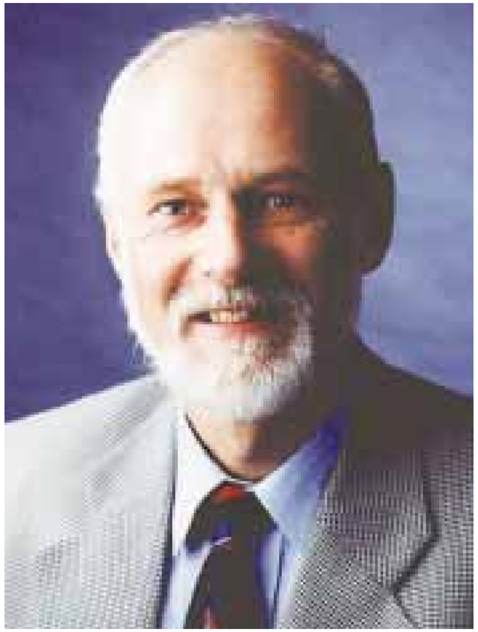
# Foreword by the Convenor of the Ministerial Group on Climate Change, Hon Pete Hodgson



Climate change is coming to New Zealand. Indeed it has already begun to arrive. We have to realise that we are at the beginning of major long-term changes, not just some cyclical climate variability. Past and present greenhouse gas emissions have already committed us to substantial climate change for the coming century – the question is no longer whether the world will warm in the future, but by how much.

We have to understand the impacts of climate change on our country.

The last government-led assessment of the impacts of climate change on New Zealand was carried out in 1990. Since then our knowledge has grown. This report provides an update of our understanding of the potential changes in temperature, rainfall, and sea level under future greenhouse gas emission scenarios, and the likely impact of these changes on our environment, economy and society.

These changes will affect how we live and how we do business in this country. Agriculture may benefit from higher carbon dioxide concentrations and warmer temperatures in some areas, but heat waves, potential water limitations and in particular extreme droughts could pose serious challenges. A warmer climate could change what we can grow and where. It will also change our export markets.

Native ecosystems may be put under additional pressure. Public health, urban infrastructure and energy supply will all be affected, in both positive and negative ways. These effects won't be distributed evenly; some sectors and regions, and some parts of the population may lose while others could gain. Even individually we will experience both positive and negative impacts of climate change.

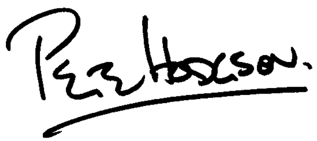
These changes won't happen overnight, and this means two things. First of all we can influence how much the climate will change over the coming century through negotiating international agreements on greenhouse gas emissions. It also gives us time to plan ahead. The biggest changes may not be in our lifetime, but our emissions decide the climate our children will live in. We won't be able to "turn off" global warming once we decide it has become a bit too cosy for comfort.

Regardless of the success of international negotiations or actions, some climate change is inevitable, and we can and must do our best to adapt to these changes as our knowledge about their impacts grows. Adaptation to climate change will increase the benefits to those sectors that could gain under a warmer climate while reducing the negative impacts on others. The cost of change is always less if you walk willingly than if you are pushed along in ignorance.

In many instances our understanding of the expected changes and impacts is still patchy, and many uncertainties remain. But this does not mean we can be complacent about these changes, expecting to deal with them "later". It takes a long time to change habits, develop new products or relocate industries.

If we want to make the best out of climate change we need to be aware of the projected changes and impacts and start to take them into account in long-term planning. This is why I urge every New Zealander, every business, every community group, to take a close look at the findings presented in this report to see what climate change could mean to your environment.

This report is one of many steps we need to take in building a long-term adaptation strategy to climate change in New Zealand. Impacts will vary between sectors, regions, and parts of society, and we need to work together to ensure the best outcome for New Zealand. Central and local government, industry and communities all have a role in preparing for the future.



Hon Pete Hodgson

# contents

# executive summary climate change impacts on new zealand

This report examines the likely impacts of climate change and global warming on New Zealand, based on expert reports and peer-reviewed scientific studies, published internationally and in New Zealand. It does not attempt to provide a comprehensive summary, but updates the last government-led assessment of climate change impacts carried out in 1990 and concentrates on areas where new knowledge has been gained over the last decade.

## Scientific basis and global impacts of climate change

A broad range of observations shows that the world has warmed during the 20th century. There is now stronger evidence that most of the warming observed over the last 50 years is attributable to human activities, namely the emission of greenhouse gases.

This report uses two emission scenarios to assess future climate change and its impacts. Scenario 1 assumes no attempts to control greenhouse gas emissions, while scenario 2 assumes that steps are taken to stabilise the atmospheric concentration of carbon dioxide and to limit emissions of the other major greenhouse gases methane and nitrous oxide. Neither scenario is a prediction or represents a policy target; both serve only to answer "what-if" questions.

Climate models predict a global warming by 2100 between 2.1 and 3.8 degrees Celsius for scenario 1 and between 1.4 and 2.6 degrees Celsius for scenario 2, compared to an observed warming of about 0.6 degrees Celsius during the 20th century.

Global impacts of climate change, particularly on world markets and developing countries, will have repercussions for New Zealand. However because very few clear predictions of these indirect effects can be made at this stage, this report focuses on the impacts of local climate change in New Zealand.

## Projected New Zealand climate changes

Temperatures in New Zealand are likely to increase faster in the North Island than in the South Island, but generally less than global average temperatures. Rainfall is projected to increase in the west of the country and decrease in many eastern regions. While these general trends are considered relatively robust findings, the magnitude of the projected changes depends on the global greenhouse gas emission sce-nario and also varies considerably between different climate models, particularly for local rainfall patterns.

Quantitative regional climate projections are more likely to undergo revision in future assessments than global projections. Comprehensive impact assessments in which rainfall is a key component therefore need to incorporate a range of different scenarios of regional climate change, even for a single given global warming assumption.

Under the projected reductions of average rainfall in eastern areas and higher temperatures, dry periods will increase in some regions. Models suggest that at the same time, extremely heavy rainfall events could become more frequent in many areas, increasing the risk of flooding and erosion. No predictions about frequency and intensity of mid-latitude storms are currently available.

Many climate models indicate a greater future variability of rainfall with an increased risk of droughts, but no quantitative predictions are possible at this stage. Other expected changes in climate extremes are, on average, fewer frost days during winter and more hot days during summer.

## Sea-level rise and coastal processes

Sea levels are expected to rise under global warming, but scientific uncertainties are large. Global sea levels are estimated to rise between 9 and 88 cm by 2100 under global warming, with ranges from 13 to 70 cm for scenario 1 and from 9 to 53 cm for scenario 2. During the 20th century global sea levels rose on average between 10 and 20 cm.

A quantitative assessment of the impact of rising sea levels on New Zealand coasts is difficult. Major earthquakes can lead to local changes in land elevation which can override the effect of a gradual sea-level rise. In addition, circulation patterns of oceans and the atmosphere cause regional sea-level variations. On time scales of decades these changes have a larger influence on the sea level around New Zealand than global warming induced sea-level rise.

In the long term, rising seas are expected to increase the erosion of vulnerable beaches and cause more frequent breaches of coastal protection structures. Quantitative predictions depend heavily on local variables, and only limited long-term data of sufficient quality exist. Hence no national-scale as-sessment of coastal risks under climate change is currently available.

## Agriculture

The agricultural sector has opportunities for productivity gains and diversification under climate change, but also faces risks.

The key benefit to agriculture is likely to be from elevated carbon dioxide concentrations which could lead to substantial improvement in growth rates and water-use efficiency. In addition, warmer conditions and lengthened growing seasons could allow the long-term southward shift of climate-limited activities, and new crops and related industries could be introduced. Currently resource-poor areas could benefit from such shifts.

The most significant risks are associated with the potential increase of droughts and floods and water limitations in some areas. Warmer temperatures could also make the growing of some fruit crops in some northern areas uneconomical. Shifting land-use activities to adapt to altered climate conditions will incur costs, resulting in regional winners and losers. Pests and diseases could spread in range and severity, and pasture composition is likely to change with uncertain outcomes to animal productivity and nutrient balances. The full range of effects has not been quantified yet.

The assessment of climate change impacts on agriculture has been greatly helped by the development of an integrated assessment programme (CLIMPACTS) which combines climate and agricultural expertise. However, information on regional climate change and its impacts is still too limited to quantify the overall economic effect on the agricultural sector. Adaptation to altered climate conditions would also influence future economic outcome through proactive utilisation of opportunities and mitigation of negative impacts. Overseas markets will also change under a warming climate, offering indirect climate risks and opportunities to New Zealand farmers.

## Native ecosystems

With few exceptions, climate change alone is unlikely to be the dominant cause of native species extinction, but may act as compounding pressure on ecosystems which are already under threat. Fragmented native forests of drier lowland environments in Northland, Waikato, Manawatu, and in the east from East Cape to Southland are probably the most vulnerable to climate change, and some terrestrial and freshwater species which are currently at their climatic limit may be at long-term risk of extinction. However many complex interactions between elements of natural ecosystems, introduced exotic species and climate are not yet fully incorporated in assessment models.

## Urban environment, transport and energy

The main threat to the urban environment comes from possible increases in heavy rainfall which would put pressure on drainage and stormwater systems and increase the risk of flooding in some areas. Erosion could also increase road maintenance costs, but warmer winters would lead to reduced costs for snow and ice clearing. Warmer conditions will substantially reduce home heating costs, leading to re-duced electricity demand during the peak winter season, but possibly increase demand for air conditioning during summer. The reduced winter demand would combine with an increased availability of water in hydroelectric storage lakes from projected rainfall increases over the Main Divide, providing the opportunity for a more balanced electricity supply and demand.

## Health

Higher temperatures are expected to reduce winter illnesses, but have also been found to be correlated with increased mortality during summer. A warmer climate would also allow the better establishment and spread of mosquitoes capable of transmitting diseases such as Ross River virus and dengue fever. The impacts of climate change on human health are however not just determined by climatic conditions, but also the vulnerability of the exposed population. Border controls, vector eradication programmes, safe food and water supply, and primary health care services all influence the impact of climate change on actual changes in disease risks and outbreaks.

Recent research also found that climate change could lead to a delay in the recovery of the ozone layer. Ozone is destroyed by chlorofluorocarbons (CFCs) used in refrigeration and as propellants. Since the banning of CFCs the ozone layer was expected to recover over the next few decades, but scientists have found that emissions of other greenhouse gases such as carbon dioxide and methane could delay this recovery by another 15 to 20 years. This would increase the period during which New Zealanders are exposed to high levels of ultraviolet radiation, which is known to lead to skin cancers. However quantitative model studies of the possible effects of greenhouse gases on the ozone layer are still highly uncertain.

## Climate impacts on Māori

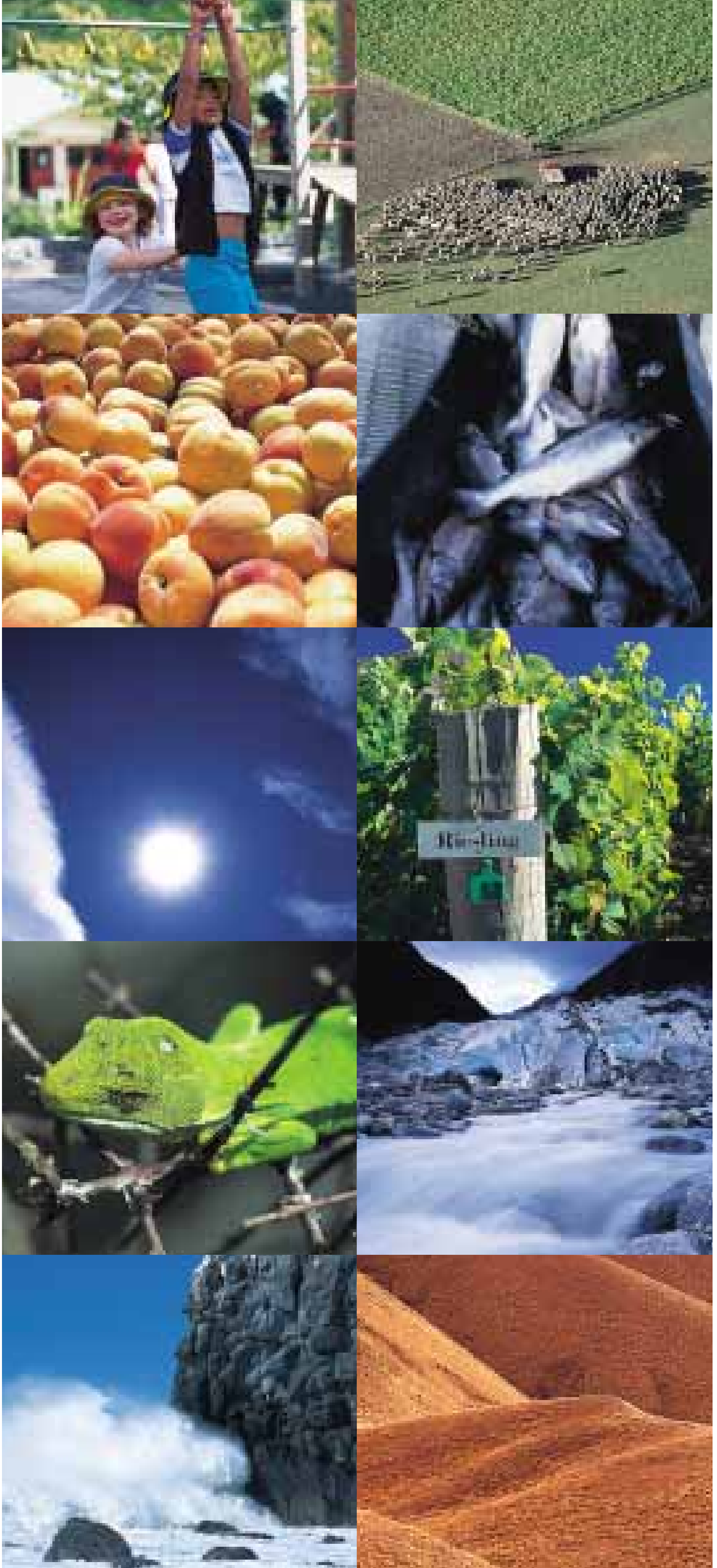
The reliance of Māori on the environment as both a spiritual and economic resource makes them more vulnerable and less adaptable to climate change. Land presently owned by Māori is often of lower quality which makes it more prone to invasion by subtropical grasses and erosion. Because of the high spiritual and cultural value placed on Māori traditional lands and statutory sales restrictions, business relocation in response to climate change may not be seen as an adaptation option. Multiple land-ownership and generally lower socio-economic status could hinder implementation of costly or non-traditional adaptation measures. This may increase the risk of reduced economic output from Māori land compared to the New Zealand agricultural sector as a whole. Impacts on the coastal environment are also of great importance to Māori culture and economy, but the impact of climate change on fisheries production is highly uncertain at present.

## International links

New Zealand has close social and institutional links with many Pacific Island countries. Many of these countries are highly vulnerable to climate change from rising sea-level, changes in rainfall patterns affecting agricultural productivity, destruction of coral reefs, and human health effects of higher temperatures and vector-borne diseases. Such impacts could have considerable flow-on effects for New Zealand through increased demand for development aid and, in worst cases, disaster relief. Climate change in competing export countries will contribute to changing commodity prices and market structures in some key export markets. These changes offer both risks and opportunities to New Zealand exports, but information is too limited at present to allow predictions or outline specific adaptation strategies.

## Summary and outlook

New Zealand's climate is very likely to change during the 21st century. Impact projections are limited by uncertainties of regional climate changes and frequency of extreme events. At this stage, an assessment of the overall impact of climate change on New Zealand society and economy is impossible, but it is likely that there will be short-term winners and losers. Negative impacts could be reduced and potential gains increased by ongoing proactive adaptation to altering climate conditions. Because of the regionally varying impacts of climate change and the different effects on different sectors, future comprehensive quantitative impact studies and development of adaptation strategies would require greater incorporation of climate effects in sector-specific models.



# introduction

Much of our nation's wealth and attraction is based on environmental and physical resources, including its climate. This report examines the likely impacts of global warming and climate change on New Zealand. It does not discuss options to reduce greenhouse gas emissions. However, it is clear that emission reductions need to complement attempts to cope with the impacts of climate change.

The findings reported in this study are largely based on peer-reviewed scientific studies, published internationally and in New Zealand over the past decade. Leading New Zealand experts in the field of climate science and impacts contributed material to and reviewed this report. It updates the findings of the last government-led summary of the impacts of climate change on New Zealand in 1990. Selected publications are listed in the back of this report.

