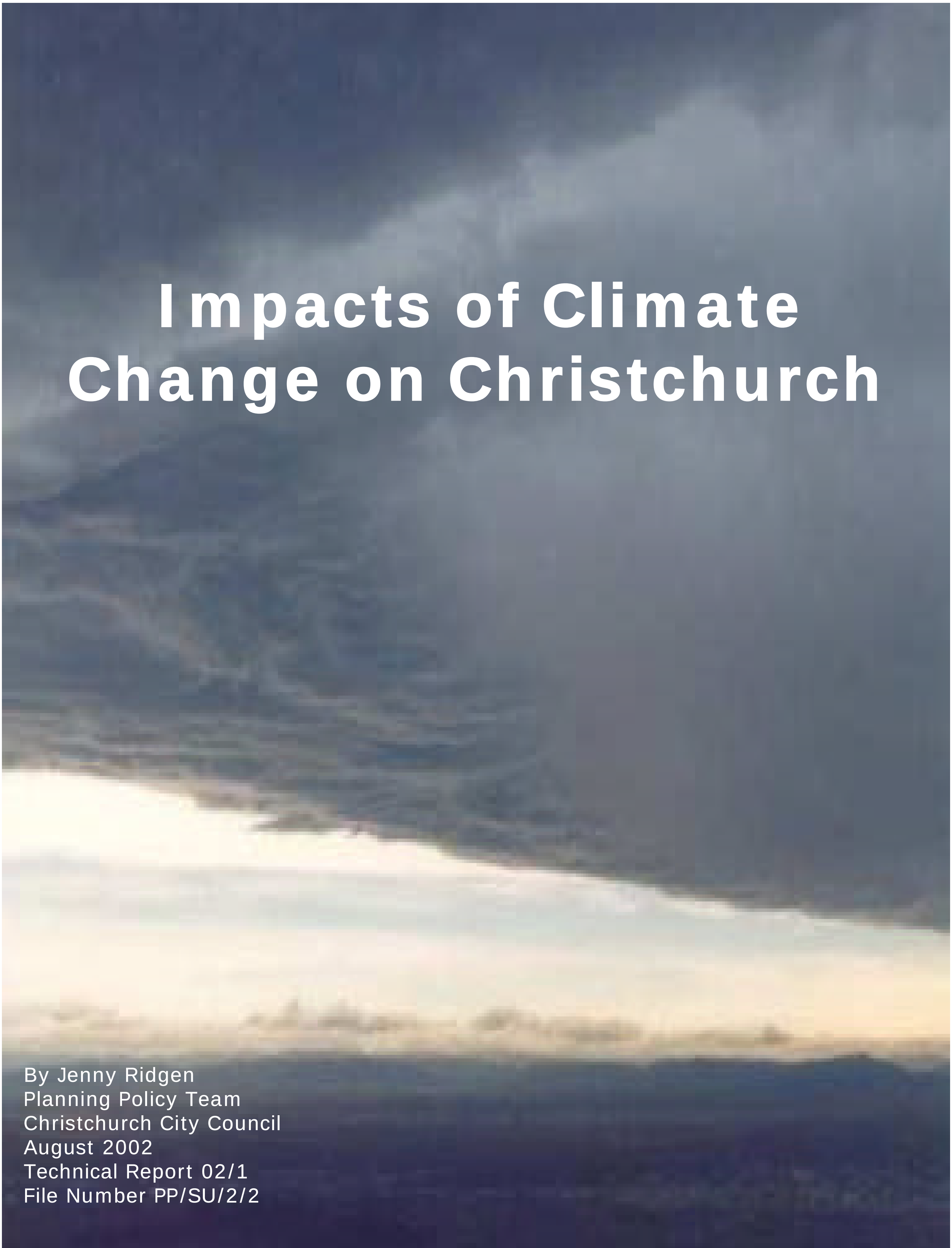

Impacts of Climate Change on Christchurch

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CHRISTCHURCH
CITY COUNCIL · ENVIRONMENT

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EXECUTIVE SUMMARY

This report examines the phenomenon of climate change and the potential impacts for Christchurch City. It examines ways in which the Council is responding to various aspects of climate change and suggests potential responses for the future. The report also provides an overview of the current national policy framework for addressing climate change issues and an overview of the Council's policy.

Climate Change

There is wide ranging evidence that the world has grown warmer over the last century. While natural changes in climate are to be expected, there is now strong evidence that most of the warming observed over the last 50 years is attributable to human activities.

The earth's atmosphere contains a mixture of gases including greenhouse gases which help to maintain the earth's temperature by providing an insulating layer. Industrialisation and intensified landuse has resulted in increased emissions of greenhouse gases, causing the earth to become warmer. The main sources of greenhouse gases in New Zealand include carbon dioxide from fossil fuel combustion, methane from ruminant livestock and landfills, and nitrous oxides from agricultural soils.

Computer models are used to simulate the interactions between the atmosphere and oceans which lead to climate change. These models can provide projections for future climate change, depending on different assumptions about future greenhouse gas emissions and responses of the climate system. One of the major unknowns is the volumes of greenhouse gases that will be emitted in the future. This will depend on political decisions, including what happens with the Kyoto Protocol, and on such factors as lifestyles, transport options, transfer of technology to developing nations and world population.

Intergovernmental Panel on Climate Change – a global picture of climate change

The Intergovernmental Panel on Climate Change (IPCC), established in 1988 by the United Nations Environment Programme and World Meteorological Organisation, is recognized as a major international authority on climate change. In 2001 it released its third series of reports assessing current knowledge on climate change. These reports are thoroughly peer reviewed and have been used as the basis for much of the work on the impacts of climate change in New Zealand.

In the third IPCC review, released in 2001, the projections for climate change include an increase in global average surface temperature of between 1.4 to 5.8 ^{o}C over the period 1990 – 2100. The rate of increase is very likely to be greater than experienced over the last 10,000 years. Rainfall patterns are expected to change, with more extreme rainfall events, and an increase in the intensity of tropical cyclones. Summer continental drying is projected, along with the risk of drought in some regions. Global mean sea level is projected to rise by 0.09 to 0.88 metres between 1990 and 2100.

It is likely that developing nations will be worst affected, with many being subjected to more negative impacts and having a reduced capacity to adapt. Crop yields in the tropics and subtropics may be reduced with warming. Some unique ecosystems will be at risk and may be irreversibly damaged or lost.

Climate Change in New Zealand

The Ministry for the Environment has commissioned a series of reports examining the likely impacts of climate change on New Zealand, based on reports by the IPCC and scientific studies carried out in New Zealand.

Due to the oceans which surround New Zealand, and their slow response to changes in global temperatures, it is expected that New Zealand will warm by only about two thirds of the global average over the coming decades. New Zealand's varied topography and the dominant feature of the Southern Alps mean that climate change will result in different effects in different parts of the country. Projections of the likely changes in regions of New Zealand, based on global climate models and meteorological observations in New Zealand, have been produced by the National Institute of Water and Atmospheric Research (NIWA). These scenarios are publicly available on their website at **http://www.niwa.co.nz/rc/atmos/clivar/scenarios**.

Under these scenarios the Canterbury Plains are expected to become warmer and drier, and to experience more frequent, and potentially more severe, droughts. By the end of this century, coastal Canterbury is expected to have experienced an average rise in temperature of between 0.8 to 2.5°C and a change in precipitation of between 20% less, to 5% more, of current rainfall. In contrast to the drier conditions expected on the coast and plains of Canterbury, more rain is expected in the foothills meaning that rivers with their headwaters near the main divide, such as the Waimakariri River, could become more prone to flood and erosion events. These events may also provide an opportunity for water-harvesting for irrigation.

Greenhouse Gas Emissions and Council Activities

The Council has both direct and indirect effects on greenhouse gases, through activities involving energy and resource use and through its planning functions, especially urban design and transport policy.

The Council has a number of policies and projects which have resulted in reduced carbon dioxide emissions from its operations, this is partly because since 1996 an Energy Efficiency and Sustainability Assessment has been carried out for all major projects which have a significant energy component. In order to gain an understanding of the effects of Council activities on the environment a Measure to Manage (M2M) project has been established which measures the monthly use of certain resources as carbon dioxide equivalents.

Significant reductions in future emissions will require changes in the way the Council operates and the technology it uses. This might be achieved through reducing the amount of coal used, replacing the existing vehicle fleet with lower emission vehicles and through mitigation measures such as plantings around the city to absorb carbon dioxide and act as carbon sinks.

Indirectly the Council can influence emissions from Christchurch by providing leadership in the reduction of emissions and implementing a planning regime which encourages low emission lifestyles through compact urban design and facilitating transport options which do not rely on private vehicles. The Council also provides an energy efficiency advisory service and jointly supports an energy efficiency show home.

Ecosystem Impacts

Climate change is not the main threat to biodiversity but does constitute another added stress on top of other threats such as fragmentation, and pest and weed invasion. It is unclear what the effects of climate change will be on our native flora and fauna. Although they have often proven resilient in the past, it is likely that changing conditions will result in loss of species from some areas and the migration of species to new areas. With different species being affected in different ways and at different rates, the relationship between species is likely to change with some dominating over others. For example, carbon fertilization may favour some fast growing weed species.

Drought and increased temperatures may result in changes in species composition, especially in our waterways and wetlands. The introduction and spread of weeds, pests and diseases and the risk of fire will all have adverse effects, whereas an increase in atmospheric carbon dioxide will generally benefit plant growth, as long as water is not a limiting factor. Planting trees as carbon sinks could result in benefits both to greenhouse gas reduction and to biodiversity.

Coastal Impacts

Sea levels around New Zealand have been rising since at least the mid 1800s and are expected to rise by approximately 0.4 metres by 2100, with best estimates ranging from 0.30 to 0.48 metres, and the total uncertainty spanning a wide range of 0.09 to 0.88 metres.

While Christchurch's dune system should continue to accrete, although at a slower rate, the low lying areas around Brooklands Lagoon and the Avon Heathcote Estuary will be at risk of inundation. In areas where development provides a barrier for the natural inland migration of coastal vegetation these ecosystems will be subjected to coastal squeeze. Some sections of Christchurch's coastline can be expected to suffer increased erosion , including the terminal end of South Brighton Spit and Sumner and Taylor's Mistake beaches. Sea lettuce may become more of a problem in the Avon Heathcote Estuary.

Planning measures should restrict greenfield development in areas at risk from coastal flooding and protective measures may be required in areas of existing development. Allowing for generous coastal buffer zones will provide room for coastal processes and reduce the potential for coastal squeeze.

Agricultural and Business Impacts

The greatest impact for agriculture is the threat of drought and increased water demand due to greater evapotranspiration. Crop and pasture irrigation will become critical to future development and the expansion of dairying within Canterbury will be dependent on water availability. Managing water resources, both surface and underground, will become more difficult, with the need to balance instream with out of stream uses.

Changing conditions may result in changed pasture composition and assist the establishment and spread of some weeds and pests. Whereas increased carbon dioxide concentrations will have a fertilizing effect for some crops, this varies with species. New crops may become viable and provide opportunities for new processing and infrastructural industries. Tourism may thrive in the warmer, drier conditions, but could increase pressure on water supplies. The ski season may be reduced in the long term and require increased reliance on snow-making facilities, although a greater influx of Australian tourists is also possible due to the stronger effect of climate change on snowfall on Australian mountains.

The introduction of a carbon charge, or similar, will affect all businesses and plantation forestry may become an attractive landuse option, depending on its value for carbon trading and domestic policy arrangements.

