Climate Change Adaptation in New Zealand

Future scenarios and some sectoral perspectives

Edited by

Richard A. C. Nottage, David S. Wratt,
Janet F. Bornman and Keith Jones

NEW ZEALAND
CLIMATE CHANGE CENTRE

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Contents

Foreword

Chris Field
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The scientific understanding of climate change and its potential impacts is continuously increasingly. The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), released in 2007, emphasised the conclusions that global warming over the last century is "unequivocal", that there is a 90% or greater probability that most of the warming since the middle of the 20th century is a result of increased emissions of greenhouse gases related to human activities, and that warming is very likely to continue into the future. The amount of future warming will depend on future emissions of greenhouse gases. With rapid, aggressive action to reduce emissions, warming may be limited to 2°C or less above pre-industrial levels. With limited emphasis, delayed action, or incomplete participation, warming by 2100 may be 4°C or more, with temperatures still not stabilised.

The world has already experienced impacts from the warming to date. Attributing these impacts to human caused warming is technically challenging, but the AR4 makes a compelling case. Abundant evidence documents the impacts associated with warm extremes from climate variability. Increasingly sophisticated projections point to a wide range of future impacts with the potential to become more disruptive, expensive, and challenging to address, as climate change progresses. Social, environmental, and economic consequences of warmer temperatures, altered freshwater availability, and rising sea levels will likely be diverse and complex. Potential impacts from still uncertain aspects of climate change, especially those related to changes in extreme events, create an additional set of challenges.

Responsible action on climate change needs to involve two major components. Reducing emissions, also called climate change mitigation, is critical for limiting the amount of warming that occurs and for constraining the impacts. Preparing societies, ecosystems, and economies to deal as effectively as possible with the impacts that cannot be avoided, also called climate change adaptation, is also critically important. Regardless of the success of climate change mitigation, some climate change has already occurred, and more is already built into the system. These built-in or committed components of climate change are often discussed in terms of the inertia and slow responses of the physical parts of the Earth system, especially the oceans, but there are important social and economic aspects as well. The infrastructure for energy generation, transportation, buildings, manufacturing, and agriculture turns over slowly, and replacing old technologies with new can require several decades. As a consequence, the agenda for climate change adaptation is an important partner to climate change mitigation. Protecting the short-term and long-term sustainability of the Earth's natural, social, and economic systems requires a balanced portfolio, with an emphasis on both adaptation and mitigation.

The range of possible strategies for climate change adaptation is incredibly broad. Options include financial tools (e.g., modified insurance), early warning systems and other kinds of impact avoidance strategies, protective structures like coastal barriers, activity shifting, and even moving people and ecosystems from one location to another. In general, we are still in the early stages of developing and testing strategies for climate change adaptation. Almost all the data from real-world practice involves adaptations established to deal with existing climate variability and not with climate change. The science and practice of moving from theoretical discussions to applications, also called mainstreaming, presents a range of challenges. But it also presents a range of opportunities. Some of the most interesting opportunities in adaptation involve approaches that represent win-win situations, in the sense that investments in improving the ability to cope with climate change also make it easier to cope with climate variability and other kinds of stressors. Many specific examples illustrate win-win opportunities with adaptation investments. Others illustrate limits and barriers to adaptation.

In general, the opportunities for adaptation, especially for win-win investments, and the constraints depend strongly on the local context. In contrast to climate change mitigation, where the consequences accrue at the global scale in relatively easily quantifiable metrics, the consequences of adaptation investments vary greatly from place to place and setting to setting. It is, therefore, critically important for each country to take a careful look at its adaptation options and to develop a portfolio tuned to its specific opportunities and constraints. New Zealand is taking important steps in that direction with the papers in this volume. With this work, the New Zealand scientific community is laying the foundations for a key component of climate policy. For a range of sectors, the papers explore existing experience with adaptation and point to important paths forward. The scientific community focused on climate change adaptation, in New Zealand and around the world, is in an increasingly strong position to provide policy relevant information. More research is clearly necessary, as are assessments of the outcomes of investments in adaptation. It is exciting to see the New Zealand scientific community at the forefront of this global agenda. I'm confident that this leadership position is providing and will continue to provide New Zealand with genuine value.

Introduction

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The papers in this volume provide sectoral perspectives on adaptation to climate change in New Zealand. These papers are based on presentations made at the conference "Climate Change Adaptation – Managing the Unavoidable", held in Wellington in May 2009. The authors put substantial further work into the papers following their presentations to pick up on points made at the conference by discussion panel members. The papers then went through two rounds of peer review and were subsequently edited.

The papers address adaptation for some of the key sectors of importance to New Zealand for economic, environmental and social reasons, and also consider adaptation through local government mechanisms. It was not possible to cover all of the sectors relevant to New Zealand from the resources available for the conference and volume. Tourism, ocean ecosystems, fisheries, and aquaculture are among the sectors that were not covered, but which could be addressed in a similar way in the future.

The focus on adaptation was deliberate. Past compilations published in New Zealand covering multiple sectors have generally focussed on impacts. Such publications include the landmark document "Climatic change – Impacts on New Zealand" (MfE 1990), the "CLIMPACTS" report (Warrick et al. 2001), and a further impacts report published in 2001 (MfE 2001). However, those responsible for planning for future changes are seeking information which goes beyond identification of likely impacts to also provide science-based guidance for adaptation.

The foreword by IPCC Working Group II co-chair Dr Chris Field and the first two papers set the scene for the subsequent sectoral material. The first paper focuses on the use of information about climate change and natural climate variability, along with non-climate information, to frame risk in a way which is helpful for decision-making under uncertainty. It provides examples of the use of likelihoods for decision-making. The second paper presents two alternative scenarios of global and local climate changes for use in impacts and adaptation assessments in New Zealand. The first scenario represents a "high carbon world", with global average temperatures reaching almost 4°C above pre-industrial by 2100. The second scenario represents a "rapidly decarbonising world" with global temperature increase by 2100 limited to 2°C above pre-industrial. The authors of the sectoral papers were encouraged to consider implications of both these scenarios within their review of impacts and adaptation options. The scenarios paper points out that it is not only the direct effects of local physical changes in climate that will be important, and thus also considers some of the likely effects of socio-economic and biophysical changes in other parts of the world besides New Zealand.

The volume then moves to sectoral perspectives. The third paper uses examples from forestry, arable, and pastoral (dairy) sectors to consider the potential impacts of climate change on enterprises and discusses challenges and opportunities for adapting to climate change. This is followed by a paper which describes a "smart farmer" approach to agricultural adaptation, based on the experience of farmers in eastern areas of New Zealand which are already prone to drought risk.

In 2008 about 65% of New Zealand's electricity supply was generated from renewable sources, and the aim

References

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MfE 2001. Climate change impacts on New Zealand. Report ME396, Ministry for the Environment, Wellington, 40 p.

Warrick, R.A., Kenny, G.J., Harman, J.J. (eds) 2001. The effects of climate change and variation in New Zealand: An assessment using the CLIMPACTS system. Hamilton, New Zealand: The International Global Change Institute (IGCI), University of Waikato, Hamilton, 127 p.

is to increase this significantly in future. This fifth paper discusses the influence of both natural climate variability and anthropogenic climate change on renewable electricity supply, and on demand for electricity. An increase in the diversity and capacity for renewable generation is suggested as the pathway for adaptation, including increasing geothermal, solar, marine, and wind generation to reduce New Zealand's reliance on rain and snow-fed hydro-generation.

The sixth paper considers New Zealand's natural systems and their conservation. It focuses on coasts, freshwater ecosystems, alpine regions, and invasive weeds and pests. Actions outlined to assist adaptation include maintaining or strengthening current efforts to preserve biodiversity, increasing biodiversity monitoring of vulnerable ecosystems, increasing surveillance of incursions of warm-temperate weeds and pests, and establishment of climate stations in high altitude and remote regions.

Whilst some of the papers to this point have touched upon aspects of the human dimensions of climate change impacts and adaptation, the next two papers focus specifically on such issues. The seventh paper considers how the environmental, economic, social and cultural elements of Māori society are likely to be impacted by climate change this century, and identifies diverse vulnerability, risks, coping capacity, and adaptation options available to Māori across key sectors, systems and groups. The paper points out that while Māori are experienced in dealing with climate variability, in many cases new strategies will be needed to ensure the long-term sustainability of different sectors and regions in the context of climate change. The eighth paper summarises the likely impacts of climate change on health globally, and focuses on adaptive measures that might be undertaken in New Zealand. It concludes that both low- and high-carbon scenarios will require major adaptation measures in key infrastructure. But in a high-carbon scenario, New Zealand could become a 'lifeboat' to those living in more vulnerable South Pacific countries who are displaced by the impacts of climate change, with the scale of health and social problems to be faced by New Zealanders becoming considerably more serious.

Most of the actions for adapting to climate change have to be undertaken locally, and this places considerable responsibility on local government. The final paper describes climate-related risks to a number of local government functions and services including water supply, wastewater treatment and disposal, transportation, flood and coastal management, waste collection, recycling, management and disposal, providing and maintaining social infrastructure, civil defence responsibilities and community support. Adaptation action by councils can be based on risk assessment, leading to plans that incorporate adaptation requirements and the identification of how these can afford opportunities for long-term community benefits. The paper suggests councils seeking to work through changes that may significantly affect communities in their regions should be innovative in communicating sustainable development and climate change adaptation messages.

The goal for the conference on which this volume is based was "to stimulate collaborative research by facilitating communication between scientists, planners, councils, engineers, businesses, Māori, and organisations dealing with climate change issues." Some of the results from this collaboration and communication are documented here.

01

A risk management approach to climate change adaptation

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This paper addresses ways in which climate information can be used to manage climate change risks. The aim is to maximise decision-making on adaptation by managing uncertainty. Many governments, including those of New Zealand and Australia, have endorsed risk management as the principal method for assessing adaptation options for climate change. The methods they recommend are developed from the standard approach to climate impact assessment, which is largely predictive in nature. While useful, this approach can be integrated with others. Incorporating predictive and diagnostic approaches, the use of planning horizons linked to types of adaptation and likelihoods expressed as the probability of exceeding a given level of outcome are proposed as methods to improve decision-making.

Using the likelihood of exceeding given levels of warming as a proxy for local risks, adaptation and mitigation can be weighted (i.e., hedged) as risk management strategies at the national scale. Adaptation can be defined as the principal strategy for managing unavoidable climate change to 2030, after which hedging between adaptation and mitigation increases in relevance.

A whole of climate approach needs to be taken at the local level because it is the scale at which impacts occur and where most adaptation will take place. This involves linking current climate and adaptive responses with future projections, and addressing short- and long-term fluctuations in natural climate variability and the consequences thereof. Planned adaptations may need to account for potential abrupt climate changes. A case study example for Victoria, Australia, shows that a recent step change in regional climate to warmer and drier conditions is larger than the worst-case model-based projections for 2030-2050. This has altered the current baseline and makes information about how climate is changing more important than the model-based projections. Projected changes in extremes over time using the changing baseline have been shown to be useful for planned, incremental adaptation. For anticipatory adaptation over the longer term, balancing the costs of adapting and the penalties of not adapting across a range of possible outcomes, ‘climate proof’ and ‘win-win’ options may be identified. For adaptations contingent on particular outcomes, some of which may involve system failure, a portfolio of actions and the ability to respond quickly to changing circumstances may be more robust than adapting to a ‘most likely’ outcome.

1. Introduction

The standard linear process of adaptation assessment, comprised of a scoping exercise, climate change scenario generation, impact analysis and development of adaptation options has been widely critiqued in recent years (e.g., Burton et al. 2002, Dessai et al. in press), largely because adaptation is a social process. Adaptation to climate change draws on learning and experience from past and present climate, so by treating adaptation last and as a factor solely of climate change it becomes dislocated from this process. Although the case for the use of risk management for adaptation to climate change has been made (e.g., Jones 2001, UKCIP 2003, UNDP 2005), and is increasingly being accepted, there remains a great deal of uncertainty about what approach to use (Carter et al. 2007).

Adaptation, being locally specific, is influenced by multiple contexts or situations. Those contexts are informed by where, what, who, why and how? Where is the area of interest, what is at risk, who are the stakeholders (including all involved in assessment), why do these risks need to be managed and how are they to be managed? Also, because adaptation is a social process where learning plays a critical role, a conditional (what if) forecast used as a trigger for action may be more important than whether or not that forecast proves to be correct.

A wide range of methods is available, including top-down, bottom-up and integrated methods. Assessments will also be governed by the complexity, knowledge and the resources (time, money, personnel) available. Frameworks trying to address all of these matters at once can become very complex (e.g., UNDP 2005), but on the other hand, simple approaches though often preferred by stakeholders, tend to be fairly one-dimensional.

The aim of this paper is to illustrate how the risk management process can incorporate a whole of climate approach (climate change and natural variability), utilise predictive and diagnostic techniques, incorporate different types and levels of uncertainty (including qualitative and quantitative information), allow the addition of non-climate information and place a central focus on decision-making. The paper focuses on the use of climate information to frame risk.

Principles applied within this framework include the following.

- Uncertainties should be acknowledged, transparent and traceable throughout an assessment.
- Where possible, include the full range of uncertainties likely to contribute to decision-making.
- It is better to use quantified estimates of subjective likelihood (properly acknowledged) than to omit them because they are not sufficiently 'objective'. Testing conditional likelihoods in a decision-making framework will determine their utility.
- Information should be framed in the simplest possible way to contribute to a particular decision (i.e., do not 'overcook' the science).

These needs are not always mutually compatible and the development of the necessary skill and experience is an important ingredient of adaptive capacity.

The paper is in two parts. The first part outlines methods designed to manage climate change likelihoods in order to maximise robust decision-making under uncertainty and sets out the framework. The second part uses examples illustrating those methods that address particular decisions. It is grouped into a) hedging or weighting of adaptation and mitigation strategies, b) "How much climate change do we need to adapt to by when?" and c) taking a whole of climate approach.

2. Framing risk and adaptation

Risk itself involves the concept of an event or set of events, often characterised as hazard, an element of likelihood, a consequence that relates to a set of values, and a timeframe within which all these events may occur. Risk evaluation and management may then take place with the aim of reducing vulnerability or maximising benefit (e.g., AS/NZS 2004). Vulnerability here can be thought of as the redisposition to be harmed. Vulnerability to climate change as defined by the IPCC (2007) is only a small part of wider social vulnerability defined by social, cultural, political and institutional factors (Adger & Kelly 2004). This broader domain is the one in which adaptation, if implemented, will take place, so vulnerability is used in this context unless otherwise stated.

The following points describe common elements of the risk management process with notes as to how adaptation fits these elements.

- *Scoping exercise* where the context of the assessment is established. This identifies the overall method to be used and establishes relationships between stakeholders and researchers.
- *Risk identification* and the identification of scenario development needs (climate, environmental, social, and economic).
- *Risk analysis*, where the consequences and their likelihood are analysed. This is a highly developed area with a wide range of available methods to undertake impact analysis.
- *Risk evaluation*, where adaptation and perhaps mitigation methods are prioritised.
- *Risk management* or treatment, where selected adaptation and perhaps mitigation measures are applied.
- *Monitoring and review*, where measures are assessed and the decision made to reinforce, re-evaluate or repeat the risk assessment process.

Two overarching activities are researcher-stakeholder interaction and communication with stakeholders and the wider community. The development of methods for research and stakeholders to exchange knowledge and incorporate stakeholder values (Saloranta 2001, Lorenzoni et al. 2005) helps to ensure the right questions are asked and aids in improving the decision-making process. It also improves learning by doing or adaptive management.

2.1 Top-down and bottom-up approaches

Top-down and bottom-up are short-hand terms used in the literature to describe the direction of an assessment. Direction can refer to the scale of institution (global to local), spatial scale (global to local) or time (present to future, or future to present). Risk management frameworks are sufficiently flexible to utilise different directional approaches or integrate two or more within a single assessment. With regard to scale, top-down assessments will commonly involve downscaling global climate to local climate before assessing impacts and adaptation, a bottom-up approach will start from the local scale and survey adaptation process past, present and future (Adger 2003, Dessai & Hulme 2004). With regard to time, a predictive approach will follow the chain of consequences from emissions to adaptation. A diagnostic approach will articulate future outcomes and then investigate the conditions that lead to those outcomes being realised. Future outcomes may be negative, in the case of critical thresholds, or positive in the case of a desired future state.

Top-down assessments tend to focus on direct cause-and-effect relationships and are convenient because they are amenable to quantitative analysis. However, as a consequence, they tend to neglect the complexity inherent within human-environment systems that a bottom-up approach attempts to include (e.g., Adger & Kelly 2004). The social context in which adaptation takes place has led to greater attention being focussed on bottom-up approaches, in which the process begins at the local scale, assessing current and emerging risks, the social, economic and environmental factors that underpin risk and the capacity for risk management (Dessai & Hulme 2004). The integration of adaptation into this setting recognises adaptation as a social process (Pielke 1998, Burton et al. 2002) rather than a set of adjustments, taking a more dynamic view of adaptation based on past and present experience of climate variability and change, and combining climate with other drivers of change, an activity known as "mainstreaming" (Huq et al. 2003). For further details on the framework concepts, see Appendix A.

3. Hedging adaptation and mitigation

One question associated with "How much climate change needs to be adapted to by when?" concerns the potential relationship between adaptation and mitigation. By linking a range of impacts to levels of mean global warming, it is possible to hedge between adaptation and mitigation uncertainties. For example, if some mitigation is expected, planning adaptation responses for the highest projections of climate change over the long-term may not be necessary. Although in the near-term, before mitigation policies can take effect, it would seem prudent to adopt adaptation measures, given that many variables are tracking at, or above, the level of IPCC projections (Rahmstorf et al. 2007, Füssel 2009).

Hedging adaptation and mitigation can help negotiate adaptation policies at the national level. For example, Australia's adaptation policy describes adaptation as being the principal way to deal with the unavoidable impacts of climate change (CoAG 2007). Which impacts are unavoidable, and which are likely, given different levels of mitigation? How does one establish which level of global warming and associated impacts should be adapted to? These questions can be addressed by understanding the commitment to climate change from past and near-term future emissions and the impact of mitigation policy. Past commitment dominates atmospheric warming over the next few decades, with subsequent policy decisions having an increasing influence over time. Commitment also has a degree of irreversibility within the limits of adaptation planning, especially for sea level rise,

> "How does one establish which level of global warming and associated impacts should be adapted to?"

which can continue for decades to centuries because of the large heat capacity of the oceans (Solomon et al. 2009).

These questions are explored using a simple model to provide conditional probabilities for mean global warming to 2100. The model, developed from version 5.3 of *MAGICC*, the simple upwelling-diffusion energy balance model (Wigley 2008), combines cumulative distribution functions (CDFs) for radiative forcing and climate sensitivity. Climate sensitivity is from Annan & Hargreaves (2006). The proportion of radiative forcing converted into warming as a function of climate sensitivity and inter-model differences are also included.

The baseline for mean global warming is 1990. Observed mean global warming and its observational uncertainty from 1990 to 2005 is taken from the Hadley Centre University of East Anglia Climate Research Unit *HadCRUt3* data set (Brohan et al. 2006). Warming from 2010 to 2095 is calculated on a 5-yearly basis using regressions based on the inverse of warming and radiative forcing in 2100 based on projections from individual scenarios (r^2= 0.99 to 0.93 with a standard error of up to ±0.2°C).

The emission scenarios used apply the current global economic high growth path (Sheehan 2008) and range from a high emissions growth scenario (Garnaut 2008) based on a revision of SRES A1FI (IPCC 2000) to a range of policy scenarios marking a departure from that growth path over five year intervals from 2010 to 2030 (Minimum Emissions Paths or MEPs; Sheehan et al. 2008). Results from all these scenarios, expressed as the probability of exceeding a given level of warming from 1990, are shown in Figure 1.

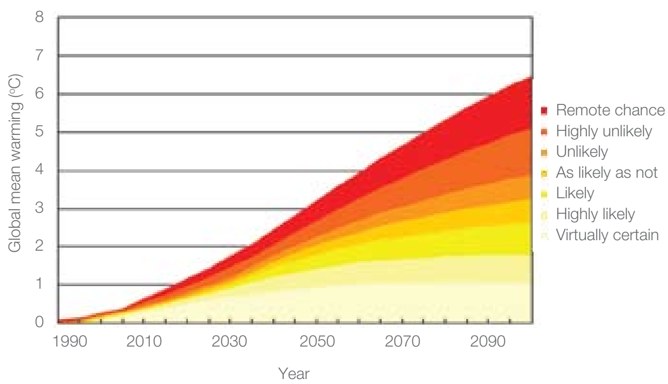

Figure 1. Probability of exceedance for observed global warming 1990-2005 and projected warming from a range of scenarios from A1FI-augmented to MEP2010.

Adaptation requirements under various levels of mitigation can be assessed by testing how different departure dates towards a minimum emissions path reduce subsequent warming. Figure 1 carries no prior assumptions as to whether mitigation is likely to happen immediately or not at all, and all possibilities are equally likely. By assuming strong mitigation will occur between 2010 and 2030, reductions in adaptation requirements can be assessed. Probabilities of exceeding specific levels of warming utilising MEPs from 2010 to 2030 are shown in Figure 2.

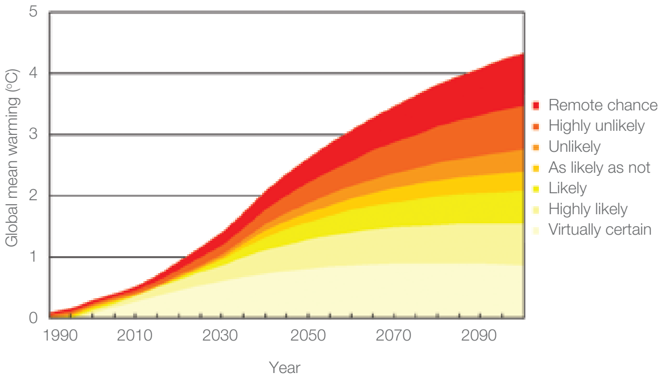

Figure 2. Probability of exceedance for observed global warming 1990-2005 and projected warming from a range of scenarios from MEP2030 to MEP2010.

However, due to the present state of mitigation policy (The Kyoto Protocol and subsequent policies developed by individual countries), a significant degree of hedging between managing climate risks with mitigation and adaptation is required, because a substantial range of risk is left unmanaged. This will change as national and international policy agreements are made and implemented. The inability of the 15th Conference of Parties meeting in December 2009 to agree to any binding targets, despite some progress, means that considerable hedging may be required until such agreements can be forged.

Four hedging strategies for adaptation (Ad) and mitigation (Mit) are defined based on the partitioning of climate risk:

1) Adaptation: below the 50th percentile of warming derived from a policy emissions scenario set;
2) Ad-Mit: between the 50th percentiles of reference and policy emissions scenarios sets;
3) Mit-Ad: from the 50th percentile of the reference scenarios set to the upper limit of the policy scenarios set;
4) Mitigation: above the upper limit of the policy scenarios set.

The adaptation hedging strategy is based on mean global warming that is >50% to be exceeded by the set of policy scenarios. Adaptation may still be warranted for higher levels of warming with lower probability of exceedance, but these risks could possibly be managed through mitigation policies – the Ad-Mit strategy. Mit-Ad strategies apply where mitigation is more likely provide a benefit than adaptation under the assumption that policies will be implemented by 2030. Finally, Mitigation hedging strategies denote the net benefits of mitigation through damages avoided under all policy scenarios. The example shown in Figure 3 contrasts the set of policy scenarios (MEP2030–MEP 2010) from Figure 2 with reference scenarios spanning the range between MEP2030 and A1FI-augmented scenario.
The results show that mitigation strategies offer substantial benefits in reduced risk but only become effective after about 2040.

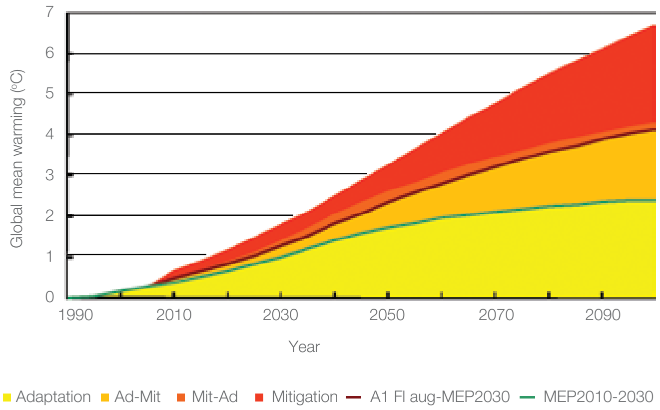

Figure 3. Zones of warming during the 21st century most suited to Adaptation, Adaptation-Mitigation hedging (Ad-Mit), Mitigation-adaptation hedging (Mit-Ad) and Mitigation dominated strategies according to a set each of reference and policy emission scenarios. The reference emission scenarios are A1FI augmented to MEP2030 (upper line is the 50th percentile) and the policy emission scenarios are MEP2030 to MEP2010 (lower line is the 50th percentile).

Therefore, combining current warming trends with updated scenarios of emissions growth and climate sensitivity provides quite a small band of uncertainty to about 2050. This will cover a great many adaptation decisions with planning horizons over the next few decades.
Other adaptation actions will be incremental so can be informed by new information as the climate changes. Substantial hedging post 2050 may be required for longer-term decisions. However, this approach to 2050 provides a narrower range than can be gained through the standard use of low, mid and high scenarios over the whole century because it accounts for climate change committed to by recent high economic growth (Sheehan et al. 2008).

4. Addressing regional change

Climate information needs to be provided at the scale at which the risks may occur and the adaptation needs to take place. This requires, at the very least, regionalised projections of climate change. Local climates may exhibit both gradual trends and non-linear changes in response to global warming. Non-linear changes are usually not resolved in General Circulation Models (GCMs), partly because of resolution issues, but also because their initial conditions are not set to represent current climate conditions. This is an active area of research.

The principle of pattern scaling allows local change to be represented as a function of global mean temperature change. This assumes that local changes will be driven by global warming, so the inherent range of uncertainty will be larger than for global mean temperature alone, depending on the degree of attribution possible and uncertainty in climate variability (Hulme & Mearns 2001). An assessment of local climate will consider whether variations may be attributed to natural climate variability or be of anthropogenic origin. Baseline climate can demonstrate coherent phases of variability, for example, decadal phases of rainfall that are flood- or drought-dominated (Vivès & Jones 2005).

Scaling local trends by global warming and comparing these to model projections will allow adaptation needs at the local and regional scale to be assessed. For example, pattern-scaled historical data can be compared with pattern scaling from GCMs (Whetton et al. 2007). This exercise has a higher degree of confidence for temperature-related impacts such as heat stress to humans, livestock, and animals in their natural habitat including coral-zooplankton symbiotes, energy demand and daily urban water demand. Less confidence can be attached to water-related impacts of climate change, where attribution of climate variability/anthropogenic change is often unresolved because of large rainfall variability. Systems affected by multiple variables such as agricultural crops, livestock production and ecosystems and those associated with changes in extreme variables usually also face high inherent uncertainty.

To address the scenarios of mean local change within the context of this paper, the scenarios upon which this volume is based (Reisinger et al. 2010) are contrasted with the cumulative distribution functions (CDFs) for global mean warming presented in Appendix A. Shown with the CDFs given in Figure 1 and Figure 2 are the upper, lower and central limits of the A2 and B1 SRES scenarios (IPCC 2000) for global mean warming and projected mean warming for New Zealand derived from 12 models for 2030-2049 and 2080-2099, respectively (Figure 4 and Figure 5).

If the world continues on the current path of CO_2 emissions higher than those projected by the IPCC, while rapidly reducing the cooling impacts of sulphate aerosols, then warming over the next few decades may accelerate faster than IPCC projections. However, the issue of climate variability, particularly at the local scale, also needs to be accounted for.

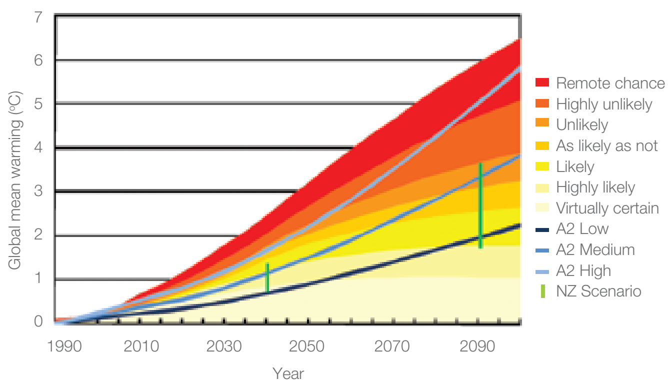

Figure 4. . Probability of exceedance for observed global warming 1990–2005 and projected warming from a range of scenarios from A1FI augmented to MEP2010, shown with the upper, lower and global mean warming from the A2 scenario (high carbon world) and mean warming for New Zealand for 2040 and 2090 based on downscaled temperatures from 12 climate models.

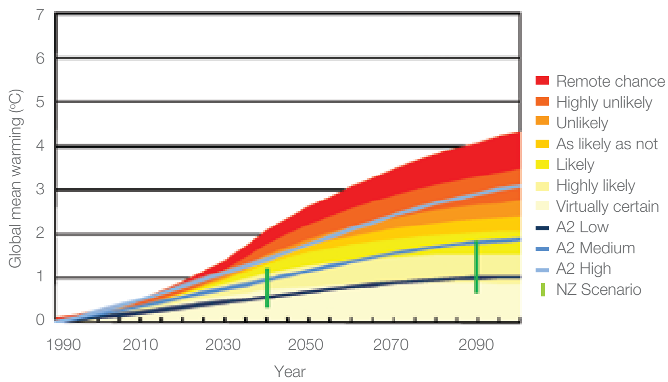

Figure 5. Probability of exceedance for observed global warming 1990–2005 and projected warming from a range of scenarios from MEP2030 to MEP2010 , shown with the upper, lower and global mean warming from the B1 scenario (rapidly decarbonising world) and mean warming for New Zealand for 2040 and 2090 based on downscaled temperatures from 12 climate models.

5. A whole of climate approach

5.1 Linking projections and observations

The rational adapter will recognise that at the local scale one has to adapt to all aspects of climate, not merely to the anthropogenic component of change caused by greenhouse gas emissions. Climate change in the broader sense involves the three global factors addressed earlier and three regional factors that affect adaptation decisions. They are:

1) greenhouse gas emission scenarios and radiative forcing
2) climate sensitivity
3) past and near future commitments to climate change
4) regional climate change projections
5) current global and local rates of change
6) natural climate variability.

The first four factors are the major elements of climate model projections; factors five and six inform researchers and stakeholders as to the changes taking place in their region. Both the changes (climate and impacts) taking place at a location and the adaptive responses to those changes are important. Key questions at the local scale concern whether climate is stationary or changing. Climate data can be analysed for trends that mark gradual shifts or step changes that mark abrupt shifts. If gradual or abrupt shifts are identified the question of attribution arises; can they be attributed to natural causes, enhanced climate change or a combination of both? The resulting conclusions can help define climate baselines, and inform assumptions of stationarity or change over time and whether such changes are temporary, singular shifts or part of a trend.

Projections are usually applied to a long-term baseline that may implicitly assume a level of stationarity in that baseline. Once climate begins to change, then the information about how climate is changing can be used to modify model-based projections. Interpretations of observed change can be used to modify scientific predictions developed from climate models. In practice this is difficult to do, but given that global temperature has been trending upwards for over 30 years following a significant change in trend in 1976 (Swanson & Tsonis 2009), suitable techniques need to be developed. Because climate is much more variable at the local scale, and adaptation takes place at that scale, techniques need to be relevant to that scale.

These issues affect the interpretation of global data applied to a region (top-down information) and observed data (bottom-up information) and their application to decision-making on adaptation. They are illustrated using examples from the greater Melbourne region in Victoria, Australia. This region has recently experienced a change in climate which is affecting, for example, fire risk, energy use, agriculture, water resources and ecosystems. These impacts have also led to adaptation decisions made on the basis of earlier assessments being re-examined. These earlier assessments utilised climate change scenarios developed from regional climate change projections applied to a static baseline (CSIRO & Melbourne Water 2005, Jones & Durack 2005) and a gradually changing baseline (Suppiah & Whetton 2007).

Regional projections offering likelihoods of future change for selected climate variables are now being made (Tebaldi et al. 2004, Tebaldi & Knutti 2007). These were constructed for projected regional changes in temperature and rainfall derived from a set of climate models averaged over the Melbourne Statistical Division and creating a probability distribution using techniques developed in CSIRO and BoM (2007). Applying these local changes to the probability distribution for mean global warming shown in Figure 2, the overall range expands slightly (not shown). The median figure is about 0.25°C less (a reduction of 10%), the lower half of the range decreases by up to 15% and the higher half reduces by less than 10%. For rainfall, the range of uncertainty increases by about 10% of mean annual change for every degree of global warming. This accounts for the first four uncertainties, but is restricted to model projections of the anthropogenic change signal only.

When measured as a linear trend, temperature in the Melbourne region over 1977-2007 (matching the period of sustained increases in mean global warming) increases by 0.13°C, 0.11°C and 0.15°C per decade, respectively, for the mean, minimum and maximum. This suggests a scaling factor of mean local temperature with global temperature of 0.94°C per degree of global warming, compared to the 50th percentile estimate of 0.90°C from GCMs. The trend in rainfall is downwards, consistent with GCM projections although the high natural variability in rainfall presents difficulties for attribution to natural or anthropogenic causes.

However, the regional climate has not been following the gradually changing patterns described by this type of projection. Statistically significant step changes for area-averaged climate over the Melbourne region have occurred in maximum and mean temperature in 1998 ($P<0.01$) and in rainfall in 1997 ($P \approx 0.05$). For Melbourne's water supply, rainfall in the catchments decreased by about 19% in 1997-2008 compared to 1950-1997, reducing dam inflows by about 40%.

"The major considerations are whether a more complex method of representing climate offers greater benefits if correct, or whether the penalty of being wrong using a simple approach is commensurate with the penalty of being wrong using a more complex approach."

The increase in maximum temperature over the same period was about 1°C and mean temperature by about 0.6°C. By regressing annual rainfall with maximum temperature from 1950, the downward shift in rainfall can account for about half the upward shift in temperature. Attribution of abrupt changes in rainfall to natural or anthropogenic causes is difficult because similar shifts have occurred in the past, resulting in periods of below or above average rainfall lasting for up to five decades (Vivès & Jones 2005).

Observed changes need proper attribution in order to be merged with model projections with any confidence. Otherwise one is left with a series of what if questions about how anthropogenic and natural elements may combine. An alternative approach is to select a strategy that learns from adaptation decisions being made – it may be that learning from adaptation proceeds faster than knowledge about climate. In such situations, higher precision may not improve decision making. The key principle is to *use the simplest approach needed to make the decision at hand*. Is the decision likely to be robust with the amount of information being applied?

Two aspects of the decision need to be assessed – the benefits of being correct and the penalties of being wrong, considered as part of a risk assessment. The major considerations are whether a more complex method of representing climate offers greater benefits if correct, or whether the penalty of being wrong using a simple approach is commensurate with the penalty of being wrong using a more complex approach. Usually, this decision should be made collaboratively with stakeholders unless practice is already well established.

5.2 Decision-making context

Specific planning and policy horizons help define the need for short- to long-term climate scenarios. How adaptation actions are likely to be implemented; for example, whether incremental, anticipatory or reactive, will determine whether projections need to be continuous (time series) or discrete (time slice), and linked to one or more future dates.

5.2.1 *Incremental adaptation*

Scenarios incorporating change over time are becoming more common, replacing time slice scenarios for a single future date. For example, continuous climate projections are being applied to adaptation decisions in energy management. The gas industry wants ongoing information about winter heating demand to inform gas pricing and decisions on pipeline capacity (Suppiah & Whetton 2007). The electricity supply industry wants information on summer demands, particularly peak energy demand, to inform shorter-term decisions on energy pricing and longer-term capacity to supply peak energy (Thatcher 2007). Investment decisions for the ratio of peak energy demand to base-load demand are important because peak energy is much more expensive to supply than base-load energy. Therefore, energy peaks supplying air-conditioning on days of extreme heat is a strong driver of generating capacity and cost. Electricity and gas planning require estimates of likely summer and winter temperatures extending from the next few years to several decades. Demand for gas can be satisfied through the provision of heating degree days and peak electricity demand through cooling degree days and daily extreme maximum temperatures.

The mean temperature for Melbourne City from 1950 to 2006 increased by 0.23°C per decade, 0.12°C of which Suppiah & Whetton (2007) attributed to the urban heat island (UHI) effect. Most of that trend increase was in minimum temperatures. They estimated trends in heating degree-days (HDD) according to the UHI effect and low, median and high values of projected warming for 2008-2012 from a 2006 baseline. HDD decreases by 0.43 days per year for the UHI alone and 0.93, 5.78 and 8.10 per year for low, medium and high projections of climate change.

A statistically significant downward shift in HDD in 1999 of 85 days from the previous homogeneous period (1972-1998), shows both linear trends and step changes in this time series. Further work will be needed to determine how sensitive the system is to such shifts, although the baseline of 2006 used by Suppiah & Whetton (2007) is post shift, so represents the new climatic state.

Maximum daily temperature, the main driver of peak electricity demand, can be assessed in a similar manner. Because daily maximum temperature shows a close to normal distribution, an increasing mean will eventually pass a point where the rate of increase in extreme temperatures accelerates. At this point, adaptation efforts will also need to accelerate. From 1974 to 2003, days above 35°C averaged 9.2 per year and above 40°C, 1.2 per year. Local change in mean temperature for MEP2010-2030 was applied to this time series for each year to 2100. The rate of increase in days above 35°C and 40°C accelerates in about 2035 and decelerates at around 2070, following the decline in greenhouse gas emissions shown in Figure 2. The 50th, 67th and 90th percentile exceedances (likely as not, unlikely and highly unlikely) reached 17, 19 and 23 days over 35°C and 4, 5 and 6 days over 40°C. All three percentiles reached an average of 13 days by 2035. Without mitigation, by 2100, the number of days of extreme temperature under the 50th percentile warming of the A1FI-augmented scenario is 30 days over 35°C and 10 days over 40°C.

The 50th percentile outcome from the MEP2015 scenario demonstrates how early mitigation slows the rate of increase. Average annual days over 35°C rise to 13 by 2035 but stabilise at 15 from 2070-2100. Near-term emissions therefore commit a certain level of change, but effective mitigation policy can limit further rises. This would be very useful information for the adaptation of housing and infrastructure to relieve health risks, for livestock management and for the management of energy demand. The analysis does not take account of changes in synoptic states such as the frequency of slow moving high pressure systems, affecting days of extreme heat, which also should be assessed if potentially severe risks exist.

The most optimal strategy for incremental adaptation is to apply probabilistic trends of short duration – up to several decades in length – and update with new climate information on an ongoing basis. At present, this can be done with limited skill, but in the medium term, the output from decadal forecasting should become available (Smith et al. 2007). It is important to recognise that forecasting climate using climate models is a useful strategy, but not the only strategy required to inform adaptation, and may be misleading if misapplied.

6. Anticipatory adaptation

Anticipatory adaptation measures come into play when long lead times in planning are required. Some of the decisions taken from the previous example, such as forward planning for new generation capacity and changes to building stock for improved management, are clearly anticipatory. However, the use of changing projections of data clearly show the potential for accelerating extremes, which time slice analysis (for say 2030 or 2050), may not.

Planning adaptation in the presence of large climate uncertainties may require a different approach. Some decisions require information on potential climate change effects decades in advance; for example, on long-lived infrastructure, the coastal zone and in the management of a range of key ecosystems. Here it will be necessary to hedge future adaptation and mitigation efforts, as climate change already committed to by historical emissions becomes less significant over time. This can be done on the basis of conditional likelihoods for regional climate change that are used to define hedging strategies as described earlier.

However, especially at the local level, it is possible that the information derived from a large model ensemble may be wrong or incomplete, most likely by under-representing climate variability. Observed climate behaviour may also be difficult to attribute to a specific cause. The 1997 shift in rainfall in the Melbourne region has been observed across southeastern Australia (Nicholls 2004, Dessai et al. 2005). Reduced rainfall and increased evaporation have led to large-scale water shortages, which have occurred much faster than projected by assessments based on climate model output. CSIRO and Melbourne Water (2005) applied probabilistic methods to a range of climate change uncertainties to estimate changes in streamflow from the long-term baseline of -3% to -11% in 2020 and -7% to -35% in 2050. Caveats about the unpredictability of climate variability were included but could not be quantified. The Victorian Government concluded that the mid-case estimate of -7% in 2020 and -18% in 2050 could be readily adapted to and, as a response, brought forward planned augmentations of the water supply.

However, following the 1997 climate shift, the decrease in water supply for the Melbourne region to 2008 has been 39%, exceeding the worst-case projections for 2050 (Figure 6). These changes, if they persist, require a much greater response than previously anticipated if per capita water supply is to be maintained. The continuation of the past 10 years' streamflow would lead to chronic long-term water restrictions (DSE 2007). As a result, large-scale augmentations of the water supply are planned, although they are highly controversial. A climate shift of significant magnitude occurred in southwest Western Australia in the late 1960s, requiring adaptation responses of a similar scale (Hennessy et al. 2007).

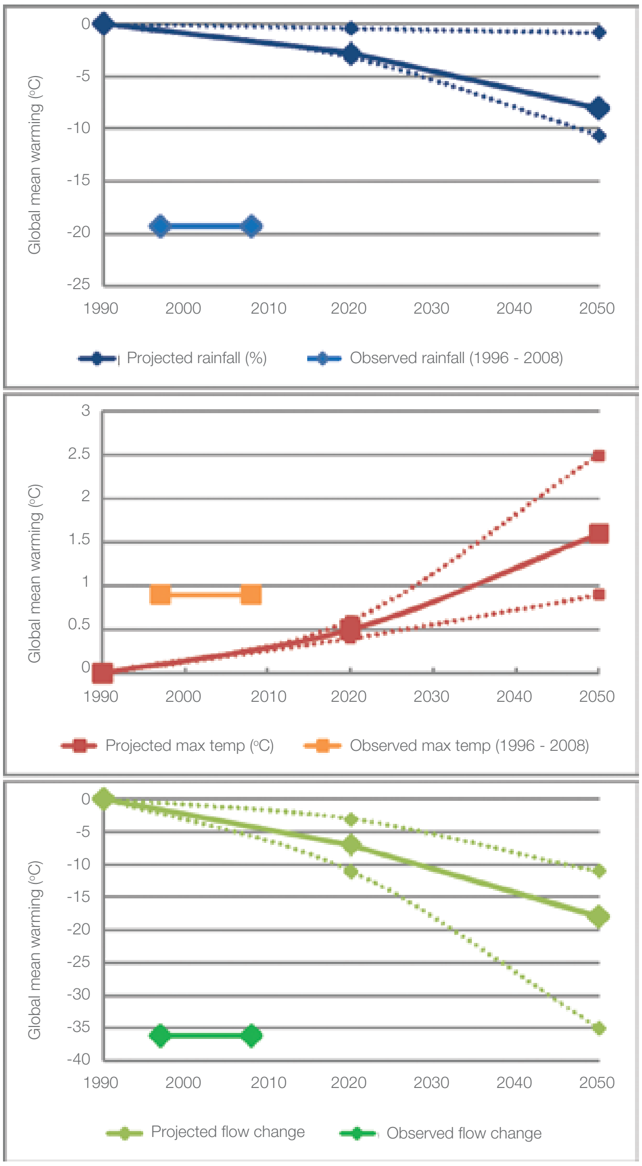

Figure 6. Projected rainfall, temperature, and streamflow changes in 2020 and 2050 for the Melbourne water system from a baseline of 1952-2001 shown with observed changes from 1997 to 2008 from the same baseline.

Figure 7 shows alternative explanations for the recent changes plus expected outcomes and benefit/penalty choices for assuming each alternative is correct. If the first alternative is assumed as true, then a return to long-term conditions of relative supply abundance could be expected. However, if wrong, resulting shortages and lack of preparedness will extract a significant penalty. The second alternative would see a response for decade-long drought conditions with partial recovery down the track. The third alternative would see a response to long-term drought with potentially drier conditions occurring over time. For planning horizons covering the next few decades, alternatives two and three would generate a similar response. Over-estimating drought conditions, then encountering conditions wetter than anticipated, would attract a lesser penalty than under-estimating drought and then encountering it.

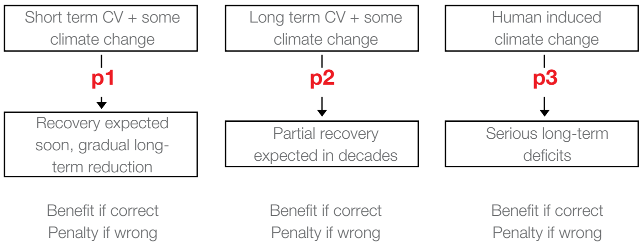

Figure 7. Alternative explanations, expected outcomes and benefit/penalty alternatives for three plausible climate diagnoses affecting water resources futures in southeastern Australia. CV abbreviates climate variability.

The assumptions in Figure 7 can be tested using subjective probabilities (p1, p2, p3) based on similar phenomena in historical climate, model runs and diagnostic climate studies (see also Dessai et al. 2005). Analyses of historical climate, which show record low accumulated rainfall (Timbal 2009) and record high temperatures that are producing streamflow lower than experienced for the past century, suggest that p1<<p2, p3. Increases in regional air pressure and patterns of change suggesting the rain-bearing westerly air flow has been interrupted have been associated with phenomena linked to global warming, but the exact cause of the decline remains uncertain (Cai & Cowan 2006, Nicholls 2009, Timbal 2009).

Given the large penalty associated with misjudging alternative 1, and with alternatives 2 and 3 suggesting similar strategies for the next few decades, planning for sustained deficits is the most appropriate response. Further research is needed to tease out the link between the natural and human-induced contributions to the step change to determine whether some level of recovery in rainfall is possible. However, even without concrete numbers, subjective probabilities derived from multiple lines of evidence can be used to test alternative possibilities. For Melbourne, continued higher temperatures and reduced water supply seem likely, with severe consequences if adaptation measures are inadequate.

The level of caution required when applying anticipatory adaptation relates to the consequences if wrong, benefits if right and the level of investment required for various adaptation measures. 'Win-win' measures provide adequate benefits if wrong on climate and 'climate proof' measures are robust in the face of a large range of outcomes so are insensitive to climate uncertainty. Circumstances where climate proofing is too expensive, or outcomes can range from small changes to critical system failure, may warrant the development of a range of adaptation measures. The development of a portfolio of actions and the ability to respond quickly to changing circumstances may be more robust than adapting to a 'most likely' outcome. Rather than developing adaptation options that can deal with all eventualities, a plan that can deal with contingencies, especially those with rapidly changing priorities, is required. This involves challenges for most organisations where incremental decision-making and 'hastening slowly' are the norm.

> "The development of a portfolio of actions and the ability to respond quickly to changing circumstances may be more robust than adapting to a 'most likely' outcome."

7. Conclusion

This paper discussed the issue of adaptation and risk by showing the compatibility of adaptation and risk assessment and management. Both the Australian and New Zealand governments have endorsed risk management guides for adaptation (AGO 2006, MfE 2008) consistent with the Australian and New Zealand Risk Management Standard (AS/NZS 2004). However, the different contexts in which adaptation may be assessed and applied require risk management to move beyond the conventional methods associated with individual disciplines and to take on a more flexible approach that borrows methods from different applications.

Climate risk is strongly influenced by human agency, such as policy choices and by substantial uncertainties, many of which are considered to be irreducible (Dupuy & Grinbaum 2005). For that reason, complementary approaches to risk assessment, here characterised as top-down and bottom-up methods, or predictive and diagnostic methods are recommended. This complexity in methods provides a greater challenge for an assessment but allows multiple perspectives to contribute to a richer set of outcomes.

Each approach has a different set of strengths and weaknesses. Event-based risk is a largely linear method used in disciplinary areas such as natural hazard and emergency management, coastal planning, flood management, environmental impact and health (through dose-response). The likelihood of specific events is used to assess outcomes from which a response is planned. This has become the default method used in climate change impact and adaptation research, largely due to its disciplinary roots in the areas of weather forecasting, environmental impacts and natural hazards. This method is most successful when the chain of consequences leading to a specific risk can be followed and quantified. However, predictive approaches can also fail as detailed above (see also Dessai et al., in press).

Outcome or diagnostic risk methods focus on the outcome, especially when it is well understood, but the precursors of that outcome have low predictability due to multiple causes and large uncertainties. Many of the contributing factors may be non-climatic. These methods are consistent with the assessment of risk with a high degree of precaution.

The linking of diagnostic and prescriptive methods allows a two-way approach to assessing adaptation that can focus on both the event and the outcome. This allows better interplay between what is known about changing climate hazards on the one hand and potential future goals on the other. These approaches can be linked quantitatively through CDFs that quantify likelihood through the probability of exceeding a given outcome. The greatest advantage of using CDFs as contrasted to probability distribution functions (PDFs), is that they are much more robust with regard to decision-making under uncertainty (e.g., non-stationarity, human agency and deep uncertainty).

Several examples of the use of likelihoods for decision making have been described. The first uses conditional likelihoods of mean global warming to show how adaptation and mitigation can be hedged over time by assessing likely commitment and scientific and policy uncertainties. Four strategies are suggested: Mitigation, Mitigation-Adaptation (Mit-Ad), Adaptation-Mitigation (Ad-Mit) and Adaptation. Adaptation is prominent until 2030, when the other three come into play, Ad-Mit and Mitigation strategies taking equal space and the Mit-Ad strategy remaining minor. These will evolve over time as both science and policy advance.

At the scale at which adaptation will take place, a whole of climate approach incorporating climate projections and ongoing global and local change, and climate variability, was described using regional examples from Melbourne, Victoria, Australia. In the past decade Victoria's climate has shifted to drier, hotter conditions, exceeding the projected worst case for 2030-2050. These changes have affected a range of sectors, such as water supply, transport, energy and emergency management, requiring reactive adjustments. The science has been unable to attribute the cause with any confidence until relatively recently. The baseline has shifted – how projected climate change can best be combined with that baseline is a question needing to be addressed.

Incremental adaptation is best approached by using time series of projected change over time rather than using the more usual time slice methods. However, rapid change can also alter exposure to extreme events, so will require a proportionately larger response. Planned adaptation that anticipates smooth change over longer-term planning horizons, such as that undertaken for water resources in the Melbourne region, can be inadequate if climate changes faster or in a different direction to that anticipated. The smoothed projections shown in individual scenarios and in probability distributions such as those presented here are simplifications. Change at the global scale can also be affected by significant variability (Swanson et al. 2009). Because adaptation has to respond to the whole of climate, anthropogenic change, natural variability and the interplay between the two need to be addressed.

Even though climate modelling improvements may eventually provide better forecasts of regional variability and change over decadal time horizons, risk assessments, particularly those with long time horizons, need to build in flexibility, rather than rely on improvement in scientific prediction. Because impacts often amplify climate signals, the role of stakeholders in observing and monitoring system response, and querying the likely role of climate in that response over short time periods, will also be very important.

Simple models of change that can be rapidly updated with new information are the most suitable for hedging risk at the global scale. At the local scale, risk needs to be addressed in a systematic way, where the relationships between all aspects, from the drivers through to outcomes, are monitored. If a change occurs at critical points within that system, it can be quickly updated to use that new information. This is preferable to the more standard approach of preparing new scenarios, updating impact models and re-examining adaptation strategies periodically, especially if the world is on a rougher ride than the climate models project.

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Appendix A: Framework concepts

1.1 Directional approaches

How an assessment deals with time influences how likelihood is combined with hazard (H) and exposure (E). Here exposure is defined as the degree of harm experienced from a given event or combination of events. There are two main approaches to assessing risk in a directional sense. These two approaches have been labelled in different ways, namely, as event and outcome risk (Sarewitz et al. 2003), natural hazard and vulnerability approaches to risk (UNDP 2005) and prescriptive/predictive and diagnostic approaches:

1) **Predictive** – event risk, natural hazard or prescriptive approach. Drivers are projected through a cause and effect process to assess vulnerability for hazards such as sea level rise, storm surge, or extreme rainfall events. Vulnerability is often measured as the likelihood of an event multiplied by the cost, such as the annualised costs of flooding or storm surge on the coast. This method is generally, though not always, identified with top-down methods.

2) **Diagnostic** – also known as an inverse, outcome, goal-oriented or critical threshold approach. Risks are associated with outcomes such as species extinctions, loss of agricultural productivity or levels of human mortality. Consequences are expressed as the risk of exceeding a given threshold or tipping point. This method is generally, though not always, identified with bottom-up methods. Testing the likelihood of exceeding a threshold of 2°C mean global warming from pre-industrial climate as a proxy for dangerous climate change is an example of a diagnostic approach.

In mathematical terms where risk is R and P is probability, the first approach is:

$R = P(H) \times E$ (Equation 1)

And the second approach is:

$R = P(E) / H$ (Equation 2)

Risk is different for the two approaches. In Equation 1, risk is the damage over a given time interval, such as damage for a flood of given average return interval, or annualised risk of storm surge. In Equation 2 risk is the likelihood of threshold exceedance. In the first, probability is attached to the hazard or combination of hazards, in the second to the outcome - this is an essential distinction for the management of likelihoods under large uncertainties.

1.2 Planning horizons

The time periods in which risks need to be assessed are linked to long-term goals, planning horizons and timeframes within which adaptation will take place. Planning horizons mark how far into the future climate information may be needed (Jones 2001, UKCIP 2003, Dessai & Hulme 2004). This timing is informed by both operational and aspirational goals. Aspirational goals relate to what is desired (e.g., sustainable operations, profitability) or to what should be avoided (e.g., critical outcomes, system failure). Operational goals relate to the pathway that is taken to achieve that goal.

The type of adaptation is also important. Incremental adaptation allows a learning-by-doing approach to be taken, informing the process along the way and allowing it to adjust to new information. The need to anticipate outcomes in advance is most relevant to adaptations that require large initial planning and investment, those with a long

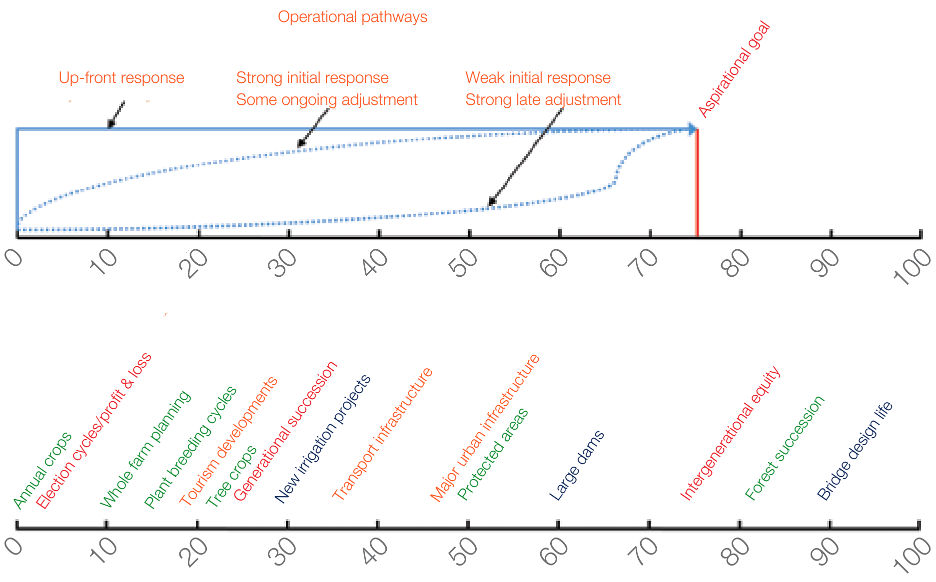


Figure A1. Relationship between goals and pathways for adaptation (upper diagram), related to a number of planning horizons of different timescales (lower diagram).

operational life (and where retrofitting is too expensive) or if the damage to be avoided is irreversible and/or unacceptable. If adaptation is straightforward and easy to implement, a wait and see strategy may allow a delayed response to changing conditions without penalty.