This report focuses on areas where new knowledge has come to light during the past decade. It shows major advancements in our understanding of basic climate science, projected changes in climate under greenhouse gas emission scenarios, and the impacts of such changes on a regional scale. However many gaps and uncertainties in our understanding remain, both in regional climate predictions and direction of some changes, and quantification of associated impacts.

As decision makers need to take the uncertainties of climate projections into account, it is important to remember that uncertainty goes both ways – within the estimated limits, changes could turn out lesser or stronger than predicted, and impacts could be more beneficial or worse than expected.

Climate change will not happen overnight, but the inertia of the climate system also means that we cannot stop the climate from changing once we decide we've had enough change. Most of the impacts characterised in this report are expected to occur over the next 20 to 100 years, in many cases well within the lifetime of our children.

The magnitude of change depends on future emissions of greenhouse gases, but the impacts will depend on our level of preparedness. Even where a warmer climate may be beneficial, proactive adaptation to the expected change will increase the gains from this change while minimising the potential risks and negative impacts.

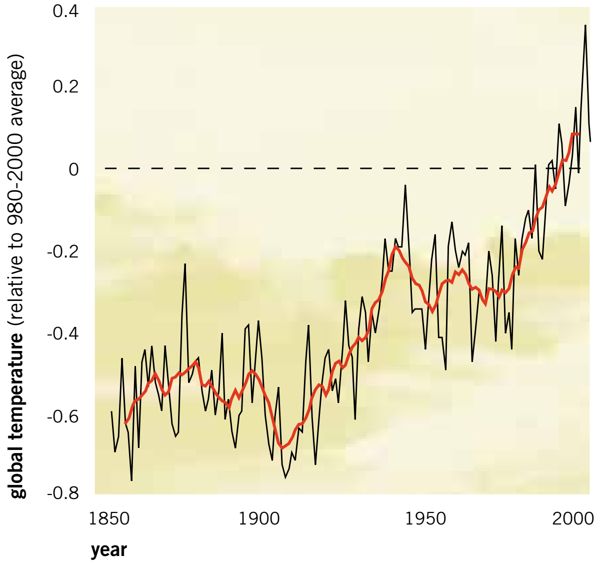
This report is not a comprehensive assessment of climate change impacts. Many sectors not mentioned in this report (such as tourism) will also be affected by climate change, but almost no new scientific research is available to predict sector-specific impacts beyond the expected changes in basic climate variables such as temperature, rainfall and sea levels. Climate change will need to be more directly linked to sector-specific models to allow quantitative impact assessments.

In virtually all sectors, knowledge of regional climate change, impacts, and adaptive opportunities is still too patchy to point to a definite way forward. This report aims to encourage a greater dialogue between climate scientists, government agencies and sector stakeholders about what the expected changes could mean, and to increase awareness of potential changes in the essential resources on which we rely as a nation.

This report does not make recommendations for future research on impacts, adaptation and vulnerability to change. Those issues form important parts of coping with climate change and will be developed by government in consultation with the National Science Strategy Committee for Climate Change, research providers and sector stakeholders.

Climate change offers business opportunities for local and overseas markets as well as long-term risks. Coping with these changes will involve solutions which vary locally and between different parts of society and the economy, and finding the best way requires participation of all parts of society. Key resources on climate change and contact details are given in the back of this report. The government welcomes your active involvement.

# climate change: the scientific basis




Global average surface temperatures have risen by about 0.6 degrees Celsius between 1861 and 2000. The main increases occurred in two steps between 1900 and 1940, and 1970 and 2000, caused by a superposition of natural and human influences on climate.

The world is getting warmer. Global temperatures today are about 0.6 degrees Celsius higher than they were in the early 1900s. Eighteen out of the twenty warmest years in the 20th century occurred after 1980, and it is likely that, at least for the northern hemisphere, the 1990s were the warmest decade of the entire past millennium.

But not only the temperature of the Earth's surface has changed. During the 20th century, glaciers retreated widely, snow and ice cover reduced in northern latitudes and the extent and thickness of Arctic sea-ice contracted, and the global average sea level rose by 10 to 20 cm.

Changes have also occurred in other parts of the global climate system. Over the 20th century, average rainfall over temperate latitudes of the northern hemisphere increased and extremely heavy rain became more frequent. At the same time, rainfall in the sub-tropics appears to have decreased and droughts in parts of Africa and Asia have become more frequent and intense.

The changes of the Earth's climate system have not been uniform, however. Some parts of the globe have warmed only very little and no significant change in Antarctic sea-ice was observed. As yet no clear trends in the intensity or frequency of storms, tornadoes or hail events can be determined.

Do we understand what causes these changes, and hence can we predict how the global climate might change in the future?

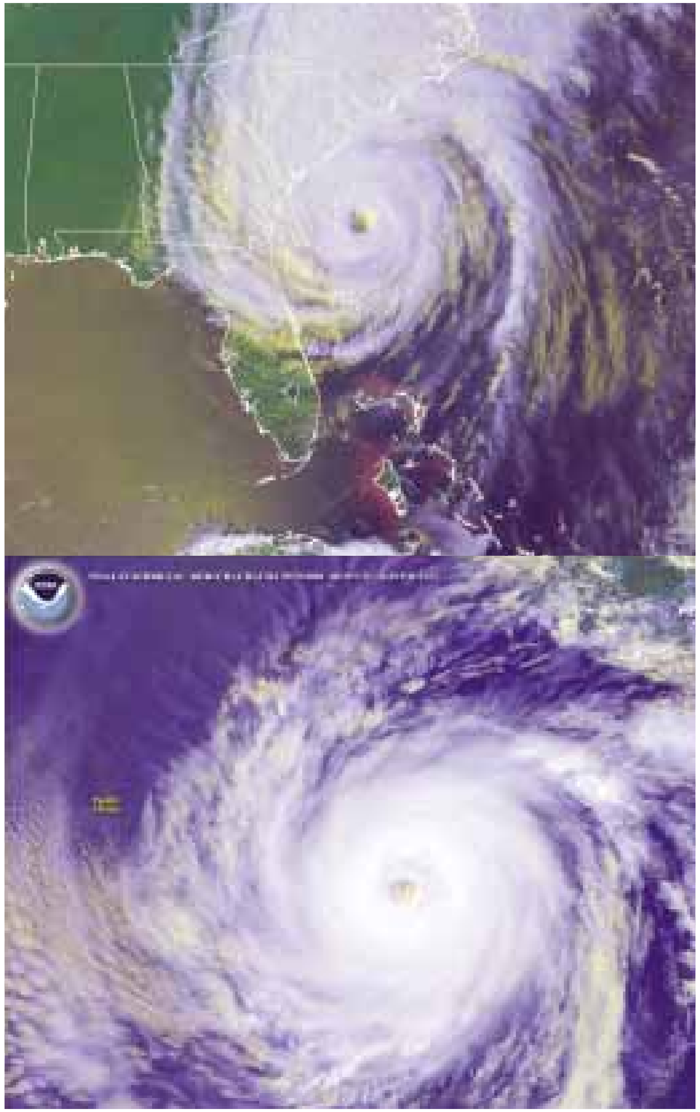
Climate scientists use complex mathematical models to study the Earth's climate system. Today's global climate models are realistic enough to simulate past climates by incorporating the heating effect of solar radiation, heat absorption and reflection by clouds, greenhouse gases and suspended particles in the atmosphere, and the coupling between oceans and atmosphere. These models show that variations of solar activity, and large volcanic eruptions have contributed to some of the changes in global temperatures over the past century.

But in addition to those natural climate factors, greenhouse gases act as an additional warming "blanket" around the globe. Over the 20th century, human activities have produced more and more greenhouse gases such as carbon dioxide and methane. This has made the warming blanket "thicker", and the Earth's climate has begun to respond. While in 1990 any human influence on global climate was only a plausible conjecture, there is now stronger evidence that most of the warming observed over the last 50 years is indeed attributable to human activities.

What does this mean for the Earth's future? The answer depends on a number of things. Firstly, scientific models of the climate system still have many uncertainties, and the warming produced by a given amount of greenhouse gases differs between models. However all models agree that the Earth will get warmer if more greenhouse gases are released.

A second, equally large uncertainty arises from the question of what quantity of greenhouse gases will be emitted in the future. The world could decide to continue its focus on fossil fuel combustion, which releases large amounts of carbon dioxide, or we could decide to reduce our energy needs and use renewable resources. Hence future emissions cannot be predicted using scientific research alone – they are political and social choices.

To get a handle on what the future climate and its impacts might be, we therefore resort to emission scenarios. Scenarios are not predictions, but tools that help answer "what if" questions: What might happen to the climate if we further increase greenhouse gas emissions? What might happen if we reduce greenhouse gas emissions so that their atmospheric concentrations reach a stable level? Under either scenario, what impacts could the resulting changes in global and local climate have on our environment? For the purpose of this report, we have selected two alternative greenhouse gas emission scenarios which are explained in more detail on the following pages.



Global warming not only leads to a rise in average temperatures, but will also change atmospheric circulation, rainfall patterns, and the frequency of extreme events such as droughts, floods and tropical cyclones. Satellite images courtesy of NOAA (National Oceanic and Atmospheric Administration/ US Department of Commerce).

# emission scenarios and global climate change

The following two emission scenarios are used to calculate the expected change in greenhouse gas concentrations and global mean climate. The resulting impacts on New Zealand are inferred from the global changes. These scenarios are not exclusive alternatives, but examples of how the world might develop and the likely consequences on global climate.

Scenario 1 assumes that the world does not explicitly attempt to control emissions of greenhouse gases while undergoing rapid global economic growth. Global population would peak at almost 9 billion in mid-century and slowly decline thereafter. World regions would see increased technological exchange and capacity building, cultural and social interactions and substantial reductions in regional differences in per capita income. The scenario assumes a mix of fossil fuel and alternative energy sources, with the introduction of new technology driven by innovation and local resource restrictions. Atmospheric carbon dioxide under this scenario would reach a concentration of about 700 parts-per-million (ppm) by 2100, almost twice the current level.[1]

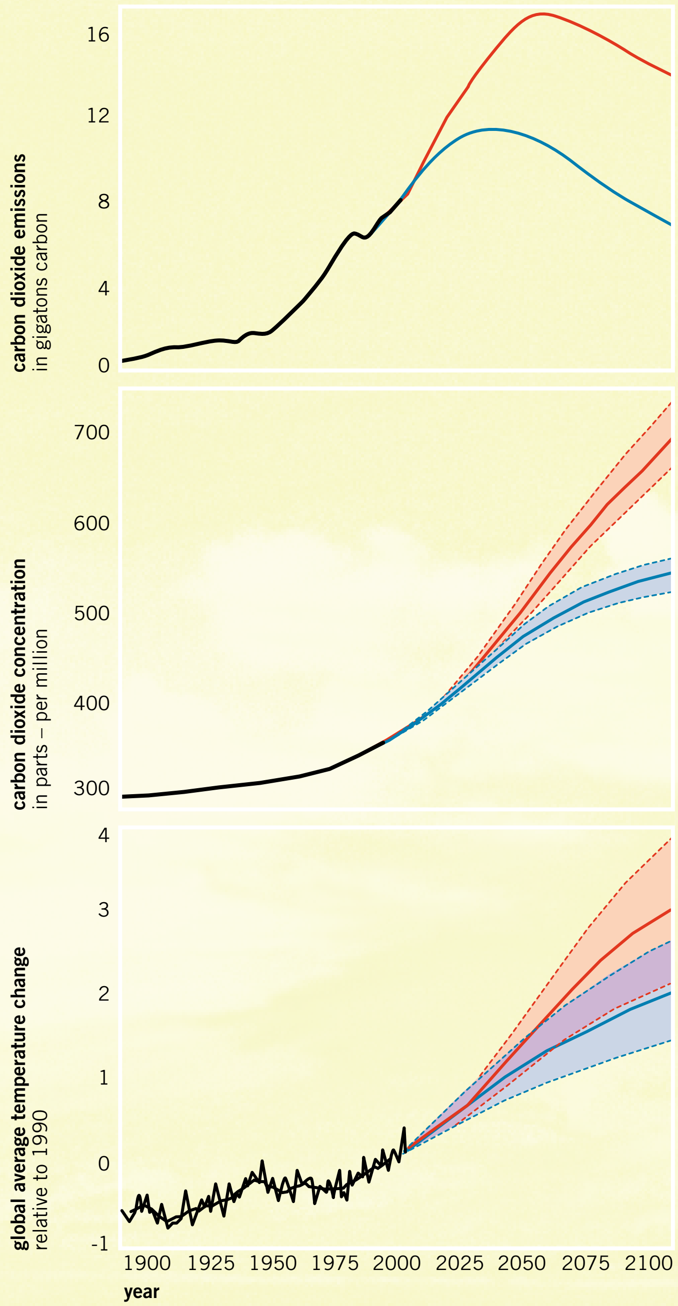
Climate models predict that under this scenario global average temperatures in 2100 would be between 2.1 and 3.8 degrees Celsius higher than in 1990, with the best estimate around 3 degrees Celsius, and the average sea level would rise between about 13 and 70 cm by 2100. The range of estimates reflects the current climate model uncertainties.

Scenario 2 assumes that the world explicitly aims to limit the atmospheric concentration of the major greenhouse gas carbon dioxide, at a level of 550 ppm. Although this concentration is still about 50% higher than today, global emissions of carbon dioxide during the coming decades would need to grow much more slowly than currently projected to achieve this goal. In 2100, global emissions would need to be lower than in 1990 and decrease even further into the future, despite increased world population and energy demand.

Scenario 2 also assumes that emissions of the other major greenhouse gases methane and nitrous oxide are limited to 1990 levels. Higher emissions of those gases would require even stronger carbon dioxide reductions to compensate for the additional warming effect, while further reductions of methane and nitrous oxide emissions would allow slightly higher carbon dioxide emissions.[2]

[1] This emissions scenario is based on the IPCC Special Report on Emission Scenarios, using the balanced scenario A1B of the A1 scenario family group.

[2] This scenario is based on the WRE550 stabilisation pathway in the IPCC Technical Report on Stabilisation Scenarios, and population dynamics and aerosol emissions follow scenario B1 of the IPCC Special Report on Emission Scenarios which assumes a highly convergent world driven by information technology.




Future global carbon dioxide emissions, concentrations, and resulting global warming for two different emission scenarios. Black lines show observations to date, red lines indicate scenario 1 with strong growth of carbon dioxide emissions and mixed use of fossil fuel and alternative energy sources, blue lines indicate scenario 2 with policies to stabilise carbon dioxide concentrations. The shaded areas indicate the uncertainties of climate models. The projections were made with a simple climate model (MAGICC) tuned to a range of complex international climate models. Source: NIWA.

The distribution of the burden of emission reductions between industrialised and developing nations is an ongoing matter of debate. The per-capita greenhouse gas emissions of industrialised nations, including New Zealand, are between five and seven times higher than those of most developing countries. Hence the largest cuts would need to be made by the richest and/or highest emitting nations, while developing nations would need to limit population growth and maintain their current low per-capita emissions despite improving their standards of living. Under scenario 2, industrialised nations would need to cut their greenhouse gas emissions by as much as 70% by 2100 for their per-capita emissions to match those of developing countries.

Emission limitations to achieve scenario 2 are far more drastic than those suggested under the Kyoto Protocol, and it is not clear how they could be achieved. Yet even under this scenario, global average temperature is projected to rise between 1.4 and 2.6 degrees Celsius over 1990 levels by 2100, with a best guess of 2 degrees Celsius. The global average sea level would rise between 9 and 53 cm by 2100.

These two scenarios are selected examples of potential futures – they are not predictions. The Intergovernmental Panel on Climate Change considered a range of 35 different scenarios which cover a wide range of global technological and socio-economic developments, but do not explicitly assume the introduction of climate policies. Under this set of scenarios, climate models predict global average temperatures to rise between 1.4 and 5.8 degrees Celsius and the global average sea level to rise between 9 and 88 cm by 2100. Because of the inertia of the climate system and past and present emissions of greenhouse gases, we seem already committed to a global warming that more than twice exceeds the warming during the 20th century.

# global impacts of a changing climate

Recent climate changes, particularly temperature increases, have already had initial impacts. Observed changes include the lengthening of mid- to high-latitude growing seasons, poleward and altitudinal shifts of plant and animal ranges, declines of some plant and animal populations, and earlier flowering of trees, emergence of insects, and egg-laying by birds. The discussion of emission scenarios shows that temperature and sea levels will inevitably rise further over the 21st century, even if serious steps are taken to reduce greenhouse gas emissions. The resulting shift in climate is likely to affect human populations and the environment in many areas of the world.