Health Impacts

Cantabrians face the risk of increased skin cancer as a warmer climate attracts people outdoors. Delayed recovery of the ozone hole means that UV levels will remain high for some years yet. Rising temperatures mean that mosquitoes capable of carrying arboviruses, such as Ross River Virus or dengue fever, will be able to establish in Canterbury, although the main risk may come from visiting warmer areas of New Zealand where conditions will be more suitable for mosquitoes. There will be more really hot days when heat stress will be a problem.

Increased heavy rainfall events may affect the quality of some water supplies and can bring added risk to lives and property from flooding. Additional stress on affected groups, especially those with limited resources, will mean that some people are more susceptible than others and may need improved access to assistance.

Urban Impacts

Climate change is likely to bring intense droughts and floods, which will place stress on the City's infrastructure. The risk of flooding is likely to increase from local heavy rainfall, increased precipitation in the Southern Alps leading to flood conditions in the Waimakariri River, and sea surge and high tides in combination with sea level rise. Droughts will place pressure on the Council's ability to provide sufficient water to meet demand.

On the brighter side, electricity demand is expected to decrease with warmer conditions and winter smog should become less prevalent.

Climate Change Policy

In response to the United Nations Framework Convention on Climate Change (UNFCCC) the New Zealand government has confirmed its intention to ratify the Kyoto Protocol in 2002. This Protocol aims to stabilize greenhouse gas emissions, from industrialized countries, at 1990 levels, on average, in the period 2008-2012. The details of how New Zealand will meet its targets are still being finalized.

Both national and regional policies recognize the possibility of sea level rise, but do not provide strong guidance on how this should be managed. The Canterbury Regional Policy Statement includes policies aimed at reducing emissions from carbon based fuels, planting vegetation for carbon sinks, and encouraging development patterns and infrastructure which decreases motor vehicle emissions.

In response to a 1995 report "Implications of Climate Change for Christchurch" prepared by Wilkinson and Smith, the Christchurch City Council adopted a series of policies. These policies in combination with other Council policies, provide a good general framework for assessing the link between Council activities and climate change. The policies from the 1995 report are as follows:

1. *That the Council acknowledge that climate change is occurring and adopt a precautionary approach when planning for future activities and works.*
2. *The Council when developing new policies and projects, takes into account the effects of climate change where this is appropriate. Policies that initiate or support activities that counter the causes and effects of those changes, are to be preferred.*
3. *That the Council's response to climate change combine the limitation and adaptation approaches.*
4. *That the Council develop a transportation policy which serves to limit greenhouse gas emissions.*
5. *The Council support ongoing monitoring of climate change indicators such as sea level rise, greenhouse gas emissions and carbon sinks.*
6. *The information in the report should be used in assessing submissions on the new City Plan during the review period and in addition the report should be reviewed in five years time.*

The approach of this report is to provide updated information which along with existing policies provides a sound base for responding to the challenges of climate change. Policies can be added to or amended as specific needs arise.

INTRODUCTION

Climate change is a natural phenomenon which has recently been given a helping hand by humans, particularly since the Industrial Revolution. The earth is currently becoming warmer, with the global average temperature increasing by about 0.6°C over last century. Since instruments were first used to record temperature in 1861, the 1990s was the warmest decade and 1998 the warmest year. In addition to becoming a warmer planet (Figure 1), sea levels are rising, weather patterns changing and snow and ice are retreating from many areas. In 2001 the Intergovernmental Panel on Climate Change (IPCC) reported that: "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities" (Houghton et al, 2001).

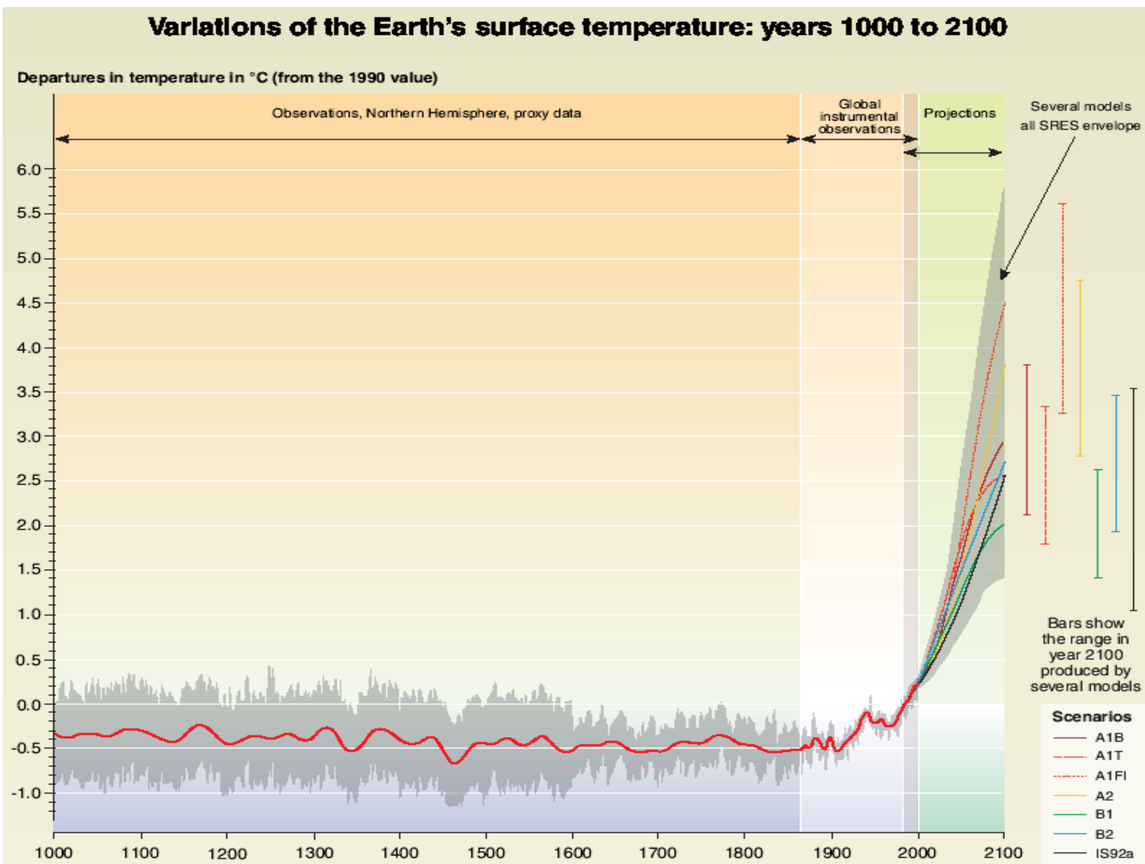

Figure 1. Variations in Earth's surface temperature: Years 1000-2100 (from Andy Reisinger, 2002, adapted from Houghton et al, 2001)

Recent trends are expected to continue. The unusual thing about these changes is the speed at which they are expected to occur. For example, projections based on a range of emission scenarios suggest that global average temperatures will rise by between 1.4 and

5.8°C by 2100, and that they will continue to rise beyond that date (Houghton et al, 2001).

The purpose of this report is to provide information on the latest projections for climate change and the potential impacts for Christchurch City. It provides an update of the technical report "Implications of Climate Change for Christchurch" (Wilkinson & Smith, 1995), prepared for the Christchurch City Council in 1995. This updated report summarises the current state of knowledge on climate change, based on the recent release of the latest IPCC report in 2001 and on information prepared by the Ministry for the Environment and others on the impacts of climate change for New Zealand and in particular for Canterbury and Christchurch. The report concentrates on the consequences of global warming and climate change at the local level, rather than the causes, which can be more effectively dealt with on the national and global scale. Potential responses to the challenges of climate change are suggested for future discussion and development. The report does not include recommendations for new Council policy, rather it provides background information and suggests areas for action and consideration when implementing existing Council policy and carrying out Council functions.

PART 1: BACKGROUND TO CLIMATE CHANGE

Climate Change – an ongoing affair

Climate change occurs naturally and has been happening for a long time. The earth's climate has been changing since its atmosphere was first formed some 4.7 billion years ago (Sturman & Tapper, 1996), however the rate of change varies. Many factors contributing to climate change are imperceptibly slow, such as the drifting apart of continents to different areas of the globe or slow changes in the earth's orbit around the sun. Other factors act more quickly, including meteor strike and major volcanic eruptions which can throw huge volumes of dust into the atmosphere. The dust prevents sunlight from reaching the earth's surface and results in cooler conditions. Some of these events may only have a temporary effect as recent instrumental records show that although volcanic eruptions can have a strong influence for 2-3 years, they are not important for long-term climate change (Sturman & Tapper, 1996). As a result of changes in climate, icefields and forests have come and gone from different areas on the globe. At times the planet has been virtually free of ice, while at other times vast areas of ocean and land have been frozen over.

Understanding past climatic events and the mechanisms that caused them is important if we are to understand, and attempt to model, future climate. While skilled interpretation is essential, there is a wealth of information about the world's climatic history to be gleaned from natural archives including ice cores, fossil pollen, tree rings and ocean, lake and terrestrial sediments. Continental drift, plate tectonics, ice ages and warm periods, changes in sea level and in the distribution of plants and animals have all left their mark (Fitzharris, 1990). By piecing together information from various sources and disciplines a picture can be built of how climate has changed in the past.

The fortunes of civilization are closely linked to the world's climate, especially in the area of agricultural production (Sturman & Tapper, 1996). Serious impacts can arise when food becomes a scarce resource, especially in highly populated regions. Because of this, and due to other effects on economics, resources and environmental management, it is important that we plan for future climatic trends and the significant changes which may be in store. The climate of the past 10,000 years, during which human civilisation emerged, has been comparatively stable on the global scale. In contrast to this, the rate of change projected for the next 100 years is very likely to be greater than any of the natural changes over the past 10,000 years.

Isolating a particular cause of climate change is difficult because a number of mechanisms can operate at the same time, and because interactions include both positive and negative feedbacks. Up until now, inbuilt checks and balances have ensured that climatic conditions have varied around a balance point and that climate change has not been too extreme. However, in the last few hundred years a new factor has begun to have an effect. Due to increasing population pressure and technological advances, particularly those associated with the Industrial Revolution, the impact of human activities in emitting greenhouse gases has reached a point where they have affected the composition of the earth's atmosphere (Houghton et al, 2001). The natural balance of the earth's climate is being tested in a way it has not been before. In this century increased greenhouse gas concentrations and the inertia of the climate system will combine to commit us to global warming that more than twice exceeds the rate of warming observed during the 20th century (Ministry for the Environment, 2001a)

Although "natural" climate change will continue, there is no guarantee that past changes will be a reliable key to the future. Recent changes have reflected a strong human influence, largely revolving around economic activity. Just as predicting economic trends is notoriously difficult, forecasting climate change is also very challenging, with economic trends being just one aspect of the equation.

Recent Changes in Climate

Over the last century the earth's climate has been getting warmer, glaciers have retreated and sea levels have risen. These changes are expected to continue and there is mounting evidence that human emissions of greenhouse gases, such as carbon dioxide and methane, are responsible. On average, the global surface temperature has increased by about 0.6 ^{o}C over the last 100 years, and the 1990's appear to have been the warmest decade in recent times – possibly in the last millennium (Houghton et al, 2001). Snow and ice cover has decreased and there has been a widespread retreat of mountain glaciers in non-polar regions. In New Zealand the temporary advance of the Fox and Franz Josef Glaciers has gone against this trend. This is due to heavy precipitation, including snowfall, in the Southern Alps in recent years however, on average, glaciers in the Southern Alps have retreated by 38% and lost 25% of their area over the 100 year period prior to 1978 (Ministry for the Environment, 2001a). There are also a few areas around the globe that have not warmed, including parts of Antarctica where satellite measurements show that the extent of sea ice hasn't changed significantly since 1978 (Houghton et al, 2001).

