DUNEDIN CITY COUNCIL
Kaunihera-a-rohe o Otepoti

Report

TO: Finance and Strategy Committee

FROM: Sustainability Co-ordinator

MEETING DATE: 26 April 2010

SUBJECT: **CLIMATE CHANGE REPORT AND SUSTAINABILITY UPDATE**

SUMMARY

This report presents the 'Climate Change Impacts on Dunedin' report by Emeritus Professor Blair Fitzharris, an internationally renowned climatologist who also has a thorough understanding of Otago conditions.

The Climate Change Impacts report is a key action in the Sustainability Framework work programme.

It is proposed that the Council respond to the Climate Change report by:

- Adopting the report so that it can be used for planning purposes
- Updating the existing Climate Change Policy 2006 with information from the report

It is proposed that staff formulate a way forward for adaptation to the impacts of climate change, reporting via the Community Sustainability Panel to the Finance and Strategy Committee.

An update is also provided on progress on the development and implementation of the framework. Awareness raising of environmental issues is a part of the Sustainability Work Programme. The Committee's agreement is sought to support the 10/10 Global Working Party event in October 2010, this year's community awareness raising event following the 350 International Day of Climate Action in 2009.

IMPLICATIONS FOR:

(i) **Policy:**	Yes – the work will result in a review of the Climate Change Policy 2006. Review of other policies and strategies may eventually be required depending on the outcome of the process.
(ii) **Annual Plan Budget:**	No
(iii) **LTCCP/Funding Policy:**	Yes - for 2011/12 and beyond. The community engagement programme involves priority setting and developing actions for sustainability which will need to be incorporated into future LTCCP's.
(iv) **Activity Management Plans:**	Yes – a sustainability checklist will be incorporated in Activity Management Plans in 2010/11 and beyond. Application of sustainability principles should improve organisational efficiency and achieve cost savings.
(v) **Community Boards:**	Yes – the intention is to involve the Boards in determining sustainability goals and priorities for the city.

RECOMMENDATIONS

1 That the "Climate Change Report and Sustainability Update" report be received.

2 That the "Climate Change Impacts on Dunedin" report (Attachment Three) be adopted by Council for planning purposes.

3 That the Committee agree to the Climate Change Policy 2006 being updated with information from the Climate Change Impacts on Dunedin report.

4 That the Committee endorse the 10/10 Global Working Party event as part of the awareness raising component of the sustainability work programme.

INTRODUCTION

This report presents the 'Climate Change Impacts on Dunedin' report by Emeritus Professor Fitzharris (Attachment Three), and proposes that a Climate Change Adaptation Group be set up to determine and lead the process of adaptation. The report was a key action from the Sustainability Framework and an update is provided on progress against other actions from this work programme.

BACKGROUND

Sustainability Framework

The climate change impacts research is part of the work programme to progress the Council's sustainability framework. As agreed in September 2009, the work programme comprises the following four elements:

A Awareness Raising
B Baseline Analysis
C Vision
D Action Programme

The climate change research is a key element of the baseline analysis work stream. A full update of progress in developing the framework is attached in Attachment One.

The further development of the Sustainability Framework through the agreed work programme will have numerous benefits for Council. It is likely that the Council will save money through reduced and more efficient resource use, particularly as many resources are becoming increasingly expensive, partly due to scarcity but also to policy responses such as the Emissions Trading Scheme. Continued implementation of the framework shows a strong response by the Council to a community who have indicated they want a Council that is 'socially responsible'. The Council will also be well positioned to manage compliance with likely future legislation. The signals are that this area will become more important over time.

Climate Change Policy

The Council has a Climate Change Policy, adopted in 2006 (Attachment Two), which contains projections for temperature, rainfall and sea level rise, based on the Intergovernmental Panel on Climate Change (IPCC) Third Assessment. This assessment has now been superseded by a Fourth Assessment.

In order to understand what this might mean for Dunedin, Emeritus Professor Blair Fitzharris was selected to undertake a review of the IPCC Fourth Assessment plus more recent research in order to produce a report detailing 'Climate Change Impacts on Dunedin'. Professor Fitzharris was ideally positioned to complete this review, given his extensive understanding of both climate change, and the local climate of Dunedin. He has been Convening Lead Author for the IPCC since 1992, and led international review, assessment and writing teams that produced chapters for Assessment Reports, most notably on the topic of 'Australia and New Zealand: Impacts, Adaptation and Vulnerability'. This is part of the IPCC Fourth Assessment Report and is the most definitive assessment taken to date. His understanding of local climate is illustrated by over 30 years experience as a climatologist at the University of Otago, where he gave lectures that included climate change and local climates of Dunedin, and supervised over 40 research theses on aspects of the city's climate.

The completed report is attached. In the report, Professor Fitzharris has used his expert judgement in interpreting the latest research and trends information plus his knowledge of the local climate of the Dunedin City area, to produce a 'best estimate' of likely climate changes out to 2090, and the potential impacts of these on infrastructure, settlement, ecosystems, and the economy.

DISCUSSION

Climate Change Policy

It proposed that the Climate Change Impacts on Dunedin report be adopted by the Council effective immediately, so that the most up to date projections can be used for planning purposes, including planning of future infrastructure requirements. It is also proposed that the existing Climate Change Policy 2006 be updated with the projections from the Climate Change Impacts on Dunedin report.

The Climate Change Impacts on Dunedin report provides a wealth of information. The challenge now is to take this information and use it to identify adaptation priorities for the Council, which will include identifying areas that require further investigation and/or action. Adaptation to climate change will be required so that Dunedin continues to thrive in a changing climate, and respond appropriately to threats, but also recognise and realise potential opportunities. The Ministry for the Environment recommend that a risk management approach is taken to adaptation. It is important that the Council take time now to fully consider possible approaches, and it is proposed that this be done through the establishment of a Climate Change Adaptation Group, using the Sustainability Project Team as the core membership, and reporting to Finance and Strategy Committee via the Community Sustainability Panel. It is recommended that this group work closely with the Otago Regional Council, possibly through the Regional Climate Change Forum proposed to be established by Otago Regional Council.

Community Awareness Raising

As a part of its awareness raising objective and leadership role the Council has supported community initiatives such as Earth Hour and the 350 Global initiative on Climate Change in 2009. Sustainable Dunedin City have approached the Council via the Community Sustainability Panel seeking the Council's endorsement of the Global initiatives event being planned for 2010. The focus of the 2010 event, to be held on 10 October 2010, is on getting communities to take local action on sustainability issues. The Community Sustainability Panel recommend that the Council endorse the 2010 Global Day of Community Action ("Global Working Party") event as a demonstration of the Council's commitment to sustainability and as part of our leadership role. It is proposed that the Council offer staff support in organising the event and be advised to apply for funding through the community grants subcommittee.

CONCLUSION

Adopting the 'Climate Change Impacts on Dunedin' report is a vital step in ensuring the organisation is using the most up to date information for planning purposes. It is proposed that a way forward regarding adaptation to likely changes in climate is progressed by a Climate Change Adaptation Group. As this is integral to the Council's Sustainability Framework it is proposed that members of the Sustainability Project Team constitute the core of the Climate Change Adaption Group, with potential for other members to be co-opted as appropriate.

Prepared by:

Sarah Weller
SUSTAINABILITY CO-ORDINATOR

Approved by:	Approved by:
Nicola Johnston **GENERAL MANAGER STRATEGY AND DEVELOPMENT (ACTING)**	Tony Avery **GENERAL MANAGER CITY ENVIRONMENT**

Date report prepared: 16 April 2010

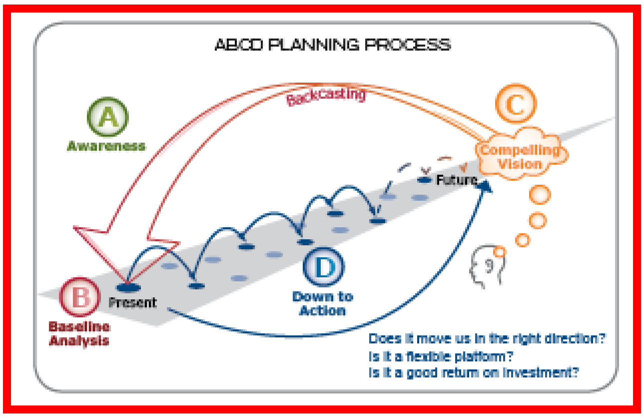
Attachments

One:	Progress Update - Sustainability Framework
Two:	Existing Climate Change Policy 2006
Three:	Climate Change Impacts on Dunedin Report by Emeritus Professor Blair Fitzharris

Progress Update - Sustainability Framework

The Sustainability Framework work programme, which was agreed in September 2009, comprises the following four elements:

- A Awareness Raising
- B Baseline Analysis
- C Vision
- D Action Programme.



The Climate change research is a significant component of the baseline analysis. Progress on the first three headings, which is the current focus, is summarised in the table below.

Table 1: Progress against actions (dark shading indicates projects have been completed).

Action	Progress
Getting Ready	
Set up Community Sustainability Panel and agree terms of reference.	Terms of reference agreed June 2009, first meeting of panel July 2009.
Step A: Awareness	
Training Programme for staff	Training workshops held in early 2009, for Councillors and CMT. Four staff attended advanced Natural Step training in May 2009. Ongoing training programme developed for 2010 and beyond.
Community Awareness Raising	Work with community groups, on awareness raising events, eg Earth Hour, 350 International Day of Climate Action.
Develop and implement Communications Plan	Draft Communications Plan being developed. Currently reviewing sustainability information on website.
Sustainability Check Box on front of Council, Committee and EMT reports.	A sustainability check box has been added to the 'Implications For' section on the front of Council, Committee and EMT reports, to ensure that staff consider sustainability implications in decision making.
Sustainability to be included in Activity Management Plans	A Sustainability Checklist has been developed and included in the 2010/11 Activity Management Plans. The checklist covers environmental, social and economic aspects of sustainability, to further embed the concept of sustainability in Council practices and the delivery of services.

Action	Progress
Investigate options for Sustainable Supply Chain Management in partnership with Otago Polytechnic.	Work with Otago Polytechnic to develop collaborative approach to Sustainable Supply Chain Management, focussed on education and support for suppliers.
Step B: Baseline Analysis	
Clarify issues raised through LTCCP consultation process	Issues analysed and summarised June 2009.
Create Assets Inventory – current initiatives, programs, policies and other actions we are already taking towards sustainability.	Assets Inventory completed November 2009.
Update NIWA's climate change predictions and assessment of effects on Dunedin.	Climate Change Projections Study released 12th April 2010.
Staff attitudes survey	Planned for May 2010, and will be delivered in partnership with the Otago Polytechnic. This will enable the Council to establish a baseline for understanding amongst staff and measure change that results from delivery of the sustainability framework.
Develop key indicators and collect baseline data.	Preliminary work undertaken assessing possible indicators during November 2009. Work put on hold until Step C is completed and sustainability goals agreed.
Evaluate stakeholder relationships.	2010
Assess likely impact of peak oil on Dunedin, using available research.	2010
Identify likely scenarios in terms of climate, sea levels and peak oil for next 50 years.	2010
Conduct a sustainability impacts assessment for DCC.	2010
Undertake purchasing audit, to inform sustainable supply chain management.	2010
Step C: Compelling Vision	
Develop a vision and goals for a sustainable Dunedin	Community Engagement as part of the joint programme during 2010 /2011 to establish vision and goals.
Step D: Down to Action	
Refine performance indicators and targets now that vision and goals are agreed.	2010
Engage with stakeholders to brainstorm opportunities for action.	This will be part of the co-ordinated 2010 /11 vision and goals process.
Screen and prioritise potential actions, prioritising first steps and quick wins. Separate community and organisational actions.	2010
Create separate sustainability action plans for community and organisation.	2010/11, although work has already started on the Decision Making Framework and inclusion of Sustainability in AMPs, which were identified as key projects, that would make a significant impact.
Actions to be assessed at the department level for alignment and integration with work-plans and other tools or initiatives, cost-effectiveness, opportunity and capacity.	2011
Continuing the Journey	
Ongoing implementation of action plan and integration of sustainability concepts.	Ongoing
Ongoing awareness raising and training	Ongoing
Ongoing monitoring	Annually
Periodic reviews of the plan	Every 5-10 years

Climate Change Predictions Policy

On 30 October 2006, the Dunedin City Council adopted the following predictions of climate change from the Intergovernmental Panel on Climate Change (IPCC). These predictions are to be used, where relevant, in all planning processes and activities undertaken by the Council, which would result in decisions, which have an effective life of greater than 50 years. Such decisions would include decisions around the renewals of existing assets, construction of new assets or facilities, all work programmes and all planning initiatives.

Any significant implications resulting from the impact of any climate change will need to be reported to the relevant Committee for full consideration.

The climate change predictions to be used are as follows:

Temperature Changes (°C)		**Summer**	**Autumn**	**Winter**	**Spring**	**Annual**
1990 – 2030's		-0.2 to 1.2	0.0 to 1.1	0.2 to 1.8	0.0 to 1.2	0.1 to 1.3
1990 – 2080's		-0.1 to 2.7	0.4 to 3.3	0.7 to 3.5	0.2. to 3.0	0.4 to 3.1
Rainfall Changes (%)						
Dunedin	2030's	-7 to +8	-2 to +3	-7 to +15	-4 to +11	-2 to +6
	2080's	+1 to +34	-9 to +46	-5 to +30	-2 to +16	+2 to +14

Sea Level Rise	**2050**	**2100**
Mean sea level increase	+0.33 metres	+0.66 metres

Examples of the sorts of consideration that will need to be given in decisions that have an effective life of greater than 50 years are as follows. Note that these are examples only and there are likely to be a wide range of potential effects that will need to be considered.

Function	**Climate Change Mechanism**	**Potential impacts**
Planning	Increase in high intensity rainfall effects	▪ Increased flood risks may require planning restrictions on flood plains etc.
	Increased sea level	▪ Planning restrictions in at risk coastal areas.
Roading	Increase in high intensity rainfall events	▪ Increase in road washouts and landslips onto roads. ▪ Increased maintenance required for water tables.
	Increased sea level	▪ Erosion of coastal roads/roadbeds. ▪ Increased closures due to sea inundation. ▪ May require road levels raised.
Stormwater	Increase in high intensity rainfall events	▪ Increased stormwater surcharging. ▪ Possible property damage.
	Increased sea level	▪ Greater reliance on pumping. ▪ Higher groundwater level impacts on underground pipe networks.
Water	Reduced annual rainfall	▪ Less secure raw water supply.
	Increased sea level	▪ Possible salt-water invasion of aquifers. ▪ Higher groundwater level impacts on underground pipe networks.

Climate change predictions are likely to change over time as new information becomes available. As any new IPCC prediction becomes available, the Council will need to consider whether this policy is updated.

ATTACHMENT THREE

CLIMATE CHANGE IMPACTS ON DUNEDIN

Report by Professor Blair Fitzharris

CLIMATE CHANGE
IMPACTS ON DUNEDIN

Prepared for the **Dunedin City Council**
by **Professor Blair Fitzharris**

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Executive Summary

Dunedin City Council is seeking an assessment of climate change impacts on Dunedin, to enable effective planning and decision making by the Council in the long term. This Report provides this assessment. It can be used to update the existing "*Climate Change Predictions Policy*" adopted by Council in 2006. It reviews and assesses new material published by the Intergovernmental Panel on Climate Change (IPCC), Ministry for the Environment (MfE) and the National Institute of Water and Atmospheric Research (NIWA).

The update can also be used as part of a sustainability framework for the Council. Given that many of the City's plans, particularly in terms of its infrastructure, are likely to extend well into the 50–100 year timeframe, it is prudent to start factoring in impacts of climate change and planning adaptation strategies. This will reduce vulnerability of future generations.

This Report provides an overview of the main characteristics of Dunedin's climate, factors controlling its climate and changes that have been observed over the last 150 years. Projected climate changes that might be expected over the rest of the 21st century are detailed and their impacts assessed for both urban and rural areas of Dunedin City. Some impacts are positive, others are negative. The report identifies sectors and communities of Dunedin City which are most vulnerable to projected climate change.

Current best estimates of projected climate change for Dunedin City are:

Decade about	2040	2090
Temperature (°C)	+ 0.7 to + 1.1	+0.8 to +2.5
Rainfall (%)	-5 to +5	-5 to +15
Sea level (m)	+ 0.1 to + 0.3	+ 0.2 to + 1.6*

*In their Fourth Assessment Report, IPCC suggest +0.6 m for the upper limit of sea level rise, but more recent research suggests a value of +1.6 m would be more prudent.

These updated projections are given as ranges, depending on the climate model used and especially on future scenarios for emissions of greenhouse gases. The amounts of warming are slightly smaller, and changes in rainfall are less variable, than those listed in the Dunedin City Council (2006) *Climate Change Predictions Policy*. Unfortunately, the upper limits for sea level rise are now more uncertain due to unknowns about future behaviour of Antarctic and Greenland ice sheets. Research since the IPCC Report suggests that loss from polar ice sheets could increase total sea level rise to between +0.7 to +1.6 m by 2090.

The factors controlling the climate of Dunedin will largely stay the same as at present. However as projected global warming takes hold, there will be: a slow increase in sea surface temperatures; an increase in the strength of the westerlies wind band over Southern New Zealand; and more frequent and vigorous frontal systems. The weather will remain changeable, but it will gradually become warmer. After the 2040s, what is currently regarded as an unusually warm year will have become the norm. Risks from frost and low level snow storms will markedly decrease.

