Climate Change: Potential Effects on Human Health in New Zealand

**A report prepared for the
Ministry for the Environment
as part of the
New Zealand Climate Change Programme**

New Zealand Climate Change Programme
Te Hōtaka Rerekētanga Āhuarangi ō Aotearoa

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Alistair Woodward and Simon Hales
Wellington School of Medicine and Health Sciences
University of Otago

Neil de Wet
International Global Change Institute
University of Waikato

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There is now agreement among most climate scientists that the globe has begun to warm as a result of increased concentrations of greenhouse gases in the atmosphere. The degree of future warming and associated other climatic changes for the next 100 years is still uncertain, but expected to be greater than the natural variability experienced over the last 10,000 years. The following conclusions can be drawn about the potential effects of this climate change on the health of New Zealanders.

- Climate trends in recent decades may already be affecting our health.
- The direct impacts of changes in climate extremes are likely to be relatively small.
- The recovery of the stratospheric ozone layer may be delayed by climate change, and this will lead to continued adverse effects from ultraviolet radiation, such as skin cancers.
- Parts of the North Island are likely to become receptive to populations of the major mosquito vector of dengue fever, while much of the country may become receptive to a less efficient vector species. If vectors become established, increased temperatures will also increase the risk of transmission of dengue and other arboviral diseases.
- Floods and droughts will have important indirect effects on health through social and economic impacts, although these secondary effects are difficult to quantify. Increased flooding and drought events could also affect water quality, with increased rates of some water-borne diseases.
- The impact of climate change depends not only on the extent and rate of warming, but also on the adaptive capacity of individuals and society.
- Pacific Island countries will find it more difficult to adapt to climate change impacts. New Zealand may need to provide for environmental refugees from many of these countries or offer increased development aid and assistance.

Adaptation options and research needs

In the long term, the health of human populations is dependent on the stability of social arrangements and, more fundamentally, on the sustainability of natural systems. There are many adaptation measures that are 'no regrets' or 'few regrets' strategies – they bring benefits that more than cover costs even if the currently projected climate changes do not fully eventuate. These benefits would also apply to the current situation in the absence of climate change.

It would be useful to gain a better understanding of the effects of current climate variability on health in this country, and also of factors that may limit adaptation. Pressures from climate change also provide another reason for developing and maintaining effective border control and other biosecurity measures, and analysing the influence of climate change on the efficiency of those measures. Contingency planning needs to include possible knock-on effects of climate change impacts in more vulnerable countries elsewhere in Asia and the Pacific.

1 Introduction

1.1 Climate change

Everyone knows that the climate varies from one month to another, and from one year to the next. However, the term 'climate change' refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural processes, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. It is worth noting, however, that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, specifically defines 'climate change' as:

> *a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods*. (Intergovernmental Panel on Climate Change, 2001)

There is now agreement among most climate scientists that the globe has, on average, already begun to warm, probably as a result of increased emissions of greenhouse gases associated with industrialisation and altered land-use patterns. This is the conclusion of the Intergovernmental Panel on Climate Change (IPCC), an governmental expert body set up by the United Nations and the World Meteorological Organisation (Albritton *et al.*, 2001). This warming is proceeding unevenly across the planet, so that island states in the south (such as New Zealand) are expected to see less rapid changes than northern continental areas over the 21^{st} century.

Our ability to model climate and to project changes over the next 100 years has improved, but there are still uncertainties, especially in projecting climate changes on a geographical scale relevant to New Zealand. In general, changes in average temperature are modelled more reliably than changes in rainfall and other climatic variables, and global or regional averages are forecast with more confidence than climate at a national or sub-national level.

While there is consensus that average global temperature will continue to rise in the future, projecting the rate and magnitude of this change is influenced by two main areas of uncertainty. The first is the future rate of emission of greenhouse gases. This will be driven by future population growth, technological developments and other trends influencing patterns of land, resource and energy use. In modelling climate change, these uncertainties are captured by using a range of greenhouse gas emission scenarios. The second area of uncertainty is the climate sensitivity, or the extent to which the climate alters for a given greenhouse gas loading. This is a scientific uncertainty relating to our incomplete understanding of the climate system, in particular, our understanding of how factors such as changing cloudiness and snow and ice cover will influence global warming.

Attempting to allow for these uncertainties, the IPCC has estimated that in 2100 the globally averaged surface temperature will be between 1.4ºC and 5.8ºC higher than in 1990 (Albritton *et al.*, 2001). This rate of change in global temperature over 100 years would very likely be greater than any natural variation that occurred over the past 10,000 years.

There are also other sources of uncertainty, such as the possibility of rapid and irreversible changes in climate due to unforeseen feedbacks or other poorly understood processes. The temperature increases projected for the 21st century may be compared with an observed rise in global average temperatures of about 0.6ºC during the 20th century.

Complex General Circulation Models (GCMs) are used to simulate changes in temperature, precipitation and other climate variables at the global and regional scales as a function of increasing greenhouse gas concentrations and other drivers. These model results are generally used to project future changes under given assumptions about future greenhouse gas emissions. While GCMs are valuable for modelling climate change at such scales, they are too coarse to capture factors that influence climate at the scale of individual countries, such as topography.

The assessment of the effects of climate change in New Zealand has been facilitated by the development of the CLIMPACTS model. This model uses local climate data, greenhouse gas emission scenarios, a range of climate sensitivities and down-scaled GCM patterns to generate country- and regional-scale scenarios of future climate change (Kenny *et al.*, 1995). Such methods have increased our understanding of the range and nature of possible climate changes in New Zealand.

For New Zealand, all models show that the climate will become warmer on average. The projected rate of warming differs between models, but is likely to be less than the global average. The projections illustrated in Figure 1 show the range of possible changes based on a range of model assumptions. Warming will be associated with an increase in the number of extreme warm days and a decrease in the number of frost days. Models are in poorer agreement on future changes in precipitation at a regional scale, with different GCMs producing more variable results for the direction, magnitude and spatial patterns of changes in precipitation than for temperature (see Figure 2).