Warming is only one aspect of the recently observed changes to our climate. As a result of the atmosphere warming, many of our oceans have warmed and, over the last century, sea levels have risen on a global average by 10-20 cm. This is a particular problem for the low lying island states of the South Pacific, but also affects the ports and coastal settlements of most countries. Climate change has affected the balance of water cycles, resulting in more floods, droughts and tropical cyclones. World rainfall patterns have changed, with heavy rain events becoming more frequent in some northern hemisphere areas, while droughts have become more frequent and intense in parts of Africa and Asia (Houghton et al, 2001).

The changes in climate have potential consequences for fires, pest outbreaks, the composition of ecosystems and primary production. Human health and socio-economic systems, including agriculture, forestry, horticulture, and fisheries, are all sensitive to the positive and negative effects of climate change.

Global Projections

In the third IPCC review, released in 2001, the projections for climate change include an increase in global average surface temperature of between 1.4 to 5.8 ^{o}C over the period 1990 – 2100. The rate of increase is very likely to be greater than that experienced over the last 10,000 years. Rainfall patterns are expected to change, with more extreme rainfall events, and an increase in the intensity of tropical cyclones. Summer continental drying is projected, along with the risk of drought in some regions (Table 1). Global mean sea level is projected to rise by 0.09 to 0.88 metres between 1990 and 2100 (Houghton et al, 2001).

It is likely that developing nations will be worst affected, with many being subjected to more negative impacts and having a reduced capacity to adapt. Crop yields in the tropics and subtropics may be reduced with warming. Some unique ecosystems will be at risk and may be irreversibly damaged or lost.

On a global scale, New Zealand is fortunate in that, due to the buffering effect of the surrounding ocean, we can expect less extreme changes than for many other areas. While there is still cause for concern, in the short term we can expect to be spared the worst effects.

Table 1 Estimates of confidence in projected changes in extreme weather and climate events (from Houghton et al, 2001)

Changes in Phenomena	Confidence in projected changes (during the 21st century)
Higher maximum temperatures and more hot days over nearly all land areas	Very likely
Higher minimum temperatures, fewer cold days and frost days over nearly all land areas	Very likely
Reduced diurnal temperature range over most land areas	Very likely
Increase of heat index[12] over land areas	Very likely, over most areas
More intense precipitation events	Very likely, over many areas
Increased summer continental drying and associated risk of drought	Likely, over most mid-latitude continental interiors. (Lack of consistent projections in other areas)
Increase in tropical cyclone peak wind intensities	Likely, over some areas
Increase in tropical cyclone mean and peak precipitation intensities	Likely, over some areas

[12]Heat index: a combination of temperature and humidity that measures effects on human comfort .

Non-Uniform Effects and Slow Response Times

Climate change and its effects do not occur uniformly around the globe, nor do they occur consistently in any given location. Since the early 20th century the mid and high latitudes of Northern Hemisphere continents have experienced the largest increases in temperature with records showing that for 1901 to 2000 the Northern Hemisphere warmed by 0.71 ± 0.31 ^{o}C compared to 0.52 ± 0.13 ^{o}C for the Southern Hemisphere. Although the average global trend for last century was an increase in temperature of 0.6 ± 0.2 ^{o}C, there are areas that have actually cooled (Houghton et al, 2001). One of the areas to have cooled during the period 1976 to 1999 is the central North Pacific Ocean. The north-western North Atlantic Ocean, around Greenland, also cooled during this period, although this trend has recently reversed. On a global average, our nights are getting warmer at a faster rate than our day time temperatures, meaning that in many places the daily temperature range is decreasing, although this trend is not universal (Houghton et al, 2001).

Regional temperature trends can be strongly influenced by regional variability in climate and can depart appreciably from a global average. Temperatures and sea levels are often related to local cycles linking the atmosphere and ocean, such as the El Nino Southern Oscillation (ENSO) and the Interdecadel Pacific Oscillation (IPO), a 10-30 year cycle which influences New Zealand climate (Chiswell et al, 2001). These phenomena mean that changes vary regionally and do not necessarily occur at a consistent rate.

As oceans warm, their density decreases and the water in them expands. Due to the large heat capacity of an ocean it can take a long time before warming on the surface is transmitted through to the full depth. This delay in reaching equilibrium means that even if global warming was to be stabilised in the short term, global average sea level would continue to rise as oceans move toward thermal equilibrium. IPCC warns that, even after greenhouse gas concentrations have stabilised, temperatures will continue to rise for decades and sea level will continue to rise for centuries (Houghton et al, 2001). The effect on ecosystems will also take time to reach equilibrium.

The Difference between Climate and Weather

While weather can be described as “the overall state of the atmosphere at a particular point in time”, climate is “the integrated weather expected by a site or region over a period of many years” (Sturman & Tapper, 1996). Hence climate change is not just the occurrence of a warm winter or a couple of dry years in a row. It involves a long term trend away from previously observed “normal” conditions and changes to natural cycles.

The Greenhouse Effect

The composition of the earth’s atmosphere is critical for the survival of life on the planet and creates the conditions necessary for the diverse range of plants and animals that depend on it. The mixture of gases in the atmosphere includes greenhouse gases, such as water vapour, carbon dioxide and trace gases including methane and nitrous oxide, which help to maintain the Earth's temperature by providing an insulating layer. This layer assists in regulating the balance between the heating of the earth by incoming solar radiation and the loss of energy back to space. It does this by reflecting some of the heat back towards the earth. Without this layer the earth's surface temperature would be about 33^{o}C colder than it is (Sturman & Tapper, 1996). Essentially the global heat budget is being modified by the heat retention of greenhouse gases. The net effect is to retain energy thus warming the earth's surface and the atmosphere (Figure 2).

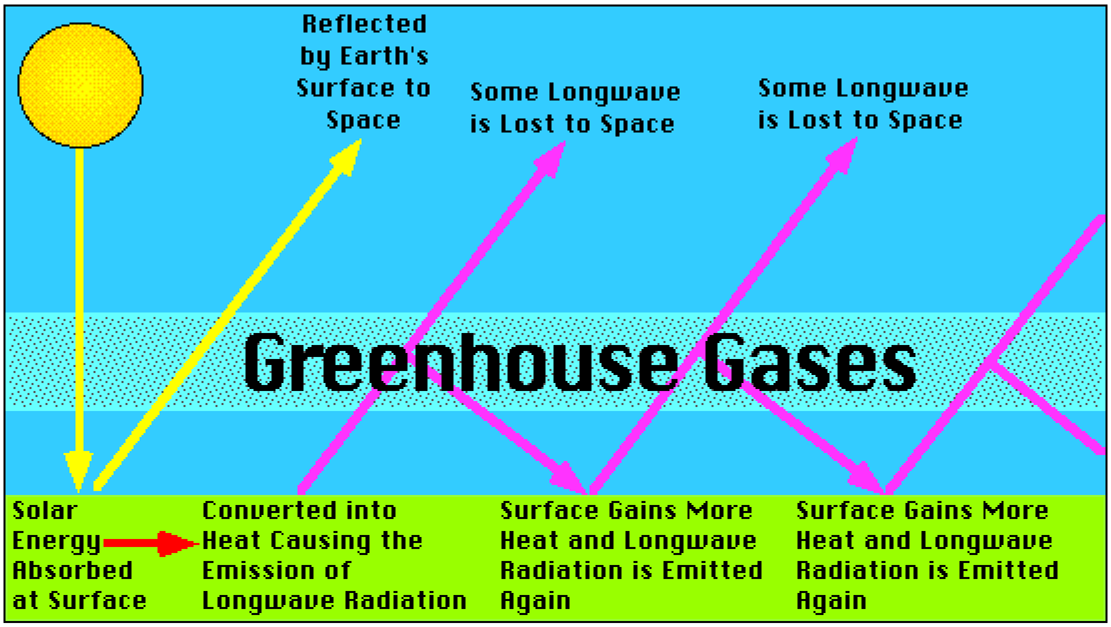

Figure 2. **The Greenhouse Effect**
(from Royal British Colombia Museum & Okanagan University College website, 2002. http://royal.okanagan.bc.ca/mpidwirn/atmosphereandclimate/geffect.html)

There is now strong evidence that the emissions of greenhouse gases from human activities are enhancing this insulation effect and causing the earth's temperature to become warmer (Houghton et al, 2001).

Greenhouse Gases

While the most prolific and important greenhouse gas is water vapour, the concentration of a number of other greenhouse gases, including carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, perfluorocarbons and hydrofluorocarbons are increasing due to human activities. Table 2 shows the main sources of these gases. Of primary concern are carbon dioxide, methane and nitrous oxide which have increased in atmospheric concentration since pre-industrial times by 28% for carbon dioxide, 145% for methane and 13% for nitrous oxide.

Table 2 Sources of Greenhouse Gases from Human Activities.

*Principal sources for New Zealand are in **bold** (from Ministry for the Environment, 1999).*

Greenhouse Gas	Sources from Human Activities
Carbon dioxide	***Fossil fuel combustion**, biomass burning, **industrial processes**, including steel, cement and aluminium manufacture, natural gas venting and fugitive emissions from geothermal energy use*
Methane	*Rice cultivation, **ruminant livestock**, coal mining, natural gas venting and leakages, and **landfills and other waste management systems***
Nitrous oxide	*Fossil fuel combustion, **agricultural soils**, nitrogenous fertilizer, and industrial processes including nylon manufacture*
Sulphur hexafluoride	***Electrical switchgear**, magnesium and aluminium smelting, fire suppression, other industrial applications*
Perfluorocarbons	***Aluminium smelting**, and other industrial applications (usually replacements for ozone-depleting substances)*
Hydrofluorocarbons	*A range of **industrial applications** (usually as replacements for ozone-depleting substances)*

The concentration in the atmosphere differs for each greenhouse gas and in most cases there are significant natural sources. The gases vary in their contribution to global warming, known as their global warming potential, and their persistence in the atmosphere. Although some gases, such as perfluorocarbons (PFCs), are only present in very low concentrations they can stay active for long periods. Natural processes, such as carbon cycling, work to remove greenhouse gases from the atmosphere, however these gases are currently accumulating faster than they can be removed. Because of this, stabilising emissions at today's levels (or even 1990 levels) will not lead to stabilised concentrations.

Greenhouse Gases in New Zealand

The three main greenhouse gases emitted in New Zealand are methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O) (Figure 3a). Unlike most developed countries, where carbon dioxide emissions are of primary concern, New Zealand's greenhouse gas emissions are dominated by methane (Ministry for the Environment, 2001b). Anaerobic bacteria found in the stomach of ruminant animals, such as sheep and cattle, were responsible for 90% of New Zealand's methane emissions in 1990. Landfills are also a source of methane. While ruminant livestock is the main source in New Zealand, on a global scale it is suggested that global warming will enhance the release of methane from vast areas of high-latitude tundra and peat bogs. Once released, methane stays in the atmosphere for approximately 10 years before conversion back to CO, and then CO_2 via photochemical oxidation in the troposphere.