Increased evaporation from higher temperatures is expected to be offset by higher rainfall. Thus drought incidence will remain largely unchanged from that at present for much of the Dunedin City Area, except for coastal areas north of Waitati, where it may increase until about mid century.

Intensity of design rainfall events will become about 20% greater, leading to higher storm runoff, but with lower river levels between events. Larger floods are expected, especially with a likely increase in the frequency of subtropical storms. When combined with rising sea and groundwater levels, low lying areas near river mouths and estuaries and on the Lower Taieri Plain will be especially vulnerable. The main communities affected will be Waldronville, South Dunedin, Waitati, Warrington, Karitane and Waikouaiti. Surface flooding and salinity will become more problematic in these areas as the 21st century progresses.

The Report identifies the impacts and their timing on the following sectors: agriculture; forestry; natural ecosystems; water resources; coasts (includes sea level rise and flooding); human health; industry; and settlement and society (includes section on Maori). Impacts at the sub-city scale are identified for key regions. Also considered is the impact of climate change on the potential for energy generation from renewable sources.

There are five sectors at *risk* in Dunedin City:

Main Sectors of Dunedin City at Risk from Projected Climate Change

1. Low lying densely populated urban areas, especially South Dunedin.
2. Coasts, especially near estuaries, and their communities.
3. Major transport infrastructure, mainly harbour roads and railway, but including Dunedin Airport.
4. Dunedin Airport from enlarged tides and more flooding.
5. Natural ecosystems.

Adaptation can alleviate or delay vulnerability to these risks for all sectors, except natural ecosystems.

A major conclusion is that Council should review its role in dealing with the issue of climate change. Council provides a number of services to the residents of Dunedin, which will be affected by climate change. Its planning function and responsibility will need to take account of climate change predictions and make appropriate land use planning decisions as a result.

Dunedin City will be required to make value judgements about risks from projected climate change. There will be trade-offs between:

- Meeting costs now, or delaying them for the distant future when risks will become much higher.
- Striking the right balance among economic, social and environmental benefits and costs.

Council needs to consider what role it wants to take as a facilitator, co-ordinator and educator of the community around climate change issues and initiatives. There are two main strategies: *adaptation*; and *mitigation* (reducing greenhouse gas emissions). Even with concerted global action on mitigation, the impacts of climate change and sea level rise will continue for the rest of this century.

Council should develop policy responses to climate change that give most attention to adaptation. This is because major long-term planning and infrastructure problems will result from the expected very large and ongoing impacts. While Council should encourage mitigation, less attention should be given to this issue, except where it leads to energy efficiencies or protects the city's tourist image.

Adaptation measures will reduce vulnerability and insure the city can better cope with climate variability. Many adaptation measures such as sand dune enhancement, raising roads, pumping and drainage are readily available now and need not involve new technology. Adaptation should be built into routine management and maintenance as an on-going and iterative process.

Other forms of adaptation can be proactive or planned: in some instances the Dunedin City will need to look forward by many decades, perhaps even more than a century. This is because future generations may find themselves locked into a situation where a changing climate creates increasing problems, but their ability to adapt at that time is rather limited.

There are four sectors that will *benefit* from projected climate change:

Main Sectors of Dunedin City to Benefit from Projected Climate Change

1. Agriculture and forestry due to longer and better growing seasons, less frost and increased rainfall.
2. Energy use, due to reduced demand in winter.
3. More comfortable and outdoor living as people benefit from warmer weather.
4. A larger water resource from increased stream flows.

These benefits will not accrue automatically. They can be realised by shrewd adaptation measures, but there may be barriers to their capture. Council may want to examine its policies so as to allow benefits to accrue more rapidly. Using the example of water resources, by 2040, mean annual runoff is expected to increase to 111% of present and by 2090 to 122%. However, for upland catchments, reductions in seasonal snow will lead to substantial seasonal shifts in runoff, with more in winter and less in summer. These seasonal changes may be problematic for potable water supply and irrigation, unless more storage is provided as an adaptation option.

After assessment of impacts of climate change, and considering appropriate adaptation capacity, five "hotspot" areas can be identified within Dunedin City. These are areas where vulnerability to climate change will become high sometime between 2040 and 2090.

Selection of hotspot areas is based on the following criteria: large impacts; limitations of adaptive capacity; substantial population; economically important; substantial exposed infrastructure; subject to other major stresses (e.g., continued population growth, ongoing development, ongoing habitat loss, threats from rising sea level).

Vulnerability is assessed for what is considered a likely greenhouse gas emissions scenario over the 21st century. It assumes a future world of rapid economic growth, global population that peaks in mid-century and declines thereafter, and a continuation of fossil fuel use, but also rapid introduction of a mix of new and more efficient technologies.

Five hotspot areas of Dunedin City especially vulnerable to climate change

1. The South Dunedin urban area, including the St Clair and St Kilda shoreline
2. Harbour side shoreline, including the entrance to Otago Harbour
3. The lower Taieri Plain, especially Dunedin Airport
4. Populated estuaries along the Pacific coast
5. Conservation lands of upland regions

The Report is divided into six major sections: Background; Climate; Impacts; Adaptation; Vulnerability; and Conclusions and Recommendations. It also includes a list of key References and two Appendices.

Information on Blair Fitzharris

Dr. Blair Fitzharris is Emeritus Professor of Geography at the University of Otago. He has undertaken research on climate change in NZ, Canada, Norway, UK, Switzerland and Australia. He has written over 130 research papers on the subjects of climate, topoclimate mapping, climate variability, climate change and climate impacts, including those related to sea level rise.

Blair was a climatologist at the University of Otago for over 30 years. He gave lectures that included the topics of climate change and local climates of Dunedin. He supervised over 40 research theses on various aspects of the city's climate.

Professor Fitzharris has been a Convening Lead Author for the Intergovernmental Panel on Climate Change (IPCC) since 1992. In this senior position he led international review, assessment and writing teams that produced chapters on four occasions for Assessment Reports of IPCC on the following topics: "Impact of Climate Change on the Global Cryosphere"; "Impact of Climate Change on the Arctic and Antarctic"; and "Australia and New Zealand: Impacts, Adaptation and Vulnerability". The last is part of the IPCC Fourth Assessment Report and is the most definitive assessment undertaken to date.

IPCC and Al Gore were jointly awarded the Nobel Peace Prize for 2007 ….

"*For their efforts to build up and disseminate greater knowledge about man-made climate change and to lay the foundations for the measures that are needed to counteract such change*".

Over the last three decades, Blair has acted as a consultant on climate matters for resource development projects involving many of New Zealand's largest corporations. These include the Clyde Dam, the proposed dam on the Clutha at Tuapeka, the Aramoana smelter proposal, Electricity Corporation of NZ, Meridian Energy, Department of Conservation, The former Tourist Hotel Corporation, Macraes Gold Mine, L& M's gold mining proposal at Earnscleugh, *growOtago*, *Topoclimate South*, the Holcim Cement works at Weston, proposed MDF plants on the Taieri and in Nelson. He holds research contracts with NIWA and the Ministry for the Environment. He led the climate and hydrology section of the *Dunedin City Lifelines Project Report* for the Dunedin City Council.

Professor Fitzharris is a past member of the Royal Society of NZ Standing Committee on Climate Change, a former President of the Meteorological Society of NZ and former Chair of the NZ Mountain Safety Council. He has served on numerous Science Advisory Committees for the Foundation for Research, Science and Technology, including those for Global Environmental Processes and Change, Marine Environments, Climate and Atmosphere, Land and Freshwater Ecosystems, Natural Resource and Environmental Science.

Figure 1. Typical view over part of the urbanized section of Dunedin City looking towards key impact features of this Report: shoreline of Otago Harbour, the Pacific coastline and adjacent lowland of the densely urbanized South Dunedin.

1. Introduction

1.1 Background to this Report

Dunedin City Council is seeking an assessment of climate change impacts on the area of its jurisdiction, to enable effective long term planning and decision making. This Report provides this assessment. It follows a Project Brief compiled by the DCC Corporate Policy Team late in 2009.

In order to undertake long term planning, it is important that the Council have scenarios about the effects of projected climate change. Current predictions are that changes in rainfall frequency and intensity, warming and sea level rise will all impact on Dunedin.

Given that many of the City's plans, particularly in terms of its infrastructure, are likely to extend well into the 50–100 year timeframe, it is prudent to factor in such impacts. For example, dealing with new estimates of climate and sea level extremes at the design stage is far more cost-effective than trying to retrofit measures once infrastructure has already been built. To some extent the Council is already doing this. What is needed now is a finer sieve on which to base future planning.

There is an existing "*Climate Change Predictions Policy*" (see Appendix A), which was adopted by Council in 2006. This policy was based on projections from the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report published in 2001. There are now newer and more robust projections, so Council wants to update their existing climate change policy.

The 2006 Policy noted that:

> "*Climate change predictions are likely to change over time as new information becomes available*"…
> and that:
> "*As any new IPCC prediction becomes available, the Council will need to consider whether this policy is updated*".

More recent projections and information are now available in the *IPCC Fourth Assessment Report* published in 2007, and at the regional level in '*Climate Change Effects and Impacts Assessment – A Guidance Manual for Local Government in New Zealand*' (MfE 2008c), and from NIWA (e.g. Reisinger et al. 2010).

A further requirement for this work has arisen from other pressures for the Council to clarify its approach to sustainability. Environmental changes, including climate change, highlight the need for a change in practices. Economic factors such as peak oil and volatile financial markets are other drivers.

There is a legislative requirement for Councils to deal with sustainability issues under the Local Government Act 2002, which requires that they address sustainability in their Long Term Council Community Plans. This Report forms a key part of the collection of baseline information for such Plans. Findings can be used to help develop the vision for long term sustainability and to determine actions required to achieve, or move closer to, that vision.

1.2 Scope of this Report

The update provided by this Report is based on a review of recent research from internationally robust sources, plus interpretation of this information, to give an assessment of impacts from projected climate change. The assessment is tailored to the Dunedin area.

Climate changes that might be expected over the rest of this century are described.

Their implications for Dunedin and its communities, both urban and rural, are then discussed. The Report identifies the possible main impacts of climate change. Some are positive and some are negative. The final part of the assessment rates the vulnerability of the different communities of Dunedin City.

The following aspects are included in the Report:

1. **Updated Climate Change and Sea Level Rise Projections**

   Estimates are made of possible changes in the main climatic variables and sea level rise that can be expected over the remainder of this century. Likely ranges are given for scenario decades beginning in 2040 and 2090.

   The return periods for infrastructure design which are used by Council are 1 in 10 year, 1 in 25 year, 1 in 50 year, and 1 in 100 year storm events. A preliminary assessment is made of the way in which these storm events will change by 2040 and 2090, but there are issues here that require further study.

2. **Impacts on Communities**

   The Report identifies the impacts and their timing on the following sectors of Dunedin City:

   - Agriculture
   - Forestry
   - Natural ecosystems
   - Water resources
   - Coasts, including sea level rise and flooding
   - Human health
   - Industry
   - Settlement and society, including Maori.

   Impacts at the sub-city scale are identified. Also considered is the impact of climate change on the potential for energy generation from renewable sources.

3. **Vulnerability and adaptation**

   The Report assess vulnerability of sectors and sub-regions to the impacts of projected climate change. Vulnerability is determined by the magnitude of the impact, but moderated by potential adaptive responses. The most vulnerable sectors and areas ("hotspots") are identified.

The Report does not undertake any new modeling or data analysis. Rather it is an assessment based on interpretation of an experienced climatology expert. The author is very familiar with the climate, hydrology and geography of the Dunedin area and has reviewed an extensive research literature on impacts, adaptation and vulnerability of climate change.

The information presented is designed to help Councilors and staff to further understand the effects that climate change may have on Dunedin, the impacts these changes may have, and the potential vulnerability of the various communities of Dunedin. The update can be used for other planning purposes, particularly those relating to land use planning, management of shorelines, transport infrstructure, wastewater, stormwater and water management.

1.3 Study Area

The study area follows the Dunedin City Council boundaries as illustrated in Figure 3 below. The land area is 3,315 square kilometres, the largest council boundary area of any New Zealand city. The main urban area spreads around the upper reaches of Otago Harbour and surrounding hills (see Figure 2).

Figure 2. Aerial view northwards over part of Dunedin City showing from left: reclaimed land of CBD; Otago Harbour; and Otago Peninsula. Part of South Dunedin is shown in right foreground.

The City of Dunedin broadens south to Taieri Mouth and north to Waikouaiti (Figure 3). It encompasses rural areas that extend far to the west, including Great Moss Swamp, the Rock and Pillar Range, and Strath Taieri, as well as extensive farming districts and small towns north and south along the coast. The city includes the Otago Peninsula, most of the Taieri Plains and other lowland areas next to the Pacific Ocean and Otago Harbour. From the Pacific Ocean shoreline, hills and mountains rise up to the west to an elevation of 1380 m above sea level on the Rock and Pillar.

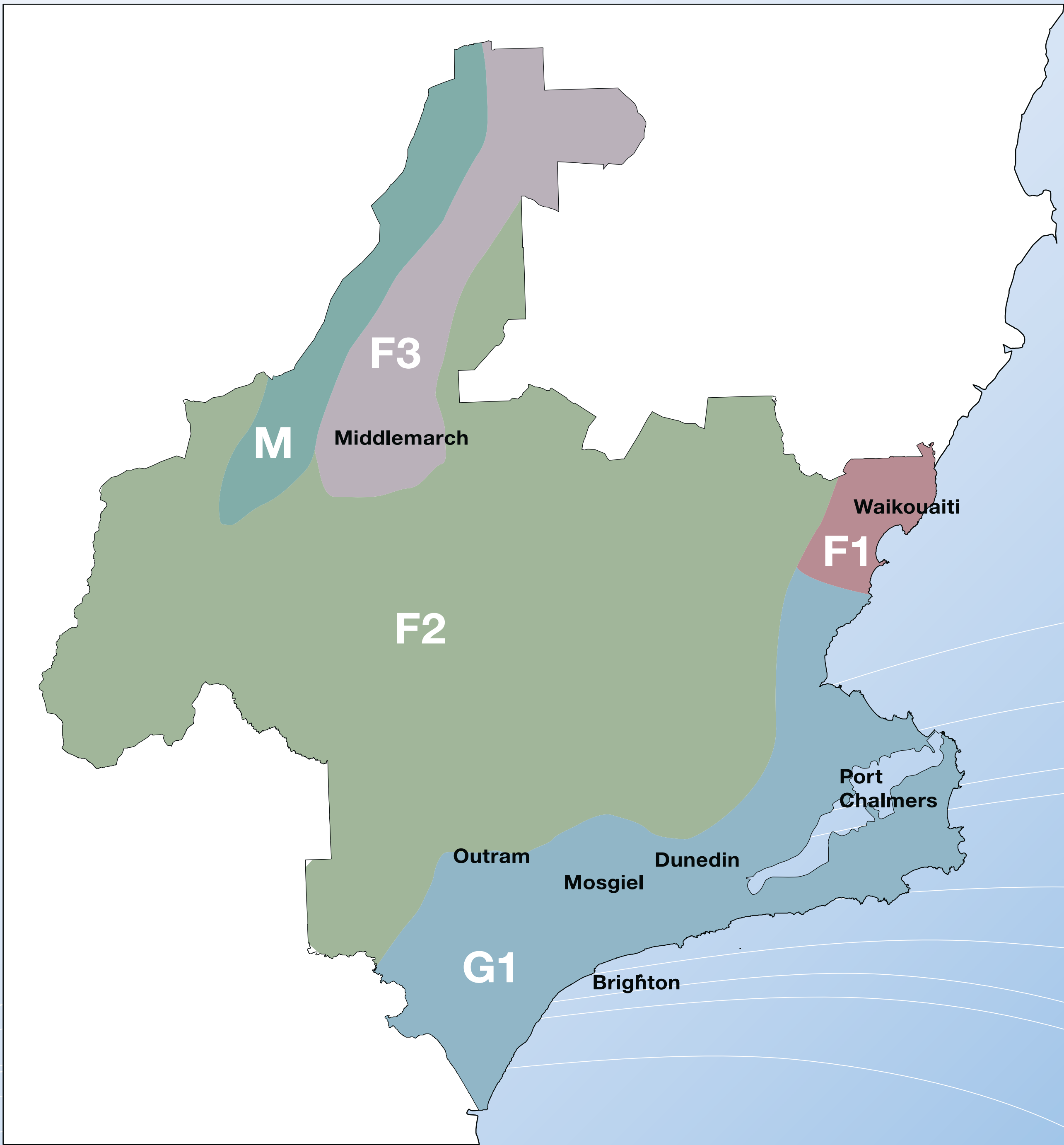

Figure 3. Boundaries and area of Dunedin City showing main climate regions as discussed in Box 1.