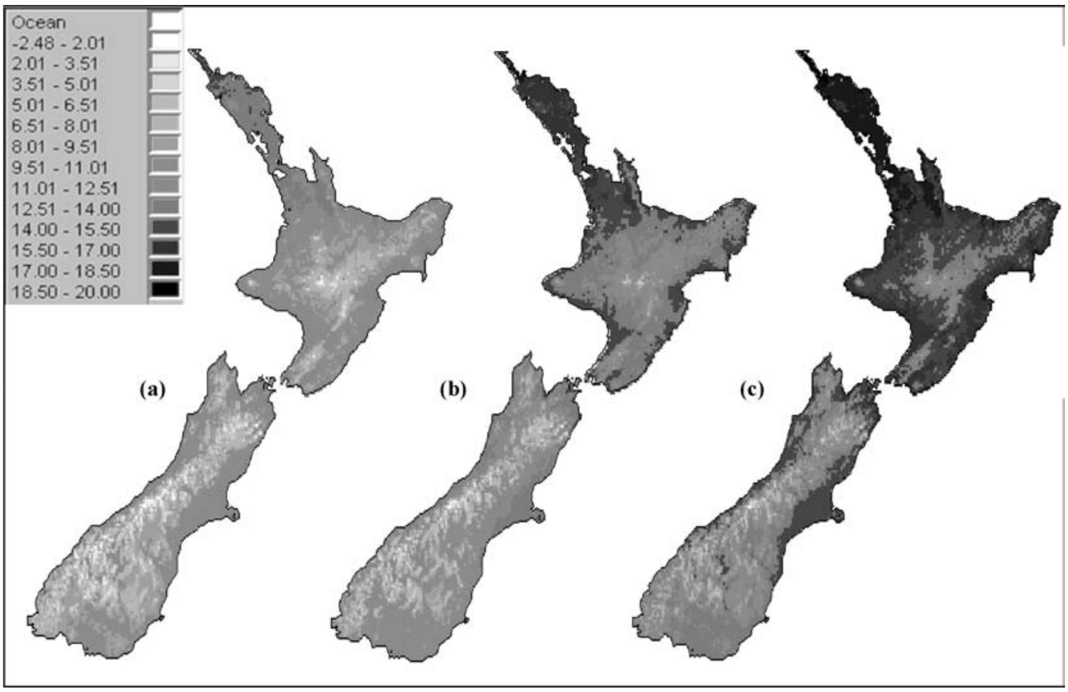

Figure 1: *Mean annual temperatures for (a) 1990, and for the year 2100 for: (b) a mid-range scenario that assumes greenhouse gas stabilisation (WRE550 emissions scenario) and a mid-estimate climate sensitivity; and (c) a high-range scenario that uses a high (SRES A2) emissions scenario and a high-estimate climate sensitivity. Greenhouse gas emission scenarios are based on reports by the Intergovernmental Panel on Climate Change (Intergovernmental Panel on Climate Change, 1997, 2000).*

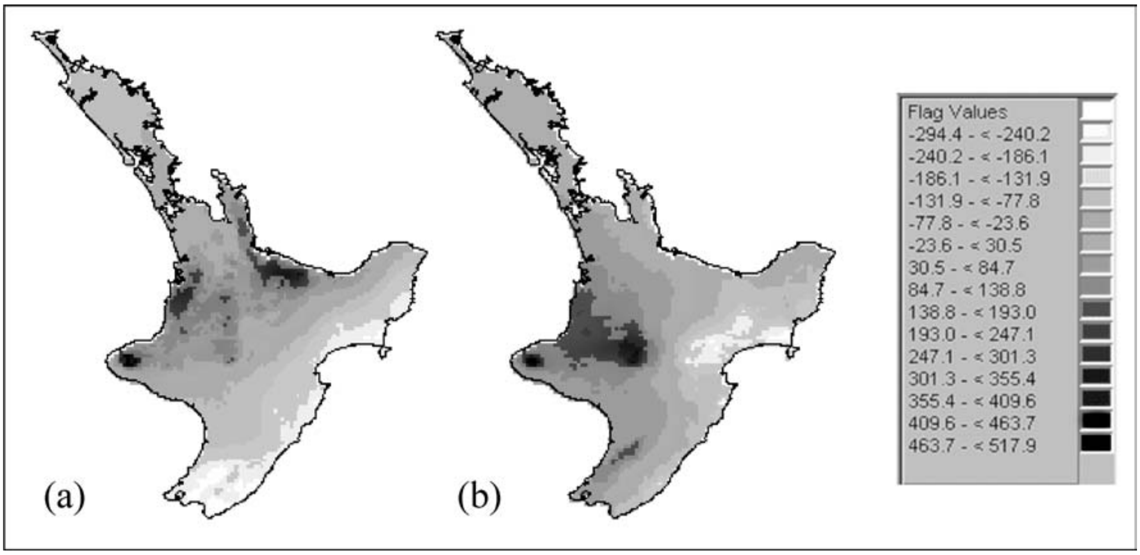

Figure 2: *The North Island – two projections of change in annual precipitation (in mm per year) for the year 2050 using the same high emission scenario and high estimate of climate sensitivity, but output from two different GCM models: (a) CSIRO 9 and (b) HadCM2. Both models show a tendency towards drier conditions in the east and wetter conditions in central and western regions, but significant differences in the magnitude and regional extent of those changes.*

Because of the differences between current climate models, and remaining uncertainties in global climate projections, regional estimates of future climate changes for New Zealand can only be given as a range of possible scenarios. Future refinement of global climate models could lead to projections that are not necessarily captured by the range of current climate models represented in this report. The scenarios and the impact assessment in this report should therefore only be seen as a case study of what might happen if a certain set of changes, which is considered plausible by the scientific community, were to take place. The scenarios do not represent a firm prediction of expected biophysical changes or their consequent impacts.

However, some general trends are consistent across several models, including an increase in westerly air flows over the country and consequently increased rainfall on the west coast and a decrease in the east. Table 1 provides a summary of the average changes projected for a mid-range climate change scenario based on several GCMs for the main regions of New Zealand. Note the potential for strong gradients in rainfall changes across some regions. There is not yet a sound scientific basis for predicting possible changes in storminess and windiness (Warrick *et al.*, 2001).

