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Climate change effects and impacts assessment

A Guidance Manual for Local Government in New Zealand – 2nd Edition

May 2008

New Zealand Government

Based on NIWA Client Report WLG2007/62, prepared for Ministry for the Environment by:

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Executive Summary

This Guidance Manual is designed to help local governments identify and quantify opportunities and hazards that climate change poses for their functions, responsibilities and infrastructure. This is the second edition of the Guidance Manual, and it supersedes the first edition published in 2004. It follows the updated assessment of the science of climate change produced by the Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment in 2007.

Why plan now for climate change?

Climate-related risks are not new to New Zealand local government planners, or resource and hazard managers. Climate change will, by and large, not create new risks, but may change the frequency and intensity of existing risks and hazards, as well as introducing some long-term shifts in climate regimes across the country. Adapting to long-term climate change will contribute to our resilience to natural fluctuations in climate, such as El Niño, which often leads to dry conditions in northern and eastern parts of New Zealand. Planning to address the effects of climate change is most likely to be effective and cost-efficient if it is integrated into local government standard work programmes, rather than done in isolation.

Local government is responsible for a range of functions that may be affected by climate change, under the Local Government Act 2002, the Resource Management Act 1991 and other legislation. For regional councils, these functions may include management of regional water, air and land resources, biosecurity, natural hazards management, emergency management, and regional land transport. For city and district councils, they include land-use planning and decision-making, building control, emergency management and provision of infrastructure and community services. Local authorities own community assets that may be vulnerable to climate change effects.

In 2007, the IPCC concluded that most of the observed increase in global average temperatures since the mid-20th century is very likely a result of the observed increase in anthropogenic greenhouse gas concentrations. The panel's assessment of data collected since 1970 showed it is likely that anthropogenic warming has had a discernable influence on many physical and biological systems. It concluded that the continued emission of greenhouse gases at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century, that would very likely be larger than those observed during the 20th century.

Thus, councils and communities should be giving serious consideration to the potential future impacts of climate change on their functions and services. Particularly important are infrastructure and developments that will need to cope with climate conditions in 50–100 years' time. Examples include stormwater drainage systems, planning for irrigation schemes, development of low-lying land already subject to flood risk, and housing and infrastructure along already eroding coastlines. Climate change may also bring opportunities (eg, growing new horticultural crops in a particular area) to which councils may wish to pay attention.

Guidance Manual contents and use

This Guidance Manual:

- provides projections of future climate change around New Zealand
- compares these projections with present climate extremes and variations
- identifies potential effects on local government functions and services
- outlines methods for assessing the likely magnitude of such effects
- explains how this information can be applied to assess the risk associated with various climate change impacts
- provides guidance on incorporating climate risk assessment into local government regulatory, assessment and planning processes.

Most users of this Guidance Manual will concentrate on the parts that help them fulfil their own responsibilities. To help users find the information relevant to their needs, the manual provides two ‘roadmaps’ (pages xvii–xviii), that set out the steps involved in typical assessments and show where to find key guidance for these steps.

Introduction (Chapter 1):

How to make assessing climate change manageable

Chapter 1 summarises key issues for councils and outlines approaches to identifying effects and adapting to changes. An incremental approach to risk assessment is recommended, which should begin with an initial screening assessment. This assessment uses simple initial estimates of how the relevant climate factors may change, with expert judgement or simple calculations of likely impacts of these changes, to test the significance of the changes for a council’s activities. Further detailed analyses are justified only if these screening studies suggest a material impact is possible. This screening approach can be applied to a particular function, asset or activity, or it can be applied across all of a council’s activities.

Councils already address extreme weather events and climate variations as they develop plans and provide services. Climate change effects should be considered as part of these existing regulatory, assessment and planning activities. It is not necessary or even advisable to develop a whole new set of procedures for dealing separately with the impacts of climate change, but it is vital to integrate climate change into standard considerations to ensure that council activities are ‘future-proofed’ and remain sustainable for future generations.

Projections of Future New Zealand climate change (Chapter 2):

New projections based on the IPCC Fourth Assessment, 2007

Projected changes in New Zealand’s climate are given for six scenarios of greenhouse gas emissions. Changes are specified for 2040 (actually the 2030–2049 average), and for 2090 (the 2080–2099 average), relative to the climate of 1990 (1980–1999 average). Most of this information is derived from statistical downscaling of output from 12 global climate models, and is supplemented by initial analyses from two simulations using NIWA’s regional climate model.

New Zealand ***temperatures*** are expected to increase by about 1°C by 2040, and 2°C by 2090. However, there is a wide range in the projected future warming owing to the different emission scenarios and differences in climate model sensitivities.

Projected changes in mean ***rainfall*** and ***wind*** patterns show a more marked seasonality than was evident in models from the IPCC Third Assessment, 2001. The latest results suggest increased westerlies in winter and spring, along with more rainfall in the west of the North and the South Islands and drier conditions in the east and north. Conversely, in summer and autumn, the models suggest decreased frequency of westerly conditions, with drier conditions in the west of the North Island and possible rainfall increases in Gisborne and Hawke's Bay.

Other changes expected are: decreased frost risk, increased incidence of high temperatures, increased frequency of extreme daily rainfalls, a possible increase in strong winds, and decreases in average snow cover.

Relationship to Current Climate Variability and Change (Chapter 3):

Natural variations will be superimposed on a long-term warming trend, and together they will create extremes

New Zealand climate varies naturally from year to year and from decade to decade. In individual years, annual New Zealand-wide temperatures can deviate from the long-term average by up to 1°C (plus or minus), whereas regional precipitation can deviate by about 20% (plus or minus). Whether the deviation will be above or below the average will depend on whether it is a La Niña or an El Niño year, and will also depend (for precipitation) on geographic location.

New Zealand also experiences decadal climate variations, related to a Pacific-wide natural feature called the 'Interdecadal Pacific Oscillation' (IPO). Research is still in progress on the predictability of the IPO and its local climatic impacts. There was a shift to the 'negative phase' of the IPO around 1999, so more La Niña (and less El Niño) activity may be expected compared to 1978–1998, with a period of higher temperatures for New Zealand. This is likely to favour reduced westerlies and southwesterlies, rainfall reductions in the southwest of the country but increases in the northeast, and faster rises in air temperature and sea level. These conditions could last for the next 20–30 years.

These natural variations will be superimposed on human-induced long-term climate changes, and together they will give us the extremes to which future New Zealand society will have to adapt. What currently is an unusually warm year could be the norm in 30–50 years, while an unusually warm year in 30–50 years' time is very likely to be warmer than anything we experience at present.

Effects on Local Government Functions and Services (Chapter 4):

How to identify what will be materially affected

Climate changes of the magnitude projected in this report could have significant effects on various council functions and activities. These effects will often be different in different parts of the country, and may be negative, positive or mixed. For example, increasing temperatures may make some parts of the South Island more suitable for horticultural development, which in turn may place increasing demands on water for irrigation. The availability of water for irrigation may itself be affected by climate changes.

The range of local and regional functions, services and activities on which climate change could impact is wide. It includes strategic and land-use planning, water supply and irrigation, stormwater and flood management, roading, coastal infrastructure, management of terrestrial and aquatic ecosystems, civil defence and emergency management, and biosecurity. Chapter 4 provides information and guidance that will help individual councils identify which of their functions are likely to be *materially affected*. It summarises data, sources of information, models and specialist expertise available in New Zealand. It also provides some examples of work that some local authorities have already undertaken.

Developing the Scenarios (Chapter 5):

Tools for initial screening and more detailed studies

A definitive single quantitative prediction of how much a particular climatic element (eg, heavy rainfall intensity) will change over coming decades is not feasible. This is because the rate of climate change will depend on future global emissions of greenhouse gases, which in turn depend on global social, economic and environmental policies and development. Incomplete scientific knowledge about some of the processes governing the climate, and natural year-to-year variability, also contribute to uncertainty in projections for the future.

Consequently, ‘scenario analysis’ is one of the most appropriate tools for assessing the likely effects of climate change. Climate, social and economic scenarios are formulated that span the likely range of future conditions. These are used in conjunction with expert knowledge and models of the sensitivity of natural or managed systems to climate to deduce a range of possible climate impacts on selected council activities and functions.

Chapter 5 provides guidance on undertaking scenario analyses, including tables of values and sources of climatic information for use in both initial screening assessments and more detailed studies. Examples are provided covering water resources (Southland), changes in agricultural water usage and resources in three river catchments (Rangitata, Motueka and Tukituki), and effects on stormwater and wastewater systems (North Shore City).

Risk Assessment (Chapter 6):

Factor in the evolution of climate-related risk over time

Local government organisations have to make long-term decisions for the community, including decisions on asset management and planning. Resources are often limited, and priorities must be set for where to apply them. Risk assessment methodology provides a systematic process for identifying risks associated with climate change, comparing them against other risks, prioritising them and developing adaptation plans or making specific decisions. Chapter 6 describes the overall risk assessment procedure in the context of climate change, outlining methods that are already familiar to most local authorities, with the addition of an initial screening-level assessment for an issue to determine whether a full risk assessment is warranted.

Integrating Climate Change Risk Assessment into Council Decisions (Chapter 7):

Legal requirements

Key principles for local government to keep in mind when dealing with climate change effects include: sustainability, provision for the needs of future generations, avoidance and mitigation of adverse effects, adoption of a cautious or precautionary approach, prudent stewardship and kaitiakitanga, consultation, financial responsibility and liability.

Case law that has developed to date, particularly through the Resource Management Act 1991, covers the following issues of relevance to local authorities:

- recognising the reality of climate change
- clarifying the respective roles of regional and territorial authorities
- indicating principles of hazard avoidance
- indicating time scales over which to consider effects
- clarifying the relationship between resource and building consents.

Chapter 7 describes the relevance of climate change to local government management and planning responsibilities, and discusses existing use rights, resource consent decisions and building consents. It recommends long-term monitoring of climate change and its effects, as a basis for ongoing adaptation to change. A checklist is provided (Appendix 5) for addressing climate change in plans developed under the Local Government Act 2002, the Resource Management Act 1991, the Civil Defence and Emergency Management Act 2002 and other legislation.

Roadmaps: Using the Guidance Manual

Understanding climate change, how it may affect different parts of New Zealand and how to go about identifying and addressing local effects, is complex. Local government will have a range of different needs. Each region, district and community will have its own issues and priorities, so the Guidance Manual does *not* provide ‘one size fits all’ solutions. Rather, it provides examples and suggestions; local authorities and communities will develop their own diverse and creative adaptive responses to climate change over time. This approach allows for the diversity of social, economic and physical situations around the country and the mandate of local government.

Most users of the Guidance Manual will concentrate on the parts that help them meet their own responsibilities. To help users find the aspects of the Manual that are most important to them, this section sets out:

- key questions that people in local government ask, and the chapters in which each question is answered (Table R1)
- a ‘roadmap’ for those who need guidance on how to apply climate change information to a specific issue, problem or responsibility (Figure R1)
- a ‘roadmap’ for those who wish to use the Guidance Manual to assist with overall policy development and planning (Figure R2).

Those who want to know more can access the most current scientific and practice information by reading the whole manual, along with other material referred to in Table 4.4 and in the References.

Table R1: Questions and where to find the answers.

Questions	Section or chapter
What are the key points I need to know about planning for climate change in New Zealand?	Executive Summary
Where do I start?	Roadmaps: Using the Guidance Manual (Figures R1 and R2)
Why should my council take any notice of and plan for climate change?	Executive Summary; Chapter 1: Introduction Chapter 7: Integrating Climate Change Risk Assessment Into Council Decisions
Isn’t this problem too big or long-term for a council to tackle, given all the uncertainties?	Chapter 1: Introduction (Box 1.1)
How is the climate in our region or district likely to change due to global greenhouse gas emissions? What are the uncertainties?	Chapter 2: Projections of Future New Zealand Change; Appendix 3: Further Details.
How large will the expected human-induced climate changes in our region or district be, compared to the natural changes which occur now?	Chapter 3: Relationship to Current Climate Variability and Change
What functions and services undertaken by my council might be affected by climate change?	Chapter 4: Effects on Local Government Functions and Services
What methods and data sources are available for assessing likely effects?	Chapter 4: Effects on Local Government Functions and Services
How should we develop future scenarios for use in (a) preliminary analyses and (b) detailed analyses of impacts?	Chapter 5: Developing the Scenarios
What climate change assumptions should be used in scenario assessments? What about the uncertainties?	Chapter 5: Developing the Scenarios (Tables 5.1 and 5.2).
How are climate change risks estimated, and prioritised relative to other hazards?	Chapter 6: Risk Assessment
How can climate change risk assessment be integrated into council decisions and plans?	Chapter 7: Integrating Climate Change Risk Assessment into Council Decisions; Appendix 5: Change in Plans – Checklist for Contents

Figure R1: **Assessing effects of climate change on a particular council function or responsibility.**

This roadmap is designed for people dealing with issues for whom climate and climate change play an important role. An example is an engineer charged with upgrading the stormwater drainage system of a city, who needs to use future rainfall projections to ensure that the system will cope with the effects of climate change in 50 years' time. The boxes on the right show where to find guidance in this Manual for each step.

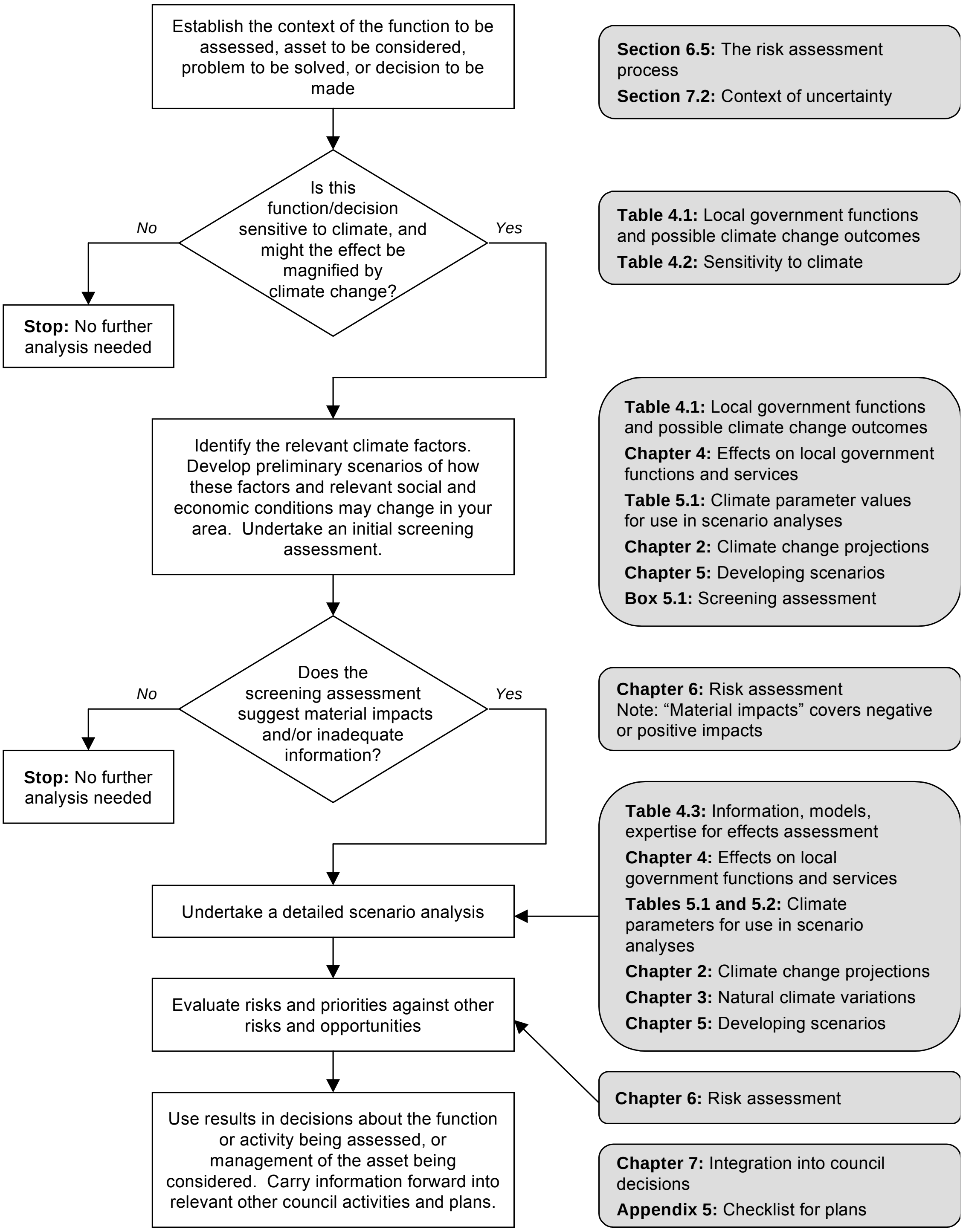
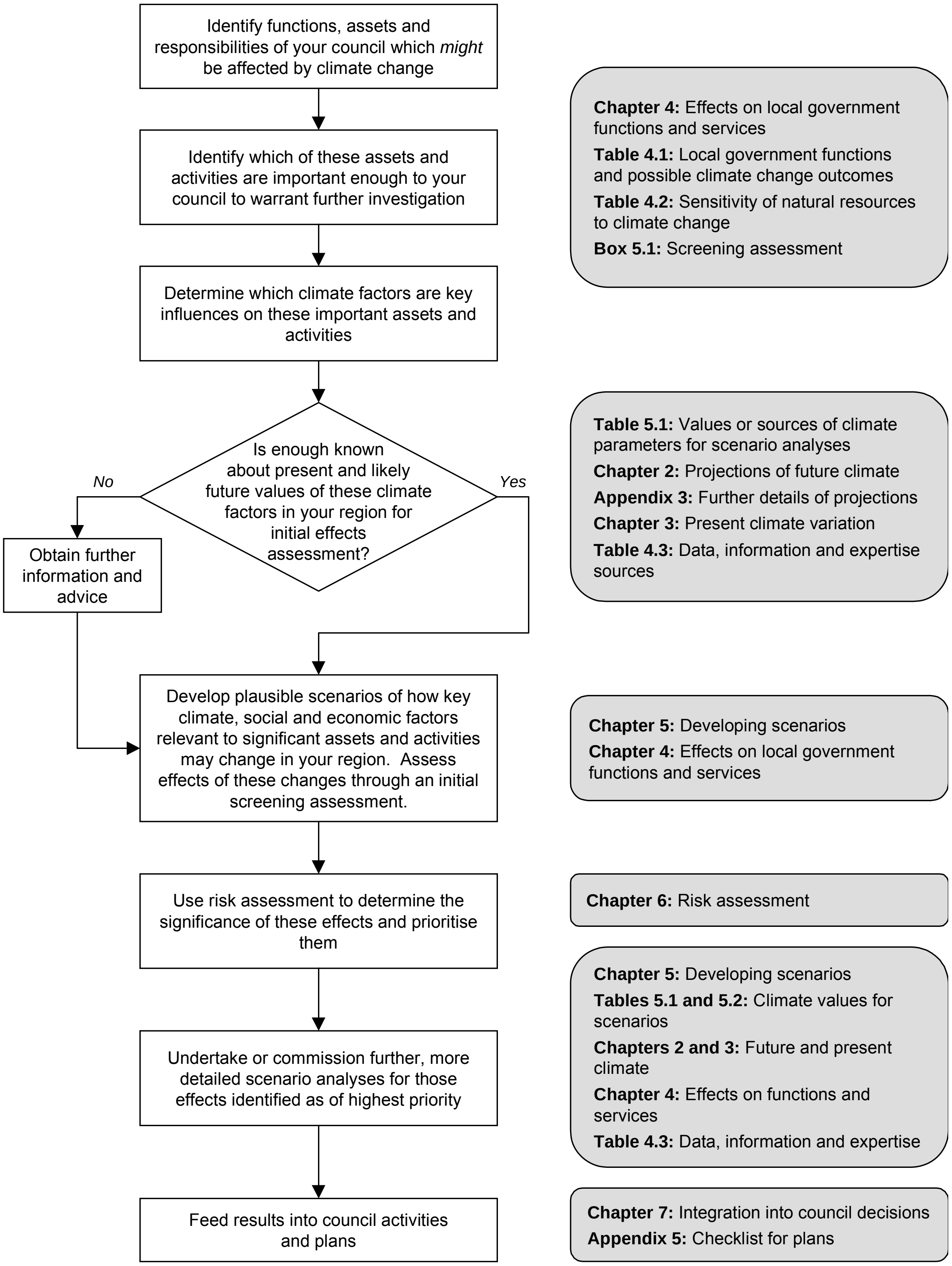


Figure R2: Identifying and prioritising climate change risks and opportunities across all council functions and responsibilities.

This roadmap is for council staff or consultants tasked with identifying and prioritising climate change effects across a council's operations. The boxes on the right show where to find guidance for each step.



1 Introduction

Key points:

- The climate is changing. It is internationally accepted that further changes will result from increasing amounts of greenhouse gases in the atmosphere. Climate change effects over the next decades are predictable with some level of certainty, and will vary from place to place throughout New Zealand.
- The climate will also change from year to year and decade to decade owing to natural processes. For example, some parts of the country often have dry summers and autumns when an El Niño climate pattern is present. Both natural fluctuations and human-induced climate changes need to be considered when developing adaptation plans and policies.
- Councils already address extreme weather events and climate variations as they develop plans and provide services. Climate change effects should be considered as part of these regulatory, assessment and planning activities. It is not necessary to develop a whole new set of procedures for dealing separately with effects and impacts of climate change. Rather, they can be built into existing practices.
- Responding to climate change is an iterative process. It will involve keeping up-to-date with new information, monitoring changes and reviewing the effectiveness of responses.

1.1 Local government and climate change

Climate change effects due to the increase in greenhouse gases in the atmosphere will be felt over time at regional and local levels, differently in various parts of New Zealand.

In the last two decades, there has been a rapid growth in understanding of both the cause and impacts of climate change due to human-induced greenhouse gas emissions. Local authorities need to keep aware of these changes so that they can plan adequately for their own communities' needs, and avoid liability for decisions where climate change may result in subsequent costs in the private sector.

Local government has a range of functions and responsibilities relating to managing climate change effects under the Local Government Act 2002, the Resource Management Act 1991 and its subsequent amendment, and other legislation. These may include, for regional councils: management of water resources, air resources and land resources where there are regionally significant management issues, biosecurity, natural hazards management, emergency management, and regional land transport. For city and district councils, they include: land-use planning and decision-making, building control, emergency management and provision of infrastructure and community services. As well as having an overall planning and management role, regional and district councils own community assets (such as stormwater systems, water supply, or council-owned roads and bridges) that may be vulnerable to climate change effects.

Local government already addresses many effects of extreme weather and climate variations. This Guidance Manual outlines how climate change effects can be addressed as part of these existing regulatory, assessment and planning activities. Early planning may not only prevent a community from being locked into an inflexible response, but may also result in considerable savings if remediation work is avoided.

Many of the effects of climate change will be negative, but some parts of New Zealand will experience changes that, if planned for, can result in positive outcomes for areas and communities. Opportunities to benefit from aspects of climate change, such as the increased temperatures that some areas will experience, will be maximised if councils identify and plan for such benefits in advance. Integrated planning may well be needed as, for example, opportunities to grow new types of crops may be maximised if a community also plans ahead for the management of its water resources to meet the needs of new crops. However, the availability of water resources themselves may be affected by climate change, which must be taken into account in forward planning.

1.2 Who is the Guidance Manual for?

Everyone has a stake in climate change. However, this Guidance Manual is particularly directed at people who advise local government decision-makers. These are most likely to be:

- strategic and policy planners who need to evaluate and advise on long-term strategies and policy for the district and region
- asset managers charged with planning future asset needs for communities and solving existing and emerging problems
- engineers charged with designing infrastructure that is adapted to meet foreseeable risks
- people handling resource, and in some cases, building consent applications
- people responsible for council databases, particularly those that provide information on hazards and risks to private landowners and other agencies
- those responsible for emergency management and ‘lifelines’.

Box 1.1: Climate change complexity

It is tempting to consign climate change to the ‘too hard basket’. The message of this Guidance Manual is that the issues can be broken down into manageable parts, and dealt with as part of normal council planning and management activities. The approach for considering climate change effects on a particular council function or asset (eg, stormwater drainage systems) is illustrated in Figure R1, and includes the following common-sense steps:

- Consider whether the particular function or service is important to your council and influenced by climate, so you can prioritise action.
- Pay particular attention to long-lived infrastructure and developments that will need to cope with climate conditions in 50 to 100 years’ time.
- Start with an initial ‘screening’ assessment, using simple estimates of how climate factors relevant to a particular function may change, and expert judgement or simple calculations of likely impacts of these changes.
- It is necessary to embark on a more detailed study of climate change effects on the function or activity, utilising more staff or consultant time, only if the screening assessment indicates possible problems or opportunities.

There are increasingly robust findings about the directions climate changes will take. This Guidance Manual provides ranges (low and high limits) for the expected magnitudes of many of the most important climate changes. These ranges can be used to develop scenarios for climate impacts. The projected range of impacts can be taken into consideration now, when designing long-lived infrastructure or planning land use. This strategy will often be less expensive and disruptive than trying to remedy ignored problems later. And, it will usually have the added bonus of making the council's activities and the community more resilient to present climate extremes.

1.3 The IPCC Fourth Assessment, 2007

The Intergovernmental Panel on Climate Change (IPCC) is the body established by the United Nations to organise impartial expert assessments of climate change knowledge.

Approximately once every six years since 1988, it has produced a full assessment of the current state of scientific knowledge on climate change and what it means for us. These reports synthesise evidence and analyses published either in peer-reviewed journals or other credible sources.

The IPCC Fourth Assessment Report[1] involved over 1,200 scientific authors and over 2,500 expert reviewers from more than 130 countries. These people are not employed by the IPCC; most work for independent scientific research organisations.

The Fourth Assessment Report broadly supports the direction of the Third Assessment on which the previous edition of this Manual was based. In most areas, however, the scientific conclusions are now more certain.

Nevertheless, there remain uncertainties in predicting the detail of future climate changes and their effects. These uncertainties range from difficulties in predicting future greenhouse gas emissions (which depend on social and economic development around the world), through to scientific and modelling uncertainties. The approach used to address these global uncertainties is to consider a range of scenarios, which span plausible future emissions and incorporate the uncertainty ranges of the models employed.

The IPCC developed 40 different future emissions pathways or scenarios (referred to as the 'SRES' scenarios[2]), which fall into four families (A1, A2, B1, B2). Each family envisages a different future, with different levels of technological development and global economic integration. While some scenarios are more environmentally sustainable than others, none includes any climate-specific international action, such as the Kyoto Protocol.

There are six SRES 'illustrative' scenarios, each broadly representative of its 'family'[3] and spanning a reasonable range of plausible futures. From lowest to highest in terms of temperature projections for this century, they are: B1, A1T, B2, A1B, A2 and A1FI. A more detailed description of these scenarios is contained in Appendix 1.

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[1] IPCC 2007a, 2007b, 2007c.

[2] 'SRES' refers to the report, The IPCC Special Report on Emissions Scenarios, in which the scenarios are presented.

[3] The reason there are six illustrative scenarios, despite there being only four families, is that the first 'family' (A1) is subdivided into three scenario groups (A1T, A1B, A1FI).

For the most part, the guidance in this manual takes account of all six SRES 'illustrative' scenarios but focuses on the 'middle-of-the-road' A1B scenario. The manual also presents results from NIWA regional climate modelling for the B2 and A2 scenarios, which flank the A1B scenario.

1.4 What's new in this edition

This is the second edition of the Guidance Manual, and it supersedes the first edition published in 2004. The Manual has been updated throughout to incorporate the findings of the IPCC Fourth Assessment Report, with many other ancillary changes. The key differences are:

- The New Zealand scenarios are completely new, based now on downscaling of simulations from 12 climate models. (The first edition used six models to mid-century, with only four continuing to 2100.)
- The same statistical downscaling approach is used as previously, but now derived from high-resolution gridded data for temperature and precipitation, instead of from climate stations.
- Very recent results from NIWA's regional climate modelling are presented for IPCC emission scenarios A2 and B2. The results allow a more physically based calculation of changes in extremes such as: high and low daily temperatures, snow, winds and heavy rainfall.
- The adjustment factors for how return periods of heavy rainfall are expected to be affected by global warming (see Table 5.2) have been revised. The adjustments are based on an analysis of rainfall changes simulated by the NIWA regional climate model.

1.5 Reasons for identifying climate change impacts and adapting to them now

Amongst other things, the IPCC Fourth Assessment, 2007 finds:

- Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.
- A global assessment of data obtained since 1970 has shown that it is likely that anthropogenic warming has had a discernable influence on many physical and biological systems.
- Continued emission of greenhouse gases at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century.
- Anthropogenic warming and sea-level rise would continue for centuries owing to the time scales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilised.

Given these findings, the IPCC[4] concluded that:

> *Adaptation will be necessary to address impacts resulting from the warming which is already unavoidable due to past emissions.*

It also stated that:

> *A wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to future climate change.*

The Fourth Assessment Report provides climate projections[5] based on scenario analysis for the period 2090–2099 relative to 1980–1999. The projections include:

- ***Temperature:*** The best estimates of global average surface warming are 1.8°C (lowest individual scenario) to 4.0°C warming (highest individual scenario) for the six SRES illustrative scenarios. (The likely[6] ranges for these lowest and highest SRES illustrative scenarios are 1.1–2.9°C, and 2.4–6.4°C, respectively.)
- ***Rainfall:*** Increases in annual rainfall are projected for some regions and decreases for others (depending on latitude among other factors). For the A1B scenario, which is one of the 'middle-of-the-road' SRES illustrative scenarios, these changes are projected to be up to 20%.
- ***Snow cover:*** It is projected to contract.
- ***Sea level:*** No best estimate or upper bound is provided because of limited understanding of some important effects driving sea level. However, a projected global mean sea-level rise ranging from 0.18 m to 0.59 m, corresponding to the temperature range above, is estimated from models that do not include uncertainties in climate–carbon cycle feedbacks or the full effects of changes in ice sheet flow.

The IPCC also identifies a range of beneficial and adverse effects on both environmental and socioeconomic systems. It concludes that the impacts of climate change will vary regionally but, aggregated and discounted to the present, that they are very likely to impose net annual costs, which will increase over time as global temperatures increase.

Projecting regional and local climate changes across New Zealand from these global projections requires further 'downscaling', since the global average does not necessarily apply to a given location in New Zealand. Chapter 2 summarises the region-specific climate projections across New Zealand associated with the IPCC emission scenarios. It explains that as well as uncertainties in global greenhouse gas emissions and concentrations, local and regional uncertainties also arise because of prediction differences between different regional climate models.

Given these uncertainties, it might be tempting to defer any actions to adapt to local climate change, but New Zealand is already experiencing climate changes. These include:

- increasing temperatures (about 0.9°C over the period 1908–2006)

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[4] IPCC 2007b.

[5] In IPCC terminology, a *climate projection* describes a potential future evolution of the climate in response to an emission or concentration *scenario* of greenhouse gases and aerosols, and is often based on a simulation by a *climate model*.

[6] The 'likely' range is the band within which the authors of the Fourth Assessment Report consider there is a greater than 66% likelihood of an outcome or result.

- reduced frost frequency over much of the country
- retreat of South Island glaciers and snowlines
- reduced alpine snow mass
- rising sea level (estimated at 0.16 m during the 20th century[7]).

Natural fluctuations in climate are also experienced from year to year and decade to decade, such as the changes in rainfall, droughts, sea level and coastal erosion associated with El Niño or La Niña conditions described in chapter 3. The recommended approach is to take action now to identify and adapt to the significant effects of both natural climate variations and climate change. As a signatory to the *United Nations Framework Convention on Climate Change*, New Zealand has commitments to formulate and implement national and regional programmes containing 'measures to facilitate adequate adaptation to climate change'.[8]

Despite remaining uncertainties about the *magnitude* of regional climate changes, certainty is growing as to the *direction* of expected changes over the coming century. These directions include:

- increasing temperatures over the whole country
- increasing annual average rainfall in the west of the country and decreasing annual average rainfall in Northland and many eastern areas
- reductions in frosts
- increasing risk of dry periods or droughts in some eastern areas
- increasing frequency of heavy rainfall events
- rising sea level.

The robustness of these findings, and the long-term and inexorable nature of climate changes, means that councils and communities do need to consider and plan for climate change. Of particular importance are infrastructure and developments with a long lifetime, which will need to cope with climate conditions in 50–100 years' time. Examples include stormwater drainage systems, planning for irrigation schemes, development of low-lying land already subject to flood risk, and housing and infrastructure along already eroding coastlines. Remedying problems with long-lived infrastructure later on is often going to be more expensive and disruptive to communities than taking future changes into account at the planning and design stage.

1.6 Methods

Risk assessment is central to the approach promoted in this Guidance Manual. We draw particularly on AS/NZS4360:2004 (Risk Assessment) (Standards New Zealand 2004), SNZ HB 4360:2000 (Risk Management for Local Government) (Standards New Zealand 2000), and the Ministry of Civil Defence and Emergency Management's Guidelines for Developing a CDEM Group Plan (Ministry of Civil Defence and Emergency Management 2002). These procedures are already well known within local government, and allow the effects of climate change to be considered as part of existing planning, assessment and regulatory activities.

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[7] Hannah 2004.

[8] Article 4.1(b), *United Nations Framework Convention on Climate Change*.

Because climate change does not occur in isolation, this Guidance Manual strongly advocates to make planning for climate change an integral part of councils' standard work. Every function or service that relies on, or is affected by, climate parameters such as rainfall, sea level or wind, has potential to be affected by climate change. Standard methods used to consider the effects of climate on a council's responsibilities generally provide a good platform to consider the effects of climate change as well, and ensure that the consideration of climate change is done efficiently and at least cost while being relevant to the problem in question.

For climate change effects, this Guidance Manual suggests an additional 'initial screening assessment' step in standard risk assessment procedures. Screening analysis uses simple initial estimates of how relevant climate factors will change, together with expert judgement or simple calculations of likely impacts of these changes, to test their significance to a council's activities. This approach can be applied either to one particular issue (such as the impacts of changed heavy rainfalls on stormwater systems), or to prioritising the relative importance of various climate change impacts. Further analysis for climate change is needed only when the screening assessment suggests that there may be a significant issue, and/or that there is clearly inadequate information to make a judgement based on a simple analysis.

A series of 'real-life' case studies have been undertaken to showcase good practice in planning for climate change events. Reports from these studies can be found at http://www.mfe.govt.nz/issues/climate/resources/case-studies (3 April 2008).

2 Projections of Future New Zealand Climate Change

Key points:

- The best estimates of New Zealand temperatures are for an expected increase of about 1°C by 2040, and 2°C by 2090. However owing to the different emission scenarios and model climate sensitivities, the projections of future warming cover a wide range: 0.2–2.0°C by 2040 and 0.7–5.1°C by 2090.
- Projected rainfall and wind patterns show a more marked seasonality than was evident in models used in the IPCC Third Assessment, 2001. Westerlies are projected to increase in winter and spring, along with more rainfall in the west of both the North and the South Island and drier conditions in the east and north. Conversely, the models suggest a decreased frequency of westerly conditions in summer and autumn, with drier conditions in the west of the North Island and possible rainfall increases in Gisborne and Hawke's Bay.
- Other changes expected are: decreased frost risk, increased frequency of high temperatures, increased frequency of extreme daily rainfalls, decreased seasonal snow cover, and a possible increase in strong winds.
- Temperature rise is expected to speed up. The rate of temperature increase from these projections is expected to be higher than a linear extrapolation of the historical New Zealand temperature record for the 20th century.
- Projected New Zealand climate changes are based on results from 12 global climate models, with additional information on extremes and other physical climate elements provided from a regional climate model.

2.1 Introduction

This chapter outlines the changes in New Zealand's climate that are expected to result from global human-induced emissions of greenhouse gases and aerosols. Most of the projections are based on results from General Circulation Model simulations prepared for the IPCC Fourth Assessment, 2007[9]. Model changes are statistically downscaled[10] to provide spatial detail over New Zealand.

Human-induced climate change should be considered within the context of the natural variability of the climate system, and this aspect is discussed in chapter 3. Chapter 5 provides advice on typical changes that local government should take into account when assessing risk. Appendix 2 provides technical details on the General Circulation Models used and the scaling applied to generate future projected ranges that appear in the tables of this chapter. Appendix 3 gives further information on topics such as the downscaling approach, the level of agreement (or otherwise) between the model projections, and changes in extreme precipitation.

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[9] Meehl et al 2007.

[10] Mullan et al 2001a.

Projected values of a particular climate element for use in an impacts assessment are available from Tables 5.1 and 5.2 of chapter 5. Those tables provide guidance on values for use in scenario analyses, and refer users back to particular parts of the current chapter.

Climate is often thought of as only the long-term averages of weather elements, but it actually also includes the range of likely values and the occurrence of extremes. Indeed, it is recognised that the largest impacts of climate change will probably be felt through changes in these extremes. Changes in extremes cannot be reliably derived directly from General Circulation Model outputs, owing to the coarse spatial resolution of the models. However, as illustrated in Box 2.1, small changes in average values (for example, in average annual temperature) can result in large changes in the frequency with which climate extremes occur (for example, for frosts and very high temperatures, and similarly for heavy rainfall, floods and drought). Thus, projections of changes in the average value of a climate element can also help us estimate how the frequency of extremes might change, although this might require additional assumptions about the shape of the distribution. Information on the distribution of daily extremes for New Zealand's future climate can now be supplemented with simulations by the NIWA regional climate model. This model is currently run at a 30-km grid spacing over New Zealand, which is an improvement in resolution over the typical global model (100- to 300-km spacing). Computational constraints mean that the regional model can presently be run only from a single global model (*ukmo_hadcm3*, see Appendix 2) and for a limited number of emissions scenarios.

2.1.1 Global climate scenarios

Predictions of future climate depend on projections of future concentrations of greenhouse gases and aerosols. These depend on projections of emissions which, in turn, depend on changes in population, economic growth, technology, energy availability, and national and international policies. The IPCC developed 40 different future emissions pathways or scenarios[11] as a basis for projecting future climate changes. These SRES scenarios formed the basis of much of the climate projection work done for the IPCC's Third and Fourth Assessments.

Figure 2.1 indicates a range of possible future global temperatures, and reflects the range of plausible emissions scenarios and the range of General Circulation Model predictions for given scenarios. The scenario labelled 'A1B', which gives an intermediate level of warming by the end of the century, has more General Circulation Model output data available than any other scenario, and is the scenario used to derive most of the projections discussed in this manual. To cover the full spread across all the IPCC emission scenarios, New Zealand projections from the A1B scenario were rescaled using the known differences on the global scale between the A1B and other scenarios (this gives the vertical grey bars in Figure 2.1).

The IPCC made subtle changes between the Third and Fourth Assessment Reports in the way it expressed the climate projections. The Third Assessment Report stated[12]: "The globally averaged surface temperature is projected to increase by 1.4 to 5.8°C over the period 1990 to 2100." These results are for the full range of 40 SRES scenarios, based on a number of climate models. In the Fourth Assessment Report, the projections were expressed as changes between 1980–1999 and 2080–2099, and projections were given separately for six illustrative scenarios (see Appendix 2) that spanned the range of all 40 SRES scenarios. For each of the six scenarios, a best estimate was provided, as well as the likely range. The full range in global temperature increase over the six illustrative scenarios used in the Fourth Assessment Report was 1.1–6.4°C.

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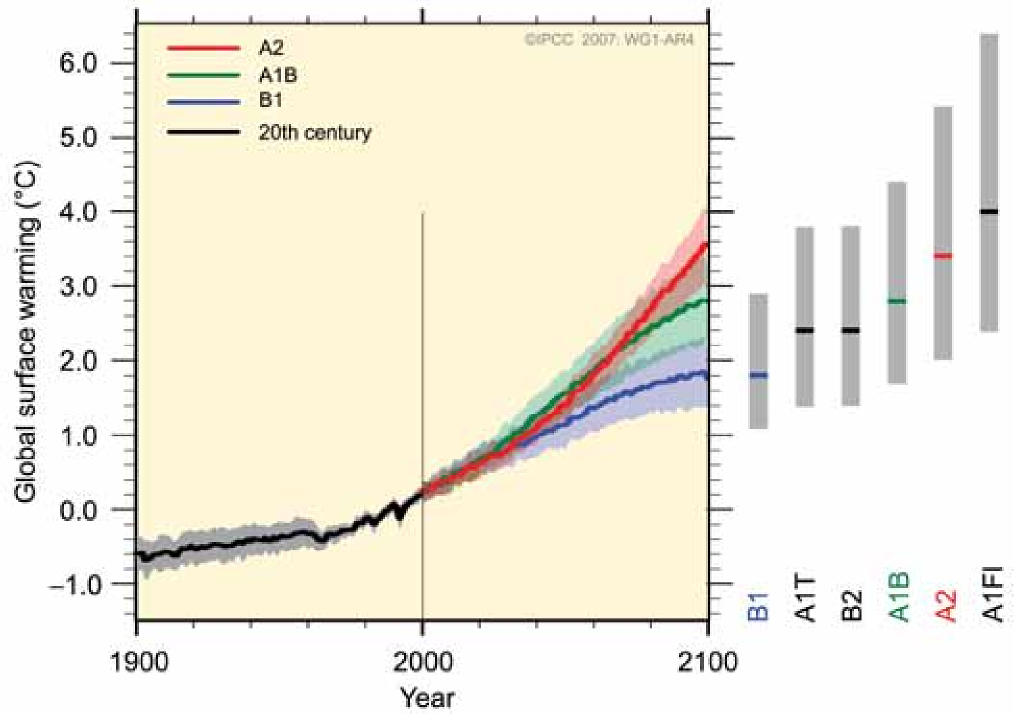
[11] IPCC Special Report on Emissions Scenarios: Nakicenovic and Swart 2000. See also Appendix 1.

[12] IPCC 2001a.

Figure 2.1: IPCC multi-model temperature projections for selected scenarios. The grey bars to the right show the range in global warming for the scenarios we have used in this manual.



Note: Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for scenarios B1, A1B and A2, shown as continuations of the 20th century simulations. The coloured shading denotes the ±1 standard deviation range of individual model annual averages. The grey bars at right indicate the best estimate (solid horizontal line within each grey bar) and the 'likely range' for all six SRES illustrative scenarios. Source: IPCC 2007a (figure SPM.5).

The SRES scenarios cover the key greenhouse gases (carbon dioxide, methane, nitrous oxide and CFCs) and the sulphate aerosols. They do not account for explicit climate change policy actions to reduce greenhouse gas emissions, such as might be taken under the Kyoto Protocol. However, some scenarios assume a reduction in world population after a mid-century peak, and the rapid and widespread introduction of clean and resource-efficient technologies. The SRES scenarios also do not account for any unexpected climate 'surprises', such as increased methane emissions from permafrost melting or undersea methane clathrates.[13]

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[13] Clathrates, also called 'gas hydrates', are crystalline solids that look like ice, and that occur when water molecules form a cage-like structure around smaller 'guest molecules' such as methane. Clathrates occur naturally in cold environments, such as the deep ocean.

Box 2.1: Small changes in average conditions can lead to large changes in the frequency with which extremes occur

Local impacts of climate are likely to depend more on changes in the frequency of extreme events (such as heavy rainfall, drought or very high temperatures) than on changes in average conditions. However, these two aspects of climate – averages and extremes – are closely connected. The figure below is a simplified illustration of how a small change in average conditions can lead to a large change in the frequency with which extremes occur. (In the real world, the curves will not be so smooth or symmetrical.)

Suppose the dashed line represents the current frequency of hourly temperatures over a year, and the heavy line a possible future distribution. The shaded area under a curve represents how often temperatures occur above a particular threshold (orange, red) or below a threshold (blue).

Suppose that in this case the cold area (blue) represents hourly temperatures below freezing, the orange area represents temperatures above 30°C, the red area represents temperatures above 35°C, and the change in mean (average) temperature shown by the arrow is 3°C. So, in this case, an apparently modest change in average temperature is accompanied by a total cessation of frosts, occurrence of higher temperatures than hitherto experienced (red area) and a substantial increased frequency of temperatures above 30°C.

This relationship between averages and extremes has important implications for adaptation (as noted by Warrick 2002). For example, a particular farming operation might already be well adapted to temperatures ranging between –2°C and 30°C, and able to cope occasionally with temperatures between 30°C and 35°C. While the changes in the mean temperature lie well within the 'autonomous' (easily coped with) adaptation region, changes into the red area are outside the 'coping' region and damage occurs. This example is overly simplistic (in the real world the shape, width and height of the curve might also change), but it serves to illustrate the importance of extremes.

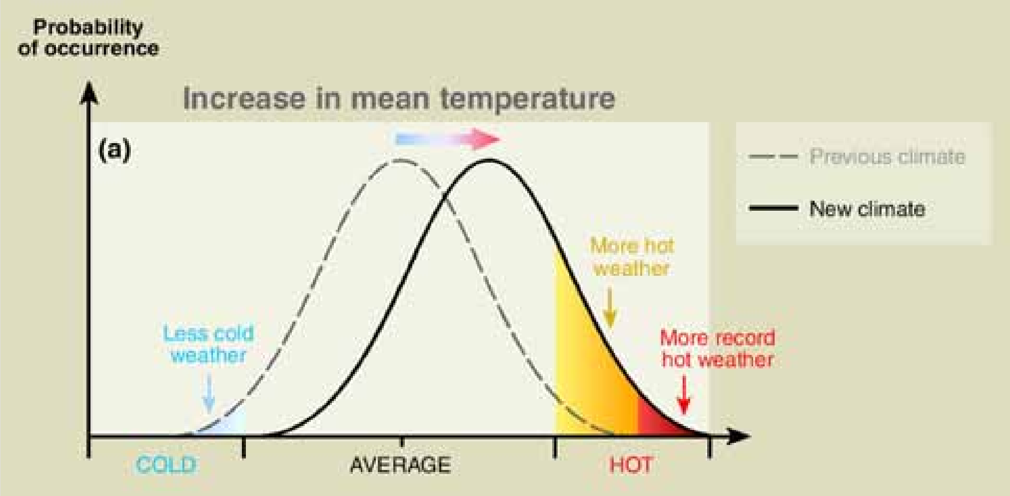


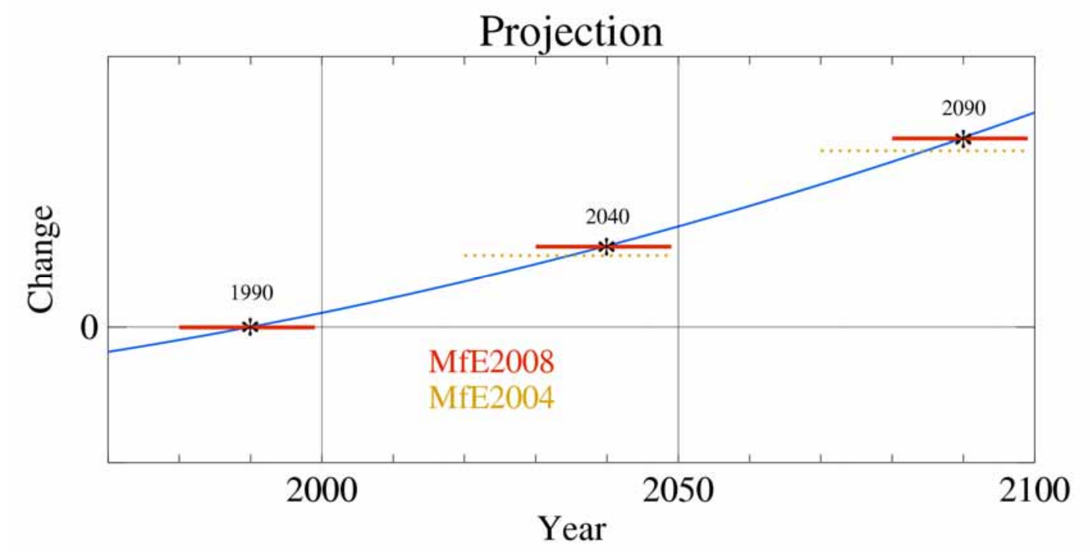
Figure Box 2.1: Effect of climate change on average and extreme temperatures. The horizontal axis represents temperature (Source: figure 4.1–IPCC Synthesis Report, IPCC 2001b). Note that the horizontal axis is not to scale, and the diagram is illustrative only.

2.1.2 Downscaling to New Zealand

To identify likely future climate changes across New Zealand, projected changes from General Circulation Models are statistically downscaled. This method is used to translate the coarse-scale information available from General Circulation Models to the local scale. Historical observations are used to develop regression equations that relate local climate fluctuations to changes at the larger scale. These historical observations are then replaced in the regression equations by the modelled changes to produce the fine-scale projections (see Appendix 3 for more information). Downscaled changes were prepared for a 0.05 degrees latitude and longitude grid (approximately 5 km by 4 km) covering New Zealand.

The New Zealand downscaled projections follow the approach of the Fourth Assessment Report. That is, changes are relative to 1980–1999, which we abbreviate as ‘1990’ for convenience. Changes are calculated for two future periods: 2030–2049 (‘2040’) and 2080–2099 (‘2090’). Thus, the New Zealand projections are for changes over time periods of 50 and 100 years from the baseline climate (centred on 1990). Figure 2.2 provides a schematic for the time horizons of the climate projections. Also shown in Figure 2.2, for reference, are the averaging periods referred to as the ‘2030s’ (2020–2049 average) and the ‘2080s’ (2070–2099 average) used in the previous edition of this Guidance Manual.