2. Climate

2.1 Main Controls on Weather and Climate of Dunedin

A hallmark of Dunedin City is the large day-to-day variability of the weather. Yet its climate is considered to be equitable, moderate and moist. To understand all this, and how global warming might change Dunedin's climate it in the future, it is necessary to consider the main controlling factors:

a) **Dunedin City's mid-latitude location**

At latitude 46oS, the city lies within the belt of the Southern Hemisphere westerlies (or "Roaring Forties"). Yet it is only a few hundred kilometers south of the domain of the subtropical high pressure belt, a region of persistent anticyclones that causes the deserts of Australia, Southern Africa and northern Chile. These circulation features shift pole-ward in the summer and equator-ward in the winter, so that Dunedin City can be influenced by one or the other depending upon the season and synoptic situation.

b) **The modulation effect of the Australian continent**

Its large landmass generates its own pressure features and distorts the seasonal pattern of wind belts in our region. During spring and summer, a thermal low pressure area forms near the surface in the interior of the continent. This tends to push the subtropical anticyclone south, so strengthening the westerly wind belt over Southern New Zealand. As a result, despite the onset of the warmer seasons, weather in Dunedin becomes even more changeable. Frontal systems and southerlies cross the city frequently, sometimes in sequences that last for many weeks. During winter, the subtropical anticyclone moves north and lies more over the centre of Australia. Air flow becomes more southwesterly over Southern New Zealand and tends to weaken. Although temperatures in Dunedin cool, the weather tends to become less changeable, with lighter winds.

c) **The great ice mass of Antarctica exerts a pervasive influence**

Even though it is several thousand kilometres far to the south, Antarctica spawns enormous quantities of cold air. Thus the Southern Ocean remains cold, even in summer.

d) **A strong oceanic influence**

Air masses that reach Dunedin must travel for many days over water. This greatly moderates their temperature. Thus seasonal temperatures near the coast tend to follow that of the surrounding ocean and vary much less than inland. The city's location in the middle of a vast ocean also means that most air masses that arrive over Dunedin are usually moisture laden.

e) **Contrasting air masses of different origin**

If the air mass has had its origins in the subtropical Pacific Ocean, then it tends to be much warmer and moister than usual for Dunedin. When combined with uplift, such an air mass can produce heavy rain. Contrast this with an air mass that has its origins over the Antarctic and Southern Ocean. Initially very dry and cold, it is modified from below as it passes over water. When reaching Dunedin, it gives a raw, cold feel to the weather. It may have picked up some moisture, but on the whole does not usually produce nearly the rainfall of subtropical air masses, and may sometimes bring snow.

f) **Terrain and relief of Southern New Zealand**

These exert a major influence on weather and help explain the tremendous variety of local climates. The orientation of the mountain ranges, more or less athwart the westerlies, is crucial for the protection they offer Dunedin for airflows from southwest to north directions. As the air descends in the lee of mountain ranges it warms and dries. The classic foehn wind, the nor'wester is the result. It is famed for its irritating gustiness, low humidity and extremely warm temperatures. At the same time the nor'wester creates distinctive cloud forms known as lenticular clouds or "hog's backs" and arches of cloud in the western sky.

g) **Dunedin's topography**

The orientation of hills and valleys funnels local winds so that they tend to be either from the southwest or northeast. Cold air ponds in lowland inland areas such as the Taieri Plains and Strath Taieri, making them frostier than their coastal equivalents. The decisive influence of topography of Dunedin City on weather creates a surprisingly wide variety of distinctive climatic types within a relatively small area.

The complexity of the topography of Dunedin City creates five distinct regions. These are shown in Box 1 and Figure 3 and are based on Fitzharris (2003).

Box 1. Climate Regions of Dunedin City

F1 North Otago Climate (eg around Waikouaiti)

Annual rainfall is low, ranging between 500 mm to 800 mm. There tends to be more in winter than in other seasons. There are less than 100 rain days and severe droughts can occur. Summers are warm, with occasional hot northwesterlies giving temperatures above 30°C. Cool winters with frequent frosts and occasional snow. Prevailing winds are southwesterly and northeasterly.

F2 Hill Climate (eg Maungatuas, Flagstaff, Silver Peaks)

These areas are cooler, cloudier and wetter than F1. Rainfalls average 800 mm to 1500 mm annually. Southwesterlies predominate, with occasional very strong northwesterlies gales. Snow may lie for weeks in winter.

F3 Transitional Central Otago Climate (eg Strath Taieri)

Tending towards a semi-arid, semi-continental climate. Annual rainfall is below 500 mm, with less than 80 rain days. Drought is endemic. Warm and sunny summers and cold frosty winters. Foggy in autumn and early winter.

G1 Eastern Otago Climate (eg Dunedin urban area, Otago Peninsula)

Moderate to warm summers and cool winters. Rainfall is 500 mm to 900 mm and evenly distributed throughout the year, but with a slight winter minimum. Rather cloudy. Winds tend to be from the southwest, or from the northeast along the coast. The Taieri Plain is a variant climate of this region in that it is frostier and sunnier.

M Mountain Climate (eg Rock and Pillar Range)

Climate varies substantially depending on elevation. Annual precipitation is at least 1200 mm. Much of winter precipitation falls as snow and may lie on the ground for many months. Temperatures cool off with elevation at about 0.7°C/100 m.

2.2 Current Trends in Dunedin's Climate

Over the 20th century there is a long term trend of warming at Dunedin City climate stations of between 0.5°C to 0.8°C. The days appear to be getting cooler and the nights warmer (Salinger and Griffiths, 2001). The warming has been detected using data from climate stations at airports and at rural stations. These are far removed from the effects of urban heat islands. The warming is consistent with known behaviour of sea surface temperatures as measured by ships in southern waters for more than 150 years.

Dunedin urban area has a temperature record dating from 1852, but there have been many site changes. Fortunately, Brown (2006) has been able to correct for these and constructed a homogeneous data set that is of global importance because it is the longest for the whole of the Southern Hemisphere south of 40o latitude.

Temperatures over 153 years show no clear pattern of change from the mid 1800s through to the early 1900s with the exception of a brief cold period that occurred around 1900. However, from the 1940s through to the 1970s both minimum and maximum extreme temperatures show strong warming and a marked decrease in cold days. The nature of extreme temperature events is changing towards less frequent cold temperature extremes and more frequent warm temperature extremes (Brown 2006).

There is a clear trend of fewer days with air frost on the Taieri Plains and Musselburgh. These declines in frost frequency are substantial and are associated with changes in atmospheric circulation patterns and night-time cloudiness. There is also a trend of more days above 25°C (Plummer et al., 1999), with Dunedin experiencing 40% more such days over the 20th century (Brown, 2006).

Over the period 1921–2003, the southern part of Dunedin City has become wetter, but Strath Taieri, the city urban area and northern part has become drier. Both wet periods and droughts have become of longer duration. Heavy precipitation events have increased in the west of the South Island, but decreased in the east (Mojzisek, 2006).

There are distinct periodicities in the rainfall record, with groups of years tending to be wetter or drier than usual. These are related to such phenomena as El Nino, La Nina, the Pacific Decadal Oscillation, the Southern Annular Mode, the Quasi-Biennial Oscillation, solar activity and sea surface temperature anomalies in ways which are not fully understood (Salinger and Griffiths, 2001; Salinger et al., 2004). Mojzisek (2006) shows that precipitation variability for Dunedin is dependent on the strength of the westerlies. There are strong relationships with the El-Niño Southern Oscillation (ENSO) on seasonal and annual time scales, and with the IPO on decadal scales.

Number of fog days is highly dependent on the vigilance of the observer, so trends over time must be examined cautiously. However, there does seem to be an increase in fog days at Dunedin.

2.3 IPCC and its Climate Change Projections

In order to plan appropriately, it is prudent to adopt international best projections of climate change. Recognising this problem, the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) established the IPCC in 1988. The role of the IPCC is to review and assess the scientific literature on climate change.

IPCC is required to function on a comprehensive, objective, open and transparent basis. It considers all scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. The IPCC does not carry out research, nor does it monitor climate related data or other relevant parameters. It bases its assessment mainly on peer reviewed, published scientific/technical literature.

The main activity of the IPCC is to provide at regular intervals an assessment of the state of knowledge on climate change. The First IPCC Assessment Report was completed in 1990 while the Fourth Assessment Report, being the latest, was completed in 2007. The IPCC has decided to continue comprehensive assessment reports and is scheduled to complete its Fifth Assessment Report in 2014.

2.4 Latest Findings on Global Climate Change

IPCC (2007) consider that warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.

Instrumental measurements of global surface temperature show that the linear trend of warming is +0.74 [0.56 to 0.92]°C/century. Even though no year has matched the warmth of 1998, the decade 2000–2009 was the warmest since 1850. The warming is widespread over the globe, but greatest at northern high latitudes. Land regions have warmed faster than the oceans.

Over the past 50 years, cold days, cold nights and frosts have become less frequent, and hot days and hot nights have become more frequent. Heat waves have become more frequent over most land areas.

IPCC (2007) finds that most of the observed increase in globally-averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations. Warming over the last three decades has had a discernible influence on observed changes in many physical and biological systems of the world.

The premise of global warming is supported by rising sea level. Global average sea level has risen since 1961 at an average rate of 1.8 [1.3 to 2.3] mm/yr and since 1993 at 3.1 [2.4 to 3.8] mm/yr. The main contributions to the rise in sea level are from thermal expansion of the oceans, melting glaciers and ice caps, and changes in the polar ice sheets. Since 1975, the incidence of extreme high sea level events has increased worldwide.

Satellite data since 1978 shows that annual average Arctic sea ice extent has shrunk by 2.7% per decade. There are larger decreases in summer of 7.4 % per decade. Mountain glaciers and snow cover have declined in both hemispheres.

From 1900 to 2005, precipitation increased over many areas of the world, but declined in the Sahel, the Mediterranean, southern Africa, Eastern Australia and parts of southern Asia. Globally, the area affected by drought has increased since the 1970s. The frequency of heavy precipitation events has increased over most land areas. However, there is no clear trend in the annual numbers of tropical cyclones. It is difficult to ascertain longer-term trends in cyclone activity, particularly prior to 1970.

2.5 Projected Global Climate and Sea Level Rise

Continued greenhouse gas emissions at or above current rates will cause further warming and induce many changes in the global climate system during the 21st century. These changes will be much larger than those observed during the 20th century. Altered frequencies and intensities of extreme weather, together with sea level rise, are expected to have mostly adverse effects on natural and human systems (see IPCC Reports, 2007).

Box 2 shows IPCC (2007c; 2007e) projections of global averaged surface warming and sea level rise at the end of the 21st century. The amount of global warming depends on the climate model and greenhouse gas emission scenario used. IPCC has developed a range of emission scenarios as shown in Appendix B. Depending on the scenario chosen, global warming will be in the range 1.1–6.4 °C. Best estimates are in the range 1.8–4.0 °C.

Figure 4 shows the geographical pattern of projected global warming. It assumes the A1B greenhouse gas emissions scenario. This visualizes a plausible future, whereby current global economic, development and population trends continue for the rest of this century

Box 2. Projected global averaged surface warming and sea level rise at the end of the 21st century as given by IPCC (2007).

Case	Temperature Change (°C at 2090–2099 relative to 1980–1999). a), d)		Sea level rise (m at 2090–2099 relative to 1980–1999)
	Best Estimate	*Likely Range*	*Model-based range excluding future rapid dynamical changes in ice flow*
Constant year 2000 concentrations b)	0.6	0.3–0.9	Not available
B1 Scenario	1.8	1.1–2.9	0.18–0.38
A1T Scenario	2.4	1.4–3.8	0.20–0.45
B2 Scenario	2.4	1.4–3.8	0.20–0.43
A1B Scenario	2.8	1.7–4.4	0.21–0.48
A2 Scenario	3.4	2.0–5.4	0.23–0.51
A1FI Scenario	4.0	2.4–6.4	0.26–0.59

Notes:

a) Temperatures are assessed best estimates and likely uncertainty ranges from a hierarchy of models of varying complexity as well as observational constraints.

b) Year 2000 constant composition is derived from Atmosphere-Ocean General Circulation Models (AOGCMs) only.

c) All scenarios above are six SRES marker scenarios. Approximate CO_2-eq concentrations corresponding to the computed radiative forcing due to anthropogenic GHGs and aerosols in 2100 (see p.823 of the WGI TAR) for the SRES B1, A1T, B2, A1B, A2 and A1FI illustrative marker scenarios are about 600, 700, 800, 850, 1250 and 1500 ppm, resectively.

d) Temperature changes are expressed as the difference from the period 1980–1999. To express the change relative to the period 1950–1899 add 0.5°C.

(see Appendix B). It shows that warming will be greatest at high northern latitudes and over land areas. Warming will be least over the North Atlantic Ocean and the Southern Ocean. The map indicates that southern New Zealand will warm at a slightly lesser rate than many other land areas of the world. It should be noted that some other scenarios, such as the A1FI, will lead to equivalent warming developing earlier in the century.

Recent climate change scenarios for New Zealand (Reisinger et al., 2010) applied the statistical downscaling methodology described in Mullan et al. (2001) to data output from 12 different global climate models developed for the IPCC Fourth Assessment Report. These models were a subset of the total number of models available, selected because their 20th century simulations validated well against current climate in the New Zealand and Southwest Pacific region.

These results have been updated by Reisinger et al. (2010) to provide regional projections for regional estimates. They indicate that by 2040 New Zealand will have warmed by 0.7–1.1 °C, depending on the emissions scenario used. By 2090, New Zealand will have warmed by 0.9–2.6 °C.

Anthropogenic warming and sea level rise will continue for centuries, even if greenhouse gas concentrations are to be stabilised. This is due to the time scales associated with climate processes and feedbacks. Many impacts will develop slowly, but some may be abrupt or irreversible, depending upon the rate and magnitude of the climate change.

IPCC (2007) projections of sea level rise indicate a range of 0.18–0.59 m by the end of the 21st century, depending on the greenhouse gas emission scenario that is used. However, based on a wide range of more recent observations and research papers, the probability of sea level rise of at least 0.5m by 2090 is very high. IPCC estimates were hampered by lack of understanding of the future rate of loss of polar ice.

Research on Greenland and Antarctica ice sheets that has been published since the IPCC Fourth Assessment Report suggests that ice loss from polar ice sheets could increase total sea level rise by 2090 to between +0.7 to +1.6 m. At this time, for impact and planning exercises sea level rise of at least one metre would be prudent. The science in this area of research needs to be monitored closely by Council so as to continually adjust this estimate.

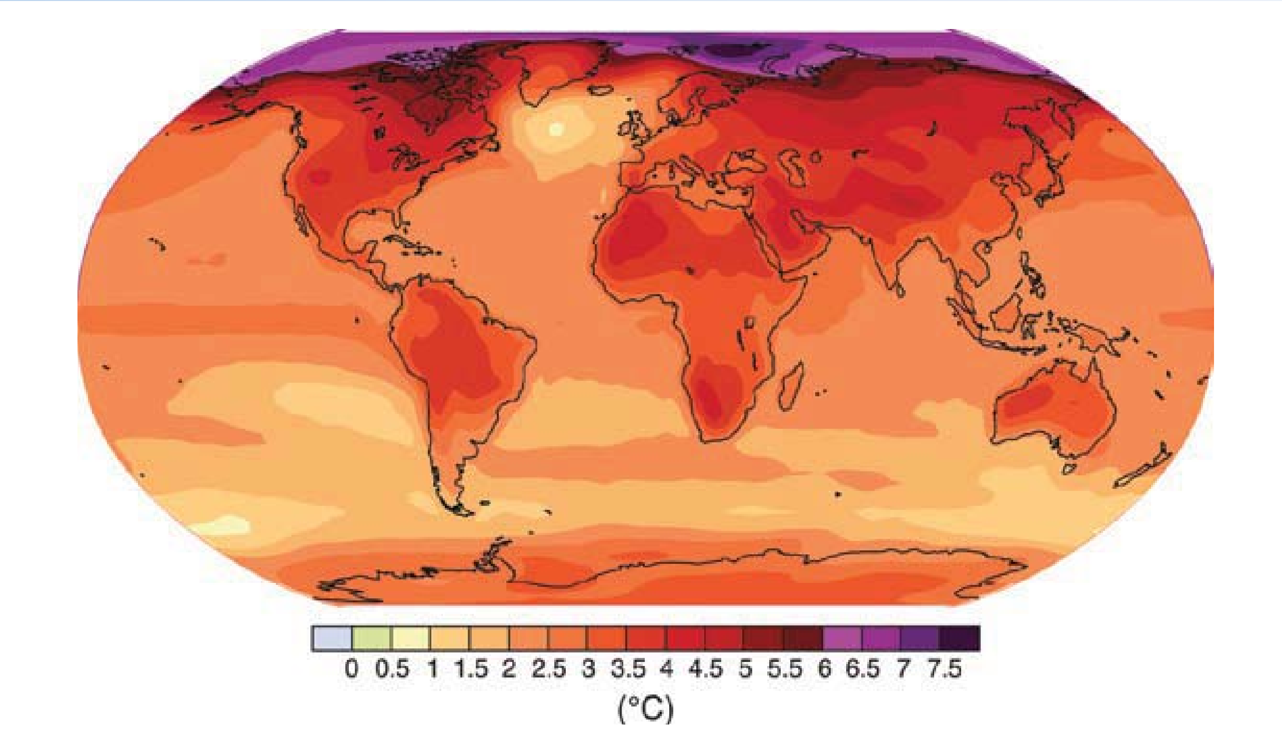

Figure 4. Geographical pattern of surface warming. The map gives projected surface temperature changes for 2090 based on the plausible A1B scenario of IPCC (2007) as described in Appendix B. Increases in temperature are relative to the period 1980–1999.

Sea level will continue to rise beyond the year 2090 for many more centuries, even if international agreements stabilise greenhouse gas concentrations. Ongoing changes in coastlines and inundation of low-lying areas are inevitable, with greatest effects in river deltas and for low lying islands. Further rapid increases in rate of sea level rise of several metres over century time scales cannot be excluded with progressive decay of Greenland or West Antarctic Ice sheets.