A common feature of many climate-change assessments is not only a change in average rainfall distributions, but also an increased risk of extremely heavy precipitation events due to the greater water-holding capacity of a warmer atmosphere. While numerical predictions of extreme events are less certain than changes in average temperature or rainfall, the frequency of their occurrence may have significantly greater implications for human health issues, as outlined in this report.

Table 1: Predicted changes in annual mean temperature and precipitation, 1970–99 and 2070–99, from four global climate models assuming a continued growth in greenhouse gas emissions

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

Note: The range of changes indicates differences between the four models.
Source: Ministry for the Environment, 2001.

1.2 The impact of climate change on health

How would these climate changes affect our health? Quantitative projections of future impacts on human health are subject to several sources of uncertainty (White *et al.*, 2001):

- There is limited scientific understanding of the underlying health–environmental relationships, and the main factors modulating these.
- Projections of climate and other relevant factors (such as population) are themselves imperfect.
- Given simultaneous changes in global social and environmental conditions, it is unclear to what extent the past will be a reliable guide to the future.

The health of New Zealanders living today reflects a range of social and environmental conditions in the past (for example, infections, smoking and diet). In the long term the health of New Zealanders – indeed of all human populations – is dependent on the stability of social arrangements and, more fundamentally, on the sustainability of natural systems. The effects of climate change on health include those that follow directly from changes in temperature, rainfall and other climate variables, and effects that are secondary to perturbations in other systems (such as agriculture or aquatic ecosystems). Direct effects of climate on health are more readily quantifiable, but probably of lesser importance than indirect effects. Indirect effects will be the result of a range of future climate impacts on social and environmental conditions which influence human health.

Climate trends in recent decades may already be affecting the health of New Zealanders, but any such effects are difficult to demonstrate unequivocally (White *et al.*, 2001) because it is often difficult to separate the true effect of changes in climate from the effects of changes in other social and environmental conditions. Human health is strongly influenced by many factors other than climate.

The impact of climate change depends not only on the extent and rate of warming, but also on how well individuals and society can adapt. New Zealand is a relatively affluent country and is generally well equipped to deal with the changes that are anticipated. However, vulnerability varies according to socioeconomic status, ethnicity and geographic factors. It is also important to note that climate projections cover a wide time span, and most climate change-related impacts will only become apparent over a period of decades, but projections of vulnerability to the projected changes are necessarily based on current health status and socioeconomic conditions. Because of the speculative nature of socioeconomic predictions for time frames of several decades, statements about vulnerability therefore cannot take into account potential future social and economic developments.

2 Direct Effects

2.1 Direct effects of temperature extremes

Over the last 50 years warming in New Zealand has occurred principally as in the form of rising minimum temperatures, with fewer cold extremes. Daytime maximum temperatures have risen less than night-time minimum temperatures. This trend is projected to continue as a result of greenhouse 'forcing'. An increase in heat-related mortality is expected, but this will probably be offset by a reduction in cold-related mortality.

In temperate countries, there is a U-shaped relationship between temperature and mortality, with a minimum number of deaths at moderate temperatures, and an increase in deaths during hot weather as well as cold weather (Kunst *et al.*, 1993; Martens, 1998). Sensitivity to cold weather appears to be greatest in countries with mild winters (Eurowinter Group, 1997). In New Zealand, heart disease death rates are up to 35% higher at the winter peak compared to the summer low (Marshall *et al.*, 1998). Seasonal variation (over 50% variation) is even greater among the elderly and for deaths from respiratory causes, but possible explanatory factors such as weather or air pollution were not analysed in this study. Air pollution and extremes of temperature are each associated with increases in mortality from all causes, although stronger effects on respiratory and/or cardiovascular mortality have been reported. The effects of temperature and air pollution are generally more severe among older people and those with underlying illness.

Local studies of daily deaths in relation to weather in New Zealand have been conducted in Christchurch (Hales *et al.*, 2000) and Auckland (Cockburn, 2001). In Christchurch, daily maximum temperatures average 20°C in summer but occasionally exceed 35°C. After removing seasonal effects using a regression method, mortality was found to be at a minimum on days where the temperature was between about 12 and 20°C. The effect of temperature on mortality on the day of death and one to two days prior to death was investigated. The strongest effect was seen on the day of death, where mortality from all causes increased by about 1% per degree Celsius for hot days. There was a stronger relationship between high temperatures and specifically deaths from respiratory causes. Conversely, there was also an increase in mortality for extremely cold weather, which would suggest a reduction in winter mortality when extremely cold days become less frequent. However, the correlation between cold days and mortality was not statistically significant. Particulate air pollution was also found to have an association with mortality, and this was independent of the effect of temperature.

In Auckland daily maximum temperatures rarely reach 29°C. Cockburn investigated the effect of temperature on mortality on the day of death and up to seven days prior to death (Cockburn, 2001). When seasonal effects were removed using a monthly running mean, mortality from all causes increased following extreme cold weather, after a lag of four days. In summer, mortality from respiratory causes increased following hot weather, but to a less marked extent than in Christchurch.

The potential effects of air pollution were not investigated in this study. Increased temperatures due to climate change will generally exacerbate the effects of photochemical air pollution in summer in areas such as Auckland. Effects on particulate air pollution are less clear, as it is not known what effect climate change will have on weather conditions that tend to trap pollution near the surface (White *et al.*, 2001). Increased temperatures will reduce the need for home heating in winter, which would tend to reduce output of particulate pollution from that source.

From the studies outlined above, it is not possible to make a reliable assessment of the overall direct effects of temperature and air pollution on years of life lost or gained, although the direct impact of temperature changes is likely to be relatively small. Some regions may experience more positive effects from a reduced number of cold winter days, while other (northern and urban) regions may experience more negative effects from increased numbers of hot days.