Figure 2.2: Schematic of time horizons for climate projections.



Note: Curve (blue line) shows a smoothly varying climate parameter, such as temperature or sea level, relative to a base level defined as the average over 1980–1999 (first horizontal red line; ‘1990’). Future 20-year averages are indicated by the other red lines at 2040 (2030–2049 average) and 2090 (2080–2099). Dotted orange lines show projection horizons used in the previous Guidance Manual (Ministry for the Environment 2004), identified as the ‘2030s’ (2020–2049 average) and the ‘2080s’ (2070–2099 average).

Councils may also be interested in projections for other decades during the 21st century. Initial projections for these non-tabulated decades can be obtained by interpolating linearly between the values for 1990, 2040 and 2090. For example, a projection for 2050 (relative to 1990) would be the change at 2040 plus 20% of the change between 2040 and 2090. Different start dates (eg, council data more recent than 1999) could also be accommodated by linear interpolation, although it is important to use a time average rather than an individual year.

Downscaling is applied to the projections obtained from 12 General Circulation Models when emissions follow the A1B middle-of-the-road emissions scenario (Figure 2.1). A range of possible values for each climate variable (temperature, rainfall, etc) is provided. The range for each variable reflects not only the range of greenhouse gas futures represented by the six SRES illustrative scenarios, but also the range of climate model predictions for individual emission scenarios. The other five SRES emissions scenarios are catered for by re-scaling the A1B results for New Zealand according to the ratio of global temperature increases, as documented in the IPCC Fourth Assessment Report (see Appendix 2 for details).

Like the IPCC, we are unable to indicate whether any one emission scenario is more likely than another, but do provide the average across all models and all emission scenarios. The extreme ends of the ranges may be slightly less likely than the central values, since they generally result from the one climate model that gives the most extreme projection, rather than reflecting the consensus from a number of models. Eliminating the most extreme models as outliers causes little change to the average from the remaining models, but can, on occasion, greatly reduce the range of the projected changes (see Appendix 3).

2.2 Projections for New Zealand

Table 2.1 summarises the main features of these New Zealand climate projections. More detail on the changes is given in the figures and tables later in this chapter. Quantitative estimates of the changes in parameters relevant to local government functions and services, and advice on how to construct relevant scenarios to estimate the importance of those changes, are given in chapter 5 (specifically Tables 5.1 and 5.2).

Each estimate in Table 2.1 is the best current scientific estimate of the direction and magnitude of change a given climate variable could undergo. The degree of confidence placed by NIWA scientists on the projections is indicated by the number of stars in brackets:

**** Very confident, at least 9 out of 10 chance of being correct. Very confident means that it is considered very unlikely that the estimate will be substantially revised as scientific knowledge progresses.

*** Confident.

** Moderate confidence, which means that the estimate is more likely than not to be correct in terms of indicated direction and approximate magnitude of the change.

* Low confidence, but the best estimate possible at present from the most recent information. Such estimates could be revised considerably in the future.

Hence, a higher degree of caution should be employed where investment decisions are based on the low-confidence estimates.

Table 2.1: Main features of New Zealand climate change projections for 2040 and 2090. (** Very confident, *** Confident, ** Moderate confidence, * Low confidence)**

Climate variable	Direction of change	Magnitude of change	Spatial and seasonal variation
Mean temperature	Increase (****)	All-scenario average 0.9°C by 2040, 2.1°C by 2090 (**)	Least warming in spring (*)
Daily temperature extremes (frosts, hot days)	Fewer cold temperatures and frosts (****), more high temperature episodes (****)	Whole frequency distribution moves right (see section 2.2.3)	See section 2.2.3
Mean rainfall	Varies around country, and with season. Increases in annual mean expected for Tasman, West Coast, Otago, Southland and Chathams; decreases in annual mean in Northland, Auckland, Gisborne and Hawke's Bay (**)	Substantial variation around the country and with season (see section 2.2.2)	Tendency to increase in south and west in the winter and spring (**). Tendency to decrease in the western North Island, and increase in Gisborne and Hawke's Bay, in summer and autumn (*)
Extreme rainfall	Heavier and/or more frequent extreme rainfalls (**), especially where mean rainfall increase predicted (***)	No change through to halving of heavy rainfall return period by 2040; no change through to fourfold reduction in return period by 2090 (**) [See note 2]	Increases in heavy rainfall most likely in areas where mean rainfall is projected to increase (***)
Snow	Shortened duration of seasonal snow lying (***), rise in snowline (**), decrease in snowfall events (*)		
Glaciers	Continuing long-term reduction in ice volume and glacier length (***)		Reductions delayed for glaciers exposed to increasing westerlies
Wind (average)	Increase in the annual mean westerly component of windflow across New Zealand (**)	About a 10% increase in annual mean westerly component of flow by 2040 and beyond (*)	By 2090, increased mean westerly in winter (> 50%) and spring (20%), and decreased westerly in summer and autumn (20%) (*)
Strong winds	Increase in severe wind risk possible (**)	Up to a 10% increase in strong winds (> 10m/s, top 1 percentile) by 2090 (*)	
Storms	More storminess possible, but little information available for New Zealand (*)		
Sea level	Increase (****)	At least 18–59 cm rise (New Zealand average) between 1990 and 2100 (****) See *Coastal Hazards and Climate Change manual (MfE 2008)*	See *Coastal Hazards and Climate Change manual (MfE 2008)*
Waves	Increased frequency of heavy swells in regions exposed to prevailing westerlies (**)	See *Coastal Hazards and Climate Change manual (MfE 2008)*	
Storm surge	Assume storm tide elevation will rise at the same rate as *mean* sea-level rise (**)	See *Coastal Hazards and Climate Change manual (MfE 2008)*	
Ocean currents	Various changes plausible, but little research or modelling yet done	See section 2.2.9	
Ocean temperature	Increase (****)	Similar to increases in mean air temperature	Patterns close to the coast will be affected by winds and upwelling and ocean current changes (**)

Note 1: Further guidance on values suggested for preliminary scenario analyses of potential climate change effects is provided in Table 5.1.

Note 2: Changes in the return period of heavy rainfall events may vary between different parts of the country, and will also depend on the rainfall duration being considered. See section 2.2.4 for further discussion.

The following sections, along with material in Appendix 3, provide more detail on the projected changes summarised in Table 2.1.

2.2.1 Mean temperature

Downscaled projections of the changes in mean temperature[14] over New Zealand are shown in Table 2.2 (for 2040) and Table 2.3 (for 2090), and in Figure 2.3 (changes in annual average temperature) and Figures 2.4–2.5 (seasonal changes).

The tables indicate the range not only across the models analysed, but also across the various emissions scenarios. The A1B projections were rescaled by the quoted IPCC global temperature changes to cover the other five illustrative scenarios. The values given in Tables 2.2 and 2.3 are averages over all grid points within each regional council region.

The figures depict the pattern of temperature change as an average over 12 climate models for the A1B emissions scenario[15]. There is considerable pattern variation among the climate models, so we also present changes in the annual average for each of the 12 models separately (Figures A3.2 and A3.3 in Appendix 3).

Averaging over all models and all six illustrative emissions scenarios gives a New Zealand-average warming of 0.2–2.0°C by 2040 and 0.7–5.1°C by 2090. For just the A1B scenario alone, the projected warming is 0.3–1.4°C by 2040 and 1.1–3.4°C by 2090, with a 12-model average (or 'best estimate') of 0.9°C and 2.1°C for 2040 and 2090, respectively. For comparison, the IPCC quotes a best estimate of 2.8°C for the global temperature increase by 2090 under the A1B scenario, with a likely range of 1.7–4.4°C. The projected New Zealand temperature changes are in all cases smaller than the globally averaged changes for the corresponding SRES scenarios (see also Table A2.1 in Appendix 2).

The pattern of warming in the annual average is fairly uniform over the country, although slightly greater over the North Island than the South. Also, the warming accelerates with time under this emissions scenario: ie, the 2090 warming is more than twice the 2040 warming. Figures 2.4 and 2.5 map projected seasonal mean changes at 2040 and 2090 for the A1B scenario. In the summer and autumn seasons, the North Island and northwest of the South Island show the greatest warming, whereas in the winter season the South Island has the greatest warming. Spring shows the least warming of all seasons. Further discussion of agreement between the various models can be found in Appendix 3 (section A3.3 and Figures A3.2 and A3.3).

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[14] 'Mean' temperature is the average of daily minimum and maximum temperatures. Simulations by NIWA's regional climate model suggest that minimum and maximum temperatures both increase at very nearly the same rate, and so no distinction between them is made for New Zealand temperatures.

[15] Note that in this 2008 edition of the Guidance Manual, the maps are specific to a single SRES emissions scenario (A1B), unlike in the previous edition where changes were scaled to cover all SRES scenarios. However, the Tables (2.2 and 2.3) do incorporate the full range of projected changes.

Table 2.2: Projected changes in seasonal and annual mean temperature (in °C) from 1990 to *2040*, by regional council area. The average change, and the lower and upper limits (in brackets), over the six illustrative scenarios are given.

	Summer	Autumn	Winter	Spring	Annual
Northland	1.1 [0.3, 2.7]	1.0 [0.2, 2.9]	0.9 [0.1, 2.4]	0.8 [0.1, 2.2]	0.9 [0.2, 2.6]
Auckland	1.1 [0.3, 2.6]	1.0 [0.2, 2.8]	0.9 [0.2, 2.4]	0.8 [0.1, 2.2]	0.9 [0.2, 2.5]
Waikato	1.1 [0.2, 2.5]	1.0 [0.3, 2.7]	0.9 [0.2, 2.2]	0.8 [0.0, 2.0]	0.9 [0.2, 2.4]
Bay of Plenty	1.0 [0.3, 2.5]	1.0 [0.3, 2.7]	0.9 [0.1, 2.2]	0.8 [0.0, 2.1]	0.9 [0.2, 2.4]
Taranaki	1.1 [0.2, 2.4]	1.0 [0.2, 2.6]	0.9 [0.1, 2.2]	0.8 [0.0, 2.0]	0.9 [0.2, 2.3]
Manawatu-Wanganui	1.1 [0.2, 2.3]	1.0 [0.2, 2.6]	0.9 [0.2, 2.2]	0.8 [0.0, 1.9]	0.9 [0.2, 2.2]
Hawke’s Bay	1.0 [0.2, 2.5]	1.0 [0.3, 2.6]	0.9 [0.1, 2.2]	0.8 [0.0, 2.0]	0.9 [0.2, 2.3]
Gisborne	1.0 [0.2, 2.6]	1.0 [0.3, 2.7]	0.9 [0.1, 2.2]	0.8 [0.0, 2.1]	0.9 [0.2, 2.4]
Wellington	1.0 [0.2, 2.2]	1.0 [0.3, 2.5]	0.9 [0.2, 2.1]	0.8 [0.1, 1.9]	0.9 [0.3, 2.2]
Tasman-Nelson	1.0 [0.2, 2.2]	1.0 [0.2, 2.3]	0.9 [0.2, 2.0]	0.7 [0.1, 1.8]	0.9 [0.2, 2.0]
Marlborough	1.0 [0.2, 2.1]	1.0 [0.2, 2.4]	0.9 [0.2, 2.0]	0.8 [0.1, 1.8]	0.9 [0.2, 2.1]
West Coast	1.0 [0.2, 2.4]	1.0 [0.2, 2.1]	0.9 [0.2, 1.8]	0.7 [0.1, 1.7]	0.9 [0.2, 1.8]
Canterbury	0.9 [0.1, 2.2]	0.9 [0.2, 2.2]	1.0 [0.4, 2.0]	0.8 [0.2, 1.8]	0.9 [0.2, 1.9]
Otago	0.9 [0.0, 2.4]	0.9 [0.1, 1.9]	1.0 [0.3, 2.1]	0.7 [0.0, 1.8]	0.9 [0.1, 1.9]
Southland	0.9 [0.0, 2.4]	0.9 [0.1, 1.9]	0.9 [0.2, 2.0]	0.7 [-0.1, 1.7]	0.8 [0.1, 1.9]
Chatham Islands	0.8 [0.2, 1.9]	0.9 [0.2, 2.0]	0.9 [0.1, 2.3]	0.7 [0.1, 1.8]	0.8 [0.2, 1.9]

Note 1: This table covers the period from 1990 (1980–1999) to 2040 (2030–2049), based on downscaled temperature changes for 12 global climate models, re-scaled to match the IPCC global warming range for six illustrative emission scenarios (B1, A1T, B2, A1B, A2 and A1FI). Corresponding maps (Figures 2.3, 2.4) should be used to identify sub-regional spatial gradients.

Note 2: If the seasonal ranges are averaged, the resulting range is larger than the range shown in the annual column, because of cancellation effects when summing over the year.

Note 3: Projected changes for the 15 regional council regions were the result of the statistical downscaling over mainland New Zealand. For the Chatham Islands, the scenario changes come from direct interpolation of the General Circulation Model grid-point changes to the latitude and longitude associated with the Chathams.

Table 2.3: Projected changes in seasonal and annual mean temperature (in °C) from 1990 to *2090*, by regional council area. The average change, and the lower and upper limits (in brackets), over the six illustrative scenarios are given.

	Summer	Autumn	Winter	Spring	Annual
Northland	2.3 [0.8, 6.6]	2.1 [0.6, 6.0]	2.0 [0.5, 5.5]	1.9 [0.4, 5.5]	2.1 [0.6, 5.9]
Auckland	2.3 [0.8, 6.5]	2.1 [0.6, 5.9]	2.0 [0.5, 5.5]	1.9 [0.4, 5.4]	2.1 [0.6, 5.8]
Waikato	2.3 [0.9, 6.3]	2.2 [0.6, 5.6]	2.1 [0.5, 5.2]	1.8 [0.3, 5.1]	2.1 [0.6, 5.6]
Bay of Plenty	2.2 [0.8, 6.2]	2.2 [0.6, 5.6]	2.0 [0.5, 5.2]	1.8 [0.3, 5.1]	2.1 [0.6, 5.5]
Taranaki	2.3 [0.9, 6.1]	2.2 [0.6, 5.3]	2.1 [0.5, 5.1]	1.8 [0.3, 4.9]	2.1 [0.6, 5.3]
Manawatu-Wanganui	2.3 [0.9, 6.0]	2.2 [0.6, 5.3]	2.1 [0.5, 5.0]	1.8 [0.3, 4.9]	2.1 [0.6, 5.3]
Hawke's Bay	2.1 [0.8, 6.0]	2.1 [0.6, 5.3]	2.1 [0.5, 5.1]	1.9 [0.3, 5.1]	2.1 [0.6, 5.4]
Gisborne	2.2 [0.8, 6.2]	2.2 [0.6, 5.6]	2.0 [0.5, 5.2]	1.9 [0.3, 5.2]	2.1 [0.6, 5.5]
Wellington	2.2 [0.9, 5.7]	2.1 [0.6, 5.1]	2.1 [0.6, 5.0]	1.8 [0.3, 4.8]	2.1 [0.6, 5.2]
Tasman-Nelson	2.2 [0.9, 5.6]	2.1 [0.6, 5.1]	2.0 [0.5, 4.9]	1.7 [0.3, 4.6]	2.0 [0.6, 5.0]
Marlborough	2.1 [0.9, 5.6]	2.1 [0.6, 5.0]	2.1 [0.6, 5.0]	1.8 [0.3, 4.8]	2.0 [0.6, 5.1]
West Coast	2.2 [0.9, 5.3]	2.1 [0.7, 5.0]	2.1 [0.6, 4.9]	1.7 [0.4, 4.5]	2.0 [0.7, 4.9]
Canterbury	2.1 [0.8, 5.2]	2.1 [0.7, 4.9]	2.2 [0.8, 5.1]	1.8 [0.4, 4.7]	2.0 [0.7, 5.0]
Otago	2.0 [0.7, 4.8]	2.0 [0.8, 4.6]	2.2 [0.8, 4.8]	1.7 [0.5, 4.3]	2.0 [0.8, 4.6]
Southland	2.0 [0.7, 4.7]	2.0 [0.8, 4.6]	2.1 [0.8, 4.7]	1.6 [0.5, 4.1]	1.9 [0.8, 4.5]
Chatham Islands	1.9 [0.8, 4.6]	2.1 [0.6, 4.9]	2.0 [0.3, 4.5]	1.8 [0.3, 4.6]	2.0 [0.5, 4.7]

Note 1: This table covers the period from 1990 (1980–1999) to 2090 (2080–2099), based on downscaled temperature changes for 12 global climate models, re-scaled to match the IPCC global warming range for six illustrative emission scenarios. Corresponding maps (Figures 2.3, 2.5) should be used to identify sub-regional spatial gradients.

Note 2: If the seasonal ranges are averaged, the resulting range is larger than the range shown in the annual column, because of cancellation effects when summing over the year.

Note 3: Projected changes for the 15 regional council regions were the result of the statistical downscaling over mainland New Zealand. For the Chatham Islands, the scenario changes come from direct interpolation of the General Circulation Model grid-point changes to the latitude and longitude associated with the Chathams.

2.2.2 Rainfall patterns

Downscaled rainfall projections are shown in Figure 2.3 (changes in annual average) and Figures 2.6 and 2.7 (seasonal changes), and in Table 2.4 (for 2040) and Table 2.5 (for 2090). Maps of the changes in annual average rainfall given by individual models are presented in Appendix 3.

There are often systematic variations in the projected rainfall within regional council regions (for example, wetter in the west and drier in the east for Canterbury). Thus, it is not very useful to tabulate averages for each region as was done for temperature. Instead, rainfall projections have been tabulated for specific places. Councils may need to carefully examine these regional gradients in rainfall changes, when considering issues related to river levels. For example, in coastal Canterbury, rainfall is projected to decrease, but large alpine-fed rivers could have increased flows because of greater rainfall in the headwaters.

Tables 2.4 and 2.5 give the estimated range in precipitation change over the six illustrative SRES scenarios, for selected sites within each region. The average change over all 12 models and six scenarios is also given. Two sites per region (for Canterbury, three sites) are included in the tables whenever there is a marked spatial variation across a region. Figure 2.2 maps the projected annual mean precipitation change for the A1B scenarios for the period from 1990 to 2040 and 2090. Figures 2.6 and 2.7 show the seasonal projections, again as an average over the 12 models for just the A1B scenario. As might be expected, there is much more spatial structure in the rainfall changes than in the temperature changes, and also a larger spread between models. For most sites, rainfall can show either an increase or a decrease, depending on which model is chosen. Appendix 3 gives further discussion on the level of model agreement.

The annual average rainfall change has a pattern of increases in the west (up to 5% by 2040 and 10% by 2090) and decreases in the east and north (exceeding 5% in places by 2090). Figures 2.6 and 2.7 show that this annual pattern of being wetter in the west and drier in the east is driven by that pattern occurring in the winter and spring seasons. In summer and autumn, the pattern is quite different. Indeed, for the North Island in particular, the pattern is reversed, with it being drier in the west and wetter in the east (although the percentage changes are smaller than for the winter and spring seasons, and winter has the largest total precipitation). These distinct seasonal differences are a new result, not apparent in the smaller sample of models used in the previous edition of this Manual. There is still a lot of variability between models, although some regions show more agreement between models than others on the sign of the projected precipitation change (see Appendix 3 for further discussion).

Figure 2.3: **Projected changes in annual mean temperature (in °C) and in annual mean rainfall (in %), relative to 1990: average over 12 climate models for A1B emission scenario. Note the different temperature scales for 2040 and 2090.**

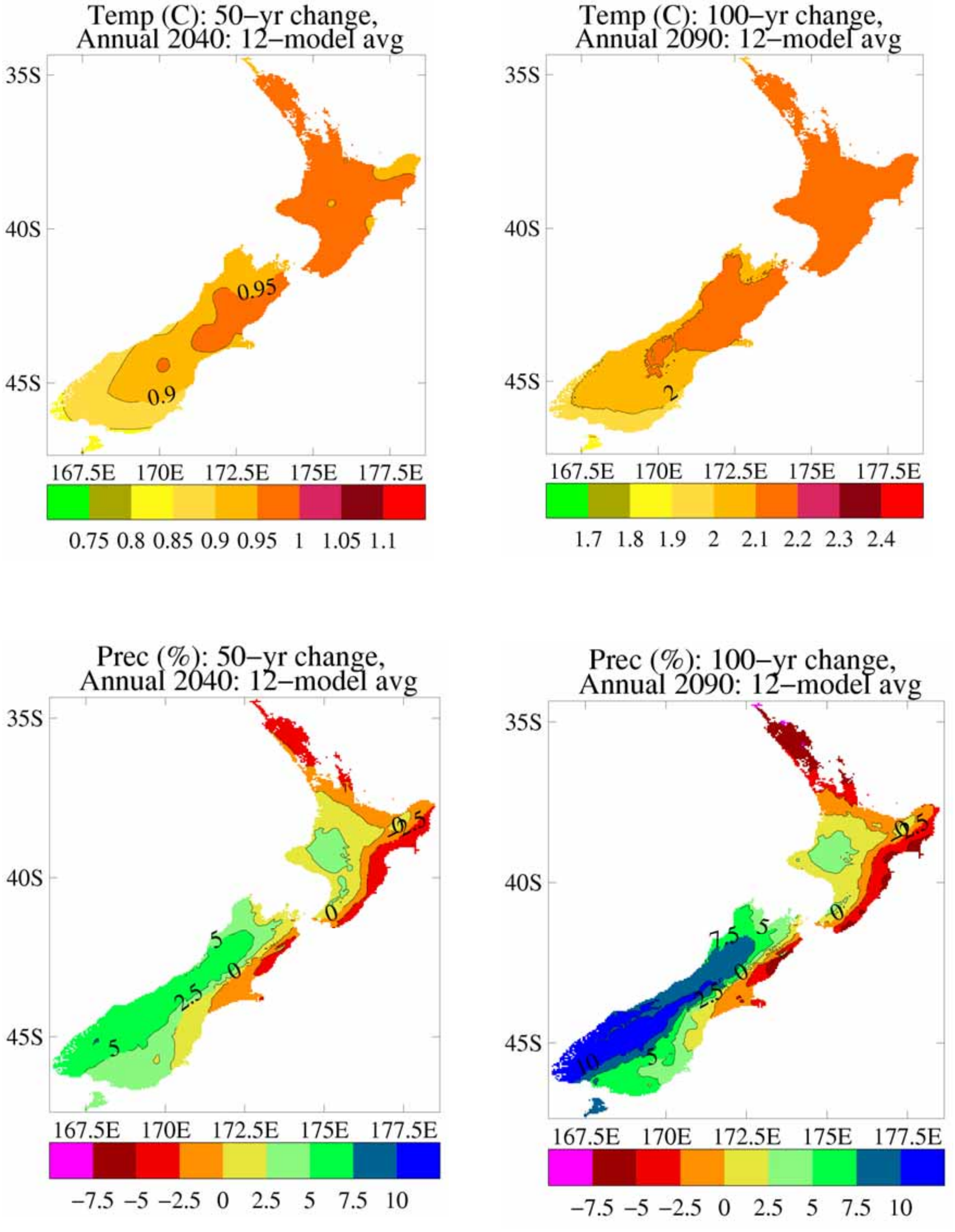
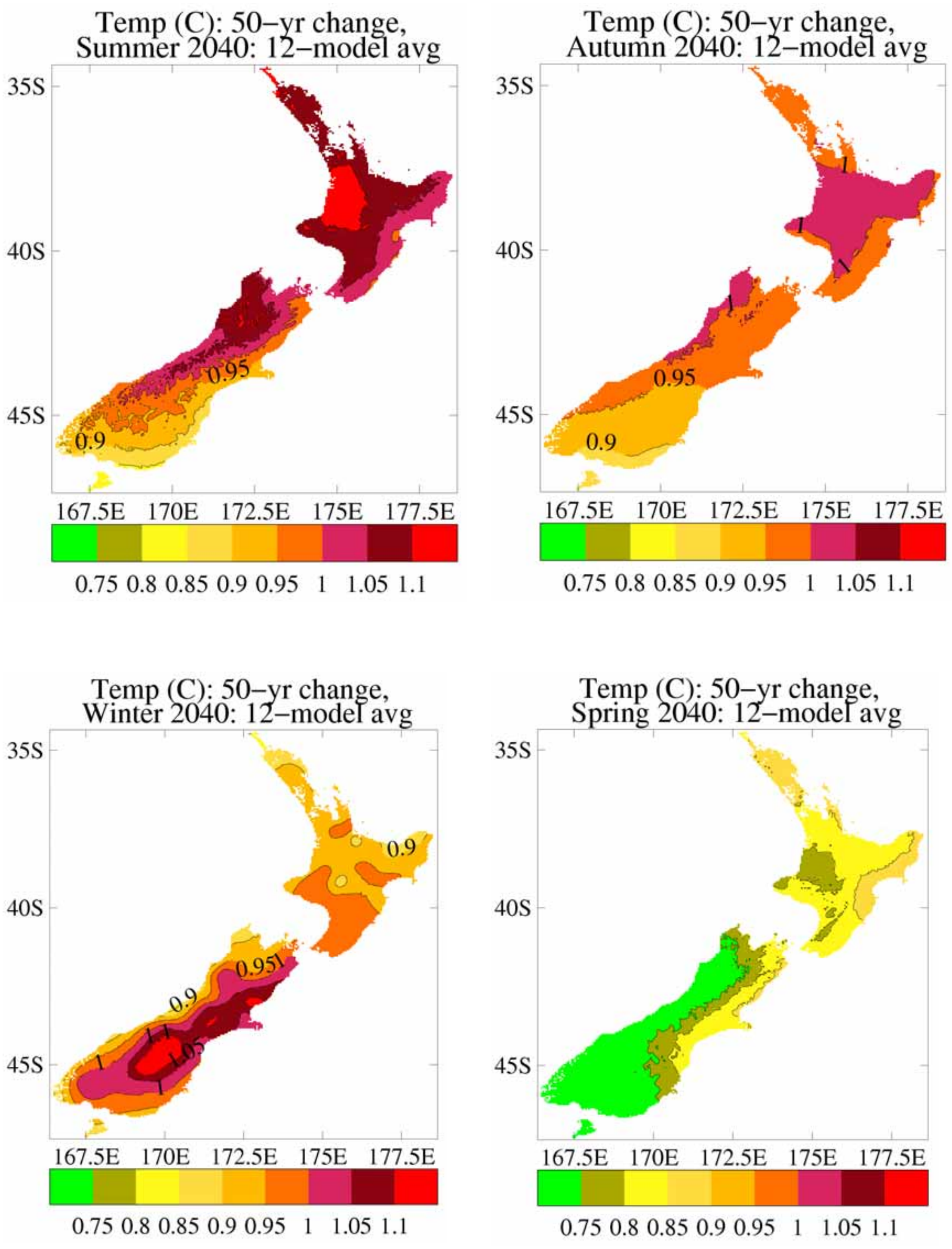


Figure 2.4: Projected changes in seasonal mean temperature (in °C), for *2040* relative to 1990: average over 12 climate models for A1B emission scenario.



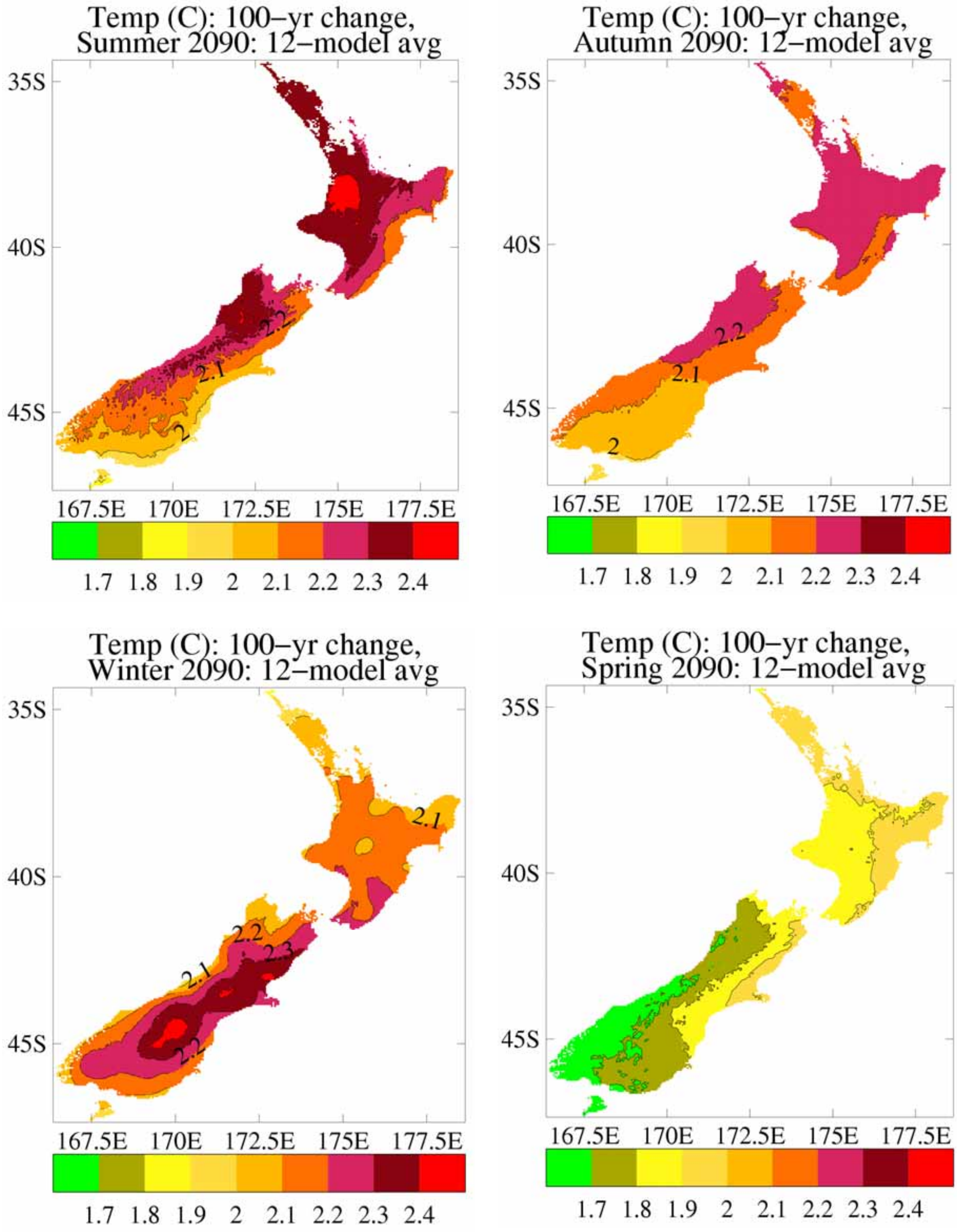
Temp (C): 50–yr change, Summer 2040: 12–model avg

Temp (C): 50–yr change, Autumn 2040: 12–model avg

Temp (C): 50–yr change, Winter 2040: 12–model avg

Temp (C): 50–yr change, Spring 2040: 12–model avg

Figure 2.5: Projected changes in seasonal mean temperature (in °C), for *2090* relative to 1990: average over 12 climate models for A1B emission scenario.



Temp (C): 100–yr change, Summer 2090: 12–model avg

Temp (C): 100–yr change, Autumn 2090: 12–model avg

Temp (C): 100–yr change, Winter 2090: 12–model avg

Temp (C): 100–yr change, Spring 2090: 12–model avg

Figure 2.6: **Projected changes in seasonal mean rainfall (in %), for *2040* relative to 1990: average over 12 climate models for A1B emission scenario.**

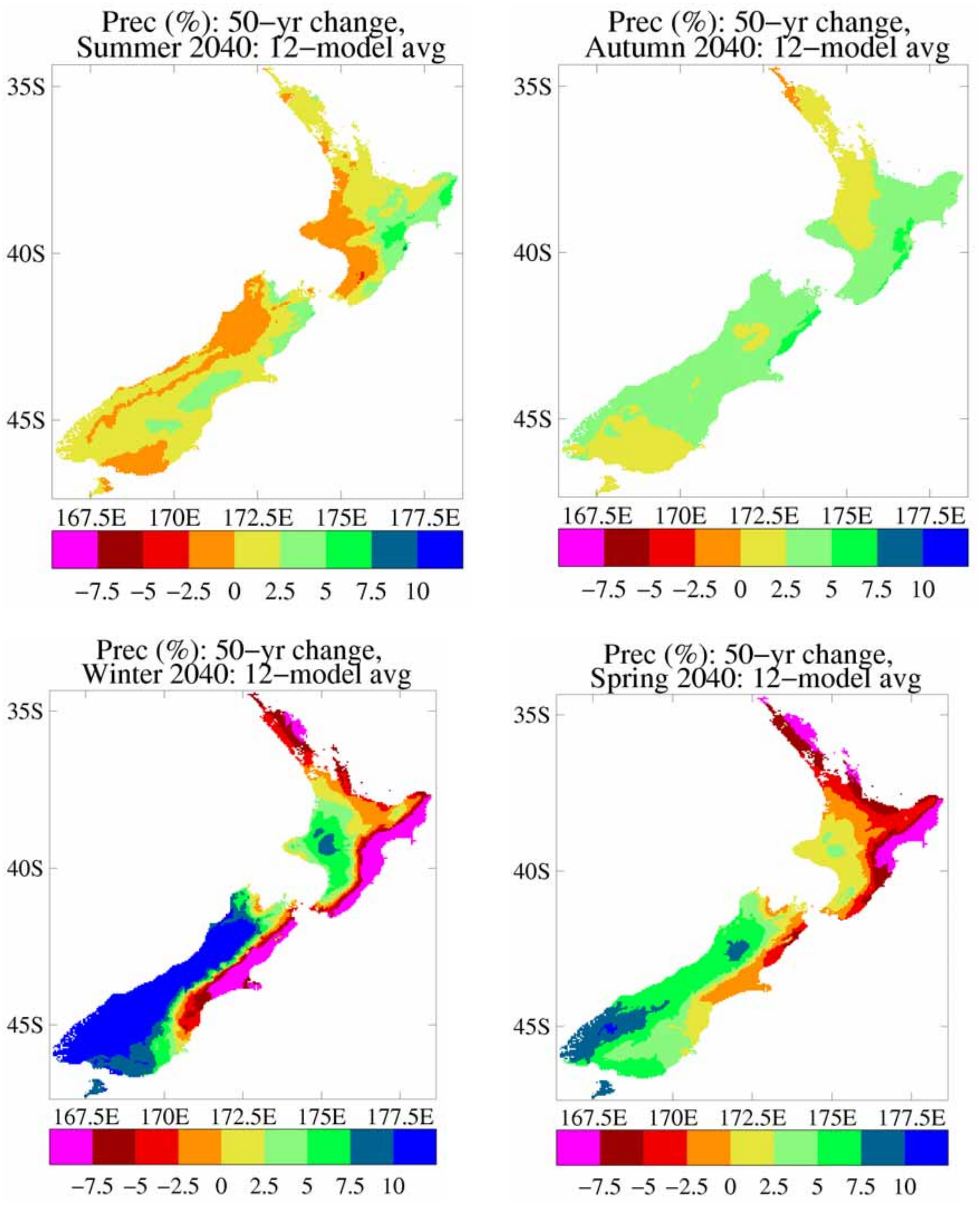


Figure 2.7: Projected changes in seasonal mean rainfall (in %), for *2090* relative to 1990: average over 12 climate models for A1B emission scenario.

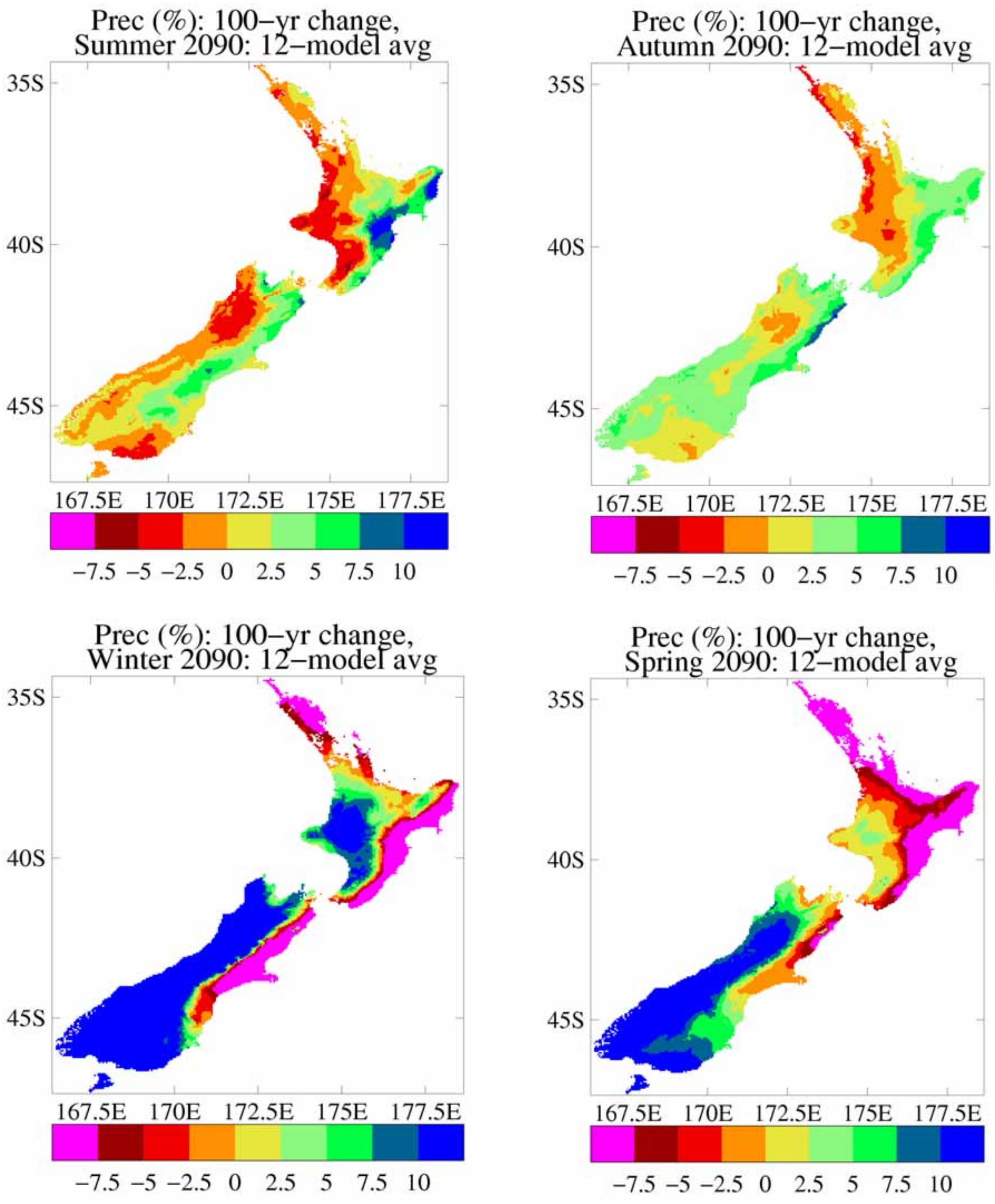


Table 2.4: Projected changes for selected stations within each regional council area in seasonal and annual precipitation (in %) from 1990 to *2040*. Lower and upper limits are shown in brackets.

Region: Location	Summer	Autumn	Winter	Spring	Annual
Northland: Kaitaia	1 [–15, 20]	–0 [-14, 16]	–5 [–23, 1]	–6 [–18, 4]	–3 [–13, 5]
Whangarei	1 [–14, 23]	1 [–15, 33]	–9 [–38, –1]	–9 [–25, 3]	–4 [–16, 7]
Auckland: Warkworth	1 [–16, 20]	1 [–13, 22]	–4 [–22, 2]	–6 [–18, 6]	–3 [–13, 5]
Mangere	1 [–17, 20]	1 [–14, 17]	–1 [–10, 5]	–5 [–15, 10]	–1 [–10, 6]
Waikato: Ruakura	1 [–18, 19]	2 [–13, 10]	1 [–4, 8]	–2 [–10, 13]	0 [–6, 6]
Taupo	3 [–16, 28]	3 [–9, 16]	1 [–4, 7]	–3 [–10, 12]	1 [–5, 8]
Bay of Plenty: Tauranga	2 [–16, 25]	3 [–12, 25]	–4 [–16, 2]	–5 [–18, 7]	–1 [–10, 8]
Taranaki: New Plymouth	0 [–20, 18]	3 [–8, 13]	2 [–2, 9]	0 [–8, 16]	2 [–3, 9]
Manawatu-Wanganui: Wanganui	–1 [–21, 13]	3 [–8, 10]	5 [–3, 15]	1 [–10, 15]	2 [–3, 10]
Taumarunui	0 [–19, 19]	2 [–10, 13]	7 [0, 17]	2 [–12, 19]	3 [0, 13]
Hawke's Bay: Napier	4 [–33, 38]	5 [–14, 42]	–13 [–34, –1]	–7 [–17, 3]	–3 [–14, 14]
Gisborne: Gisborne	3 [–26, 33]	4 [–18, 46]	–11 [–30, –2]	–9 [–21, 3]	–4 [–15, 14]
Wellington: Masterton	2 [–17, 25]	4 [–8, 32]	–6 [–20, 4]	–1 [–8, 10]	–1 [–7, 9]
Paraparaumu	0 [–21, 13]	4 [–3, 14]	4 [–1, 13]	2 [–5, 14]	2 [–3, 10]
Tasman-Nelson: Nelson	4 [–14, 27]	5 [–2, 19]	1 [–4, 9]	0 [–8, 9]	2 [–3, 9]
Marlborough: Blenheim	3 [–16, 25]	4 [–4, 24]	–1 [–10, 7]	–1 [–7, 10]	1 [–5, 9]
West Coast: Hokitika	0 [–22, 19]	3 [–11, 18]	11 [1, 24]	5 [–1, 18]	5 [–2, 20]
Canterbury: Christchurch	2 [–15, 22]	5 [–10, 30]	–8 [–30, 7]	–1 [–8, 9]	–1 [–10, 9]
Hanmer	2 [–16, 25]	4 [–5, 19]	–7 [–26, 6]	0 [–6, 12]	–1 [–8, 7]
Tekapo	1 [–16, 16]	2 [–12, 10]	8 [–1, 19]	6 [–3, 17]	4 [0, 13]
Otago: Dunedin	1 [–11, 13]	2 [–9, 10]	3 [–10, 13]	2 [–5, 11]	2 [–4, 9]
Queenstown	1 [–16, 20]	2 [–15, 23]	16 [2, 38]	8 [–3, 21]	7 [1, 22]
Southland: Invercargill	–1 [–15, 22]	2 [–17, 22]	10 [2, 30]	7 [–3, 22]	4 [–2, 19]
Chatham Islands	–2 [–10, 10]	4 [–7, 29]	4 [–10, 43]	3 [–8, 19]	3 [–5, 23]

Note 1: This table covers the period from 1990 (1980–1999) to 2040 (2030–2049), based on downscaled precipitation changes for 12 global climate models, re-scaled to match the IPCC global warming range for six indicative emission scenarios. Corresponding maps (Figures 2.3, 2.6) should be used to identify sub-regional spatial gradients.

Note 2: If the seasonal ranges are averaged, the resulting range is larger than the range shown in the annual column, because of cancellation effects when summing over the year.

Note 3: Projected changes for the 15 regional council regions were the result of the statistical downscaling over mainland New Zealand. For the Chatham Islands, the scenario changes come from direct interpolation of the General Circulation Model grid-point changes to the latitude and longitude associated with the Chathams.

Table 2.5: Projected changes for selected stations within each regional council area in seasonal and annual precipitation (in %) from 1990 to *2090*. Lower and upper limits are shown in brackets.

Region: Location	Summer	Autumn	Winter	Spring	Annual
Northland: Kaitaia	–1 [–26, 21]	–3 [–22, 11]	–8 [–32, 2]	–11 [–33, 8]	–6 [–22, 5]
Whangarei	0 [–20, 19]	1 [–27, 26]	–12 [–45, –0]	–16 [–45, 1]	–7 [–28, 2]
Auckland: Warkworth	–2 [–31, 20]	–1 [–20, 12]	–4 [–24, 5]	–12 [–33, 6]	–5 [–19, 6]
Mangere	–1 [–33, 20]	–2 [–21, 12]	–1 [–12, 9]	–9 [–30, 11]	–3 [–13, 9]
Waikato: Ruakura	–1 [–34, 18]	–1 [–24, 10]	3 [–7, 15]	–4 [–23, 16]	–1 [–11, 11]
Taupo	4 [–19, 30]	1 [–16, 9]	3 [–8, 15]	–5 [–23, 13]	1 [–7, 10]
Bay of Plenty: Tauranga	2 [–20, 23]	2 [–15, 16]	–3 [–16, 8]	–9 [–32, 12]	–2 [–12, 5]
Taranaki: New Plymouth	–2 [–38, 15]	1 [–18, 15]	6 [–6, 20]	–1 [–17, 21]	1 [–10, 11]
Manawatu-Wanganui: Wanganui	–3 [–42, 12]	–1 [–20, 12]	8 [–5, 25]	–0 [–16, 23]	1 [–11, 11]
Taumarunui	–1 [–36, 18]	–2 [–25, 12]	13 [1, 36]	1 [–16, 26]	3 [–7, 15]
Hawke's Bay: Napier	9 [–46, 52]	5 [–14, 25]	–16 [–45, –1]	–13 [–38, 9]	–4 [–20, 11]
Gisborne: Gisborne	5 [–38, 41]	4 [–25, 27]	–13 [–41, 1]	–16 [–42, 7]	–5 [–22, 8]
Wellington: Masterton	4 [–28, 32]	3 [–7, 13]	–7 [–28, 2]	–4 [–20, 16]	–2 [–15, 7]
Paraparaumu	–1 [–38, 16]	2 [–12, 14]	9 [0, 26]	2 [–15, 26]	3 [–7, 14]
Tasman-Nelson: Nelson	6 [–13, 30]	5 [–4, 18]	6 [–2, 19]	–1 [–20, 19]	4 [–3, 14]
Marlborough: Blenheim	5 [–15, 28]	5 [–5, 16]	1 [–14, 9]	–1 [–18, 20]	2 [–7, 13]
West Coast: Hokitika	–1 [–44, 32]	3 [–28, 26]	21 [5, 52]	8 [–11, 46]	8 [–5, 31]
Canterbury: Christchurch	3 [–17, 25]	6 [–6, 20]	–11 [–41, 10]	–2 [–15, 25]	–2 [–14, 16]
Hanmer	4 [–25, 32]	3 [–7, 15]	–10 [–34, 6]	–1 [–13, 29]	–2 [–14, 15]
Tekapo	2 [–30, 31]	0 [–16, 17]	18 [5, 41]	10 [–6, 47]	8 [0, 29]
Otago: Dunedin	0 [–29, 19]	2 [–11, 16]	7 [–16, 24]	6 [–1, 32]	4 [–9, 23]
Queenstown	1 [–38, 37]	2 [–32, 20]	29 [7, 76]	15 [–5, 50]	12 [–2, 34]
Southland: Invercargill	–2 [–44, 27]	2 [–31, 19]	18 [1, 51]	13 [0, 47]	7 [–12, 29]
Chatham Islands	–3 [–20, 16]	4 [–14, 29]	8 [–16, 67]	6 [–14, 45]	4 [–11, 35]

Note 1: This table covers the period from 1990 (1980–1999) to 2090 (2080–2099), based on downscaled precipitation changes for 12 global climate models, re-scaled to match the IPCC global warming range for 6 indicative emission scenarios. Corresponding maps (Figures 2.3 and 2.7) should be used to identify sub-regional spatial gradients.

Note 2: If the seasonal ranges are averaged, the resulting range is larger than the range shown in the annual column, because of cancellation effects when summing over the year.