2.6 Projected Climate Changes for Dunedin

Atmospheric circulation changes

The factors controlling the climate of Dunedin outlined in the previous section will largely stay the same. However as projected global warming takes hold, there will be:

- A slow increase in sea surface temperatures
- An increase in the strength of the westerlies
- More frequent and vigorous frontal systems

There are certain commonly occurring weather patterns that form part of Dunedin's climate. These will continue to occur into the future, but with changed frequency as indicated in brackets in Box 3.

On a day to day basis, the weather of Dunedin City will continue to be determined by the relative positions of high and low pressure systems, their movement and whether they are in a process of development or decay. A succession of eastward moving troughs and associated fronts will cross the area at average intervals of 6–7 days. Troughs will be separated by ridges, although the centre of anticyclones will tend to be located to the north of the region. In a typical sequence, an anticyclonic ridge will be followed by a trough of low pressure, often with one or more fronts. As a front approaches it will be preceded by fresh northwest to northeast winds, and followed by winds from a westerly or southerly quarter, and a lowering of temperatures.

The changeability of Dunedin's weather will continue, but air masses will gradually become warmer as the 21st century progresses and the surrounding oceans slowly increase in temperature.

Box 3. Commonly Occurring Weather Patterns of Dunedin City and possible changes in frequency with Projected Climate Change

Fine weather spells (less frequent)

Prolonged spells of fine weather of four days or more associated with a ridge or anticyclone moving slowly eastward over the South Island.

Brief periods of rain (more frequent)

Cold fronts from the west to south will continue to move over Dunedin City. Cumulus and nimbus clouds heralding fronts will bring periods of rain lasting a few hours and be accompanied by southerly to southwesterly wind changes. Fronts will tend to be more vigorous than in the present climate.

Showery weather (about the same)

Sustained, disturbed southwesterly airflows will continue to produce showery weather from fast moving cumulus clouds over Southern New Zealand. Inland, the cumulus clouds and associated showers will be confined to the surrounding hills, where precipitation will occasionally occur as snow. Over time, snow will be confined to winter and upper levels of the Rock and Pillar.

Heavy rain (more frequent)

Several distinctive synoptic situations will give heavy rain to the region. The first will occur when a slow moving depression with complex frontal systems develop east of the South Island. The weather will remain dull and cloudy for several days, with steady rain amounting to 50–150 mm. These events will occur as frequently as at present. The second is when a subtropical depression drifts southward over New Zealand. Rainfall amounts will exceed 200 mm over a 24 hour period. These events are likely to occur more frequently than at present.

Average Temperature

Interpretations from Reisinger et al. (2010), that use a composite 12–model projection, indicate that by 2040 annual temperatures for Dunedin City will have warmed by 0.7–1.1 °C, depending on the emissions scenario used. By 2090, annual temperatures will have warmed by 0.8–2.5 °C. These updated projections of warming are slightly smaller than those listed in the Dunedin City Council (2006) *Climate Change Predictions Policy*.

These increases in temperature can equally be applied to spring, summer, autumn and winter. These updated projections of warming for each season are more consistent than those listed in the Dunedin City Council (2006) *Climate Change Predictions Policy*. There is little spatial variation in these projections. Thus these warmings can equally be applied to inland, coastal, southern and northern parts of Dunedin city.

Average Precipitation

Interpretations from Reisinger et al. (2010) that use composite 12-model projections can also be used to estimate future precipitation changes. Results show that by both 2040 and 2090, average precipitation over the Dunedin City area is likely to change little, relative to 1980–1999. However, there is a substantial difference from model to model and thus some uncertainty in the magnitude of the projected changes. There is a tendency for rainfall increases to be greater for inland and southern areas of Dunedin City. North from Waitati, the period about 2040 may be drier than present.

Coastal areas will be 5% wetter in spring/winter and 5% drier in summer/autumn. Inland areas will be 5% wetter in all seasons, except by 2090 when spring/winter precipitation increases by 15% above present values. These updated projections of precipitation are more conservative and seasonally consistent than those listed in the Dunedin City Council (2006) *Climate Change Predictions Policy*.

The periodicities in rainfall, which are a feature of the current climate, are likely to continue. Thus groups of years, possibly extending up to a decade in length, will continue to be wetter or drier than usual.

Sunshine

There are no studies for Dunedin City that deal with possible changes in hours of bright sunshine or receipt of solar radiation. It could be speculated that an increase in the strength of westerlies over Southern New Zealand, combined with warmer sea surface temperatures, may lead to more cloud and lower bright sunshine hours.

Growing degree days

Estimates of growing degree days (GDD) by Fitzharris (1988) show substantial increases by 2090. For example with a 3°C temperature rise, annual GDD on the Taieri Plains increase from 600 for the present climate to 1110. For Musselburgh, they increase from 670 to 1200. For the *F2 Hill Climate* areas GDD increase from 370 to over 800. Such changes dramatically improve the prospects for grass growth, horticulture and forestry over wide areas.

Climatic extremes

Projecting changes in extremes is generally much less understood. Nonetheless, a key lesson from many climate studies is that even small changes in average climate can lead to a disproportionate increase in the incidence of damaging extremes. A modest increase in say average temperature will result in a significant change in the number of events that exceed a specific threshold. As examples, with projected climate change the annual number of frosts will decline markedly, while the incidence of days of very hot weather might increase.

Another important point is that over time-scales of one to two decades, natural modes of climate variability such as the ENSO or the IPO may dominate both changes in annual average temperatures and the occurrence of extremes. Thus up until about 2040, these influences may exert more influence over climate than those indicated by the climate change models.

However, beyond mid-century the underlying warming trend is expected to dominate, even for low greenhouse gas emission scenarios. Thus after the 2040s, what is currently regarded as an unusually warm year will have become the norm. By the same token, an unusually warm year of those future times will lie above the range of temperatures currently experienced in Dunedin.

Such changes in extreme events, which result from even small changes in average conditions, can lead to large impacts. Some impacts will become critical when they exceed the limit that society is adapted to. Examples of such negative events include overtopping of stop banks and more flooding as precipitation increases, or decreases in soil moisture with higher summer temperatures and lower rainfall to below the minimum needed for plant growth. Examples of positive effects are warmer homes from a rise in winter temperatures leading to reduced health risks for vulnerable populations, or less frost risk enabling expansion of horticulture.

Temperature extremes

Decreases in frost occurrence and increases in high maximum temperatures are probably the most robust findings from analyses of climate change simulations (e.g., Kharin et al., 2007). Indicative results for New Zealand can be found in Reisinger (2010). For Dunedin City they suggest that average incidence of annual frosts will decrease and annual number of days with temperatures above 25°C will increase.

Heavy rainfall extremes

The maximum 10, 20, 30, 60 and 120-minute rainfalls for the present climate for the Dunedin Airport, Cherry Farm Hospital, and Musselburgh are analysed by Stewart (2006a) using standard extreme value analysis (EV1) and the 10, 50, and 100-year return period rainfalls for each duration. His results are as follows:

Duration (minutes)	Musselburgh (mm) Area 1			Dunedin Airport (mm) Area 2			Cherry Farm (mm) Area 3			Middlemarch (mm) Area 4		
	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr
10	9.3	12.9	14.5	8.4	11.2	12.3	7.9	10.6	11.7	7.4	12.8	17.0
20	11.7	16.1	17.9	11.5	15.0	16.5	9.4	12.1	13.3	10.0	17.0	22.2
30	13.3	17.9	19.9	13.4	17.6	19.4	10.6	13.3	14.5	12.0	20.0	26.0
60	16.0	20.6	22.6	18.4	24.1	26.5	15.2	19.4	21.2	16.3	26.5	33.9
120	23.0	29.7	32.6	24.1	30.9	33.8	22.5	28.9	31.6	22.0	35.0	44.3

These data are used to estimate design values for such infrastructure as culverts, stormwater pipes and bridges within Dunedin City. Such values will change with global warming, but there are difficulties in estimating future rainfall intensity durations. This is because precipitation extremes are not always portrayed well by climate models. Thus how they might change in the future is problematic and requires more research. See Box 4 for a discussion.

Box 4. Precipitation extremes with Projected Climate Change

Increases in the frequency and magnitude of heavy rainfall with projected climate change are a widespread finding of climate models. This is because the potential low level moisture content of the atmosphere rises at about 7–8% /°C increase in temperature (MfE, 2008b, Allan and Soden, 2008). As the world warms, heavier rainfall events can be expected. However, there is considerable discussion and ongoing research into upper limits of precipitation extremes (Lenderink and van Meijgaard, 2008).

For the purposes of predicting future extreme short duration rainfalls in the greater Dunedin City area, Stewart (2006a) decided that the worst-case scenario should be used in preference to the mid-range climate change predictions. This conservative approach was chosen to ensure that stormwater systems maintain design flows over the lifetime of the asset. After a series of assumptions, Stewart (2006a) makes estimates of design storms with climate change for Dunedin City and produces a series of rainfall intensity duration design curves. In a companion report, Stewart (2006b) details how to obtain rainfall intensity in millimetres per hour for various areas of Dunedin City. Example calculations are given as well.

A summary of design rainfall intensities assuming climate change are shown (top of page 20) and are appropriate for the period about 2090. Values are about 20% higher than those currently used for design purposes.

Design rainfall intensities with mid-range climate change predictions (based on Stewart 2006)

Duration (minutes)	Musselburgh (mm) Area 1			Dunedin Airport (mm) Area 2			Cherry Farm (mm) Area 3			Middlemarch (mm) Area 4		
	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr
10	11.2	15.6	17.5	10.0	13.5	14.9	9.5	12.8	14.1	8.9	15.5	20.5
20	14.1	19.4	21.5	13.8	18.0	19.9	11.3	14.6	16.0	12.0	20.5	26.7
30	15.9	21.5	23.9	16.0	21.1	23.3	12.7	16.0	17.4	14.4	24.0	31.2
40	17.0	22.6	24.8	18.3	24.1	26.5	14.7	18.6	20.2	16.5	27.0	34.9
50	17.9	23.3	25.5	20.3	26.8	29.3	16.5	21.1	22.8	17.9	29.5	37.9
60	19.1	24.6	27.0	21.9	28.8	31.7	18.1	23.2	25.3	19.4	31.7	40.5
70	20.4	26.3	28.8	23.3	30.3	33.3	19.7	25.2	27.5	20.7	33.6	42.9
80	21.7	27.9	30.8	24.4	31.7	34.9	21.1	27.1	29.6	21.9	35.3	44.9
90	23.2	29.8	32.8	25.3	33.0	36.3	22.5	28.8	31.7	22.9	36.8	46.8
100	24.6	31.7	34.7	26.4	34.3	37.6	23.9	30.7	33.6	23.9	38.4	48.9
110	26.0	33.5	36.9	27.4	35.6	39.0	25.3	32.6	35.5	24.9	40.0	50.8
120	27.2	35.3	38.9	28.5	36.8	40.3	26.7	34.4	37.7	26.1	41.6	52.8

For floods in rivers, rainfall over 24 hour periods or several days are usually considered in design exercises. Current guidance for New Zealand (MfE, 2008b) suggests that 24-hour extremes with a 100-year return period could occur approximately twice as often (i.e. equivalent to a 50-year return period, or twice as often) under a local warming of about 2°C. When considering daily rainfalls for design purposes in Dunedin City, sub-tropical cyclone events are the main concern. Projected climate change suggests that these events will affect the Dunedin area more frequently this century. Although rare in the city's climatology, they have occurred twice in the 1920s and once in the 1960s.

Such events produce extraordinary amounts of rain, in excess of 220 mm in 24 hours, and major flooding. For example, the flood of 1929 was likened to a lake extending over much of North Dunedin (Fitzharris et al. 1999). A provisional estimate is that a probability of four of these events can be expected to affect Dunedin City over the remainder of this century. These amounts are far larger than 24 hour rainfalls with 10 year return period given in Stewart (2006a), which vary from 80.7 mm at Musselburgh to 126.4 at Sullivans Dam. At this stage, it is suggested that the 1929 event be used for design purposes, but more studies are required on this important issue.

Drought

Drought magnitude and frequency are expected to increase in a warmer climate as evapotranspiration increases. Mullan et al. (2005) concluded from a study of two IPCC Third Assessment models that current 1-in-20 year drought could occur at least twice as often in eastern parts of New Zealand (parts of Northland, Bay of Plenty, Wairarapa, Marlborough, Canterbury and Otago) under a warming of about 2°C. The Fourth Assessment Report of IPCC also identified increased drought as major climate changes factor in eastern New Zealand (Hennessy et al., 2007).

Fortunately, for inland and southern areas of Dunedin City the increased evaporation from higher temperatures is expected to be offset by small increases in rainfall. Thus drought incidence will remain largely the same over large areas of the city and for the urban area of Dunedin City will increase only slightly. However, drought is expected to increase for coastal areas north of Waitati.

Extreme Winds

A number of international studies suggest an increase in the frequency of strong winds under global warming, but there is very little information currently available for New Zealand. Because climate models show an increase in the frequency and strength of the westerly wind belt over this century, the incidence of gales over the area of Dunedin City will increase.

Fire Risk

A study by Pearce et al. (2005), by adopting the moisture scenarios of Mullan et al. (2005), found increases in a range of fire indices under higher warming scenarios, especially in eastern parts of New Zealand.

Big snow events

The DCC Dunedin Lifelines Project clearly showed that for the present climate, heavy snowfall events lasting several days produce the biggest weather risk to everyday life and infrastructure in the Dunedin urban area. These isolate the city, cause traffic chaos and disrupt energy supplies (Fitzharris et al., 1999). Heavy snowfalls are expected to become less common as the 21st century progresses, so this threat should diminish. Spring snowfalls will continue to threaten new borne lambs on hill country, but their frequency will become rare after 2040.

The snow line will rise by 120 for about 2040 and by 270 m by the 2080s based on scenarios by Fitzharris (2004). Thus snow will appear less often on the hills surrounding the urban area of Dunedin, on the Silver Peaks and the Maungatuas. The occurrence of seasonal snow will continue on the Rock and Pillar Ranges, but its depth and water volume will be much reduced.

Storage of seasonal snow

Taieri River and Deep Stream supply a good part of Dunedin's water supply. Changes in the water balance of these catchments can be expected because precipitation and evaporation and will alter. Storage of seasonal snow is also an important consideration when considering possible changes to flows. Filmer and Fitzharris (2002) have examined snow storage for the following:

- Current climate
- Scenario 1 (equivalent to about 2040): warming of 1°C and 5% wetter
- Scenario 2 (equivalent to about 2090): warming of 2°C and 10% wetter

Changes in seasonal snow storage for the Taieri catchment are shown in Figure 5. Snow storage for the current climate is estimated at 105 mm, but drops to 85 mm for 2040 and to below 60 mm by 2090. For the Deep Stream catchment, snow storage is less, but similar relative decreases can be expected.

2.7 Projected Sea Level Rise for Dunedin

New Zealand studies have predicted increases of sea level in a range of 5–7 mm per year. IPCC projections of global sea level rise indicate a range of 0.18–0.59 m by the end of the 21st century. Recommended planning values for sea level rise by 2090 by MfE have been of the order of 0.3 m by 2040 and 0.6 m.

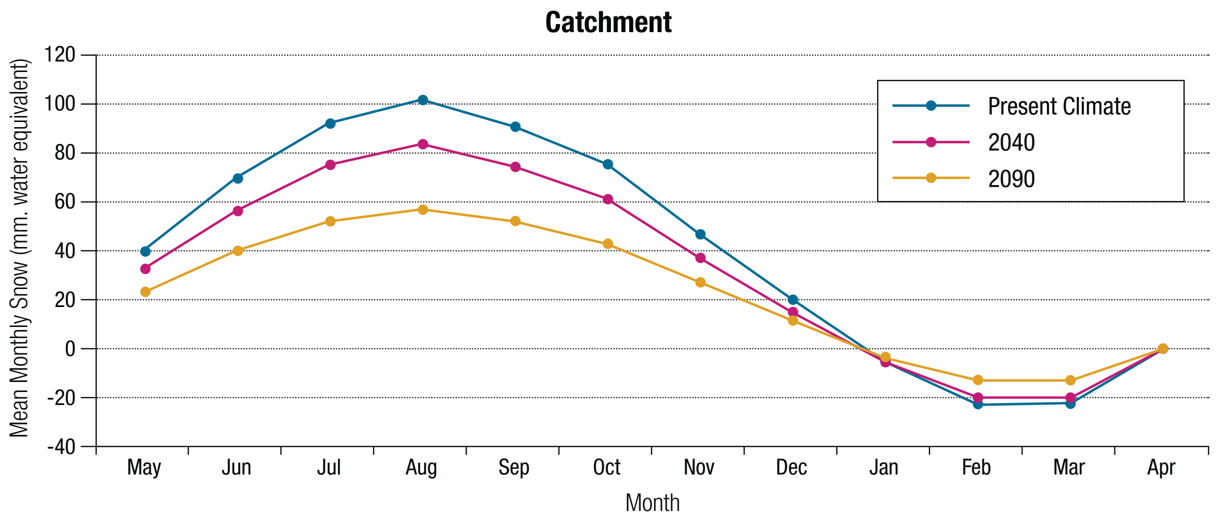

Figure 5. Mean monthly storage from seasonal snow in the Taieri Catchment above Outram for the Current Climate, 2040, and 2090.

