ministry for the Environment	1990	Climatic Change - Impacts on New Zealand, Implications for the Environment, Economy, and Society
225	Ministry for the Environment	1990	Climatic Change - A review of Impacts on New Zealand
237	Ministry for the Environment.	1990	Responding to climate change: A discussion of options for New Zealand.
220	Ministry of the Environment	1988	Climate Change - The New Zealand Response
221	Ministry of the Environment	1988	Climate Change: The New Zealand Response - A background paper
275	Mosley, M.P.	1988	Climatic Change: Impacts on Water Resources.
272	Mosley, P.M.	1988	Water and Catchment Management
279	Mullan, A B	1989	Calculating the Climate
232	Mullan, A.B and Salinger, M J	1994	Climpacts 1993/94:Climate change and scenarios from GCM output and palaeoclimate data.
270	Pickrill, R.A.	1988	Sea Level Rise and Sediment Transport.
40	Salinger, J.	1995	Expect changes in a warming climate
215	Salinger, J.	1991	Greenhouse New Zealand-Our Climate: Past, Present and Future
211	Salinger, M.J.	1987	Green House Warming - Preparing for a Climate Change
256	Salinger, M.J. (et al.)	1996	Observed Variability and Change in Climate and Sea Level in Australia, New Zealand and the South Pacific.
281	Salinger,M.J., Hicks,D.M.	1990	The Scenarios
166	Sims, O.C., Warrick, R.A. and Kenny, 0.J.	1996	The development of CLIMPACTS, a model for spatial and temporal analysis of the effects of climate change and variability on the New Zealand environment
45	Sinclair, Jan	1995	Climate change: the evidence heats up
210	Smith, K.R; Hume, T.M.	1987	Global Warming and our Coastline
276	Smith, R.G.	1988	The Effects of Global Warming on Coastal Estuaries
222	The Royal Society of New Zealand	1988	Climate Change in New Zealand
223	The Royal Society of New Zealand	1989	New Zealand Climate Report 1990
224	The Royal Society of New Zealand	1992	The 1992 Supplement to the 'New Zealand Climate Report 1990'
293	The Royal Society of New Zealand	1996	Climate Change: IPCC 95 and Beyond
44	Upton, Simon	1997	New Zealand's climate change policy
255	Warrick, R., Oerlemans, J.	1990	Sea Level Rise
189	Warrick, R.A.	1996	Report on the IPCC Workshop on Regional Climate Change Projections for Impact Assessment: Summary and Implications for New Zealand.
294	Warwick, R A	1996	Sea Level Aspects of Climate Change
253	Watson, R.T, Zinyowera, M.C, Moss, R.H (ed)	1996	Climate Change 1995: Impacts, Adoptions, and Mitigation of Climate Change; Scientific-technical Analyses.
257	Whetton, P.; Mullan, A.B; Pittock, A.B.	1996	Climate - Change Scenarios for Australia and New Zealand.
217	Wratt D.S (at el)	1991	Climate Change - The Consensus and the Debate

ID = the number of the record in the data base that this piece of the literature refers to

APPENDIX A

ACCESS DATABASE OF LITERATURE REVIEW

APPENDIX B

SUMMARY OF INFORMATION ON IPCC AND THEIR GLOBAL CLIMATE CHANGE SCENARIOS

Appendix B: Summary of Information on IPCC and Their Global Climate Change Scenarios

B1 Inter-government Panel on Climate Change (IPCC)

Following the international Villach Conference 1985 on the impacts of Greenhouse Effect and climate change, the (IPCC) was established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in 1988. It is charged with assessing the most up to date scientific, technical and socio-economic research in climate change. Each of these three areas is set up as a Working Party Group of the IPCC. The IPCC has developed procedures for the preparation, review and approval of its assessment reports aimed at guarding their objectivity and ensuring all relevant information is considered. Report preparation and review involves several hundred scientists from a large number of countries, including New Zealand. Hence the IPCC assessments represents a consensus of international thinking on the causes, magnitude, effects and best responses to climate change. However, there are a number of scientists who do not support the IPCC assessments. Some of these doubts are summarised in Section 9.1.

The IPCC produced major assessment reports in 1990 and 1995, and their Third Assessment Report is scheduled for completion in 2000. These assessments cover the cause, impacts and possible responses to climate change, whether due to natural variability or as a result of human activity. Additional IPCC reports include; Strategies for the Adaption to Sea Level Rise in 1990, An interim correction to the 1990 predictions in 1992, and an Assessment of Regional Vulnerability in 1997.

A brief summary of the climate scenarios and predictions that are relevant for SLR and coastal processes from each of the IPCC reports is included in Section B4.0 and a good summary of IPCC activities can be found on the NIWA web site (http://katipo.niwa.cri.nz./ClimateFuture/about_IPCC.htm)

More detailed information about the IPCC, lists of its publications, and the Policymakers' Summaries of its 1995 assessment are available on the IPCC Web Site (http://www.ipcc.ch/about.htm).

B2 General Circulation Models

The IPCC predictions have been developed from the use of three dimensional computer models**.** The following summary of the models is from the NIWA web site **(**http://katipo.niwa.cri.nz./ClimateFuture/Models.htm**).**

Models which simulate the atmosphere are called Atmospheric General Circulation Models (AGCMs), and have been developed from weather forecasting models. Similarly, Ocean General Circulation Models (OGCMs) have been developed to simulate the ocean. These models typically divide the atmosphere or ocean into a horizontal grid with a horizontal resolution of 2° to 4° latitude and longitude, with 10 to 20 layers in the vertical. Both AGCMs and OGCMs have been used in "stand-alone" mode, however, because the oceans have such a large heat capacity, and can transfer heat around the globe, it is vital to couple atmosphere and ocean models in order to simulate climate variability and changes. This has led to the development of coupled atmosphere ocean models.

The early models used in the late 1980's and early 1990's, including those used for the IPCC 1990 assessments, involved "equilibrium" climate change simulations, in which CO_2 was held constant at twice the current concentrations without increases over time. These models also treated the ocean as a "slab" or a "swamp", in which heat was assumed to enter the ocean by vertical diffusion and ocean currents and/or ocean heat storage were not taken into account.

By the time of the IPCC 1995 assessment, the modelling involved had developed to use full Atmosphere Ocean General Circulation Models (AOGCM), and "transient" model runs, in which greenhouse gas concentrations are gradually increased. The cooling effects of sulphate aerosols were also taken into account in the more recent models. However, AOGCMs are as yet imperfect representations of the real world, with considerable uncertainties in many climate projections, particularly at smaller scales than global.

B3 United Nations Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC) was negotiated under United Nations auspices to deal with the impacts of human activities on the global climate system. The agreement came into force on 21 March 1994.

The ultimate objective of the Convention is:

... stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

Developed countries which are parties to the UNFCCC (called "Annex 1 countries in the wording) agree to limit carbon dioxide and other human - induced greenhouse gas emissions, and to protect and enhance greenhouse gas sinks and reservoirs. Parties also agree to promote and cooperate in research, systematic observation and development of data archives related to the climate system, to share information, and to cooperate in education and training related to climate change. Annex 1 parties are required to report periodically on the measures they are undertaking to address the objective of the convention, and on their projected emissions and sinks of greenhouse gases. There are also commitments to assist developing countries that are particularly vulnerable to adverse effects of climate change, with costs of adapting to adverse effects, and to facilitate transfer of environmentally sound technologies to developing countries.

The UNFCCC itself contained no legally binding targets or timetables, but the general interpretation was that developed countries should reduce their emissions to 1990 levels by the year 2000.

At the first Conference of the Parties to the Convention, in April 1995, it was decided that existing commitments in the UNFCCC were inadequate to achieve the objective of avoiding dangerous human-induced interference with the climate system. Further negotiations led to the Kyoto Protocol, which was agreed to in December 1997. This is a legally binding protocol, under which industrialized countries will reduce their collective emissions of greenhouse gases by 5.2%. This collective reduction in total developed country emissions will be achieved through member countries achieving various different set reduction rates.

The agreement aims to lower overall emissions from a group of six greenhouse gases by 2008-12, calculated as an average over these five years. Cuts in the three most important gases CO_2, CH_4, and N_2O will be measured against a base year of 1990, while cuts in three long-lived industrial gases - (HFCs, PFCs & SF6) - can be measured against either a 1990 or 1995 baseline. However, if compared to expected emissions levels for the year 2000, the total reductions required by the Protocol will actually be about 10%; due to many industrialized countries have not succeeded in meeting their earlier non-binding aim of returning their emissions to 1990 levels by the year 2000. In some countries, emissions have in fact risen since 1990.

The full text of the Convention and the full text of the Kyoto Protocol are available from the **official Web site of the UNFCCC**.

A good general description can also be found in Allan (1993).

B4 Global Climate Change Scenarios and Predictions

The following is a brief summary of the climate scenarios and predictions that are relevant for SLR and coastal processes from each of the IPCC reports.