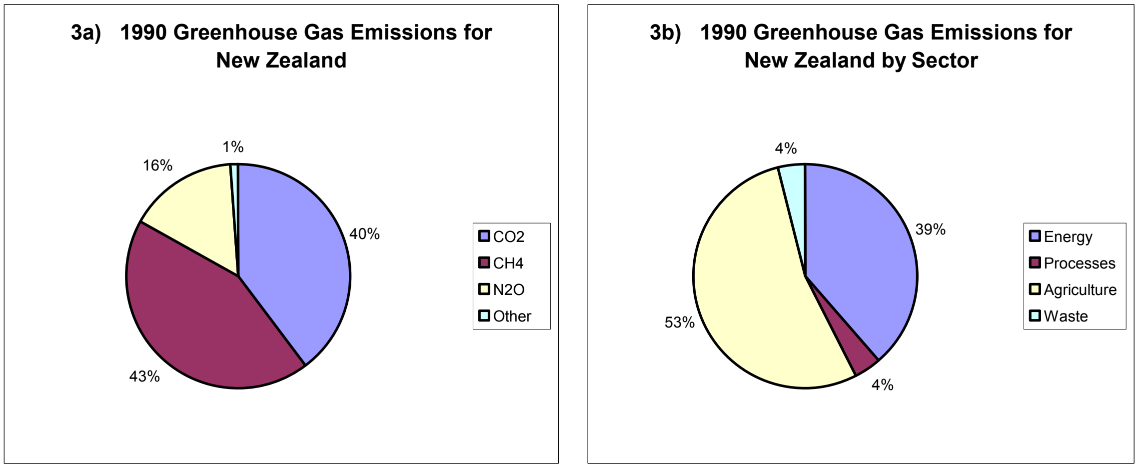

Figure 3 **a) 1990 Greenhouse Gas Emissions for New Zealand** **(the proportion shown for each gas reflects its contribution to global warming)**
b) 1990 Greenhouse Gas Emissions for New Zealand by Sector **(the proportion shown for each sector reflects its contribution to global warming)**
(from Ministry for the Environment, 2001b, p.28)

In addition to methane, New Zealand's agricultural sector is also responsible for almost 95% of the nitrous oxide emissions which come from the use of fertilizer and from microbial activity in the soil. Nitrous oxide emissions made up 16 % of New Zealand's contribution to global warming in 1999. The carbon dioxide emitted in New Zealand is derived mainly from the energy sector (90%), with the remainder coming from industrial processes (Figure 3).

Ozone

Ozone (O_3) occurs both naturally in the atmosphere and as a pollutant at ground level. Most importantly, it is found in low concentrations in the stratospheric layer of the earth's atmosphere, 10 to 50 km above the surface, where it acts to shield the earth from solar ultraviolet (UV) radiation (Christie, 2001). Ozone is not evenly distributed around the globe and distribution changes with time. Observations at Lauder (approximately 40 km north of Alexandra in Central Otago) show that total column ozone concentrations can vary by up to 30% on a weekly basis (NIWA website, 2002).

Significant increases in ozone destroying chemicals from human activities have led to an increase in the ozone hole over Antarctica as well as a general decrease in ozone globally, resulting in increased UV radiation at ground level. Among the chemicals responsible are chlorofluorocarbons (CFCs), these are used as refrigerants and in industrial processes and are very effective at destroying ozone in the stratosphere. New Zealand is a signatory to the 1987 Montreal Protocol, an international agreement which has helped to reduce the use of CFCs and other ozone depleting substances.

Greenhouse gases trap infrared radiation, resulting in warmer temperatures at the earth's surface, however they also prevent radiation from reflecting back through the stratosphere and warming it, thus causing the stratosphere to cool down. Ozone destroying chemicals can function more efficiently in the cooler temperatures so, despite reducing emissions of CFCs and other ozone depleting chemicals, the greenhouse effect means that it may take 15-20 years longer than expected for the ozone layer over New Zealand to recover (Ministry for the Environment, 2001a).

Modelling Climate Change

Computer modeling has become an essential tool in understanding the interactions between the atmosphere and the oceans which lead to changes in climate. Only in the last few years has it been possible to design computer models that realistically simulate these interactions, including wind direction, ocean currents, the transport of heat and gases around the earth and the effects on sea ice and vegetation cover (Mullan et al, 2001).

These complex models, known as Atmosphere-Ocean General Circulation Models (AOGCMs), are expensive to run and, even on large capacity computers, can take up to two months computing to simulate the climate for one century. Even so, due to the complexity of the factors and interactions which affect the climate, these models will always represent a simplified version of reality without close spatial detail and are therefore most useful on a global scale.

Although improvements are continuous, the task of modelling climate change is still full of uncertainties. Two main approaches are taken, using past climate records to predict future climate variations and using computerised numerical methods to simulate three dimensional circulation models of the atmosphere over long periods of time.

The first approach is limited by an incomplete record and limited knowledge of the past. It also assumes that the same mechanisms will continue to operate in the future. A major difficulty is that past climate events, which appear similar, may have been caused by a different combination of factors.

The second approach also has its problems in that some processes are not well understood and may be difficult to model on an appropriate scale, while also correctly reflecting the interactions between different elements. As a result, this type of model tends to be more useful for global, rather than regional, predictions. Although different models give different results, they all agree that if greenhouse emissions continue the earth will get warmer.

Interactions and feedback systems mean that it is difficult to predict how the atmosphere might respond to additional heating. For example, water vapour produces a strong feedback mechanism with warmer air having a greater water holding capacity resulting in increased cloud coverage. Clouds reflect incoming solar radiation, leading to cooling, but also absorb long-wave radiation from the ground, leading to warming (Figure 4). The net result depends on many factors including cloud height and form. The extent of snow and ice on the earth's surface are also important as this has a major influence on surface albedo, a measure of the radiation reflected by a surface (Figure 5).

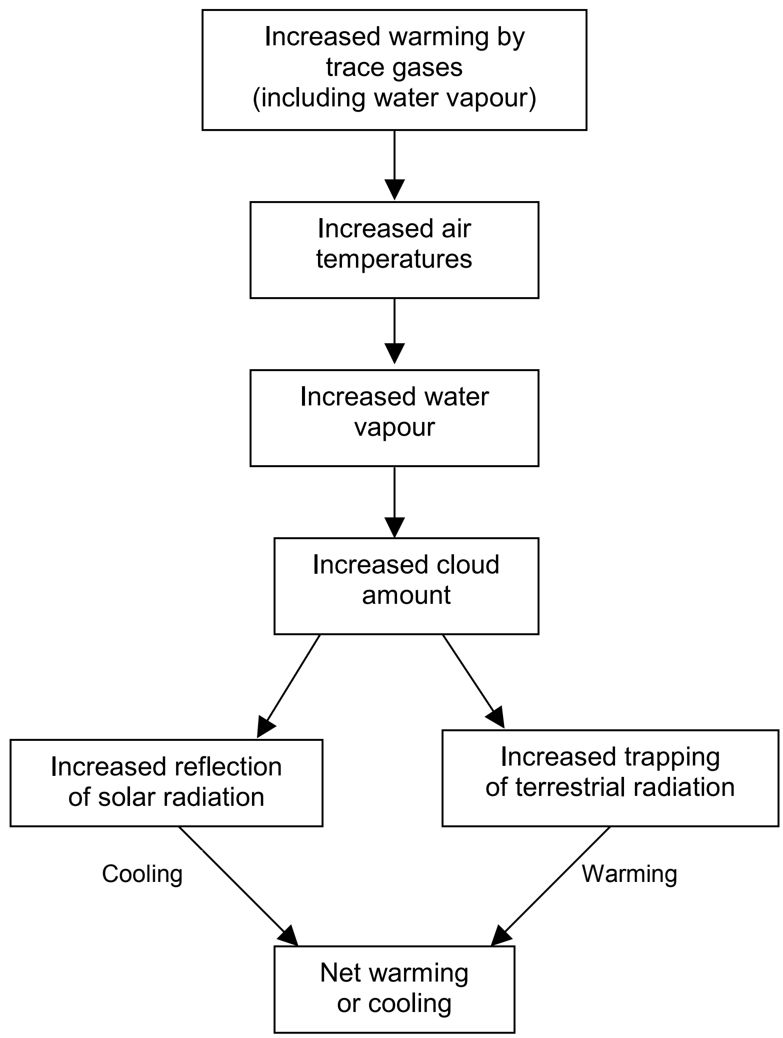

Figure 4. **Effect of Clouds on Cooling and Warming of the Earth**

(from Sturman & Tapper, 1996, p. 392)

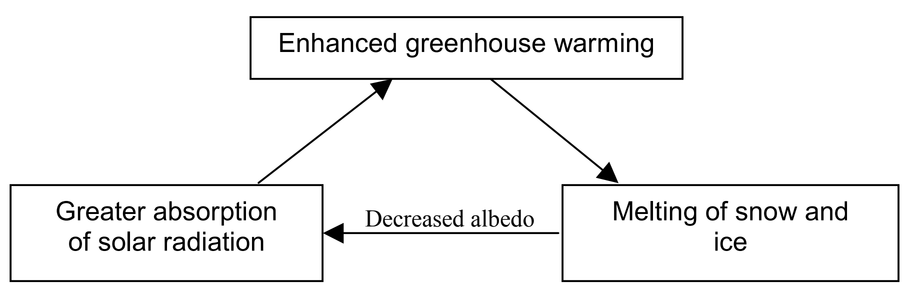

Figure 5. **Positive feedback by snow and ice albedo in the atmosphere**

(from Sturman & Tapper, 1996, p. 393)

Many uncertainties, such as pre-industrial levels of carbon dioxide, sensitivity of climate to predicted changes in gas concentrations, thermal inertia of oceans and the capability of oceans to absorb carbon dioxide, still remain. Knowledge of the budgets, sinks and sources of greenhouse gases is also limited, making it difficult to accurately predict effects. Models are used to test different scenarios depending on the economic, technological, social, fossil fuel, population and other profiles being considered to obtain climate projections under different scenarios, rather than straight forward predictions of what the future might bring. The uncertainties are not just in the models as the outcome will depend on such factors as lifestyles, economic trends, transport options and world population.

Climate Change Scenarios

Climate change models are used in an attempt to answer "what if" questions e.g. what if the concentrations of greenhouse gases are different, what if atmospheric circulation patterns change, and what if the rates for reducing emissions were accelerated. The assumptions and conditions for each scenario must be clearly stated to allow results to be usefully interpreted. The results can then be used to develop potential impact assessments.

It is generally accepted that global warming will result in the movement of climate zones and temperature gradients towards the poles. Normally a number of scenarios are modelled and results are compared, enabling a better understanding of the different factors and how they interact.

One of the major unknowns is the volumes of greenhouse gases that will be emitted in the future. Much will depend on the outcome of political decisions and agreements to reduce emissions as well as on social choices concerning how to meet emission targets. This may be achieved by increasing efficiency and reducing energy use, relying on carbon sinks or transferring to renewable energy sources. An important aspect will be the success of transferring reduced-emissions technology to developing countries.

The IPCC Process

The Intergovernmental Panel on Climate Change (IPCC) is recognised as a major international authority on climate change. The panel was established in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP). Its role is to assess scientific, technical and socio-economic information relevant to understanding the risk of human-induced climate change. IPCC does not carry out new research, but bases its assessment on published and peer reviewed scientific literature (IPCC, 2002).

The reports prepared by IPCC are thoroughly peer-reviewed. "Climate Change 2001: The Scientific Basis" (Houghton et al, 2001) forms part of IPCC's third assessment report on climate change. To prepare the report, 122 lead authors gathered submissions from 515 contributing scientists. Twenty-one review editors then incorporated comments from 700 peer-reviewers. The resulting 881 page document took three years to complete

(Houghton et al, 2001; Schrope 2001). Two further reports were also produced, dealing with the consequences of climate change and strategies for dealing with them.