However, since the IPCC Fourth Assessment Report was published in 2007 numerous studies have noted the possible acceleration of glacier flow from polar ice sheets and their potential additional contribution to global sea level rise through basal melt and iceberg calving. Such ice loss from polar ice sheets could increase total sea level rise by 2090 to between 0.7–1.6 m. Even 2.0 m cannot be ruled out entirely (see e.g. Rahmstorf 2007; Holland et al. 2008; Joughin et al. 2008; Stearns et al. 2008; Nick et al. 2009; Velicogna 2009). New analyses of sea level rise during previous global warm periods have provided evidence that rates of 1.6 m per century have happened before (Rohling et al. 2008; Blanchon et al. 2009).

Such a wide range of values means that a reliable upper bound for sea level rise by 2090 can not be specified at this time. All models indicate that sea level rise will accelerate in a warmer world, but there remain considerable uncertainties arising from our incomplete understanding of the processes leading to loss of polar ice sheets.

Figure 6. Karitane and the estuary of the Waikouaiti River; one of many small communities along Dunedin's coastline where sea level rise will have an impact.

This state of affairs is unsatisfactory for design and hazard assessment purpose. For Dunedin City, it is suggested that coastal risk assessments should assume that the probability of sea level rise of at least 0.5 m by 2090 is very high, and it could be as much as 1.6 m. Furthermore, sea level will continue to rise beyond 2090 for many more centuries.

Consequently there is considerable uncertainty when assessing the impacts of sea level rise and adaptation options. However, this approach is consistent with current national guidance on coastal hazards assessments in New Zealand (MfE 2008a, 2009).

Appropriate adaptation responses will depend on the lifetime and nature of infrastructure and investments as well as their ability to be adapted over time. Responses must also evolve as knowledge about the upper limits of future sea level rise becomes more certain.

2.8 Storm Surges

Otago Regional Council (ORC) contracted NIWA to undertake a study of potential inundation of the Otago coast due to extreme sea level events with return periods of 20, 50, 100 and 500 years (NIWA , 2005a, 2008). Extreme sea levels occur as a consequence of a combination of tides, storm surge and wave set-up and run-up. Storm surges result from low atmospheric pressure and wind stress.

NIWA (2005b) derived values for the extreme sea level that start at around 1.4 m above mean level of the sea (MLOS) for a 2-year return period. None of these extreme sea levels included wave set-up and run-up. Extreme sea levels were predicted up to 1.7–1.8 m on open coast and 1.9 m in Otago Harbour (Dunedin) for a 100-year return period. These water levels are much larger than those predicted with the maximum high tide (assuming zero storm surge). For the Spit at Otago Heads over a 100 year period, water levels are 1.16 m above MLOS and a Mean High Water Spring (MHWS) of 0.8 m above MLOS. All of the above numbers assume no global warming.

In a later study considering more processes and locations, NIWA (2008) show that for the present climate, the maximum predicted sea level from storm surge is 2.63 m above MLOS. This occurs to the south of the city boundary and has a return period of 500 years. The maximum level with a return period of 20 years is 2.36 m above MSOL. The lowest predicted sea level from storm surge is at Warrington, with 20- and 500-year return sea levels of 1.55 m and 1.78 m above MSOL, respectively.

NIWA (2005b) point out that a period with an El Niño and negative phase of the IPO could raise MLOS even further, perhaps by about 0.4 m over the above values. Anticipated future rises in sea level will increase the depth and extent of inundation even further. Thus by 2090, the worst case extreme event of a combination of higher global sea levels, large storm surge, El Niño during negative IPO, and a king tide could see water levels reach over 3 m above present MSOL.

A number of low-lying areas in Dunedin City are at risk of extensive inundation from storm events even in the present climate, especially Long Beach, Purakanui and Karitane. Future climate change and sea level rise will increase that risk, extend it to other coastal communities and threaten to breach the protective dune systems of South Dunedin.

3. Impacts on Dunedin City and its Communities

3.1 Overview

The Fourth Assessment Report of IPCC (Hennessy et al., 2007) identified four critical impacts on the New Zealand region from projected climate change:

- By 2020, significant loss of biodiversity is projected to occur in some ecologically rich sites including mountain areas.
- By 2040, production from agriculture and forestry is projected to decline over parts of eastern New Zealand, due to increased drought and fire. However, in New Zealand, initial benefits are projected in well watered regions.
- By 2050, ongoing coastal development and population growth in some areas of New Zealand are projected to exacerbate risks from sea level rise and increases in the severity and frequency of storms and coastal flooding.
- By 2040, water security problems are projected to intensify in some eastern regions of New Zealand

This Report revisits these key impacts and judges their applicability to Dunedin City. The analysis is extended to identify the impacts of projected climate change and sea level rise and their timing on the following sectors:

a) Agriculture

b) Forestry

c) Natural ecosystems

d) Water resources

e) Human health

f) Industry

g) Coasts and flooding

h) Settlement and society.

Impacts at the sub-city scale are identified for key regions of Dunedin. Also considered is the impact of climate change on the potential for energy generation from renewable sources.

Figure 7. Strath Taieri looking eastwards from the Rock and Pillar Range. This area of Dunedin City illustrates the many faceted impacts of climate change. There will be less seasonal snow on the mountains leading to changes in alpine ecosystems and threatening some native flora and fauna. Less snow will affect runoff, so that there will be more in winter and less in summer, the main irrigation season. However, increased rainfall will lessen these impacts. Agriculture will be more productive due to less frost, a longer growing season and more growing degree days. Much middle elevation country shown in the distance, now largely given over to extensive grazing, will become suitable for intensive agriculture.

3.2 Impacts on Agriculture

Overall, projected climate change will bring substantial benefits to agriculture as the 21st century unfolds. These will arise because:

- growing degree days increase substantially at all localities
- there is much less frost
- rainfall amounts remain similar today or even increase (especially in F3 climate region around Middlemarch)
- the growing season lengthens
- increased levels of CO_2 enhance plant growth.

The exception is for F1 climate region (north of Waitati, see Figure 3), where drought could increase towards 2090.

Cropping

Climate change will change land use. Cropping will expand with warmer temperatures and higher CO_2 in the atmosphere. Observed warming trends are already reducing frost risk and increasing yields (Howden et al., 2003b). The net impact in irrigation areas depends on the availability of water (Miller and Veltman, 2004). However, elevated atmospheric CO_2 concentrations slightly reduce crop evapotranspiration.

For crops such as wheat, oats and barley, the CO_2 response will more than compensate for a moderate increase in temperature (Jamieson et al., 2000). With an increase in growing degree days, maize will be an option in many lowland agricultural areas of the city. Other crops may also be possible with adaptation through adjustment of planting dates as the growing season lengthens.

The review of Hennessy et al. (2007) emphasises the downside of climate change on cropping. Grain quality is also likely to be affected. Firstly, elevated CO_2 reduces grain protein levels (Sinclair, 2000). Significant increases in nitrogenous fertiliser application or increased use of pasture legume rotations would be needed to maintain protein levels (Howden et al., 2003c). Secondly, there is increased risk of development of undesirable heat-shock proteins in wheat grain with temperature increases greater than 4°C (Howden et al., 1999d). Impacts of climate change on pests, diseases and weeds, and their effects on crops, remain uncertain (Chakraborty et al., 2002).

Horticulture

The dramatic increases in growing degree days with warming mean that by 2090 large areas of Dunedin City, including most lowlands, will be suitable for horticulture. Growing of commercial crops such as cherries, apricots, nectarines, kiwifruit and even grapes will be viable. Annual development of temperate fruits and nuts require winter chill or vernalisation. Projected climate change reduces winter chill units, but even by 2090 will not be a factor, except right at the coast (Fitzharris, 1988). Crops reliant on irrigation are unlikely to be threatened, because irrigation water will continue to be available, except in the area about Waikouaiti.

Apples will flower and reach maturity earlier, with increased fruit size, especially after 2040 (Austin et al., 2000). Viticulture has expanded rapidly in Central Otago in recent decades. By 2040, grape growing areas will emerge in the Strath Taieri on favoured topoclimates and by 2090 on the Taieri Plains.

Pastoral and rangeland farming

Higher temperatures, a longer growing season, higher CO_2 concentrations and less frost will increase annual pasture production by 10 to 20% by 2040, although gains may decline thereafter (MfE, 2001). Less winter feed will be required. In northern coastal areas without irrigation, pasture productivity could start to decline by 2040, due to increased drought frequency.

Dunedin City has extensive areas above 400 m elevation, where pastoral farming in the current climate is limited by constraints of frost, snow, a short growing season and insufficient growing degree days. With projected climate change, many of these constraints will be alleviated as the 21st century progresses, most notably in the F2 climate region of Figure 3. By 2040, an estimated 100,000 hectares of land will have become suitable for intensive pastoral farming. By 2090, a further 200,000 hectares of land will have become suitable.

Elevated concentrations of CO_2 significantly decrease leaf nitrogen content and increase nonstructural carbohydrate, but cause little change in digestibility for sheep and cows

(Lilley et al., 2001). In farming systems with high nitrogen forage (e.g., temperate pastures), these effects will increase energy availability, nitrogen processing in the rumen and productivity. In contrast, where nitrogen is deficient (e.g. rangelands at higher elevations), warming may decrease non-structural carbohydrate concentrations and digestibility.

Climate change may increase the range and incidence of many pests and diseases and the potential distribution and abundance of exotic weeds and native woody species. The latter will increase competition with pasture grasses, reducing livestock productivity. Increased thermal stress on animals is currently rare in Dunedin City, but may increase in the future. In contrast, less cold-stress will reduce lamb mortality.

However, the same climate changes will provide increased opportunities for woody weed control through increased burning opportunities (Howden et al., 2001b). A warming of 2.5°C could lead to a 15 to 60% reduction in rabbit populations via the impact on biological control agents, e.g., myxomatosis and rabbit haemorrhagic disease virus (Scanlan et al., 2006).

3.3 Impacts on Forestry

Dunedin City has both indigenous and exotic forests, the latter providing substantial income. Research confirms that climate change will have both positive and negative impacts on both types of forest. Productivity of exotic softwood plantations and native bush will be increased by CO_2 fertilisation effects, although the amount will be limited by feedbacks such as nutrient cycling (Howden et al., 1999c; Kirschbaum, 1999a, 1999b). Where trees are not water-limited, warming expands the growing season, but pest damage will negate some gains. Increased rainfall intensity will exacerbate soil erosion problems and pollution of streams during forestry operations (Howden et al., 1999c).

Commercial growing of trees above 500 m elevation is limited by frost and snow damage under the present climate. These constraints will be alleviated with warming as the 21st century progresses, most notably in the F2 climate region of Figure 3. An estimated 50,000 hectares will become suitable for commercial forestry by 2040, expanding to a further 200,000 hectares by 2090 (Fitzharris, 1988).

In *Pinus radiata* and *Eucalyptus* plantations, fertile sites will have increased productivity for moderate warming, whereas infertile sites will have decreased production (Howden et al., 1999c). Growth rates for plantation forestry (mainly *P. radiata*) will increase in response to elevated CO_2 and wetter conditions in the south and west. Studies of pine seedlings confirm that the growth and wood density of *P. radiata* are enhanced during the first two years of artificial CO_2 fertilisation (Atwell et al., 2003).

Tree growth is likely to reduce for the Waikouaiti area due to projected rainfall decreases and increased fire risk. However, uncertainties remain regarding increased water-use efficiency with elevated CO_2 (MfE, 2001), and whether warmer and drier conditions could increase the frequency of upper mid-crown yellowing and winter fungal diseases (MfE, 2001).

3.4 Impacts on Natural Ecosystems

Climate change will lead to some irreversible impacts on natural ecosystems. The flora of New Zealand has a high degree of endemism (80 to 100% in many taxa). Many species are at risk from rapid climate change because they are restricted in geographical and climatic range. Most species are well-adapted to short-term climate variability, but not to longer term shifts in mean climate and increased frequency or intensity of extreme events. Many areas reserved for conservation are small and isolated, particularly in the agricultural areas of Dunedin City, so that the ability of species to migrate across the landscape is constrained.

Hennessy et al. (2007) note that approximately 20–30% of species will be at increased risk of extinction if global warming exceeds 1.5–2.5°C (relative to 1980–1999). As global warming exceeds 3.5°C, model projections suggest significant extinctions (40–70% of species assessed) around the globe. Bioclimatic modelling studies generally project reductions and/or fragmentation of existing climatic ranges. Climate change will also interact with other stresses such as invasive species and habitat fragmentation. The most vulnerable ecosystems include isolated habitats in lowland areas, coastal and freshwater wetlands.

Major changes are expected in all vegetation communities. In the rangelands of Dunedin City, shifts in rainfall patterns will favour establishment of woody vegetation and encroachment of unpalatable woody shrubs. Fragmented native forests of lowland eastern areas will be vulnerable to summer drying and changes in fire regimes (McGlone, 2001; MfE, 2001). In alpine zones, reductions in duration and depth of snow cover will alter distributions of communities, favouring an expansion of woody vegetation into herbfields (Pickering et al., 2004).More fires are likely in alpine peatlands (Whinam et al., 2003). Alpine vertebrates dependent on snow cover for hibernation will be at risk of extinction (Pickering et al., 2004).

Saltwater intrusion as a result of sea level rise, increases in river flows and warmer temperatures will alter species composition of freshwater habitats, with consequent impacts on estuarine and coastal fisheries

(Bunn and Arthington, 2002; Hall and Burns, 2002; Herron et al., 2002; Schallenberg et al., 2003). There is concern for coastal plant communities from salt water inundation of coastal wetlands and low lying areas. In marine ecosystems, ocean acidification will decrease productivity and diversity of plankton communities along the Pacific coast. Warmer seas will lead to further southward movement of fish and kelp communities (Poloczanska et al., 2007).

3.5 Impacts on Water Resources

The water resource

Dunedin City has a 3 Waters Strategy (wastewater, stormwater, potable water). It notes for that for potable water the distribution network is generally comprehensive and robust. There are multiple ways to feed each zone of the network, which provides a degree of security of supply. The system is robust enough to provide for population growth to 2060.

Climate change will enhance further this favourable situation because annual flow from larger river and streams will increase. This is illustrated by Filmer and Fitzharris (2002), who examined runoff of the Taieri River for the current climate and for two scenarios equivalent to 2040 (warming of 1°C and 5% wetter) and 2090 (warming of 2°C and 10% wetter). Changes in runoff of the Taieri River as measured at Outram are shown in Figure 8. Mean annual runoff for the current climate is estimated at 385 mm. By 2040, mean annual runoff increases to 427 mm or 11% more than for the current climate. By 2090 it increases to 470 mm or 22% more. Thus the water resource is substantially increased with climate change. Similar increases are expected for runoff from the Deep Stream and Leith catchments, other important sources of Dunedin's water supply

However, the seasonal distribution of runoff changes dramatically. There are substantial increases in winter runoff and reductions in summer runoff for 2040 and 2090. Thus the amount of water available in Strath Taieri during the summer irrigation season will be less than at present. Irrigators will need to make substantial investment in storage to take advantage of the overall increased water resource.

Seasonal changes in runoff expected for the Deep Stream and Leith catchments will not be so marked because seasonal snow changes and upstream irrigation abstraction are not important factors. The amount of water for Dunedin's water supply from Deep Stream and the Water of Leith will be increased in winter. Stream flow in summer will be about the same as present, or slightly reduced. The 3 Waters Strategy of Council notes that the present system lacks strategic water storage to better cover seasonal shortages during droughts. Climate changes will exacerbate this deficiency. Either more storage will need to be installed, or access negotiated to allow water extraction from Lake Mahinerangi to cover dry weather contingencies.

The effects of climate change on flood and drought frequency are virtually certain to be modulated by phases of ENSO and the IPO (McKerchar and Henderson, 2003). There are no integrated assessments of the impacts of climate change on water pricing and trading policies.

Flood management

Rain events will become more intense, leading to greater storm runoff, but with lower river levels between events. This will cause greater erosion of land surfaces, more landslides (Glade, 1998; Dymond

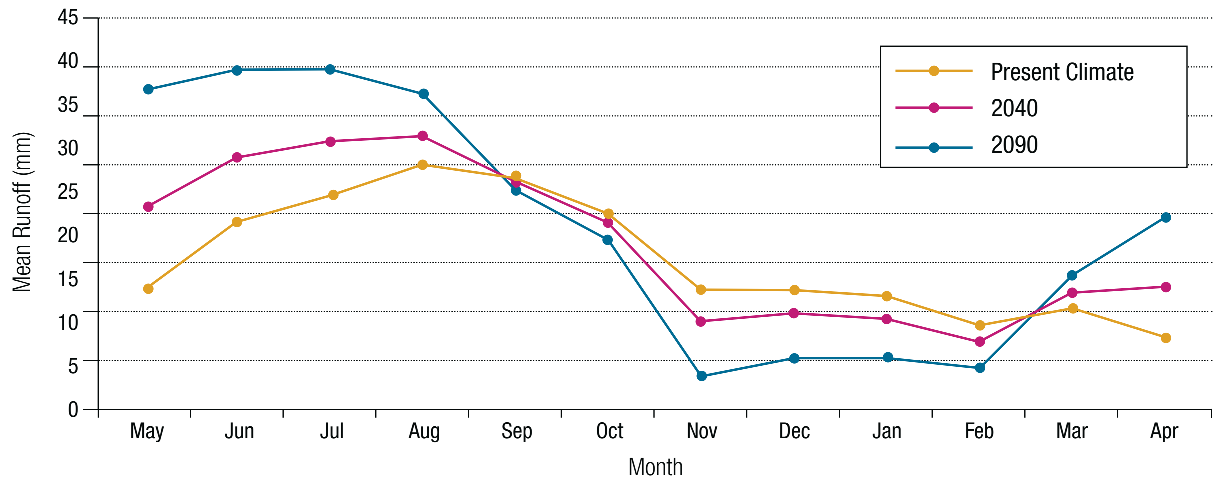

Figure 8. Mean monthly runoff for Taieri River catchment above Outram for Current Climate, for 2040 and for 2090.

et al., 2006), redistribution of river sediments (Griffiths, 1990), larger floods and a decrease in the protection afforded by stop banks. Dunedin City regularly assesses risk from flooding in its flood design of culverts and stop banks as part of current practice and through such reports as Stewart (2006a, 2006b) which update rainfall intensities with climate change.