B4.1 IPCC 1990 Scientific Assessment

- Global mean surface air temperature has increased by 0.3°C to 0.6°C over the last 100 years.
- Under "Business-as-usual scenario" for emission of greenhouse gases, mean global temperature will increase at a rate of 0.3°C per decade with an uncertainty range of 0.2°C to 0.5°C per decade. This is a greater rate of temperature rise than experienced over the past 10,000 years.
- The resulting global mean temperature is estimated to rise above its current value by 3°C by the year 2100, with an uncertainty range of 1.5°C to 4.5°C.
- Results from the models become less reliable at smaller scales, and regional climate changes may be different from the global mean. The least confidence in predictions is for the tropics and the Southern Hemisphere.

B4.2 IPCC 1992 Supplementary Report

- Established six scenarios for global climate change based on different assumptions of population, economic growth, energy supplies, and emission of CFC and other gases
- For the mid range scenario is IS92a, involving a population of 11.3 billion by 2100 and a phrase out of CFC emissions by 2075, the predicted global mean temperature rise is estimated to be 2.5°C, with the same range of uncertainty as the 1990 assessment for low (IS92c, lower population) and high (IS92e, higher energy use and CFC emissions) scenarios.

B4.3 IPCC 1995: The Science of Climate Change

- No change in the range of estimates of increase in global mean air temperature over last century (0.3-0.6°C), but regional changes has become evident. There is inadequate data to determine whether consistent global changes in climate variability or weather extremes have occurred.
- Considerable progress has been made in attempts to distinguish between natural and anthropogenic influences on climate. This progress has been achieved by including effects of sulphate aerosols in addition to greenhouse gases, thus leading to more realistic estimates of human-induced radiative forcing. In addition, new simulations with coupled atmosphere-ocean models have provided important information about decade to century timescale natural climate variability. A further major area of progress is the shift of focus from studies of global-mean changes to comparisons of modelled and observed spatial and temporal patterns of climate change.
- Most of the recent studies show that the observed warming trend is unlikely to be entirely natural in origin. However, our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors.
- For the mid-range IPCC emission scenario, IS92a, including the effects of future increases in aerosol, models project an increase in global mean surface air temperature relative to 1990 of about 2°C by 2100. This estimate is approximately one third lower than the "best estimate" in 1990. This is due primarily to lower emission scenarios (particularly for CO2 and the CFCs), the inclusion of the cooling effect of sulphate aerosols, and improvements in the treatment of the carbon cycle.

- The lowest projected rise is about 1°C by 2100 (scenario IS92c), and the highest rise is projected to be about 3.5°C (scenario IS92e).
- Because of the thermal inertia of the oceans, only 50%-90% of the eventual equilibrium temperature change would have been realised by 2100 and temperature would continue to increase beyond 2100, even if concentrations of greenhouse gases were stabilised by that time.
- Regional temperature changes could differ substantially from the global mean value.
- Confidence is higher in the hemispheric-to-continental scale projections of coupled atmosphere-ocean climate models than in the regional projections, where confidence remains low. Also the spatial and temporal distribution of aerosols greatly influences regional projections, which are therefore more uncertain. Hence, regional temperature changes could differ substantially from the global mean value.
- Warmer temperatures will lead to a more vigorous hydrological cycle. Several models indicate an increase in precipitation intensity, suggesting a possibility for more extreme rainfall events, however, there is more confidence in temperature projections than hydrological changes.
- Knowledge is currently insufficient to say whether there will be any changes in the occurrence or geographical distribution of severe storms, e.g., tropical cyclones.

B4.4 IPCC 1997: The Regional Impacts of climate Change: An Assessment of Vulnerability

- Includes a chapter on regional impacts for Australasian, which is summarised in Appendix C -1.2.

B4.5 IPCC 2000: Preliminary Scenarios

The IPCC have commissioned a Special Report on Emissions Scenarios (SRES) to generate a new set of scenarios for use in the Third Assessment Report. These new scenarios - currently termed the Preliminary SRES scenarios - are currently going through an open review process (June to December 1998) and are posted on the CIESIN Web Site. A preliminary version of the scenarios has been made available to the DDC for use in climate change scenario construction and impacts and adaptation assessments. The Preliminary SRES scenarios have been constructed to explore future developments in the global environment with special reference to the production of greenhouse gases and aerosol precursor emissions. All the Preliminary SRES scenarios are 'non-mitigation' scenarios with respect to climate change. They use the following terminology:

- Storyline: a narrative description of a scenario (or a family of scenarios), highlighting the main scenario characteristics and dynamics, and the relationships between key driving forces.
- Scenario: projections of a potential future, based on a clear logic and a quantified storyline.
- Scenario family: one or more scenarios that have the same demographic, politico-societal, economic and technological storyline.

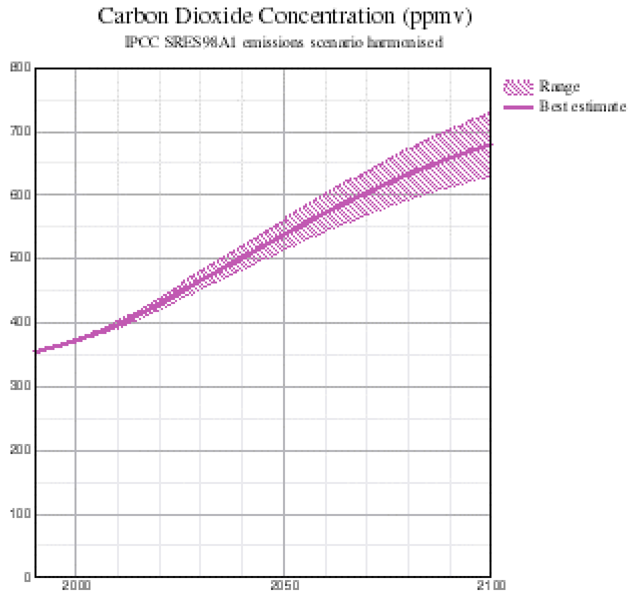
The approach has been to develop a set of four "scenario families". The storylines of each of these scenario families describes one possible demographic, politico-economic, societal and technological future. Within each family one or more scenarios explore global energy industry and other developments and their implications for greenhouse gas emissions and other pollutants. The scenarios have been built to explore two main questions for the twentyfirst century, neither of which we know the answer to:

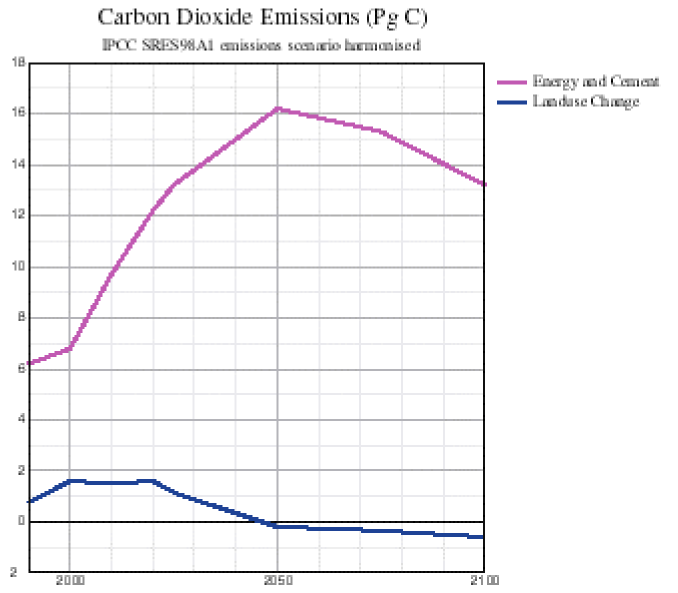
- Can adequate governance - institutions and agreements - be put in place to manage global problems?
- Will society's values focus more on enhancing material wealth or be more broadly balanced, incorporating environmental health and social well-being.