Figure A1 shows a sample of planning horizons for different activities (lower diagram) and operational pathways towards achieving a specific goal (upper diagram). These are not intended to represent a complete set of pathways – many paths are possible depending on circumstance. The decision-making process for deciding which adaptation(s) to implement includes assessing the most suitable adaptation pathway. If aspirational targets are some decades away, an assessment may need to investigate strategies over a range of different timescales.

1.3 Estimating climate risk likelihoods

This section describes climate-related uncertainties within the context of managing climate risk over time. Table A1 describes the two major types of likelihood and how they expand in assessing climate risks, before adding a temporal element to show how the changing envelope of climate variability affects the ability to cope, and then showing how both frequentist and single-event uncertainties combine in describing risk. The final diagram appears very complex (Table A1f), but this complexity can be managed by using the same risk assessment framework for different levels of input; for example, using a low and a high climate change scenario as contrasted with a full probabilistic assessment.

Frequentist likelihoods describe recurrent events. Most types of variability and extremes that result in significant climate impacts, such as drought and flood risk, fire and storm, are frequentist. A history of events can be used to construct a probability distribution function of event frequency and magnitude that is normally distributed for most climatic variables, or a power law (e.g., daily rainfall exceedance). These distributions can change under climate change, particularly as rainfall and storm-related events become more intense.

A single-event likelihood describes a once-only event for which there may be no or limited history. An event may be described for how likely it is to occur, how large it is, or both. Single-events linked to anthropogenic climate change include most of the changes to mean variables such as temperature, rainfall, and sea level rise, emission scenarios and variables such as climate sensitivity. Statistics range from being plausible through to tightly bounded probabilities (Kandlikar et al. 2005), but the most common characterisation is as a range of uncertainty with upper and lower limits, sometimes including a best estimate.

The major difference between the two types of uncertainty is that all outcomes within a known frequentist distribution can occur, whereas a single event can occur only once. The combination of scientific uncertainties and human agency involved in assessing the chain of events contributing to climate change and impacts (Table A1d) means that any estimates will have some element of subjectivity, and therefore are conditional on the assumptions used to construct them (Dupuy & Grinbaum 2005). It is important to determine the proportion of each of these uncertainties and how they combine in affecting a particular risk and its management.

In most measures of climate impact these uncertainties are intertwined. Changing variability and extreme events are subject to single-event and frequentist uncertainties that will vary their relative influences over time. Vulnerability occurs whenever the coping range for a given activity is exceeded. This can be caused by a change in mean over time (Table A1e), or in variability, or both. One way to manage this complexity is by focusing on a given threshold within a broad range of uncertainty to determine its likelihood of being exceeded within a given planning horizon. This also focuses attention on impacts and adaptation, rather than on climate change itself.

1.4 Likelihood of occurrence vs risk

In Equation 2 above, $R = P(E) / H$, likelihood expressed as the probability of exceeding a given level of change is more closely linked to risk, allowing better management of uncertainty (Jones 2004a, b). Although the likelihoods applied to assess Equations 1 and 2 are mathematically equivalent, for Equation 1, $R = P(H) \times E$, likelihood is expressed as a probability distribution function (PDF), whereas Equation 2 expresses likelihood as a cumulative distribution function (CDF).

Risk of exceedance using mean global warming as the principal metric inversely links likelihood to consequence. The most likely thresholds to be exceeded in any given location are usually those of least consequence, with consequence increasing with the hazard of the magnitude. Confidence is highest with the lowest levels of change because the easiest-to quantify-aspects of components of a particular risk are better constrained and usually limited in magnitude.

Figure A2 illustrates the use of exceedance risk using sea level rise as an example. The range on the upper left shows the range of global mean sea level rise in 2100 as projected by the IPCC in its Third Assessment Report (IPCC 2001). A uniform distribution is considered a conservative interpretation of this type of information (Jones 2000), although the range as communicated by the IPCC (2007) contained no internal likelihood. On the upper right are two PDFs created using different assumptions about underlying uncertainties, showing that 'most likely' outcomes can be very different in a predictive sense when different but plausible underlying assumptions are used.

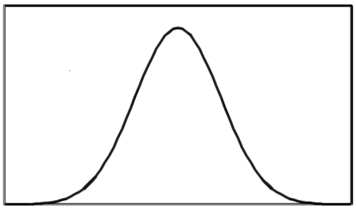
The lower panels show the same distributions reformatted as CDFs with three arbitrary thresholds at 25, 50 and 75 cm. The lowest threshold is the most likely to be exceeded and the highest threshold, the least likely. Even for the left-hand panels that show the least sophisticated estimates, the CDF communicates much better than the PDF, even though the underlying probabilities are equivalent. Also labelled are general areas of confidence in the underlying science, showing that confidence can be assessed in proportion to the risk using the CDF approach.

Table A1. Uncertainty types affecting changing climate risks involving a) frequentist uncertainties, b) single-event uncertainties, ci & ii) how changes in these uncertainties are estimated, d) expanding single-event uncertainties affecting climate risks, e) the coping range, climate variability and change, and f) the schematic description of changing single-event and frequentist uncertainties over time.

a: Frequentist

Recurring events with a frequency-magnitude relationship, distributed around a mean value.
Examples: rainfall events, daily, monthly and seasonal temperature measurements, storms.

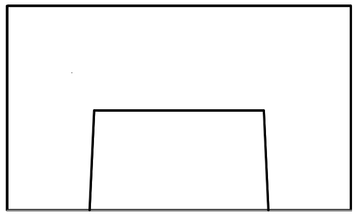
Statistics: Mean and standard deviation, often normally distributed.



b: Single event

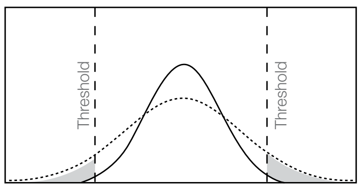
Single or once-only event with a range of uncertainty. Can range from qualitative knowledge that event may occur to tightly bound probability distribution.
Examples: emission scenarios, 21st century warming, local mean climate change.

Statistics: Guess, expert judgment, bounded range, uniform uncertainty (shown on right), joint probability (shown below left & right) (Listed in terms of increasing confidence).



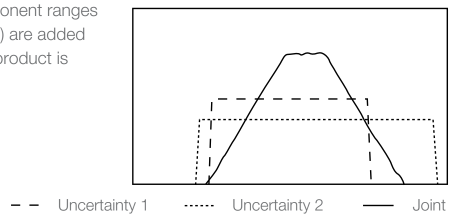
ci: Changing frequentist uncertainties

The distribution of a frequentist uncertainty can change its spread, height and skewness, which may alter the probability of exceeding a given threshold.



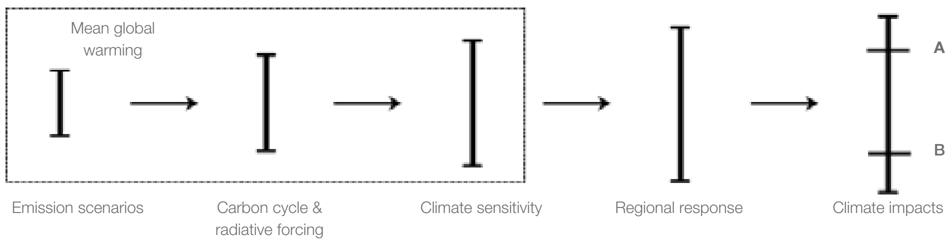
cii: Changing single-event uncertainties

When two or more component ranges (or sets of fuzzy numbers) are added or multiplied the sum or product is non-linear.



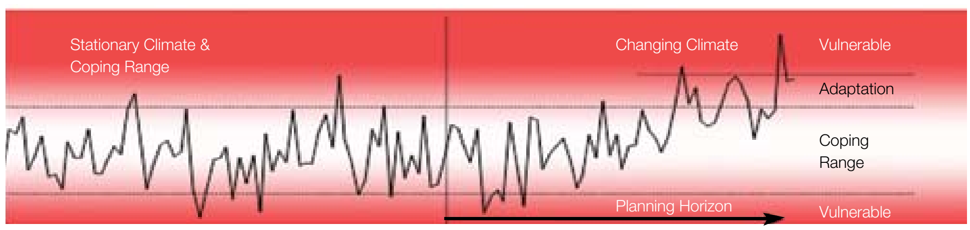
d: Expanding uncertainties

Expanding uncertainties following the chain of consequences from emissions to climate impacts are shown with two nominal impact thresholds A and B. Note that several feedbacks exist in this sequence but are not shown (e.g., between climate impacts and the carbon cycle and climate sensitivity and radiative forcing). These are all compounding single-event uncertainties. This represents uncertainty at a given point in time.



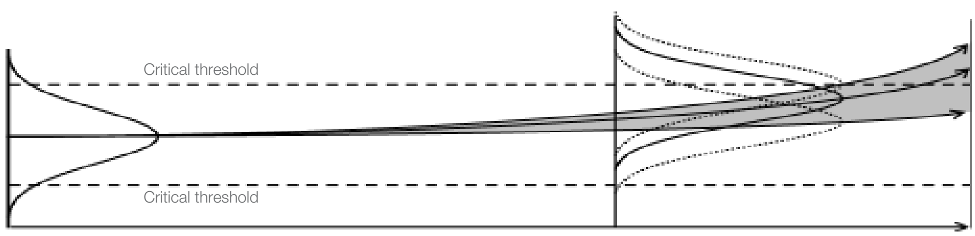
e: Coping range, climate variability and change

Single scenario showing change in mean over time, leading to increased exceedance of thresholds as climate moves beyond the ability to cope (the coping range). Also shown is the idea of whether given limits are likely to be exceeded within a planning horizon and adaptation to those changes (Carter et al. 2007).



f: Schematic description of change single-event and frequentist uncertainties over time

A similar schematic to the above, showing that both single event and frequentist uncertainties can change over time. Whether a particular uncertainty needs to be incorporated into an analysis depends on whether it contributes to risks to the degree where adaptation may be required.



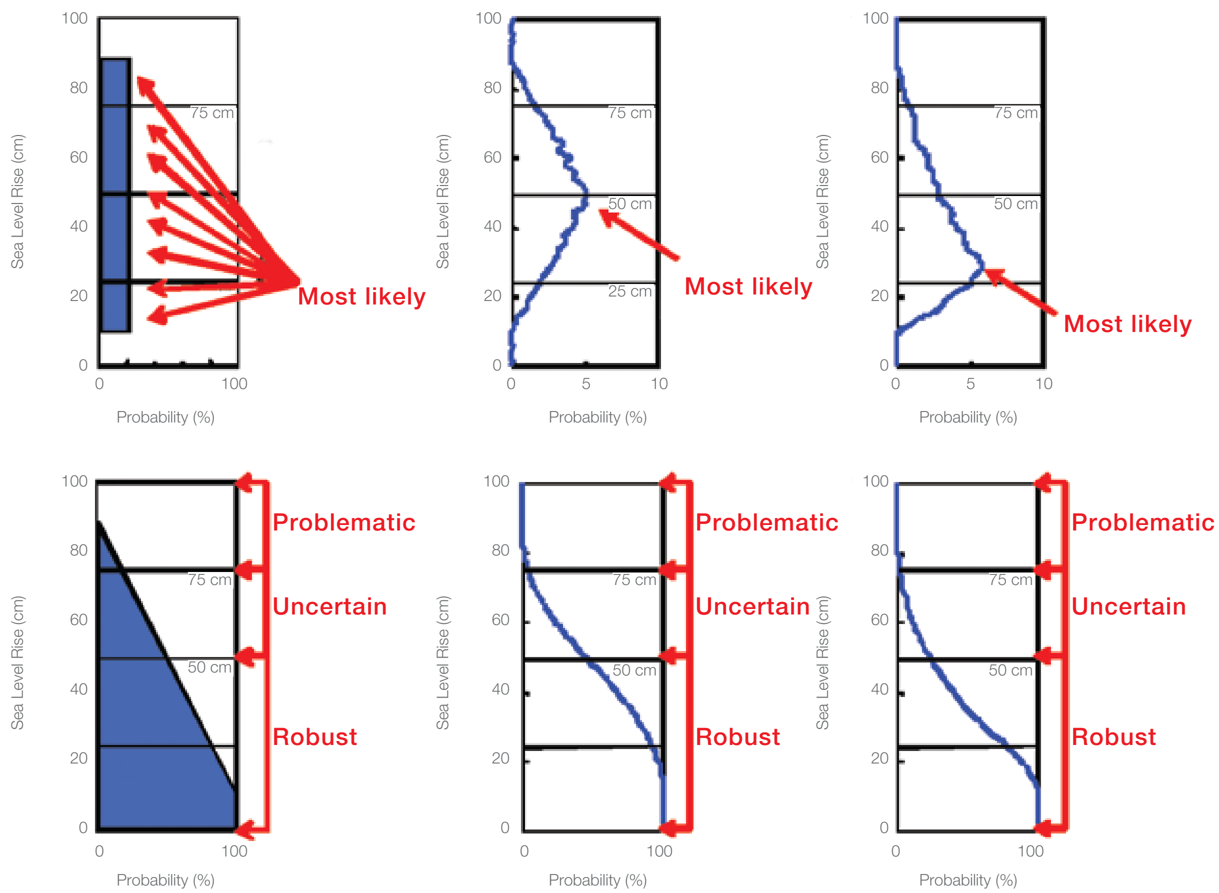


Figure A2. Examples of probability distributions encompassing a range of potential sea level rise in 2100 (based on IPCC 2001). The upper panels show a uniform distribution on the left, the construction with least confidence (all outcomes plausible), and two likelihood distributions in the centre and on the right. The lower panels show the same distributions as cumulative distribution functions. Both also show three thresholds at 25, 50 and 75 cm. The confidence levels indicate the magnitude of sea level rise that is robust, uncertain and problematic.

The use of a CDF allows different assumptions to be tested within the context of the risk being faced, particularly the level of vulnerability that may result if a given threshold is exceeded. For example, a threshold that represents large-scale inundation of an important stretch of coastline may warrant a closer look at qualitative information to see whether the risk may be worse than conveyed by numerical projections. Qualitative information about past high sea level stands or rates of sea level rise during warm periods may be used to set higher levels of precaution than quantified by the modelling of projected ice sheet melting during the 21st century. If it would be prohibitively expensive to protect the whole stretch of coastline, a mixed strategy of protecting the most valuable sites, retreat where possible and a moratorium on development in vulnerable zones could be adopted. New scientific information about sea level rise would allow these strategies to be revisited; however, that information would have to be sufficiently different to warrant a change in strategy.

Therefore, small improvements in the underlying likelihoods of a CDF may not be enough to change an adaptation strategy. On the other hand, different underlying assumptions affecting a risk can be explored to assess how new knowledge may influence specific decisions. This can help identify which climate information can aid decision-making. If it is possible to identify when new information is likely to become available from long-term research programmes, specific decisions may be delayed until that time.

Therefore, the use of a CDF is more robust than a PDF in several respects.

- CDFs provide a more integrated view of risk by linking hazard, likelihood and consequence, rather than dealing with them sequentially.
- The effect of uncertainties on decision-making can be tested, including mixing information with different confidence levels, testing subjective assumptions and the impact of potential new knowledge on adaptation decisions.
- CDFs link bottom-up and top-down approaches to risk, allowing different approaches to achieve some level of equivalence.

02

Global & local climate change scenarios to support adaptation in New Zealand

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We present two alternative scenarios of global and local climate change for use in impacts and adaptation assessments in New Zealand. The two scenarios represent “high carbon” and “rapidly decarbonising” worlds with rapidly diverging global greenhouse gas emissions. Global average temperatures by 2100 would be (best estimates) almost 4°C above pre-industrial under the high carbon world, but the increase would be limited to 2°C under the rapidly decarbonising world. Annual average temperatures over New Zealand would increase by (best estimates) 0.7 and 1.1°C under the rapidly decarbonising world and by 0.9 and 2.6°C under the high carbon world by 2030-2049 and 2080-2099, respectively, relative to 1980-1999. We also outline the regional pattern of precipitation changes projected for New Zealand under those two scenarios and the uncertainties arising from differences between climate models. We then comment briefly on likely changes in extremes such as heat waves, heavy rainfall and extreme winds, and provide an update of current knowledge of potential changes in global and regional sea level and implications for impacts assessments. Apart from projections of domestic climate change, understanding of climate change impacts and adaptation options under alternative scenarios also requires an appreciation of the global socio-economic and biophysical changes associated with those scenarios. Such global changes could have significant flow-on effects on New Zealand through alternative global and regional socio-economic and policy developments, as well as global climate change impacts and global-scale responses to those impacts.

We therefore include an overview of the global socio-economic developments that could be associated with the high carbon and rapidly decarbonising worlds, the likely global-scale impacts and adaptation challenges, and the potential consequences of those global and regional changes for New Zealand. Finally we provide a brief review of the likely scale of the adaptation challenge in New Zealand and the steps involved in successful implementation of adaptation at the local scale in response to the scenarios described.

1. Introduction

Future climate change depends primarily on future emissions of greenhouse gases and aerosols, associated increases in greenhouse gas and aerosol concentrations in the atmosphere, and the response of the climate system to these changes. Natural climate variability further influences short- and longer-term trends, particularly at small spatial scales.

Future global and regional socio-economic developments responsible for greenhouse gas and aerosol emissions, including the implementation of climate policies and new technologies, remain difficult to predict in any objective sense and may follow a range of alternative pathways (IPCC 2000). Studies of potential climate change impacts and adaptation responses therefore have to explore a range of scenarios that reflect alternative global development paths and their consequences on the global climate system. Such scenarios can inform impacts and adaptation studies in two ways: one is to describe the range of future climatic conditions that human or natural systems of concern will be exposed and have to respond to; the other is to characterise the regional and global socio-economic context in which impacts and adaptation responses in any specific location and for specific sectors would occur (IPCC 2007a, Chapter 2).

This paper describes two alternative scenarios of socio-economic developments and global and regional climate changes that can be used to assess potential climate change impacts and adaptation responses in New Zealand.

Section 2 provides an overview of the two selected scenarios from a global perspective, namely the underlying socio-economic trends and greenhouse gas and aerosol emissions, the resulting global climate changes, and the likely global-scale impacts associated with each scenario. We also briefly review the potential flow-on effects from those global-scale changes for New Zealand. Section 3 describes the methodology used to downscale global climate change scenarios to New Zealand and presents projected changes in key climate variables for different geographic regions of New Zealand for 2030-2049 and 2080-2099. This includes a discussion of uncertainties arising from differences between climate models, and current knowledge of likely changes in climate extremes. Section 4 reviews the current information on projections of sea level rise and their implications for impacts and adaptation studies. Section 5 discusses the broad implications and challenges arising from these two climate change scenarios for the process of adaptation in New Zealand. Section 6 presents the summary and conclusions.

2. Two scenarios of global socio-economic and climatic change

2.1 Global scenarios and their climatic and socio-economic relevance to New Zealand

The literature contains a wide range of scenarios of how the world may develop in terms of social, economic and technological change over the 21st century (IPCC 2007b, Chapter 3; Meinshausen et al. 2009). Different socio-economic development paths will result in different greenhouse gas and aerosol emissions and consequences for the climate system. Figure 1 shows a selection of emissions scenarios that reflect alternative social, technical and political developments, along with the resulting changes in global average temperature. To date, no objective means have been developed to identify any particular scenario as being more or less likely than others, reflecting the indeterminacy of collective human choices.

All scenarios, even those where emissions decline rapidly over the 21st century, lead to further warming, but the rate and amount of

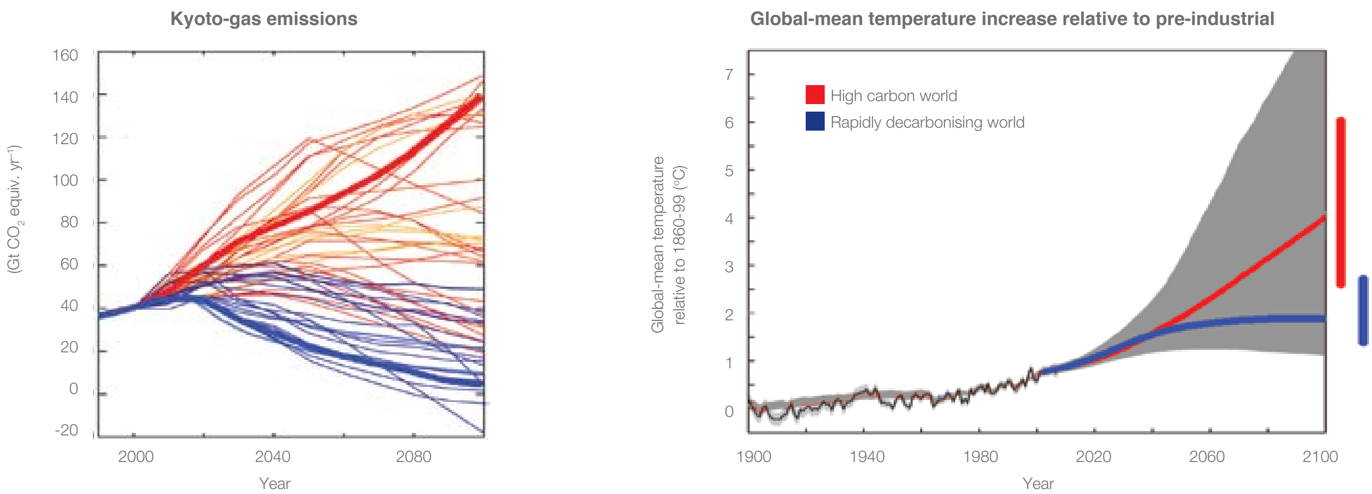

Figure 1. Global greenhouse gas emissions and changes in global average temperature for a range of different scenarios. Left panel: alternative scenarios of global greenhouse gas emissions covered by the Kyoto Protocol (in CO_2-eq) from 1990 to 2100, based on a review by Meinshausen et al. (2009). Thin red lines indicate scenarios in the absence of additional climate policies, thin blue lines indicate scenarios that assume climate policies of various stringency. The thick red and blue lines illustrate the selected high carbon and rapidly decarbonising worlds, respectively. Right panel: observed (black line) and modelled changes in global average temperature. The grey area shows the range of temperatures simulated for the 20th and 21st centuries and the full range of emissions scenarios in the left panel and include uncertainties in the climate system. The red and blue lines show changes in global average temperature for the two selected scenarios (best estimates). The vertical bars at the right indicate the 'likely' warming range for each scenario during 2090-2099 (at least 66% probability based on the IPCC assessment; Meehl et al. (2007)). (Emissions pathways and overall range of climate responses are based on Meinshausen et al. (2009)). Global temperature increases for the two selected scenarios were simulated with the simple climate model MAGICC (version 6; Meinshausen et al. (2008) tuned to emulate results from the more complex climate models assessed by the IPCC (Meehl et al. 2007)).

warming depends heavily on the assumed emissions scenario. To help make sense of the vast array of scenarios and wide range of climate outcomes, and to support scenario-based impacts and adaptation studies, we selected two alternative scenarios that follow divergent emissions pathways and hence lead to contrasting global climate change outcomes (illustrated schematically in Figure 1).

- The first scenario describes a *high carbon world* (based on the SRES A2 scenario; IPCC 2000) with associated climate changes over the 21st century that are about eight times larger and faster than those observed already over the 20th century (in terms of global average temperature change). This scenario represents a highly fractured world with no concerted efforts to reduce greenhouse gas emissions, heterogeneous socio-economic and technological development in different parts of the world, and with large rates of climate change, warming of almost 4°C above pre-industrial levels, and severe impacts resulting in many regions of the world.

- The second scenario describes a *rapidly decarbonising world* with rapid concerted global action to reduce greenhouse gas emissions and to limit greenhouse gas and aerosol concentrations to about 450 ppm CO_2-equivalent. This results in a long-term increase in global temperature of about 2°C above pre-industrial levels, consistent with the goals stated by many countries for a global climate change agreement (UNFCCC 2008, 2009). The reduced warming would limit the severity and extent of impacts, but some regions and systems, such as coral reefs, the Arctic, and some water–stressed areas in the mid-latitudes and subtropics would still experience significant negative impacts.

The increases in global average temperature under the high carbon and rapidly decarbonising worlds differ only slightly by 2030-2049, but there are dramatic differences by the end of the century. This implies a significant time lag between actions to reduce emissions and benefits in terms of reduced further climate change. If time lags in both the climate and energy system are taken into account, this implies that if warming is to be limited to about 2°C above pre-industrial levels by the end of the 21st century, global greenhouse gas emissions would have to peak before 2020 and be reduced by about 50% below 1990 levels by 2050 (Meehl et al. 2007, Fisher et al. 2007, IPCC 2007d, Anderson & Bows 2008, Allen et al. 2009, Meinshausen et al. 2009).

The two emissions scenarios have been selected from a wide range of possible futures but should not be seen as strict either/or options. Neither do they represent the extreme alternative ends of the spectrum of possible futures – the real world may lie in between those two scenarios and potentially even outside them.

These two contrasting scenarios would have obvious consequences for the changes in climate that New Zealand would experience and to which adaptation would need to occur. The main goal of this paper is therefore to present detailed climate change projections for New Zealand for those two alternative scenarios which can be used to explore the impacts and adaptation options under alternative futures. Key results are presented in Sections 3 and 4, and these scenarios form the basis for some of the sector-specific impacts studies included in other chapters of this publication.

As noted in the introduction, a full appreciation of the impacts in New Zealand associated with either scenario depends also on the socio-economic context in which those climatic changes would be experienced. New Zealand is intimately linked with the rest of the world through tourism, export goods and services, security, aid, migration, technology, and access to internationally traded raw materials. Each scenario would affect those international links differently through impacts of climate change experienced world-wide as well as the general socio-economic drivers and international policy settings that underlie those scenarios. Global changes in terms of climate, socio-economic trends and international policies could therefore have significant flow-on effects on New Zealand. No quantitative studies of this flow-on effect for New Zealand exist at present, but given New Zealand's strong dependence on exports, tourism, import of fossil fuels, biosecurity risks, and immigration, we suggest that the magnitude of such flow-on effects could well be on a par, and in some cases even outweigh, the direct impacts of climate change within New Zealand.

In the remainder of this section we present more detailed information on the global socio-economic drivers underlying the two scenarios, as well as the likely global-scale impacts and challenges to adaptation under either scenario. This information provides important context for studies that wish to assess not only the biophysical impacts of climate change in New Zealand but also discuss the relevance of these impacts and the scope of adaptation responses in New Zealand that would be consistent with those global scenarios.

2.2 Underlying socio-economic drivers and international policies

2.2.1 *The high carbon world*

The high carbon world is based on the IPCC Special Report on Emissions Scenarios (SRES) A2 scenario (IPCC 2000). This scenario is characterised by a continued growth in global population and a heterogeneous, regionalised economic growth and technological development, with no implementation of any additional climate policies.

This uneven progress and lack of dedicated climate policies are the key reasons for the continued growth in greenhouse gas emissions based on continued extraction and use of fossil fuels, deforestation, and regionally divergent progress in industrial and agricultural production efficiency (IPCC 2000). The fractured nature of policy responses in this high carbon world suggests that international trade and security would be characterised by regional alliances and centres of dominance rather than globally coordinated approaches, with continued trade barriers and selective resource scarcity resulting from the pull of the largest, and hence most powerful, economies.[1]

2.2.2 *The rapidly decarbonising world*

By contrast, the rapidly decarbonising world is based on a mitigation scenario that explicitly aims to limit the increase in global average temperatures to about 2°C relative to pre-industrial levels (or about 1.5°C relative to 1980-1999). This would require rapid reductions in global emissions of CO_2 to almost zero by 2100, as well as significant reductions in emissions of non-CO_2 greenhouse gases to stabilise total greenhouse gas and aerosol concentrations at about 450 ppm CO_2-equivalent.

The rapid global-scale decarbonisation would imply a rapid and coordinated shift towards new globally distributed technologies and standards of efficiency in various processes, and effective linkages of global and regional climate, trade, and energy policies (IPCC 2007b). In addition, one might assume that a greater ethical value is placed by consumers and governments on sustainability and environmentally friendly activities.

[1] Note that not every global scenario associated with high carbon emissions would necessarily have to be a politically highly fractured and heterogeneous world. The IPCC Special Report on Emissions Scenarios (IPCC 2000) includes a range of scenarios with high carbon emissions with different global assumptions about governance and collaboration. The high carbon world described in this paper, based on the SRES A2 scenario, is simply one example of several alternative scenarios that would result in high levels of greenhouse gas emissions.

2.3 Global and regional climate projections for the two scenarios

2.3.1 *The high carbon world*

Climate models project global average temperature increases under this scenario (relative to 1980-1999) of about 1.2°C by 2040 and about 3.3°C by 2090 as best estimates. Most continental land masses would warm by more than 5°C and high northern latitudes even more by 2100[2] (see Figure 2). Precipitation would likely decrease by 20% or more by the end of the 21st century in many already dry subtropical and some mid-latitude regions (e.g., the Mediterranean and southwest United States), while precipitation would very likely increase by a similar magnitude in most high latitudes. Seasonal shifts in precipitation patterns are expected to exacerbate water security issues in some regions even where annual average precipitation increases, particularly south and southeast Asia. Heavy precipitation events would increase significantly in most regions except the dry subtropics (IPCC 2007c, Chapters 10 and 11; 2007a, Chapters 3 and 10). In this type of scenario the climate system has not reached an equilibrium by 2100 so that further climate changes are still in the pipeline.

2.3.2 *The rapidly decarbonising world*

In this scenario, global average temperature would still increase for about the next two to three decades similar to the high carbon world (about 1.0°C by 2040) but would then level off, with warming of about 1.5°C by 2090 (relative to 1980-1999) (IPCC 2007c, Chapter 10). Although detailed simulations from Atmosphere-Ocean General Circulation Models are not yet available for such a stringent mitigation scenario, we expect the broad geographical pattern of change to be similar to the high carbon world (Mitchell 2003), but the magnitude and rate of change to be significantly less. Figure 3 shows the projected global temperature changes, and is derived from simulations under the SRES B1 scenario modified as described in Section 3, consistent with the evolution of global average temperature under the rapidly decarbonising world illustrated in Figure 1. Continental land masses would warm more than the global average but by less than about 3°C in most regions. Precipitation decreases in subtropical and some mid-latitude regions and increases in high latitudes would likely be limited to 10% or less. Heavy precipitation events would increase by less than half of the change under the high carbon world (IPCC 2007c, Chapters 10 and 11).

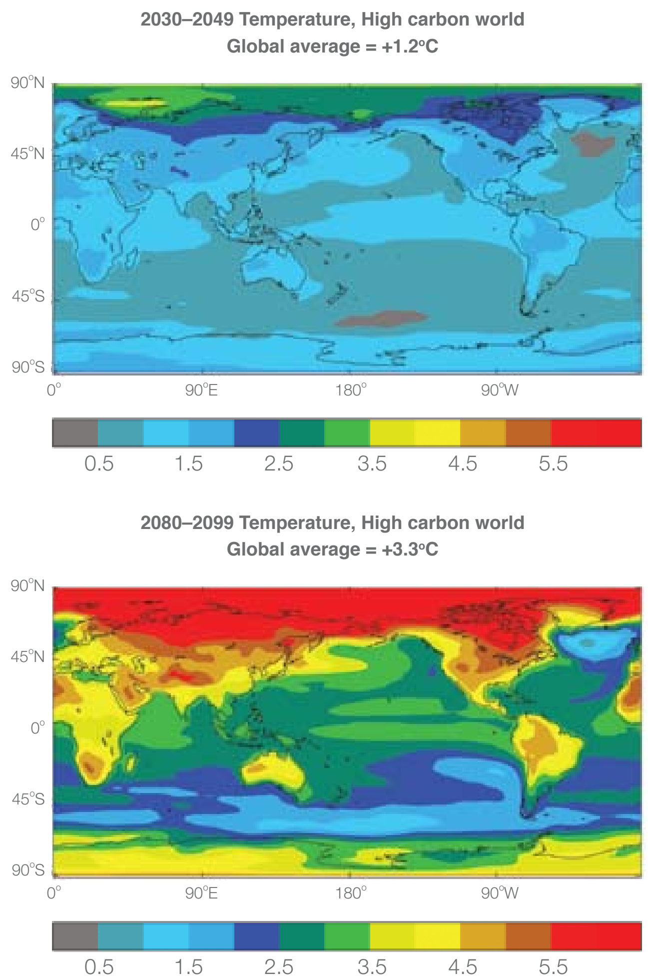

Figure 2. Global temperature change (in °C) from 1980-1999 to 2030-2049 (upper panel) and to 2080-2099 (lower panel) for the high carbon world, as averaged over 12 global models. The global-average change is indicated in the figure heading. For details on the selected models, see MfE (2008c).

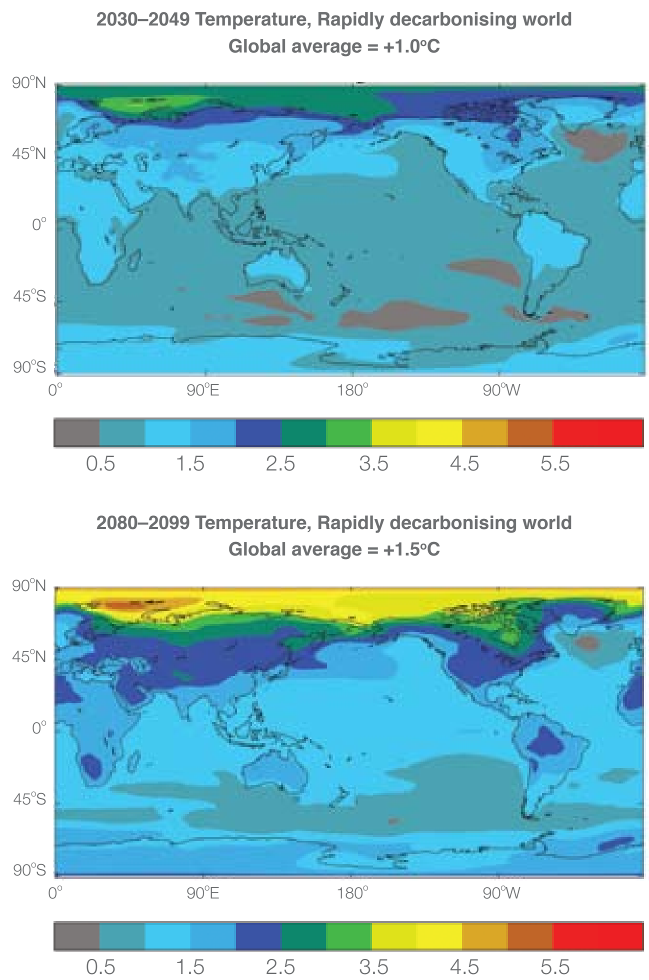

Figure 3. Global temperature change (in °C) from 1980-1999 to 2030-2049 (upper panel) and to 2080-2099 (lower panel) for the rapidly decarbonising world, as averaged over 12 global models. The global-average change is indicated in the figure heading.

[2] Add 0.5°C for temperatures relative to pre-industrial.

A significant caveat regarding the broad similarity of geographical patterns of climate change is that the necessary switch to zero-carbon fuels and technologies under a rapidly decarbonising world would likely also result in a significant reduction of aerosol emissions. This would remove some of the current cooling effect of aerosols and as a result, warming could proceed even more rapidly for the next few decades under the rapidly decarbonising world than under the high carbon world. This possibility of a slightly faster warming is illustrated in Figure 1, but the actual rate of change would depend on the specific technologies employed to reduce carbon dioxide emissions and their effect on regional and global aerosol emissions. In addition, regional precipitation patterns could differ from those in the high carbon world due to the reduced presence of cloud condensation nuclei from aerosols in some regions (Rotstayn et al. 2009).

2.4 Key global-scale impacts, adaptation challenges, and flow-on effects for New Zealand

2.4.1 *Impacts and global adaptation challenges under the high carbon world*

A widespread retreat of glaciers and snow cover would be expected under the high carbon world, with loss of many glaciers in the world's major mountain ranges. This would further exacerbate water security issues in densely populated regions of south and southeast Asia and Latin America. Overall, the number of people exposed to increased water resource stress due to climate change could lie in the order of two to three billion by the end of the 21st century. For current cultivars, crop production would decline in most subtropical and tropical regions, leading to an overall increase in the number of people at risk of hunger and increasing inequity of food distribution (IPCC 2007c, Chapters 10 and 11; 2007a, Chapters 3, 5 and 20).

Significant losses of ecosystems and species extinctions could be expected, including annual bleaching and eventual death of most coral reefs and conversion of large areas of rain forest in the Amazon, central Africa and southeast Asia into savannah and increased risk of wild fire. Increased heat waves in all regions would increase pressure on public health systems, along with the potential spread of some infectious diseases, including cholera, diarrhoea and dengue fever. The combination of sea level rise, river flooding and increased tropical storm activity would present significant pressures on coastal systems in both the developed and developing world (IPCC 2007a, Chapters 4, 6, 8, and 20).

Understanding the potential for adaptation in such a world, and the likely international policies affecting trade and other exchange of services, including tourism, requires an appreciation of the socio-economic drivers that underpin this scenario. The high carbon world (with its specific socio-economic features derived from the SRES A2 scenario) describes a society that fails on many fronts to develop globally coherent responses or share equitably the benefits of technological development, improved efficiency, and economic growth. Poverty would remain a major, and in some regions increasing, concern, with hundreds of millions more poor people living in places that are vulnerable to the effects of climate change. These people would have limited capacity to adapt due to lack of technological or financial resources and information. It is likely that in such a world, regional, national and local governance systems would more likely result in limited and uneven distribution of international resources to support adaptation. Thus multiple non-climate stresses could be expected to add to the negative impacts from climate change in this scenario (IPCC 2000, 2007a, Chapters 17 and 20). It should be noted that not all high-emissions scenarios necessarily share these socio-economic features – they represent but one particular choice amongst a range of high-emissions scenarios in the literature (see IPCC 2000 and for example the A1FI scenario as alternative).

2.4.2 *Implications for Australia and regional and global flow-on effects for New Zealand*

New Zealand's closest neighbour, Australia, would likely be severely affected by climate change impacts under the high carbon world. Projections (IPCC 2007a, Chapter 11) include significant water shortages in the Murray-Darling basin and southwestern Australia within the next few decades, increased coastal damages from sea level rise and tropical cyclones, and significant loss of biodiversity in alpine regions, the Great Barrier Reef, and the Queensland wet tropics. Agricultural production could be reduced in many regions, including the most productive ones, by a combination of reduced rainfall, higher extreme temperatures and recurrent drought, as well as substantially increased risk of wildfire. While the capacity of Australia to adapt is high (IPCC 2007a, Chapter 11), the scale and combination of these different impacts in a high carbon world presents serious challenges to Australia's social, environmental and economic sustainability. This could result in greater population pressure on New Zealand, but also a more protectionist attitude in Australia regarding its own national interests as it deals with pressures within and on its own borders.

The implications of this high carbon world for New Zealand are obviously a matter of some conjecture and difficult to quantify, but possibilities may include the following.

- Instability in the Pacific Islands could become serious due to a combination of climate related natural disasters, sea level rise, and economic and environmentally induced migration. This may cause varying stability of Pacific governments resulting in increased migration pressure; however, international assistance may become more limited due to increasing global problems.
- The general impacts of failure to deal with climate change may lead to major political instability in some world regions affecting global and regional security, and a broader suppression of global environmental issues.
- The impacts of climate change on Australia could lead to a competitive advantage for New Zealand in some areas, such as agriculture and tourism, but the social, political and economic challenges to both countries could lead to a less harmonised or beneficial situation. The outcome from international changes in economic, trade, political and environmental issues is difficult to predict at present.
- The regional impacts of developments in the high carbon world may lead to subsequent re-emphasis by some countries on efforts to mitigate climate change; given the need for common policy objectives to control global climate, such a growing discrepancy between different countries may create a basis for military interventions.
- Escalation of regional social, political, economic and technological differences could hamper New Zealand's trade and international relationships including the possibility of trade barriers, security concerns and alliances between smaller groups of countries.

2.4.3 *Impacts under the rapidly decarbonising world*

A theme of "similar pattern but lower magnitude" under the rapidly decarbonising world compared to the high carbon world applies also to other climate changes and their immediate impacts. Many small glaciers and snow fields are expected to disappear even under the rapidly decarbonising world, but with less risk of losing very large glaciers that represent major regional water sources. The total number of people exposed to increased water stress due to climate change would probably be a few hundred million by 2100 rather than several billion. Cereal production would likely increase in mid to high latitudes, while much of the decline in subtropical and tropical regions could be avoided by changing cultivars and shifting planting times. This would allow a significant reduction of the global number of people at risk of hunger from currently about 800 million to about 100 million by 2100 (IPCC 2007c, Chapters 10 and 11; 2007a, Chapters 3, 5, and 20).

Damages to sensitive ecosystems could not be avoided, particularly in the Arctic and other ecosystem hotspots, and increasing occurrence of wild fire would still be expected in some regions. However, the large-scale collapse of tropical rainforest would become significantly less likely; increased coral bleaching could not be avoided but large-scale death of coral reefs would be much less likely. Similarly, increased heat waves would still be a problem in some regions, but the overall climate-related burden on the health sector would be significantly less. Sea level rise and other pressures on coastal systems would be reduced largely due to reduced risk of river flooding and tropical storms; in the longer term though (beyond 2100), sea level rise may still challenge the existence of many low-lying areas (IPCC 2007a, Chapters 4, 6, 8, and 20). However, projections of future sea level rise are uncertain and this aspect is discussed in more detail in Section 4.

Global population in this scenario would be very unlikely to continue to grow as in the high carbon world. This is because the greater equalisation of incomes and transfer of technology would reduce the key drivers for population growth in developing regions, namely poverty, disempowerment of women, and insecurity about old age. This suggests that in a rapidly decarbonising world, fewer poor people would be placed in harm's way, which in turn would reduce the overall scale of impacts for a given amount of climate change. This relationship between global number of people affected and socio-economic development has been clearly established for areas such as water scarcity and coastal flooding (IPCC 2007a, Chapters 6 and 20).

In a rapidly decarbonising world one may assume that not only the impacts of climate change would be less but also the ability to adapt to changes would be greater. This is because the scale of emission reductions required to meet a 2°C target is only feasible under global cooperation, including rapid technology development and transfer, financial assistance, and an acceptance that achieving long-term sustainability warrants near-term costs including opportunity costs. A world that follows these principles appears much more likely to achieve effective adaptation through information, technology, good local and national governance, and international cooperation, including financing and other assistance to the most vulnerable regions. This suggests that even though warming of 2°C still implies significant potential impacts for some regions and sectors, the ability to reduce those impacts through adaptation would be significantly higher than in the highly heterogeneous and politically fractured high carbon world (IPCC 2007a, Chapters 17 and 20).

"Cereal production would likely increase in mid to high latitudes, while much of the decline in subtropical and tropical regions could be avoided by changing cultivars and shifting planting times."

2.4.4 *Implications for Australia and regional and global flow-on effects for New Zealand*

Australia would still be negatively affected by climate changes under the rapidly decarbonising world, most significantly in the area of water resources and agricultural production, coastal settlements, and natural ecosystems, but much less so than under the high carbon world (IPCC 2007a, Chapter 11). The cooperative nature underlying the rapidly decarbonising world also implies a greater likelihood of a harmonised approach between Australia and New Zealand in mitigating climate change and adapting to its impacts through coordinated actions, standards and regulations, which could be expected to spread the risk from local impacts of climate change more evenly and reduce the risk of severe climate-related disruptions in the Pacific region.

The implications of this rapidly decarbonising scenario for New Zealand are equally subject to conjecture, but possibilities include the following.

- Rapid changes in energy production systems and technologies are likely to involve changes in industrial systems and in economic conditions. New Zealand is likely to have both benefits, e.g., from new local energy sources, and costs, e.g., from avoidance of fossil fuels, that lead to structural changes.
- Structural changes in energy technologies could lead to an increased need for imports, exacerbating New Zealand's relatively large offshore debts; strategically this could be countered by an increase in opportunities for agricultural and forestry exports.
- International trade is likely to be governed by global trade agreements and rules, including efficiency standards linked to climate and environmental implications.
- Globalisation of efficient technologies suggests that New Zealand technology and expertise would have to meet international standards to be competitive and recognised by trading partners, and a growing cost would be associated with any process that produces greenhouse gas emissions.
- Financing mechanisms would encourage the distribution of technologies to developing countries; markets for new products and services from New Zealand would depend on our ability to meet consumer expectations related to resource efficiency and meeting development as well as efficiency goals.

3. Climate change scenarios for New Zealand for the high carbon and rapidly decarbonising worlds

3.1 Methodology to produce climate change scenarios for New Zealand

The global climate change information presented in Section 2 for the two alternative emissions scenarios provides the basis for climate change projections for New Zealand that are consistent with those global patterns of change. As for the global changes, we focus on two key time periods, 2030-2049 and 2080-2099, with changes expressed relative to the average climate during the period 1980-1999.

Recent climate change scenarios for New Zealand (MfE 2008c) applied the statistical downscaling methodology described by Mullan et al. (2001) to data output by 12 global climate models developed for the IPCC Fourth Assessment Report (AR4). These 12 models were a subset of the total number of models available, selected because their 20th century simulations validated well against current climate in the New Zealand and Southwest Pacific region (MfE 2008c, Mullan & Dean 2009). However, the downscaled patterns in MfE (2008c) were presented only for results from the SRES A1B emissions scenario, which lies in between the high carbon and the rapidly decarbonising worlds. This study now extends this approach to these two alternative scenarios and thus allows a more comprehensive assessment of possible future climates.

The first step in developing the two scenarios used here was to apply the same downscaling approach to climate model data driven by the SRES A2 emissions scenario (the high carbon world) and by the SRES B1 emission scenario (the lowest emissions forcing for which detailed model simulations are available).[3]

Downscaled changes were calculated on NIWA's Virtual Climate Station (VCS) 5-kilometre grid over New Zealand (Tait et al. 2006). The climate scenarios are expressed as changes between the 20-year current climate period 1980-1999 and the future 20-year periods of 2030-2049 and 2080-2099. This 20-year averaging removes much, but not all, of the natural variability as represented in the models.

New Zealand changes under the high carbon world were determined by directly downscaling global model runs for the SRES A2 scenario, for both 2030-2049 and 2080-2099 periods. For the rapidly decarbonising world at 2030-2049, the same direct downscaling was applied using model runs for the SRES B1 scenario. For changes over the following 50 years, from 2030-2049 to 2080-2099, a scaling factor[4] was calculated such that the 12-model average *global* warming over the full 100-year period from 1980-1999 to 2080-2099 was exactly +1.5°C (or about 2°C above pre-industrial temperatures). This factor (of 0.62) was then applied to the global model changes and input to the downscaling algorithm to obtain changes over New Zealand for 2080-2099.

Table 1 shows the annual-average temperature increases for New Zealand for the two time periods and the two scenarios. Averaged over all 12 models, temperatures are projected to increase by about 0.7°C to 2030-2049 under the rapidly decarbonising world, and slightly more (0.9°C) under the high carbon world, relative to 1980-1999. Towards the end of the century (2080-2099), the differences between the two scenarios are far more substantial: the rapidly decarbonising world shows New Zealand warming by an average of about 1.1°C (relative to 1980-1999) versus 2.6°C for the high carbon world. Note that even though all models agree that New Zealand will warm along with rest of the world, there is a large range in projected warming between models.

Table 1. New Zealand-wide average annual temperature increases (°C) from 1980-1999 to 2030-2049 and to 2080-2099, by model, for the rapidly decarbonising and high carbon worlds. Asterisks indicate the two models where the B1 and A2 changes had to be estimated (see footnote 3).

	Rapidly decarbonising world		High carbon world	
Model No.	2030-2049	2080-2099	2030-2049	2080-2099
1	0.90	1.27	1.09	2.92
2	0.48	0.76	0.78	2.43
3	0.43	0.60	0.75	1.65
4	0.82	1.14	0.85	2.53
5	0.84	1.18	0.97	2.62
6	1.22	1.89	1.30 *	3.56 *
7	0.67	1.12	0.96	2.48
8	0.44	0.95	0.31	2.20
9	0.67	1.05	0.84	2.20
10	0.92	1.15	1.28	3.05
11	0.46	0.86	0.94	2.13
12	0.89 *	1.23 *	1.09	2.96
Model-Avg	0.73	1.10	0.93	2.56

3.2 Model-average changes in temperature and precipitation under the two scenarios

Maps of temperature changes projected for New Zealand under the two emissions scenarios are presented in Figure 4. Only the annual changes are presented here, with the same contour intervals used on all maps. No model has a strong spatial gradient in temperature change[5], but the average level of warming varies substantially from model to model (see Table 1). In some models, the north of the country warms slightly faster than the south, and in others the opposite occurs. The 12-model average displays slightly greater warming in the north of New Zealand relative to the south. There is a relatively small variation seasonally in the projected temperature changes. In the North Island, summers warm slightly more than winters (by up to 0.3°C in the Waikato by the end of the century under the high carbon world).

[3] Of the 12 models used, one of them (*ukmo_hadgem1*) had no B1 simulation and the other (*miroc32_hires*) no A2 simulation. For consistency (e.g., the very high resolution model *miroc32_hires* model has the most rapid warming of any of the IPCC models), it was considered essential to use the same 12 models for all underlying scenarios. Climate changes for the two missing model runs were estimated by taking the same spatial patterns as in SRES A1B, but assuming the missing model (in B1 or A2) had the same ranking relative to the other 11 models as it had in A1B. Together with the constraint that the *miroc32_hires* model was at the top of the IPCC range for A2 (i.e., a global increase of +5.4°C by the decade 2090-2099), these assumptions lead to a consistent set of 12 model simulations for both scenarios.

[4] Note that this is not formally "pattern scaling" (Mitchell 2003) where the pattern is invariant with time and only its amplitude changes according to the global temperature increase. Here, the 2040 and 2090 patterns can be different if the global models show a changing evolution in the latter half of the 21st century.

[5] Weak spatial gradients, at least for temperature, are a consequence of the statistical downscaling algorithm which doesn't explicitly model physical characteristics such as soil moisture or snow melt.

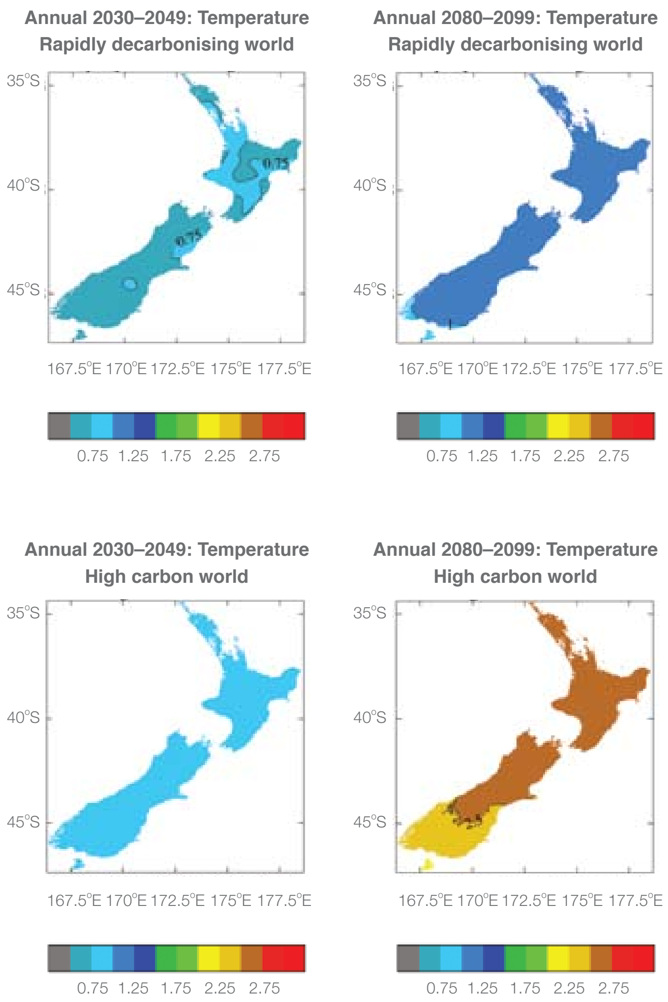

Figure 4. Projected New Zealand annual temperature change (in °C) from 1980-1999 to 2030-2049 and to 2080-2099 for the rapidly decarbonising world (upper panels), and for the high carbon world (lower panels), as averaged over the downscaled patterns from 12 global models.

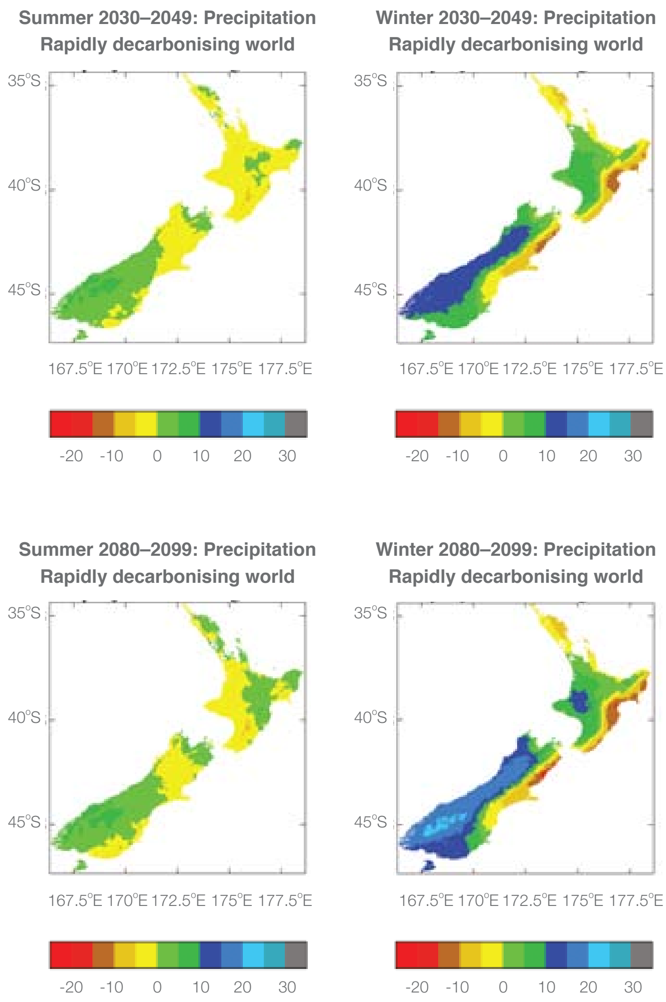

Figure 5a. Projected New Zealand seasonal precipitation change (in %) from 1980-1999 to 2030-2049 (upper panels), and to 2080-2099 (lower panels), for the rapidly decarbonising world as averaged over the downscaled patterns from 12 global models. Summer and winter seasons are shown.

Figure 5 (a and b) shows the 12-model average patterns of projected precipitation change at 2030-2049 and 2080-2099 for the two scenarios. Because of substantial seasonal differences in precipitation changes, maps are shown for both summer and winter. In general, autumn changes are similar to those in summer, and spring similar to winter.

Winter changes have a consistent pattern of increases in the west of both islands, and decreases in the east of both islands and in the north of the North Island. The amplitude of this pattern increases with time and with the magnitude of global warming. Thus, the local New Zealand precipitation pattern scales to some degree with the rate of global warming (Mitchell 2003). This strong west-east gradient in precipitation change is driven by the increase in southern hemisphere westerly winds, which is a very consistent feature across all the AR4 models.

Summer precipitation changes are generally smaller than those of winter, and lie within ±5% over almost the whole country for both periods of the rapidly decarbonising scenario, and for the first 50 years of the high carbon world. The pattern of summer rainfall change, however, is noticeably different from winter in the North Island: a decrease is projected for the southwest and an increase in the east, in the 12-model average. This pattern becomes more marked under the high carbon world by the end of the century (See Figure 5b, lower left panel) with up to 10% less summer rainfall in Taranaki, Wanganui and Manawatu, and increases of 10% or more in parts of Hawke's Bay and Gisborne by 2080-2099. These summer changes in the North Island are the opposite of those in winter, but smaller, so the winter pattern will dominate the annual average.