A recent study by the Intergovernmental Panel on Climate Change showed that impacts of climate change will be distributed unevenly over the globe, with poor developing nations being most vulnerable. The ability to adapt to altered climatic conditions in these nations is generally low because their economy relies on often marginal land and water resources, populations are rapidly expanding, and there is limited financial and institutional capacity to react to environmental pressures. In contrast, developed nations can reduce negative impacts of climate change through changes to their infrastructure and productive systems, and some could even benefit in the short to medium term through foresighted adaptation mechanisms.

In most tropical and subtropical countries crop yields are expected to deteriorate as a consequence of any warming, whereas in temperate latitudes yields could increase if there is a small warming of less than a few degrees, but decrease under stronger warming. Decreased water availability from reduced rainfall in the subtropics will add stress on urban areas and food supply, while in other regions higher average rainfall could relieve water-limited areas. The regional distribution of rainfall patterns is still relatively uncertain, however, and limits the reliability with which impacts on agricultural systems can be predicted.

Together with rising average temperatures, extreme climate events such as droughts and heavy rainfall are projected to become more common in many areas, although quantitative predictions are still uncertain. Some changes have already been observed. During the 21st century, the risk of drought will increase in many subtropical countries, but in most areas heavy rainfall will also become more frequent and increase the risk of flooding and erosion. Tropical cyclone intensities are expected to increase, but little is know about changes in mid-latitude storms. Regional climate patterns such as the Asian Monsoon and El-Niño-Southern Oscillation could become more variable, leading to greater extremes of regional rainfall and drought. An increase in extreme climatic events would put pressure on some sectors in all economies, resulting in a mix of economic gains and losses even for the most developed countries.

Higher temperatures will reduce energy demand for winter heating but increase summer demand for air-conditioning. A warmer climate would aid the spread of vector- and water-borne diseases such as malaria and cholera, and increase heat-stress mortality in urban populations, but also reduce winter illnesses in mid- and high-latitude countries.

Rising sea levels are likely to have the biggest impact on low-lying Pacific Islands, flood plains and river deltas, where tens of millions of people could be displaced by loss of land and salinisation of water supplies. Other regions with existing sea defences or rocky coastlines are more resilient against sea-level rise. Many major cities are built along coasts or waterways.

The global economy is likely to undergo adjustments to altered climate conditions, and the interconnectedness of the global markets implies that climate impacts in one part of the world are likely to influence many other parts. The remainder of this report concentrates on the potential impact of local climate change in New Zealand since no clear predictions about these indirect links are possible at this stage. Nonetheless, the global impacts of a changing climate will affect New Zealand and must be remembered when domestic impacts are assessed.

Source: National Oceanic and Atmospheric Administration/US Department of Commerce.

## long-term impacts of climate change

The long-term impacts of climate change are still poorly understood. Some of the projected climate changes during the 21st century have the potential to lead to large-scale and possibly irreversible changes beyond 2100 with impacts at continental and global scales. Examples include the slowing of the global ocean circulation, large reductions in the Greenland and West Antarctic ice sheets, and accelerated global warming due to positive feedback loops. Global mean sea levels are expected to continue to rise for several centuries after greenhouse gas concentrations have stabilised (even at present levels) as a result of ongoing thermal expansion of the oceans and changes in ice sheets. The likelihood of many of these changes is not well known but probably very low at present; however, their likelihood is expected to increase with the rate, magnitude, and duration of climate change.

# future new zealand climate

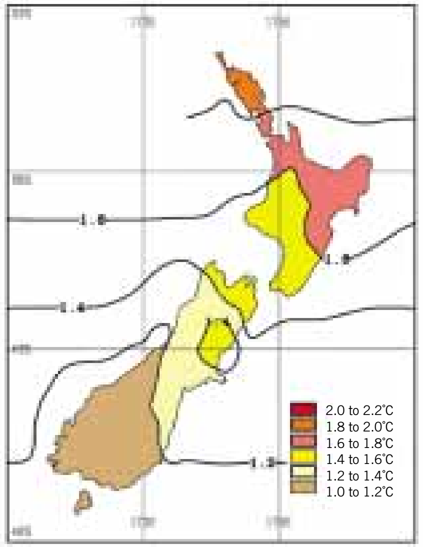
## The broad picture for the future

Global climate models show that New Zealand is likely to warm by only about two-thirds of the global mean temperature change, largely because its climate is controlled by the South Pacific and Southern Ocean which respond only slowly to global temperature changes. The most recent global models also predict that continued greenhouse warming will lead to intensification of the prevailing westerly winds in southern mid- to high-latitudes, consistent with basic physical principles.

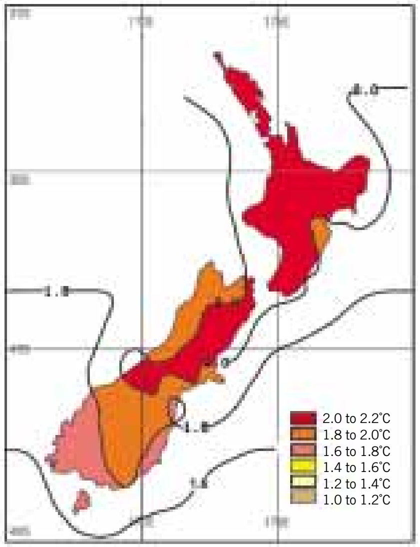
The National Institute of Water and Atmospheric Research (NIWA) has recently developed new regional New Zealand climate scenarios to study what such general projections could mean for New Zealand. Several different global climate models were used to project the average climate change for the New Zealand and South Pacific region for the years 2070 to 2099, based on greenhouse gas increases similar to those in global emission scenario 1 of this report. A so-called “downscaling” technique was then applied to capture the way mountains and other terrain features modify the local climate in various New Zealand regions.

### Mean temperature

Summer increase °C
2080s
4 model average

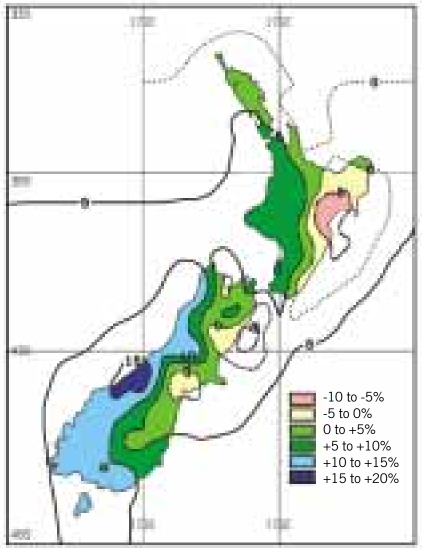



Winter increase °C
2080s
4 model average

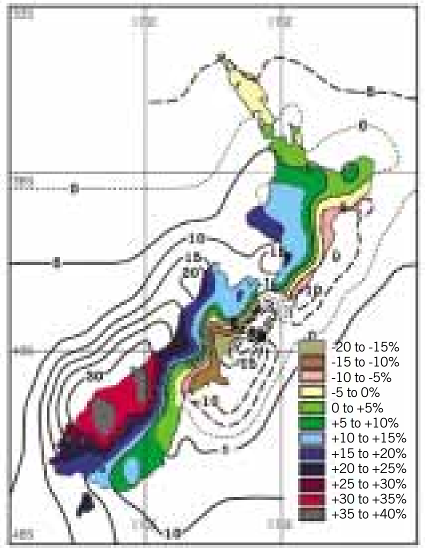



### Precipitation

Summer
2080s
4 model average




Winter
2080s
4 model average




Average summer and winter projected temperatures and rainfall for the 2070 to 2099 period, under a global greenhouse emission scenario similar to scenario 1 as defined in this report. Temperatures are expected to increase faster in the North Island than in the South Island, and faster in winter than in summer. Rainfall is projected to increase in the west of the country and decrease in the east, with changes being more pronounced in winter than in summer.

In general, New Zealand temperatures are expected to increase faster in the North Island than in the South Island, and faster in winter than in summer. The difference in average rainfall between western and eastern parts of New Zealand is expected to become stronger, with rainfall likely to increase in the west of the country and decrease in the east. These changes are likely to be more pronounced in winter than in summer.

Scientists are more confident about such general statements than they are about predicting absolute temperature and rainfall in particular places. Global climate models differ in their resolution and ability to account for the presence of the New Zealand land-mass, and different model calculations and downscaling techniques lead to a range of results. As aconsequence, quantitative projections about local and regional climate changes, in particular rainfall patterns and the rate of temperature increases, are less certain than global and hemispheric average projections.

Projections of a future climate for New Zealand can therefore only be given as a range of possible scenarios which need to be incorporated in sectoral impact assessments. Future refinement of global climate models could lead to projections that are not necessarily captured by the range of current climate models represented in this report.

Table 1 summarises the projected annual mean temperature and rainfall changes for major New Zealand districts, and shows the considerable uncertainty for the expected changes in temperature and rainfall at the regional level due to the spread of currently available model calculations. Impacts associated with future climate changes may however be greater than the numbers suggest, since changes in average climate are also projected to lead to greater rainfall variability and higher frequency of extreme events such as heat waves.

Because complex global climate models require hundreds of hours to complete a single simulation, specific results are at this stage only available for emissions corresponding approximately to scenario 1. For the global emissions scenario 2, New Zealand temperature and rainfall changes are expected to be only about two thirds of those listed above, assuming that a lesser global warming will lead to a proportionately smaller change in local New Zealand climate. Similarly, emissions higher than those under scenario 1 would likely lead to stronger changes, but insufficient information is currently available to ascertain potential non-linear responses of the local climate to different global change scenarios.

Table 1. *Predicted changes in annual mean temperature (°C) and precipitation (%) between 1970-1999 and 2070-2099 from four global climate models, for greenhouse gas emissions similar to those under emission scenario 1 in this report. The range of changes indicates differences between the four models. Note the potential for strong gradients in rainfall changes across some regions.*

| Region | Temperature | Precipitation |
|---|---|---|
| Northland, Auckland | +1.0° to +2.8°C | -10% to 0% |
| Western North Island from Waikato to Wellington | +0.8° to +2.7°C | 0% to +20% |
| Eastern North Island from Bay of Plenty to Wairarapa | +0.9° to +2.7°C | -20% to 0% |
| Nelson, Marlborough, to coastal Canterbury and Otago | +0.8° to +2.5°C | -20% to +5% |
| West Coast and Canterbury foothills | +0.6° to +2.5°C | +5% to +25% |
| Southland and inland Otago | +0.6° to +2.2°C | 0% to +30% |

## Hydrological cycle in New Zealand – rainfall, snowfall, rivers, evaporation

Apart from rising temperatures, projected rainfall changes for the coming 100 years would substantially affect river flows, the soil moisture available for plant growth, and the amount of snow and ice present in the mountains.

### 1. Drier conditions expected in eastern New Zealand

Quantitative estimates of the likely changes in river flows and soil moisture under the most recent New Zealand climate change scenarios have not yet been published. However the projected rainfall decreases for eastern areas of the Gisborne, Hawke's Bay, Wairarapa, Marlborough and Canterbury regions, in tandem with the expected increases in temperature in these regions, would likely lead to decreased runoff into rivers and increased evaporation.

Earlier climate scenarios predicted a similar decrease in rainfall in eastern parts of Canterbury, Gisborne, Hawke's Bay and Wairarapa and are thus still a useful guide to estimating future changes. This suggests we could experience runoff decreases of around 40% in eastern Marlborough and Canterbury, and decreases of 10 to 40% in eastern areas of the Gisborne, Hawke's Bay, and Wairarapa regions.

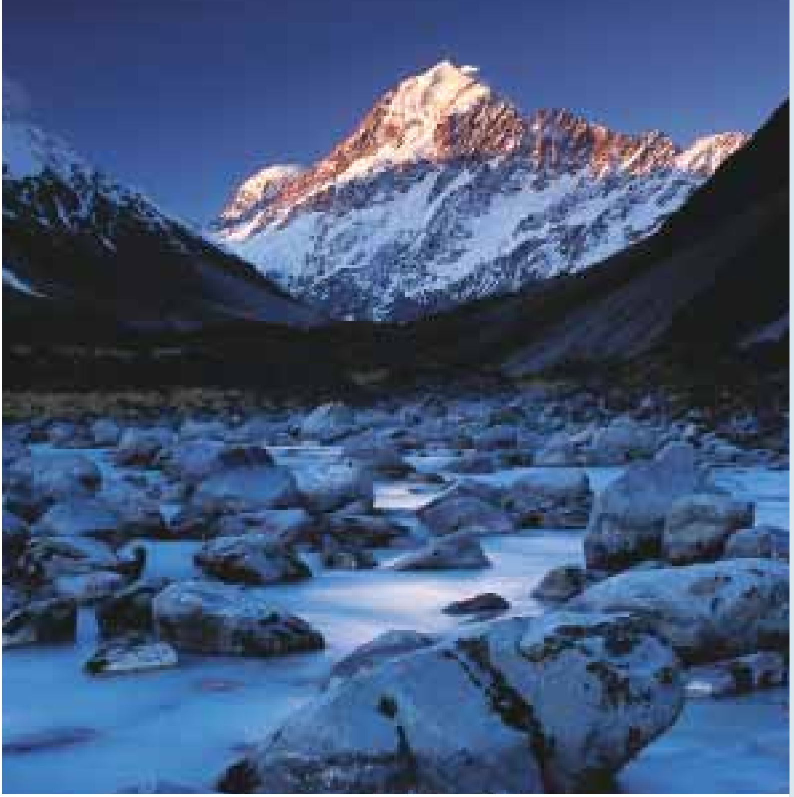
However, some major eastern rivers whose catchments reach back into the Main Divide or the central North Island high country could maintain or even increase their flows because of projected rainfall increases in these central areas. While the generally drier conditions in eastern areas and increased precipitation in the west are considered relatively robust long-term projections, the magnitude and decadal variability of rainfall changes, their impact on river flows and the separation between drier and wetter conditions over the centre of the North and South Islands are still uncertain and the focus of ongoing research.

It is likely that under reduced average rainfall and increased evaporation, droughts in the east of the South Island would become more frequent and some river reaches could dry up in non-irrigated lowland areas, putting increased pressure on current water resources. While little change to groundwater recharge is projected for Canterbury, a greater demand on groundwater for irrigation is likely. Similar conclusions about ground water, drought and river flows can be drawn for the eastern North Island regions which are subject to decreasing rainfall.

### 2. More frequent floods?

The Intergovernmental Panel on Climate Change recently concluded that more intense and frequent precipitation events are likely over many areas. No detailed work on observed changes has been published yet for New Zealand, but a recent model study led to a range of possible scenarios for the frequency and intensity of heavy rainfalls in Australia and New Zealand. The study estimated that under global greenhouse gas emissions similar to those assumed under scenario 1, the frequency of heavy precipitation events over the entire area could increase up to fourfold by 2070, although it was not ruled out that no discernible increase could occur.

Impacts expected from more intense precipitation events include increased flooding, landslides, avalanches and mudslides; increased soil erosion; and increased pressure on government and private flood insurance schemes and disaster relief. Areas most prone to such events are the western coasts of New Zealand, and rivers with catchments near the Main Divide in the South Island or the central plateau of the North Island, but even in drought-prone areas the risk of extremely heavy rainfall is expected to increase.



### 3. Retreating snowlines and glaciers

On average, glaciers in the Southern Alps shortened by 38% and lost 25% of their area in the 100 years leading up to 1978, a period during which New Zealand's temperature increased by about 0.6°C. Glacier models estimate that for a warming of 1.5 to 4.5°C, one-third of the more than 3,000 glaciers present in the South Island could disappear within a few decades, and the snowline could be raised by several hundred metres. These changes will also affect seasonal river flows in the central and southern South Island. However large glaciers, such as the Tasman Glacier, respond very slowly to climate change, and because of their large ice mass are expected to continue to exist for at least several centuries under all warming scenarios currently considered. Some glaciers would likely experience increased average snowfall which could balance the increased melting and even lead to a temporary advance (as has been the case for the Fox and Franz-Josef Glaciers).

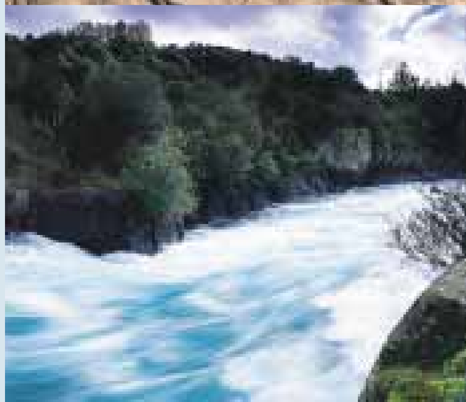
## changes in climate extremes

Other climate changes that will have implications for New Zealand are more frequent occurrences of extreme climate events. These include higher maximum temperatures and more hot days, as well as higher minimum temperatures, fewer cold days and fewer frosts.