The IPCC aims to provide information without endorsing specific policies. This approach can only work if IPCC is perceived to represent a highly credible and unbiased consensus. Participation from a wide range of countries is important as climate change means different things to different nations, for example sea level rise is of greater significance to small island states than to land-locked countries (Schrope, 2001).

A summary for policy makers (SPM) accompanies each report. Formulating the wording for this summary is a difficult, but critical process, involving delegates from participating countries, non-governmental organisation (NGO) representatives, and scientists. The draft SPM for "Climate Change 2001: The Scientific Basis" attracted roughly 20 words of comment for every word of the original with every word agreed on unanimously before it was accepted (Schrope, 2001). The inclusion of decision makers within the process is one of the keys to the success of the process used by IPCC. Without this, a global response to climate change would probably be impossible.

It should be remembered that, in contrast to the rigorous peer-reviewed process used by the IPCC, many of the critics of climate change have not subjected their theories to such close scrutiny by the scientific community nor had their views accepted by such a broad range of people from the international community. Regardless of this, there are still considerable uncertainties concerning climate change and healthy scientific debate is an essential part of the process for dealing with these issues and arriving at robust conclusions. The IPCC attempts to capture the range of opinions in its reports through its extensive peer-review process, by adding appropriate uncertainties to estimates, and by including different methods for calculating certain effects. Nevertheless, some scientific opinions remain beyond the limits of the IPCC projections and the uncertainties these encompass.

PART 2: IMPACTS OF CLIMATE CHANGE

General Climate Change Impacts

Due to the oceans which surround New Zealand and their slow response to changes in global temperatures, it is expected that New Zealand will warm by only about two thirds of the global average over the coming decades (Ministry for the Environment, 2001a).

In general, temperatures are expected to increase faster in the North Island than the South Island, and in winter compared to summer (Table 3 & Figure 6). The gradient between rainfall on the west and east coasts is expected to increase, with more rain in the west and less in the east. This trend is likely to be more pronounced in winter than in summer (Table 3 & Figure 7).

Table 3 Predicted changes in annual mean temperature (^{o}C) and precipitation (%)
(from Ministry for the Environment, 2001a, p.11)

The table shows predicted changes from four global climate models, under a scenario where greenhouse gas emissions continue to grow to reach about 700 parts per million (ppm) by 2100, almost twice the current level. The range of changes indicates differences between the four models, which extend as far as 2099.

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

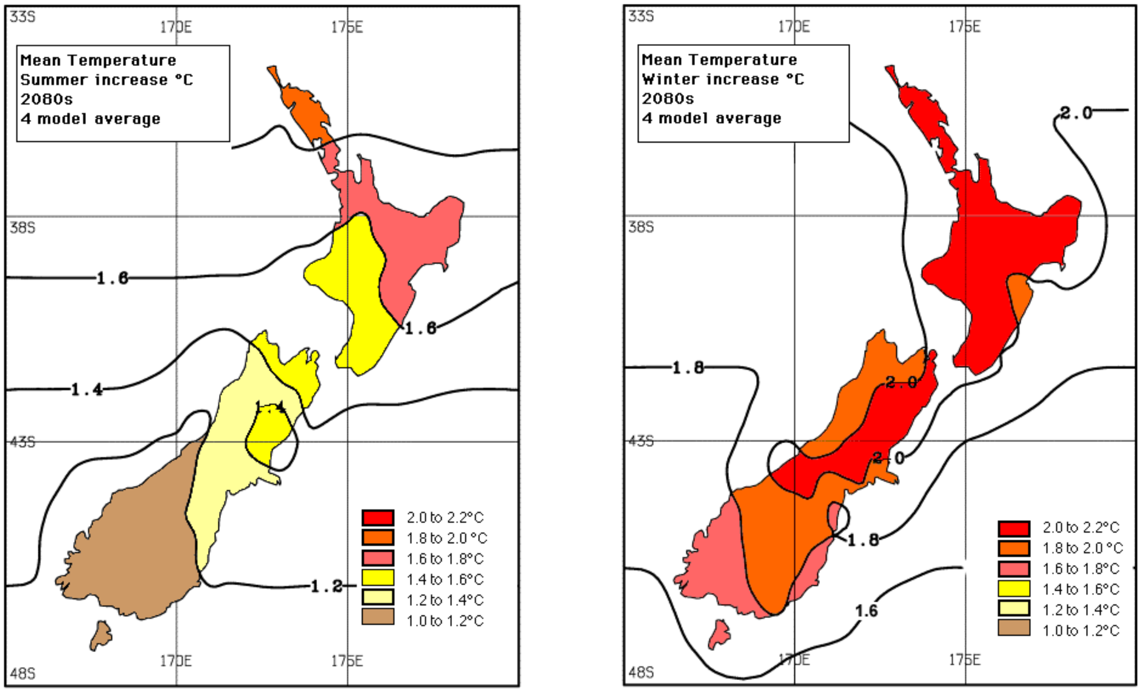

Figure 6 **Projected average summer and winter temperatures for the 2070 to 2099 period** (from http://katipo.niwa.cri.nz/ClimateFuture/Scenarios)

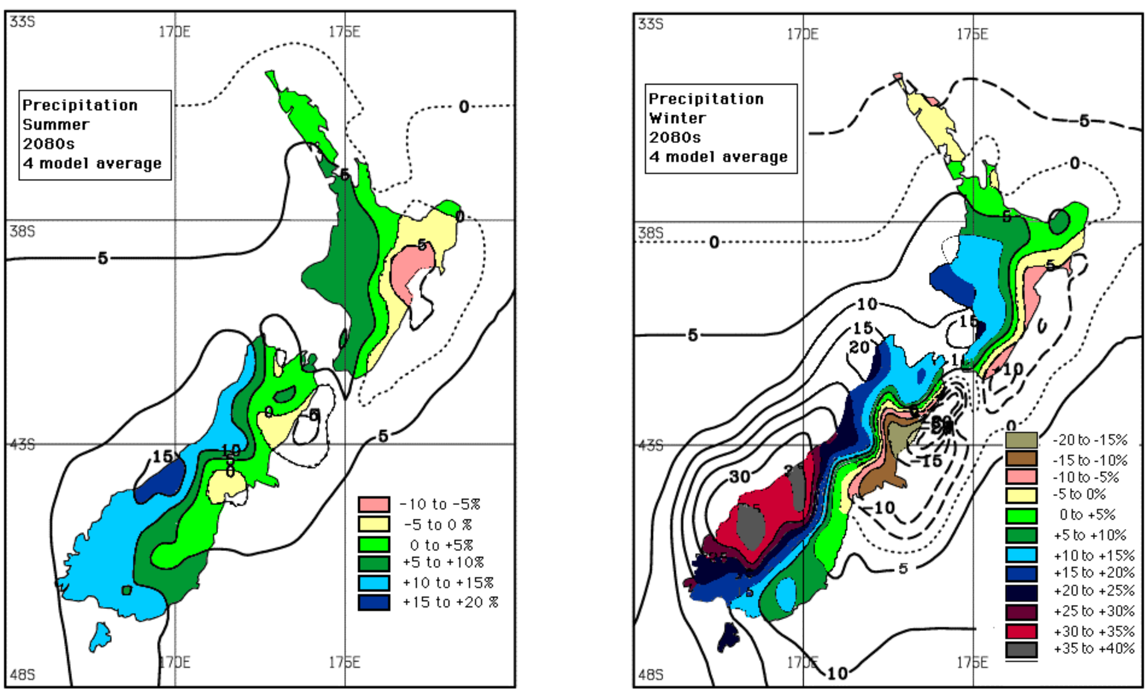

Figure 7 **Projected average summer and winter rainfall for the 2070 to 2099 period** (from http://katipo.niwa.cri.nz/ClimateFuture/Scenarios)

By the end of this century coastal Canterbury is expected to have experienced an average rise in temperature of between 0.8 to 2.5^{o}C and a change in precipitation of between 20% less, to 5% more, of current rainfall (Ministry for the Environment, 2001a). The Canterbury Plains are expected to become warmer and drier. As a result of higher average temperatures and reduced rainfall the region is likely to experience more frequent, and potentially more severe, droughts. However, average temperatures and rainfalls can be misleading as projections suggest that there will also be a greater variability in rainfall and more extreme events including floods, droughts and heat waves.

While the coast and plains of Canterbury are expected to become drier, rainfall is expected to increase in the Canterbury foothills, making the gradient between wet and dry more pronounced, especially in winter. With reductions in runoff, river levels will generally be lower, while at the same time evaporation losses could increase (Table 4). However, rivers with headwaters in the Southern Alps may experience increased flows as a result of higher rainfall in the mountains. These rivers could also become more prone to flood and erosion events.

Table 4 Effects of Climate Change on Water Resources in Canterbury
(from Griffiths, 1990)

	Effects of Climate Change on Water Resources in Canterbury
•	*Little change to groundwater recharge, but an increase in the number of days of soil moisture being below wilting point suggests greater demands for groundwater supplied irrigation*
•	*Greater incidence of drought and river reaches drying up and major aridity problems on non-irrigated downland areas*
•	*Reduced baseflows in foothills and on Banks Peninsula*
•	*Greatly increased competition for water between instream and out of stream uses.*
•	*Forested areas in the east with low rainfalls would supply a reduced water surplus to streamflow and groundwater recharge*
•	*Less water in rivers in late spring and early summer where snowmelt is now important*
•	*Significant increase in irrigation demand*
•	*Increased water use by permanent grassland and shortening of period of recharge of soil water*

The following sections look at some of the different sectors expected to be affected by climate change and examines potential responses by the City Council and those associated with the sector. These suggestions are included as a starting point for discussion and are not intended to be all inclusive.

Greenhouse Gas Emissions and Council Activities

What is the City Council doing?

The Christchurch City Council has both direct and indirect effects on greenhouse gases through activities which involve energy and resource use, as well as through its planning functions, particularly with respect to urban planning and how the Council provides for compact urban design and energy efficient transport options.

Since 1994, the Council has implemented a variety of policies and projects that have reduced the carbon dioxide emissions from its operations. These measures were not taken solely to reduce emissions but were based on three main principles:

- improving energy efficiency;
- substituting high carbon dioxide emitting energy sources with lower ones; and
- substituting fossil fuels with renewable energy sources.

To ensure that energy efficient solutions and technologies are applied at any new facilities developed by Council, an "Energy Efficiency and Sustainability Assessment" is carried out for major projects which have a significant energy component. This involves a comparative analysis of different energy sources and their impact on the environment (including greenhouse gas emissions). Examples include replacing a coal-fired boiler at QEII swimming complex with a heat pump and LPG-fired boiler, thus reducing energy consumption and carbon dioxide emissions. Another example is the installation of a new generator at the wastewater treatment plant to use the biogas from the plant as a carbon dioxide neutral energy source. This now provides over 16% of the Council's electricity requirements. The Council has also entered into a contract to purchase wind energy. This carbon dioxide free electricity source should be available by 2003 and will replace 3.3% of the Council's electricity requirements (Itskovitch and Moody, 2002). Projections show that by 2008 carbon dioxide emissions from Council activities could be reduced to 57% of 1994 levels (Figure 8).