2.2 Direct effects of heavy rainfall

Possible direct effects of greater variability in rainfall include accidental drowning due to flooding. Flooding is a major issue on New Zealand's steep terrain, particularly on the west coast of both islands. At the time of early European settlement, drowning was the commonest cause of accidental death. New Zealand still has relatively high rates of drowning by comparison with other economically developed countries (Langley *et al.*, 2000). This reflects geography, lifestyle and (possibly) less well-developed injury prevention programmes. Approximately one drowning a year is recorded by the New Zealand Health Information Service as due to "floods and civil emergencies" (Margaret Warner, personal communication), but this is almost certainly an under-estimate of the number of deaths in which extreme weather conditions are a contributing element. The vulnerability to drowning is clearly strongly dependent on infrastructure, lifestyle and attitudes towards perceived risks, and this vulnerability is likely to change significantly over the time scales that climate change would affect the frequency of flooding events.

3 Indirect Effects

3.1 Stratospheric ozone depletion

Rising greenhouse gas levels may delay the recovery of stratospheric ozone by several decades. When heat is trapped close to the surface of the earth by CO_2 and other greenhouse gases, the outer layers of the atmosphere cool. These outer layers include the stratosphere, where most of the atmospheric ozone is found. Stratospheric ozone provides an important protective layer against incoming solar ultraviolet radiation, but ozone levels are reduced by the action of chlorofluorocarbons (CFCs) and other ozone depleting substances. The link with climate change, appreciated only recently, is that lower temperatures in the stratosphere accelerate the destruction of ozone by CFCs. Emissions of ozone-depleting chemicals such as the CFCs have fallen significantly as a result of international agreements. However, global climate change means the recovery of the stratosphere may be delayed due to the increased efficiency of ozone-destroying reactions in the stratosphere, and high levels of ultraviolet radiation will continue to pass through to the earth's surface for longer than would occur without climate change.

The causes of skin cancer are not fully understood, but solar ultraviolet radiation is thought to be an important factor. It is difficult to determine exactly how common these diseases are since the most common forms of skin cancer (squamous cell and basal cell carcinomas) are not officially recorded. However, reported (serious) skin cancer rates in New Zealand are among the highest in the world, and this is most likely due to a predominantly pale-skinned population living in an environment with relatively low air pollution, plentiful sunlight and an outdoors-oriented lifestyle (Armstrong, 1994). The annual cost associated with the treatment of skin cancer in New Zealand is estimated by the Cancer Society at $33 million, and 250 deaths from skin cancer occur every year. These high rates cannot be attributed to relatively recent phenomena such as ozone depletion or climate change because of the relatively long incubation time of serious skin cancer forms such as melanoma, but they do signal a high degree of vulnerability to prolonged high levels of UV radiation (McKenzie and Elwood, 1990).

How big an effect climate change might have on ozone depletion in the future is not known, but preliminary estimates suggest that increased levels of greenhouse gases could delay the recovery of stratospheric ozone by 15 to 20 years. This is only indicative – there are many uncertainties associated with the calculations. It is not known, for instance, what the downstream effects of enhanced ozone depletion might be on skin cancer rates. In the United States it has been estimated that CFC depletion of the ozone layer, without any added climate change effect, could increase skin cancer rates by between 5 and 20% by the middle of the 21^{st} century (Slaper *et al.*, 1996).

3.2 Vector-borne diseases

Indirect effects are frequently more difficult to assess than the direct effects of climate on health, but at least in New Zealand are likely to be more important. Dengue fever has been identified as a vector-borne disease that is likely to pose an increased risk to New Zealand as climate changes. The mosquito species *Aedes aegypti* and *Aedes albopictus* are the two principal vectors of dengue. If they were inadvertently introduced, a warmer (and possibly wetter) climate would increase the likelihood that they would survive and become established. An increased understanding of this risk has been facilitated by the development of HOTSPOTS (De Wet *et al.*, in press). This is a computer model that estimates potential vector distribution patterns for New Zealand under present and future climatic conditions. The model also allows policymakers to identify areas where the presence of the vector will coincide with other risk factors (such as the introduction of the virus by infected travellers, and shipments of goods containing virus vectors).

Under present climatic conditions it is unlikely that introduced *A. aegypti* would establish in New Zealand. For a mid-range climate change scenario that assumes some stabilisation of greenhouse gas emissions, New Zealand remains unsuitable for *A. aegypti* until near the middle of the 21st century, when foci with suitable climatic conditions would begin to appear in the extreme northern areas of Northland. In 2100 suitability would remain limited to this northern area. However, under a high-range climate change scenario these northerly foci appear as early as 2025 in Northland, by 2050 in Auckland, and by 2100 potential distribution includes most of Northland, much of the Waikato and many other coastal areas of the North Island such as the Coromandel Peninsula, Bay of Plenty and Hawke's Bay (see Figure 3). It is improbable that *A. aegypti* would survive anywhere in the South Island even under the highest scenarios of climate change.