The biggest negative impact of climate change on New Zealand could arise not from a gradual change in average temperatures and rainfall, but from possibly more frequent and more intense droughts and floods, because the adaptation mechanisms needed to cope with irregular but extreme droughts and floods differ from those required to cope with gradual changes.

Over the past two decades, more frequent and intense El-Niño events have been observed, and scientists have speculated whether those changes could be linked to global climate change. Complex climate models are not yet able to fully simulate regional patterns such as the El-Niño event, and current projections show little change or a small increase in amplitude for El-Niño events over the next 100 years. However even with little or no change in El-Niño amplitude, global warming is likely to lead to greater extremes of drying and heavy rainfall similar to those that occur with El-Niño events in many regions.

In addition, many climate models predict a continuation of recent trends towards a more El Niño-like mean state of sea surface temperatures in the tropical Pacific, which may influence large-scale circulation patterns. The intensity of wind and rainfall of tropical cyclones is expected to increase with global warming, but there is little agreement between current climate models about whether the intensity or frequency of mid-latitude storms is likely to increase.





# sea-level rise, coastal effects and fisheries

## Underlying issues surrounding oceans and climate change

Global warming leads to a rise in the average sea level due to the thermal expansion of ocean water and melting of glacial and polar ice. During the 20th century, local sea levels in New Zealand have risen between 10 and 25 cm, consistent with the global average of 10 to 20 cm. Projections for global sea-level rise by 2100 are 38 cm for scenario 1 and 29 cm for scenario 2, but considerable uncertainties are attached to these estimates. The worst-case scenario considered by the Intergovernmental Panel on Climate Change would result in a sea-level rise up to 88 cm by 2100.

Under the projected further temperature increases, sea-level rise during the 21st century could be between one and four times as fast as during the 20th century. No significant acceleration of sea-level rise has yet been detected. This is not inconsistent with current model projections since the inherent 'noise' in sea-level observations from natural fluctuations, and the slow response of polar oceans and ice sheets to the current warming, make it difficult to detect a small acceleration over periods of a few decades.

One of the wildcards in predicting sea-level rise has long been the response of grounded polar ice sheets (i.e. those of Antarctica and Greenland) to global warming. A substantial melting of these ice sheets is now considered very unlikely during the 21st century.

Long-term projections of sea-level rise and its impacts for New Zealand are complicated by two additional factors. One is the fact that the entire New Zealand landmass is rising as an after-effect of the removal of glacial ice-caps since the last ice age, and oceans still adjust to this uplift (so-called 'iso-static rebound'). The rate of this uplift is uncertain but estimated at about 4 cm per century, leading to a smaller relative sea-level rise in New Zealand. However, this correction is small compared to the projected rate of absolute sea-level rise and its uncertainty.

Secondly, plate tectonic movements can result in large local changes in land elevation, especially when combined with major earthquakes (in the order of 0.5 to 1 m). Such changes can over a short time frame have a much larger local impact on relative sea levels than the gradual sea-level rise expected from global warming. However, because major tectonic changes tend to occur in discrete and localised jumps in either direction, their long-term effect on relative sea levels is difficult to generalise. All historical sea-level gauges in New Zealand (at Auckland, Wellington, Lyttelton and Dunedin) show a rising trend broadly consistent with the global average, indicating that tectonic movements do not necessarily override the effect of gradually rising seas within a 100 year time frame.

Table 2 *Projected average changes in relative sea levels for New Zealand under two global warming scenarios (with uncertainty bounds) and the IPCC worst case. The relative rise assumes an iso-static rebound effect of 4cm per century, but no tectonic events.*

| Global warming scenario | 2050 | 2100 |
|---|---|---|
| Scenario 1 | 13cm (3 - 25cm) | 34cm (9 - 66cm) |
| Scenario 2 | 12cm (3 - 24cm) | 25cm (5 - 49cm) |
| IPCC worst case | up to ~30cm | Up to ~84cm |

## Impacts of rising sea levels on New Zealand coastlines

Future accelerated sea-level rise would likely increase the rate of erosion along coasts which are already retreating, while currently stable or advancing coasts would tend to stop their advance or begin to erode. A general quantitative assessment of the response of New Zealand coasts to rising sea levels is difficult, however, because shore type, sediment supply and wave characteristics show great regional variability in New Zealand. Future climate change will lead to locally different changes, so that no national-scale assessment of the impact of a sea-level rise is available at this stage. The sections below summarise, on a mostly qualitative level, the key factors determining the expected impacts.

### 1. Short-term sea-level oscillations

A recent analysis for the port of Auckland indicates that the sea level remained almost static for the past 25 years, but has risen markedly by about 5 to 7.5 cm during 1999-2000. These and other findings are part of growing evidence that sea levels around New Zealand in the short to medium term are dominated by interannual and interdecadal variations of climate patterns, such as the El-Niño-Southern-Oscillation (ENSO), which varies on time scales of 2 to 5 years, and a longer-term (10 to 30 years) ocean-atmosphere variation known as the Interdecadal Pacific Oscillation (IPO).

Sea levels around New Zealand are therefore not expected to rise gradually, but to exhibit stepwise changes which can locally offset or enhance the long-term sea-level rise projected under global warming. In the long run, their effect is likely to be net zero or at least small compared to the global average rise in sea levels if the mean state of regional climate patterns does not change. Over time scales of a decade, however, marked jumps in sea levels caused by shifts in regional climate patterns are likely to be of greater importance than gradual sea-level rise under all but the worst-case scenario.

The relative importance of short-term local variations or the long-term average rise in sea levels therefore depends on the lifetime of coastal structures and their expected replacement dates. Climate change could also influence long-term local sea levels around New Zealand compared to the global average if atmospheric or ocean circulation patterns change their mean state, but no models exist at present that would allow a prediction of the direction or extent of such changes.

### 2. Erosion from gradual sea-level rise

The response of a given shoreline to a rising sea level depends on the type of shore, and the balance between wave erosion and sediment supply from river mouths, local currents and the continental sea-shelf.

Cliffed bedrock shores and built structures are relatively resilient against gradual erosion from rising seas, provided they can withstand increased breaking wave heights. The advance or retreat of sandy beaches is a more continuous process which depends on the ongoing dynamic equilibrium between shoreface sand supply and wave erosion.

Changes in local climate patterns are expected to affect both wave erosion and sediment supply, leading to regionally different responses of otherwise identical shore types to climate change. Altered rainfall patterns will affect coastal sediment supply through changes in river run-off, while changes in regional climate patterns and wind systems could alter wave structure and littoral currents. The projected increase in westerly winds would tend to accelerate erosion at western beaches but increase sediment deposition at eastern beaches. This trend could however be countered by changed rainfall patterns which are expected to lead to a greater sediment supply from rivers in the west.

Severe weather events can contribute significantly to erosion processes, but no reliable projections on changes in storm frequency or intensity in New Zealand under climate change scenarios are currently possible.

As a result of these regionally varying factors, no national-scale assessment of the quantitative impact of rising sea levels appears feasible at this stage but must rely on detailed studies of particular coastlines. Models are available to predict the magnitude and direction of coastal erosion processes, but depend on site-specific factors. The uncertainty of climate scenarios affecting wind patterns and sediment supply from rivers implies that even in cases where beach structures are relatively well understood, erosion changes under sea-level rise can only be projected within relatively wide bounds of uncertainty.

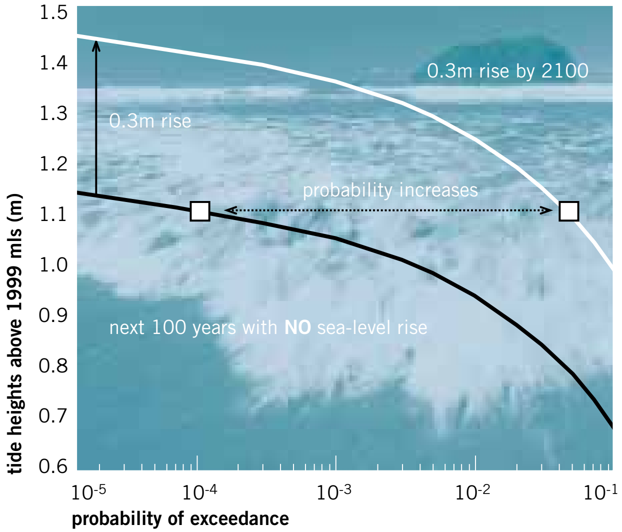
Erosion of coastlines depends on the balance between wave action and sediment supply. Cliffed coasts such as this Taranaki coastline tend to erode in distinct steps, whereas sandy beaches undergo more gradual changes.

## 3. Storm surges and extreme tides

Rising sea levels will increase the risk of storm surges leading to breaches of sea defences. Coastal flooding in the Thames region occurred after two closely spaced storm surges in 1995 and 1997, which had led to a local elevation of sea levels. The 0.6m storm surge on 14 July 1997 coincided with one of the highest tides that year and caused an estimated damage of $3-4 million in the Thames area. If the characteristics of extreme high tides do not change markedly under increased sea levels, the frequency and magnitude with which a given embankment level is exceeded will increase with rising sea levels as the tide height is superimposed on a higher background level.

However, only few tidal records in New Zealand allow robust quantitative statistical estimates of maximum tidal heights or long-term changes in tidal characteristics. No comprehensive analysis of the expected frequency of sea-defence breaches under increased sea levels has been carried out to date, but a methodology exists to carry out such an analysis once longer tidal records accumulate. A complicating factor is the fact that an increase in the average sea level does not necessarily lead to corresponding changes in maximum tidal heights, as currents, open ocean wave generation and morphological changes (e.g. sandbars) may alter the propagation of the tide wave into coastal and estuarine areas.

In some areas, local non-climatic factors may dominate over climate-induced sea-level rise. For example, stop-banks protecting the Hauraki lowlands are currently subsiding due to consolidation of underlying peat and soft sediment. In some places this occurs at a rate of as much as 5 cm per year, greatly exceeding the expected rate of sea-level rise.




Cumulative exceedance probability of tide heights from a 100-year forecast of tidal heights for Moturiki (Bay of Plenty), based on existing records and assuming no change in tidal characteristics. The lower line assumes a constant sea level, while the upper line assumes a nominal 30cm increase in sea levels (similar to the sea-level rise by about 2080 under scenario 1, or after 2100 under scenario 2). For a given land level, e.g. 1.1m above the 1999 mean sea level (MSL), the probability of a tide exceeding that level during the next 100 years is $10^{-4}$ (0.01%) if the sea level remains constant. For a 0.3m sea-level rise, the probability of exceeding that same level would increase to 0.05 (5%). Source: NIWA

## 4. Saltwater intrusion

Rising sea levels increase the risk of saltwater intrusion into groundwater aquifers and tidal stretches of rivers. In general, this is most likely to occur in alluvial plains subject to prolonged drought with high urban and/or rural irrigation demands from groundwater aquifers. Under climate change scenarios considered in this report, increased pressure on groundwater from irrigation is expected in areas such as Hawke's Bay and parts of Canterbury, but changes to aquifer water supply would also depend on rainfall patterns in the source regions.

## 5. Summary

In summary, areas of concern regarding rising sea levels around New Zealand are increased local coastal erosion where increased wave erosion is not balanced by sediment supply, or where cliffed shores are unable to withstand the increased breaking wave height; increased likelihood of inundation from storm surges; and saltwater intrusion particularly where rising sea levels combine with increased groundwater abstraction. Variations of sea levels caused by changes in regional climate patterns are superimposed on long-term sea-level rise. This variability can locally override, enhance or reduce the effect of sea-level rise from global warming over time scales of decades.

Quantitative impacts can only be established by local studies which account for a rising average sea level and wave characteristics, specific coastal structure and sediment supply, and regional climate patterns and trends affecting sediment supply along coastlines, river mouths and estuaries.

# ocean productivity and fisheries

Climate induced changes to the ocean circulation and wave generation, and shifts in regional climate patterns such as IPO and ENSO, would affect ocean productivity within the New Zealand region. Possible impacts include recruitment variability and survivorship of marine species that supply important fisheries. Recent research indicates that climate variability has had significant influences on stock availability in the past. Information on the effects of climate variability on major fish stocks and possible long-term changes to regional climate patterns, however, is still insufficient to allow projections and to determine whether impacts of climate change will have a positive or negative affect on New Zealand fisheries. Changes in fish populations will also be species specific, whereby some may increase and others decrease.

Climate change will similarly influence variability in coastal productivity through changes in coastal processes such as upwelling, river run-off, sea-bed sedimentation and sea surface temperatures and mixing. Such changes will affect nearshore communities, and potentially influence the occurrence of noxious organisms such as toxic algae. Variability in nearshore productivity and the occurrence of toxic algae have had a negative impact on our growing shellfish farming industry during recent years. Any changes to the coastal marine environment in response to climatic change could therefore have major long-term implications for aquaculture in New Zealand, but knowledge is still insufficient to allow reliable predictions or to attribute any observed recent events to long-term climate patterns.

# agriculture and forestry

Agriculture continues to be the backbone of the New Zealand economy. As an industry that relies heavily on environmental resources, it is particularly sensitive to changes in climate. The industry has undergone major adjustments over recent decades in response to non-climatic changes, such as overseas market shifts and developments in production technology. These changing circumstances have made agriculture in New Zealand highly adaptive and could position it relatively well to respond to the effect of slow changes in climate.

Most scientific research into climate change impacts on agriculture in the past decade has concentrated on changes in average climate. This research, summarised below, indicates that a warmer climate would bring both benefits and risks to the farming sector. The effect of changes in climate variability and extremes, in particular the potential increase in heavy rainfall and droughts in eastern regions, has not been studied in detail. Projections about future climate variability are still relatively uncertain, but recent experience shows that climatic extremes can have substantial negative impacts which could affect long-term average productivity in some regions. A case study of previous drought impacts is given on page 32.

## Pastoral farming

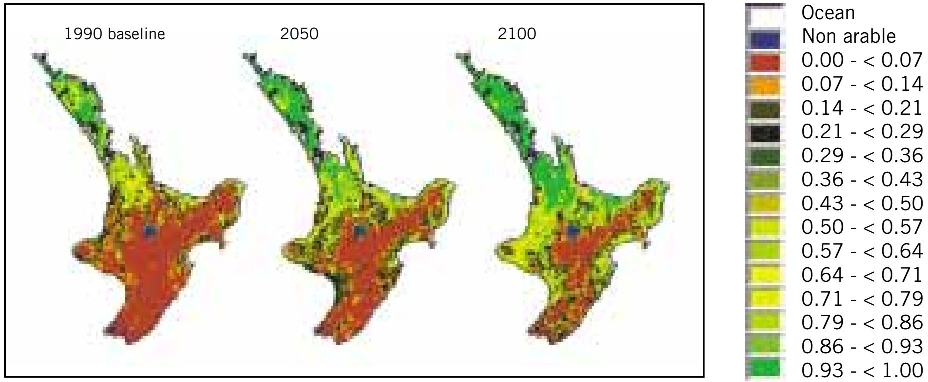
Higher atmospheric concentrations of carbon dioxide in the future will increase photosynthesis (the so-called 'carbon-fertilisation' effect) and impact positively on water use efficiency and growth rates, particularly with temperate pasture.

Experimental and modelling studies indicate that the higher temperatures and carbon dioxide concentration expected by 2030 will lead to a 10-20% increase in annual pasture yields. Rates of increase are predicted to slow down in the latter part of the century. Highest increases are expected in cooler wetter areas, e.g. southern South Island, while already warm and dry areas are expected to gain least.

Little change in the seasonal distribution of pasture yield is expected in most areas. However, some reduction in summer productivity could occur in areas where an increased risk of drought is predicted, mainly Hawke's Bay, Wairarapa, the eastern South Island and Central Otago.