3.3 Variation across models in projected changes

The 12-model average patterns described above provide a useful general picture of future temperature and precipitation changes for the two scenarios. However, as was evident from Table 1, there is a substantial difference from model to model, and thus a substantial uncertainty in the magnitude of the projected changes.

One way of presenting the extent of model agreement is through 'box and whisker' plots[6] of the model projected changes. Examples are

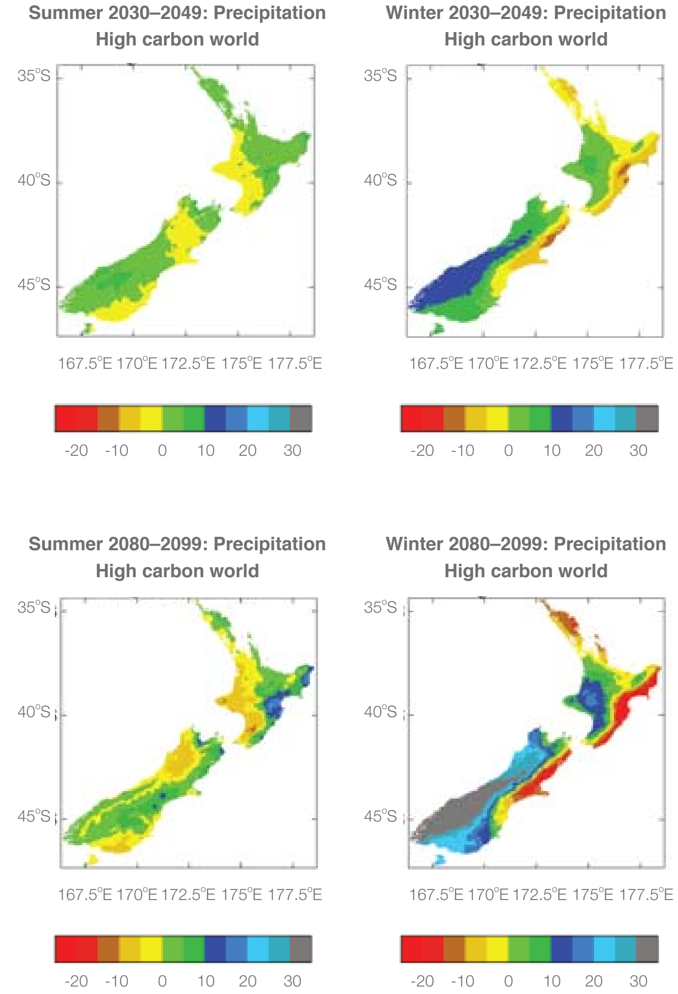

Figure 5b. Projected New Zealand seasonal precipitation change (in %) from 1980-1999 to 2030-2049 (upper panels), and to 2080-2099 (lower panels), for the high carbon world as averaged over the downscaled patterns from 12 global models. Summer and winter seasons are shown.

shown for temperature (Figure 6) and for precipitation (Figure 7). Plots have been generated by averaging the changes over the six geographical regions of New Zealand used by NIWA in its seasonal outlooks.[7]

One of the 12 models (*miroc32-hires*, labelled as model number 6 in Table 1) is very much warmer than all others (globally as well as locally). In the temperature box and whisker plots, this model is the one marked as an outlier or at the position of the upper whisker where there is more of a spread between the other 11 models. Including this warmest model obviously had a large effect on the range of projected temperature increase, but only a modest influence on the 12-model average: e.g., at 2080-2099 under the high carbon scenario, the warming for the North of the North Island (NNI) is 2.66°C for the 12-model average and 2.54°C for the 11-model average excluding the warmest model. Nonetheless, we cannot at this stage exclude this model or assume that it is less likely to be correct than any of the other models used in this study.

Focussing on just the inter-quartile range, between the 25th and 75th percentiles of the model distribution, also produces a much tighter band on projected warming: e.g., for NNI at 2080-2099 under the high carbon scenario, the 12-model full range of warming is 1.59 to 3.99°C, whereas the inter-quartile is range is 2.37 to 2.94°C, with the model median at 2.64°C.

Another feature of the model spread evident from Figures 6 and 7 is that the inter-quartile range narrows with time over much of New Zealand under the rapidly decarbonising world: e.g., from the left panels of Figure 7, comparing 2030-2049 with 2080-2099, the inter-quartile range is smaller in the later period for all regions except the west of the South Island (west coast, Southland and inland Otago).[8]

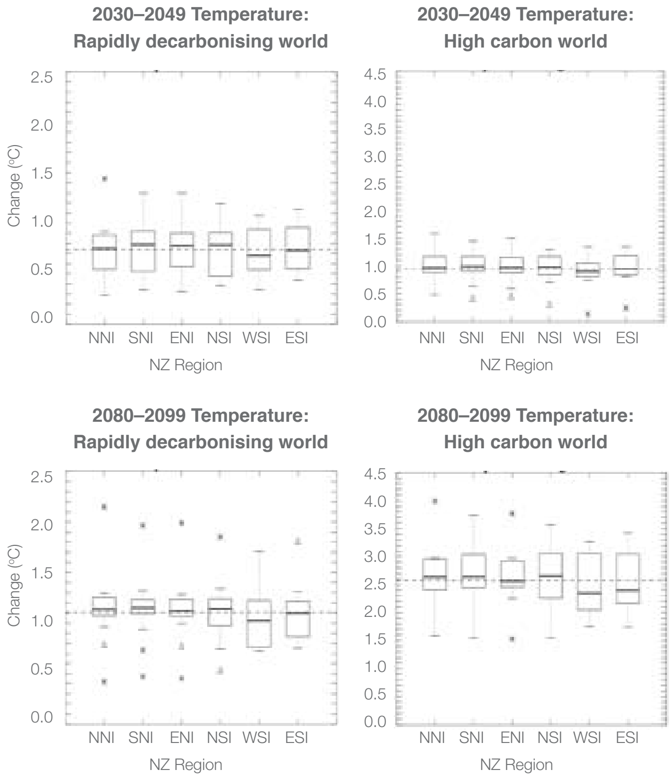

Figure 6. Box and whisker plots of downscaled annual temperature projections for 6 New Zealand regions from 12 climate models. Plots show the range of warming projected by the 12 models for the 2030-2049 and 2080-2099 periods, and for the rapidly decarbonising and high carbon scenarios. The dashed line across all regions marks the national average temperature change. Note the different y-axis scale for the high carbon scenario.

[6] In each box and whisker plot (Tukey 1977, Wikipedia 2009), the median change is indicated by the heavy black line, with the surrounding "box" extending from the estimated 25th percentile to 75th percentile of the data known as the inter-quartile range (IQR). The "whiskers" are indicated by the short horizontal lines, and are positioned at the last data points that lie within 1.5 times the IQR of the 25th and 75th percentiles. The only data points plotted explicitly are those that lie outside the whiskers (considered as outliers): triangles mark any model between 1.5 and 3 times the IQR out-side the 25th and 75th percentiles, and asterisks mark any model more than 3 times the IQR from the box.

[7] The 6 regions constitute the North, South-West and East of the North Island and South Islands, respectively (e.g., NNI= *North of North Island*, comprising Northland, Auckland, Waikato and Bay of Plenty; SNI= *South (and west) North Island*; WSI= *West (and south) South Island)*.

[8] However, the full range across all 12 models, and the standard deviation of model changes, continues to increase with time.

Figure 7. As Figure 6 but for summer and winter precipitation. Left panels show changes in 2030-2049, right panels show changes in 2080-2099 (in percent relative to 1980-1999). Separate panels are shown for each of the 6 New Zealand regions, and within each panel the rapidly decarbonising and high carbon worlds. The dashed line indicates “no change” from the current climate.

Figure 7 displays a series of box and whisker plots of the projected precipitation changes, by region and time period and scenario. In this case, changes are broken down by season. Some of the key features include:

- the most noticeable departures from the ’no change’ line occur for: SNI, NSI and WSI in winter (increasing) and ENI in winter (decreasing)
- in most cases towards the end of the 21st century, the inter-quartile range (i.e., differences between different climate models) is larger in the summer than in winter.

The six regions selected to show the changes in precipitation still lead to some averaging that reduces the amount of change that could be seen in some particular locations. However, variations between different models generally increase and thus projections become less certain the smaller the geographical scale of scenarios. To illustrate this, Table 2 shows the changes in precipitation projected from all 12 models for 2080-2099 for the high carbon world during summer and winter in three locations: Gisborne, Blenheim, and Haast. There is excellent agreement between models on the sign of the winter precipitation changes at Gisborne (all decreasing) and at Haast (all increasing). In the summer, rainfall changes are sensitive to how far south the subtropical ridge expands in the different model simulations, and the consequent effect on prevailing wind direction.

Table 2. Projected precipitation changes (in %) for the high carbon world for 2080-2099 relative to 1980-1999, for summer and winter seasons at Gisborne, Blenheim, and Haast.

	Gisborne		Blenheim		Haast	
Model No.	Summer	Winter	Summer	Winter	Summer	Winter
1	15	-7	-10	2	-36	12
2	26	-37	-1	-13	-23	15
3	-15	-17	11	-12	20	22
4	-2	-18	-6	1	-21	34
5	15	-18	17	3	-5	41
6	5	-19	16	-0	24	2
7	11	-26	1	5	-32	46
8	-13	-28	-1	0	12	42
9	13	-18	3	1	-16	30
10	16	-15	42	-6	37	10
11	-18	-13	3	4	34	47
12	21	-8	16	9	-4	59
Model-Avg	6.1	-18.6	7.7	-0.4	-1.0	30.1

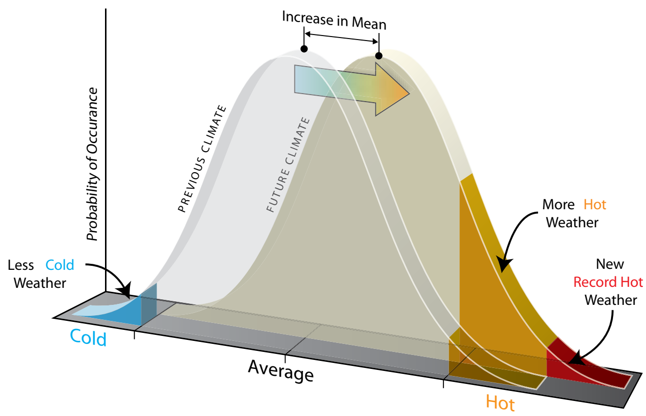

Figure 8. Illustrative diagram of the changes in the occurrence of extremes for a small shift in the average climate. The diagram shows a probability distribution of the occurrence of temperature extremes under a reference climate and for a future climate shifted towards higher average temperatures. This shift results in a significant increase in the number of occurrences of hot weather, and the occurrence of more record hot weather, even though the increase in mean temperature is well within the typical range of temperatures experienced under the reference climate conditions. Conversely, this shift results in a significant decrease in the occurrence of extreme cold weather (e.g., frosts). Figure from Reisinger (2009), based on IPCC (2007c) WGI Box TS.5 figure 1.

3.4 Changes in other climate elements

The material above has focussed exclusively on the climate elements of seasonal temperature and precipitation. However, climate extremes (such as incidents of heat waves, heavy rainfall and flooding, extreme winds) are an important part of the overall climate and play a key role in causing climate-related damages.

Our understanding of changes in extremes is generally much more limited than that of changes in average climate conditions. Nonetheless, a key lesson from many climate studies is that even small changes in average climate can lead to a disproportionate increase in the incidence of damaging extremes. This is illustrated in Figure 8 for the example of changes in average temperature and the occurrence of temperature extremes. The occurrence of specific temperatures (or any other climate extreme) follows a roughly bell-shaped distribution, where most occurrences fall near the average condition, and a lesser number of events are significantly higher or significantly lower than this average. A modest shift in this distribution, assuming that the shape of the distribution itself is not changed, will result in a significant increase or decrease in the number of events that exceed a specific threshold. Impacts of climate change are often related to changes in extreme events that exceed some limit that society is adapted to (e.g., overtopping stop banks, exceeding indoor temperatures that lead to health risks for vulnerable populations, or decrease in soil moisture below the minimum needed for plant growth).

Figure 8 demonstrates that even modest changes in the average climate, which as such may well lie within the range of natural variability that is currently experienced, can lead to a significant change in the damages caused by extreme events (e.g., flooding, heat-induced mortality, or loss of agricultural production).

Most of the projected changes in extremes for New Zealand to date have employed this methodology where changes in the average climate are superimposed on historical variability. More recent work with more complex regional climate simulations offers the ability to investigate not only changes in the mean climate, but to also simulate possible changes in the distribution of extremes (MfE 2008c). This work will offer a more realistic and relevant understanding of changes in extremes and regional and local variations, but results have not yet been published in the peer-reviewed literature.

For these reasons, no quantitative information specific to the two scenarios presented in this paper is provided here on projected changes to other climate elements or to extremes. The remainder of this section provides an overview of the current understanding of these issues based on work carried out to date and international studies, recognising that international studies may not be directly transferable to New Zealand and the earlier New Zealand work was not specific to the scenarios presented here and perhaps not even to the AR4 models. The list below is not comprehensive.

3.4.1 *Temperature extremes*

Decreases in frost occurrence and increases in high maximum temperatures are probably the most robust findings from analyses of climate change simulations (e.g., Kharin et al. 2007). Indicative results for New Zealand can be found in MfE (2008c).

Over time scales of one to two decades, natural modes of climate variability such as the El Niño-Southern Oscillation or the Interdecadal Pacific Oscillation can significantly modify the annual average temperatures and occurrence of extremes in any given year. For example, if the temperature increase is fairly modest, such as is likely to 2030-2049 under the rapidly decarbonising world, then changes in circulation can dominate at the local scale. New Zealand studies (MfE 2008c, A. Clark, NIWA Wellington, pers. comm.) suggest that some limited eastern regions have experienced an increase in frosts since 1970 (but an overall decrease since 1950), possibly caused by a reduction in onshore easterly flow and hence fewer cloudy nights over winter.

However, in the longer term, the underlying warming trend is expected to dominate even for the rapidly decarbonising world. As a rough guidance, we would expect that by the 2030s, what is currently an unusually warm year will have become the norm, whereas an unusually warm year in the 2030s will lie outside the range of temperatures experienced in New Zealand to date. Changes in occurrence of heat waves and hot days have not been quantified to date for New Zealand, but similar comparisons could be expected to apply.

3.4.2 *Precipitation extremes*

Increases in the frequency and magnitude of heavy rainfall are also a widespread finding of climate models. The potential low level moisture content of the atmosphere rises at about 7-8% per degree Celsius increase in temperature (MfE 2008c, Allan & Soden, 2008), although there is considerable discussion and ongoing research into constraints on precipitation extremes (Lenderink & van Meijgaard 2008).

Current guidance for New Zealand (MfE 2008c) suggests that a currently experienced extreme rainfall (e.g., 24-hour extreme with a 100-year return period) could occur approximately twice as often (i.e., 50-year return period) under a local warming of about 2°C. Conversely, increases in dry spells are also possible (Sillmann & Roeckner 2008).

Similar to temperature, natural climate variations will continue to be superimposed on these long-term trends and can lead to deviations from these trends over time scales of one to two decades. Adaptation to changes in precipitation will therefore need to incorporate both these shorter term (decadal) natural variations in precipitation and associated risk of extremes as well as longer-term trends, with emphasis depending on the lifetime of infrastructure investments, commercial developments, or vulnerability of ecosystems to specific changes.

Increasing flood peaks resulting from increased precipitation extremes will interact with rising sea levels (see Section 4) and could create particular challenges for some coastal settlements and stormwater drainage in low-lying areas (Hennessy et al. 2007).

3.4.3 *Drought*

Drought magnitude and frequency are expected to increase in a warmer climate as evapotranspiration increases, unless this increase is compensated by a simultaneous increase in precipitation. Mullan et al. (2005) concluded from a study of two IPCC Third Assessment models that current 1-in-20 year drought could occur at least twice as often in eastern parts of New Zealand (parts of Northland, Bay of Plenty, Wairarapa, Marlborough, Canterbury and Otago) under a warming of about 2°C.

3.4.4 *Extreme Winds*

A number of international studies suggest an increase in the frequency of strong winds under global warming (e.g., Rockel & Woth 2007), but there is very little information currently available for New Zealand.

3.4.5 *Fire Risk*

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

4. Sea level rise scenarios

The scenarios outlined above did not include a discussion of sea level rise. This section sets out the currently available information on global and regional sea level rise.

4.1 Understanding based on the IPCC Fourth Assessment Report

Current models used to project global and regional sea level rise have important limitations that result in significant uncertainties, particularly regarding the upper bounds of projections. Dynamical processes related to ice flow, which are not included in current models but suggested by recent observations, could result in increased loss of ice from the polar ice sheets and lead to more rapid sea level rise than projected by current models. This possibility was noted as a major reason for increased concern about climate change (IPCC 2007d, Meehl et al. 2007).

The AR4 provided model-based estimates of sea level rise for the 2090s (2090-2099) relative to 1980-1999. These projections include thermal expansion, loss of land-based snow and ice from mountain glaciers and small ice caps, and surface ablation of the Greenland ice sheet. They also include a contribution due to increased ice flow from Greenland and Antarctica at the rates observed for 1993 to 2003, but the IPCC noted that these current glacier flow rates could increase or decrease in future (Meehl et al. 2007).

Projected ranges of global average sea level rise based on these contributions are given in Table 3 for the six SRES marker emissions scenarios (i.e., scenarios of future greenhouse gas emissions in the absence of additional climate policies). However, the AR4 warned that sea level rise could exceed these ranges because these projections do not include uncertainties due to climate-carbon cycle coupling, which could lead to additional warming and related sea level rise, nor the possible future acceleration of the flow of glaciers that drain the polar ice sheets. Such an acceleration has been observed during the past decade where glaciers lost their buttressing ice shelves. The AR4 noted that if the enhanced ice flow from Greenland and Antarctic glaciers were to increase linearly with temperature, this would add another 10 to 20 cm sea level by the end of the 21st century, but greater increases could not be ruled out (Meehl et al. 2007).

Table 3. Projected global average sea level rise excluding rapid dynamical changes in ice flow (Meehl et al. 2007).

Case	Sea level rise (m at 2090-2099 relative to 1980-1999)
	Model-base range Excluding future rapid dynamical changes in ice flow
B1 scenario	0.18 – 0.38
A1T scenario	0.20 – 0.45
B2 scenario	0.20 – 0.43
A1B scenario	0.21 – 0.48
A2 scenario	0.23 – 0.51
A1FI scenario	0.26 – 0.59

4.2 Inferred sea level rise for New Zealand in 2090-2099 based on IPCC projections

The high carbon world is identical to the A2 scenario in Table 3, which gives a global average sea level rise of 23 to 51 cm by the end of the 21st century if there are no rapid further dynamical changes in ice flow (Meehl et al. 2007). Equivalent estimates for sea level rise for the rapidly decarbonising world are not available but may be inferred to be about 17 to 36 cm in the global average, based on a rough scaling of sea level rise with global average temperature increase under this low-emissions scenario compared to the B1 scenario (Meehl et al. 2007), also assuming that there would be no rapid further dynamic changes in ice flow.

Sea level rise is not expected to be globally uniform. While current models differ significantly in their regional distribution of sea level rise, the average estimate from current models is that sea level rise in the New Zealand region would be up to about 10 cm above the global average for a medium-high emissions scenario (IPCC 2007c, figure 10.32; Yin et al. 2009, figure 1). Regional sea level changes could be further enhanced if significant loss of polar ice were to occur, due to the resulting changes on Earth's gravitational balance (e.g., Milne et al. 2009).

4.3 More recent studies of the possible additional contribution from ice sheets

Numerous studies during 2007 and 2008 have attempted to better understand and quantify the possible acceleration of glacier flow from polar ice sheets in a warming world and their potential additional contribution to global sea level rise. Most recent studies point to a potentially significant additional contribution from dynamic ice sheet discharge that could increase total sea level rise by 2100 to between about 70 and 160 cm, although even 2 m cannot be ruled out entirely (see e.g., Rahmstorf 2007, Alley et al. 2008, Das et al. 2008, Holland et al. 2008, Horton et al. 2008, Joughin et al. 2008, Pfeffer et al. 2008, Stearns et al. 2008, Nick et al. 2009, Velicogna 2009). In addition, new analyses of sea level during the last global warm period have provided evidence that rise at rates of 160 cm per century have happened before (Rohling et al. 2008, Blanchon et al. 2009).

There is insufficient convergence or technical consistency yet amongst those studies to allow a comprehensive view of new estimates of ranges for global sea level rise projections or to assign probabilities to projections. The broad range of values derived by recent studies rather suggests that, at present, no specific figure for sea level rise for 2100 represents a reliable upper bound. Given the large uncertainties in current model-based projections, a differentiation between individual emissions scenarios (e.g., between the high carbon and rapidly decarbonising worlds) is in most cases not appropriate. All models indicate that sea level rise would accelerate in a warmer world, but the uncertainties arising from our current incomplete understanding of the processes leading to loss of polar ice are much greater than the differences arising from different global scenarios of greenhouse gas emissions.

As a result, the impacts of sea level rise and associated adaptation needs will generally need to be evaluated based on the more open question, "What are the impacts and adaptation options if sea level were to rise by x m by a given date?" It is noteworthy that almost all recent studies that provided estimates for global sea level rise indicated values at the upper end of or above the range provided in the AR4 (Meehl et al. 2007). We therefore suggest that coastal risk assessments should assume that the probability of sea level rise of at least 0.5 m by 2100 is high, but the possibility of even 2 m can not be absolutely excluded, and sea level will continue to rise beyond the year 2100 for many more centuries. This more open-ended approach to assessing the impacts of sea level rise is consistent with current national guidance on coastal hazards assessments in New Zealand (MfE 2008a, 2009). Appropriate adaptation responses will depend on the lifetime and nature of infrastructure and investments as well as their ability to adapt over time as knowledge about future sea level rise and confounding factors such as storm surges and changes in wave climates increases.

5. Key challenges for the process of adaptation in New Zealand

The scenarios outlined in the preceding sections provide a basis for evaluating the potential impacts of climate change on a range of systems and sectors. In turn, such impacts assessments can serve as the basis for an evaluation of adaptation options and prioritisation of responses.

5.1 Does adaptation present a significant challenge for New Zealand?

Adaptation decisions face a number of challenges, some of which are specific to New Zealand. The relatively lesser rate and magnitude of climate changes projected for New Zealand compared to the rest of the world (see Figure 2), and our location in temperate latitudes, could suggest that adaptation is of lesser importance than for other countries around the world. Such a conclusion would be short-sighted though, for several reasons.

- Sea level rise on New Zealand's coast will be the same if not slightly more than the global average rate of change (see Section 4).
- New Zealand faces the same range and complexity of issues related to management of its varied ecosystems and natural hazards, ranging from the coast to the alpine environment – but it has to make its decisions on the basis of much smaller budgets and pools of expertise than many other countries, which could limit the effectiveness and timely implementation of adaptation measures (Adger et al. 2007).The decentralised approach to decision-making in the area of managing natural resources and hazards under the Resource Management Act (1991) and Local Government Act (2002) further encourages a regionalisation and potential inconsistency of responses, although this diversity can also be an opportunity.
- Social and cultural attitudes towards managing shared natural resources, and scepticism towards climate change with some local decision-makers, could further limit the range and effectiveness of adaptation responses (Adger et al. 2007).
- New Zealand is highly dependent on natural resources through its reliance on agriculture, forestry and tourism, but the relatively short period of settlement means that data records that crucially underpin our understanding and management of natural hazards and ecosystems are often short and patchy.

- New Zealand's economy is strongly interlinked with global processes through international policies, technologies, trade and flow of people, goods, and services. This makes an understanding of and adaptation to global climate change particularly complex and challenging for New Zealand.

Dealing with the challenges introduced by these issues is inevitably difficult, but decisions can have major consequences for economic, social and environmental well-being. The IPCC's AR4 provides a high-level overview of the degree to which various sectors in New Zealand and Australia are regarded as vulnerable to the impacts of climate change and may require proactive adaptation. The result of this assessment is shown as a schematic diagram in Figure 9.

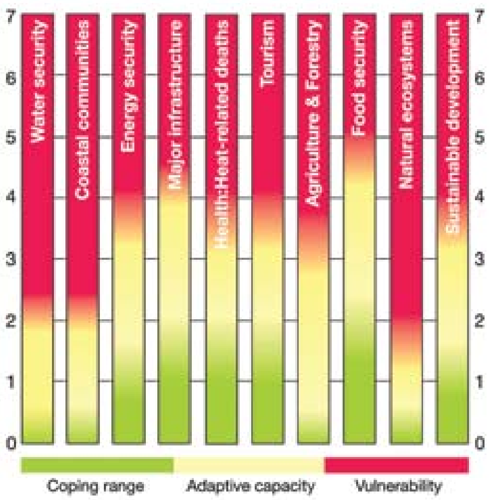

Figure 9. Schematic assessment of the coping range, adaptive capacity, and vulnerability of different sectors of Australia and New Zealand with increasing temperature. Numbers on the vertical axis indicate changes in global average temperature (°C) relative to pre-industrial conditions (from Hennessy et al. 2007).

Figure 9 clearly involves substantial generalisations about the projectedimpacts and the need and ability to adapt. It is intended to apply to Australia and New Zealand combined and therefore does not necessarily allow interpolation to New Zealand alone, let alone specific sectors and regions of New Zealand.
However, the diagram does highlight that, in the judgement of the IPCC authors, several key sectors (mainly water security, coastal communities and natural ecosystems) would exceed their natural coping range and require proactive adaptation for almost any degree of warming, and could become vulnerable to climate change even with adaptation for warming of 2°C. Such levels of warming would be realised in the rapidly decarbonising world by the end of the 21st century, or by the middle of the 21st century in the high carbon world. Based on the studies used in the IPCC assessment, agriculture and forestry also require proactive adaptation for almost any degree of warming, but effective adaptation measures should be able to avoid significant vulnerabilities as long as the global average temperature increase remains below about 3°C.

5.2 Understanding adaptation as an iterative process involving many stakeholders

The uncertainties involved in projections of climate change, its impacts and the vulnerabilities of different parts of communities and sectors force us to recognise that adaptation is not a one-off event or a single step, but rather an iterative *process* (Warrick 2000). This process is illustrated in Figure 10. It involves awareness raising and capacity building, the development of knowledge, data and tools to understand relevant changes and their impacts, and risk assessments that clarify the relevance of changes and key vulnerabilities. If significant risks are identified, adaptive responses need to be integrated (or 'mainstreamed') into existing natural hazard and resource management practices, such as local and central government plans, policies and strategies. In New Zealand, central government provides guidance and a measure of technical support, while local government is responsible for the actual risk management and implementation of measures within a community context (MfE 2008b). Beyond this, continuous monitoring of both the changing risks and emerging knowledge, as well as effectiveness of adaptive responses, is necessary. In turn, this monitoring feeds into the further creation of awareness and capacity building. All elements are needed to achieve effective implementation of adaptation measures. They typically involve a range of stakeholders from the science sector, local government, business, local communities and organisations from civil society and central government.

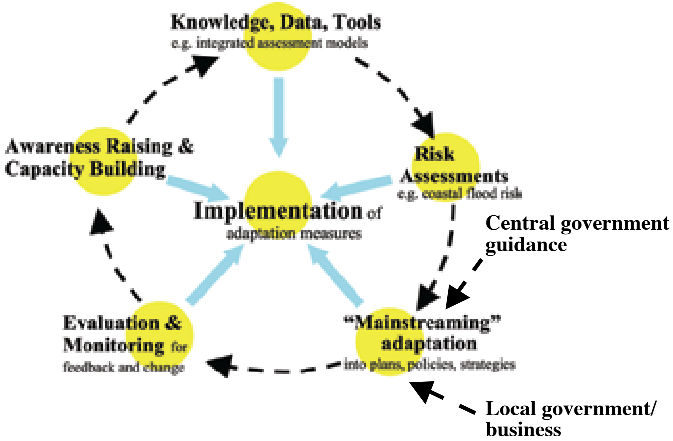

Figure 10. Schematic diagram illustrating the process of adaptation (reproduced from Hennessy et al. 2007, based on Warrick 2000).

5.3 Value judgements underpinning adaptation decisions and risk management

The complexity of the process outlined clearly creates some major challenges, particularly because decisions about many parts of the adaptation process can be informed by science but ultimately require judgements that reflect social and cultural values.

One set of challenges relates to the timing of adaptation. Adaptation can be reactive, where we change as and when a need or opportunity arises from a change in the climate. Adaptation can also be prompted by a change in some other driver, for example it makes more sense to do a comprehensive climate risk assessment *before* a major new infrastructure development is undertaken, rather than a year afterwards. Or adaptation can be proactive or planned: in some instances we need to look forward by many decades, perhaps even more than a century, to avoid creating a situation where future generations would find themselves locked into a situation where a changing climate creates increasing problems but their ability to adapt is rather limited (Adger et al. 2007). The increasing coastal squeeze between residential developments and sea level rise may be one of those areas, where eventually retreating from the coast is the only option but an incredible challenge in densely populated and high-value regions (Adger et al. 2007, MfE 2009). The amount of foresight that decision-makers and communities are prepared and able to use in the adaptation process (particularly for ensuring the availability of data, models and tools, and risk assessments) often reflects their general attitudes towards long-term sustainability and best use of limited resources.

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

Adaptation decisions also reflect individual and societal attitudes to risk, and perceptions about how risks should be managed: some people are more comfortable to take a punt and hope that the big catastrophic event may not happen, or may not happen in their lifetime. For others, mitigating the risk of unlikely but catastrophic events for their own sake and that of future generations or other members of the community is much more important even if it comes at a personal cost. Such considerations also reflect general attitudes about how economic values should be balanced against social and environmental issues, and what the concept of sustainability of a community should mean in practice. Potential conflicts over the distribution of costs and benefits of adaptation, and the balancing of economic, social and environmental goals, often arise in the context of developing or changing district and regional plans and policy statements and resource consents that regulate use of natural resources or exposure to natural hazards.

Resolving these issues requires scientific information about potential impacts, risks, vulnerabilities and adaptation options, but science alone cannot solve these issues. They do require societal debate, and we should not expect everybody to agree. What science can do though is to be clear about the implications of any specific decision that may be taken (Reisinger 2009). A risk management framework is generally regarded as the most appropriate approach to deal with the uncertainties involved in climate change projections and policy responses (IPCC 2007d, MfE 2008c). Exploring alternative future scenarios of climate and socio-economic change is critical to such a risk-based approach as it allows the weighing up of different societal attitudes to risks and their implications for adaptation decisions, and the costs and benefits of alternative responses that may borne by different parts of society both in the present and future.

The regulatory framework within New Zealand provides for such discussions to be held at the local community level, with broad guardrails provided by the provisions of the Resource Management Act (1991) and the New Zealand Coastal Policy Statement, Local Government Act (2002), and Civil Defence and Emergency Management Act (2002). There is on-going discussion whether and to what extent clearer and more binding guidance from central government is required to ensure that local decisions on adaptation, particularly in small councils with limited resources, are not captured by special interests but enhance and sustain societal well-being, including that of future generations (Reisinger et al. in press - publication expected 2010).

6. Summary and conclusions

We have presented two alternative scenarios of global and local climate change for use in impacts and adaptation assessments in New Zealand. The two scenarios represent a high carbon and a rapidly decarbonising world with divergent greenhouse gas emissions, leading to almost 4°C warming under the high carbon world but limit warming to about 2°C under the rapidly decarbonising world (by 2100, relative to pre-industrial conditions).

The two scenarios are characterised by very different global socio-economic drivers and international agreements on controls on greenhouse gas emissions. The high carbon world implies significant regional differences in policies, technologies and socio-economic development, while the rapid decarbonisation scenario implies a rapidly converging world that cooperates in many policy, technology and social areas. The high carbon world would result in significant impacts of climate change in all parts of the world, while the rapidly decarbonising world would result in more muted impacts, with some significant negative impacts in some regions but benefits for some sectors in other regions. The global ability to adapt to those changes would also likely differ between the two scenarios due to different regional levels of poverty and population increase as well as international cooperation.

These contrasting global socio-economic and climate changes would have significant implications for New Zealand. Not only would the different global climate change scenarios imply different climate changes over New Zealand, but the different global socio-economic developments and responses to climate change would also have flow-on effects on New Zealand through international policies, trade, migration and security, including those associated with regional changes in the southwest Pacific and Australia. These flow-on effects are poorly understood and quantified but may have significant implications for the scale and relevance of, and response options to, domestic impacts of climate change.

We presented detailed projections of climate change for New Zealand for those two scenarios, focusing on annual average temperature and seasonal precipitation for different regions, including an analysis of uncertainties based on current differences between global climate models. We also summarised the current understanding of likely changes in climate extremes, and explained why even a small change in mean climate could result in significant changes in the occurrence (frequency and/or severity) of extremes. Projections of sea level rise under the two scenarios are hampered by current lack of understanding of the future rate of loss of polar ice. Based on a wide range of recent observations and current models, we consider that the probability of sea level rise of at least 0.5 m by 2100 is high, but the possibility of even 2 m can not be ruled out entirely. Sea level will continue to rise beyond the year 2100 for many more centuries.

Even though New Zealand is expected to warm less than the global average due to it being surrounded by the Southern Ocean, the challenge of adapting to the projected climate changes under either scenario is significant. The 2007 assessment by the IPCC suggests that, for Australia and New Zealand combined, several key sectors (mainly water security, coastal communities and natural ecosystems) would exceed their natural coping range and require proactive adaptation for almost any degree of warming, and could become vulnerable even with adaptation for warming of 2°C (globally, relative to pre-industrial conditions). Other sectors, including agriculture and forestry, also require proactive adaptation but should be able to avoid significant vulnerabilities for warming of 3°C or more. Other chapters in this publication provide more recent research on some key findings about impacts and adaptation options of various sectors and systems in New Zealand.

Adaptation is not a one-off event or a single step but should be regarded as an on-going and iterative process that involves multiple stakeholders. This presents both opportunities for effective implementation and risks because many adaptation decisions depend not only on scientific information but also on value judgements about risks and the trade-off between costs in the near and distant future, and the balance between economic, social and environmental benefits and costs. A risk-management approach that explores the implications of alternative scenarios of future changes is the most appropriate approach to deal with risks and different societal attitudes to risks and the costs and benefits of specific adaptation decisions. Adaptation decisions can be informed but not determined by scientific inputs; they require a societal debate as well as guidance from central government about the management of natural resources and hazards in the face of climate change.

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03

New Zealand's land-based primary industries & climate change: Assessing adaptation through scenario-based modelling

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The land-based primary industry sectors are essential to New Zealand's current and future export earnings. Evaluations of the impact of climate change and climate variability on the land-based sectors has to date been restricted to considering the sectors at a regional level. However, the business or enterprise level will have a key role in adaptation to climate variability and change. Here we explore the use of systems modelling to investigate adaptation in three sectors: forestry, arable, and pastoral.

The impact of climate change on the risk from diseases in individual forests within and across regions of New Zealand was investigated using systems modelling. The modelling highlighted the differences, both within and between regions, in the likely susceptibility of individual forests to fungal diseases.

The second case study was from the arable sector. The modelling identified the opportunities for businesses to benefit from faster maturing crops with increased productivity due to CO_2 fertilisation. Capturing the opportunities for arable business will require increased inputs of both nutrients and water. This raises issues for future irrigation needs and the vulnerability of dry land arable businesses.

The third case study, a Manawatu dairy farm, modelled the impact of climate change on the pastoral sector. This region is predicted to have similar or higher productivity, compared to present-day conditions, with a changing climate. The modelling of a farm system identified the challenges to managing declining pasture quality over time as C4 grasses invade pastures. Adaptation measures that were modelled included earlier calving dates and increased cow numbers which were required to maintain high quality pastures. The modelling did not consider the impacts of multiple external pressures on the potential for a business to adapt to climate change, for example, the impact of an emissions trading scheme or nutrient caps.

The three modelling case studies illustrate that there is already considerable adaptive capacity in New Zealand's primary sector based on technologies and management practices that are currently known. The challenge lies in how well the primary sector can adopt existing and future technologies and incorporate them into their production systems in the future.

1. Introduction

The land-based primary industries are key drivers of the New Zealand economy. These sectors combined have export earnings of $25 billion per year and employ directly and indirectly more than 200 000 people[1].

New Zealand's land-based primary industries have a competitive advantage over producers in other parts of the world. The temperate climate and environments, which are relatively free of pests and diseases, have contributed to highly productive and efficient land-based sectors. The producers are innovative and adaptable and, as past experiences have shown, are able to live with climate variability, fluctuating currencies, commodity prices and other external pressures. An important question is whether these producers will be adaptable enough to manage a changing and variable climate?

There have been several assessments of the impacts of climate change on land-based primary industries sectors since 1990 (Korte et al. 1990, Clark & Newton 2001, Wratt et al. 2008). These assessments consider future climate scenarios and projections which include both production and economic effects of climate change on agriculture. Details for both sectors and regions are supplied; however adaptation will also be needed at the enterprise, forest or farm level where individual managers or owners will assess risks and make management decisions (White 2008, Payne & White 2009). Thus much of the economic impact within a region will depend on the mix of enterprises and key decision makers within the region. In addition, for pastoral systems, previous assessments have produced mean annual or seasonal predictions of changes in forage supply. Unfortunately these predictions are at too coarse a scale for simulating on-farm impacts where at least monthly data are required (Newton et al. 2008). Research is required to build on this regional knowledge through developing our understanding of the sectors, enterprises, and systems which operate in land-based primary industries. It is also important to recognise the role of the producer, community, and policy regulations in adapting to climate change.

Farming systems are underpinned by complex biological systems of soils, plants and ruminant animals, and are subject to external and internal economic drivers interacting with human decision making. These systems are difficult to study as components interact within the farm system with feedback loops and lag effects (Stafford Smith et al. 2003). These interactions and feedbacks are potent, sometimes to such an extent that they dominate the system behaviour and limit the usefulness of component analysis when considering adaptation to climate change and variability.

Using examples from forestry, arable, and pastoral (dairy) sectors, this paper considers the potential impacts of climate change on enterprises and discusses challenges and opportunities for adapting to climate change. It is important to note that different regions, models, and climate change scenarios were used for each sector: these are described below.

> “The producers are innovative and adaptable and, as past experiences have shown, are able to live with climate variability, fluctuating currencies, commodity prices and other external pressures.”

2. Forestry

Planted forests cover about 1.8 million hectares of New Zealand and contribute export earnings of $3.4 billion[1] per annum making this sector New Zealand's third largest export earner after dairy and meat. Forests are distributed widely across New Zealand and climate change is likely to have wide and varied impacts on them. This will be an important factor in decisions about the locations of new forests. A major review on climate change impacts, risks, and opportunities for New Zealand's planted forests undertaken in 2008 comprehensively summarises knowledge in this area (Watt et al. 2008).

A number of projected changes will occur under climate change. Productivity is likely to be significantly affected by climate change from the effects of changed CO_2 levels, rainfall and temperature. Fire and wind risks are likely to change, with fire danger increasing in most areas of New Zealand. Increased severe wind events are also predicted to occur in some parts of the country. Pests and fungal diseases are likely to be affected strongly by climate change. The impacts of weeds and fungal pathogens on forests could change, as could the establishment and distribution of insect pests.

To date, little or no forestry modelling work has been done using climate change scenarios, though a number of initiatives are now underway within a conceptual framework outlined by Watt et al. (2008). As a first step this section of the paper utilises the “high carbon world” and “rapidly decarbonising world” climate scenarios developed by Reisinger et al. (2010) to predict possible impacts of these scenarios on the existing planted forests. We used fungal diseases as a case study, as they are very strongly influenced by rainfall and to a lesser extent temperature changes (Watt et al. 2008).

There are two major fungal pathogens that affect radiata pine in New Zealand, *Dothistroma pini*, and *Cyclaneusma minus*. These fungal diseases can have a significant impact on forest productivity with 50 to 67% of the plantations affected to a greater or lesser degree. Estimates of the annual financial impact (Watt et al. 2008) lie between $23 million (*Dothistroma*) and $61 million (*Cyclaneusma*). The fungi respond positively to warm and humid conditions so a warmer, wetter climate is likely to increase the severity of the impact.

Both the high carbon and rapidly decarbonising (low carbon) world scenarios for 2040 and 2090 (Reisinger et al. 2010) were projected onto a 1 km grid, and the impact of the change in winter and summer

[1] AgResearch analysis from: MAF (2008), Infoshare, http://www.stats.govt.nz/infoshare and, http://search.stats.govt.nz/nav/ct2/workincomespending_employment/ct1/workincomespending/0 (accessed 12 January 2010)

rainfall levels on the existing plantation forests, as represented in the LCDB2 land cover database, was analysed. Results were expressed as changes in rainfall as a percentage from a 1990 rainfall baseline. These changes were then mapped across the plantation forests to give a visual representation of the expected variation in rainfall for the low carbon and high carbon world scenarios for both 2040 and 2090.

The scenarios suggest quite different effects on the rainfall in the forests. The low and high carbon world scenarios showed quite different curves for summer rainfall (Figure 1). For example, the high carbon world showed a small general increase in rainfall of about 3%, while the low carbon world showed a more conservative picture, tending to more balanced change.

The differences between the two scenarios become much more extreme by 2090 with some very large departures from the 1990 baseline for the high carbon world (between -15 and +24%) (Figure 2). The 2090 scenario was much more conservative for the low carbon world.

There were also quite strong regional and seasonal pattern differences. Figure 3 shows a map of the expected difference in summer rainfall in the East Cape plantation forests as an example of the regional variation.

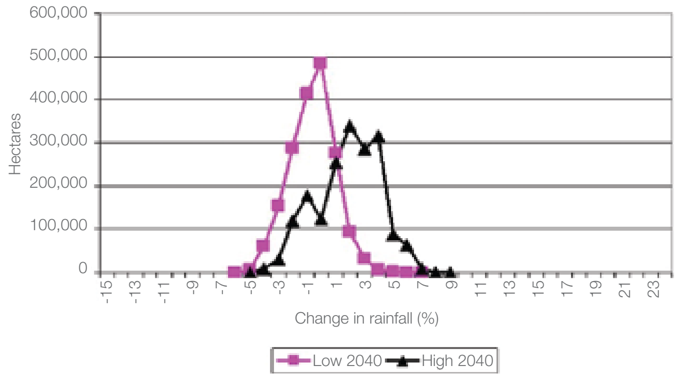

Figure 1. Area of forest and projected percentage change in summer rainfall in 2040 across New Zealand's plantation forest estate under a low and high carbon world scenario.

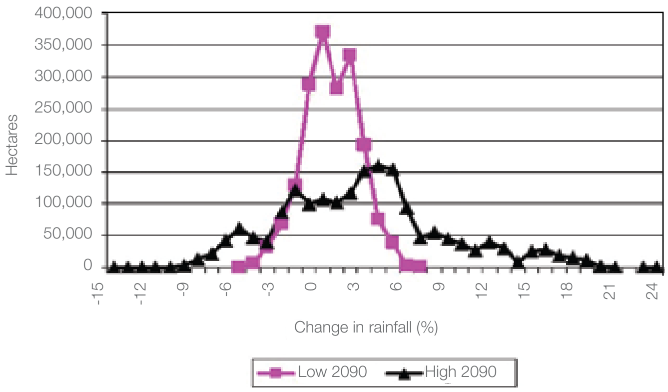

Figure 2. Area of forest and projected percentage change in summer rainfall in 2090 across New Zealand's plantation forest estate under a low and high carbon world scenario.

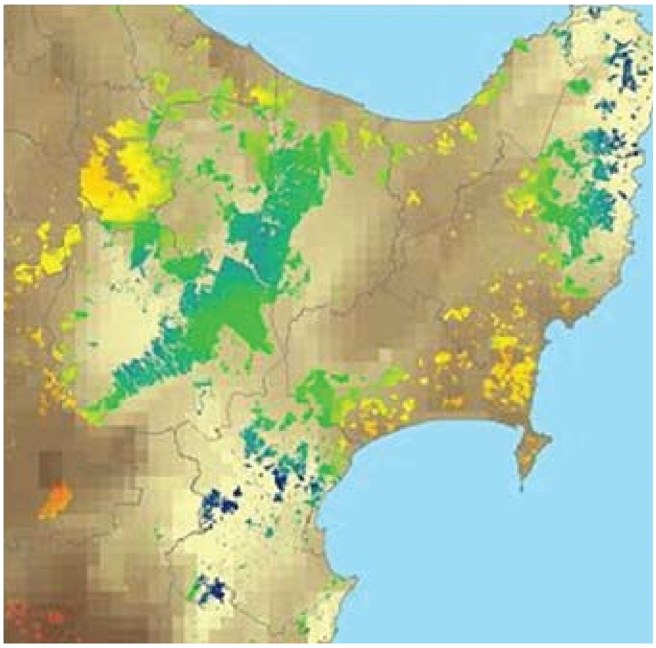

Figure 3. East Cape - projected summer rainfall changes in planted forests in 2040 under the high carbon world scenario (dark blue = +6%, orange = –6%).

Using this approach we are now able to identify regional areas of concern for our existing plantation forests. We are unable to present all the combinations of the scenarios and seasons here: these will be expanded on in a subsequent forestry specific paper. Our ability to map the risk areas for *Dothistroma* and *Cyclaneusma* will allow us to develop appropriate adaptation responses, and hence better prepare the sector ahead of the likely climate change.

Adaptation options for these two diseases are similar. *Dothistroma*, unlike *Cyclaneusma*, responds to aerial application of copper oxychloride. An adaptation strategy would involve identifying risk areas and, if the increased impact could be quantified, planning for changed levels of aerial application. Other adaptation options for both diseases will focus on developing disease resistant genotypes, changing the silvicultural regimes to modify the within forest microclimate (especially air movement and humidity), changing the tree species totally on at risk sites, and possibly moving the forests to less risky sites as the climate changes.

To adapt successfully we will need to improve our understanding of the impacts of climate on forest biological processes and carry out thorough and in-depth scenario analyses to drive the development of adaptation strategies. Adaptation strategies in general will involve normal forestry practices and, because climate change is a relatively slow process, a structured approach based on good understanding of forest processes. This structured approach is likely to be effective and allow us to maintain the health and productivity of our forests.

3. Arable farming

Broad acre cropping is a major contributor to export earnings from the land based sector, currently the fifth largest sector by dollar value[1]. The range of crops grown in New Zealand is shown in Table 1.

Table 1. The types of arable crops and main crops grown by arable farmers in New Zealand.

Type	Main crops grown				
Grain	Wheat	Barley	Oats	Maize	Peas
Small seeds	Grass	Clover	Vegetables	Forage	
Vegetables	Potato	Sweet corn	Onions	Squash	Brassicas
Forages	Cereal	Annual rye	Brassice	Maize	
Pastoral phase	Grass / Clover pastures				

Climate determines which crops are most productive in a given region: for example, maize crops are grown in North Island and upper South Island only, while small seed crops are predominately grown in Canterbury. Within climatic limitations, arable farmers tend to run very flexible rotations. The decisions on which crops to grow involve balancing a range of factors which include financial (which crop will return best gross margin), risk management (diversification, chance of partial or full crop loss), and system fit (sowing and harvesting times and the need for a break crop between more profitable crops).

If we first consider an arable system where nutrients and water supply are not limited, climate change will give an increased production potential and greater management flexibility. This is caused by a number of factors. Firstly, CO_2 fertilisation will increase the production on unstressed crops, with a doubling in CO_2 levels giving a 30% increase in crop growth rates (Jamieson et al. 2000). In addition, because crops grow in thermal time rather than chronological time, an increase in temperature will cause crops to progress through their development phases faster, be harvested earlier and leave more options for subsequent crops to be grown. A warmer, drier spring will mean soil will be suitable (dry enough) for cultivation and sowing operations earlier in the season. An expanded frost-free period will mean frost sensitive crops can be sown over a wider range of times and tropical crops, such as maize, will become viable options in more southern latitudes. All of this means the grower will be able to choose from a wider range of crop types and crop growth duration, giving greater flexibility in their management.

To demonstrate the potential benefits of climate change to arable crops, an existing plant growth model was used to determine the effect of the Reisinger et al. (2010) climate scenarios of high carbon and rapidly decarbonising (low carbon) world's for 2040 and 2090 on crop growth patterns. The model uses a linear response between yield and CO_2 (350 to 700 ppm) which predicts yield increases of 18% at 550 ppm and 30% at 700 ppm. The crop was planted in October and harvested at maturity, which was early March under a current climate scenario (Figure 4). Both the rapidly decarbonising (low) and high carbon world scenarios resulted in increased yields and earlier harvest by 2040, with further changes by 2090. The high carbon world 2090 resulted in a 16% increase in yield and a 3 week earlier harvest compared to the baseline year.

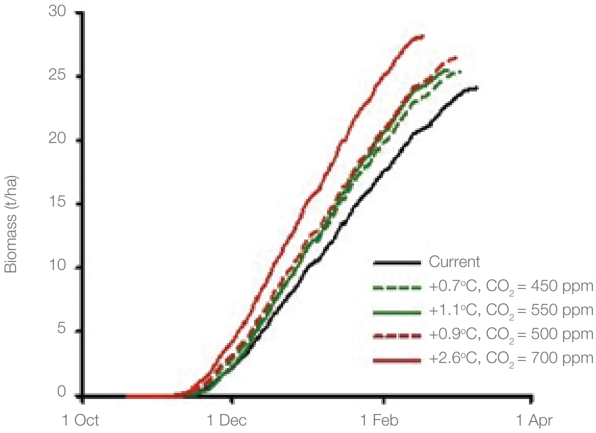

Figure 4. Growth profile for a potato crop grown with no nutrient or water limitations in current climate conditions or under low (green) or high carbon world scenario (red) in 2040 (- - -) or 2090 (–).

The caveat on the increased yield potential under climate change is that more inputs will be required to realise these increased potentials. More irrigation, nitrogen, phosphorus, and other nutrients will also need to be supplied. Most cropping occurs on the east coast of New Zealand, the increase in the westerly weather pattern will result in more hot, dry weather which will increase crop demand for water and reduce supply (less rain). For fully irrigated systems this will mean more irrigation is required to achieve potential yields. Upgrading irrigation to systems that are able to give more precise irrigation applications and improve irrigation efficiency will become more important. Similarly more rigorous use of irrigation scheduling and improved medium term rainfall forecasts could also be employed to improve irrigation efficiency to reduce wastage and better meet crop demands with limited water.

The use of more efficient crops could also reduce demand for water. For example, crops with a deeper root system (wheat vs potato) or greater transpiration efficiency (maize vs barley) may have a role to play. There is a limit to how much can be gained from increasing efficiency and it may be necessary to expand the capacity and coverage of irrigation schemes to allow areas to adapt to climate change. Planning and development of such expansions is required sooner rather than later.

To this point we have discussed how climate change will increase yield potential and management flexibility in systems that have no production limitations (water in particular). However, for dryland systems, and those with limited irrigation, the situation will be the opposite, reduced crop yields and reduced management flexibilities. An increase in water demand and reduced rainfall will increase water stress which will reduce yields and the timing of sowings will be limited to when soil moisture is adequate. In these systems different adaptation strategies will be required to keep farm systems viable. For example, growers may opt for an earlier planting date or a faster maturing cultivar to ensure the crop produces some yield before the driest parts of summer arrive. Growers may also have to consider not planting in years when the risk of crop failure is very high.

Dryland farmers will become more limited in the range of crops they can grow as the risk associated with crops that are more sensitive to moisture stress becomes too great. This will reduce possibilities for diversification, and these farm systems may also need to reduce their debt loading to increase the financial resilience of the farm and allow the business to pass through seasons of poor yield or crop failure.

4. Pastoral farming

The combination of milk, meat and wool is the single biggest contributor to New Zealand's agricultural exports, with about $18 billion in export revenue per year[1].

Wratt et al. (2008) in the EcoClimate report consider productivity and economic impacts for the pastoral farming industry by both sector and region. For the climate scenarios modelled, both average and worst year production for sheep/beef and dairy were projected to decline for east coast locations (parts of Wellington, Hawke's Bay, Canterbury, Bay of Plenty, and Gisborne) and Northland. Improvements in production were projected for Southland and the west coast. The modelling did not consider CO_2 fertilisation, which earlier studies suggested could increase pasture production but reduce quality (Allard et al. 2003). An earlier start to pasture growth in late winter/early spring would be expected as temperatures and growing degree days increase (Wratt et al. 2008).

Anecdotal comments from farmers involved in a series of workshops over two years in the MAF-SFF/ PGgRC project 'Understanding climate change and greenhouse gas emissions, impacts, adaptation and mitigation options on farms' 2008, 2009 suggest that, with the exception of the east coast areas of New Zealand, many farmers and other stakeholders from other regions believe adapting to climate change will be 'business-as-usual', within the usual adaptation to climate variability. To explore this business-as-usual concept further, we modelled the impact of climate change on a Manawatu dairy farm for two soil types (sand and clay). The Manawatu-Whanganui region contributes substantially to New Zealand's export revenue and is highly productive for both dairy and sheep/beef production. This region is predicted to maintain or slightly improve production in an average year, while production is predicted to drop by about 60% in the driest years in the future (Wratt et al. 2008).

4.1 Manawatu dairy farm climate change impacts modelling

Several modelling tools were used for the Manawatu dairy farm modelling. First, appropriate climate files were developed and used for the biophysical simulation modelling of the grazed pasture system. The simulation modelling then provided the pasture growth data for the farming systems model.

4.1.1 *Climate scenarios used in modelling the Manawatu dairy farm*

This modelling was completed as part of an earlier project, so did not use the climate change scenarios developed by Reisinger et al. (2010) as used in the previous case studies in this paper. The climate files for 2030s and 2080s were developed using the data available in May 2008 (MfE 2004). The scenario modelled represented a "mid-range" (which is approximately between the two Reisinger et al. (2010) climate change scenarios) and this is illustrated in Table 2.

Table 2. Temperature and rainfall changes (w = rainfall in winter months only) in 2040 and 2090 for the low and high carbon world scenarios and the (mid-range) scenario used for pastoral modelling (2030 and 2080) for the Manawatu dairy farm.

	Temperature (°C)				Rainfall change (%)			
Year	2030	2040	2080	2090	2030	2040	2080	2090
Low carbon		0.5		1.0		+6%w		+8%w
Mid-range	0.7		2.1		+10		+22	
High carbon		0.75		2.5		+4%w		+14%w

4.1.2 *EcoMod simulation results*

The results described below were obtained using the EcoMod simulation model. EcoMod is a biophysical model designed to simulate pastoral farm systems of Australia and New Zealand (Johnson et al. 2008). This model includes, with a relatively high level of detail, the major processes that take place in the soil-water-plant-animal system of pastoral farms. It includes a management module, which allows the simulation of farm systems, as well as research setups, such as cutting trials (regular harvesting of pasture grown by mechanical cutting rather than grazing animals). The water balance, including runoff and leaching, the nutrient and organic matter (carbon and nitrogen) dynamics, the growth of several different species of pasture and forage plants and the general animal metabolism are simulated by specific integrated modules. Comparison of EcoMod simulated growth rates against data can be found in Cullen et al. (2008), Johnson et al. (2008), and White et al. (2008). The purpose of the modelling was to provide growth rates and metabolisable energy concentration information for the farm-scale farming systems modelling. The modelling results are based on a cut-trial regime with return of the nutrients harvested in the cut pasture to the soil as dung and urine, and the pasture cut to 1.5 t DM/ha every 21 days. To explore the range of adaptation options that may be needed over small spatial scales, two farms were modelled, one on clay and the other on sand. Such variability in soil type is often present within regions and sometimes within farms. Pasture growth rate (Figure 5) and metabolisable energy concentrations (Figure 6) data for both soil types and all climate scenarios are presented below. Total pasture production is presented in Table 3.