Gray et al. (2005) have considered the consequences of increased river flooding and rising sea level for Westport, a somewhat typical coastal community near the mouth of a river. By using a regional atmospheric model, a rainfall-runoff model, projected sea-level rise, and a detailed inundation model, they show that projected climate change leads to a dramatic increase in urban flooding. Assuming the current stop bank configuration, the proportion of the town inundated by a 1-in-50 year event is currently 4.3%, but rises to 13–30% by 2030, and 30–80% by 2080. During flood events, peak river flow increases 4% by 2030 and 40% by 2080. Projected climate change brings the combination of increased flood size and sea level rise which is devastating for coastal river mouth communities and greatly increases the flood hazard.

Should such dramatic increases be applied to the Taieri River, the Silverstream, the Water of Leith, Waitati River and the Waikouaiti River, then there will be substantial flooding to higher levels than historically expected and with more frequency. This would increase flood threats to Outram, Mosgiel, Dunedin Airport, Dunedin North, Waitati and Karitane. Increased demands for enhancement of flood protection works are likely, as evidenced by the response to large floods elsewhere in New Zealand in 2004 (MCDEM, 2004; CAE, 2005).

Wisely the city is placing pipelines from Deep Stream under the Taieri River rather than on the bridge at Outram. This will eliminate the risk to security of supply should the bridge fail during a large flood.

Groundwater

The groundwater aquifers for Dunedin City will have increased recharge over winter but less over summer. On the whole though, the effects of climate change will be positive for the groundwater resource. Thus Dunedin City potable water supplies are likely to be secure from this source.

However near the coast, groundwater levels will be affected by sea level rise and salt water intrusion. Ground water levels are expected to become steadily higher in most low-lying coastal communities. These include the Lower Taieri and Dunedin Airport, Brighton, Waldronville, South Dunedin, Waitati, Warrington, Karitane and Waikouaiti. Surface flooding will become chronic in these areas as the 21st century progresses.

Salt water will begin to enter the potable water supply system in these low lying areas as sea levels progressively rise. A series of three bores in a transect across South Dunedin reveal that groundwater is less than 0.6 m below the surface, displays a tidal fluctuation of almost 0.3 m with a 1.5 hour lag and exhibits signs of salt water intrusion. Clearly any increase in sea level will bring groundwater closer to the surface, especially during storm surges and king tides.

Water quality

Many lowland waterways in agricultural catchments of Dunedin City are under pressure

from land-use intensification and increasing water abstraction demands (Larned et al., 2004). There is no literature on impacts of climate change on water quality in New Zealand. However, with increased dairy farming and other intensification of agriculture, eutrophication is a growing water-quality problem (Davis, 1997; SOE, 2001).

Toxic algal blooms in estuaries of Dunedin City are likely to become more frequent and to last longer due to climate change. They can pose a threat to human health, for both recreation and consumptive water use, and can kill fish and livestock (Falconer, 1997). Simple, resource-neutral, adaptive management strategies, such as flushing flows, can substantially reduce their occurrence and duration (Viney et al., 2003).

3.6 Impacts on Human Health

Based on studies in Auckland and Christchurch, heat-related deaths per year in people aged over 65 will rise by 100%, 360% and 630% for warmings of 1°C, 2°C, and 3°C, respectively (McMichael et al., 2003). Note though, these rates are from a very low base in the present climate of less than 10 deaths per year.

More importantly, the winter peak in deaths in Dunedin City will decline as temperatures become warmer during the colder months. The indoor climate of homes will improve. Thus the incidence of respiratory diseases will also decline. By 2090, Dunedin will be a much more comfortable place in which to live. The outdoor climate will be less challenging so that fewer layers of clothing will be required.

Much of New Zealand becomes receptive to new vector species (DeWet et al., 2001; Woodward et al., 1998; Woodward et al., 2001), but the risk of dengue in Dunedin City will remain below the threshold for local transmission beyond 2050 (McMichael et al., 2003). Warmer temperatures and increased rainfall variability will increase the intensity and frequency of food-borne (D'Souza et al., 2004) and water-borne (Hall et al., 2002) diseases.

3.7 Impacts on Industry

Tourism

Tourism is a major and growing industry in Dunedin City. For the country as a whole, tourism accounts for 9% of GDP and 16% of exports. Few regional studies have assessed potential impacts on tourism, but elsewhere there is evidence that climate change has direct impacts (Agnew and Palutikof, 2001; Maddison, 2001). Climate change is unlikely to affect the heritage and cultural values of the city and tourism based on these should persist.

Some tourist destinations may benefit from warmer conditions, e.g., for beach activities, viewing wildlife, tramping, camping, climbing, wine tasting and fishing. However, rising risks to tourism are likely from increases in hazards such as flooding, increased storminess, storm surges, and subtropical cyclones (World Tourism Organisation, 2003; Scott et al., 2004; Becken, 2005; Hall and Higham, 2005; Becken and Hay, 2007). These adversely affect transport, personal safety, communication, water availability and natural attractions such as bird sanctuaries, beaches, freshwater wetlands, and forests.

Most tourism and recreation in relies on resources of the natural environment. Changes in species distribution and ecosystems of conservation lands and of the tussock grasslands of Dunedin City are probable. Little is known as to possible changes in wildlife assets such as the Taiaroa albatross, seal and penguin colonies. Tourist flows from Australia to southern New Zealand might grow as a result of the relatively poorer snow conditions in Australia.

Energy

Energy consumption is projected to grow due to demographic and socio-economic factors However, average and peak energy demands are also linked to climatic conditions. There will be significant reduction in winter heating demand. One estimate is that electricity demand decreases by 3%/°C warming in mean winter temperature (Salinger, 1990). There is likely to be increases in summer peak energy demand due to increased air-conditioner use.

More extreme weather will affect energy infrastructure, including wind power stations, electricity transmission and distribution networks, oil and gas product storage and transport facilities. However, most costs and damages can be avoided by adaptation and mitigation. An assessment of potential risks by PB Associates (2007) found that if climate changes gradually, both the generation utilities and the equipment manufacturers will have enough time to adjust their standards and specifications.

Fisheries

In New Zealand, of 84 stocks of demersal fish where landings were greater than 500 tonnes/yr, five were regarded as over-fished, 24 were assessed as not over fished, and 55 were of uncertain status (Ministry of Fisheries Science Group, 2006). Climate change will be an additional stress (Hobday and Matear, 2005). The key variables expected to drive impacts on marine fisheries are changes in ocean temperature, currents, winds, nutrient supply, acidification and rainfall.

Changes in four emergent biological properties are likely as a result of climate change:

- distribution and abundance of impacted species
- phenology
- community composition
- community structure and dynamics (including productivity).

Few climate-change impact studies have been undertaken for fisheries. Hennessy et al. (2007) noted that assessment mostly relies on extrapolation of observed relationships between climate variability and fisheries. With sea level rise, increasing marine intrusions will affect coastal fisheries and inshore sub-tidal breeding and nursery areas (Schallenberg et al., 2003). Overall, future climate-change impacts will be greater for temperate endemics than for tropical species (Francis, 1994, 1996) and on coastal and demersal fisheries relative to pelagic and deep-sea fisheries (Hobday and Matear, 2005).

Changes in sea surface temperature or currents will affect the distribution of commercial fisheries off the coast (Lehodey et al., 1997; Lyne, 2000; Hobday andMatear, 2005). In particular, circulation changes may increase the availability of some species and reduce others. Different management regimes will be required: commercial fishers will be faced with relocation or reduced local catches.

Recruitment will be reduced in cool-water species. For example, for red cod, recruitment is correlated with cold autumn and winter conditions associated with El Nino events (Beentjes and Renwick, 2001; Annala et al., 2004). In contrast, for other species high recruitment and faster growth rate of juveniles and adults are correlated with warmer conditions during

La Nina events (Francis, 1994; Maunder and Watters, 2003), with decreases in larval recruitment during El Nino events (Zeldis et al., 2005). A similar pattern of recruitment exists for gemfish (Renwick et al., 1998). Thus warmer water fish are likely to appear off the Otago coast for the first time.

If species cannot adapt to the pace of climate change, then major changes in distribution are likely, particularly for species at the edges of suitable habitats (Hampe and Petit, 2005). Seasonal to inter-annual variability of westerly winds and strong wind events are associated with recruitment and catch rates in several species (Thresher et al., 1989, 1992; Thresher, 1994). Thus projected changes in Southern Ocean circulation will affect fisheries.

Light Industry

Light industry in Dunedin City (there is no heavy industry) will be affected by climate change through increased risk of flooding alongside streams and rivers and near the coast. Much warehousing and large retail barns are located on low lying and reclaimed land. As sea level rises, there will be increased threat from storm surges and higher water tables. Although vulnerable in the long term, the hazard is less for modern reclaimed areas around Otago Harbour. These are generally higher than older settled parts of the South Dunedin flats.

There will be less need for factory heating. Storage of perishable food (e.g. fruit and vegetables, chocolate) may become problematic without refrigeration.

3.8 Impacts on Coasts

Coastal communities are potentially at risk from long-term sea-level rise (sea level datum has increased by 0.2 m since the 1950s) and large storm surges. The risks of inundation by a 1-in-100 year storm surge will more than double after 2040. Rises in sea level, together with vigorous and regular swells, will lead to ongoing coastal erosion (Bell et al., 2001).

Coasts will also be affected by changes in sediment loads from changes in the intensity and seasonality of river flows, and future impacts of river regulation (Kennish, 2002). There will be changes in coastal geomorphology, especially erosion of fore-dunes, rapid shift in the shape and stability of spits and breaching of lagoons. All these effects will threaten South Dunedin and small communities along the coast (e.g. Warrington, near the mouth of the Waitati River in Blueskin Bay, Karitane).

Sea-level rise is virtually certain to cause greater coastal inundation, loss of wetlands and salt-water intrusion into freshwater sources (MfE, 2004a), with impacts on roads, railways, other infrastructure including stormwater and sewerage wastewater systems, coastal resources and existing coastal management programmes. Most of central Dunedin from Kensington through to Logan Park is greater than 2.5 m above sea level and therefore unlikely to be at risk during the 21st century.

The most critical impacts will be on the more heavily populated shorelines around Otago Harbour and along the coastline of St Clair and St Kilda. The fore-dune is the main line of defence against some future storm surge at higher sea level. Its protection and strengthening must be of high priority to the Council.

Investigations for metropolitan coasts elsewhere in Australasia reveal that large increases in costs for protection of existing management systems will be inevitable (Bell et al., 2001). Mid-range sea-level rise projections by 2040 will require hard protection and sustained sand replenishment along dunes at Tomahawk, St Clair and St Kilda. Rock protection walls around Otago Harbour will need to be continually strengthened and eventually raised.

Sea level rise is almost certain to be ongoing. By 2090, protection of the South Dunedin Flats will become a constant battle. Any breach in the Pacific coastal dune system will be catastrophic for this densely populated area. The steady rise of water levels in the harbour will also need to be dealt with. Many homes and commercial buildings worth hundreds of millions of dollars will be at risk of high groundwater levels, surface flooding and salt water intrusion. Important decisions will be required before 2090 as to how this growing and sustained hazard should be managed.

A similar decision will eventually be required as to protection for Dunedin Airport, where the land is close to existing sea level and enlarged tides in the lower Taieri River are expected. While wave action is no threat there, protection will have to be implemented by 2040 so as to prevent a possible rise in salinity and increased risk of river flooding from tides penetrating progressively further up stream in the lower Taieri River.

The main trunk railway, coastal roads around Otago Harbour and estuaries will be subject to increased flooding during storms and king tides. An ongoing programme of raising these by at least 0.3 m by 2040 and by more than 1.0 m by 2090 will be required. Much of this work could be undertaken incrementally as part of the regular cycle of maintenance and resealing.

Figure 9. Inundation threatening a home with a king tide. Such events will become more common around all estuaries of Dunedin City and its harbour as the 21st century and sea level rise progresses.

Box 5. Climate Change and Energy Generation from Renewable Sources

There is a substantial wind resource in Dunedin City, particularly along the coast and on inland upland areas. Increased westerly wind speed will further enhance the wind generation resource. Thus installation of wind turbines is unlikely to be compromised by projected climate changes.

It is difficult to estimate cloudiness changes into the future. However, incoming solar radiation and hours of bright sunshine will change little from present values. Thus installation of solar panels is unlikely to be compromised by projected climate changes.

Increased westerly flow over southern New Zealand will lead to increases rainfall and runoff in the Waipori catchment. Warming is virtually certain to increase snow melt, the ratio of rainfall to snowfall, and river flows in winter and early spring. This will assist hydroelectric generation at the time of highest energy demand for heating.

3.9 Impacts on Settlement and Society

Impacts on the main urban area

For most citizens of Dunedin's hill suburbs the projected climate changes will not be a problem and will provide considerable benefits. Economic, cultural and sporting life will continue as usual. Climate change is unlikely to affect the heritage, cultural, education and retail precincts of the city.

People will continue to complain about weather, for it will remain changeable, but the outdoor climate will be more comfortable and winter heating costs will be less. Gardens will flourish with opportunities to plant new species and grow a wider variety of fruits and vegetables. Journey to work will be less hampered by dangers of frost and snow.

The downside will be for those near sea level, especially in South Dunedin. Protection of the coastline at St Clair and St Kilda will become progressively more expensive and desperate as sea level rises. There are likely to be periodic failures of the dune system or hard concrete structures.

There will be ongoing anxiety about rising water levels and decreasing property values as future Councillors decide among very difficult options: *protect*; or *retreat*; or *evacuate*. All have large costs. It will be a difficult choice for the City and fierce debate over several decades can be expected.

Increased expense will be required to protect harbour side roads and the main trunk rail line. Other expensive infrastructure connected with wastewater and stormwater will also be at risk.

Impacts on wastewater

The DCC 3 Waters Strategy notes that dry weather capacity of the system is satisfactory, but reduces during rain events, when overflows and spilling can occur. There are known infiltration, cross contamination and inflow issues with siltation build up within sewers. During storm surges and king tides there is spillover into the system from the Otago Harbour. These events create saline spikes that cause difficulties with sewerage treatment at the Tahuna Station.

Climate change will exacerbate these problems. There will be increased flood risk in areas currently prone to flooding and new areas will flooded. Current bottlenecks in the wastewater system will be exacerbated. Saltwater intrusion will become problematic at the Tahuna Station. Small sewerage systems at both Waikouaiti and Warrington will be severely impacted by backwater and salinity effects associated with sea level rise.

Impacts on stormwater

The DCC 3 Waters Strategy notes that the existing stormwater system tends to occupy low lying areas with minimal pipe gradients and limited capacity. While the Musselburgh pumping station has enough capacity to cope with large storms, backflows mean that there is substantial flood risk in many areas for any rainfall event with greater return period of 1 in 10 years. The pumping station also appears to be inadvertently keeping groundwater levels lower than normal through leakage into damaged waste water and potable water pipes. Pumping is thus effectively draining the South Dunedin flats and keeping groundwater levels in check. As sea level rises, this de facto defence system will be overloaded, with sudden, widespread occurrence of surface flooding.

Figure 10. Concrete protection wall at St Clair. Structures like this along the coast will need to be strengthened to combat ongoing rise of sea level and higher storm surges, but will be expensive if valuable inland housing and infrastructure is to be protected.

Thus climate change has serious implications for stormwater. More local flooding can be expected in low lying areas because of more intense rainfall events. Back water effects will also be exacerbated as sea and ground water levels continually rise. Salt water invasion of the system may corrode pipes and pumping equipment. Future defence systems for South Dunedin will require significant new investment e.g. further deep drainage and pumps, or peripheral drains and subsidiary pipe networks, barrier defences with tidal flaps on outlets, and provision for more storm water storage.

Mosgiel's stormwater system struggles when rainfall intensities exceed 23 mm/h and the problem is growing with ongoing development. Climate change will exacerbate this situation through rise in groundwater levels, higher intensity of rainfall and larger floods in the Silverstream.

Impacts on coastal towns

The main issue for residents of coastal towns will be protection against rising sea levels. Some coastal land and infrastructure may have to be abandoned in a planned retreat inland and to higher ground. These communities are unlikely to afford the cost of building and maintaining protection structures.

Impacts on other rural communities

Projected climate change will on the whole benefit rural communities. The outdoor climate will be more comfortable for both people and animals. Winter heating costs will reduce and farming will be less hampered by hazards of frost and snow. Production from the land, be it trees, grass or animals, will increase. A wider variety of crops will become commercially viable. Intensive grassland farming or forestry will expand to cover significant upland areas. All other things being equal, the productivity and wealth of land owners should increase.