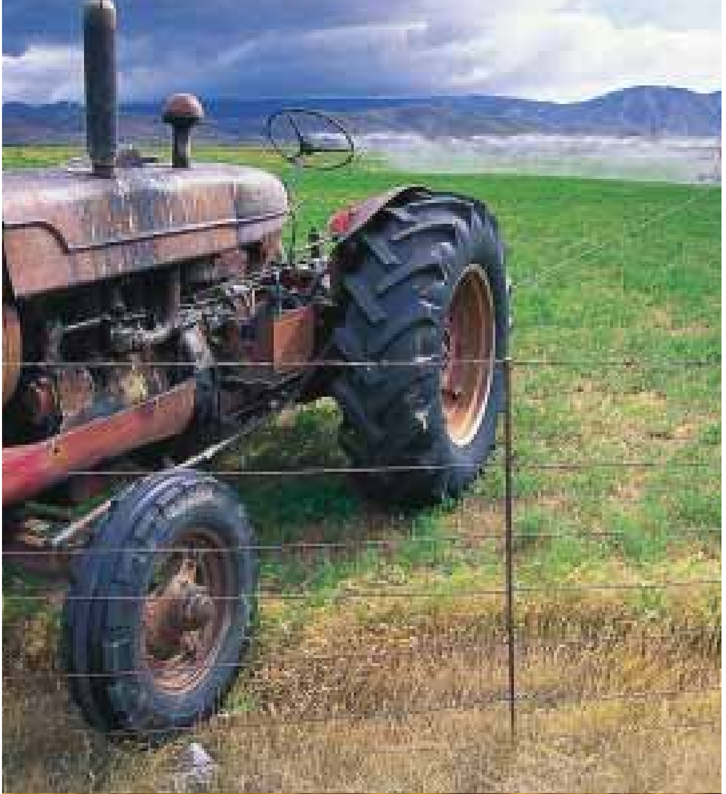
The response of pasture species to increased carbon dioxide, temperature and moisture supply is not uniform, and pasture composition is likely to change. Legumes and weedy species respond more strongly to carbon fertilisation than most grasses and experimental evidence points towards an increased legume component in pasture communities. However, this shift is also likely to depend on soil moisture availability, temperature and the legume and grass species present. For example, white clover is particularly drought sensitive and will be more quickly lost under drought conditions. Changes will therefore differ from region to region.

A matter of concern is the potential spread of lower feed-quality subtropical grasses into pastures. A 1990 study found a southward shift of 1.5º latitude (roughly from mid-Waikato/East Cape to Wanganui/Cape Kidnappers) in the occurrence of the subtropical grass *Paspalum dilatatum* between 1976 and 1988. Under warmer conditions predicted under emission scenario 1, paspalum could become prevalent in all of Waikato, and parts of Taranaki and the North Island east coast. Under scenario 2, this spread would be only slightly more limited by 2050, but significantly less by 2100. Increased prevalence is also projected for the other major subtropical grass in New Zealand, kikuyu (pennisetum clandestinium). While subtropical grasses are of lower feed quality than temperate species, they do have the potential to provide animal feed during periods of soil moisture deficit.




The regional probability of occurrence of the subtropical grass *Paspalum dilatatum* on managed pastures is expected to increase under emission scenario 1. Under scenario 2 the spread is more limited and by 2100 would be only slightly more than that in 2050 under scenario 1. Source: CLIMPACTS programme.

The overall impact of climate change on pasture quality is difficult to quantify and will vary with region. Increased legume content will improve quality but an increased presence of subtropical grasses will be detrimental. Careful management and targeted plant breeding will be necessary to ensure that the increased presence of subtropical species can benefit rather than reduce animal performance.



Higher temperatures will increase the range and incidence of many pasture pests and fungal diseases. However, the overall impacts of climate change have not been quantified yet.

Overall, the pastoral sector could gain under climate change conditions if it manages the potential changes in soil moisture availability and species composition. This would likely require a range of adaptation measures, targeted regionally, including the wider use of current drought-tolerant species, and the development of new drought-tolerant forage species and high-quality subtropical grasses.

## Arable crops

Arable cropping is common in Waikato, Bay of Plenty (maize) and Manawatu, Canterbury and Southland (wheat, oats, barley, peas). As with pasture, productivity of these crops is expected to increase under carbon fertilisation and higher temperatures, albeit to varying degrees. This could allow a slow southward shift of some crops and even the introduction of new species, but this depends on the availability of other resources such as water for irrigation and long-term soil fertility.

Crop models estimate an increase in wheat productivity under carbon fertilisation and warmer temperatures of about 15% under scenario 1 and 10% under scenario 2 by 2050. However, increased use of nitrogen fertiliser would be required to achieve these higher growth rates, and irrigation would be important to prevent crop failure particularly in Canterbury, and seasonally in Manawatu.

Similar opportunities and constraints apply to the production of grain maize in Canterbury. Under scenario 1, the climate in Canterbury is expected to become increasingly suitable for maize production from about 2030 onwards due to reduced risk of frost and warmer summer temperatures. However, maize has a high demand on soil moisture and would probably require irrigation, while rainfall in the region is expected to decrease. Additionally, the low carbon content of Canterbury soils could make the growing of nutrient demanding crops such as grain maize unsustainable.

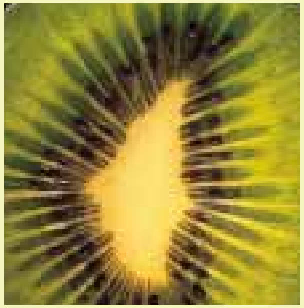
## Fruit production

Fruit crop production is a significant contributor to the New Zealand economy. Temperate fruits require cool winters to promote bud break, and there has been a concern that warmer temperatures might not produce enough flowers to make production economically viable in northern areas of New Zealand. Regions such as Marlborough, Canterbury and Central Otago could become increasingly suitable as a result of warmer summers and lower frost risk if sufficient water for irrigation is available. Research on responses has, to date, focused on the economically most important two crops, apples and kiwifruit.

Despite the basic requirement of winter chilling, fruit crop scientists believe the pip and stonefruit industries are well placed to actively adapt to the effects of warmer temperatures. This is because winter chilling in New Zealand production regions is currently sufficient for ample flowering and summers are relatively cool compared with overseas production regions. The industry also has ongoing breeding programme to develop regionally adapted cultivars.

The predicted decrease in rainfall in the eastern areas of New Zealand, coupled with a continued growth in demand for ground water, would lead to reduced water availability for irrigation in the apple-growing area of Hawke's Bay, and limit the expansion of the industry into other areas. Targeted adaptation strategies such as alternative rootstocks and irrigation management may be required to maintain fruit yields and quality. Incidence of pests and diseases could increase, with an increased risk of new invasive species establishing. Such impacts have not yet been quantified.

Productivity of pastures and arable crops is generally expected to increase, provided that sufficient water resources are available.



# kiwifruit – a case study in climate change impacts and adaptation options

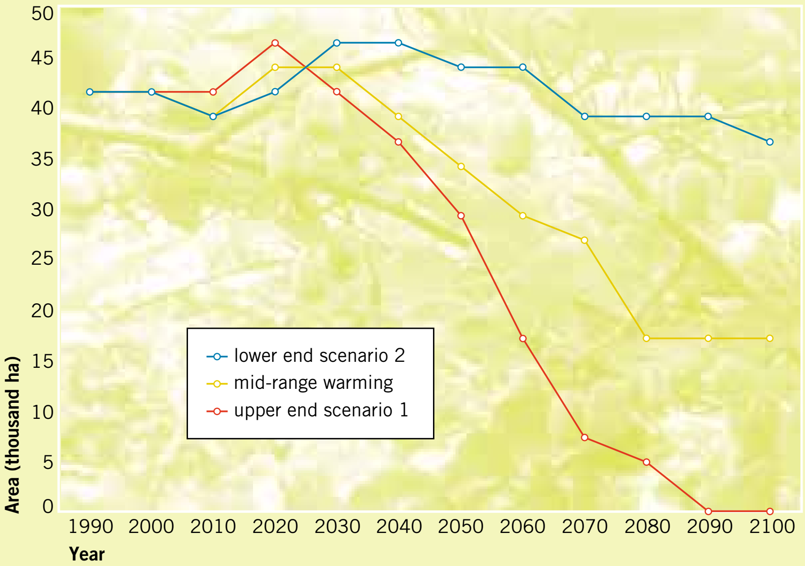
In many cases the costs or benefits of impacts of climate change will be strongly dependent on the successful implementation of appropriate adaptation measures. The kiwifruit crop provides a useful case study to examine in detail the likely interaction of impacts and adaptation. It highlights some of the complexities that exist, even for an industry that is still largely dependent on a single cultivar, and points to the benefits of a proactive approach to adaptation.

## Impacts

Kiwifruit share with other temperate fruit crops the need for winter chilling to promote bud break and to produce sufficient numbers of fruits per vine. Under scenario 1, rising temperatures could lead to a significant decline in kiwifruit viability in the Bay of Plenty from 2050 onwards, while under scenario 2, conditions likely remain viable until 2100. Chemicals which artificially break dormancy and encourage bud break are already used widely in the Bay of Plenty (mainly HiCane). However, their effectiveness under increasingly warmer winters is expected to decline after 2040. At the same time, conditions in the Nelson, Marlborough and Hawke's Bay regions would become increasingly viable from about 2020 onwards under scenario 1 and would remain suitable throughout the 21st century, although additional irrigation would be required. In Northland (Kerikeri), where conditions are already marginal for kiwifruit, conditions are expected to become uneconomic from about 2050 under scenario 1 even with extensive use of dormancy-breaking chemicals.

An indirect impact of climate change on kiwifruit production in New Zealand could arise from altered climate conditions in other countries, such as Italy and Chile. As climate warms in these places, established kiwifruit growing areas may also become marginal. The rate of change and adaptive capacity, relative to that experienced in New Zealand, would have a strong influence on future competitive advantage.

Thus, the economic opportunities and risks from changing overseas markets could be as large for New Zealand growers as the impacts of domestic climate change. Detailed studies of international linkages will have to wait until comparable work on climate impacts becomes available for competing countries.




The area suitable for kiwifruit growing in the Bay of Plenty is projected to change depending on the warming scenario. The calculations were made using emission scenarios similar to the range covered by scenarios 1 and 2 in this report. Source: HortResearch and CLIMPACTS programme.

## Adaptation options

The increased use of dormancy-breaking chemicals to compensate for warmer winters may bring problems of consumer resistance. Organically acceptable alternatives to HiCane are presently being developed and evaluated and, alongside various crop management practices that are already in use, may be adequate over the next few decades.

A further adaptive solution to increased winter temperatures would be the breeding of cultivars that are less affected by warmer winter temperatures. The new Zespri Gold variety has a similar sensitivity to winter chilling as the traditional Hayward cultivar, but produces more flowers and thus has a greater adaptive potential to warm winters. However, higher crop production is required to offset the significantly higher costs of growing Zespri Gold. Future breeding programmes may need to specifically aim for cultivars with reduced chilling requirements. This is not currently a high priority for the kiwifruit industry, but it will need to become so over the next 10-20 years, based on the changes that are projected.

In the long-term (70-100 years) relocation of kiwifruit production to other areas could provide important new economic opportunities for some regions, but would be restricted by the cost of relocating industry infrastructure and the availability of sufficient water resources to provide irrigation.

## Forestry

Wood production through planted forests, mainly of radiata pine, has become an important component of New Zealand's primary industry. Since forests also represent an important sink for atmospheric carbon dioxide by absorbing and storing carbon in their biomass, interest in forestry development will continue into the foreseeable future.

The 25 to 30 years rotation period of forestry plantations implies that over the lifetime of a tree, relatively significant climate changes may occur. Many other farming systems work with shorter planning horizons and hence can adapt on shorter time scales.

The growth rate of trees under carbon fertilisation is expected to increase like that for most crops. Studies carried out on pine seedlings confirm increases of about 20% under doubled carbon dioxide concentrations, but questions have been raised over the long-term effect of carbon fertilisation. Older trees showed very little response to carbon fertilisation under growth chamber experiments. The full effect of increased carbon dioxide over the lifetime of a tree under free environment conditions, including the possibility of earlier harvesting, has yet to be verified.

A negative impact of climate change on plantation growth rates could lie in changes in rainfall patterns. Radiata pine requires about 1500mm of annual rainfall for optimal growth, and drier areas in the East Coast of the North Island could experience growth reductions under projected rainfall reductions. However, this reduction could be offset by increased water efficiency of trees under increased carbon dioxide concentrations. Data and models are still too limited to allow quantitative predictions.

Higher temperatures may be beneficial to radiata pine growth in many areas, but may also increase the occurrence of damaging conditions such as upper mid-crown yellowing under dry conditions, and fungal diseases in warmer winters. The fact that night-time temperatures rise relatively faster compared to day-time temperatures, as predicted under the global warming scenarios, could have a negative effect on tree growth. Trees gain resources and energy during the day through photosynthesis, but are likely to lose a greater proportion of these resources during the night under higher temperatures. Recently developed process-based models increase our understanding of the environmental factors contributing to tree growth rates, but they have yet to be linked with climate scenarios to allow quantitative predictions under future climate conditions. Warm and dry summer conditions could also increase the risk of fire to forest stands in areas where average rainfall is likely to decrease.

## extreme events and their impact on agriculture

One of the predictions of the biophysical impacts of climate change on New Zealand is that both frequency and magnitude of extreme events, such as droughts and floods, will increase. Case studies of past droughts, such as the 1997/98 El-Niño event, provide examples for the impacts of climate extremes and allow the development of long-term adaptation mechanisms if such extreme events were to become more frequent.

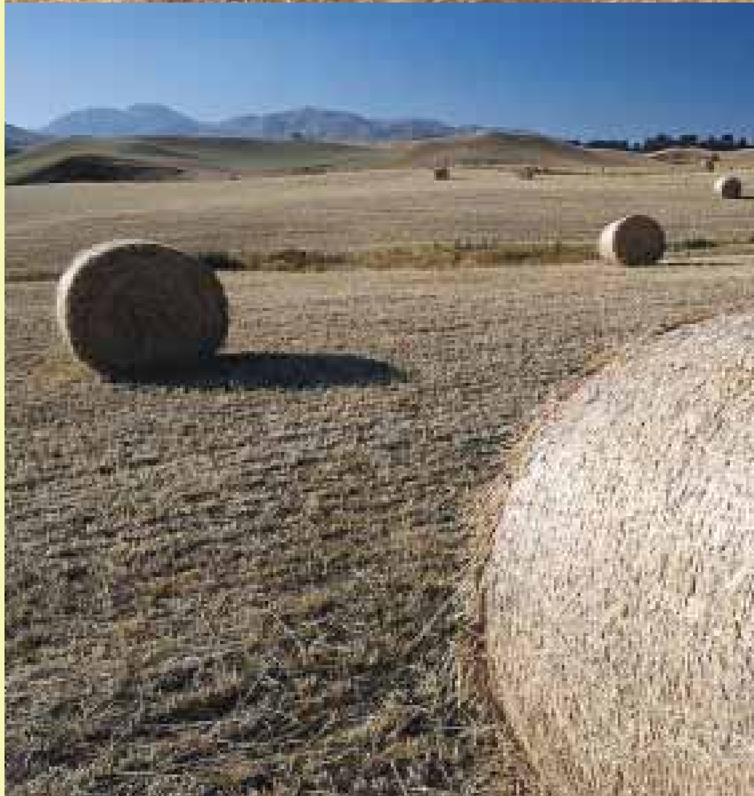
The El-Niño of 1997/98 was one of the strongest events the country has experienced. The associated serious summer drought brought heavy losses for farmers in eastern areas and heavy rain in western areas of the South Island. The Ministry for Agriculture and Forestry estimated the combined losses to farmers and value-added production at more than $1 billion, or a decline in GDP of approximately 1%.