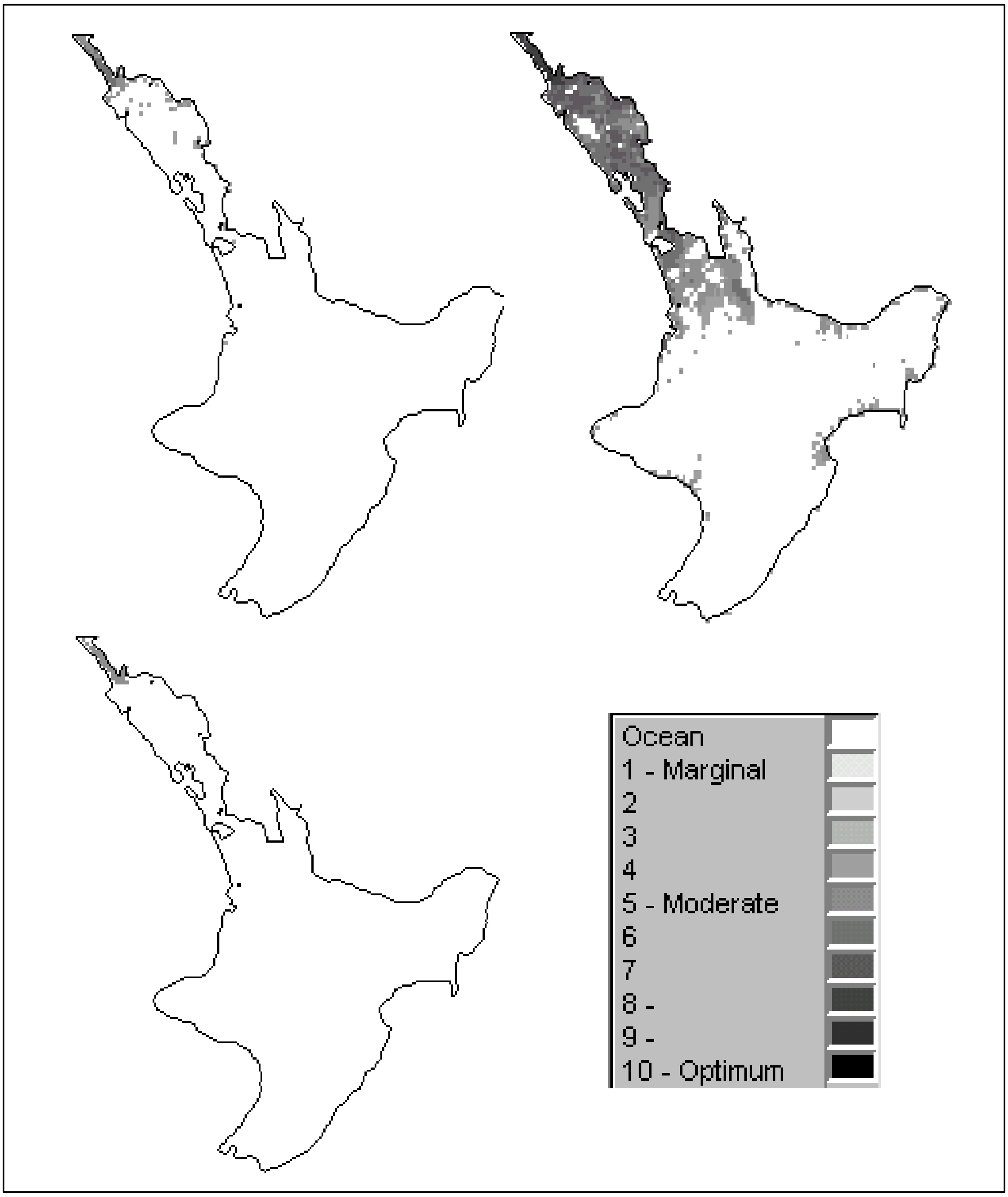

Figure 3: *Potential distribution of Aedes aegypti for: (a) a high-range scenario for 2050; and (b) for 2100; and (c) a mid-range scenario for 2100.*

A. albopictus is more cold tolerant and its current modelled potential distribution includes many northern and coastal areas of the North Island, but still excludes the South Island. With climate change the potential distribution in the North Island expands to include most coastal areas and also inland. Climate change would have significant implications for *A. albopictus* in the South Island, allowing foci of suitability to appear in the Marlborough and Nelson areas as early as 2010. By 2100, for a mid-range scenario, the potential distribution includes Christchurch and the coastline north of Christchurch and has expanded in Nelson and Marlborough. By 2050, under a high-range scenario, the distribution includes these areas as well as the Canterbury plains. By 2100 most coastal areas of the South Island north of Dunedin would be within the mosquito's climatic tolerance limits (see Figure 4).