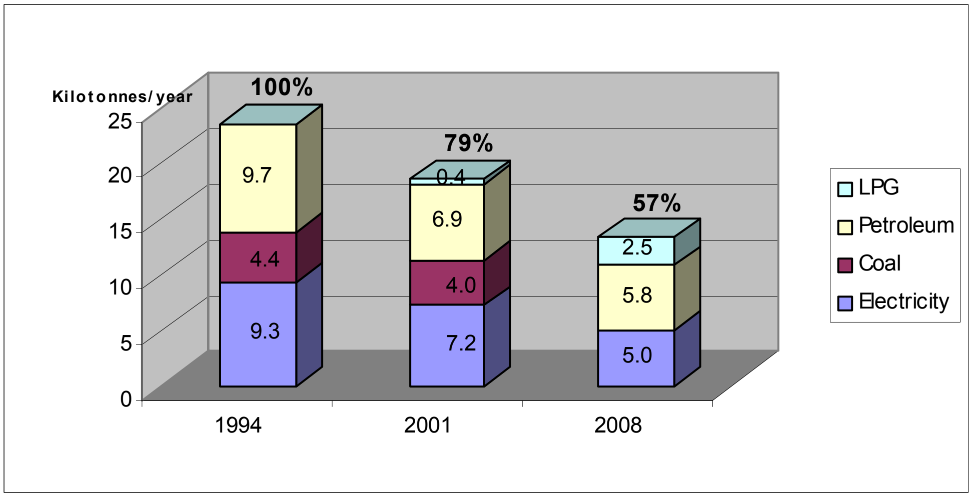

Figure 8 **CO_2 emissions associated with energy consumption by CCC operations** (adapted from Itsovitch & Moody, 2002)

In order to gain an understanding of the effect of Council activities on the environment, and the economic costs involved, the Council measures its use of certain resources, as carbon dioxide equivalents, each month in a "Measure to Manage" (M2M) programme (Christchurch City Council, 2002). The resources measured include paper (used for printing and copying), domestic air travel, vehicle fuel and coal consumption. For the purposes of this project, electricity consumption is assumed to be solely from hydro-electric sources and free of greenhouse gas emissions.

Significant reductions in future emissions will require changes in the way the Council operates, and the technology it uses. Examples of how this might be achieved include further reducing the amount of coal used, and reducing the existing fleet of diesel and petrol powered vehicles and replacing them with lower-emission vehicles. Mitigation measures, such as increased plantings around the city to act as carbon sinks, will also help. Such plantings can have the additional benefit of landscape enhancement, while also providing shade and natural air filters. Retention and revegetation of existing natural areas, such as Travis Wetland and sites on the Port Hills, can also provide for carbon sequestration while benefiting biodiversity.

Indirectly the Council can influence greenhouse gas emissions from the city of Christchurch by providing leadership in reducing net emissions from its own activities and implementing a planning regime that encourages low emission lifestyles. The latter can be achieved through compact development to reduce travel distances and allow for employment, schools and services within close proximity to dwellings. Local employment opportunities avoid the need for long commuting trips. Efficient roading systems and the provision of alternatives to private vehicles e.g. cycle and walkways and ready access to public transport, will also reduce emissions. The Council is able to encourage new technologies e.g. windpower, both for its own use and, through economy of scale, making such options more accessible to other organizations. Encouraging building design which maximises solar gain and makes full use of insulation will reduce energy requirements for heating, whereas recycling and waste reduction will reduce landfill gases. Facilitation of ecovillage concepts, which adhere to sustainable design principles, can also have benefits for greenhouse gas reduction.

Potential Responses:

- Provide leadership by reducing greenhouse gas emissions from Council business activities. Energy management of Council's operations has resulted in a 21% reduction in carbon dioxide emissions from 1994 to 2001, and a target is proposed of a further 22% reduction by 2008 (Itskovitch & Moody, 2002).
- Provide leadership in the use of sustainable energy sources which reduce greenhouse gas emissions e.g. using windpower and hybrid powered vehicles
- Continue to provide an energy efficiency advisory service and to support the energy efficiency show home.
- Encourage urban consolidation through planning mechanisms
- Provide alternative transport options to reduce emissions
- Increase citywide plantings to provide carbon sinks
- Encourage waste minimization to reduce landfill gas emissions

Ecosystem Impacts

How will ecosystems be affected?

(unless otherwise noted the reference material for this section is taken from Ministry for the Environment, 2001a)

Increased carbon dioxide and changes in temperature and rainfall regimes will inevitably impact on ecosystems and affect the spatial range of some species. McGlone (2001) lists four main impacts which are likely to occur over the next 100 years:

(i) alteration of latitudinal and altitudinal ranges with movement of species and communities southwards and upwards, accompanied by disruptive transitions;
(ii) strong impacts on ecosystems and biota already under stress if extreme weather events become more frequent and severe;
(iii) changes to productivity and nutrient cycling within ecosystems due to a combination of climate change and carbon dioxide increases; and
(iv) disruption of freshwater ecosystems through low flows or drying of streams and rivers and warming of water.

Climate change is not the only threat, or even the main threat, to New Zealand's biodiversity but does constitute yet another added stress. The most serious impacts may arise from the interaction of climate change with pre-existing threats, particularly pests and weeds (McGlone, 2001). It is unclear how resilient our native flora and fauna will be to climate change. Few discernible changes have been attributed to the 0.6^{o}C increase in temperature experienced over the last 100 years, for example the position of the upper treeline has remained static. However, a Landcare study shows that forests on lowland sites are likely to be most sensitive to the predicted temperature increases, whereas beech forests, such as those found in the Canterbury foothills, are expected to be most resilient.

With increasing temperatures and more frequent droughts there is potential for changes in species composition, especially in our waterways and wetlands, and the introduction of new weeds, pests and diseases. Warmer, drier conditions will suit rabbits, rats and mice and could lead to an increase in stoats and cats. The resulting increase in predation on native birds may result in increased problems for the pollination of some of our native plants. The risk of fire is likely to increase, with the potential for severe damage to plant communities which are not adapted to fire and take a long time to recover.

An increase in the atmospheric carbon dioxide concentration will benefit plant growth rates as long as water is not a limiting factor. In addition, the advantages of providing carbon sinks under the Kyoto Protocol agreement may result in projects involving the planting of native forests and the regeneration of scrub and bush areas.

Wetlands will be at increasing risk with increased drought conditions and increased demand on water resources for agriculture, stock and domestic use during dry conditions (Warrick et al, 2001).

Potential Responses

- Use of drought tolerant species in City Council plantings
- Install irrigation in planted areas and increase mulching
- Take a pro-active approach to pest and weed control
- Encourage tree planting to provide carbon sinks e.g. through increased involvement in EBEX21 projects (see below).

EBEX21 – The Emissions/Biodiversity Exchange 21 Project

This project is a partnership between Landcare Research and other organisations, designed to raise awareness of the environmental impact of the greenhouse gases which organisations produce from their activities. The project aims to look ways of changing how a business is run, in order to reduce and mitigate emissions. This is done in combination with opportunities for investing in indigenous forest, thus supporting both national biodiversity and climate change strategies.

On-going auditing and monitoring ensures that continual improvements are made in business processes to reduce greenhouse gas emissions. Measuring emissions ensures better awareness and encourages positive action to reduce and mitigate against them, thus helping to achieve the United Nations Framework on Climate Change (UNFCC) aim of stabilising greenhouse gas emissions at 1990 levels.

The Christchurch City Council is involved in the programme as a landowner, providing an opportunity for restoration of indigenous forests on Council owned land on the Port Hills. In partnership with MacPac, almost 2,000 plants were planted over 0.3 ha in 2001. MacPac provided the labour for planting in return for promotional advantages from the site, which is near a mountain biking track. The plants will store carbon and, in a small way, will help to reduce atmospheric carbon dioxide.

Coastal Impacts:

How will Christchurch coastal areas be affected?

Sea levels and sea temperatures around New Zealand have been rising for some time, with data to confirm this going back to the mid 1800s. The historic rate of rise for the Canterbury coast has been around 2.1 mm/year or approximately 0.2 m over the past 100 years (Bell, 2001). Even a small acceleration in the rate of sea level rise could eventually lead to catastrophic situations in some developed areas if planning fails to mitigate the effects of coastal erosion, flooding from the sea and backed-up rivers, property damage and inadequate drainage (Bell et al, 2001).

Canterbury sea levels are expected to rise by between 30-48 cm by 2100, with a midpoint of approximately 0.4 m. This means that the probability of exceeding the present day mean high water springs (MHWS) mark will change from 12% to 93% of the time (Bell, 2001). Climate change will also affect waves, winds, river flow and storms, leading to changes in the sediment supply to the coast (Bell et al, 2001). These changes will alter coastal processes, causing coastal erosion in some areas and deposition in others.

Along Christchurch's coastline, sea level rise could lead to the inundation of low lying areas around Brooklands Lagoon and the Avon-Heathcote Estuary, and an increased incidence of tidal flooding in low lying riparian areas near the mouths of the Avon and Heathcote rivers. With higher water levels dune erosion may increase however the net result should be continued accretion of the dune-backed beaches between the Estuary and Brooklands Lagoon, albeit at a slower rate than at present (Tonkin & Taylor, 1999). It is uncertain exactly how climate change will affect sediment supply to, and along, the coast, with changes to flows in the Waimakariri River and to prevailing wind conditions being important (Bell, 2001). As sea levels rise and begin to encroach on the buffer zones between the coast and developed areas, the area available for marginal coastal vegetation, including areas of salt marsh, eelgrass and marsh ribbonwood, will be reduced resulting in losses to these ecosystems and ultimately to Christchurch's biodiversity. This effect is known as "coastal squeeze" (Tonkin & Taylor, 1999).

Rising sea levels are expected to result in increased coastal erosion at the terminal end of South Brighton Spit and an increase in the width of the Estuary mouth. Loss of sand from Sumner and Taylor's Mistake beaches is likely as more sediment becomes tied up in the Avon Heathcote Estuary circulation system (Tonkin & Taylor, 1999).

Sea level rise will cause an upstream migration of the interface between sea water and fresh water in rivers with potential for bank erosion due to a breakdown in soil structure, dieback of vegetation intolerant to saline conditions, and the invasion of mudcrabs. Other potential effects include an increased risk of saltwater intrusion into groundwater and of saline contamination in wells (Tonkin & Taylor, 1999). Warmer water temperatures and changing water depth in the Estuary may affect growing conditions for sea lettuce.

Potential Responses

- Set minimum floor levels in low lying coastal areas
- Restrict new development in areas at risk from coastal flooding
- Increase the height of stopbanks in lower river areas, maintain seawalls and other protective structures, including drainage outlets and coastal roads, at effective heights
- Maintain vegetation cover on the dunes to help resist erosion
- Allow for generous coastal buffer zones for dunes and low lying coastal areas to provide room for coastal processes and the inland migration of coastal ecosystems
- Beach sand renourishment at Sumner and Taylors Mistake
- Careful management, and potential redistribution, of water abstraction from municipal supply wells in coastal areas

Agricultural & Business Impacts

How will local agriculture be affected?

(unless otherwise noted the reference material for this section is taken from Kenny, 2001)

The most significant impact of climate change for the eastern South Island is the threat of drought. This will affect all types of farming and, in some areas, irrigation of crops and pasture will become critical. Expansion of dairying within Canterbury will be particularly dependent on water availability. In the 2000/2001 season irrigation bans resulted in high demand for supplementary feed. It is expected that this situation will be repeated unless more reliable water sources are secured.

Although it is expected that there will be little difference in the rate of groundwater recharge, the pressure on this resource will increase. The management of surface water will also become more difficult, with the need to balance instream and out of stream uses (Griffiths, 1990). A potential solution to this problem may lie with the proposed Central Plains Irrigation Scheme.

Increases in temperature and more frequent drought conditions may affect the composition of pastures, with more drought tolerant and often less palatable species dominating. The feed quality of pastures will reduce as conditions become too hot and dry for ryegrass and clover to thrive. The change in conditions may also assist the establishment and spread of certain weeds and pests, while on the positive side, warmer, drier conditions will reduce the vulnerability of crops to rusts and fungal diseases.