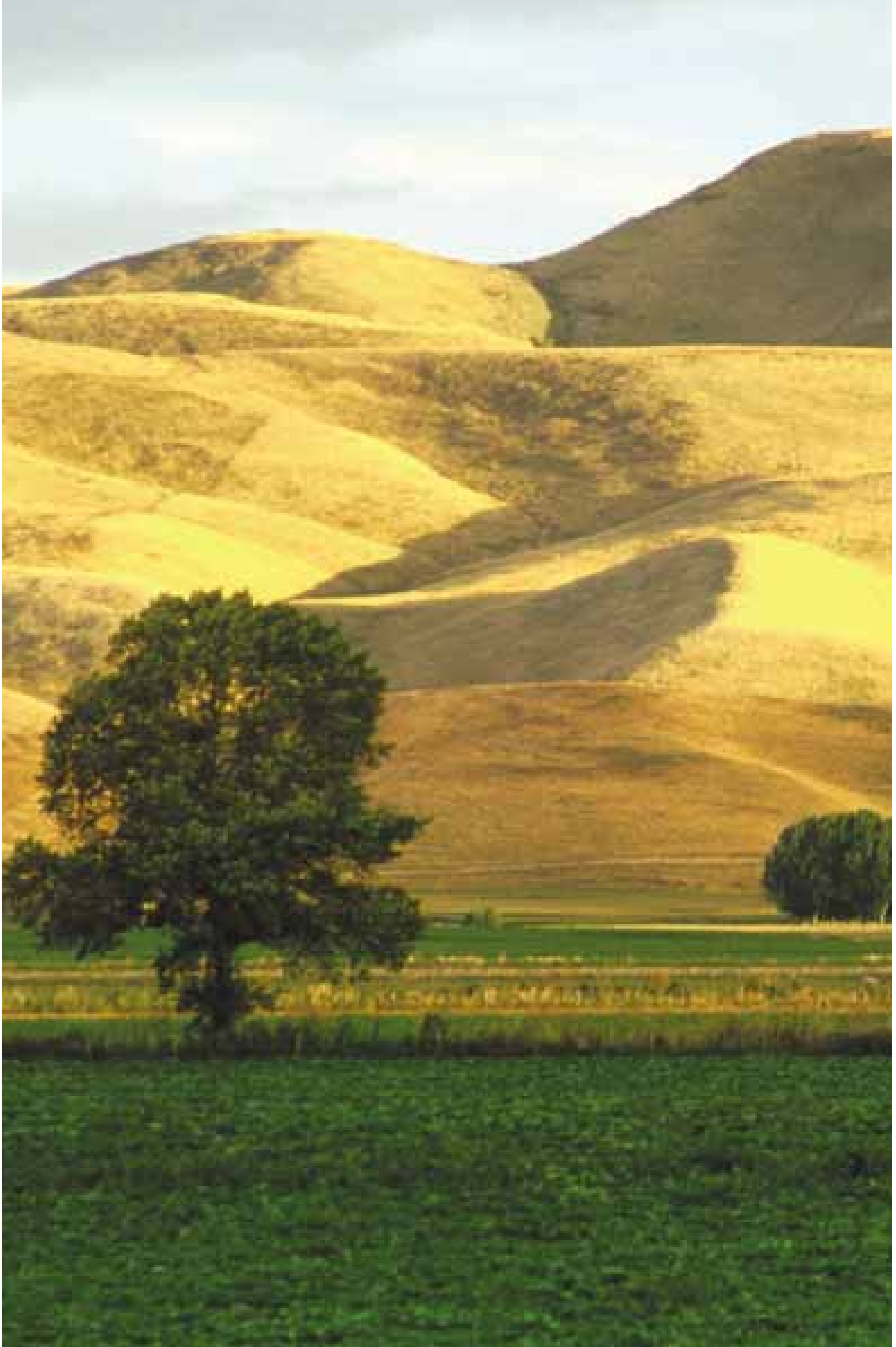
Moisture stress was the main limiting factor in pastoral agriculture, particularly in Marlborough, North Canterbury and Hawke's Bay. Farmers reacted to the feed shortages by selling or moving stock, thereby minimising their direct negative impacts. For the country as a whole, milk production was estimated to have declined by about 7% for the December 1997 to March 1998 period, compared to 1996/97, with flow-on effects for the following year because of reduced stock numbers. Short-term adaptation mechanisms employed by sheep farmers included substantial stock number reductions. If this type of adaptive response to more frequent droughts remained the only available solution in the long term, it would lead to a permanent reduction of pastoral farming in these areas. A the same time, pastures on the South Island's west coast suffered from water-logging due to the increased westerly air flow and associated higher rainfall.

The impact of the 1997/98 El-Niño on arable crops was varied, with good yields and quality reported for irrigated farms, whereas production from dryland farms was reduced by around 25%. The need for increased irrigation leads to water restrictions in many areas including Nelson and Canterbury, with lowered groundwater tables in some regions of Canterbury and Marlborough. Some aquifers in the Nelson region were at risk from saltwater intrusion for some months.

Horticulturists reported a mixed picture of high-quality fruit for some cultivars and major losses for others. Particular problems were found with apples developing sunburn and watercore in Hawke's Bay, Marlborough, Nelson and Canterbury. At the same time, fungal problems were reduced because of the drier than usual summer conditions. Kiwifruit in the Bay of Plenty, as well as peaches and nectarines, developed well as irrigation water was sufficient.

These snapshots of the impact of a recent El-Niño drought indicate a common emerging theme – the availability of water and its effective management. While plant breeding programmes can provide an adaptive capacity for warmer temperatures, water resources and competition for water by other users and ecosystems are likely to remain limiting factors for many industries. The heavy impact of the 1997/98 drought implies that any changes in the frequency of such extreme events would be a key determinant in the overall impact of climate change on the agricultural sector in New Zealand.





## Summary


The agricultural sector has substantial opportunities for productivity gains and diversification under climate change, but also faces some serious long-term risks.

The most significant risks are associated with the potential increase in the number of extreme events such as droughts and floods, causing more damage and reducing recovery time for farmers. The generally drier conditions projected for eastern areas of the country mean that water could become a more limited resource in some areas, and competition between agriculture and other water users could increase. In some areas, higher temperatures would make the growing of some existing fruit crops uneconomical or reliant on chemical enhancements, an adaptive solution which would not be available to organic growers. Changing land-use activities and relocation between geographical locations to adapt to altered climate conditions incurs a financial and social cost and will result in regional winners and losers.

Pasture composition is likely to change with uncertain effects on animal productivity and long-term nutrient balances. Pests and diseases could spread in range and severity, and additional chemical treatment could meet consumer resistance. The potential impact of climate change and pest and disease shifts has not been quantified yet.

The key benefit to agriculture will not be from climate change as such, but from the fertilising effect of elevated carbon dioxide concentrations which increase plant growth and improve water use efficiency. In addition, warmer conditions and lengthened growing seasons will allow the long-term southward shift of pastoral farming and some existing crops (e.g. kiwifruit, maize, radiata pine, wine and nuts), and new crops and related industries (mainly subtropical crops) could be introduced into northern regions of New Zealand, potentially benefiting currently resource-poor areas.

The overall economic impact of climate change on the agricultural sector is difficult to quantify. One of the main reasons is the uncertainty of some key climate predictions, in particular rainfall patterns and the frequency of extreme events such as droughts and associated risks such as fires. Adaptation to altered climate conditions will also play a major role in determining whether opportunities are fully utilised and negative impacts reduced. Finally the viability of New Zealand agriculture depends on overseas markets. These markets will no doubt also change under a warming climate, offering indirect risks and opportunities to New Zealand farmers. The quantification of all these factors remains a task for future assessments, but it is likely that the sector will experience regional winners and losers under current climate projections.

# native ecosystems

Non-climatic pressures from human settlement have dominated environmental change in New Zealand and will inevitably continue in the 21st century. Most of the major transformations of vegetative cover in the past resulted from either the indigenous vegetation being cleared through logging or fire, and/or from the spread of introduced weeds and herbivores such as possums. As the climate continues to warm, and perhaps extreme events become more common, these disruptive influences will become more severe as natural protection mechanisms of ecosystems are progressively affected by changing climatic conditions.

Results from an ongoing Landcare study of forest – climate relationships underline the likely sensitivity of our forests to climate conditions. The study examined relationships between forest composition and factors such as temperature, solar radiation, soil water stress, drying winds, and geological substrate. Initial results indicate that forests on warm lowland sites are likely to be most sensitive to predicted temperature increases, while beech forests on cooler sites appear least likely to undergo major compositional changes, in part because of their strong competitiveness when growing with other tree species.

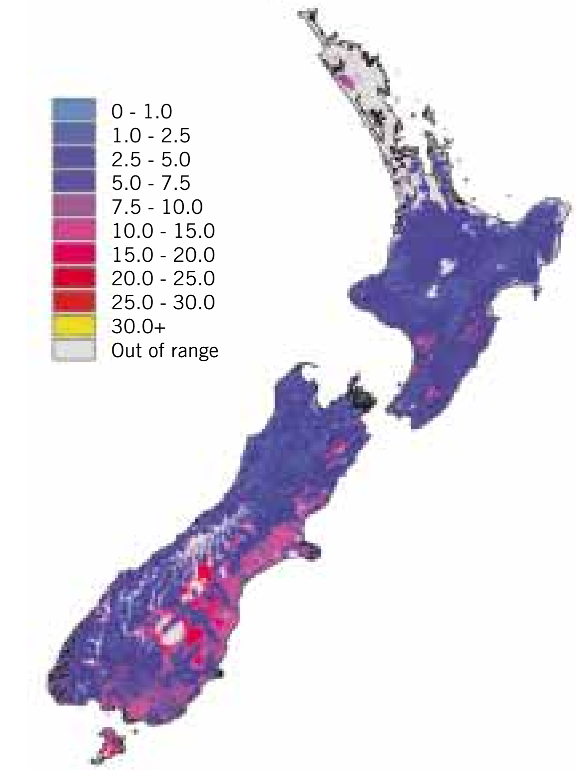
Similarly, increased water stress resulting from reduced rainfall and more frequent dry westerly winds is predicted to have greatest impact in environments that are already subject to some degree of drought. The fragmented native forests of drier lowland environments in Northland, Waikato, Manawatu, and in the east from East Cape to Southland are therefore probably the most vulnerable to global warming. Adjustment of natural forest remnants to global warming will be severely hampered by loss and fragmentation of seed sources through forest clearance, loss of avian dispersers through predation and habitat loss, and invasion by alien weed species from adjacent developed land. In addition, they probably also face increased threats from wild fires, both the incidence and severity of which are likely to increase during the more frequent extreme climatic events predicted to accompany global warming. Since New Zealand native forests are generally not adapted to fire, any increased occurrences will impact on ecosystem balances with long recovery times.

Other biotic changes associated with climate variability are mast fruiting of tussocks and beech trees following warmer than average summer seasons, possibly connected with more intense El-Niño fluctuations. More frequent fruiting results in a more reliable food source for rats and mice, which in turn boost the numbers of stoats and cats with predictable detrimental flow-on effects on endangered bird populations.

A warmer climate may also make New Zealand's native flora and fauna more vulnerable to invasion by introduced species. Of particular concern is the possibility that once the climatic envelope in which the New Zealand native vegetation has evolved is breached, it will become more vulnerable to invasion by exotic trees, shrubs, and climbers. Current studies are examining the biosecurity risk from invasive temperate and subtropical species, and their likelihood of introduction through international visitors and cargo shipments.

Similar concerns as for native forests apply to freshwater ecosystems. Many of the potential changes in aquatic ecosystems under climate change commence with effects on surrounding vegetation type and cover, and altered amounts of run-off to streams and rivers. More specific impacts expected on freshwater ecosystems include warmer temperatures, which affect lake mixing and associated eutrophication processes, decrease the available habitat for native species and increase habitat and growth of undesirable exotic species. Also expected are changes in the magnitude and seasonality of river flows, which reduce habitat for native species (particularly at low flows) and increases nutrient loadings, and further loss of wetlands and associated wildfowl populations. These changes are also likely to affect the availability of goods and services provided by freshwater ecosystems.

### Predicted change in average forest species abundance (%)




Species abundance in New Zealand indigenous forests is expected to change for a 1.6 degree rise in mean annual temperature. Predictions have been made based on current observed species distributions and climate zones. No predictions have been made for areas, shown in grey, for which future temperatures are predicted to lie outside the currently observed maximum. Source: Landcare Research (unpubl. data).

Continued uncertainties are associated with estimating the climatic resilience of native species. Limited systematic observations in New Zealand so far show no major changes in species distribution that could be attributed to the 0.6 degrees Celsius warming during the 20th century. For instance, the upper tree line has remained static and there is little sign to date of changes in the density or extent of vegetation above the treeline.

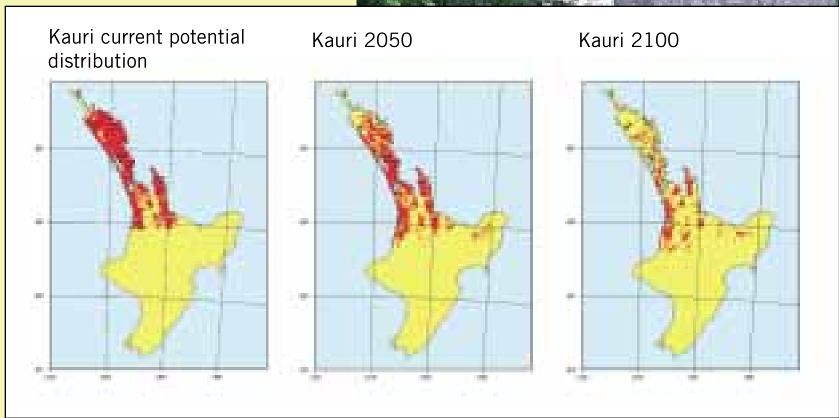
The complex interdependence of native ecosystems and their constituents makes quantitative predictions of climate impacts particularly difficult, and few linked model studies have been developed for New Zealand. With few exceptions, climate change alone is unlikely to be the dominant cause of native species extinction, but may have a compounding effect on those ecosystems that are already under high pressure from human settlement.

## kauri under threat from global warming?

Kauri trees cover a limited geographical range in New Zealand, and some scientists believe that their distribution may be strongly limited by climatic conditions. They may therefore serve as an example of what could happen to species that currently appear close to their upper temperature limit.

Model studies at the University of Auckland, based on the tree's present distribution and climate data, indicate that most of Northland, Auckland, Coromandel and parts of western Waikato are currently climatically suited for kauri. Under a warmer climate such as predicted under scenario 1 this area would fragment and decline 25% by 2050, and 65% by 2100, with the potential range moving southwards and eastwards. Under scenario 2, the suitable area would decrease some 20% during the 21st century. Death of existing trees is however considered unlikely as mature trees are very resilient to climatic fluctuations and can persist for many centuries, but an increasing failure of reproduction and/or regeneration would lead to the slow but inevitable decline of the species.

The predictions of this model rest on the assumption that the correlation between present limited distribution and climate can be used as an indicator for the kauri's climate sensitivity. Since kauri are endemic to New Zealand, no observations of their actual response to higher temperatures in other countries are available, and more work on underlying processes would be required to validate the model predictions.




Projected change in distribution of areas suitable for long-term survival of kauri (marked in red), under a global warming scenario similar to scenario 1. Source: University of Auckland and CLIMPACTS programme.

# urban environment, transport and energy

Compared to other countries in the Pacific, the urban environment in New Zealand is relatively robust against climate impacts. However, the long average lifetime of urban constructions means that the design of new structures must account for climate scenarios several decades into the future. Other pressures on the urban environment from population growth and transport management are likely to outweigh climate impacts in many instances.

## Urban design and infrastructure

Based on the possible increase in frequency and intensity of extreme weather events, the biggest direct threat to housing will likely come from heavy rainfall and associated floods. Increased peak flows within urban catchments will put pressure on stormwater and wastewater infrastructure. Currently marginal housing areas near river banks and lake shores are also likely to become more prone to floods.

Model-projected changes in return periods of extreme floods are inherently difficult to confirm by observations over limited time spans. A statistical analysis shows that more than 50 years of observations would be required to test whether a "1-in-100 year" flood has in fact become more frequent and now occurs, for example, every 25 years. If the flood did become more frequent, substantial damage would occur while waiting 50 years for proof. Urban planning therefore cannot necessarily rely on historical climate records alone, but would need to give model projections of rainfall changes adequate weight when considering protective actions to reduce risk against their costs. The weight given to model projections should depend on the level of uncertainty associated with them, which is expected to reduce over time as models improve.

Some housing areas, particularly near sandy beaches, may become increasingly prone to erosion under rising sea levels, but general quantitative statements are impossible because of the strong local variation of erosion and sedimentation processes (see discussion on coastal impacts).

The likely increase in drought conditions in some eastern areas of New Zealand (Hawke's Bay, Canterbury, Marlborough and Nelson) may result in increased competition for water uses between agricultural irrigation and domestic and industrial use.

Potential increases in heavy rainfall would likely cause more road erosion and require more frequent repair work, while new structures such as bridges may need to accommodate higher flood peaks in their design. However, roads traditionally affected by winter closures (such as the Desert Road and several roads in the central and southern South Island) would incur reduced winter maintenance costs due to less frost and snowfall.

The changes in the mean and the daily range of temperatures will impact on individual home and business energy use. Research by the Building Research and Manufacturing Association (BRANZ) showed potentially substantial reductions in space heating depending on geographic location and climate scenario, modest reductions in hot water heating, and in some areas substantial increases in the number of summer overheating days which could lead to increased use of air-conditioning.

| Location | Potential relative heating reduction 2030 | 2070 |
|---|---|---|
| Auckland | 12-70% | 69-79% |
| Wellington | 25-33% | 29-86% |
| Christchurch | 4-14% | 9-62% |
| Invercargill | 12-19% | 15-51% |

Source: BRANZ

The biggest direct threat to the urban environment from climate change probably lies in the increased risk of flooding and erosion, and consequent landslips at exposed sites. Photo: BRANZ

### Electricity supply

Climate change could play an important role in the South Island-based supply of hydro-electricity. In the South Island, the water supply is controlled by run-off, which depends on rainfall, melt of seasonal snow and ablation of glaciers. In the present climate regime, river flows in hydro-catchments tend to be lowest in winter, when the demand for electricity is largest, and rise in spring and summer due to snow and glacier melt.

Under warmer conditions, the seasonal asymmetry of run-off is reduced because of increased winter rainfall over the Main Divide, less seasonal snow storage and a reduced contribution from shrinking glaciers.