"The Manawatu-Whanganui region contributes substantially to New Zealand's export revenue and is highly productive for both dairy and sheep/beef production."

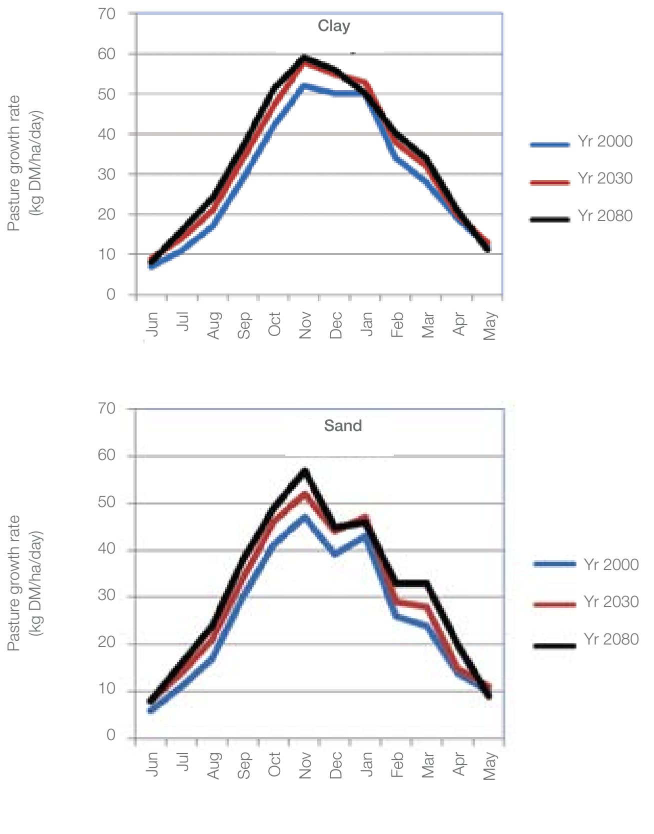

Figure 5. Monthly pasture growth rate for the clay and sand soil types under the various climate scenarios for the Manawatu dairy farm.

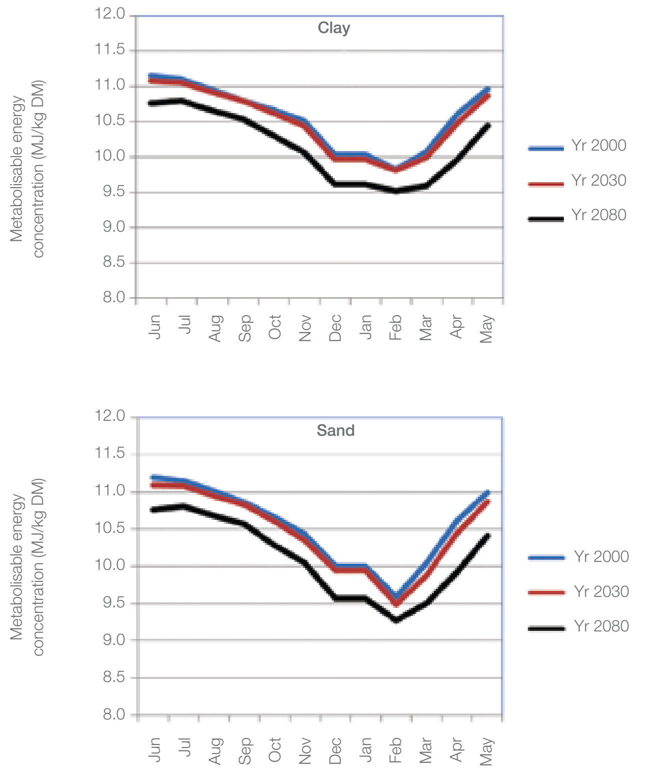

Figure 6. Estimated metabolisable energy concentration of pasture for the clay and sand soil types under the various climate scenarios for the Manawatu dairy farm.

Table 3. Pasture production for the clay and sand soil types under the various climate scenarios for the Manawatu dairy farm.

Soil type	Clay			Sand		
Year	2000	2030	2080	2000	2030	2080
Pasture production (tonnes DM/ha/yr)	10.7	12.0	12.4	9.4	10.6	11.5

4.1.2.1 *Key points for the modelled Manawatu dairy farm*

- Pasture production increases from the baseline (2000) to 2080. The largest increase was evident between 2000 and 2030 for both soil types.
- The largest increases in monthly pasture growth rates were seen in late winter, spring and summer. This is potentially due to increased temperatures and solar radiation, more summer rainfall and increased prevalence of C4 grasses.
- The increased prevalence of C4 grasses led to a reduction in pasture quality during summer and spring as indicated by lower metabolisable energy concentrations. This was most noticeable when comparing 2000 and 2080. Conditions in 2080 were particularly favourable for C4 growth.

4.1.3 *Farmax Dairy Pro simulations*

Initially average monthly pasture growth rate and metabolisable energy information for clay and sand soils estimated by EcoMod under current (2000) climatic conditions were used to construct biologically feasible farm systems in Farmax Dairy Pro (Marshall et al. 1991, Bryant et al. 2010). Biological feasibility ensured pasture cover did not exceed 2800 kg DM/ha for significant periods, cow body condition score did not go below 3.5 and milk solids performance per cow did not fluctuate greatly from month to month beyond what would be expected with a typical lactation curve. To create these biologically feasible systems, areas were conserved as pasture silage or hay when average pasture mass increased above 2400 kg DM/ha. Conserved silage and hay was then fed to the herd at times when pasture supply was limited, but generally in winter for dry cows (pasture silage and hay), and early spring and autumn for milking cows (pasture silage). Bought in maize silage, equivalent to 0.8 t DM/ha, was fed to milking cows in early spring and autumn. No nitrogen was applied. Per cow and per hectare expense information was extracted from economic survey data provided by DairyNZ.

The effect of the mid-range climate scenarios in 2030 and 2080 were then explored for the Manawatu dairy farm. The monthly pasture growth and pasture quality for 2030 and 2080 were applied to the 2000 baseline simulations to determine the impact on the farm system without any adaptation measures. The farm was run with the cow numbers, calving date, supplement fed and grazing management rules used in 2000 but with the 2030 and 2080 pastures. The estimated monthly milk solids yields per cow and pasture cover for unadapted systems for each soil type are shown in Figure 7 and 8 respectively. The baseline data (2000) was compared with 2030 and 2080 using key parameters in Table 4.

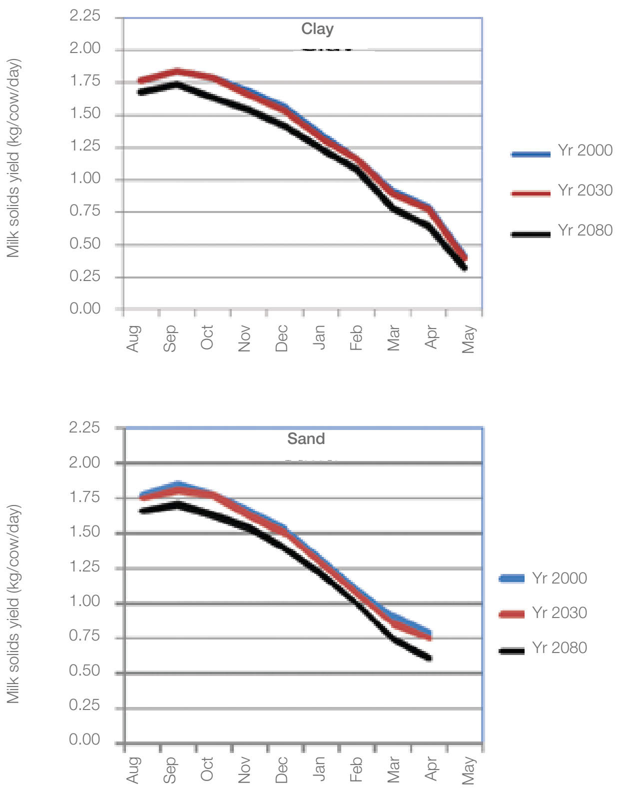

Figure 7. Estimated milk solids yield per cow for the clay and sand soil types under the various climate scenarios for the Manawatu dairy farm.

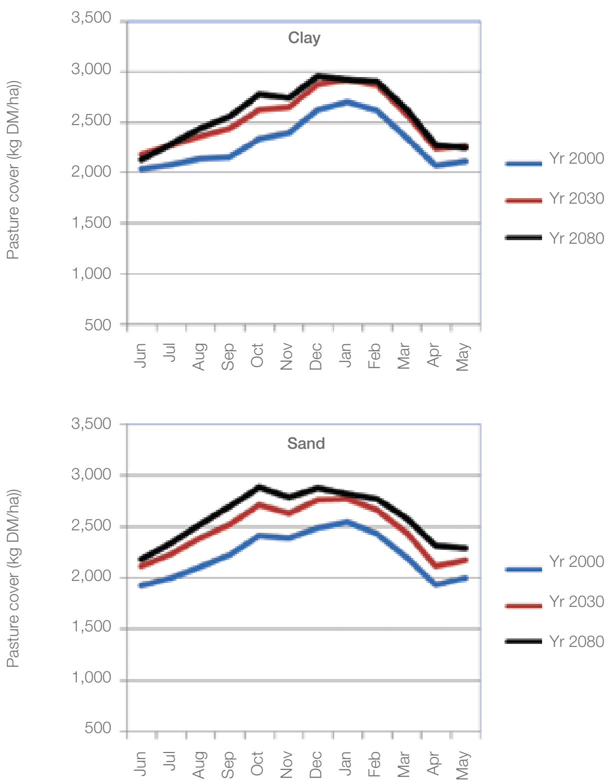

Figure 8. Estimated pasture cover for unadapted systems for the clay and sand soil types under the various climate scenarios for the Manawatu dairy farm.

Table 4. Estimated milk solids (per ha and per cow) and profitability for unadapted systems for the clay and sand soil types for 2030 and 2080 compared to 2000 for the Manawatu dairy farm.

Soil type	Clay		Sand	
Year	2030	2080	2030	2080
Milk solids (kg/ha)	-17	-64	-11	-53
Milk solids (kg/cow)	-9	-35	-7	-33
Profitability ($/ha)	-90	-337	-58	-275

4.1.3.1 *Key points – unadapted systems for the modelled Manawatu dairy farm*

- Total and monthly milk solids production per cow and per hectare declined in both 2030 and 2080 compared with 2000 estimates. The difference was most marked when comparing 2000 with 2080, and is attributable to the marked reduction in pasture quality by 2080. The reduction in pasture quality led to lower energy intakes. Reductions in farm profitability were observed for both 2030 and 2080.
- Average pasture cover increased throughout the year in both 2030 and 2080, resulting in more decay and accumulation of dead matter in the sward. Pasture utilisation dropped by 10 and 13% for 2030 (65%) and 2080 (62%) compared to 2000 (75%) levels for the sand. Similar reductions in pasture utilisation were observed for clay when comparing 2000 with 2030 and 2080.

The effects of 2030 and 2080 climate scenarios were then explored but with adaptation. Adaptation was through changes to cow numbers, calving date, supplements fed and grazing rules. Figures 9 and 10 show the estimated monthly milk solids yields and pasture cover, respectively, for adapted systems for each soil type. Production data in 2030 and 2080 are shown in Table 5 as a unit increase above the production in the baseline year (2000).

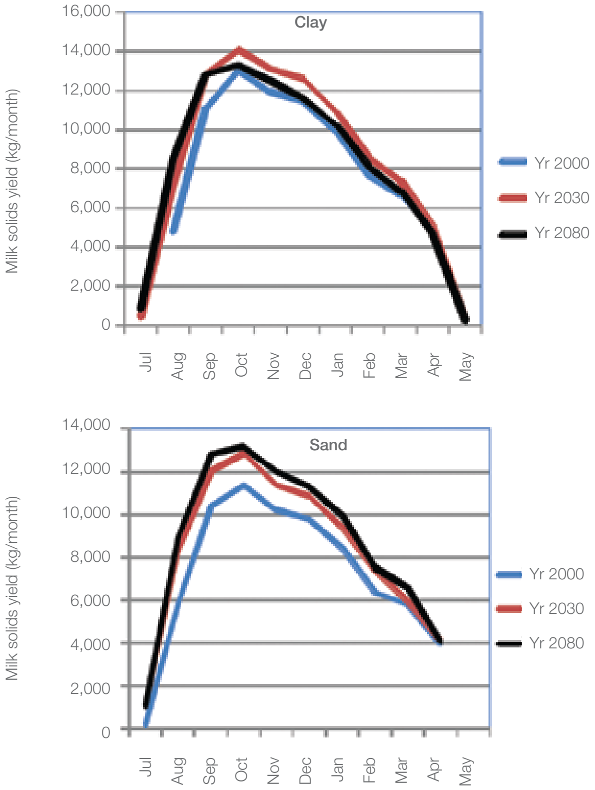

Figure 9. Estimated total milk solids yield per month for adapted systems for the clay and sand soil types under the various climate scenarios for the Manawatu dairy farm.

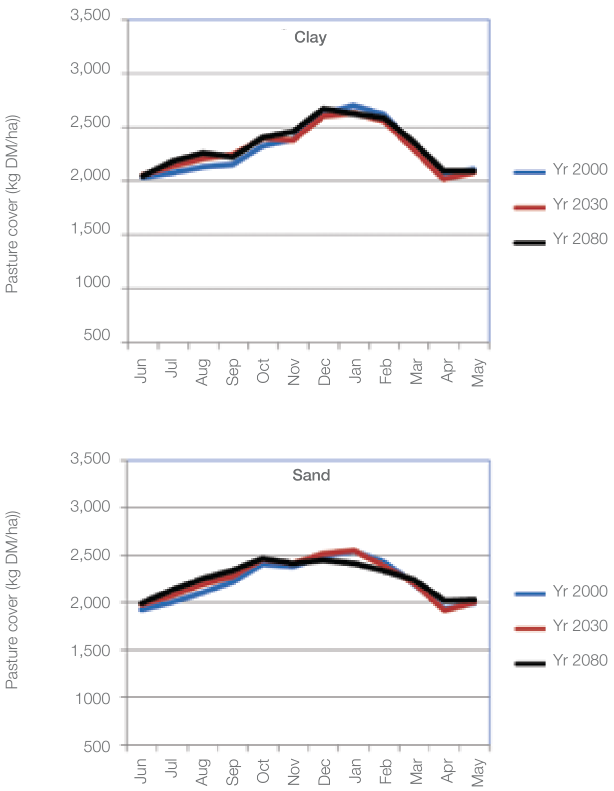

Figure 10. Estimated pasture cover for adapted systems for the clay and sand soil types under the various climate scenarios for the Manawatu dairy farm.

Table 5. Estimated milk solids (per ha and per cow) and profitability for adapted systems for the clay and sand soil types for 2030 and 2080 compared to 2000 for the Manawatu dairy farm.

Soil type	Clay		Sand	
Year	2030	2080	2030	2080
Milk solids (kg/ha)	+85	+64	+87	+118
Milk solids (kg/cow)	+15	+31	+18	+19
Pasture intake (t DM/ha)	+0.82	+0.67	+0.85	+1.39
Cow numbers (1st july)	+8%	+1%	+10%	+14%
Days in milk/cow	+10	+15	+10	+10
Profitability ($/ha)	+233	+262	+316	+412

4.1.3.2 *Key points – adapted systems for the modelled Manawatu dairy farm*

- Key adaptation measures for the clay soil type included the following.
  - Increased late winter pasture growth allowed calving date to be brought forward by 10 days in 2030 and another 5 days in 2080.
  - Increased summer and autumn growth allowed increased summer feeding for both 2030 and 2080.
  - It was also possible to lift cow numbers by 8% in 2030 compared to 2000, although by only 1% in 2080 compared to 2000.
  - To achieve the same level of per cow performance in 2080 as 2000 per cow intakes needed to increase to achieve the same level of energy intake. This also resulted in increased cow body condition scores at drying off.
  - More supplements were harvested in spring, with these additional supplements fed to dry cows to ensure they reached the same condition scores at calving in 2030 and 2080 as in 2000.
- Effects of these adaptations for the clay soil type.
  - Increased feeding levels per cow meant it was only possible to lift cow numbers by 1% when comparing 2080 with 2000.
  - Milk solids per cow and per hectare increased when comparing both 2030 and 2080 with 2000. This was attributable to the increase in lactation length, increased summer feeding levels and greater cow numbers in 2030. In 2080 compared to 2030, the increase in milk solids per cow and per hectare was mainly attributable to an increase in lactation length (+5 days) and increased summer feeding levels.
  - Profitability compared to 2000 levels increased in both 2030 and 2080, although the increase in profitability per year decreased when comparing 2030 to 2080 with 2000 to 2030.

- Key adaptations for the sand soil type included the following.
  - Increased late winter pasture growth allowed calving date to be brought forward by 10 days in both 2030 and 2080.
  - Increased summer and autumn growth in both 2030 and 2080 allowed feeding levels to be increased over this period.
  - It was also possible to lift cow numbers by 10 and 14% in 2030 and 2080 respectively compared to cow numbers in the baseline year of 2000.
  - To achieve the same level of per cow performance in 2080 as 2000 per cow intakes needed to increase to achieve the same level of energy intake.
  - More supplements were harvested in spring, with these additional supplements fed to dry cows to ensure they reached the same condition scores at calving in 2030 and 2080 as in 2000.
- Effect of these adaptations for the sand soil type.
  - Milk solids per cow and per hectare increased when comparing both 2030 and 2080 with 2000. This was attributable to the increase in lactation length, increased summer feeding levels, and greater cow numbers in 2030. In 2080 compared to 2030, the increase in milk solids per cow and per hectare was mainly attributable to an increase in lactation length and greater cow numbers.
  - Profitability compared to 2000 levels increased in both 2030 and 2080, although the increase in profitability per year decreased when comparing 2030 to 2080 with 2000 to 2030.
- Key differences between adapted systems with clay and sand soil types.
  - The percentage increase in pasture production from 2000 to 2080 was greater for sand than clay. This allowed for a greater increase in stocking rate for sand than clay.
  - The increase in pasture production from 2030 to 2080 was greater for sand than for clay. Consequently, stocking rate could increase further leading to higher milk solids per hectare and greater profit lifts for sand than for clay.

The system modelling has identified the challenges to business-as-usual for a dairy farm in the Manawatu region. Increased temperatures and rainfall led to increased pasture production and invasion of C4 grasses resulting in a potential loss in production. The modelling identified the opportunities which exist to adapt to the higher production of lower quality feed through a range of farm management decisions which included earlier calving and increased stocking rates. These scenarios resulted in more milk production and increased profitability of the farming system. In addition the modelling identified potential small scale intra-regional variability (here generated by using different soil types) which will affect the type of adaptations that could be made. These differences (and their benefits) would be missed if coarser scale, regional modelling was used. The modelling did not consider the impact of the increase in cow numbers on nutrient losses or on total or intensity of greenhouse gas emissions. Further, modelling tools for a farming system do not as yet exist to evaluate the impact of pests, diseases or weeds, the usefulness of existing tools, or the impact of other multiple external pressures on future pastoral farming systems.

“The modelling identified the opportunities which exist to adapt to the higher production of lower quality feed through a range of farm management decisions which included earlier calving and increased stocking rates.”

5. Summary

Systems modelling has demonstrated some opportunities and challenges for forestry, arable, and pastoral sectors adapting to climate change. The long-term modelling with 50 to 100 years of continuous pasture growth was essential for highlighting the gradual changes in pasture quality and composition which farmers will need to adapt to, to maintain a sustainable farming system.

The potential for farmers, foresters, sectors, and regions to adapt to a climate with increasing climatic variability and change will depend on many factors, only some of which can be modelled using existing models and knowledge. The role of some key factors potentially associated with climate change have not yet been quantified. This includes the threat to adaptation from weeds, pests and diseases (although these are likely to increase (Hennessy et al. 2007)) and from more frequent incidence of adverse events, which were not considered in the scenarios modelled here.

The forestry scenario was developed to investigate potential threats to planted forests (Watt et al. 2008) and the focus was on the two major fungal pathogens which affect radiata pine in New Zealand. Fungal diseases can have a significant impact on forest productivity and are very responsive to changes in temperature and rainfall (Watt et al. 2008). There were both regional and temporal differences in the response of fungal diseases to the high and low carbon world scenarios, with very large departures from the 1990 baseline by 2090. Regional differences were significant in the planted forest scenarios modelled. Using systems modelling to identify at risk sectors within regions or vulnerable regions will enable targeted tactical and strategic planning for adaptation to climate change. The modelling provides an objective tool which can be used to investigate an extensive range of scenarios over many years which cannot be achieved with field experiments or sampling. However, the scenario modelling identified the need for more understanding of the impacts of climate change on planted forests before modelling could effectively analyse the challenges and opportunities of climate change.

The impact of climate change on arable crops remains uncertain and is limited again by the lack of understanding of the impacts on pests and diseases (Hennessy et al. 2007). An existing plant growth model highlighted the potential earlier harvesting and increased yields from crops grown under future high and low carbon world scenarios. The real challenge to capturing this potential will be the need to meet all the water and nutrient requirements of a higher yielding crop.

The east coast of New Zealand is the dominant arable producing area of New Zealand and a region which is likely to be warmer and drier with more droughts (Hennessy et al. 2007). Adapting to climate change with higher yields and earlier harvests provides real opportunities for farmers, but the resilience of the businesses and region will be very reliant on the supply of water and nutrients to meet higher demands.

There remains significant uncertainty around the impacts of climate change on water flows in the major alpine rivers (Hennessy et al. 2007) which underpin our east coast irrigation water supply. On-farm or regional water storage and more irrigation schemes may be an adaptive strategy to reduce vulnerability of the arable sector. Such large-scale investment will require non-agricultural stakeholder, regional and national legislative support and significant infrastructure investment: all will be significant challenges.

Systems modelling of a pastoral system demonstrated that adaptation to climate change can be profitable and turn a potential negative (lower pasture quality) into a positive (more production). It demonstrated the potential for climate change to result in a declining pasture quality on a Manawatu dairy farm. This modelling supports the conclusions that there will be a likely spread southwards of subtropical pasture species (Clark et al. 2001). The farming systems modelling demonstrated that several changes were needed to the farming system to effectively adapt to climate change. More cows were grazed on the farm and the calving date was earlier to enable the business to benefit from the changed pasture growth and quality, especially by 2090. The systems modelling did not address all the implications of adapting to climate change. For example, earlier calving and running more stock is a more complex and challenging system to run. This places greater demands on staff and may require more staff to be employed with greater technical skills.

The pastoral modelling did not consider the impacts of the adaptations to climate change on significant environmental issues and pressures. More cows will consume more feed but also may increase nutrient and greenhouse gas losses from the farm which will impact on environmental and economic outcomes. These factors were not captured in the current modelling. Future modelling will need to be expanded to be able to capture the impact of multiple external pressures (for example, an emissions trading scheme or regional council nutrient cap) together with the soil, plant, animal and farm management dimensions of existing farm systems models. A single model will not deliver all the dimensions which will be required, rather a suite of tools will be needed with appropriate field experimentation. These approaches will enrich understanding, provide a robust platform for objective learning, and identify opportunities, constraints, and the unintended consequences of our adaptations to climate change.

For many farm businesses, adaptation may well be incremental change and result in business as usual. Much of this resilience will depend on the responses of managers, how they perceive and respond to risks (White 2008, Payne & White 2009). The availability of tools and strategies to identify and manage new threats and the knowledge to use these tools effectively will build resilience and enable the systems to adapt to climate change. Adopting these tools within complex land-based primary industry businesses with increasing multiple external pressures is the real challenge.

The modelling case studies of the forestry, arable, and pastoral sectors show that there is potential for adaptive capacity in New Zealand's primary sectors, at least in some environments. The modelling results suggest that implementation of management and technologies, that are readily available to producers now, have the potential to mitigate the direct impacts of projected mid range climate changes in the future. This provides a more positive interpretation on climate change impacts than is sometimes portrayed. However, there are clearly significant challenges in building farmer/forester understanding and an appropriate level of risk awareness, testing of existing technologies, and their adoption and implementing change in a complex biophysical and economic environment.

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04

Adaptation in agriculture: Lessons for resilience from eastern regions of New Zealand

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Assessments of adaptation in agriculture have evolved considerably from early, top-down, impact assessments. These early assessments, internationally and in New Zealand, provided a limited view of 'smart farmer' adaptation. While impact assessment provides some useful insights, experience with vulnerability and adaptation assessment provides a more appropriate foundation for understanding and characterising practical smart farmer adaptation. Findings are presented from eight years of engagement with farmers in eastern regions of New Zealand. A comprehensive farm resilience picture has emerged from this work. This picture reflects a strong belief from real-world smart farmers that there is sufficient knowledge and experience to adapt to climate change. Proactive farmers are already reading multiple signals, including changes in climate, and are responding. The farm resilience picture provides a foundation for exploring alternative adaptation options and pathways for agriculture. These are presented and discussed in response to two proposed climate change scenarios, a high carbon world scenario and a rapidly decarbonising world scenario. Knowledge intensive, low input systems are consistent with the resilience picture drawn from farmers. Such systems are also consistent with a rapidly decarbonising world scenario and, it is argued, are likely to become increasingly attractive under a high carbon world scenario. A smart farming approach, focused on resilience, provides the basis for development of a response capacity, with potentially significant co-benefits in terms of adaptation and mitigation to climate change. Wider issues and needs to support the further development of farm resilience, and more widely landscape or regional resilience, are identified and discussed. It is apparent from this work that ongoing engagement with smart farmers, focused on resilience, can contribute significantly to development of a coordinated 'bottom up' and 'top down' response capacity. Addressing the psychology of change is a fundamental need to ensure wider engagement.

1. Introduction

Adaptation has been a fundamental component of agriculture since hunter gatherers took their first steps towards crop cultivation and animal husbandry. However, it has developed a more specific meaning through the development of climate change science over the last three decades. Adaptation was identified in the First Assessment Report of the IPCC (IPCC 1990) as part of a two-fold response to climate change, involving adaptation and mitigation. Since then, separate research and policy streams on adaptation and mitigation have developed, with a very strong international focus on mitigation. This evolution of research and policy has been very evident in the agriculture sector in New Zealand.

While the focus of this paper is adaptation, with an emphasis on agriculture, there are themes of relevance to both adaptation and mitigation. A brief review of the development of impacts and adaptation research is provided. This offers the context for the implementation of a participatory research approach to adaptation. Findings from interactions with farmers[1] in eastern regions of New Zealand are summarised. Information drawn from these provides the basis for considering possible adaptations to the two climate change scenarios presented by Reisinger et al. (2010). A final discussion is provided, reflecting on insights gained from eight years of interacting with farmers on climate change. This includes some reflections on what adaptation and mitigation mean in a real-world context.

2. The development of impacts and adaptation research

Research on adaptation emerged in the 1990s as a component of impacts, vulnerability and adaptation assessment. Many early assessments followed, in general, the IPCC guidelines on impact and adaptation assessment (Carter et al. 1994). This approach identified evaluation of adaptation as the last step in a seven-step linear assessment process. These steps involved problem definition, methodology selection and testing, scenario selection, impact assessments, assessment of autonomous adjustments, and evaluation of adaptation options. In agriculture, the primary application of this approach has been through crop-modelling studies (Carter et al. 1991, Kenny et al. 1993a,b, Rosenzweig & Iglesias 1994) with some international research on inter-linking between crop models and economic models (Rosenzweig & Parry 1994, Darwin et al. 1995, Parry et al. 1999). In some early studies the focus was solely on impact assessment (for example; Carter et al. 1991, Rosenzweig & Iglesias 1994) with no consideration of adaptation. Impact assessments that exclude consideration of any form of adaptation response are referred to as a 'dumb farmer' approach.[2] Those that include consideration of adaptation are referred to as a 'smart farmer' approach, often assuming optimal adaptation based on perfect information about future climate change. However, given that these approaches are applied in modelling, the consideration of a smart farmer is inherently static and can only consider adaptations that can be represented by parameter changes in the model.

Through the 1990s there was an evolution away from the linear assessment process, with increased attention to vulnerability and adaptation. Vulnerability and adaptation assessment is rooted more in an understanding of the implications of and responses to current climate variability. This was given impetus through requirements for developing countries to produce national communications to the UNFCCC (for example, see Feresi et al. 2000). The result was an evolution from impact assessment to what Füssel & Klein (2006) refer to as first and second generation vulnerability assessments and, finally, adaptation policy assessments. A similar array of approaches has been identified by Smit & Wandel (2006). However, in contrast to Füssel & Klein (2006), they include approaches that are aimed at contributing to practical adaptation initiatives among the four general types of analysis discussed.

Throughout this evolution of assessment approaches there has been the development, and increasing refinement, of the smart farmer concept (Füssel & Klein 2006), with increased focus on what the smart farmer means in practice. Until recently this has been driven through either policy assessments or more practical initiatives in developing countries or vulnerable communities (see Smit & Wandel 2006). Adaptation in developed countries, whether focused on policy or practice, has not been given much attention until the last few years. This has also been the situation in New Zealand.

In New Zealand the development and application of assessment approaches began with the publication of the first national assessment of impacts in 1990, which included some consideration of adaptation options for the agriculture sector (Salinger et al. 1990, Martin et. al. 1990). Over the following decade the only impact and adaptation assessment research for the agriculture sector in New Zealand was through the CLIMPACTS research programme (Kenny et al. 1995, Warrick et al. 1996, 2001). This work paralleled the development of integrated assessment models internationally. A software product, referred to as the CLIMPACTS system, was developed as an integrated model that linked a climate change scenario generator with a number of crop models. This development coincided with an emergent international dialogue on critical thresholds (Parry et al. 1996), leading to an examination of thresholds for New Zealand agriculture using CLIMPACTS (Kenny et al. 2000). Examination of uncertainties was included in this study. For example, a threshold analysis of areas suitable for kiwifruit in the Bay of Plenty, using an array of greenhouse-gas emissions scenarios, showed a range of crop responses from minimal change to current areas of production becoming unsuitable by mid-century. Invariably this led to questions about how farmers (kiwifruit growers for this particular example) would deal with such information in terms of adaptation responses. So, while this work provided a potential platform for refinement of the smart farmer approach in a modelling context, it increasingly raised questions about the use of this information in the real world. These questions could be addressed only by direct engagement with farmers.

The potential for further refinements using CLIMPACTS were not realised, with the disbanding of the research team in 2000. This was followed by a period of relative inactivity up until the latter part of 2007 when a Climate Change Plan of Action was put in place by the Ministry of Agriculture and Forestry. During this timeframe, beginning in 2001, a practical adaptation approach was developed and implemented in eastern regions of New Zealand. The development of this work and its continuation is the focus of the remainder of this paper.

[1] This paper uses 'farmer(s)' to refer to both farmers (sheep and beef, dairy) and growers (kiwifruit), unless referring to a specific group.

[2] The 'dumb farmer' assumption – which is not unique to agriculture – is a metaphor for any impacted agent that is assumed not to anticipate or respond to changed climate conditions but continues to act as if nothing has changed (Rosenberg 1992, Easterling et al. 1993, Smit et al. 1996). From Smit et al. (2001).

3. The development and implementation of a practical smart farmer approach

Model-based approaches have proved valuable in addressing 'what if' questions relating to different scenarios of climate change, identification of thresholds, and quantification of possible changes. However, as indicated above, the incorporation of the idealised smart farmer into impact and adaptation assessments using crop models invariably led to questions as to how 'smartly' farmers might respond in reality, given imperfect information, subjective preferences and other non-climate (e.g., regulatory, market or environmental) constraints or opportunities for responding to climate change. In real world situations there is a spectrum of farmers, ranging from those who are proactive and innovative to those who will never change, unless it is forced upon them. This has led to a realisation that understanding what people do in reality is an important part of adaptation assessment, as identified by Adger et al. (2007). *"With an explicit focus on real-world behaviour, assessments of adaptation practices differ from the more theoretical assessments of potential responses or how such measures might reduce climate damages under hypothetical scenarios of climate change."* The implicit message in this quote is that if climate change is a real issue then it needs to be made real to people on the ground. This involves dealing with human attitudes and behaviour as against idealised model parameters.

While there has been a significant increase in adaptation research over the last decade (for example, see Tompkins & Adger 2005, Fussel & Klein, 2006, Smit & Wandel 2006, Adger et al. 2007) there has been relatively little methodological development and research aimed at what adaptation means in a practical sense, particularly in developed countries. Much of the international research effort has focused on the science and policy domain, adaptation in developing countries, and issues such as 'mainstreaming' adaptation.

From 2001 onwards a participatory research approach to adaptation in New Zealand was developed. With little work being carried out, even internationally, to understand the practice of adaptation in developed countries at this time, a 'learning by doing' approach was developed drawing on experience with other adaptation work. A foundation of experience was laid through an EU-funded project (Kenny et al. 1993a,b) and the CLIMPACTS programme (Warrick et al. 2001). However, experiences in developing country projects were particularly influential. Such work typically provides a stronger grounding in bottom-up assessments of vulnerability and real-world opportunities and constraints on adaptation. These included:

- A climate change impact, vulnerability and adaptation assessment project in Bangladesh (Warrick et al. 1996).
- Capacity building and professional development in Pacific Island nations on climate change vulnerability and adaptation assessment through the Pacific Island Climate Change Assistance Programme (Campbell et al. 1999).
- A development assistance project on participatory research methods with farmers in northern Viet Nam (May & Kenny 2000).

While the approach developed over the last eight years is described as participatory it has not followed a prescribed methodology, because no single methodology for such research has been established in the literature. Although it has involved an active learning process, it has not involved specific on-farm actions, and cannot be strictly termed 'participatory action research'. The key element has been to listen, learn and adapt the approach accordingly through a process of engagement with farmers. This approach includes: consultation with key industry stakeholders; identification of farmer participants with stakeholder input; workshops with farmers to share information on climate change, and address key questions relating to current and possible future climate; individual interviews and development of case studies; identification of knowledge gaps and research needs to support adaptation.

Work has focused in eastern regions of New Zealand, completed through a number of projects:

1) A scoping project on adaptation with farmers and growers in Hawke's Bay (Kenny 2002).
2) A two-year adaptation project with farmers in eastern regions, including Bay of Plenty, Hawke's Bay, Nelson/Marlborough, Canterbury (Kenny & Fisher 2003, Kenny 2005).
3) Adaptation in the kiwifruit industry (Kenny 2008).
4) Development of an adaptation component in the early stages of the Starborough/Flaxbourne project (Kenny 2006a).
5) Adaptation with coastal dairy farmers in eastern Bay of Plenty (Earthwise Consulting Limited and NIWA 2009).
6) A current two-year project on adaptation with hill country farmers in Hawke's Bay (Kenny et al. 2009).

The rationale for focusing on eastern New Zealand, beginning with the Hawke's Bay region, was because of consistent projections that eastern regions will experience warmer, drier conditions in the future (MfE 2008, Mullan et al. 2005). Along with drier average conditions, current scenarios also suggest increased frequency of drought and extreme rainfall events.

The approach of this research required a shift away from the inherent top-down approach of impact and adaptation assessment. When first interviewing farmers in Hawke's Bay (Kenny 2002) the response of farmers was 'we're already adapting'. In this early work a spread of farmers was interviewed, from what might be called innovators or early-adopters through to laggards (Rogers 1964). This spread of behaviour has been characterised in Rogers' (1964) 'Diffusion of Innovations' theory. Subsequently the focus shifted to engaging with, as much as possible, innovators or early-adopters. This shift in focus was guided through outcomes of the initial work in Hawke's Bay (Kenny 2002) and subsequently through consultation with participating farmers and industry representatives. Three key messages emerged (Kenny 2006b).

1) The importance of targeting people who might be called innovators or leaders of change; people who are already proactively adapting and providing leadership in their community.
2) The importance of documenting the good things that are already being done of relevance to adaptation and, through this process, identifying more clearly what else needs to be done.
3) The need to communicate information in an easy to read and informative manner.

This led to a more in-depth inquiry into what smart farmers are doing in reality and how information drawn from them might be of relevance to climate change (Kenny & Fisher 2003, Kenny 2005), and more widely to other farmers as well as wider communities. Characterising resilience[3] has been an integral part of this work. The early guidance given in relation to this was that "you won't find one farmer who is the ideal, but if you pull together a number of stories you might start getting close to an overall picture of resilience" (Alec Olsen, Hawke's Bay farmer, pers. comm.).

4. Outcomes from adaptation work with farmers

A considerable amount of insight and valuable information has been gained from interactions with farmers. It is neither possible to present all of the information here nor to represent all of the views that have been shared. However, there are some key responses that have either been consistently heard or have emerged over time. There are inevitably differences relating to region, or even location within a region, and between different primary industry groups. These are identified where relevant.

As indicated above the focus has been primarily, but not exclusively, with farmers who might be referred to as innovators or early-adopters. A consistent message is that farmers learn most by looking over the fence and seeing what their neighbours are doing. Proactive, innovative farmers generally serve as role-models for others in their community.

Building understanding of resilience from the farm level helps develop understanding of adaptive capacity and needs to support ongoing adaptation. Perhaps more importantly it gives valuable insight into response capacity at both the farm and landscape or regional level (see Tompkins & Adger (2005) for a discussion of response capacity in relation to climate change policy).

5. Emerging climate challenges and impacts

It is a reality of New Zealand's location and orography that we have an inherently variable climate. Only about half of the temperature variability in a growing season is predictable (Madden & Kidson 1997). The seasonal predictability of rainfall is lower, at 30 percent (Madden et al. 1999). New Zealand farmers have, for the most part, learned to live with this variability. However, an emergent view is that the weather patterns have become a lot less reliable over the last five years or so. For example, a Bay of Plenty dairy farmer recently commented (Earthwise Consulting and NIWA 2009) that "Summers are too dry, spring is too wet, there are more extremes, and when it does rain it's intense and hard to utilise properly." Increased incidence of late spring frosts has been an issue for kiwifruit and wine grape growers. This increased incidence of late spring frosts has accompanied a trend towards fewer frosts overall. Warmer winters in recent years (excluding 2009) and autumns have provided fruit set and post-harvest storage problems for the kiwifruit industry. Increased incidence of drought has emerged as a major challenge for hill-country farmers in regions such as Hawke's Bay. The 1980s and 1990s were characterised by a number of El Niño events that resulted in drought conditions in eastern regions. In recent seasons some Hawke's Bay farmers have experienced three consecutive droughts (2006/07, 2007/08, 2008/09). This has focused current attention on drought management in Hawke's Bay.

These climate challenges are consistent with climate change scenarios for New Zealand but do not, on their own, provide proof of climate change. At present a minority of farmers understand and recognise the connection with climate change. In general, these are individuals who have taken the time to be more informed. Many have questions as to whether it is due to human-induced climate change or simply because of natural cycles. The perceived inaccuracy of seasonal forecasting is taken by some as a good reason not to believe climate change science. These contrasting views are apparent in the following two quotes from Hawke's Bay farmers (Kenny et al. 2009).

"The one farming tool that is missing is accurate forecasting. With regard to NIWA and/or the Met Service, when they say it's going to be dry I'm stocking up and when they say it's going to be wet I'm prepared to destock. They've got just about every one wrong since 97."

"There's plenty of information out there now saying that the potential through climate change is for more droughts, more wind, perhaps heavy rainfall events. That's enough to work to. A lot of people will say that's all rubbish and if they choose to go another way then good luck to them. Maybe they're right, but I'm taking information as well as what I see going on in the world and making my decisions."

There is lot of consistency in impacts that are either emerging or anticipated with a changing climate (Table 1). The potential for more climatic extremes in the future is the principal concern that is consistently raised by farmers when asked about climate change.

"Building understanding of resilience from the farm level helps develop understanding of adaptive capacity and needs to support ongoing adaptation."

Table 1. Emerging and anticipated impacts of a changing climate.

Eastern New Zealand farmers	Bay of Plenty kiwifruit growers
More extreme weather events	More extreme weather events
Changes in seasonality of production	Less winter chill will be a challenge, particularly for 'Hayward' kiwifruit
Effects on pasture composition and grazing management	Warmer winters will create more challenges at harvest and post-harvest
Increased erosion problems	Salt water intrusion in coastal areas
Effects on water resources	Effects on water resources
Animal health effects	More pest and disease problems
More pest and disease problems	Increased social and economic pressures
Increased social and economic pressures	

[3] The Resilience Alliance (http://www.resalliance.org/576.php) (accessed 9 December 2009) defines resilience as follows: "Ecosystem resilience is the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes. A resilient ecosystem can withstand shocks and rebuild itself when necessary. Resilience in social systems has the added capacity of humans to anticipate and plan for the future."

Farmers are already dealing with a variable, and changing, climate, and climate change signals more challenges. A number of issues related to production are identified, included southward spread of subtropical grasses, changes in pasture composition, and consequences of less winter chill for 'Hayward' kiwifruit. Increased pest and disease problems are anticipated, with anecdotal evidence of emerging problems. Changes in water availability are a big concern for many, particularly if rainfall variability increases and conditions become drier on average over time. Increased social and economic pressures are also a big concern, and are already being experienced by many farmers.

6. Farm resilience and adaptive capacity

While there is now certainty that climate change is happening, there will continue to be uncertainties as to how climate change will manifest locally and regionally in New Zealand. Smart farmers are used to dealing with uncertainty including climatic extremes in their decision making, and are proactive in developing resilience. So what does their resilience picture look like? A detailed smart farmer resilience picture was developed over a two-year period through a series of workshops and in-depth interviews with selected farmers in Bay of Plenty, Hawke's Bay, Nelson/Marlborough, and Canterbury (Kenny & Fisher 2003, Kenny 2005). It was developed in response to potential impacts identified in Table 1. This picture (Figure 1) incorporates: trees providing protection systems; efficient water storage and use; diversification in keeping with land class; smart management of soil fertility including a focus on soil organic matter; pasture diversity and grazing management; a flexible and diverse stocking policy; cropping options to provide supplementary feed in times of shortage; a good infrastructure to deal with climatic extremes; aiming for energy efficiency and self sufficiency; and waste management. Some farmers have been implementing key elements of this picture over the last 40 years. The view shared by farmers is that adaptation to climate change can be achieved through development and implementation of this picture, tailored to local climate and land classes. Two key ingredients to success are a flexible, balanced approach from the farmer and effective on-farm research to support ongoing practical innovations and adaptations. There are also some wider issues that need to be addressed, which are discussed in Section 8.

Recent work in the Bay of Plenty and Hawke's Bay (Kenny 2008, Earthwise Consulting and NIWA 2009, Kenny et al. 2009) has identified a number of adaptations that are either being adopted now or considered as needs or likely actions for the future (Table 2). These findings are, on the whole, consistent with the farm resilience picture (Figure 1).

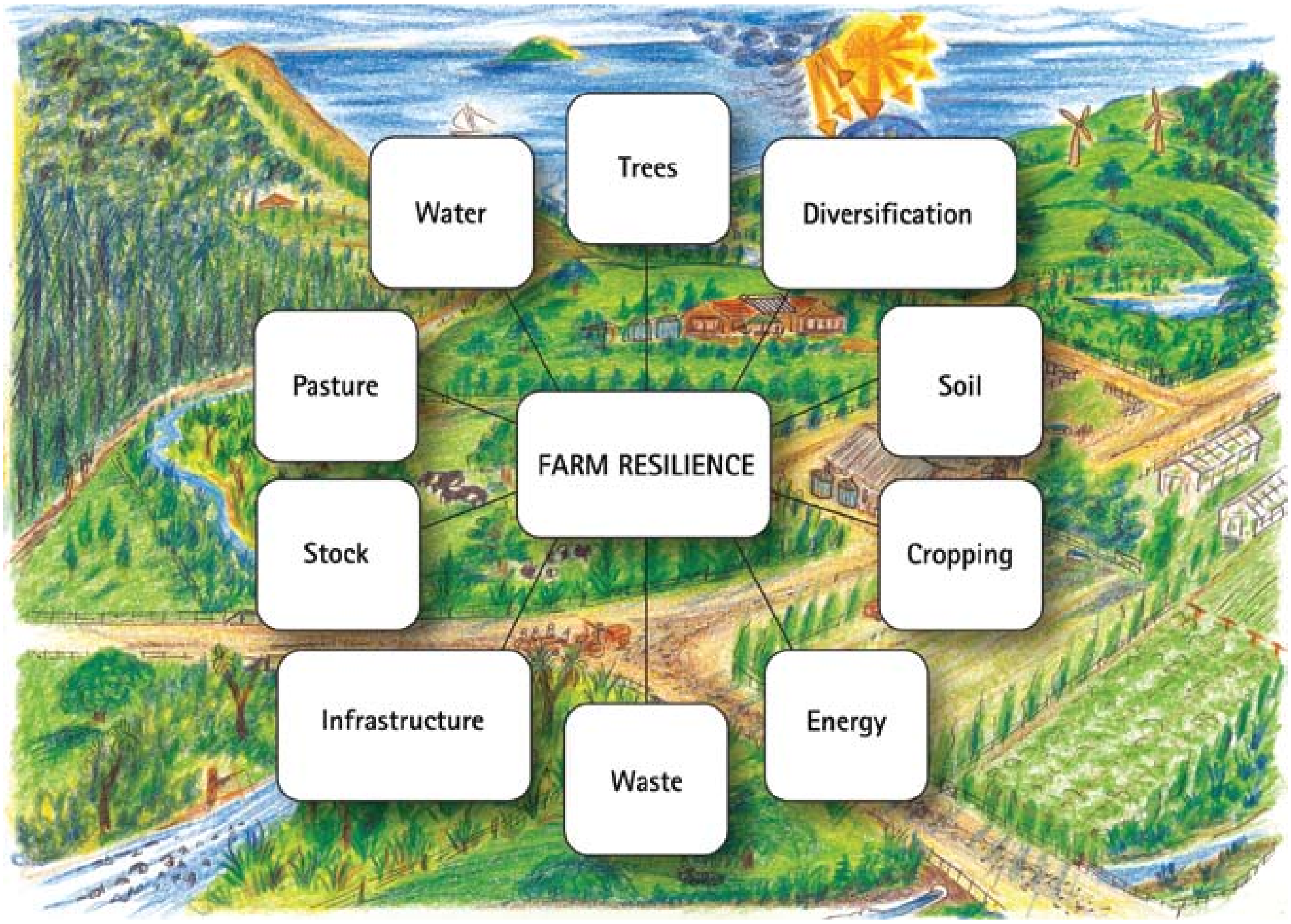

Figure 1. The farm resilience picture (from Kenny 2005).

Table 2. Adaptation options shared by farmers.

	Bay of Plenty dairy farmers	Bay of Plenty kiwifruit growers	Hawke's Bay sheep and beef farmers
Water	Drainage improvements Irrigation	Water storage and allocation	Water security Fencing of riparian areas
Trees and shelter	Trees for shade	Artificial shelter developments	A greater role for trees for multiple benefits
Management systems and varieties	Drought proofing with more diverse pasture Crops to break pest cycles Changes to grazing and milking regimes Diversification	Biennial cropping New varieties Hi-Cane substitutes Increased plantings of Gold kiwifruit	Alternative pasture species Longer pasture covers More trading stock and fewer breeding stock, with more cattle Match land use to land class Diversification
Low input/organic approaches	Look at organic and biological approaches	More organic type approaches	Increased interest in low input and/or biological farming
Energy	Energy efficient machinery	Better cool-store design	

Over the last decade or so there has been a strong focus on increased intensification and profitability in New Zealand agriculture. This is clearly evident in the dairy industry for example (Parliamentary Commissioner for the Environment 2004). While profitability remains important to farmers there is an emerging view of a need to be working within the limits of nature a lot more. This is evident through increased awareness of the role of trees, on-farm experimentation with different pasture species, changes to grazing management, benefits of diversification, and interest in low-input, biological or organic-type approaches. Recent work with Hawke's Bay farmers (Kenny et al. 2009) has identified increased interest in low input or biological farming systems. This is associated with longer pasture covers during the dry, summer months and a focus on deeper rooting pasture, higher organic matter and a goal of increased retention of soil moisture. Experience with a greater frequency of dry years since the early 1980s, and consecutive droughts in recent years, is sharpening the focus of farmers on long-term solutions. Increased awareness of global trends, including climate change, is emerging as a result. This is exemplified in the two quotes below from Hawke's Bay farmers.

"As a species most humans are living outside their means. That's the crux of the problem."

"One of the things about biological farming is that deep down you know that what we've been doing is not right and we've got to change."

Smart farmers are reading climate and other signals and are being proactive in developing resilience. Some have been doing so for decades and have served as role models in their local communities. The view shared by one Hawke's Bay farmer, and reinforced by others, is that "change is happening but it may not be visible." An important question, in the context of climate change, is whether change towards resilient farming systems is happening fast enough. If not, what is needed to support increased resilience? This leads to a discussion of adaptive capacity.

Adaptive capacity is defined by the IPCC (IPCC 2007) as "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences." Evidence gathered from farmers in eastern regions over the last eight years indicates the following.

1) Many farmers are experiencing pressure to meet multiple demands. The two key issues they are dealing with are the need for economic profitability and increasing need for environmental sustainability.
2) Smart farmers have recognised the potential to be environmentally or ecologically sustainable and economically profitable. They are already adapting to changing climate as well as to other changes.
3) There are farmers who admit that they are pushing the margins with high input, intensive systems. Some of these farmers believe that ongoing technological inputs will help buffer against climate change; others admit that they are potentially more vulnerable.
4) There is a strong belief that there is sufficient knowledge and experience to adapt to ongoing climate change. This is reinforced by the resilience picture (Figure 1).
5) There are some wider issues and needs (see Sections 8 and 9) to support ongoing adaptation, and development of long-term resilience.

Overall, there is evidence of potential for a high adaptive capacity among smart farmers. Both in interviews and through workshops, they have collectively shared a lot of ideas and options. A very important message is that a lot that has been done and is being done to adapt to changing climate conditions. The modern farmer is responding to a whole range of signals. Climate and market signals are at the forefront. Farmers are, for the most part, inherently adaptable. However, there are differences in how individuals respond to signals with some doing it better, and more proactively, than others. With climate, the majority tend to adopt a 'watch and see' approach and might be called crisis reactors. A minority are proactive in implementing and managing change. Overall there is a lot of knowledge, experimentation and experience of relevance to adaptation. The key is to harness what the smart farmers are doing and make it more visible to others, as well as supporting on-farm research. The kiwifruit industry provides a good

> "While profitability remains important to farmers there is an emerging view of a need to be working within the limits of nature a lot more. This is evident through increased awareness of the role of trees, on-farm experimentation with different pasture species, changes to grazing management, benefits of diversification, and interest in low-input, biological or organic-type approaches."

example of a proactive approach to addressing this issue, with a very clear focus on identifying and working with innovators. This approach was a key element in the successful implementation of the KiwiGreen programme, which has now become the bottom-line standard for the kiwifruit industry (Aitken et al. 2005).

7. Adaptation pathways and response capacity

Two climate change scenarios have been proposed by Reisinger et al. (2010), a high carbon world and a rapidly decarbonising world scenario. In this paper, two alternative adaptation options are explored (Figure 2), those based on high energy inputs[4] (energy intensive) and those based on high knowledge inputs (knowledge intensive), but low energy inputs. These proposed contrasting adaptation options and associated pathways for adaptation in agricultural systems (Figure 3) are consistent with and correspond to these two global scenarios.

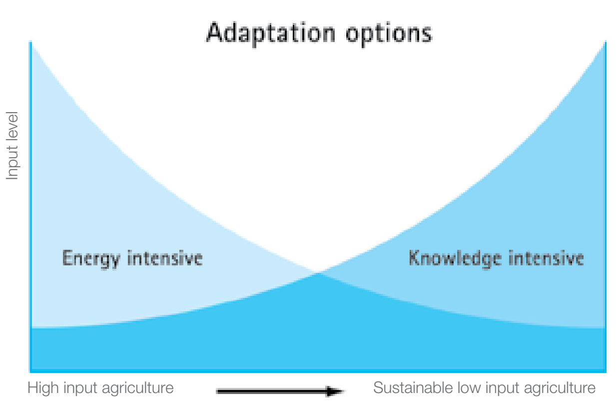

Figure 2. Adaptation options for agriculture, modified from House & Brust (1989) and Stinner & House (1988).

Agriculture, particularly in developed countries, became highly dependent on high fossil fuel inputs through the 20th century, and this continues today. In New Zealand, the consequences of energy intensive agriculture were recently addressed in the 'Growing for good' report of the Parliamentary Commissioner for the Environment (2004). This report documents the growth in direct and indirect energy use in agriculture since the 1990s, in particular the rapid growth in use of fossil-fuel based fertiliser. The potential problems arising from rapid growth in dependence on fossil fuels were identified nearly 40 years ago, and well articulated, by the renowned American ecologist, Howard Odum (Odum 1971).

"The demands of man and his machines for high energy of concentrated type contrast with the broad dilute field of incoming light energy from the sun. The surge of industrial and population growth is derived from fossil fuels now being consumed at accelerating rates. The relative magnitudes of these new power flows, while still only a fraction of that of the whole biosphere, begin now to be sufficiently large to change and disturb the earlier checks and balances of the earth system wherever they are concentrated."

The consequences of displacing ecological complexity and knowledge systems with a high fossil fuel subsidy (direct and indirect) were discussed in depth by Odum (1971). When the fossil fuel subsidy is removed, as with so-called low input agriculture systems, the maintenance of productivity requires a "high input of information and, in many situations, superior management skill" (House & Brust 1989). Knowledge intensive, low input, agriculture is not a new phenomenon, having evolved over the last 60-70 years. Early proponents of such an approach include the likes of Howard (1940), Odum (1971), Schumacher (1973), Merrill (1976), and Berry (1977). Early pest ecology research contributed to a further evolution of thinking and practices (see, for example, van Emden & Williams 1974, Pimentel & Goodman 1978, Altieri & Letourneau 1982). In New Zealand, knowledge intensive systems are evident through a diversity of approaches, including low input farming (organic agriculture, biological farming, lime-based regimes), smart grazing management, integrated pest management systems, and farm forestry systems.

Energy intensive farming systems are consistent with a high carbon world (Figure 3). Farmers engaged in energy intensive systems admit that they are pushing the margins much more than in the past. Their solutions to climate change are generally more technologically focused, requiring higher investment in adaptation over time. The challenge for these systems is their current high dependence on fossil fuels (e.g., for fertiliser production) and a likely increasing dependence on ongoing investments to find solutions. With higher capital and input investments, along with lower ecological complexity, high input systems have the potential to be higher risk and more vulnerable over time. This suggests greater potential for maladaptation. Given the greater impacts of climate change that will be experienced in a high carbon world it is likely that energy, and capital, intensive systems will become increasingly unsustainable. This is supported, for example, by the combined effects of high fertiliser prices, extended drought, and consequences of intensive grazing regimes in Hawke's Bay. Farmers in this region are already moving towards knowledge intensive, low input systems. Similarly, dairy farmers and kiwifruit growers have, for the most part, identified knowledge intensive, low input systems as a more likely adaptation pathway for the future (Table 2). There are examples of tension between the two adaptation pathways, for example with the growth in demand for water, particularly for irrigation, in some areas.

[4] High energy inputs are defined here as inputs involving direct and indirect use of fossil fuels. Indirect use includes fertilisers and pesticides that are derived from, or through use of, fossil fuels; N-fertiliser is an obvious example that is very relevant in a New Zealand context. Conversely, low energy inputs are those involving minimal use of fossil fuels, or products derived from, or through the use of, fossil fuels.

The future cost of adaptation with energy intensive systems could become increasingly prohibitive, leading to an inevitable higher future cost of adjustment towards lower input systems (indicated by the black arrow in Figure 3). Factors that could drive this include increasing costs of fossil-fuel based inputs over time, increased consequences from ongoing loss of ecological complexity and resilience, and increased consumer demand for products from knowledge intensive systems.