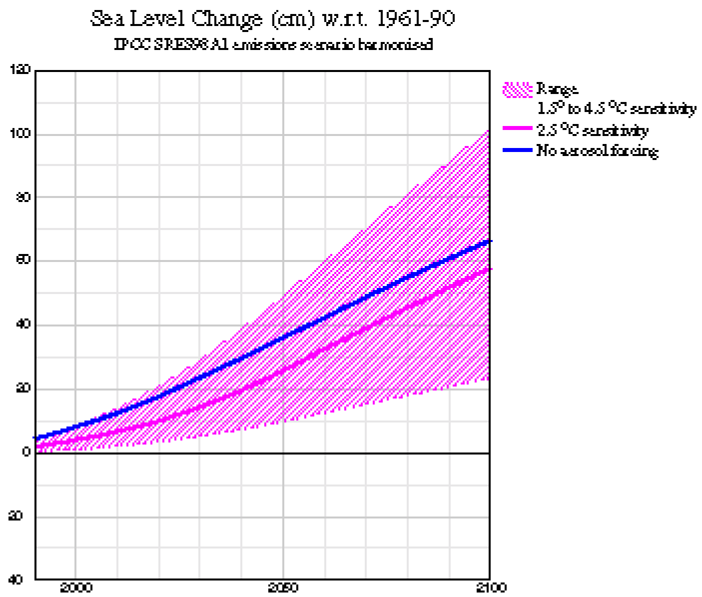
The way these questions are answered leads to four families of scenarios. Within these scenario families, plausible energy industry and other developments which will contribute to greenhouse gas emissions are examined. Although the storylines do not contain explicit climate change policy measures, there are examples of indirect mitigation measures in some of the scenarios. The scenario quantifications of the main indicators related to growth of population and economy, the characteristics of the energy system and the associated greenhouse gas emissions all fall within the range of prior studies.
The following links provide tabular listings of the different Preliminary SRES emissions scenarios, as well as an interpretation - using models used in the IPCC Second Assessment Report - of what these different scenarios signify for future

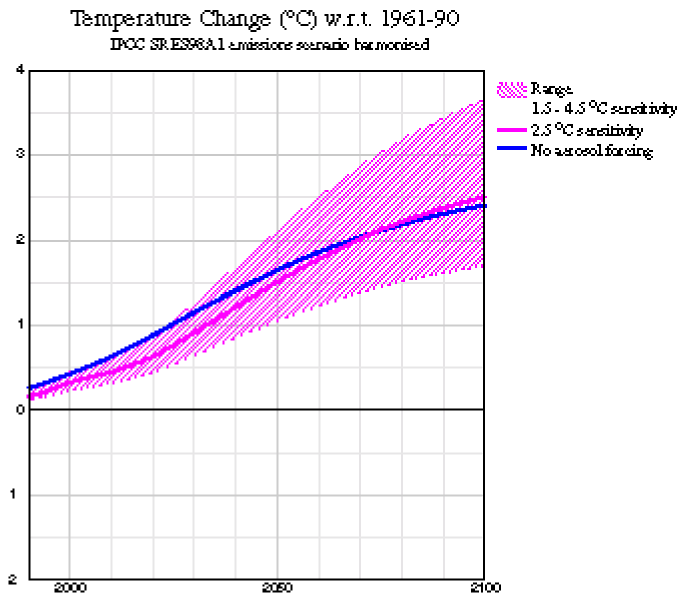
global temperature and sea-level change. Information about the non-climatic scenario assumptions (population, economic growth, etc.) that underlie these Preliminary SRES emissions scenarios can be found at the Non-Climatic Scenarios page

- Preliminary SRES A1: a future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technology. Major underlying themes are economic and cultural convergence and capacity building, with a substantial reduction in regional differences in per capita income. In this world, people pursue personal wealth rather than environmental quality.

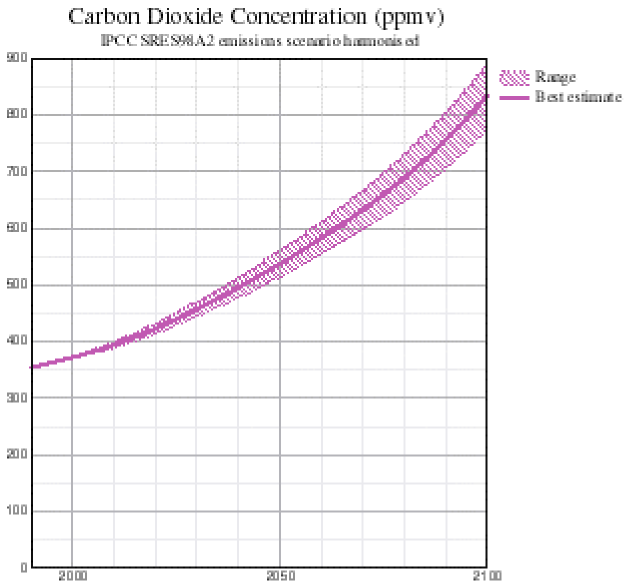


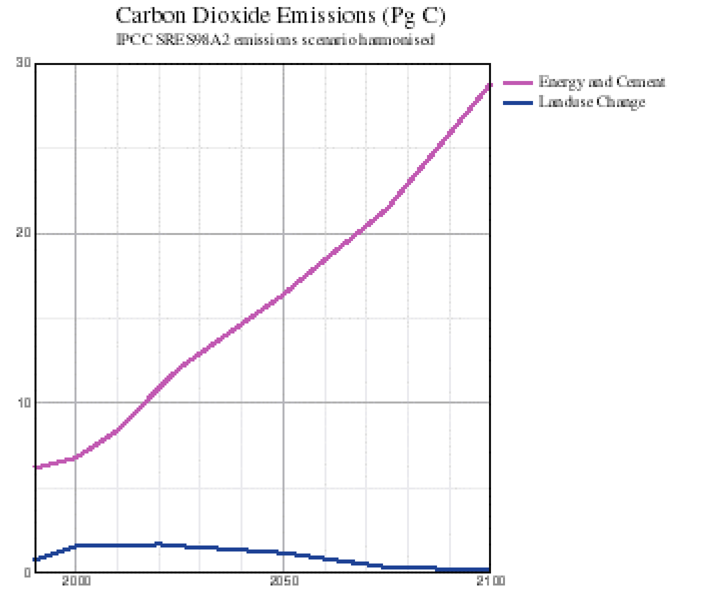


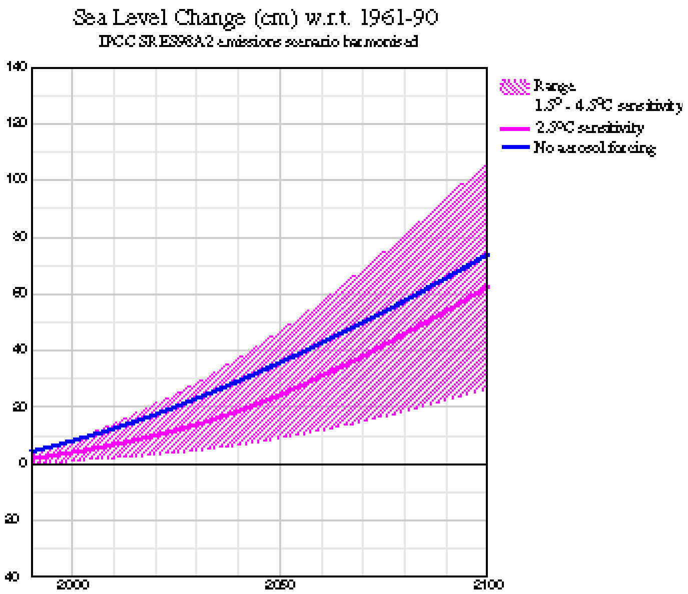


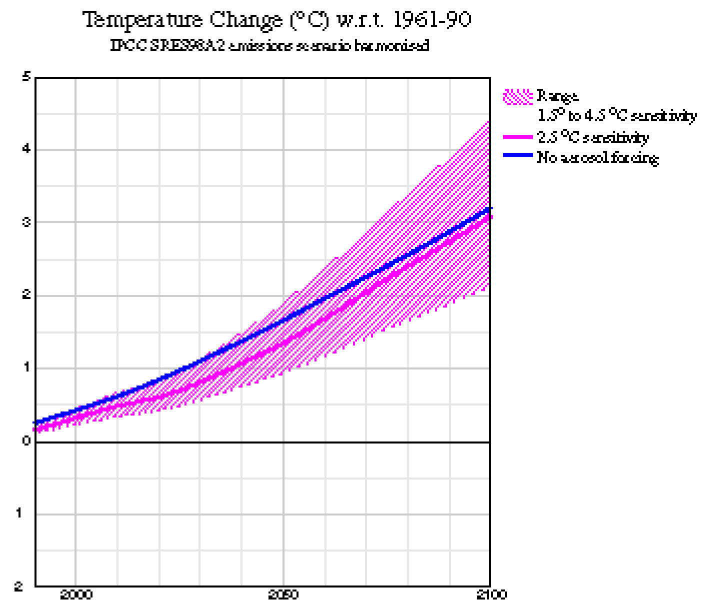


- Preliminary SRES A2: a very heterogeneous world. The underlying theme is that of
strengthening regional cultural identities, with an emphasis on family values and local traditions, high population growth, and less concern for rapid economic development.