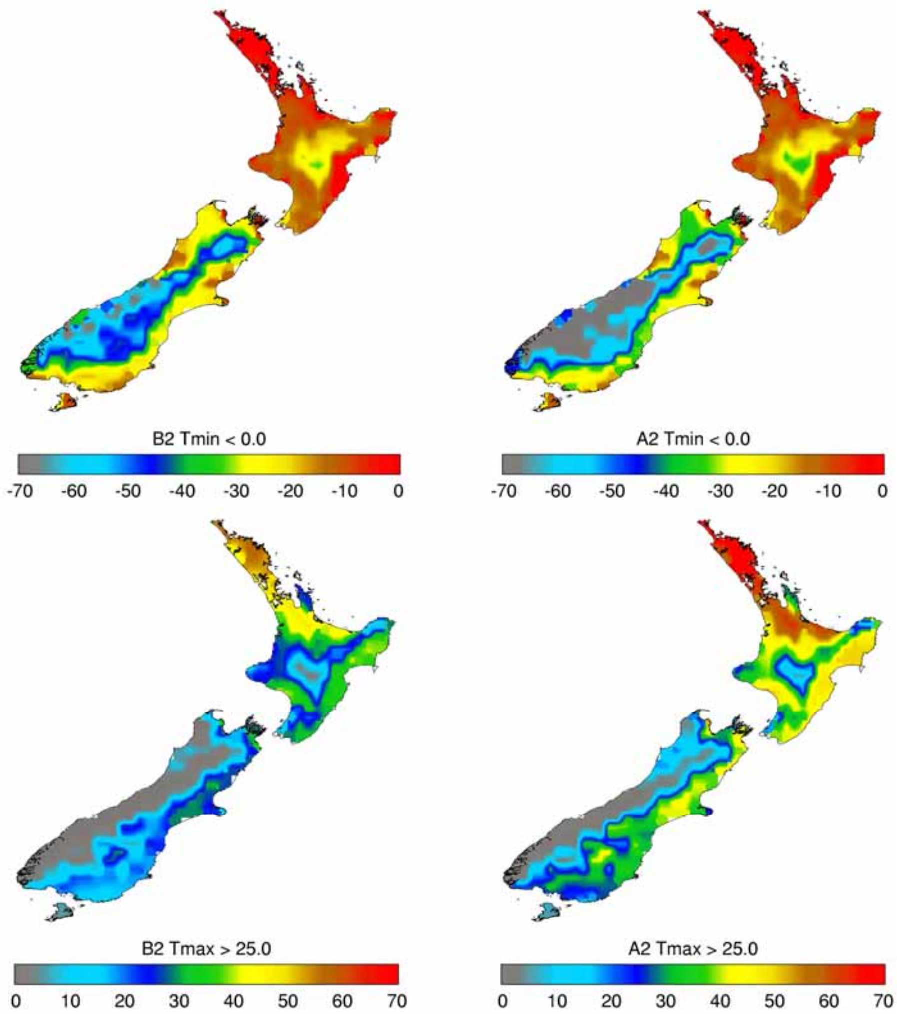
Note 3: Projected changes for the 15 regional council regions were the result of the statistical downscaling over mainland New Zealand. For the Chatham Islands, the scenario changes come from direct interpolation of the General Circulation Model grid-point changes to the latitude and longitude associated with the Chathams.

2.2.3 Daily temperature extremes

Daily temperature extremes (overnight minimum and daily maximum) will also vary with regional warming, in addition to changes in mean temperature. Box 2.1 illustrates that small changes in the mean temperature value can have a potentially large effect on how often a specified high temperature is exceeded, or how often temperatures below a certain low value (such as 0°C) occur.

Figure 2.8 is an example of how the frequency of frosts, and of hot days above 25°C, could change for two of the SRES scenarios (B2 and A2) that have so far been run using the NIWA regional climate model. Maps were generated by examining the time series of simulated daily maximum and minimum temperatures, and counting the number of times extremes occur. Larger changes in extreme temperatures occur for the higher emission scenario (A2).

Figure 2.8: Change in the number of days per year with extreme temperatures, between a control run (1980–1999) and two future climate runs under the B2 (left) and A2 (right) scenarios for 2080–2099. Top panel: days below freezing; bottom panel: days above 25°C.



Note: Maps generated from NIWA regional climate model simulations using the UK Met Office Unified Model. The emission scenarios B2 and A2 straddle the A1B scenario (see Figure 2.1). All changes in the top panel are negative, indicating fewer days of air frost in the future. All changes in the bottom panel are positive, indicating more hot days.

There are large decreases in the number of frost days in the central North Island and in the South Island[16] (upper panel). For example, in the central plateau of the North Island, the number of air frosts is projected to decrease by around 25 days or so per year for this particular simulation under the B2 emission scenario, and by a few more with the A2 scenario by the end of the 21st century. For comparison, there are typically 30–40 frost days per year currently in this part of the North Island (away from the actual alpine areas such as Ruapehu).

A substantial increase is projected for the number of days above 25°C, particularly at already warm northern sites. For example, for Auckland under the B2 scenario, an additional 40 days or more per year by the end of the century are projected with the maximum daily temperature exceeding 25°C. Under the A2 scenario, this becomes more than 60 extra hot days. For comparison, Auckland currently has approximately 21 days per year with maximum temperature exceeding 25°C. Current values for other locations include: 26 days for Hamilton, 3 days for Wellington, and 31 days for Christchurch.

2.2.4 Heavy rainfall

A warmer atmosphere can hold more moisture (about 8% more for every 1°C increase in temperature), so there is an obvious potential for heavier extreme rainfall under global warming. The IPCC, in its Fourth Assessment Report, declared that more intense rainfall events are "very likely over most areas".[17] The mountainous nature of New Zealand, with its starkly contrasting rainfall climates, makes it difficult to be sure if this situation is universally applicable across the country. Any change in the mix of circulation patterns will have a major impact on the spatial distribution of precipitation.

An early study[18] on New Zealand changes in extreme rainfall suggested that by 2030 there would be "no change through to a halving of the return period of heavy rainfall events" and by 2070 "no change through to a fourfold reduction in the return period". The return period[19] is the probable number of years between events with rainfall exceeding some specified high value.

More recent climate model simulations confirm the likelihood that heavy rainfall events will become more frequent. Studies have suggested empirical adjustments to historical rainfall distributions[20] that can be applied to estimate a range of possible changes in extreme rainfall under global warming for a particular site. For example, for Auckland, the worst case (most severe) end of the range for 2100 indicates that a rainfall amount currently with a return period of 50 years (AEP=0.02) would have a return period of less than 10 years (AEP>0.10) by 2100 (see Appendix 3 for details). The same approach could be applied to other New Zealand sites with long rainfall records.

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[16] Because the far north of New Zealand already experiences very few frosts, the frost frequency there cannot decrease substantially.

[17] Table SPM.2, *Summary for Policy Makers*, IPCC 2007a.

[18] Whetton et al 1996.

[19] Return periods can be translated into annual exceedance probabilities (AEP) that specify the likelihood of a rainfall amount being exceeded in any given year. For example, a 100-year return period event has an AEP of 0.01, a 20-year return period event has an AEP of 0.05, and so on.

[20] Semenov and Bengtsson 2002.

Preliminary analyses have now been made of changes in extreme rainfall, based on runs of the NIWA regional model under the B2 and A2 emission scenarios. Extreme value theory was applied to 30 years of daily rainfall data for the model 'control' climate (30 years ending 1999), and comparisons were made with the changed climate (ending 2099). For extremes with return periods of 30 years and longer, the increase in rainfall depth was approximately 8% per 1°C of local warming, when averaged over the entire country. This figure (8% per 1°C) matches the increased moisture content of the atmosphere with warming, and is the value widely accepted as a reasonable upper limit for heavy rainfall changes, provided the circulation patterns remain essentially the same.[21]

However, changes in extreme rainfall were not geographically uniform: in some parts of New Zealand, increases well in excess of 8% per 1°C of warming were found; in other parts of the country, there were decreases (ie, the change per 1°C of warming was negative). The pattern of changes in extremes can be related to the simulated change in storm track frequency and in intensity of cyclones crossing the country. This variation in circulation is very likely to be model-dependent, at least if it follows a similar pattern to the change in mean rainfall. Moreover, even a 30-year run for a particular model is probably not long enough to get stable statistics. Thus, it is recommended that the same changes to rainfall return periods be applied everywhere across New Zealand. It may be possible in future to have projections for regionally varying changes, but this will require comprehensive modelling studies. The recommended adjustment factors are given in Table 5.2, with a worked example in Appendix 4.[22]

Increased rainfall intensity has obvious implications for increased flooding. The Fourth Assessment Report summarises a number of international studies[23] that analyse the increased risk of floods in a future warmer climate. In a recent New Zealand study[24], three storm events for the West Coast Buller catchment were modelled, both for the current climate as well as for three different scenarios of temperature increase. Rainfall increased on average (for the three storms) by 3%, 5% and 33% for temperature changes of 0.5°C, 1.0°C and 2.7°C, respectively. Averaged over the three storm events, peak river flow increased by 4%, 10% and 37%, respectively, for the three temperature scenarios. Using these factors to modify the 1-in-50-year design storm, flooding was estimated to increase from 4% of the township being inundated under the current climate, to 13%, 30% and 80% for each of the temperature respective scenarios.

2.2.5 Snowfall and snowline

It is generally expected that snow cover will decrease and snowlines rise as the climate warms. However, there are confounding issues. As stated in section 2.2.4, warmer air holds more moisture, and during winter this moisture could be precipitated as snow at high elevations. There could also be instances of increased winter snowfall to low elevations, for the same reason. However, with the expected increase in temperatures, any snow cover will melt more quickly, and thus the duration of seasonal snow lying on the ground is expected to be shortened.

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[21] Pall et al 2007.

[22] For situations that could involve serious loss of life, there should be consultation to determine the latest scientific advice on projected changes in extreme rainfall amounts.

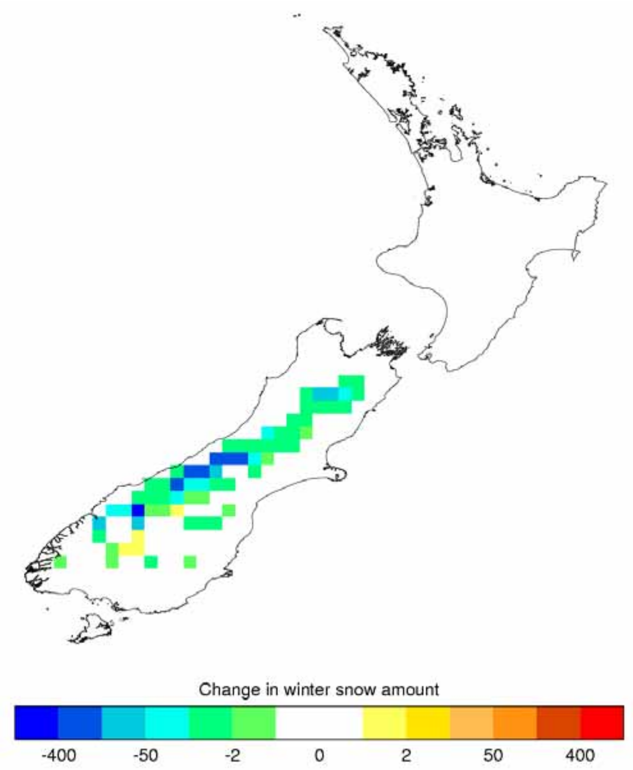
[23] Meehl et al 2007.

[24] Gray et al 2005.

Figure 2.9 shows an example projection of snow amount changes from the NIWA regional climate model, run under the A2 emissions scenario. There are decreases in seasonal snow almost everywhere. This is particularly evident in the South Island, but decreases also occur over the North Island central plateau (although changes here are too small to be visible with the contour interval used in Figure 2.9).

A decrease in winter snowfall and an earlier spring melt can cause marked changes in the annual cycle of river flow. Some analyses of seasonal river discharge and flood magnitude have been carried out for major rivers of the world,[25] but not for New Zealand as yet.

Figure 2.9: Change in winter snow (in kg/m^2) between a control run (1980–1999) and a climate simulation under the A2 scenario (2080–2099).



Note: The contour intervals are not equally spaced. Changes in snow amount smaller than 1 kg/m^2 are not shown (ie, white space). The snow amount is that *lying on the ground* averaged over the season, which is not the same as the average snowfall over the season. The unit 1 kg/m^2'corresponds to a water equivalent of 1 mm rainfall.

2.2.6 Sea level

The rise of sea level[26] around New Zealand is likely to be similar to the global projections of sea-level rise by the IPCC Fourth Assessment, 2007. This statement is based on the similarities

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[25] Arora and Boer 2001.

[26] This refers to what is often called 'absolute' sea-level rise. What is actually measured by tide gauges is the 'relative' sea-level rise, which includes any local vertical land movement (uplift or subsidence of land or coastal seabed) that may occur, for example, as a consequence of earthquake activity. See the Coastal Hazards and Climate Change manual (Ministry for the Environment 2008) for further discussion.

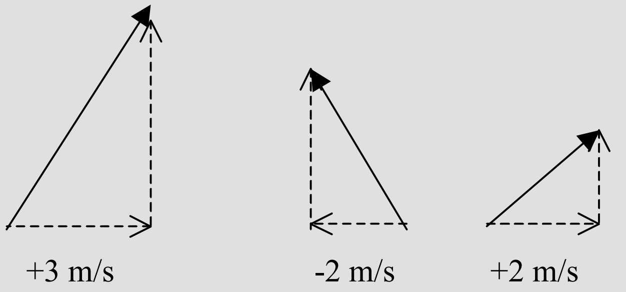
between the New Zealand average and the global average over last century of around 1.8 mm/year. Sea-level rise will continue for several centuries even if greenhouse gas emissions are reduced.

Using the same approach as for global temperature change, the IPCC projects that mean sea level will rise by at least 18–59 cm by the 2090s (2090–2099 average) from the 1990s (1980–1999 average), taking the full range of SRES scenarios into account. A further 10–20 cm rise above current levels would occur if melt rates of Greenland and Antarctica were to increase linearly with the future temperature increases. The IPCC notes that even larger sea-level rises cannot be excluded, but no consensus was possible because of limited understanding of the processes involved. They say "The projections do not include uncertainties in carbon-cycle feedbacks nor the full effects of changes in ice sheet flow, therefore the upper values of the ranges are not to be considered upper bounds for sea level rise."[27] More information about sea-level change, its likely impacts and possible response options, is provided in the companion *Coastal Hazards & Climate Change. A Guidance Manual for Local Government in New Zealand* (Ministry for the Environment 2008).

2.2.7 Wind patterns

It is expected that the annual mean westerly wind component across New Zealand will increase this century.[28] As shown in Box 2.2, this 'mean westerly' is built up from conditions when the actual east–west wind component is sometimes westerly (positive) and sometimes easterly (negative). The average southerly component is built up similarly from the north–south wind component.

Box 2.2: Westerly component of the wind across New Zealand



The solid arrows represent individual wind speed and direction values. The dashed horizontal arrows are the 'westerly components' of these winds – positive when they point to the right and negative when they point to the left. The 'mean westerly component' is the average of these individual westerly components. It is 1 m/s for the three periods shown above (ie, average of +3, –2 and +2). If the middle period of easterlies is excluded, the mean westerly component increases substantially to 2.5 m/s, even though the mean wind speed (average length of solid arrows) is hardly changed.

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[27] IPCC 2007d

[28] Mullan et al. (2001b) suggested a 10% increase in westerly component wind speed over the next 50 years.

Table 2.6 provides projected changes in the seasonal and annual average westerly and southerly components of the flow across New Zealand. These are broad-scale changes only, calculated from model changes in the Auckland–Christchurch pressure difference (related to west–east wind flow) and in the Hobart–Chathams pressure difference (north–south wind flow). Changes determined from the 12 General Circulation Models under the A1B scenario were re-scaled to span the six SRES emission scenarios, as for the temperature and precipitation tables. The average change is shown for each season, as well as the range over all models and emission scenarios.

A strong seasonality is apparent in the projected wind changes from the models used in the Fourth Assessment Report,[29] with increased westerly flow in winter and spring and decreased westerly flow in summer and autumn. In spring, the mean westerly flow increases by about 10% by 2040 and 20% by 2090. Winter westerlies increase even more, but there are projected decreases of 5–20% in the summer and autumn westerlies, in the average over all models and scenarios. There is clearly still substantial uncertainty about the projected future wind changes, as evidenced by the wide range across the climate models. Only for winter do all the models project increasing westerly flow across New Zealand.

Table 2.6: Projected changes in seasonal and annual westerly and southerly wind components (in m/s).

	Summer	Autumn	Winter	Spring	Annual
Westerly wind speed component					
1970–1999 climate	2.9	2.2	2.1	4.2	2.9
Change by 2040:					
Mean	–0.3	–0.1	+0.9	+0.5	+0.3
Range	[–1.6, +1.3]	[–2.1, +1.3]	[+0.2, +2.4]	[–0.6, +1.4]	[–0.5, +1.2]
Change by 2090:					
Mean	–0.6	–0.4	+1.4	+0.8	+0.3
Range	[–2.5, +1.4]	[–2.3, +1.0]	[0.0, +3.6]	[–0.7, +2.0]	[–0.6, +1.5]
Southerly wind speed component					
1970–1999 climate	–0.3	0.6	0.9	0.2	0.4
Change by 2040:					
Mean	–0.3	–0.1	0.0	+0.1	0.0
Range	[–0.8, +0.5]	[–0.6, +0.3]	[–0.7, +0.5]	[–0.4, +0.6]	[–0.5, +0.4]
Change by 2090:					
Mean	–0.3	–0.3	–0.2	0.0	–0.2
Range	[–1.2, +0.6]	[–0.6, +0.2]	[–1.3, +0.5]	[–0.6, +0.6]	[–0.9, 0.0]

Note: The ‘westerly’ component is derived from the Z1 Index (Auckland minus Christchurch pressure difference), and the ‘southerly’ component from the M1 Index (Hobart minus Chatham Islands pressure difference). For comparison, the current climatology (1970–1999) based on NCEP reanalyses is also given. A positive value means more westerly or more southerly, as appropriate.

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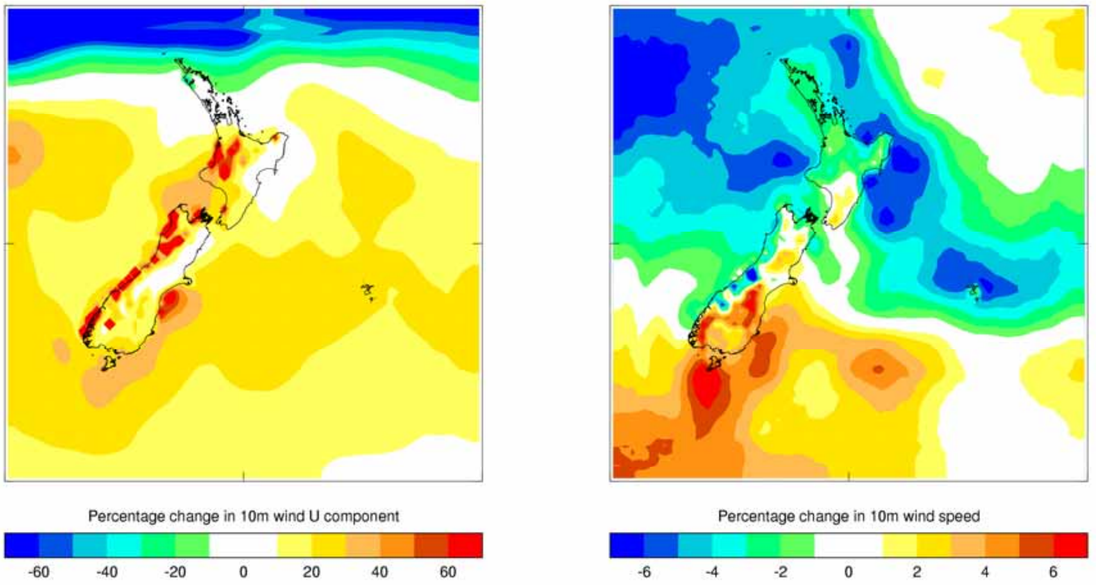
[29] With the Third Assessment models reported in the previous Guidance Manual edition (Ministry for the Environment 2004), six models for the 2030s and six for the 2080s, there was a tendency for increased mean westerly flow over New Zealand in all seasons individually.

Projected changes in the north–south wind component are less clear. Note that the climatological values are positive in all seasons except summer, meaning that the prevailing winds over New Zealand are from slightly south of west. There is a tendency for more northerly flow in future (ie, southerly component changes are negative), but the changes are not large enough to alter the prevailing wind direction from the west-southwest.

As noted in the example of Box 2.2, an increase in the mean westerly component does not in itself imply an increase in total wind speed. Strong[30] winds are associated with intense convection (expected to increase in a warmer climate) and with intense low-pressure systems, which might also become more common (see extra-tropical cyclones below). Thus an increase in severe wind risk could occur.[31] Since strong winds can cause damage to structures, forests and crops in New Zealand, there is much interest in trying to understand how climate change might impact on winds.

Higher temporal resolution is required to quantify future changes in wind speed. Figures 2.10 and 2.11 show preliminary analyses from the NIWA regional climate model, where data on daily time scales allow the full wind distribution to be examined. The two panels of Figure 2.10 together help clarify the relation between the westerly wind component and the total wind speed.

Figure 2.10: Change (in %) in wind in the winter season between a control run (1980–1999) and a climate simulation under the A2 scenario (2080–2099) for a 10-m wind westerly component (left) and 10-m wind speed (right).



Note: Panels show changes in near surface winds, identified in the regional model with an altitude of 10 m.

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[30] We use the term 'strong' here in a non-technical sense to cover wind speeds above about 10 m/s. A 'strong' wind is formally defined on the Beaufort Wind Scale as Level 6 (in the range 22–27 knots, or 11–14 m/s), one level above 'fresh' and one level below 'near gale'.

[31] Knippertz et al. (2000) identified an increasing number of strong wind events over the North Atlantic in their climate model simulation, which they relate to the increasing number of intense cyclones.

Figure 2.11: Change (in %) in the 99th percentile wind speed in the winter season between a control run (1980–1999) and a climate simulation under the A2 scenario (2080–2099).

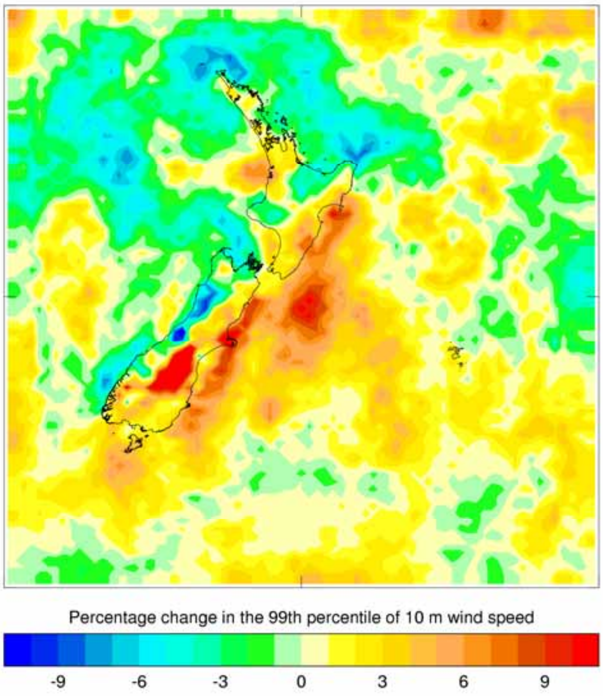

Figure 2.10 shows (left panel) an increase in the mean westerly wind component over New Zealand in the order of 20% by late in the century. This result from the NIWA simulation, shown for the winter season only, is consistent with the global model run by the UK Met Office and the ensemble of other models used in the Fourth Assessment Report. The corresponding change in wind speed is shown in the right-hand panel. Over most of the North Island, in this single example, average winter wind speed is projected to either change minimally or actually decrease by the end of the century. The implication is that there are fewer days of high-speed easterly wind days in the simulation. Over the lower South Island, and south of New Zealand, the projected wind speed increases by around 5%, a much smaller percentage change than the change in mean westerly.

Since Figure 2.10 presents an average over a season, there remains the possibility of stronger winds in individual storms.[32] More research is needed on intensity and storm tracks, but Figure 2.11 shows a preliminary analysis of the upper tail of the daily wind distribution. The 99th percentile represents the daily wind speed level that is exceeded only 1% of the time, which is currently about 10 m/s over the land (and 15 m/s or more over the ocean) in this model. Figure 2.11 suggests an increase in these strongest winds over much of the country by 2100. The changes are fairly small for the most part (averaging out at a 2.3% increase over all land points in the model), but reach about 10% in some eastern locations.

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[32] This particular regional model simulation shows a decrease in the number of low-pressure centres crossing the North Island by the end of the century; hence fewer storms, even if individually stronger, could still result in lower average wind speeds over each season.

2.2.8 Ex-tropical cyclones, and mid-latitude storms

The IPCC Fourth Assessment Report concludes that it is *likely*[33] that future tropical cyclones will become more intense, with larger peak wind speeds and more heavy precipitation. There is less confidence in projected changes in numbers of tropical cyclones. Tropical cyclones have changed their characteristics by the time they reach New Zealand, by which stage they are generally called ‘ex-tropical’ cyclones. Such systems tend to affect mainly the northern and eastern regions of the North Island, although occasionally they track further south. During El Niño periods, tropical cyclones tend to track further east in the South Pacific, and are less likely to affect New Zealand directly. Many climate models show an El Niño-like change in the mean state of the tropical Pacific over the next 50 years, but just how this might affect the likelihood of future ex-tropical cyclones reaching central New Zealand is not yet clear (see also section 3.2.1).

Of particular interest to New Zealand is the future behaviour of mid-latitude storms and low-pressure systems, also known as ‘*extra*-tropical cyclones’. The IPCC[34] says: ‘Extra-tropical storm tracks are projected to move poleward, with consequent changes in wind, precipitation and temperature patterns’.

Based on our understanding of weather dynamics, an increase in southern hemisphere storminess is certainly possible. The mid-latitude cyclones draw their energy from both the horizontal north–south temperature gradient (which is expected to increase for at least the next century, as the tropics will warm faster than will southern polar regions) and the release of latent heat (which will increase with the temperature-related moisture increases). Latent heat drives the tropical cyclones, but its importance varies enormously from storm to storm with mid-latitude circulation systems.[35] Also, a change in storm tracks could overwhelm any local impact of change in storm intensity. Nevertheless, increases in the peak wind speeds are possible, and increases in extreme precipitation likely, as discussed earlier in this chapter.

2.2.9 Ocean currents and wave patterns

The coupled atmosphere–ocean global climate models do not include enough detail to show the narrow ocean currents that flow around New Zealand, and very little analysis has been done of future wave patterns. This means that no quantitative statements about these climatic features can be made at this stage.

Changes in the winds do hold clues to what might be expected in the ocean.[36] The warm currents flowing down the eastern coast of the North Island are part of the subtropical gyre and are driven primarily by the ‘twisting’ action of the winds over the subtropical South Pacific. These wind patterns over the subtropics show little change in the model runs, but are projected to increase in higher latitudes, and this increase is expected to impact on the ocean current systems. Recent research[37] has linked warm conditions around New Zealand in the late 1990s to an enhanced Southern Annular Mode with increased westerlies south of New Zealand. The

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[33] In IPCC terminology, ‘likely’ has the technical meaning of greater than 66% probability of occurrence.

[34] IPCC 2007a.

[35] Revell 2002; 2003.

[36] Mullan et al. 2001b. See also the MfE 2008 *Coastal Guidance Manual*, section 2.3 and *Factsheet 10*.

[37] Roemmich et al 2007.

model projections of further increases in the westerly winds over the southern oceans could, therefore, be expected to cause a ‘spin-up’ of the subtropical gyre, with slightly stronger flows and warmer conditions in the gyre centre (ie, around New Zealand). The projected increased westerlies in high latitudes would also be expected to accelerate the cold Antarctic Circumpolar Current.

In addition, increased westerly winds could have impacts on stratification and, therefore, the input of nutrients from the deep ocean into the euphotic zone. The first mechanism for this is simply the increase in mechanical stirring from stronger winds. The second is increased wind-driven upwelling along the New Zealand coast. For a straight westerly, the coasts affected are the northward-facing coasts (ie, the West Coast of the South Island, and the northeast coast of the North Island), but changes in the north–south wind component could substantially modify which regions are affected.

Increased westerlies would also influence the ocean wave climate that impacts on New Zealand. In particular, coastal regions exposed to the prevailing winds would be subject to an increase in the frequency of heavy swells that would add to effects of higher sea levels. (Refer to the *Coastal Hazards and Climate Change manual* (Ministry for the Environment 2008) for further discussion.)

3 Relationship to Current Climate Variability and Change

Key points:

- New Zealand climate varies significantly from year to year and from decade to decade. Human-induced long-term trends will be superimposed on these natural variations, and it is this combination that will provide the future climate extremes to which New Zealand society will be exposed.
- New Zealand-wide temperatures can deviate from the long-term average by up to 1°C (plus or minus) on an annual basis, whereas regional precipitation can deviate by about 20% (plus or minus). The sign of the deviation will depend on whether it is a La Niña or an El Niño year, and also (for precipitation) on geographic location. Details can vary considerably from one event to another. These variations of the climate in individual years have amplitudes comparable to the mid-range projected changes expected over 30 to 50 years.
- New Zealand also has decadal circulation and climate variations that appear to be related to the Interdecadal Pacific Oscillation (IPO). The predictability of the IPO, and how consistently it is reflected in local climate, is still a topic of active research.
- The temperature increases projected for 2040 and 2090 lie generally above the linear extrapolation of the historical New Zealand temperature record (1908–2006).

3.1 Introduction

The projected changes in New Zealand's climate, as discussed in chapter 2, must be viewed within the context of natural yearly and decadal variability in circulation and climate. Chapter 3 provides this context by briefly summarising variations in current climate, and comparing the projected climate changes with past changes and variability.

New Zealand's climate varies all the time, and this natural variability will be superimposed on the future long-term trends described in chapter 2. Much of the variation in New Zealand climate is random and short-lived, but some of the variations are quasi-cyclic[38] in nature and some have long spans, lasting from seasons to years to decades. Figure 3.1 shows the historical national-average temperature for New Zealand, and sets the scene for discussing past and future changes and variability. This particular time series is derived by combining records from seven long-term climate stations (Auckland, Masterton, Wellington, Nelson, Hokitika, Christchurch, and Dunedin).

Records from all seven sites are available from 1908; since this date, New Zealand temperatures have increased by 0.90°C (ie, the linear trend between 1908 and 2006, as marked on Figure 3.1).

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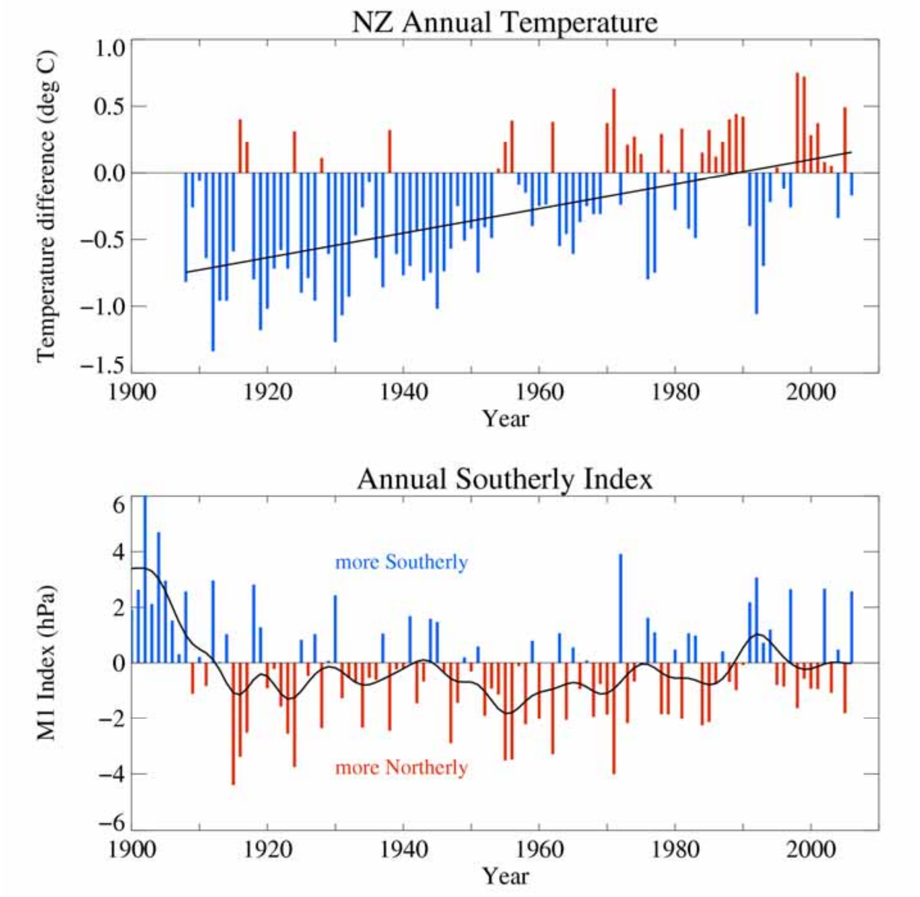
[38] There are very few true cycles in climate records, apart from the daily (diurnal) and annual cycle, in the sense of having a clearly defined period and being predictable for many cycles into the future. For this reason, the term 'oscillation' is often used in preference to 'cycle'.

A linear trend fitted to the New Zealand annual temperature record is statistically significant for data starting 1950 or earlier.[39] Global temperature trends achieve significance over much shorter periods than is found with New Zealand data; this is understandable because, at the regional scale, circulation patterns such as the El Niño-Southern Oscillation move heat back and forth and increase the interannual variability. At the global scale, this natural climatic 'noise' is evened out, and the reduced variability means the global warming signal can be detected earlier.

Figure 3.1: Observed New Zealand national-average temperature (top; in °C) and Southerly Index (bottom; in hPa).



Note: The figures show deviations from the climatological values for 1980–1999 for consistency with the baseline used for the projected values. Upper panel: annual mean temperatures (histogram bars, red if they are higher than the 1980–1999 mean) and the linear trend (solid black line). Lower panel: M1 Southerly Index (histogram bars, red when it is more northerly than the 1980–1999 mean; these periods generally match with relatively warm years in upper panel) and the same data smoothed (black line) to show the decadal M1 variation and highlight the trend towards more southerly airflow since the mid-1950s.

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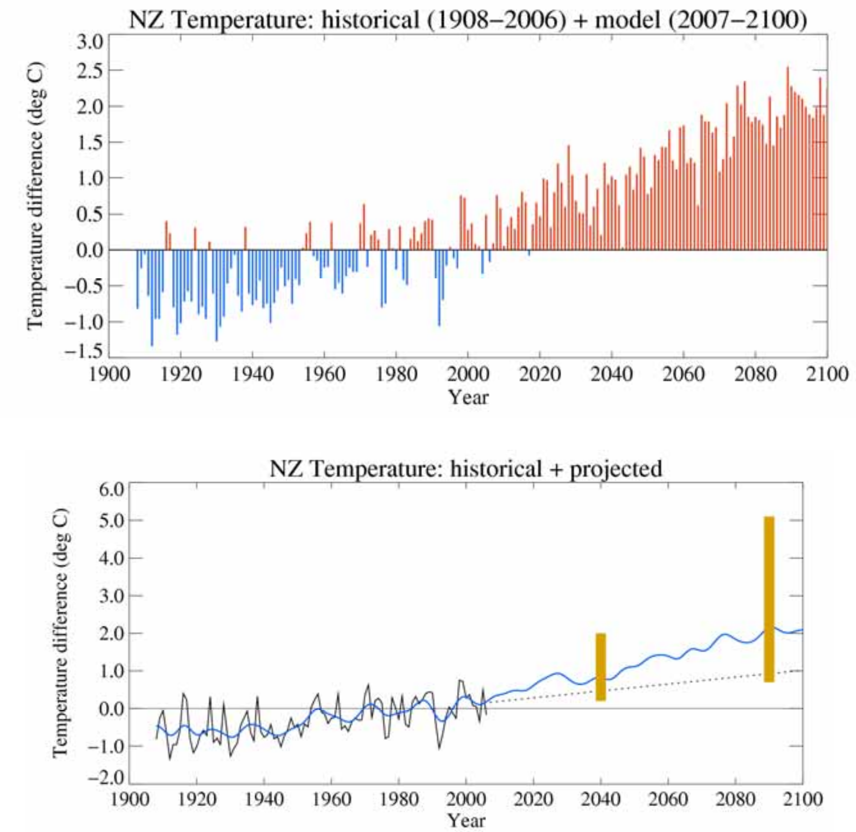
[39] Linear trends for shorter periods (1951–2006, 1952–2006, etc) have a *p*-value exceeding 0.05, and are, therefore, not significant at the 5% level.

For the New Zealand region, a good measure of the circulation variability that influences temperature is given by the Trenberth M1 Index[40] and a plot of the M1 Index has been included in Figure 3.1: more positive index values imply stronger mean southerly flows into the Tasman-New Zealand region. Hence, positive values (more southerly) tend to coincide with colder years in the New Zealand record, and negative values (more northerly) with warmer years. When the linear regression equation between the temperature and M1 data is calculated, then the residual temperature series (with the effect of northerly–southerly fluctuations removed) shows a significant warming trend much sooner (1986 or earlier). Moreover, Figure 3.1 shows that New Zealand has become warmer in spite of more southerly airflow in recent decades.

Figure 3.2: New Zealand temperature (in °C) – historical record, and schematic projections illustrating an example of future year-to-year variability (upper panel) and the full range of multi-decadal warming over the IPCC emissions scenarios (lower panel).



Note: Temperature is deviation in °C from the 1980–1999 mean. Upper panel: annual mean temperature, shown in red if it is higher than the 1980–1999 mean. For the observed period (1908–2006) the temperature shown is the average over seven long-term NIWA climate stations. For the schematic projection period (2007–2100) the temperature shown is the national-average of year-by-year downscaled temperatures from one of the Fourth Assessment models. Lower panel: Data from the upper panel displayed as a line plot (black) and a smoothed curve (blue line) showing the decadal variation in the observations and the example model projection. Vertical bars at 2040 and 2090 represent the full IPCC range of New Zealand warming in the six IPCC emission scenarios. The linear extrapolation to 2100 of the observed 1908–2006 trend line is also shown (black dashed line).

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[40] M1 is defined as the normalised pressure difference between Hobart and Chatham Islands. See Trenberth 1976; Jones et al 1999.

Figure 3.2 illustrates how natural variations will be superimposed on the long-term warming trend. It extends the historical temperature record by appending scenarios out to 2100.

In the upper panel, the historical period of 1908–2006 exactly reproduces Figure 3.1. Appended to this record is a time series of downscaled changes in New Zealand-average annual temperature, as simulated by one of the global climate models[41]. In this case, the downscaling has been applied year by year, instead of for the 20-year averages used in chapter 2. Natural variability (or at least the model's simulation of it) causes large year-to-year fluctuations about the general warming trend, and these fluctuations appear to be of similar magnitude to those observed historically. For example, 2043 (in this particular simulation) has a temperature similar to the current 1980–1999 climate, although it would be an abnormally cold year in the context of the 2040s. This model projection in Figure 3.2 is presented as a schematic *only*: the exact sequencing of future cold and warm years is random relative to how the actual future climate will evolve. A different climate model would give different sequencing, and indeed so would the same model if the simulation was run on another computer or with another start year.[42]

The lower panel of Figure 3.2 presents the broader context across the range of models and emission scenarios considered in chapter 2. The historical temperature record is given by the (black) line plot, to which has been added a smoothed curve (blue line) representing the decadal variation (observed and projected) from the example in the top panel. Two further features have been added. The linear temperature trend observed over 1908–2006 has been extrapolated to 2100 (dashed black line). Coloured vertical bars show the full scenario range at 2040 and 2090,[43] taking account of the different sensitivities of the various climate models and the six IPCC illustrative emission scenarios.

The extrapolation of past temperatures lies near the lower bound of the future projections. Only the combination of a low emissions scenario and a low sensitivity model gives a temperature at 2100 that is close to that extrapolated from the historical record. Note that the temperature projections in the lower panel of Figure 3.2 are decadally-smoothed curves. We would expect some individual years to fall outside the envelope, especially in the early years of the 21st century.

3.2 Variability of current climate, extremes and natural oscillations

3.2.1 Climate variability and natural oscillations

New Zealand's climate varies naturally with fluctuations in the prevailing westerlies and in the strength of the subtropical high-pressure belt. Local climate changes often have a strong spatial pattern imposed on them by interactions between the circulation and the southwest/northeast

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[41] The *gfdl_cm21* model. (It projects a warming of about 2°C by 2090. Other models have similar realistic interannual variability, but different rates of warming. See Appendix 2.) Changes are relative to the model average over 1980–1999, and are for the national average calculated over all land points of the gridded dataset used for the downscaling (Appendix 3), and not just at grid points co-located with the seven-station dataset used for the historical record.

[42] Chaotic behaviour in the atmosphere not only affects weather forecasts over the next few days, but also feeds into interannual and multi-decadal variability over the climate timescale.

[43] As in chapter 2, the nominal years '2040' and '2090' actually represent an average over the 20-year periods 2030–2049 and 2080–2099, respectively.

alpine ranges. Many of the circulation fluctuations that affect New Zealand are short-lived or random. However, other changes are associated with large-scale patterns over the Southern Hemisphere or Pacific Ocean. There are a number of key natural oscillations that operate over timescales of seasons to decades. This section focuses particularly on the El Niño-Southern Oscillation (ENSO, operating on the interannual timeframe) and the Interdecadal Pacific Oscillation (IPO, which persists in one phase for two or three decades).

Other factors that affect New Zealand's climate include large volcanic eruptions in the tropics (leading to cooling for a year or more),[44] and possibly solar variations over a range of timescales. On the extremely long timescale of thousands of years, there are the well-documented ice age cycles caused by systematic and predictable variations in the earth's orbit, but these do not concern us here.[45] On timescales shorter than 1 year, the most significant oscillation affecting New Zealand is the Antarctic Oscillation (also known as the 'High Latitude Mode'[46]). This oscillation appears to change sign on a month-to-month basis with very little predictability. Recent work has identified a long-term trend towards a stronger positive phase in the Antarctic Oscillation (meaning stronger westerlies at 50°S), which has been related to trends in stratospheric ozone depletion. This trend is also reproduced in climate model studies driven by greenhouse gas increases, so it is likely that both ozone and carbon dioxide contribute to the changes observed in high-latitude circulation.[47]

The Southern Oscillation, or more generally ENSO, is a tropical Pacific-wide oscillation that affects pressure, winds, sea-surface temperature (SST) and rainfall. In the El Niño phase, the easterly trade winds weaken and SSTs in the eastern tropical Pacific can become several degrees warmer than normal. There is a systematic eastward shift of convection out into the Pacific. Australia then experiences higher pressures and droughts, while New Zealand experiences stronger than normal southwesterly airflow. This generally results in lower seasonal temperatures for New Zealand, and drier conditions in the northeast of the country. The La Niña phase is essentially the opposite in the tropical Pacific, and New Zealand experiences more northeasterly flows, higher temperatures and wetter conditions in the north and east of the North Island. Pressures tend to be higher than normal over the South Island, and this can lead to drought conditions in the south. Thus, drought can occur in New Zealand in both El Niño and La Niña phases. Figure 3.3 shows average rainfall anomalies (that is, the differences from the multi-year averages) in New Zealand associated with El Niño and La Niña summers. Individual ENSO episodes can differ substantially from the average pattern.

Figure 3.4 (upper panel) shows a time series of the Southern Oscillation Index (SOI), a common measure of the intensity and state of ENSO events derived from the pressure difference between Tahiti and Darwin. Persistence of the SOI below about –1 coincides with El Niño events, and periods above +1 with La Niña events. Because the tropical Pacific SST anomalies persist for up to a year, there is substantial predictability in how ENSO events affect New Zealand's climate, and there has been considerable research to identify local impacts.[48] The ENSO cycle varies between about 3 and 7 years and there is large variability in the intensity of individual events.

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[44] Salinger (1998) quantified the effects of large tropical volcanic eruptions on New Zealand climate; on average, they lead to a cooling of 0.6–0.8°C over 1–2 years. The impact of the May 1991 Mt Pinatubo eruption is clearly evident in the New Zealand temperature record during 1992.

[45] Hays et al. (1976) predicted a cooling trend over the next several thousand years and glacial conditions in 20,000 years time. However, this prediction of very long-term cooling was based on only natural changes in radiative forcing (due to Earth orbit changes), with anthropogenic effects explicitly excluded.

[46] First described by Kidson (1988).

[47] Thompson and Solomon 2002; Cai et al 2003.

[48] For example: Gordon 1986; Mullan 1995.

Figure 3.3: **Differences between the long-term average rainfall and that in ENSO years (the rainfall anomaly), in percent, for summer (December, January, February). The ENSO rainfall is the average of the 10 strongest ENSO events between 1960–2007. (The insert box shows the ENSO years, where 1964 is December 1963 to February 1964, etc.)**

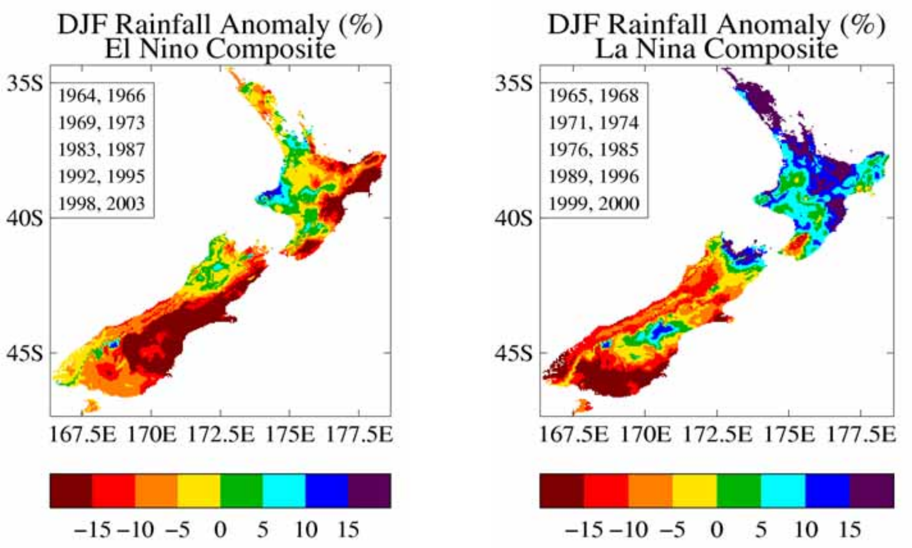
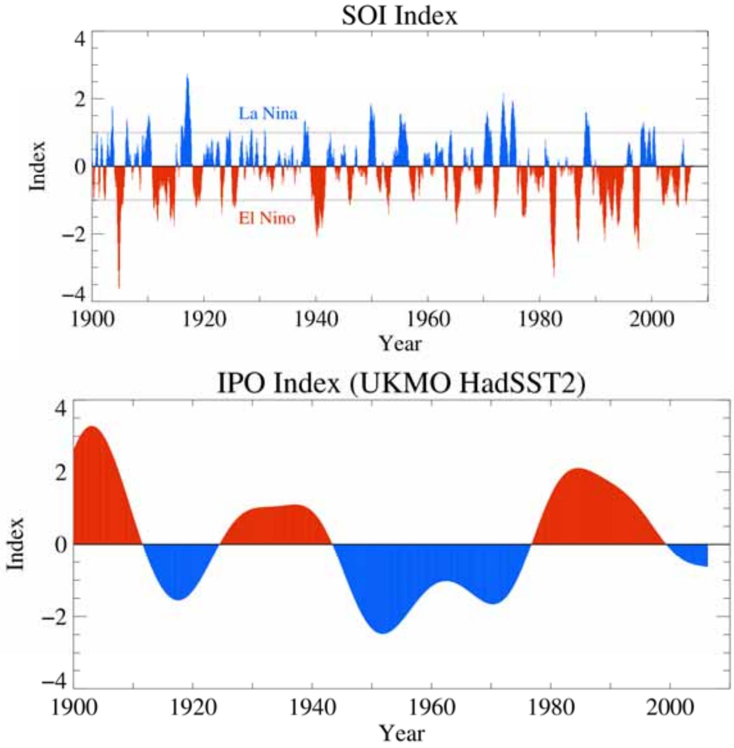


Figure 3.4: **Time series of Southern Oscillation Index (SOI, upper panel) and Interdecadal Pacific Oscillation (IPO, lower panel) from 1900.**



There has been an increase in the frequency of El Niño events since the late 1970s, and there has been much debate about whether this is a consequence of global warming.[49] The issue is

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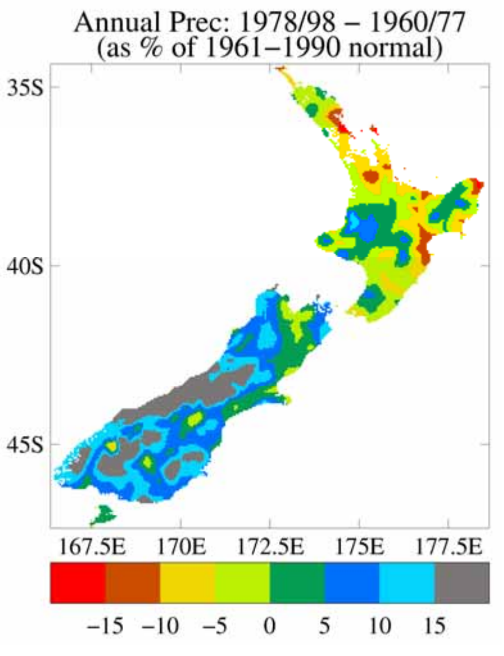
[49] Trenberth and Hoar 1996.

still not settled (see chapter 2). Another possible explanation for increased El Niño activity in the last two decades is minor natural variability in climate. The IPO has been shown to be associated with decadal climate variability over parts of the Pacific Basin,[50] and to modulate interannual ENSO climate variability over Australia[51] and New Zealand.[52] A time series of the IPO, derived from a UK MetOffice analysis of global SST patterns is shown in Figure 3.4 (lower panel). Three phases of the IPO have been identified during the 20th century: a positive phase (1925–1943), a negative phase (1944–1977), and another positive phase (1978–1999). The pattern associated with the positive phase is higher SSTs in the tropical Pacific (more El Niño-like) and colder conditions in the North Pacific. Around New Zealand, the SSTs tend to be lower, and westerly winds stronger.

Long-lived fluctuations in New Zealand climate show some association with IPO changes. The increase in New Zealand temperatures around 1950 (Figure 3.1) occurred shortly after the change from positive to negative-phase IPO (Figure 3.4). The switch from negative to positive IPO in the late 1970s coincided with significant rainfall changes. Figure 3.5 maps annual rainfall changes between negative and positive IPO periods centred on 1978, and Figure 3.6 shows the corresponding rainfall time series for the southwest part of New Zealand. In the later (positive IPO) period, rainfall increased in the southwest of the South Island, but decreased in the north and east of the North Island, relative to the earlier (negative IPO) period.

Figure 3.5: Percentage change in average annual rainfall for 1978–1998 compared to 1960–1977.



Note: In 1978–1998 the IPO was in its positive phase, compared to preceding 18 years, when the IPO was negative. Any local rainfall response due to global warming would also be contained within this pattern of rainfall trends.

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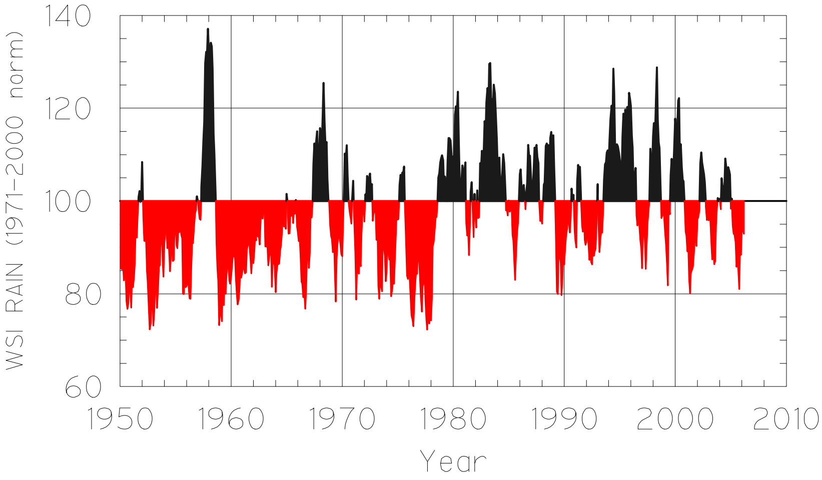
[50] Mantua et al 1997.

[51] Power et al 1999.

[52] Salinger et al 2001.

Figure 3.6: Annual rainfall (as a percentage of that between 1951 and 1980) for the southwest part of the South Island, 1950–2006.



Two main circulation changes affecting New Zealand in 1930–1994 have been identified as occurring around 1950 and 1975.[53] The period 1930–1950 was one of more south to southwest flow. Temperatures in all regions were lower in this period. Wetter conditions occurred in North Canterbury, particularly in summer, and drier conditions in the north and west of the South Island. In 1951–1975 (corresponding approximately with the negative IPO phase), there was increased airflow from the east and northeast, and temperatures in all regions increased. Conditions became wetter in the north of the North Island, particularly in autumn, and drier in the southeast of the South Island, particularly in summer. From 1976 onwards, west to southwest flow was more frequent, with little additional warming relative to the 1951–1975 period. There were significant rainfall trends, with summers becoming drier in the east of the North Island and wetter in the southeast of the South Island, and winters becoming wetter in the north of the South Island.[54]

What are the implications for future climate of a shift in the IPO phase? Analysis of the sea temperature data for up to about the year 2000 suggested the IPO had switched to the negative phase in 1998. For several years subsequent to 2000, it was unclear whether the 1998 shift was a true shift to the negative phase.[55] However, the 2007 UK MetOffice analysis (Figure 3.4) seems to confirm that the negative phase is now established.[56] If this IPO phase persists, then more La Niña (and less El Niño) activity could be expected compared to the 1978–1999 period. Weaker westerlies are likely, along with an implied weakening in the west–east rainfall gradient across the country. This gradient would act to partially counter the projected anthropogenic trend of increasing westerlies for perhaps the next 20–30 years or so, but at the same time increase the rate of New Zealand temperature and sea-level rise above the trend expected from global warming.

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[53] Salinger and Mullan 1999.

[54] Mullan et al 2001b.

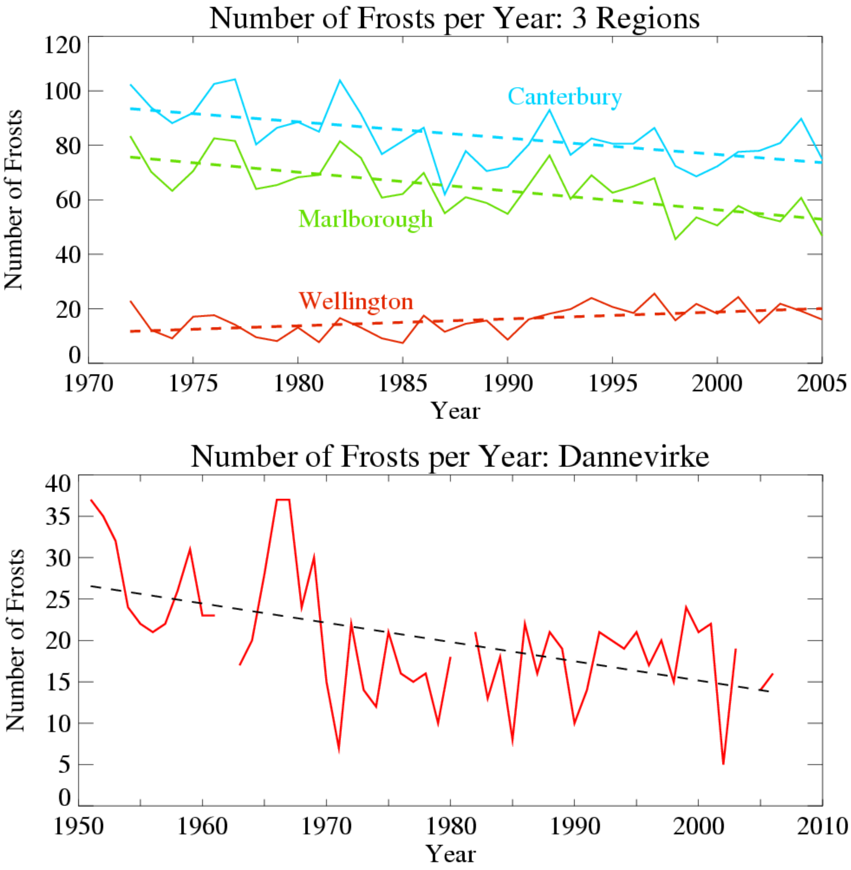
[55] The negative phase is also often called the ‘cold’ phase (and the positive phase, the ‘warm’ phase) because of the sign of the associated decadal anomaly in tropical Pacific sea surface temperature.

[56] Parker et al 2007.

3.2.2 Variability of extremes

Trends in New Zealand's historic daily temperature and rainfall extremes have been calculated.[57] Some of the trends (such as a decrease in frequency of frosts) are in agreement with trends in the global climate model projections, but most of the observed past changes have marked temporal variations and can be related qualitatively to regional decadal circulation changes as outlined in section 3.2.1 above.

Figure 3.7: Frequency of days per year with daily minimum temperature below 0°C.



Note: Upper panel: Average number of frosts per year in three Regional Council regions, 1972-2006, from NIWA gridded daily minimum temperature data set. Lower panel: Number of frosts per year at Dannevirke (NIWA station number D06212) in the eastern part of the Manawatu-Wanganui region, 1951–2006. (Dannevirke is taken for this example because it is the station nearest to the eastern Wellington region with a long continuous record – see text.) The straight trend lines in both panels are least-squares fits to the annual values.

Higher mean temperatures obviously increase the probability of extreme warm days and decrease the probability of extreme cold days. The IPCC also notes that climate models forecast a decrease in diurnal temperature range at many locations;[58] that is, the nighttime minimum increases faster than the daytime maximum. The evidence for increasing numbers of very warm

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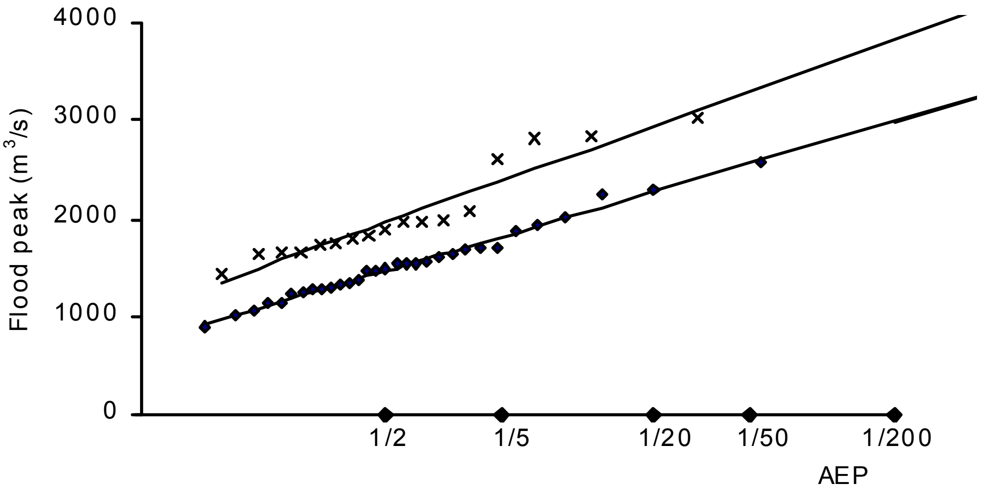
[57] Salinger and Griffiths 2001.

[58] Cubasch et al 2001.

days in New Zealand is not consistent, with regionally varying patterns that can be related to circulation fluctuations. However, there is clear evidence of a decreasing number of frost days at many New Zealand sites, as can be seen in Figure 3.7. For example, both Canterbury and Marlborough regions show about 20 fewer frosts per year now than in the early 1970s. However, the change in frost occurrence is not uniform, and shorter periods can give counter-intuitive results. Figure 3.7 (upper panel) actually shows an *increase* since 1972 in the frost incidence in the Wellington regional council region, which is due to increases in the eastern (Wairarapa) side of the lower North Island. This tendency for increased frost since 1972 is also evident in other east coast sites, including Gisborne, south Canterbury and coastal Otago. However, even for these sites, there has been a decrease in frosts on the longer timescale (eg, lower panel of Figure 3.7, record from 1951). Analyses of New Zealand temperature records have shown that trends in maximum and minimum temperatures are strongly linked to atmospheric circulation changes; slight changes in prevailing airflow direction can affect the frequencies of frosts and hot days in localised areas.[59]

Historical changes in New Zealand's extreme rainfall have also been documented.[60] The variations in extremes are quantified by measures such as the annual 95th percentile amount of rainfall, or number of days per year with rain exceeding the long-term, mean 95th percentile. Changes in extreme daily rainfalls are strongly related to changes in mean rainfall. Station 1-day rainfall extremes were highly correlated to westerly circulation across the country. Thus, increases in mean and extreme daily rainfall over 1930–2004 were found in the west of the country, and decreases were found in the north and east of New Zealand.

Figure 3.8: Flood frequency analysis for the Lake Te Anau 3-day annual maxima for 1947–1977 (lower line) and 1978–1994 (upper line).



Note: AEP is 'annual exceedance probability'. The fitted lines are Gumbel, Extreme Value Type 1, distributions fitted using Probability Weighted Moments. Figure from McKerchar and Henderson (2003).

Analysis of historical records of extreme river flows, both very low flows and floods,[61] has shown very marked changes in the frequency of extreme flows with the phase of the IPO in

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[59] Salinger and Griffiths 2001; Salinger 1995.

[60] Salinger and Griffiths 2001; Griffiths 2007.

[61] McKerchar and Henderson 2003.

some parts of New Zealand. A decrease in flood size has occurred since 1978 in the Bay of Plenty, and increases in flood size have occurred in the South Island for most rivers with headwaters draining from the main divide of the Southern Alps and in Southland. An example is given in Figure 3.8, which shows an analysis of flood return periods for Lake Te Anau. A high flow with an estimated return period of 50 years during 1947–1977 (a period of negative phase IPO, the lower line in the figure) has a return period of approximately 7 years during 1978–1994 (a period of positive phase IPO, upper line).

3.2.3 Storminess

Whilst there appears to be a public perception that 'increased storminess' is likely under climate change, the evidence of changes in storminess in New Zealand to date is far from conclusive. The concept of 'storminess' is itself somewhat ambiguous: it could refer to the number of storms, or to storm intensity – which, in turn, could be judged on the basis of strong winds or heavy rainfall. Storms can also approach New Zealand from the subtropics and from mid-latitudes (extra-tropics), and different trends are possible in those two regions.

The IPCC Third Assessment reported that:[62]

> *Changes globally in tropical and extra-tropical storm intensity and frequency are dominated by inter-decadal to multi-decadal variations, with no significant trend evident over the 20th century. Conflicting analyses make it difficult to draw definitive conclusions about changes in storm activity, especially in the extra-tropics.*

Since 2001, there have been a number of articles published about increases in intense tropical cyclones. These results are still controversial, and the Fourth Assessment Report was cautious in its conclusions:[63]

> *There is observational evidence for an increase in intense tropical cyclone activity in the North Atlantic since 1970 … There are also suggestions of increased intense tropical cyclone activity in some other regions where concerns over data quality are greater.'*

The only conclusion about mid-latitude circulation changes that was sufficiently clear-cut to bring forward into the *Summary for Policymakers* was:

> *Mid-latitude westerly winds have strengthened in both hemispheres since the 1960s.*

A limited number of studies have described observed changes in the Southern Hemisphere relevant to New Zealand, and most of these have been summarised in the IPCC Fourth Assessment Report.[64] Tropical cyclones that develop in the southwest Pacific could affect New Zealand. From 1971 to 2004, tropical cyclones in this region averaged nine per year, with no observed trend in either frequency[65] or intensity.[66] In any case, only about one cyclone per year

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[62] IPCC 2001a.

[63] IPCC 2007a.

[64] Trenberth et al 2007 (Chapter 3 of *Fourth Assessment, Working Group I*); Hennessy et al 2007 (Chapter 11 of *Fourth Assessment, Working Group II*).

[65] Burgess 2005.

moves south of 30°S and comes close enough to New Zealand to have a direct impact. Thus, there has been no increase in New Zealand's storminess from this source to date.

Trends in the frequency and strength of extreme winds across New Zealand since the 1960s have been examined.[67] These show an increase in the number and strength of extreme westerly wind episodes to the south of the country, but only a slight increase over New Zealand itself. At the same time, extreme easterlies decreased across New Zealand. These local changes relate well to the observed increase in southern hemisphere westerly wind-flow during the latter part of the 20th century noted earlier. These trends are also consistent with climate model simulations for an increasing trend in what is known as the 'positive phase of the Southern Annular Mode', which has been linked both to increases in greenhouse gases and to the size of the ozone hole over Antarctica. Thus, there is some evidence of an increase in westerly 'storminess' (ie, strong westerly wind episodes) in the late 20th century in the New Zealand region.

In terms of increasing heavy rainfall, it has already been noted that an increase has been observed in extreme precipitation in western parts of the North and South Islands, but also decreases in extremes in eastern regions.[68] While a contribution to these trends from global warming cannot be ruled out, the simplest explanation is natural decadal variability (in this instance, the IPO described above).

Several recent studies have been made of trends in southern hemisphere extra-tropical cyclones. Over the period 1979–1999, there has been about a 50% increase in the number of explosively deepening cyclones (the so-called 'weather bombs') per year.[69] These rapidly deepening systems occur mainly to the south of 50°S, but can form in the western Tasman Sea in the winter. However, they are a small percentage (around 1% or less, depending on location) of the total number of cyclones.

Changes in the number of Southern Hemisphere cyclones have also been documented.[70] Over the 40 year period 1958–1997, there has been a general reduction in the mean cyclone density over most regions south of 40°S, with the greatest reductions near 60°S but little change in the Tasman Sea. At the same time, systems have become more intense, on average, in the Australian Bight and the Tasman Sea, and weaker over the eastern Pacific. Just why the reduction in overall numbers should be occurring is not well understood, although one modelling study[71] has suggested that under more moist conditions (as would occur in a warmer atmosphere) cyclonic eddies transfer energy poleward more efficiently, and thus fewer cyclones would be 'required' to effect the same energy transport.

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[66] Diamond 2006.

[67] Salinger et al (2005), whose analysis was based primarily on daily pressure gradients rather than winds directly.

[68] Griffiths 2007.

[69] Lim and Simmonds 2002.

[70] Simmonds and Keay 2000.

[71] Zhang and Wang 1997.

3.2.4 Variability of sea level

Observations dating back to the early to mid-19th century show that sea level is rising around New Zealand. The historic rate of rise has been around 1.6 mm/year, based on analysis of tide-gauge data from the four main ports (Auckland, Wellington, Lyttelton and Dunedin).[72] This value also lies midway in the range of estimated global sea-level rise of between 1 mm and 2.5 mm per year since the early 1800s.

There is no sign yet of any definitive acceleration in the rise of sea level from any New Zealand sea-level gauges, although detection of such an acceleration has been claimed[73] for the global record. However, the Fourth Assessment Report of the IPCC concludes that it is unclear whether the recent faster rate of sea-level rise is a trend or is just a reflection of natural decadal variability.

The IPO, which spends 20–30 years in each phase, appears to have switched around 1999–2000 to the negative phase. If this current negative phase dominates for the next two decades, it is likely to bring more La Niña episodes than seen over the last 20 years, and produce a faster rate of sea-level rise locally than that experienced over the previous positive phase of IPO from 1978 to 1999. This pattern of more rapid sea-level rise during negative phases of the IPO has been demonstrated from the Port of Auckland tide-gauge record, and has been observed again in 2000–2005.[74] Other records show that a similar trend is occurring around the southern North Island; therefore, the next 20–30 years should see a faster rise in sea level than that attributable to the mean long-term trend of 1.6 mm per year. This local acceleration of sea-level rise is irrespective of any changes in the rate of sea-level rise attributable to global warming.

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[72] Hannah 2004.

[73] Church and White 2006.

[74] Tait et al 2002. See also *Coastal Hazards and Climate Change.* (Ministry for the Environment 2008)

4 Effects on Local Government Functions and Services

Key points:

Assessing the effects of climate change can be broken down into manageable steps, as follows:

- Use Tables 4.1 and 4.2 to identify specific resource effects relating to identified functions and services, and associated climate variables.
- If undertaking an initial screening analysis, use this information in association with material in chapter 5 (and its references to chapters 2 and 3 and Appendix 3) to evaluate whether climate change is likely to be a consideration in the particular area or issue. Then, decide on the need for further information and analysis.
- Use Table 4.3 to identify relevant sources of information and expertise.
- Identify, as far as possible, the limitations (assumptions and assessment capability) that exist.
- Use the examples in Section 4.3 as a guide to summarising the above information for the particular area or issue.
- Review any published information (Table 4.4) and, if appropriate, consult relevant experts (Table 4.3).

4.1 Introduction

This chapter provides guidance on identifying which local government functions and activities *could* be affected by the climate changes and fluctuations identified in chapters 2 and 3. It lists key climate influences and *possible* effects of climate change, for each of these functions and activities. It provides guidance on data, sources of information, models and specialist expertise in New Zealand that councils can use, along with the climate change scenarios covered by chapter 5, to quantify the likely magnitude of particular effects. Examples are given of some expected climate change effects, from studies that have been carried out in various parts of New Zealand.

The interactions between climate change and local government functions and services are likely to be quite complex. Identifying which effects are important in terms of responding now might seem quite a daunting task. However, assessing the effects of climate change can be broken down into manageable steps, as explained in chapter 1, and risk assessment can be used to guide judgements on where to focus adaptation effort (chapter 6). Practical hints are as follows:

- Staff responsible for a particular council function or service should integrate consideration of climate change into their assessment and planning activities.
- Prioritise and then focus on only those functions and services of importance to your council and for which climate change may have a material effect.
- For a particular function or service, start out with a straightforward initial screening analysis using simple initial estimates of how climate factors relevant to this function may change (chapter 5). It is necessary to embark on a more detailed effects study only if this initial analysis indicates material climate change impacts or opportunities are likely.

4.1.1 Making use of this chapter

This chapter provides resource material to help users follow through the assessment steps outlined in the ‘Roadmaps’ at the beginning of this Guidance Manual. We recommend that you refer to Figures R1 and R2, and to the Risk Assessment chapter (particularly section 6.4) for background. There are two particular ways in which information from the current chapter can be applied:

(a) When assessing effects of climate change on a particular council function or responsibility (Roadmap Figure R1). In this case, examine the entry for this particular function in Table 4.1 and the related entries in Table 4.2 to identify key climate variables and possible climate change effects. Then, use Table 4.3 for guidance on sources of information, models and expertise for use in quantifying these effects, in combination with the climate scenario guidance from chapter 5.

(b) When identifying and prioritising climate change risks and opportunities across all council functions and opportunities (Roadmap Figure R2). In this case, most of the entries in Tables 4.1 and 4.2 should be examined; they will aid identifying the council functions possibly affected by climate change and the key climate influences on them. Once these functions have been identified, an initial screening analysis can be performed (the fifth box on the left of Figure R2), using scenarios from chapter 5 and information from Table 4.3.

4.1.2 Making use of Tables 4.1, 4.2 and 4.3

Central to these tables is the link:

Key climate influence → **Possible effects**

Table 4.1 looks at this relationship from the perspective of:

Who is affected That is, which function(s)/asset(s)/activity(ies) – primarily of interest to city and district councils

Table 4.2 looks at this relationship from the perspective of:

What is affected That is, which resource(s) – (primarily of interest to regional councils

Table 4.3 provides useful information for all councils.

Tables 4.2 and 4.3 both help the reader through an assessment:

- by looking at the present and future (Table 4.2)
- by identifying who has expertise and what tools could be used (Table 4.3).

In using these tables, keep in mind that climate change and its effects should be considered relative to other changes. Climate change will not occur independently of other future changes, including changes due to natural climate variability, and future social and economic changes.

4.2 Links between climate influences and possible impacts

Table 4.1: Local government functions and possible climate change outcomes.

Function	Affected assets or activities	Key climate influences	Possible effects	Section in Table 4.2 giving type/explanation of effects
Water supply and irrigation	Infrastructure	Reduced rainfall, extreme rainfall events, and increased temperature	Reduced security of supply (depending on water source) Contamination of water supply	See Rivers, Groundwater, Water quality, Water availability, Coastal areas. (Note that there are also rainfall effects in areas dependent on rain water.)
Wastewater	Infrastructure	Increased rainfall	More intense rainfall (extreme events) will cause more inflow and infiltration into the wastewater network. Wet weather overflow events will increase in frequency and volume Longer dry spells will increase the likelihood of blockages and related dry weather overflows	See Drainage
Stormwater	Reticulation Stopbanks	Increased rainfall Sea-level rise	Increased frequency and/or volume of system flooding Increased peak flows in streams and related erosion Groundwater level changes Saltwater intrusion in coastal zones Changing flood plains and greater likelihood of damage to properties and infrastructure	See Rivers, Drainage, Coastal areas
Roading	Road network and associated infrastructure (power, telecommunications, drainage)	Extreme rainfall events, extreme winds, high temperatures	Disruption due to flooding, landslides, fallen trees and lines Direct effects of wind exposure on heavy vehicles Melting of tar	See Drainage, Natural hazards
Planning/ policy development	Management of development in the private sector Expansion of urban areas Infrastructure and communications planning	All	Inappropriate location of urban expansion areas Inadequate or inappropriate infrastructure, costly retrofitting of systems	See particularly Rivers, Groundwater, Drainage, Coastal areas, Natural hazards

Function	**Affected assets or activities**	**Key climate influences**	**Possible effects**	**Section in Table 4.2 giving type/explanation of effects**
Land management	Rural land management	Changes in rainfall, wind, and temperature	Enhanced erosion Changes in type/distribution of pest species Increased fire risk Reduction in water availability for irrigation Changes in appropriate land use Changes in evapo-transpiration	See Water availability, Erosion, Biodiversity, Biosecurity, Natural hazards
Water management	Management of watercourses/lakes/ wetlands	Changes in rainfall and temperature	More variation in water volumes possible Reduced water quality Sedimentation and weed growth Changes in type/distribution of pest species	See Rivers, Lakes, Wetlands, Water quality, Drainage, Erosion, Biosecurity
Coastal management	Infrastructure Management of coastal development	Temperature changes leading to sea-level changes Extreme storm events	Coastal erosion and flooding Disruption in roading, communications Loss of private property and community assets Effects on water quality	See Coastal areas, Natural hazards
Civil defence and emergency management	Emergency planning and response, and recovery operations	Extreme events	Greater risks to public safety, and resources needed to manage flood, rural fire, landslip and storm events	See Natural hazards
Biosecurity	Pest management	Temperature and rainfall changes	Changes in range of pest species	See Biosecurity, Biodiversity
Open space and community facilities management	Planning and management of parks, playing fields and urban open spaces	Temperature and rainfall changes Extreme wind and rainfall events	Changes/reduction in water availability Changes in biodiversity Changes in type/distribution of pest species Groundwater changes Saltwater intrusion in coastal zones Need for more shelter in urban spaces	See Groundwater, Drainage, Water availability, Biodiversity, Coastal areas
Transport	Management of public transport Provision of footpaths, cycleways, etc.	Changes in temperatures, wind and rainfall	Changed maintenance needs for public transport (road, rail) infrastructure Disruption due to extreme events	See Drainage, Natural hazards
Waste management	Transfer stations and landfills	Changes in rainfall and temperature	Increased surface flooding risk Biosecurity changes Changes in ground water level and leaching	See Biosecurity, Natural hazards
Energy	Transmission lines	Extreme wind, high temperatures	Outages from damaged lines	See Natural hazards

Table 4.2: Sensitivity of natural resources to present climate and climate change.

Natural resource	Key climate influence	Impacts of climate change	Present sensitivity to climate
Rivers	Rainfall	River flows likely to, on average, increase in the west and decrease in the east of New Zealand More intense precipitation events would increase flooding (by 2070 this could be from no change, up to a fourfold increase in the frequency of heavy rainfall events) Less water for irrigation in northern and eastern areas Increased problems with water quality	Strong seasonal, interannual and interdecadal fluctuations (see the example in Box 4.1 at the end of section 4.4, on peak flows in Bay of Plenty)
Lakes	Temperature and rainfall	Lake levels likely to increase, on average, in western and central parts of New Zealand, and possibly to decrease in some eastern areas Higher temperatures and changes in rainfall, particularly in areas such as the Rotorua Lakes, could result in a range of effects, including: • an increased degree of eutrophication and greater frequency of algal blooms • altering of lake margin habitats, including wetlands, with either increased or decreased rainfall • negative impacts on aquatic macrophytes, particularly native species, if lake levels fall • a decrease in the range of trout with increased water temperatures • increased ranges of pest species (eg, carp), placing even more pressure on aquatic ecosystems	Seasonal and interannual fluctuations
Wetlands	Temperature, rainfall, sea-level rise	Coastal and inland wetlands would be adversely affected by temperature increases, rainfall increases or decreases and sea-level rise	Many already under threat
Groundwater	Rainfall	Little change to groundwater recharge is expected in eastern New Zealand, but increased demand for water is likely Some localised aquifers in northern and eastern regions could experience reduced recharge. For example, small coastal aquifers in Northland would be under threat from reduced rainfall	Seasonal fluctuations; but at present, generally stable over the longer term
Water quality	Temperature and rainfall	Reduced rainfall and increased temperatures could have significant impacts on the quality of surface water resources in northern and eastern New Zealand Lower stream flows or lake levels would increase nutrient loading and lead to increased eutrophication	Most sensitive during summer months and in drier years
Drainage	Rainfall	Increased frequency of intense rainfall events could occur throughout New Zealand, which would lead to increased surface flooding and stormwater flows, and increased frequency of groundwater level changes	Natural year-to-year variation in the location and size of heavy rainfall events
Water availability	Rainfall	Decreases in rainfall, which are most likely in the north and east of New Zealand, coupled with increased demand, would lead to decreased security of water supply	Dry summers, or extended droughts
Erosion	Rainfall and wind	Increased rainfall in the west, and more intense rainfall events throughout New Zealand, could lead to increased soil erosion, including landslides	Intense rainfall events can arise with subtropical lows, and localised low pressure cells

Natural resource	**Key climate influence**	**Impacts of climate change**	**Present sensitivity to climate**
Biodiversity	Temperature, rainfall, wind	Increased temperature, reduced rainfall and more frequent drying westerly winds (possible in the east) would lead to changes in distribution and composition of native forest ecosystems throughout New Zealand Most vulnerable will be fragmented native forests in the north and east of New Zealand An increased biosecurity risk, with invasive temperate and subtropical species, would also have negative impacts on native flora and fauna	Drought can have a severe impact, eg, some native vegetation was adversely affected in Hawke's Bay with the 1997/98 El Niño drought
Biosecurity	Temperature and rainfall	Even small increases in temperature will significantly increase the incidence of pest outbreaks in New Zealand, particularly in the North Island and the north of the South Island Both existing and potential new plant and animal pests could become established more widely, even with a slight increase in temperature	Pest outbreaks can be triggered by specific weather events, or from steadily changing conditions, eg, spread of Tasmanian grass grub in Hawke's Bay was triggered by the warmer, drier conditions in the late 1980s and early 1990s
Coastal areas	Sea-level rise, storm frequency and intensity, wave climate, sediment supply	Effects of sea-level rise and other changes will vary regionally and locally Coastal erosion is likely to be accelerated where it is already occurring and erosion may become a problem over time in coastal areas that are presently either stable or are advancing	Short- and medium-term fluctuations in sea levels (ie, up to about 30 years) are dominated by ENSO and IPO variations
Air	Temperature, rainfall, wind	Increased temperatures in Auckland might increase photochemical smog Fewer cold nights may reduce particulate smog problems in winter in affected towns and cities	
Natural hazards	Temperature, rainfall, wind	The general indications are that New Zealand could experience more climatic extremes in the future. These could include: • more intense rainfall events, and associated flooding, in most parts of the country • more frequent and/or intense droughts in the east • more damaging windstorms • more heat waves • increased fire risk in drier eastern areas	There have been more frequent and intense El Niño events in recent decades, possibly associated with the IPO. The worldwide cost of extreme weather damage has increased owing to a mixture of climatic, economic and social factors

4.3 Assessing effects – methods, data, sources of information

There are three main approaches to assessing the effects of climate change at regional and local levels in New Zealand:

(1) **Modelling**. These incorporate computer-generated scenarios of climate change. An example is modelling that links historical weather data and information generated from General Circulation Models (translated to New Zealand's situation, see chapter 2) to a model of river flow. This approach can be readily applied to existing models and data used by hydrologists and engineers. A variation of this approach is to draw on historical data to determine possible effects in the future (for example, using information on past flood events to assess what the effects would be if floods comparable to those experienced in the past, such as those connected with El Niño-Southern Oscillation

(ENSO) or different Interdecadal Pacific Oscillation (IPO) phases, become more prevalent).

(2) **Expert opinion**. Seeking expert opinion can involve the presentation of plausible scenarios of climate change for your region (chapters 2 and 3) to knowledgeable people in your region, or national experts, to seek their views. In a flooding example, analysis as in (1) above could be undertaken using the input of experts. Often (see Table 4.3), there may be insufficient data and capability to follow the modelling approach, and it may be necessary to rely strongly on expert opinion. For example, local pest management people will have a good knowledge of current pest problems, and will have the capability to provide 'expert opinion' on the likely effects of climate change.

(3) **Monitoring**. The real effects of climate change will be detected only through ongoing monitoring. In some cases, monitoring may be the only way that effects can be quantified over time. See section 7.9 for further discussion on monitoring.

When selecting the assessment method, some judgement will be required on which is most applicable to the problem or issue of concern. Considerable capability already exists for assessing physical impacts – in terms of expertise, data and quantitative models. For example, there is a strong capability in New Zealand for predicting river flows in many parts of the country. In general, there is a much lower capability for quantitative assessment of biological and social/human impacts. In areas such as asset management (where investment in infrastructure is required), quantitative modelling is the principal approach. For issues such as biodiversity, a combination of approaches may be necessary, with monitoring playing a very important role. A broad summary of the capabilities that exist for identifying the effects of climate change on key local government services and functions is provided in Table 4.3.

4.3.1 Uncertainties and assumptions

Whichever method or approach is chosen, there will be assumptions that are made and/or inherent uncertainties. These need to be taken account of, along with the uncertainties that presently exist in projections of future climate.

In a study by Lincoln Environmental (see Table 4.4) on the impacts of climate change on water resources,[75] there were key assumptions made with the models that were used. For example, key assumptions made with the river flow model were:

- *There will be no hydrologically significant changes in vegetation (eg, no major conversions between pasture and forest).*
- *There will be no new diversion or abstraction of river water (nor any new extraction of groundwater that sustains river flow).*

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[75] Lincoln Environmental 2001.

Table 4.3: Data, sources of information and assessment capabilities relating to the effects of climate change.

Natural resource	**Key climate influence**	**Source of information**	**Assessment capabilities**
WATER		***Models*** NIWA 'Topnet model', MIKE11; Lincoln Environmental (irrigation model) ***Databases*** Regional council water quality and quantity databases; National HIRDS dataset; National Climate Database; National River Water Quality and Quantity Network and Database; National Hydrometric Database	Good predictive capability in most cases
Rivers			
• flooding	Peak rainfall and/or flows and/or levels		
• water quality	Seasonal rainfall and/or flows and temperature		
Lakes			
• lake levels	Rainfall		
• water quality	Seasonal rainfall and temperature		
• ecosystems	Decadal rainfall and temperature		
Wetlands			
• ecosystems	Decadal rainfall and temperature		
Groundwater			
• irrigation	Seasonal to decadal rainfall		
Water quality	Daily to monthly temperature, rainfall		
Drainage	Rainfall, groundwater levels, land use		
Storm water and waste water drainage	Hourly peak rainfall		
Water supply and irrigation	Rainfall and/or flows, projected demands		
LAND		***Models*** CLIMEX (developed in Australia to predict distributions of insect pests); Landcare Research have a range of models for predicting biodiversity changes and ecosystem responses; CLIMsystems (an evolution of CLIMPACTS); Hotspots (mosquitoes) ***Databases*** National vegetation survey, soil and land databases (Landcare Research)	Some predictive modelling capability exists, principally in the science community. In many cases, it will be necessary to gather biological and physical data over a period of time.
Erosion	Rainfall		
Biodiversity	Decadal rainfall and temperature		
Biosecurity	Seasonal to decadal rainfall and temperature		
COAST		***Models*** Various dynamic 1-, 2- and 3-D models and empirical models ***Databases*** Sea levels, winds, waves, tides, sea surface temperature, beach profiles	Variable
Inundation	Long-term changes in sea level		
Erosion	Increase in storm intensity and frequency		
Saltwater intrusion into rivers and water supplies	Changes in sediment supply		
	Changes in wave climate		
AIR		***Models*** CALPUFF and other dispersion models; TAPM ***Databases*** National Air Quality (NIWA/MfE) and National Climate Database	Specific modelling capability limited to a small number of experts Limited current data at relevant scales
Air quality	Hourly temperature		
	Hourly wind speed and direction		
	Hourly solar radiation		
GENERAL	24-hour to seasonal weather extremes (temperature, rainfall, wind, snow)		
Natural hazards			

Note: HIRDS is the High Intensity Rainfall Design System available on CD from NIWA, or (HIRDS Version 3) via the NIWA website.

4.4 Examples of what is known about effects

The following examples demonstrate how the information presented in the preceding tables might be drawn together. The summary information on effects comes from a variety of sources. In the first example relating to water allocation, results from a published study are briefly presented. In the other examples, information on effects is mostly based on the expert opinion of regional council staff. Finally, a brief example of the interrelationships between climate change and climate variability (in this case the IPO) is presented, drawing from an Environment Bay of Plenty study.

4.4.1 River flows and irrigation

Local government function: water allocation for irrigation

Natural resource: rivers

Key climate variables: 30-year time series of daily precipitation, maximum temperature, minimum temperature, dew point temperature, solar radiation and wind run

Climate change effects: reduced river flows possible in eastern New Zealand

Key risk: less surface water available for irrigation

Uncertainty: changes in river flows in catchments that reach into the Main Divide or central North Island are dependent on precipitation changes in these areas, which are uncertain

A study for the Tukituki catchment in Hawke's Bay predicted that river flow would generally decrease by 2050 with climate change. Based on the climate change scenarios used, river flows would decrease by 20–30% in summer and autumn, and by 0–10% in winter. It was concluded that peak irrigation demand could increase by 10% by 2050, but that there would not be any change in irrigation days lost (principally because there is already a 100% frequency of occurrence of irrigation seasons with some irrigation time lost). This study was based on mean changes in climate and did not take account of the possible effects of changes in frequency or intensity of climatic extremes. (Source: Lincoln Environmental 2001.)

4.4.2 Erosion and landslides

Local government function: erosion control

Natural resource: land

Key climate variables: intense rainfall events

Climate change effects: increasing frequency of intense rainfall events

Key risk: increased erosion risk

Uncertainty: lack of regional detail

On the West Coast of the South Island an increase in rainfall would also increase the potential for landslides, and potentially landslide dam-break flood events, as occurred in the Poerua River catchment in 1998. (Source: West Coast Regional Council 2002.)

Erosion risk is high over significant tracts of land in Manawatu. For example, 500,000 hectares of hill country is at risk of accelerated erosion in Manawatu. This risk could be exacerbated with any increase in rainfall frequency and intensity. (Source: Horizons.mw 2002.)

4.4.3 Water supply and demand

Local government function: water supply

Natural resource: surface and groundwater

Key climate variables: average rainfall (monthly, seasonal, annual)

Climate change effects: decreased rainfall in the north and east of New Zealand

Key risk: decreased security of water supply

Uncertainty: average decreases in rainfall appear more likely in the east of New Zealand than in the north

Peak daily water demand in Wellington is usually at the end of an extended dry, hot spell of 10 days or more. If such events increase with climate change, then the number of peak days can be expected to increase. (Source: Wellington Regional Council 2002.)

4.4.4 Biosecurity

Local government function: pest management

Natural resource: land

Key climate variables: temperature and rainfall

Climate change effects: increasing temperatures and rainfall changes

Key risk: increased biosecurity threats

Uncertainty: the rate and magnitude of climate change, which remain uncertain, will determine the extent of the problem

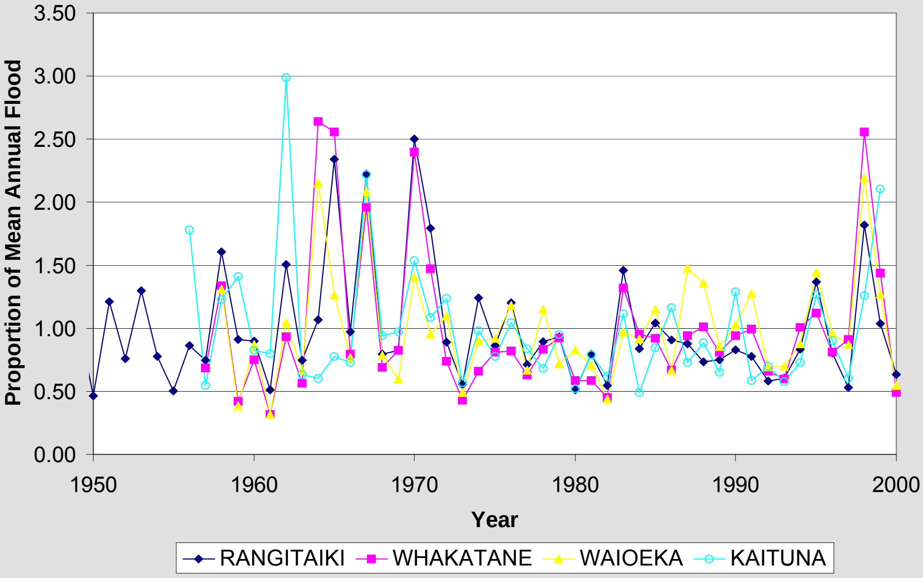
Warmer conditions in recent years have highlighted the sort of pest problems that are likely to arise more often in coming decades. For example, the tropical grass webworm, a wind-blown invader from Australia, has decimated all pasture species, in fact anything green, on the Aupouri Peninsula in the far north of Northland in recent years. There are several pest plants currently found in small or not very vigorous infestations in Northland that would become a serious pest, not only in Northland but also through other parts of northern New Zealand, if there were even a slight increase in temperature. (Source: Northland Regional Council 2002.)

Box 4.1: Effects of climate variability

A comment on IPO relationships with river flows from Peter Blackwood, Manager of Technical Services, Environment Bay of Plenty 2003.

IPO is much more strongly correlated than ENSO, particularly to flood flows. Attached are graphs from the December 2000 Environmental Data Summaries showing peak flow for Waioeka, Whakatane and Rangitaiki. These show abnormally large floods during the phase of IPO prior to the mid-1970s and following 1998. The period from the mid-1970s to 1998, on the opposite phase of IPO, was conversely very benign.

Figure Box 4.1: Annual maximum flow as a proportion of the mean annual flood for the Rangitaiki, Whakatane, Waioeka and Kaituna rivers in the Bay of Plenty 1950–2000.



4.5 Published studies on effects and adaptation

Various studies and reports published since 2000 that have focused on climate change effects and adaptation in New Zealand are listed in Table 4. Some of these contain results from quantitative assessments (such as the CLIMPACTS report (Warrick et al 2001) and the Lincoln Environmental study (Lincoln Environmental 2001), and some are reviews of what is known, drawing from published studies and the knowledge of experts. Many of these reports, plus some further background material, are available through the Ministry for the Environment's web page of local government guidance materials on climate change http://www.mfe.govt.nz/issues/climate/resources/local-govt/index.html (3 April 2008). There are still many gaps in knowledge about regional and local detail, along with the uncertainties that exist about future changes in climate.

Table 4.4: Reports on the effects of, and adaptation to, climate change in New Zealand.

Science reports
The effects of climate change and variation in New Zealand: an assessment using the CLIMPACTS system – Warrick et al 2001
National reports
A methodology to assess the impacts of climate change on flood risk in New Zealand – Gray et al 2005.
Assessment of the need to adapt buildings in New Zealand to the impacts of climate change – Bengtsson et al 2007
Australia and New Zealand (in *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*) – Hennessy et al 2007.
Australia and New Zealand (in *Climate Change 2001: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*) – Pittock and Wratt 2001
Changes in drought risk with climate change – Mullan et al 2005
Climate change adaptation: guidance on designing New Zealand's built environment for the impacts of climate change – O'Connell and Hargreaves 2004
Climate Change Impacts on New Zealand – Ministry for the Environment 2001a
Climate change: likely impacts on New Zealand agriculture – Kenny 2001
Climate change: potential effects on human health in New Zealand – Woodward et al 2001
Implications of Climate Change for the Construction Sector: Houses – Camilleri 2000
Impact of climate change on long-term fire danger – Pearce et al 2005
Incorporating climate change into stormwater design: why and how – Shaw et al 2005
Linkages between climate change and biodiversity in New Zealand – McGlone 2001
Planning for climate change: effects on coastal margins – Bell et al 2001
Report on some implications of climate change to Department of Conservation activities – McFadgen 2002
Regional reports
Adapting to Climate Change in Eastern New Zealand: A Farmer Perspective – Kenny 2005
Adapting to climate change: A view from the ground – Kenny 2006
Climate Change: An analysis of the policy considerations for climate change for the Review of the Canterbury Regional Policy Statement – O'Donnell 2007
Climate Change and Land Management in Hawke's Bay: A pilot study on adaptation – Kenny 2002
Impacts of climate change on agriculture water usage and water availability – Lincoln Environmental 2001
Meteorological hazards and the potential impacts of climate change in the Manawatu-Wanganui Region – Tait et al 2005
Meteorological hazards and the potential impacts of climate change in the Wellington Region: a scoping study – Tait et al 2002
The impact of predicted climate change on hazards in the Auckland Region: scoping study – Auckland Regional Council 2002
Forces Shaping the 21st Century: Climate Change/Natural Hazards – Auckland Regional Council 2006.
Local reports
Impacts of Climate Change on Christchurch – Christchurch City Council 2002
Project CARE: Impacts of Climate Change to the Wastewater Network Strategic Improvement Plan – North Shore City Council et al 2003

Note: Full citations for these reports, including web locations for many of them, are provided in the References section located immediately before the appendices in this Guidance Manual.

5 Developing the Scenarios

Key points:

When developing future scenarios, include the following –

- Identify the scenario categories to be explored. The principal category will be climate change, but it may also be appropriate to consider changes in population and land use, for example.
- Use the guidance in Table 5.1 in a staged approach to assessments. This table provides information for developing initial scenarios for screening assessments, and for undertaking more in-depth studies if a screening assessment indicates these are warranted.
- Consider the cost involved with different scenario approaches and the relative sensitivity of the natural resource to the effects that are to be examined. This will influence the scenario approach to be taken (refer back to section 4.2 for guidance).
- Use the published information on climate change scenarios, the CLIMPACTS system where appropriate, and consult relevant experts, to identify the specific scenarios to be used.
- Identify additional expertise that will be required to quantify other scenarios and to quantify effects.
- Remember always that, whichever scenarios are chosen, they will be bound by important assumptions and thus will provide information only on *plausible* futures.

5.1 Introduction

This chapter provides guidance on developing and applying scenarios. A scenario is a plausible description of how the future may develop, based on a coherent and internally consistent set of assumptions about key drivers. Climate, social and economic scenarios can be formulated that span the likely range of future conditions. These can then be used together with expert knowledge and models of the sensitivity of natural or managed systems to climate (the information outlined in chapter 4) to deduce a range of possible climate impacts on selected council activities and services.

Scenario analysis is an appropriate tool for effects assessment because it is not feasible to make a definitive single quantitative prediction of exactly how much a particular climatic element (for example, heavy rainfall intensity) will change over the coming decades. This is because rates of climate change will depend on future global emissions of greenhouse gases, which in turn depend on global social, economic and environmental policies and development. Incomplete scientific knowledge about some of the processes governing the climate, and natural year-to-year variability, also contribute to uncertainty about the future. Thus, it is necessary to consider a range of possible futures when assessing climate impacts and developing adaptation strategies.

As already outlined in chapters 1 and 4, we recommend a staged approach to assessing climate effects. For a particular council function or service, this begins with a straightforward initial screening assessment using simple initial estimates of how climate factors relevant to this function may change. A more detailed effects study is justified only if this initial analysis indicates that material climate change impacts or opportunities are likely, at least for the upper end of the scale of potential future climate changes. The current chapter provides guidance both on simplified scenarios for initial screening assessments, and on which scenarios to use in more detailed studies when these are justified.

In developing scenarios, factors other than those related to climate variables need to be considered. Climate change will occur along with many other changes (social, economic, environmental) that are expected to occur in the coming decades, many of which also carry uncertainties. It must also be remembered that climate change is an underlying long-term trend on which future variability in climate will be superimposed. Therefore, deciding on the scenarios to use, is an important step. The scenarios chosen will determine the bands of uncertainty that will be quantified, which will feed through to decision-making processes in terms of what to do and what not to do about climate change, and over what timeframe.

There are three broad categories of scenario that should be considered:

- social
- economic
- physical/environmental.

Each of these is described briefly in this chapter. Some examples are provided to illustrate how scenarios can be developed and applied, drawing in part from the climate change information provided in chapters 2 and 3. When developing all scenarios, it is good practice to consider the range of uncertainty, which may encompass the upper and lower end of projected climate change, high and low population projections, or different scenarios for economic development.

5.1.1 Making use of this chapter

This chapter identifies the key aspects that need to be considered in developing scenarios for a climate change impact assessment, and provides some guidance to help develop a scenario study (or impact or effects assessment). The key things to consider are as follows.

1) Climate change will not occur in isolation from other changes. Thus scenarios need to be developed for more than just climate (refer to section 5.2 below, and the examples).
2) A staged approach to developing and applying scenarios of climate change is recommended. Refer to Table 5.1 for examples, and sources of information/expertise for more in-depth scenario studies.
3) Be sure to consider the range of uncertainty (see the example in Figure 5.2).

A note on timeframes

Climate has effects over a range of timeframes. On an interannual basis, there are variations in climate that can be affected in some years by El Niño or La Niña events. On a decadal basis, there are fluctuations associated with, for example, the Interdecadal Pacific Oscillation (IPO: see chapter 3). Climate change, in the context of this Guidance Manual, relates to changes that are only now becoming apparent as underlying trends and that will be manifested increasingly over the next hundred years.

Local government planning can also occur over a range of timeframes. Infrastructure investments (such as flood protection) generally consider 50- to 100-year timeframes, which are consistent with climate change. Other planning activities (a good example might be biosecurity) are not presently closely linked to climate timeframes. Marrying decision-making timeframes with climate science timeframes needs to be an implicit part of an assessment of climate change effects.

Box 5.1: Screening assessment

In this Guidance Manual, we recommend an initial screening assessment for a particular council function, activity or service, to decide whether a more detailed climate change effects assessment and formal risk analysis is warranted. A screening assessment can be done for a particular function or service (Roadmap R1) or across all council activities (Roadmap R2).