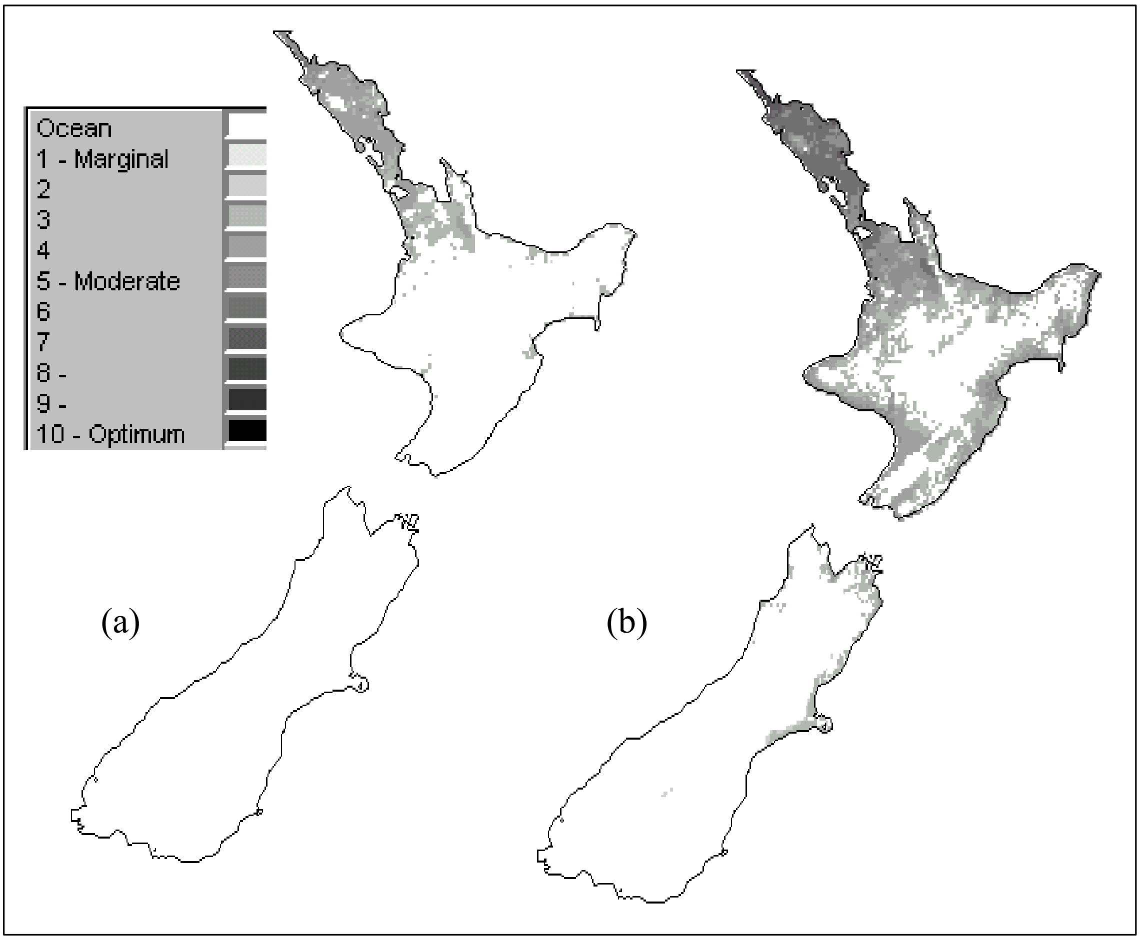

Figure 4: *Potential distribution of Aedes albopictus for: (a) present climate; and, (b) for 2050 for a high-range scenario of climate change. A mid-range scenario for 2100 produces a similar pattern to (b).*

Spatial overlays of other dengue fever risk factors, such as demographic risk factors and virus and vector introduction risks, suggest that the areas of highest dengue fever risk are the greater Auckland area and foci in Northland. These areas display a convergence of epidemic risk factors, would potentially support *A. albopictus,* and, particularly under the high-range climate change scenario, could also become suitable for *A. aegypti* (which is a much more efficient vector of dengue than *A. albopictus)* (see Figure 5).

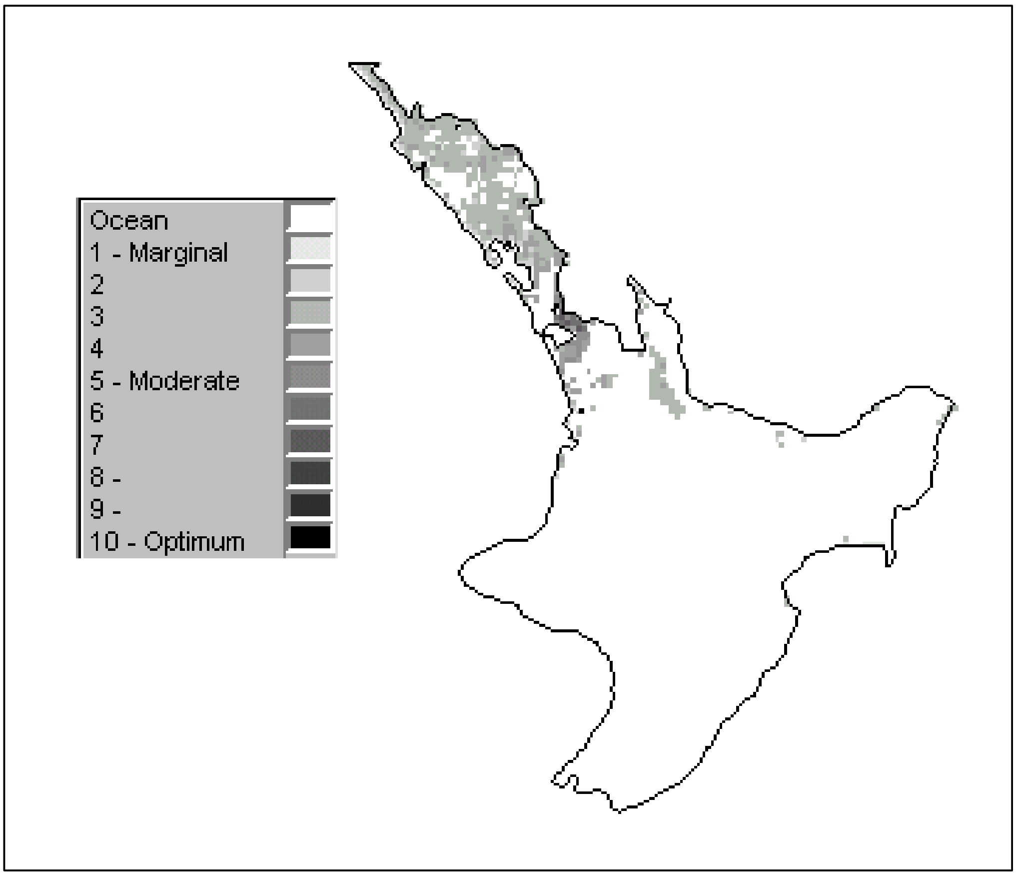

Figure 5: *Dengue fever risk map, for the North Island, combining virus and vector introduction risk, demographic risks and potential distribution for A. aegypti for a high-range climate scenario for 2080. This risk pattern is similar to that for A. albopictus under present average climatic conditions.*

On a global scale malaria distribution and risk would be sensitive to climate change. However, the biology of the disease is different from that of dengue, and in New Zealand the socioeconomic conditions and standard of health service are likely to preclude malaria from being a significant future threat.

In terms of vector-borne disease risk, stabilising global greenhouse gas emissions would have quantifiable local benefits for New Zealand. However, we also need to develop complementary response measures to reduce our vulnerability. While climate change may increase the potential distribution of introduced dengue vectors, our ability to prevent the introduction of, or respond to and control, an introduced vector would decrease our vulnerability. Similarly, vulnerability to epidemics of dengue fever would be strongly influenced by socioeconomic factors, such as high population densities, crowded living conditions, poor-quality housing and poor living standards. Such conditions are not the norm in New Zealand, but do exist in some disadvantaged communities, and predispose these communities to a wide range of infectious diseases. The same factors would tend to accelerate the spread of dengue once an outbreak began.

This means an adaptation response is likely to comprise a range of strategies that have many benefits besides reducing dengue fever risk specifically. Such strategies would include focused measures to improve biosecurity, public health risk management capability, modelling capability supporting activities to pre-empt introduction or limit distribution, and health service provision. Initiatives to reduce socioeconomic inequalities would also have benefits in terms of climate change adaptation.