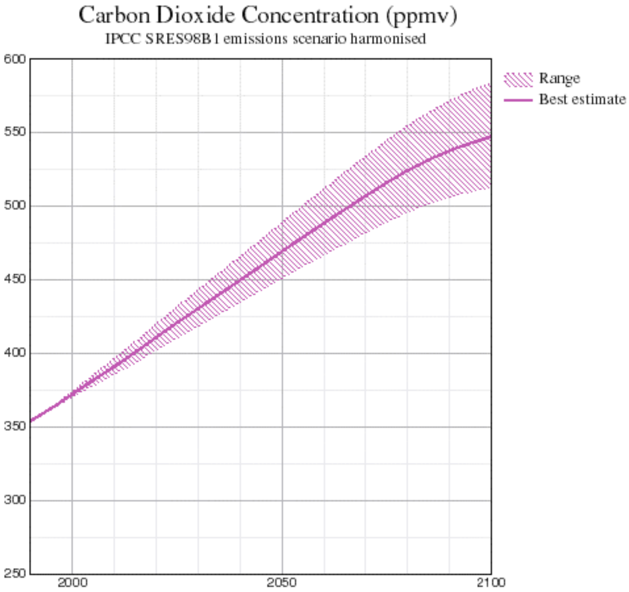


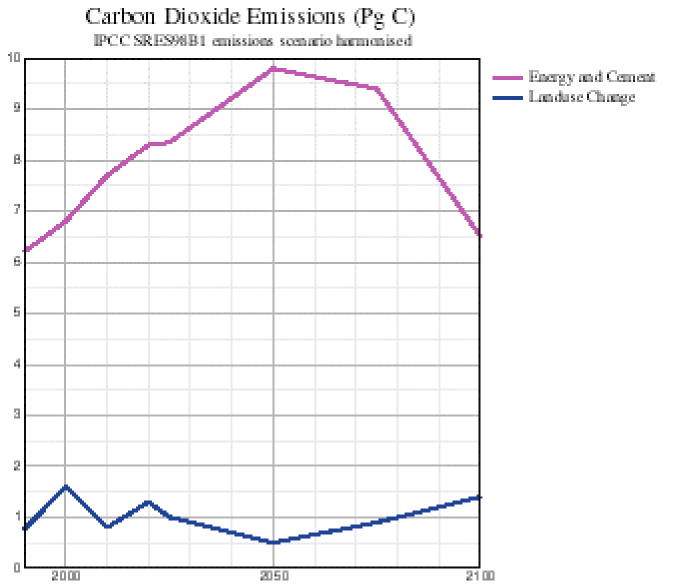


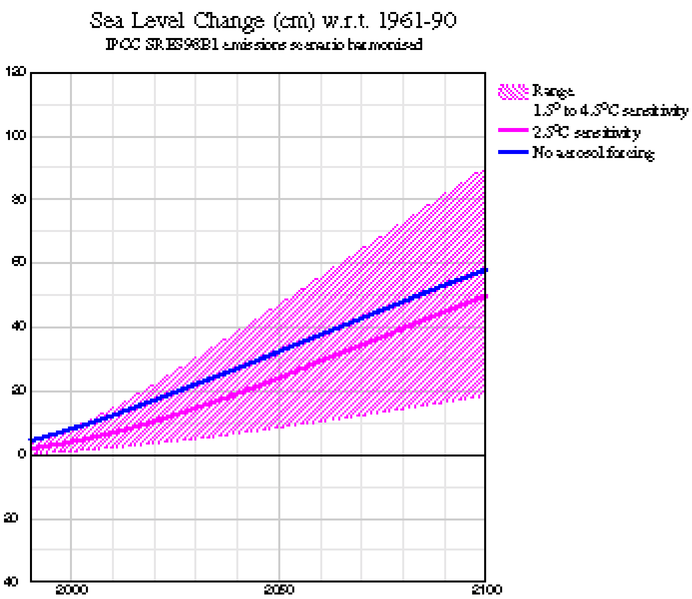


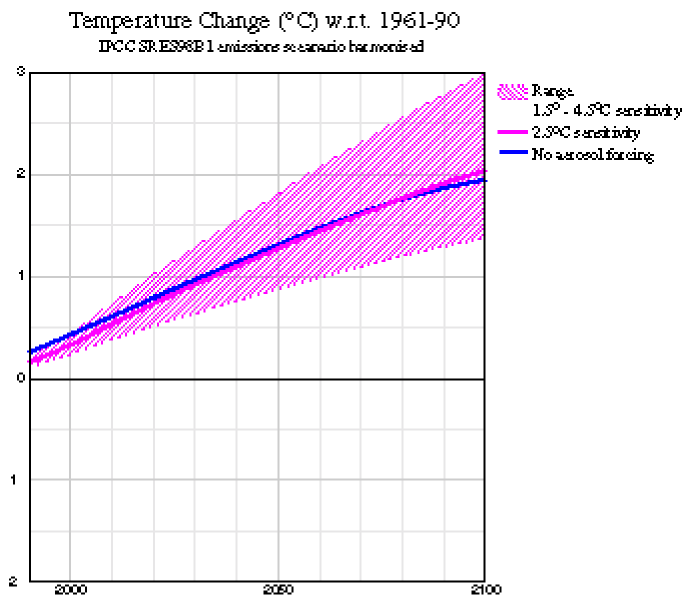


- Preliminary SRES B1: a convergent world with rapid change in economic structures,
  "dematerialization" and introduction of clean technologies. The emphasis is on global solutions to environmental and social sustainability, including concerted efforts for rapid technology development, dematerialization of the economy, and improving equity.