The first step of a screening assessment is to identify whether a particular function or service is important to your council and whether it might be sensitive to climate change. This can be done by simply ticking the ‘yes’, ‘maybe’ or ‘no’ column for questions in the screening assessment table provided below, taking into account the context of evolving risk over time and the life of the project. More detail on the characteristics to be evaluated is given in section 7.2. If you answer ‘yes’ or ‘maybe’ to Question 1 or 2, as well as to any of Questions 3–6, you should then probably answer ‘yes’ to Question 7 and undertake a scenario-based initial screening analysis using climate scenario guidance from the screening assessment column of Table 5.1. This analysis may well be all that is needed. However, if the results of this analysis lead you to answer ‘yes’ or ‘maybe’ to Question 8, a more in-depth risk assessment is appropriate, using more detailed scenario guidance from the right-hand column of Table 5.1.

Characteristic	Question	Yes	Maybe	No
Current driver	1. Is there an existing problem that may be exacerbated by climate change? (eg, recurrent inundation)			
Future driver	2. Is there a foreseeable problem that may be caused or exacerbated by climate change?			
Complexity	3. Is this a complex issue? (eg, locating a new suburb as opposed to locating one house)			
Location	4. Is the location sensitive to climate change? (eg, a flood plain as opposed to bedrock hillside)			
Duration	5. Is it a permanent long-term change? (eg, locating a new suburb as opposed to permitting development of a campsite)			
Extent	6. Does it involve a lot of infrastructure and services provided? (eg, in an urban area as opposed to being remote rural)			
7. Is an initial screening analysis using a screening scenario from Table 5.1 justified?				
8. Does this scenario-based initial screening analysis indicate that material climate change impacts might occur? (A screening analysis must be performed in order to answer this question.)				
9. Should a full risk assessment be done for this issue?				

5.2 Developing scenarios

5.2.1 Social scenarios

The most obvious social scenarios relate to demographic changes, of which changes in population size and distribution are probably the most commonly used. Future population changes are likely to have a significant influence on the demand and supply of local government functions and services, and consequently on the natural resources that are managed by local government.

5.2.2 Economic scenarios

Regional and district councils are increasingly focusing on economic development goals and how these relate to their functions and services. Future trends in activities such as agriculture, industrial development and tourism will all have consequences for local governments and the resources they manage. In predominantly rural regions, changes in land use could have significant effects on resource demand and supply. For example, a trend towards land-use intensification could lead to increased demand for water. Similarly, growth in industry and tourism will have significant effects in various regions.

5.2.3 Physical/environmental scenarios

The predominant physical or environmental scenarios that will need to be developed relate to possible future changes in climate. As described in Box 5.1, we recommend a staged approach to impact assessment, which involves a preliminary screening assessment followed by a more detailed analysis if justified by the screening process. This requires two levels of scenario development: simple initial scenarios, and more detailed scenarios for in-depth analysis.

Table 4.3 summarises the sources of information currently available, for assessing the effects of changes in climate. Generally, making use of the sources requires specific climate values (or statistics based on these) as input. These statistics, or methods for deriving them, are not always immediately apparent from chapter 2. Therefore, some further advice on obtaining appropriate climate parameters is provided in Table 5.1.

Scenarios for initial screening assessment. The second column of Table 5.1 outlines how to obtain region-specific values of climate parameters for use in these initial scenario studies, based largely on numbers available from this Guidance Manual. The emphasis is on mid-range climate projections. If use of these mid-range values in a screening assessment indicates that material climate change impacts or opportunities are plausible, then a more detailed analysis is recommended (Figure R1). If the mid-range scenario does not reveal any significant impacts, it is good practice to also examine the effects resulting from a scenario near the upper bound of possible future climate changes. This initial screening analysis is essentially a climate sensitivity study. It may also be useful to examine historical data, perhaps carrying out statistical analysis (as used in the North Shore City example in section 5.5 below), or use data from past events (eg, floods, droughts, warmer years) as analogues for the future.

Scenarios for more detailed studies. If the initial screening assessment suggests that material climate impacts are plausible, then more detailed scenarios are often needed for the subsequent detailed study. These may rely on a more complex physical or statistical modelling approach, draw on detailed analyses of current climate statistics in a location, and cover the high and low ends of the downscaled (to New Zealand) IPCC SRES scenario bands. These detailed scenarios should be considered across timeframes that are relevant to the particular function or natural resource being considered. Guidance on developing these more detailed scenarios is provided in the third column of Table 5.1.

Table 5.1: Values for, or sources of, climate parameters suggested for use in scenario analysis.

Climate factor	For screening assessment scenarios	For detailed study scenarios
Mean temperature	Mid-range 2040 and 2090 projections (upper panels Figure 2.3; central values from Tables 2.2 and 2.3)	Low, mid and high scenarios from ranges given in Tables 2.2 and 2.3, or approach a science provider for regional numbers
Frost occurrence	For 2090, two top panels of Figure 2.8. For 2040, use mid-range CLIMPACTS[1] or move current seasonal frequency distribution of daily minimum temperature to the right by seasonal mean change[2]	Use CLIMPACTS to develop low, medium and high scenarios for frost changes, and/or approach a science provider for regional numbers
Extreme high temperatures	For 2090 use lower two panels of Figure 2.8	Use CLIMPACTS to develop low, medium and high scenarios for maximum temperatures and/or approach a science provider for location-specific weather generator-based results
Growing degree-days (GDDs)	Use CLIMPACTS for a mid-range scenario	Use CLIMPACTS to develop low, medium and high scenario changes for GDDs; approach a science provider for location-specific projections
Winter chilling		Approach a science provider for weather generator-based location-specific projections
Mean rainfall (annual, seasonal)	Mid-range 2040 and 2090 projections (lower panels Figure 2.3; central values from Tables 2.4 and 2.5)	Low, mid and high scenarios from ranges given in Tables 2.4 and 2.5
Heavy rainfall[3]	Use factors from Table 5.2 with 5, 10, 50, 100 year ARI values from HIRDS[4] or from local data analyses	Obtain assistance from a science provider with site-specific applications of the gamma function analysis outlined in Appendix 3, or obtain updated guidance based on modelling results published after this Guidance Manual
Flood	Use factors from Table 5.2 with the rainfalls used to drive the design floods	Approach specialist hydrologists for targeted advice
Water deficit (for irrigation)		Use weather generator in CLIMPACTS for locations of interest, for low, middle and high greenhouse gas scenarios
Snow	Assume snowline rises by 140 m for each 1°C increase in annual average temperature	Requires research and development of linked spatial weather generator/snow budget modelling software for future projections
Strong winds	Increase 99th percentile wind speed by 10% for 2090	Changes in the frequency of strong winds and ARI of damaging winds are still very uncertain. Consult with a science provider if screening indicates possible problems
Sea level, coastal hazard	Refer to the *Coastal Hazards and Climate Change* manual (Ministry for the Environment 2008)	Refer to the *Coastal Hazards and Climate Change* manual (Ministry for the Environment 2008)

Notes for Table 5.1: These are suggestions for scenario analyses, and not firm scientific predictions. Entries in this table – especially for strong winds and heavy rainfall – are likely to be revised as science and modelling develop further. Many of the entries in the 'initial screening study' column focus on 2040 and 2090. For other planning horizons within the coming century, climate factors for screening studies can be estimated by interpolating between present, 2040 and 2090 values.

[1] CLIMPACTS is an integrated assessment model developed by the International Global Change Institute (IGCI, University of Waikato) and a consortium of CRIs (see Glossary). An 'open-framework' version of the model, called 'SimCLIMtm', is now available which allows users to develop their own model for any area and spatial resolution. To find out more about CLIMPACTS or SimCLIMtm, contact CLIMsystems at http://www.climsystems.com/site/home/ (3 April 2008).

[2] This requires site-specific historical temperature data.

[3] As explained in section 2.2.4, there is still considerable uncertainty about the likely size of future changes in heavy rainfall events. The heavy rainfall guidance provided here should continue to be viewed as interim.

[4] HIRDS is the High Intensity Rainfall Design System available on CD from NIWA, or (HIRDS Version 3) via the NIWA website.

Table 5.2 shows recommended percentage adjustments per 1°C of warming to apply to extreme rainfalls when you are developing screening assessment scenarios. This is a new table and supersedes the corresponding table in the previous edition of this Manual. Note that preliminary analysis of NIWA regional climate model results indicates that increases substantially higher than the upper limit of 8% given in this table are possible in limited areas.

As indicated in Table 5.1, current extreme rainfall rates for selected locations, durations and average recurrence intervals (ARIs) can be obtained from analysis of historical rainfall datasets from particular sites, or from the HIRDS CD. For temperature, use the projected changes in annual mean temperature from the rightmost columns of Tables 2.2 and 2.3, or from Figure 2.3. At least two screening calculations should be undertaken – for low and high temperature change scenarios. A worked example of the application of this information is provided in Appendix 4. In carrying out such site-specific analyses, one should also bear in mind the uncertainties in return period estimates for the present climate. In many places, rainfall records cover a past period of only a few decades, so that design rainfall estimates for 50- or 100-year ARIs contain statistical assumptions and data-based uncertainties.

Table 5.2: Factors for use in deriving extreme rainfall information for screening assessments.

ARI (years) → **Duration ↓**	**2**	**5**	**10**	**20**	**30**	**50**	**100**
< 10 minutes	8.0	8.0	8.0	8.0	8.0	8.0	8.0
10 minutes	8.0	8.0	8.0	8.0	8.0	8.0	8.0
30 minutes	7.2	7.4	7.6	7.8	8.0	8.0	8.0
1 hour	6.7	7.1	7.4	7.7	8.0	8.0	8.0
2 hours	6.2	6.7	7.2	7.6	8.0	8.0	8.0
3 hours	5.9	6.5	7.0	7.5	8.0	8.0	8.0
6 hours	5.3	6.1	6.8	7.4	8.0	8.0	8.0
12 hours	4.8	5.8	6.5	7.3	8.0	8.0	8.0
24 hours	4.3	5.4	6.3	7.2	8.0	8.0	8.0
48 hours	3.8	5.0	6.1	7.1	7.8	8.0	8.0
72 hours	3.5	4.8	5.9	7.0	7.7	8.0	8.0

Note: This table recommends *percentage* adjustments to apply to extreme rainfall per 1°C of warming, for a range of average recurrence intervals (ARIs.). The percentage changes are mid-range estimates per 1°C and should be used only in a screening assessment. The entries in this table for a duration of 24 hours are based on results from a regional climate model driven for the A2 SRES emissions scenario. The entries for 10-minute duration are based on the theoretical increase in the amount of water held in the atmosphere for a 1°C increase in temperature (8%). Entries for other durations are based on logarithmic (in time) interpolation between the 10-minute and 24-hour rates. Refer to the discussion in section 2.2.4.

Applications of climate change scenarios for screening and more detailed assessments are shown in Figures 5.1 and 5.2. In these examples, changes in the area of land suitable for kiwifruit have been calculated. An initial screening assessment, using a mid-range scenario, indicated that the Bay of Plenty climate could become unsuitable for kiwifruit by the end of this century (Figure 5.1). A more in-depth study was then carried out (Figure 5.2), to evaluate incremental changes over the next 100 years and to identify the range of uncertainty associated with these changes.[76] This latter result gives more detailed information about when climate change could become critical for the kiwifruit industry in the Bay of Plenty.

Figure 5.1: **An example of a screening assessment of kiwifruit suitability, using a mid-range climate scenario for the year 2095.**

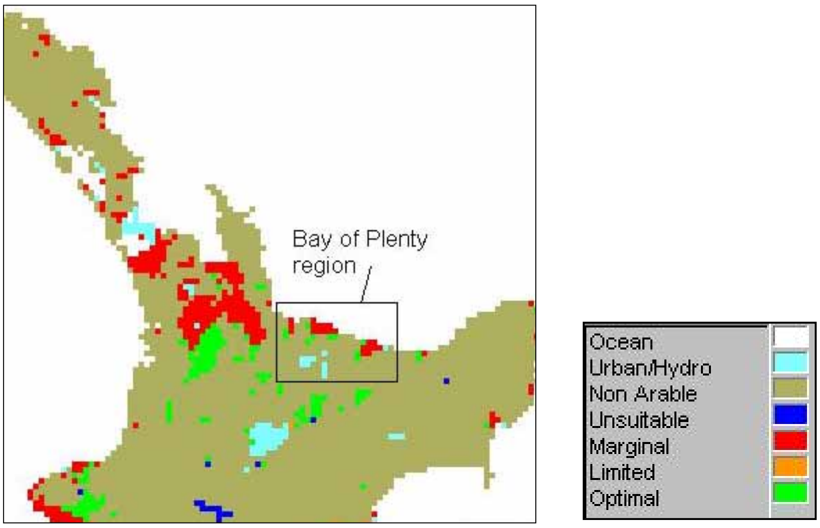
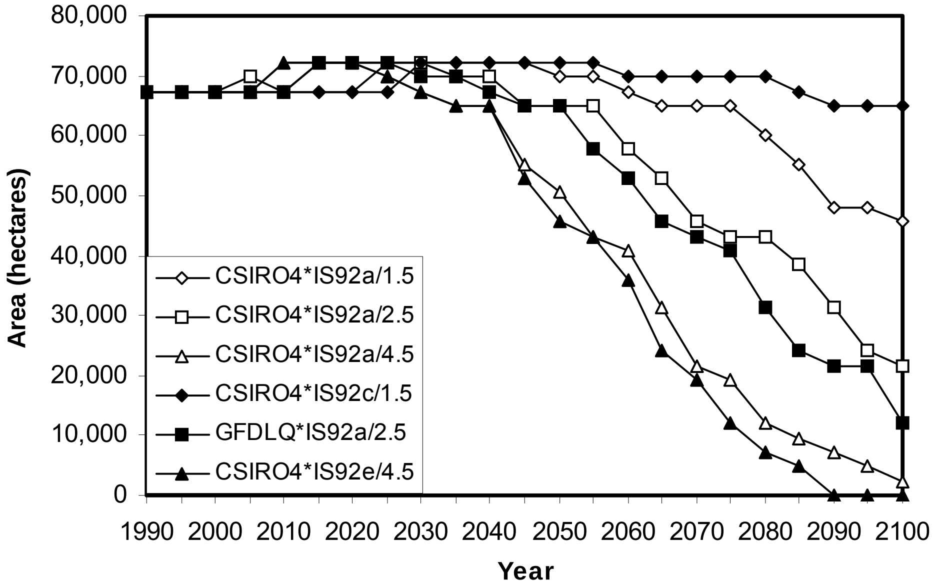


Figure 5.2: **An example of a detailed scenario analysis showing changes in the area suitable for kiwifruit in the Bay of Plenty, using a range of scenarios over a 100-year timeframe.**



The following examples describe the developed scenarios for some climate change studies that have been undertaken recently.

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[76] Kenny et al 2000.

5.3 Example 1: Southland water resources

In a *State of the Environment* report for water, Environment Southland (2000) identified three main drivers of change that would have impacts on Southland's freshwater environment in future. These were: environmental drivers (principally climate); population changes; economic development. Trends were identified in all three of these drivers as follows:

- **Environmental:** The greatest change has been an increase in the average minimum temperature in Southland over the last 40 years. The daily temperature range is decreasing at a greater rate than elsewhere in New Zealand.
- **Population:** Both urban and rural areas in Southland have been experiencing population declines since the late 1970s.
- **Economic:** Agriculture is a major contributor to the Southland economy and accounts for 82% of the total land area in the region that is not conservation land. Agricultural activities are the largest contributor of nutrients, microbiological and other contaminants, to freshwater resources. Changes in land use can have a major effect on resultant environmental pressures. Over the last decade, there has been a rapid expansion of dairy farming and associated industry infrastructure. Other economic activities that could lead to increased pressure on freshwater resources in the future include tourism.

Thus, if Environment Southland were intending to conduct a study on the possible effects of climate change on Southland's freshwater environment, it would need to consider changes in the above key drivers over the next 30–100 years. This would require some consideration of alternative scenarios for each driver (see Table 5.3 for examples).

In this example, some linkage has been made between the different climate change scenarios and different population and economic scenarios. The climate change information presented here is drawn from the information provided in chapter 2. It is important to reiterate that these are presented as *plausible* futures only and also that there will be sub-regional variation in climate change parameters.

Table 5.3: Scenarios for key drivers affecting Southland freshwater resources.

	Environment	Population	Economic
Scenario 1	Low scenario of climate change: • Slight temperature changes, in the order of 0 to 0.5ºC in most seasons • Slight increase in summer rainfall, decreases of –20% to –10% in other seasons	Downward trend in population stabilises, with low growth over the next 50–100 years	Moderate land-use changes, with slightly warmer and drier average conditions
Scenario 2	High scenario of climate change: • Temperature increases in the order of 3ºC, with greater increases in winter than in summer • Precipitation increases greater than 20% in all seasons, with likely increased proportion that falls as heavy rain	Downward trend in population stabilises, with more rapid growth over the next 50–100 years owing to more favourable climate (particularly for the agricultural sector, such as dairy farming)	Greater intensification of land use with warmer, wetter conditions

Note: Climate change scenarios for the 2080s only (from an earlier assessment than the current report) are used here, and are provided here in summary form.

5.4 Example 2: Water resource changes in three river catchments

The Ministry of Agriculture and Forestry commissioned Lincoln Environmental and NIWA "to quantify the potential change in agricultural water usage and availability due to climate change, and assess the implication of these changes on the potential pressures on water sources and water allocation issues" (Lincoln Environmental 2001).

Changes in three river catchments were studied: Rangitata in South Canterbury, Motueka in Nelson, and Tukituki in Hawke's Bay.

For this study, scenarios were developed for two of the three categories identified above. These were the environmental (climate and river flow changes) and economic (land-use changes) categories. However, as is explained below, the land-use changes themselves were generated principally from projected climate changes.

Climate and river flow changes

The main steps in developing these scenarios were:

- gathering historical climate and river flow data for the period 1971–1995 for selected sites in each catchment
- generating two climate change scenarios for 2050, and site changes (monthly) for precipitation, maximum temperature, minimum temperature, dew point temperature and wind run. Two different General Circulation Models were used for these scenarios, with the same greenhouse gas emissions scenario used for both
- using a weather generator to synthesise 30 years of daily climate data for 2050 for key sites, based on the monthly changes in the parameters listed above
- generating river flow scenarios, using the NIWA 'Topnet' model.

There were some important assumptions made with these scenarios:

- The climate scenarios provided mean changes only for 2050, with no allowance for changes in the interannual variability of climate, eg, as a result of El Niño-Southern Oscillation (ENSO) events and IPO shifts.
- There were two key assumptions with the use of weather generators, the first being the manner in which weather elements were simulated and the second being that monthly mean values only were changed, with no change in other properties (for example, no change in the typical variability and relative intensity of rainfall and temperature extremes).
- There were two key assumptions with the river flow model: "no hydrologically significant changes in vegetation" and "no new diversion or abstraction of water, nor any new extraction of groundwater that sustains river flow".

Land-use changes

Land-use changes were determined for each of the three catchments by calculating changes in mean monthly degree-days, and by consulting local experts.

In determining these changes, economics were held constant. That is, it was assumed that present economic trends for different crops and farming systems would hold for 2050. In general, the pattern presented was one of more intensive land use.

To complete this study, the scenarios of climate, river flow and land-use change were brought together to quantify possible changes in water demand and supply, using an irrigation scheme simulation model.

5.5 Example 3: Stormwater and wastewater effects in North Shore City

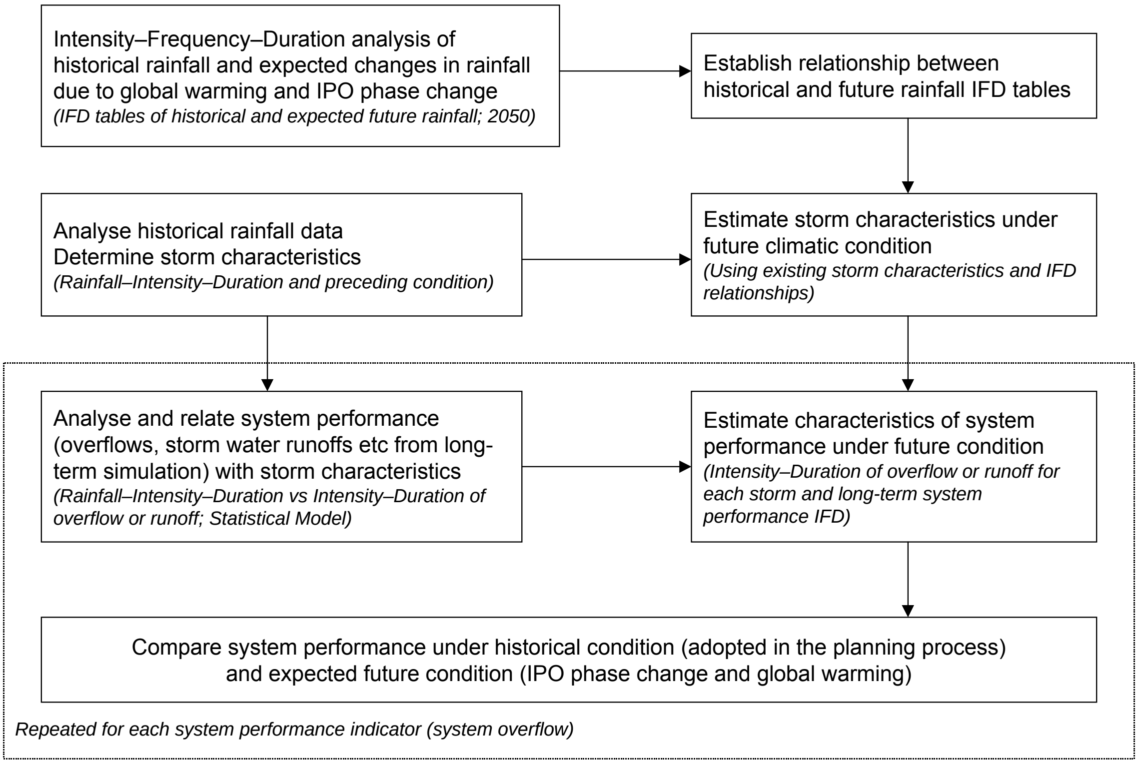
North Shore City Council commissioned a major study (as part of Project CARE) on its wastewater system (North Shore City Council et al 2003). As part of this study it was decided, for a relatively small incremental cost, to examine the possible effects of climate change on future wet weather overflows.

The approach taken by the consultants for North Shore City is summarised in Figure 5.3, and in the accompanying text. In brief, existing system performance was translated into expected future performance based on changing rainfall (extreme events) using a statistically established relationship between existing rainfall patterns and existing system performance.

A number of key points, relating principally to the steps taken in developing climate change scenarios, are presented below. These are taken the Executive summary of the North Shore City report:

- *The existing condition of the receiving environment was determined by hydrologic, hydraulic and water quality simulation of the system based on 17-year historical rainfall record.*
- *A study was carried out to determine the rainfall changes due to global warming and phase changes in the Interdecadal Pacific Oscillation (IPO) for the planning scenarios. Global mean temperature was expected to increase by 1°C by year 2050 and this may be accompanied by more rainfall. The study suggested that there would be heavier, longer-duration extremes in IPO negative phase and heavier, shorter-duration extremes in IPO positive phase resulting in more rainfall.*
- *A statistical approach was considered to evaluate the system performance due to IPO phase change and global warming, as the long-term hydrologic and hydraulic simulation using future rainfall time series is considered to be time-consuming, costly and may only provide a similar confidence level.*
- *Expected future storm characteristics (year 2050) were estimated from the historical storm characteristics, and historical and predicted future rainfall IFD tables. Future storm characteristics were estimated separately for both positive and negative IPO phases, expected to be experienced by 2050.*
- *Although climate change is well accepted by professionals worldwide, the analysis adopted in this study is based on a number of simplified assumptions with inherent uncertainties associated with modelling the effects of global warming. The results, therefore, should be used to assess trends more than provide absolute values, and their interpretation should be carried out by suitably qualified and experienced professionals.*

Figure 5.3: Approach used to generate and apply future scenarios for the North Shore City Council study on future wet weather overflows.



Source: North Shore City Council et al 2003.

6 Risk Assessment

Key points:

- Use risk assessment techniques to rank risks, and include ranking types of climate change risks against each other and against other risks.
- Do a screening assessment of the issue first, to identify key risks for the region, district or area, or to obtain preliminary guidance on the climate change-related risks associated with a particular function or service. Then, if warranted, do a full risk assessment.
- Follow accepted methods, which are usually already familiar to local authorities.
- Take into account the time context in evaluating risk. This means that a single risk assessment may involve repeated assessments for different time scales.
- Use the best information available for the local area. Where risks are found to be high or extreme, consider seeking additional information prior to decision-making.
- Decisions can then be made on appropriate responses and plans can be developed for communication, consultation, monitoring and evaluation.

6.1 Introduction

To ensure that climate change is appropriately factored into local authorities' planning and decision-making processes now and into the future, a sound risk assessment procedure is fundamental. The purpose of risk assessment, in the context of climate change, is to identify risks and hazards that may be induced or exacerbated by climate change and to evaluate their effects and likelihood. This procedure also allows the climate change risks and subsequent adaptive responses to be prioritised with confidence and compared equitably with other risks, resource availability and cost issues (including works) that the local authority faces.

The risk assessment procedure described in this chapter has two steps. Firstly, the screening assessment set out in section 6.4 should be used. This step will help determine whether a formal risk assessment is necessary for the issue being considered. Secondly, a formal risk assessment process**,** as described in the subsequent sections, should be followed. This process is intended for identifying and evaluating risks for a single issue but it can also be applied to the local authority's operations as a whole.

While this assessment refers only to the risks associated with climate change, these risks are best assessed together with risks from other hazards and climate variability where possible; that is, not in isolation. Also, this process is not the only one that can be used, and where a local authority has an existing risk assessment process, climate change should simply be added into it.

6.2 Terminology

For the purpose of this Guidance Manual, the following definitions apply:

Risk	The chance of an 'event' being induced or significantly exacerbated by climate change, that event having an impact on something of value to the present and/or future community. Risk is measured in terms of *consequence* and *likelihood*.
Hazard	A source of potential harm to people or property. Examples are erosion or inundation.
Event	An incident that is induced or significantly exacerbated by climate change and that occurs in a particular place during a particular interval of time. Examples are floods, very high winds or droughts.
Consequence (or impact)	The outcome (of an event), expressed qualitatively in terms of the level of impact. Consequences can be measured in terms of economic, social, environmental or other impacts.
Likelihood	The probability or chance of something happening (can be a qualitative or quantitative measure).

6.3 The evolution of risks over time

A risk may not exist now but may evolve, owing to climate change, during the lifetime of the development, service or infrastructure. Consequently, a major difference between traditional risk assessments and those described in this chapter is the introduction of time. The time factor/horizon that must be considered is the lifetime of the development, service or infrastructure.

This risk assessment, therefore, recognises the time evolution of risks by introducing a planning horizon and it includes considering the risk at various steps along the way. That is, for a lifetime of 100 years, the risk may be evaluated as it is now and as it will be in 25, 50, 75 and 100 years' time. This regular evaluation allows the user to assess the evolution of response options over time – that is, of how much latitude there is in the response options that address the risk. If the risk is not addressed now, despite it occurring only in the future, the community may very well end up being locked into a position where it cannot avoid, remedy or mitigate the risk any more.

6.4 Initial screening

As shown in Figures R1 and R2, and discussed in chapters 4 and 5, we recommend an initial screening assessment for a particular council function, activity or service, to determine whether material climate change impacts are likely. A methodology and checklist for carrying out such an assessment is provided in Box 5.1. If a screening assessment for a particular function shows that climate change-related risks are likely to be small, then the necessary risk assessment has been completed for that function. However, if the screening assessment suggests that climate change could have material effects on the function or service, a more detailed assessment of climate change effects and formal risk analysis as outlined in the remainder of this chapter are warranted.

6.5 The risk assessment process

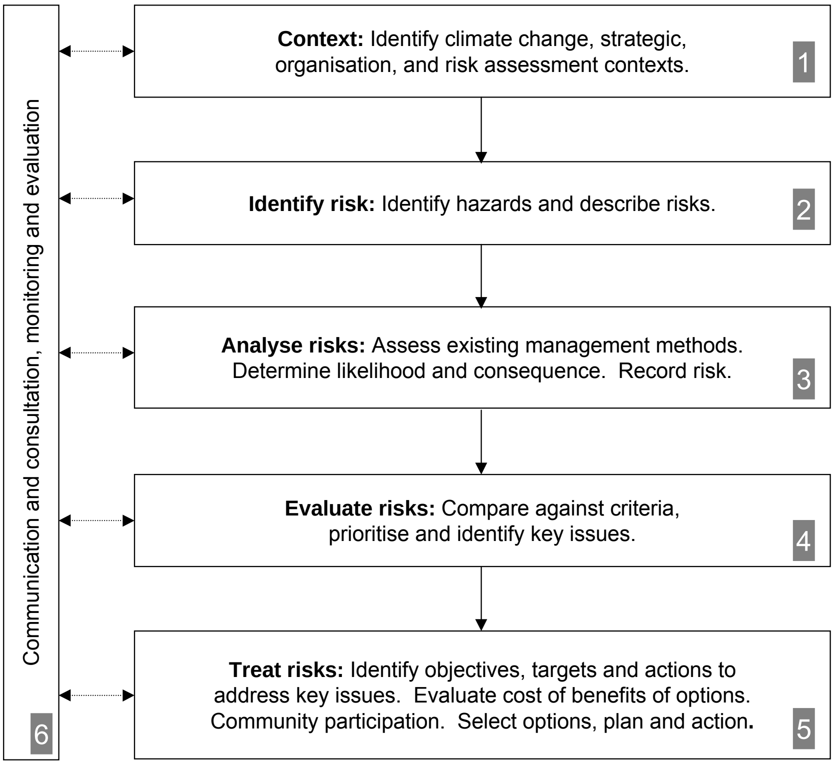
The risk assessment process described in the following sections is based on the New Zealand Standard for Risk Management, AS/NZS4360. A scenario-based approach has been adopted, as suggested in AS/NZS4360 (section 4.2.3). This involves developing a list of climate change event scenarios applicable to the issue and areas potentially affected, and assessing the risk presented by each scenario. The description in this chapter has been kept as concise as possible; reference will need to be made to chapters 2–5 when carrying out the risk assessment.

As large uncertainties are involved in climate change, a mixture of quantitative and qualitative information should be used. While the risk assessment process is systematic, the stakeholders must use their judgement, based on a range of information sources, to assess the risks for each hazard scenario.

Steps 1 to 4 are detailed in the remaining sections of chapter 6. Steps 5 and 6 are only briefly covered, as risk treatment, communication, consultation, monitoring and evaluation are considered organisation-wide initiatives, that are best undertaken in a wider context than just climate change risk assessment. Some information on these aspects is also included in chapter 7.

This Guidance Manual provides only an overview. For greater detail on coastal hazards see *Coastal Hazards and Climate Change* (MfE 2008).

Figure 6.1: The risk assessment process.



Step 1: Establish the context

This step ‘sets the scene’ within which the risk assessment process takes place. Establishing the context involves defining what the local authority is responsible for, what it owns, what services it provides, its structure and its objectives, and considering what climate change may affect. This step helps to clarify the bounds of responsibility, and ensures that all the risks, and the risk acceptance of the local authority, are addressed.

Establishing the context can be undertaken by defining the strategic context, organisational context and the climate change context.

Step 1.1: Define the strategic context – what the local authority is responsible for and is aiming to achieve

The strategic context should take into account the following areas within the local authority:

- local authority strategic plans (see chapter 7 for more details)
- the assets it has, functions and services it provides (chapter 4)
- the physical environment
- the stakeholders (including other local government stakeholders).

Step 1.2: Define the organisational context – what resources and information the local authority has

The organisational context should look at the sources of the local authority, including:

- the staffing
- locations
- IT systems and data available
- goals and objectives, etc.

Step 1.3: Define the climate change and risk assessment context – what the problem and/or driver is, and what is to be done about it

The climate change and risk assessment context involves defining the scope and key performance indicators for these activities. This includes:

- defining the current or foreseen problem or the activity to be undertaken
- the climate change variables (chapter 2), climate change variability (chapter 3)
- specifying the outcomes anticipated from the risk assessment process and how they are going to be used in planning and decision-making (chapter 7).

Step 2: Identify hazards and describe risks

Once the context – including the issue(s), problems or activities to be assessed – has been established, Step 2 involves developing a range of hazard event scenarios for each locality and/or activity, with specific assumptions about the community context; and then describing the risks associated with each.

With a complex issue, this step can be carried out in a workshop environment, involving all key stakeholders. For example, policy planners, the regulatory manager, engineers and the emergency management co-ordinator should be involved, with input from regional council planners and scientists, where required. The process can then be expanded to include community representatives as needed.

Step 2.1: Identify localities by land use, natural resources, development and services provided

Firstly, the affected locality or list of localities that may be affected by the development or issue under consideration should be discussed. The localities will be characterised by differences in land use, natural resources (eg, river, lake) and development factors. It is important to include a brief description of the known history of hazards and services provided, if possible.

Examples might include:

- residential; on the hillside, with clay soil with the potential to liquefy if water is retained; erosion is a problem. Services: water supply, wastewater, stormwater, roading, Civil Defence and Emergency Management
- residential and commercial; on flood plain of a major river, flooding has been a problem in the past. Services: watercare, water supply, etc.
- agricultural on a flood plain of major river; water shortage is a problem in dry seasons
- major state highway and railway line adjacent to a river or estuary
- proposed residential subdivision and small shopping centre; on greenfields site, bordering a sedimentary rock sea cliff with a history of intermittent erosion (stable for last 10 years).

Step 2.2: Identify hazard type based on current and historical information

Depending on the extent of the activity or issue, the event scenarios relevant for each locality, and the local government functions provided there, need to be identified. These can be taken from Tables 4.1 and 4.2.

Example

A proposed new subdivision on the first land-use type example given above (residential land, on hill) would not be vulnerable to inundation but would be vulnerable to increased erosion due to increased rainfall, and increased water shortage, etc.

Step 2.3: Identify long-term changes in hazard due to climate change or other processes

Identify the effects that climate change could have on the hazard, taking into account the planning horizon for the service or activity. The information gained from earlier chapters should be used during this step. The regional policy statement, or the life of the infrastructure or asset, dictate the planning horizon. For example, climate change effects for a greenfield subdivision may need to be considered over a 100-year planning horizon in accordance with the regional policy statement. Over this time horizon, the overall hazard could increase markedly, owing to both coastal erosion and inundation hazards.

Note that Step 2.1 may come *after* Steps 2.2 and 2.3, depending on whether the issue is driven by a specific proposal or activity, or by more generic resource investigations.

Step 2.4: Choose the consequence scenario and time reference

Choose a range of plausible consequences that could result from the hazards identified in Step 2.2 if no additional measures are taken to avoid, remedy or mitigate the hazard. These should range from moderate impacts to very large ones and involve time references up to the planning horizon, eg, ‘the likelihood of X happening now is rare, but it is possible in 50 years and likely in 100 years’. Small impacts that occur frequently may also be considered.

Example

Location: Nikau Bay, Marlborough

Scenario: Inundation to 0.5 metres above mean sea level, MSL (ie, to just above most house floor levels) for 100 m inland (ie, the first two rows of houses behind the beach), but no major erosion.

The Regional Policy Statement has a planning horizon of 100 years (therefore, likelihood is evaluated in time steps up to 100 years).

Likelihood:

Likely	> 100 years
Possible	75–100 years
Unlikely	25–75 years
Rare	0–25 years

Impact/consequence:

Human:

- No loss of life, possible injury.
- Possibly elderly people trapped in their homes.

Economic:

- Negative impact upon regional reputation and tourism industry.

Social:

- Temporary loss of access through Queen Charlotte Drive.

Infrastructural:

- Water supply: possible contamination
- Wastewater: possible leakage (public health risk).
- Damage and disruption to road (temporary disruption to access in and out).

Geographic:

- Possible wastewater contamination of streams in the bay.

Step 3: Analyse the risk

Having identified the list of hazard scenarios in Step 2, the next step is to analyse the risks presented by those hazards over the lifetime of the development, asset or infrastructure. The objective is to separate the minor acceptable risks from the major risks and to provide data to assist in the evaluation and treatment of risks. Risk analysis involves considering the sources of risk, the risks' consequence and the likelihood that those consequences may occur at each intermediate time step in the lifetime of the development, asset or infrastructure.

Step 3.1: Assess consequence of hazard occurring

Assess the level of the impact (consequence) on the land, built environment and people for each hazard scenario in the time indicated. Refer to section 4.3 for assistance with choosing the appropriate level of impact. The choice of the appropriate level of impact is somewhat subjective. However, so long as the approach is applied consistently to each locality and scenario, the choice of the relative level of impact will be consistent. To assist in this assessment, the local authority may wish to state the level of impact in a more quantitative way, using a dollar equivalent and/or looking at the economic, environmental, social and cultural impacts separately.

Once the analysis has been done, choose the appropriate level of impact from Table 6.1.

Table 6.1: Level of impact for a locality and/or hazard scenario.

Designation	Impact	Examples
1	Catastrophic	• Huge financial losses involving many people and/or corporations and/or local government • Large long-term loss of services • Permanent loss of many people's homes; large-scale loss of employment • Loss of life or serious injury
2	Major	• Major financial losses for many individuals and/or a few corporations • Some long-term impacts on services • Some homes permanently lost • Complete loss of an important natural environment • Serious injury
3	Moderate	• High financial losses, probably for multiple owners • Disruption of services for several days; people displaced from their homes for several weeks; major impacts on valued natural environment
4	Minor	• Moderate financial losses for small number of owners; disruption of services for a day or two; moderate distress to some individuals; some impacts on significant natural environment
5	Insignificant	• Minimal financial losses; short-term inconvenience

For each locality, there may be several scenarios that need to be considered. These scenarios will have different levels of impact.

Note: Take care not to be influenced by vulnerability due to other natural factors, or effects of climate change, when assessing level of impact; this will be assessed in Step 3.2.

When assessing the level of impact, consider a range of issues, such as:

- What is the existing and future density of development?
- What are the approximate or relative values of the assets in measurable terms (eg, in dollars per square metre, or in dollars per metre of coastline)?
- Is the value of the assets likely to rise markedly in the future (eg, because of redevelopment of residential property)?
- Is the effect of the hazard a brief inconvenience (eg, road flooding) or high cost (eg, flooding of many houses, destruction of property due to landslides, or several days inundation of pasture)?
- Are assets easily relocatable (eg, for flooding cabins at a camping ground with no plumbing/drainage services, compared with flooding concrete slab-on-grade houses).
- How should publicly owned land be valued, especially in relation to privately owned land? (Care is needed to avoid public land being sacrificed in order to protect private property, without proper benefit–cost assessment.)
- Are there particular environmental issues to be considered (eg, undermining of septic tanks or erosion or waterlogging of effluent disposal fields, causing water pollution)?
- Are there particular social issues that need to be considered (eg, housing occupied by people who have limited ability to recover from financial losses, or cultural ties and rights to an area)?
- What are the insurance implications? For example, are responsibilities clear, can they be covered via insurance, are all people at risk equally aware of the risk and liabilities?
- Is the effect of the hazard continuous (eg, coastal erosion) or intermittent (eg, flooding)?

Step 3.2: Assess likelihood of hazard scenario

For each time step in the planning horizon, assess the likelihood (or probability) of the hazard event scenario occurring. Choose the appropriate likelihood from Table 6.2. For additional clarity, some local authorities may wish to quantify the likelihood in terms of time (ie, daily, monthly, annual, several times per lifetime, etc).

Table 6.2: Likelihood of scenario occurring within the selected planning horizon.

Designation	Frequency	Description	IPCC definition
			Virtually certain (> 99% chance that a result is true)
A	Almost certain	Is expected to happen, perhaps more than once	Very likely (90–99%)
B	Likely	Will probably happen	Likely (66–90%)
C	Possible	Might occur; 50/50 chance	Medium (33–66%)
D	Unlikely	Unlikely to occur, but possible	Unlikely (10–33%)
E	Rare	Highly unlikely, but conceivable	Very unlikely (1–10%)
			Exceptionally unlikely (< 1%)

Note: If you are reading material prepared by the IPCC, its definitions of likelihood are very similar, as expressed in the right-hand column of Table 6.2.

When assessing likelihood, the following factors need to be considered:

- type of hazard and its likelihood
- natural resource factors
- changes to likelihood caused by climate change.

Note: Although the risk assessment process is designed for use by non-experts, this phase (ie, likelihood assessment) would benefit from input from people with specialist knowledge or who can access monitoring and historical data. Regional council staff or specialist consultants might provide this.

Hazard type and likelihood

Refer to chapter 2 for a description of the climatic variables that may be influenced by climate change, and the amount of change and likelihood of it occurring in the area being evaluated.

Natural resource type

The type of natural resource will strongly influence the likelihood of impacts, depending on the hazard type. Refer to Table 4.2 for detailed descriptions of the sensitivity of natural resource types to climate change.

Example

The hazard scenario might be erosion effect from a 1% AEP storm on a sandy coast; the planning horizon might be 50 years.

The assessed level of impact might be designated 3 (moderate) in Step 3.1; the likelihood under the present situation might be D (unlikely); but when we take into account climate change, this might be elevated to C (likely) in 25 years' time.

When carrying out the likelihood assessment, a series of questions should also be developed and addressed, such as:

- Is there a history of hazard experience at the site? Can this history be objectively assessed to determine likelihood of future impacts (eg, what is the present return period for different flood levels, how often has coastal erosion occurred, under what conditions has coastal erosion occurred and how much, etc)?
- Are certain parts of the locality more exposed than others to specific hazards, such as predominant winds or storm direction?
- Is local knowledge based on an adequately long timeframe (eg, how long ago was the last major flood and how large was it)?
- Do regional council staff have any relevant information?
- Is the planning horizon sufficiently long (say greater than 20 years) that climate change effects will increase the likelihood of the event?
- How will climate change affect the hazard (eg, will it cause an increase in mean sea level, or an increase reduction in the return periods for major floods or duration of drought)?

Step 4: Evaluate the risk

Use the results from Tables 6.1 and 6.2 to position the activity in Table 6.3. This will yield the risk of each hazard scenario. For example, an activity with moderate (3) consequence but which is unlikely to occur (D) has a risk of M (moderate). It should be included in response planning but given lower priority. Remember, there will be a different risk rating assigned for each time step.

Table 6.3: Risk table.

Year	**Consequence**				
Likelihood	**1** **Catastrophic**	**2** **Major**	**3** **Moderate**	**4** **Minor**	**5** **Insignificant**
A (almost certain)	E	E	E	H	M
B (likely)	E	E	H	H	M
C (possible)	E	E	H	M	L
D (unlikely)	E	H	M	L	L
E (rare)	H	H	M	L	None

Legend:

E: Extreme risk; immediate action required
H: High risk; high priority for action, begin planning as soon as practicable
M: Moderate risk; include in response planning, but lower priority.
L: Low risk; minimal action likely to be required; monitor the situation
None: Negligible risk; no response required

Please note that this is one example and that each local authority needs to determine its own risk classifications or which squares are ‘H’, ‘M’ or ‘L’.

Example

A risk may have a consequence of 4 (minor), a present likelihood of D (unlikely), but will become C (possible) in 30 years and B (likely) in 100 years. Thus, the risk rating will go from low to high in the next 100 years.

Step 5: Assess appropriate responses based on the risks

Steps 1 to 4 should result in a good understanding of the implications of and risks associated with climate impact. Once completing these steps, particular types of climate change risks can be placed in the context of other types of risks, and in the context of each other, within a district or region.

Risk assessment should take place in a context of continuing reassessment and review, where the responses relating to risks (council decisions) are also taken within the context of a range of statutory and other responsibilities, including responsibilities to consult and plan ahead.

Chapter 7 addresses the context of adaptive response options.

Step 6: Communication and consultation, monitoring and evaluation

At each step of the risk assessment and management process, communication and consultation, and monitoring and evaluation are important considerations.

A communication plan should be developed for both internal and external stakeholders. This plan should address issues relating to climate change, the associated risks and the process to manage them. Ideally, this plan should be a part of the overall local authority communication and consultation plan.

It is necessary to monitor climate change and its associated risks, as well as the effectiveness of any risk treatment plans and strategies. Risks and the effectiveness of control measures need to be monitored to ensure that changing circumstances, such as climate change speed and scale or land-use type, do not alter risk priorities. Even outside of climate change, few risks remain static.

Ongoing review is essential to ensure that the risk mitigation plans remain relevant. Factors that affect likelihood and consequences may change and so the suitability, timing or cost of the various treatment options may also change. It is, therefore, necessary to regularly repeat the risk assessment process. Note that revisions will generally be simpler and less time consuming once the framework has been developed.

7 Integrating Climate Change Risk Assessment into Council Decisions

Disclaimer

Chapter 7 has been prepared for the Ministry for the Environment by external contractors, as noted on page ii of this document. To the extent that this guide deals with legal matters, it does not necessarily represent the views of the Ministry for the Environment and readers should not rely on it as legal advice.

Key points:

- Risk assessment procedures (see chapter 6) provide a method to evaluate the implications of elements of climate change, in terms of risks to communities and community assets. The risks can then be prioritised, and response options evaluated in terms of costs and benefits to assist a council in making a wide range of decisions.
- In applying risk assessment in local government decision-making, keep in mind also:
  - the range of established principles influencing local government decisions, which relate to environmental and financial responsibility and the needs of the future
  - the growing recognition of climate change effects in planning case law
  - uncertainty, which can lead to a range of responses – from ‘avoid if possible’ for issues that are long-term and have significant implications, to ‘manage’ for shorter-term issues with smaller-scale implications.
- It is essential to recognise that climate change effects are going to occur, over time, and that risks that are slight now will increase. Thus, responses can and should be planned in advance. Elements of climate change should be built into most council planning, depending on risk assessment and priorities.
- Monitoring undertaken by councils helps build up a picture of change over time, and contributes to more accurate future predictions.

7.1 Introduction

Climate change considerations are unlikely to drive or initiate local government action on their own. Rather, through the application of risk management procedures in assessing and prioritising possible responses to climate change effects, these considerations may modify an outcome.

The emphasis in this Guidance Manual is on understanding the scope and variation of climate change, and using risk assessment procedures to determine adaptation responses based on the risks. Climate change is relevant to a wide range of local government functions, and is another factor to take into account among the range of factors that local government already considers in all its decision-making.

Climate change risk assessment and decision-making does not take place in a vacuum, particularly within the local government context.

This chapter outlines the uncertainty associated with climate change and key considerations in taking account of climate change in decision-making. It sets out some important concepts relating to local government's roles and responsibilities, and gives some examples of local government practice into which climate change considerations have been incorporated.

A key element in adapting to climate change will be ongoing flexibility and responsiveness in seeking the best response options.

Box 7.1: Is Climate Change an Issue for the Region or District?

Many councils have taken first steps towards integrating climate change into plans through policy and rules, and decision-making on specific consent applications, but there is still a great deal of uncertainty about how and when to take notice of and act on projected climate change effects.

In addition to the other material in this Guidance Manual, the following list can assist councils in thinking about climate change:

- What are the potential climate change issues in the region, city or district?
- For any issue, has the council done a risk screening assessment that indicates that there are risks that require a response?
- What does the most recent scientific information show about likely climate changes in the region or district?
- What are the most plausible scenarios for the region, city or district?
- Is a more detailed evaluation of risk warranted?
- Look at what others nearby are doing. Is the regional council advocating action? Are district or city councils within the region identifying issues or already taking action? What can you learn from them?
- What are the most appropriate methods to respond to risks?
  - policy responses – where and how?
  - community education and/or awareness-raising?
  - changes in engineering practices and standards?
  - plan rules – setbacks, floor levels, hazard lines, down-zoning?
  - land purchase?
  - monitoring?
  - budget implications for the Long-term Council Community Plan?
- Should your council be working with others to ensure consistency of approach?
- Some specific legislation, such as the Land Transport Management Act 2003, requires consideration of greenhouse gas outputs. Are they a relevant consideration for your council?

7.2 Context of uncertainty

All local government business takes place in a framework of uncertainty. Nevertheless, local government has developed a range of mechanisms and approaches for dealing with uncertainty through all its planning and review processes.

'Best' knowledge of climate change together with use of risk assessment procedures can help local government prepare to help the community adapt to known climate change, and, through no- and low-regrets approaches, can contribute to national and international techniques aimed at reducing the causes and effects of climate change.

Climate change considerations should become one of the factors woven into many council decision-making processes. The extent to which climate change is important will depend very much on:

- the duration of the issue being addressed
- whether there is a particular 'driver' at present (such as a major investment decision)
- the location of the issue being addressed
- the extent of the issue being addressed
- the nature of the issue being addressed.

Risk management fits comfortably into plan preparation and review processes at the stages where issues are being identified and a range of possible response options evaluated. With the advance of knowledge about climate change effects, rarely should there be the need for an unplanned response to climate change. The iterative process of plan administration, monitoring and review allows for plans to be modified over time to take account of improved understanding of risks and effects associated with climate change.

Box 7.2: Rules controlling discharge of greenhouse gases

Since 2004, regional councils have been given specific direction under sections 70A and 104E of the Resource Management Act 1991 that, when making rules controlling discharges of greenhouse gases to air or considering applications for such discharges, they are not to have regard to the effects of such discharges on climate change. The only exception is in situations where the use and development of renewable energy enables a reduction in the discharge into air of greenhouse gases. Greenhouse gas discharges are managed primarily through central government mechanisms, and only indirectly by local government through plans and policies developed and implemented under the Resource Management Act and actions, under other legislation.