These projections apply less to low lying rural communities such as the Lower Taieri, where rising water tables, enlarged tides and larger flooding events are likely.

Impacts on Maori

Changes in Dunedin's climate over the rest of this century will challenge the Maori economy and influence the social and cultural landscapes of Maori people (Packman et al., 2001). While the majority of Maori live in urban environments, they also occupy small coastal towns and rural areas where the economy and social and cultural systems are strongly tied to natural environmental systems.

Some Maori have significant investment in fishing, agriculture and forestry and the downstream activities of processing and marketing (NZIER, 2003). They are also important stakeholders in the growing tourist industry (McIntosh, 2004). Economic performance and opportunities will be influenced by pest and disease prevalence, drought, and loss of biodiversity, which, in turn, will affect the ability to raise development capital in these industries (MAF, 2001; 2006; Cottrell et al., 2004).

The capacity of the Maori people to plan and respond to threats of climate change to their assets (i.e., buildings, farms, forests, native forest, coastal resources, and businesses) varies greatly. Their response will be governed by access to funds, information and human capital (TPK, 2001). Multiple land-ownership and decision making processes can be complex, often making it difficult to reach consensus and to implement costly or non-traditional adaptation measures. The high spiritual and cultural value placed on traditional lands/resources can restrict or rule out some adaptation options such as relocation (NZIER, 2003).

Some Maori use public and private land, often in coastal areas, for hunting and fishing to supplement household food supplies, recreation, and the collection of firewood. These will be affected by changing distribution and abundance of culturally important flora and fauna. Values associated with these resources, are likely to be adversely affected by climate change, including spiritual well-being and cultural affirmation (NIWA, 2006). These challenges may affect cultural wellbeing and compound the sensitivity of the Maori to climate change.

Wider indirect impacts

Different global socio-economic developments and responses to climate change will have flow-on effects through international policies, trade, migration and security, including those associated with regional changes in the south-west Pacific and Australia. These are poorly understood and quantified but may have significant implications for the scale and relevance of response options to domestic impacts of climate change. The wider implications of projected climate change for Dunedin City are a matter of some conjecture and difficult to quantify, but may include:

- Instability in the Pacific Islands could become serious due to a combination of climate related natural disasters, sea level rise, and economic and environmentally induced migration.
- ew Zealand's closest neighbour, Australia, is likely to be more severely affected by climate change impacts, especially under high emissions scenarios. Projections by Hennessy et al. (2007) point to significant water shortages within the next few decades, increased coastal damages from sea level rise and tropical cyclones, and significant loss of biodiversity. Agricultural production could fall in many regions, including the most productive ones, by a combination of reduced rainfall, higher extreme temperatures, recurrent drought and substantially increased risk of wildfire.
- While the capacity of Australia to adapt is high, the scale and combination of these different impacts presents serious challenges to Australia's social, environmental and economic sustainability. This could result in greater population migration to a more well-watered and green New Zealand.
- The impacts of climate change on Australia could lead to a competitive advantage for New Zealand in some areas such as agriculture and tourism.
- Outcomes from international changes in economic, trade, political and environmental issues are difficult to predict at present. Escalation of a regionally fractured world could well hamper New Zealand's trade and international relationships, including the possibility of trade barriers, security concerns and new alliances.
- Failure to deal with climate change may lead to major political instability in some world regions affecting global and regional security.

3.10 Synthesis of Impacts Assessment

Climate change adds new dimensions to the challenges already facing communities, businesses, governments and individuals. Assessment of the information given above leads to the conclusion that climate change will give rise to both risks and benefits.

There are five sectors at *risk* in Dunedin City as illustrated in Box 6.

Box 6. Main Sectors of Dunedin City at Risk from Projected Climate Change

1. Low lying densely populated urban areas, especially South Dunedin.
2. Coasts, especially near estuaries, and their communities.
3. Major transport infrastructure, mainly harbour roads and railway.
4. Dunedin Airport from enlarged tides, rising salinity and flooding.
5. Natural ecosystems.

Adaptation can alleviate or delay vulnerability to these risks in the last three sectors, but not to natural ecosystems. Some extreme events will trigger multiple and simultaneous impacts across systems, e.g. more subtropical storms and ongoing sea level rise leading to flooding, coastal surge and destructive erosion with widespread loss of homes, roads, railways and prolonged closure of the airport.

There are also four key benefits for particular sectors as illustrated in Box 7. Adaptation can reduce barriers to change and allow benefits to accrue more rapidly.

Box 7. Main Sectors of Dunedin City to Benefit from Projected Climate Change

1. Agriculture and forestry due to longer and better growing seasons, less frost and increased rainfall.
2. Energy use, due to reduced demand in winter.
3. More comfortable and outdoor living as people benefit from warmer weather.
4. The water resource from increased stream flows.

4. Adaptation

4.1 Overview

There are two main policy responses to climate change: mitigation and adaptation. Most public and political debate centres on mitigation. But at the local level, adaptation deserves far greater attention because planned adaptation can greatly reduce vulnerability and can easily be implemented.

This is especially so for territorial authorities. Attempts to mitigate climate change through reducing greenhouse gases by Dunedin City are well meaning. They make sense when considering the prospect of peak oil, the economic benefits of conserving energy and the need to protect the city's tourist image as a place of nature. But local mitigation measures will matter little on a global scale. No matter how strenuous the city's efforts may be, they will do very little to moderate the projected global climate changes and will not prevent local climate change nor modify its impacts.

Mitigation is most effective when pursued through instruments such as carbon taxes or cap and trade schemes. These policy responses are more suited to central government and the global community as negotiated through the United Nations Framework Convention on Climate Change (e.g. the Kyoto Protocol). The reality is that over the rest of the 21st century, effective mitigation of climate will depend on emission reduction measures taken by just a few big players, namely the USA, Europe, China and perhaps emerging nations such as India and Brazil.

Rather the city's policy response to climate change should pay most attention and funding towards adaptation. This is because the local impacts and costs of climate change will occur regardless of any mitigation, will be substantial and be borne by local communities. Also where benefits arise from climate change, they can be captured by local adaptation. Global or central government agreement is not required. Adaptation measures are particularly effective when undertaken by individuals, farmers, local institutions, local companies and local authorities.

Expected impacts will make some communities very vulnerable to climate change. Adaptation can lessen these impacts. Most economic and societal activity has evolved in Dunedin City to cope with climate variability. This coping ability is based on many decades of experience and practice. Adaptation can greatly extend that coping range, which reduces vulnerability.

4.2 Adaptation as Risk Management

A risk management framework is generally regarded as the most appropriate approach to deal with the uncertainties involved in climate change projections and policy responses (IPCC 2007d; MfE 2008c). Exploring alternative future scenarios of climate and socio-economic change is critical to such a risk-based approach. It allows the weighing up of different societal attitudes to risks and their implications for adaptation decisions. It also considers the costs and benefits of alternative responses that may be borne by different parts of society both in the present and future.

Adaptation decisions will reflect individual and societal attitudes to risk, and perceptions about how risks should be managed. Some people are more comfortable to take a punt and hope that the big catastrophic event may not happen, or may not happen in their lifetime. For others, mitigating the risk of unlikely but catastrophic events for their own sake is important. Other important considerations are costs to future generations, or to other members of the community.

Many adaptation decisions depend on scientific information to assess risk for different scenarios. However, assessment also depends on value judgments about risks. There has to be a trade-off between reducing risk of future impacts with measures taken now, against costs in the distant future. There must also be a balance between benefits and costs using economic, social and environmental criteria.

4.3 The Process of Adaptation

Adaptation is not a one-off event or a single step, but rather an iterative process as illustrated in Figure 11 (Warrick 2000). It involves awareness raising and capacity building, the development of knowledge, data and tools to understand relevant changes and their impacts, risk assessments that clarify the relevance of changes and key vulnerabilities.

Where significant risks are identified, adaptive responses need to be integrated (or 'mainstreamed') into existing natural hazard and resource management practices, including local government plans, policies and strategies. In New Zealand, central government provides guidance and a measure of technical support, while local government is responsible for the actual risk management and implementation of measures within a community context (MfE 2008b).

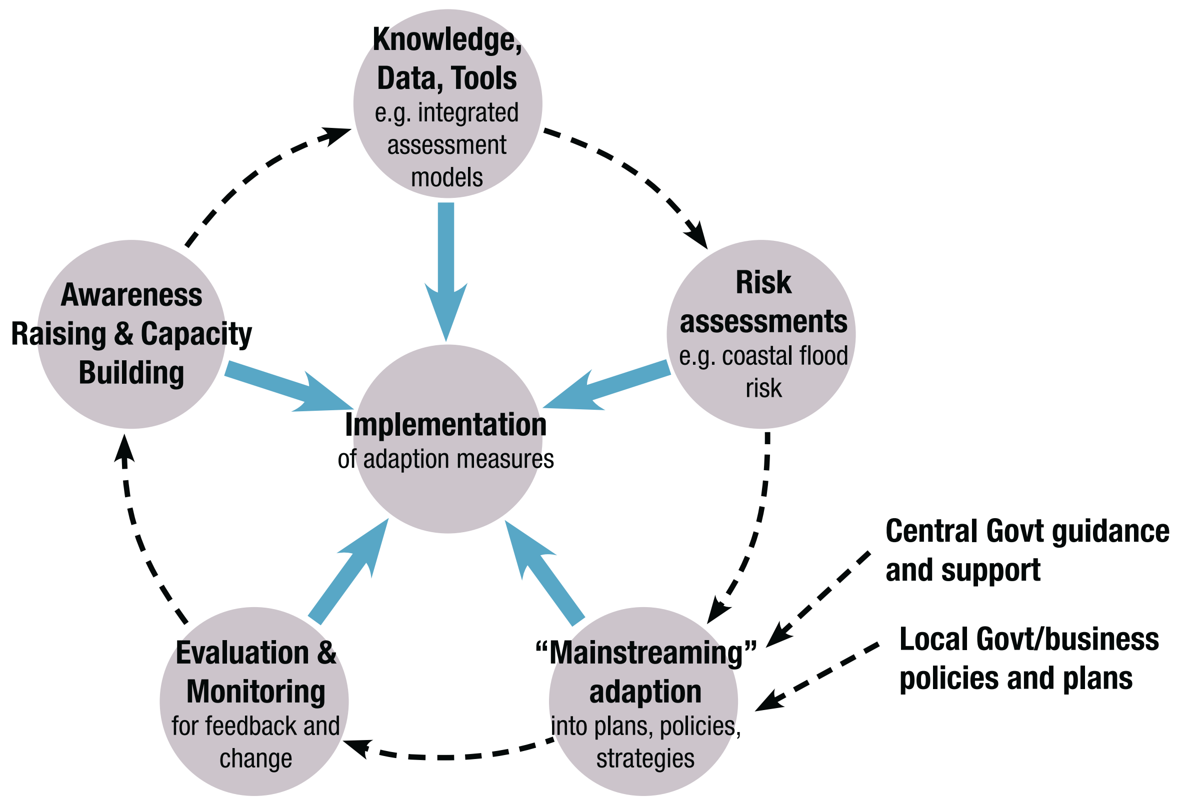

Figure 11. **Schematic diagram illustrating the process of adaptation (Figure reproduced from Hennessy et al., 2007, and is based on Warrick 2000 as modified by Reisinger et al., 2010).**

Beyond this, the Dunedin City Council will need to continuously monitor the changing risks and emerging knowledge, as well as effectiveness of adaptive responses. In turn, this monitoring feeds into the further creation of awareness and capacity building.

All elements are needed to achieve effective implementation of adaptation measures. They typically involve a range of stakeholders from the science sector, local government, business, local communities and organisations from civil society, and central government.

4.4 Adaptation and the Role of Council

Adaptation decisions should be informed by scientific inputs, but Council should require that these are clearly expressed with respect to specific decisions that it may take (Reisinger 2009). It is up to Council to encourage a societal debate as to various adaptation options and costs. The regulatory framework within New Zealand provides for such discussions to be held at the local community level, with broad guard rails provided by the provisions of the Resource Management Act (1991) and the New Zealand Coastal Policy Statement, Local Government Act (2002) and Civil Defence and Emergency Management Act (2002).

Some planned adaptation to climate change is already occurring on a limited basis. For example, there is a long record of managing the impacts of weather and climate related events within Dunedin City (e.g. Musselburgh pumping station, the harbour rock wall, St Clair beach wall, and flood protection banks along the Taieri River). Then too, there is evidence that individuals are using adaptation to capture benefits of climate change and to protect against climate variability (e.g. more irrigation, changed farm practices and more outdoor dining).

A wide array of further adaptation options is available. Many are immediately viable and can be implemented in some sectors at low cost, and/or with high benefit-cost ratios. Options include providing information, guidelines and tools, zoning for high impact areas setbacks for risk-based planning and management of coastal hazards (Bell et al., 2001; MfE, 2004a) and improved storm and waste water systems. All reduce vulnerability, especially when embedded within broader sector initiatives.

For many natural ecosystems, impacts have limited reversibility. Planned adaptation opportunities for offsetting potentially deleterious impacts tend to be limited due to fixed habitat regions (e.g. the alpine zone in both Australia and New Zealand). One adaptive strategy is to provide corridors to facilitate migration of species under future warming. This will require changes in land tenure in many regions, with significant economic costs, although schemes to promote such connectivity are already under way in Australia (Hennessy, 2007). Another strategy is translocation of species. This is a very expensive measure, but it may be considered desirable for some iconic, charismatic or particularly vulnerable species.

For agriculture, there are opportunities for planned adaptation via improvements in crop varieties and rotations and changing land use. Implementation will require new investment and significant managerial changes (Howden et al., 2003a). Farmers elsewhere in eastern New Zealand are engaging in local discussion of risks posed by future climate change and how to enhance adaptation options (Kenny, 2002; 2005). They stress the need for support and education for ‘bottom-up’ adaptation (Kenny, 2007).

In coastal areas, Hennessy et al. (2007) considered that there is solid progress in risk assessments and in fashioning policies and plans at the local and regional level in New Zealand. However, there remain significant challenges to achieving concrete actions that reduce risks. Consistent implementation of adaptation measures such as setback lines, planned retreat and dune management, building designs, prohibition of new structures and siting requirements that account for sea-level rise) has been difficult (Dahm et al., 2005). Differences in political commitment, lack of strong and clear guidelines from government, and legal challenges by property owners are major constraints (MfE, 2003).

Box 8. Key Adaptation Issues for Dunedin City

- Investigation of adaptation options and their timing to reduce impacts of sea level rise on the Pacific coast and Otago Harbour.
- Investigation of adaptation options for ongoing protection of shoreline roads and railways.
- Investigation of adaptation options and their timing for planned protection, retreat or eventual evacuation of South Dunedin.
- Investigation of adaptation options for ongoing long term protection of flooding and salinity rise at Dunedin Airport (Figure 12).
- Investigation of adaptation options to reduce vulnerability of sea level, groundwater and salinity rise on stormwater and sewerage systems.
- Updating design criteria to take into account increased flood risk with projected climate change.
- Investigation of adaptation options for preserving natural ecosystems.
- Investigation as to how farming and forestry can optimally adapt to better growing conditions.
- Educating the wider public as to the opportunities and risks of climate change.

Dunedin City will have to develop or encourage specific adaptation measures so as to reduce the impacts and vulnerability of its communities to projected climate change. Key issues are identified in Box 8. It is recommended that the City develops a plan and programme to address these.

Figure 12. Dunedin Airport during the flood of 1980. The Airport will be vulnerable to the impacts of climate change from enlarged tides, rising salinity and increased flood risk. Adaptation options including groundwater pumping and higher stop banks can reduce this risk.

4.5 Timing of Adaptation

One set of challenges relates to the timing of adaptation. Adaptation can be reactive, where we change as and when a need or opportunity arises from a change in the climate. Adaptation can also be prompted by a change in some other driver, for example it makes more sense to do a comprehensive climate risk assessment before a major new infrastructure development is undertaken, rather than a decade afterwards.

Other forms of adaptation can be proactive or planned: in some instances the Dunedin City will need to look forward by many decades, perhaps even more than a century. This is because future generations may find themselves locked into a situation where a changing climate creates increasing problems, but their ability to adapt at that time is rather limited (Adger et al., 2007). The increasing coastal squeeze between urbanized areas and sea level rise may be one of those areas (Adger et al., 2007; MfE 2009). Eventually retreating from the coast may be the only option, but an incredible challenge in densely populated and high-value parts of the city such as South Dunedin.

The timing of adaptation also has implications for the distribution of costs and benefits resulting from adaptation actions. Proactive adaptation may involve a near-term opportunity cost (e.g. not developing a coastal property into high-value housing estate because of its vulnerability to future sea level rise). The cost of foregone development opportunities is often borne by private entities in the present, but it avoids social costs in future, such as community tension and loss of environmental amenities (e.g. when a sea wall would need to be erected to protect private property).

4.6 Barriers to Adaptation

Barriers may limit both the implementation and effectiveness of adaptation measures. Whether or not adaptation occurs will depend on a range of factors. These include natural and man-made capital assets, social networks and entitlements, technology, human capital, response of institutions, governance, and the city's income. Considering all sectors, and following Hennessy et al. (2007), there are six broad barriers to adaptation:

- A lack of methods for integrated assessment of impacts and adaptation that can be applied on an area-wide basis.
- Lack of well-developed evaluation tools for assessing planned adaptation options, such as benefit-cost analysis, incorporating climate change and adapted for Dunedin City application.
- Ongoing scepticism about climate change science, uncertainty in regional climate change projections, and a lack of knowledge about how to promote adaptation.
- Lack of guidance as to how impacts of sea level rise should be dealt with.
- Little support for building capacity to undertake the necessary actions so that regional and local responses have been limited, variable and inconsistent.
- Cost and unresolved debates as to who should pay.