Increases in CO_2 concentration can have a significant fertilising effect for some crops e.g. for wheat and barley, resulting in stronger plant growth and better water use efficiency. In areas where rainfall is not an issue, it is expected that annual pasture yields will increase by 10-20% by 2030, however in warm dry areas these gains are expected to be limited. Increased irrigation and fertilisers may be needed to maximise growing conditions.

Canterbury is an important area for arable farming with a 1999 statistical survey showing that 67% of the 212,000 ha in cropping in New Zealand was in Canterbury. The main crops were wheat, barley, peas and grass seed. As a result of the expanding dairy industry, there is also increasing demand for silage maize and feed crops. While wheat and barley respond well to increasing CO_2 concentrations, maize does not. Maize will, however, grow better as temperatures increase, although this is a crop with a high demand for water and nitrogen fertilisers.

Farmers will need to adapt to climatic uncertainties and develop their skills for managing seasonal risks. Access to accurate and timely information will become more important, including long-term weather forecasts and information on feed availability. Proactive strategies are needed to avoid the worst adverse effects and to recognise the benefits of climate change. These strategies will need to include farm management planning, water resource management and planning, plant breeding programmes and the use of new cultivars and new crops such as olives, grapes and soy beans. With higher temperatures and a longer growing season, additional crops may become viable in Canterbury. Some crops, such as apples, will be susceptible to heat damage and may suffer from water-core and sunburn. Adjustments will be required to combat new regimes of pests and weeds and infrastructure needs will increase e.g. for irrigation and the processing of new crops.

Warmer, drier weather conditions may attract more tourists, but could also increase pressure on water supplies. With warmer winters the ski season may be reduced making some skifields less viable and more reliant on snow-making facilities. Those that are able may relocate to higher altitudes. A potential positive would be a greater influx of Australian tourists, due to the stronger effect of climate change on snowfall on Australian mountains.

The introduction of carbon charges, or similar, will affect many businesses and in some cases may impact on their viability. As national policy to reduce emissions develops there may be opportunities to offset costs by planting trees for carbon sinks. Depending on its value for carbon trading, plantation forestry may become an increasingly attractive land use (see inset: Forestry Impacts and Carbon Sinks).

Potential Responses

- With drier conditions on the east coast of the South Island, drought-proofing measures will become increasingly important for agricultural crops and stock on the Canterbury Plains and also for the management of City Council parks and reserves. Drought resistant grasses may become the best option for large grassed areas.
- The preparation of management plans and responses to deal with seasonal variability will continue to be critical. There is no guarantee that the current fluctuations from one year to the next will decrease.
- Increased experimentation with new crops, changes to staffing requirements and expenditure on infrastructure will become more important and may open up new opportunities for the Canterbury economy.
- More intensive farming may result in increased environmental effects with respect to water availability and discharges. Both regional and local planning initiatives need to be aware of the potential impacts on water quality and quantity.
- If carbon charges are introduced these will affect the Council along with other businesses. There may be opportunities to offset some of the impact with increased planting, for example indigenous species on the Port Hills, with benefits for biodiversity.

Forestry Impacts and Carbon Sinks

(from Ministry of Agriculture and Forestry, 2001)

Plantation forests are an important part of New Zealand's primary production. Forests established since 1990, known as "Kyoto forests", will play a major role in meeting New Zealand's emission targets. The rules of the Kyoto Protocol allow these forests to be accounted for as carbon sinks, ie a system which absorbs more CO_2 than it releases. While a growing forest acts as a carbon sink, the carbon content of a mature forest remains approximately constant and, when harvested, carbon can again become available as CO_2. Thus, forestry clearance, without replanting, is treated as a carbon source.

During New Zealand's first commitment period to the Kyoto Protocol, 2008 - 2012, "Kyoto forests" are expected to remove the equivalent of approximately 100 M tonnes of CO_2 from the atmosphere. This amounts to just under one third of the 363 M tonnes of CO_2 equivalent that makes up New Zealand's assigned target for the first commitment period. The planting rate for new forests has been high over the last eight years, averaging at 65,000 ha/yr.

To qualify as a "Kyoto forest", a forest must meet four tests:

i) it must meet the definition of a "forest" as defined by Article 3.3 of the Protocol
ii) its establishment must have been "direct(ly) human-induced" eg planted, seeded, or, if New Zealand's position is adopted, through human induced promotion of natural regeneration
iii) established since 1 January 1990; and
iv) established on land previously in some other land-use and not containing forest on 1 January 1990.

In addition to helping New Zealand meet its own Kyoto targets, international trading of "sink credits" may mean that overseas emitters may pay for sink credits from New Zealand forests which meet the "Kyoto forest" criteria.

With a crop rotation period of 25-30 years, forestry requires a longer planning timeframe than most crops and significant changes may occur to the climate during a single rotation period. Studies show that the growth rate of pine seedlings increased by 20% when CO_2 concentrations were doubled, however older trees show very little response to carbon fertilisation. The potential for early harvesting, due to carbon fertilisation, is fairly uncertain and the potential for a drier climate on the east coast is expected to impact negatively on tree growth. Radiata pine requires approximately 1,500 mm per year for optimal growth (cf 653/year recorded in the Botanic Gardens). If Canterbury does become significantly drier, forests could experience growth reduction due to reduced rainfall, although this could be offset by increased water efficiency due to higher CO2 concentrations. Higher temperatures may also increase the incidence of some plant diseases and the risk of fire.

Health Impacts

How will climate change affect our health?

(unless otherwise noted the reference material for this section is taken from Woodward, Hales & de Wet, 2001)

Perhaps the most insidious effect of climate change is the increase in the amount of UV light reaching the earth's surface. For Cantabrians this means an increased risk of skin cancer and the need to be vigilant about exposure to the sun. This risk is exacerbated with warmer temperatures and the temptation to head outdoors. Already the rate of skin cancer in New Zealand is one of the highest in the world with 250 deaths per year (Ministry for the Environment, 2001a).

Rising temperatures will also mean that New Zealand's climate will become more suitable for mosquito species which have the ability to carry Ross River virus, dengue fever and other arboviruses. In Canterbury the establishment of mosquitoes capable of carrying dengue fever is of concern and conditions are already likely to be present for the establishment of the Southern Saltmarsh mosquito (Ochlerotatus camptorynchus), a competent vector of Ross River virus. Conditions in the North Island will be even more suitable for mosquitoes and the main risk of disease may come from domestic travel to warmer areas of New Zealand. Canterbury may well benefit from any national control programmes aimed to alleviate the more serious problem in northern areas (see inset: Mosquitoes).

There will be an increase in the number of really hot days causing a greater incidence of heat stress, which can be expected to result in an average increase of 1.3% in mortality for each additional degree Celsius (see inset: Temperature Extremes and Mortality). Warmer ambient temperatures are also associated with a higher incidence of food poisoning.

With the potential for increased floods comes the added risk of flood related drownings. Water supplies can also be in danger of contamination, especially with torrential rainfall washing animal effluent, contaminated with pathogens such as cryptosporidium, into water supplies. Drought also affects human health and can lead to poor water quality and water restrictions, as well as mental stress. The later is especially a problem in rural areas where suicides can increase as droughts become prolonged.

The increased arrival of refugees and of goods from tropical countries provides the opportunity for tropical pests and diseases to be introduced. As New Zealand becomes warmer their potential for survival increases. Climate change may result in additional stress on disadvantaged groups in society who have limited resources to deal with the risks and may be more susceptible to such things as contaminated water supplies, lack of mobility and accessibility to health care.

Potential Responses:

- Provide more shade in public places to allow people the choice of reducing their exposure to direct sunlight
- Increase surveillance and destruction of exotic species of mosquito
- Ensure the provision of secure and reliable high quality water supplies
- Improve communication with at risk groups, and increase social awareness of disadvantaged sections of society and stressed groups in the community in order to improve their access to assistance.

Mosquitoes
(from Woodward, Hales & de Wet, 2001)

Two main species of mosquitoes which are of concern for NZ are Ochlerotatus aegypti and Ochlerotatus albopictus, as they are the two principal vectors of dengue-fever, the vector-borne disease identified as most likely to pose an increased risk to NZ as climate changes.

Computer models have been developed which estimate the potential distribution for the mosquitoes under climate change. The model shows it is unlikely that O. aegypti would survive anywhere in the South Island, even under the warmest scenarios of climate change. However O. albopictus is a more cold tolerant species. Although current climatic conditions in the South Island are unsuitable for this species, with climate change (mid-range scenario) the potential distribution by 2100 includes Christchurch and the coastline north of Christchurch. Under a high-range scenario, by 2050 potential distribution also includes the Canterbury plains.

Little or no climate change is expected to have to occur to allow for the establishment of the Southern Saltmarsh mosquito (O. camptorynchus). An eradication effort for this species, capable of carrying the Ross River virus, is already underway in Napier and Northland.

Susceptibility to dengue fever is influenced by a number of other factors including socio-economic factors, monitoring and control of mosquito populations, and proximity to potential points of entry, eg ports. This means that a range of strategies to limit its potential would need to focus on improved biosecurity, public health risk management, and the surveillance and control of mosquitoes. Initiatives to reduce socio-economic inequalities would also have other benefits in adapting to climate change.

Temperature Extremes and Mortality

(from Hales et al, 2001)

In a recent study, Hales et al (2000) looked at daily mortality in relation to weather and air pollution in Christchurch. They found that mortality was at a minimum on days when the temperature was between 12 – 20^{o}C. High temperatures tend to be associated with an increase in deaths from respiratory causes, while extremely cold weather is also associated with an increase in mortality. With climate change predicted to result in an increase in warmer days in Christchurch and fewer really cold days in winter any increases in mortality due to high temperatures can be expected to be offset by a reduction in cold-related mortalities, as extreme cold days become less frequent.

Further benefits may arise from warmer winters as home heating requirements are reduced and less particulates are emitted from the burning of solid fuel, resulting in better air quality for the City.

Urban Impacts

How will Christchurch's infrastructure be affected?

Climate change will bring with it the potential for more irregular and extreme events. Rather than the gradual changes, it is the sudden and more frequent arrival of intense droughts and floods that will test the City's infrastructure. Droughts will place stress on the City's water supply, whereas flooding can result in damage to dwellings, and affect services and infrastructure including bridges, roads, and wastewater reticulation. Drainage networks, especially in low lying coastal areas may need to be upgraded from gravity systems to more expensive pumping options.

Heavy rainfall can result in erosion and rockfall in hilly areas. Modelling of different scenarios for New Zealand and Australia suggests that we could expect up to a fourfold increase in the frequency of heavy precipitation events by 2070 (Ministry for the Environment, 2001a), meaning that there may be less time between events to repair any damage and that those local streams and stormwater drains which already overtop their banks at times, will do so more frequently.

The risk of flooding from the Waimakariri River is also likely to become an increased threat with an expected increase in rainfall in the Southern Alps. An upgrade in the stopbank system is currently in the planning stage and this will be designed to provide protection from larger flood events of up to 10,000 cumecs. Fortunately, in the coastal reaches of the river the stopbanks have been designed conservatively and should be sufficiently robust to cope with sea level rise over the coming decades (Pers.com.: Tony Boyle, Environment Canterbury).

Along the coast, rising sea level will mean that any storm event will have a greater potential to cause flooding. Extreme high tides and storm surges at current levels, when superimposed on a higher sea level, will result in significant overtopping and inundation in low lying areas such as Brooklands Lagoon and in the vicinity of the Avon Heathcote Estuary. For example, a 0.4m rise in sea level, as expected by around 2100, would increase the probability of exceeding the present day Mean High Water Springs (MHWS) mark from 12% to 93% of the time (Bell, 2001). These impacts will be exacerbated if storms become stronger and more frequent, as some models suggest might happen. However, no reliable projections on changes in storm frequency and intensity are currently available, as there is little agreement between current climate models (Ministry for the Environment, 2001a).