7.2.1 The duration of the issue being addressed

In considering climate change issues, the period over which a decision will have effect is fundamentally important. Generally, whenever a decision is likely to have effects that will last 30 years or more, the implications of climate change should be taken into account in decision-making. Local government decisions have a range of implications in terms of time. For example:

- A decision to allow a new development area, a renewable energy generation project or a coastal reclamation is effectively permanent, as existing use rights apply unless there is community buy-back with full compensation.
- While the former (1991) Building Act was based on an assumed building life of 50 years, the current Building Act (2004) does not include an assumed building life. Many structures are intended to, or do, last a century or more.
- Infrastructure decisions generally assume a life of 50–80 years, but some infrastructure can be designed to be built in stages to enable responses to climate change to evolve over time.
- Decisions on structures in rivers, most coastal structures and infrastructure that involves regional council consents have a term of 35 years or less (depending on consent conditions). However, in reality their lifespan may be much longer (eg, significant bridges) and they should be recognised as near-permanent.
- Decisions on land care, biodiversity and pest management strategies may be in the context of a 3-, 5- or 10-year strategy. However, some decisions may have enduring consequences, so a long-term view may be appropriate.

The most reliable climate change information available at the time should be taken into account in terms of the duration of the decision being made.

Box 7.3: Provisions for forest planting –example

Tasman District’s Resource Management Plan includes provisions that limit the extent of forest planting in the headwater of specified catchments, to protect aquifer recharge for water supply for the horticulture areas downstream. A range of possible future weather scenarios (but not specifically climate change scenarios) were built into the studies, which led to the plan provisions. Climate change scenarios were omitted in part because of lack of reliable relevant information at the time, but also because it was considered that the relatively short 30-year tree harvesting cycle would allow for modification of provisions over time as climate change information improved.

This example is explained fully in Wratten v. Tasman District Council (Decision W008/98).

7.2.2 Whether there is a particular driver at present

Although it is important for local authorities to acknowledge climate change, and to include it in policy across a range of council functions, climate change considerations come particularly to the fore when specific decisions are required. For example, any significant investment in infrastructure should always be preceded by a risk assessment that builds in climate change implications and a cost–benefit analysis.

When climate change is factored into new investment decisions, the resulting asset ‘life-cycle’ costs should be less than the additional costs from premature retirement of the asset or later unprogrammed upgrades. In some situations, the design of new infrastructure may ‘lock in’ resource requirements in a way that makes later upgrading virtually impossible.

Decisions on subdivisions and developments are largely driven by applications from the private sector. Councils must make decisions relatively quickly and, as court decisions have demonstrated, decision-making must take into account climate change effects, and that these might exacerbate natural hazards. If a council deems that inadequate consideration has been given to climate change factors in an application and that such factors are relevant, further information should be sought in preference to making a hasty decision.

As regional and territorial authorities increasingly plan for growth, projected long-term climate change effects need to be taken into account when the authorities are identifying suitable areas for future development. The process may include not allowing areas likely to experience increased risk of flood events to be sites of future development, or ensuring that new areas will have adequate water supply in the long term.

Box 7.4: Modifying wastewater system design – example

North Shore City experienced in 1997 a significant number of beach pollution events linked to an unusually high number of wet weather overflow events from its wastewater system.

Community concern led to a detailed analysis of what would be needed to modify the wastewater system so that a performance level of two overflows per year in 2050 could be achieved (taking into account increased population and other factors).

Scenarios based on historic rainfall information, and predictions of increased frequency of intense rainfall events due to climate change, were applied to designing the modifications, and a risk and cost–benefit analysis undertaken.

The cost analysis showed that meeting the desired level of service by 2050 in the face of climate change effects would add $100 million to the cost, which had been estimated at $260 million when climate change effects were not considered. The community chose to accept the increased risk of events due to climate change (and, therefore, a long-term reduced level of service) rather than meet the additional cost of the desired level of service.

However, reviews of the system will incorporate consideration of climate change effects every 3–5 years, and ‘future proofing’ decisions on different components of the system (such as extensions into new development areas) will be made when and where opportunities or needs arise.

7.2.3 The location of the issue being addressed

Some locations are more vulnerable than others to climate change effects. For example, all proposals in the vicinity of the coast should be evaluated in terms of expected sea-level rise over the next century, as well as other downstream effects, including increased coastal erosion, salt water intrusion and increased flooding in the vicinity. Development in flood plains also needs to take account of the possibility of reduced flood return periods and greater flood peaks.

Box 7.5: Flood protection versus limiting urban development – example:

The value of development and the social and economic implications of a major flood in the Hutt Valley are so significant that the community has made decisions to mitigate effects through investment in flood protection rather than through limiting the intensity of development. One of the factors driving increased robustness in flood protection was the expectation of climate change effects. Although there was inadequate information on possible climate change impacts for modelling purposes when the decisions were made, the community chose a flood return period of 400 years as the basis for flood protection design, knowing that the level of protection was likely to decrease over time owing to climate change impacts.

The Hutt Valley 2001 Flood Plain Management Plan provides detailed information on design considerations and levels of protection, taking into account climate change.

7.2.4 The extent of the issue being addressed

Decisions that involve for example a single building or a small part of an infrastructure asset (unless the latter constrains the rest of the system) are less likely to have fundamental and long-term implications than decisions that affect larger areas (eg, an urban growth area). The exception is where a small development has precedent value, leading to acceptance of subsequent applications.

Box 7.6: Exceeding an existing use right – example

Nikau Bay (Marlborough) is an example given in chapter 6. Sea-level rise will exacerbate the effects of wave action and storm surges. There are a number of dwellings close to the mean high water springs tide level in the settlement. Most are modest traditional holiday houses or small permanently occupied dwellings, but a major upgrade of one has been allowed. The change exceeds what could have reasonably been accepted as an existing use right (given that the ‘effects’ of the upgrade in section 10 of the Resource Management Act can include climate change effects). While one example may seem insignificant, the greatly extended, now high-valued dwelling may have a precedent effect, leading other property owners to put pressure on the council for all dwellings in similar locations to be upgraded. If future sea-level rise has not been taken into account in any of the relevant decisions, the council may find itself liable for future damage to expensive dwellings.

7.2.5 The nature of the issue being addressed

Is the issue affected by a single climate parameter, or a complex issue with multiple effects and implications over time? The answer to this question should show up in the risk management worksheet. Complex long-term issues need to be identified and addressed at the policy level, and decision-making must be carried through consistently over time. Relatively general information may be adequate to start policy development, and information can be refined over time as policies are reviewed and revised.

For example, in planning for an urban expansion, if there are options, low-lying coastal areas should be avoided; and, if flood plains are being considered, higher and more frequent floods than in the past should be assumed.

Box 7.7: Identifying coastal hazard areas – example

Napier City Urban Growth Strategy 1992 (and a review in 1996) identified sea-level rise due to climate change as a hazard with consequences in terms of urban sustainability. The IPCC ‘business-as-usual’ scenario was used to predict the amount of sea-level rise and the consequent coastal erosion and flooding.

Since 1996, the council has undertaken several successive studies of coastal hazards and has imposed and reviewed coastal hazard areas north of the city, within which future development is to be strictly limited.

Sea-level rise is just one of the factors being taken into account in analyses of long-term erosion trends in the areas. However, the issue is recognised and accounted for in a risk-based planning approach.

The city’s Asset Management Plans for infrastructure also note possible effects of climate change. Because of the low-lying nature of much of the city area, all systems are pumped, and so groundwater level changes as well as increased flood frequencies could result in additional costs. The city regularly reviews its suite of plans, taking into account updated information on climate change.

7.3 Key principles for local government

Local government actions are undertaken in the context of a range of principles that are set out in law, or have evolved through good practice and case law. All must be kept in mind when dealing with climate change effects.

7.3.1 Sustainability

The concepts of sustainable development under the Local Government Act 2002, and sustainable management of an area’s natural and physical resources under the Resource Management Act 1991, imply the ongoing ability of communities and people to respond and adapt to change in a way that avoids or limits adverse consequences. Since 2004, the Resource Management Act has included a requirement that people making decisions in terms of the Act must have particular regard to the effects of climate change.

Over the past decade or more, during which people have become aware of climate change and its causes and effects, the causes of climate change have been tackled at international level. At the same time, local communities have been encouraged to adopt no- or low-regrets responses to climate change. Such responses fit within the concept of sustainability. They involve applying adaptive responses (and sometimes limitation responses) that will not be regretted irrespective of the eventual nature and magnitude of climate change effects. Examples are a range of energy efficiency and conservation practices, forest planting and avoidance of new development in areas that are already or potentially hazard-prone.

However, more recent understanding of the variability of climate change effects, and the possible implications of decisions made in a framework of uncertainty, has meant a shift to risk-based assessments of climate change effects and responses by local authorities, prior to decisions being made in the interests of long-term sustainability.

7.3.2 The reasonably foreseeable needs of future generations

This means taking into account the interests of future communities, and the direct and indirect costs that future generations may bear, as a result of decisions made in the present. The concept is found in key sections of the Local Government Act 2002 (section 14) and the Resource Management Act 1991 (section 5), and is the fundamental basis for international, national, regional and local responses to climate change.

Even where the need for a climate change response is not yet apparent, this principle applies. It integrates concepts of research and forecasting of trends and potential biophysical impacts with present expectations of future community needs. It requires responsible action in the context of balancing the needs of the present with those of the future.

7.3.3 Avoid, remedy or mitigate adverse effects

The Resource Management Act 1991 imposes a duty to avoid, remedy or mitigate adverse effects which applies to the preparation of plans by local authorities under that Act, to every decision made under that Act, and to everyone who carries out an activity or development under the Act. ‘Effect’ is defined to include temporary or permanent effects, present and future effects, cumulative effects over time and potential effects of high probability, or of low probability with high potential effects (section 3). This means that, through reasonable understanding and analysis of future environmental change, climate change impacts can and should be taken into account when contemplating new activities and developments.

Questions of scale and type of change, and implications in terms of specific decisions, can best be worked out through a risk assessment process taking into account permanency of the decision and anticipated future impacts. This may result in decisions to avoid future effects (such as ‘no go’ areas for development), or at least to mitigate them by specific design responses (such as minimum floor levels). If ‘future remedy’ is to be an option (such as relocatable buildings in coastal locations), the implications for present and future owners and the community need to be clearly identified at the time of consent and conveyed into the future by some mechanism (such as conditions of land-use consents or consent notices on titles at the time of subdivision).

7.3.4 Precautionary/cautious approach

A precautionary approach is implied in the Resource Management Act 1991 (and in the New Zealand Coastal Policy Statement prepared under that Act) and directly stated in the Civil Defence Emergency Management Act 2002 (section 7). Such an approach requires an informed but cautious approach to decisions where full information on effects is not available during decision-making, particularly when there is a high level of uncertainty and where decisions are effectively irreversible.

A precautionary approach is also particularly relevant when there is a low probability of effects but those effects have high potential impact, such as the effects of infrequent but high flood levels in developed flood plain areas. Section 32 of the Resource Management Act requires an evaluation of a plan provision to consider the risks of ‘acting or not acting’ if there is uncertain or inadequate information.

This is directly relevant to addressing climate change effects in plans, as well as other situations where a cautious approach may be appropriate.

7.3.5 The ethic of stewardship/prudent stewardship/ kaitiakitanga

The Local Government Act 2002 and the Resource Management Act 1991 both contain these concepts. Section 14 of the Local Government Act requires a local authority to apply prudent stewardship and the efficient and effective use of its resources in the interests of the district or region. Decision-makers under the Resource Management Act are required to have particular regard to kaitiakitanga and the ethic of stewardship in terms of the wider environment.

The principle underpins sound planning decision-making in the interests of the community, to avoid or minimise loss of value or quality over time. Its relevance to climate change relates particularly to asset management, landcare and watercare, biosecurity and biodiversity.

7.3.6 Consultation and participation

Principles of consultation with communities and affected people lie at the heart of local government decision-making. ‘Consultation’ implies informed input into decision-making processes. For decisions relevant to climate change, those being consulted must have sufficient information to understand the likely scenarios and associated risks for their communities. Ensuring that adequate information is available within a community for consultation to be effective is a responsibility for regional and local government, and will involve the translation of international and national knowledge to local levels, with indications of degree of certainty and uncertainty.

Consultation and participation can also be used to raise awareness of risk and appropriate responses – for example, flood risk and how people should respond when it happens in their locality.

7.3.7 Financial responsibility

Local government is expected to act according to normal codes of financial responsibility on behalf of the community. The Local Government Act 2002 sets out requirements for local government to identify in detail the reasons for any changes to a current provision, and the associated cost, when it is undertaking its own activities, particularly asset provision and management. For infrastructure enhancements to successfully anticipate the future effects of climate change, both evaluation of risks and the costs of different levels of service will need to be expressed in a transparent way.

7.3.8 Liability

Local government can be financially liable for decisions that are shown to have been made in the face of information that should have led to another decision. This is a complex area of law, and councils use a range of techniques to reduce the risk of liability. For example, where single property-based decisions are involved, instruments such as covenants or consent notices attached to titles may be used to identify risks. Such devices are not necessarily particularly effective, as they are almost completely untested in law, may not limit peoples’ expectations of further capitalisation, and do not appear to have any effect on land values.

Larger climate-related issues, such as frequency of flooding of a developed area, are less likely to result in direct liability unless areas become uninhabitable as a result. However, community costs in enhancing or retrofitting infrastructure can become considerable, and questions of equity in relation to wider community interests also arise.

7.4 Case law

There is a small but growing amount of case law that is directly relevant to climate change effects. Prominent cases under the Resource Management Act 1991 have now acknowledged climate change, its effects and their potential extent. There is also some relevant case law that relates to local authorities’ responsibilities for managing natural hazards, particularly coastal and flood hazards. Detailed case law has not yet emerged in relation to all the other potential impacts of climate change.

Case law to date assists local authorities by:

- recognising the reality of climate change
- clarifying the respective roles of regional and territorial authorities
- indicating principles of hazard avoidance, generally, and in areas which are already developed
- indicating time scales over which to consider effects
- clarifying the relationship between resource and building consents
- adopting climate change information and a cautious approach.

7.4.1 Recognising the reality of climate change

In *Environmental Defence Society Incorporated and Taranaki Energy Watch Incorporated* v. *Taranaki Regional Council* (Decision A184/2002), the court summarised its understanding of ‘the enhanced greenhouse effect’ and its consequences as follows:

> *The preponderance of scientific evidence indicates that the temperature of the earth’s surface has risen over the past 100 years. Most of the warming over the past 50 years is a result of greenhouse gas emissions caused by human activity.*
>
> *Climate models predict that greenhouse gas emissions will continue to increase atmospheric temperatures. The rise predicted for the next 100 years is likely to be more rapid than any natural variation over the past 100 years.*
>
> *Climate change will increase the frequency of some extreme weather and climate events such as heat waves, droughts and floods. These changes are likely to influence native ecosystems, agriculture, coastlines, and our economy, infrastructure, health and security. It is anticipated the adverse effects will outweigh the positive.*

This case looked mainly at the request for limitation or offset of discharges of CO_2 set out in the appeals, and did not consider adaptive responses.

7.4.2 Respective roles of regional and territorial authorities

The regional policy statement is the primary document for environmental management in the region and should clarify the respective roles of regional, city and district councils in addressing natural hazards, including hazards that are exacerbated by climate change. District plans must give effect to regional policy statements or regional plans.

The primacy of regional councils in addressing hazards that are of regional significance was tested in *Canterbury Regional Council* v. *Christchurch City Council* (1995 NZRMA 452), where the Court of Appeal found that the regional council had ‘the power to prohibit or restrict activities such as residential occupation and the erection of building in the Waimakariri Flood Plain, for the purpose of avoiding or mitigating natural hazards’. In *Canterbury Regional Council* v. *Banks Peninsula District Council* (1995 3 NZLR 189) the Court of Appeal confirmed:

> *the control of the use of land for the avoidance or mitigation of natural hazards is within the powers of both regional councils and territorial authorities. There will no doubt be occasions where such matters need to be dealt with on a regional basis, and occasions where this is not necessary, or where interim or additional steps need to be taken by the territorial authority.*

7.4.3 Indicating principles of hazard avoidance

In *Bay of Plenty Regional Council* v. *Western Bay of Plenty District Council* (Decision A27/02, 8 February 2002), the court took into account climate change and sea-level rise effects, and noted that voluntary assumption of risk by private property owners did not abrogate the council's responsibility of controlling the use of 'at risk' land for the purpose of avoiding or mitigating natural hazards. The court found that 'failure to manage known actual and potential effects of natural hazards ... under the (Resource Management) Act's regime would not, in our view, be consistent with the legislative purpose of sustainability'.

However, in *Opotiki Resource Planners* v. *Opotiki District Council* (Decision A15/97), the court determined that existing levels of development and existing mitigation (including stopbank protection works and an ongoing scheme directed at their maintenance and improvement) in an area should be taken into account. The appeal related to an existing modern building in the main shopping street of Opotiki, which was proposed to be converted into a health centre. The site had recognised susceptibility to flood risk, taking into account sea-level rise, and to aggradation of riverbeds over time, and there was lack of a guarantee that stopbanks would not fail during major flood events. The court made broad comments as follows:

> *Much of the evidence we heard was really pertinent to the basic question whether the location of the town itself is appropriate on account of the flood risk element, despite the measures taken to protect the town. It lies well beyond the realm of this appeal to draw so bold a conclusion on an 'across the board' footing, and then go on to illustrate such a finding by rejecting the proposal.*

7.4.4 Time scales for consideration of effects

In *Bay of Plenty Regional Council* v. *Whakatane District Council* (Decision A003/94), the sea-level rise predictions of the IPCC were discussed. The court decided that because of uncertainty, the prediction based on a time horizon of 2050 should be adopted.

The court noted:

> *We accept ... that it is notoriously difficult to make a reliable prediction as to the sea level change that will affect the subject land as far ahead as 2050, let alone beyond that. Nevertheless, we consider that the best prediction currently available of the likely sea level rise that will affect the country generally as at 2050 should be adopted.*

A key aspect of this decision is that the court took into account the state of knowledge at the time, and also, in the absence of detailed locality information, chose to adopt the New Zealand average. This case does not preclude an updated and more specific approach as knowledge improves.

In later cases in the same area, *Bay of Plenty Regional Council* v. *Western Bay of Plenty District Council* (Decision A27/02), *Skinner* v. *Tauranga District Council* (Decision A141/02), and also in *Fore World Developments Limited and Bayside Villas Limited* v. *Napier City Council* (Decision W29/2006), the court applied a 100-year risk period, taking into account the potential effects of future changed climate conditions as well as sea-level rise.

7.4.5 Relationship between resource and building consents

In *Bay of Plenty Regional Council* v. *Western Bay of Plenty District Council* (Decision A27/02), the court considered whether controlling the development of hazard-prone land should be left to building consent stage. It concluded that both the Resource Management Act 1991 (RMA) and the Building Act 2004 should be viewed as 'both individually and in combination' assisting to serve the public good. The court decided that:

> *Each in fact serves its particular purpose – that under the RMA of promoting the sustainable management of resources in the context of the wide environmental perspective that the Act embraces; and that under the Building Act by focusing on the integrity and safety of buildings wherever they are located. Logically, any relevant controlling provisions that govern a development proposal under the holistic management regime of the RMA will generally fall to be invoked initially, with the application of controls under the Building Act following as appropriate in terms of that Act.*

Section 106 of the Resource Management Act was amended by the Resource Management Amendment Act 2003, to provide councils with discretion to refuse to grant subdivision consents in respect of hazard-prone land and discretion to grant such consents with conditions addressing hazardous situations. Decisions may take into account existing and future structures on the land, subsequent uses of the land, and legal and physical arrangements.

7.4.6 Climate change information and the cautious approach

In *Fore World Developments Limited and Bayside Villas limited* v. *Napier City Council* (Decision W029/2006), appellants sought to have land zoned as residential to enable subdivision, despite coastal erosion concerns.

The court acknowledged that sea-level rise will result in wave action occurring at a higher elevation on shore and thus cause coastal erosion. In order to calculate the rate of coastal erosion, the court accepted the sea-level rise estimates of the IPCC.

In its overall assessment, the court stated that climate change aspects such as increased storminess require the consideration of an additional buffer allowance. This was explained as follows:

> *It is not a situation where it is necessary to be overly cautious but it would be prudent to provide for a buffer in addition to the estimated extent of the coastal erosion to make some sort of allowance for the factors that have not been estimated and included ... That buffer should be in the order of 25% of the sum of the estimated distance.*

7.5 Local government management and planning responsibilities

Both regional and territorial authorities have responsibilities and duties relating to natural hazards, and thus to climate change, under the Resource Management Act 1991 and a range of other legislation. Regional councils have a primary role at regional level in assisting territorial authorities through providing policy guidance, information and hazard assessment data. Regional councils, through regional plans, have the ability to address land-use issues and existing use rights in matters of regional significance (including matters such as significant exposure to flood risk). Councils can delegate responsibilities relating to risks and hazard management to the authority most appropriate to address the issue. It is important that regional and territorial authorities work together in planning for both the negative and the positive effects of climate change.

Central government has made it clear that control of the emissions that contribute to climate change are a matter for central government, rather than local government (eg, Inquiry into the Role for Local Government in Meeting New Zealand's Climate Change Target, November 2001, section 70A, Resource Management Act). However, local government in some circumstances must consider 'offsets', such as the benefits to be derived from the use and development of renewable energy when making relevant decisions in terms of section 7 of the Resource Management Act. There are other situations where the actions of a council to resolve another issue also has beneficial effects on reducing emissions. For example, improved public transport systems and compact urban form intended to provide improved urban living conditions, also should have the effect of limiting fossil fuel use.

Box 7.8: Context for council decisions

The Local Government Act 2002 requires councils to prepare a limited number of plans – long-term council community plans and annual plans. Water and other sanitary services must be assessed from time to time by the council and service provision must be included in the long-term council community plan, but asset management plans per se are not a requirement. The annual plan must set out details of council asset administration and costings.

All plans provide a decision-making framework, but, beyond that, all council decisions must be made in a context that involves:

- each decision relating to a stated objective or community outcome
- consideration of all reasonably practicable options, their benefits and costs, and their efficiency and integration with stated objectives
- consideration of the implications of the decision in relation to present and future needs, and all statutory responsibilities
- consideration of Māori values
- consideration of the views of affected people at varying stages of decision-making, and through consultative procedures
- consideration of prudent stewardship of the councils resources, and of sustainable development (for both, in proportion to the significance of the decision).

This underlying framework means that councils need to remain aware and informed of climate change implications in much of what they do.

Local government has a wide range of responsibilities that relate to adaptive responses to climate change. These responsibilities are formalised through a range of plans, prepared in different statutory contexts, along different time lines.

The key plans in which climate change implications should be considered are set out in Appendix 5, along with a checklist of possible components for each. Note that the variability of potential climate change effects (as well as councils' prioritisation of different effects) around the country means that not all plans will provide specifically for climate change. The important thing is that councils and communities are at least alert to the possible implications of climate change, and take the projected changes into account as part of plan preparation and review, and other decision-making processes.

In introducing objectives, policies, rules or other methods into a policy statement or plan, the Resource Management Act requires that a section 32 analysis – consideration of alternatives, benefits and costs – of the provision must be undertaken. This includes the requirement that councils must consider the implications of ‘the risk of acting or not acting’ if there is uncertain or insufficient information about the subject matter of the provision.

Box 7.9: Examples of relevant plan provisions

Wellington Regional Policy Statement, extracts from the natural hazards chapter

Issue 5: The frequency and magnitude of natural hazard events in the Wellington Region may also alter due to climate change. Warmer global temperatures may increase the Region’s exposure to tropical cyclones such as the Wahine storm, which would increase the frequency of major flood and landslip events and may increase coastal erosion hazard from projected sea level rise.

Regional Policy Statement for Southland, extracts from the natural hazards chapter

Policy 15.14: ‘Plan for sea level rise of 35 cm by the year 2050, until such time that there is evidence that the rate of rise is higher or lower.’

Policy 15.19: ‘Recognise the most likely effect of climate change will be reflected in a changing rainfall pattern in the region.’

Regional Coastal Plan for Southland, the coastal processes section

Issue 12.1.1: ‘Global sea level rise could impact upon structures, reclamations and other activities in the coastal marine area.’

Policy 12.1.1: ‘The design of structures and reclamations is to take into account the effects of a possible sea level rise of 35 cm prior to 2050 AD, until such times as there is evidence that the rate of this is higher or lower.’

Policy 12.1.64: ‘Encourage and assist territorial authorities to identify coastal hazard zones in the coastal environment especially areas subject to erosion (wind/water) or inundation.’

Nelson Regional Resource Management Plan, district-wide objectives for natural hazards; environmental results anticipated and performance indicators

Anticipated environmental results	Indicators	Data source
DO2e.1 Safer communities	DO2e.1.1 Low incidence of damage to property and risks to life from natural hazards.	Insurance claims, council records
DO2e.2 Low density of development and improved design and construction standards in areas where this Plan identifies major risks from natural hazards.	DO2e.2.1 Consistent refusal of development proposals or increased design requirements when resource consents are applied for.	Council records, aerial photos

7.6 Existing use rights

Under the Resource Management Act 1991, there are no existing use rights for structures in rivers and lakes or in the coastal marine area (except for reclamations), or for water takes and discharges. All consents are given for specific terms. Note, however, that the term of a consent, once set, cannot be changed. Reviews of conditions by a local authority can require changes to mitigate effects, but cannot extinguish the rights granted with the consent.

Land uses, if established through permitted activity status under a district plan, or through a consent, have existing use rights and are thus effectively permanent, unless a rule in a regional plan provides otherwise (see sections 9(3) and 20A(2) of the Resource Management Act). However, the wording of section 10 of the Act, which provides existing use rights, incorporates the ability to consider the effects of a use or development whenever an alteration is proposed. This may mean, for example, that building upgrades or extensions in hazard areas may not be able to rely on existing use rights.

Councils should consider carefully the implications of permitted activities in a district plan, the terms of consents granted, and the extent of existing use rights – in circumstances where hazards may be exacerbated or new hazards may occur within the lifetime of a development or new activity.

Regional land-use rules, which may relate to the avoidance or mitigation of natural hazards (enabled through the provisions of section 30(1)(c) and section 68), effectively extinguish existing use rights if they are incorporated in a regional plan (see section 20A(2) of the Resource Management Act). These provisions override district plan provisions.

7.7 Resource consent decisions

Any decision that will have an implication for more than about the next 30 years should be assessed for its climate change implications.

For many developments, the district plan will provide permitted activity status, and a consent will not be needed. Subdivisions almost always require a consent of some type, and conditions can be applied that may avoid, remedy or mitigate climate change-related effects such as erosion slippage or inundation.[77]

Where regional plans require consents to be obtained (such as for buildings in identified hazard areas, or for all structures in rivers or the coastal marine area), or the activity needs a land-use consent in terms of a district plan, implications of granting the consents in terms of climate change should be taken into account. Where a regional plan specifically controls buildings in hazard areas, this is a very powerful tool, as existing use rights are extinguished.

Climate change impacts may be particularly relevant for:

- subdivisions and developments in floodplain areas, close to rivers, or within or over river channels
- subdivisions and developments close to or within the coast (cliffs, beaches or low-lying areas)
- subdivision and developments on or close to steeper hillsides (including at the top and bottom of the hill)
- lifeline infrastructure components in the above locations
- subdivision and developments that rely on rain water supply.

Evaluations need to take into account possible effects on access routes and any on-site infrastructure, including wastewater management systems and water supply.

Plans should specify information that must be provided with applications for subdivision or development that are likely to be affected by hazards, including the potential implications of climate change.

7.8 Building consents

One of the four purposes of the Building Act 2004 is to ensure that buildings are designed, constructed, and able to be used in ways that promote sustainable development (section 3).

The Building Act provides the framework for building consents where responsibilities lie with district and city councils. This includes structures in the coastal marine area that are technically outside the district. However, building consents relating to dams are the responsibility of regional councils. The Building Act also includes provisions relating to LIMs (Land Information Memoranda) and PIMs (Project Information Memoranda). LIMs are provided for in the Local Government Official Information and Meetings Act 1987. LIMS, in particular, have become key elements for conveying site and risk information to people who seek such information. District and city councils need to periodically update their LIM database in response to any new information on climate change that can be identified as requiring a modification of normal building practice (eg, new coastal hazard or flood frequency information). LIMs provide a more immediate and detailed source of information than district plans, and allow for individual decisions on whether to proceed with the purchase of land or an application for specific development.

Generally, the Resource Management Act 1991 will set the framework for the building consent. For example, if an area is notified as hazard-prone in a plan, resource consent for development

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[77] The Resource Management Act 1991 in sections 106 and 220 makes provision for hazard avoidance or mitigation where subdivision (and future development on new subdivisions) is concerned.

may be able to be obtained, but it may include a range of conditions relating to the development. The situation is reviewed at building consent stage, and a further range of conditions may be attached to meet the Building Act's requirement to address safety and integrity of the structure. Building consents must be refused if land is unstable, unless the work will not increase the instability.

As climate change is known about in advance, plans under the Resource Management Act should provide the relevant decision-making context. An appropriate response to climate change should not have to wait until building consent stage.

Building codes are reviewed and updated over time at national level for local use. Response to some elements of climate change that are not locality or site-specific, such as increased temperature and more extreme winds, would be expected to be developed through codes, rather than applied to specific building consents.

7.9 Research, monitoring and reporting

Section 35 of the Resource Management Act 1991 provides councils with the responsibility of gathering information and undertaking or commissioning research to enable them to carry out their functions. Councils also need to keep available, and make public, research on natural hazards. Under the same section of the Act, councils are also responsible for monitoring the state of the whole (or any part) of the environment "to the extent that it is appropriate, to enable the local authority to effectively carry out" its Resource Management Act responsibilities. As well as this direct responsibility, monitoring conditions, where consent holders provide ongoing information relating to specific resource consents, can contribute to overall environmental monitoring.

Most regional councils undertake extensive monitoring of river systems and groundwater, and coastal areas. Several have long-term monitoring programmes relating to sea-level change. Some councils also monitor knowledge about climate change and climate change effects.

The availability of such information helps provide a baseline. Over time this information will help build up a picture of change in a district or region and will contribute to a better national understanding of the climate trends affecting the whole of New Zealand. This information gives a basis for national and local ongoing adaptation to change.

Box 7.10: Monitoring provisions – example

The Wellington Regional Policy Statement, national hazards section, includes the following:

Method 6: The Wellington Regional Council will periodically review the current knowledge on climate change and possible effects on natural hazards.

Climate change effects resulting from the 'greenhouse effect' are not yet well understood, and are the subject of major studies worldwide. This method requires the council to review regularly the available information and assess possible effects on the frequency and magnitude of natural hazards in the region.

Note: This council included climate change in its State of the Environment Report 2005 in response to this Method.

7.10 Some examples

This section gives hypothetical examples of how a local authority might work through the whole process of investigation and decision-making relating to climate change.

Box 7.11: Stormwater system asset management decision: a growing and infilling suburban area – example

Key driver: Need to upgrade and extend parts of a stormwater system to accommodate urban growth.

Climate change identified as an issue in area? Yes, in Regional Policy Statement, District Plan, previous Asset Management Plan.

Key climate variable: Peak 24-hour rainfall intensity.

Climate change effect: Reduced return period for heavy rainfall events (likely).

Key risk: More frequent stormwater overflows and 'downstream' consequences.

Uncertainty: No change, to fourfold increase in frequency of annual events by 2070.

Tools: Develop plausible scenario, undertake risk assessment (see chapters 5 and 6).

Response options:

From now, when making decisions for new, extended or replacement stormwater systems evaluate risks and costs of the following:

- larger-sized pipes/drains
- enhanced pumping capacity
- staged capacity upgrades over time.

From now, change the District plan to specify maximum hard surface area per site.

From now, encourage or require on-site or local area storage of peak stormwater in new subdivisions through consent conditions.

Note: The range of responses requires co-ordination across council departments.

In the future, provide budget and personnel for more frequent maintenance and repair of stormwater systems.

Box 7.12: Water supply asset management decision for a medium-sized city – example

Key Driver: Water restrictions imposed in two recent dry years, and the council is now consulting on new water supply options for the community.

Climate change identified as an issue in area? Yes, in the Regional Policy Statement, District Plan.

Key climate variable: Average annual rainfall.

Climate change effect: Reduced annual rainfall (likely), extended periods of drought (very likely).

Key risk: Demand for water exceeds supply.

Uncertainty: Average 10% reduction in rainfall in catchment, to average 40% reduction in rainfall in catchment. Drought (no rain period) likely to increase from 20 days to 30 days in summer. Both by 2050.

Tools: Develop plausible scenario, undertake risk assessment (see chapters 5 and 6).

Response options:

From now, investigate and re-evaluate existing city supply storage capacity and alternative supply sources.

From now, develop the plans to meet increased needs (taking into account population growth and a higher average demand per household) in the face of reduced security of supply. Evaluate risks and costs of the following:

- do nothing
- extend the reservoir area
- duplicate the reservoir area
- enhance groundwater
- the staging and timing of the above measures.

From now, encourage or require on-site collection and storage of rainwater (specify storage capacity in engineering standards) in all new developments.

From now, commence education programmes on water conservation and sustainable gardening.

From now, allow for staff time and budget for the consent process, the design and the construction of enhanced supply.

In the future, budget to monitor the use and effectiveness of on-site storage, and the effectiveness of water conservation education programmes. Budget to continue the education programmes.

Box 7.13: New industrial expansion area decision – example

Key Driver: Major development with long-term lock-in of physical resources and some hazard exposure.

Climate change identified as an issue in area? Yes, in the Regional Policy Statement, District Plan.

Key climate variable:

1) Peak 24-hour rainfall intensity.

2) Air temperature (inversions), wind directions.

Climate change effect:

1) Reduced return period for heavy rainfall events (likely).

2) Altered frequency of inversions (likely).

Key risk:

1) Adequacy of stormwater retention provision within industrial area.

2) Air quality effects arising from industrial emissions close to existing residential area.

Uncertainty:

1) No change, to fourfold increase in frequency of annual events by 2070.

2) No change, to reducing the current frequency of inversions by 30%.

Tools: Develop plausible scenario, undertake risk assessment (see chapters 5 and 6).

Response options:

Now, analyse and decide whether an increased frequency of significant stormwater events is a 'fatal flaw' making this site unsuitable and thus preventing rezoning, or whether there are adequate utilisation, management and/or design options. Note: In this example, increased temperatures and reduced inversions are positive effects in the long term and neutral or slightly positive in considering long-term effects and land suitability.

If land is rezoned:

- From now, determine and identify on a structure plan adequate stormwater detention areas for scenario design rainfall. Determine the appropriate management option, and protect the land, for the stormwater system (as a designation or through rules), in district plan provisions.
- From now, incorporate the cost of a complete stormwater system in an analysis of financial or development contributions.
- From now, identify a stormwater detention area and the remainder of the stormwater system as an item for consideration in the next review of the Long-term Council Community Plan, and its costs and sources of funding.
- In the future, provide the budget and personnel for ongoing maintenance, etc.

Glossary

Adaptation to climate change	Undertaking actions to minimise threats or to maximise opportunities resulting from climate change and its effects.
Aerosols	A collection of airborne solid or liquid particles, with a typical size between 0.01 and 10 microns, which reside in the atmosphere for at least several hours. Aerosols may be of either natural or *anthropogenic* origin.
Agenda 21	An outcome of the 1992 United Nations Conference on Environment and Development (the Earth Summit) held in Rio de Janeiro. Agenda 21 provides the philosophy and process for community-led sustainable development.
Aggregated impacts	Total impacts integrated across sectors and/or regions. The aggregation requires assumptions about the relative importance of impacts in different sectors and regions.
Anomaly	A difference from the long-term average (eg, of a climate variable). For example, the El Niño summer rainfall anomaly is the difference between the rainfall averaged over summers when El Niño conditions are present and the rainfall averaged over all summers.
Antarctic Circumpolar Current	The westward flowing ocean current circling Antarctica, also known as the 'West Wind Drift'. It is the largest ocean current on Earth (with about three times the flow of the Gulf Stream). A branch of it flows north around the Campbell Plateau to the south of New Zealand.
Anthropogenic	Produced by human beings or resulting from human activities.
Anthropogenic emissions	Emissions of *greenhouse gases*, greenhouse gas *precursors* and *aerosols* associated with human activities. These activities include burning fossil fuels for energy, deforestation and land-use changes that result in a net increase in emissions.
AOGCM	Acronym for *atmosphere-ocean general circulation model.*
AR4	Acronym for *IPCC Fourth Assessment Report,* 2007.
ARI	Acronym for Average Recurrence Interval. Same as *return period.*
Atmosphere-ocean general circulation model (AOGCM)	A comprehensive *climate model* containing equations representing the behaviour of the atmosphere, ocean and sea ice and their interactions.
Black carbon aerosol	An *aerosol* that consists of soot, charcoal or other light-absorbing organic material.
Carbon dioxide (CO_2)	A naturally occurring gas, also a by-product of burning fossil fuels. It is the principal anthropogenic greenhouse gas.
CFC	Acronym for *chlorofluorocarbon.*

Chlorofluorocarbons	Manufactured gases containing chlorine or fluorine that are used in refrigeration, air conditioning, packaging, insulation, solvents or aerosol propellants. Since they are not destroyed in the lower atmosphere, CFCs drift into the upper atmosphere where, given suitable conditions, they break down *ozone*. CFCs are also *greenhouse gases*, but are covered under the 1987 *Montreal Protocol* and explicitly excluded from the *Kyoto Protocol* and the *United Nations Framework Convention on Climate Change* (UNFCCC).
City and district councils	The management bodies of territorial authorities, of either predominantly urban or predominantly rural character.
Climate	The 'average weather', over a period of time ranging from months to thousands or millions of years. The classical period for calculating a 'climate normal' is 30 years.
Climate change	A statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer).
Climate model	A numerical representation (typically a set of equations programmed into a computer) of the *climate system*. The most complex and complete climate models are known as '*General Circulation Models*' (below).
Climate prediction	An attempt to provide a most likely description or estimate of the actual future evolution of the *climate*.
Climate projection	A potential future evolution of the climate in response to an emission or concentration *scenario* of *greenhouse gases* and *aerosols*. Often based on a simulation by a *climate model*.
Climate system	The interacting system comprising the atmosphere, hydrosphere (liquid water in lakes, rivers, seas, oceans), cryosphere (snow, ice, permafrost), land surface and biosphere (ecosystems and living organisms), which determines the earth's *climate*.
Climate variability	Variations of the *climate* (eg, of the mean state, standard deviations and extremes) on all temporal and spatial scales beyond those of individual weather events.
CLIMPACTS	An integrated assessment model for conducting analyses of the sensitivity of New Zealand's managed environments to climate variability and change. Both spatial and temporal variations can be examined. For further information, see website: http://www.climsystems.com/site/home/ (3 April 2008).
Consent notice	A condition on a subdivision consent, under section 221 of the Resource Management Act 1991, which must be complied with on a continuing basis by the subdividing owner and any subsequent owner. A consent notice is issued by a territorial authority and is deemed to be an instrument creating an interest in the land and a covenant on the land.
Consequence (or impact)	The outcome (of an event), expressed qualitatively in terms of the level of impact. Consequences can be measured in terms of economic, social, environmental or other impacts.

Discount rate	This is a term used in the *IPCC* Working Group III report (2007c), and refers to the degree to which consumption now is preferred to consumption 1 year hence, with prices held constant, but average incomes rising in line with GDP per capita.
Diurnal temperature range	The difference between the maximum and minimum temperature during a day.
Downscaling	Deriving estimates of local climate elements (eg, temperature, wind, rainfall), from the coarse resolution output of *global climate models*. Statistical downscaling uses present relationships between large-scale climate variables and local variables. Nested regional climate modelling uses the coarse resolution output from a global climate model to drive a high resolution *regional climate model.*
Down-zoning	Reducing the intensity of future development in an area by, for example, increasing minimum lot sizes.
El Niño	A significant increase in sea surface temperature over the eastern and central equatorial Pacific that occurs at irregular intervals, generally ranging between 2 and 7 years. Associated changes occur in atmospheric pressure patterns and wind systems across the Pacific. These can lead to changes in seasonal rainfall and temperature in parts of Australia and New Zealand.
El Niño-Southern Oscillation (ENSO)	Term coined in the early 1980s in recognition of the intimate linkage between *El Niño* events and the *Southern Oscillation*, which, prior to the late 1960s, had been viewed as two unrelated phenomena. The interactive global ocean-atmosphere cycle comprising El Niño and La Niña is often called the ‘ENSO cycle’.
Euphotic zone	The upper, illuminated zone of the marine ecosystem where photosynthesis occurs, typically reaching 30 m in coastal waters but extending to 100–200 m in open ocean waters.
Evapotranspiration	The combined process of evaporation from the earth’s surface and transpiration from vegetation.
Event	An incident that is induced or significantly exacerbated by climate change and that occurs in a particular place during a particular interval of time. Examples are floods, very high winds or droughts.
Extreme weather event	An event that is rare at a particular place. ‘Rare’ would normally be defined as rare as or rarer than the 10th or 90th percentile.
ENSO	Acronym for *El Niño Southern Oscillation*.
General Circulation Model (GCM)	A global, three-dimensional computer model of the *climate system*, which can be used to simulate the general circulation and climate of the atmosphere and ocean, and particularly human-induced climate change. General Circulation Models are highly complex and they represent the effects of such factors as reflective and absorptive properties of atmospheric water vapour, greenhouse gas concentrations, clouds, annual and daily solar heating, ocean temperatures and ice boundaries. General Circulation Models include global representations of the atmosphere, oceans and land surface.
GCM	Acronym for *General Circulation Model* or *Global Climate Model.*

Global Climate Model (GCM)	The same as *General Circulation Model.*
Global surface temperature	The global surface temperature is the area-weighted global average of: (i) the sea surface temperature over the oceans (ie, the subsurface bulk temperature in the top few metres of the ocean), and (ii) the surface-air temperature over land at 1.5 m above the ground.
Global warming	Generally used to refer to the rise of the earth's surface temperature predicted to occur as a result of increased emissions of *greenhouse gases*.
Greenhouse effect	An increase in the temperature of the earth's surface and the lowest 8 km or so of the atmosphere, caused by the trapping of heat by *greenhouse gases*. Naturally occurring greenhouse gases cause a greenhouse effect at the earth's surface of about 30°C. Further temperature increases caused by *anthropogenic emissions* are termed the 'enhanced greenhouse effect'.
Greenhouse gases	Gases in the earth's atmosphere that absorb and re-emit infra-red (heat) radiation. Many greenhouse gases occur naturally in the atmosphere, but concentrations of some (such as *carbon dioxide*, methane and nitrous oxide) have increased above natural levels because of *anthropogenic emissions*.
Hazard	A source of potential harm to people or property. Examples are erosion or inundation.
Homogenised climate record	A climate record that has been screened and adjusted for errors (because of changes in site, observing location environs, instrumentation and observation methods) to produce a high-quality climate record for the purpose of detecting climate trends and variability.
Hotspots	An integrated assessment model to facilitate risk assessment and management of exotic mosquitoes of public health concern to New Zealand. http://www.waikato.ac.nz/igci/hotspots/about1.htm (3 April 2008).
IFD	Acronym for Intensity, Frequency and Duration, relating to extreme rainfall events. Alternatively known as 'DDF' (Depth, Duration, Frequency).
Interdecadal Pacific Oscillation (IPO)	A long timescale oscillation in the Pacific Ocean–atmosphere system that shifts climate every one to three decades. The IPO has positive (warm) and negative (cool) phases. Positive phases tend to be associated with an increase in *El Niño*, and negative phases with an increase in *La Niña* events.
Intergovernmental Panel on Climate Change (IPCC)	The body established in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) to objectively assess scientific, technical and socioeconomic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation.
IPCC	Acronym for *Intergovernmental Panel on Climate Change*.
IPO	Acronym for *Interdecadal Pacific Oscillation.*
Kaitiakitangi	Stewardship, or the awareness of and care for natural and cultural resources, according to customary principles.

Kyoto Protocol	The Kyoto Protocol to the *United Nations Framework Convention on Climate Change* (UNFCCC) was adopted at the Third Session of the Conference of the Parties (COP) to the UNFCCC, in 1997 in Kyoto, Japan. It contains legally binding commitments on countries included in Annex B of the Protocol (most Organization for Economic Cooperation and Development countries and other countries with economies in transition) to reduce their anthropogenic greenhouse gas emissions to some (negotiable) value below 1990 levels in the commitment period 2008 to 2012. Different countries have different targets to achieve. New Zealand's target is to reduce its greenhouse gas emissions to the level they were in 1990, or take responsibility for excess emissions. New Zealand ratified the Kyoto Protocol in December 2002. The Protocol entered into force on 16 February 2005.
La Niña	A significant decrease in sea surface temperature in the central and eastern equatorial Pacific that occurs at irregular intervals, generally ranging between 2 and 7 years. La Niña is the cool counterpart to the *El Niño* warm event, and its spatial and temporal evolution in the equatorial Pacific is, to a considerable extent, the mirror image of El Niño. Like El Niño, there are associated changes in atmospheric pressures and wind systems across the Pacific, and related changes can occur in temperature and rainfall in parts of Australia and New Zealand.
Lifelines	Key networks for communication and survival during emergency conditions, including connected links and operating facilities in electricity, telecommunications, roading, water supply and wastewater systems. They may also include key emergency services such as ambulance, fire and civil defence services, and facilitates such as hospitals and medical centres.
Likelihood	The probability or chance of something happening (can be a qualitative or quantitative measure).
Limitation adaptations	Those adaptations that are aimed at lessening or minimising the consequences of the most adverse effects of climate change as they arise over time.
Low-regrets adaptations	Those adaptations that are aimed at pro-actively minimising adverse effects that may arise over time from climate change.
Mitigation (of climate change)	Activities undertaken to reduce the sources or increase the sinks of *greenhouse gases.*
Montreal Protocol	An international agreement adopted in 1987 to control the consumption and production of chemicals such as *chlorofluorocarbons* that destroy stratospheric *ozone*.
Natural variability	Non-anthropogenic climate variability that may be irregular or quasi-cyclic. *El Niño-Southern Oscillation* is probably the best-known example of a natural oscillation of the climate system, but there are many others. Changes caused by volcanic eruptions and solar variations can also be considered 'natural'.
No-regrets adaptation	Those adaptations that generate net social, economic and environmental benefits whether or not there is anthropogenic climate change climate, or at least have no net adverse effects.

Ozone	The triatomic form of oxygen (O_3). It acts as a *greenhouse gas* in the *troposphere*. In the *stratosphere* (about 10–50 km above the ground) it absorbs harmful UV radiation emanating from the sun.
Percentile	Used to give an observed value a ranking within the historical record. For example, only 5% of observations lie *below* the 5th percentile (ie, the coldest 5% of the temperature record) and 5% of observations lie *above* the 95th percentile (ie, the warmest 5% of that record).
Precursors	Atmospheric compounds that are not themselves *greenhouse gases* or *aerosols*, but which take part in processes regulating their production or destruction.
Radiative forcing	The perturbation to the energy balance of the earth–atmosphere system following, for example, a change in the concentration of *carbon dioxide* or a change in the output of the sun. The *climate system* responds to the radiative forcing so as to re-establish the energy balance. A positive radiative forcing tends to warm the earth's surface and a negative radiative forcing tends to cool the surface.
Regional Climate Model (RCM)	A *climate model* that is run at high resolution over a 'region' (eg, the eastern part of Australia, Tasman Sea plus New Zealand) to describe climate at the regional scale. RCMs are typically driven with data from *Global Climate Models,* which run at lower resolution and, therefore, do not accurately simulate, for example, the effects of the Southern Alps on New Zealand's climate.
Regional councils	Constituted under the Local Government Act 2002 with the functions and responsibilities that relate to defined local government regions.
Relative sea level	Sea level measured by a tide gauge with respect to the land upon which it is situated. Mean Sea Level (MSL) is normally defined as the average Relative sea level over a period, such as a month or a year, long enough to average out transient fluctuations such as waves.
Return period	The probable time period between repetition of *extreme weather events*, such as heavy rainfall or flooding, in a stationary climate (that is, a climate without global warming or other trends). In the case of rainfall, a return period is always related to a specific duration (eg, 50-year return period of 24-hour extreme rainfall).
Risk	The chance of an 'event' being induced or significantly exacerbated by climate change, that event having an impact on something of value to the present and/or future community. Risk is measured in terms of *consequence* and *likelihood.*
Scenario	A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about key driving forces.
Screening assessment	An initial risk assessment that involves identifying current sensitivity to climate and possible future sensitivity to climate change, and the likely duration and extent of effects that may arise as a consequence of climate change.
SOI	Acronym for *Southern Oscillation Index*.