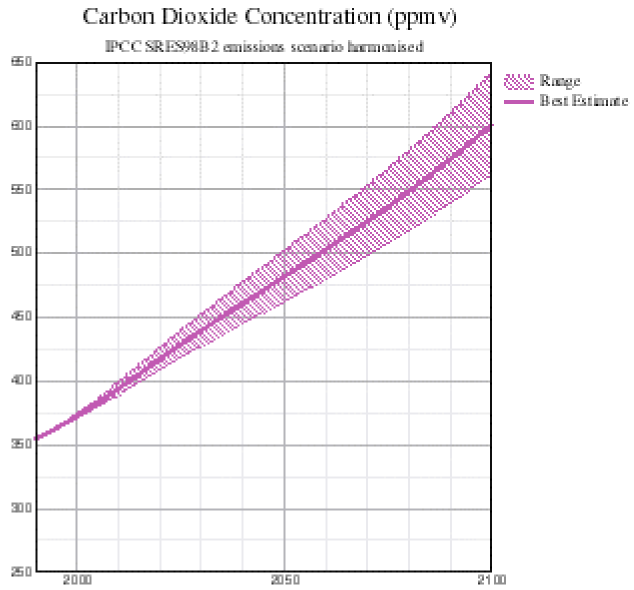


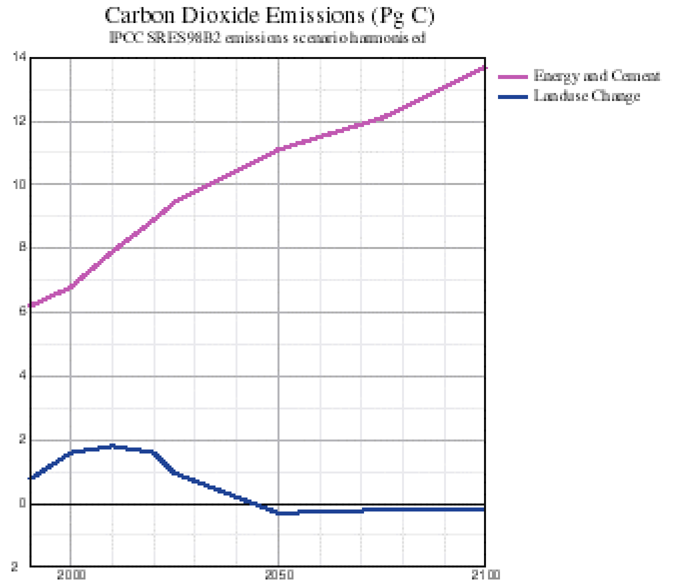


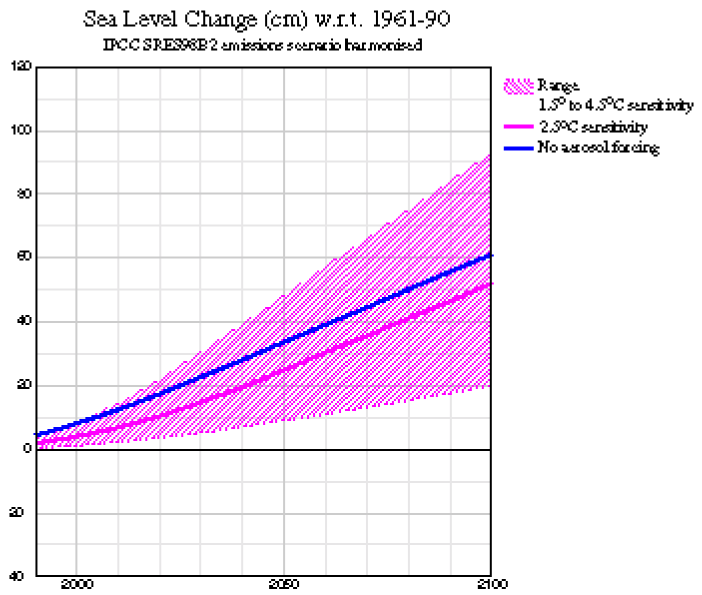


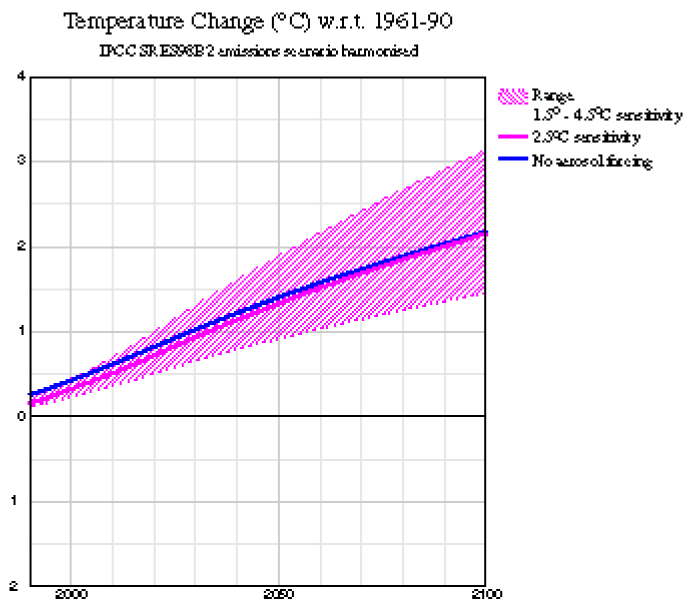


- Preliminary SRES B2: a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is again a heterogeneous world with less rapid, and more diverse technological change but a strong emphasis on community initiative and social innovation to find local, rather than global solutions









B5 Criticisms of IPCC Assessments

While the IPCC assessments are presented as representing the consensus of scientific opinion, they are by no means universally accepted by all of the scientific community. There are a number of criticisms of the selective data used and biased reporting of the assessments. The majority of these criticisms relate to climate change rather than sea level rise, but have relevance to the latter topic. Briefly these criticisms cover the following areas:

- Use of selected temperature data to exaggerate the signal of increasing temperature in the past century.
- Not a true scientific peer review of the assessments including changing of the scientific results to down play opposing views to evidence of human induced climate change.
- Lack of validation of models used in assessments with weather satellites.
- No account of natural variability and low rate of increase in atmospheric CO2 levels which indicate that CO2 levels will not double by the middle of next century as assumed in climate change scenarios.
- Problems with other assumptions in climate change scenarios regarding population growth, and future energy sources.
- Rushing to implement potentially economically damaging policies to limit CO2 emissions when the there is no significant effect of waiting at least 30 years for a clearer sign on climate change.

For future information on the criticisms of the IPCC assessment, a good summary can be found at the web site of the Chicago Heartland Institute (www.heartland.org/gray-study.htm) in a 1997 appraisal by New Zealander Vincent Gray, a peer reviewer for IPCC. One of the conclusions to this appraisal is that "*if radiative forcing continues to increase at a rate below that of all the IPCC scenarios, then temperature rises over the next century will be below all of those projections, and so below 1°C by the year 2100". If this is correct, there will be a corresponding dramatic reduction in the rate and magnitude of sea level rise*".

At the other end of the scale, some scientists still have serious fears that the Western Antarctic ice sheets are on the point of melting which could signal a 6m rise in sea level in less than a century (CHCH Press, 28/01/99)

Other recent studies indicate that global warming may not be caused by fossil fuel emissions, but could be due to changes in the sun, (BBC News, 3 June 1999). Research suggests that the magnetic flux from the sun, which is closely linked to the strength of light reaching Earth, has more than doubled this century. It is further suggested that this increase in solar activity has caused the global temperature to rise, resulting in warmer oceans which absorb less CO_2 from the atmosphere, hence resulting in an increase in greenhouse gas in the atmosphere.

APPENDIX C

NEW ZEALAND CLIMATE CHANGE SCENARIOS

AND SEA LEVEL PREDICTIONS

C1 New Zealand Climate Change Scenarios

C1.1 Salinger and Hicks 1990

Presents two scenarios for NZ climate to the year 2050 derived from the 1989 "facts" report of the NZ Climate Committee (Royal Society 1989).

Scenario 1 was based on maximum temperature 8-10,000 years ago and is considered to be the most likely scenario. The key factors in this scenario were:

- temperature 1.5 degrees C warmer than present
- lighter westerly winds(specially in winter)
- fewer rainy days in west of both islands but not necessarily less rain
- lower rainfall in Southeast of both islands
- MSL 20-40 cm higher than present.

Scenario 2 was a more extreme scenario based on upper limit of greenhouse warming. The key factors in this scenario were:

- average temperature increase of 3 degrees C above present (greater in lower South Island and in winter)
- decrease in average westerlies winds and frequent incursion of tropical air from the north
- rainfall decreases in south of both islands
- MSL 30-60 cm above present
- southern limit of tropical cyclones about 300 km further south resulting in extra tropical depressions affecting Northern NZ, particularly if southern oscillation is in La Nina phase more frequently.
- for extreme events: increased water vapour associated with higher temperature will result in increases in 24 hour rainfall intensities and increase in the probability of occurrence of these events.

Salinger & Hicks also presented regional climate scenarios for each of the 2 scenarios. For Canterbury under Scenario 1, it is suggested that there will be a mean annual temperature rise of 1.8 degrees C, a 5 % decrease in rainfall on the plains and little change in foothills and Alps, and an increase in the frequency of NE wind. Under Scenario 2 a mean annual temperature rise of 3 degrees C was predicted on the plains (2.5 degrees inland), a 5% increase in annual rainfall on higher plains and little change elsewhere, and a marked decrease in frequency of westerly winds with coastal easterlies and NE more frequent.

C1.2 IPCC 1997: The Regional Impacts of Climate Change: Australasian

The impacts presented in this report are derived from Australasian climate change modelling presented in Whetton, Mullan & Pittock (1996). The modelling involved downscaling of AOGCM results to take account of New Zealand topography and vast expanse of surrounding ocean. The resulting key projections for coastal processes included:

- Temperature increase of 0.5-1.5°C by 2030, and 1-3°C increase by 2070.
- An increase in the strength of the mid latitude westerly winds, and hence increased rainfall on the west of the Southern Alps and less on the Canterbury Plains
- An increase in water vapour and deep convection activity resulting in increased intensity and frequency of heavy rainfall events. The resulting predictions of change in the average return period of point-based heavy rainfall events was for up to a halving of the return period by 2030, and up to a four-fold reduction in the return period by 2070.
- Suggestion that the frequency of low-pressure troughs and depressions passing over NZ might increase slightly.

It is notable that these models predict an increase in the strength of westerly winds over New Zealand, whereas previous scenarios predicted a decrease. From a Canterbury coastal processes point-of-view, this suggests that the previously predicted decrease in wave energy from southerly approach directions is unlikely, and that predominant northward littoral drift is likely to persist.

Whetton, Mullan & Pittock (1996) note that there is not enough knowledge to predict whether frequency of tropical cyclones in South Pacific will change or how far further south they may track. This is a retraction on the more definite predictions of Salinger & Hicks in this area. Whetton, Mullan & Pittock also note that the models are unable to reliably predict the interaction of El-Nino-Southern Oscillation phenomenon with climate change.

C1.3 Initial Sea Level Projections: 1986 – 1988

The initial estimates of SLR for New Zealand were generally based on northern hemisphere predictions. These included:

<u>Gibb (1986)</u>
Suggested that for planning purposes, NZ should expect accelerated global SLR of: 0.2-0.3 m by 2025, 0.5-0.7 m by 2050 ,and 1.1-1.8 m by 2100.

<u>Gibb (1988)</u>
Based on the mean global rate of SLR obtained from averaging the results of 9 international authors, recommended that planners, mangers and developers allow for SLR of: 0.5 m by 2050, and 1.5 m by 2100.

The first reference to SLR from New Zealand data appears to be in Gibb & Aburn (1986), who based on the tide gauge record at Auckland and Wellington Ports, suggested that sea level was rising at a rate of 1.6 mm/year since 1900. While this compared favourably to the average global rate over the same period, Gibb & Aburn went on to suggest that the rate of rise has been accelerating since 1944, with the Auckland gauge showing a rate of rise of 2.59 mm/year from 1946 to 1985. Kirk (1988) noted that this interpretation was based on data collected for other purposes (tidal records) in enclosed harbours which have long-standing deficiencies for recording long-term changes in sea level.