3.3 Floods, droughts and water supplies

Floods and droughts have important effects on health through social and economic impacts, although these secondary effects are difficult to quantify. Effects on human health may include repercussions arising from vulnerabilities in the agricultural sector (such as changing crop suitability, susceptibility to droughts and enhanced spread of some agricultural pests), vulnerabilities relating to water resources (such as impacts on water availability and quality, agricultural irrigation and power generation) and impacts in the coastal zone (such as loss of land, and damage to infrastructure resulting from coastal erosion and flooding). For example, the 1997/98 drought in eastern parts of New Zealand caused direct economic losses at the farm-gate of about $425 million, concentrated in rural areas (Pittock and Wratt, 2001). Unless communities are well prepared, losses of this magnitude cause hardship that affects mental and physical health in many ways.

Droughts add to the pressures on drinking water supplies, jeopardising both the quantity of flows and their quality. Heavy rainfall events may also be associated with outbreaks of water-borne infections. For example, research in the United States has shown an association between intense rainfall events and outbreaks of campylobacteriosis (Rose *et al.*, 2001). One explanation for this finding is that heavy run-off may cause animal wastes to be washed into reservoirs in sufficient quantities to overwhelm treatment processes. Similar studies have not been carried out in this country. However, the high density of farm animals in many parts of the country, the fact that many communities rely on ground water sources, and the variable level of monitoring and treatment of drinking water supplies mean that New Zealand may be equally susceptible.

Notifications of enteric infections show marked seasonal patterns in this country, and most of the pathogens involved are known to be highly temperature-sensitive. A study in the UK found that the monthly incidence of food poisoning was associated with temperature (especially in the previous month). Using published data on the relationship between reported and actual numbers of cases of food poisoning, it was estimated that annually there might be an additional 179,000 cases of food poisoning by the year 2050 as a result of climate change (Bentham and Langford, 1995).

The quality of monitoring and control of water supplies varies substantially across New Zealand. Parts of the country at greatest risk are likely to be relatively dry rural areas without reticulated supplies where household incomes are low. The East Cape is a good example of a high-risk region. Areas that rely increasingly on irrigation and ground water sources, such as parts of Canterbury, will also be more vulnerable to the health effects of more frequent floods and droughts.

3.4 Effects on regional stability

In terms of public health in general – and the planning and provision of health services in particular – it is important to look beyond our borders and consider the possible implications of climate change and sea-level rise on Pacific Island countries. These have been identified as being among the countries most vulnerable to climate change and associated sea-level rise. Many of the densely populated atoll islands, such as Tarawa in Kiribati and Funafuti in Tuvalu, have a maximum elevation of no more than 3 or 4 metres above mean sea level. Increased sea levels, especially if associated with an increased intensity of storms and tropical cyclones, would result in accelerated coastal erosion, inundation, and loss of land area in low-lying islands and coastal areas. Agricultural production, human health and in particular freshwater resources have also been identified as areas of concern in many Pacific Island countries (see Table 2).

A recent economic assessment of climate change impacts has provided a useful indicator of vulnerability (World Bank, 2000). It is estimated that for Viti Levu (Fiji), an example of a high volcanic island, impacts would amount to between US$23 million and US$52 million a year by 2050 (or 2 to 4% of Fiji's GDP for 1998). For the low-lying Tarawa atoll in Kiribati, losses were estimated at US$8 million to US$16 million a year by 2050 (or 17 to 34% of the 1998 GDP for Kiribati). The economic losses associated with climate change would probably put additional pressure on the funding and extension of health services in developing countries.

Table 2: Anticipated adverse sectoral effects of climate change in Pacific Island countries

Sector	Key Impacts
Coastal zone	• Accelerated coastal erosion rates • Inundation of low-lying areas and atoll islands • Coral bleaching and degradation • Possible loss of areas of mangrove ecosystems
Water resources	• Increased severity and frequency of flood events • Increased severity and frequency of droughts • Salinisation of atoll and other coastal groundwater resources
Agriculture	• Decreased crop yields due to droughts and increased severity of extreme events • Salinisation of soils
Human health	• Direct effects of extreme events such as cyclones • Increased heat stress and discomfort • Increased risk of vector-borne disease (such as malaria and dengue fever) and diarrhoeal diseases • Indirect effects on health and nutrition arising from socioeconomic impacts of extreme events such as droughts and cyclones

It is anticipated that the impacts of climate change and sea-level rises, both direct and cumulative, would in many cases exceed the adaptive ability of natural systems and communities in Pacific Island countries. Population displacement from the Pacific may lead to a relatively rapid influx of new settlers. New Zealand has a long history of involvement in the Pacific Island region and consequently has developed significant political and, in some cases, constitutional links and responsibilities. Considering this, our aid commitments, and the extensive cultural, community and familial ties with the region, it is likely that New Zealand would be expected to play a direct role in providing for environmental refugees from Pacific Island countries or increasing its assistance to those countries.

4 Responses

Mitigation – reducing emissions – is the primary response to climate change, but is not dealt with in this report. However, it should be noted that there could be appreciable health benefits in the short term from many mitigation strategies. Transport policies to cut emissions may lead, for example, to lower levels of particulate and gaseous air pollution and increased physical activity.

Climate change differs from the environmental health problems we are accustomed to dealing with because of its gradual onset, widespread rather than localised effects, and the fact that the most important effects will probably be indirect. These factors inevitably affect perceptions of the problem. In particular, there is a danger that the problem will not be recognised until it is too late to respond effectively, or a substantial cost has already been incurred.

The long causal chain between climate variation and human health outcomes underlines the critical role of adaptation. Climate change may bring conditions that are more favourable for disease, but we may not actually see an increase in diseases as long as there is capacity to adapt to the changing circumstances. Does this mean that climate change is a non-issue in the health sector? A shift in average temperatures of several degrees over a hundred years might appear a trivial challenge compared with the variations that humans already cope with in different settings. Humans are unique in their ability to adapt to new environments, as shown by the spread of settlements across the globe (and even, for a short time at least, into space).

But we should not be dazzled by human ingenuity: the challenge of climate change is a fundamental one. The natural systems that sustain human health are subject to thresholds and complexities that we understand very poorly. The limits to adaptation may be closer than we think. Altering the world's climate could lead to surprising outcomes, with major effects of new and unexpected kinds. Examples are abrupt and severe 'flips' in climate as a result of reversals of ocean currents.