Southern oscillation	A multi-year low-latitude seesaw in sea level pressure, with one pole in the eastern Pacific and the other in the western Pacific/Indian Ocean region. This pressure seesaw is associated with a global pattern of atmospheric *anomalies* in circulation, temperature, and precipitation. Its opposite extremes are the *El Niño* and *La Niña* events.
Southern Oscillation Index (SOI)	An index calculated from *anomalies* in the pressure difference between Tahiti and Darwin. Low negative values of this index correspond to *El Niño* conditions, and high positive SOI values coincide with *La Niña* episodes.
SRES scenarios	A set of *greenhouse gas* and *aerosol* emissions *scenarios* developed in 2000 by Working Group III of the *IPCC* and used, among others, as a basis for the climate projections in the IPCC Third Assessment Report (2001a, 2001b).
SST	Acronym for *Sea Surface Temperature* (see *Global surface temperature*).
Storm surge	The excess above the level expected from the tidal variation alone at a given time and place. The temporary increase in the height of the sea is caused by extreme meteorological conditions such as low atmospheric pressure and/or strong winds.
Stratosphere	The region of the atmosphere extending from about 10 km to 50 km altitude.
Sustainability	"... development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Bruntland Report, *Our Common Future, Report of the World Commission on Environment and Development*, 1978).
Territorial authorities	Constituted under the Local Government Act 2002, comprising *city and district councils* and (for some functions) *unitary authorities*.
Troposphere	The lowest part of the atmosphere, which in mid-latitude locations like New Zealand extends from the earth's surface to about 10 km altitude.
Unitary authorities	Territorial authorities that also have regional council responsibilities.
United Nations Framework Convention on Climate Change (UNFCCC)	The Convention was adopted on 9 May 1992 in New York and signed at the 1992 Earth Summit in Rio de Janeiro by more than 150 countries and the European Community. Its ultimate objective is the 'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. It contains commitments for all parties. Under the Convention, parties included in Annex I aim to return *greenhouse gas* emissions not controlled by the *Montreal Protocol* to 1990 levels. The convention entered into force in March 1994. See also *Kyoto Protocol*.
Weather generator	Weather generators produce multiple time series of numbers with statistical properties that resemble those of historical weather records. The most common weather generators produce output representing daily time series of maximum and minimum temperature, rainfall and solar radiation. The numbers preserve observed characteristics such as persistence of temperature (eg, one hot day is often followed by another), as well as inter-relationships (eg, wet days tend to have lower solar radiation and lower maximum temperature but higher minimum temperature).

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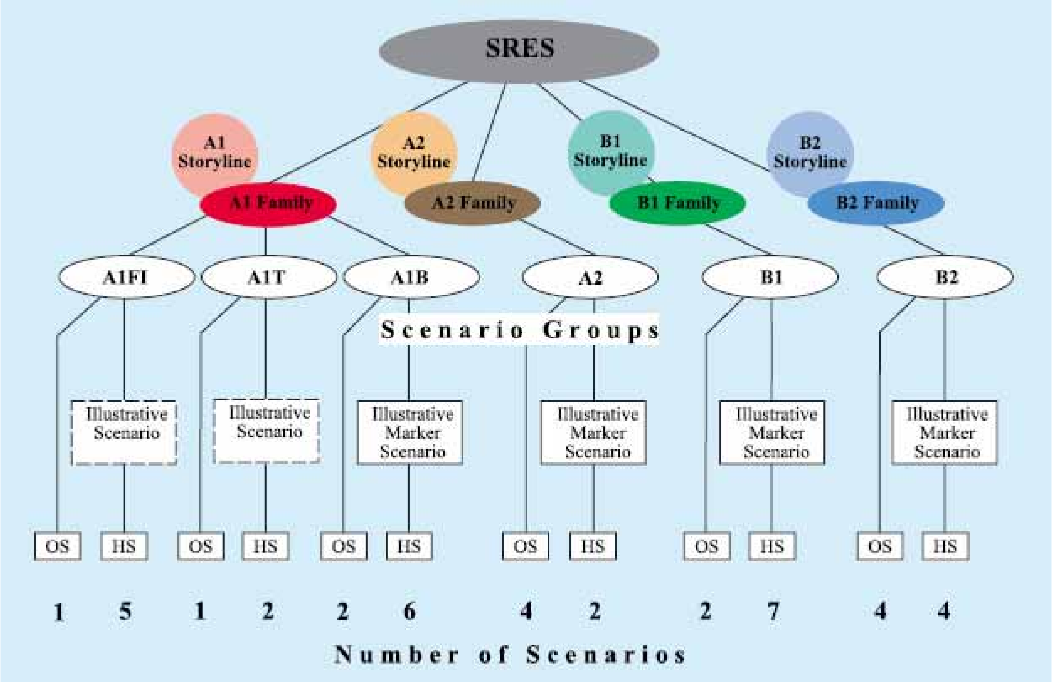
Appendix 1: IPCC Emissions Scenarios

For ease of reference, a brief summary of the IPCC emissions scenarios is provided here, taken from Nakicenovic and Swart (2000).[78] These scenarios are known as the ‘SRES scenarios’ after the name of the report, the *Special Report on Emissions Scenarios*.

The SRES scenarios are divided into four families, or storylines, that describe distinctly different future developments of economic growth, global population and technological change. These four families are known as ‘A1’, ‘A2’, ‘B1’ and ‘B2’. The A1 family is further subdivided into three groups (A1FI, A1T and A1B), so there are in total six scenario groups, for which so-called ‘illustrative’ emissions scenarios were developed by IPCC Working Group III in 2000. The SRES scenarios are shown schematically in Figure A1.1, and the storylines summarised in Box A1.1.

Figure A1.1: Schematic illustration of SRES scenarios.



Note: Four qualitative storylines yield four sets of scenarios called ‘families’: A1, A2, B1 and B2. The scenarios specify global annual emissions of the major greenhouse gases, together with sulphate aerosols, from 1990 to 2100. Altogether, 40 SRES scenarios have been developed, all considered equally valid with no assigned probabilities of occurrence. Within the A1 family there are three scenario groups (A1FI, A1T, A1B), characterising alternative developments of energy technology. Within each of the six scenario groups, there is a shared set of so-called ‘harmonised’ assumptions about global population, gross world product and energy use (labelled ‘HS’ for harmonized scenarios). There are other scenarios (labelled ‘OS’) that explore additional uncertainty in these forces that drive future emissions.
Source: Nakicenovic and Swart 2000: figure 1.

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[78] Nakicenovic and Swart 2000.

Box A1.1: Storylines of SRES scenarios

The **A1** scenario family describes a future world of very rapid economic growth, global population that peaks mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. A major underlying theme is convergence among regions of the globe, with a substantial reduction over time in regional differences in per capita income. The A1 family is split into three groups that describe alternative directions of technological change in the energy system: fossil intensive (A1FI), non-fossil energy sources (A1T) or a balance across all sources (A1B).

The **B1** scenario family describes a convergent world with the same population trajectory as in the A1 storyline, but with rapid changes towards a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies.

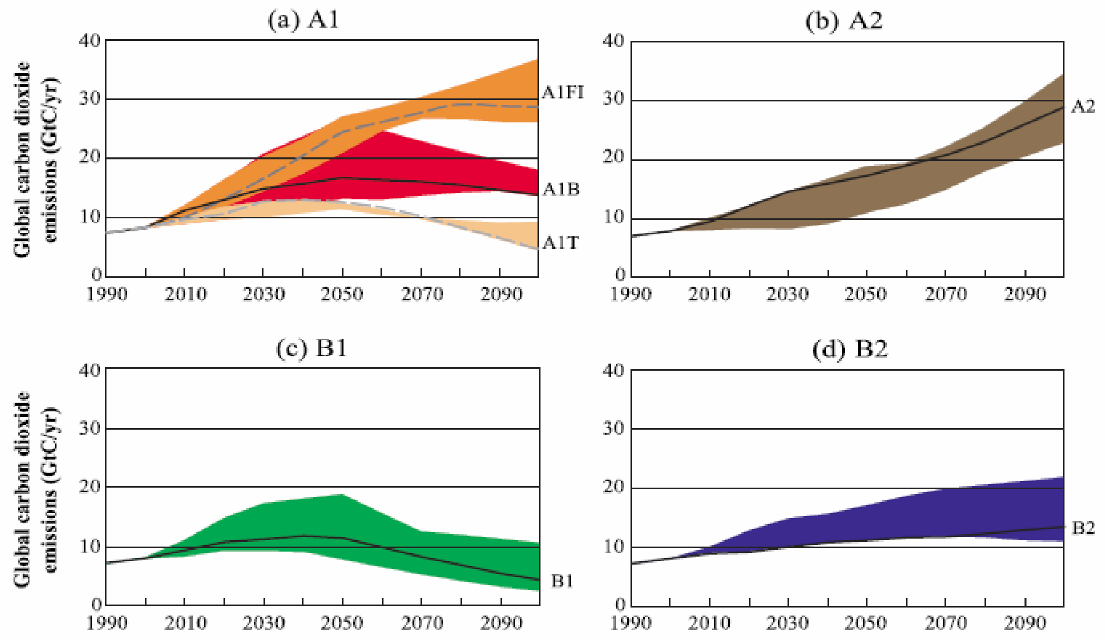
The **A2** scenario family describes a very heterogeneous world, with the underlying theme of self-reliance and preservation of local identities. Global population increases continuously, economic development is regionally oriented, and per capita economic growth and technological change are more fragmented and slower than in the other storylines.

The **B2** scenario family describes a world that emphasises local solutions to economic, social and environmental sustainability (ie, a heterogeneous world as in A2). Global population increases continuously at a rate slower than A2, with intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines.

The scenarios specify global annual emissions of the major greenhouse gases (carbon dioxide, methane, nitrous oxide and the HFCs) and sulphate aerosols. Figure A1.2 illustrates the carbon dioxide emissions. The lowest CO_2 emissions occur under the B1 scenario, and the highest cumulative emissions over the 21st century under the A1FI scenario. The SRES scenarios do not include specific initiatives to mitigate climate change, which means that none of the scenarios explicitly assume implementation of the *United Nations Framework Convention on Climate Change* or the emissions targets of the Kyoto Protocol.

All the SRES emissions scenarios project ongoing increases in the atmospheric concentration of greenhouse gases over the coming century, even for those scenarios where the emissions start to decrease at some point before 2100. The projected global temperature increases from all scenarios over the next 50 to 100 years are much larger than those that have occurred over the past 1000 years. The IPCC does not promote any one SRES scenario as being more likely than any other.

Figure A1.2: **Total global annual CO_2 emissions from all sources (energy, industry and land-use change) from 1990 to 2100 (in gigatonnes (Gt) of carbon per year) for the four scenario families A1, A2, B1 and B2.**



Note: The solid lines indicate the four illustrative marker scenarios of these four families, with the coloured bands showing the range of emissions scenarios within each group. For the A1 scenario, the two illustrative scenarios A1FI and A1T are also shown (dashed lines). Source: Nakicenovic and Swart 2000: figure 3.

Reference

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Appendix 2: Scaling to Full IPCC Range of Emissions

A2.1 Introduction

The rates of anthropogenic greenhouse gas and aerosol emissions that influence future climate will vary according to changes in population and economic growth, technology, energy availability and national and international policies. The Intergovernmental Panel on Climate Change developed 40 different future emissions pathways, the so-called 'SRES scenarios' (see section 1.3 and Appendix 1), with no evaluation of their relative probabilities of occurrence.

In order to drive detailed regional projections from such global emissions, it is necessary to use complex atmosphere–ocean global climate models (AOGCMs). These model simulations require months of supercomputer time for each scenario of forcing emissions (or atmospheric concentration). The SRES emission scenarios were not produced early enough for climate modellers to incorporate them into model projections for the IPCC Third Assessment of 2001. However, for the Fourth Assessment of 2007 (referred to as 'AR4'), a large number of model simulations were carried out, focusing particularly on the six illustrative scenarios (A1B, A1FI, A1T, A2, B1 and B2 – see Appendix 1). The *Summary for Policymakers* (IPCC 2007) states that all these scenarios should be considered equally sound.

A2.2 Selection of Models

An enormous amount of data processing is required to cover the range of model and scenario information available from the AR4 modelling community (global fields of many climate variables, each for 100 years and more, for 15–20 General Circulation Models and for six emission scenarios). Initially, NIWA focused in its FRST-funded work (contracts C01X0202, C01X0701) on model simulations for the A1B emissions scenario, and this dataset is used as the basis of the present report.

Data were downloaded from the IPCC data centre, http://www-pcmdi.llnl.gov/software-portal/esg_data_portal/dapserver/ (3 April 2008) for 17 General Circulation Models that had produced projections forced by the A1B emissions scenario. The climate variables of interest are those required for downscaling over New Zealand – specifically, mean sea-level pressure (mslp), precipitation, and surface air temperature. Since we are interested in *changes* from the current climate, it was also necessary to download simulated data from the 20th century control run (which typically begins in the mid- to late 19th century). The 20th century data end in either 1999 or 2000 (depending on modelling institution), with the A1B simulation following on for a further 100 years to either 2099 or 2100. In some cases, the A1B simulation was extended for a further 100 years or 200 years with atmospheric concentrations of radiatively active gases fixed at the 2100 scenario level, in what were called 'stabilisation experiments'.

Extensive validation of the control climates of the 17 General Circulation Models was carried out, comparing the period 1971–2000 (or 1970–1999[79]) in the models with gridded observational data for 1971–2000 from the widely-used NCEP re-analysis (Kalnay et al 1996). The validation focused on the New Zealand–South Pacific region, and calculated correlations and root-mean square differences between observed and simulated climatology of: spatial pattern and seasonal variation in mslp, precipitation and temperature; position and intensity of the westerly wind maximum south of New Zealand and the high-pressure maximum north of New Zealand; the Southern Oscillation Index; and the Trenberth circulation indices Z1 and M1 (used in the downscaling procedure). The results (to be reported elsewhere) indicated that five of the 17 models performed significantly poorer than the remaining 12. For example, some of the poorer five models had the Southern Hemisphere westerly winds much further north than observed, and no clear Southern Oscillation signal in their interannual variability.

Table A2.1 lists the 12 models retained for the downscaling exercise, along with the global annual temperature changes and (downscaled) New Zealand-average annual temperature changes relative to the base period 1980–1999, under the A1B scenario. Multi-decadal variations in the rate of warming can be seen: for example, the *mpi_echam5* has the least New Zealand warming by 2040 (+0.33°C), but by 2090 the model *csiro_mk30* has least warming (+1.13°C). The average 100-year warming to 2080–2099 over the 12 models for the A1B scenario is 2.80°C for the globe (range 1.84–4.15°C), and 2.10°C for New Zealand (range 1.13–3.44°C).

No model projected New Zealand warming faster than the global average. The ratio of New Zealand to global warming over 100 years (1980–1999 to 2080–2099) varies between 0.56 and 0.96, with an average rate over the 12 General Circulation Models of 0.75. For the 50-year period (1980–1999 to 2030–2049), there is a larger scatter in the estimated trend, with the New Zealand-to-global warming ratio varying between 0.30 and 0.94, but an average rate over the 12 General Circulation Models of 0.73.

Table A2.1: Annual temperature changes (in °C) relative to 1980–1999 for 12 General Circulation Models forced by the SRES A1B scenario. Changes are shown for different end periods, the global and downscaled New Zealand average.

Model (Country)	Global change to 2090–2099	Change to 2030–49		Change to 2080-99	
		Global avg	NZ avg	Global avg	NZ avg
cccma_cgcm3 (Canada)	3.10	1.47	1.27	2.99	2.69
cnrm_cm3 (France)	2.75	1.30	0.87	2.60	1.83
csiro_mk30 (Australia)	1.98	0.65	0.54	1.84	1.13
gfdl_cm20 (USA)	2.90	1.29	0.82	2.83	1.96
gfdl_cm21 (USA)	2.53	1.31	1.22	2.44	2.16
miroc32_hires (Japan)	4.34	2.00	1.35	4.15	3.44
miub_echog (Germany/Korea)	2.86	1.19	1.12	2.76	2.23
mpi_echam5 (Germany)	3.31	1.09	0.33	3.15	1.75
mri_cgcm232 (Japan)	2.20	0.97	0.71	2.16	2.07
ncar_ccsm30 (USA)	2.71	1.57	1.19	2.63	2.11
ukmo_hadcm3 (UK)	2.90	1.24	0.66	2.79	1.56
ukmo_hadgem1 (UK)	3.36	1.35	1.14	3.22	2.21

Note: Information on these models can be found in Chapter 10 (Meehl et al 2007) of the *Fourth Assessment Report*, 2007 and on the website http://www-pcmdi.llnl.gov/ipcc/model_documentation/ipcc _model_documentation.php (3 April 2008).

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[79] Since we are comparing features of the simulated climate, and are not concerned with exact sequencing in the time series, the 1-year difference in control climate periods is unimportant. The effect of a 1-year difference in radiative forcing will likewise be trivial.

A2.2 Scaling methodology

The *Summary for Policymakers* (IPCC 2007) summarises the projected global warming between 1980–1999 and 2090–2099,[80] as shown below in Table A2.2. For the A1B scenario, the global-average surface temperature change varies between 2.0°C and 4.3°C for the 12 models that perform well in the South Pacific region. Including the other five models increases this range slightly to 1.9–4.3°C, which corresponds fairly closely to the IPCC range of 1.7–4.4°C. The reason for the small discrepancy is that the IPCC range incorporates some expert judgement after considering a wide range of climate models that are simpler numerically than the General Circulation Models but that encompass more uncertainties such as difference rates of carbon cycling through the climate system. In simple terms, the IPCC range arises from taking the ‘best estimate’ temperature change, and subtracting 40% to get the low end, and adding 60% to get the high end of the range (see Meehl et al 2007: caption to figure 10.29 in chapter 10). This simplification was also a sensible approach given that the number of model experiments varied with the scenario (up to 23 General Circulation Models for the B1, A1B and A2 scenarios, and a lot fewer for B2, A1T and A1FI).

Table A2.2: Projected global average surface warming (in °C) from 1980–1999 to 2090–2099 for the six illustrative IPCC SRES emission scenarios. Source: Table SPM.3 in IPCC (2007).

Scenario	Best estimate	Likely range
B1 scenario	1.8	1.1 – 2.9
A1T scenario	2.4	1.4 – 3.8
B2 scenario	2.4	1.4 – 3.8
A1B scenario	2.8	1.7 – 4.4
A2 scenario	3.4	2.0 – 5.4
A1FI scenario	4.0	2.4 – 6.4

For the purposes of this Ministry for the Environment Guidance Manual, maps are presented of changes only for the A1B scenario, rather than trying to rescale to cover a range of emission scenarios (as was done in the earlier Guidance Manual, Ministry for the Environment 2004). Thus, the maps in chapter 2 (Figures 2.3–2.7) are the downscaled changes from the A1B-driven General Circulation Model projections. However, in the tables of chapter 2 (Tables 2.2–2.5), a rescaling is carried out to mimic the impact over all six illustrative scenarios, which span the full range of the 40 SRES scenarios.

Rescaling is done by taking the 17-model A1B range (ie, 1.9–4.3°C), and calculating the factors required to match this to the IPCC ‘likely ranges’ for each scenario of Table A2.2, while maintaining the same relative spacing (in global temperature change space) between the models. This scaling factor is then applied to the local change (in temperature, precipitation, etc.) from the downscaling, where only 12 models are ultimately considered. This assumption of a proportional relationship between the global temperature change and a local change is a very common one in integrated assessment modelling (Kenny et al 2001). The scaling factors vary between about 0.6 for the B1 scenario to about 1.0 for A1B and 1.4 for A1FI (but are model-dependent).

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[80] Note that the end period starts at the year 2090 in the IPCC table, and we use ratios for the approximately 105-year changes to rescale the A1B results to the other SRES scenarios. However, the New Zealand downscaled changes are calculated between two 20-year periods: for example, 1980–1999 to 2080–2099.

A2.3 Probability distribution of climate projections

The IPCC Fourth Assessment, 2007 does give some consideration to describing projected warming in terms of probability distributions, in addition to a simple best estimate and likely range (eg, section 10.5.4.5 in Meehl et al 2007). The distributions are estimated across the multi-model ensembles, and evaluated separately for each emission scenario. By IPCC convention, probabilities or likelihoods are not assigned to the emission scenarios themselves.

Estimated probability distributions often demonstrate a slight positive skewness (ie, a longer tail to the right or high end of projected changes). To some extent, this is expected because changes in many variables (temperature, sea level) are truncated to be non-negative at the low end of the range, at least in the global average although perhaps not regionally. Even though the high end of projected changes has a low probability, the higher risks associated with these extreme projections suggest they be given serious consideration (Kerr 2007). We also see examples of this positively skewed distribution of changes in the local downscaling results (see Appendix 3).

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Meehl GA, Stocker TF, Collins WD, Friedlingstein P, Gaye AT, Gregory JM, Kitoh A, Knutti R, Murphy JM, Noda A, Raper SCB, Watterson IG, Weaver AJ, Zhao ZC. 2007. Global climate projections. *In*: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* . Cambridge University Press: Cambridge, United Kingdom and New York, NY, USA. http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf (2 April 2008).

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Appendix 3: Further Details of Projected New Zealand Climate Change

Chapter 2 provides quantitative and qualitative projections of future changes in a number of key climate variables for New Zealand. This appendix provides additional background on the downscaling and model projections, the level of agreement between the models and changes in extreme precipitation.

A3.1 Downscaling

The global climate models used in the IPCC Fourth Assessment, 2007 tend to have improved spatial resolution relative to those of the Third Assessment, 2001. Yet the resolution is still too coarse to show much detail over New Zealand. For the 12 General Circulation Models retained for the downscaling exercise, the grid-point spacing varies from 1.125° to 3.75° in longitude, and 0.56° to 2.5° in latitude at the equator[81]. Of the five models rejected of the original 17, three had the coarsest resolution of all (up to 5° longitude grid spacing).

Clearly, it is necessary to 'downscale' the General Circulation Model to represent the effects of New Zealand's complex topography. The statistical downscaling algorithm used is exactly the same as that applied in the previous edition of this Guidance Manual (Ministry for the Environment 2004), and the same as that described in Mullan et al (2001). The difference occurs in the observational datasets that were used. In the previous edition the downscaling algorithm was applied to individual climate station time series, evaluated at 58 temperature sites and 92 rainfall sites. For this edition, the downscaling is applied to a gridded dataset that covers all of New Zealand with 0.05° latitude–longitude boxes. There are approximately 11,500 grid points over the New Zealand land mass. The gridded data were developed by interpolating observed daily rainfall plus maximum and minimum temperatures from some hundreds of daily reporting sites (Tait et al 2006). The gridded data begin in January 1960 for rainfall, but not until January 1972 for temperature.

The downscaling procedure uses monthly anomalies over the period 1972–2003 to develop regression equations for precipitation and mean temperature. For each climate element, the grid-point anomaly is related to three predictors: the large-scale zonally-averaged anomaly over 160–190°E at the same latitude as the grid point, and the anomalous components of two wind indices known as the 'Trenberth Z1' and 'M1' indices (Trenberth 1976). The large-scale anomaly field, and the Trenberth indices that are derived from pressure differences (Z1=Auckland minus Christchurch, M1=Hobart minus Chatham Islands), are well-defined at the scale of the global climate model. These observed predictors are evaluated from NCEP re-analysis data[82] in the New Zealand region.

The regression equations are seasonally stratified and use the three contributing months in each season. As an example, Figure A3.1 shows the explained variance in the winter for both temperature and precipitation. Generally, the winter months have the lowest explained variance in temperature and the highest explained variance in precipitation, compared to other seasons.

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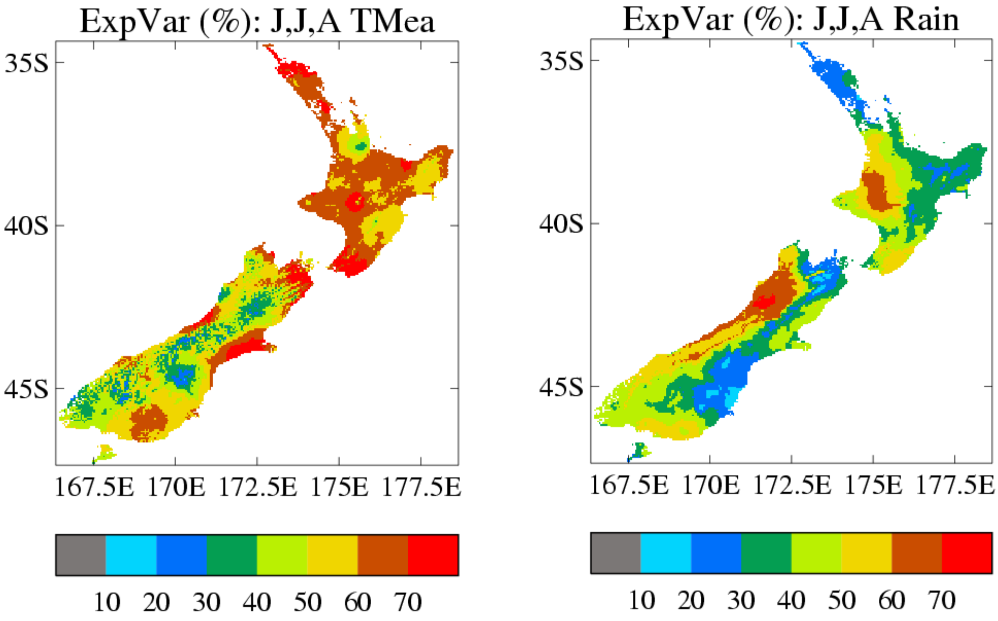
[81] 1° latitude corresponds to a distance of approximately 110 km.

[82] See reference to Kalnay et al. (1996) in Appendix 2.

This seasonal pattern in the explained variance in precipitation is what we might expect: in winter, precipitation is more strongly determined by large-scale weather systems (which are detected in the latitude-averages and wind indices), whereas in summer, much of the rainfall might be convective in nature and quite local to the observing site.

Figure A3.1: Explained variance of downscaling regression equation for the winter months (June, July, August), for mean monthly temperature (TMea, left panel) and monthly precipitation (Rain, right panel).



A useful amount of interannual variability is explained by this approach: more than 50% of the variation in monthly temperatures is explained at most locations, except at high altitude in the South Island. The underlying patterns with respect to Z1 and M1 variation are as we would expect: for example, more rain in the west and less in the east under positive Z1 anomaly (more westerly); and lower temperatures under positive M1 anomaly (more southerly).

The regression relations are formulated so that the departure of the local anomaly from the latitude-average anomaly is calculated from the anomalies in the wind indices. In simple terms, the circulation anomaly imposes spatial structure on the broad-scale change. Thus, if there is very low explained variance in the regression at some location, the climate change at that point will effectively be the same as the latitude-average evaluated at the model grid scale. In applying the regression to the future projections, the changes in circulation (Z1, M1 indices derived from the model mslp field) and in latitude-average climate (from model precipitation or temperature field), relative to the base period of 1980–1999, replace the observed monthly anomalies.

One further adjustment is made before downscaling the future changes. Mullan et al (2001) noted that there can be a systematic bias in the model simulation of the current climate: eg, the westerlies might be too strong over New Zealand in the model relative to observations, and this will cause the monthly variability and longer-term trends to also be too large. Thus, the changes (eg, 1980–1999 to 2030–2049) in the wind indices are scaled by a factor that makes the model interannual variance match the observed variance in the respective index. It turns out that all the models but one (*cnrm_cm3*) over-estimate the variation in the west–east wind component, and about half the models underestimate the variation in the north–south component.

A3.2 Model Projected Changes

Chapter 2 presents of the downscaled precipitation and temperature changes under the SRES A1B emissions scenario. Maps are shown for the annual average and seasonal average changes, as an average over the 12 climate models.

The range of projected changes, particularly when rescaled to the full IPCC emission range (Tables 2.2–2.5 in chapter 2), is often quite large. Indeed, for rainfall the results can sometimes suggest anything from a large decrease to a large increase in the amount of precipitation. We appreciate that this can make it difficult for a user to decide on an appropriate value to use in a risk assessment. The purpose of this section is to help the reader make these decisions by providing more information on the level of model agreement. In particular, while there are situations where model agreement is low, there are also instances (eg, a particular season or part of the country) where agreement is high.

A3.2.1 Annual mean projections for individual models

Figures A3.2 to 3.5 show projected changes in annual mean temperature or rainfall, at 2040 and 2090, separately for each of the 12 climate models analysed. The same colour scale is used in the 12 panels within each figure, to facilitate comparison between model projections.

The models tend to be fairly consistent through time in the relative amplitude of their respective changes and the spatial pattern. In the temperature projections, four of the models (*gfdl_cm20, miroc32_hires, mpi_echam5, mri_cgcm232*) tend to indicate that the North Island will warm faster than the South Island, whereas another four models (*cccma_cgcm3, csiro_mk30, ncar_ccsm30, ukmo_hadgem1*) show larger temperature increases in the South Island. The remaining four have a more complex pattern or little north–south gradient in the rate of warming. Two models (*csiro_mk30, mpi_echam5*) indicate noticeably less warming than the majority, and one (*miroc32_hires*), markedly more.

The projected changes in precipitation depend very much on whether the projected westerlies will increase or decrease across New Zealand. Nine of the models show a marked drying in the north and east of the North Island, and down the eastern coastal part of Marlborough and Canterbury, in the annual mean.[83]

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[83] The seasonal changes can, in some instances, be the opposite of the annual change (see Figures. 2.6 and 2.7, and Appendix 3.2.3).

Figure A3.2: Projected changes in annual mean temperature (in °C) for *2040*, relative to 1990 for the first six individual climate models for A1B emission scenario.

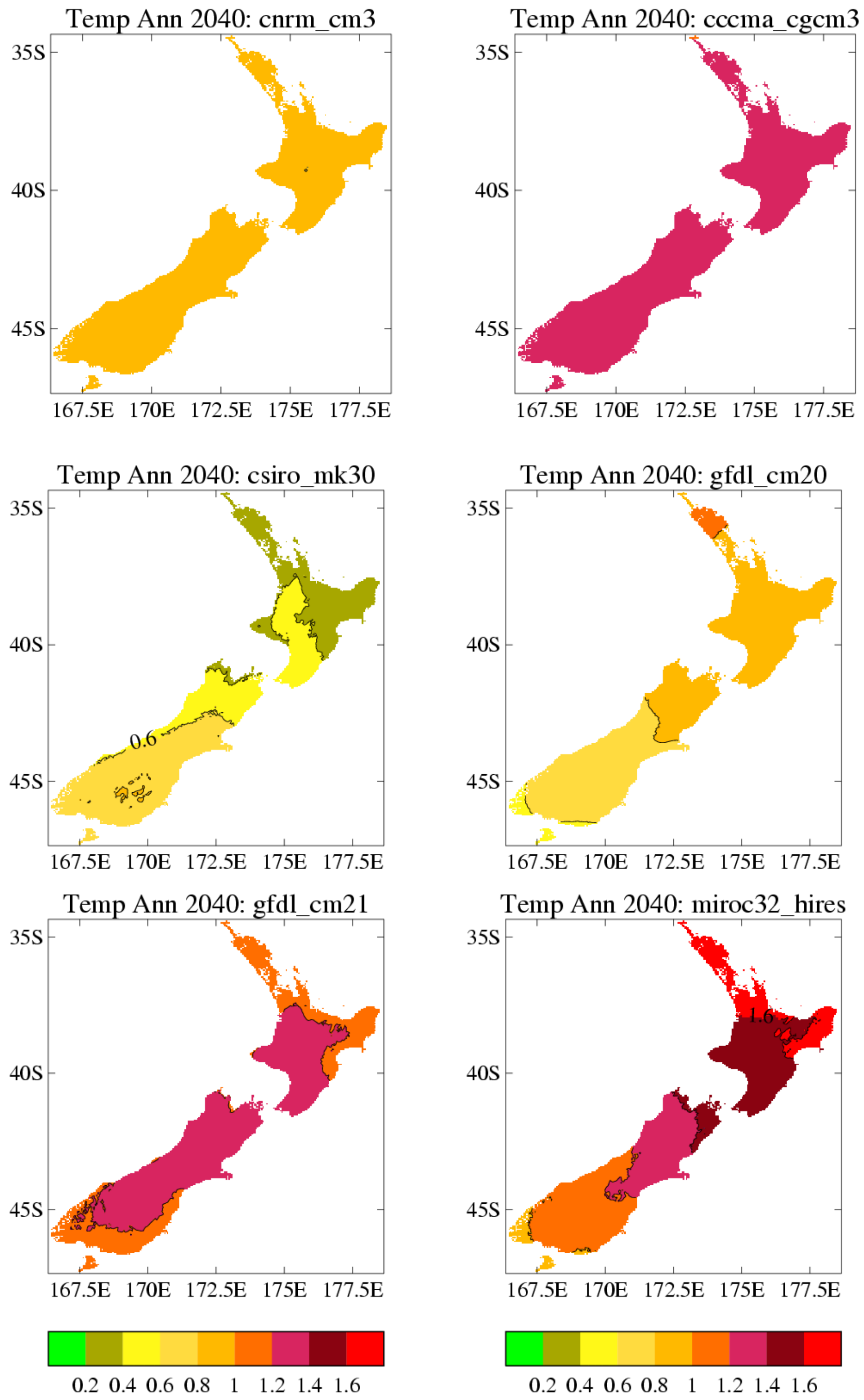


Figure A3.2 (cont.): Projected changes in annual mean temperature (in °C) for *2040*, relative to 1990 for the second six individual climate models for A1B emission scenario.

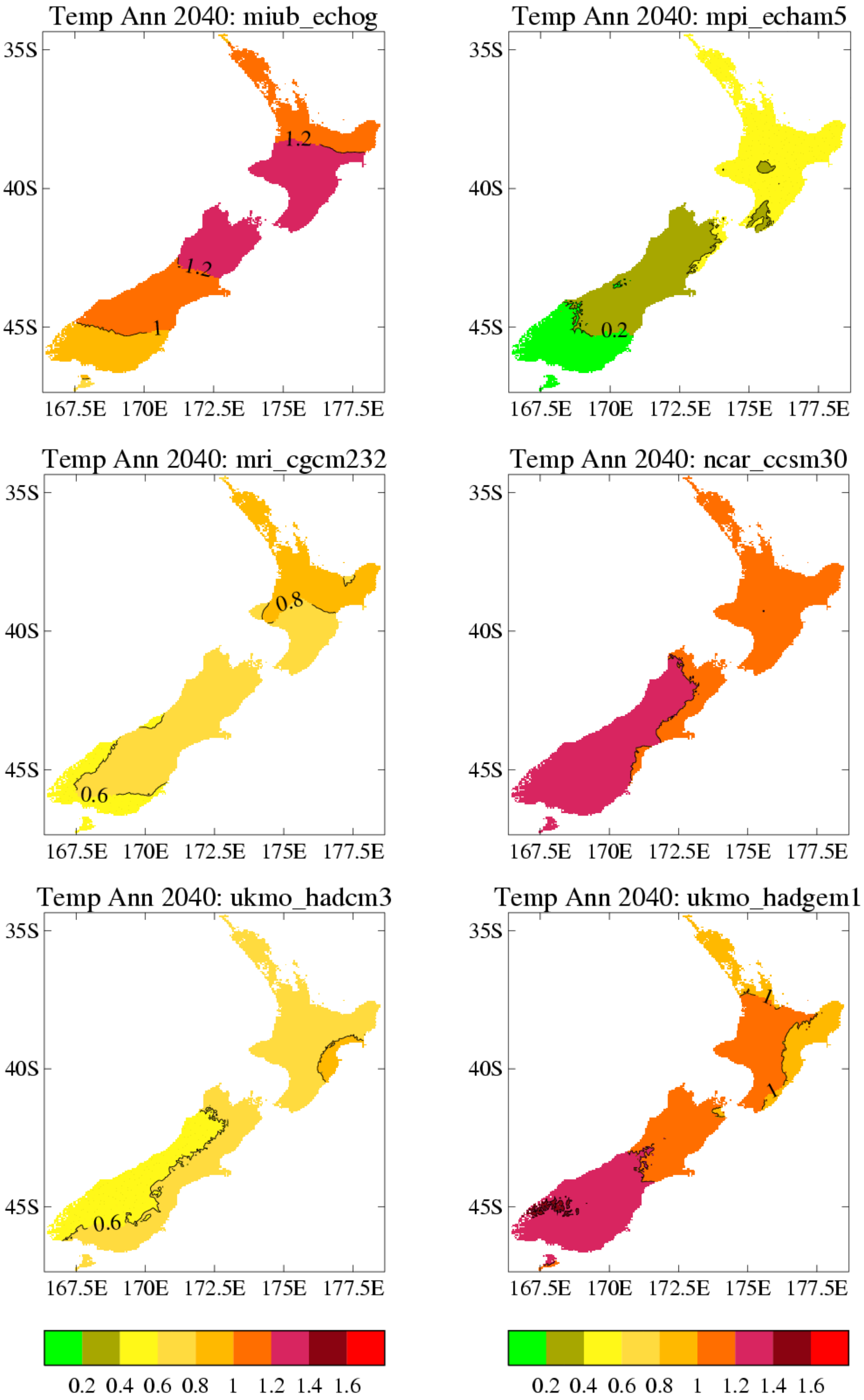


Figure A3.3: Projected changes in annual mean temperature (in °C) for *2090*, relative to 1990 for the first six individual climate models for A1B emission scenario.

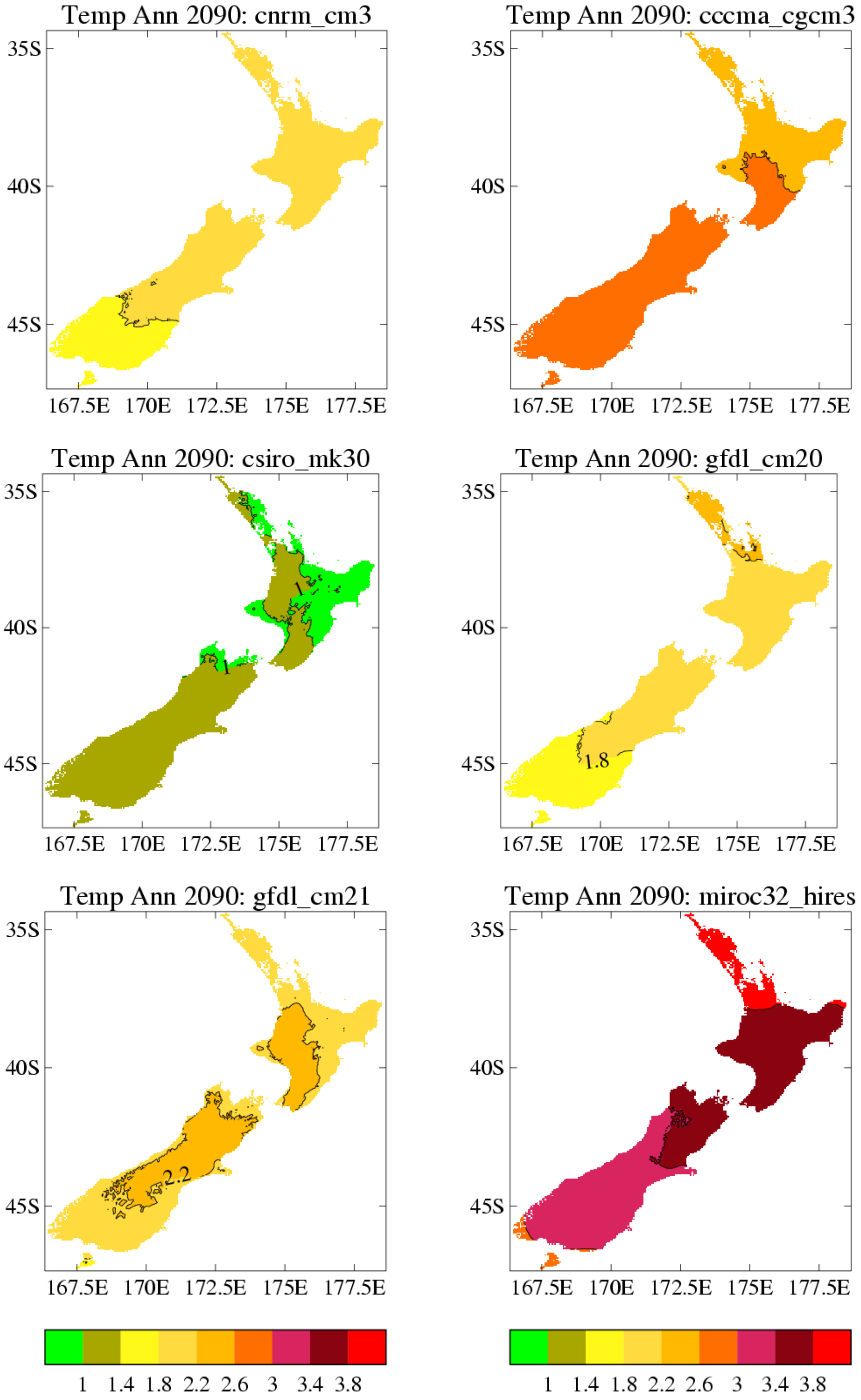


Figure A3.3 (cont.): Projected changes in annual mean temperature (in °C) for *2090*, relative to 1990 for the second six individual climate models for A1B emission scenario.

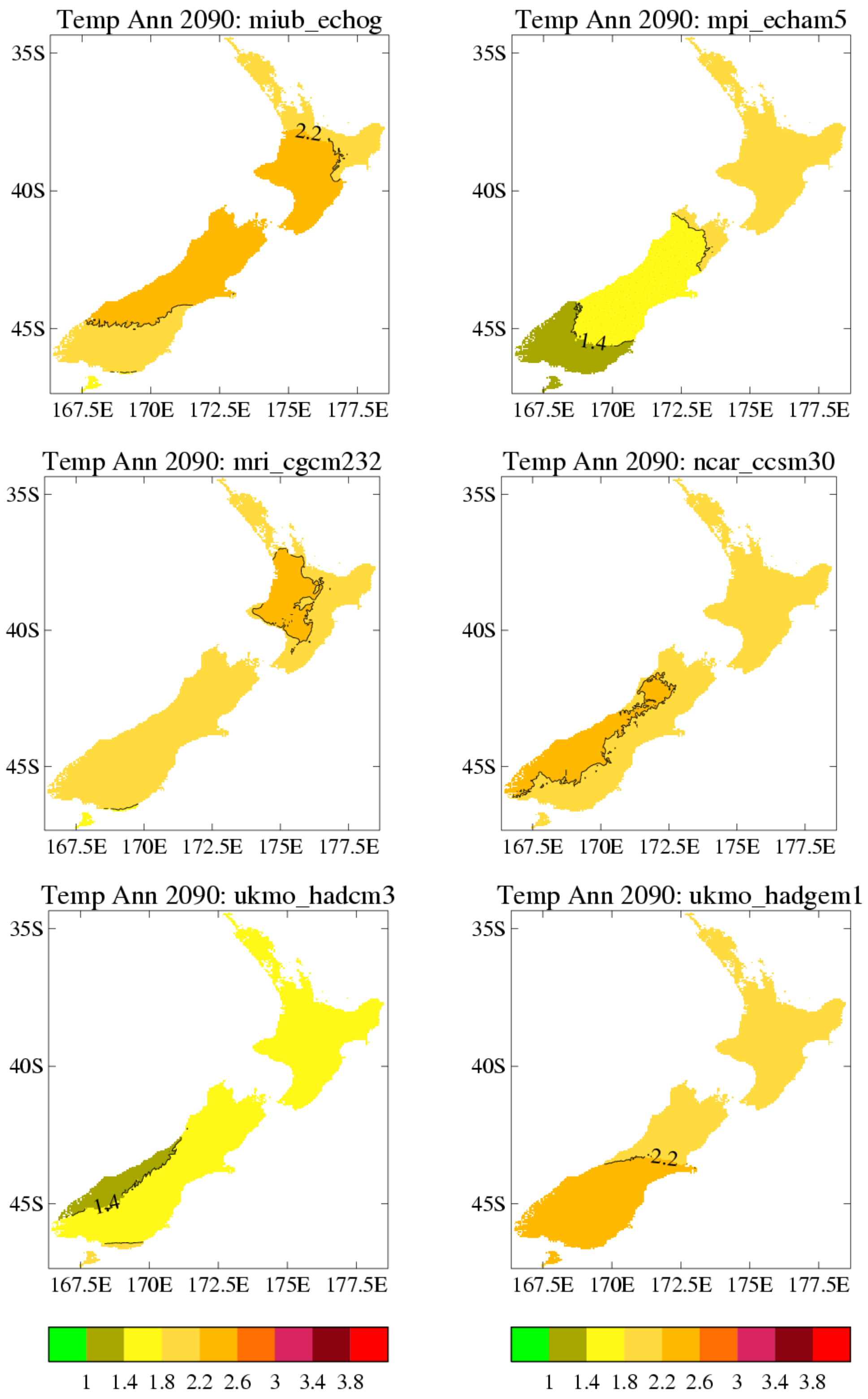


Figure A3.4: Projected changes in annual mean rainfall (in %) for *2040*, relative to 1990 for the first six individual climate models for A1B emission scenario.

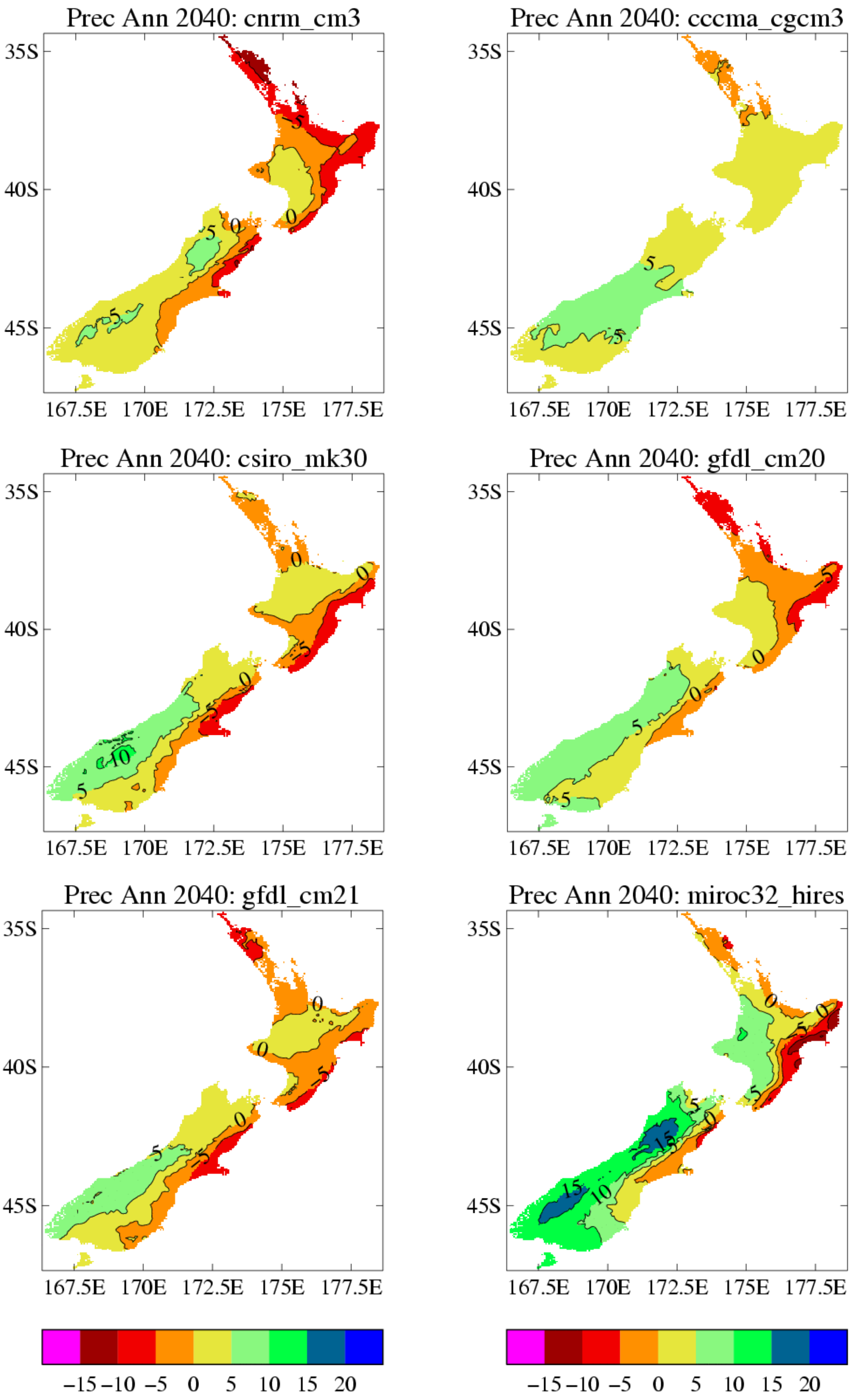


Figure A3.4 (cont.): Projected changes in annual mean rainfall (in %) for *2040*, relative to 990 for the second six individual climate models for A1B emission scenario.