There are currently some efficiency improvements evident in energy intensive systems. Examples include effluent management, nutrient budgeting and irrigation management. These, and other approaches that involve input substitutions, might be termed intermediate approaches. Depending on the nature of inputs and management, adaptation costs of such systems are likely to be somewhere between high and low input systems.

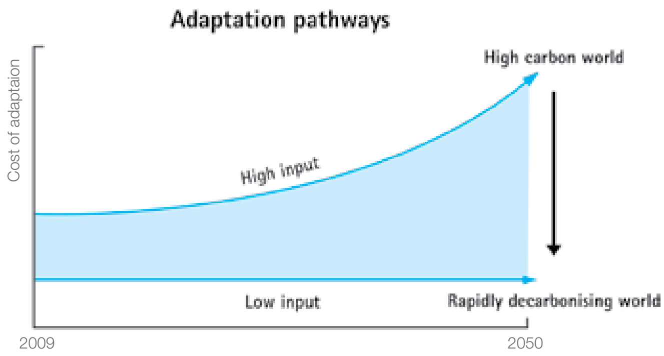

Figure 3. Adaptation pathways for agriculture,based on conceptual rather than actual costs.

Knowledge intensive systems are more consistent with a decarbonising world (Figure 3) and are likely to become more attractive over time for a high carbon world. The latter is particularly true as resources such as fossil fuels become increasingly limited. Knowledge intensive systems are strongly consistent with the resilience picture shared by smart farmers in Section 6. Farmers engaged in such systems, even if not developed to their potential, talk about their greater buffering capacity. They affirm the extra knowledge input required on their farms, whether it be for farm forestry or soil biology management. They are, in general, active knowledge seekers, using all available media and opportunities for gathering information.

Farming for resilience, with knowledge intensive, low input systems has the potential to provide both adaptation and mitigation benefits (Table 3). Greater understanding of this potential provides the opportunity for development of a coherent, integrated response capacity. The potential and opportunity for such a response capacity has not yet been explored in New Zealand. Possible mitigation benefits in particular, from a resilient farming approach, need to be understood much more.

This characterisation of adaptation pathways, and their correspondence to energy intensive and knowledge intensive systems and to high and rapidly decarbonising carbon worlds, is based on an emergent picture drawn from a process of engagement with farmers. More research is needed to further characterise and quantify the options and pathways presented here, working with farmers in different regions of New Zealand. Consistent with the needs identified from farmers there is a clear need for a more comprehensive understanding of the potential costs and benefits of the different adaptation pathways. There are enough working examples in New Zealand to facilitate such an understanding. Ideally this needs to incorporate identification of benefits and costs in terms of both mitigation and adaptation. Concurrently there needs to be explicit consideration, and full accounting, of the ecological services and costs provided by different systems. The potential benefits from a dedicated focus on knowledge intensive, low input systems could be considerable.

The farm resilience picture (Figure 1, Tables 2 and 3) provides the basis for design of knowledge intensive systems. As already indicated there is a foundation of knowledge, and working examples, that can be drawn on in further development and refinement of this picture. This further development will require a process of change and transition towards what has been termed ‘redesign’ by Hill (1985, 1998) and MacRae et al. (1990). The need for redesign of New Zealand agriculture towards lower energy input systems was identified by the Parliamentary Commissioner for the Environment (2004). The principal challenge is how to manage the transition. A three-stage process has been identified by Hill (1985, 1998) involving efficiency improvements, input substitutions and redesign. Efficiency improvements and input substitutions are likely to be easier to implement, with a shift towards redesign invariably involving some form of psychological shift (Hill 1991). Responses from farmers indicate that a psychological shift involving fundamental change often, but not always, arises from crisis (Kenny 2006b). The psychology of change, and the role of crisis, needs to be understood and worked with much more. With the clear evidence of climate change, and potential for significant challenges, there is a pressing need to be seriously considering alternative approaches that involve redesign and fundamental changes in ways of thinking and doing. With farmers already acting towards low input systems these alternative pathways need serious attention.

8. Wider issues

Beyond the farm resilience picture there are wider issues of relevance that have been consistently identified. These are water, the urban/rural divide, the role of regulators and regulations, and education of the wider community.

Water supply, demand, quality and allocation have all been identified as water-related issues. Many individuals have been acting to secure their water supplies for the future. This has been prompted by various factors, including experience with recent droughts, awareness that demand is increasing and will increase in the future, and intensification of land use. How water is managed on a catchment-wide basis in affected regions is vital to the future resilience of all forms of land use and eastern regions as a whole. In most eastern regions of New Zealand surface water resources are fully allocated, as is groundwater in regions such as Canterbury. There is, currently, a relatively poor understanding of water resources in some hill country areas, such as Hawke’s Bay. There is anecdotal evidence of springs and creeks drying up during summer months more frequently than in the past. While this is most likely a consequence of drier than average conditions over the last few years, it is consistent with what could be experienced with greater frequency in the future. Water storage, for example in dams, could therefore become more widespread in hill country farms over time. This could have implications in terms of runoff and recharge of groundwater that is allocated to intensive land uses. Another water-

Table 3. Adaptation and mitigation co-benefits from smart farming.

Smart farming for resilience	Adaptation benefits (increasingly understood but need to be understood more)	Mitigation benefits (need to be understood much more)
Trees for multiple purposes	Shelter and shade benefits Stock fodder Erosion control Drought and flood resilience Biodiversity enhancement	Carbon storage Lower methane emissions from reduced feed demand with shelter & shade and improved feed quality
Pasture Mixed species Low input regimes Longer pasture covers Deferred grazing Deeper rooting plants Focus on pasture quality	Drought and flood resilience Improved animal health	Carbon storage in soil from greater root mass to a greater depth Lower methane emissions from improved feed quality
Soil Lower inputs/soil biology management Clover and other legumes instead of N-fertiliser	Buffering against flood and drought from increased organic matter, soil porosity and soil health Improved animal health through improved pasture quality	Carbon storage with deeper rooting pasture and soil organic matter increases to a greater depth Reduced nitrous oxide emissions Lower fossil fuel use and emissions with reduced demand for and production of N-fertiliser and other fertilisers
Stock Focus on quality rather than quantity Stock ratio and breed selection	Greater resilience through smarter grazing management Animal health improvements, more resilient animals	Reduced emissions through smarter grazing management and improved animal health
Water Storage Efficient reticulation and use Soil biology management Riparian protection	More efficient and effective water use Greater resilience	Improved carbon storage and reduced carbon emissions from greater moisture retention Lower emissions from a healthier, less water-stressed, farm system
Whole farm An integrated sustainable management programme	Long-term resilience Off-farm benefits (e.g., catchment protection, biodiversity corridors)	Efficient capture, storage and cycling of solar energy, carbon, and water Reduced emissions

related issue is the growing tension, in some areas, between urban and rural demand for water.

Many farmers have identified the growth in urbanisation as a fundamental issue. New Zealand is part of a global trend towards a more urbanised population. In 1886 the majority of New Zealanders lived in rural areas. By 2001 New Zealand was considered to be one of the most urbanised countries in the world (Statistics New Zealand 2001). Despite the continued importance of agriculture to the economy the proportion of people working in agriculture has fallen.
These changes have had a number of consequences including increased competition for resources such as water, decreased understanding of farmers and what they do, and a tendency for media attention to be focused on the perceived or actual negative aspects of agriculture. There is a general feeling that many urban people aren't aware of the good things that are being done by farmers, and have been done over decades in some cases. On the other hand it could be argued that more farmers need to be more aware of their role in managing fundamental ecological services. Underlying this is the history of land-use in New Zealand, in particular the clearing of forest from erosion-prone land, which has been shaped through individual actions and changing government policies over the years. Some individual farmers have been proactive in engaging with the wider community to highlight the positive things they are doing, with a few providing public access to their farms and participating in environmental education programmes.

Farmers in New Zealand generally mistrust rules and regulations. Our farmers are still far less regulated than their European counterparts. However, the amount of information and paperwork that farmers have to deal with has increased significantly in recent years. This has been a consequence of emerging concerns about environmental degradation and health (for example water quality), demands from export markets, increased demand and competition for resources, among other factors. In general this situation has made them more wary of any measures that are perceived as imposing more costs and regulation.
The proposed 'fart tax' and the emissions trading scheme have emerged within this context. Willingness to believe the science of climate change and act accordingly has, for many, been conditioned by a perception of more regulations being imposed.

The need to educate the wider community, particularly the younger generation, is considered by many farmers to be the key to addressing wider issues. This includes education relating to the important role that farming has to play both economically and in managing ecological resources. Further, it requires development of an understanding of what responses to climate change (adaptation and mitigation) mean in a practical sense (for example, Table 3). This needs to be founded on a comprehensive understanding of what resilience means at a regional, landscape scale as well as locally. Furthermore, it requires an active process of community engagement in developing positive, practical visions for the future. Some brief case studies of how this visioning approach might work in the context of adaptation were developed by Kenny (2005).

Discussions relating to regional resilience and redesign of rural landscapes in New Zealand have been developed by the Parliamentary Commissioner for the Environment (2001) and Swaffield (2008). The latter author has suggested the need for a longer term collective vision and a strategic landscape approach focused on the creative regeneration of multifunctional landscapes. He proposes a target, for 2050, of a minimum of twenty percent of all productive landscapes as "green blue networks and reserves, centred upon waterways and steep land."

9. Key needs to support resilient farming

Farmers are, for the most part, independent and self-contained people. Faced with a problem or issue their focus is to do something about it. This creates an inherent challenge with an issue like climate change, which many farmers struggle to relate to in terms of what they are doing in the present. The following are the most consistent responses received from smart farmers, aimed at wider engagement of farmers and supporting a proactive approach to development of long-term resilience.

1) An ongoing need for communication and education regarding climate change and associated issues. Communication of the fundamentals of the science of climate change to farmers and more widely hasn't been done well in the past. The very strong focus on mitigation from the early 2000s has tended to distort people's perceptions of what responding to climate change is about. These views have consistently been shared by farmers over the last eight years. This has been reinforced by a general lack of understanding, inquiry, and support in relation to potential co-benefits to adaptation and mitigation from a range of actions already being implemented on the ground.

2) A need for coordination between all parties for the benefit of all. Most recently this has been summed up by Hawke's Bay farmers who have talked about the need for a 'New Zealand Incorporated' approach. Climate change is one of multiple, inter-related pressures that are coming to bear on farmers and wider communities. The message from farmers is that we need to be working together for the benefit of all.

3) A need to bridge the gap between town and country. There needs to be better understanding by urban people of the ecological and economic services that farmers provide. At the same time farmers need to appreciate more, as they increasingly are, their important role in building and sustaining ecological and economic resilience. The latter is evident among farmers who, for example, are fencing and protecting riparian areas and, in some cases, are providing public access to their farms.

4) A very strong need to support on-farm innovation and research. This needs to be focused, in particular, on those farmers who have historically gone outside the square (e.g., farm foresters) and those who are currently going outside the square (e.g., organic, biological and low-input farmers). There is currently very little understanding of knowledge intensive, high resilient systems that are already being implemented by proactive farmers. This is founded on a relatively poor appreciation or understanding of the fundamentals of ecology and resilience in our farming systems. Closer understanding of these fundamentals, focused on real farm situations, could provide valuable insights in terms of adaptation and mitigation co-benefits.

5) There is a consistently expressed need for role models of sustainability and resilience. Over the last decade or so the principal emphasis, particularly in pastoral farming, has been on profitability. While profitability remains important to farmers, there are questions emerging relating to long-term sustainability of some practices and a need to develop greater resilience. Some dairy farmers are increasingly concerned about the consequences of high nitrogen inputs. Sheep and beef farmers in Hawke's Bay have suffered through successive droughts. In the past they have received advice that has promoted intensive grazing regimes to maximise returns from available grass. From hard experience with the consequences of droughts there are increasing numbers of farmers who are questioning such advice and looking for alternatives.

10. Conclusions

This paper began with a discussion of the evolution of impacts and adaptation research. It particularly focused on the development and application of the smart farmer approach in model-based assessments. Questions arose, for example relating to the communication of uncertainty and how to make climate change real to real people, that led to direct engagement with smart farmers. The outcome of this work does not necessarily translate into a quantitative comparison of how effective smart farmers might adapt in the real world compared to a top-down model-based concept of 'smart' adaptation, but it has resulted in a much deeper, and more comprehensive, understanding of resilience and response (adaptation and mitigation) capacity than could otherwise have been achieved. More importantly, this approach identifies pathways for realising adaptation options in practice, rather than relying on provision of information as the sole driver for behavioural changes.

Climate change science has tended to either consider adaptation as something new for farmers and growers, or as something that will be driven exclusively and entirely by provision of information about future changes. In contrast, a participatory research approach gives insight to adaptations that have already been made, and are being made, to changing conditions. Some farmers are dealing with issues and implementing innovations that are either ahead of, or quite separate from, current research. Engagement with farmers in eastern regions of New Zealand has provided critical insight and direction for adaptation research, policy and development of long-term resilience. There is significant response capacity amongst smart farmers, but there are key actions required to fully realise the potential of this more widely.

These include:

1) systematic engagement with 'smart farmers' around New Zealand to fully identify and document what they are doing;

2) addressing the key needs identified in this paper, in particularly actions to support on-farm research (in support of what smart farmers are already doing), wider dissemination to other farmers, education of the wider community, and development of collective visions aimed at resilient, multi-functional, regional landscapes.

Understanding of this capacity and associated needs addresses a fundamental issue, identified by Adger et al. (2007). This is the importance of developing interconnected 'bottom up' and 'top down' approaches to adaptation. Of equal, if not more, importance is the need to recognise and realise the co-benefits to adaptation and mitigation that emerge from in-depth engagement with farmers. With a focus on adaptation, the work summarised here did not explicitly seek to question the distinction between adaptation and mitigation. However, a focus on resilience invariably leads to a realisation of potential for significant co-benefits. An integrated sustainable land management, and regional landscape management, approach provides the opportunity for a coherent response capacity. Such real world responses have not been given the attention that they deserve in New Zealand, particularly in the shaping of mitigation research and policy. As discussed by Tompkins & Adger (2005), "Climate change adaptation and mitigation decisions made by governments are usually taken at different policy domains. At the individual level however, adaptation and mitigation activities are undertaken together as part of the management of risk and resources." This view has been reinforced in the IPCC Fourth Assessment Report in a discussion on the inter-relationships between adaptation and mitigation (Klein et al. 2007). The agricultural sector is identified as one of a number of areas where the opportunities for synergies between mitigation and adaptation are potentially quite high.

An emergent picture, drawn from engagement with farmers in eastern regions of New Zealand, is one of redesign towards knowledge intensive, low input, farming systems. This picture has paralleled a rapid growth in intensification of agriculture. Furthermore, it is argued that knowledge intensive, low input, farming systems are more consistent with a low-carbon future and are likely to become increasingly attractive with a high-carbon future. More comprehensive development of knowledge intensive farming is required, working with practising farmers. Transition pathways need to be developed, with a focus on the psychology of change. Climate change, along with other global changes, is requiring fundamental changes in human behaviour and activity. The key to addressing this is identification of appropriate ways to overcome behavioural barriers and empowering people to act (Adger et al. 2007). This paper does not provide all of the solutions. It does provide important insight into what has been learnt from smart farmers and actions that can be taken based on this insight.

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05

The effects of climate variability & change upon renewable electricity in New Zealand

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Renewable electricity generation capacity in New Zealand is strongly affected by climate variations, mainly through modulation of inflows to hydro-generation lakes.
This paper discusses the influences of large-scale climate signals (the El Niño-Southern Oscillation, the Interdecadal Pacific Oscillation, and anthropogenic climate change) upon renewable electricity supply, and upon demand for electricity. While natural variability will continue to be an important factor, climate change effects will assume increasing importance over the coming century, especially if greenhouse gas emissions remain high. Climate change is likely to not only bring changes in mean rainfall, wind and temperature patterns, but also a changing seasonality of the regional climate for renewable generation, and a changing risk profile of extreme weather and climate events. Generation capacity is likely to be higher in winter and spring, while capacity is likely to be lower in summer and autumn. Wintertime demand for heating is likely to decrease, and summertime demand is likely to increase. Such expected changes can be used in planning to increase the diversity and capacity for renewable generation to reduce energy supply risk.

1. Introduction

This paper provides an overview of observed and potential impacts of climate variability and change on the electricity sector in New Zealand, with a focus on renewable electricity generation. It also discusses energy demand and the transmission and distribution of electricity. New Zealand's energy sector is especially sensitive to climate influences, since a large fraction of the country's electricity is generated from climate-sensitive renewable fuel sources, and since the climate of New Zealand varies widely on all time scales.

The key drivers of New Zealand climate variability and change discussed here are the El Niño-Southern Oscillation (ENSO) phenomenon, the Interdecadal Pacific Oscillation (IPO), and anthropogenic climate change/global warming. The ENSO cycle has a significant effect on New Zealand climate, in particular upon rainfall over the South Island. Summer inflows to the main South Island hydro-generation reservoirs are significantly lower during La Niña conditions than in non-La Niña summers. The IPO acts as a longer-term modulator of ENSO activity and is associated with decadal-scale variations of mean inflows of about 10-15%. Long-term climate change is projected to bring about warming, changes in windiness and rainfall, and changes in the seasonality of the climate over New Zealand. Hence it is likely to have a number of inter-related effects upon hydro storage and other renewable generation capacity, as well as on the seasonality of demand for electricity.

The discussion below summarises elements of the New Zealand electricity system, and discusses climate effects upon generation, transmission, distribution, and demand. It includes an outline of the likely effects of possible "rapidly decarbonising" and "high carbon" world futures, in terms of the climate of New Zealand and the electricity system. Note that the material presented here does not take account of the recently - released Energy Outlook from the Ministry of Economic Development (MED 2009a)).

2. The electricity system in New Zealand

2.1 Renewable generation

New Zealand has one of the world's highest proportions of renewably - generated electricity. In 2008, around 65% of the national electricity supply was generated from renewable sources (MED 2009b). Renewable sources are dominated by hydro-electric generation (52% of total electricity generation in 2008), with a significant component of geothermal (9% in 2008), and a small but increasing fraction of wind generation (2.5% in 2008) . Most of the remaining electricity is generated using gas (24%) and coal (11%).

Water storage for hydroelectric power generation is dominated by a few key reservoirs: Lakes Pukaki and Tekapo in the Waitaki River basin; Lake Hawea in the Clutha River basin; and Lakes Te Anau and Manapouri, all in the South Island; and Lake Taupo in the North Island (Figure 1). The South Island lakes are fed by precipitation spilling over the Southern Alps in westerly storm events, meaning that inflow variability is intimately linked to variations in the strength and direction of the predominant westerly wind circulation across the country.

Snow storage in winter is a key component of the annual cycle of hydro-generation capacity. Snow melt currently provides an average of 50% (20-70%) of spring and summer inflows into New Zealand's main hydro storage reservoirs (the Waitaki catchment lakes) (McKerchar et al. 1998).

New Zealand's current wind energy resource is predominantly from westerly winds. Te Apiti wind farm in the Tararua range north of Wellington receives 66% of its wind generation from westerly quarter winds, and only 34% from the three other quarters (data from Meridian Energy Ltd). New Zealand's maximum wind generation currently occurs in October-November, the windiest months of the year. Wind generation capacity is closely tied to hydro-generation capacity, since strong westerly wind events tend to be associated with widespread rain, especially along the Southern Alps. The correlation between estimated wind generation capacity for 12 monitored wind sites, and current installed hydro–generation inflows for New Zealand as a whole is 80% on an annual basis. South Island hydro inflows correlate strongly positively to most New Zealand wind sites, but North Island hydro inflows relate slightly negatively to Southland wind sites (data from Meridian Energy Ltd). It is important to understand such relationships in order to correctly model storage needs and the complementarity of wind- and hydro-generation.

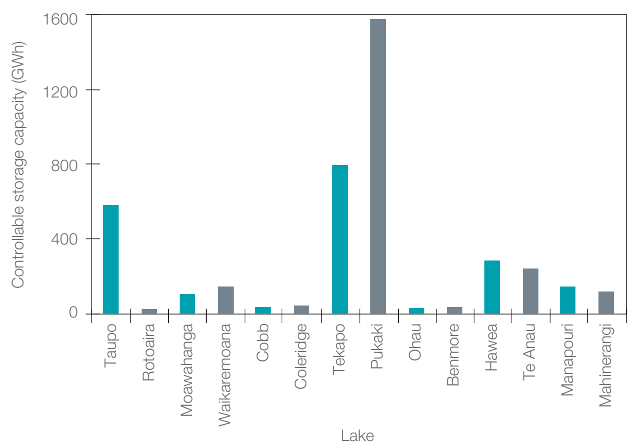

Figure 1. Controlled storage available for hydroelectric power generation in New Zealand.

> "New Zealand's energy sector is especially sensitive to climate influences, since a large fraction of the country's electricity is generated from climate-sensitive renewable fuel sources, and since the climate of New Zealand varies widely on all time scales."

[1] www.med.govt.nz/templates/ContentTopicSummary_21274.aspx (accessed 4 December 2009)

2.2 Demand and transmission

New Zealand's electricity demand increased consistently at an average growth rate of around 1.8% per annum over the period 1969-2007 (Figure 2), and currently stands at around 42 TWh in 2009. Demand growth, despite flattening off in the past couple of years, is expected to continue in New Zealand, at least over the next 20 years, but at a lower rate, perhaps around 1.5% per annum (MED 2009a, Electricity Commission 2008). This growth rate takes into account recent and ongoing improvements in energy efficiency. Peak demand, which occurs in winter, is around 7 GW (Meridian Energy Ltd 2008). National peak generation stands at around 9 GW.

New generation plant will continue to be built to supply this demand, and improvements in transmission networks will be required to transport this electricity to the demand sources. It is estimated that an additional 70-100 MW of baseload electricity capacity will be required each year on an ongoing basis (Meridian Energy Ltd 2009). This new build requirement is currently being exceeded, with about 200 MW of new generation being added each year since 1996. Of this, only 31% has been from renewable technologies, but this is likely to increase when a carbon price is introduced into the economy with the emission trading scheme.

3. Climate variability and change

3.1 Climate variability

New Zealand lies in the middle latitudes of the southern hemisphere (34° to 47°S). The climate is affected all year round by the band of mid-latitude westerly winds and by the subtropical high pressure belt. Both major circulation features move north and south with the march of the seasons. The westerlies are farthest north in winter and spring and the influence of the subtropical high is strongest in summer and autumn (Figure 3). The windiest season of the year is spring, as the subtropical high begins to migrate southwards and the surface pressure gradient across New Zealand strengthens. Much of the country's weather is influenced by the passage of fronts and depressions in the westerlies, which cross New Zealand longitudes every 4-5 days at all times of year (Maunder 1971, Sturman & Tapper 2006).

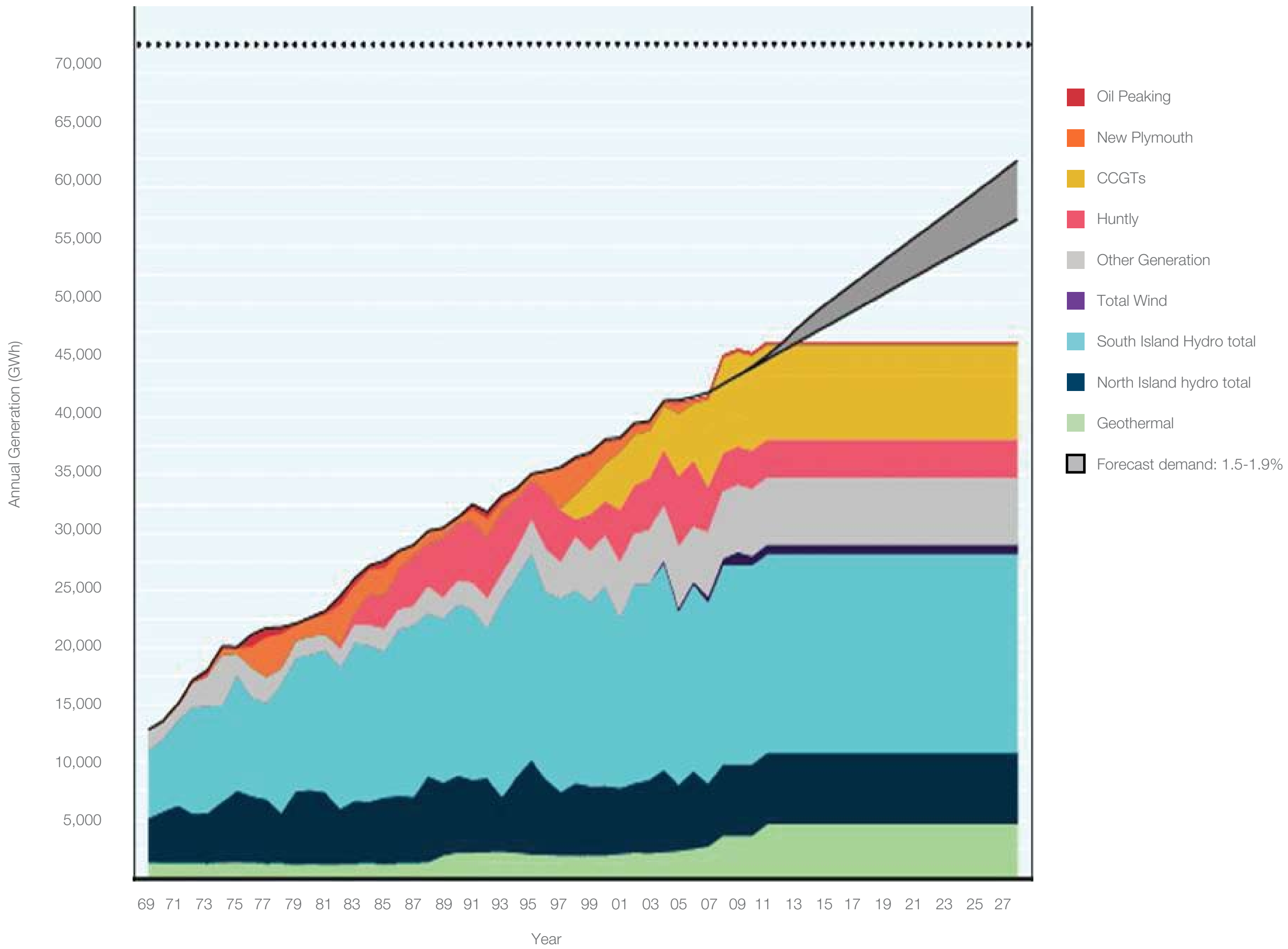

Figure 2. Electricity demand and generation production observed (1969-2008) and forecast (2009-2028). Source: Meridian Energy Ltd (2009).

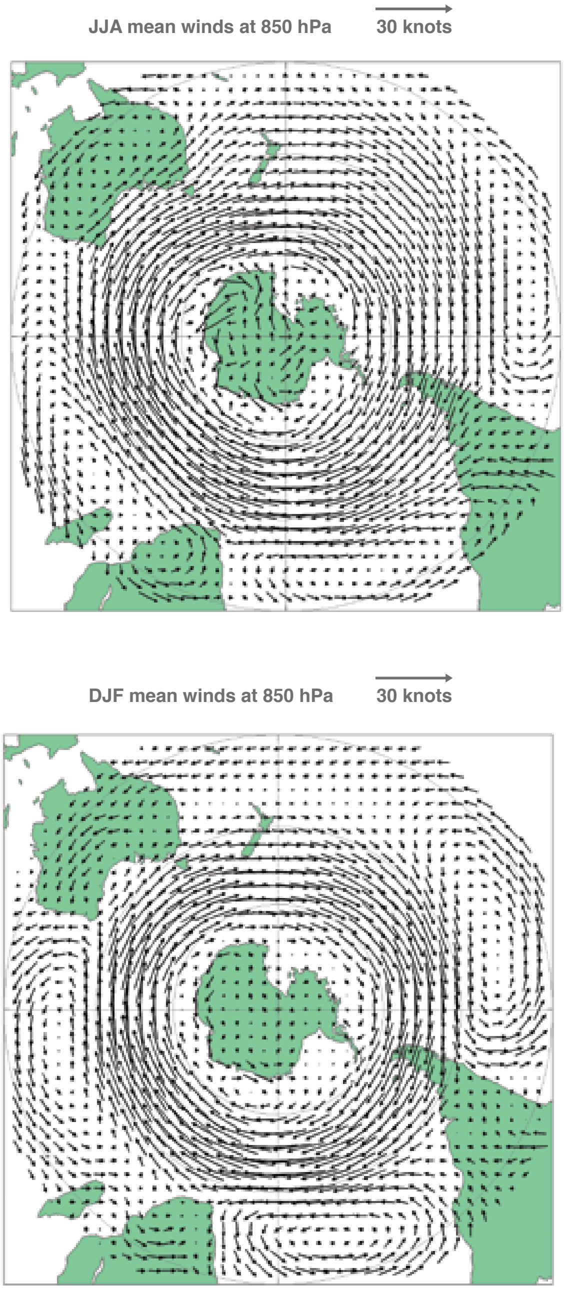

Figure 3. Southern hemisphere mean wind circulation for winter (JJA, upper panel) and summer (DJF, lower panel), on the 850 hPa pressure surface (approximately 1 km above ground level). Data are an average over 1971-2000 from NCEP/NCAR reanalyses (Kistler et al. 2001).

The main New Zealand mountain chains, particularly the Southern Alps, are aligned almost at right angles to the prevailing westerly wind flow and provide a significant barrier to that flow. Much of the rich regional detail in New Zealand climate comes from complex interactions between the large-scale atmospheric circulation and the rugged topography. The most notable effect is the east-west gradient in rainfall, ranging from 3 to 4 m per year in Westland to 12 m or more in the Alps, but less than 500 to 700 mm in Otago and Canterbury (Wratt et al. 1996) (Figure 4).

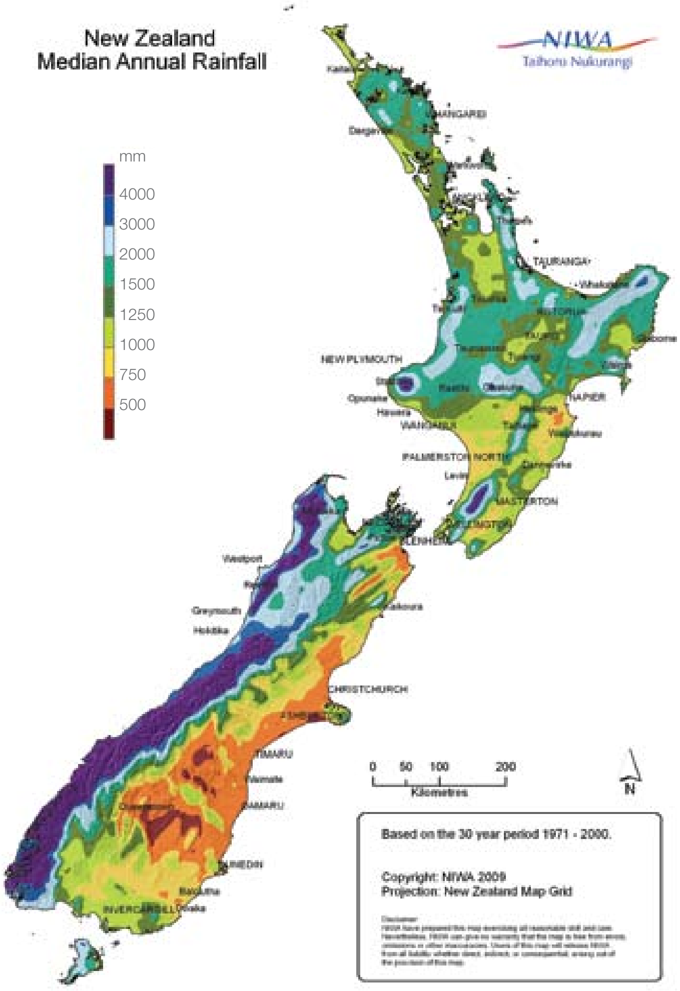

Figure 4. New Zealand median annual rainfall (mm).

Year to year variability in New Zealand climate is influenced by a number of components of the large-scale climate system, primarily through their influence on the mid-latitude westerly circulation that defines much of the country's climate. The most notable are the El Niño-Southern Oscillation (ENSO) cycle (Gordon 1986, Mullan 1996) and the Interdecadal Pacific Oscillation (IPO) (Salinger et al. 2001).

The ENSO cycle involves an irregular exchange of heat in the upper layers of the ocean between the western and eastern Equatorial Pacific. The normally cool region off the coast of South America warms up in an El Niño, associated with a weakening of the trade winds and changes in tropical rainfall patterns. Such tropical shifts have flow-on effects across the Pacific, resulting, on average, in cooler conditions with stronger westerly winds over New Zealand. Rainfall tends to be enhanced in western regions, with an increased risk of dry conditions in the east and north. In a La Niña, the eastern Equatorial Pacific cools and the trade winds increase in strength. The net effect on New Zealand is on average reduced westerly winds, with warmer conditions, especially over the summer months. Rainfall is on average enhanced in the north and east, and reduced in the west and south.

The IPO is essentially a long-term modulation of the ENSO cycle, bringing 20-30 year periods of stronger and more frequent El Niño events, alternating with periods of weaker El Niño and stronger

La Niña conditions. The IPO is manifested as a change in the background state of the Pacific Ocean, moving towards an El Niño state during the positive phase (e.g., late 1920s to mid–1940s, late 1970s to late 1990s), and towards a La Niña state during the negative phase (e.g., late 1940s to mid 1970s, and since 2000). During the positive IPO, with a predominance of El Niño events, New Zealand tends to experience generally stronger westerly wind flow, with higher mean rainfalls in western and alpine regions. During the negative IPO, the mean westerly circulation over New Zealand slackens, and rainfalls tend to reduce in western regions, while increasing somewhat in the east of the country.

3.2 Climate change

The extent of future climate change depends in large part on future concentrations of atmospheric greenhouse gases and aerosols. In the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), the range of global mean temperature increase during the 21st century was given as 1.1-6.4°C, over the six 'illustrative scenarios' (Figure 5). Projections based upon the "A1B" scenario result in mid-range changes in global mean temperatures and other parameters of the climate system. Using the A1B scenario, global mean warming is projected to average a little under 3°C by the end of this century, relative to average temperatures in the late 20th century (or about 3.5°C relative to pre-industrial temperatures).

Global warming of around 3°C this century, under the A1B emissions scenario, would translate to a mean warming over New Zealand of around 2.1°C (Mullan et al. 2008), a warming rate about 70% of the global mean. A consistent signal from global climate model projections is for an increase in the westerly wind circulation over New Zealand, especially in winter and spring. During summer, there may be a tendency for reduced westerly winds over New Zealand, but this is less certain (Mullan et al. 2008).

As a result of expected wind changes, there is likely to be an increase in annual mean precipitation in western regions of New Zealand, and a decrease in rainfall in the east of the country. Such changes are likely to be most pronounced in winter and spring. During summer, there may be a reversal of this trend, with somewhat increased rainfall in the east of the country, and decreases in the west (Mullan et al. 2008).

Such changes in the mean climate would result in many changes in extremes of climate: reduced frost frequency and increased risk of heat waves over the whole country, reduced soil moisture and increased risk of drought in the east of the country, increased risk of forest fires in many eastern and northern regions, and increased risk of heavy rainfalls in most places.

As a result of temperature and rainfall changes, reductions in snow pack are likely in the Southern Alps. Recent modelling (Mullan et al. 2008, Hendrikx et al. 2008) projects decreases in seasonal snow cover

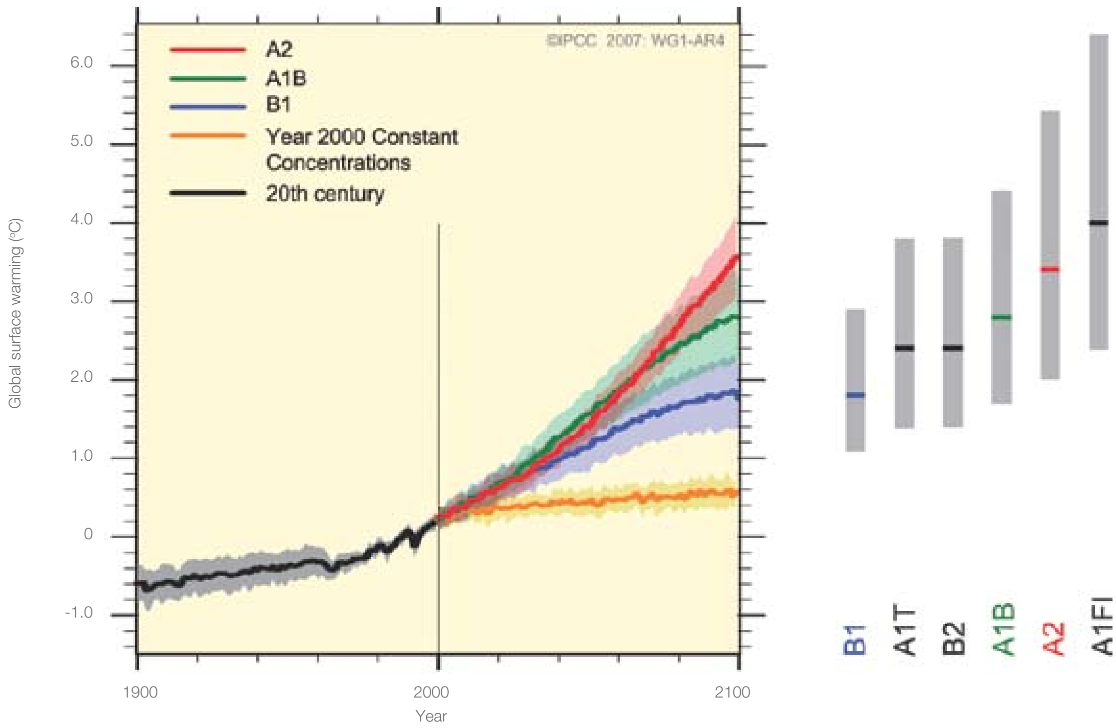

Figure 5. Global mean surface warming for a range of emissions scenarios and climate models. Solid lines are multi-model global averages of surface warming (relative to 1980-1999) for the scenarios A2, A1B, and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate (solid coloured line within each bar) and the likely range of warming by 2100 for the six SRES marker scenarios. (Source: figure SPM.5, IPCC (2007)).

and depth throughout the country, particularly in the South Island. Under a "middle of the road" scenario (IPCC A1B), there are likely to be significant decreases in snowpack right through the 21st century.

Heavy rainfall events are projected to be more frequent and intense across New Zealand. Modelling by Pall et al. (2007) suggests that extreme rainfall events with a return period of greater than 30 years will have on average about 8% more rain for every 1°C rise in air temperature. Gray et al. (2005) modelled three storm events for the west coast Buller catchment of New Zealand for the current climate and for three scenarios of temperature increase (0.5°C, 1.0°C, and 2.7°C). Modelled rainfall increased on average 3%, 5%, and 33%, respectively. Analyses of this kind for other New Zealand catchments have not yet been carried out.

A substantial increase is projected for the number of warm days (days with maximum temperatures above 25°C), particularly at already warm northern sites. For Auckland, an additional 40 to 60 days above 25°C are projected by the end of the century, dependent on the greenhouse gas emissions scenario. Currently, Auckland has about 21 days per year with maximum temperature exceeding 25°C, so this would translate to a tripling or quadrupling of the number of warm days. Current values for other locations include: 26 days for Hamilton, 3 days for Wellington, and 31 days for Christchurch (Mullan et al. 2008).

There are indications of an increased risk of extreme wind events with climate change. As the westerly circulation increases over the country in winter and spring, the frequency of strong winds above a given threshold will almost inevitably increase. Research is ongoing in this area, but work to date suggests that up to a 10% increase in wind speeds above the current 99th percentile (top 1% of wind speeds) is possible by the end of the century (Mullan et al. 2008).

The sequence of climate experienced in New Zealand over coming decades will be a combination of natural variability (ENSO, IPO, and other components of the climate system) and anthropogenic effects as discussed above. Different components can work together or can cancel out: the negative phase of the IPO is associated with wind and rainfall changes opposite in form to what is expected from multi-decadal climate change, implying that an extended negative excursion in the IPO (such as that which began around 1999-2000) would act to damp the climate change signal over New Zealand. Conversely, a switch to the positive IPO could enhance anthropogenic climate change trends.

"A consistent signal from global climate model projections is for an increase in the westerly wind circulation over New Zealand, especially in winter and spring."

4. Climate and the electricity sector

As discussed above, key factors modulating rainfall and wind circulation (hence hydro- and wind-power generation capacity) over New Zealand are the ENSO cycle, the IPO, and projected anthropogenic climate change. The effects of natural variability upon hydro capacity are illustrated in Figure 6, which shows annual mean flow in the Clutha River (measured at Balclutha). The Clutha flow is representative of flows in other major alpine-sourced South Island rivers, and of mean precipitation in the Southern Alps (McKerchar & Pearson 1997, McKerchar et al. 1998). The annual mean flow in the Clutha has exhibited an approximately 15% change between negative (1947-1976, 2001-) and positive (1977-2000) phases of the IPO (Folland et al. 2003) as a result of changes in the mean westerly circulation over New Zealand, and associated changes in rainfall in the western South Island and the Southern Alps. Superimposed on this is the strong year-to-year variability related to ENSO events, fluctuations in the Southern Annular Mode (Kidston et al. 2009), and more random/chaotic variations associated with internal variability in the regional climate. For example, the highest mean flow on record was in the 1957-1958 year, during a relatively "dry" negative IPO period.

Table 1 shows frequencies of occurrence of high, medium, and low inflows to Manapouri Power Scheme for the 30 years pre- and post-1976, the time of a switch from negative to positive IPO. There is roughly a doubling in the frequency of wet or dry years (defined in Table 1) with the phase of the IPO. As highlighted in bold and italic, the frequency of occurrence of a wet year during the negative IPO is about the same as the frequency of occurrence of a dry year during the positive IPO, and vice versa.

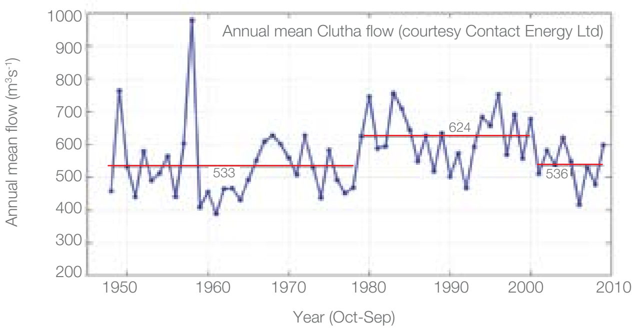

Figure 6. Mean annual (1 Oct-30 Sep) flow ($m^3 s^{-1}$) in the Clutha River, at Balclutha, 1947-2009 (data courtesy Contact Energy Ltd).

Table 1. Frequency of occurrence of high, medium, and low inflows to Manapouri Power Scheme for the years 1947-2006. As highlighted in bold and italic, the frequency of occurrence of a wet year during the negative IPO is about the same as the frequency of occurrence of a dry year during the positive IPO, and vice versa. (Data courtesy Meridian Energy Ltd).

Type	Inflow	All years	1947-1976	1977-2006
Wet years	>507 m^3s^{-1}	10 (1 yr in 6)	**3 (1 yr in 10)**	*7 (1 yr in 4.3)*
Typical years	367-507 m^3s^{-1}	39 (1 yr in 1.5)	20 (1 yr in 1.5)	19 (1 yr in 1.6)
Dry years	<367 m^3s^{-1}	11 (1 yr in 5.5)	*7 (1 yr in 4.3)*	**4 (1 yr in 7.5)**

The years 2000-2008 were particularly dry for all the South Island hydro lakes compared with the preceding 22 years, but not compared with earlier years. There are highly statistically significant increases (about 15%, $p<0.005$) when inflows for 1978-1999 are compared with inflows for preceding or following years. This is illustrated in Figure 7 which presents box plots of the Lake Tekapo annual mean inflows, grouped according to IPO phases. This pattern is evident in other hydro lake inflow series (e.g., Lakes Ohau, Hawea, Wanaka, Wakatipu, and Te Anau) and long rainfall series such as the Hermitage and Milford Sound. For the Lake Pukaki inflow data, this pattern is obscured by apparent faults in the data (McKerchar & Pearson 1997).

Given the level of variability in the record, it is helpful to take a probabilistic or risk management view of the effects of large-scale climate variability. In this framework, we can say that the positive IPO (and El Niño events) increase the probability of high flows in major South Island rivers, and reduce the risk of dry years. Conversely, negative IPO periods (and La Niña events) decrease the probability of high flows in major South Island rivers, and increase the risk of dry years (Table 1). In the same vein, the tendency with climate change towards stronger westerly winds, and increased rainfall in western regions, would over several decades act to increase the probability of high flows and to decrease the dry-year risk. This is especially likely in winter and spring. Increased rainfall and flows also imply increased peak flood volumes, which may pose significant problems for water management in reservoirs.

On top of the circulation effect, higher temperatures suggest that there is likely to be less precipitation falling as snow in those seasons, and more falling as rain, again implying an enhanced probability of high flows in winter and spring. Moreover, glacier melt currently contributes approximately 6-10% of hydro lake inflows to the Waitaki catchment annually (Purdie & Fitzharris 1999), and is likely to make a small contribution to other South Island hydro catchments. Future climate changes will probably enhance this proportion, giving "bonus" inflows to the hydro lakes. However, while warming associated with climate change may enhance glacier melt contributions to hydro lakes in the short term, it will eventually deprive them of this extra resource, as glaciers shrink significantly or disappear all together.

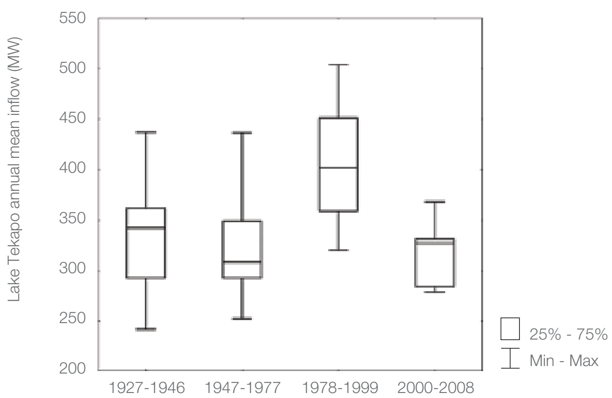

Figure 7. Annual mean inflows for Lake Tekapo as potential power and grouped according to IPO phase. The boxplots show the minimum, the 25%, 50% (median), 75%, and maximum for each phase. (data courtesy MCo).

While a greater probability of increased flows is likely over winter, the reverse situation may occur in summer. Summer precipitation and river flows/lake inflows are likely (with less certainty than in winter) to be reduced, as a result of reduced westerly circulation and as a result of reduced winter snow pack leading to reduced snow melt in spring and early summer. The net result of increased flows in winter and spring, and reductions in the summer, would likely be a flattening of the annual cycle of flows and hydro-generation capacity from the major South Island lakes (currently, annual mean flow into the Waitaki catchment is about 21 m^3s^{-1} and the amplitude of the annual cycle is about 30 m^3s^{-1}). Analogously, wind generation capacity is likely to increase in winter and spring, with a greater likelihood of stronger westerly flows over the country, while it may decrease in summer with reduced westerly circulation.

Expected changes in the westerly wind circulation over New Zealand will likely mean an increase in windiness and wind generation capacity in the least windy season (winter), and in the windiest season (spring). Summer may see only a minor increase, or little change, in wind generation. Increases in windiness could result in wind farms currently under construction producing significantly more than their forecast generation. An increased frequency of extreme winds, as outlined in the previous section, would increase the risk of wind damage to infrastructure, especially lines and pylons, and could lead to reduced wind generation as turbines cannot operate at wind speeds above about 30 m^3s^{-1}. It must also be noted that increases in the frequency and magnitude of temperature extremes are likely to be associated with decreased line ratings across some of the transmission grid to compensate for the increases in ambient warming of transmission lines and systems.

At the same time that the seasonal cycle of renewable generation capacity may flatten out, climate-related demand for electricity is also likely to see a changed seasonal cycle. At present, there is a wintertime peak in demand related to domestic heating. In future, there is likely to be more of a peak in summer as a result of reduced wintertime heating demand, and increased summertime cooling demand. Moreover, the diurnal demand curve is likely to change over time, with less night-time heating demand and more day-time cooling demand.

New generation sources to meet increasing electricity demand are planned well in to the future (the life of a hydro–generation station is in the order of 70 to 100 years). It may be that the new build programme currently underway will be partially redundant in the future, due to increases in both rainfall in the main hydro catchments and increased westerly winds resulting in increased productivity from existing plant.

The future mix of New Zealand generation sources will be highly influenced by the global carbon market, the price and supply of gas, government policies around renewable energy targets and emissions trading, and resource consent conditions. Even looking only on a least-cost basis, it is expected that a greater share of renewable projects will proceed relative to thermal projects using gas and coal. For example, at a carbon price of NZ $25/t CO_2-e (roughly equivalent to early 2009 European emission trading scheme prices), most coal projects would probably be uneconomic (Meridian Energy Ltd 2009). In addition to these influences, it could be expected that as the century progresses there will be an increase in legislation demanding renewable generation over non-renewable and carbon-producing generation as climate change affects societies at an increasing rate.

5. Future scenarios for electricity generation in New Zealand

The material in this section is based upon two future scenarios for New Zealand, labelled the "rapidly decarbonising" and "high carbon" world scenarios developed for the New Zealand Climate Change Centre conference *Climate Change Adaptation: Managing the Unavoidable*. Further information on these scenarios can be found in Reisinger et al. (2010). While the actual pathway for New Zealand is likely to be a course somewhere between these two scenarios, they provide an insight into the consequences of choices made in the near future.

5.1 Rapidly decarbonising world

Under the rapidly decarbonising world scenario, global greenhouse gas emissions have been brought under control, so as to keep global mean warming at no more than 2°C. This scenario assumes global collaboration in adaptation and mitigation, as well as more harmonised approaches to other global issues, such as trade and security, resulting in lesser impacts with some regional exceptions.

Here we further assume that New Zealand will move aggressively towards an even greater proportion of renewably generated electricity compared to the present. A likely outcome is an average of at least 90% renewable electricity supply in any given year backed up by quick-start gas-fired peaking plant. Associated greenhouse gas emissions would be significantly reduced compared to the present. For example, emissions from the New Zealand electricity sector were 3449 kt CO_2-e in 1990 and 7686 kt CO_2-e in 2008. By 2020, phase-out of the four Huntly coal-fired boilers, compensated by new renewables (mainly geothermal and wind) and gas plant, would likely reduce emissions to around 4600 kt CO_2-e.

The mix of renewables would still have a substantial fraction of hydro-generation, but would also be likely to include significant wind generation, plus solar and marine generation technologies. The transport sector would have a significant component of electric vehicles, substantially reducing emissions in that sector also. The focus would be on local action and solutions, with reduced international trade and travel. A high degree of international consensus and stability would be required to achieve this scenario.

In terms of the climate of New Zealand, the rapidly decarbonising world scenario would be likely to result in around 1°C of warming by the end of the century, with a rise in the mean snow line of about 100 m and a 20% reduction in maximum snow pack. The westerly wind circulation over the country would likely be 5-10% stronger, especially in winter and spring, associated with 10-15% more precipitation in western and alpine regions (Mullan et al. 2008). Such changes are roughly comparable in magnitude to the effects of a sign change in the IPO, or the effects of a moderate El Niño or La Niña event. Hence, natural variability in the climate system would still be a very important factor in New Zealand climate, and would strongly modulate the effects of human-induced climate changes.

The relatively mild climate changes outlined above would result in changes to the seasonal cycle of river flows and hydro-generation capacity. Similarly, there would likely be some reduction in winter heating demand, and a moderate increase in demand for cooling and energy for irrigation in summer. The biggest effect may be increases in flood volumes associated with a moister atmosphere (Mullan et al. 2008). Water storage would need to be carefully managed, given present-day infrastructure, to cope with significantly larger flood flows.

"In terms of the climate of New Zealand, the rapidly decarbonising world scenario would be likely to result in around 1°C of warming by the end of the century, with a rise in the mean snow line of about 100 m and a 20% reduction in maximum snow pack."

5.2 High carbon world

Under the high carbon world scenario, greenhouse gas emissions continue to rise much as they are doing at present, with associated rapid and large climate changes over the coming century. This scenario assumes a highly fractured world with no concerted efforts to reduce greenhouse gas emissions and with large impacts in many regions of the world. In this future, New Zealand (and the globe) would further expand the mining industry, including increased coal exports. While renewable electricity generation would probably have expanded (notably with wind power), coal-based thermal generation is likely to also have expanded rapidly.

There would still be a strong focus on global trade and export markets. However, climate changes would reduce the reliability of food production in many regions and would deliver considerable volatility in financial markets, leading to economic instability for many of our trading partners. Resource scarcity and environmental migration pressures would lead to international tension and a heightened level of political instability globally.

Climate change in New Zealand, under the high carbon world scenario, would be considerably greater than in the rapidly decarbonising world future. Mean temperature rise would be likely to be around 2.5°C by the end of the century, with a rise in the mean snow line of 200-300 m and a 30-50% reduction in snow pack. Westerly winds over the country would likely be 15-20% stronger, especially in winter and spring, associated with 30% more precipitation in western and alpine regions, and reductions of 10% or more in eastern regions (Mullan et al. 2008). Change of this magnitude in the mean climate would exceed much of the background natural variability in New Zealand climate, putting us very clearly in a new climate state. However, natural signals such as IPO changes and the ENSO cycle would still significantly modulate the local climate, but around a new warmer base state, with a stronger west-east precipitation gradient.

"Moreover, warming would be associated with increased sagging of transmission lines, implying a reduction in peak load on lines. An increased frequency of strong winds during winter and spring, combined with more intense storms, would increase the risk of damage to lines, pylons, etc."

Large climate changes such as these would result in considerable changes to the seasonal cycle of river flows and hydro-generation capacity, with Southern Alps snow storage reducing by up to one half. Winter heating demand would reduce significantly, with no frosts likely in major population centres by the end of the century. Summertime demand for cooling and irrigation would be substantially increased. Management of flood flows is likely to become more of an issue for hydro-generation, as the magnitude of warming would imply significant increases in heavy rainfalls and floods.

Moreover, warming would be associated with increased sagging of transmission lines, implying a reduction in peak load on lines. An increased frequency of strong winds during winter and spring, combined with more intense storms, would increase the risk of damage to lines, pylons, etc.

Such issues have also been clearly identified in Australia, where higher maximum temperatures, more frequent and intense storms with higher wind speeds, plus more frequent and intense lightning are the major risks for transmission and distribution systems. The Australian response to these risks is to decrease thermal ratings (for instance by decreasing the output of a transformer at extreme temperatures and by hardening transmission and distribution systems against more extreme wind events). Effects on the electricity system are likely to include decreased capacity, decreased reliability, decreased safety, and decreased quality of supply (Elder 2009).

The next step in New Zealand is to model the effects of the climate change scenarios described above on the electricity system to obtain quantitative information for planning.

6. Summary

Climate change presents the energy sector, and the renewables component especially, with significant risks, challenges and opportunities. The larger the magnitude of global and regional changes in the climate system, the greater the challenges for New Zealand. Beyond the gradually changing background climate, a major issue for the sector will be the changing seasonality of the climate for renewable generation, changing patterns of demand, and the changing risk profile of extreme weather and climate events.

Rising temperatures, combined with changes in wind circulation, precipitation, and snow storage, will result in a changing seasonality of electricity generation capacity. Generation capacity is likely to be higher in winter and spring, with increased rainfall, river flows, and windiness, while capacity is likely to be lower in summer and autumn with reduced snow melt, and generally drier, more settled and less windy summers in many key regions.

As supply changes, so too will demand. Wintertime demand for heating is likely to decrease, especially in the North Island, as temperatures rise and the risk of cold nights decreases. A combination of increased demand for cooling, and increased energy needs for irrigation, is likely to increase overall electricity demand in the summer.