The seasonal change in supply will coincide with a reduced electricity demand during winter brought about by warmer conditions. Electricity demand models predict that for a warming of about 2 degrees Celsius, as predicted on average under scenario 1 in this report by 2100, annual average electricity demand would decrease by about 6%. Future climate change may therefore be expected to bring net benefits to hydro-electricity supply through reduced summer storage needs and increased generation potential during winter peak demand.

Summer demand for electricity could increase through a growing use of air-conditioning in buildings, but in the current climate this is not very sensitive to summer temperatures. A greater frequency and intensity of extreme rainfall could also increase unavoidable spills and flooding risks to hydro dams and downstream areas, although recent such events cannot necessarily be attributed to climate change.

# health effects

Many people would intuitively welcome warmer weather in New Zealand. Warmer winters would be expected to reduce cold-related illnesses and deaths, and reduced use of open fires for heating should lessen typical winter air pollution. Higher summer temperatures on the other hand will increase the risk of summer smog, particularly in the Auckland region.

More importantly, climate change will lead to more frequent climate extremes with direct health implications, in particular heat waves. A recent study in Christchurch found a strong correlation between mortality and summer maximum temperatures, with an average increase of 1.3% in mortality for every degree Celsius. The same study also found a reduction in deaths for warmer winter temperatures, but this correlation was not significant. No similar studies have been carried out for other cities, but the negative impacts of a warmer climate in New Zealand are likely to be most marked in northern regions, while benefits would be greater in southern regions. Air-conditioning to reduce heat exposure for sick and elderly people could become desirable to reduce heat stress, but may not be available to all.

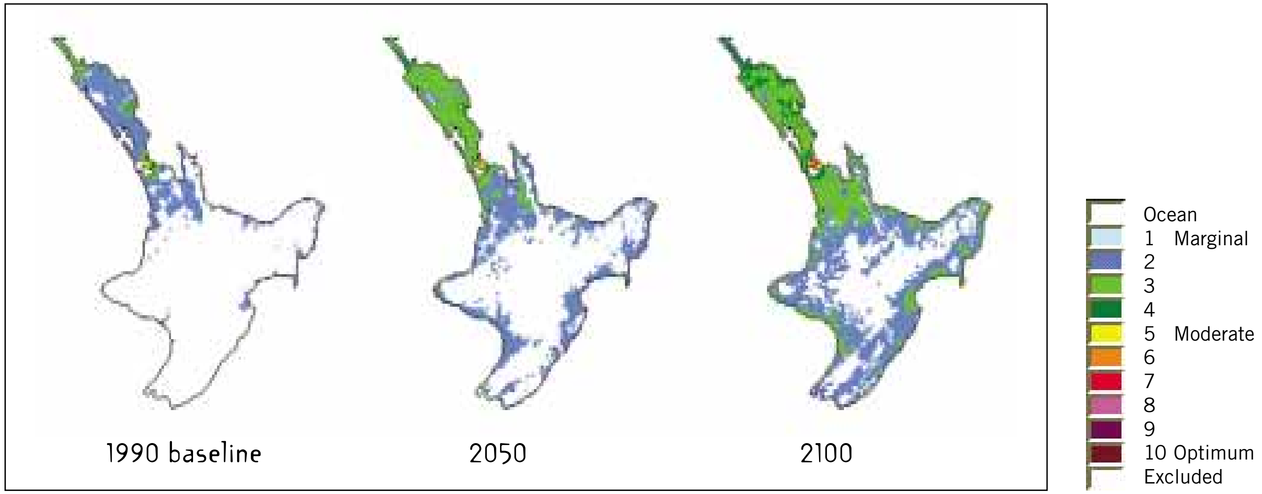
Another effect of climate change is the establishment risk of mosquito populations capable of transmitting infections such as the Ross River virus and dengue fever. Many studies suggest that under warmer conditions parts of Australia and New Zealand will become more favourable breeding sites for disease-carrying mosquitoes.

*A. albopictus*

Warmer conditions will encourage humans to spend more time outdoors. They will also tend to extend the range and transmission efficiency of these disease carriers. Increased arrivals of goods and travellers from subtropical and tropical destinations increase the risks of introducing and establishing populations of these virus species.

Recent work incorporates the risk of introduction from international shipments and travel into general climate assessments and is thus able to indicate potential dengue fever 'hotspots'. Researchers forecast that under emission scenario 1, the area at risk of establishment of the mosquito species *Aedes albopictus*, an important cold-tolerant vector for dengue fever, would by 2100 spread into Gisborne, Hawke's Bay and coastal Manawatu. The actual occurrence and spread of the disease will however not only depend on the distribution of the disease vector, but also on living conditions and ability of the health system to control potential outbreaks.

On the positive side, there are presently no mosquitoes capable of transmitting malaria in New Zealand, and even under most global warming scenarios the possibility of a suitable exotic vector becoming established is considered small.




Establishment risk (climatic suitability and risk of introduction) for dengue-vector *A. albopictus*, for 1990, 2050 and 2100, under emission scenario 1. Under emission scenario 2, the suitable area in 2100 would be similar to that in 2050 under scenario 1. Source: HOTSPOTS dengue fever risk model by International Global Change Institute, University of Waikato, and CLIMPACTS programme.

Additional health impacts from climate change could arise from increased variability of rainfall. High risk water supplies encourage the spread of diseases which are transmitted between animals and humans, such as cryptosporidiosis. New Zealand already has a relatively high level of occurrence of this notifiable disease. Increased heavy rainfall events predicted under climate change scenarios could distribute pathogens by washing animal excreta containing the organism into water supplies. Drought periods would also lead to poorer water quality in areas where water supplies struggle to meet demand.

Particularly in the area of health, it is important to recognise that the impact of climate change is not just determined by the change in climatic conditions, but also the vulnerability of the exposed population. New Zealand is less vulnerable to threats from climate change than some of its Pacific neighbours because of its more efficient health infrastructure, relatively affluent population, and established pest control schemes to detect and control introduced pests.

However, within New Zealand there are groups that are more susceptible than others. Sources of disadvantage include poverty, low standard housing, high-risk water supplies, and lack of mobility and of accessible health care. These additional risk factors currently tend to be focused around particular geographical regions and groups such as Māori and Pacific Island communities. Future developments in social structures and the health system will largely determine the vulnerability of these and other groups to health-related climate impacts.

# climate change and ultraviolet radiation

One health impact of climate change may come from an unexpected corner. It has long been known that the emission of chlorofluorocarbons (CFCs) leads to the destruction of the ozone layer, which shields the Earth's surface from harmful ultraviolet solar radiation, known to cause skin cancer.
New Zealand has one of the highest skin cancer rates of the world, assumed to be due to a combination of a largely pale-skinned population, regular outdoor activities, and naturally high levels of ultraviolet radiation because of lower ozone and pollution levels than in the northern hemisphere.
Public awareness about the risks of skin cancer and required behavioural change is high because of information campaigns in the eighties and nineties. Nonetheless the rate of skin cancer in New Zealand is one of the highest in the world, with 250 deaths per year and estimated total health system costs of $33 million.

A recent study demonstrated that ultraviolet radiation over New Zealand increased by 12% between 1989 and 1999, associated with the depletion of stratospheric ozone caused by past emissions of CFCs. CFC emissions are now banned under the 1987 Montreal Protocol on the Protection of the Ozone Layer and subsequent amendments, and gradual recovery of the ozone layer is expected by the middle of the 21st century.

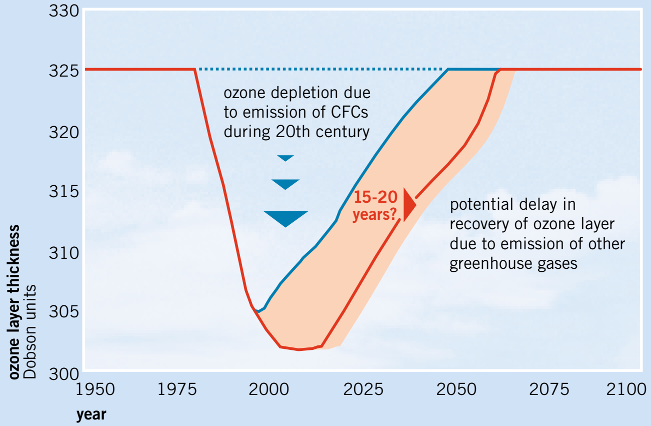
The issues of ozone depletion (increased ultraviolet radiation) and climate change (higher global temperatures, rising sea levels and rainfall changes) are at first sight unrelated phenomena. However, increasingly stronger links have been discovered between these two subjects. One such link has long been recognised, which is the fact that CFCs not only destroy the ozone layer, but are also very potent greenhouse gases. Thus emissions of CFCs not only lead to ozone depletion but also enhance global warming.

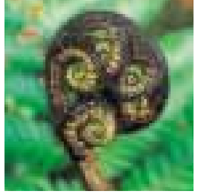
Yet a new connection has only become evident over the past decade. Greenhouse gases lead to a warming of the Earth's surface, but result in a cooling of upper layers of the atmosphere, such as the stratosphere where the bulk of the ozone resides. Since some chemical reactions destroy ozone more effectively at lower temperatures, further greenhouse gas emissions could thus promote ozone depletion and delay the expected recovery of the ozone layer over New Zealand by 15 to 20 years.

Rising greenhouse gas concentrations would also impact on ozone concentrations in other regions of the southern hemisphere, in particular the severity of the Antarctic ozone hole. Although the Antarctic ozone hole does not extend over New Zealand, recent research shows that ozone-depleted air from the polar regions is episodically transported to mid-latitudes, leading to temporary reductions of ozone over New Zealand during the summer months.

In summary, recent evidence indicates that greenhouse gas emissions could extend the period during which New Zealanders are exposed to higher than average ultraviolet radiation and increased risk of skin cancer, despite the ban of CFC emissions and expected recovery of the ozone layer. Model predictions of these issues are however still highly uncertain and scientific research to quantify the impacts on ultraviolet radiation levels in New Zealand is ongoing.

Expected recovery of the ozone layer during 21st century, following depletion during the 20th century due to CFC emissions. The blue line shows the expected recovery after banning of ozone-destroying CFCs. When the influence of climate change on the ozone layer is taken into account, the recovery could be delayed by 15-20 years (red line). Considerable uncertainties exist regarding this estimated delay, indicated by the shaded red area. Source: NIWA.





# climate change impacts on māori

Māori see the world as a unified whole, where all elements including tāngata whenua are genealogically interconnected. Emphasis is placed on the balance of cultural and spiritual values in the environment while utilising resources for social and commercial purposes. The potentially damaging effects of climate change to the environment combined with an only recently improving economic position make Māori under their current socio-economic status more vulnerable and less adaptable to some aspects of climate change than non-Māori. While little research into these aspects has been carried out over the past decade, a number of themes are emerging with greater clarity.

## Land use

The Māori asset base is predominantly land and fisheries, and a large proportion of Māori earnings depends on the export of primary commodity and processed products. Māori land covers 5.6% of New Zealand's total land mass, with 95% located in the North Island where it is disproportionately represented in lower land classes. Particularly for drier and less productive areas such as Northland and the East Cape region, timely and proactive adaptation to climate change impacts will be important to avoid loss of productivity from invasion of subtropical grasses, erosion and increased frequency of floods and droughts (see section on agricultural impacts on page 18). Strategic decisions may also be required to exploit new growing and marketing opportunities.

Māori land is generally under multiple ownership, which reduces the flexibility of the decision making process. Due to the high cultural value accorded to Māori land and statutory restriction on land sales, business relocation in adaptation to climate change is not generally an option. Māori landowners often have lower economic power, restricted access to finance and currently tend to rely on traditional farming methods. Because costly or non-traditional adaptation measures may not be fully employed, the commercial output from Māori land risks being reduced compared to the New Zealand agricultural sector as a whole.

## Coastal issues

Coastal areas tend to be of traditional and cultural importance and are often fundamental to Māori in their identity as tāngata whenua. In addition the coastal environment is an important food resource. Coastal erosion and changes to the productivity of inshore and nearshore fisheries could therefore have significant social, cultural and economic impacts on Māori in some regions. However, as outlined in preceding sections, coastal erosion predictions tend to be site specific and the impact of climate change on fisheries production is highly uncertain at present.

## Indigenous flora and fauna

Climate change has the potential to change the indigenous flora and fauna which Māori consider as tāonga. Apart from inshore fisheries, particular areas of concern are potential changes in the habitat of regionally distinct plants or animals used in traditional medicine or art (such as kauri, see section on native ecosystems on page 25).

Other environmental pressures will likely have much larger effects on many ecosystems than climate change over the next few decades, but climate change will add to the stress on ecosystems in ways that traditional land management systems may be unable to cope with.

There is also only limited interaction between individuals trained in kaupapa Māori and the scientific community engaged in climate change impacts. An increased outreach from either side to encourage collaborative programmes would be valuable to better identify key areas of concern.

## Health and social impacts

Māori are likely to be more vulnerable to the health impacts of climate change. Many Māori communities are located in rural areas which may become more prone to new diseases (see section on health on page 28). Preventive utilisation of the public health system by Māori is less than that by non-Māori and climate change impacts on public health risk widening the disparity between Māori and non-Māori health. Lower levels of labour force participation, under-representation in higher-paying occupations, and higher rates of unemployment also imply that changes in regional employment and prices of essential goods due to climate change will have a larger than average impact on Māori, but these effects could be both positive and negative in different times and regions.

However, projected health impacts and resilience against economic and social change are clearly based on current socio-economic status and do not take future social developments into account. Such impacts of climate change are therefore not specific to Māori but apply equally to other groups in society with limited access to health resources and limited disposable income.

# international links

Climate change is a world-wide phenomenon. Due to the increasing interconnectedness of economic and political systems, impacts on one country will not only be determined by the change in domestic climate, but also by impacts on key political and trading partners.

New Zealand strongly depends on trade relationships with traditional partners such as Great Britain, Europe and the United States, but developed and developing countries in south-east Asia and South America also play an increasing role as export destinations, resources, and trade competitors. Politically, New Zealand plays an important role in the South Pacific through development aid, close cultural and family ties, diplomatic interests and constitutional links with countries such as the Cook Islands, Niue and Tokelau. Impacts on South Pacific countries will therefore have implications for New Zealand.

## Pacific Island impacts and consequences for New Zealand

Small island states are among the countries most exposed to extreme events such as tropical cyclones and droughts. In the 1990s, the six most serious climatic disasters in Pacific Island countries, out of which five were tropical cyclones, caused losses approximating US$1.25 billion, disrupted the lives of well over two million people, and resulted in hundreds of fatalities for an entire regional population of less than eight million people. Recent model studies suggest that the intensity of wind and rainfall associated with tropical cyclones could increase. This would imply not only increased average damages, but also reduced recovery periods between events which could threaten some island communities.

Long-term sea-level rise is of particular concern for countries such as Tuvalu and Kiribati, where maximum elevation of the densely populated atolls is typically only 3 to 4m above current sea levels. Many settlements and much of the economic activity on other islands with higher elevations are concentrated on low-lying coastal plains and are therefore also highly vulnerable to erosion and inundation risks associated with rising sea levels. As in New Zealand, sea levels in Pacific Island regions are also influenced by regional climate patterns, and resulting fluctuations in sea levels over decadal time scales are likely to be superimposed on the expected long-term gradual rise due to global warming (see section on coastal impacts).

Coral reefs generate essential food supply sources and provide attractions for tourism, and their potential degradation from rising water temperatures forms an additional threat to regional economies and subsistence livelihoods.

As many islands have only limited or no freshwater resources, any increase in droughts and cyclones could have serious impacts on agricultural production, particularly non-traditional cash cropping systems. Adaptation would require strengthening of traditional dry-season cropping systems, amongst other measures. Atoll island crops are also threatened by increased salinisation from inundation events.

Attempts have been made to develop comprehensive environmental vulnerability indices for a range of Pacific Island countries, and to estimate the economic impact of climate change. These studies, which rely on a number of assumptions and simplifications, expect reductions in GDP by 2050 between 2-4% for relatively resilient countries such as Fiji, and up to 34% for some highly vulnerable islands, compared to expected global average reductions of 1 to 2% GDP. Increased pressures from economic development, population growth, and urbanisation tend to increase vulnerability of island nations, while sustainable development strategies, including traditional subsistence schemes which increase the welfare of the poorest members of those societies, would enhance the adaptive capacity and reduce vulnerability to climate change and other stresses.

Consequences for New Zealand potentially consist of increased needs for development aid and disaster relief, and, in a worst-case situation, environmental and economic refugees, and a general political destabilisation of the South Pacific region through environmental degradation, social disruption and economic instability. While New Zealand has a special relationship and responsibility towards its Pacific Island neighbours, similar impacts can be expected for a wide range of other vulnerable developing countries which have poor resources to cope with climate change.