C1.4 Hannah: Sea Level Projections for 1988 and 1989

The first comprehensive review of sea level trends in New Zealand was undertaken by in 1988 by John Hannah of the Department of Land & Survey Information, which involved a detailed analysis of the historical mean sea level trends from New

Zealand's four main ports (Auckland, Wellington, Lyttelton & Dunedin). This included confirming the accuracy of each of the records by checking the survey datum's used, and taking into account tectonic and wharf submergence considerations. The results from this analysis were then extrapolated to give predictions of MSL in the future under two scenarios:

1. continuation of past trends since 1900, and
2. the contribution of ocean thermal expansion associated with a 3°C increase in temperature.

The results from this analysis and extrapolation were further refined in Hannah (1989). The following points briefly summarises the results:

- All ports show a statistical significant linear rate of SLR since 1900, averaging 1.7± 0.23 mm/yr. based on records from harbours. Lyttelton had a higher mean SLR of 2.3 ± 0.17 mm/year
- No evidence to support acceleration in the rate of SLR since 1950.
- Suggests that SLR in NZ is reduced by 1mm/yr due to effect of glacial isostatic rebound (the slow up rising of land in post glaciation due to reduction in weight loading of land elevations. This adjustment should be used when applying global estimates of SLR to NZ.
- Extrapolation of existing trends for Lyttelton gives the following SLR in relation to 1990 levels.
- 2030: 0.07m (Range 0.06-0.08m)
- 2070: 0.14m (Range 0.13-0.16m)
- 2100: 0.20m (Range 0.18-0.22m)
- Including a component for the effect of climate warning on thermal expansion, small glacier and Greenland ice melt associated with a 1°C temperature rise by 2025 and a 2°C temperature rise by 2050, Hannah suggested that NZ should plan for SLR of 0.07-0.17 m by 2025, and 0.17-0.35m by 2050.

These predictions were used in the preparation of the first New Zealand climate change impact scenarios (Salinger & Hicks, 1990). It is also notable that these predictions by Hannah in 1989 are in the range of predictions from IPCC 1995.

C1.5 Previous Assessments of Canterbury Coastal Impacts

Hicks (1990), notes that there is some uncertainty in Hannah's figures owing to his method of calculating SLR components from melt of the Greenland and West Antarctic ice-sheets (using a higher average temperature rise of 3°C) which are likely to result in an over-estimate of sea level rise.

Hicks (1990) assessed the main coastal impacts for each region of New Zealand. The following are the key points from the assessment for Canterbury.

- Existing rates of cliff erosion and gravel barrier beach retreat will tend to increase with SLR
- The heights of shingle barriers will increase, thereby indirectly increasing flooding and drainage problems in adjacent lowlands
- A greater frequency and duration of river-mouth and lagoon closures requiring artificial openings
- Sandy pocket beaches of Banks Peninsula should tend towards stable shorelines as historical accretion is offset by SLR
- The sandy shore of Pegasus Bay, which has historically been stable will retreat with SLR. However the rate of retreat will depend on sediment supplies from the Waimakariri, sediment trapping in the estuaries, storm frequencies and beach profile and planform adjustments to a stronger north-east wave wind regime.
- The lower Waimakariri flood protection scheme will be less effective
- Major drainage, flooding, and salt-water intrusion problems in Christchurch
- Reduced freeboard on wharves at Lyttelton, and increased dredging requirements from increased catchment erosion.

APPENDIX D

COUNCIL RESPONSES – CLIMATE CHANGE ACTION/POLICIES

APPENDIX D

COUNCIL RESPONSES – CLIMATE CHANGE ACTION/POLICIES

Maurice Hoban – Auckland City Council
Telephone conversation:
ACC have not broached the issue in any plans at all, although they are aware of the potentially significant impacts for the city assets. Their State of the Environment report recommends the need to investigate trends in climate change and provide for effects. However, methods are limited to lobbying ARC for action rather than taking the initiative themselves. The council are considering reviewing the natural hazards section of their plan, but there is no budget, and the topic of climate change impacts has not been discussed at a council level to date. Would be very interested in the results of the CCC study to spur action in ACC.

Trevor Mackie – North Shore City Council
Email response:
North Shore City Council has included a policy in its Proposed District Plan:
"8.3.1 Policy 16 By restricting development in locations which may be subject to any effects of a rise in sea level."

The policy is to be implemented by rules in the Plan. This includes management of flood plains, and effects of development on the natural character of the coastline. The Council has very little information on sea level rise and the policy has not been used to my knowledge apart from the stormwater catchment management aspects.

Harvey Brookes – Auckland Regional Council – coastal
Email response:
“You will be aware that our concern relates to the impact of climate change on sea level, and also on the occurrence of extreme events such as storms and their resulting wave and surge.

The direction established in our RPS was the take into account the most recent findings of the IPCC in relation to predicted accelerated sea level rise. Of course the IPCC predictions are rather fluid, and the '95 predictions for sea level were 26% lower than the first assessment in 1990. New predictions are expected in 2000, and all indications are that they will point to a more refined figure based on better GCM's (Global Circulation Models), and a better understanding of the relationships between the atmosphere and anthropogenic aerosols (esp sulphur, which has a negative effect on surface temperature). The '95 predictions are detailed and you are best to go to the IPCC web site to see the full report, but its conclusions include a best estimate rise in mean surface temp of 2 degrees by 2100 (relative to 1990) with a lower range of +1 degree. Best estimate sea level rise is +50cm by 2100 and to the same degree beyond. The IPCC scientists are confident with their predictions at a hemispheric and continental scale, but not so at finer scales, and less so for hydrological predictions - the net effect of which is to have real doubts as to the local effect of the enhanced greenhouse effect on coasts in an area such as NZ.

It is interesting to note that the IPCC predicted rates are now not that much above the measured rates of SL rise for the Port of Auckland as reported by Hannah (1990), who reported a rise of about 1mm p.a without any real evidence of an enhanced rate up until that time. Hannah estimated on this basis a rise of between 0.2-0.4 by 2050, which would be pretty close to the predicted 0.5 by 2100.

The ARC's view is also that sea level rise will most immediately affect low lying areas, and will also likely only have a slight to moderate effect elsewhere where it will slightly affect the dynamic envelope of beach change, and will, in all likelihood, be at least partially masked by natural variability. Any effect will most likely be manifest during storm events where a higher still water level will increase storm water penetration inland.

The proposed coastal plan (August 1998 version post committee decisions) at chapter 21 (natural Coastal hazards) (clause 21.4.8) states "In assessing the effect that a rise in mean sea level may have on subdivision, use, development and protection of the coastal environment, the best available estimate of mean sea level rise for the locality in question shall be used" (p 21-4).

The assumption made at present is that IPCC estimates are a reasonable indication of global trends, but its also accepted that they don't provide too much assistance at the very local level- hence the reference also to Hannah.

As to your other questions, [Does ARC have a specific committee or course of action to address or deal with climate change impacts, particularly as regards avoidance and mitigation of these impacts? Has ARC addressed issues of the potential loss of coastal environments/habitats, the potentially huge increase in the need for coastal protection works, and saltwater intrusion into aquifers?] they are all very good questions for which I suspect the ARC response has been rather limited. So far as I am aware there is no committee looking exclusively at this problem, and there is no policy of a more specific nature than above. The political response here has been very much the same as that taken towards the "precautionary approach" (i.e if there is any uncertainty or dissension on this issue (even from outside the scientific community)) then it becomes politically blacklisted and the Council will not lead the charge so to speak (hence the mealy nature of the above policy).

Nevertheless, the professional advice we have on coastal response ranges from the highly theoretical (applying the Bruun rule which makes really really big assumptions and in effects multiplies the errors in the SL estimates out of the roof) through to the view of Bob Kirk that there is no acceleration- that the past century or two of SL rise have caused no real problems and that people adapt if the change is gradual enough etc. So in that respect I would tend to support the political position that there is no real scientific/management consensus in NZ that justifies a firm stance on way or another.

Whether some of our coastal erosion problems are in fact SL rise induced problems is probably a good question, and one which has not been at all well addressed by anybody. Clearly in the urban area of Auckland there is no real room for adjustment and the chance of people moving out of eroding areas and relocating or abandoning assets is low. Indeed, most of our urban coast is already peppered with engineering structures.

In less developed areas I think that the impact may be less significant- esp in estuaries where the transitional zone betwen land and water is often large in any case. What we are now trying to do is to get ahead of urban development, and determine the extent to which factors such as SL rise create hazardous areas on the coast- and then manage those areas by avoiding development and/or enhancing their natural function as a buffer. We have almost completed a coastal hazard strategy to begin this process.

So, while we are not charging out there and doing it all so to speak, I don't think we are entirely waiting to see what happens."

Debra Yan – Auckland Regional Council – Air Quality
Email Response:
"The ARC does not have a specific committee dealing with climate change. Specific policy is set out in the Proposed Auckland Regional Policy Statement in Chapter 10 - Air Quality. Our policy on ozone depleting substances basically supports any measures undertaken by central government set out in the Ozone Layer Protection Act 1990. The methods to this policy relate to an education program e.g. promote awareness of adverse effects, promote good housekeeping practices in industry.