Where we are reasonably confident we can foresee the general shape of the consequences of climate change at least in the relatively short term of the next 50 years, and that appropriate adaptation can occur, this does not mean it will. Many individuals and communities are likely to lack the resources required. Air conditioning is one way of coping with extremely hot conditions, but even in New Zealand there are many who cannot afford to heatproof their houses. And even if adaptation is affordable in the short term for some, it may not be sustainable as a global strategy. The environmental costs of air conditioning the whole population of continental Asia, for example, would be overwhelming.

It would be shortsighted to imagine that adaptation provides a complete answer to the problem of climate change. Nevertheless, adaptation must be part of the response: we are stuck with climate change to some extent, and mitigation cannot undo the effects of past carbon emissions. Moreover, there are many adaptation measures that are 'no regrets' or 'few regrets' strategies, as they bring other benefits that more than cover costs, whatever climate changes unfold.

In this context, it would be sensible to gain a better understanding of the effects of current climate variability on health in this country, and also the factors that may limit adaptation. Climate change pressures provide further reason for developing and sustaining effective border control and other biosecurity measures, which are already seen to be on high priority to protect the country's future well being even in the absence of climate change as a confounding factor.

5 Research Needs

Several research streams are currently going on to provide a better understanding of future global climate change and its influence on New Zealand's regional climate, and its effects on environmental conditions which have direct or indirect impacts on human health. This research is mainly funded by government agencies (such as the Foundation for Research, Science and Technology and the Health Research Council) and universities.

However, additional research is needed to fill the gaps in our current knowledge of the effects climate change will have on human health, and to develop the technical and scientific capacity to support appropriate adaptive responses. Research areas and examples of possible studies are outlined below, in approximate order of priority, to inform the National Science Strategy Committee for Climate Change in its development and review of a comprehensive national climate research strategy and its advice to government on the overall balance of climate change research priorities.

5.1 Vector-borne disease modelling

We already have the capacity to model broad-scale changes in the potential distribution of two dengue fever vectors and changes in dengue fever risk. This modelling capacity needs to be developed for other vectors of dengue fever, and especially other disease vectors that may pose an increased risk to New Zealand under conditions of climate change (such as for the mosquito *Aedes japonicus*, the vector of Japanese encephalitis). Improving vector-borne disease modelling capacity is necessary to support biosecurity, surveillance and control measures and the development of early warning systems for vector introduction and disease risk.

Specifically, modelling the potential further spread of *A. camptorhynchus* and Ross River virus disease should be considered. The recent introduction and likely establishment of *A. camptorhynchus* in New Zealand provides material for a valuable case study in vector introduction risk. A systems approach is needed for this case study in order to analyse the range of factors – from the biophysical through to the organisational and policy-related – that contribute to risks posed by exotic vectors. Outcomes from such a study would enhance the scientific basis informing future biosecurity and public health planning and response measures.

The modelling capability of disease vector establishment risks could produce important spin-off benefits for general biosecurity and border-control issues, as hotspots for other potential invaders besides mosquitoes could be predicted and attention focused in response to climatic conditions.

5.2 Collaborative research in the Pacific

We should strengthen and promote collaborative research in Pacific Island countries to identify ways of reducing vulnerability and increasing adaptive capacity in these countries. Such research needs to focus on improving disease-monitoring systems and health risk assessment capacity, strengthening local institutions responsible for dealing with climate hazards, developing environmental safeguards, and promoting sustainable livelihoods. It should also involve the transfer of relevant methods and technology to the Pacific, and would need to be supported by training activities to enhance technical and institutional capacity (as appropriate).

5.3 Effects on water availability and quality

There needs to be further research done on the effects of climate variability and change on water supplies and consequent human health effects. Areas of importance include:

- analysis of the relationship between heavy rainfall and biological contamination of water supplies
- the influence of climate variability and extremes on notified illnesses
- in parts of the country susceptible to water stress, the quantification of the burden of water-related illnesses (including non-notifiable conditions such as gastroenteritis and skin infections).

Climatic effects on water supplies are likely to be greatest where reticulated supply systems are poorly developed (or absent altogether), and communities do not have the resources to import water or pay for private treatment facilities. An example of a suitable case study area for this research is the East Cape. Research outcomes are likely to have immediate public health and water supply planning and policy implications as well as benefits in terms of climate-change adaptation.

5.4 Impacts on vulnerable groups

Socioeconomic deprivation and ethnicity may be important direct or indirect determinants of vulnerability. In order to identify vulnerable groups or sectors of the population, further research is needed into the role of socioeconomic and cultural factors in determining climate-related health risk. This information would be valuable for developing appropriate and targeted public health intervention strategies.

The vulnerability of population groups may change over time, and vulnerability assessments are therefore by their nature snapshots of current conditions. However, it is unlikely that the effects of factors such as poor housing, low incomes and physical isolation will differ greatly in the future, although the specific population groups that exhibit these disadvantages may change.

The effects of climate change are likely to be most severe in developing countries and the neighbouring Pacific region, leading to increased immigration pressures. Thus an important focus for this research would be the development of primary health care systems for migrant groups. There would be immediate benefits from research of this kind, as well as reduced vulnerability to climate change impacts.

5.5 Culturally appropriate adaptation

Adaptation measures such as water resource protection, development and management are likely to raise cultural issues of importance to Maori. It is important that these issues be researched and documented so that responses to the potential impacts of climate change on public health are culturally appropriate.

5.6 Public health impacts of mitigation measures

Many of the measures aimed at reducing emissions of greenhouse gases will also have secondary health benefits. For example, transport strategies that reduce dependence on private motor vehicles could reduce road traffic accidents and particulate air pollution, as well as emissions of CO_2. Understanding and quantifying these potential co-benefits will require a research effort that is co-ordinated across health, environment and transport sectors.

5.7 Direct impacts of climate change and ozone depletion

Some of the direct impacts of climate change and ozone depletion could be modelled on a national scale. Examples include the potential effects of temperature extremes on mortality, and the effect of ozone depletion on skin cancer risks.

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