An increase in the diversity and capacity for renewable generation will help to reduce energy supply risk. Significant increases in geothermal, solar, marine, and wind generation technologies would help improve the security of renewable electricity supply by reducing the country's reliance on precipitation as the raw material for generation.

With moderate climate change, present-day natural climate variability will continue to be a very significant factor in management of renewable electricity generation infrastructure. Larger changes, such as envisioned under the high carbon world scenario, would shift the base state of New Zealand's climate outside the range associated with present-day natural variability. But even in this case, natural variability would continue to play a significant role and would need to be managed for.

The challenge for the research community is to provide improved information to reduce the uncertainties around the risks and opportunities related to climate change and variability. Areas likely to yield useful results include better understanding of how different modes of natural variability (e.g., ENSO) will evolve under a changing climate and better modelling of the effects on New Zealand, and reduced uncertainty around the sensitivity of components of the climate system (notably rainfall and wind) to increased anthropogenic forcing. Moreover, planning and adaptation is likely to be enhanced through improved understanding of the vulnerability of electricity infrastructure to changing climate risks.

To be effective, information from this work must be in a form that enables those who produce, sell, transmit, distribute and consume electricity to make good decisions. Innovative solutions will be required to provide not just the quantity of energy required, but to ensure it is available in the right place at the right time to meet user needs. A key part of this process will be the availability of information to energy users so they can configure their demand to both meet their needs and to minimise costs. Combined with new technologies and management approaches, information on climate change and variability is a vital tool to help energy companies to define, deploy, and operate an effective and efficient electricity industry.

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06

Climate change, natural systems & their conservation in New Zealand

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The c. 0.9°C warming the New Zealand landmass has experienced in the course of the 20th century has resulted in very little observed biodiversity change. Sea bird populations have undergone declines in some parts of southern New Zealand, possibly influenced by altered ocean states, but otherwise changes have been subtle. The mean annual temperature warming trend has been slight since a major mid-century increase although there has been considerable temperature and precipitation variability around the trend line. This situation is unlikely to last and we should be prepared for a major, rapid increase in temperature and accompanying extreme events within the next few decades. Our focus should be on:

- coasts, where rising sea levels will squeeze native ecosystems against developed, hardened landscapes
- freshwater ecosystems where dams and water abstraction have left biodiversity vulnerable to drought and high temperatures
- alpine regions, where increased woody growth and increased pest pressure is likely to threaten a diverse, species-rich biota
- invasive weeds and pests which are likely to be increasingly advantaged by warmer, less frost-prone winters.

From a practical conservation point of view, the best response to approaching climate change is to ensure current efforts to preserve biodiversity are maintained, if not strengthened. Increased biodiversity monitoring of vulnerable ecosystems (especially alpine and freshwater), increased surveillance of warm-temperate weeds and pests, and establishment of climate stations in high altitude and remote regions would be also highly desirable.

1. Introduction

We are now more certain than ever that anthropogenic emissions of greenhouse gases will have a substantial effect on global environments (IPCC 2007a). Under the general heading of climate change we can include not only warming and precipitation change, but also other factors such as CO_2 increase, sea level rise, and massive retreats of snow and ice extent. These will collectively and individually impact biodiversity[1]. Many factors (historical contingency, soil structure and nutrients, presence or absence of competitors or predators, etc) influence biotic distributions and abundances, but climate is fundamental. There is no doubt whatsoever that as climates change in the near future, natural ecosystems and their biodiversity will respond. However, what form that response will take is less clear. We need to answer four fundamental questions.

1) How does climate affect biodiversity and are these effects predictable?
2) How do atmospheric CO_2 concentrations affect biodiversity?
3) Is anthropogenic warming affecting New Zealand's biodiversity, and is it likely to do so in the future?
4) If there is a high probability that biodiversity will alter in response to climate change, how should we respond?

Here we attempt to answer these questions.

2. How does climate affect biodiversity and are these effects predictable?

Climate, in combination with the physical substrate, be it soil or water, controls the growth, productivity and survival of individual organisms. While it is convenient to express climate as seasonal or annual means, short-duration events affect biodiversity and ecosystem function as much as long-term trends. A few hours of below freezing temperatures once every few years may be enough to eliminate some species from a region. Timing of extreme events can be critical: a severe frost or snow storm in the middle of winter has a lesser effect than a similar event in spring. Drought in late summer when plants have largely completed growth does not have the devastating impact of late winter/early spring drought that prevents achievement of full productive potential.

Despite this undoubted complexity in climate-biodiversity relationships, there is regular, easily observed patterning to biodiversity across landscapes and regions. The overall number of terrestrial species in a region declines with decreasing mean annual temperatures and water availability, and simple models incorporating these two factors alone can predict the number of species of vascular plants, birds and mammals in a given region with a fair degree of skill and reproduce individual distributions (Qian 2009). The biodiversity-temperature relationship in particular is very strong across most groups of organisms, probably because cold temperatures impose stresses that few species historically have been able to overcome. Many plant and animal groups are less speciose and less genetically diverse in the cooler, poleward part of their range, but New Zealand provides many exceptions in that it has a rich and often unique alpine biota and some groups (for instance birds) show no strong temperature-related trend (Robertson et al. 2007). Wetter climates have higher overall biodiversity and globally this is also a strong correlation – especially for plants. New Zealand has a limited extent of dry climates and many of the wet climates are in mountainous areas and thus also cool, and the correlation can be expected to be somewhat less. In general, lack of moisture stress in New Zealand encourages greater species richness (e.g., trees, Leathwick et al. (1998), snails, Overton et al. (2009)).

Wetter, warmer climates boost productivity, all things being equal, and net ecosystem productivity is closely correlated with species richness at a regional scale (Field et al. 2009). Hence a proxy for available energy such as potential evapotranspiration provides a good first-order predictor of biodiversity. We have to be somewhat cautious in applying these general correlations because of the influence of other factors such as soil nutrients. For instance, the common assumption of high net productivity in the tropics versus lower net productivity in temperate zones is almost certainly incorrect because of the neglect of soil fertility as a driver (Huston & Wolverton 2009). Nevertheless, because of these strong first-order relationships, correlational or niche-based models have had some success in reproducing broad-scale biodiversity patterns.

Whether correlational models are robust enough to predict biodiversity under an altered climate regime is debated, although they are widely used for just that purpose. In New Zealand, forest types and distributions of major trees have been modelled for the country and projections made for future patterns under a warmer climate (Leathwick 2001, Leathwick et al. 1996). Combination of these correlational biodiversity-climate models with the well established observation that numbers of species present in a given patch of habitat decline as it is reduced, have been used to make highly influential predictions for loss of biodiversity as a result of future global climate change (e.g., Thomas et al. 2004).These predictions have met with widespread criticism (for instance, see Lewis 2006) and theoretical (Beale et al. 2008) and empirical tests of the correlational models on which they are based (see Duncan et al. 2009) have demonstrated that they may have little predictive (as distinct from descriptive) skill when confounding factors such as diseases, competitors, dispersal and historical limitations are unaccounted for. Process-based models for predicting biodiversity, which incorporate theoretical and mechanistic understanding, should be more robust (Sitch et al. 2008). However, unless they are based on excellent theory, experimentation, careful parameterisation and testing as well as incorporation of missing biological factors, they are unlikely to be much better. The information demands of process models are such that it is unlikely that they will be developed for any but the most widespread, dominant or critical elements of any biota (for instance, major tree species in New Zealand, Hall & McGlone (2006), Waring et al. (2008)).

Ecosystems contain extremely large numbers of species, all of which potentially may interact. It is the myriad of interactions between individuals that eventually determines the abundance of species, composition of their communities and ecosystem function. Moreover, plant responses to diseases, herbivores, mutualists and other species may have important community level effects that cannot be discerned from plot-scale global change experiments. Even at a functional level, where groups of species that perform similar ecosystem roles are combined for analysis, the complexity of the

[1] "Biodiversity" is often defined as the variety of all forms of life, from genes to species, through to ecosystems, although there are many variations on this simple definition. Here we use the term in this broad sense.

interactions defies any simple conclusions regarding global change (Tylianakis et al. 2008).

Future climate predictions tend to be most robust for broad multi-annual trends and major components (mean annual temperatures, precipitation for instance), less reliable for extremes (frost, drought frequency, cyclonic storms) and even less reliable for inter-annual variations (ENSO, Pacific Decadal Oscillation, etc). We therefore have poor projections for future climatic variation around long-term means that could be as ecologically significant as the means themselves. For the foreseeable future our ability to predict with any certainty the biodiversity or ecosystem effects of a given climate change will therefore be weak. Nevertheless, it would be a mistake to wait for a better quantitative understanding before deciding what must be done. Historic records, past and current observations, existing models, and our general understanding of the biology of the biota are sufficient to provide interim guidance.

The most common predictions for temperate regions are as follows (Parmesan 2006).

- *Range & altitude change:* Many species will find, under a warming regime, suitable habitats opening up further south beyond their current geographic or altitudinal range, and that some species that are unable to migrate will find their current range increasingly unsuitable.
- *Species interactions altered:* Local abundance fluctuations and changing range limits will bring new combinations of organisms and new interactions with implications for both species and ecosystems, including diseases.
- *Trophic interactions altered:* Plant productivity, below ground processes (decomposers, mycorhyzial associations), predator-prey interactions, etc, are changed by climate and increasing CO_2 levels.
- *Exotic organisms advantaged:* Warm temperate and subtropical areas of the globe typically have many times the number of species in most groups than temperate-oceanic or cool temperate regions such as New Zealand (for ants see: Dunn et al. (2009), for plants see: Weiser et al. (2007)). Regardless of how these patterns arose, there are more organisms adapted to warm rather than cool climates and this fact alone suggests increasing invasive pressure under a warming world scenario.

3. How do increasing atmospheric CO_2 concentrations affect biodiversity?

Of all the predictions made for the near future, the most secure is that atmospheric CO_2 concentrations will continue to increase, perhaps by as much as 730 to 1020 ppm by 2100 (Meehl et al. 2007). Rapidly increasing atmospheric concentration of CO_2, may thus potentially affect plant production and palatability. CO_2 is the key plant nutrient, and experimental studies have shown that plant growth is positively affected by increasing ambient CO_2 concentrations under non-limiting soil nutrient supply, and that water use will diminish in some species (but not, for example, conifers) as the stomata do not have to remain open as long (Lambers et al. 2008). Elevated CO_2 changes the composition of live tissue, commonly increasing carbohydrates and decreasing proteins. Herbivorous insects may alter behaviour in response to this change in tissue composition, e.g., by consuming more or less, or by generalists switching to different species. However, Beier (2004) stresses how limited current understanding is:

> "Increased CO_2 availability does not necessarily result in increased growth: availability of other nutrients, nitrogen, phosphorus in particular, the soil type and status, and space for growth are more likely to be limiting."

"The effects of CO_2 alone and to a lesser extent warming alone each show some general and consistent patterns, but the few examples of combinations point in all directions and results are not predictable based on the individual effects. The complexity and unpredictability becomes even worse when we realise that important effects may be driven by changes in off-season processes, seasonality and extreme events." (p. 244)

Dukes (2007) points out that the predictive power for natural settings of CO_2 experiments based on isolated plants is essentially zero. Korner (2003) has reviewed current understanding of plant and ecosystem response to elevated CO_2.

His conclusions are:

- plant species respond differently to CO_2 enrichment (irrespective of the type of response involved) and these translate into ecosystem responses
- plant responses depend on soil type, nutrition, light, water and age
- the quality of plant tissue (more carbon, less of other elements) and the amount of exudates from roots change, so plant consumers are affected
- responses to CO_2 concentration are nonlinear, with the strongest relative effects under way right now, and few additional effects beyond c. 550 ppm.

Little experimental work has been done on indigenous New Zealand plants and elevated CO_2 (Ross et al. 2006) and none in natural settings. We therefore have to rely on generalised findings that suggest that in typical nutrient and/or climatically constrained communities, the direct effects of CO_2 fertilisation will be minor and, at this point, unpredictable. Increased CO_2 availability does not necessarily result in increased growth: availability of other nutrients, nitrogen, phosphorus in particular, the soil type and status, and space for growth are more likely to be limiting. The effects on plant herbivore guilds will be even less predictable as the number of species involved is large and the effects recorded in experiments have been both positive and negative depending on specific plants and insects involved. Given this, we will not further consider the role of increasing CO_2 as an independent driver.

4. Is current greenhouse warming affecting New Zealand's biodiversity

Recent (since 1860 AD) changes in New Zealand climate are summarised on a NIWA web page (Wratt et al. 2008) and in a manual for the guidance of local authorities (Mullan et al. 2008). It is clear New Zealand is already experiencing significant climate changes. These include:

- increasing temperatures over land and sea
- 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).

Mean temperatures have warmed strongly since 1900 (+ 0.92°C from 1908 to 2007), minimum temperatures increasing at nearly twice the rate of maximum temperatures (0.4°C versus 0.1°C per decade respectively 1951-1998 Salinger & Griffiths (2001)) (see Figure 1). About 0.7°C of the long-term trend is accounted for by a sustained warming in annual temperatures between 1945 and 1956. Very little change in mean temperatures (0.06°C/decade) has occurred since 1970 although frost frequency has decreased in some areas (Salinger & Griffiths 2001). Over the last 100 years, the most significant and consistent climate trend is towards warmer, less frosty winters. Major oceanic and precipitation variations have been recorded over the past 40 or so years, but they are connected with the Southern Oscillation Index (SOI) and the Interdecadal Pacific Oscillation (IPO) (Mullan et al. 2008) and demonstrate no clear overall trend. Westerly circulation has increased over the past 40 years and the interaction of this factor with New Zealand's rugged topography has affected cloudiness and diurnal temperature ranges. Diurnal temperature range and sunshine has decreased (-0.6%/decade). Cloud cover has also decreased. Precipitation changes have been complex and regionalised. Rainfall has decreased in the north of the North Island and increased over much of the South Island, except in the east. Winter rainfall has increased in all parts of New Zealand except the southeast. Western sites have shown a trend toward more daily rainfall extremes, but eastern sites a decrease. Pan evaporation declined at 2 mm yr^{-1} from the 1970s on (Roderick et al. 2007), an effect believed to be mainly due to decreasing wind speeds or increasing cloudiness (Roderick & Farquhar 2005). Rainfall has been responsive to major circulation indices El Niño-Southern Oscillation (ENSO), IPO and Southern Annular Mode (SAM). All of these indices interact, and we have only a limited understanding as to what may happen to them in the future. Net primary marine production in the New Zealand region is close to the global average and has not changed markedly in the recent past (Willis et al. 2007).

From a biological perspective, long-term trends and even annual means are only part of the story. Day-to-day weather and seasonal variability is as important. To give an example: from a plant productivity point of view, extra warmth during winter will lead to increased respiratory costs but no extra growth, and therefore no net increase if summer temperatures do not change. Likewise, poor weather conditions during critical seasonal life history phases will markedly affect a species' population growth. As an example we present the temperature trends on subantarctic Campbell Island over the last 68 years (Figure 2). A net warming trend since 1941 of c. 0.4°C has been insufficient to change tree line on the island (Bestic et al. 2005). If the seasonal trend of the cooler years before 1966 is compared to those of the years since, the year-to-year variability clearly shows why. Similar results obtain for mainland sites.

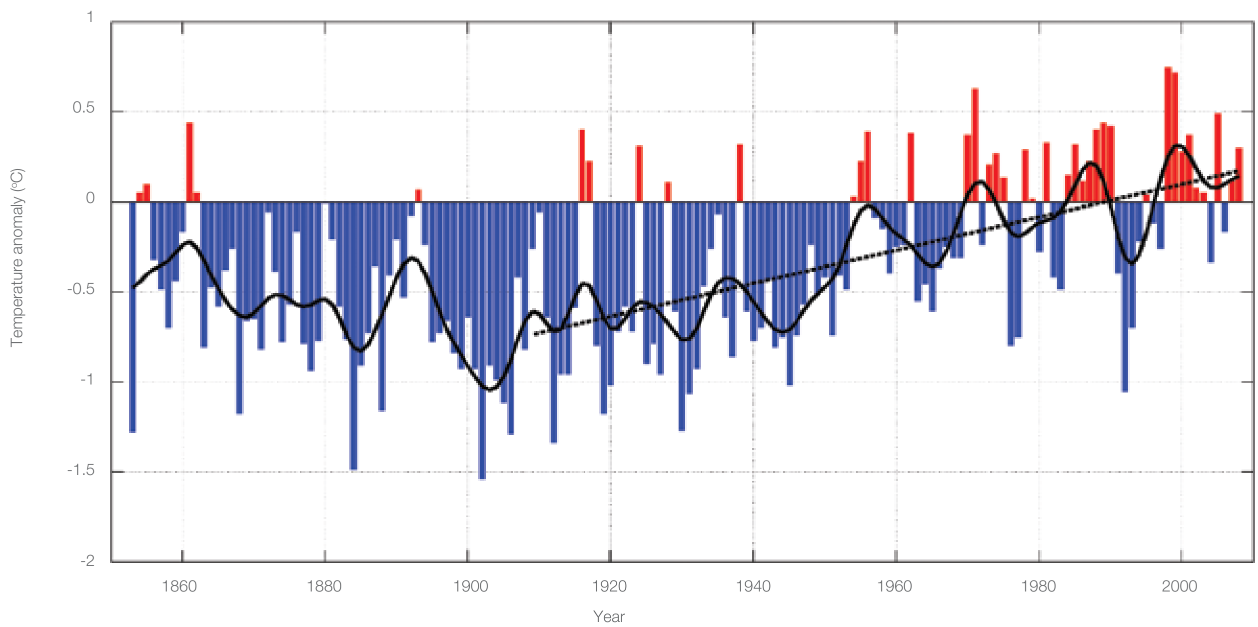

Figure 1. New Zealand mean annual temperatures, 1857-2008.
(Source: James Renwick, NIWA Wellington, pers. comm. 2009).

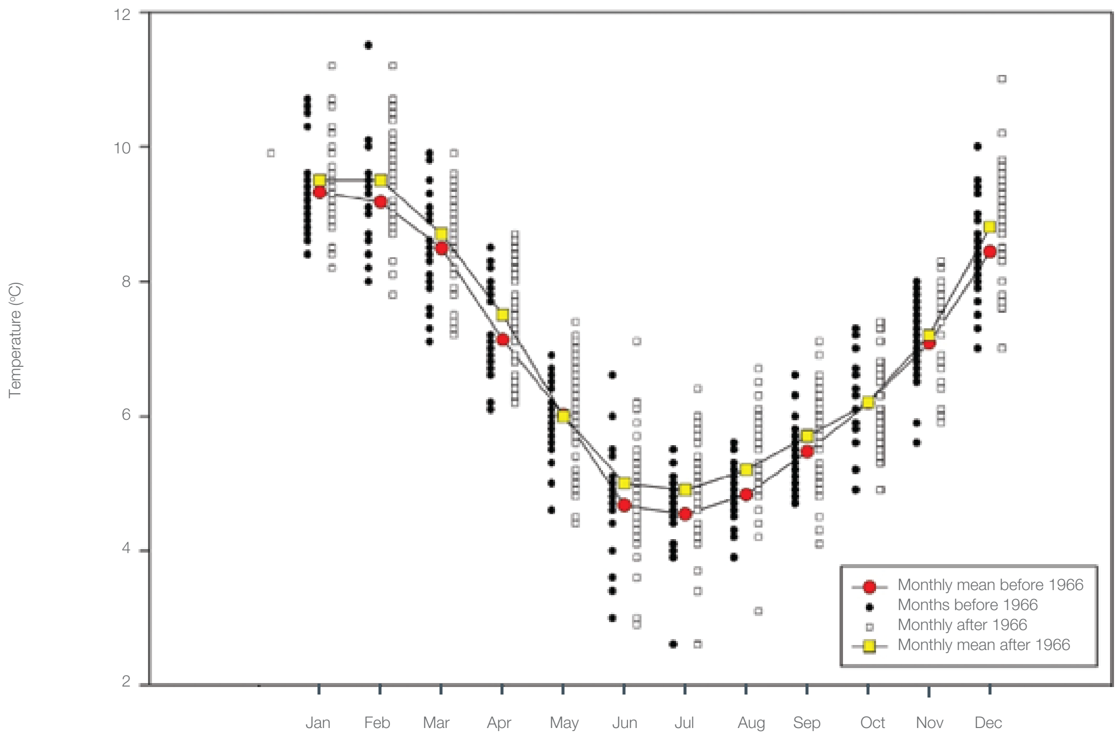

Figure 2. Campbell Island 1941-2009. Mean monthly temperatures before and after 1966. (Source: James Barringer, Landcare Research Lincoln, pers. comm. 2009).

A major issue therefore in assessing biological responses to climate change in New Zealand is that little net warming change has happened over the last 55 years (that is since the decade 1945-1955) while there have been major changes in the SOI and IPO. There are very few continuous records of biodiversity change in New Zealand and nearly all post-date 1955. Climate trends over this period have been almost flat (c. 0.2°C) and very noisy. While short periods of flat or slightly cooling trends have not been uncommon globally (Easterling & Wehner 2009), the long period of little warming in the mid-latitude Southern Ocean is anomalous (IPCC 2007a). This has to be taken into consideration when comparing the New Zealand experience with that of many areas of the northern hemisphere where there has been a rapid rise in temperatures since the mid 1970s (Jones et al. 2009) and an abundance of biological observations (Parmesan 2006).

Climate warming, especially if it is associated with increased cloudiness or overall precipitation increases (which could buffer the system), will lead to decreased cold-related phenomena – such as low altitude snow fall, frost, freeze-thaw cycles and out-of-season frosts. In turn, these should have marked effects on temperature-related phenological responses (Visser & Both 2005) and in turn could strongly affect ecosystem function. Likewise, alteration in drought and flood frequency could potentially impact biodiversity.

In Table 1 we present published evidence on biodiversity changes in New Zealand over the last 100 years where it has been suggested that recent climate change may be responsible. There are two striking features of this list. First is the complete absence of invertebrate records and dominance by oceanic birds. The second is that only one record (rockhopper penguins) extends back beyond 1945. We therefore have virtually no biodiversity records that would enable us to say with any confidence that the 0.7°C warming between the mid 1940s and mid 1950s affected New Zealand biodiversity in any significant way.

> “From a biological perspective, long-term trends and even annual means are only part of the story. Day-to-day weather and seasonal variability is as important.”

Table 1. Recent, climate-related biodiversity changes.

Taxa	Observed changes	References
Mammals	Long-tailed bats (*Chalinolobus tuberculatus*) declining possibly due to warm winter effects	Pryde et al. 2005
Mammals	Rabbits (*Oryctolagus cuniculus*) established above treeline on Ruapheu as a result of reduced snow cover	Flux 2001
Birds	Earlier (by 30 days) egg laying in welcome swallow (*Hiroundo tahitica*) between 1962 and 1995	Evans et al. 2003
Birds	Population decline in red-billed gull (*Larus novaehollandiae scopulinus*) linked to changes in circulation indices (PDO and ENSO) between 1983 and 2003	Mills et al. 2008
Birds	Decline in sooty shearwater (*Puffinus griseus*) populations throughout Pacific due to warming oceans and loss of productivity	Shaffer et al. 2006, Lyver et al. 1999
Birds	Declines in yellow-eyed penguins (*Megadyptes antipodes*) since 1980 linked to long-term climate-related trend towards lower ocean productivity	Peacock et al. 2000
Birds	Decline in rockhopper penguins (*Eudyptes chrysocome*) by 94% since early 1940s linked to rising ocean temperatures between 1945 and 1956	Cunningham & Moors 1994
Fish	Decline in recruitment of *Anguilla* spp and several weeks advance of main migration over last 30+ years possibly linked with changing thermal fronts in spawning grounds	Jellyman et al. 2009
Reptiles	Tuatara sex ratios increasingly male with increasing temperature	Mitchell et al. 2008
Plants	Seed production increased in mountain beech (*Nothofagus cliffortioides*) along elevation gradient related to warming during flower initiation (1973-2002)	Richardson et al. 2005

The changes in sea bird numbers appear to be due to large fluctuations in marine productivity rather than to climate directly (Shaffer et al. 2006). Marine productivity is closely linked with strong upwelling and thus is affected by shifting wind fields reflecting fluctuations of major indices such as SOI and IPO (Mills et al. 2008). There is currently no consensus on what might happen to these indices other than they will continue to vary (IPCC 2007a) and thus provide no basis for extrapolating these sea bird fluctuations into the future. Furthermore, longline fishing can adversely affect populations of long-lived birds.

One of the best studied climate-plant interactions has come about because of the long records of seed fall (17 species at 34 sites) that have been collected since the mid 1960s (Schauber et al. 2002). Synchronous episodic seedfall (or masting) has increased in some species but appears to be mainly affected by the La Niña phase of the SOI in nearly all cases and thus not directly connected to climatic warming per se (Schauber et al. 2002). A detailed study of tree line mountain beech showed a trend towards higher seed production between 1973 and 2002, and that high seed years were primarily driven by late summer-autumn (flower primordium development period) warming in the year before (Richardson et al. 2005). As there was no net trend in annual or seasonal warming over these years, it is possible that it also was driven primarily by interannual variability.

Tree lines are an interesting case by virtue of the fact that trees can be easily aged and are long-lived, and thus we potentially have a long record of change. Tree lines represent the altitudinal limit to forest, that is a continuous canopy of woody plants 3 or more m in height. In New Zealand, tree lines coincide with the tree species limit and are typically abrupt (Wardle 2008). Tree lines are a temperature-controlled phenomenon, and their position tends to coincide with a mean average growing season temperature of c. 7°C globally, but in New Zealand are at least 200 m lower or 1-2°C warmer (Korner & Paulsen 2004). It thus could be expected that tree lines would have increased in altitude in New Zealand by at least 100 m (using 0.6oC per 100 m as a rough guide) given that more than 50 years have elapsed since a major warming of about that magnitude. However, intensive investigation of numerous sites suggests that current tree lines have been in approximately the same position for several hundred years and the response to warming in the 20th century has been less than 10 m altitudinal advance of saplings, if that (Wardle & Coleman 1992, Cullen et al. 2001, Wardle et al. 2005). Wardle et al. (2005), after considering non-climatic explanations for the small altitudinal extension of tree line, attributed it either to a lag, in which environmental hurdles such as winter frosts or lack of mycorrhizal infection prevented seedling establishment, or to the current tree line having established during a warmer-than-19th century interval some centuries ago and having persisted until the current 20th century warming. A global survey of tree lines showed that only half are advancing (although none appear to be retreating) and offered as one explanation that infrequent outbreaks of cold weather causing mortality in young plants, especially in winter, may

> "We therefore conclude that there are no records of biodiversity change during the last century in New Zealand that can be attributed with any degree of certainty to global warming as distinct from climate variability."

prevent many tree lines showing altitudinal advances despite an overall warming trend (Holtmeier & Broll 2005, Harsch et al. 2009). However, it may not be necessary to resort to these types of explanations. The Campbell Island climate data show how little temperature change has occurred at this tree line site and how interannual variability completely swamps the trend (Figure 2).

We therefore conclude that there are no records of biodiversity change during the last century in New Zealand that can be attributed with any degree of certainty to global warming as distinct from climate variability. The lack of systematic biodiversity records for New Zealand, extending back further than the mid 1960s, is one reason for this lack of observed change. As important is that the mean change over the years we do have records is too slight, and the interannual variability too great, to lead to observable biodiversity trends.

5. How will climate change affect New Zealand biodiversity in the near future?

5.1 What climate changes are predicted?

The theory of how greenhouse gas fluctuations drive climate change is now firmly established. Past and present changes in climate have been shown to link to greenhouse gas fluctuations and modellers are now more confident of their predictions (IPCC 2007b). Therefore, while there has been little significant change in climate over the last 50+ years in New Zealand (and generally across southern latitudes from 45°S to 60°S) there is every reason to expect that New Zealand will experience significant warming over the next 50 or more years. Mullan et al. (2008) have produced a detailed account of the consensus view of climate change over the next 80 years based on 12 global climate models and a finer scale regional climate model for additional information. Their key points are these.

- Best estimate increase of mean temperatures by 1°C by 2040 and 2°C by 2090. Projections range from 0.2-2.0°C by 2040 and 0.7-5.1°C.
- Decreased frost risk, increased frequency of high temperatures, increased frequency of extreme daily rainfalls, decreased seasonal snow cover.
- Temperature rise will accelerate. Rate of increase projected to be higher than a linear trend from historical 20th century record.
- Westerlies increase in winter and spring, and possibly an increase in stronger winds, along with more rainfall in the west and drier conditions in the north.
- Decrease of westerlies in summer and autumn, with drier conditions in the west of the North Island and possible increased rainfall in Gisborne-Hawke's Bay.
- The frequency of severe droughts is expected to increase across many eastern parts of New Zealand by 2080, such as inland and north Otago, eastern Canterbury and Marlborough, parts of Wairarapa, Hawke's Bay, the Bay of Plenty, the Coromandel and Northland. For example, in a 'low-medium' scenario, Marlborough could experience a one-in-20-year drought event every three to five years by 2080.
- Droughts may happen in spring and autumn, not just summer.
- Temperatures are expected to increase, with greater increases in the winter, and in the north of New Zealand.

They further comment:

"…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." (p. xii)

In the past 100 years there has been a great deal of year-to-year variability, and extremely warm years (0.5°C above the 1971-2000 average) have occurred only in ones or twos and, even since the early 1970s, there have been similar brief clusters of cold years. A 550 year record of growing season temperatures in New Zealand based on tree-ring analyses has shown that this region has at times warmed and cooled out of phase with the northern hemisphere (Duncan et al. in press). These fluctuations are likely to be driven by interactions between the major ocean indices (Interdecadal Pacific and Atlantic Multidecadal Oscillations). It therefore seems likely that New Zealand will experience another of these abrupt fluctuations within the next 20 years and, if it is of the magnitude experienced between 1945 and 1977 for the IPO, it should be of biological significance.

Sea level has been rising at a rate of 1.7 mm per year over the last 100 years and is predicted to accelerate. Best estimates predict sea level rise of 18 to 59 cm by 2090-2099 relative to 1980-1999 (Hume & Blackett 2007). Much less is known about how future changes may affect oceans around New Zealand. (Willis et al. 2007) make the following predictions.

- Waves: increase in frequency of heavy seas and swells along western and southern coasts
- Storm surges: heights and extreme storm-tide levels may increase
- Various changes plausible, but little research done. Antarctic Circumpolar Current likely to accelerate and increase flow of cool water to Chatham Rise. Increased upwelling of cooler subsurface waters along the coast.

Predicted changes in the New Zealand region are for warmer conditions (there has already been an increase of 0.6°C in the upper 700 m since 1950), an increase in westerly winds in winter/spring, and a strengthening of northeasterly winds in summer. More "La Niña'-like conditions are likely to prevail (Willis et al. 2007), although what will happen long-term to important ocean-atmosphere indices such as the Southern Annular Mode (SAM), El Niño-Southern Oscillation (ENSO) or the Pacific Decadal Oscillation (PDO) is unclear.

5.2 How might biodiversity react?

New Zealand has an extremely oceanic and variable climate regime in a high solar radiation mid-latitude setting. This has two consequences. First, because of the regular progression of cyclones across the country, New Zealand rarely experiences the prolonged hot or cold spells that regularly occur in continental temperature areas; and second, the ocean buffers the extremes. It seems possible, although it has not been demonstrated, that the New Zealand biota is pre-adapted to climate change because temperature and rainfall vary so much in any given season. The essential predictability of the tropics and subtropics, with their small fluctuations in temperature throughout the year, and large but highly seasonal changes in rainfall, could actually induce a greater sensitivity to climate fluctuations than in species from the temperate zone. Recent work (Deutsch et al. 2008) has suggested that temperate ectotherms (animals aside from birds and mammals) may be far less sensitive to increasing temperatures than tropical animals because their temperature optima and thermal maxima are much higher than their current ambient temperature range. Nevertheless, we cannot assume that because so little biodiversity change has been observed in response to the 0.9°C rise in temperature since the early 1900s that there will an equally muted response to a similar increase over the next 30 years, especially if, as seems likely, there is an abrupt shift to warmer conditions.

Below we outline the major areas where we feel New Zealand biodiversity may be at risk, in particular with regard to loss of species or through extreme reduction of indigenous habitat. Coastal and alpine ecosystems are potentially threatened because they sit on clear ecological boundaries which warming climates are certain to move. Coastal and aquatic ecosystems are at risk because of overuse and development rendering even small changes in climate significant risks. Weeds and pests are already major biodiversity stressors and are highly likely to be even more difficult to manage under warming climates.

5.2.1 *Coastal ecosystems*

Climate change is likely to affect sea and shore birds through alteration of the sea conditions altering the abundance of marine food or their ability to access it but, as discussed above, this depends critically on the unknown factor of how major ocean-atmosphere indices might respond. We have little basis therefore for making predictions. Leaving this aside, sea level rise will be the most important consequence of global climate change for coastal ecosystems. Soft shores are likely to be more severely affected by sea level rise than hard shores because of greater erosion risk and the typically greater extent of low-lying land adjacent to them. Dune systems, estuaries, and a range of saline, brackish (mixed saline and fresh) and freshwater lagoons, shallow lakes and marshes will be most affected. Changes in estuaries will affect mangroves, saltmarshes, and seagrass meadows, while in shallow lakes and marshes the changes will impact various macrophyte assemblages (of emergent, submergent or floating aquatic plants). These coastal ecosystems are highly productive, and are also exceptionally important breeding, resting and feeding sites for indigenous marine mammals, fish and birds (Burns et al. 1990, Turner & Schwarz 2006). Several New Zealand sites are also important habitats for migratory birds and of international ornithological significance (e.g., Miranda and Kaipara harbours).

Where coastlines are in a more or less undeveloped state, soft shore coastal ecosystems are likely to adjust naturally to rapid sea level rise, albeit with some spatial reconfiguration. New areas of estuary and marshland habitat will generally replace that inundated. However, this is unlikely to occur along most New Zealand soft shorelines. Development on land close to sand-dunes, marshes and estuaries means it is unlikely that people will readily allow new areas of dunes, marshland or estuary to form behind those now present. The most probable response to sea level rise will be to protect assets and infrastructure by erecting new hard barriers to prevent erosion, planting sand dunes to stabilise them, and infilling encroaching wetlands and installing new drainage. This scenario (often termed 'coastal squeeze' in the international literature, for instance, Schleupner (2008)) means that rising sea levels will probably remove large areas of the rich biological habitat.

Estuarine systems and coastal brackish lakes and marshes are already under severe and increasing stress from human activities because their catchments are a focus for human settlement and the ultimate repository of the sediment created by land uses in the waterways that feed them. Sedimentation, eutrophication and pollution by waste resulting from human activities and development are important current drivers of biotic depletion. Mangrove (*Avicennia marina var australasica*) has been expanding seawards in New Zealand as a result of increased sediment influx largely driven by intensification of human activities in the coastal zone (Harty 2009). Coastal dune systems have been widely stabilised by exotic species and developed for agriculture, forestry and settlement. Sea level rise and coastal squeeze will compound these effects. Loss of productive estuarine habitats and biota is likely to accelerate, with the more visible ecological effects being reduced populations and altered migratory patterns of coastal birds, and declines in certain marine fishes. Economic impacts of current estuarine quality decline will also be accentuated (e.g., through depletion of commercial and recreational fishery stocks such as snapper, whitebait and some shellfish).

General warming and extreme warm events will also affect coastal ecosystems, and estuaries in particular. Warming could extend the potential range of mangroves, thus adding to an already controversial enlargement of its distribution (Harty 2009), but threaten biologically important *Zostera* seagrass meadow habitats, which are possibly sensitive to low salinities at high temperatures (Burns et al. 1990).

5.2.2 *Alpine ecosystems*

Globally, arctic-alpine communities are at risk through increasing shrubby growth and loss of herbaceous taxa (Wilson & Nilsson 2009). The New Zealand alpine zone is extensive, species-rich and has many range-limited and endemic plants and animals. Many alpine clades have radiated extensively in the alpine zone (e.g., *Ranunuclus*, stoneflies). New Zealand has many unusual alpine organisms including a mountain parrot, the kea, high altitude skinks, cicadas, and flatworms that occur in alpine zones with 3 month snow cover (Johns 1998). Not all organisms found in the alpine zone belong to obligate alpine species. For instance, about 40% of the plant species regularly occurring in the alpine zone are also found below treeline, and a significant number occupy similar open habitats at sea level (Mark & Adams 1995).

The alpine zone environment is complex. Bare rocky sites, bogs and scree slopes exist in close juxtaposition to forest, tall shrubland, closed grassland and herbfields. Snow cover is highly variable from site to site, in the course of a year and between years. Many plants and animals are either adapted to snow cover or strongly affected by it. In turn, snow cover interacts with the temperature regime to control freeze-thaw cycles, avalanches and snow melt freshets. Warming that results in a loss of alpine environment could result in serious loss of indigenous biodiversity, particularly if it eliminates isolated patches of alpine terrain or opens it up to easier access or increase by invasive species (Halloy & Mark 2003).

As we have seen, tree line has not advanced in New Zealand despite warming over the last century of more than 0.9°C or the equivalent of a 150 m rise. However, the retreat of glaciers over that time has been consistent with a 0.6°C rise in mean annual temperature (Chinn 1996, Hoelzle et al. 2007) although with considerable fluctuation around the trend (Chinn 1995). Snow accumulation is highly variable, with far less during positive ENSO phases (McKerchar et al. 1996). There has been little seasonal trend in snow storage since 1930 (Fitzharris & Garr 1994, 1996), but recent surveys have indicated that the end of summer snowline is 130 m higher than the position needed to maintain glacier ice mass, which has shrunk 50% over the last century[2] and is now the lowest on record. End of summer snowline is a composite of winter snow accumulation and summer ablation and therefore not a simple metric. Ablation is approximately twice as significant as accumulation in determining snowline. Moreover, the complex interaction of atmospheric pressure, prevailing wind flow, and temperature that controls snow fall means that winter snow distribution over much of the alpine zone may not necessarily be related strongly to the glacier line. It is therefore possible that, aside from annual temperature, the snow and frost aspects of alpine environment that are crucial to many alpine organisms may have changed little.

The true cold-specialised alpine species tend to occur in the higher, more extensive alpine areas where, even with considerable warming, open habitat is likely to remain. In contrast, many restricted alpine endemics tend to be found in isolated upland sites and, while potentially threatened by increased woody growth, often are confined to certain habitats such as bogs, shingle slides, bluffs and outcrops, which may persist even under an upward moving tree or shrub line. Vegetation change is slow in montane grasslands (Lee et al. 2000, Lloyd et al. 2003) and in high alpine cushion communities (Mark & Wilson 2005). Therefore it is by no means clear that warming has directly affected the distribution of alpine plants or that continued warming necessarily must.

Little work has been done on alpine animals from this point of view, and the few examples studied suggest their ecology is complex (Sinclair et al. 2001). A study of alpine grasshoppers (White & Sedcole 1991) demonstrates how complex the effect of warming can be on organisms with variable-length lifecycles, and different morphological stages. Their conclusion was that warming would lead to grasshopper populations shrinking and being displaced to higher altitudes and marginal habitats. A study of microhabitats of an alpine cockroach has shown that decreased snow cover led to increased thaw-freeze cycles in the alpine zone and thus, paradoxically, warmer winters with less snow resulted in a much more stressful climate (Sinclair 1997, 2001).

Overall, there is no basis for simplistic assumptions about the results of warming on alpine organisms, and counter-intuitive outcomes are possible (Bannister et al. 2005, Sinclair & Byrom 2006).

5.2.3 *Freshwater ecosystems*

New Zealand freshwater ecosystems are relatively simple. There are just 39 currently recognised indigenous species of fish (although the number is likely to increase) and 16 exotic species (McDowall 2010). None of the freshwater invertebrate groups are particularly rich in species (Winterbourn 1987). Food chains are generally short. In the case of freshwater systems, little is known as to the temperature tolerances of aquatic invertebrates (but see Quinn et al. 1994), and there are few data on fishes (McDowall 1992). The freshwater fish fauna is split between diadromous species (those that move between the sea and freshwater, 18 species) and non-diadromous species, that are more strictly confined to freshwater habitat. Diadromous species are found from north to south and at high and low elevations and appear to be highly flexible in habitat; non-diadromous species are much less resilient to habitat change and more likely to be localised, and thus vulnerable (McDowall 2010). A considerable amount of New Zealand invertebrate diversity is found in flowing water systems (rivers, streams, springs and seepages) and these can be key in retaining diversity during dry spells (Maxted et al. 2005, Collier & Smith 2006, Barquin & Scarsbrook 2008).

Many species in the indigenous freshwater fish fauna may be little affected by temperature change. New Zealand field records show that only two species of native freshwater fish have a significant relationship between density and water temperature, and native species are able to thrive within a wide temperature range (Richardson et al. 1994). Leathwick et al. (2005) found that January air temperature, upstream average temperature and rain days, river flow, and riparian shade were all significant factors in a predictive model for indigenous diadromous fish. A subset of the fish and invertebrate fauna are adapted to cool waters (peak temperatures below 16-18°C). These may be particularly affected. Quinn & Hickey (1990) noted stoneflies had restricted distributions compared with mayflies in streams, and Quinn et al. (1994) experimentally showed that a representative stonefly of cool waters was unable to acclimate to higher temperatures. For example, with the warming of alpine streams as glaciers vanish, alpine mayflies (*Deleatidium* spp) are likely to suffer reduced ranges and local extinction (Winterbourn et al. 2008). Other freshwater organisms may be affected strongly if average highs exceed this range, as is likely in streams that have lost tall shading vegetation along their banks, and if water flows drop through drier conditions and greater abstraction of water for agriculture (Quinn et al. 2009). Collier & Smith (2000) have shown that lethal water temperatures for stoneflies occur much more commonly in streams flowing through pasture rather than forested landscapes. Eels (*Anguilla* spp) are almost completly inhibited from migrating up rivers where the temperature exceeds 22°C (August & Hicks 2008).

New Zealand's lowland and eastern freshwater ecosystems are already under considerable pressure from abstraction and pollution. Drought combined with low water in rivers poses major risks to aquatic life. In agricultural and pastoral catchments lack of dilution and flushing results in higher loadings of nitrogen and phosphorus and increase of bacterial contamination (Caruso 2001). Fish kills occur with stranding of populations from the main flow with no deep pool refuges. Adverse effects from drought and high temperatures (over 25°C) can be widespread in some districts and locations but recovery is usually rapid (Caruso 2001). The indigenous fish community in New Zealand gravel-bed rivers appear to be resilient to both flood and droughts as long as refuges are available during low flows (Jowett et al. 2005, Davey

[2] http://www.niwa.co.nz/our-science/climate/news/all/2008-09-15 (accessed 21 December 2009)

et al. 2006). Many of the generalised impacts suggested for flowing water systems apply to lakes: pollution, abstraction of water, drought lowering of water levels, and increase in water temperature (Meyer et al. 1999). Heating of the upper lake water layers has a large potential to create biotic change because of increased lake stratification and warmer temperatures in the upper few metres. In large, deep lakes this can have a positive effect on fish, but in smaller lakes, reduction in dissolved oxygen and deepening of the thermocline can reduce or eliminate thermal refuges for cool or cold water species (Meyer et al. 1999). Wind has a marked effect in reducing lake stratification and thus predicted increase in wind in some districts in New Zealand could offset the heating effect, but will be very much site dependent.

A global analysis shows that climate change will impact most strongly on rivers already compromised by dams and extensive development (Palmer et al. 2008), a situation typical of most of New Zealand's major river catchments. In eastern areas, the effects of the predicted increased incidence and severity of droughts will therefore be compounded by increased abstraction for irrigation and control of flows for hydroelectric generation rather than river health.

While there may be movement within catchments and between habitats in response to temperature change, southwards movement seems unlikely for many non-diadromous freshwater species which are trapped in east-west flowing river systems or lakes. Modelling of exotic fish populations suggests that there could be a shift southwards in the northern limit for brown trout (Jowett 1992), with possible benefits for indigenous fish they compete with and prey on in the northern North Island.

5.2.4 *Weeds*

Novel weeds and increased invasiveness of existing weeds is one of the most troubling likely consequences of climate change. All other factors being equal, the warmer a region, the greater the number of plant species. For instance, in the Americas, moving from latitude 40°S to 25°S results in more than an order of magnitude increase in the number of woody species (Weiser et al. 2007). As frost is a key factor separating low diversity and high diversity regions (Woodward 1987), once it ceases to be a factor, a much greater range of plant species will be able to compete with local species. The net outcome of CO_2 increase and global warming is predicted to be higher local plant diversity, nearly entirely driven by naturalisation of cosmopolitan weeds (Woodward & Kelly 2008). Furthermore, alien weedy species are more likely to be advantaged by climate warming than indigenous species (Marini et al. 2009).

From a conservation point of view, weed species number per se is not the primary problem as, theoretically, a very large number of species can co-exist. An ecosystem in which native species dominate biomass and processes but in which a large number of exotic species find a home, is not ideal, but tolerable. Much more important is the handful of ecosystem transforming weeds which dominate to the extent that previous native occupants are reduced to low numbers and all essential ecosystem processes are controlled by non-indigenous plants. Here we can expect a knock-on effect in which native specialist animals, above and below ground alike, are also reduced to a remnant. One needs no further example than what has happened in Hawaii, Mauritius and other oceanic islands where tall woody exotic shrubs and trees have completely dominated broad swathes of the landscape (Denslow 2003). In Hawaii, expansion of exotic trees such as *Psidium guajava, P. cattleianum, Melastoma candidum* and the N-fixing *Falcataria moluccana* has created a situation where even without disturbance 'the native components of [lowland forests] may soon no longer be self-sustaining' (Zimmerman et al. 2008). Clearly, this is about as bad a biodiversity outcome as can be imagined.

Nearly as many naturalised vascular plant species occur in New Zealand as named native species (c. 2200), and there is a much larger (over 30 000) reservoir of species grown in gardens and as crops which potentially could become naturalised (Williams & Cameron 2006). A survey of aquatic plants within the New Zealand aquarium and nursery trade revealed over 180 species (many weeds elsewhere) that have yet to naturalise, the majority tropical species unlikely to survive but some of temperate environments and high potential risk (Champion 2004). The rate of naturalisation is not slowing, and therefore the pool of genotypes from which the weeds of the future will appear continues to grow. Weeds are hard to control and operations to remove them tend to be expensive. Broad spectrum herbicides used on an infested area without targeting will do as much or more damage to native plants and, given the propensity of other weeds to expand into areas where a given weed has been eliminated, such control is often ineffective. On the other hand, locating and killing individual plants by physical or targeted chemicals, and then monitoring and returning to ensure regeneration from seeds, underground structures or fragments of clonal plants is prevented, is very expensive. Successful total elimination of weed species in New Zealand has been confined to limited incursions.

The current outlook in New Zealand is not good. While biocontrol has been deployed successfully against a few weeds and has reduced the danger posed by others, it has limitations. Some weeds have a very large potential for transforming ecosystems but are problematic candidates for biocontrol. Prime among these are those conifers (e.g., *Pinus contorta, Pseudotsuga menzesii* and *Larix decidua*) which have the greatest potential to extend closed forest above the native tree line, and have markedly higher growth rates than native tree competitors (Ledgard 2001, Waring et al. 2008).

Weed assessment frameworks, bioclimatic and plant trait models are now widely used with good success (over 80%) to predict what plants are likely to become invasive (Gordon et al. 2008, Potter et al. 2009). The key criterion is whether a plant species in similar environments elsewhere has become invasive. However, totally accurate prediction of naturalisation and invasiveness is difficult, as there are many influential non-bioclimatic factors such as genetic adaptation, intensity of introduction effort, and interaction with local pathogens or pests. Some weeds that were major New Zealand weeds or considered likely to become so (for instance, sorrel, Rumex acetosella, in the 1960s) are no longer regarded as serious weeds, while others have become much more prominent (e.g., hawkweeds, *Hieracium* spp).

Not all weeds currently invasive in New Zealand will benefit from climate change (e.g., exotic broom *Cytisus scoparius*, Potter et al. (2009)) but the large number of cold-sensitive species already in the country, and the very large numbers that could invade, argue for the balance being in favour of more and more highly invasive weeds. The warmer and more northerly areas of New Zealand are the ones where the phenomenon of 'greenhouse weeds' should first manifest. Williams (2008) suggests there are possibly 100 terrestrial weeds that potentially threaten Northland, and 17 weed threats (including 5 trees) in Northland that are already in the exponential growth phase. While not strictly weeds, C4 pasture grasses have undesirable characteristics in New Zealand and there is evidence that some of them are spreading.

The most convincing observations are for paspalum (*Paspalum dilatatum*) which is expanding from Northland southwards. Field & Forde (1990) suggest climate warming between 1978 and 1990 may have expanded by over 1.5° of latitude the region in which 40% or more of the pasture contains this species.

5.2.5 *Pests*

Predation has been the major factor in New Zealand in driving numerous birds, reptiles, amphibians and invertebrates to extinction or severely restricting their ranges (Clout & Lowe 2000). Fast-breeding predatory mammals, in particular rats, stoats, ferrets, possums and cats, have been the primary cause, although hedgehogs, pigs, dogs, wasps and some birds, such as the thrush, have had effects on some populations at various times.

The primary predators in New Zealand are mammalian and therefore little affected directly by temperature in comparison to food supply; hence the wide distribution of many of these animals (rats, possums, stoats). However, warmer, drier winters are thought to extend the breeding seasons of rodents, goats, pigs and possums and, while this alone would not necessarily increase their population sizes in the absence of increased food, it would permit them to recover more quickly from control operations (Hay 1990). Nearly every part of the lowland and montane environment is saturated with mammalian predators. While climate driven fluctuations in food supply may initiate predator-prey population cycles, with strong effects on endangered native species during peak predator events, it is not clear that climate change per se is going to increase predator pressure on vulnerable indigenous organisms. A study of survival of long-tailed bats (*Chalinolobus tuberculatus*) in southern New Zealand (Pryde et al. 2005) indicated that survival was lower when predator numbers were higher and winter temperatures warmer. The authors offered two explanations: the warm winter temperatures could have increased bat activity at a time when food was scarce, thus depressing survival; or, warmer temperatures may have affected rodent (the key predator) survival and food supply (beech seed), thereby increasing predation intensity.

The alpine zone provides habitat for a number of threatened indigenous birds, reptiles and invertebrates. It seems possible that the prevailing cool alpine climates, high rainfall and snow have limited mammalian predation on these species. Certainly, the survival of the takahe at high altitudes in Fiordland and the kakapo in the cool, very high rainfall areas of the same region, both species which in pre-human times had a widespread distribution throughout lowland New Zealand, suggests that these areas offered some protection. Warming of the alpine zone may possibly reduce this limited protection for alpine animals. As an example, the rock wren (*Xenicus gilviventris*) lives between 900 and 2500 m altitude, and is highly vulnerable to predation by stoats, rats and mice (Leech et al. 2007). Stoats are thin with short fur, and thus vulnerable to cold and wet conditions and need warm, dry nests (King & Murphy 2005). However, they have been shown to be better suited to alpine grasslands than once thought, and it has been demonstrated that they can subsist on an almost exclusive invertebrate diet (Smith et al. 2008), meaning that a rapid decline of vertebrate prey would not necessarily release survivors from predation pressure. Ship rats (*Rattus rattus*) are limited by mean monthly temperatures below 2°C, which probably results from the effect of prolonged cold on foraging for food (Studholme 2000). They are increasingly uncommon with altitude (Innes 2005) and have been only occasionally recorded in alpine tussock. If the current trend of large fluctuations of temperatures on a seasonal or multiannual basis continues in the alpine zone, the fast-breeding, short-lived rapidly dispersing stoat and ship rat would be ideally placed to create damaging predation pulses in warm years.

In contrast to mammals, fish and invertebrate predators are directly sensitive to climate. Fish are often sensitive to water temperature and thus warming can be expected to decrease pressure from temperate invasives, and increase it for thermophilic species. While at present the risk of aquarium escapes is moderated by lack of tropical or subtropical character in our waterways, this risk will grow with rising temperatures (Koehn & McDowall 2004).

Given that the vast majority of invertebrates occur in the tropics, subtropics and warm temperate zones of the world, warming of New Zealand cannot help but increase the range and pressure exerted by invertebrate pests. Some 2000 exotic invertebrates have already become established, but few of these have had major effects on native ecosystems (Brockerhoff et al. 2010). The major introduced invertebrate predators in New Zealand are social and paper wasps, and ants. Wasps are implicated in reduction of indigenous invertebrate abundance through direct predation, and in reducing bird populations through competition for nectar, honeydew and invertebrates and attacks on nestlings (Clout & Lowe 2000, Beggs 2001). Common wasps (*Vespula vulgaris*) in New Zealand attain some of the highest densities recorded anywhere in the world (Barlow et al. 2002). Wasps are highly responsive to climate conditions: wet winters characterised by flooding do not favour nest survival and can lower populations, while warm, dry conditions are ideal for explosive population growth (Beggs 2001). However, a crucial factor appears to be the negative effect of late September rainfall (Barlow et al. 2002) and this underlines how sensitive pests can be to crucial aspects of the annual weather cycles. Ants are a major biodiversity threat and are abundant in warmer areas overseas (Dunn et al. 2009). The temperature match between New Zealand climates and current global distribution of an ant species is good predictor of its potential to invade (Lester 2005). On this basis, at least six or more species are likely to invade (Harris & Barker 2007, Ward 2007). The big-headed ant (*Pheidole megacephla*) and Argentine ant (*Linepithema humile*), which are regarded as among the worst invasive species in the world as they have the capacity to wreak havoc on the arthropod fauna, are already present in the exotic fauna. Continued warming and drying eastern climates is likely to encourage their spread from current patches.

> “While climate driven fluctuations in food supply may initiate predator-prey population cycles, with strong effects on endangered native species during peak predator events, it is not clear that climate change per se is going to increase predator pressure on vulnerable indigenous organisms.”

> "In the global literature, the climate change impacts most often claimed to pose the greatest risk for biodiversity are those related to shifting ranges for species and the associated dislocation of ecosystems by the disruption of mutualisms through altered distributions and phenologies (breeding seasons, bud burst, flowering times etc.)."

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5.2.6 *Range shifts and phenology*

In essence, species are thought to be at risk through being stranded in space in a warmer than optimal climate or stranded in time through phenological change. Landscape disruption through anthropogenic activity (fire, fragmentation, weed and pest introduction) is seen as exacerbating these direct climate change effects. Aside from seeding records, New Zealand has a lack of long phenological records and it is difficult to assess what effect changing phenology will have. We argue that although range shifts and phenology change will have some effect on New Zealand biodiversity, the oceanic, very variable climate regime experienced in this country, and the presence of steep topographic and climatic gradients, will minimise potential change due to these factors alone.

6. What should we do?

Climate change projections, at least from a biodiversity point of view, provide a rather uncertain basis for action both in magnitude and timing. On the other hand, the immediate threats through pests, weeds, disease and continuing land use intensification are all too certain in their outcome. We are clearly failing to deal with the current biodiversity crisis (Green & Clarkson 2005). Under these circumstances, taking expensive measures to combat climate change threats alone seems foolish. Whatever we do must show a clear immediate benefit for biodiversity, and therefore the clear priority is to continue programmes currently dedicated to reducing all risks to biodiversity. With regard to the priority ecosystems we have identified, the following climate-specific measures seem called for.

6.1 Coastal ecosystems

A systematic appraisal of the location and intensity of threats to coastal biodiversity from sea level rise is urgently needed to guide and justify actions and programmes to mitigate them. A priority is to map future coastlines (based on high resolution Digital Elevation Models (DEMs) and geological estimates of uplift/subsidence) and areas of coastal squeeze in relation to infrastructure and land use. A programme of public land purchases and/or public funding for land retirement agreements will likely be needed to enable managed retreat of ecosystems from advancing coastal zones and retirement of infrastructure. In some localities there will be scope for engineering intervention where relatively small structures may prevent inundation of large areas. Coastal land is generally expensive, and resistance and holdouts from private parties can be anticipated. In not all cases is there a clear biological imperative for action. For instance, the spread of mangroves seaward at present and southwards in the future with climate and landuse change is an example of an indigenous species responding in a way that conflicts with other biodiversity and ecosystem services (Harty 2009). Therefore successful programmes will require strong cooperative partnerships between conservation agencies and local government regulators as well as careful planning, coordination and management, including (and perhaps especially) the social dimensions.