Long-term planning will need to consider how best to manage all of these hazards. Potential threats can be addressed by avoiding new development in areas which will be at risk, by providing defence systems, such as flood protection measures, to protect existing development, or by considering managed retreat from threatened areas.

Electricity demands over summer may well increase with greater use of air-conditioning for cooling buildings, including an increasing number of dwellings, to comfortable levels. However this is likely to be offset by a reduction in overall demand for electricity due to warmer winters. Projections suggest that for a warming of about 2 ^{o}C, the annual average electricity demand would decrease by about 6%. The potential for shortages of stored water for hydro-electricity in the southern lakes is also likely to be reduced with lower demand and increased rainfall during winter although, with less precipitation falling as snow, spring flows and summer storage will be reduced.

Increased water useage, as a result of drought, is also likely to place stress on existing water resources. With drier conditions, competition between instream and out-of-stream use will increase as will demand for agricultural irrigation resulting in competition between urban, industrial and rural demands on the groundwater resource. Management of all these conflicting uses will become increasingly difficult. It is likely that there will be a greater focus on the efficient use of water and avoiding waste.

On the positive side, the warmer temperatures expected during winter should result in less carbon-based fuels being used for home heating and should help to reduce particulate concentrations which cause smog conditions in Christchurch.

Potential Responses:

- Relocate critical infrastructure away from areas at risk of increased inundation, rockfall or other hazard
- Install, redesign or rebuild protection measures, where appropriate, to ensure they are sufficiently robust to deal with expected changes
- Strengthen policy measures to avoid new development in "at-risk" areas
- Assess long-term retreat options for existing development which may become increasingly threatened by climate change impacts
- Develop measures to reduce impact of reduced availability of water during drought conditions e.g. education and awareness programmes to assist in water conservation

PART 3 CLIMATE CHANGE POLICY

National Policy

In response to the United Nations Framework Convention on Climate Change (UNFCCC), negotiated at the Rio Earth Summit in 1992, and subsequent international agreements, the New Zealand government has confirmed its intention to ratify the Kyoto Protocol (1992) in 2002. This Protocol aims to stabilise greenhouse gas emissions from industrialised countries at 1990 levels, on average, in the commitment period 2008-2012. Parties to the Protocol are required to enter into legally binding agreements to meet emission targets and are required, by 2005, to show demonstrable progress towards achieving their commitments.

The details of how New Zealand will meet its targets are still being finalised and are currently being worked on by central government. In addition to directly reducing emissions at source, the mechanisms for meeting targets will include carbon sinks such as forests to enhance the removal of greenhouse gases.

Summary of Government's Preferred Policy Package

In April 2002 the government released its "Preferred Policy Package" for dealing with its obligations under the Kyoto Protocol (Department of the Prime Minister and Cabinet, 2002). The principles used to guide the development of the policy package are as follows:

- Policies must result in permanent reductions in emissions over the long term
- Policies need to be responsive to the changing international context
- Policies need to be consistent with a growing and sustainable economy
- Policies will not disadvantage the vulnerable in our society.

The proposal includes the following provisions:

1. A price on carbon dioxide emissions, applied at first through an emissions charge on carbon fuels. The price will approximate the international price of carbon, but be capped at $NZ25 a tonne of carbon dioxide equivalent, and will apply in the Kyoto Protocol's first commitment period 2008-2012 and not before 2007. Revenue will not be used to improve the Crown's fiscal position but will be recycled, for example through the tax system. The Government retains the option of introducing emissions trading as an alternative to an emissions charge if the international carbon market is functional and the price is reliably below the $NZ25 cap.

2. Provision of government incentives for projects that will deliver defined reductions in greenhouse gas emissions, in any sector of the economy. Incentives can include funds or the allocation of emissions units and the government will seek bids from firms or groups. To qualify, projects must be additional to business-as-usual. The

provision of incentives will accelerate the uptake of emission reduction initiatives, including new technologies and practices, that would otherwise be uneconomic.

3. Negotiated Greenhouse Agreements for sectors and industries that would face difficulty in adjusting to a full price on emissions in the first commitment period. These sectors and industries are identified as having their competitiveness at risk. Negotiated Greenhouse Agreements would comprise a contractual commitment by the industry or sector to achieve international best practice in managing emissions, in return for exemption from an emissions charge.

4. Exemption for the agricultural sector from any price measure (emissions charge or trading regime) in the first commitment period for non-CO_2 emissions (i.e. methane and nitrous oxide). This exemption depends on the sector being willing to invest, in partnership with the Government, in research to identify options for reducing agricultural emissions. The Government retains the option of imposing a research levy if the research effort falls below what is required.

5. Government retention of the sink credits and associated liabilities allocated to New Zealand under the Protocol in recognition of the carbon sink value of post-1990 forest plantings. These credits will be retained and managed by the Government at least for the first commitment period, with a portion of the revenue used to provide incentives for the establishment and enhancement of sinks. As with emissions charges, additional revenue from the sale of sink credits will be recycled back into the economy. The Government, rather than forest owners, will assume the liability created by the Protocol for deforestation, although the liability will be capped nationally at 5% of the area of forest expected to be harvested over the first commitment period.

New Zealand Coastal Policy Statement

The New Zealand Coastal Policy Statement (Department of Conservation, 1994) is a national policy statement required under the Resource Management Act 1991. It provides policy direction for coastal management under regional and district plans and includes policies relevant to the issue of climate change i.e. "*a precautionary approach should be adopted towards activities, particularly those whose effects are as yet unknown or little understood*" (Policy 3.3.1), and " *Policy statements and plans should recognise the possibility of a rise in sea level, and should identify areas which would, as a consequence, be subject to erosion or inundation. Natural systems which are a natural defence to erosion and/or inundation should be identified and their integrity protected*" (Policy 3.4.2).

Unfortunately these policies do not recognise that sea levels have risen over the last century and that sea level rise is more than just a possibility, nor do they provide guidance on the timeframes that should be considered for planning.

Regional Policy

The Canterbury Regional Policy Statement (Canterbury Regional Council, 1998a) includes policies aimed at reducing net emissions from carbon based fuels and encouraging vegetation cover which acts as carbon sinks. Methods to implement these policies include the development of an Air Quality Management Strategy which includes measures to reduce net carbon dioxide and other greenhouse gases, and the inclusion of air quality measures within regional and district plans to encourage development patterns and infrastructure which decrease motor vehicle emissions.

Sea level rise is recognised as an issue in the Regional Policy Statement, with an acknowledgement in the Natural Hazards chapter that a rise in mean sea level could exacerbate natural hazards arising from forces of the sea. A precautionary approach is recommended and the Policy Statement commits the Regional Council to monitor changes in sea level along the Canterbury coast.

The Proposed Canterbury Regional Coastal Environment Plan (Canterbury Regional Council, 1998b) contains no policies dealing directly with sea level rise and in the text refers only to "possible" sea level rise. The only method stated in the plan for addressing this issue is to prepare maps of the coastline where risk of damage from natural events may be increasing "*due to possible climatic warming, associated sea level rise and Tsunami, for amendment of the Plan within five years of it becoming operative*." The prospect of the Plan becoming operative is still some time away, with references on the Plan still being heard by the Environment Court.

In the absence of stronger policy direction there is little incentive for local territorial authorities to consider sea level rise, and no proactive, regionally consistent approach for dealing with it. Despite this, the Regional Council, in association with NIWA, have complied with the monitoring requirements set out in the Regional Policy Statement by monitoring sea level rise at Sumner. The data set is still too short to be very meaningful, but with time a good record should be established.

Christchurch City Council Policy

In 1995 a report was prepared for Council on the "Implications of Climate Change for Christchurch" (Wilkinson & Smith, 1995). This report provides background information on climate change, discusses impacts for the City and sets out the policy framework for climate change issues. The following policies were adopted by Council as a result of this report (p. 33).

1. *That the Council acknowledge that climate change is occurring and adopt a precautionary approach when planning for future activities and works.*
2. *The Council when developing new policies and projects, takes into account the effects of climate change where this is appropriate. Policies that initiate or support activities that counter the causes and effects of those changes, are to be preferred.*

3. *That the Council's response to climate change combine the limitation and adaptation approaches.*
4. *That the Council develop a transportation policy which serves to limit greenhouse gas emissions.*
5. *The Council support ongoing monitoring of climate change indicators such as sea level rise, greenhouse gas emissions and carbon sinks.*
6. *The information in the report should be used in assessing submissions on the new City Plan during the review period and in addition the report should be reviewed in five years time.*

Since this report a number of initiatives have been undertaken by the City Council. These include:

- Introduction of the hybrid/electric powered shuttle bus for reduced emission travel in inner Christchurch
- A study of the effects of sea level rise in Christchurch (Tonkin & Taylor, 1999)
- Council submissions on various national policy documents concerning greenhouse gas emissions and climate change e.g. *Climate Change. Domestic Policy Options Statement. A Consultation Document* (Ministry for the Environment, 1999).
- Providing funding for the power supply for the sea level rise monitoring buoy at Sumner
- Involvement in the EBEX21 programme
- Establishment of the Measure to Manage programme for Council activities
- Development of cycling, pedestrian and public transport strategies to reduce use of private vehicles
- Work has begun on a pilot project for "Green Travel Plans" where Council staff are encouraged to reduce vehicle emissions through the use of carpools, public transport, walking and cycling
- Development of policies with an energy efficiency focus, often with a subsequent reduction in greenhouse gas emissions e.g.
  - *The Council will follow energy strategies that minimise energy consumption, select sustainable energy supplies and minimise impacts on the environment* (26.11.1997);
  - *The Council is committed, in its operations, to the efficient use of energy and energy conservation* (27.11.1996); and
  - *For new projects and major retrofits with a significant energy component an Energy Efficiency and Sustainability Assessment must be carried out (27.11.1996).*
- Providing financial support for the establishment of a wind energy venture by entering into a contract to purchase electricity from this carbon dioxide free source.

In addition to the policies and actions listed above, there are a number of policies in the proposed City Plan (Christchurch City Council, 1999) which promote energy efficiency and the use of renewable energy. Two policies with a direct bearing on climate change are:

Policy 2.5.4
To avoid higher intensity forms of built development in areas that could be subject to anticipated sea level rise, (p.2/21) and
Policy 3.1.6
To increase tree planting throughout the City and encourage the development of alternative sinks for carbon dioxide absorption. (p. 3/4).

These policies still provide a good general framework for Council activities and it is appropriate for additional policy which affects specific Council functions to be developed on a case by case basis. One such example is the Floodplain Variation of the City Plan which is currently being developed and which will recognise the issue of increased coastal flooding expected with sea level rise.

CONCLUSION

This report provides an overview of climate change, the factors involved and the process used by IPCC to assess recent climate change studies. Since the first IPCC report in 1990, evidence has mounted to support the view that global warming is occurring and that human activity is a major cause of this.

The second part of the report looks at the impacts climate change is expected to have on New Zealand and in particular on Christchurch. These impacts range from coastal flooding, to droughts and an increased risk of skin cancer and mosquito-borne diseases. There will also be opportunities to grow new crops, develop tourism and increase biodiversity through planting trees as carbon sinks. The final section of the report considers the current policy framework. Existing Council policy provides a sound base for responding to the challenges of climate change and can be added to and amended as specific needs arise.

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