The policies for greenhouse gases seek that trade or industrial operators adopt measures that reduce the discharge of CO_2, and that greenhouse gas offsets shall be promoted. This is also linked to policies in Chapter 15 - Waste. The methods to these policies include the ARC's promotion of energy efficiency measures, an advocacy role and investigation into methods for promoting the use of equitable, sector based offsets for greenhouse emissions.

At this stage we have not commissioned any studies or produced any reports, however we will be drafting a regional plan for air in the near future. I would expect that additional work will be carried out in the future. I guess we are taking a wait and see approach, waiting for central Govt etc. However, we have dealt with 2 major consents (Southdown & Contact Energy power stations) and in both consents we specified conditions on CO_2. This issue was covered comprehensively in both consents."

Andrea Marshall – Manukau City Council – Acting Manager of Environmental Monitoring
Email Response:
"Manukau City Council has undertaken very little work with regard climate change. The Council's State of the Environment Report, which is to be launched on 8 April, does however make some reference to climate change as an issue. I will make arrangements for the relevant chapters to be forwarded to you once they become available from the printers."

Max Griffiths – Thames Coromandel District Council
Telephone Conversation
So far the council have had very little response to climate change impacts. They are taking the approach of "take it as it comes". In terms of land management rules, they have coastal and river/stream set backs, requiring that buildings in certain areas are removable, and floor levels in some areas. However, climate change in general is not seen as a high priority for policy or regulation, and coastal erosion as a result of sea level rise has not specifically been provided for.

Chris Turbott – Environment Bay of Plenty
Email Response:
"There is some very general policy on page 103 of our Proposed Bay of Plenty Regional Policy Statement Version 9a. There are also some general advocacy and education methods regarding green house gas emissions in the Proposed Bay of Plenty Regional Air Plan.

The Proposed Regional Coastal Environment Plan contains specific policies promoting the identification of coastal hazard zones in district plans and allowing for sea level rise in the calculation of coastal erosion and coastal flood hazards. These provisions have been controversial.

I gather that our operations staff are taking into account sea level rise and possible changes to rainfall intensity in their design and maintenance work on the major flood protection schemes."

Marie Willetts – Environment Bay of Plenty
Email Response:
“The relevant pages from the Proposed RPS are included below. There may be a few minor changes as a result of negotiations to settle references to the Environment Court.

7.3 Objectives, Policies and Methods

7.3.1 Global Issues

7.3.1(a) Objective

Within the Bay of Plenty Region the adverse effects of greenhouse gas production and the release of ozone depleting substances will be avoided, remedied or mitigated.

7.3.1(b) Policies

7.3.1(b)(i)
To promote public awareness and improve understanding of the processes and activities that have an impact on the production of greenhouse gases and ozone depletion.

7.3.1(b)(ii)
To encourage land use practices which minimise the release and maximise the uptake of greenhouse gases.

7.3.1(b)(iii)
To encourage waste management practices which minimise their greenhouse effect.

7.3.1(b)(iv)
To encourage urban design and form which takes into account factors aimed at reducing fossil fuel consumption.

7.3.1(c) Methods of Implementation

Environment B·O·P and District Councils are encouraged to:

7.3.1(c)(i)
Ensure that their own contributions to the greenhouse effect and ozone depletion are minimised.

7.3.1(c)(ii)
Promote energy conservation and efficient use of energy to mitigate net greenhouse contributions.

7.3.1(c)(iii)
Ensure that the effects of transportation on the environment are taken into account when assessing urban development options.

Environment B·O·P will:

7.3.1(c)(iv)
Support, where appropriate, the development and implementation of initiatives, policies and standards to control the emission of greenhouse gases and ozone depleting substances.

7.3.1(c)(v)
Identify the major sources of ozone depleting substances and greenhouse gases in the region.

7.3.1 (c)(vi)

Seek from central government, information on methods of reducing emissions of greenhouse gases and ozone depleting substances.

7.3.1(c)(vii)

Promote, to the regional community, ways of achieving efficient fuel use and reducing fuel consumption, and the [use of alternative fuels].

7.3.l(c)(viii)

Advocate to central government the need to promote [alternatives to fossil fuels].

7.3.1(c)(ix)

Facilitate interaction between Environment B·O·P, district councils, Transit New Zealand and major road user groups with the aim of developing strategies and adopting technologies which will minimise greenhouse gas emissions.

7.3.l(c)(x)

Encourage the planting of sustainably managed plantation forests on suitable land.

7.3.1(c)(xi)

Disseminate information on the effects of greenhouse gas emissions and measures available to mitigate those emissions.

7.3.1(d) Explanation/Principal Reasons

It is now widely believed (although there is some scientific debate over the matter) that increases in the concentration of greenhouse gases as a result of human activity may lead to global climate change, commonly referred to as the greenhouse effect. Possible consequences include rises in sea-level and changes in weather patterns. Recently, it has also become apparent that natural destruction of ozone is being aggravated by human activities, namely the production of chloroflurocarbons. The human health consequences of ozone depletion may include increases in skin cancer and in eye disease. Stock will be particularly vulnerable to increased ultraviolet radiation due to high levels of exposure. Moreover, the life-supporting capacity of Earth may be compromised as all living things become overexposed to damaging radiation.

While the extent and rate of these consequences is still widely debated, the possible consequence should be addressed while the option to do so is still available. Many "good housekeeping" options are practicable and beneficial in their own right. Climate change and ozone depletion are both global issues which must be addressed by resource managers world-wide. This will involve changes in resource practices at a 'grass roots' level; the maxim "think globally – act locally" must apply and regional action is therefore appropriate.

Air is a collection of gases and moves from place to place, from region to region and around the globe. For this reason, air management can not halt at regional boundaries. For global problems, global and national initiatives (such as reduction in the release of ozone depleting substances and the use of fossil fuels, and changes in land use and waste management practices) can be used as guidelines for council policies. For example, the flaring of landfill gases significantly reduces the greenhouse effect from that of methane to that of carbon dioxide. Identifying the size of the region's contribution to these global problems (i.e. identifying the sources) is important to this process, and must be coupled with the minimisation of the production of greenhouse gases and ozone-depleting substances."

Peter Blackwood – Manager Technical Services – Environment Bay of Plenty
Email Response:
The following are the ways global warming is being incorporated in the Bay of Plenty:

1. Building platforms: In areas subject to coastal inundation (both estuarine and open coast) include the 1995 IPCC IS92A 100 year SLR estimate of 0.49 m. This being added to the estimated 2% AEP inundation level from storm surge, tide, estuary effects (differential effects from wind stress across enclosed estuary plus dynamic effects), wave runup plus 0.5 m freeboard.

2. Stopbanks and Floodwalls: In previous designs (late 80's early 90's) 0.14 m was incorporated for SLR to 2020. Current practice would be to include a minimum of 0.20 m (1995 IPCC IS92 A 50 year SLR) on both floodwalls (generally regarded as 50 year design life - although some may well last longer) and stopbanks; and 0.49 m where practicable. Factors to determine whether 50 year or 100 year include both difficulties (engineering wise, space, cost) in achieving 100 year SLR provision now and opportunities for subsequent upgrade

3. Stormwater: Tauranga District Council are adding 8% to HIRDS estimates to account for global warming for design of stormwater reticulation.

4. River Scheme Design Discharges: Currently provision is being made for the non-representativeness of the "benign" period of some our short-term records (abruptly shattered by some large flood events July 1998). However, we are not explicitly including an intensification factor for global warming at this stage. We are however, most interested in whether a trend for inclusion of some global warming factor is developing in NZ.

5. Bridges: In locations affected by sea levels (downstream boundary condition) 100 year SLR of 0.49 m included.

The building platform standards are in the Proposed Regional Coastal Environment Plan. The bridges will be included in the Proposed Regional Water Plan. Being an engineer I am uncertain exactly what the RPS said on this. Stopbanks and floodwalls are generally internal TS Policy – although we are yet to formulate how we will handle private/District Council applications.

Tony Seymour – Gisborne District Council
Telephone Conversation:
This council has quite a bit of policy direction on climate change. They have decided on a prescriptive policy framework for the Proposed Regional Coastal Environment Plan, predominantly in the natural hazards section of the plan. These policies have been well received, with no submissions in opposition and only one which wanted to amend the policy. Essentially they revolve around the establishment of coastal hazard zones which will be re-evaluated as new information on sea level rise, storminess, storm surges, etc. comes to light. They have used the IPCC estimates of sea level rise, and will continue to focus on this data as the primary source of information as the estimates are updated. Their district plan also includes land use rules which relate to climate change impacts such as floor levels and setbacks.