6.2 Freshwater ecosystems

While the immediate biodiversity threat is dams, water abstraction, waterway and lake pollution, and weed spread, climate change will severely impact compromised elements through increasing heat stress, drought, changing the season of maximum water flow and increasing the need for irrigation. Unfortunately, given New Zealand is facing severe energy and water allocation issues, the nation is unlikely to be willing to sacrifice water use in order to enhance biodiversity. Further biodiversity degradation of waterways is therefore likely. While many lakes and rivers are buffered by their very size from some of these impacts, much freshwater biodiversity is contained in relatively small streams, seepages and springs that are at high risk. Nevertheless, some of the worst climate impacts can be avoided if minimum water flows are maintained and riparian vegetation cover encouraged (Maxted et al. 2005, Barquin & Scarsbrook 2008).

6.3 Alpine ecosystems

Halloy & Mark (2003) make brief mention of two mitigating measures to counter shrinking alpine habitat effects. The first is to remove trees and tall shrubs to maintain open habitat; and the second, transfer of endemic species trapped in shrinking patches to other more secure habitats in the same region. It is easy to envisage that both might become necessary if and when habitat reduction becomes apparent. As we have discussed, tree line movement and shrub growth in the alpine zone is likely to be slow, so there will be time enough to assess, plan and act. However, some key aspects of the alpine habitat might change without any warning whatsoever. Snow lie is highly variable from year to year (Clare et al. 2002), but is significant for some snow-bank and ice patch specialists. Likewise, annual minimum temperatures are highly variable, and are likely to be a key influence on the distribution of some indigenous specialists and a key restraining influence on the spread of exotic weeds and pests.

While it is not difficult to imagine managers keeping a few key sites free of competing indigenous woody growth where endangered species are at risk (as similar activities are carried out already to prevent loss of certain plants), wholesale loss of snow and ice across a region cannot be compensated for by habitat manipulation. Many alpine species appear to have low dispersal rates (McGlone et al. 2001) and exacting habitat requirements. If it is deemed necessary to move species to a more secure location because of widespread habitat loss, or invasion by exotic predators or weeds, the undertaking will be expensive and success uncertain.

6.4 Invasive species

Climate change will put more pressure on the environment through permitting many more already introduced or naturalised species (for the most part weeds and invertebrates) to expand, and make New Zealand more vulnerable to invasive organisms not already in the country. An example of a priority immediate biodiversity risk is that of continued spread of *Pinus contorta* above the treeline as it is already well established above the limit to native treeline species in numerous locations (Ledgard 2001) and is likely to respond well to continued warming (Wardle 1985).

Better tools (often statistically based) to identify weeds and pests with a high propensity to become invasive is clearly an ongoing need (Gordon et al. 2008). Those assessing risk need to take into account the high probability of warmer (and in the east) somewhat drier conditions in their deliberations as to the risk posed by potential and present invasive species. However, if these tools are to serve any purpose, an effective surveillance mechanism is needed. The most cost-efficient way of containing weeds and pests is to prevent them establishing or, failing that, preventing them reaching the exponential spread phase (Mack et al. 2000). Past history and current practice do not provide any comfort that this phase of the operation will be effective, in part because prevention of a problem rarely gains any notice, and in part that lessons do not seem to be learned from heroic but pointless attempts to control invasions (aside from a disquieting trend to curtail potentially effective efforts too soon). We will therefore need to continue to invest in the development of tools that can contain damaging environmental weeds and pests (such as biocontrol and improved conventional approaches for area operations).

With regard to weeds, which probably pose the most pressing problems because of the sheer abundance of potential weeds already in New Zealand, whole landscape approaches are the only ones likely to succeed. In particular, strategies focused on controlling or eliminating weeds in sensitive areas or preventing them becoming established are needed. Most weeds likely to become 'greenhouse weeds' are already in the country, and have been introduced for ornamental purposes, as aquarium or pond plants, or as warm climate crops (e.g., kiwifruit). A list of already present species which are likely to be advantaged by warmer/drier climates should be assembled, and consideration given to risk-reduction actions such as education campaigns, banning sale, proscribing the planting of high risk plants or legislating for their removal. Then practical actions have to be undertaken. Examples are eliminating spot occurrences or reducing the presence in gardens and translocation of plants with major weed potential such as strawberry guava (*Psidium cattleianum*) or palms under a warming climate.
As important will be finding ways to develop a better social awareness of the highly threatening climate-change future of today's valued garden ornamentals. Widespread public acceptance of the need to eradicate potential weeds ahead of their actually being troublesome would be needed. The social and economic resistance to such preemptive control should not be underestimated. For instance, in Auckland, mere discussion of listing of bangalow palm (*Archontophoenix cunninghamiana*; distribution Queensland to just south of Sydney) in the Auckland Regional Pest Management Strategy because of its preference for nikau-like habitats led to organised protests and legal threats from nursery owners (New Zealand Herald, 12 January 2006).

6.5 Monitoring

The world is embarked on what can be described as an uncontrolled warming experiment. We need to monitor this experiment in order to be prepared to intervene and in order to learn what we can from it. A great deal of biodiversity monitoring activity is already underway in New Zealand and systematic networks of monitoring sites are being established by the Department of Conservation. These are likely to give the sort of information that will be needed in the near future to assess climate impacts. Given the high cost of permanent monitoring, specific climate change activities should, as much as possible, be coordinated with the Department of Conservation network. As much warning as possible must be allowed for; it would be prudent to maintain early warning sites where possibility of loss of habitat and threat to biodiversity elements of most value and most at risk could be assessed on a regular basis (see Dickinson et al. (2007), for an example).
A start on such a system has begun in New Zealand (Global Observation Research Initiative in Alpine Environments, GLORIA; Mark et al. 2006). However, two issues remain: climate and phenological recording.

Climate recording stations are concentrated in populous and agriculturally important regions and relatively few are positioned in remote or high altitude sites. As the cost and convenience of climate recording stations has fallen dramatically with technological improvements, augmentation of the current climate station network should be a priority.

New Zealand has never had good phenology (seasonal attributes of populations such as breeding, migration, leaf flush, flowering etc) recording systems, seed crop of some trees and snow tussocks being a notable exception. Leaving aside the fact of a small scientific and amateur workforce available for the task, and the challenges faced in making meaningful measurements in an oceanic environment, the most likely explanations are:

- the rather muted phenological change typical of New Zealand has not attracted much scientific attention
- the under-representation in New Zealand of butterflies, migratory birds, deciduous trees, large, conspicuous flowers, and hibernating animals that have been the focus elsewhere, relative to the northern hemisphere temperate zone
- the dominance of non-indigenous ecosystems and species (birds in particular), close to major population centres.

Despite these constraints, efforts continue. A number of tree seed sites are regularly monitored. The recently developed New Zealand Biodiversity Recording Network[3] registers species observations made by professional and amateur ecologists and in three years has added over 260 000 plant observations and over 43 000 bird observations. However, in the near-term, comprehensive phenological and migratory data for a range of New Zealand taxa extending over a long time period will remain rare. Consideration should therefore be given to establishing long-term ecological observatory sites where a range of phenological attributes could be measured systematically and consistently.
While virtually any phenological data will be of use, those that directly relate to the physiology of major plants, such as leaf expansion, flowering and fruiting times, and seed crop size are clearly of greatest significance. Population trends in short-lived and mobile species are also a high priority as only long-term records can enable climate-related trajectories to be separated from year to year variation which may have little significance.

[3] http://www.nzbrn.org.nz (accessed 21 December 2009)

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07

The climate change matrix facing Māori society

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Determining the impacts of climate change on particular economies, industries and socio-cultural groups and activities is an extremely difficult task, yet one that must be undertaken in order to identify risks and priorities and to develop appropriate response and adaptation strategies. This paper attempts to make some sense of how the environmental, economic, social and cultural elements of Māori society are likely to be impacted by climate change this century; and further considers the diverse vulnerability, risks, coping capacity, and adaptation options available to Māori across key sectors, systems and groups. Understanding the matrix of linkages between these elements and factors is regarded as a key component in responding to "what needs to be done". It is highly likely that climate change will exacerbate many of the socio-economic difficulties and disparities already faced by Māori. The most vulnerable regions, communities, organisations and groups are those that are exposed to not only existing climatic variability and hazards, but those that have limited access to economic resources, low levels of technology, poor information and skills, remote and substandard infrastructure, unstable or weak institutions and governance structures, and inequitable empowerment and representation in local, regional and central government planning. While Māori are experienced in dealing with climate variability, in many cases new strategies will be needed to ensure the long-term sustainability of different sectors and regions in the context of climate change. Māori will do this in different ways, from defining their own aspirations, collaborating and driving new research and strategies, drawing on customary values and knowledge, and participating in discussion and active solutions at all levels from the *marae* (traditional meeting place and buildings) and *kura* (school) to regional and national business and political forums.

He uaua rawa atu te whakamārama i ngā pānga 'tūturu' o ngā rerekētanga o te āhuarangi ki ngā tūmomo ōhanga, ūmanga, rōpū ā-iwi me ā rātou mahi. Ēngari me tautuhi ka tika kia āta kitea ngā mōrearea me ngā whāinga tōmua ka raupapahia ai ngā whakautu me ngā takatūranga tika. Ko te whāinga o tēnei pepa he whakamārama ki te reo ngāwari te pānga o ngā rerekē tanga o te āhuarangi ki ngā take ā-taiao, ā-ōhanga, ā-pāpori, ā-tikanga o te ao Māori i tēnei rautau; tae atu ki te aro ki ngā tūmomo whakaraerae mai, ngā mōrearea, me te āhei ki te tū pakari tonu, otirā ngā kōwhiringa takatū e wātea ana ki ngā iwi Māori huri noa i ngā wāhanga, ngā pūnaha, me ngā tūmomo rōpū. He mea whakahirahira te mārama ki te papatau o ngā tūhonotanga o waenga o ēnei take hei whakautu i te pātai, 'Me pēwhea rā?' He pānga kino anō o ngā rerekētanga o te āhuarangi ki ngā toimahatanga kei runga i te ao Māori i tēnei wā. Ko ngā hapori, ngā rōpū tino kahakore, ko ērā e kohura ana ki te piki, te heke o te āhuarangi me ngā mōrearea o nāianei, heoti rā ko ērā me uaua kē te wātea mai o ngā rauemi ā-pūtea, o te hangarau rauangi, o te mōhiohio, o ngā pukenga tūturu, o ngā hanganga tōtika; he ngoikore anō pea nō ngā whakanōhanga me ngā mana whakahaere, kāore hoki i te whaimana ki roto o ngā rautakinga o ngā kāwanatanga o te takiwā, o te rohe, o te motu. He wheako anō a te Māori ki te taiao me ōna rerekētanga, heoi anō me whai huarahi rautakinga anō i ngā pānga ki ngā rerekētanga o te āhuarangi kia tika tonu ai te manaaki mauroa i ngā wāhi me ngā rohe. He momo huarahi nā te iwi Māori, mai i te tautuhi i ā rātou ake wawata; mai i te mahi ngātahi, me te kōkiri i ngā rautakinga me ngā rangahau hōu; he mea here ki ngā tikanga me ngā mātauranga o mua; he whai wāhi hoki ki te whakawhitiwhiti kōrero, me te kimi whakataunga ki ngā marae, ki ngā kura, me ngā hui ā-rohe, ā-pakihi, ā-tōrangapū o ngā takiwā, o te motu rā anō hoki.

1. Introduction and background

Evidence is accumulating that human-induced climate change is underway and that these changes are very likely due to an increase in greenhouse gas emissions (IPCC 2007). Yet, despite this evidence and the increasing scientific consensus there remains a list of associated and unanswered questions related to (i) how societies and the varied sectors and groups within them are likely to be impacted, and (ii) how specific places and populations might adapt to reduce vulnerability, build resilience and accommodate climate change risk? These questions are particularly important when considering the distinctive character of, and challenges already facing, Māori society. This paper builds upon work submitted for inclusion into the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) (Hennessy et al. 2007) and explores further some of the projected impacts and adaptation options of climate change facing key sectors, systems and groups across Māori society.

To begin, the paper sets a context and provides some relevant background information, including consideration of the key drivers of influence that complicate the climate change issue for Māori society. Based on this framework, we work through the nature of linkages between climate and Māori institutions, which is essential for understanding the vulnerability, impacts and adaptation options available to Māori society. It is important to recognise that our projections of vulnerability to projected climate changes are necessarily speculative based on current social and economic conditions.

Let us consider some important realities facing Māori society at the beginning of the 21st century that affect the vulnerability[1] and adaptive capacity[2] of different *whānau/hapū/iwi* (family/sub-tribe/tribe) and Māori business to limit and/or exploit the social, economic and environmental impacts of climate variability and change. Māori constitute about 15% of the New Zealand population (about 600 000 at last census) (Statistics New Zealand 2007). Of this figure, some 80% of Māori dwell in urban environments, with about 20% of Māori living in rural environments. This mix of living arrangements is enriched, but also complicated, by virtue of iwi affiliations. It is also often underpinned by a distinct worldview and identity associated with whakapapa: that is, ancestral lineage and sacred connection to the natural environment. High levels of economic hardship also characterise Māori society with some 52% of Māori regarded as "economically deprived" (Statistics New Zealand 2007). Based largely on household incomes (and high unemployment) this figure reflects to a large degree the limited financial capacity of Māori families to respond to everyday issues. This also reflects an historical legacy of loss of land and resources (Durie 1998).

Māori economic, social and cultural systems are strongly tied to the natural environment – with almost 50% of the total Māori asset base invested in climate sensitive primary industries (forestry, fishing, agriculture and to a lesser extent tourism) (NZIER 2003). Related to this, about 60% of Māori businesses are export-dependent compared with some 30% for the national average (TPK 2002). This situation can create a different economic playing field for Māori that can result in different objectives and different outcomes (Packman et al. 2001).

Many of the land and ocean-based resources owned by Māori are also held in multiple or communal ownership. It is estimated that 80% of Māori land is governed in this way, creating a distinct set of governance rules and processes for Māori that are sometimes quite different from those faced by other groups in New Zealand society (TPK 2002). Under this system many individuals, often from the same *whānau, hapū* or *iwi*, share ownership in a single block of land or associated business activity such as sheep and beef farming. Depending on the size of the asset and/or scale of the activity, decision-making authority is typically vested with *kaumatua* (elders) and/or elected leaders that manage these assets, most notably through Ahuwhenua trusts and Māori incorporations, on behalf of Māori landowners and shareholders (Funk & Kerr 2007). While there are significant opportunities and strengths that come from these structures across a range of operational scales (TPK 2007a), they can also create a set of obstacles that encumber decision-making and affect the success of trusts and incorporations (Cottrell et al. 2004), particularly when commercial experience is limited and Māori are forced to balance responsibilities under the New Zealand legal and commercial system as well as their own *tikanga* (NZIER 2003).

Although it is not the intent of this paper to fully discuss the range of governance or company structures under which Māori assets are managed, Māori businesses like any other in New Zealand when operating under the Companies Act (1993) must comply with the obligations set out in that legislation. Perhaps the key points of difference or complications for Māori businesses relates to the additional compliance required under such legislation as the Treaty of Waitangi (Fisheries Claims) Settlement Act (1992), where specified governance structures and management activities are detailed in the enabling legislation, and Te Ture Whenua Māori Act/The Māori Land Act (1993), which requires that elected Trustees ultimately operate under a Trust Deed and are accountable not only to their beneficiaries but also to the Māori Land Court if they are in breech of their Deed.

A final distinction related to Māori land is the role of the Māori Land Court and associated statutory sales restrictions related to land tenure that can restrict and/or rule out options such as sale and relocation that are normal practice for mainstream groups (MfE 2001). Add to this that a disproportionate amount of Māori land is remote and marginal (about 95% is located in the North Island) and these factors, combined, contribute to the overall exposure, sensitivity and capacity of different Māori to adapt to social, economic and environmental challenges.

Like many groups in New Zealand society, vulnerability and the capacity to cope and adapt to climate change is likely to be driven not only by physical changes in the climate, but also by political, economic, social and cultural factors (Tompkins & Adger 2003, Adger et al. 2004, 2007). As we will see, some Māori (*whānau/hapū/iwi* and business enterprises) may sometimes be more vulnerable and/or differently affected than other groups in New Zealand society.

[1] Vulnerability to climate is typically defined and assessed as a function of the exposure of a particular system/group, the sensitivity of the system/group to change, and the capacity of the system/group to adapt to that change. Systems and groups that are exposed, sensitive and less able to adapt are considered highly vulnerable (IPCC 2007).

[2] Adaptive capacity is about the *potential* of different sectors, systems and groups to change and/or make adjustments in their processes (both natural and human), practices, and/or structures to reduce or offset the potential for damage associated with climate variability and change (i.e., reducing exposure and/or sensitivity) (Tompkins & Adger 2003).

> "The question Māori have to ask, and are starting to ask, is "How will climate change affect me, my whānau, and my community?""

2. Previous research

To date, limited research has been conducted on Māori issues related to climate change. The earliest formal work involved a stakeholders group convened in 2001 by the New Zealand Climate Change Office (NZCCO) to consider how Māori might be affected by the Government's decision to ratify the Kyoto Protocol (Packman et al. 2001). This included a brief consideration of how aspects of Māori society might be impacted by changes brought on by a warming climate. Shortly thereafter, this led the National Institute of Water and Atmospheric Research (NIWA) to hold the first and second Māori Climate Forums in 2003 and 2006 which brought together Māori stakeholders from across the country to discuss climate change concerns and research priorities for the future (King & Penny 2006). Research outcomes from these meetings included a crop-suitability mapping project for Ngati Porou Whanui Forests Ltd (Tait et al. 2008), a pilot study with elders from Te Whānau-a-Apanui and Ngāti Pare examining *Matauranga Taiao* (Māori environmental knowledge) of local weather and climate change (King & Skipper 2006), and the submission of an indigenous section to the IPCC's Fourth Assessment Report (AR4) on 'Impacts, Adaptation and Vulnerability' (Hennessy et al. 2007). During this same period, Landcare Research initiated a project to examine carbon farming opportunities (and barriers) for Māori land-owners on the east coast (Carswell et al. 2002, Harmsworth 2003, Funk & Kerr 2007). This work is ongoing – some of the findings of which will be returned to later in this paper. The NZCCO also convened a national meeting in 2004, which led to the formation of the "The Māori Issues Group" and an abridged report that summarised the potential economic, cultural, environmental and social impacts on Māori arising from climate change and related policies (Cottrell et al. 2004). One key conclusion was the need for future work to effectively communicate the risks and opportunities arising from climate change to Māori communities and Māori trusteeships. The most recent piece of work, facilitated by the Ministry for the Environment in 2007, involved 13 regional *hui* (meetings/forum) with Māori around the country to discuss climate change policy and related energy issues (MfE 2007). While many issues were raised, such as the need for Māori-specific analysis and information (including some dissent over the engagement process), there was widespread acknowledgment by those consulted that current and future projected climate change is an important and urgent issue for Māori (Te Aho 2007). Clearly, there has been some research conducted to date, but much more is needed, including an associated process of integrating research findings into meaningful and realistic actions, if we want to make constructive change.

3. The climate change matrix

There is a diversity of influences that complicate the climate change issue for Māori and make it difficult to specify the "implications" with any certainty. In Figure 1 we present a modified conceptual model (Bradshaw & Smit 1997) to illustrate the main factors and processes that drive climate change impacts, vulnerability and coping capacity that lead to response and further change. In this context, and with respect to sustainability generally, these linkages are seldom conceptually elucidated and important relationships between human and physical systems are often poorly identified, defined and understood (Rayner et al. 1994). Therefore, a necessary starting point is to arrange the main factors and processes in a way that broadly reflects the biophysical, economic, social and cultural realities of Māori society. This makes it possible to see the context within which different sectors, systems and groups experience change, and thereby respond, on a range of spatial scales. The model begins from the premise that no Māori individual, group, community or business enterprise exists in isolation.

A key feature of impacts and vulnerability is that environmental changes brought on by climate change are likely to be unevenly distributed, both spatially and temporally. That is, regional changes in climate across New Zealand will vary depending on geographic location and inter-annual to decadal scale variations in climate (e.g., La Niña or an El Niño). Hence, Māori at the household, business, *hapū* or tribal level will be affected differently by the biophysical impacts of climate change. This in itself presents a challenge to Māori. That is, each *iwi*, *hapū*, Māori business or community must assess and address climate change from their own perspective and exposure, but in order to do so effectively must collaborate with others to understand and interpret the issues they face. The question Māori have to ask, and are starting to ask, is "How will climate change affect me, my *whānau*, and my community?"

While the environmental effects on their own are diverse and complex, this is further compounded when applied to a diverse group such as Māori. While this may seem obvious, it is too easy to fall into the trap of considering Māori society as being homogeneous as is so often done in our media. Obviously this is not so. Today, Māori cannot adapt, relocate, or change resource use activities as easily as they may have been able to do in the past, because most now live in permanent communities and have to negotiate greatly circumscribed social and economic situations. Most Māori live in planned settlements with elaborate infrastructures, and their resource activities are determined to a large extent by regulatory and legal regimes, land use and land ownership regulations, quotas and local and global markets. Further, across Māori society different groups have different skills, different knowledge and serve different roles, they are situated in different places and within different environmental contexts and have access to different resources and capital. Consequently, the responses of different Māori to these external influences are likely to be quite variable given differing perceptions and sensitivities, both of which are a function of the particular attributes and social capital of individuals, *whānau, hapū, iwi* and business institutions.

It is also important to acknowledge that Māori are affected by the decisions, policies and actions of others here and overseas (TPK 2002). That is, the livelihoods of Māori are subject both to the historical

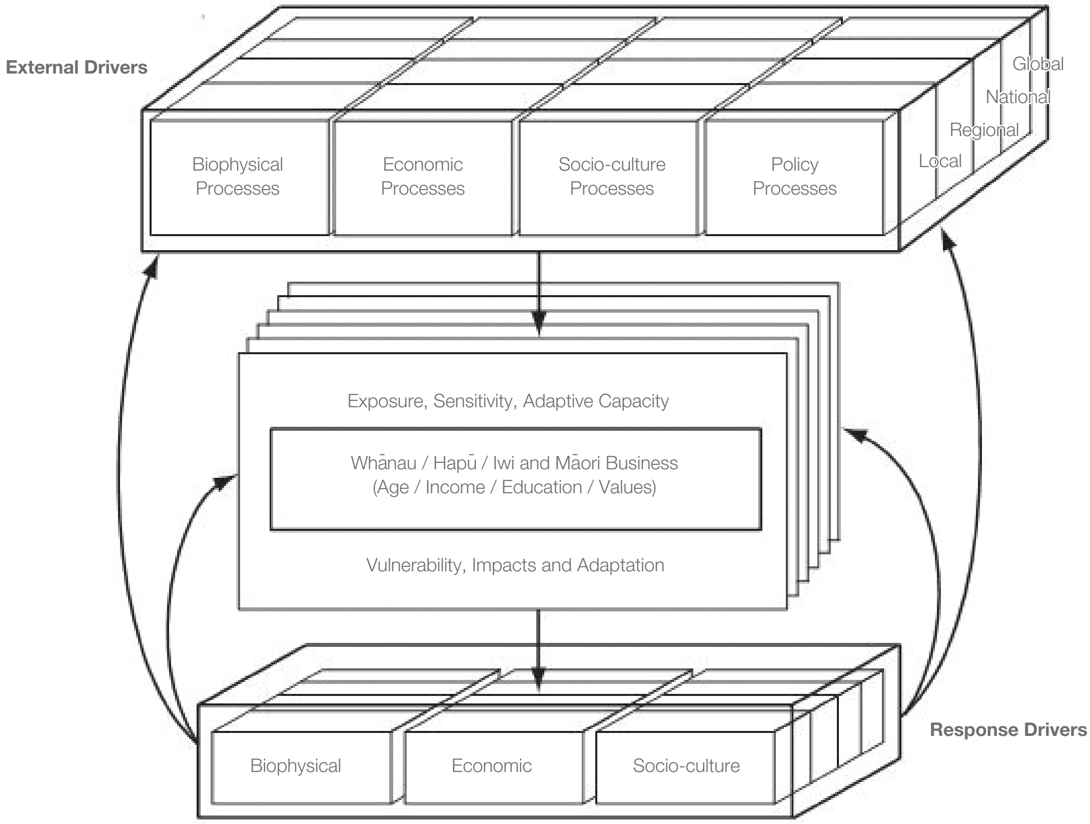

Figure 1. The climate change matrix facing Māori society.
Modified from: Bradshaw & Smit (1997).

development and the contemporary influences of markets and to the implementation of government policy and resource management regimes. For example, the New Zealand Government's decision to ratify the Kyoto protocol and associated proposal to introduce an Emissions Trading Scheme to reduce greenhouse gas emissions raises issues of equity for both pre-1990 Māori held forestry assets and past as well as future Treaty of Waitangi land settlements (Te Aho 2007). Such arrangements might unfairly disadvantage Māori who cannot leverage off land forested in perpetuity as well as restrict the ability to use settlement lands for anything else other than forestry (MfE 2007). As has been the case in the past, there is no doubt that Māori will continue to be affected by the processes, policies and decisions of governments, businesses, and markets here and overseas with regard to climate change and other matters.

Given this matrix-like setting, we have to take the effects of multiple variables into account and work through the linkages in some detail to begin to form a clearer view of what the problems, options and opportunities are for Māori. Change one variable, force or response and the outcomes are also likely to change.

4. Sectors, systems, and groups

In the following section we review key sectors, systems, and groups across Māori society that are, in some way or another, already sensitive to climate variability and thereby future climate change. For each sector, system and group we consider the present context, projected impacts, coping capacity and adaptation options. Importantly, the sectors, systems and groups are not discrete units, nor static, but rather are influenced by driving forces that are integrated, produce feedbacks, and depend on context and scale.

4.1 Agriculture sector

The livelihoods of Māori are strongly linked to land use with many Māori agricultural investments already exposed and vulnerable to climate variability (Packman et al. 2001). This century, there is a high probability that Māori farmers in northern and eastern areas of the country will be highly challenged by a warmer and drier climate as temperature and evaporation rates increase causing more frequent drought (Mullan et al. 2001, 2005, 2008). Warming temperatures bring a number of challenges to pastoral based investments, with a potential reduction in pasture quality through earlier maturation, evolution of the

[3] This Counsel is similarly conveyed by Shea et al. (2001) who maintain that distinguishing between climate variability and change has no practical meaning from the standpoint of those who are doing the adapting. The best option these authors argue is to implement strategies that help deal with present climate variability and this experience can be used to reduce vulnerability and enhance resilience to future climate related adverse impacts.

pasture base toward less palatable herbage, intensification of carbon and nutrient cycles, changes to pest and disease occurrence and increases in heat stress days for the animal. An associated reduction in frost frequency is also likely to adversely impact some horticultural operations as many temperate fruits need winter chilling to ensure normal bud-burst and fruit set (Atkins & Morgan 1990). Amidst these projected changes, Māori may find also new opportunities connected with warming temperatures, such as faster growth of pasture and longer seasons for harvesting, expansion of current agricultural ranges to new areas and diversification of horticulture practice (Stroombergen et al. 2008). Any beneficial effects of climate change in the short term, however, are expected to diminish if greenhouse gas emissions are not reduced or at least capped. Further, with the expected intensification of the hydrological cycle, any changes in the magnitude or frequency of extreme weather events and climate related hazards such as storms and floods are expected to place additional stress on this sector. These challenges will almost certainly affect production rates, yields and GDP from agriculture (Clark et al. 2006). Even areas that may not be directly impacted by the physical constraints of changes in climate may nonetheless be affected by the impacts of climate change on agricultural production, markets and policies in other regions or countries (Kingwell 2006).

In terms of coping capacity, some Māori may be well placed to respond to climate change, having access to modern infrastructure and storage systems, agri-business and research services, a range of marketing networks and more resilient farm land. Underpinning adaptation are factors like Māori innovation and creativity, traditional and contemporary knowledge, learning and networks, right and access to both physical and natural capital and the financial capacity to make change. Some have already shown considerable capacity to adapt to climate variability by introducing new land management systems, changing stocking rates and feeding regimes, and selecting new technologies to increase efficiency of water use. These types of examples signal the kinds of adaptive response that can be made to respond to future changes in climate (Kenny 2001)[3]. Notwithstanding these adaptations, there will be other Māori farmers who do not have access to a similar quality or quantity of resources and skills, and this group appears vulnerable and restricted in their capacities to adapt to the changing conditions (Clark et al. 2006). Furthermore, farms that can no longer rely on coping strategies in the face of low rainfall, high temperatures, high evaporation rates and associated drought may inevitably be forced away from activity in this sector (Kingwell 2006). Assessing the capability of specific groups within this sector to adapt is a critical element in identifying the industry's risk from a changing climate. Future adaptation options might include staggered planting times to reduce crop production risk and re-design of existing farm infrastructure to manage low irrigation water availabilities (Howden et al. 2003). Further, breeding new cultivars that are suited to changing conditions in the different arable cropping regions in New Zealand may be required. However, the success of such crops will be strongly dependent on future market requirements and conditions. Adaptations need to be appropriate to local circumstances, financially viable, environmentally sustainable, and consider potential changes under greenhouse gas mitigation policies. Future adaptation research must be informed by thorough and ongoing analysis of the vulnerability, sensitivity and exposure of the Māori agricultural sector to climate change, recognising all the inter-linkages and dependencies between people and the physical environment.

4.2 Fisheries sector

Māori own about 40% of the national fisheries quota and have substantial shares in several large fishing companies. This includes significant investment in fishing fleets, processing and marketing (NZIER 2003, TPK 2002, Hennessy et al. 2007). While there is little consolidated knowledge of the potential direct and indirect impacts of climate change on this sector, climate-induced changes in regional ocean temperature, currents, winds, nutrient supply, ocean chemistry and increasing acidification (as well as extreme weather conditions) are expected to alter regional fisheries productivity and operations, fishing incomes and ocean-based investment (Preston et al. 1997, Hobday et al. 2008). Other possible impacts include changes in the productivity of warm and cold water marine species that supply important commercial and customary (i.e., non-commercial) fisheries such as *kina* (sea-egg), *koura* (crayfish), *paua* (abalone), *kanae* (mullet) and *tāmure* (snapper). Climate variability has been shown to have significant influences on New Zealand fish stock availability (Renwick et al. 1998, Beentjes & Renwick 2001, Dunn et al. 2009). Such information is increasingly important for connecting the threats to the impacts on the environment as well as the socio-political realities facing Māori ownership, management and utilisation of commercial and non-commercial fisheries in New Zealand. Add in climate change mitigation policies, such as increased fuel costs and taxes related to food miles, and again we have an increasingly complex array of factors around which Māori will have to make investment decisions (NZBCSD 2009). The coping capacity of the sector will depend on the flexibility of the industry to modify their practices and investments, and to take advantage of new opportunities. Very little information, however, is available on this matter at present (MfE 2001).

In terms of adaptation options, the ecology of marine environments are likely to benefit from the introduction of new marine protected areas, reserves and parks, managed resource protected zones, and other types of marine management areas (COS 2009). However, Māori have widely expressed that maintaining ecosystem health and sustainability should not preclude economic development in this sector (King & Penny 2006). Anecdotal evidence suggests that many *whānau/hapū/iwi* are concerned with such options as they deny Māori access to commercial and non-commercial fishing grounds through the Deed of Settlement and the Treaty of Waitangi (Fisheries Claims) Settlement Act 1992, irrespective of Māori values[4]. Māori are likely to find new opportunities connected with land-based, inshore and offshore aquaculture developments (TPK 2007b). The aquaculture industry has already demonstrated considerable adaptation potential via selective breeding, regulating of the environment, flexibility of aqua-feed formulations and new species opportunities[5]. Notwithstanding these advancements, there is a need for fisheries and aquaculture management policies to better integrate the effects of climate variability and climate change in establishing harvest levels and developing future strategies. The southward shift of tropical species as a result of changing ocean temperatures may also present new opportunities for some wild fisheries (Hobday et al. 2008). Lack of information at present, however, is regarded as a significant adaptation barrier. Better understanding of the impacts of climate change on reproductive success, species invasions and changes in habitat and productivity due to physical changes in the environment (e.g., storms and inshore sedimentation) is required to assist with decision-making and planning in a sector where there are very significant existing risks to the sustainability of fisheries in New Zealand (Hurst et al. 2009, COS 2009).

[4] Many Māori continue to advocate a sustainable utilisation approach to marine management, based on a responsible environmental ethic and adaptive management.

[5] However, for coastal and offshore aquaculture, stronger and more frequent storm conditions could result in increased physical damage to infrastructure such as ports and vessels, and stock losses, which are all costly to operations (Preston et al. 1997).

4.3 Forestry sector

Māori have substantial production forests and are becoming actively involved in integrated processing of exotic and indigenous wood products (NZIER 2003). This evolving ability to add value and generate business opportunities may be impacted as climate changes are expected to affect production rates, wood quality, pest presence and fire-risk and to some extent, determine the scale and species-mix in future plantations (MAF 2001, Pearce et al. 2005). As projected west-east coast rainfall gradients become more pronounced, growth rates of economically important plantation forests (mainly *Pinus radiata*) are expected to increase in the south and west of the country, while tree growth reductions are more likely for the east of the North Island (Hennessy et al. 2007). Given the location of most Māori forestry land at present, this is likely to disproportionately affect Māori investment on the east coast. Some Māori investments in forestry may be well placed to respond to climate change, having access to modern infrastructure, research and development, and financial markets. However, by contrast there will be others that do not have access to a similar quality or quantity of resources – particularly some remote groups and businesses who stand to suffer disproportionately from more expensive fuel and higher roading costs (Cottrell et al. 2004). Regions most at risk in the coming years will be those that are currently at the edge of climate tolerance, those already stressed by economic and social and biophysical conditions, and those where long-term investments have been made that restrict adaptation options (e.g., slow growing plantation species).

Carbon trading could be an adaptation option to achieve both monetary returns and reforestation on marginal and erosion-prone hill country (Funk & Kerr 2007). Recent government commitments under the Kyoto Protocol to reduce carbon emissions to 1990 levels have created carbon trading opportunities for Māori land managers and owners who are willing to plant their land in native and exotic forests to act as carbon sinks. Māori may be interested in exploiting some of the opportunities presented by this market mechanism – including the attraction of external investment and improvement in existing land management practice through reforestation, erosion and flood control, and biodiversity protection. Notwithstanding these potential benefits, there are also some concerns that range from the setting of 1990 as an arbitrary date for carbon credit eligibility and the impact this will have on those who already hold their lands in forests (Te Aho 2007) to the carbon market promotion of quick-to-grow monoculture plantations and the subsequent downstream effects on water availability and use (Reeson 2009). According to participatory work coordinated by Landcare Research there are potentially some 200 000 hectares of Māori land eligible for carbon trading (Harmsworth 2003). However, the lack of clarity surrounding the certification of projects and uncertainty over the monetary returns in a new market environment has affected the uptake of carbon markets as a tool for sustainable development (Funk & Kerr 2007). Further, any measures to reduce deforestation will inevitably affect the flexibility of landowners to realise and implement new land use opportunities (Te Aho 2007). This has important implications for many Māori landowners who may wish to explore new land use options and/or intensify existing agricultural production regimes, as well as others who are concerned about inter-generational equity. Anecdotal feedback suggests that a number of Māori land owners will wait and see how the initiatives of others develop before committing *whānau/hapū* and *iwi* owned lands to carbon forests.

4.4 Settlements and infrastructure systems

Although most Māori live in urban environments, they also occupy remote and rural areas, where some vital infrastructure and settlements are vulnerable to extreme weather events (Harmsworth & Raynor 2005). Projected changes in weather extremes this century are expected to increase the risk of damage to life-line services such as roads, buildings, flood-plain protection and urban storm-water systems, particularly as the design criteria for heavy rainfall and floods are exceeded more frequently (Hennessy et al. 2007). Impacts such as these pose risks for local economies and may jeopardise future investment opportunities, leading to loss of jobs and income for local people (Chapman et al. 2006). Important contextual factors that influence the exposure and sensitivity of Māori settlements and infrastructure to climatic hazards include low investment in rural infrastructure (e.g., clean water resources, housing, roading), the marginal nature of some Māori land-blocks and the building of settlements and infrastructure close to waterways, floodplains and coastal areas (King et al. 2008). Add to this that many Māori landowners often have lower economic power and restricted access to finance and these factors contribute to an overall reduced capacity to cope. This situation will be worse in areas where communities have negligible or no insurance cover (ICNZ 2005, Allen Consulting Group 2005). Better information on insurance standards and clauses that may limit effective cover for Māori would assist Māori households and *hapū/iwi* infrastructural investments to make informed decisions about present and future needs.

Adaptation options include setting construction and development away from floodplains and flood zones, improving water supply, drainage and wastewater systems, and future-proofing new infrastructural developments such as the introduction of minimum floor levels for building. Adaptations such as these will contribute to making community infrastructure more resilient to current and future climatic hazards (O'Connell & Hargreaves 2004). Further, designing and building new housing or infrastructure to cope with a changing climate is likely to be more cost effective than retrofitting later (Chapman et al. 2006). Incorporating climate change issues into *iwi* management plans and meaningful participation for Māori in the development of local and regional planning, such as hazard management, are needed to prepare and reduce the exposure of Māori businesses, institutions and the community to climate variability and change. In urban areas more work is urgently required to better understand the exposure, sensitivity and resilience of Māori groups to climate change. As most Māori now live in cities and towns, those in private and state-owned residential, commercial and industrial dwellings will need to accommodate these risks to ensure basic standards of wellbeing, health, safety and quality of life are not jeopardised. In state housing there may be increased demand for maintenance and upgrades, restricted access to suitable development land and a need to include climate change considerations in the design, standards and materials used in new housing.

At present precise strategies and actions to reduce the vulnerability of Māori groups to climate change are being stalled by inadequate Māori representation and ineffective participation in local, regional and central government planning and decision-making and research (King & Penny 2006). Other key barriers relate to a lack of clarity from Government in terms of climate change policy and response, ongoing financial inequalities and people with the right expertise who can walk successfully between worlds (Harmsworth 1995, Matunga 2006, King et al. 2008).

> "Incorporating climate change issues into iwi management plans and meaningful participation for Māori in the development of local and regional planning, such as hazard management, are needed to prepare and reduce the exposure of Māori businesses, institutions and the community to climate variability and change."

4.5 Water resource systems

Water availability, allocation and quality are already challenges for some *whānau/hapū/iwi* and Māori businesses, particularly in eastern and northern areas of the country where droughts currently place pressure on water supply for communities and agricultural end-users (Woods & Howard-Williams 2004). This century, the number of Māori living under water stress is likely to increase substantially, as increased water demand is heightened during hot, dry summers (Hennessy et al. 2007). Higher temperatures and lower rainfall are expected to reduce soil moisture, groundwater supplies and river flows for some areas, further aggravating water availability and water quality problems (Mullan et al. 2005, 2008). Meanwhile, the effects of changing hydrological regimes on water supplies are likely to seriously affect those places and populations where reticulated supply systems are poorly developed (or non-existent), and where there are inadequate resources to import water or pay for private treatment facilities (Woodward et al. 2001). Within these groupings are a handful of highly vulnerable communities and land-based businesses that should be targeted for water supply planning and adaptation research. The outcomes from such work are likely to have immediate public health implications as well as longer term climate-change adaptation benefits (Woodward et al. 2001). Further analysis is required to better understand how water resource systems are likely to be affected geographically (i.e., changes in water demand, low stream flows, lake storage, and groundwater recharge) including the downstream effects of these changes on irrigation, hydro-power, waste-water and fire management.

Adaptation options include the enhancement of existing water protection measures such as greater water use efficiency and conservation, planning for alternative water sources and artificial groundwater recharge (Kundzewicz et al. 2007). However, in many instances, adaptation to new conditions will require additional financial resources and technological capacity that many *whānau/hapū/iwi*, Māori communities and businesses do not currently possess (King et al. 2008). It should be noted that adaptation measures such as water resource protection, development and management are also likely to raise important social and cultural issues for Māori (Waitangi Tribunal 1983). It is imperative these issues be understood and acknowledged so that responses to the potential impacts of climate change on water planning and public health are aligned with the values of the people they are intended to help. This process would be greatly assisted by greater Māori involvement in local, regional and national water resource planning and management; and is acknowledged in the Government's new strategic direction for water management in New Zealand (i.e., New Start for Fresh Water). Further work is needed in this vital system to provide critical information that will assist *whānau/hapū/iwi* and Māori businesses to make informed decisions about future needs, allocation, and adaptation measures for commercial and non-commercial water resource uses. At the same time, in spite of the uncertainties, in many areas and sectors there is sufficient information and knowledge available on water resource strategies and plans to implement adaptation activities now (Chapman et al. 2006).

4.6 Natural ecosystems

Many terrestrial and freshwater ecosystems are under substantial pressure from increasing populations, land-use change and pests (Fischlin et al. 2007). The well-being of these natural systems is of paramount importance to *whānau/hapū/iwi* and Māori business – particularly given the fundamental role of the natural environment in Māori values and the continuing rural and urban utilisation of public land, waterways and coastal resources for hunting, fishing, recreation and the collection of cultural resources (Penny et al. 2007a, 2007b). This century, the production and ecology of important flora and fauna will likely be challenged by new plant and animal pests, as well as the spread of pathogens and diseases as warmer weather favours conditions for increased competition (McGlone 2001, McGlone et al. 2010). Some vulnerable species may face habitat loss and even extinction. While natural ecosystems have some capacity to adapt naturally, increasing human populations, habitat loss and projected rates of climate change are likely to limit species migration and in some cases exceed rates of evolutionary adaptation and thereby seriously limit coping capacity (Hennessy et al. 2007). Impacts such as these are expected to adversely affect economic, social and cultural values across Māori society (King & Penny 2006). At the same time, Māori ethics, expressed through *tikanga* (Māori custom, codes, and conventions), recognise that cultural order comes from the natural environment and hence people have a responsibility to care for these systems. Lack of respect, honour and protection of this natural order compromises the well-being of these systems on which all people depend (Te Huirangi Waikerepuru, 2009: pers. comm.). A chorus of Māori voices has indicated that adaptation should focus on *kaitiakitanga* (environmental stewardship) – with families, and communities being involved in habitat protection and enhancement (King & Penny 2006, MfE 2007). Adaptation options might involve innovative collaborative management structures with local and regional authorities, Māori imposed standards on resource allocation and use, and cultural state of the environment reporting (Harmsworth 1995). However, growing populations, unsustainable modern living arrangements, fragmented local knowledge and the changing social structure of communities who have no connection to place, all present barriers to a more steward-like approach.

4.7 Coastal communities

Many Māori communities are situated along coastal margins, and these areas are highly vulnerable to sea level rise and other climatic events such as storms and high tides. They are also highly valued by Māori for recreation, for hunting and fishing to supplement household food supplies, as sources of identity and places of learning connecting the living with the past (Hennessy et al. 2007, Penny et al. 2007a, 2007b). We are currently seeing many of these areas and values compromised by environmental changes (including coastal erosion, floods, catchment runoff, landslides, mangrove establishment and pest species incursions), increased pressure on resources and widespread coastal development – in both urban and rural areas (Goff et al. 2003, Penny et al. 2007a, 2007b, COS 2009). This century, climate change induced sea level rise in tandem with more intense storms (MfE 2008) is likely to cause widespread and more frequent coastal inundation, erosion of coastal infrastructure such as roads, homes and life-line services, and loss of inter-tidal food gathering areas and sacred places such as *urupa* (cemetery) and *marae* close to the coast (Bell et al. 2001). While there is considerable uncertainty about the projected upper range estimates of sea level rise at present (MfE 2008, Mullan et al. 2008), many Māori communities are likely to be disproportionately affected by these changes because of their socio-economic characteristics and the physical location of valued infrastructure and places on exposed, erosion-prone coastal lands make them vulnerable (MfE 2001, Packman et al. 2001). Analysis of the comparative risks for Māori coastal communities is important for understanding the sensitivities and exposure of this group and for identifying priorities for adaptation planning and implementation.

Adaptation options such as coastal protection (seawalls, rock revetments, beach re-nourishment and artificial reefs) may be short to medium-term solutions in some areas, while in other areas major long-life infrastructures (such as roads and causeways) will likely need climate change factors incorporated into future design, planning and construction (Turbott & Stewart 2006). Dune management and development of set-back zones can also reduce the effects of climate change through restoring and maintaining a protective natural dune buffer between coastal development and the sea (Dahm et al. 2005). However, for especially low-lying areas on receding coastlines, gradual to permanent sea inundation, degradation of dunes, sediment infilling, erosion and flooding is expected (Turbott & Stewart 2006, MfE 2008). Under these circumstances managed retreat may be the only sustainable solution (Bell et al. 2001). At this early point in time, the main barriers to adaptation by Māori include access to quality technical knowledge on which to make decisions, lack of participation in local planning arrangements, lack of capital for infrastructure and design, and poor infrastructure and services in some remote and isolated settlements. Another barrier may include the high spiritual value placed on coastal land and resources which can restrict, and may even rule out, conventional adaptation options being proposed by mainstream groups such as managed retreat and relocation (MfE 2001, 2008). Notwithstanding this reality for some Māori, pragmatic and timely decision-making are not foreign to *whānau/hapū/iw*i. That is, Māori will coordinate, plan, collaborate and make important decisions very quickly for the common good when required (TPK 2007a, King et al. 2008). Partnerships based on enduring relationships are regarded as vital to achieving the best outcomes for Māori and wider society in this space.

4.8 Health and well-being

The health and well-being of Māori people is dependent on the stability of social and cultural arrangements and, more fundamentally, on the sustainability and condition of natural resource systems (see: Natural ecosystems) (Durie 2001, Woodward et al. 2001, Penny et al. 2005). Climate change is likely to have both direct and indirect effects on these arrangements and systems, and thereby impact the health and well-being of Māori. The direct effects of climate change on Māori health include those that emerge from changes in temperature, rainfall, solar radiation, and other climate variables. For example, higher temperatures can result in heat stress (even mortality), hotter summers could lead to higher rates of skin cancer, and higher rainfalls can lead to floods posing direct risks to life and property, depending on standards of housing and the resilience of populations to cope (Hennessy et al. 2007). Indirect effects typically relate to secondary impacts on physical, social and economic conditions which influence human health. For example, changes in ecology and the introduction of new subtropical diseases normally found in warmer climates – such as dengue fever – pose an increased risk to already sensitive and exposed groups (Hennessy et al. 2007). Further, adverse mental health and psychological issues can result from climate change effects, such as ongoing drought and the associated impact on local economies (Howden-Chapman et al. 2010) and valued flora and fauna (Penny et al. 2005). It is important to recognise that many factors influence human health, and hence it can be difficult to distinguish the effects of climate change from other social and environmental conditions (Woodward et al. 2001). The direct and indirect effects of climate change on Māori health in urban areas and cities are much more integrated and even less clear at present.

Again, the coping capacity of different Māori to plan and respond to climate-related impacts on health is likely to be challenged by low levels of economic development, restricted access to funds for projects, substandard housing, equitable access to technical information, physical isolation and the provision of affordable health care services (Woodward et al. 2001)[6]. The impact of climate change on Māori health therefore depends not only on the extent and rate of climate change but also on secondary effects such as climate change mitigation policies and how well individuals and society can cope and adapt to these. Improved housing and insulation – as well as affordable access to domestic energy and heath care – are vital and existing needs for Māori (Waldegrave et al. 2006). The resolution of these issues would go a long way in improving the health and well-being of Māori now and in the future. In many situations, adaptation to new conditions will require additional and ongoing financial resources and support, as well as the transfer and uptake of technological capacity. Insurance for a range of covers is another area that has been identified as an important component of future action on adaptation (Allen Consulting Group 2005). It is important to acknowledge that the nature and character of Māori social and cultural relationships and networks can strengthen the resilience and adaptive capacity of communities and groups. That is, some Māori groups may be better able to respond to the pressures presented by climate variability and change because of strong partnerships, diversity, and the belief that life on earth is more about people. Building resilience through strong social networks is becoming increasingly important in natural hazards management and research (Adger et al. 2007). Further research is required to help understand how socio-economic and cultural factors determine climate-related health risk (Woodward et al. 2001). This information is a prerequisite first step in helping to develop effective community responses and public health intervention strategies.

[6] According to Tompkins & Adger (2003), the challenge is to promote adaptive capacity in the context of competing sustainable development objectives.

5. Concluding remarks

A matrix of climate change influences faces Māori society – and these drivers of change are expected to result in differential impacts across different sectors, systems and groups. It is likely that climate change will exacerbate many of the difficulties and disparities already faced by Māori. As outlined throughout this paper, these issues include access to economic and technological opportunities, governance challenges, lack of participation and representation in local, regional and central government planning, population movement, the extent to which government support and services are forthcoming, social cohesion, and lengthy Treaty settlement processes, among others. What is certain is that climate change and climate-related policies will rearrange things, economic signals will change, priorities will change, technology will change and relationships will change. While Māori are experienced in dealing with climate variability, in many cases new strategies will be needed to ensure the long-term sustainability of sectors and regions in the context of climate change. This means learning about climate change and its ramifications by sorting the rhetoric from reality; it also means engaging in the right networks and processes and gaining access to the right information and skills. Māori will do this, not only by defining their own aspirations but by participating in this discussion at all levels from the *marae* and *kura* to regional and national business, science and political forums.

There is an urgent need to better understand the vulnerability and adaptive capacity of *whānau/hapū/iwi* and Māori businesses in both rural and urban areas. Prioritisation for research (and development and demonstration assistance) depends on understanding the inter-linkages and dependencies between these variables (across local, regional and global scales) as well as identifying vulnerable systems or regions where failure is likely to carry the most significant consequences. This will assist with the identification of priorities for future adaptation as well as the likely limits to adaptation. Work also needs to be carried out to understand what makes some stakeholders more resilient than others. Learning from the mistakes and successes of different sectors, systems and groups is not only common sense but crucial in designing scale-appropriate adaptation options for different regions and communities. Many Māori have already recognised the need to (i) reduce their vulnerability to these increasing risks through adaptation, and (ii) strengthen their human and institutional capacities to assess, plan, and respond to these challenges. Considerable advantage is likely to be gained by those who consider and plan early for the future impacts of climate change – particularly given that many decisions today will have consequences well into the future.

"This means learning about climate change and its ramifications by sorting the rhetoric from reality; it also means engaging in the right networks and processes and gaining access to the right information and skills."

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08

Climate change & human health: Impact & adaptation issues for New Zealand

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Adaptation to climate change is important and necessary because climate change is already happening and substantial impacts in the future are inevitable. Successful adaptation will require individual as well as collective action at the community, national and international level in order to reduce the direct and indirect impacts on health. This paper briefly summarises the likely impacts of climate change on health, globally, but focuses on adaptive measures that might be undertaken in New Zealand.

Climate change will have a wide variety of health impacts; many are predictable but some not. Higher maximum temperatures will lead to water shortages, occupational health concerns for outdoor workers, increased heat-related deaths and illnesses, and contribute to an extended range of some pest and disease vectors. In some areas, there will be increased droughts leading to forest fires, increasing hospital admissions, while in other areas more intense rainfall will lead to mudslides, flooding and contaminated water supplies. More intense weather events are likely to increase the risk of infectious disease epidemics and the erosion of low-lying and coastal land. Indirect effects of climate change, such as mental health problems, are likely to occur from economic instability and forced migration.

Adaptation policies should be as equitable as possible, because some groups in society have less knowledge and less social, human and financial capital with which to adapt. If proposed policies are considered equitable and fair, they are likely to be more generally acceptable. Because of existing socio-economic disadvantages, some groups will require special consideration and deliberate support by local and central government.

Both low and high carbon world scenarios require major adaptation measures in key infrastructure such as housing and the supply of drinking water and energy. But in a high-carbon world scenario, New Zealand could become a ‘lifeboat’ to those living in more vulnerable South Pacific countries who are displaced by the impacts of climate change, and the scale of health and social problems to be faced by New Zealanders could become considerably more serious.

1. Introduction

It has become clearer as the science of climate change has consolidated that societal adaptation to climate change will be necessary because a significant amount of climate change is inevitable (IPCC 2007, Parry et al. 2009). The exact amount of global warming 'in the pipeline' is a matter of scientific uncertainty: '…we are still left with a fair chance to hold the 2°C line, yet the race between climate dynamics and climate policy will be a close one' (Schellnhuber 2008). Human systems, and to some extent the natural systems on which they depend, must adapt in response to the present and future effects of climate change (Rogeli et al. 2009).

Successful adaptation may be possible if people take collective responsibility for this problem, but it will require major changes in policy, as well as cultural and behavioural change (Chapman & Boston 2007, Lorenzoni et al. 2007). It will also require ongoing efforts to ensure the adaptation burden does not become too large. However, many people think that the risks from climate change are still uncertain, mostly in the future and more likely to affect people in other countries (Rathzel & Uzzell 2009). Along with a disregard for future generations, these are all factors that lead people to discount the risks and the need for action sooner rather than later (Swim et al. 2009).

Some of the major impacts of climate change are likely to be on population health (Hales & Woodward 2006). A recent review concluded that climate change is potentially the biggest global health threat of the 21st century (Costello et al. 2009). Higher maximum temperatures will lead to increased heat-related deaths and illnesses and contribute to an extended range of some pest and disease vectors. In some areas, there will be increased severity and frequency of droughts leading to forest fires; in other areas more intense rainfall will lead to slope instability, flooding and contaminated water supplies. More intense, large-scale cyclones will increase the risk of infectious disease epidemics (e.g., via damaging water supplies and sewerage systems) and cause the erosion of low-lying and coastal land through storm surges. Indirect effects of climate change will occur from economic instability, loss of livelihoods and forced migrations.

A range of policies based on early indications of change and the precautionary principle in relation to future change is essential if communities are to protect their health and well-being in the face of climate change. The structure of social systems underpinning population health and adaptive capacity, and the interaction between the vulnerability and resilience of individuals, families and communities and regions, is of crucial importance. "Prevention is better than cure", so we need to make strenuous efforts in both mitigation and adaptation, if we wish to avoid major health impacts.

Politically and socially, adaptation to climate change requires that we recognise social inequalities and the related ethical issues of who will benefit from particular policies. Adaptation policies should be as equitable as possible, because some groups in society have less knowledge and less social, human and financial capital with which to adapt. Indeed, there is some UK evidence that if the actions proposed by these policies were equitable and fair, more people would be more likely to adopt them (Darier & Schule 1999). Clearly, some groups will require special consideration and deliberate support by local and central government.

The rest of this paper is structured as follows. We begin with consideration of the projections of climate change effects, focusing in particular on infectious disease and flooding impacts, probably the two areas of greatest direct health impact. We then turn to indirect effects on health, drawing out the implications of socio-economic impacts. The rest of the paper considers adaptation at different scales, starting with adaptation at the micro level and working up, through the community level, cities, the national level and lastly to global level adaptation issues.

2. Projection of climate change effects

Projections of future climate change come from past observation, observed interventions and modelling. The NIWA models, outlined by Reisinger et al. (2010) detail the potential effects of two climate change scenarios. The first is the 2°C scenario, the "rapidly decarbonising world" scenario, in which there are local effects of heat and air pollution and an extended range of vector-borne infectious diseases. The second is the 4°C scenario, the "high carbon world" scenario, in which there will be a substantial increase in all these effects. The 4°C scenario is now starting to look increasingly likely (Ramanathan & Feng 2008, Rogelj et al. 2009, WBGU 2009). There are already major direct and indirect impacts globally, including in the Pacific, which are beginning to involve considerable social disruption and, potentially, migration (Oxfam 2009). While both these scenarios call for major adaptation measures in key infrastructure such as housing and the supply of drinking water and energy, in the more extreme scenario, New Zealand becomes a 'lifeboat' to those living in more vulnerable countries that are displaced by the impacts of climate change, and the scale of health and social problems New Zealand will have to face becomes considerably more serious (Hales & Woodward 2006).