Table 3. *There are few positive impacts associated with climate change in Pacific Island countries. Benefits could arise from regional rainfall increases and shifts in fisheries, but the balance of evidence suggests predominantly negative impacts on the region. Some of the more clearly characterised adverse effects are summarised in this table.*

### Sectors and key impacts

**Coastal Zone**

- Accelerated coastal erosion rates
- Inundation of low-lying areas
- Coral bleaching and degradation
- Possible loss of areas of mangrove ecosystems

**Water Resources**

- Increased severity and frequency of flooding
- Increased severity and frequency of droughts
- Salinisation of coastal groundwater resources

**Agriculture**

- Decreased crop yields due to extreme events (droughts, storms) and, for some introduced crops, due to higher temperatures
- Salinisation of soils

**Human Health**

- Direct effects of extreme weather events
- Increased heat stress
- Increased risk of vector-borne (such as malaria and dengue fever) and diarrhoeal diseases

## International trade and economic links

No studies to date can quantify global climate impacts in sufficient detail and precision to allow robust predictions of national or sectoral changes in economic output. Changes in key trade relationships are equally difficult to forecast, largely because of a lack of reliability of regional climate change predictions and uncertainty over adaptation processes. It is likely that climate change and associated extreme events will result in shifts within domestic economies, with regional and temporal winners and losers, in all countries.

Of particular relevance to New Zealand is the fact that agricultural production of specific goods in many countries could either increase or reduce, and the timing of market availability could change due to earlier maturation of crops. This generates both risks and opportunities for New Zealand exports. Early development of new cultivars or a shift towards new crops whose production in overseas countries is likely to decline could open new market opportunities and thus significantly reduce potential losses and increase benefits from climate change occurring outside of New Zealand. An integrated social and economic assessment of the impacts of climate change is not possible at this stage because of the large uncertainties of the physical changes, biological impacts, and adaptive measures taken by the various sectors in different parts of the world.

# summary and outlook

We are not in a position yet to estimate whether climate change might bring a net cost or benefit to New Zealand in the near future, and at what specific point positive impacts could turn negative. Many issues are still unexplored or poorly understood. However, it is already becoming clear that there will be temporary winners and losers in New Zealand. In the long term, if climate change continues unabated, there is little question that the global economy and human welfare would be put under substantial threat.

Yet climate change is a long-term gradual process, which implies two things. Firstly, greenhouse gas emissions over the next few decades will to a large extent control the climate of the 21st century. Secondly and of equal importance, as our knowledge about future climate change in New Zealand increases, we can develop strategies to cope with the projected changes. Adaptation to climate change will increase the benefits to those sectors that could gain under a warmer climate, while it will reduce the negative impacts for others.

This report shows that there are still large gaps in our knowledge about climate change impacts, but it also shows common themes. Climate change impacts will differ between regions and between sectors within the same region. This makes it impossible to devise a single adaptation strategy for the entire country, but all parts of society need to work together to recognise the implications of climate change, and to contribute their local and sectoral expertise to finding the best solutions to the problem – or making the best out of regional opportunities.

Many adaptation options could benefit sectors even under existing climate and its variability. We invite you to put the potential impacts of climate change on your 'radar screen', whether you are a local or national business, local government, or community organisation. It is only through your input and contribution that this report can form the starting point to building a long-term adaptation strategy to benefit all New Zealanders.

We welcome your feedback to this report and involvement in future work.

### For feedback on this report and development of future work programmes, please contact:

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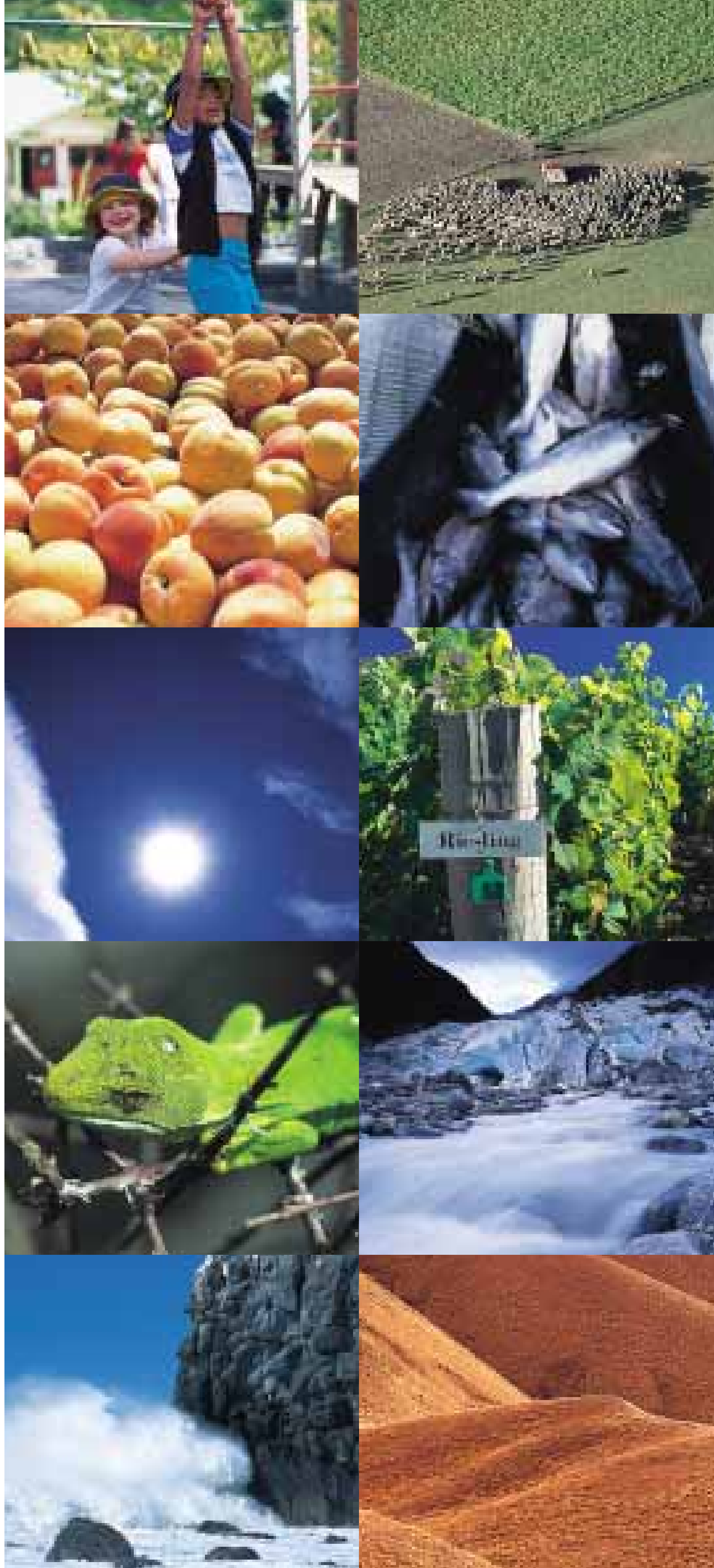

## resources

This report represents a summary of current scientific and expert knowledge about global and regional climate changes and their impacts on New Zealand. It draws on a wide range of internationally peer-reviewed scientific literature, and a large number of New Zealand scientists have provided material and/or reviewed this report. Members of the CLIMPACTS programme, a collaborative climate impacts research programme between several Crown Research Institutes and universities, allowed use of proprietary modelling software to prepare figures for the climate scenarios used in this report.

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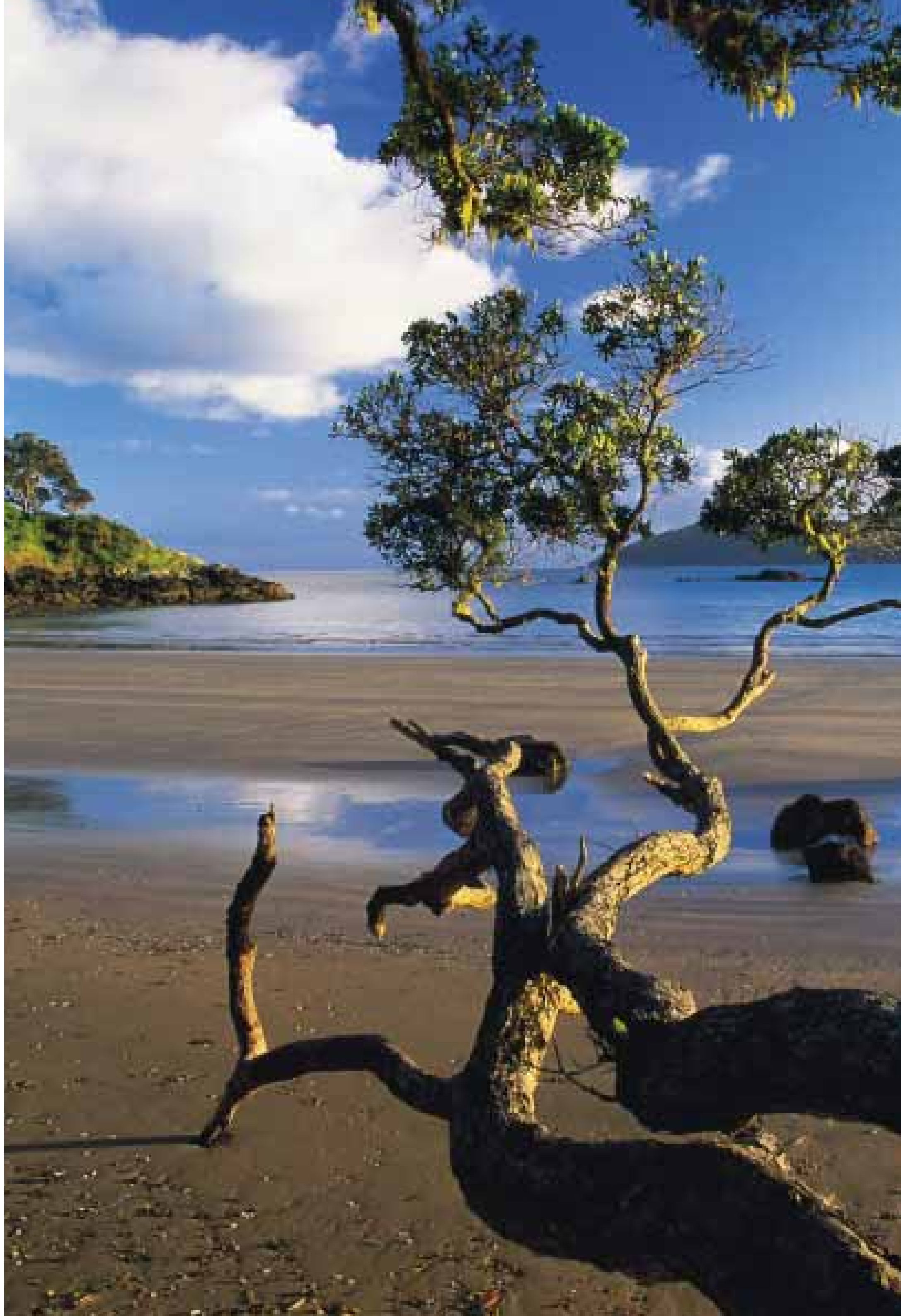

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**For information on the web**

IPCC home page, with electronic copies of reports: http://www.ipcc.ch

IPCC data distribution centre: http://ipcc-ddc.cru.uea.ac.uk/ipcc_ddc

New Zealand climate data and model projections: http://katipo.niwa.cri.nz/ClimateFuture

New Zealand Government Climate Change programme: http://www.climatechange.govt.nz

# glossary

### Anthropogenic
Caused or generated by human activities

### Carbon dioxide ($CO_2$)
A major anthropogenic greenhouse gas. It is produced by humans mainly through the combustion of fossil fuels and deforestation, but it is also taken up and stored by growing forests.

### Climate change
Any change in climate (or key climate variables such as temperature, rainfall, wind, sea levels and sea – temperatures) that occurs over time scales of decades or longer. This is in contrast to climate variability which is deemed to occur over time scales approximately less than a decade.

### El Niño
One of two states of the El Niño-Southern Oscillation (ENSO) climate pattern which occurs in the tropical Pacific, but affects weather patterns in many regions of the world. In New Zealand, El Niño conditions are generally characterised by increased westerly winds, leading to drought tendencies in eastern parts of the country, and cooler temperatures, particularly during winter. The opposite part of the El Niño state is called La Niña, which tends to bring more easterly winds and higher winter temperatures.

### Emission scenario
An estimate of future greenhouse gas emissions based on potential future social, cultural, technological, and economic developments. The world could follow a range of equally plausible future development paths, and hence one needs to consider a range of emission scenarios. Emission scenarios are plausible alternatives of future emissions, not firm predictions.

### ENSO
El Niño – Southern Oscillation. A regional climate pattern in the Pacific, characterised by fluctuations of surface pressure and mean sea levels and sea –temperatures between the east and west Pacific. These fluctuations take place over time scales of 3-7 years and cause changes in average rainfall, wind speed, and temperature in Pacific and South American countries, but also have an influence on weather patterns outside this region as far as Africa.

### Evaporation
The amount of moisture that escapes from soil into the atmosphere due to the combined effect of solar heating and wind.

### Extreme event
A weather or climate event that lies outside the standard climate variability. Examples include very heavy rainfall, prolonged or intense drought, and very high daily temperatures.

### Global climate model
A sophisticated computer programme that simulates down to regional scales the way the atmosphere and oceans respond to global changes in figreenhouse gases and natural variables. It can be used to predict average temperature, rainfall, sea level and sea-surface temperature.

### Global warming
A long-term increase in the average surface temperature of the world, usually associated with increased greenhouse gas concentrations. Global warming is only one part of climate change, as other variables such as rainfall and wind patterns are also likely to change with an increase in the Earth's surface temperature.

### Greenhouse effect
The trapping of heat by greenhouse gases that makes the Earth's surface warmer than if these gases did not exist. Both naturally occurring gases and those generated by humans contribute to this effect. If there were no greenhouse gases at all, the Earth would be some 30 degrees Celsius colder than it is today.

### Greenhouse gas
Gases in the Earth's atmosphere that absorb and re-emit infrared (heat) radiation, causing a warming of the Earth's surface temperature. Greenhouse gases can be generated by both natural and human-influenced processes.

### Heat-stress
Hot temperatures lead to discomfort and even increased mortality, particularly when combined with high atmospheric moisture levels. The physical strain on the human body is called heat stress.

### Interdecadal Pacific Oscillation,or IPO
A regional climate pattern affecting the Pacific over time scales of several decades (typically 20 to 30 years). The 'cool' phase of the IPO is characterised by a cool wedge of lower than normal sea-surface heights/ocean temperatures in the eastern equatorial Pacific and a warm horseshoe pattern of higher than normal sea-surface heights connecting the north, west and southern Pacific. In the 'warm' or 'positive' phase, which appears to have lasted from 1977- 1999, the west Pacific Ocean becomes cool and has a relatively lower sea level and the wedge in the east warms. The mechanisms triggering changes of the IPO from one phase to the other are still only poorly understood.

### IPCC, or Intergovernmental Panel on Climate Change
An international body of climate science experts and government representatives. The IPCC is charged with evaluating current scientific knowledge on questions related to climate and climate change. It produces its reports following a thorough review process by leading experts in the field, and the reports' Summaries for Policymakers are approved in a plenary consisting of government delegates from typically over 100 of its member countries, including developed and developing nations.

### Kikuyu
A subtropical grass that is already prevalent in some parts of the northern North Island, but with a lesser spread than paspalum.

### Methane ($CH_4$)
A major anthropogenic greenhouse gas. It is produced mainly by rice paddies, some fossil fuel combustion, and enteric fermentation in ruminant animals (such as cattle, sheep, deer).

### Nitrous oxide ($N_2O$)
A major anthropogenic greenhouse gas. It is caused mainly be fertilisation of soils through either artificial nitrogen fertilisers which are not fully absorbed by the soil, or animal excreta. Combustion of fossil fuels and some industrial processes are also thought to make a minor contribution to the total of human emissions.

### Paspalum dilatatum
A subtropical grass that is already prevalent in some parts of the northern North Island.

### ppm (parts-per-million)
A measure for gas concentrations. One part per million implies that for every molecule of a given gas, there would be one million molecules of air.

### Precipitation
A general term covering rain, hail and snow.

### Run-off (river)
The amount of water carried by a river that is dependent on rain- or snowfall in the river's catchment area.

### Subtropical grass
A grass which is typically of lower feed value and high sensitivity to cold temperatures and frost, but high drought resistance.

### Vector-borne disease
Any disease that is transmitted through specific carriers such as mosquitoes, ticks, fleas. The carriers are also called vectors.