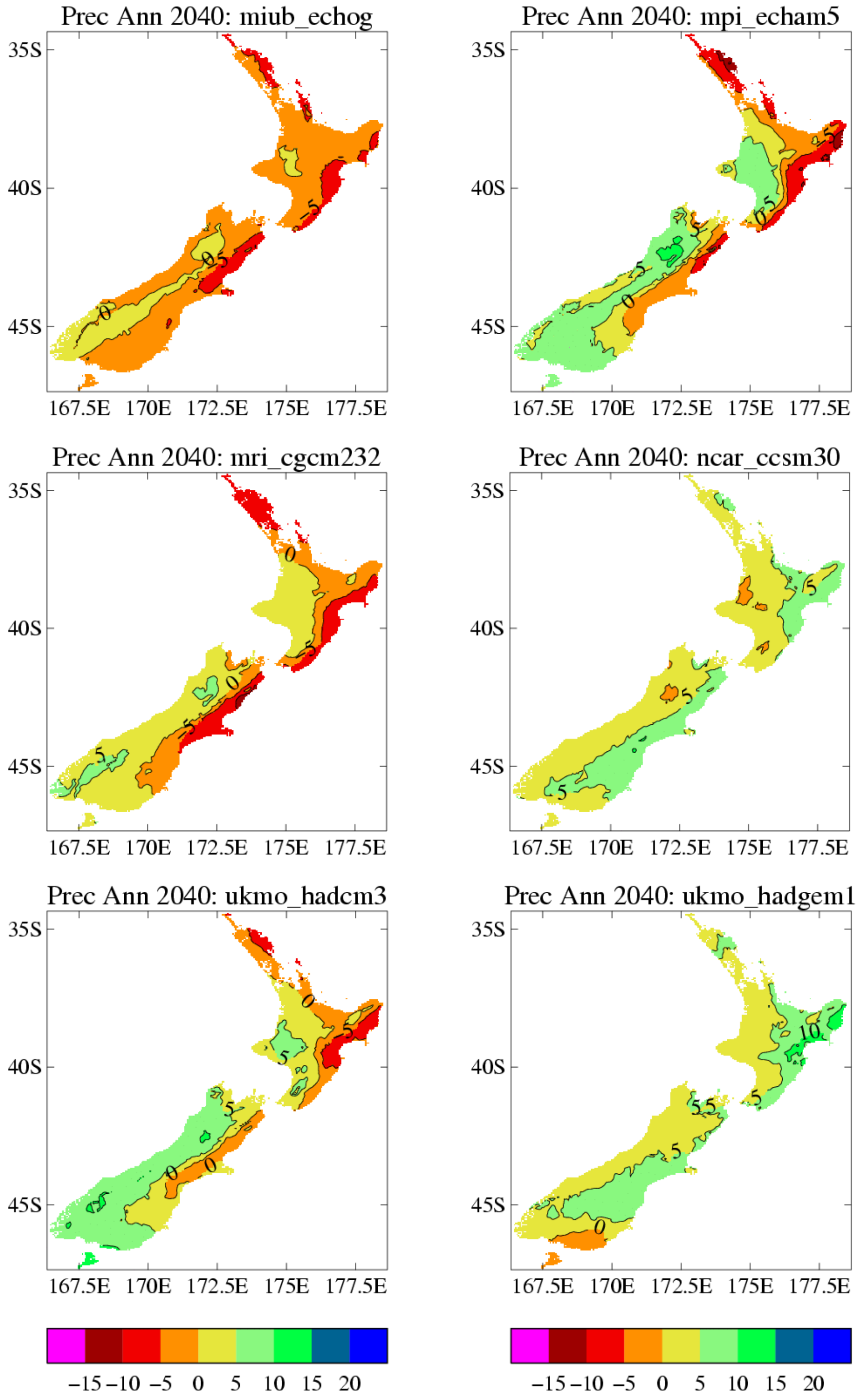


Figure A3.5: Projected changes in annual mean rainfall (in %) for *2090*, relative to 1990 for the first six individual climate models for A1B emission scenario.

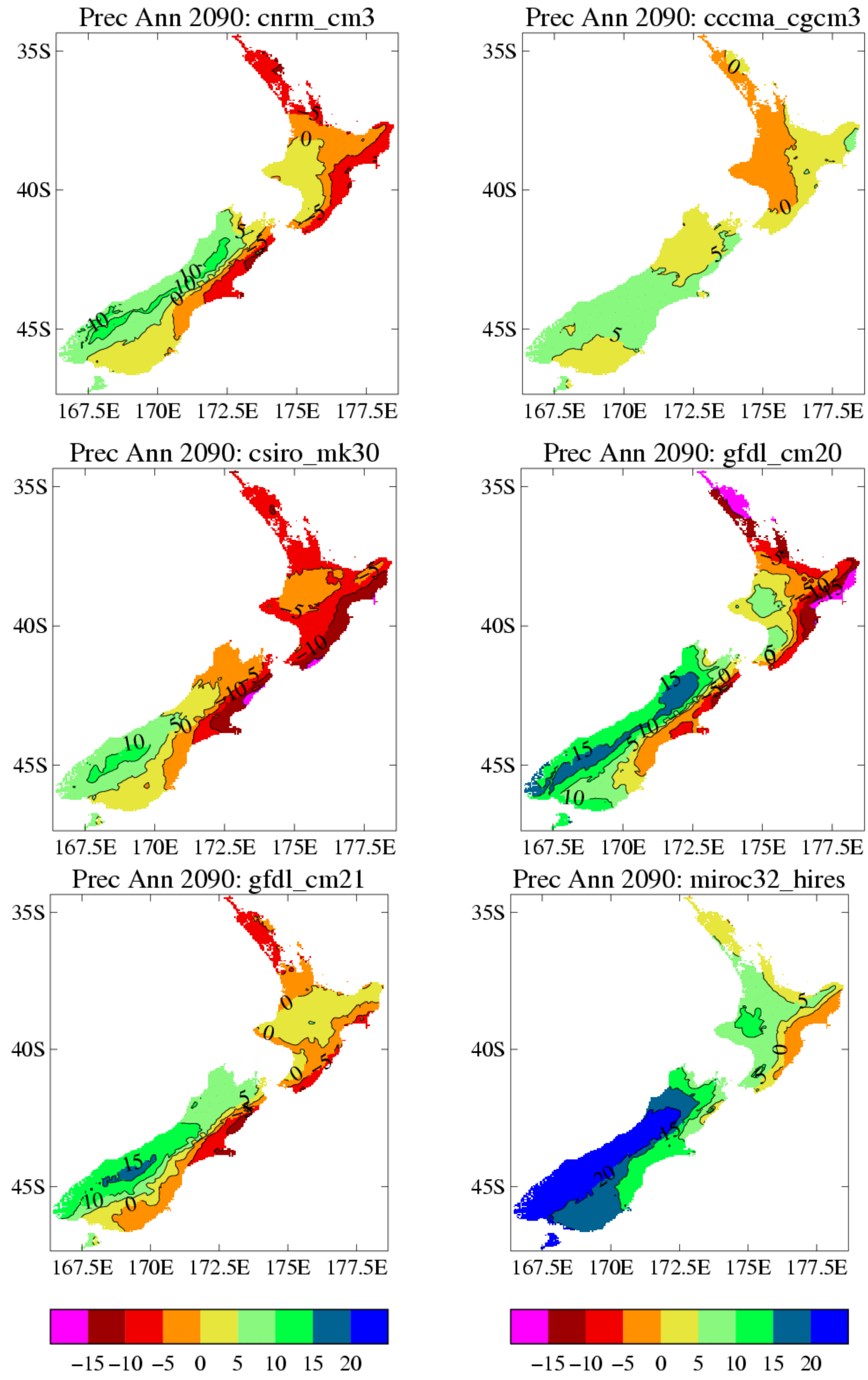
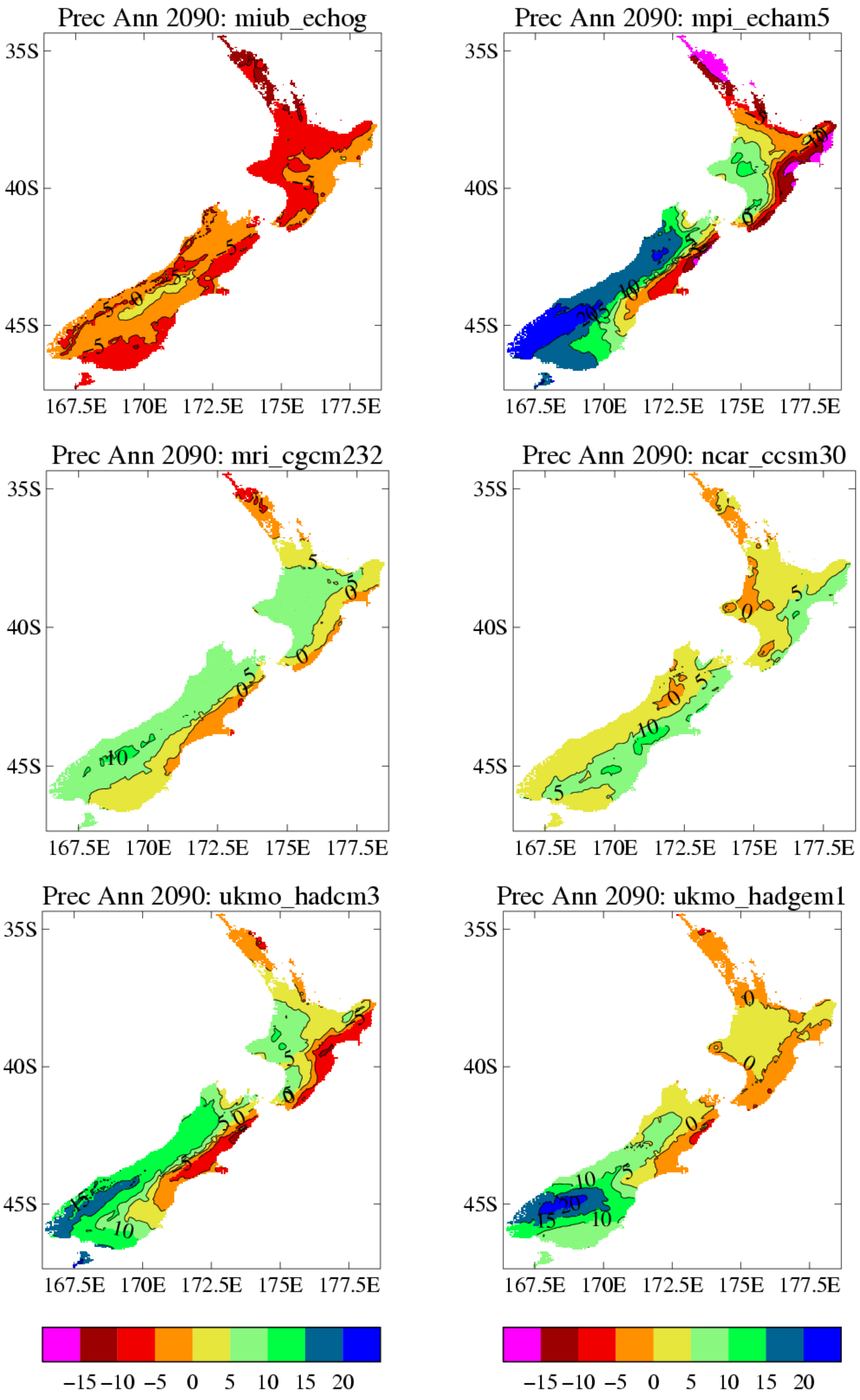


Figure A3.5 (cont.): Projected changes in annual mean rainfall (in %) for *2090*, relative to 1990: for the second six individual climate models for A1B emission scenario.



Prec Ann 2090: miub_echog

Prec Ann 2090: mpi_echam5

Prec Ann 2090: mri_cgcm232

Prec Ann 2090: ncar_ccsm30

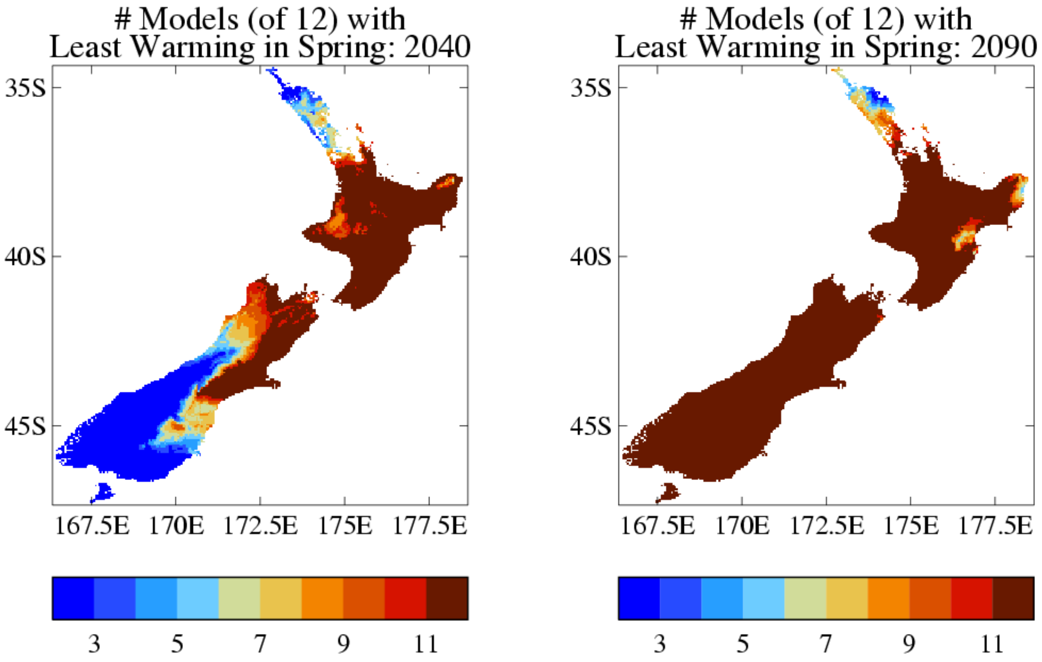
Prec Ann 2090: ukmo_hadcm3

Prec Ann 2090: ukmo_hadgem1

A3.2.2 Agreement on projected temperature change

An examination of Tables 2.2 and 2.3 in chapter 2 shows that the projected future warming is least in the spring season. This feature was not apparent in the previous New Zealand scenarios (Ministry for the Environment 2004). Figure A3.6 shows this result is very consistent across the 12 General Circulation Models.

Figure A3.6: Number of models, out of 12, that indicate spring will be the season with the least warming, by 2040 (left) and 2090 (right).



In Figure A3.6, the darkest red colour means 11 or 12 models have spring as the season of least warming. The darkest blue colour means just 0, 1 or 2 models choose spring. The second to darkest blue means three models choose spring, which is the number expected by chance if there is no systematic difference with season in the rate of warming. It is clear that there is strong agreement on the spring season showing the least warming. By 2090, only Northland shows no preference for the spring season. There is no season preferred for the most warming[84] (not shown) – at least, not for the country as a whole (Figure 2.4 shows of all four seasons, winter to have the greatest warming in the eastern South Island).

Figures 2.7 and 2.8 present maps of the annual temperature increase for each of the 12 models individually at 2040 and 2090. It is apparent that one model (*miroc32_hires*) indicates markedly more warming than any of the other 11. This is actually the main reason why the upper end of the projected warming is substantially higher in this updated edition than in the earlier edition of the Guidance Manual (Ministry for the Environment 2004).[85]

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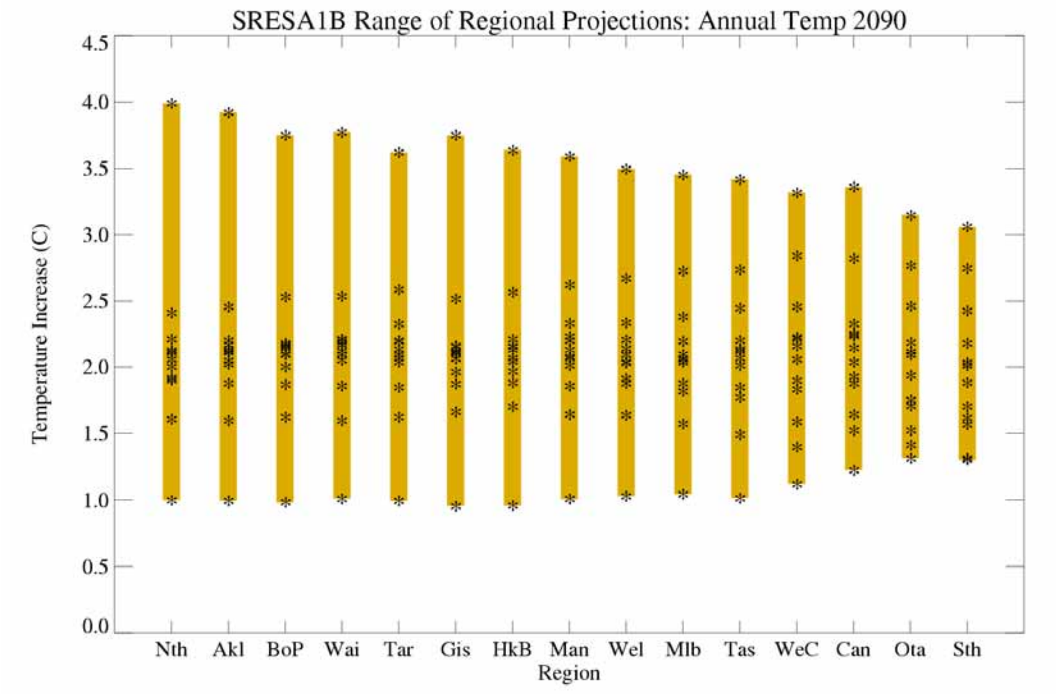
[84] In the corresponding Tables 2.2 and 2.3 of Ministry for the Environment (2004), winter appeared to be the season of most rapid warming in all regions (although by only a few tenths of a degree at most by the end of the 21st century).

[85] For example, the upper end of the annual warming range at 2090 (2080–2099 average) in Northland is now +5.9°C (Table 2.3), compared to +4.0°C to the 2080s (2070–2099) in the previous edition (Ministry for the Environment, 2004).

Figure A3.7 shows the situation across all regional council regions. The upper star on each vertical bar corresponds to the warming projected by the *miroc32_hires* model. If we consider the two extreme models as outliers in the distribution of projected temperature increase, then the average increase over the remaining 10 models is only slightly smaller than the 12-model results of Tables 2.2 and 2.3. However, the range of projected increases in annual temperature by 2090 is dramatically reduced for North Island regions: for example, in Northland the 12-model range of about 3°C (+1.0 to +4.0°C warming) decreases to less than 1°C (+1.6 to +2.4°C) for the A1B scenario shown in Figure A3.7.

Figure A3.7: Range in projected annual temperature change (in °C) by 2090 for the A1B emissions scenario.



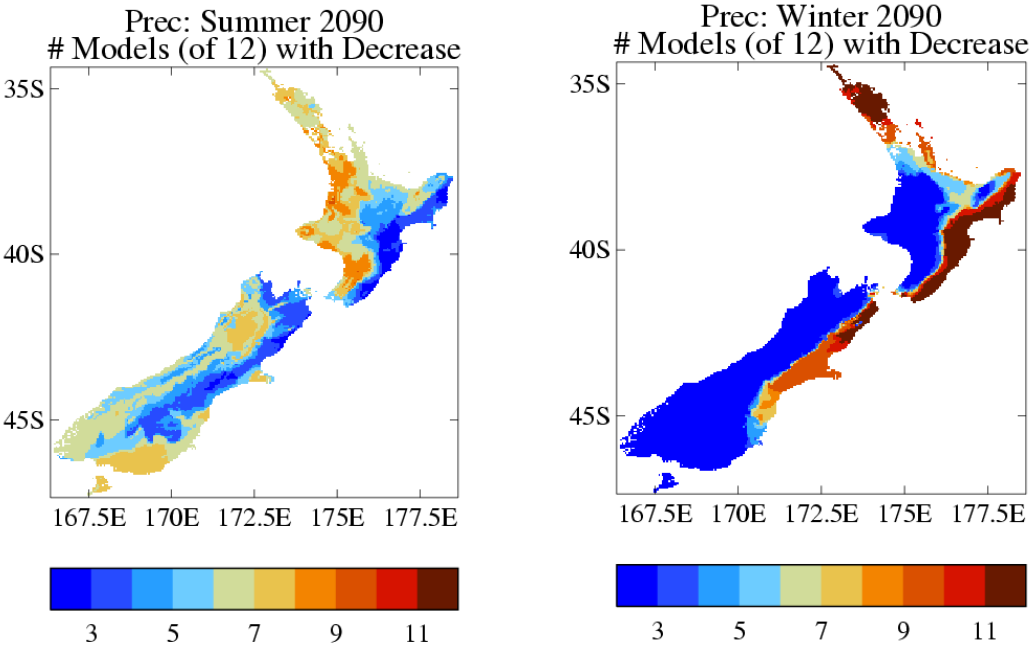
Note: 1990–2090 changes are averaged over all grid points within each of 15 regional council areas (as listed in Table 2.2). Regions are abbreviated by a three-letter code, but occur in the same order (north to south) as in Table 2.2. Vertical coloured bars show the range over all 12 models, and stars the 12 individual model values.

A3.2.3 Agreement on projected precipitation change

Agreement between the models on regional precipitation changes may not be that apparent from Tables 2.4 and 2.5, but actually does occur in some seasons and parts of New Zealand, as illustrated by Figure A3.8, at least if we restrict ourselves to considering just the sign of the precipitation change.

In Figure A3.8, the darkest red colour means 11 or 12 models predict decreases in the seasonal precipitation under the A1B scenario. The darkest blue colour means just 0, 1 or 2 models have decreases (or alternatively, 10–12 models agree on increased precipitation). It is clear that there is strong agreement that there will be wetter conditions in the western South Island, and simultaneously drier conditions in the north and east of the North Island, in the winter season (and also in spring, not shown). For the summer season (and also autumn, not shown), there is lower agreement between the 12 models on the sign of the precipitation change, but there is a tendency for wetter conditions in the eastern North Island.

Figure A3.8: Level of agreement between models on summer (left) and winter (right) precipitation changes to 2090. Each map gives the number of models, out of 12, that indicate decreased precipitation in the season shown.



This seasonality of projected precipitation changes can be understood to some degree by examining the pressure changes. Figure A3.9 illustrates changes at 2090 in the summer and winter pressure fields, averaged over all 12 climate models used in the downscaling. Under a global warming scenario, precipitation increases in the tropics, and the overturning Hadley circulation intensifies and expands to higher latitudes (Meehl et al 2007; Yin 2005). This results in higher pressures in the descending branch of the Hadley cell, which in the present climate is located just north of New Zealand in the annual mean, but moves down over the North Island in summer. The circulation changes simulated for 2090 suggest that in the summer season (Figure A3.9, left panel) the high pressure belt is sufficiently far south that there is more of an easterly component to the wind flow over the North Island. The southward movement of the anticyclone belt does of course vary from model to model, but is consistent with increased rainfall in the east of the North Island.

The situation is different in the winter season, when the Hadley cells move northward with the sun. Even with a future southwards expansion, the axis of highest pressure is still to the north of New Zealand. There is, therefore, an increase in the north–south pressure gradient across the country, which drives stronger or more persistent westerly winds. This circulation response is very consistent across the global climate models, and is the reason for the strong agreement on increased rainfall in the west of the South Island and decreases in the east of the North Island in the winter season.

Figure A3.9: Change by 2090 in mean sea-level pressure (in hPa) for summer (left) and winter (right), averaged over 12 climate models.

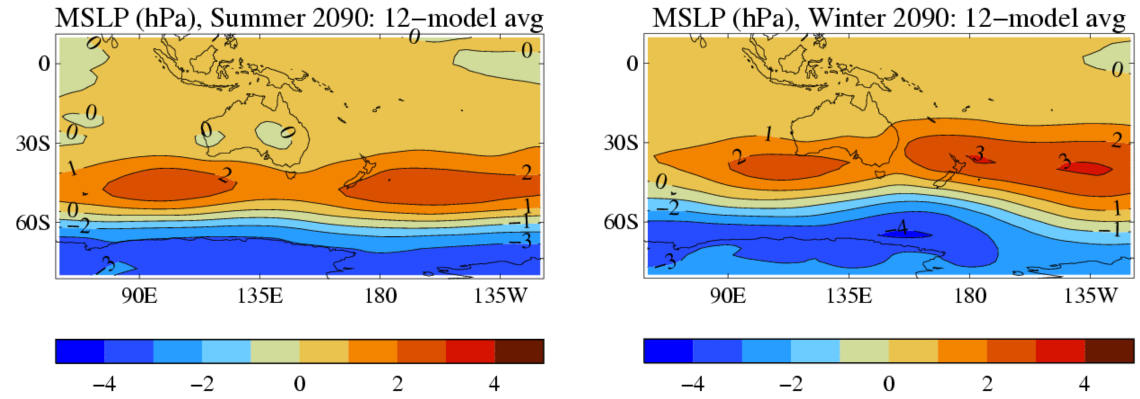
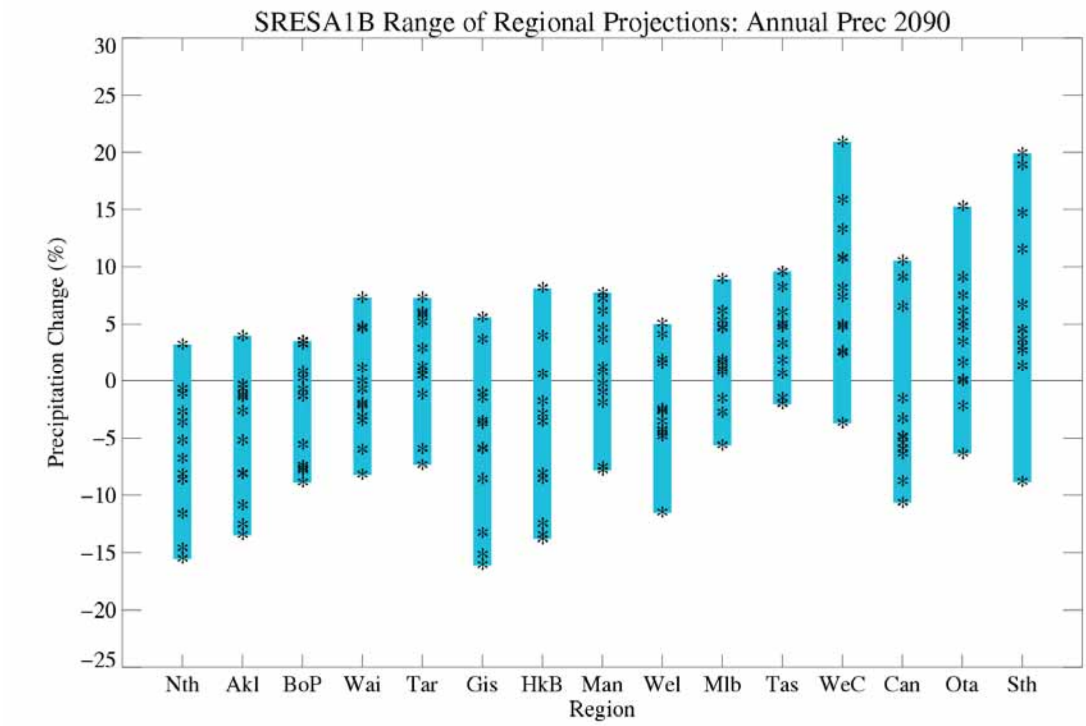


Figure A3.10: Range in projected annual precipitation change (in %) by 2090 for the A1B emissions scenario.



Note: 1990–2090 changes are shown for one site within each of 15 regional council areas (the grid point is co-located with the first named city for each region, as listed in Table 2.4). Thus, the Northland (Nth) site is Kaitaia, the Canterbury (Can) site is Christchurch, etc. Vertical coloured bars show the range over all 12 models, and stars the 12 individual model values.

Figure A3.10 indicates the model spread in annual precipitation for a selection of sites across all 15 regional council regions. If the lowest and highest models are again considered as outliers, the projected range from the remaining 10 models is (of course) reduced, but not as dramatically as it is for temperature. In most regions, the projected rainfall still covers both increases and decreases. Nevertheless, four of the regional sites in Figure A3.10 show full agreement among models on the sign of the rainfall change, in the annual mean, after removing the low and high outliers. Thus, the Northland and Auckland sites have decreased annual rainfall indicated by all (10) models, and the West Coast and Southland sites have increased annual rainfall from all models.

A3.3 Changes in Extreme Precipitation

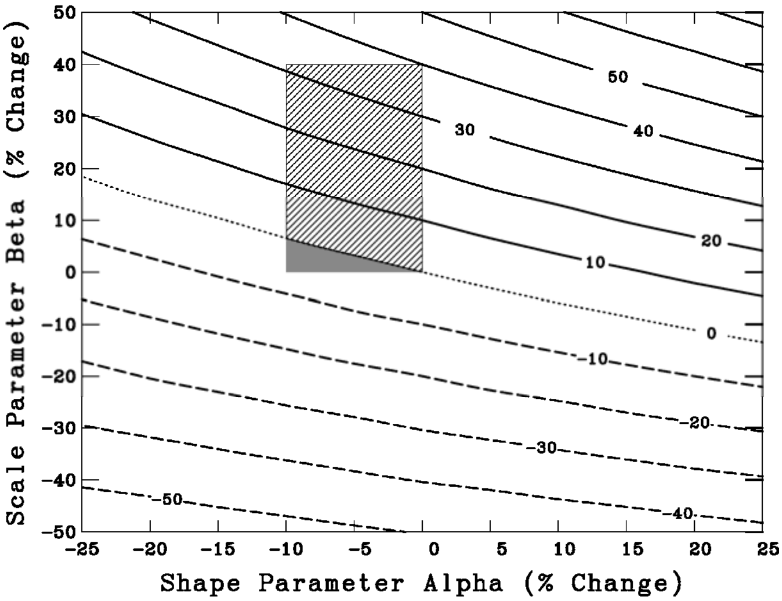
The Fourth Assessment Report, relying on both observational and modelling studies, declared that more intense precipitation events were ‘very likely’ to increase over many areas of the globe (IPCC 2007: table SPM.1). This might not necessarily apply to a region as small as that of New Zealand, particularly to those parts where the annual mean rainfall is projected to decrease. However, a warmer atmosphere can hold more moisture (about 8% more for every 1°C increase in air temperature), and so there is potential for heavier extreme rainfalls.

An alternative way of viewing these systematic increases in average rainfall intensity is to say that a reduction in the return period of heavy rainfall events is expected. Estimates of projected changes in return periods for New Zealand were provided by Whetton et al (1996), who suggested that: by 2030, there would be ‘no change through to a halving of the return period of heavy rainfall events’, and by 2070, ‘no change through to a fourfold reduction of the return period’. This statement was based on analysing daily precipitation time series from a regional climate model, driven by the CSIRO equilibrium General Circulation Model. Very recent results from the NIWA regional climate model are described in chapter 2.

Further useful information on how daily precipitation extremes could change for New Zealand is available in the paper by Semenov and Bengtsson (2002). These authors present global maps of changes in total rainfall and in the 95th percentile daily value. They also analyse changes in the rainfall distribution. The ‘normal’ distribution (Figure Box 2.1), which is symmetrical about the mean, is not appropriate for rainfall, which is commonly represented by the so-called ‘gamma’ distribution (see Figure A3.12). The parameters of the gamma distribution are known as the ‘shape factor’ (‘alpha’, α) and the scale factor (‘beta’, β). For alpha less than 1, as is always the situation for New Zealand, the higher the rainfall amount, the less frequently it occurs. If alpha increases above 1, then there is a peak mode or most likely rainfall amount. As alpha increases further, the gamma distribution tends to the same shape as the normal distribution. The mean rainfall averaged over days when it rains (the so-called ‘rainfall intensity’) is simply the product of these two factors (ie, $\alpha\beta$). The gamma distribution applies only to rain days. The other relevant factor is the likelihood of it raining at all (probability of a wet day, P_w). The change in mean rainfall (section 2.2.2) is, therefore, the change in the triple product $P_w\alpha\beta$.

Semenov and Bengtsson (2002) mapped the changes in alpha and beta, as simulated by their model (which corresponds to the MPI model used by Mullan et al 2001). Outside the tropical and subtropical oceans, alpha generally decreases (by up to 10%), whereas beta generally increases (by up to 40%). Figures A3.11 and A3.12 illustrate how this projection might be applied at a particular site. Thirty years of observed daily winter rainfall data at Auckland (Whenuapai) are used to compute the distributional parameters alpha (= 0.735) and beta (= 10.19). By systematically varying alpha and beta from their observed values, we can generate a surface that represents how the daily winter rainfall might change by 2100. In this case, Figure A3.11 shows how the 95th percentile winter daily rainfall amount for the present climate (= 25.0 mm) could change. Over the (shaded) range of alpha and beta parameters suggested by Semenov and Bengtsson (2002), Figure A3.11 shows that this winter extreme rainfall could vary from about 6% less than present (10% decrease in alpha, with no change in beta) to 40% more than present (no change in alpha, with 40% increase in beta). Either of these changes could be made consistent with the scenario of mean rainfall change by adjusting the number of wet days. A similar study of rainfall distributional changes (Voss et al 2002) found virtually no change in the alpha parameter, but consistent increases in beta, when averaged over large areas of the globe.

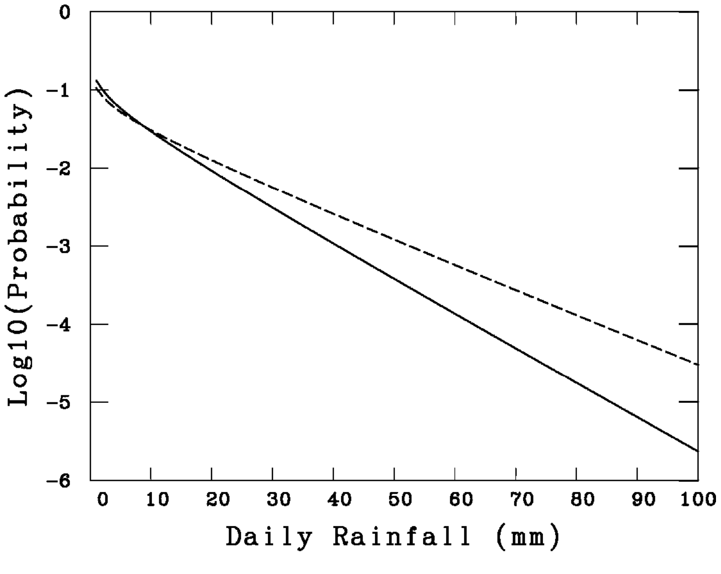
Figure A3.11: Percentage change in Auckland's 95th percentile daily rainfall amount, as a function of changes in the parameters (alpha and beta) of the gamma distribution.



Note: Shaded region shows the range of changes by 2100 in alpha and beta projected for the New Zealand region by Semenov and Bengtsson (2002). Hatched shading indicates increases in the 95th percentile value, and solid shading indicates decreases.

Figure A3.12 plots the gamma distribution for this 2100 extreme case of no change in α but a 40% increase in β. The figure shows that a daily winter rainfall amount of about 100 mm, which was exceeded only once in the 30 years of observed record, would become at least 10 times more likely under this particular scenario.

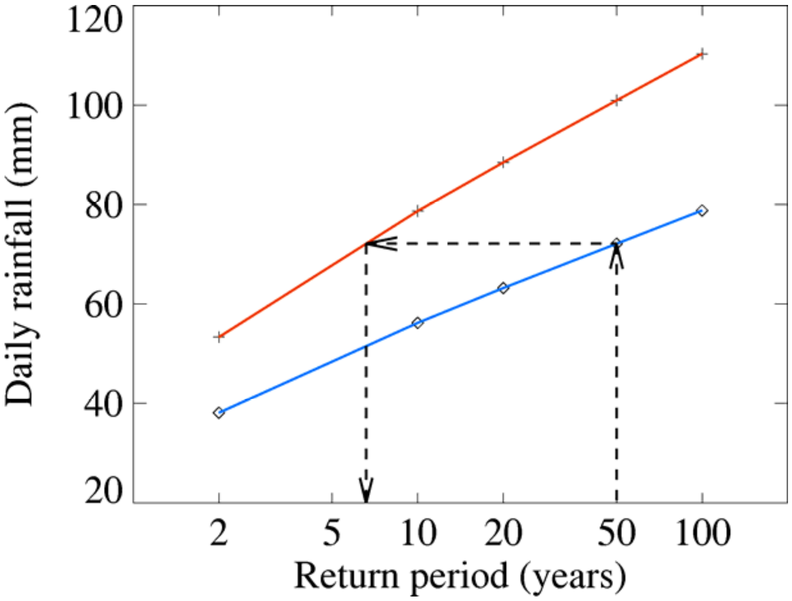
Figure A3.12: Effect on probability of extreme daily winter rainfall at Auckland for an increase in the beta parameter of the gamma distribution, but no change in the alpha parameter.



Note: Lines show the probability (on a logarithmic scale) of a particular daily rainfall amount for present winter daily rainfall at Auckland (solid line), and for a changed climate with a 40% increase in beta (dashed line). An increase of one unit on the vertical axis corresponds to a 10-fold increase in probability of occurrence.

Figure A3.13 shows the extreme rainfall data translated into return periods. The data were generated by random sampling from the gamma distribution, firstly using the α,β parameters fitted to winter observations at Auckland, and repeated with a 40% increase in β. Return periods were estimated by fitting an EV1 (Extreme Value type 1) distribution to the highest daily rainfall for each of 30 winters. The result (Figure A3.13) indicates that a rainfall amount with a return period of 50 years under the present climate has a return period of about 7 years at 2100 in this worst case. This sevenfold reduction in return period is broadly consistent with the earlier estimates of Whetton et al (1996).

Figure A3.13: Effect on return period of extreme daily winter rainfall at Auckland for an increase in the beta parameter of the gamma distribution, but no change in the alpha parameter.



Note: Comparing the present climate (blue line, below) with the extreme change at 2100 (red line, above), as inferred from the gamma distributions changes of Semenov and Bengtsson (2002). The dotted lines shows how the 50-year return period under the present climate, associated with a rainfall amount of about 72 mm, changes to a return period of about 7 years for this worst case scenario.

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Appendix 4: An Example of the Preliminary Scenario Method for Extreme Rainfall

This Appendix illustrates the application of the preliminary scenario method for extreme rainfall using information from Table 2.2 and Table 5.2. The example is for Christchurch Airport. A table showing current design rainfall rates for various durations and return periods was first prepared. Further tables were then developed for percentage increases to the design rainfall rates for low and high temperature change scenarios for 2030. The percentage increase tables were then applied to the first table, to provide low and high scenario tables for actual rainfall rates in 2030. These could be used in, for example, a preliminary examination of the resilience of existing stormwater drainage systems to plausible 2030 extreme rainfall rates.

This appendix does not address uncertainties in the base period design rainfall depth estimates. As mentioned in Section 5.2, it is good practice to consider such uncertainties as part of the assessment of the likely impacts of changes in heavy rainfall.

Table A4.1 shows design rainfall depth frequency estimates for Christchurch Airport data from the period 1971–2000.[86]

Table A4.1: Base data for design rainfall depth (in mm) for 1971–2000, Christchurch Airport. ARI is average recurrence interval (ie, return period).

ARI (years) → Duration ↓	2	5	10	20	50	100
10 minutes	4.4	6.2	7.9	9.9	13.3	16.6
30 minutes	7.9	11.2	14.2	17.9	23.9	29.8
1 hour	11.4	16.3	20.6	25.9	34.7	43.2
2 hours	16.1	22.4	27.9	34.5	45.3	55.5
6 hours	27.8	37.2	45.1	54.3	69.0	82.5
12 hours	39.3	51.2	61.1	72.3	90.0	106.0
24 hours	55.5	70.5	82.7	96.4	117.4	136.2
48 hours	68.4	87.0	102.1	118.9	144.9	168.1
72 hours	77.4	98.4	115.4	134.5	163.9	190.1

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[86] Calculated using a beta-test version of HIRDS3.

From Table 2.2 of this Guidance Manual, projected annual mean temperature changes for Christchurch for 1990–2040 are 0.2 (low), 0.9 (medium) and 1.9°C (high).

The percentage increases in extreme rainfall for the preliminary screening analyses are obtained by multiplying entries from Table 5.6 by these temperature changes, resulting in the following two tables (Table A4.2 and A4.3).

Table A4.2: Increase (in %) in extreme rainfalls, 2040, Christchurch Airport, *low* scenario. ARI is average recurrence interval (ie, return period).

ARI (years) → Duration ↓	2	5	10	20	50	100
10 minutes	1.6	1.6	1.6	1.6	1.6	1.6
30 minutes	1.4	1.5	1.5	1.6	1.6	1.6
1 hour	1.3	1.4	1.5	1.5	1.6	1.6
2 hours	1.2	1.3	1.4	1.5	1.6	1.6
6 hours	1.1	1.2	1.4	1.5	1.6	1.6
12 hours	1.0	1.2	1.3	1.5	1.6	1.6
24 hours	0.9	1.1	1.2	1.4	1.6	1.6
48 hours	0.8	1.0	1.2	1.4	1.6	1.6
72 hours	0.7	1.0	1.2	1.4	1.6	1.6

Table A4.3: Increase (in %) in extreme rainfalls, 2040, Christchurch Airport, *high* scenario. ARI is average recurrence interval (ie, return period).

ARI (years) → Duration ↓	2	5	10	20	50	100
10 minutes	15.2	15.2	15.2	15.2	15.2	15.2
30 minutes	13.7	14.1	14.4	14.8	15.2	15.2
1 hour	12.7	13.5	14.1	14.6	15.2	15.2
2 hours	11.8	12.7	13.7	14.4	15.2	15.2
6 hours	10.1	11.6	12.9	14.1	15.2	15.2
12 hours	9 1	11.0	12.4	13.9	15.2	15.2
24 hours	8.2	10.3	12.0	13.7	15.2	15.2
48 hours	7.2	9.5	11.6	13.5	15.2	15.2
72 hours	6.7	9.1	11.2	13.3	15.2	15.2

Actual low and high scenarios for 2040 depth frequency values can now be estimated, as given in the tables below, by adjusting values from the first table in this appendix by the values in the percentage change tables, as follows:

Table A4.4: Extreme rainfall rate scenario for 2040, Christchurch Airport, *low* temperature change scenario. ARI is average recurrence interval (ie, return period).

ARI (years) → Duration ↓	2	5	10	20	50	100
10 minutes	4.5	6.3	8.0	10.1	13.5	16.9
30 minutes	8.0	11.4	14.4	18.2	24.3	30.3
1 hour	11.5	16.5	20.9	26.3	35.3	43.9
2 hour	16.3	22.7	28.3	35.0	46.0	56.4
6 hours	28.1	37.6	45.7	55.1	70.1	83.8
12 hours	39.7	51.8	61.9	73.4	91.4	107.7
24 hours	56.0	71.3	83.8	97.7	119.3	138.4
48 hours	68.9	87.9	103.3	120.6	147.2	170.8
72 hours	77.9	99.4	116.8	136.4	166.5	193.1

Table A4.5: Extreme rainfall rate scenario for 2040, Christchurch Airport, *high* temperature change scenario. ARI is average recurrence interval (ie, return period).

ARI (years) → Duration ↓	2	5	10	20	50	100
10 minutes	5.1	7.1	9.1	11.4	15.3	19.1
30 minutes	9.0	12.8	16.2	20.5	27.5	34.3
1 hour	12.8	18.5	23.5	29.7	40.0	49.8
2 hours	18.0	25.2	31.7	39.5	52.2	63.9
6 hours	30.6	41.5	50.9	62.0	79.5	95.0
12 hours	42.9	56.8	68.6	82.3	103.7	122.1
24 hours	60.1	77.8	92.6	109.6	135.2	156.9
48 hours	73.3	95.3	113.9	135.0	166.9	193.7
72 hours	82.5	107.4	128.3	152.4	188.8	219.0

Appendix 5: Climate Change in Plans – Checklist for Contents

Statute	Name of plan	Duration of plan	Purpose	Checklist for contents
Local Government Act 2002	Long-term Council Community Plan	10 years, but reviewed every 3 years. Can be changed when an annual plan is prepared.	Describe community outcomes for the district or region. Provide a long-term focus for local authority decisions. Provide financial estimates to manage council/ community assets.	Are the long-term implications of climate change identified anywhere in relation to community outcomes? Is any statement clear and able to be measured or monitored? If not, is there a comment explaining why not? How is the time frame of climate change effects handled? Is there adequate explanation of the need to act within the framework of the current plan, although effects may become apparent only during the preparation of future plans? Are adaptive responses to potential climate changes identified in relation to specific assets or activities (water supply, wastewater, stormwater, roading, pest management, parks and reserves management, etc.)? Are these responses specific and targeted to the asset? If a change in level of service, or additional capacity, is planned owing to climate change (ie, requirements will be beyond the level of service or capacity based on other considerations), is this explicit and explained? Are other programmes or plans relating to climate change identified (eg, biosecurity, biodiversity) and details and budgets specified? Is a monitoring regime relating to the aspect involving a climate change response identified and are mechanisms, costs and duration foreshadowed? Are the levels of uncertainty involved in the forecasts of climate change explained, and an estimate of the uncertainty provided?
	Annual Plan	Annual	Support the Long Term Council Community Plan in integrated decision-making and co-ordination of the local authority resources; and provide an annual budget and funding impact statement for the local authority.	Are the budget requirements, in relation to climate change responses identified in the Long Term Council Community Plan, explicitly followed through • for development, maintenance and management of specific assets? • in terms of any investigation or research needs for the year? • in terms of ongoing monitoring?

Statute	Name of plan	Duration of plan	Purpose	Checklist for contents
	Annual Report	Annual	Report on the Annual Plan, measuring activities and expenditure against desired community outcomes and sustainable development.	Are specific Annual Plan provisions relating to climate change reported appropriately, including asset management? If the expected outcome has not been achieved, has this been explained?
Resource Management Act 1991	Regional Policy Statement	10 years, but can be reviewed or changed at any time.	Achieve the sustainable and integrated management of natural and physical resources, by providing an overview of a region's resource management issues, policies and methods.	Is climate change and its effects identified as a regional issue requiring a response? Does the Policy Statement explain the national policy context? Does the Regional Policy Statement specify the time horizon for different types of decisions on climate change and its effects? Does the Regional Policy Statement give pointers for the formulation of regional and district plan contents relating to managing the effects of climate changes? Are the respective roles and responsibilities of the regional and district councils in managing natural hazards in the region set out? Does the Regional Policy Statement promote consistency of approach towards climate change by local authorities within the region and across boundaries with neighbouring regions? Does the Regional policy Statement promote public education as a method of response to climate change and its effects? Does the Regional Policy Statement promote avoidance or limitation of damage and costs from natural hazards, including those exacerbated by climate change, such as: • sea-level rise • increased rainfall intensity • increased incidence of severity or drought • wind events? Does the Regional Policy Statement include provisions for monitoring the effects of climate change, and any relevant statements of environmental outcomes?

Statute	Name of plan	Duration of plan	Purpose	Checklist for contents
	Regional plans	10 years, but can be reviewed or changed at any time.	Achieve the integrated management of natural and physical resources; managing and controlling land for soil erosion and natural hazards; managing and controlling water resources and beds of rivers and lakes; and managing and controlling the coastal marine area.	Depending on the plan ... Is climate change and its implications identified as an issue? If it is not, is there a valid explanation for why not? Are the approach and policy for climate change consistent with the Regional Policy Statement? Are there one or more objectives relating to climate change, which are adequately explained and integrated with policy and rules? If there are rules or methods that relate to or rely on climate change as a partial or complete justification for their existence (eg, water allocation, flood design clearances, prohibiting building areas), is the provision clearly explained? Are there any decision-making criteria related to taking the implications of climate change into account? Are these explained? Are there provisions for monitoring relevant to climate change effects, and relevant statements of environmental outcomes as a result of the provision(s)? Is there a specific commitment that the council will keep up-to-date with changing understanding of climate change and its implications?
	District Plan	10 years, but can be reviewed at any time.	Integrated management of the effects of use, development and protection of a district's natural and physical resources; and control of land in relation to natural hazards.	Is climate change identified as an issue in the District Plan with adequate explanations? How is the issue expressed in terms of objectives and policies? Is the approach and policy for climate change consistent with the Regional Policy Statement? Have areas of enhanced risk (eg, hazard zones, building lines) due to climate change been identified, with appropriate policy and rules? Do the decision-making criteria relating to natural hazards refer to climate change and its implications?

Statute	Name of plan	Duration of plan	Purpose	Checklist for contents
Civil Defence Emergency Management Act 2002	Civil Defence Emergency Management Group Plan	5 years, but can be reviewed sooner.	Developing an integrated community-based response to the sustainable management of hazards.	Has the risk management analysis taken into account changes due to climate change? Does the recognition of the effects of climate change reflect the current level of uncertainty in the region and adopt a cautious approach as a result? If not, is this explained? Does the plan include a specific commitment to keep up-to-date with changing understanding of climate change and its implications, including any relevant local monitoring or liaison?
Plans under other legislation, and/or plans that have no specific statutory basis	For example, Reserve Management Plans, Asset Management Plans, Catchment Management Plans, Landcare and Biosecurity Management Plans	Usually no set times. Plans should state their review periods.	A range of purposes. Plans should explain their purpose through stated objectives and policies.	Depending on the plan ... Are there any statements or provisions relating to climate change and managing the effects? If there are, are these appropriately linked to aspects of the plan that have long-term consequences (eg, a Reserve Management Plan may appropriately incorporate climate change considerations in relation to species choice for major planting programmes, or recognition of increased drought or flooding in design and subsequent maintenance costs of playing fields; Asset Management Plans may include expectations of changed levels of service needed in the future due to climate change; Landcare Plans may identify aspects such as reduced soil moisture in an area and promote a gradual shift in types of production/management as a response). What monitoring regimes are incorporated?