> "We should be aware of the potential for surprises: the European heat-waves in 2003 were estimated to have killed 70 000 people, but no epidemiological models predicted this scale of mortality before the event."

In the rapidly decarbonising world scenario, it is possible to estimate health impacts. We already know that in Auckland and Christchurch a small number of heat-related deaths occur annually in people aged over 65, and the incidence of these heat-related deaths is likely to increase (McMichael et al. 2003, Hennessy et al. 2007). Core body temperature is approximately 37°C in all human beings and it requires only a relatively small change to higher or lower temperatures around this optimum before health is affected (Parsons 2003, Kovats & Hajat 2008). Currently, in New Zealand there are around 1600 excess winter deaths, largely due to respiratory and coronary conditions. Warmer temperatures from climate change may reduce the number of the very old and the very young dying in winter (Davie et al. 2007).

Because people in New Zealand increasingly understand that cold, damp winter weather is bad for their health, the prospect of rising temperatures may reduce their concerns around climate change. This belief may then become another barrier to changing their behaviour to mitigate climate change and supporting appropriate government actions to do likewise.

We should be aware of the potential for surprises: the European heat-waves in 2003 were estimated to have killed 70 000 people, but no epidemiological models predicted this scale of mortality before the event (Hales & Woodward 2006, Gosling et al. 2007). Apart from heat-related deaths, there are other possible harmful health effects from increasing temperatures. For example, there is growing awareness that there are likely to be serious non-fatal effects from heat stress in outdoor workers, particularly if they have prolonged exposure to higher temperatures without breaks and without opportunities to rehydrate (Kjellstrom 2009).

The combination of warmer temperatures and increased rainfall variability is likely to increase the intensity and frequency of food-borne and water-borne diseases. Several studies have found relationships between temperature and food poisoning, as well as between temperature and specific enteric diseases (Bentham & Langford 2001, Kovats et al. 2005, Hashizume et al. 2007). A European study found that temperature influenced transmission of salmonellosis infection in about a third (35%) of all cases of this enteric disease (Kovats et al. 2004). This association between temperature and salmonellosis has also been found in Australia (D'Souza et al. 2004, Zhang et al. 2007). A recent New Zealand study found a similar association, namely, that a 1°C increase in monthly average ambient temperature was associated with a 15% increase in salmonellosis notifications within the same month (Britton et al. in press). Diarrheal disease in the Pacific islands is also sensitive to both temperature and extremes of rainfall (Singh et al. 2001).

European studies have shown that higher temperatures increase the amount of allergen-producing pollens, potentially leading to exacerbation of asthma symptoms (van Vliet et al. 2002). Higher temperatures and lower rainfall worsen droughts, in turn increasing the risk of forest fires and dust-storms, both of which increase the likelihood of hospital admissions from respiratory and cardiovascular conditions (Emanual 2000, Motta et al. 2005). There is potential for synergistic impacts from higher temperatures on the current respiratory and coronary impacts of photochemical smog (Dickerson et al. 1997, Bernard et al. 2001) and fine particulate matter (Ebi & McGregor 2008).

Higher temperatures are already having an impact on water supplies in many places. Increased variability of rainfall affects the supply of water for drinking as well as for agriculture and horticulture. In New Zealand, areas with higher socio-economic deprivation have a poorer quality of reticulated water (Hales et al. 2003). So we would expect that, as a result of climate change, any competition for dwindling supplies would particularly affect the already socially and economically disadvantaged. Climate projections suggest that there will be a reduction in rainfall and more frequent dry conditions in the north and east of the North Island and most of the east coast of the South Island, which is likely to have an impact on agriculture and forestry and exacerbate regional inequalities (Mullan et al. 2005, MfE 2008). It could also affect household water supplies in dry periods. Currently, 11 of 73 local authorities in New Zealand have water metering systems that meter and charge for water supplied to households (Hide 2009). Unless there is a policy developed to ensure that households have a right to a minimum amount of water at no charge, water charging could further increase inequalities and infectious diseases that are influenced by hygiene levels (e.g., skin infections and gastrointestinal infections). Indeed, minimum access to water to allow hand-washing and general cleanliness can be considered a basic public good that helps protect the whole community from infectious disease spread.

3. Infectious diseases

There is a major concern about the impact of climate change on infectious diseases (Crump et al. 2001). Warmer temperatures and increased rainfall variability are likely to increase food-borne and water-borne diseases. Infectious agents, such as protozoa, bacteria and viruses, and vector organisms, such as mosquitoes, ticks and sandflies, have no thermostatic mechanisms, so reproduction and survival rates are strongly affected by temperature levels and fluctuations.

In terms of vector-borne diseases, parts of the North Island may become suitable for breeding the mosquitoes that are a competent major dengue vector. But while much of New Zealand will become receptive to other less-efficient vector species, the risk of dengue in New Zealand may remain below the temperature threshold for local transmission even beyond 2050, under both scenarios, unless of course these scenarios turn out to underestimate future temperature increases (Hales et al. 2002). Competent mosquito vectors for Ross River virus are already established in New Zealand (McMichael et al. 2003) and a study in Australia found a relationship between high levels of rainfall and outbreaks of Ross River virus infection (Woodruff et al. 2002). Consequently, there may also be potential for climate change to lead to outbreaks of Ross River virus infection in New Zealand.

There has been a rise in tuberculosis globally and nationally. The incidence of tuberculosis in Tuvalu (295 per 100 000 per year) and Kiribati (372 per 100 000 per year)[1] is at least an order of magnitude higher than the rates of tuberculosis in New Zealand (7 per 100 000 per year) (Lim et al. 2009). We know that population movement increases the transmission of tuberculosis, but the main risk factor requiring rapid societal and housing adaptation is crowding in households (Baker et al. 2008). Recent reports have estimated that by 2050, in just three low-lying Pacific atolls, all with strong political and social links to New Zealand, about 235 000 people in the Republic of Kiribati, 20 000 people on Tuvalu and 800 people on Tokelau will likely be at high risk of climate change-related migration. This is because these islands are extremely vulnerable to the projected changes in sea level because of their small size, low elevation above sea level, lack of resources, population pressures and insecure water, food and financial situations (Mimura et al. 2007, Britton 2009).

Families that are forced by the consequences of climate change to leave their island homes are likely to form a pattern of chain migration to New Zealand (Pene et al. 2009). Unless New Zealand recognises the need to rapidly build extended-family houses, or generally increase the supply of low-income family housing to accommodate these immigrants, we are likely to see an increase of overcrowding in state houses and other low income houses. This could dramatically increase the risk of a number of infectious diseases for which crowding is a risk factor (Baker et al. 2000).

[1] WHO 2008: Core Health Indicators. Available from: http://www.who.int/whosis/database/core/core_select.cfm (accessed 9 December 2009)

4. Flooding

Flooding from extreme weather events and the effect on water catchment areas is already a key civil defence issue and a regional water and land management issue in New Zealand. Adaptation to more flooding will require increased work throughout catchments, such as stop-banks to minimise flooding, planting trees, retiring farmland on unstable hill country, and restricting, as well as re-locating, housing developments.

Coastal flooding is likely to be one of the most dramatic consequences of climate change globally, and perhaps for New Zealand as well. Current estimates of the number of people at risk globally from flooding by sea level rise and coastal storm surges vary from 600 million to 1.2 billion (Wilbanks et al. 2007). According to mid-range IPCC climate scenarios, based on a 40 cm rise in sea level by the 2080s, there could be 200 million affected (Patz et al. 2005). Since the Fourth Assessment Report by the IPCC, however, estimates for sea level rise have been increasing, with some research suggesting a risk of 1.5-2 m by 2100 (Richardson et al. 2009).

The impact of Hurricane Katrina on New Orleans (USA) provided a tragic example of the possible consequences of extreme weather events and cumulative socio-economic disadvantage. Several structural factors in this situation meant that low-income African-American people were most affected: they lived in the residentially segregated, low-lying areas; there was little public transport available for evacuation; the levees were poorly maintained; there was endemic corruption and no functional emergency plan; and generally there was poor policy implementation (Kates et al. 2006).

As Sen (1999) has highlighted, inherent capabilities as well as ability to function in society are important for health. Those with higher incomes and wealth, as well as social and cultural capital, have many more resources available to them through their networks. It is important that adaptive responses, such as health and housing protection and provision during and after extreme events, should not increase health inequalities. The deaths from drowning and destruction caused by Hurricane Katrina and the mass evacuations led to a doubling of mental health problems among the survivors, particularly in those who were already vulnerable through not having partners (Kessler et al. 2006). In contrast, there were *lower* rates of suicide ideation than before the disaster, with this being associated with increased closeness to loved ones, developing faith in one's own abilities to rebuild one's life, increased spiritual or religious feeling, and finding deeper meaning and purpose in life. This pattern of differing mental health responses graphically illustrates the variable adaptive capacity of communities and population and highlights the concept of individual and community resilience.

The fate of New Orleans also highlights the precarious location of many settlements in relation to the availability of secure freshwater supplies, as well as the location of many towns and cities in relation to river flooding. Apart from freshwater and adequate food supplies, other essential infrastructure for maintaining health and saving lives following extreme events includes electricity supply, transport and telecommunications.

Government policies to ensure that water and energy infrastructure and systems work well during extreme events need to consider equity as well as efficiency. Concerns about extreme events having a repeated impact on certain locations, and the difficulty of maintaining hygiene and contagion controls, mean that in some cases whole towns, or even parts of cities, may need to be relocated. For example, in New Zealand, the small far north town of Kaeo has been flooded several times in recent years and questions have been raised as to whether its location is sustainable. But given low income levels and less disposable income for private insurance in such towns, government assistance is likely to be needed to facilitate such major adaptation.

“The deaths from drowning and destruction caused by Hurricane Katrina and the mass evacuations led to a doubling of mental health problems among the survivors, particularly in those who were already vulnerable through not having partners.”

5. Indirect impacts on health from socio-economic effects of climate change

There are also likely to be indirect impacts on health from climate change, through multiple economic consequences and environmental problems, such as disruption to food and water supplies, which could lead to civil conflict. While New Zealand is less likely to be affected by these consequences than elsewhere in the world, we are already seeing the consequences of uncertainties arising from an economic recession, possibly interacting with people's future planning taking into account climate change, which may have led to more migrants coming to New Zealand in 2009 than in the previous five years.[2]

Mental health issues, as mentioned above, have been shown to follow environmental disasters. Mental health problems ranging from depression to suicide can arise from a range of effects associated with climate change, such as prolonged drought and the economic losses that follow. For migrants, who have to leave their homes, there is a deep sense of cultural loss as well as the stresses that come from forced relocation (Oxfam 2009).

6. Adaptation at an individual level

People living in remote communities are likely to be at increased risk due to their isolation and poor access to services. There is a clear relationship between flooding, drought and fire, leading in some cases to suicide, and severe mental health impacts in rural communities

[2] http://www.stats.govt.nz/~/media/Statistics/Browse%20for%20stats/IntTravelAndMigration/HOTPAug09/InternationalTravelAndMigrationAug09HOTP.ashx (accessed 9 December 2009)

(Smith et al. 1990, Fritze et al. 2008). These extreme weather events are likely to be increased by climate change as the 2008 fires in the state of Victoria and projections by CSIRO suggest (Hennessy et al. 2006).

Clearly, not all populations have equal access to material resources and services. For example, households with low income and little or no wealth are more likely to be less educated and therefore are less able to make contingency plans. The very young and old, sole parents with children and those with chronic illnesses and disabilities are all likely to be similarly disadvantaged. Indeed, those living in socio-economically disadvantaged, residentially segregated areas, where there is less public transport and fewer people who own or have access to cars, are likely to be particularly at risk from climate change impacts.

We know from the work of Paul Slovic and colleagues that those who are vulnerable are understandably more risk averse than those with more material resources and may be more attached to riskier places where they can access resources through local networks (Slovic 1987). By contrast, those with more economic power are more likely to be risk-takers, because they are better resourced to cope (Flynn et al. 1987). Furthermore, Douglas & Wildavsky (1982) asserted that people, acting within social groups, downplay certain risks and emphasise others as a means of maintaining and controlling the group. As an illustration, when Slovic wrote his seminal article in 1987, the only risk factor related in any way to climate change that he included among a long list of risks was "coal burning (pollution)" and this was positioned as a "known risk" with a low "dread factor".

Taking appropriate individual action is more difficult than it might seem. It has been shown that in the area of consumption patterns and energy efficiency, people frequently misinterpret the actual causes of actions that mitigate or increase climate change (Nolan et al. 2008). However, consideration of co-benefits associated with mitigation actions could potentially provide powerful incentives to change individual behaviour. For example, walking, cycling and taking public transport could be presented in social marketing campaigns as being less a sacrifice of time and convenience, and more an opportunity to socialise, keep fit and do one's bit towards having a smaller carbon footprint. Likewise, eating a low-meat or vegetarian diet could be presented as a way of reducing coronary and cancer risks, as well as lowering one's carbon footprint associated with food production emissions (Costello et al. 2009). Recent work highlights that about 7% of national emissions (at least for the USA) could be achieved from a range of household level measures "with little or no reduction in household well-being" (Dietz et al. 2009). Indeed, many of these household measures would save householders money in the long term.

7. Adaptation at a community level

Because of its many local features, including the need to engage local communities, a critical path to better adaptation is from local government action (including by regional councils). For example, some adaptation requires a range of infrastructure investments, including even the progressive modification of urban form, although planning lags make the latter a slow process (Chapman 2008). Intensifying housing can, for example, reduce the vulnerability of dispersed communities and at the same time help build social capital that links together different social and ethnic groups, while reducing car dependence and energy use (Kennedy et al. 2009). This could have a variety of health and environmental (mitigation) advantages.

Councils have a key role to play through their planning processes for infrastructure development, such as Long-Term Council and Community Plans and Regional Land Transport Programmes, and their roles under the Resource Management Act. They also have key roles in the management of the 'three' waters, fresh-water, storm-water and waste-water. In all these areas, spending decisions can strongly influence community choices and adaptation options. Councils can also support civil society organisations including NGOs undertaking mitigation, adaptation and resilience building in their local communities. One example of this sort of organisation is the 'transition towns' movement, which is focused on local solutions to issues such as peak oil and climate change. However, it is unclear whether this movement will increase or decrease inequalities in resilience and preparedness in low-income communities, as it appears to be largely a middle-class initiative in New Zealand. Many of these potential local government actions to adapt to climate change can be supported by central government actions. These include ensuring greater legislative powers for local government and allowing local government to improve its resourcing (e.g., by raising revenue from petrol and other taxes).

8. Adapting cities

Most New Zealanders (85%) live in cities; however, most of our cities do not have high density housing and apartments and have instead developed large sprawling suburbs. Urban sprawl increases carbon emissions – a mitigation issue – but may also increase people's everyday vulnerability to extreme weather events, as more transport infrastructure per person is needed for more distributed populations.

Urban design and planning is beginning to incorporate climate change adaptation considerations (Ruth & Coelho 2007, Kirshen et al. 2008). Most attention so far seems to have focused on dealing with storm-water run-off and urban heat island effects in urban areas. Temperatures in large urban areas can be between 5 and 11°C higher than their surrounding rural environs, because heat from the sun absorbed by urban building materials during the day is slowly released back into the urban atmosphere at night (Patz et al. 2005). Ways to reduce the heat island effect include increasing the number of trees on streets, the area of parks, roof-top gardens and reducing new roads and other hard and artificial surfaces such as parking lots.
Passive cooling of buildings, through good design and construction and the painting white of some surfaces (especially roofing), can also reduce heating. Regarding storm-water, rooftop water collection can reduce run-off risks, as can ground-level features such as replacement of hard surfaces by pervious paving and having well vegetated swales (i.e., low lying areas of vegetated land which can hold run-off). Reducing the risk of storm-water incursion into sewerage systems also has clear health benefits, especially if existing capacity is otherwise at risk of being over-whelmed, with sewage-contaminated overflows into back gardens, streets, streams, rivers and harbours. The latter may have particular importance for Māori, in terms of protecting traditional marine food sources such as shellfish.

At the community level, enhanced social networks can provide closer monitoring of, and assistance to, vulnerable people and populations in times of need. Mixed land-use urban planning can foster socio-economically and ethnically integrated suburbs and strengthen 'weak ties', the social contacts that can provide people with new information that they are less likely to gather from close friends and family (Granovetter 1983). These social contacts are important to prevent deaths in extreme weather. As was evident in recent overseas heat waves, lack of trust can keep people locked in over-heated rooms (Klinenberg 2002).

9. Adaptation at a national level

National efforts to adapt to climate change to ensure that the social, economic and environmental determinants of population health do not move in an adverse direction will require a major reconsideration of many existing policies. An analysis of recent New Zealand Government initiatives suggests that policies across a range of areas show little forward progress and a number of retrogressive actions (Wilson et al. 2009). A lack of progress on mitigation has the longer-term effect of making adaptation more difficult.

The policy approach of emphasising co-benefits to human health and social and economic well-being seems to hold the most hope for policies that encourage both mitigation and adaptation. For example, improved urban design will have benefits for social capital and mental health, providing adaptive capacity and resilience as well as increasing the eco-efficiency of living in the city (Hales et al. 2007).

Similarly, there are demonstrable multiple benefits from retrofitting houses to make them more energy efficient, in terms of health and education outcomes, and energy savings (Chapman et al. 2009). Raising standards in the Building Code so that houses are better able to withstand extreme winds and rain is also likely to lower the relatively high level of excess winter deaths in New Zealand (Telfar Barnard et al. 2008).

In anticipation of an increase in climate change-related migration, there is a case for greater provision of extended family housing for families who are likely to come to New Zealand through chain migration (Pene et al. 2009). Some of this new housing stock needs to be social housing. Research on social housing tenants has shown that when tenants from the private rental market are moved into social housing their rate of hospitalisation reduces significantly; this indicates an improvement in their health and a saving for the taxpayer (Baker et al. 2009).

While many of these changes require central government level actions, they may also involve a re-balancing of power with local government, even a shift in power to the latter, as discussed earlier in this paper.

10. Adaptation at a global level

If a high carbon world eventuates (as projected in the higher carbon and higher temperature scenario earlier in the paper) it will intensify many population health problems. However, with complex systems we cannot simply extrapolate existing quantitative models of health impact, so that it is more difficult to specify adaptive measures. It seems likely that the flow-through effects of global social dislocation under this scenario will be important and major social and health impacts on New Zealand could be expected, especially through the impact of increased climate change-related migration and global economic and social insecurity, even if some of the more worrying possible developments are avoided (Dyer 2008).

Some authors have called for dramatic global solutions requiring global government decisions to over-ride national considerations, as national adaptation measures are likely to be increasingly ineffective, especially in poorer countries. Some have suggested that global imperatives will require New Zealand cities to become rapidly intensified to restrict urban sprawl and enable more intensified agriculture (Vince 2009). Yet others have argued that we need to optimise land use globally in order to maintain adequate food supplies and exchange migration rights and food security in return for protection of "terrestrial commons" (Müller et al. in press). However, this would present major governance challenges, and it is not clear that we are equipped to do this in the limited time available before major impacts occur. As Vaclav Smil has argued, "[e] ffective planetary management is far beyond our intellectual and social capabilities [although] …we are doing it anyway" (Smil 2002). Such proposals would require a major rethinking of the requirements of economic development and climate adaptation, to balance individual rights with the survival of whole human populations (Sen 1999).

11. Conclusion

Planned adaptation to climate change, driven by the need to sustain economic development, health and well-being in the face of potentially major disruptions to critical natural systems, is essential for New Zealand. Fortunately, well managed adaptation can potentially make substantial positive contributions to the health and social and economic well-being of the whole population. Fundamentally, there are many co-benefits to health of moving to a low-carbon economy and one of the biggest is the reduction of the future burden of adaptation. Meanwhile, a major aim must be to improve the resilience of vulnerable communities.

There are many adverse direct and indirect health effects of climate change already apparent, and with substantial climate change already 'in the pipeline', greater effects will become apparent over time. Maintaining population health in the face of these major changes must be a central aim of adaptation policy. This will be a stretch even in a rapidly decarbonising world, but will present profound and unprecedented challenges if a high carbon world eventuates. The direct health effects may be largely driven by extreme weather events, but globally the indirect effects flowing from forced migration and economic and political uncertainty are likely to have a greater impact on health over time, by acting on the broader determinants of health. Factors such as the indirect impact of acidification of oceans affecting food supplies remain as yet imponderable, but of increasing concern.

The high carbon world scenario is likely to involve major global social disruption, which will bring further risks of infectious diseases and other impacts on health. However, we cannot extrapolate health impacts in a simple linear fashion as we cannot as yet delineate, let alone quantify, all the threats to health that will arise from a rapidly changing climate system.

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09

Local government adapting to climate change: Managing infrastructure, protecting resources, & supporting communities

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Climate change presents risks to a number of local government functions, including water supply, wastewater treatment and disposal, transportation, flood and coastal management, waste collection, recycling, management and disposal, providing and maintaining social infrastructure, civil defence responsibilities, and community support.

Projections of the likely climate change impacts for New Zealand enable local government to undertake risk assessments to an appropriate level across their range of services, allowing them to focus on areas of high risk. Once key risk management areas have been identified, local government has a legislative mandate to undertake both adaptation and mitigation as well as requiring others to manage these risks. Incorporating adaptation measures into plans can also present opportunities for long-term community benefits.

Key Resource Management Act related instruments which seek to increase national and regional integration, and hence have the potential to greatly assist local government with implementation of adaptation planning, are National Environmental Standards, National Policy Statements and Regional Policy Statements.

The communication requirements to engender the changes required should not be underestimated. Innovative approaches to communicating sustainable development and climate change adaptation messages should be used by councils seeking to work through changes that may significantly affect communities in their regions. A number of excellent local and international case studies demonstrating climate change adaptation are available giving insight into the adaptation risks and requirements for council decision makers and communities.

1. Introduction

This paper discusses a range of issues relating to local government, the effects of climate change on the communities they support and the infrastructure they manage. It focuses on opportunities to promote adaptations to avoid or mitigate significant negative impacts on the natural environment, and on communities and the infrastructure they depend on. It also identifies potential barriers to the adoption of these approaches.

Adaptation measures to protect communities from flooding, coastal inundation, water resource availability risks or other climate related hazards are already commonly in place. Risk management, hazard management, low impact urban design, energy saving, water efficient design, community resilience and other terms are in common use to describe these adaptation measures. All of these approaches can be central to, or assist with, climate change adaptation.

We define local government or local authorities as regional councils, district and city councils and unitary authorities. As the effects of climate change are likely to impact on all infrastructure that local government is responsible for, including transportation, this paper should also be of interest to national infrastructure providers such as the New Zealand Transport Agency (NZTA), Transpower and the New Zealand Railways Corporation (NZRC).

The legislative framework for local government management of infrastructure and natural resources is interpreted for climate change adaptation, highlighting opportunities and risks.

There are a number of local government functions that have the potential to be significantly influenced by climate change. These include:

- policy and plan making
- infrastructure provision
- resource management and allocation
- community services provision.

The risks, challenges and opportunities associated with effects of climate change are outlined here. The necessity for prudent development and use of legislative and policy instruments is discussed. The final sections of this paper relate to the human aspects of communication about climate change. We present some ideas and insights into effective communication about complex and sometimes uncertain science and impact assessment that may help us to collaborate with communities.

2. Local government functions

Many of the functions of local government relate to or can be affected by climate change. The Local Government Act 2002 (LGA), states that the main purpose is "…to promote the social, economic, environmental, and cultural well-being of communities, in the present and for the future." Inherently this requires councils to have policies and plans that include a view of the future encompassing climate change.

A core function of local government under the Resource Management Act 1991 (RMA) is the integrated management of natural and physical resources. This includes a requirement to plan for the future in managing the effects of land use, avoiding and mitigating natural hazards, and to have particular regard to the effects of climate change.

With the powers that local government holds in policy and plan-making comes the ability to approve and control both development by third parties and the development and maintenance of the councils' own infrastructure. Councils have responsibilities to ensure that their decision making in planning policy and zoning is based on defendable science, is transparent to stakeholders and is fairly administered. A good example is the case study of industrial land rezoning in Invercargill City (Case Study 1).

Case Study 1.

Industrial land rezoning programme, Invercargill City, 2008.

Invercargill City purchased 600 ha of land for industrial development following a site selection exercise. A change to the Invercargill District Plan was required to enable the land to be rezoned from rural use to industrial use. During the process the potential effects of climate change were raised by Environment Southland. Invercargill City was required to identify and quantify as far as possible the long-term effects of sea level rise, the impacts of changes of storm patterns on coastal processes, and changes in stormwater runoff patterns resulting from changes in rainfall intensity/duration.

The studies confirmed that the site was suitable for industrial development, but required a more extensive coastal buffer and greater setback conditions from flood prone areas. Once these amendments were made to the planned change for rezoning, Environment Southland withdrew its submission in opposition to the change. The rezoning process required technical inputs on climate change impacts and demonstrated the need for best possible information. It also highlighted the effectiveness of a risk-based approach and the desirability of consultation with key stakeholders early in the planning process.

Councils are responsible for many functions which provide support for their local communities, all of which may be affected by climate change. These include:

- constructing and managing roads
- water supply and water resource management
- water and wastewater treatment and disposal
- waste collection, recycling, management and disposal
- providing and maintaining social infrastructure, including recreation and leisure facilities
- civil defence responsibilities
- community support and outreach.

Councils will also often be the first port of call for individuals or community groups seeking information and advice on climate change impacts.

"Councils will also often be the first port of call for individuals or community groups seeking information and advice on climate change impacts."

3. Future risks from climate change

A summary (MfE 2008a) of the report originally commissioned by the Ministry for Environment (MfE), 'Climate Change Effects and Impacts Assessment (2nd ed)' (MfE 2008b) outlines the following broad climate change projections for New Zealand:

- an increase in the average temperature and sea levels
- southern and western areas generally becoming wetter
- eastern and northern areas generally becoming drier
- an increase in drought frequency, particularly in the eastern parts of the South Island and central North Island, and
- a likely increase in the occurrence of extreme storm events.

Some of the projected changes to New Zealand's climate may lead to the exacerbation of weather related hazards, such as flooding, coastal inundation, rainfall-induced landslides and potable water security. With increased flooding risk, for example, comes increased chance of loss of life, damage to property, landslides affecting property and infrastructure and the potential for loss of productive soils. The 2004, 1 in 100-year, floods in the Manawatu were estimated to cost $150 million. There is potential for 1 in 100-year events to occur more frequently in the future with clear consequences for the associated costs of disasters.

It is no longer acceptable for local government to base projections for the future on the lessons of the past. Predictive models that take into account the latest projections of climate change from the Intergovernmental Panel on Climate Change (IPCC) integrated with more local knowledge are required. The National Institute of Water and Atmospheric Research (NIWA) has updated the High Intensity Rainfall Design System (HIRDS) database for prediction of storm intensity, for example, and similar expert knowledge should be sought by local government where other meteorological, sea level or storm surge data are critical.

Many of the impacts of climate change are focused on the coastal environment and include significant consequences for coastal property and infrastructure due to storm surge, erosion and saltwater intrusion. In addition there are likely to be impacts on the terrestrial habitats of the coastal zone which in some cases provide shoreline or estuarine protection.

There have been significant investments on the coast, with an estimated $1 billion of real estate being situated in the Coromandel coastal hazard setback zone alone. This hazard zone was determined by the Thames Coromandel District Council (TCDC) and incorporated in their district plan.

To assist local government in selecting an appropriate sea level rise projection to plan for, MfE is currently scoping the development of a National Environmental Standard (NES) on future sea level rise. The NES prescribes a base threshold of future sea level rise to plan for, along with requiring consideration of the consequences of a higher sea level rise. For planning and decision timeframes out to 2090-99 a base value sea level rise of 0.5 m relative to the 1980-99 average will be used. The potential consequences of a range of possible higher sea level rise values will also be assessed. At the very least, all assessments will consider the consequences of a mean sea level rise of at least 0.8 m relative to the 1980-99 average (MfE 2009).

National Environmental Standards are regulations issued under the RMA. They apply nationally and all councils must enforce them. The development of an NES with a prescribed sea level rise will be of significant assistance to local government because it will remove the risk of litigation as councils will not have to determine for themselves appropriate levels to be adopted in regional and district plans.

As changes can be made to NES's, future sea level rise projections can be amended if necessary to reflect the best available information.

3.1 Assessing climate change risks

MfE (2008a) described a pragmatic approach for local government in deciding how to assess climate change risks. The guide describes three stages in risk assessment tailored to be cost and time effective. An overview of the assessment is presented below.

3.1.1 *Stage One: Qualitative assessment of the influence on climate change*

The first stage is a qualitative assessment of the role of climate and hence climate change for a wide range of council functions and services. Functions are tabulated with narrative on affected assets or activities, key climate influences and possible effects. Reference is also made to natural resources, the key climate influences on that resource, impacts of climate change and their sensitivity. Examples are presented in Tables 1 and 2.

After the high level assessment of climate change impacts on council services a decision is required as to whether the impact warrants a stage two, quantitative, analysis. Asset management driven assessments are most likely during major infrastructure development or upgrades. Council plan reviews will also warrant further assessments.

Table 1. Local government functions and possible climate change outcomes (extracted from MfE 2008a).

Function	Affected assets or activities	Key climate influences	Possible effects	Type / Explanation of effects (See Table 2)
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	Rivers Groundwater Water availability Coastal areas
Roading	Road networks and associated infrastructure (power, telecoms, 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	Drainage Natural hazards

Table 2. Sensitivity of natural resources to present climate and climate change (extracted from MfE 2008a).

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 rain events)	Strong seasonal, interannual and interdecadal fluctuations
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

3.1.2 *Stage Two: Preliminary assessment of the impact of climate change*

Due to the uncertainties regarding the extent of climate change, various scenarios can be useful in the preliminary assessment of the impacts of climate change. MfE (2008a) recommends three broad categories of scenario.

1) Social: Demographic changes leading to changes in demand and supply of council services and natural resource requirements
2) Economic: Changes in land use which affect demand and supply of natural resources
3) Physical/environmental: Projected future climate change

The report summary also provides some basic data on temperature projections and rainfall intensity projections that can be used by local authorities.

For rainfall predictions MfE recommends using HIRDS (high intensity rainfall design system) from NIWA with percentage adjustments per degree of climate warming for different rainfall occurrence interval's and rainfall durations. For other climate impacts, such as crop growing degree days, frost occurrence, extreme high temperatures and water deficit for irrigation, the CLIMPACTS model is recommended (Warrick et al. 2001).

The preliminary assessment of impacts based on quantitative climate data should focus on categorisation of the magnitude of risks to infrastructure, development, communities and property. Where these impacts are significant, the investment in a full risk assessment is justified.

3.1.3 *Stage Three: Detailed risk assessment of climate change effects using complex scenarios*

Detailed risk assessments can be undertaken in three main ways as set out below, and often rely on combinations of these for a final assessment or likely range of outcomes.

- Modelling, computer-generated scenarios
- Expert opinion, often required where there is a lack of data or data certainty
- Monitoring, will assist in providing assurance about modelled scenarios over time or provide data for modelling or verification of expert opinion

The decision on which approach to take will be based on the availability of verified data and modelling capability, and assumptions will need to be made regardless of which approach is taken.

Case Study 2 is a recent example of the application of risk methods to climate change impacts assessment on infrastructure.

Case Study 2.

New Zealand Transport Authority (NZTA) research, climate change risks to the land transport network.

The New Zealand Transport Authority (NZTA) commissioned MWH and NIWA to research climate change risks to the land transport networks (state highways, railways, ports and coastal shipping) (Gardiner et al. 2009a, 2009b).

Stage One involved identifying the state of knowledge and prioritising further research for Stage Two. The extensive Stage One review involved stakeholder interviews, reviews of literature, climate change data, and legislation and policy issues, and gap analysis. It also included a risk assessment to identify and prioritise the dominant risks to road, rail and ports/coastal shipping. The results of this risk prioritisation are presented below (Gardiner et al. 2009a).

In summary, the top priority risks relate to:

- *coastal inundation from sea level rise combined with storm surge (ports but also coastal land transport corridors potentially at risk)*
- *inland flooding (all modes)*
- *high rainfall and inland erosion/instability (road and rail)*
- *prolonged high temperatures (heat stress leading to rail buckling in particular).*

Stage Two (Gardiner et al. 2009b) examined the regional effects of climate change on the physical infrastructure of land transport systems with a focus on:

- *temporal and spatial distribution of significant climate change effects*
- *which parts of the surface transport networks are most at risk*
- *multimodal corridors at risk (e.g., common road/rail routes)*
- *when these risks may emerge*
- *what priority adaptation responses are needed to counter these effects.*

A national risk profiling approach was developed to determine the likely regional effects of three high priority risks to the national land transport networks:

- *heat stress (buckling) affecting the national rail network as a result of high temperatures*
- *inundation of low-lying coastal land transport infrastructure (road and rail) caused by sea level rise and storm surge (including a port risk profile study)*
- *future flood risk under climate change for sections of the state highway and rail networks that are currently prone to flooding.*

Scenarios were developed for current (nominally 10-year) and future (50-year and 100-year) timeframes and regional impacts for each mode were illustrated using GIS maps that overlay climate change predictions and transport infrastructure.

√√√√ = Top priority √√√ = High priority

Climate change effect category	Risk	Additional factors	Priority
Coastal flooding (sea level rise and storm surge)	High risk to all three modes	• Top five risk to coastal shipping ('top five' as per the risk prioritisation exercise) • Only some coastal locations affected • Significant costs likely for response options • Particularly important for assets with a long design life	√√√√
Inland flooding	High risk to all three modes	• Top five risk to road • Significant costs likely for reinstatement or rebuilding • Particularly important for assets with a long design life	√√√√
Rainfall	High risk to road and rail	• Top five risk to road and rail • Significant costs likely for reinstatement or rebuilding • Particularly important for assets with a long design life	√√√√
Inland erosion and instability	High risk to road and rail	• Top five risk to road and rail • Significant costs likely for reinstatement or rebuilding	√√√√
High temperature	High risk to rail	• Top five risk to rail • Rail has a long design life • Forward planning is required to allow stage replacement of at-risk rail, and to ensure new designs are adequate	√√√√
Storminess	High risk to all three modes	• Aggregate effects (extreme rainfall and high winds) are top risks for all modes and recommended priorities to progress • Potentially widespread distribution of effects	√√√
Coastal erosion	High risk to road and coastal shipping	• Not a top five risk • Only some coastal locations affected • Significant costs likely for response options • Particularly important for assets with a long design life	√√√
High winds	High risk to road and coastal shipping	• Top five risk to coastal shipping • Most high risks can be mitigated at short notice; however, protecting ports may be difficult	√√√

4. Legislative framework

Key legislation that provides local government with the powers and responsibilities to manage the risks associated with climate change and consider climate change adaptation are:

- The Resource Management Act 1991 (RMA)
- Local Government Act 2002 (LGA)
- Building Act 2004
- Civil Defence Emergency Management Act 2002 (CDEMA).

4.1 Resource Management Act 1991

With its overarching emphasis on sustainable management, future generations, and avoiding, remedying and mitigating effects the RMA forms a backbone for local government in addressing the risks arising from climate change. Part 2 of the RMA is of critical importance and sets out its principles and purpose, in particular to "Promote the sustainable management of natural and physical resources". The principles of the RMA also require that RMA decision makers have particular regard to the effects of climate change.

An interesting aspect of the RMA is the categorisation given to effects (not just those related to climate change):

- past and future effects
- cumulative effects
- potential effects of high probability
- potential effects of low probability that have high potential impact.

The RMA is implemented through a hierarchy of planning instruments:

- National Policy Statements
- National Environmental Standards
- Regional Policy Statements
- Regional Plans
- District Plans.

This hierarchy is designed to achieve national alignment on matters of national significance such as climate change while ensuring the decision making is devolved to those most affected.

Other provisions in the RMA relating to climate change responsibilities include the requirement for councils to gather information, undertake monitoring and keep records including those of natural hazards, and that decision making be undertaken with regard to this information.

An essential element of planning for climate change adaptation is the integration of decision making relating to land use planning and resource allocation locally, regionally and nationally. RMA mechanisms, strengthened in the 2009 amendments, include the ability for councils in a region to come together and produce a combined plan that includes a regional policy statement, regional plans and district plans. This mechanism provides the opportunity for a region to undertake fully integrated planning approaches, particularly in addressing significant cross-boundary issues such as climate change adaptation. However, strong support and commitment will be required from local government politicians to take full advantage of the opportunities for integrated planning provided for under these new provisions.

4.2 Local Government Act 2002

The Local Government Act (LGA) 2002 also adopts a sustainability approach but refers to sustainable development specifically rather than "sustainable management" as in the RMA. Section 3 of the LGA states that "the Purpose of this Act is to provide for the democratic and effective local government that recognises the diversity of New Zealand communities; and, to that end this Act... (d) provides for local authorities to play a broad role in promoting the social, economic, environmental and cultural well-being of their communities, taking a sustainable development approach."

Further to the purpose of the Act, section 14(1) states "in performing its role, a local authority must act in accordance with the following principles... (h) in taking a sustainable development approach. A local authority should take into account:

i. the social, economic, and cultural well-being of people and communities; and
ii. the need to maintain and enhance the quality of the environment; and
iii. the reasonably foreseeable needs of future generations."

The requirement under the LGA to reasonably foresee the needs of future generations with the aim of ensuring community well-being and maintaining and enhancing the quality of the environment places a firm requirement on local government to develop, understand, communicate and manage, risks associated with climate change in their regions, districts and cities. The key instrument, required by LGA for developing the approach and communicating the message is the ten year long-term council community plan (LTCCP). The main tool for addressing risk management for key council assets is an Activity Management Plan. Owners of LTCCP and Activity Management Plans can and should include climate change risks in the review of these documents on an ongoing basis using up to date projections of change.

The LGA provides local government with a mandate to investigate the risks in their regions, districts and cities, to provide for the means and mechanisms to address these risks through the LTCCP and incorporate climate change risk management into Activity Management Plans.

4.3 Building Act 2004

The Building Act also includes sustainability in its core purpose, ensuring that "buildings are designed, constructed, and able to be used in ways that promote sustainable development" (section 3(d)).

The Building Code, along with the responsibility of city and district councils to enforce the Code, provides the strongest opportunity under the Act to ensure that buildings are completed to the required standards while taking into account the latest meteorological predictions. Of particular significance is Clause B1 of the Building Code which requires physical conditions that could affect structural stability, including snow and wind loads to be taken into account in building design. Also of importance is Clause E1 which deals with surface water.

In terms of new building codes, data from NIWA, the Building Research Association of New Zealand (BRANZ) and the local authorities should be interpreted together so that appropriate decisions can be made on climate change adaptation. Active communication between building consent and resource consent divisions in councils is essential to ensure consistency of approach for developers and the community. This integration is critical for the provision of up-to-date information for project information memoranda where there is a requirement to disclose information on special features of the property concerned, including natural hazards. Under section 71 of the Building Act, a building consent cannot be granted if the land is subject to natural hazards such as erosion (including coastal erosion) or inundation (including flooding, overland flow, storm surge, and tidal effects).

4.4 Civil Defence Emergency Management Act 2002

There are several requirements for local authorities under the Civil Defence Emergency Management Act 2002 (CDEMA). The Ministry of Civil Defence and Emergency Management (CDEM 2002) lists these as the following.

- Unite with your regional neighbours and emergency services to form a Civil Defence and Emergency Management (CDEM) Group
- Develop a coordinated CDEM Group plan for how your Group manages its hazards
- Plan and provide for CDEM in your district
- Ensure you are able to function to the fullest possible extent during and after an emergency

A local authority may also be requested to:

- help define the Crown's CDEM goals and objectives in a National CDEM Strategy
- participate in developing a National CDEM Plan
- provide technical advice on CDEM issues to the Director of Civil Defence Emergency Management or another CDEM Group.

There are expectations that the local authority will:

- coordinate, through the CDEM Group, planning and activities related to CDEM in risk reduction, readiness, response, and recovery
- develop plans cooperatively with others
- ensure individual functions (business units) are capable of managing their own response to emergencies to the fullest possible extent
- ensure business units coordinate across their respective sectors.

The process of planned community adaptation to climate change with hazard information being regularly updated should reduce the likelihood of a local authority needing to invoke a civil emergency.

4.5 Health Act 1956

The Health Act 1956 includes a requirement for city and district councils to protect and promote public health and to determine if conditions exist that are likely to be injurious to health. If such conditions do exist, councils are required to take reasonable steps to ensure they are abated or removed. These requirements can include emerging threats to public health associated with climate change (Howden-Chapman et al. 2010).

5. Infrastructure

Local government, and in some cases its subsidiaries, has major responsibilities in the planning, development, operation and maintenance of critical infrastructure for towns, cities, districts and regions. Required activities include:

- securing water sources for municipal supply, and the treatment of that water to potable standards for supply to homes, businesses, etc.
- management of stormwater runoff from roads and urban areas
- provision of safe sanitation, sewage collection, treatment and disposal
- collecting solid waste, recycling and operating landfills
- management of all roads other than state highways, and other infrastructure located in road reserve such as power, gas, and telecommunications
- flood management (stopbanks, ponding areas, pumping stations, etc.).

Some infrastructure, particularly infrastructure located in vulnerable locations such as the coast, riverbanks, and flood plains, will be at risk from climate change. For example, many of our towns and cities discharge treated wastewater into the coastal environment, and as a consequence many wastewater treatment plants are located on the edge of harbours and estuaries and are at risk of inundation by sea level rise and/or storm surges.

Intake structures for municipal water supply in the banks of rivers and streams may also require assessment. During the 2007-08 Waikato droughts a number of councils became very concerned that river levels would drop below the level of the intake structure, putting at risk the security of water supplies.

Case Study 3 presents an example for stormwater disposal from the Indoor Community Sports Centre (ICSC), in Kilbirnie, Wellington.

Case Study 3.

Indoor Community Sports Centre (ICSC) Stadium, Kilbirnie, Wellington City Council.

Modelling and reviewing future stormwater scenarios resulted in climate change being considered in the design and planning procedures for the ICSC Stadium. The proposed stormwater disposal options involved either direct disposal into Wellington Harbour or connecting to the Wellington City stormwater system. The first option involved crossing a major highway. The second option required upgrading of the stormwater network.

The Wellington City Council used the opportunity this project presented to review climate change impacts on the stormwater management plans for the whole of Kilbirnie. Following the review and updating of the stormwater models, the preferred solution was stormwater pumping to the harbour from the two major stormwater outlet pipes. The study highlighted serious impacts from climate change and sea level rise on "levels of service" for low lying coastal stormwater networks and that stormwater pumping is a likely outcome of such assessments in the future.

Many councils are seeking efficiencies and innovation in their approaches to providing and managing infrastructure. Such approaches can have multiple benefits, including climate change adaptation. A good example of this is the work councils are undertaking with the integration of the three urban waters (stormwater, potable water, and wastewater) and the adoption of green technologies. A research project undertaken over the past few years led by Landcare Research and the University of Auckland entitled Low Impact Urban Design and Development (LIUDD) has investigated practices, practicalities, opportunities and barriers to implementation of green design for stormwater management in urban areas. The research project web-portal[1] contains a wealth of information and a wide range of case studies.

6. Challenges for local government

Local governments face many challenges in delivering their infrastructure responsibilities, including the following.

- **Access to reliable and relevant data.** All infrastructure design and development works must be based on local information that needs to be collected, managed and applied, especially if councils are adopting regulatory approaches. There can be significant costs associated with obtaining and verifying this information along with the political commitment to provide the necessary funding. There are also technical challenges in the type of data and the level of detail required.
- **Climate change will impact on different councils in different ways.** Different councils will have different climate change impacts and adaptation requirements. 'One size will not fit all' in adaptation approaches. The 'Urban Impacts of Climate Change Toolbox' currently being developed by NIWA, MWH, GNS Science and BRANZ will provide multiple assessment and adaptation options that can be designed to provide individual council needs and resources (NIWA et al. in progress).
- **Challenges in translating the big picture to regional and local levels.** There is evidence that communities see climate change as a global issue for which central government is responsible. Councils need to make people aware that it is a local issue, particularly in terms of climate change adaptation. Councils have a responsibility to provide local information and tools for adaptation to empower communities to make choices and take action.
- **Need to manage political risks and get councillor 'buy-in' and support.** This can be challenging given the short-term three year electoral cycle and the long term investment required for climate change adaptation. Anecdotal evidence suggests that many councillors, and regional councillors in particular, question the need to plan for managing the effects of climate change and adopting adaptation measures. It is a case of the costs come now, but the benefits are long-term – this can be a hard message to sell, especially with councillors who have been elected on a no rates increase platform.

Local government has faced, and will continue to face, significant challenges when adopting regulatory methods that restrict how people use and develop their properties. Introducing such restrictions through district and regional plan changes and reviews can lead to expensive and protracted litigation due to concerns about loss of property values and restrictions on resource use and allocation.

Local government has also come under increasing pressure from landowners to carry out works to protect properties threatened by natural hazards such as sea inundation, storm surges and flooding. It is anticipated that these pressures will only increase where such hazards are exacerbated through the effects of climate change. This raises the contentious issue for local government and its communities as to whether and to what extent it is appropriate to use ratepayer money to protect private property. There is also concern that some of the smaller councils do not have the resources to act and respond because of their limited rating base.

The ability and agility of councils to respond to climate change through the planning process is hampered by New Zealand's cumbersome plan-making processes. If councils need to act quickly in adapting to climate change, then making changes to district and regional plans may not deliver a quick result. From start to finish, to change a plan takes about 3 years, and to review an entire plan takes, on average, over 8 years. Government has attempted to address this significant issue through the Resource Management (Simplifying and Streamlining) Amendment Act 2009, but the changes made to the plan-making provisions fall far short of addressing this challenging and complex issue.

District and regional plans do, however, provide longer term, strategic opportunities to bring about land use changes and changes to urban form to assist with climate change adaptation.

Councils in their roles as consent authorities can also influence the location of activities, resource use and allocation to minimise the effects of, and risks associated with, climate change and to require measures to be undertaken to assist adaptation.

“This raises the contentious issue for local government and its communities as to whether and to what extent it is appropriate to use ratepayer money to protect private property.”

7. Opportunities – the way forward

There are many apparent challenges for New Zealand in adapting to climate change, but it seems that there is a will for change. The New Zealand Business Council for Sustainable Development (NZBCSD) and ShapeNZ undertook a survey in March 2009 investigating New Zealanders' attitudes to climate change. The survey polled 2851 individuals and presented the following findings (NZBCSD & Shape NZ 2009):

- 76% believe climate change is a problem
- 65% believe that there are already climate change effects
- 53% worry about climate change
- 44% believe personal lifestyles will be affected.

[1]Available from: http://www.landcareresearch.co.nz/research/built/liudd/casestudies/case_studies.asp (accessed 11 January 2010)

These statistics support and reinforce the importance of local authorities communicating with and assisting their communities in adapting to a changing climate and to clearly articulate their expectations for their region, district or city. Ensuring that their policies and plans then reflect these expectations and that the necessary actions are taken to deliver desired outcomes is as important. Anecdotal evidence indicates that in some areas the concerns of the community regarding climate change may be ahead of any commitment and action by the local council. Where such change is grass roots-driven, councillors will be required by the communities they serve to undertake and commit to actions if they expect to be re-elected by that community.

While some local bodies may appear to be slow in responding, other councils are taking action to assist with climate change adaptation. These actions may have originally commenced for another purpose but are now being recognised for their multiple co-benefits, including those of adaptation.

An example of community adaptation by another name is the 'Living Streets' project in Christchurch. Living Streets employs holistic design methods for traffic calming, storm water management and treatment, and landscaping, and promotes bicycle and pedestrian access (Case Study 4). At the same time, these designs increase biodiversity, capture carbon, encourage people out of their cars and assist in reducing the impact of extremes of temperature. The project provides a multiplicity of social, environmental and economic benefits. More information can be found at the Case Study Portal of the Landcare Research-led LIUDD research programme[2].

That adaptation projects can have multiple benefits is a key message for council and community. Communication on changing climates, flooding and coastal hazards can easily be led by, or lead to, fear and subsequent lack of integrated and innovative thinking for solutions.

The insurance industry is providing support and placing pressure on local government to take adaptation actions by increasing premiums or refusing to insure properties and businesses where there are potential climate change risks that are not being addressed by local government actions. In the United Kingdom insurers are producing guidelines for small businesses and the development industry on climate change adaptation. Similar approaches could be followed in New Zealand if the insurance industry considers that this type of information is required and is not being provided by local or central government.

8. Integrated approaches

Integration and coordination are keystone concepts in both the adaptation and mitigation of climate change, whether working at a global level through the United Nations or at a community level in rural New Zealand. Integration is required between levels of government and between the top down and bottom up development of issues, objectives and solutions. Integration is required between departments, disciplines, cultures and communities to build a holistic view of risks and opportunities, and to provide the most productive environment to encourage adaptation solutions.

Where there is an overlap of responsibilities, particularly with regional and city and district councils, it is important, that these are resolved and agreed upon. Regional councils are well placed to provide leadership and ensure integrated and consistent approaches. City and district councils are critical in implementing adaptation, but they need support from regional councils, ongoing commitment, and capabilities and the tools to be proactive and responsive.

As previously discussed, the 2009 amendments to the RMA provide additional opportunities for regional, district and city councils to prepare combined planning instruments. These new abilities provide an excellent opportunity to take an integrated approach to such significant issues as climate change. It will be interesting to see whether there is the political commitment along with incentives from central government to capitalise on these opportunities.

Case Study 4.

Addington streetscape, Christchurch City Council.

Addington is an old neighbourhood that is in need of revitalisation. A Neighbourhood Plan aims to "gradually renew the older residential areas of the city to standards appropriate to today". The kerb and channel renewal project for Addington involves traffic calming, street tree planting, creation of green space, opening up and restoring waterways, landscaping, provision of seats and installation of art features.

Christchurch City Council (CCC) undertook extensive public consultation, hosting community meetings and updating residents and interested parties on the projects in the community newsletter 'Addington Update'. The community was asked what they would like to see in their reconstructed street.

CCC's stormwater management policies promote the improvement of the quality of stormwater run-off before entering waterways. CCC's Waterways, Wetlands and Drainage Guide assists in ensuring that drainage is no longer the sole focus and that projects should be developed that integrate other values, including ecology, landscape, recreation, heritage and culture. The guide encourages people to work with natural features and processes in the landscape.

Addington's unique, wide catchment, combined with anthropogenic issues influenced the approach to the stormwater management in this area. The quantity and quality of stormwater in Addington were the main drivers for CCC undertaking ecological enhancements of the waterways in the area.

CCC has installed a first flush pond, rain gardens and a vegetated swale. These are features designed to help with the ecological enhancement of Addington, and help to slow and filter stormwater run-off through vegetation and soils/sands. Pollutants are trapped and processed (through plant uptake) before they reach downstream waterways. The amount of impervious area has also been reduced following enhancement works.

The risk of flooding has also been reduced. Historically, during heavy rainfall events gutters cannot always cope and surface flooding can occur. First flush ponds, rain gardens and swales reduce the likelihood of flooding both in the immediate area and further downstream by providing greater drainage capacity and detaining stormwater run-off so that it discharges into waterways at a slower rate.

[2]Available from: http://cs.synergine.com/CaseStudies/tabid/73/Default.aspx (accessed 11 January 2010)

9. Communicating the messages

A critical component of implementing climate change adaptation is communication and ensuring communities understand the message and have the tools to make choices and take action. Councils are likely to be the first port of call for their communities for information on climate change and guidance on adaptation. Local authorities in New Zealand should also consider recent research and experience in other countries when planning their communications strategies. Some useful communication messages have been developed by Futerra, a UK based communications organisation that promotes sustainability. Key messages include the following (Futerra, no date).

- Keep it personal – make climate change messages as personal as possible. Create climate messages about 'my region, my town, my street, my house, my business'
- Help people to help – climate change communications can make people feel bad, irrelevant and useless. Help people to understand (and trust) that they are making a difference
- Use fear with caution – fear can create apathy if individuals do not have the ability and tools to act upon that fear
- Give people the knowledge to decide and the tools to act – change will occur when people know what to do, decide for themselves to do it, have access to infrastructure in which to act, and understand that their contribution is important
- Link climate change adaptation to positive outcomes – home improvement, saving money and resources, business opportunities, self-improvement, and green space, biodiversity, etc.
- Seeing is believing – climate change is language heavy, but light on visuals. Many climate change awareness programmes provide detailed scientific information and expect communities to understand and act on this information. Many people do not have the knowledge to understand graphs and figures, and raw scientific information is unlikely to be effective in motivating behavioural change. To have an effective impact, materials need to send clear messages in a manner that the audience will understand – "see it, feel it", "see it, believe it".

10. Conclusions

Actions relating to planning for and implementing adaptation to climate change are required across a wide range of local authority responsibilities and activities. There is both a legislative requirement for risk assessments and risk management to be undertaken and a mandate for local authorities to implement change and require others to change.

Some climate change risks are very significant. They include threats to homes, communities and critical infrastructure. These risks require political engagement and a commitment to manage. Sound planning and communication are essential for the development of acceptable and efficient adaptation and mitigation strategies. Sound decision-making should be based on good data for modelling, expert opinion from a wide range of disciplines, and careful integration of this data and opinion into planning processes and plan implementation.

There is clear evidence that planning processes and projects that include climate change adaptation will produce multiple benefits in the long term. It is essential that case studies of well planned and executed sustainable development projects which include climate change adaptation are shared nationally and internationally to motivate and inspire. There is great potential for local governments to work collaboratively and in partnership with each other and with central government to ensure that efficient and effective adaptation is implemented across New Zealand.

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New Zealand Climate Change Centre

The New Zealand Climate Change Centre (NZCCC) is a joint initiative by New Zealand's Crown Research Institutes and two universities. Present members are:

- AgResearch
- Environmental Science & Research (ESR)
- GNS Science
- Industrial Research Ltd (IRL)
- Landcare Research - Manaaki Whenua
- National Institute of Water & Atmospheric Research (NIWA)
- Plant & Food Research
- Scion
- University of Canterbury
- Victoria University of Wellington.

Our goal is to enhance the capacity of New Zealand, both domestically and in partnership with other countries, to anticipate, mitigate, and adapt to climate change. We facilitate collaboration to develop, communicate, and apply science-based solutions to climate change-related issues.

www.nzclimatechangecentre.org

NEW ZEALAND
CLIMATE CHANGE CENTRE

Climate Change Adaptation in New Zealand: Future scenarios and some sectoral perspectives consists of nine individual papers based on presentations delivered at the conference "Climate Change Adaptation – Managing the Unavoidable", held in Wellington, New Zealand, in May 2009.

The papers address climate change adaptation for some of the key sectors of importance to New Zealand for economic, environmental or social reasons, and also consider adaptation through local government mechanisms. Papers include:

- A risk management approach to climate change adaptation
- Global & local climate change scenarios to support adaptation in New Zealand
- New Zealand's land-based primary industries & climate change: Assessing adaptation through scenario-based modelling
- Adaptation in agriculture: Lessons for resilience from eastern regions of New Zealand
- The effects of climate variability & change upon renewable electricity in New Zealand
- Climate change, natural systems & their conservation in New Zealand
- The climate change matrix facing Māori society
- Climate change & human health: Impact and adaptation issues for New Zealand
- Local government adapting to climate change: Managing infrastructure, protecting resources, & supporting communities.

With a foreword from Dr Chris Field, IPCC AR5 Working Group II co-chair (Impacts, adaptation, and vulnerability), this volume covers climate change adaptation perspectives from a global to local scale, resulting in new collaborations between organisations researching or managing climate change issues. The New Zealand Climate Change Centre hopes that the results of these collaborations will be useful to those dealing with the practical issues of adapting to climate change.