Rowan Wallace – Napier City Council
Telephone Conversation:
There is no reference to climate change *per se* in the City Plan. However, there was a coastal hazard study done investigating a 100 year period which included an assessment of likely change in MHWS marks, although this was not specified as change resulting from anthropogenically induced sea level rise. The council perceives the city to have a coastal erosion problem rather than a climate change problem and have identified a coastal hazard line or area on planning maps. Within these areas they originally prohibited subdivision but buildings were permitted if the applicant could prove that the building would not accelerate coastal erosion through a s36 notice on the title. However, the Environment Court has reversed this to allow subdivision but prohibit buildings (Foreworld vs Napier City Council, c. October 1998).

Liz Lambert – Hawkes Bay Regional Council
Telephone Conversation:
HBRC have general policies in the Coastal Environment Plan. These specify that when the council is undertaking its coastal management role (eg auditing resource consents), it must have regard to coastal hazards including tsunamis, coastal erosion and sea level rise. In addition, a second policy specifies that the council must encourage TA's to do the same when carrying out their roles in land management near the coast. The RPS has a general policy with regard to avoiding further coastal development, and taking into account coastal hazards when assessing development proposals, including sea level rise.

Geoff McNeill – Planning Manager –Manawatu-Wanganui Regional Council
Telephone Conversation:
The council has not commissioned any studies and have no specific policies dealing with climate change. They have conducted an air emissions survey which found that vehicles and livestock were the largest contributors to the regions greenhouse gas emissions. However, they have decided that trying to tackle the issue at a regional level is pointless, so have adopted an approach of supporting the national strategy to the problem. With regard to specific issues such as coastal erosion, coastal residential development and coastal ecosystems, the region has mainly rapidly prograding coastlines due to the effect of the main rivers (Whanganui and Manawatu) and therefore the issues facing Christchurch City are not necessarily applicable in the M-W region.

Eleanore Jamieson – Wellington City Council
Telephone Conversation:
Is not aware of anything referring to climate change, sea level rise or other impacts in the city plan. It may be mentioned but if so, it will be superficial coverage and not a serious issue for the city in terms of natural hazards compared to the earthquake and river flooding risks.

Rachel Scott – Wellington City Council
Email Response:
We rely on up to date information regarding climate changes in terms of disaster planning and response activities but do not produce this information ourselves. We depend heavily on information provided by the likes of the Met Service and the Wellington Regional Council, and have used this information over the past two years to determine likely effects on Wellington City from El Nino and La Nino in particular and factored this information into any disaster planning activities we have undertaken.

Michael Green – Wellington Regional Council
Email Response:
"The purpose of the report [that I am writing] is to review the available information on climate change. Now, as you know this is a huge job so I have called it a brief review! The report looks at climate change and its effects at a global scale, examines some of the politics and international requirements on NZ. It describes some of the likely effects on the Wellington Region in a fairly general sort of way.

There has been no specific work looking specifically at climate change. Despite this climate change is addressed in the Reg. Policy Statement and Reg. Air Quality Management plan. I suggest you have a look at these on our web site (www.wrc.govt.nz). An emissions inventory has been prepared for the Wellington Region of Industrial and Mobile sources of CO_2/NO_x etc and a Domestic Sources Inventory is due in a couple of months. Floodplain Management Plans consider climate change with respect to building in allowances for sea level rise in floor levels estimates and design of works structures. Monitoring of gravel profiles and gravel extraction in low parts of the rivers is a good way of seeing how rainfall and flood events relate to changes in climate (rainfall distribution/intensity etc.)"

Paul Sheldon Monitoring Co-ordinator – Nelson City Council
Email Response:
"While there have been a number of discussions on the issue Council does not have many specific policies related to climate change. The most developed would be the chapter of the Regional Policy Statement which deals with greenhouse gasses. I have attached a word file containing the appropriate chapter to this reply. The other area where climate change has been taken into account in our combined district/regional coastal plan where minimum floor levels have been set taking into account potential sea level rise."

Tide Levels (m)				
	Tide Gauge	**NCC Datum**		**Notes**
Max Predicted Spring Tide	4.60	14.40		
Max Tidal Surge	0.60	0.60		1
Current Max Tide Level	5.20	15.00		3
Predicted Sea Level Rise by 2050	0.30	0.30		2
Tide Level 2050	5.50	15.30		
Minimum Ground and Floor Levels (m)				
	Ground Level	**Concrete Floor**	**Timber Floor**	
Tide Level 2050	15.3	15.3	15.3	
Safety Margin	0.05	0.2	0.35	
New Standard	15.35	15.5	15.65	4
Allowance for Wave Set	0.2	0.2	0.2	
Standard for Monaco Peninsula	15.55	15.7	15.85	5
Notes:				
1. Tidal surge produce by northerly winds and low pressure fronts. This is the combination that produces Nelsons worst rainfalls. Tidal surge of 650mm was measured in 1994.				

2. Ministry for Environment are forecasting 600mm rise in 100 years.			
3. Maximum tide level recorded reached 14.92 (NCC Datum) in 1929.			
4. Very little of Nelson has direct frontage to the sea. The boulder bank, airport and state highways act as abuffer against wave action.			
5. Monaco Peninsula is within the Waimea Estuary. Potential for wave action is not significant.			

Rose Biss – Tasman District Council
Telephone Conversation;
TDC have one Resource Management Plan. They have a coastal environment zone within which buildings need consent if they are within 200 metres of MHWS. Sea level rise is specified as a potential impact in the reasons/explanation for the creation of the zone, (Ch18.14.5). In addition, the Natural Hazards chapter mentions sea level rise in the explanation for its coastal hazard lines, but more emphasis is placed on coastal erosion as TDC have a large proportion of eroding coastline including spits and rock armoured protection. The council are addressing erosion trouble spots as they present themselves rather than taking a long term approach to climate change. In addition, they will adopt the MfE information on sea level rise in assessments based on the plan rules. The RPS has no specific mention of climate change.

Jon Cunliffe – Marlborough District Council
Telephone Conversation:
Suspects that there is no mention of climate change in general or specific impacts in either of their Resource Management Plans (Sounds, Wairau-Awatere). In terms of measuring any changes, MDC are looking to national agencies to collect data, analyse and report on climate change and climate change impacts. MDC are really only trying to put in place some method of keeping in contact with these information gatherers rather than collecting the information themselves.

Wayne Harrison – West Coast Regional Council
Telephone Conversation:
Currently the council have a Proposed Air Quality Plan and a Proposed Regional Policy Statement. The Air Quality Plan (an 83 page document) has 5 ½ pages devoted to climate change, specifically looking at greenhouse gas emissions and ozone depleting substances. The main methods proposed are education, advocacy and reduction efforts. However, one of the methods focuses on the assessment of potential environmental effects of climate change on the region, although the method of assessment and timeframe are not specified.

The RPS originally had some 2-3 pages dealing with climate change impacts, but this has been reduced to a “token” mention of the topics potential impacts on the region and supporting efforts at a national level. There is some opposition within council about concentrating any effort on climate change impacts. This is due to some councillors questioning the credibility of the science to date with regard to whether there is any climate change at all. This has had a significant impact on how the council has addressed the topic in their policy documents to the extent that climate change is effectively a non-issue for the region. However, there is an awareness of climatic instability and potential sea level rise impacts given that there are some areas of active coastal erosion directly effecting residents.

There is the possibility of the council developing a strategy on natural hazards within the next few years which will deal with erosion, sea level rise and storm frequency, but councillors have not yet been approached about this.

Richard Keyes & Brian Caruso – Otago Regional Council
Telephone Conversations:
The regional council has a Coastal Environment Plan which requires the council to "have regard to" global warming and sea level rise, but nothing more significant than that. There are no coastal hazard zones or other measures which take sea level rise or other climate change impacts into account. In addition, the RPS mentions climate change with regard to keeping a watch on the IPCC data, but the coverage of anthropogenically induced climate change impacts is very superficial and it is not considered to be a major issue for Otago in comparison to the focus on natural hazards.

NIWA have been contracted to produce a report on local climate variability and change. NIWA already produce a national publication using FORST funding to which organisations can subscribe. However, ORC wanted a better regional climate focus, as they perceived that there was considerable interest in climate variability by landholders. NIWA have been contracted to take their national information and focus it on Otago's microclimates. This information is put into a brochure which ORC regularly send out to interested land holders. NIWA are also putting together comprehensive reports concentrating on climate variability and change, particularly with regard to the drier conditions expected with global warming in the Otago Region.

Stewart ? – Invercargill City Council
Telephone Conversation:
While there is a reference to sea level rise in the Regional Policy Statement, the city council has taken very little if any other action with regard to climate change impact policies for the city, and is unlikely to in future unless significant impacts begin to present themselves.

Ken Swinney – Southland Regional Council
Telephone Conversation:
Nothing substantial being undertaken with regard to climate change impacts. The council are considering piggy-backing on the NIWA climate reports being commissioned by Otago Regional Council. The Coastal Environment Plan and RPS do require a regard for sea level rise, but there are no coastal hazard zones which take climate change impacts into account or any provision for coastal protection works. Copies of RPS relevant sections were faxed.