4.7 Adaptation and Sustainability

Adaptive capacity is intimately connected to social and economic development. There are broad issues as to general attitudes about how economic values should be balanced against social and environmental issues, and what the concept of sustainability of a community should mean in practice. The amount of foresight that decision-makers and communities are prepared and able to use in the adaptation process (particularly for ensuring the availability of data, models and tools, and risk assessments) often reflects their general attitudes towards long-term sustainability and best use of limited resources.

Intense international negotiations are proceeding under the UNFCCC to find a replacement for the Kyoto Protocol. The goal is to restrict the rate of greenhouse gas emissions so as to prevent “dangerous” climate change. As witnessed by the weak outcomes from the UNFCCC Copenhagen meeting of late 2009, the global community cannot agree on mitigation measures. If no effective agreement is reached, then climate and sea level changes will eventually become so large that the City’s ability to adapt will be exhausted.

5. Vulnerability

An assessment of aggregate vulnerability for key sectors of Dunedin City is given in Figure 13. It synthesises relevant information about current sensitivity, coping ranges, potential impacts, adaptive capacity and vulnerability. It follows similar diagrams and concepts published elsewhere (Jones et al., 2007, Hennessy et al., 2007). Vulnerability is assessed using criteria of:

- magnitude of impact
- timing
- persistence and reversibility
- likelihood and confidence
- potential for planned adaptation
- geographical distribution
- importance of the vulnerable system.

Natural ecosystems have a narrow coping range and quickly reach vulnerable status even with less than 2.0°C of warming. For coastal communities (includes urbanized low lying areas of South Dunedin) and transport infrastructure (mainly harbour side roads, railway and Dunedin Airport) vulnerability becomes significant for 1.5°C to 2.0°C of global warming, even if adaptive capacity is realised. An estimated 10 km of railway and 70 km of roads are likely to be affected.

Energy security, health, agriculture and tourism have larger coping ranges and adaptive capacity. They are unlikely to become vulnerable, even if global warming exceeds 3.0°C. Also shown in Figure 13 are the three key vulnerability factors identified in Article 2 of the UNFCCC that define "dangerous" climate change: natural ecosystems; sustainable development; and food security(agriculture).

After assessment of likely impacts of climate change and considering appropriate adaptation options, certain "hotspot" areas can be identified within Dunedin City. These are areas where vulnerability to climate change will be high sometime between 2040

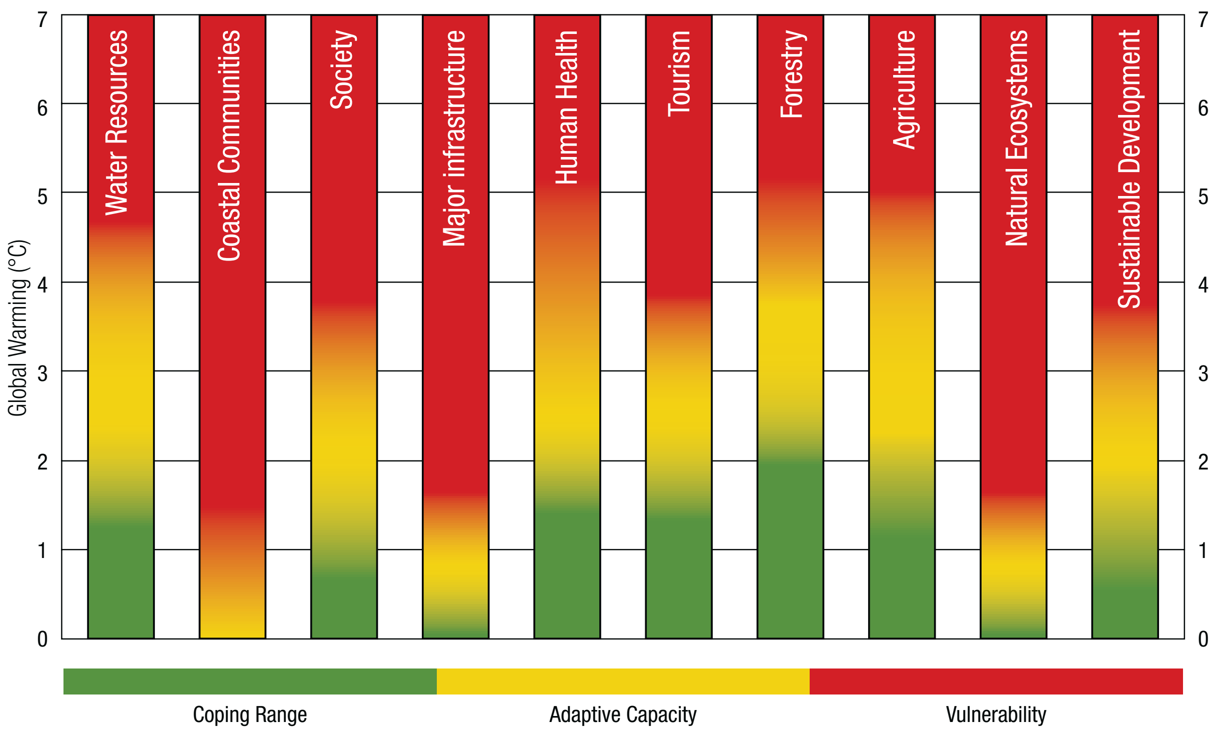

Figure 13. **Vulnerability to climate change for key sectors of Dunedin City relative to the amount of global warming. This is a schematic diagram that assesses vulnerability after taking into account coping range for the current climate and estimated adaptive capacity.**

and 2090, assuming a A1B global emissions scenario of Appendix B. This scenario envisages a future world of rapid economic growth, global population that peaks in mid-century and declines thereafter, and a continuation of some fossil fuel use, but rapid introduction of a mix of new and more efficient technologies. It should be noted that some other fossil fuel intensive scenarios, such as the A1FI, will lead to hotspot areas appearing earlier in the century.

Their selection following Hennessy (2007) is based on the following criteria:

- large impacts
- low adaptive capacity
- substantial population
- economically important
- substantial exposed infrastructure
- subject to other major stresses (e.g., continued population growth, ongoing development, ongoing habitat loss, threats from rising sea level).

There are five hotspot areas within Dunedin City (see Figure 14):

1. ***The South Dunedin urban area, including St Clair and St Kilda shorelines***

   This is the most vulnerable area of Dunedin City because the impacts of sea level and groundwater rise will threaten substantial retail, warehousing and residential areas. Adaptation options will become expensive and ongoing by 2090. An estimated 360 hectares could be at risk. There will be ongoing anxiety about rising water levels and decreasing property values as the Council decides among the difficult options: protect; or retreat; or evacuate.

2. ***Harbour side shoreline, including the mouth of Otago Harbour***

   Rising sea levels will lead to inundation of infrastructure (mainly roads and railway), especially during northeast storm surges and king tides. Up until 2040, it will be possible to raise infrastructure in ongoing stages, perhaps with regular maintenance work. Sea level rise will be ongoing and by 2090 may be accelerating at such a rate that other options may be required.

3. ***The lower Taieri Plain, including Dunedin Airport***

   Enlargement of tides in the lower Taieri River, rising salinity levels and more flooding will hamper agriculture and local roading. The substantial investment in Dunedin Airport (Figure 13) and its critical role for Dunedin citizens and tourism will require substantial protection (e.g. upgraded pumping, higher stop banks).

4. ***Populated estuaries along the Pacific coast***

   The most vulnerable areas are around Blueskin Bay and Karitane. Rising sea levels and potential erosion of beaches and spits will lead to inundation of infrastructure (mainly roads) and housing. Adaptive capacity is likely to be restricted by a limited ratepayer base. Drought will increase.

5. ***Conservation lands of upland regions***

   Natural ecosystems have a narrow coping range and will quickly reach vulnerable status as warming progresses. Climate change will lead to some irreversible impacts on natural ecosystems. Many areas reserved for conservation are small and isolated, so threatened species will have nowhere to go. In alpine zones, reductions in duration and depth of snow cover will alter distributions of natural communities.

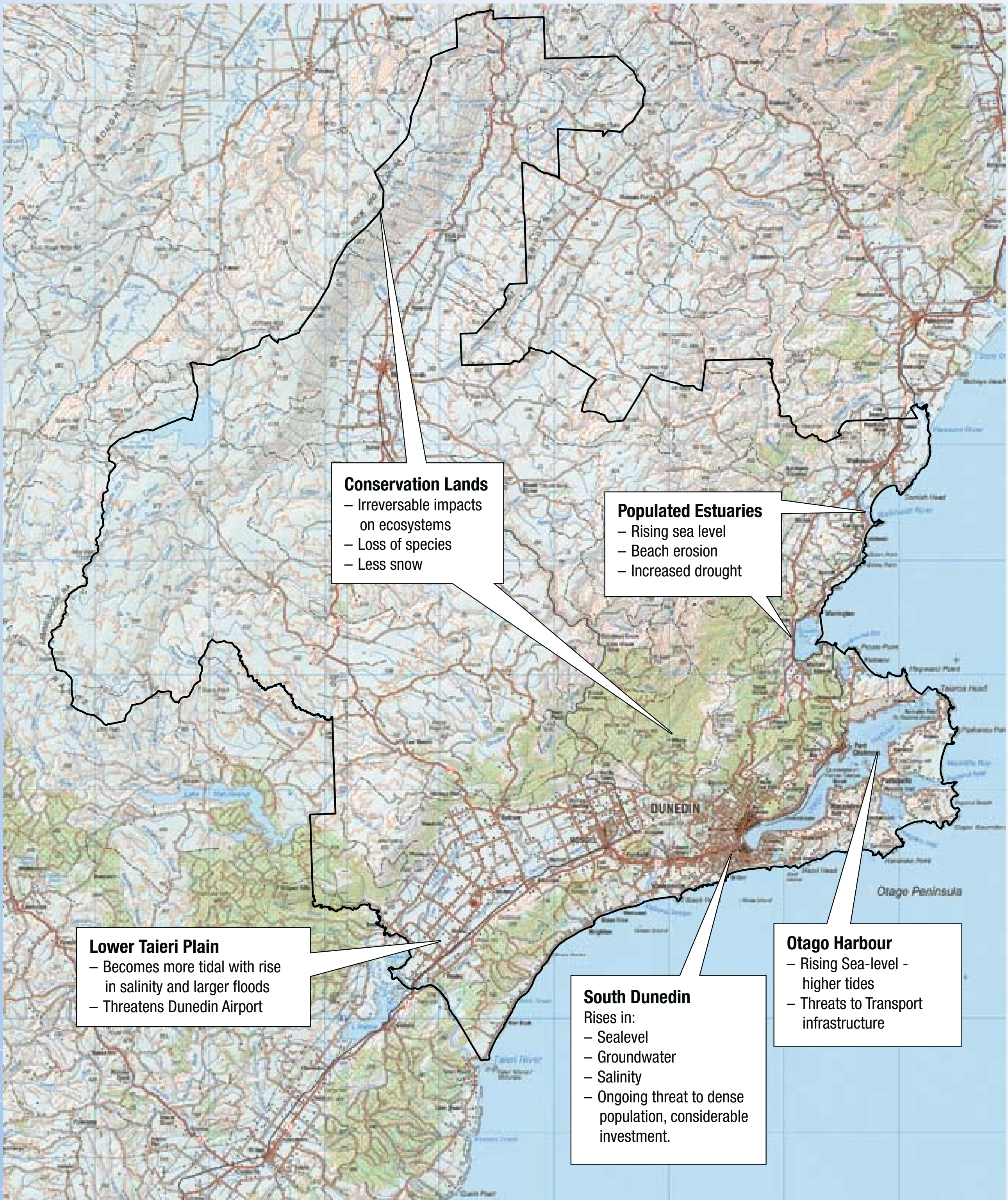

Figure 14. Key hotspots identified for Dunedin City where vulnerability to climate change will become apparent between 2040 and 2090. Vulnerability is assessed for what some consider a likely greenhouse gas emissions scenario over the 21st century (A1B scenario of Appendix B). It assumes a future world of rapid economic growth, global population that peaks in mid-century and declines thereafter, and a continuation of some global fossil fuel use, but rapid introduction of a mix of new and more efficient technologies. It should be noted that some other scenarios that assume intensified fossil fuel use, such as the A1FI, will lead to hotspot areas developing earlier in the century.

6. Conclusions and Recommendations

With the release of the IPCC Fourth Assessment of climate change, and updated modeling of NIWA and MfE, the Dunedin City Council has updated projections for its own territory. These can now be used for planning purposes so as to combat the impacts of climate change.

Council should consider its role in dealing with the issue of climate change. Council provides a number of services to the residents of Dunedin, which will be affected by climate change. Its planning function and responsibility will need to take account of climate change projections and make appropriate land use and infrastructure planning decisions as a result.

Council needs to consider what role it wants to take as a facilitator, coordinator and educator of the community around climate change issues and initiatives. Less attention should be given to issues of mitigation of climate change through reduction of greenhouse gases, unless they lead to energy efficiencies. Rather, most attention should be directed at adaptation.

This is because there are major long term planning and infrastructure issues related to very large impacts with projected climate change and sea level rise. Council needs to focus on these and develop a long term adaptation plan to reduce vulnerability over the rest of this century. Some impacts will be beneficial, but many are not and will affect important communities and infrastructure, especially near the coast.

As a result of the main findings of this Report, the following recommendations are made:

1. Council should review its role and strategy in dealing with the issue of climate change and its likely impacts.

2. Council should develop policy responses to climate change that give most attention to adaptation.

3. At this time, projected sea level rise of at least one metre by 2090 would be prudent for impact and planning exercises. The science in this area is currently inconclusive and needs to be followed closely by Council so as to continually adjust this estimate.

4. The present systems for monitoring of groundwater and salinity levels of the South Dunedin flats and around Dunedin Airport at Momona need to be expanded to better understand interactions with changing sea level and to provide data for modeling of impacts.

5. More research is required as to the implications of climate change on one and two day rainfall extremes and on flood peaks of the city's streams. At this stage, it is suggested that the very large 1929 event be used for design purposes.

6. Coastal dune systems are the main line of defence against catastrophic flooding from future storm surges at higher sea level. Their protection, strengthening and hardening adjacent to vulnerable communities must be of high priority to the Council.

7. Dunedin City will have to develop or encourage specific adaptation measures so as to reduce impacts and vulnerability of its communities to projected climate change. It is recommended that the City develops a plan and programme to address adaptation issues that are identified in Box 8.

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Appendix A: DCC Climate Change Predictions Policy 2006

On 30 October 2006, the Dunedin City Council adopted the following predictions of climate change from the Intergovernmental Panel on Climate Change (IPCC). These predictions are to be used, where relevant, in all planning processes and activities undertaken by the Council, which would result in decisions, which have an effective life of greater than 50 years. Such decisions would include decisions around the renewals of existing assets, construction of new assets or facilities, all work programmes and all planning initiatives.

Any significant implications resulting from the impact of any climate change will need to be reported to the relevant Committee for full consideration.

The climate change predictions to be used are as follows:

Temperature Changes (°C)	**Summer**	**Autumn**	**Winter**	**Spring**	**Annual**
1990 – 2030's	-0.2 to 1.2	0.0 to 1.1	0.2 to 1.8	0.0 to 1.2	0.1 to 1.3
1990 – 2080's	-0.1 to 2.7	0.4 to 3.3	0.7 to 3.5	0.2. to 3.0	0.4 to 3.1
Rainfall Changes (%)	**Summer**	**Autumn**	**Winter**	**Spring**	**Annual**
Dunedin2030's	-7 to +8	-2 to +3	-7 to +15	-4 to +11	-2 to +6
2080's	+1 to +34	-9 to +46	-5 to +30	-2 to +16	+2 to +14

Sea Level Rise	**2050**	**2090**
Mean sea level increase	+0.33 metres	+0.66 metres

Examples of the sorts of consideration that will need to be given in decisions that have an effective life of greater than 50 years are as follows. Note that these are examples only and there are likely to be a wide range of potential effects that will need to be considered.

Function	**Climate Change Mechanism**	**Potential impacts**
Planning	Increase in high intensity rainfall effects	Increased flood risks may require planning restrictions on flood plains etc.
	Increased sea level	Planning restrictions in at risk coastal areas.
Roading	Increase in high intensity rainfall events	Increase in road washouts and landslips onto roads. Increased maintenance required for water tables.
	Increased sea level	Erosion of coastal roads/roadbeds. Increased closures due to sea inundation. May require road levels raised.
Stormwater	Increase in high intensity rainfall events	Increased stormwater surcharging. Possible property damage.
	Increased sea level	Greater reliance on pumping. Higher groundwater level impacts on underground pipe networks.
Water	Reduced annual rainfall	Less secure raw water supply.
	Increased seal level	Possible salt-water invasion of aquifers. Higher groundwater level impacts on underground pipe networks.

Climate change predictions are likely to change over time as new information becomes available. As any new IPCC prediction becomes available, the council will need to consider whether this policy is updated.

Appendix B: Emission Scenarios used by the IPCC for Projections of Future Climate and Sea Level Change

A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income.

The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil-intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B, where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

The scenarios do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol.