Climate Change and Environmental Health

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EXECUTIVE SUMMARY

Anthropogenic climate change has been described as the greatest threat to global health in the 21st century. Our planet is expected to continue to warm over the next 100 years and this will result in changes to our weather in New Zealand. This review summarises a number of health risks projected from a changing climate that could impact on future generations.

The result of projected changes in climate are most likely to worsen environmental health risks that already exist including: exposure to air irritants and pollutants, extreme weather events, exposure (or lack of) ultra-violet solar radiation, potential establishment of vector-borne diseases and illnesses related from exposure to toxins, water-borne and infectious diseases. Future rises in sea level will amplify some of these issues. New risks are more likely to occur under high heat-trapping or greenhouse gas emission scenarios. There are also a number of indirect impacts on health such as increased water and food insecurity and population migration.

The effect on our health will depend on a number of factors: the level of severity will relate to heat-trapping gas emissions in the future; how both heat-trapping gas emissions and current environmental risks are managed (mitigated); and how prepared the Government, public and the health sector are in terms of management of projected impacts (adaptation). A range of adaptation mechanisms (eg, early warning systems) exist to cope with these effects which are discussed in this review. Many are already employed in New Zealand, such as surveillance, public education and civil defence alerts. These will remain important tools to reduce environmental health risks.

Some knowledge gaps were also found that relate to the impacts from short-term, prolonged and new environmental health risks. Understanding those gaps and the direction of future studies will be critical to informing adaptation planning and policy and to reduce future climate related risks to health. Many adaptive responses, encompass co-health benefits, benefits that go beyond those that the adaptive measures will bring. These “win-win” opportunities will benefit all New Zealanders immediately, regardless of the future.

1. INTRODUCTION

This document provides an overview of the projected effects of climate change on environmental health, and how it may impact on the health of New Zealanders.

In the context of this report, climate change refers to changes in the mean climate and/or variability of the climate that persist over long periods (IPCC 2014). Anthropogenic climate change refers to the the warming of earth in response to human activities, which have increased the concentrations of heat-trapping gases or greenhouse gases such as carbon dioxide (CO_2) in the atmosphere (PCE 2014). The changes in heat-trapping gas concentrations go beyond natural climate fluctuations that are expected. They are brought about by land use changes and gases being released through human activities such as burning fossil fuels. The large-scale long-term (50-100 year) effects of climate change include rising sea levels and changing weather patterns, but the impact of climate change is likely to vary both regionally and globally.

The air, soil, water and land are interconnecting components of the environment and climate system. All these components are connected to humans and human health. “Environmental health” refers to this relationship between the state of the environment and human health, where environmental changes may lead to beneficial or harmful outcomes for people. Changes in the environment that lead to harmful health outcomes for people are called “environmental health risks or human health risks” in this review. The changes examined are those arising as a result of climate change.

Climate change is often thought of in terms of its effects on the physical environment: heat-waves, storms and floods. Some of these events will impact on human morbidity or mortality. There is now evidence to show that the interaction between the environment and our health, ie, environmental health, will be impacted by changes to climate and likely to become a major challenge in years to come unless we are prepared.

A review of the relevant local and international literature was conducted to identify environmental health risks for New Zealand linked to climate change, and to anticipate future risks over the next 50-100 years. This is the timescale in which modelled climate projections are the most reliable. Section 1 provides background and context, including local and global information on changing climate. Each section from 2-8 discusses a component of environmental health (e.g air quality impacts on health) and how climate may modify this relationship. At the end of each of these sections some of the available options for responding to these environmental health risks are explored. These “adaptation options” are summarised at the end of each relevant section. Section 9 includes a section on mitigation and adaptation for the health sector, recognising that both are required to reduce health impacts whilst also reducing heat-trapping gas emissions. The main points of the entire review are included in the conclusion at the end of section 9 with gaps identified in the literature of particular importance to New Zealand.

1.1 LITERATURE REVIEW SCOPE AND METHOD

The information in this document has been gathered from a review of relevant literature related to climate change and environmental health.

The environmental health-related factors examined were:

- air pollution
- ultraviolet radiation
- extreme weather events
- infectious disease and
- vector-borne disease

Other environmental health risks that are related to climate change but not covered above are also examined in Section 8. They include environmental health risks associated with:

- water treatment and management
- water security
- social change and migration to New Zealand
- antimicrobial resistant bacteria and
- emerging and re-emerging infectious disease

The following areas were excluded from the scope of this review due to either time constraints, areas outside the environmental health realm, or the Ministry of Health is not the primary lead for the issue:

- calculation of the economic savings in environmental health from adequate adaptation to climate change

- communicable diseases (person to person)
- zoonotic diseases (animal to person)
- health effects specifically related to cancer, cardiovascular disease, stroke and nutrition
- human developmental effects
- mental health and stress-related disorders, neurological diseases and disorders
- social and economic disruptions
- health effects related to food security and safety
- governance, legislation, policy or regulation and
- effects on the workforce/occupation.

The main source of information was from peer reviewed publications specific to New Zealand. Publications from other countries particularly Australia, the United Kingdom, Europe, North America and Pacific Island nations where possible, have been included for comparison, and where no New Zealand specific information was available.

The following databases were searched for relevant literature: Web of Science, Google Scholar, Science Direct and PubMed. The search was restricted to the period 2010-2017 inclusive, but the general search terms “climate change”, “New Zealand” and either “environmental health” or “health” were used.

Subsequent literature searches were conducted when needed. These searches extended the publication period to 1985-2017, and included more specific search terms eg, “climate”, “climate change”, “health”, “health effects”, “dengue”, “malaria”, “heat”, “heat waves”, “time-series”, “floods”, “extreme weather”, and “harmful algae”.

Information from relevant publications by regulatory authorities or other reliable sources were also incorporated. This information was located using more general internet searches using the same search terms in Google and Google scholar. Retrieved documents included global and New Zealand-specific key reports on climate change scenarios, particularly those that have focussed on health impacts.

1.2 GLOBAL CLIMATE CHANGE

On a global level, there is sufficient scientific evidence to show that the earth is warming and that this warming has been caused mostly by humans (Ministry for the Environment 2016a,b; The Royal Society of New Zealand 2016; Zalasiewicz et al 2011). This warming is due to the increased amount of heat-trapping gases such as carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and other compounds such as chlorofluorocarbons (CFCs), that have been released into the earth's atmosphere by human activities. These are called heat-trapping gases because they absorb radiative energy from the sun and trap it within the earth's atmosphere, decreasing the amount of energy released back into space. This increase in earth's temperature is what is known as global warming.

Global warming, and the resulting changes to our climate system, is accelerated by "feedback loops" (PCE, 2014). As the earth warms, more water is evaporated and this rises into the atmosphere where it also contributes to the warming effect, increasing the amount of heat trapped around the globe. Ice cover also shrinks, which reduces the amount of radiation reflected back into space.

Between the beginning of the Industrial Revolution (1750 and 2009), carbon dioxide levels have increased by almost 38% and methane levels have increased 148% (Riebeek 2010). Figure 1 is an update of Fig. 9a in Hansen et al (2010). It shows that the average global surface temperature has increased by approximately 0.6-0.9°C between 1906 and 2005. This may seem like a small increase, but the rate of increase has nearly doubled in the last 50 years.

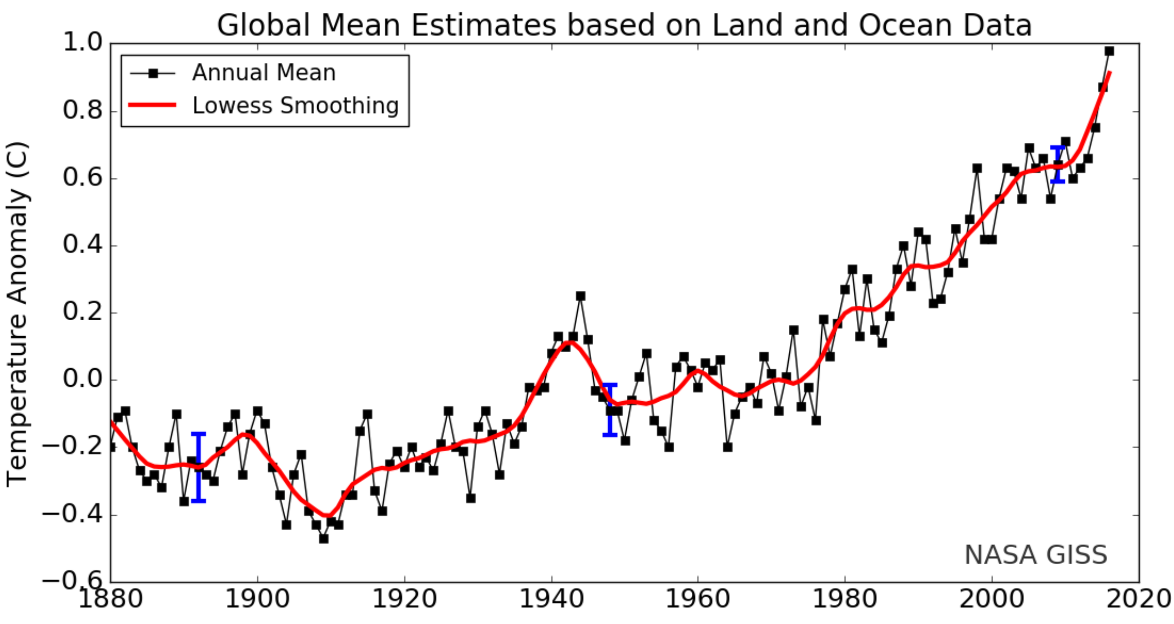

Figure 1: Land-ocean temperature index, 1880 to present, with base period 1951-1980. The solid black line is the global annual mean and the solid red line is the five-year lowess smooth. The blue uncertainty bars (95% confidence limit) appear when spatial sampling was incomplete.

Source: https://data.giss.nasa.gov/gistemp/graphs/ (accessed 2 June 2017).

The United Nation's Intergovernmental Panel on Climate Change (IPCC) fifth assessment report (AR5) is the fifth of a series of reports that assess the most recent scientific, technical and socio-economic information on climate change at a point in time (IPCC, 2014). The IPCC defines climate change as "*a statistically significant variation in the mean state of the climate or its variability, persisting for an extended period (typically decades or longer*)."

The AR5 findings are based on an international climate modelling effort known as the Coupled Model Intercomparison Project Phase 5 (CMIP5) and Earth System Model simulations. This CMIP5 model simulates changes in the earth's climate by modifying carbon dioxide (CO_2) concentrations in the atmosphere. The global mean estimate of CO_2 concentration in May 2017 was 407.05 parts per million (ppm) compared with the annual average of 285.2 ppm in 1850 (NOAA 2016), an increase of almost 58%.

1.3 CLIMATE CHANGE IN NEW ZEALAND

Increased atmospheric warming is predicted as the 21st century progresses and is "virtually certain" along with other changes in climate as identified in the IPCC [Australasia] report (Reisinger et al 2014). Projected overall changes for New Zealand have been calculated using a regional climate model developed by the National Institute of Water and Atmospheric Research (NIWA) and the New Zealand Ministry for the Environment (Ministry for the Environment 2016a). The model estimated the following atmospheric mean air temperature increases for New Zealand, relative to the 1986-2005 period:

- 0.8°C (0.2 to 1.7°C) by 2040
- 1.4°C (0.1 to 4.6°C) by 2090 and
- 1.6°C (0.3 to 5.0°C) by 2110.

The temperature ranges associated with these projections are wide due to the different possible concentrations of heat-trapping gases in the atmosphere. In New Zealand, annual average air temperatures have already risen 0.92°C over the period 1909 to 2015, and coastal sea levels (based on available tide gauge data across the country) show an average increase of 1.7 mm per year between 1900 and 2013 (Hannah 2004; Wong et al 2014). This is comparable to the global average increase in sea-level of 1.9±1.7-2.1 mm (1901 to 2010) (IPCC 2014). Temperature and sea level are expected to continue to rise due to global warming.

The Ministry for the Environment climate projections for New Zealand show increased rainfall during winter and spring in the west of both the North and South Islands and in the east of both islands in the summer. Extreme rainfall is likely to increase in most areas. Areas such as the West Coast are projected to have the largest increase as mean rainfall is also expected to increase. Rainfall is also likely to be affected by shifts in the prevailing winds and phenomena such as the El Niño – Southern Oscillation (ENSO), a natural climate and sea temperature pattern that is capable of affecting weather across the Pacific and wider regions. Other variations to the climate include decreased relative humidity (RH) across almost the entire country during all seasons as a consequence of higher temperatures. The rate of decrease in RH over New Zealand is around 1 to 2 per cent per degree increase in mean temperature. The only notable exception to this pattern is an increase in RH in a narrow strip down the West Coast in winter, a reflection of increased rainfall and reduced solar radiation. The absolute water content, as measured by specific humidity, increases everywhere with time, but the temperature effect is larger (Ministry for the Environment 2016a).

Sea surface temperatures have increased by on average about 0.07°C per decade over 1909–2009 for New Zealand with the greatest increase observed in the Tasman Sea region (Reisinger et al., 2014). The projected magnitude of change is expected to follow mean air temperature for coastal waters. Currently, sea surface temperature trends could not be determined for New Zealand's oceanic, subtropical, and sub-Antarctic waters and the Tasman Sea for 1993 to 2016 (at the 95% confidence level) (Ministry for the Environment and Statistics New Zealand, 2017). While there are trends in sea surface temperature in the region, the changes are insufficient to create gradients across the currents and therefore transport is not increased (despite increasing warming) (Bowen et al 2017).

There is currently no physical evidence that, in the last 20-30 years, the currents around New Zealand are strengthening or significantly changing with the exception of external factors such as El Niňo and Rossby (planetary) waves that are natural phenomenon that influence the climate. There is some evidence that the East Australian Current extension (south of 34°S) and the Tasman Front vary at the expense of each other: when the East Australian Current extension is strong the Tasman Front is weak, conversely when the East Australian Current extension is weak the flows of the Tasman Front are stronger (Hill et al 2011).

Relatively small changes in average climate may also have large effects on the likelihood or frequency of extreme events. Even though it is not possible to predict the occurrence of individual extreme weather events, climate models suggest intermittent extreme weather events are likely to increase as *variability* in the climate system also changes. For instance, as average temperatures rise, there will be more hot days and fewer colder days observed (The Royal Society of New Zealand 2016). A poleward (southerly) shift of mid-latitude cyclones and a possible small reduction in frequency of cycles is also expected in the future. The most severe ex-tropical cyclones are also likely to be stronger, although their frequency is expected to decrease slightly or remain unchanged (Climate Change Adaptation Technical Working Group 2017). However, more analysis in this area is required.

Projections of climate change are complex, and specific local and regional changes to New Zealand's climate over the coming century are not certain. However, it is important to consider a range of what might happen. A more detailed summary of New Zealand's observed and projected changes is included as an appendix (Table A1, modified from Ministry for the Environment (2016a,b) and Reisinger et al (2014).

1.3.1 Low and High Carbon Scenarios for New Zealand

The IPCC developed a number of carbon scenarios to describe possible futures in which, in the simplest sense, comparisons can be made between different global scenarios to demonstrate the likely effects. This includes low carbon scenarios resulting from rapidly reducing heat-trapping gases (namely CO_2) versus high carbon scenarios or an approach in which CO_2 increases to proportions that have the potential for catastrophic climate change.

The Royal Society of New Zealand (2016) recently summarised the expected changes faced by New Zealand as the result of a low or a high carbon path. In a low carbon world [RCP2.6][1] mitigation scenarios that reduce heat-trapping gases emissions are used to limit the increase of global mean temperature to 2°C. From this scenario there will still be significant changes to our climate. They include changes to the frequency of extreme events, including heat waves, floods and droughts, and associated climate- related human health risks. This is because the heat-trapping gases already in the atmosphere would continue to drive global warming and climate change for many decades. However, many of the worst effects from projected changes in climate can be avoided following this low carbon path.

A high carbon path [RCP8.5] describes a world with high heat-trapping gas emissions and no policy changes to reduce them. In this scenario by 2100, atmospheric concentrations of CO_2 are projected to be three to four times higher than pre-industrial levels. This would result in further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems (IPCC 2014). For New Zealand, a high carbon world [RCP8.5] is projected to result in a mean temperature increase of +1.0°C by 2040 and between +0.7 to 3°C by 2090 (Ministry for the Environment 2016a).

1.3.2 Climate Change and Environmental Health in New Zealand

The New Zealand health strategy recognises that "*Climate change has health and social consequences*" (Ministry of Health 2016a). The Royal Society of New Zealand have produced a factsheet on the public health effects from climate change (The Royal Society of New Zealand 2017). The precise extent of the consequences from a changing climate however, are difficult to quantify because there are many different factors to consider. The complex processes and pathways through which climate change influences human health have been summarised by McMichael (2013) (Figure 2).

[1] RCP refers to Representative Concentration Pathways, see glossary and van Vuuren DP, Edmonds J, Kainuma M et al. 2011. The representative concentration pathways: an overview. *Climatic Change* 109 (1): 5

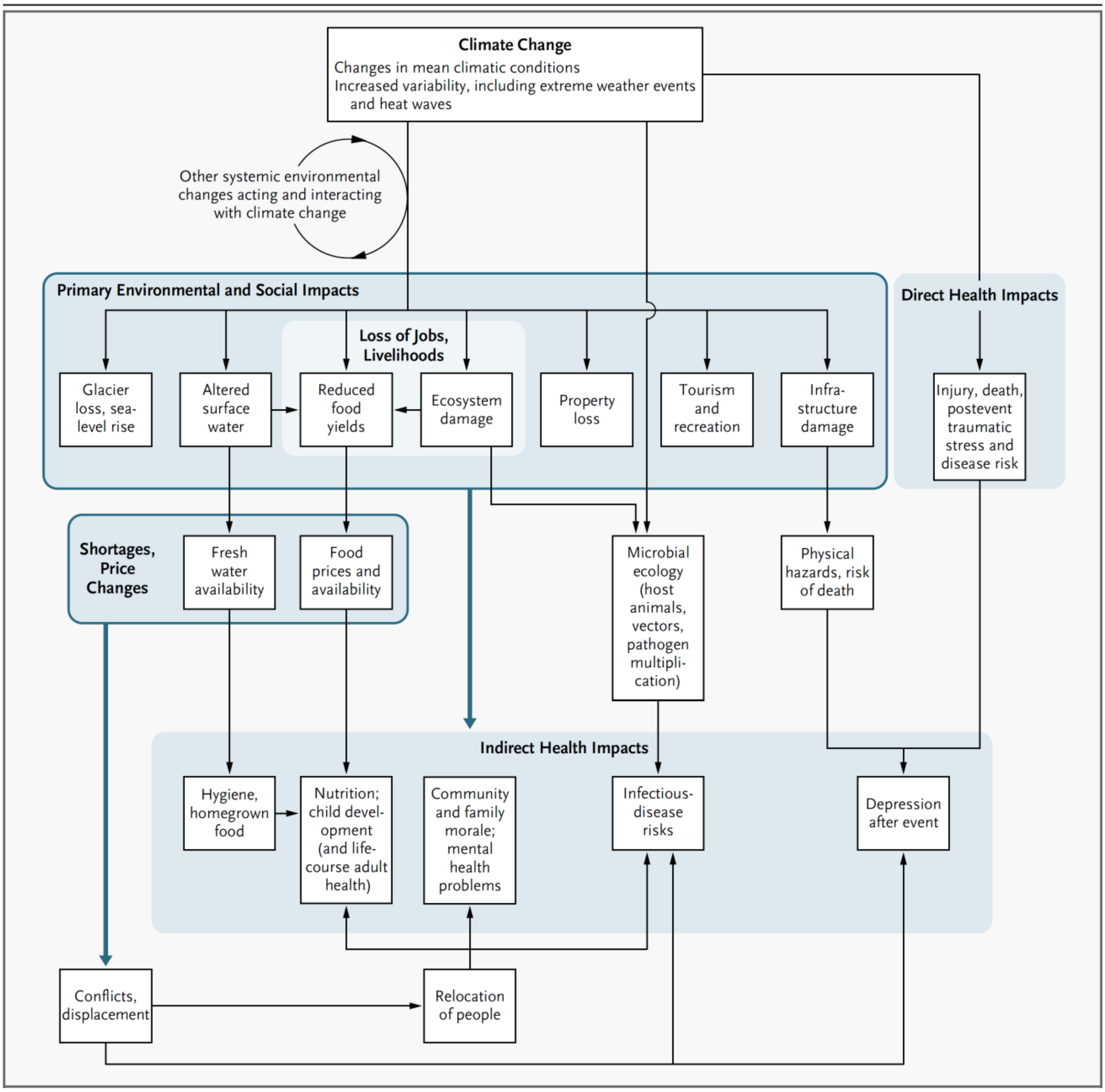

Figure 2: Process and pathways through which climate change influences human health.

Source: McMichael (2013)

Figure 2 illustrates the connection between climate change and direct and indirect health impacts. For example, climate change may affect ecosystems, damaging or altering them so that future food yields decrease, which in turn increases food prices and leads to nutritional problems. At the same time food shortage and prices may also lead to conflict and displacement, causing people to relocate, increasing health risks such as those from infectious diseases. How societies will develop economically, technologically, and demographically are important factors that will determine health in the future (McMichael et al 2006).

2. AIR QUALITY

2.1 INTRODUCTION

This section reviews how climate change may negatively affect air quality by increasing the type and concentration of airborne allergens and irritants. Both outdoor and indoor air quality are considered.

Atmospheric changes have the potential to greatly alter general weather patterns and other meteorological elements such as humidity, temperature and precipitation. Those changes could alter the seasonal production of airborne allergens (eg, pollens), plus affect transportation of those allergens and other airborne irritants such as particulate matter (PM) and smog. Increased concentrations of allergens and irritants will negatively affect people both outdoor and indoor. Climate change may also alter the concentration of airborne irritants associated with indoor environments, particularly mould spores. Changes will be localised and perhaps difficult to predict, since air quality is affected by a wide variety of factors including local geography, the nature and extent of the built or rural environment (and changes to these over time), regional air quality rules or guidelines, and proximity to sources of airborne allergens/irritants (eg, fields/crops, roads, chimneys).

2.2 OUTDOOR AIR QUALITY AND HUMAN HEALTH

The environmental health risks from airborne irritants and allergens are wide and range from minor upper respiratory irritation to acute respiratory infections, asthmatic attacks, chronic respiratory and heart disease (including aggravation of pre-existing heart and lung disease) and lung cancer (Kampa and Castanas 2008). When exposure to airborne irritants and allergens increases, an increase in the prevalence of respiratory diseases is likely. This section is separated into two sub-sections: aeroallergens are discussed in 2.2.1 to 2.2.3 and airborne irritants from 2.2.4 to 2.2.6.

2.2.1 Environmental health impact of aeroallergens

Airborne allergens, hereafter called aeroallergens, are small airborne materials such as pollen, mould, spores, particles or dust that can trigger an allergic reaction (Portier et al 2010; Damialis et al 2015). In New Zealand, the most common environmental aeroallergens are pollen, mould, animal hair, dust and dust mites (Ministry of Health 2015a). This section focusses on pollen, dust and fungal spores because these are important causes of allergic responses among people exposed to outdoor air, but information on other aeroallergens where possible, is also included.[2]

[2] Mould (fungi), and the spores released from these microorganisms, are considered to be a greater problem for indoor air quality, and so are discussed more fully in section 3.3. For particulates released from wildfires, see section 5: extreme weather events.

In New Zealand, the most common allergic conditions in response to all aeroallergens are allergic rhinitis, asthma and skin problems (eg, eczema, rashes, and hives) (Ministry of Health, 2015a). It has been estimated that, at any particular time, one in seven children aged between two and 14 years (ie, 15% of children) and one in nine adults (ie, 11%) are currently taking asthma medication (Ministry of Health 2016b). The prevalence of children and adults suffering from symptoms of allergic rhinitis (hay fever) in New Zealand, is also one of the highest in the world (Asher et al 2001; Pearce et al 2000). Of the people that have been tested for allergy sensitivity using serum or skin tests (in the population of Europe, the USA and Australia–New Zealand), 40-50% showed sensitisation to aeroallergens (Bousquet et al 2008). The prevalence of eczema among the New Zealand population has also been estimated to be up to 20% (DaVeiga 2012).

Pollens are one of several causative agents of respiratory disorders such as asthma, allergic rhinitis, and other reactions such as allergic conjunctivitis and eczema. Pollen is amongst one of the most common allergens in atopic patients, ie, people that are more likely to develop certain allergic reactions (Singh and Mathur 2012). The severity of these allergic reactions can also vary in response to the type(s) of pollen inhaled and their concentrations (D'Amato et al 2015; Rossi et al 1993).

Exposure to natural sources of dust (eg, soil) can also initiate increased respiratory disorders including asthma, tracheitis (inflammation of the trachea), allergic rhinitis and pneumonia (Goudie 2014; Morman and Plumlee 2014). The lung disease silicosis can result from prolonged exposure to dusts containing silica, although this usually occurs as a result of occupational exposure. Dust exposure could also lead to cardiovascular disorders such as stroke (Mormon and Plumlee 2014).

Mould spores are considerably smaller than pollen, and range in size from 2 to 10 µm. *Alternaria* and *Cladosporium* are types of fungi that are universally dominant outdoors whereas *Penicillium* and *Aspergillus* are more commonly detected indoors (Aggarwal and Chakrabarti 2013). Multiple studies have suggested that exposures to *Alternaria* and *Cladosporium* may contribute to the development of respiratory symptoms including asthma (Ozdemir 2015). In an overseas study, seasonal changes in *Cladosporium* and *Aspergillus-Penicillium* have been associated with acute asthma admissions suggesting an association between the two (Hasnain et al 2004).

2.2.2 Climate change impacts on aeroallergens

Climate change in New Zealand may affect the prevalence, concentration or distribution of outdoor aeroallergens by:

- Increasing ambient temperature and prolonging warmer seasons
- Increasing carbon dioxide (CO_2) concentrations in the atmosphere
- Changing weather conditions (rainfall, humidity, wind speed and wind direction).

Changing rainfall, humidity, wind speed and wind direction all affect the concentration and distribution of pollen, dust and fungal spores. Increased rainfall helps decrease airborne concentrations, whereas drier, windier days blow aeroallergens around. Warm and moist conditions generally favour the production and release of airborne allergens such as fungal spores and plant pollen (Stitt 1991). Warmer conditions and earlier springs, less frost and fewer extreme cold days are expected (Ministry for the Environment 2016a). The average wind strength is also expected to increase by up to 10% in the southern half of North Island, and throughout the South Island. Changes in wind patterns may increase long distance transport of aeroallergens as observed in other countries (D'Amato et al 2007). Work in the USA has shown that drought conditions are likely to create more dust, particulates, and when present, wildfire smoke (Takaro et al 2013). Higher CO_2 levels have been shown to stimulate plant growth and lead to production of more pollen allergens (Albertine et al 2014; Rogers et al 2006; Wan et al 2002; Ziska et al 2005).

Schauber et al (2002) showed that warmer than average summers appeared to cue mast flowering and seeding 1 to 2 years later in a number of New Zealand plant species. This has also been reported in the USA for different plant species (Rees et al 2002). A New Zealand study published in 2016 noted some important broad patterns and trends in pollen from different data sources with what appears to be variation between pollen type and latitude (Medek et al 2016). They suggest that pollen peaks occur later in the season at more northerly locations. Differences in study design make these data sources difficult to compare, however, it was proposed that the peaks were a result of increased production from grasses adapted to warmer conditions. In contrast, southern regions were more likely to have shorter, intensified seasons. The authors advised caution with their findings and suggested that more specific studies were needed to confirm those trends. In a 12-month prospective study on a population of mild to moderate asthmatic subjects in Blenheim, during 1992-1993, there was no relationship found between changes in weather, airborne fungal spores and pollen counts to asthma. This appears contrary to many northern hemisphere studies (Epton et al 1997). However, it was noted that pollen counts and temperatures were lower than usual during the study period.

Evidence from other countries link climate change with increased aeroallergen production. Laboratory and field studies in Europe, North America, Australia and Asia have shown that allergic pollen from tree, grass, and weeds increased with higher carbon dioxide (CO_2) concentrations, earlier spring onset, and increased ambient temperatures (D'Amato et al 2007; Ziska et al 2011, 2012). Multiple studies also suggest that increased temperatures and CO_2 concentrations are already affecting growing seasons, geography and pollen productivity (Barnes et al 2013; Cuneo and Leishman 2006).

No New Zealand-specific studies were located investigating how climate change will affect dust emission and its transport. Warmer and longer summers are likely to produce more drought conditions and if coupled with high winds, airborne dust would increase. Dust can also be blown from one region in New Zealand to another and from as far as Australia (Marx et al 2005). It has been suggested that Australian dust transported to New Zealand may lead to increased respiratory problems (Cowie et al 2010).

2.2.3 Climate-related environmental health impacts from aeroallergens

Few New Zealand based studies were found on climate change and aeroallergens. Haberle et al (2014) reported that the diversity and quality of airborne pollen in New Zealand is substantially modified by climate change and land-use and that more studies were needed. Internationally, D'Amato et al (2015) found that climate change was projected to increase the global incidence and prevalence of allergic respiratory conditions of asthma by affecting the start, duration and intensity of the pollen season. In Canada, researchers found a significant positive association between the number of medical consultations for allergic rhinitis and pollen levels (Breton et al 2006). They also found that the increase in the length of the pollen season correlated with the rate of consultations between 1994 and 2002. A review of international studies on climate and mould, showed that changes in climate appeared to trigger more fungal spore production and alter their distribution timing and patterns (Aggarwal and Chakrabarti 2013). These changes varied across regions, and the authors noted that there was limited availability of extensive aerobiological and epidemiological datasets over long periods. This lack of data presents difficulties in confirming such associations. Other studies from the UK examined long term measurements of the spores of *Alternaria,* a common allergen to humans. Increases in *Alternaria* concentrations were associated with increases in local temperature as well as earlier production (Corden and Millington 2001; Gabriel et al 2016). Similar conclusions were made when *Alternaria alternata* were grown under experimental conditions (Wolf et al 2010). The experiments showed that under high CO_2 concentrations, almost three times more spores and more than twice the total antigenic protein (a substance foreign to the body that causes an immune response) were produced.

2.2.4 Outdoor air pollutants in New Zealand

Outdoor air can carry multiple pollutants from both natural and human sources. This sub-section examines four air pollutants released from human activities: particulate matter, ozone, nitrogen dioxide and smog.

Particulate matter is a generic term for particles and liquid droplets. Secondary particles are formed when primary pollutants interact with each other in the atmosphere. Particulate matter also ranges in size. The size fractions often measured are PM_{10} (particulate matter that are smaller than 10 µm in diameter), $PM_{2.5}$ (smaller than 2.5 µm, also called fine particulate matter) and ultrafine particles (smaller than 0.1 µm/100 nm). Fine particulate matter ($PM_{2.5}$) is present in vehicle exhausts, smoke from forest fires and home heating (wood and coal), windblown dust, and other chemical products released from power plants and industry.

Ground level ozone (O_3), also called tropospheric ozone[3], is a pollutant gas with direct effects on the human respiratory system. It is also a chemical involved in smog formation. Ground level ozone is not directly emitted into the outdoor air, but is formed through chemical reactions that involve nitrogen oxides (NO, NO_2, N_2O, NO_5 also referred to as NOx), carbon monoxide (CO), methane (CH_4), and volatile organic compounds (VOCs) in the presence of sunlight and elevated temperatures (Myhre et al 2013).These gases and VOCs are released by human activities such as vehicle emissions (NOx, CH_4 and VOCs) and incomplete combustion of fossil fuels (CO) (eg, petrol in cars, and wood and coal burnt in home heating). Ground level ozone is more likely to form on sunny days in areas of dense urban development with high volumes of traffic.

Nitrogen dioxide (NO_2) is formed when nitrogen oxide (NO) and other nitrogen oxides (NOx) react with other chemicals in the air (Ministry for the Environment, 2016c). In New Zealand, the main human-made source of nitrogen dioxide is from motor vehicle emissions (Ministry for the Environment and Statistics NZ, 2015a). Like ozone, nitrogen dioxide contributes to the formation of smog (eg, Figure 3).

Figure 3: Comparison of visibility degradation caused by winter smog (left) with clear spring air (right) in Christchurch.

Source: http://www.Ministry for the Environment.govt.nz/air/specific-air-pollutants/particles (accessed 13/7/2016)

Most air pollutants of concern in New Zealand are regularly monitored by regional councils, including PM_{10}, NO_2 and O_3. Poor air quality is generally associated with certain towns and cities during the winter (eg, Christchurch, Timaru), when temperature inversions trap air pollutants during cold nights. For some of those nights, the air quality exceeds the World Health Organisation short term standard (PCE, 2015a). However, it is now understood that long-term exposure to poor air quality has a higher health impact than short term exposure (House of Commons 2010; Kelly and Fussell 2015).

[3] The troposphere is the lowest layer of earth's atmosphere. Ozone forming in the troposphere is different to the ozone layer in the stratosphere, which absorbs most of the sun's ultraviolet radiation.

2.2.5 Environmental health impacts from outdoor air pollutants

More detailed descriptions of the environmental health impacts from air pollutants on different human organs and systems can be found in Kampa and Castanas (2008). Briefly, health effects from short or long-term exposure to air pollution range from nausea, difficulty in breathing and skin irritation, to cancer, heart disease, bronchitis and premature death (Fisher et al 2007; Kampa and Castanas 2008; Reilly et al 2003). Exposure to air pollution has also be associated with birth defects, serious developmental delays in children, brain disease and reduced activity of the immune system that leads to a number of diseases (Ghorani-Azam 2016; Kelly and Fussell 2015; WHO 2005).

Particulate matter is considered to be the most concerning of air pollutants because of its many negative human health effects. Exposure has been related to the development of acute and chronic cardiovascular diseases (eg, heart attacks, ischemic stroke, vascular dysfunction, cancer) (Davidson et al 2005; Du et al 2016; Kim et al 2015). Research is currently focussed on the health effects from smaller particles ($PM_{2.5}$ and ultrafine) that can penetrate deep into the lung tissue, irritating and corroding the alveolar wall and causing impaired lung function (Xing et al 2016). In a study of six USA cities, $PM_{2.5}$ was positively correlated with the daily mortality of humans, particularly older people (Kaiser 2000).

In 2012, an estimated 1,000 premature deaths were associated with particulate matter in New Zealand (Ministry for the Environment and Statistics NZ 2015b). Studies on human exposure to ground-level ozone or photochemical smog have associated these pollutants with increases in respiratory symptoms such as coughing and wheezing and reduced lung function, increased hospital admissions (including asthma-related hospitalisations), and premature mortality (Betts and Sawyer 2015; Simoni et al 2015; Takaro et al 2013).

In addition, NOx's, SO_2, VOCs and ground level ozone that constitute photochemical smog have similar health effects (Fisher et al 2007; The WHO European Centre for Environment and Health 2013). Nitrogen dioxide can affect the respiratory system by inflaming the lining of the lungs and reduce immunity to lung infections. It also causes problems such as wheezing, coughing, colds, influenza and bronchitis, and may aggravate asthma. In children, it may also increase their risk of respiratory infection and lead to poorer lung function in later life (Ministry for the Environment, 2016a). It can also cause more frequent and more intense asthma attacks in children and older people with heart disease.

Sunnier days are known to worsen photochemical air pollution. In particular, urban areas that produce higher transport emissions (eg, Auckland) (NZCPHM 2013). The largest sources of air pollutants in New Zealand are wood and coal fires and motor vehicles (PCE 2015a). The 2012 Health and Air Pollution in New Zealand (HAPINZ) study estimated that air pollution from all sources in New Zealand was responsible for approximately 1,400 premature deaths per year, of which 1,100 premature deaths were attributed to anthropogenic (human-caused) sources (Kushel et al 2012). A previous report estimated that harmful emissions from vehicles were associated with 256 premature deaths (with social costs of $934 million) annually in

New Zealand (Fisher et al 2007). Respiratory illness in young children is commonly associated with exposure to air pollution and for respiratory hospital admissions during the HAPINZ study, one third of the cases were reported in children aged 1 to 4 years (Kushel et al 2012).

2.2.6 Climate-related environmental health impacts from outdoor air pollutants

Climate change in New Zealand may affect the prevalence, concentration or distribution of air pollutants by:

- increasing ambient and winter temperature
- increasing in the number of extremely hot days and
- decreasing the number of cold and frosty days.

Air quality should improve during the winter due to less cold and frosty days (Reisinger et al 2014; Tait 2008), reducing the need for home heating. Ground level ozone concentrations currently measured in New Zealand are relatively low when compared to the World Health Organisation air quality standards, and their contribution to negative health effects is minor compared with other pollutants (Fisher et al 2007). In future summers, air quality may become more problematic as temperatures are projected to increase, with more hot days expected (The Royal Society of New Zealand 2016). This would result in higher ground level ozone by increasing the speed of chemical reactions if other ozone causing pollutants are present in the future (Ebi and McGregor 2008; Tsai et al 2008). Ozone levels are most likely to affect Auckland because of its location and large volume of vehicle emissions.

The IPCC Fifth Assessment reported that post-2006, most studies that investigated projected impacts of future climate change on air pollution-related morbidity and mortality have focused on ozone (Smith et al 2014). International studies suggest that by the year 2050, ozone levels will increase the number of summertime deaths (Ebi and McGregor 2008).

There are few detailed projections for the future effects of climate change on air pollution in Europe and even recent studies on air pollution (eg, Thematic Strategy on Air Pollution[4]), have not factored in how climate change might influence air quality levels (Bennett et al 2014).

Increased efforts to reduce heat-trapping gas emissions in European countries are focussing on traffic sources. Some countries have gone as far as banning the most polluting cars and vans by 2025 in a number of cities (Paris, Madrid, Athens and Mexico). Others countries are making stricter traffic emission standards for vehicles, introducing ultra-low emission zones and incentivising the switch to low emission or zero emission vehicles. This is expected to improve air quality in the future (EC

[4] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52005DC0446

2016). Reducing or even eliminating road vehicle emissions by shifting to cleaner technology is therefore likely to determine future air pollution in cities with high pollutants, rather than changes in climate.

2.3 INDOOR AIR QUALITY AND HUMAN HEALTH

Indoor air pollutants are a mixture of irritants and allergens that originate from outdoor and indoor sources. Outdoor sources include those discussed in the previous section. Air pollutants can be generated indoors from human activities such as cooking, heating and smoking, but also released from building materials and products within the home. These pollutants include nitrogen dioxide, particulate matter, tobacco smoke, formaldehyde, volatile organic compounds, phthalates, persistent organic pollutants and flame retardants. In addition, houses with poor ventilation or dampness promote the growth of fungi (including moulds) and bacteria. The faeces from dust mites living in soft furnishings also cause an allergic response in some people.

For the purposes of this review, only airborne allergens and irritants that might be affected directly or indirectly by climate change will be discussed. They are: air pollutants (nitrogen dioxide and particulate matter) and aeroallergens (fungi and bacterial spores). Environmental health risks from house dust mites are only briefly considered.

2.3.1 Environmental health risks from indoor air pollutants

Indoor air quality may affect human health from exposure through:

- damp conditions (high humidity)
- inhalation of mould and bacterial spores
- inhalation of airborne biological allergens (eg, faeces from house dust mites) and
- higher concentrations of outdoor pollutants

Pollutant concentrations in indoor air are generally much higher than those in outdoor air (Taptiklis and Phipps 2017). This is due to a wide variety of pollutants, irritants and allergens and the air exchange rates within buildings. A review of epidemiological studies in Europe suggested some association with indoor air pollution and health effects but also recommended more quantitative studies that examined different exposure levels, health outcomes, cultural habits, lifestyle, building type and climate (Hulin et al 2012). Other irritants and allergens include fungal spores (mould). Sorenson (1999) associated the inhalation of spores with an increased risk of asthma and chronic obstructive pulmonary disease (COPD), toxic pneumonitis (inflammation of lung tissue), hypersensitivity pneumonitis, tremors, chronic fatigue syndrome, kidney failure and cancer.

A literature review of indoor air quality in homes and schools, including some studies from New Zealand, found that health effects from poor indoor air quality included increased respiratory infections (viral and bacterial), asthma, allergies and COPD

(Taptiklis and Phipps 2017). A six-week pilot study measuring indoor air pollutants in a school located at a busy intersection in Wellington found that air pollution levels were often elevated well above WHO guidelines (Bennett et al 2017). Other sources of indoor air pollution include indoor gas heating which correlated with early childhood acute respiratory infections in a New Zealand longitudinal child cohort study (Tin et al 2016). An earlier study on respiratory symptoms and environmental factors in school children from the Bay of Plenty found consistent evidence of an effect on respiratory morbidity from natural fumes, industrial air pollution and climate (Moyes et al 1995).

Most studies on indoor air quality and their effects on human health focus on issues associated with damp, poorly ventilated housing. The relationship between damp homes and respiratory illnesses, such as upper respiratory tract symptoms (coughing, wheezing) and asthma, is well known (D'Amato et al 2015). Indoor dampness and mould, plus a number of other factors including biological allergens, have been linked to asthma, respiratory infections and rheumatic fever (Krieger et al 2010). However, more quantitative studies have been less conclusive (WHO 2009; Fisk et al 2007; Mendell et al 2011) and proving cause and effect is difficult.

Epidemiology based studies have found an association between damp homes and mould spores, fungal growth and asthma. This includes new onset of asthma in children (Mendell et al 2011). Indoor dampness and mould exposure was attributed to childhood asthma cases in a 2011 World Health Organization report (WHO 2011). The WHO reported that children living in homes with signs of dampness have 2.4 times the risk of developing asthma than children in dry homes. A USA meta-analyses showed that building dampness and mould were associated with approximately 30 to 50% increases in a variety of respiratory and asthma-related health outcomes (Fisk et al 2007).

There is currently limited data on indoor air quality and resulting health effects in New Zealand. What is known is that the prevalence of indoor dampness and mould is high compared with other Western societies (Taptiklis and Phipps 2017). A New Zealand study estimated that damp housing and mould indoors was associated with an 11% increase in the odds of at least one self-reported episode of wheezing/whistling in the chest in adults over the last 12 months (Keall et al 2012). In a cohort of children < 5 years old residing in Auckland, the presence of mould in a child's bedroom was correlated with an increased risk of developing pneumonia (Grant et al 2012).

The presence of house dust mites in homes has been associated with atopic dermatitis and asthma (Bremmer and Simpson 2015; Calderón et al 2015; Fitzharris and Riley 1999). It has been suggested that exposure to house dust mites alone was not associated with the development of asthma risk in children and that interactions between other factors (environmental tobacco smoke, unflued heaters and poor air quality) were more important (Dick et al 2014).

New Zealand studies on house dust mites have found high concentrations of dust mite allergens (proteins from the mites and their faeces). Some studies focus on where their concentrations are high such as bedding (Mills et al 2002) and certain floor coverings (Wickens et al 1997). A study of the health impacts from the exposure to house dust mite allergens during infancy, showed an increase in the prevalence of asthma among the children studied (Siebers et al 2006).

2.3.2 Climate-related impacts on indoor air pollutants

Climate change could negatively affect indoor pollution via:

- increasing ambient temperatures
- increasing the number of hot days and
- increasing CO_2.

Ambient temperature and the number of hot days in New Zealand is projected to increase (Ministry for the Environment 2016a). If outside concentrations of air pollution worsen through ambient temperature increases, this will lead to an increase in indoor concentrations. The adverse health effects will be compounded by the fact that most people spend 80-90% of their time in buildings.

Relative humidity is expected to decrease across the country (Ministry for the Environment 2016a). This change is small (mostly 1 to 2 percent per degree increase in mean temperature) and it is not known whether this will have a significant effect on indoor relative humidity levels. Increases in storms, heavy rain and flooding are more likely to increase the proportion of buildings with damp problems (Douwes 2009). Indirect health effects may also result from extreme events, for example, disrupting the electricity supply. The use of alternative sources of heating (unflued gas heaters) as a result of such disruptions would increase the risk of exposure to harmful levels of carbon monoxide and nitrogen oxides that typically exceed those outside (Fisher et al 2007; Tin et al 2016). Gas heaters also increase indoor moisture levels (Boulic et al 2015). Conversely, projected drier parts of the country may see health benefits due to higher ambient winter temperatures and decreased use of heating appliances.

In terms of indoor mould, a study in the UK found a positive correlation between *Cladosporium* spores and regional temperature and a negative correlation with rainfall at allergenic concentrations (Hollins et al 2004). More studies are required to determine how indoor moulds may change in the future in New Zealand, but more importantly how they can be prevented altogether.

There is limited evidence that climate change will increase the concentration of house dust mites and their allergens. Indoor humidity appears to be the key environmental condition that increases their survival rate and concentration. Levels of relative humidity in New Zealand are expected to decrease across the country, as ambient temperature increases. More studies are required to determine whether lower relative humidity will reduce health related impacts associated with indoor dust mites.

As described in Section 2.2.3, increased CO_2 concentrations and ambient air temperature may promote pollen and fungal spore production and therefore increase exposure to aeroallergens. This may affect indoor concentrations if windows are opened more frequently (eg, due to more hot days).

2.4 POPULATIONS VULNERABLE TO OUTDOOR AND INDOOR ALLERGENS AND AIR IRRITANTS

The populations identified as the most vulnerable include those pregnant, the very young, people living close to high traffic zones, people aged 65 and over, those with poor nutritional status, those with respiratory or cardiovascular disease, cyclists, Māori, Pacific peoples and those already suffering from conditions such as asthma, serious allergies or COPD (Asher et al 2001; Bousquet et al 2008; CEC 2005; D'Amato et al 2015; Kampa and Castanas 2008; Kingham et al 2013; NZCPHM 2013; Pattemore et al 1989; PCE 2015a; USGCRP 2016). Suggestions to reduce exposures are explored in Table 1.

2.5 ADAPTATION MEASURES TO REDUCE POPULATION VULNERABILITY TO OUTDOOR AND INDOOR AIR IRRITANTS AND ALLERGENS

Adaptation measures are essential to minimise the effects of climate change and its associated health burden. Table 1 provides a summary of mitigation and adaptation options from various international and local studies related to indoor and outdoor air pollutants. These adaptation approaches are largely focused on reducing the exposure of people to airborne allergens and irritants through:

- reducing fossil fuel combustion (traffic, heating)
- reducing conditions that promote indoor mould/spore and
- reducing other allergens (pollen, dust mite allergens).

Globally, transport is projected to have the fastest proportional growth in heat-trapping gas emissions of any sector from 1990 to 2020, and there are direct connections with urban air pollution (around 800 thousand deaths per year globally) (WHO 2008). In New Zealand, intensive dairy farming, road transport and industry have together pushed up gross heat-trapping emissions by 23% since 1990 (OECD 2017). The annual cost of adverse health effects (mortality, bronchitis and related disease, respiratory/cardiac admissions, cancer and restricted-activity days) associated with air pollution from vehicles was estimated to be NZ$ 494.6 million (Fisher et al 2007).

Smith et al (2014) determined that lowering emissions through a variety of adaptive solutions would lead to improved health, as well as economic benefits, through increased physical activity in the population. Adaptive solutions included: reducing vehicle miles, increased active transport (walking, cycling), transport alternatives (bus, train, carpool) and changes to transport policy to enable safer commuter bicycling. However, other studies in New Zealand and overseas, agree that policy options remain challenging (Denne and Atkins 2015; Fisher et al 2007; Spickett et al 2011).

Changes to replace combustion engines with cleaner vehicles and regional council initiatives to improve air quality by gradually removing old inefficient wood burners (CDHB 2014; O'Connell et al 2010), would also have health benefits by reducing indoor and outdoor particulate matter.

How climate change will impact on indoor health in general will depend on a number of risk factors including geography, housing conditions, improvements in housing insulation and building design, planning and policy (Woodcock 2007; Grimes et al 2011). In particular, exposure to mould and spores is an on-going health and policy concern. Telfar-Barnard et al (2015) noted that ethnicity and socio-economic status are more likely to relate to health rather than the impact of climate itself. Increases in winter ambient temperature are likely to reduce the number cases associated with air pollution and respiratory illness in young children, provided that indoor environments are improved to reduce damp and mould. However, this is unlikely to occur in households of modest income unless appropriate mechanisms are devised to reduce fuel poverty and improve housing conditions (insulation, air tightness, heating).

Other health benefits could be realised by replacing unflued gas heaters or small plug-in electric heaters with heat pumps, flued gas heaters or wood pellet burners. These measures would improve conditions for asthma sufferers and reduce the risk of respiratory infections. However, controlling indoor humidity requires adequate ventilation systems. Ventilation rates must ensure adequate exchange of indoor air as they may otherwise indirectly increase indoor air irritants and allergens. In order to reach the goal of improving housing or future proofing housing from climate change, legislative and specific building design including retrofitting is required.

Improved research on building design, policy, and management of future of allergens will be important for the future. Without these considerations there is the possibility that climate change will increase environmental exposure of some pollutants, and contribute to increased rates of asthma and other diseases (Cecchi et al 2010; D'Amato et al 2015; Ziska et al 2005).

Table 1: Summary of mitigation and adaptation options to reduce the environmental health risks from climate modified changes to air quality

Risk	Mitigation/Adaptation Options	Direct Health Benefit	Reference
Increases in particulate matter, ground level ozone, nitrogen dioxide and smog	• Reduction in vehicle miles (active transport (walking, cycling) or alternatives (bus, train, carpool), transport policy that enables safe commuter bicycling • Increased urban tree cover (non-allergenic) • Increased energy efficiency and/or shift away from fossil fuels • Improved clean technology and shift towards zero emission transport • Reduction in solid fuel wood burners and conversion to cleaner modes of heating	• Reduced health problems related to air pollution • Reduced vehicle related injuries	Bowles et al 2014; D'Amato et al 2015; Kingham et al 2013; Lindsay et al 2011; Macmillan et al 2014; Patz et al 2014; Smith et al 2014
Changes in exposures to outdoor pollen, spores and dust	• Continued monitoring to determine the changes in clinically significant allergens and provide forecasting • Early warning systems[5] • Allergenic plant management • Access to health care and medications • Education • Research, and improved anticipatory public-health messaging.	• Reduction in hospital admissions • Community preparedness	Beggs 2004;Beggs et al 2006,2010; Breton et al 2006; Davies et al 2015; Haberle et al 2014; Khwarahm et al 2017; Reid and Gamble 2009
Increased exposure to mould and dust mites indoors	• Improved building design including retrofitting of existing buildings, heating, ventilation, and air-conditioning	• Reduction in morbidity from poor housing and poor indoor air quality	Institute of Medicine 2011

[5] This can be a technology, associated policy or procedure that is designed to predict and mitigate the harm of natural and human-initiated events.

2.6 CONCLUSIONS

Climate change is likely to change exposure to air irritants and allergens that will bring both positive and negative health effects.

Health Benefits

- Less use of indoor wood burners in the future due to warmer winter temperatures. This will reduce particulate matter production.
- Decreases in humidity may reduce the amount of fungal spores outdoors (but not necessarily indoors). Future prevention and remediation of indoor dampness and mould are likely to reduce health risks regardless of climate change.

Adverse Health Effects

- Higher levels of outdoor allergens may lead to higher personal exposures and more pollen infiltration into dwellings. This will lead to increased allergic disease.
- Although the evidence is currently limited, climate change, through increased temperatures, may also increase the atmospheric concentration of pollen which, combined with an earlier seasonal start in pollen production, may further increase the overall disease burden of allergic diseases and asthma. However, the evidence is currently still limited and the magnitude of these effects is unclear.

The research gaps identified from this review and of particular importance to New Zealand include:

- Experimental research on the impacts of elevated CO_2 and temperature on pollen and allergen production of new or existing plant species in New Zealand. Similarly, modelling and surveillance of future changes in allergenic plant and transport of dust ranges may help forecasting.
- Understanding climate related long-term patterns of aeroallergen concentrations, particularly for airborne indoor and outdoor fungal spore concentrations.

3. ULTRAVIOLET RADIATION

3.1 INTRODUCTION

This section reviews the effect climate change might have on human exposure to ultraviolet radiation (UVR) in New Zealand.

Ultraviolet radiation is naturally emitted from the sun. Ultraviolet radiation A and B (UVA and UVB) are different wavelengths of radiation. UVB is a shorter wavelength (higher energy photons) and potentially more damaging than UVA. Only 5% of UVB reaches the earth's surface as it is mostly absorbed by the ozone layer, a layer of gas in the stratosphere, before it can reach the earth's surface (IARC 2012). Consequently, the majority of UVR (95%) reaching the earth's surface is in the form of UVA.

Generally, exposure to UVR is measured as UVI (ultraviolet index) – a standard way of measuring the intensity of the sun and its ability to burn skin. Values of UVI greater than 10 are considered extreme and a UVI of less than 3 is considered low (McKenzie 2008).

Ultraviolet radiation contributes to the development of a number of environmental health risks. Without appropriate protection, during times of high exposure, UVA rays can penetrate deep into the skin. UVB rays may also burn the uppermost layers of the skin (WHO 2017) and combined they play a key role in the development of skin cancers (Moan et al 2008). This includes the development of 65% of melanomas worldwide (95% in high exposure contexts like Australia) and 99% of non-melanoma skin cancers such as basal cell and squamous cell carcinomas (Reeder et al 2012)[6]. Other negative health effects include sunburn, cortical cataracts, sun spot (solar kertosis), surfer's eye (pterygium), reactivation of herpes labialis, eye cancer and eye disease (eg, macular degeneration), immune suppression and altered well-being (eg, depression) (see Lucas et al 2015; McMichael et al 2003b; Ministry for the Environment 2016b; Norval et al 2011; Thomas et al 2012).

Exposure to UVR is dependent on a number of factors including: (a) the intensity of the sun, which changes geographically, seasonally and daily (including altitude and surface reflection such as snow), (b) behaviour, where clothing, effective use of sunscreen, time and length of day spent outdoors influence exposure, and (c) pigmentation of the skin, where fairer skin is more susceptible to burning (McKenzie et al 2003; Thomas et al 2012).Other risk factors include age, genetics and in some cases, immune function (Leiter and Garbe 2008). These health conditions, and evidence for their link to UV exposure, are discussed in Section 3.3.

[6] Melanoma occurs when the pigment-producing cells that give colour to the skin become cancerous. Non-melanoma skin cancer refers to all the types of cancer that occur in the skin that are not melanoma. Several types of skin cancer fall within the broader category of non-melanoma skin cancer, with the most common types being basal cell carcinoma and squamous cell carcinoma.

3.2 EXPOSURE TO ULTRAVIOLET RADIATION IN NEW ZEALAND

Figure 4 shows differences in UV intensity within New Zealand. The amount of UVR exposure depends on, the ozone layer, location, time of year, time of day and the weather.

The ozone layer is a layer of high concentration ozone (O_3) in the earth's stratosphere. It protects the earth from excessive UVR by absorbing most of it before it reaches the earth's surface. In the past, ozone depleting substances such as chlorofluorocarbons (CFC's), chlorine- and bromine-containing compounds were emitted into the atmosphere, accelerating the depletion of the stratospheric O_3 layer (Maione 2013). Since the 1980's in the South Pole, each spring the ozone layer or "ozone hole" was observed to be thinner because atmospheric and chemical conditions unique to that region increased the effectiveness of ozone depleting substances. However, ozone levels in New Zealand are not directly affected by the ozone hole as it is confined to the Antarctic (Ministry for the Environment and Statistics NZ 2015c). Since the ban of ozone depleting substances (see Montreal Protocol, glossary), the ozone layer has been recovering and is expected to return to 1980 levels by the mid-century (Chipperfield et al 2015).

At the equator the sun is more directly overhead, and the ozone layer is naturally thinner so UVI levels are higher compared with those at more southern or northern latitudes. Towards mid-parts of the earth (mid-latitudes) such as New Zealand, the sun is lower in the sky, so UV intensity is reduced.

During the New Zealand summer (December/January) the earth is closer to the sun than it is during the northern summer (June/July). This is due to the elliptical orbit of the Earth about the Sun. This difference means that the New Zealand summer receives on average about 7% more UVR (maximum intensity per day) than the northern hemisphere summer (McKenzie et al 2006). During the day, UVR levels are typically highest around noon when the sun is at its maximum elevation.

The weather and air pollution levels also influence daily UVR levels. Clouds reflect and scatter UVR so that cloudy days reduce exposure to UVR by about 30%. In some parts of the country, New Zealand's relatively 'clean' atmosphere (lack of air pollution) means that UVR can also pass through the atmosphere more easily, increasing the level of exposure.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Auckland	10	8	7	4	2	1	2	2	3	6	8	9
Wellington	9	8	6	3	1	1	1	2	2	5	7	8
Christchurch	8	7	5	2	1	1	1	1	2	4	7	8
Central Otago	8	7	5	2	1	1	1	1	2	4	6	8
Invercargill	7	6	4	2	1	0	0	1	2	3	5	6

Mean UVI (including clouds)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Auckland	13	11	7	4	2	2	3	5	6	8	11	13
Wellington	13	9	6	3	2	1	2	4	5	8	11	12
Christchurch	12	8	5	3	1	1	2	3	4	8	10	11
Central Otago	10	8	5	2	1	1	1	3	4	7	10	11
Invercargill	8	7	4	2	1	1	1	2	3	5	9	10

Peak UVI (cloudless)

Figure 4: Seasonal range of peak UVI in New Zealand (averaged over 1 hour at solar noon) at 5 sites that span north to south of New Zealand with and without clouds (upper and lower half respectively).

Source: http://www.ehinz.ac.nz/indicators/uv-exposure/daily-uv-levels/, accessed 21/6/2017

Solar noon is when maximum solar intensity occurs (in a cloudless sky) and the sun is at its highest point in the sky each day (not necessarily at 1200 hrs). UVI values over 10 represent extreme potential exposure. These arise during the summer months, particularly in the northern parts of the North Island, although during December high UVI values arise as far south as Invercargill.

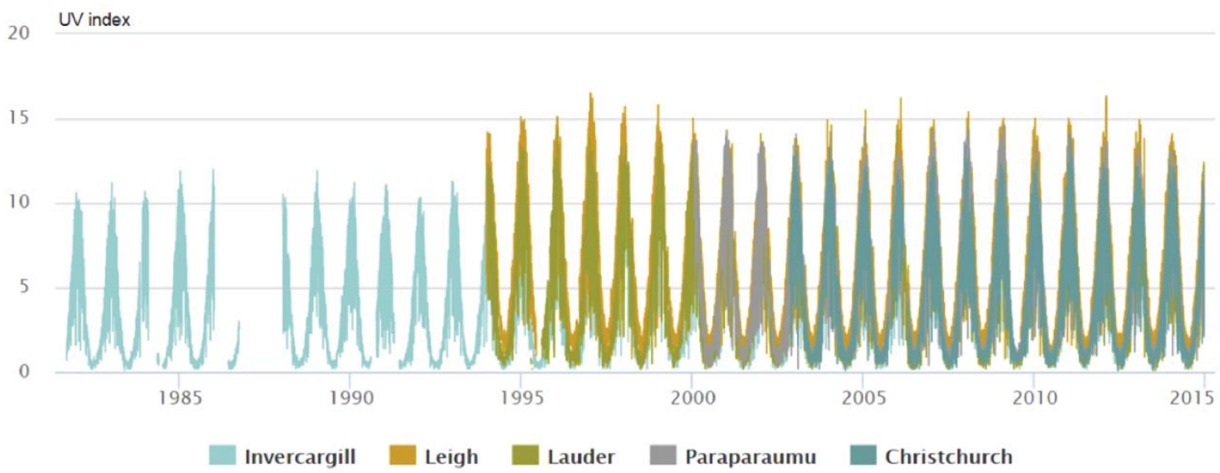

Figure 5: Daily peak UVI values measured at five sites across New Zealand between 1981 and 2014
Source: NIWA. URL: http://www.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/home/atmosphere-and-climate/uv-intensity.aspx.

Figure 5 shows historical UVI daily measurements across five sites in New Zealand from south to north (Invercargill, Lauder (Otago region), Christchurch, Paraparaumu (Wellington region), and Leigh (Auckland region). The longest record of measurements (Invercargill) shows a statistically significant increasing trend with time (higher UVI now compared with when measurements began) (Ministry for the Environment and Statistics NZ 2015d). However, the opposite trend is seen at Lauder and Leigh. There is no trend in the Christchurch and Paraparaumu data. No clear general trend in UVI levels at present can be concluded.

3.3 THE ENVIRONMENTAL HEALTH EFFECTS FROM EXPOSURE TO ULTRA VIOLET RADIATION IN NEW ZEALAND

Most of the New Zealand based studies on health effects from UVR focus on skin cancer (cutaneous melanoma). This is not surprising given that New Zealand has one of the highest incidence and mortality rates for skin cancer in the world (Ministry of Health 2015b; IARC 2014). A study by O'Dea (2009) estimated that for each person dying from skin cancer, an estimated 15.5 years potential years of life are lost, with an estimated direct health system cost of NZ$57.1 million per annum, and total annual economic cost of NZ$123. The high rates have been associated with a predominantly pale-skinned population, relatively low air pollution and higher than average ambient UVR compared with similar latitudes in the northern hemisphere (Armstrong 1994; Lucas et al 2006a).

Builliard (2000) found that most melanomas in New Zealand are likely to be caused by recreational related acute exposure to the sun, especially on untanned skin. Another New Zealand study using data from 2000 to 2004 found that older men (>59 years old) had the highest risk of developing cutaneous melanoma (Liang et al 2010).

The total age-standardised rate of melanoma between 1996 and 2013 in New Zealand did not show a statistically significant trend (Ministry for the Environment and Statistics NZ 2015e) with a few exceptions. A statistically significant increasing trend for the age-standardised rate of melanoma was found for males but not females. However, given the long lag (years to decades) between exposures to UVR and its health effects, any occurrence of skin cancer may not yet be evident (Beddingfield 2003; Wu et al 2014).

Studies on non-melanoma skin cancer in New Zealand have also found an increased annual incidence of basal cell carcinoma (BCC) and squamous cell carcinoma (SCC) since 1999 (Brougham et al 2010). The increase was 4.0% and 1.1%, respectively and the highest increases were also observed in those over the age of 50 (Beddingfield 2003; Wu et al 2014).

Few New Zealand studies could be found for other negative health effects or trends associated with exposure to UVR. In a Christchurch study, there was evidence to suggest that prolonged (unprotected) exposure to sunlight may cause ocular (eye) damage (Borthwick and Clement 1990). In a study on oral cancer, exposure to UVR was found as a risk factor though alcohol and smoking were considered the more important (Yakin et al 2017). Among urban New Zealanders (15-69 years) sunburn was associated with greater time spent outdoors and occurred most frequently during water-based, passive recreational activities and paid work (McLeod et al 2013).

Skin colour (pigmentation) is another risk factor associated with developing skin cancer (Callister 2008). Melanoma rates are higher among fair skinned populations compared with those in darker skinned populations. Data collected from melanoma registrations in New Zealand from 2001-2013 showed that Māori had much lower rates than non-Māori. In 2013, the age-standardised Māori rate for melanoma registrations was 7 per 100,000, compared with over 40 per 100,000 for non-Māori (provisional data) (Ministry of Health 2014a). Although darker skinned people have a much lower chance of developing melanoma, those that do develop melanoma often have more serious lesions (Ministry of Health 2017a).

3.4 CLIMATE-RELATED ENVIRONMENTAL HEALTH IMPACTS FROM EXPOSURE TO ULTRAVIOLET RADIATION IN NEW ZEALAND

Future climate scenarios for New Zealand project warmer and more frequent, hot days nationally (by 2040, a 40% [RCP2.6] to 100% [RCP8.5] increase) (Reisinger et al 2014; The Royal Society of New Zealand 2016). The number of dry days is also predicted to increase (by 2090, a 40% [RCP2.6] to 300% [RCP8.5] increase), especially in the east.

Exposure to UVR is likely to vary regionally according to the combination of: levels of UVR, (which are governed by the ozone layer), local climate and sun exposure behaviour.

This section discusses how climate change may affect the factors leading to exposure to UVR in New Zealand. These factors include:

- depletion of stratospheric ozone
- changes in cloud cover and
- decreased atmospheric pollution.
- moderating influences such as behaviour and culture (see Figure 6 from Thomas et al 2012).

Latitude, season, altitude and pre-existing conditions are not discussed further.

3.4.1 Climate-related changes in stratospheric ozone concentration

A global reduction in the emission of ozone-depleting gases has allowed the ozone layer (stratospheric ozone) to recover. Climate change may delay this recovery. The ozone layer absorbs most of the sun's UVR, however increasing levels of heat-trapping gases that warm the troposphere (the lowest region of the atmosphere up to 6-10 km high), also cool the stratosphere. Indirectly this slows down the ozone layer’s recovery. Projections by Williamson (2014) suggest that UV irradiance will remain below 1960 levels by 2100. UVR is likely to peak around 2020, with an estimated 10% increase in effective UVR relative to 1980s.

3.4.2 Climate-related changes in cloud cover

Clouds usually reduce UVR. The New Zealand summer is characterised by a combination of high sun angles (high levels of UVR) coupled with relatively clear skies. Measurements have shown that our summers have similar levels of erythemal[7] radiation to higher latitude parts of Australia (McKenzie et al 2014).

Climate projections (NIWA 2016a) show that:

- by 2100 there will be increases of up to 10 % solar radiation on the West Coast in summer, as a result of less cloud cover, and smaller increases elsewhere with the notable exception of coastal Canterbury where sunshine levels are predicted to decrease
- the reduced summer sunshine levels in coastal Canterbury are consistent with increased summer rainfall
- increased cloud cover in western parts of New Zealand is predicted for the winter months, resulting in decreased solar radiation of about 5 % in western parts of the North Island and 10 % or more in western and southern parts of the South Island and
- the eastern North Island is projected to have an increase in winter sunshine levels.

7 Erythemal UV exposure is a measure of the potential for biological damage due to solar ultraviolet radiation.

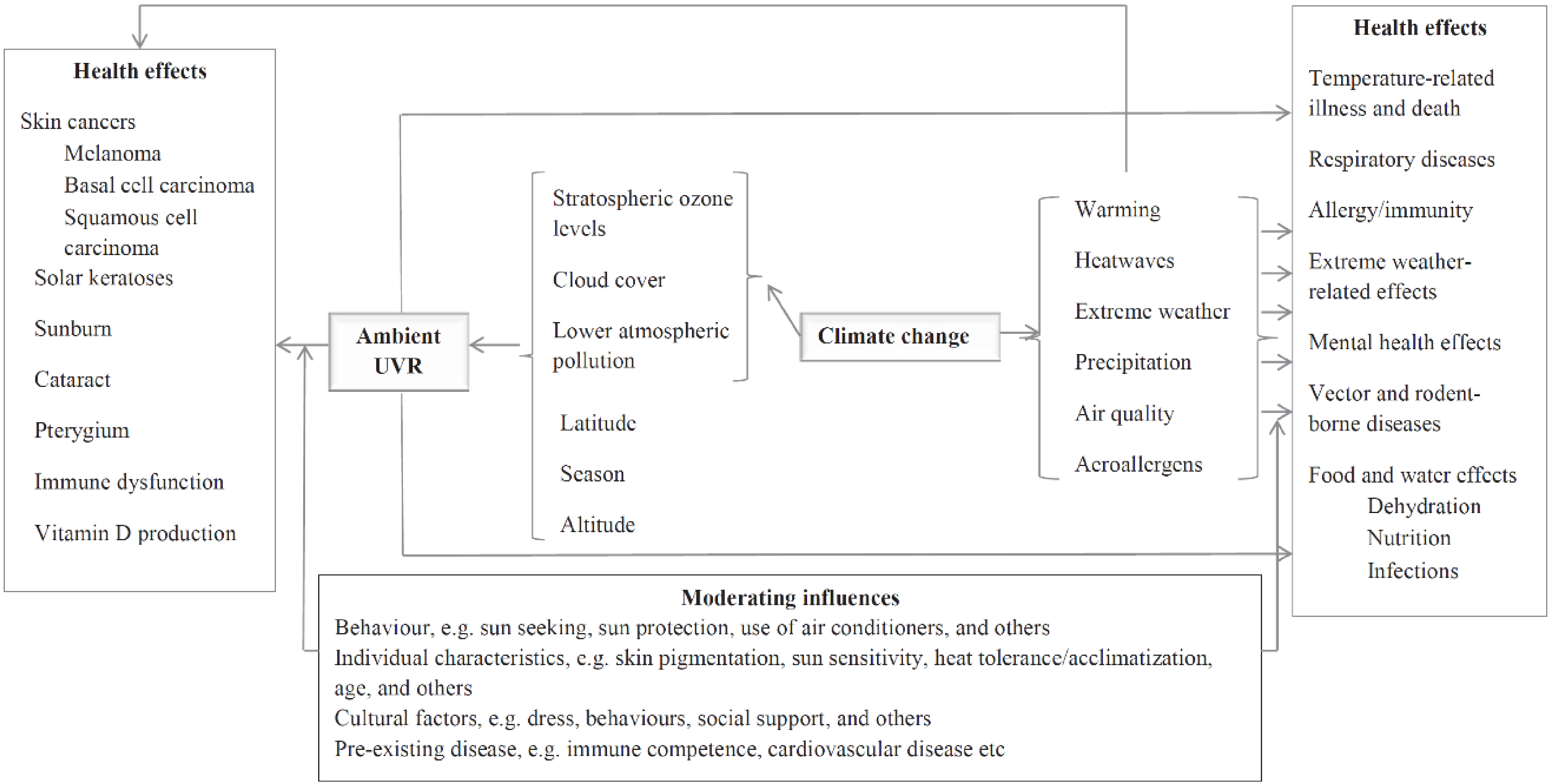

Figure 6: Summary of the effects of climate change and ultraviolet radiation exposure on human health

Source: Thomas et al (2012)

3.4.3 Moderating influences: Changes in behaviour due to climate change

Rates of skin cancer, and possibly rates of eye disease and vitamin D levels will be influenced by recreational exposure and how we protect ourselves from UVR exposure (Bennett et al 2014; Confalonieri et al 2007; Williamson et al 2014).

Studies in the UK suggest that warmer, drier weather is likely to encourage people to spend more time outdoors and increase their exposure to UVR (Diffey 2004). In Europe, the incidence of skin cancers has increased by 50% or more since 1980 and this has been attributed to changes in cheap air travel, clothing and other perceptions surrounding skin colour and appearance (Williamson et al 2014). Other work showed that intense UVR in spring and early summer coincided with outdoor activities, and that personal exposures from overseas holidays also contributed to UV exposure[8].

An Australian behavioural study found that temperatures between 19 to 27°C doubled the chances of sunburn compared with temperatures of 18°C or lower (Bharath and Turner 2009). When temperatures rose above 27°C however, this likelihood fell as people sought shelter from the sun.

3.5 VITAMIN D LEVELS IN NEW ZEALAND

This section discusses how climate change could indirectly alter vitamin D levels by changes in exposure to UVR. Exposure to UVR is important for vitamin D formation (and for increasing calcium and phosphorus absorption from food), which plays a crucial role in skeletal development, immune function and blood cell formation (WHO 2017). Vitamin D is therefore an essential key requirement for human health. Up to 90% of vitamin D is synthesised in the skin upon exposure to UVB radiation, with the lesser proportion coming from the diet. Low levels of vitamin D are linked to rickets in children and osteoporosis and osteomalacia in adults. Adequate vitamin D levels optimises bone health and muscle function, and helps reduce the likelihood of falls and fractures. Low vitamin D levels are associated with increased risk of colorectal cancer, cardiovascular disease and all-cause mortality.

3.5.1 Vitamin D levels

Vitamin D levels are defined by the Ministry of Health as:

- severe deficiency (serum 25-OHD[9] levels less than 12.5 nmol/L)
- mild to moderate deficiency (serum 25-OHD levels of 12.5 to 24.9 nmol/L) and
- below recommended level but not deficient (serum 25-OHD levels of 25.0 to 49.9 nmol/L).

Equal to or above the recommended level vitamin D levels are defined as:

[8] http://www.eurosun-project.org/Home.html (accessed 16 Sept 2016).
[9] Vitamin D levels are determined by measuring "25(OH)D" in blood serum.

- serum 25-OHD levels of 50.0+ nmol/L

High levels of vitamin D are defined as:

- serum 25-OHD levels of 125+ nmol/L

No long term studies following the trends of vitamin D deficiency in New Zealand were found from this literature review. An analysis of vitamin D data taken from the 2008/09 New Zealand Adult Nutrition Survey on adults over the age of 15 years showed that 5% of people were deficient (less than 25 nmol/L) with 27% below recommended levels of between 25 and 50 nmol/L (Ministry of Health 2012a). In another New Zealand study, children under three years of age were found to have a higher incidence of vitamin D deficiency than those aged three to less than 15 years (Wheeler et al 2015). A global summary of maternal and new-born vitamin D status noted a 57% vitamin D deficiency[10] in new-borns from New Zealand from 1997 to 2001 (Camargo et al 2010). In a separate study, 42% of women enrolled from an ethnically diverse sample of pregnant women from a community maternity clinic in South Auckland, were found deficient in vitamin D (Ekeroma et al 2015). The study found that winter/spring seasons and non-European ethnicity were the only independent risk factors for the deficiency.

Studies conducted in New Zealand (Wheeler et al 2015), Australia (Munns et al 2012), and the United Kingdom (Elder and Bishop 2014) have all identified child and parental ethnicity or skin colour trends as vitamin D deficiency risk factors. Rockell et al (2005) found that Māori and Pacific children have, on average, lower vitamin D levels than European children. This is assumed to be the result of the amount of melanin, or skin darkness that reduces absorption of UVR and therefore increases the risk of vitamin D deficiency. However, in adults, a range of other factors may be influencing levels, including prevalence of obesity, type of diet and level of exercise (Thacher and Clarke 2011). The relationship between sun exposure and skin type in New Zealand, and these lower levels of vitamin D has not yet been validated against an objective measure of skin colour (Callister et al 2011).

In the southern provincial regions of Otago/Southland, vitamin D deficiency rickets was found to be three times higher than the national average for children under three years of age (30.6 cases/100,000 and 10.5 cases/100,000, respectively) (Wheeler et al 2015). This is compared to the Nelson-Marlborough region that typically experiences the highest number of sunshine hours per annum and reported the lowest number of rickets cases. A study in Canterbury showed that most Christchurch people are vitamin D deficient[11] most of the time (Livesey et al 2007).

Perception is known to influence our behaviour toward exposure to UVR, particularly in summer months. Influences on UV exposure during the winter however are poorly understood. The high rates of melanoma in New Zealand, and skin cancer education

[10] Deficiency was defined as either <25 or <50 nmol/l measured as serum levels [of 25-hydroxyvitamin D (25(OH)D)] in cord blood.

[11] In this study, deficiency was defined as (<25 nmol/L) based on plasma 25(OH)D

campaigns, mean that more people are aware of using sunscreen (which prevents production of vitamin D via the skin) and/or avoid going out in the sun. Vitamin D production from UV exposure will be restricted among people who spend limited time outdoors or take extra precautions to reduce their exposure to UVR. Populations identified at risk of deficiency include people with dark skin and people who cover up more. New migrant populations may fall into both these categories. Whilst sun protection is important for prevention of sun-related health effects, children "over-protected" against sun exposure, particularly early in their life, were also considered at increased risk of developing vitamin D deficiency (Williamson et al 2014).

3.5.2 Climate-related environmental health impacts on vitamin D levels in New Zealand

Vitamin D levels that are indirectly influenced by changes in climate will be difficult to predict. However, behavioural influences are likely to play a key role in the future.

Potentially, the largest effect of climate change on vitamin D levels will be through increasing migration to NZ from people with darker skin eg, due to sea level rise, increased temperature or weather events. People with darker skin are more prone to vitamin D deficiency in New Zealand.

3.6 MITIGATION AND ADAPTATION TO CLIMATE CHANGE AND AMBIENT ULTRAVIOLET RADIATION IN NEW ZEALAND

The incidence of UVR-related skin tumours continues to increase in many countries, despite measures such as sun protection programmes (Thomas et al 2012). However, most skin cancers are potentially preventable, with reduction of excessive UVR exposure, particularly from a young age.

The conditions that arise from vitamin D deficiency are also preventable (Thomas et al 2012). Populations identified at risk of low vitamin D levels include: those living in the South Island, people leading a sedentary lifestyle and spending limited time outdoors, people who deliberately avoid the sun or cover up more, older people, migrants and those with darker skin (higher levels of melanin) (Camargo et al 2010; Ministry of Health 2012a; Ministry for the Environment 2016b; Norval et al 2011; Nowson et al 2012; Stamatakis et al 2013; von Hurst et al 2010). Behavioural changes, accompanied by surveillance systems and education (particularly in school children) (Table 2) may lead to reduced exposure to UV exposure during the summer. Ensuring adequate exposure for the production of vitamin D throughout the rest of the year will remain a challenge. Increased daytime temperatures could provide a more comfortable environment for outdoor activities during winter months when UVI levels are as high. With this in mind, intervention measures (eg, supplementation for vulnerable populations) to reduce levels of vitamin D deficiency may not be needed.

Table 2: Summary of mitigation and adaptation options to reduce the environmental health risks from climate modified exposure to ultraviolet radiation

Risk	Mitigation/Adaptation Options	Health Benefit	Reference
Increased incidence of UVR related skin cancers and other negative health effects	• Continued advice for protection against solar UVR particularly during summer or at high altitudes. • Promote education of sun smart[12] • Potential use of skin patches[13] or other tools to more accurately provide individual advice and assessment of risk • Ensuring adequate standards of UV protection are met eg, sunglasses, sunscreen.	• Reduction of morbidity and mortality related to skin cancer • Reduction in premature deaths • Reduction of morbidity and mortality related to heat stress, sunburn and other associated health effects	Chang et al 2014; Ministry of Health 2015b; Lucas et al 2006a; Lucas et al 2015; Mckenzie et al 2008
Decreased levels of Vitamin D in certain adult populations and in children	• Increased education on sensible sun exposure with particular efforts to target the most vulnerable • More research examining suitable intervention methods for populations susceptible to vitamin D deficiency eg, dietary supplements • Improvements to control early life sun exposure in schools	• Greater balance between UV exposure for vitamin D deficiency and reducing of sunburn and other associated health effects, thus reducing rates of rickets and osteomalacia	Lucas et al 2015; Ministry for the Environment 2008; Norval et al 2011; Reeder et al 2012

[12] http://sunsmart.org.nz/
[13] http://www.laroche-posay.us/my-uv-patch

Risk	Mitigation/Adaptation Options	Health Benefit	Reference
Increased health risks from excessive sun exposure	• Improve services to urban poor including heat wave early warning systems	• Reduction of morbidity and mortality heat stress, sunburn and other associated health effects.	Lowe et al 2011; Lucas et al 2006a; McKenzie et al 2011; Norval et al 2011; WHO 2003

3.7 CONCLUSIONS

Climate change is expected to change exposure to UVR by:

- prolonging recovery of the stratospheric ozone layer
- changes to cloud cover
- changes in air quality and
- changing behaviour due to increased ambient temperatures and drier and hotter days.

Behaviour may decrease exposure (sun avoidance) or increase exposure (encourage people to spend more time outdoors), depending on personal preferences, public perception, education and adherence to advice. In terms of prevention of exposure to high levels of UVI, the interplay between other risk factors (skin colour, lifestyle, extreme sunburn history versus preventative measures such as sun protection, education and cumulative exposure) will remain central for reducing environmental health risks, particularly in later life.

Vitamin D deficiency is most likely to occur in the population during the winter months especially at higher latitudes such as Canterbury and Southland where the UVR levels are lowest in winter or in persons who deliberately avoid exposure to the sun for behavioural or cultural reasons. In addition, changing immigration and birth demographics suggest an increase in the the population people with darker skin colour in New Zealand who are more at risk of vitamin D deficiency.

In the future, studies looking at the long-term health impact of seasonal variations in vitamin D status, and exploring technological tools for better assessing individual UVR exposure with personalised feedback would be useful for balancing UVR risks and benefits.

4. EXTREME WEATHER EVENTS

4.1 INTRODUCTION

This section reviews how changes to extreme weather events may impact human health. The extreme weather events considered are: drought (and wildfire risk), extreme hot and cold days and also wind and storm events (including storms of tropical origin or ex-tropical cyclones). Wind and storms can lead to coastal inundation, heavy rain, flooding and landslides. Direct and indirect exposure to these events might increase environmental health risks including:

- physical injury, disease and death
- risk from food- and water-borne disease
- impacts on mental health and
- cold and heat-related mortality and morbidity.

4.2 EXPOSURE TO EXTREME WEATHER EVENTS IN NEW ZEALAND

Extreme weather events in New Zealand are presently considered rare. For example, every year an average of seven tornadoes, one ex-tropical cyclone and various degrees of drought are expected. Although they are rare they are considered dangerous and costly, both socially and economically (Statistics NZ 2015). Predicting these events is difficult, apart from the short-term meteorological outlooks that are provided by the Metservice[14].

4.2.1 Drought

Drought is a period of below-average rainfall over an extended period of time in a given region. Drought typically occurs in the months from September to April[15].

The Environmental Health Indicators New Zealand (EHINZ) reported that eastern areas of New Zealand have been most affected by a lack of rainfall over recent years (EHINZ 2017). Other parts of the country that historically experience drought include the northern part of the North Island and the west of the central North Island.

4.2.2 Extreme hot days and cold nights

Hot days in New Zealand are defined as days with a maximum temperature of 25°C or higher (Ministry for the Environment 2016b). Mean daily maximum temperatures for each month from 1981 to 2010 recorded at NIWA's weather stations show that on average January has the highest maximum air temperatures, with Alexandra, Gisborne and Napier recording the highest temperatures over the recorded period.

[14] http://www.metservice.com/rural/monthly-outlook, accessed on 18/8/2017
[15] https://www.niwa.co.nz/natural-hazards/hazards/droughts, accessed on 18/8/2017

The hottest temperature recorded in 2016, of 35.5 °C, was in February in Clyde (Central Otago)[16]. Cold nights are defined as nights where minimum temperatures are 0°C or lower (Ministry for the Environment, 2016a).

4.2.3 Wildfire

A wildfire is a fire in an area of combustible vegetation. They can be characterized in terms of the cause of ignition, their physical properties, the combustible material present, and the effect of weather on the fire. Non-human causes include lightning, electrical faults (power cables) and hot temperatures and dry climate creating a high risk of spontaneous ignition. Their severity depends on the location, type of material burnt, and the weather. Strong winds, high temperatures, low humidity and seasonal drought can all contribute towards increased fire risk (Pearce and Clifford 2008). Wildfires can cause damage to property, human life and decrease water quality by increasing erosion, which adds sediment to rivers and reservoirs. In New Zealand, wildfires have historically occurred in the eastern and northern parts of both of the two main islands as they are most prone to foehn wind[17] and drought conditions (Pearce and Clifford 2008). Fire weather may occur at any time of the year.

4.2.4 Wind and storms (including ex-tropical cyclones)

High- or low-pressure systems, or the heating or cooling of the sea and land produce air flows, or wind. In New Zealand the prevailing wind direction is westerly. During some months' easterlies can predominate, and north of Taranaki the general flow is south-westerly (Metservice, 2017). In coastal areas such as Canterbury, sea breezes are the predominant winds in summer where northeasterlies are almost as frequent as the predominant southwesterlies. In Wellington, the wind can gust over 60 km/h on average 173 days per year. This is compared with Rotorua, where on average wind gusts exceed 60 km/h for only 30 days per year (Metservice 2017).

Storms are associated with periods of strong, often damaging, winds, heavy flood-producing rainfall, thunder and lightning, heavy snowfall or blizzard conditions (NIWA 2016a). In the last 11 years, the worst storm was Cyclone Fergus in December 1996. This storm released over 300 mm of rain in 24 hours on the Coromandel Peninsula. A cyclone is an area of low pressure around which the winds circulate clockwise in the Southern Hemisphere. An intense storm that originates in the tropics, forming in a single, warm air mass is known as a tropical cyclone. When the winds around the tropical cyclone reach gale force (greater than 62 km/h knots), the storm is named. Tropical cyclones can occur in New Zealand. As they move towards New Zealand they become weaker because the cooler seas provide less heat (NIWA 2016a). The worst cyclones tend to occur from December to April.

4.2.5 Heavy rainfall, flooding, landslides and coastal inundation

Heavy rainfall is one of the most common and widespread severe weather hazards that affects New Zealand. The Metservice[18] defines heavy rainfall as rain that

[16] https://www.niwa.co.nz/news/hottest-november-temperature-in-15-years, Accessed 15/6/2016
[17] A föhn or foehn is a type of dry, warm, down-slope wind that occurs in the lee (downwind side) of a mountain range
[18] http://www.metservice.com/warnings/weather-warning-criteria

reaches 100 mm or more in a 24-hour period or 50 mm or more within a 6-hour period over an area of 1000 square kilometres or more.

New Zealand's mountainous environment affects rainfall and is one of the reasons for heavy rainfall occurrence.

The Metservice[19] has summarised the other main weather-related causes of heavy rainfall in New Zealand:

- ex-tropical cyclones
- North Tasman Sea lows moving to the New Zealand region
- depressions/lows from the south and
- cold fronts.

Heavy rainfall tends to occur most often in the western coastal region of the South Island and the middle and upper North Island. It is the least common on the east side of the South Island due to the prevailing westerlies. Heavy rainfall can lead to a number of hazards including flooding and landslides. Overflowing rivers as a result of heavy rainfall are the most common cause of flooding (Figure 7) (Ministry for the Environment 2008). In June 2015, Whanganui and Raetihi declared states of emergency after 142.8mm and 197mm of rain fell within a 24-hour period. This caused the Wanganui River to breach its banks and flood over 100 homes, resulting in 250 people requiring evacuation. In July 2017 a storm affected large parts of the South Island. The Metservice recorded more than 220mm of rain on the hills north of Dunedin, 162mm in Oamaru and 104mm in Ashburton with a number of landslides reported. Heavy rain increases the risk of landslides. Landslides are generally instabilities of slopes leading to mass movements of rock, debris, and soil down a slope of land. Other causes of flooding in New Zealand include heavy rain associated with storm surges, coastal storms and ex-tropical cyclones.

[19] http://www.metservice.com/warnings/weather-warning-criteria#chart

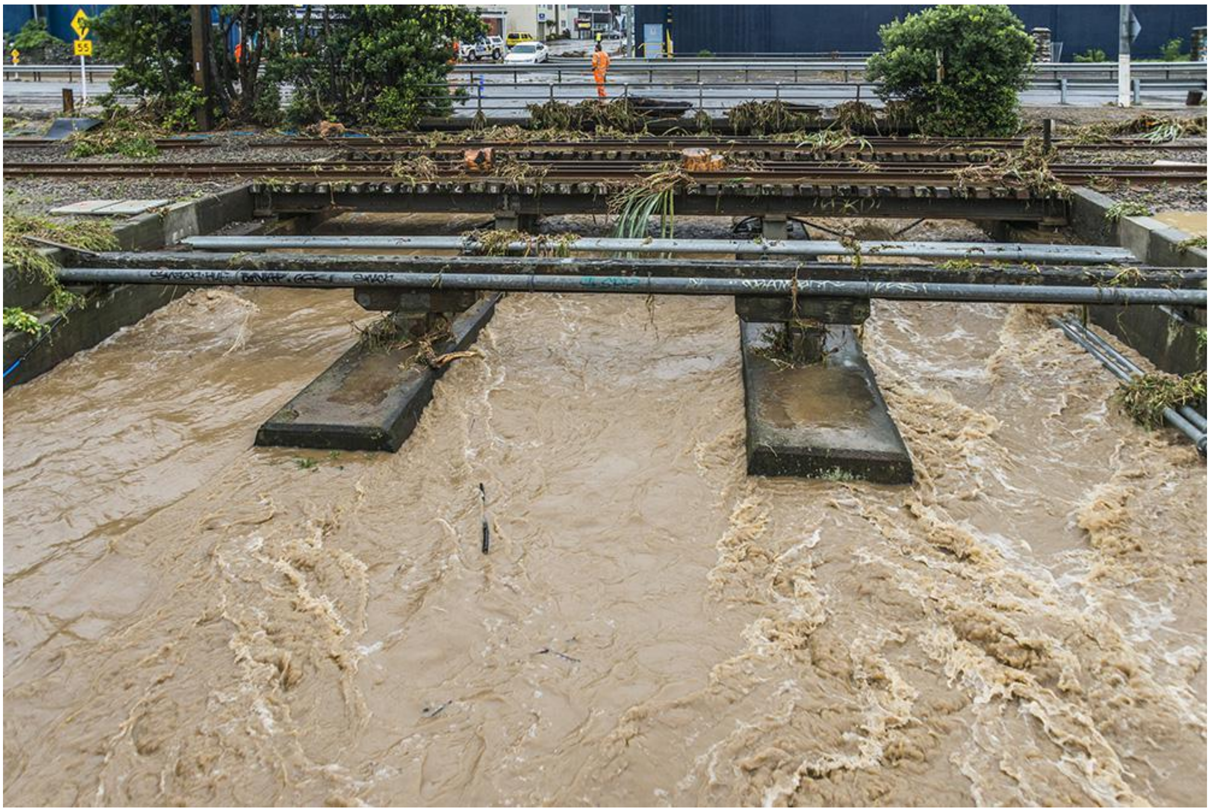

Figure 7: Data from the regional council showed parts of Wellington recording the heaviest hourly rainfall in more than 50 years on 14 May 2015. Drainage systems struggled to cope, causing disruption to major transport routes around the city and the Kapiti Coast. Photograph by Dave Allen on 14 May 2015.

Accessed 15/7/2016. Source: https://www.niwa.co.nz/news/understanding-and-predicting-floods-and-their-impacts

Coastal storm surges occur when low-pressure weather systems affect the coast and continental shelf. Sea level rises in response to lower barometric pressure, and strong winds can pile water up against the coast. When coastal storms coincide with a high tide or king tide they produce higher than normal sea levels known as a storm tide (NIWA 2017a). Perigean spring tides, king tides or highest high tides occur when the moon is new or full, and at the same time, is aligned with the sun and the earth. This increases the gravitational pull on the oceans causing sea level to rise higher than normal. Coastal inundation is particularly likely when high tides, storm surge and/or large waves occur at the same time. At these times, areas where rivers or creeks meet the sea are also more vulnerable because high seas often cause the rivers to back up inland. On 14 July 1995 a small-scale high intensity low-pressure storm generated a large storm surge in the Firth of Thames that coincided with a high king tide (NIWA 2017a). The resulting storm tide flooded extensive areas of low-lying coastal land around Thames and the suburb of Moanataiari.

4.3 THE HEALTH EFFECTS FROM EXTREME WEATHER EVENTS IN NEW ZEALAND

Extreme weather events and potential health effects in New Zealand are summarised in Table 3.

Table 3: Summary of extreme weather events in New Zealand and their associated potential health effects

Risk (Extreme weather event)	Potential impacts	Health risks/benefits
Drought	• Reduced food and water quality and availability • Reduced air quality (dust) • Increased risk of fire • Depletion of water flow affecting hydroelectric power generation	• Increased risk of pathogen contamination and illness (water and hygiene related) • Respiratory impacts (dust-related disease) • Fire-related impacts (see wild fires, below) • Those reliant on steady power supply (critical care devices, hospitals, health care etc.) • Mental health impacts, particularly for those in rural areas who rely on favourable climatic conditions for their livelihoods.
Extreme hot days	• Higher and more frequent or prolonged daily maximum temperature • Damage to essential infrastructure (eg, roads) • Increased risk of fire	• Heat-related death and heat stress • Heat-stress, prolonged exposure to high temperatures, dehydration (Basagaña et al 2011) • Increases in other diseases such as cardiovascular and respiratory disease • Increased hospital admissions • Aggressive behaviour, violence, and suicide (Dossey 2017; Page et al 2012; Ranson et al 2014)
Extreme cold days	• A decrease in the average number of extreme cold days	• Potential reduced winter mortality and cold-related hospitalisations[20] • Reduced infectious disease (eg, influenza)

[20] See section 5.5.2 for further discussion

Risk (Extreme weather event)	Potential impacts	Health risks/benefits
Wildfire	• Smoke • Fire • Damage to property, public infrastructure and essential services	• Asthma exacerbations and respiratory disease • Burns and other traumatic injury • Mental health impacts • Those reliant on steady power supply (critical care devices, hospitals, health care etc.)
Wind and storms (including ex-tropical cyclones)	• Damage to people, property, public infrastructure and essential services • Flooding and landslides leading to communities requiring rescue and isolating others; potentially affecting more areas than present	• Traumatic death and injury • Hypothermia • Mental health impacts • Reduced food and water quality and availability
Heavy rainfall, flooding, landslides and coastal inundation	• Flooding • High winds • Landslides • Storm surges • Damage to property, public infrastructure and essential services • Coastal erosion where coastlines erode due to rising seas and storms. Coastal cliffs can also become eroded, threatening buildings above them • Saltwater intrusion into coastal aquifers. • Damage to agricultural land by physical erosion and contamination by salt water so affecting agricultural productivity and livelihoods.	• Microbial and chemical contamination of floodwater and consequently water used for drinking-water production (Balbus et al 2013; Britton et al 2010a; Davies-Colley 2013; McMichael et al 2006; Patz et al 2000) • Failure of water treatment plants leading to contaminated drinking water (MacKenzie et al 1994; Ministry of Health 2016c) • Traumatic injury (eg, being trapped or swept away) • Drowning • Shock (mental health impacts) • Loss of steady power supply might affect critical care devices, hospitals, health care etc. • Post-flood related illness

The health impacts from extreme events in New Zealand are not well documented. In terms of flooding, deaths are rare, compared with other natural hazards (Ministry of Civil Defence & Emergency Management 2010). Extreme weather events are likely to contribute to New Zealand's total injury burden (including non-fatal injuries) (Bennett et al 2014; NZCPHM 2013) and the burden of poor mental health across urban and rural communities (Berry et al 2010; NZCPHM 2013).

4.4 POTENTIAL CLIMATE RELATED CHANGES TO THE INCIDENCE OF EXTREME WEATHER EVENTS IN NEW ZEALAND

An increasing number of researchers have argued that numerous recent heat waves and floods have been exacerbated by climate change (Hansen et al 2012; Rahmstorf and Coumou 2011; Trenberth 2011). Intermittent extreme weather events are anticipated to increase as the *variability* in the climate system also changes. Even relatively small changes in the average climate may have a large effect on the likelihood or frequency of extreme events. Extreme weather events and their climate projections are discussed in the next sub-sections.

4.4.1 Climate change impacts on drought

The frequency and severity of major droughts are expected to increase in most parts of the country, with the exception of Taranaki-Manawatu, West Coast and Southland (Ministry for the Environment 2016a). This projection therefore includes areas that are not currently known to be drought prone (Figure 8).

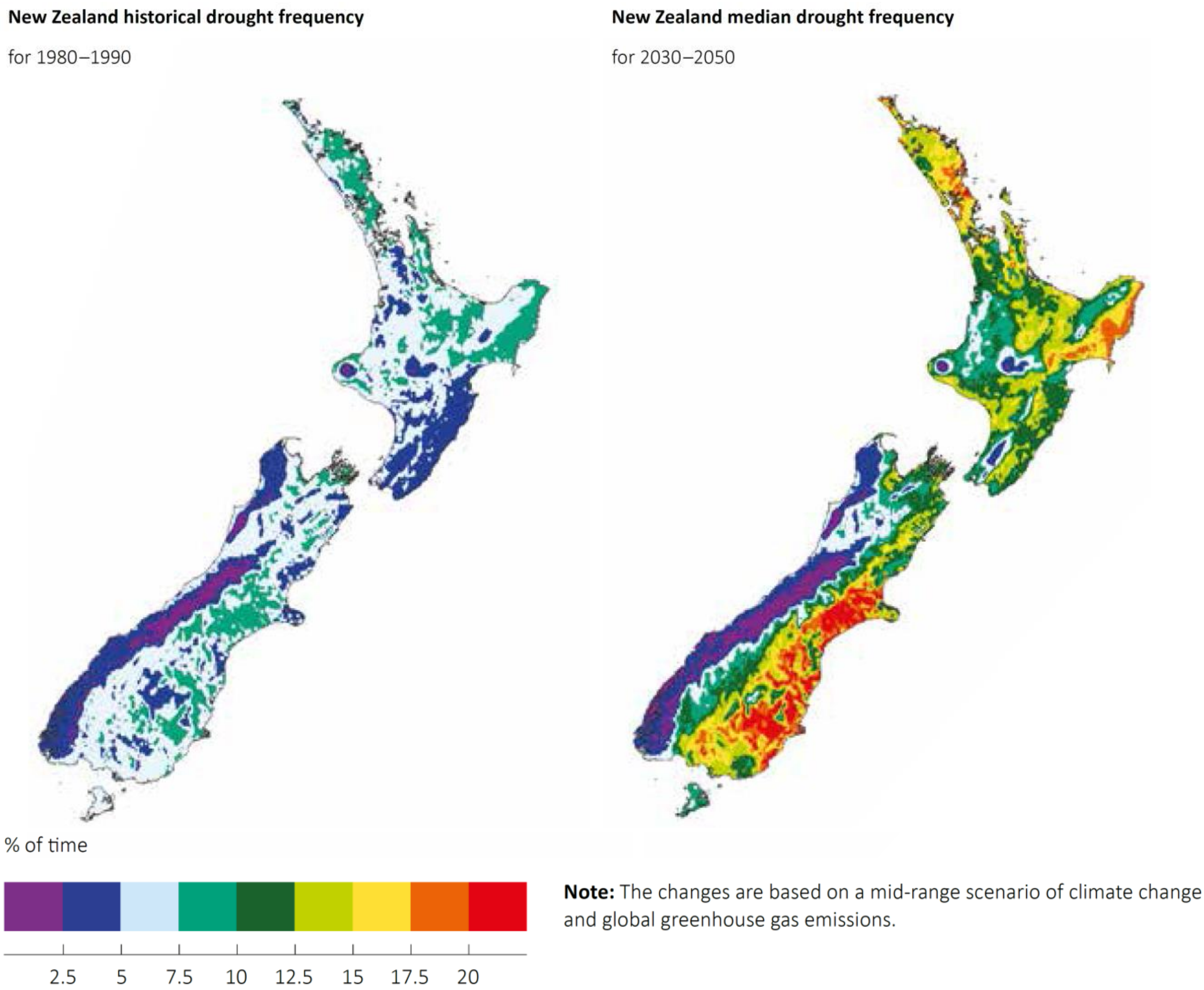

Figure 8: Projected changes in drought frequency across New Zealand under a climate change scenario midway between low- and high-carbon futures.

Source: Clarke et al 2011 in The Royal Society of New Zealand (2016).

Figure 8 shows the average percentage of time that a location is in drought, historically (left map) and projected for the period 2030-2050 (right map). The frequency of droughts is projected to double in some regions such as Canterbury and parts of Otago, which currently are (on average) in drought less than 10% of a year. This could rise to more than 20% of a year after 2030. Rural populations, and communities that depend on non-reticulated water supply systems for their fresh water will become increasingly more vulnerable without suitable adaptation (King et al 2010).

4.4.2 Climate change impacts on hot and cold days/nights

Temperatures are likely to exceed 25°C (Figure 9) during the summer (December to February), in particular at the top of the north and south islands or in the eastern parts of both islands (Ministry for the Environment, 2016a). Low carbon scenarios project a 40% to 100% increase in extreme hot days by 2040 and high carbon scenarios project an increase from 40% to 300%. Figure 9 shows the observed number of days with maximum temperatures exceeding 25°C for 1986 to 2015 and for 2081 to 2100, under the high carbon scenario. Under all scenarios it is very likely that the number of hot days will increase everywhere and the areas with the highest number of hot days include Northland, Hawke's Bay and Waikato (Figure 10).

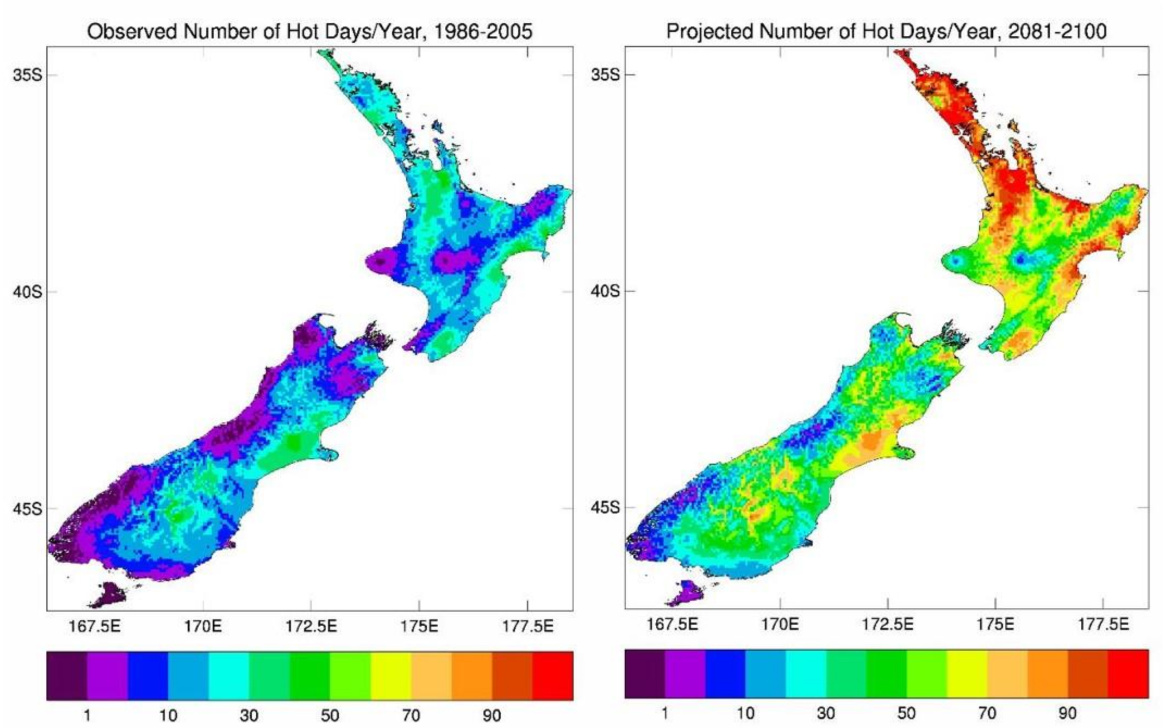

Figure 9: Observed number of days with maximum temperatures exceeding 25°C for 1986 to 2005 (left), and projected number days with maximum temperatures exceeding 25°C for 2081 to 2100 under the high carbon scenario (RCP8.5) using a multi-model average (right).

Source: NIWA, http://www.climatecloud.co.nz/CloudLibrary/nz-climate-change-projections-final.pdf. Accessed 18/8/2017

Under all scenarios average winter temperatures increase (ie, the number of cold nights with a minimum temperature of 0°C or lower will be less) (Ministry for the Environment 2016a).

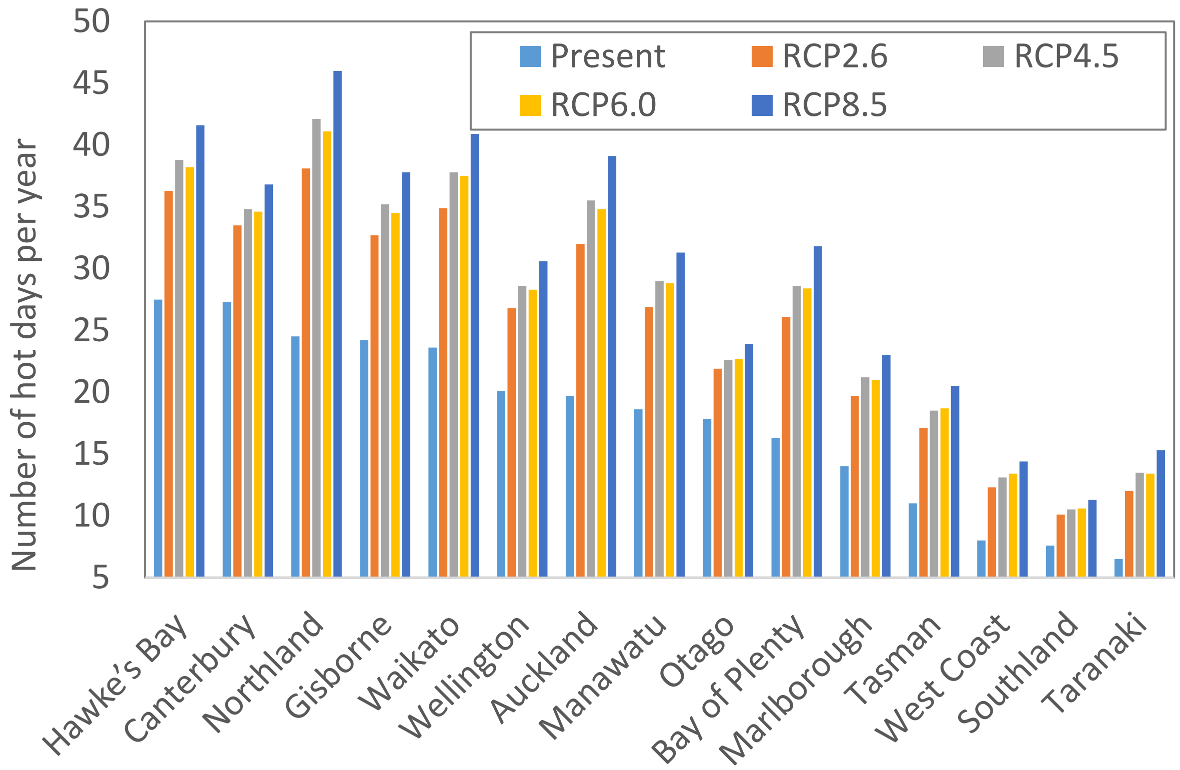

Figure 10: Average number of 'hot days' per year (maximum temperature ≥25°C), by region for (2040) under the four emission scenarios (RCP2.6, 4.5, 6.0 and 8.5).

Source: Ministry for the Environment 2016a Climate Change Projections for New Zealand: Atmosphere Projections Based on Simulations from the IPCC Fifth Assessment.

4.4.3 Climate change impacts on wild fire

Wildfire severity is likely to rise significantly by the middle of the 21st century in many parts of the country due to reduced summer rainfall and increasingly dry vegetation (Pearce et al 2010). In particular, strong winds, high temperatures, low humidity and increased seasonal drought conditions may combine to produce dangerous fire weather situations (Jollands et al 2007; Pearce and Clifford 2008; Renwick et al 2009). Further research by The Royal Society of New Zealand (2016), predicts a doubling or trebling of fire risk in many parts of the country, particularly in the Bay of Plenty, the east of both islands and central (Wellington/Nelson) regions. Other estimates on fire danger have indicated that climate severity is likely to rise significantly with climate change, particularly in the east and south of the South Island (especially coastal Otago and Marlborough and southeastern Southland), and the west of the North Island (particularly around Wanganui) as a result of increases in temperature or wind speed, and lower rainfall or humidity (Pearce and Clifford 2008; Pearce et al 2010; SCION 2011).The projected changes in the average number of days per year of very high and extreme (VH+E) fire danger each fire season (Oct-Apr), from current to 2040 and 2090s, based on an average of 16 global climate models, are shown in Figure 11 (SCION 2011).

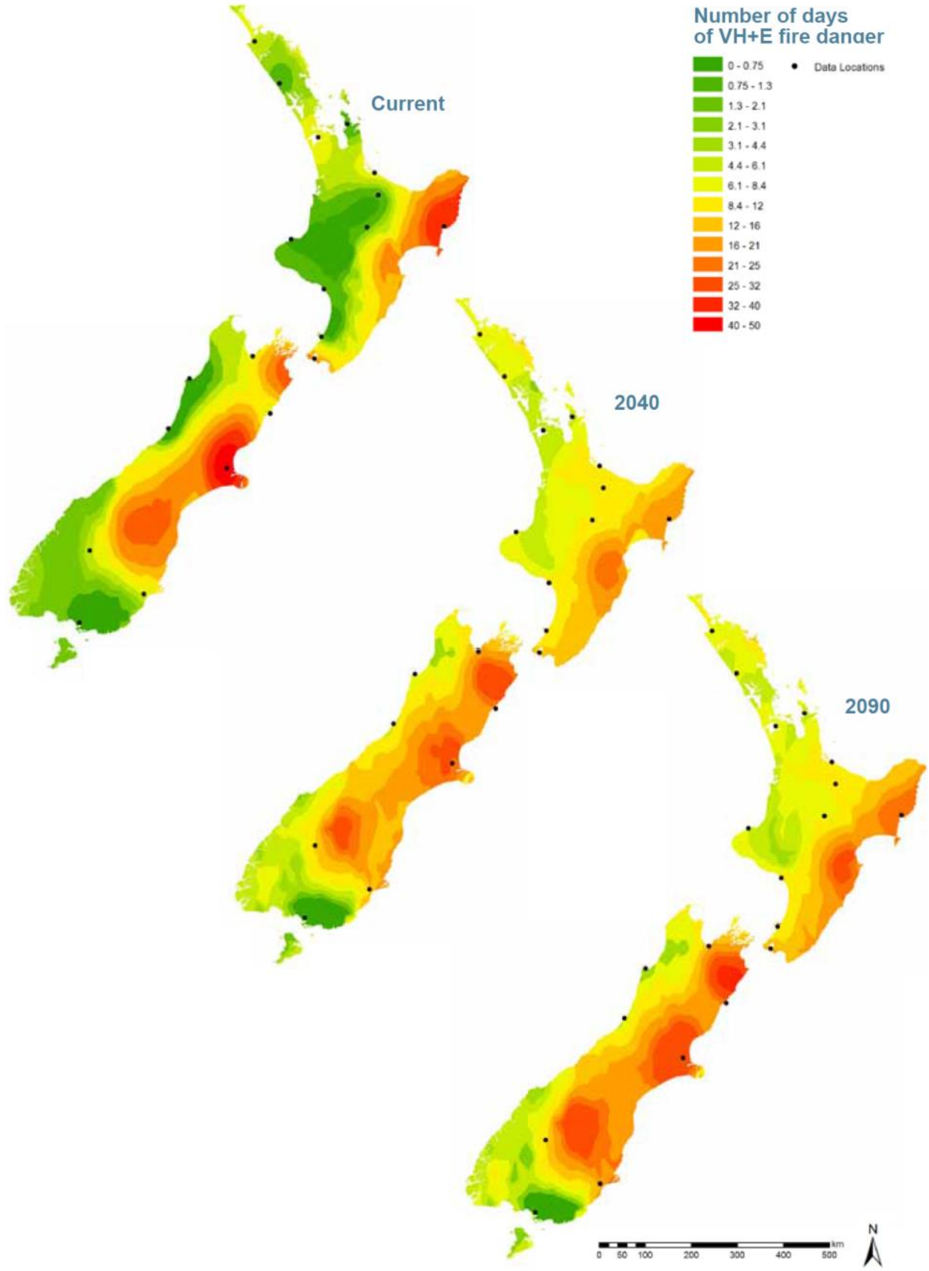

Figure 11: Pattern of projected changes in the average number of days/year of very high and extreme (VH + E) fire danger each fire season (Oct-Apr) from (left) current climate, to (centre) the 2040's to (right) the 2090's, based on the overall average of 16 global climate models investigated.

Source: SCION, 2011, https://www.mpi.govt.nz/dmsdocument/27082-rural-fire-research-update-future-fire-danger

4.4.4 Climate change impacts on wind and storms

Extreme storms, rain and flooding can affect large parts of the country and with very little warning. Daily extreme winds and wind speeds are projected to increase in eastern regions, especially in Marlborough and Canterbury (Ministry for the

Environment 2016a; The Royal Society of New Zealand 2016). There is a likely shift southward of mid-latitude cyclones and possibly a small reduction in their frequency but increase in intensity, although more analysis is needed to be more certain of this (Ministry for the Environment 2016a).

Coastal and river mouth areas may be particularly susceptible to storm surges, increasing exposure from coastal inundation in many areas of New Zealand, including many areas that do not currently have a history of inundation (Ministry of Civil Defence & Emergency Management 2010). Combined with rising seas, future storms may intensify so areas inundated occasionally will increase in frequency. Sea level rise is discussed in more detail in section 4.6.2.

4.4.5 Climate change impacts on heavy rain, flooding and landslides

Increases in annual rainfall are projected for the west and south of New Zealand (Nelson, West Coast, Otago, Southland) in winter, and decreases in the north (Auckland, Northland and Bay of Plenty in spring) and east (Waikato, Gisborne, Hawke's Bay and Canterbury) in winter (Ministry for the Environment 2016a).

Increased heavy rainfall events will increase the frequency of flooding, although any impacts will be dependent on the catchment characteristics of the area. For example, flood statistics across New Zealand as a whole do not show an increase in floods through time to date, rather, increased losses arising from floods are due to increased development in flood-prone areas (Smart and McKerchar 2010). However, heavy rainfall in Golden Bay during 2011, and the resulting flooding, was partly attributed to climate change (Rouse 2012).

Other studies indicate increased rainfall and river flows in areas where there are some major eastern rivers whose catchments reach back into the Main Divide, or in the high country of the central North Island (Ministry for the Environment 2016a; The Royal Society of New Zealand 2016). Those changes may increase the risk of flooding (Easterling et al 2000; Ministry for the Environment 2010; Milly et al 2002). Floods are the most common natural hazard in New Zealand, with approximately two-thirds of New Zealand’s population living in flood-prone areas (Rouse 2012). This population is expected to grow, and therefore flood risk management will provide future challenges, including those related to health risks.

The growth of towns and cities has also been associated with storm water runoff issues. Changes in climate are likely to increase the volume of urban runoff in areas where rainfall is projected to increase in frequency and volume. The increased volume and velocity of storm water runoff, combined with the concentration of pollutants in the storm water, may contribute to changes in hydrology and environmental water quality that may lead to adverse human health effects. These effects include chronic and acute illness resulting from exposure to pollutants in drinking-water, seafood and waters used for contact recreation. Health effects include diarrhoeal and paralytic illnesses caused by pathogenic bacteria (Sales-Ortells and Medema 2015) such as *Vibrio* species and agents such as hepatitis A and Noroviruses and marine biotoxins formed by algal blooms (Gaffield et al 2003). Urban run-off can also contain high levels of heavy metals including copper and lead and also polyaromatic hydrocarbons (PAHs) that are known for their toxic (heavy metals) and carcinogenic effects (PAHs) in humans (Kelly 2010; Tchounwou et al 2012).

Excess nitrogen from urban and agricultural sources, such as fertilizer, may also enter water systems exacerbating harmful algal blooms and impacting on environmental and public health indirectly. Drinking-water containing excessive nitrate concentrations is a concern because of it causing methemoglobinemia in infants (Gaffield et al 2003).

A report by the Parliamentary Commissioner for the Environment (PCE) stated "Overflows from combined stormwater and sewage systems in parts of Auckland during heavy rain have the potential to create major health and environmental problems including adverse effects on local amenity values" (PCE 1996). Changes to climate variability and extremes, current and future deficiencies in areas such as watershed protection, infrastructure, and storm drainage systems will probably further exacerbate the risk of contamination events related to urban and residential runoff.

4.5 HEALTH EFFECTS FROM PROJECTED CHANGES IN EXTREME WEATHER EVENTS

The IPCC (2012) summarised the relationship between climate change and extreme weather and climate events, including health effects, in its summary for policy makers. In New Zealand, Howden-Chapman et al (2010) documented the many health effects from extreme weather events that have historically been problematic, and are expected to become more frequent and severe (eg, flooding) as a result of climate change.

The environmental health effects from projected changes to extreme weather events are summarised in the following sub-sections. Additional indirect social and economic effects on human health from these extreme weather events are expected in the future (Bennett et al 2014) but they are beyond the scope of this review. They include:

- increased pressure on water and food availability
- price changes to food and water, changes in nutritional content of food
- risks related to economic change (lost work capacity/lower labour productivity in vulnerable populations
- loss of livelihoods
- displacement and
- forced migration.

4.5.1 Climate change related health risks from drought

Climate change-related health risks from drought are likely to include the following:

- water shortage for food production (and associated impacts on health)
- water shortage and potential for decreased water quality for drinking including seawater intrusion and
- disruption of infrastructure that depends on water.

Water shortages may lead to decreased food production because plant growth decreases when it is very dry. If this occurs globally and locally, food prices will increase, reducing the ability of some groups to afford nutritious food (Bennett et al 2014; Stanke et al 2013).

Water shortage and water quality also affect health through controls on water use, for both reticulated and non-reticulated supplies. There is some evidence to suggest that the incidence of exposure to the pathogens *Cryptosporidium* and *Giardia* in humans will increase with increasing drought conditions. Lal et al (2013) suggested that parasite cysts or oocysts may concentrate in the surface water during a drought, and later be flushed from the water source when the drought breaks. Communities that use non-reticulated systems, such as roof water supplies, are not required to adhere to water quality testing programmes, so may not be aware of any pathogen contamination in their drinking water supply. These communities do not have to demonstrate compliance with the drinking water standards and may also have inadequate resources to tanker in water or pay for point of use treatment systems (Ministry of Health 2017b; King et al 2010; Major et al 2011). For communities without a secure water supply, in areas where drought is expected to increase and that experience a reduction in population and economic prosperity, the risk from waterborne infectious disease, toxins and contaminants may occur more frequently (Eberhart-Phillips et al 1997; Simmons and Smith 1997). In coastal areas, water shortages may arise because of seawater intrusion into water supply aquifers because of reduced fresh water levels in the aquifer.

Overseas, concerns in the USA are increasing over the enhanced risks of transmission of some infectious illnesses during drought periods. Such diseases include coccidioidomycosis (Valley Fever) from fungal spores inhaled from disrupted soils, and cerebral infections arising from *Naegleria fowleri*, a pathogen found in untreated surface waters, that have proved fatal in recreational swimmers (Brown et al 2013; Visvesvara 2010). The growth of these pathogens is favoured in warmer water, which may result during drought as surface waters decrease in volume. The fungi responsible for coccidioidomycosis are not present in New Zealand and do not pose a concern. *Naegleria fowleri* related cases in New Zealand are rare, and are usually associated with contaminated (usually warm) fresh or inadequately treated water (Ministry of Health 2012e). No specific studies were found related to this organism and climate change in New Zealand, although international studies suggest an increase in its geographical range (Kemble et al 2012; Marcogliese 2008; Rose et al 2001).

In general, times of high temperature, will lead to an increased demand for water. This will require ways of managing both the water supply and the careful use of water by the consumers. There may also be an increased risk of power supply disruption to essential services because of the possible reduced availability of hydroelectric power (Klinger et al 2014).

4.5.2 Climate change related health risks from hot and cold days

The number of hot days in New Zealand is expected to increase and with this the incidence of:

- heat stress (Kjellstrom et al 2016)
- heat-related deaths and illness (Smith et al 2014)
- complications to chronic conditions --- eg, diabetes and cardiovascular disease increase sensitivity to heat stress (Bunker et al 2016; Ye et al 2012)
- poor mental health including increases in aggressive behaviour and negative impacts in those already suffering from mental health issues.

In Europe, heat related mortality, remains an on-going concern. There is growing evidence from the EuroHEAT[21] study that the effects of heat-wave days on mortality are greater, particularly among older people, when levels of ozone or particulate matter are high.

In France, an excess of 14,947 deaths in 2003 were caused by a heat wave. The excess mortality was directly attributable to dehydration, hyperthermia and heat stroke (Poumadère et al 2005). Although diversely impacted or reported, many parts of Europe have suffered from other losses, including in farming and forestry through drought and fires that have also had secondary impacts on health (Bambrick et al 2011; Poumadère et al 2005).

A study by Taylor et al (2015), found that temperature increases may be compounded by the urban heat island effect, resulting in increased mortality rates. In particular, certain dwellings (eg, top floors of high buildings facing the sun) were found to exhibit overheating risks, and population age was considered a risk factor for heat mortality. The increases in heat-related morbidity and mortality will also put pressure on future hospital services.

Increased numbers of hot days will also affect behavioural choices and could lead to acute sunburn whilst increasing the long-term risks of skin cancers and other UVR-related diseases (see section 3).

[21] http://www.euro.who.int/en/health-topics/environment-and-health/Climate-change/publications/2009/improving-public-health-responses-to-extreme-weatherheat-waves.-summary-for-policy-makers.-euroheat

The predicted decrease in the number of cold days is likely to result in a decreased incidence of winter mortality and hospitalisations, since these are generally associated with poor housing, fuel poverty and cold effects (Howden-Chapman et al 2012). However this decline is uncertain because winter deaths may also be influenced by seasonality (eg, cycles of infectious disease) rather than temperature (Bennett et al 2014). In a multi-country[22] observational study that examined temperature attributable deaths from heat and cold, more deaths were caused by cold than by heat by a factor of nearly 20 (Gasparrini et al 2015).

4.5.3 Climate change-related health risks from wild fire

The frequency of wild fire events is projected to increase with changing climate, including changes in season and length of fire season (Clarke et al 2011; Lucas et al 2007). Many rural regions also face threats to future sustainability as greater proportions of the aged reside in these areas (Horton et al 2010).

Increased fire risk in the future could lead to an increased incidence of:

- burns and other injuries
- smoke inhalation injuries (Finlay et al 2012; Handmer et al 2012).
- exacerbation of respiratory conditions such as asthma (Beggs and Bennett 2011; Bennett et al 2014; Johnston et al 2002) and indirectly,
- decreased water quality from increased erosion (Shakesby et al 2007; Smith et al 2011; Wilkinson et al 2009).

4.5.4 Climate change related health risks from wind, storms, ex-tropical cyclones, tornadoes, sea level rise and storm surges

Storminess is likely to increase with the move towards a high carbon world [RCP 8.5] and with this the incidence of:

- food and water insecurity
- pressure on health services
- infectious diseases
- mental health problems and
- exacerbation of pre-existing medical conditions.

4.5.5 Climate change related health risks from heavy rain and flooding

Flooding is likely to increase in frequency and intensity and with this the incidence of:

- physical damage to people, property, public and health infrastructure and essential services
- disease outbreaks, toxins, chemical contamination
- negative effects from living in damp buildings and
- mental health problems.

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[22] The countries analysed included Australia, Brazil, Canada, China, Italy, Japan, South Korea, Spain, Sweden, Taiwan, Thailand, UK, and USA but did not include New Zealand.

A systematic global review of waterborne outbreaks following extreme weather related events by Cann et al (2013), found heavy rainfall and flooding were the most common events preceding outbreaks. Of those, the most common pathogens that were reported were *Vibrio* species (21·6%) and *Leptospira* species (12·7%). Many of the outbreaks were the result of contaminated drinking-water supplies. As this was a global review, the majority of the *Vibrio* outbreaks were from Asia. Another zoonotic bacterium of concern is *Leptospira*. This can be introduced into water from the urine of animals (Bharti et al 2003). An observed increase in illness rates in humans has been linked to warm temperatures and flooding events (Hartskeerl et al 2011; Lau et al 2010; Lau et al 2012). Again most of those outbreaks occurred in Asia or North America. Further information on health risks related to waterborne infections and contaminants in New Zealand are discussed in section 5.

Other contaminants can be sourced from agricultural land, including pesticide residues and heavy metals. Increased flooding may result in chemical contamination of food and water sources. However, the effect of these residues on human health is complex. Some studies suggest that degradation of pesticides will occur faster at higher temperatures (Miraglia et al 2009; Wheeler 2015). Concentrations of heavy metals may also increase as a result of periodic exchange between wet and dry conditions, which can lead to less stable forms of metal deposits and consequently an increase in the bioavailability (available to the body) of heavy metals (Hershey 2017).

4.5.6 Climate-related health risks from sea level rise and storm surges

Increases in rainfall, and sea level rise in the future may have numerous effects on environmental waters. Some of the most important changes include:

- increases in the peak flow in waterways which may lead to erosion and sediment input
- changing flood plains and greater likelihood of damage to properties, infrastructure and increased risk of waterborne diseases
- changes to groundwater levels and
- saltwater intrusion in groundwater in coastal zones.

The environmental health implications associated with such events are similar to those faced by flood prone communities.

They include:

- physical harm, injury and death
- marine submersion with direct flooding affecting homes and infrastructure
- erosion of cliff coasts, threatening buildings above them and
- contaminated drinking water from aquifers at the coast because of seawater intrusion
- mental-health effects

4.6 MODULATION OF EXTREME CLIMATE

4.6.1 El Niño Southern Oscillation (ENSO)

The earth's climate is naturally variable and can fluctuate on timescales of 10 to 100s of years. A modifier of climate that can impact New Zealand's weather is El Niño and La Niña or El Niño Southern Oscillation (ENSO). ENSO is a periodic fluctuation in sea surface temperature and the air pressure of the overlying atmosphere across the equatorial Pacific Ocean. An El Niño year in New Zealand normally results in drier-than-normal conditions in east coast areas and more rain than normal in the west from stronger or more frequent winds from the west in summer (NIWA, 2016b). In winter, ENSO can mean colder southerly winds, while in spring and autumn, southwesterlies tend to be stronger or more frequent, bringing a mix of the summer and winter effects. La Niña years tend to result in warmer than normal temperatures over much of the country with some regional and seasonal exceptions. North–easterly winds are characteristic, bringing moist, rainy conditions to the north–east of the North Island, and reduced rainfall to the south and south–west of the South Island. ENSO can also play an important role in the occurrence of fires, storm events, flooding and drought (Cai et al 2009; Pearce et al 2003; Pearce et al 2007; Ashok et al 2007). The probability of climate variations occurring in association with events such as ENSO are sufficient to warrant management actions and planning to be taken when an El Niño or La Niña year is expected or in progress (Murphy and Timbal 2008; NIWA 2016b; Ummenhofer and England 2007).

Other variations to climate include the Southern Annual Mode (SAM) and the Interdecadal Pacific Oscillation (IPO). The SAM is the leading mode of variability in the southern hemisphere and can modify climate on month to month and year to year basis. Its variability also has large impacts on aspects of southern hemisphere climate including in New Zealand (Marshall 2016). The IPO is a naturally variable fluctuation in wind and rainfall that occurs over a decadal (10's of years), timescale, and results in changing river flow and flooding. The relationship between the IPO and flooding is discussed in detail in Parts 1 and 2 of the Ministry for the Environment report, "Preparing for future flooding: A guide for local Government in New Zealand" (Ministry for the Environment 2010). The report states that IPO and climate change effects may need to be considered together when calculating flood risk.

4.6.2 Sea Level Rise

Coastal areas are physically at risk from climate change in New Zealand and were examined in the PCE's report on rising seas (PCE 2015b). Globally, the oceans have risen by approximately 20 cm on from 1901 to 2010 (Church et al 2013). In New Zealand, sea level rise is comparable with global records, but could rapidly increase with the destabilisation of polar ice sheets. The PCE estimated that approximately 9,000 homes are currently less than 0.5m above high spring tide levels (PCE 2015b). Dunedin has 2600 homes below this threshold and Napier, Lower Hutt, Christchurch, Dunedin and Whakatane are currently at risk from sea level rise.

Tropical cyclones, storm surges and flooding are also likely to interact with higher mean sea-levels (Ahern et al 2005).

Without adequate mitigation and adaptation, coastal erosion may force some communities to relocate if not properly managed, as observed in some parts of the West Coast. Changes in land use may also affect social wellbeing because some activities may no longer be feasible.

Saltwater intrusion in the context of this review is principally connected to rising sea levels and the contamination of drinking-water drawn from coastal aquifers. Human factors such as groundwater abstraction rates and increased water demand during the summer may affect the balance between the rates of freshwater recharge in the aquifer and saltwater intrusion. Potential future impacts from saltwater intrusion for fresh water use will require careful monitoring of coastal aquifers.

4.7 VULNERABLE POPULATIONS

The most vulnerable populations or communities at risk from extreme weather events in general are (EHINZ 2014; Bennett et al 2014; The Royal Society of New Zealand 2017):

- the young and old
- those with chronic illness
- those with respiratory illness
- those with mental or cognitive illness
- pregnant women
- schools and hospitals that are located close to risk prone areas
- those living in isolated areas
- those housebound or reliant on a secure source of power and
- potential future populations that may move into new areas that are prone to extreme events.

4.8 ADAPTATION OPTIONS TO REDUCE ENVIRONMENTAL HEALTH RISKS ASSOCIATED WITH CLIMATE RELATED EXTREME EVENTS

The World Health Organisation, and many other New Zealand-based organisations have produced in-depth guidance to adapting and managing a number of extreme events including early warning system development (McGregor 2015), toolkits and decision-making software (eg, RiskScape[23]) and integrating climate change risks into disaster risk management (IPCC 2012). However other studies suggest that adaptation strategies should focus on moderate non-optimum conditions instead of record-breaking weather to obtain the greatest health benefits (Dear and Wang 2015).

We can also learn from countries that are already dealing with the adverse effects of extreme weather and those that have already developed extensive health plans,

[23] https://www.riskscape.org.nz/

planning guides and tools (Table 4). The following section summarises a number of adaptation options for extreme events in New Zealand.

4.8.1 Adaptation to drought

Drought is expected to increase in the eastern parts of the country. The Ministry for Primary Industries leads work with rural communities to respond to droughts[24]. Other projects mapping out the vulnerability of populations to drought events, particularly those without reticulated water supplies are required.

4.8.2 Adaptation to heavy rain, flooding, coastal storms, storm surges and sea-level rise

For flooding, guidance exists to provide decision-makers to deal before, during and after flooding events (Ministry of Civil Defence & Emergency Management 2010; Menne and Murray 2013; Ministry for the Environment 2010). Early warning systems for flooding and fires are becoming more established in European countries given the risk of these occurring more often and severely in the future. In New Zealand careful planning and integrated responses from all levels of Government is required. In coastal communities, adaptation options include protection (eg, installation of hard or soft structures in areas vulnerable to coastal erosion), accommodation (eg, green buffer zones such as wetlands and parks) and retreat (eg, moving houses away from the coast) (Rouse et al 2016).

4.8.3 Adaptation to wind and storms (including ex-tropical cyclones)

Structurally damaging winds are rare although some preparation in terms of building design could be considered should wind and storm events increase in intensity. BRANZ have compiled a report on how to adapt existing housing stock to climate change related impacts (Bengtsson et al 2007).

4.8.4 Adaptation to hot days

Extreme heat related events in the future could increase morbidity, particularly in vulnerable populations. Heat risk plans will help prepare communities and health authorities. Some of the adaptive measures may include increased cooling in buildings. This is likely to impact on those from lower socio-economic status who may be unable to afford air conditioning. However, it must also be recognised that winter mortality may also continue to be an issue in colder parts of the country, and adaptive measures to improve housing also need to be balanced to reduce the burden on health, particularly in vulnerable populations. More effort should be placed on improving overall building standards.

Although reduced physical activity due to extreme heat may be a concern, this could be addressed by education and improved indoor environments. In built-up, highly populated urban environments broad structural changes to building codes (Jonas et al 2007), urban design (Bambrick et al 2011), policy and infrastructure capacity could increase levels of physical activity, improve air quality and build resilience to physical

[24] https://www.mpi.govt.nz/protection-and-response/responding/adverse-events/classifying-adverse-events-/dealing-with-drought-conditions/

weather related risks (Canyon et al 2015; Jollands et al 2007; Lindsay et al 2011; Stamatakis et al 2013).

Extreme events are also capable of leading to complex indirect effects such as reduction in locally grown food, which may lead to food price increases. A lack of water may force councils into introducing stricter regulations around domestic water use. These may include the implementation or increase of water charges where they are not already in use, which has the potential to lead to health inequalities. These issues are described in Table 4.

4.8.5 Adaptation to cold days

Improvements in building design, energy efficiency and access to affordable heating will help to decrease winter morbidity and mortality related to poor quality housing. It is important to consider potential health related inequalities, particularly where replacement of home heating could disadvantage poorer families. For example, a health impact assessment review of Environment Canterbury's air plan and the potential effect of wood burner restrictions on wood burning households in Christchurch (CDHB 2014) found that:

- a ban on wood burner use could exacerbate a range of health impacts related to low household temperatures
- the high capital cost to replace wood burners would lead to the purchase of inexpensive heating sources that are up to 3 times more expensive in energy costs and
- the quality of rental accommodation is a key factor related to potential health risks.

4.8.6 Adaptation to wildfire

For mitigation and adaptation to increased wildfire risk, improved co-ordination between the New Zealand Fire Service and local authorities to consider and plan for wildfires and their impacts on public health infrastructure would be beneficial. Prevention is clearly the preferred route, and careful planning is needed in areas targeted for reforestation as part of the Government's emission trading scheme.[25]

[25] https://mpi.govt.nz/growing-and-producing/forestry/forestry-in-the-emissions-trading-scheme/

Table 4: Summary of mitigation and adaptation options to reduce the environmental health risks from climate-modified extreme events

Risk	Mitigation/Adaptation Options	Direct Health Benefit	Reference
Drought	• Improve understanding on how drought may affect health, including indirect impacts, and how these may change over time eg, aerosolisation of pathogenic fungi • Increasing opportunities for water reuse • Development of crops resistant to drought and disease • Alternative storage of freshwater (eg, reservoirs) • More efficient water usage (public and private)	• Reduction in future health risks • Food security will reduce risk related to escalated food prices and nutritional issues	Renwick et al 2010; Royal Society of New Zealand 2016; Water New Zealand 2015
Fire	• Readiness of emergency services and communities • Co-ordinate environmental health responses with the New Zealand fire service • Improve planning and regulations to incorporate controls for wild fire (eg, submissions on district and regional plans) • Building design and development of new materials to reduce flammability • Improve fuel management and control • Couple early warning systems with real time fire prediction • Improve fire detection and suppression technologies • Education (particularly with controlled burns) • Smoke dispersal warnings • Improve understanding of climate drivers of fire risk	• Control of fires, reduced risk of spread • Fire prevention • Reduction of health effects from uncontrolled fires	Crompton et al 2010; Handmer and Haynes 2008; Handmer et al 2012; McMichael et al 2006; Pearce et al 2011; Pearce and Clifford 2008; Reisinger et al 2014

Risk	Mitigation/Adaptation Options	Direct Health Benefit	Reference
Heavy rain Flooding Coastal storms Storm surges Sea-level rise	• Modelling to examine the effect of climate change on infectious diseases. • Protection from coastal storm surges • Improved sentinel case surveillance for infectious diseases • Flood protection engineering (soft and hard approaches) • Improved urban drainage • Infrastructure adaptation • Ecosystem based approaches (eg, riparian planting)	• Improved understanding between various hazards and their relationship to climate and health for efficient emergency planning	Leyer et al 2012; Thacker et al 2017; Shao et al 2017; Yao et al 2013

Extreme Heat	• Development of a register of at-risk individuals and developing methods to 'check-up' on their health status
	• Examination of use of alternative technology (eg, smart phone applications) as early warning systems
	• Using a heat-health action framework protecting the public and minimizing public health effects of hot days
	• Model for projection of heat-related mortality attributable to climate change
	• Education and planning of areas suitable to seek refuge in larger cities
	  • Health care system preparedness such as advanced warning (vulnerable persons), health interventions (eg, shade areas in parks, schools, cool building refuges)
	  • Water supply plan for periods of high water usage that encompass the risks to health care workers and the health care system
	• Consideration of a summer-fuel payment in high impact areas (ie, air conditioning) for the vulnerable, similar to that of the winter fuel
		• Reduction of at-risk individuals
		• Mitigation of adverse impacts during extreme events
			Akompad et al 2013; Climate ADAPT 2016; Freeman 2015; Honda et al 2014; Huang et al 2013; NYC'S RISK LANDSCAPE 2014; PWC 2011; US EPA and CDC 2017; Victoria State Government 2016;WHO 2013

	payment[26] offered in the UK and other countries		
Extreme cold	• Improvements to housing (eg, insulation, energy efficient heating) • Winter fuel subsidies for vulnerable populations	• Decreased mortality related to poor housing • Decrease health related inequalities	NZCPHM 2013
Overarch -ing risks	• Streamlining climate change related impacts with those of disaster risk management to develop early warning and emergency response plans	• More efficient health response	ISDR 2009

4.9 CONCLUSIONS

This section suggests that some extreme weather events in New Zealand will increase in either frequency, severity or both. Flooding in particular remains one of the most important natural hazards in New Zealand and is likely to increase in frequency and intensity as a result of extreme weather events. Coastal and low lying communities are also at risk from the combined effects of sea level rise, coastal flooding and erosion without adequate adaptation.

Overarching issues that affect environmental health in relation to extreme weather events include:

- disruption of infrastructure including power, water, transportation, communication and health care systems and services
- the need to improve community awareness to reduce adverse exposures and
- social support for those most at risk.
- District health board public health units should also regularly review their mitigation of risks and responses to extreme events in submissions on district and regional plans.

The research gaps identified from this review and of particular importance to New Zealand include:

- understanding population vulnerability and resilience in particular:
    - Impacts on older people. By 2051, one in every four of all New Zealanders is expected to be over the age of 65 which will increase the number of vulnerable people at risk from extreme weather events.
    - understanding individual and community vulnerability to health impacts after extreme events particularly social and behavioural characteristics

[26] https://www.gov.uk/winter-fuel-payment/overview

    and how they might contribute to or mitigate risks of adverse health outcomes
  - examination of the complex connections between health, inequality, social wellbeing and risks in the most vulnerable populations and
  - how evacuation of communities can cause stress, and post-event psychological effects.
- evidence that relates health impacts to extreme events to support policy, mitigation and adaptation. For example, preliminary work examining post-flood risk from housing materials has found *E. coli* and fungi were present following a number of submersion and drying treatments on glass wool insulation (S Halford, Victoria University of Wellington, personal communication, 2 February 2017).

5. INFECTIOUS DISEASE

5.1 INTRODUCTION

This section reviews how climate change could modify human exposure to organisms that cause infectious disease. Infectious diseases are caused by pathogens such as viruses, bacteria, parasites or fungi. They can be transmitted from one host to another, ie, between humans (communicable), between animals and humans (zoonotic), indirectly through a carrier organism (vector-borne, eg, mosquito) or through the environment (eg, via water or soil), objects (eg, door handles, bedding), food and drinking water.

Pathogenic microorganisms (referred to as infectious agents) are the specific focus, these are organisms that are transferred through the environment. This includes those naturally-occurring in the atmosphere (air), soil and water.

5.2 EXPOSURE AND HEALTH EFFECTS FROM INFECTIOUS DISEASES IN NEW ZEALAND

Infectious diseases of interest, their exposure routes and health effects are listed in Table 5. Areas in bold indicate those transmitted through environmental routes.

Table 5: Infectious disease of interest, exposure routes and health effects

Disease of interest[27]	Infectious Agent	Exposure Route	Primary Health Effect(s)
Campylobacteriosis	*Campylobacter* bacterium	Undercooked contaminated food and **water**. Direct spread from an infected person or animal	Stomach pain, fever, nausea, diarrhoea and/or vomiting
Cryptosporidiosis	*Cryptosporidium* parasite		
Giardiasis	*Giardia* parasite		
Salmonellosis	*Salmonella* bacterium		
Legionellosis	*Legionella* bacterium	Inhalation of **mists** or **spray** (aerosols) from a **water source** that contains *Legionella* bacteria or inhaling dust from **soil** containing *Legionella*.	Range from mild respiratory illness (Pontiac fever) to pneumonia (Legionnaires disease)

[27] Modified from https://www.healthed.govt.nz/resource/infectious-diseases

Disease of interest[28]	Infectious Agent	Exposure Route	Primary Health Effect(s)
Vibriosis	*Vibrio* and *vulnificus* bacterium	Contaminated food and **water**.	Stomach pain, fever, nausea, diarrhoea and/or vomiting, wound infection, septicaemia

5.3 POTENTIAL CLIMATE RELATED CHANGES TO INFECTIOUS DISEASES OF INTEREST

There is evidence that climate warming is causing profound and complex changes in the prevalence of some infectious diseases, through changes to the pathogen's life cycles, transmission and distribution (Altizer et al 2013; Baker-Austin et al 2013; Bezirtzoglou et al 2011; Burge et al 2014; Harvell et al 2002). The anticipated changes to the incidence and distribution of infectious disease due to climate change and the link to environmental exposure routes are summarised in Table 6 and discussed in more detail in the following sub-sections.

5.3.1 Waterborne infectious agents

An increase in the incidence of waterborne infectious agents is expected as a result of climate change in New Zealand. Climate change and its impact on the water cycle is likely to result in increased concentrations of infectious agents in water bodies. Infectious agents can become concentrated during drier months or transported into water bodies as a result of heavy rainfall flow (see Section 4.2.5). Heavy rain events also carry the risk of increased infectious disease because of treatment systems failing to remove or inactivate pathogens. The increases are likely to impact on drinking-water quality and transmission via faecal-oral routes (Few et al 2004). In water used for recreation, users could be exposed to increased concentrations of waterborne pathogens that lead to infection through direct contact, ingestion or inhalation (CPHR 2016; McBride et al 1998; Yusa et al 2015).

[28] Modified from https://www.healthed.govt.nz/resource/infectious-diseases

Table 6: Potential climate related changes to infectious disease and their environmental exposure routes Infectious disease of interest, exposure routes and health effects

Infectious disease	Anticipated change in incidence rates related to climate	Potential environmental exposure routes	Reference
Campylobacteriosis	• Increase, particularly during the summer due to strong link with temperature	Water contamination: • drinking water • irrigation water • overflowing sewage pipes or inadequate drainage • land run-off • living close to areas with high cattle densities	Lal et al 2015; Ministry for the Environment & Statistics NZ, 2015f
Cryptosporidiosis	• Increase, particularly during drought periods or heavy rainfall. • Negative association with temperature	Water contamination: • drinking water • irrigation water • overflowing sewage pipes or inadequate drainage • land run-off	Bradbury et al 2013; Cann et al 2013; Collins and McGonigle 2008; Funari et al 2012; Lal et al 2013; Ministry for the Environment & Statistics NZ, 2015f; Till et al 2008
Giardiasis	• Increases with increasing temperature and rainfall	Water contamination: • drinking water • irrigation water • overflowing sewage pipes or inadequate drainage • land run-off	Bradbury et al 2013; Cann et al 2013; Collins and McGonigle 2008; Funari et al 2012; Lal et al 2013; Till et al 2008

Infectious disease	Anticipated change in incidence rates related to climate	Potential environmental exposure routes	Reference
Salmonellosis	• Increase, particularly during summer and following heavy rainfall	Water contamination: • drinking water • irrigation water • overflowing sewage pipes or inadequate drainage • land run-off	Ministry for the Environment & Statistics NZ, 2015f; Stephen and Barnett 2016;
Legionellosis	• Potential increase in soils and water systems • Risk in self-supplies if water level low and sludge increases in temperature in the presence of Legionella	Land contamination: • soils, particularly potting mix and compost Water contamination: • drinking water • aerosols produced by vehicles • water systems such as showers and mist-types of air conditioning. • green walls and roofs, rainwater harvesting and greywater recycling systems in buildings.	Funari et al 2012; Graham et al 2012; Sakamoto 2015; Schenck et al 2010; van Heijnsbergen et al 2015; Vardoulakis et al 2015
Vibriosis	• Increases with increasing temperature	Water contamination: • contact with estuarine or marine water	Cruz et al 2015; Siboni et al 2016; Vezzulli et al 2012

5.3.2 Climate Change and Exposure to *Campylobacter, Cryptosporidium, Giardia* and *Salmonella*

Changing climate conditions can become more favourable to particular pathogens (Vardoulakis et al 2015). In New Zealand, McBride et al (2014) reported that the incidence of diseases caused by two pathogens of human health significance, the bacterium *Campylobacter* and the protozoan parasite *Cryptosporidium*, would increase under changing climate. Their modelled projections revealed substantial changes in reported rates of illness across the country. The annual rate of campylobacteriosis was projected to increase by 20-36% in children by the year 2090. In another New Zealand study, infections caused by *Campylobacter* were correlated with increased temperature (Kovats et al 2005). Similarly, a study based in Germany found an increase in ambient temperature positively correlated with an increase in cases of campylobacteriosis and salmonellosis, with a five-week lag (Yun et al 2016). In comparison, a study from the Netherlands examining infection risks from simulated runoff from land to surface water did not find any significant effect of climate change on infection risks from *Campylobacter* or *Cryptosporidium* (Sterk et al 2016). It should be noted that a number of non-climatic risk factors also exist for campylobacteriosis including transmission through food. Therefore, foodborne related illness may also be important risk factors associated with warming temperatures (Rind and Pearce 2010; Sears et al 2011).

The Health Analysis & Information for Action (HAIFA) study modelled projections of climate change on the incidence of campylobacteriosis and cryptosporidiosis for New Zealand (Tompkins et al 2012a). Projections using the emission scenario[29] A2 (high) for the year 2090, show that the percent change in incidence risk for *Campylobacter* was positive and ranged from a 3% increase in the winter and spring, to a 30% increase in the summer. For the year 2040, projections show a similar spatial and seasonal pattern with the projected percentage change reduced in magnitude. For autumn, winter and spring, the change includes negative percentages (Figure 12a and b). The range of projected change spans from a 4% decrease in the autumn to a 15% increase in the summer.

When repeated for the emission scenario A1B for the year 2090, the projected percentage changes in incidence are all positive and range from a 2.2% increase in the autumn and spring, to a 25% increase in the summer. The pattern across the four seasons and across the country is the same as that seen for the A2 projections. For 2040, projections show a similar spatial and seasonal pattern with the range of projected percentage change reduced in magnitude (2.4% decrease in autumn and spring, to a 15% increase in summer).

The HAIFA model also projected the percent change in incidence risk for cryptosporidiosis as more variable for all years. The incidence rate for the A2 scenario in 2090 projected a 51% decrease in the winter to a 40% increase in the spring and autumn with spatial differences across the country (Figure 12c and d).

[29] The [GHG] emission scenarios used in the HAIFA model included: A1: Rapid economic growth followed by rapid introductions of new and more efficient technologies; A2: A very heterogeneous world with an emphasis on family values and local traditions; A1B climate scenario is derived from the A1 scenario with an influence from B1, focusing on a balanced technological change in energy systems and economic growth; B1: Introduction of clean technologies; B2: Emphasis on local solutions to economic and environmental sustainability.

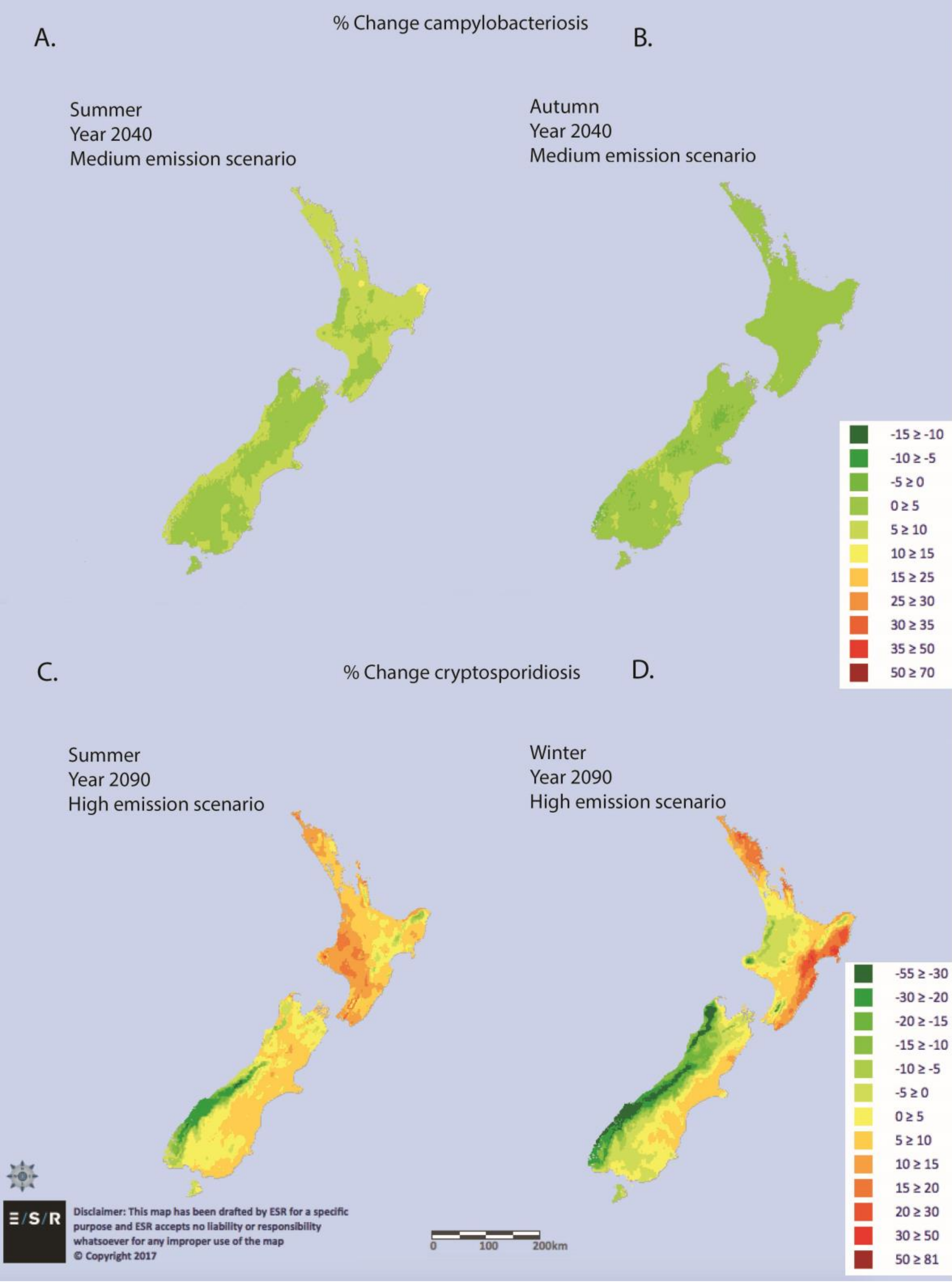

Figure 12: Compiled projections of % change for campylobacteriosis for (a) summer 2040, medium emission scenario (b) autumn 2040, medium emission scenario; Compiled projections of % change for cryptosporidiosis (c) summer 2090, high emission scenario, (d) winter 2090, high emission scenario

Source: https://haifa.esr.cri.nz/

Another New Zealand study found that cryptosporidiosis notifications were negatively associated with temperature and positively associated with rainfall (Britton et al 2010a). In two Australian studies, no association was found between rainfall and monthly cryptosporidiosis incidence (Hu et al 2007; Kent et al 2015). Kent et al (2015), suggested that increases in cryptosporidiosis notifications during spring and summer were related to recreational exposures (ie, more outdoor activity) and rainfall runoff rather than ambient temperature increase. Overall, the effect of climate change on cryptosporidiosis notifications suggests some level of spatial complexity, as other environmental factors are involved. They include locality (rural vs urban), socioeconomic level, water quality and whether the geographical area had a reticulated water supply. Despite this, climate is considered to be a factor that will influence cryptosporidiosis rates.

For *Giardia*, rainfall was significantly and positively associated with giardiasis but temperature was not (Lal et al 2013). Further studies found a positive association between giardiasis and a number of environmental factors: temperature, rainfall, drinking water quality, deprivation and farm-animal density (Lal et al 2015). Britton et al (2010) also found a positive association between rainfall and temperature based on cases reported between 1997 and 2006. A review by Wilson et al (2011), found that reticulated water supplies may be more vulnerable to climate related increases in protozoan disease, presumably due to lack of monitoring and treatment. For example, both cryptosporidiosis and giardiasis parasitic oocysts can be washed into the water supply from (for example) cattle farms (Bambrick et al 2011).

Projected increases in ambient temperature may have localised health impacts in New Zealand with regards to salmonellosis (Lal et al 2016). A study examining salmonellosis notifications from 1965 to 2006 observed a positive association with average ambient temperature increase (Britton et al 2010b). It was predicted that a 1°C increase in monthly average ambient temperature would result in a 15% increase in salmonellosis notifications, which was in agreement with international studies. *Salmonella* concentrations in freshwater streams were also found to increase significantly during summer months and following heavy rainfall (Britton et al 2010a; Vereen et al 2013). Some considerations remain, including the need to adjust for population increase and potential pathways from food production, storage and consumption.

Studies investigating *Salmonella* infections in the US, Europe and Australia found a positive correlation between temperature and salmonellosis (Jiang et al 2015; Luma et al 2014; McMichael et al 2006; Zhang et al 2012). Warming trends were projected to increase *Salmonella* infections in the US (Luma et al 2014), and were found to be associated with extreme temperature/precipitation events. Coastal communities were also projected to be disproportionately affected. Although the reasons for this could not be quantified, it was thought that increased contamination of water from point sources such as municipal wastewater treatment plants, following flood events, could play an important role (Jiang et al 2015).

5.3.3 Climate Change and Exposure to *Legionella*

No specific studies on *Legionella* and climate change in a New Zealand context were found. International studies suggest that the main source of legionellosis is from contaminated building water systems. However, New Zealand studies suggest that humans are more likely to be infected by *Legionella* species that are naturally found in soil (Ministry of Health 2012b). Most individuals who are exposed to those *Legionella* species, do not become infected by this bacterium. Rather, vulnerable persons such as those with weakened immune systems, older people, and smokers are more susceptible (Ministry of Health 2016c).

Legionella can amplify in warm water reservoirs if they are not properly disinfected and maintained. This may include evaporative cooling systems and cooling towers (CDC 2017; Morey 2010; Sakamoto 2015). With a warming climate, the ambient water temperatures in buildings (ie, the internal reticulated water system) may rise to the lower growing range for *Legionella*. Sakamoto (2015) argued that Legionnaire's disease should now be added to the IPCC's list of important climate sensitive health risks.

5.3.4 Climate Change and Exposure to *Vibrio* species

Recreational exposure to *Vibrio* species is the main environmental exposure route considered for this review. Handling or consuming fish are also risk factors (Dechet et al 2008; Oliver 2005).

Increased water temperature promotes the growth of *Vibrio* bacteria, which are natural inhabitants of coastal marine environments. International studies have associated *Vibrio* growth with increasing sea surface temperatures (Bambrick et al 2008; Ralston et al 2011; Siboni et al 2016; Vezzulli et al 2012). Other studies also suggest a relationship between water salinity and multiplication of *Vibrio*, whereby growth is favoured with decreased salinity (eg, brought on by increased delivery of freshwater to coastal waters), but this finding of the relationship is inconsistent and probably site-specific (Froelich et al 2013; Froelich et al 2012; Griffitt and Grimes 2013; Vezzulli et al 2012b).

In New Zealand, evidence suggests that concentrations of *Vibrio parahaemolyticus* and *Vibrio vulnificus* increase when seawater temperatures are above 19ºC (Cruz et al 2015, 2016). In an Australian study, Bambrick et al (2008) considered *Clostridium perfringens*, *Vibrio parahaemolyticus*, *Aeromonas* species, giardia, norovirus and rotavirus to be important climate sensitive pathogens.

However, the specific response of *Vibrio* to climate change and the degree of growth may vary by species and geography. If water temperatures increase in New Zealand, it is likely this will result in *Vibrio* becoming more prevalent and widespread, including areas where it was not previously considered an environmental health risk.

5.3.5 Climate Change and Exposure to Pathogenic Fungi

It is unknown how climate change may affect fungal diseases in New Zealand. The international literature suggests a general increase in pathogenic fungi poleward, in association with increases in temperature and humidity (Brown et al 2013; Saad-Hussein et al 2011; Talley et al 2002).

5.4 MITIGATION AND ADAPTATION TO CLIMATE RELATED CHANGES TO INFECTIOUS DISEASE IN NEW ZEALAND

Table 7 summarises the mitigation and adaptation options to reduce the environmental health risks from climate modified infectious disease as identified from the literature.

Table 7: Summary of mitigation and adaptation options to reduce the environmental health risks from climate modified infectious disease

Risk	Mitigation/Adaptation Options	Direct Health Benefit	Reference
Potential increase of climate sensitive infectious diseases (generic)	• Modifying or expanding current surveillance programs • Combined use of satellite imagery and environmental and climate variables to produce predictive models • Develop tool kits eg, https://toolkit.climate.gov/image/505 • Conduct vulnerability and adaptation assessments related to climate change and communicable diseases • Development of strategies focused on mitigating the transmission of communicable diseases. • Regulatory interventions	• Surveillance will inform control programs and enable reducing measures • Lower future disease burden • Provision of data will enable and enhance science informed policy changes • Reduction of infectious disease	CEC 2009; ECDC 2005-2016; Lindgren and Ebi 2010; Sears et al, 2011; Semenza et al 2012a,b

Risk	Mitigation/Adaptation Options	Direct Health Benefit	Reference
Rapid changes in regional climate that require adjustment to early warning systems	• Early warning systems that can be adjusted over time to incorporate projected increases in climate variability	• Increased future resilience • Identification of trends confirming climate related disease • Forecasting of infectious diseases	Pulwarty et al 2014; National Academy of Sciences. 2013
Increased pathogens in surface water due to increases in ambient temperature	• Specific studies to improve knowledge related to increases in pathogen concentration in surface waters and their relationship with different climate variables and other environmental factors (eg, runoff fluxes versus UVR)	• Decreased risk from pathogens in surface water • Improved wellbeing from recreational use of waters	Sausen et al 2005; Sterk et al 2016; Yaun et al 2003
Increased illness in vulnerable populations	• Improving community awareness to reduce adverse exposures • Developing early warning and emergency response plans • Improving infrastructure capacity	• Self-empowerment of communities • Improved water security and water quality • Less financial stress • Reduced waterborne related illness	Kouzminov et al 2007a; Wang and McAllister 2011
Increased run-off in agricultural areas	• Fencing off streams and bridging crossings to keep livestock out and to prevent diffuse pollution on farms. • Reduce over-use of nutrients	• Reduced waterborne related illness • Reduced pollution	PCE 2012

5.5 VULNERABLE POPULATIONS

Specific populations identified as vulnerable to the infectious diseases of interest described here include:

- older people
- children and
- those with poor and intermediate drinking-water quality.

5.6 CONCLUSIONS

There is strong evidence that changes to both the environment and climate will impact the incidence of infectious disease in New Zealand by:

- increased contamination of water sources by pathogenic microorganisms due to more favourable growth conditions and/or changes to the water cycle
- increased contamination of water sources coupled with inadequate treatment of raw water following heavy rain events
- increased risk of exposure to *Vibrio* in recreational water from increased water temperature and
- increases in ambient temperature may favouring the growing range of *Legionella* in water reservoirs, cooling systems and air conditioning appliances.

Studies do however, caution that other factors such as changing patterns of migration, growth in tourism, health inequalities and changes in socioeconomic conditions, lifestyle and behaviour may be more important than solely changes in climate (Arundel et al 1986; Wilson et al 2011). Some of those factors are not new; global trade and travel, arrival and establishment of new pathogens, disease vectors and reservoir species will remain important to consider in monitoring programmes (Lindgren et al 2012). Other factors that drive disease prevalence are likely to be complex, unpredictable, non-linear[30] and indirect (Lafferty and Mordecai 2016; Walther 2010).

The research gaps identified from this review and of particular importance to New Zealand include:

- reducing contamination in order to mitigate potential health impacts
- use of disease surveillance tools such as those GIS based (eg, HAIFA) to expand to other diseases of interest
- long term data to quantitatively determine the relationship between climate change and infectious disease rates in New Zealand and
- improved methods to detect and predict disease-causing fungi in the environment.

[30] Where the the change of the output is not proportional to the change of the input.

6. VECTOR-BORNE DISEASE

6.1 INTRODUCTION

This section reviews the effect climate change might have on human exposure to vectors, the diseases that they carry and how they may potentially infect humans.

6.1.1 Vector-borne disease

A vector is an organism that can transmit pathogens and parasites (viruses, bacteria and protozoa) from one infected person (or animal) to another, leading to disease. Well known vectors include mosquitoes, ticks and fleas.

6.1.2 Vectors in New Zealand - Mosquitoes

Mosquitoes are flying insects of the family *Culicidae*. Females of specific species are able to transmit disease through injection of saliva and anti-coagulant that may contain virus or parasites (Meissner 2013). Currently, New Zealand has 15 species of mosquitoes; 3 are introduced and 12 are native. The introduced species are *Aedes australis*, *Aedes notoscriptus* and *Culex quinquefasciatus*. These species have the potential to carry diseases (eg, In some parts of the world, *Culex quinquefasciatus* is an important vector of West Nile Virus)). However, none of the mosquito species in New Zealand are of current concern, as they are not established as efficient vectors and there is no widespread disease among the human population (or other host species). In addition, the absence of locally-acquired mosquito-borne disease outbreaks indicates that they are not high-risk vectors of major mosquito transmitted disease at present (Kramer et al 2011).

6.1.3 Vectors in New Zealand – Ticks and Fleas

Ticks are parasites that require a blood meal for their life cycle (Ministry of Health 2015c). They can feed on mammals (including humans), reptiles, birds and amphibians. Although ticks endemic to New Zealand are capable of transmitting disease to humans, they generally do not as the main diseases of concern (eg, Lyme disease) are not currently present. Rickettsial disease and Zika virus infections are exceptions. Rickettsial disease is caused by a *Rickettsiae* bacteria with the exception of *R. typhi* which causes murine typhus and is endemic in the northern parts of the North Island. Rickettsial disease can be transmitted to humans via an insect vector (tick, louse, flea or mite). The oriental rat flea (*Xenopsylla chepois*) is a major vector of the bacterial pathogen *R. typhi,* although other fleas can carry the pathogen. Although the diseases carried by fleas can be transmitted via bites, people are usually infected with *R. typhi* by contact between flea faeces and abraded skin or possibly from inhaling or ingesting flea faeces containing *Rickettsial* bacteria or *R. typhi* (Bryant 2012). At least one bacterium associated with Rickettsia is endemic to New Zealand (Ministry of Health 2012d; Kelly et al 2005a; Kelly et al 2005b).

6.1.4 Vectors in New Zealand - Blackflies

In New Zealand, blackflies are better known as sand flies and are from the family *Simuliidae* of which there are 19 species present. Three of these bite humans: the New Zealand blackfly (*Austrosimulium australense*) found in the North Island and coastal areas of the South Island, the West Coast blackfly (*A. ungulatum*) found in the South Island and abundant in Westland and Fiordland and *A. tillyardianum*. Only small numbers of the species *A. tillyardianum* can be found on both islands and generally only south of Auckland through to Canterbury (Ministry of Health 2014b; SMS 2014). To date, there have been no reports of blackflies transmitting disease to humans in New Zealand.

6.1.5 Vector-borne disease in New Zealand

Vector-borne diseases have been notifiable in New Zealand since 1997 with the exception of Q fever, previously reported under rickettsial diseases that became a notifiable disease on 13 December 2012 (Figure 13).

Notifiable vector-borne diseases are listed below:

- Barmah-Forest virus infection
- Chikungunya fever
- Dengue fever
- Japanese encephalitis
- Malaria
- Murine typhus
- Q fever
- Rickettsial disease
- Ross River virus infection
- Zika virus

A high number of vector-related notifications were reported in 2016 (Figure 13). For that year, dengue fever notifications increased by 53% (191 cases) compared with 2015 (125 cases) (ESR 2016). In the same year, Zika virus reports were the highest recorded since 2002, (167 cases from 1 case in 2002). From 2010 to 2016, the most common notified diseases were dengue fever, malaria and Zika virus, which combined accounted for 86% of all vector-borne disease notifications in New Zealand. Other vector-borne disease notifications reported in 2016 included chikungunya fever (28 cases), Ross River fever (4 cases), murine typhus (3 cases), rickettsial disease (2 cases), and Lyme disease (1 case).

The majority of notifiable disease cases reported an overseas history of travel to a country where the disease was present. A number of cases also reported no overseas travel, and presumably had acquired the disease in New Zealand. Those cases include rickettisial disease (17 notifications since 1997), murine typhus (72 cases since 1989) and Zika virus (1 case) although for some other cases the travel history was unknown or not reported. For the case of Zika, no travel history was reported and sexual transmission was determined as the infectious route (Harrower et al 2016). The cases of *Rickettsia typhi* were reported from Auckland and Waikato (Lim et al 2016).

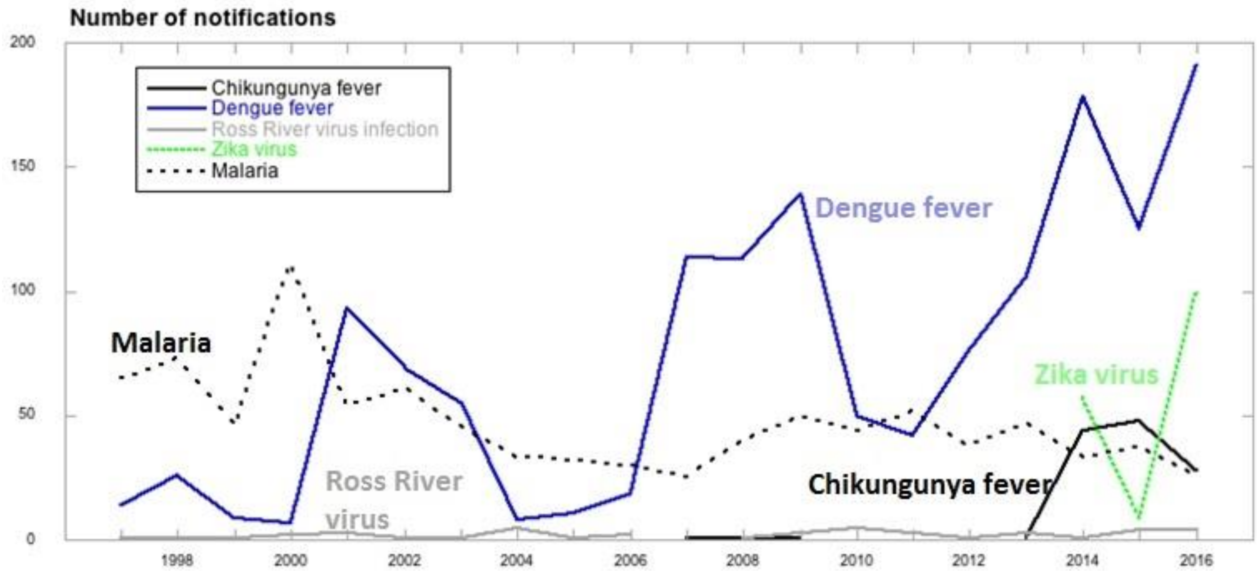

Figure 13: Selected vector-borne disease notifications in New Zealand, 1997 to 2016. Total notifications with less than 6 cases have been excluded (Q-fever, Barmah forest virus, Japanese encephalitis, Rickettsial disease and Lyme disease).

Source: ESR 2016

6.2 CLIMATE CHANGE IMPACTS ON VECTOR AND VECTOR-BORNE DISEASE IN NEW ZEALAND

The IPCC report states with medium confidence that "*local changes in temperature and rainfall have altered the distribution of some waterborne illnesses and disease vectors, and reduced food production for some vulnerable populations*" (Reisinger et al 2014).

Climate variability and climate change in conjunction with many other factors may result in the establishment of vectors and their associated diseases in new areas (Githeko et al 2000; Gubler 2011; Huang et al 2016 ;Patz et al 2014).

Whether they establish as competent (able to acquire, maintain and transmit disease efficiently) vectors in New Zealand will depend on:

- specific climate conditions
- adaptive capacity of the vector
- distribution of the vector
- how the pathogenic microorganisms the vectors carry adapt and change
- the availability of reservoirs and hosts

- geography and levels of urbanisation (population density)
- population mobility
- socioeconomic factors
- sanitation
- changing ecosystems and land use (eg, natural vegetation)
- demographics
- human behaviour and
- prevention, surveillance and eradication measures.

6.2.1 Exotic mosquito vectors and the risk of establishment in New Zealand

Mosquito vectors of interest to New Zealand can be found on the unwanted organism register[31] (Appendix B, Table B1). One of the most significant threats globally is the Asian tiger mosquito (*Aedes albopictus*). It has become the most invasive species globally due to its ability disperse rapidly and widely and use a wide variety of natural and artificial habitats (Holder et al 2010). It is also the most frequently intercepted species at New Zealand borders, is associated with imported goods and known for its transmission of Zika, yellow fever, dengue, chikungunya, and Usutu viruses.

Table 8: Potential establishment or expansion of some endemic and introduced vectors and toxin producing organisms in New Zealand as a result of climate change

Agent (disease)	Vector	Reference
Alphaviruses (Ross River virus, Barmah forest virus, Murray Valley encephalitis Chikungunya, Sinbis[32])	Mosquito: *Culex quinquefasciatus^, Culex pervigilans*, Opifex fuscus*, Aedes (Ochlerotatus) camptorhynchus, Aedes notoscriptus^, A. australis^, Aedes (Ochlerotatus) vigilax, Aedes (Finlaya) notoscriptus^, Aedes (Ochlerotatus) procax, Aedes (Ochlerotatus) antipodeus**	Cashman et al 2008; Derraik and Slaney 2004; Jacups et al 2008; Kean et al 2015; Kelly-Hope et al 2002; Kramer et al 2011a; Maguire 1994; Tong et al 2004; Ministry of Health 2012d
Flaviruses (dengue, yellow fever, chikungunya, Zika fever Japanese encephalitis, West Nile, Murray Valley encephalitis, Kunjin, Kokobera)	Mosquito: *Culex species including Culex quinquefasciatus^, Culex pervigilans*, Aedes antipodeus*, Aedes aegypti Aedes notoscriptus^, Aedes australis^, Aedes (Ochlerotatus) camptorhynchus*	Beebe et al 2009; de Wet et al 2005; Faddy et al 2015; Hales et al 2002; Huang et al 2016; Kramer et al 2011a; Maguire 1994; Monaghan et al 2016; Spurr and Sandlant 2004; Tompkins et al

[31] https://www1.maf.govt.nz/uor/searchframe.htm
[32] Note Sinbis established in bird populations on the West Coast of the South Island. Human infection without disease has been documented serologically.

		2012a; Williams et al 2016; Yu 2009
Agent (disease)	**Vector**	**Reference**
Rickettsial disease *(R. typhi is endemic in NZ)*	Fleas and ticks	Ministry of Health 2012d; Murdoch 2001; Roberts et al 2001
Theileriosis, tick-borne encephalitis, Lyme disease, ehrlichiosis, rocky mountain spotted fever, tularemia, tick-borne relapsing fever	Ticks (*Haemaphysalis longicornis)*	Heath and Hardwick, 2011

*denotes species endemic to New Zealand; ^denotes species introduced to New Zealand, rest=not present or eradicated

Mosquitoes already established in New Zealand and of greatest significance in terms of disease vectors include: *Culex quinquefasciatus* (North Island and northern South Island, possibly a vector for encephalitis viruses); *Aedes notoscriptus* (North Island and South Island and a potential vector for Barmah forest, dengue virus and Murray Valley encephalitis (Kay 1997), Ross River virus (Ritchie et al 1997) and Rift Valley fever (Turell and Kay 1998; Watson and Kay 1998); *Aedes australis* (Southern South Island, a vector for dengue and Whataroa viruses and potential vector of Ross River virus), and *Culex pervigilans* (throughout NZ, a vector of Whataroa virus in birds and potential vector of Ross River virus). Laboratory experiments by Kramer et al (2011), found a number of potentially disease competent native vectors which are summarised in Table 8 (refer to those with asterices).

The movement of people and goods, particularly in terms of biosecurity and migration from the Pacific where high-risk vectors are present increases the risk of incursions into New Zealand (Holder 1999; Mackereth et al 2007). The number of people carrying viruses that can also be transmitted by vectors are also risk factors (Kay 1997).This issue is becoming more relevant due to the increasing number of vector-borne diseases being notified (ESR 2015a; 2015b). It is also important to consider that some diseases can also be transmitted via other non-vector related routes. For example a systematic review of Zika virus infections by Grischott et al (2016), found that non-vector-borne Zika virus transmission plays a role in the spread of this virus. This includes a mother-to-foetus route during pregnancy and also sexual transmission (Besnard et al 2016; Cauchemez et al 2016).

Some native New Zealand mosquitoes were hypothesised to be capable of transmitting disease to humans (Mackereth et al 2007). Experiments have since demonstrated this capability under laboratory conditions (Kramer et al 2011). In Auckland there are known populations of people that are viraemic (that have introduced viruses in the bloodstream), and the presence of local mosquito species but no local transmission of disease. This suggests that current conditions are not suitable for disease transmission.

6.2.2 Climate change impacts on mosquito diseases in New Zealand

Specific diseases of interest related to mosquitoes and the potential impact of climate change are discussed in this section. The viruses mosquitoes may potentially carry in New Zealand include flaviviruses (eg, Murray Valley encephalitis; dengue [serotypes 1, 2, 3, 4] and West Nile virus), alphaviruses (eg, Ross River, Barmah Forest, Chikungunya and Sindbis), viral haemorrhagic fever and yellow fever (Table 8, ESR 2015a; 2015b; Wilson et al 2011). Whataroa virus is an endemic pathogen established in bird populations on the West Coast of the South Island and human infection without disease has been documented serologically (in blood serum) (Ministry of Health 2012d). Other species of concern include a temperate mosquito that is a potential malaria vector (Boyd and Weinstein 1996; Petersen et al 2013a).

Some disease agents (viruses, bacteria, parasites) are faster at incubating within mosquitoes, and are therefore more readily spread (EHINZ 2016). Globally there have been suggestions that increased global temperatures are related to increased malaria incidence but there is no clear evidence to support this view (Nabi and Qader 2009). Other studies argue that climate is not the major factor in temperate regions as many countries have since eradicated malaria due to improved social economic conditions and effective control measures (Caminade et al 2014). The risk from acquiring malaria in New Zealand is currently low because the tropical mosquito vectors (*Anopheles* mosquito) are not established here due to New Zealand's climate. Boyd and Weinstein (1996), reviewed the potential for a temperate mosquito species (*Anopheles annulipes*) which is not present in New Zealand to vector malaria. They concluded the potential of this species becoming introduced from Australia and the likelihood of malaria transmission was low due to the integrity of the health care system. In similar work, Petersen et al (2013b) considered the risk from the parasite that can cause malaria (*Plasmodium vivax*) being introduced to New Zealand from a temperate zone. They concluded that the highest risk of transmission would be from migrants or refugees from the People's Democratic Republic of Korea (North Korea) which is the last place where temperate zone *P. vivax* variant is highly endemic.

Dengue, Ross River and Zika viruses and their mosquito vectors are not established in New Zealand. Risk assessments have shown that the New Zealand climate is unlikely to become suitable for maintenance of the mosquito vector for dengue in the next 50 years (McMichael et al 2003b). In another study, specific humidity[33] was found to be a significant predictor of dengue fever and the modelled estimated population at risk in 2085 for New Zealand was found to be small (Hales et al 2002). However, climate models using the more extreme scenarios do suggest an increased risk of new vectors becoming established (Howden-Chapman et al 2010; Maguire 1994; NZCPHM 2013; Wilson et al 2011; Yu 2009). Using the RCP4.5 and 8.5 scenarios (year 2061 to 2080), Monaghan et al (2016) suggest that northern parts of New Zealand will become more suitable for the *A. aegypti* mosquito. A modelling study by Tompkins et al (2012a) that included dengue and Ross River virus, examined how climate change projections for scenarios B1 (low), A1B (medium), and A2 (high) and the three time periods 2015, 2040, and 2090 may impact disease potential. They found that dengue potential would be predominantly constrained to the North Island with far northern New Zealand showing the greatest disease potential, using *A. aegypti* as an introduced vector. In 2040 and 2090 dengue potential showed a marked increase from the Waikato region northward with further inland dengue potential into the South Island (Figure 14). Two other mosquito species on the unwanted organisms register, *A. albopictus* and *A. polynesiensis* which both mimic the dengue potential profile of *A. aegypti* were also considered in the projections. As these species considered in the model are not currently present, they remain a low-moderate biosecurity threat.

[33] Specific humidity is the ratio of the mass of water vapour in air to the total mass of the mixture of air and water vapour.

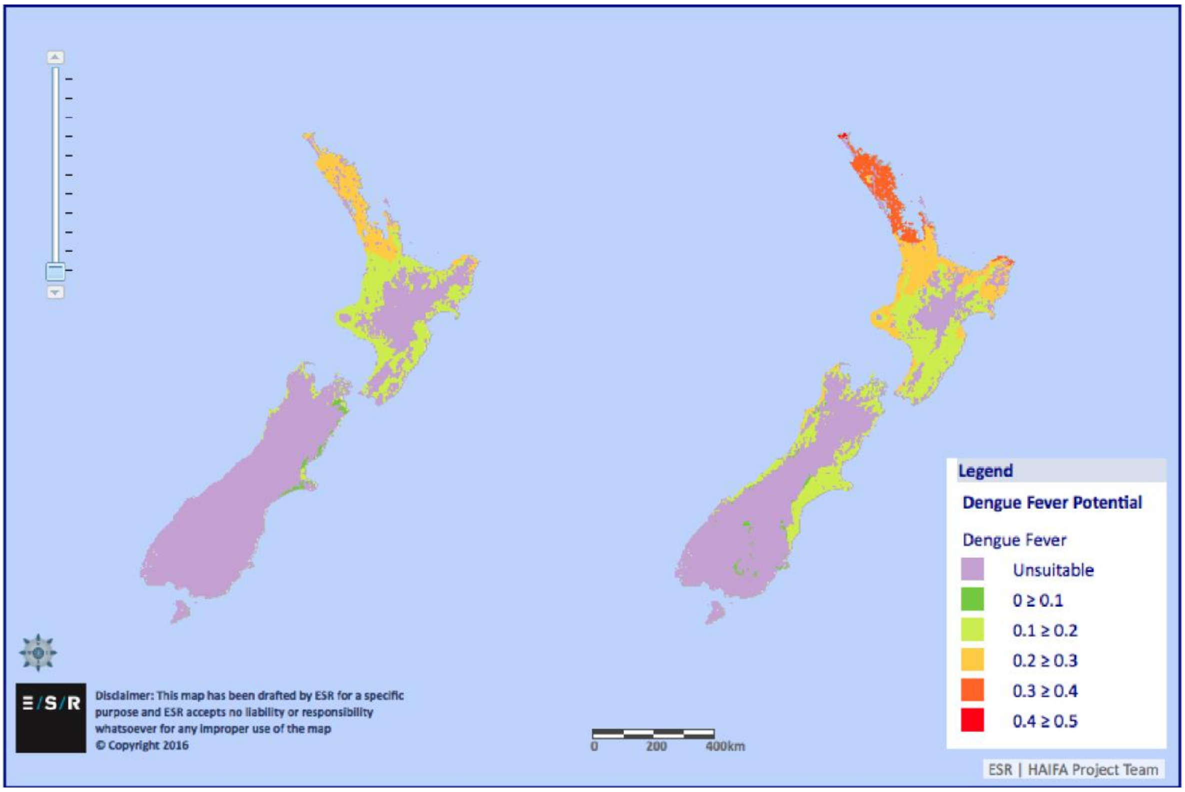

Figure 14: Dengue fever potential probability projections for high emission climate scenario (A2) in 2040 (left) and 2090 (right).

Source: https://haifa.esr.cri.nz/modelling-and-map-portal/

Chikungunya fever, Zika virus infections and dengue fever, are also major public health concerns in the Asia and Pacific region. The Pacific region is experiencing an alarming increase in the burden of arbovirus[34] conditions with concurrent outbreaks and ongoing circulation of infections. The risk for further spread of arbovirus infections in the Pacific is high because of the competence of the vector and the climate conditions that can favour the breeding of mosquitoes. The potential for further transmission of diseases carried by infected travellers into New Zealand from the Pacific islands may therefore increase due to climate change. Other risks include the movement of viraemic Pacific populations into the country as a result of climate migration.

6.2.3 Climate change impacts on mosquito diseases in Australia

The majority of mosquitoes intercepted at New Zealand borders originate from the Asia-Pacific region, mostly from Australia[35]. Studies in Australia can therefore provide insights for New Zealand. For example, in Australia and other parts of the

[34] transmitted by arthropod vectors eg, mosquitoes

[35] http://www.ehinz.ac.nz/news/our-newsletter/ehi-newsletter-11-dec2016/

world dengue fever is emerging or re-emerging (Faddy et al 2015). In February 2017, three outbreaks of dengue fever were declared in Australia (Innisfail, Townsville and Cairns) (ESR Public Health Aberrant Infectious Diseases Email, 1 March 2017). In the future, the endemic locations may expand further within temperate regions, and epidemics may become more frequent (Jacups et al 2008). As climate change results in drier parts of Australia, changes towards large domestic water storage may provide increased breeding sites for *A. aegypti* mosquitoes if not tightly controlled (Beebe et al 2009). Moreover, other mosquito vectors such as, *A. albopictus* (Faddy et al 2015), have been found on islands of the Torres Strait, showing potential for disease spread (Huang et al 2016). Williams et al (2016) modelled dengue transmission for Australia and found that under the A2 (high) emission scenario, reductions were predicted due to mosquito breeding sites becoming drier and mosquito survival declining. This demonstrates the complex relationship between climate, mosquitoes and other environmental factors.

Within Australia, arthritides (Ross River virus (RRV) and Barmah Forest virus (BFV)) and encephalitic Murray Valley virus, are of major concern (Githeko et al 2000; Lyth and Holbrook 2015). Ross River Virus is Australia's most common and widespread mosquito-borne pathogen and both RRV and BFV have been isolated from many mosquito species. The viruses and their transmission are related to suitable mosquito breeding sites and environmental conditions (Russell 1998). In particular, flooding appears to be a major factor in the outbreak of arboviral and other diseases there. Outbreaks of RRV and Murray Valley encephalitis were observed following heavy rain events in the Southeast of the country (McMichael et al 2003b). Inter-annual (particularly ENSO-related) variations affect outbreaks across the globe (McMichael et al 2006), and are increasingly observed in Australia (Maelzer et al 1999; Tong et al 2004; Woodruff et al 2002).

6.2.4 Climate change impacts on tick and flea-borne disease

Currently the disease risk from a tick or flea bite in New Zealand is low as the pathogens that cause human diseases are rare. There is a risk of diseases being introduced by travellers who have been in contact with disease carrying ticks or fleas.

Common diseases transmitted by ticks include *Theileriosis*, caused by a protozoan pathogen (*Theileria* sp.), Lyme disease, caused by *Borrelia* bacteria, and Spotted fever, caused by *Rickettsia* bacteria. There is one strain of *Theileria* bacteria (*T. orientalis*) found in New Zealand but it has not been shown to be pathogenic in humans (Ministry of Health 2015c). Lyme disease which is common throughout Central Europe and North America, is not present in New Zealand. *Riskettsial typhi* is endemic in some parts of New Zealand and transmitted by rat fleas (*Xenophsylla cheopis*) (Ministry of Health 2012d; Sekra et al 2010). Climate change may increase the range and abundance of vector carrier species such as rats (Christie et al 2016) but no further studies of *R. typhi* and climate change in New Zealand were found.

The global incidence of flea-borne infections is increasing and could be exacerbated by changing climate (Bitam et al 2010). Similarly, changes in tick distribution have been observed in Europe, where the boundaries of tick distribution were found to be shifting northwards and to higher altitudes. In the US and Europe, studies indicate an increase in the tick-borne Lyme disease. A change to milder winters may lead to the expansion of tick populations and consequently, human exposure to Lyme borreliosis and tick-borne encephalitis (CEC 2009). Tick-borne disease incidence is shifting towards spring and autumn in Europe (Rizzoli et al 2011). Some of these shifts have been associated with climate change, although other factors include changes in land cover and land use. For example, Steere et al (2004) found that increased reforestation, and people living in or close to forested areas where deer and mice (tick hosts) were present (ticks also feed on these species), were associated with increased reports of Lyme disease.

6.2.5 Climate change impacts on blackfly disease

No information was found on the potential for the establishment of exotic blackflies in New Zealand under future climate change. Studies of vector competence under future climate scenarios are mostly limited to economically important animals.

In Europe there are reports of changes in the geographical distribution of sand flies (a type of blackfly), which are vectors of *Leishmania*. Further work is therefore required to determine the role of climate change in the future epidemiology of this and other blackfly diseases.

6.3 VULNERABLE POPULATIONS

If vector-borne diseases were to establish in New Zealand, a high percentage of New Zealand residents would be vulnerable due to not having protective antibodies (Maguire 1994). Other vulnerable populations at risk include those living in areas of projected vector-borne disease potential (ie, northern most parts of the North Island where temperature increases will be the greatest) and those of lower socio-economic status who may be less able to afford mosquito-protection (repellent, screens, air conditioning) and over time more likely to live in areas prone to arboviral diseases as wealthier residents move to other areas.

6.4 MITIGATION AND ADAPTATION

A lower-emission scenario (eg, RCP2.6) may mitigate future human exposure to a number of vector-borne diseases globally. Regionally, Australia, Europe and North America are projected to have the largest percentage increases in human exposure to *A. aegypti* resulting from climate change (Monaghan et al 2016). However, every year at the New Zealand border there are interceptions of exotic mosquitoes and tick species that can carry diseases of concern to human health (Heath and Hardwick, 2011).

Table 9 summarises some of the mitigation and adaptation options for vector-borne disease identified by various international and local studies. Pest management, surveillance at borders (early detection is important for wind-transported vectors), and eradication plans remain key strategies for the effective management of these risks.

Models can be used to examine the risk of vector-borne disease distribution and habitat suitability together with other risk factors such as population, livestock density eg, ECDC 2005–2016; HAIFA (see Tompson et al 2012). Such models however, are subject to uncertainty due to the complex transmission cycles that involve vectors, other intermediate zoonotic hosts, humans and significant social and environmental drivers of vector-borne disease transmission in addition to climate change (USGCRP 2016).

Although the approach is challenging, some Governments and major health organisations are considering complete eradication of certain vectors rather than treatment or prevention of the diseases they carry (Bouyer and Lefrançois 2014; Fang 2010; Ferguson et al 2010; Killeen et al 2002; McGraw and O'Neill 2013; Roberts and Enserink 2007; Veitch 2011). Mosquitoes, for example, can carry more than one disease. Control measures, which require continuous resourcing, only suppress populations, whereas eradication, although expensive at the outset, results in permanent removal provided future incursions can be prevented. The Ministry of Agriculture and Forestry Biosecurity New Zealand estimated that the likely economic cost of the Southern saltmarsh mosquito (Aedes camptorhynchus) becoming permanently established in New Zealand to be over $120 million for direct health costs alone for the first epidemic (Kay and Russell 2013). This estimate did not include the costs of lifestyle impact, lost productivity, reduced tourism and the costs of mosquito control, screens and repellents.

The Pacific region remains an area vulnerable to many climate impacts, including those from vector-borne disease. Assistance to the Pacific to support the health, wellbeing and adaptation of Pacific Island nations would reduce the risk of incursions into New Zealand and other countries.

Table 9: Summary of mitigation and adaptation options from various international and local studies

Risk	Mitigation/Adaptation Options	Direct Benefit	Reference
Establishment of exotic disease vectors	• Surveillance and disease monitoring (including links to Australia and the Pacific islands) combined with a climate change focus, ENSO, travel related factors, movement of people and goods, borders and ports and creation of potential suitable habitats for vectors	• Effective early warning • Assessment of trends • Prevention of establishment of vectors and sources • Reduction in health care required	ESR 2015a; 2015b; Ministry of Health 2012d; Holder et al 2010; Kelly et al 2005a; Kelly et al 2005b; Wilson et al 2011
Vector-borne disease transmission in established New Zealand vectors	• Modelling to assess whether the mosquito vector populations already present in New Zealand should be managed to prevent climate change increasing their capacity to vector disease.	• Prevention of potential vector-borne disease transmission in endemic vectors	Tompkins et al 2012; Tompkins and Slaney 2014
disease incursions and outbreaks	• Modelling of the relationship between climatic factors and disease outbreaks to help in the prediction of future potential consequences of climate change.	• Improved risk communication and prevention strategies. • Early warning systems for vector-borne disease infection outbreaks • Improved understanding of environmental data with data on disease cases and vectors to provide forecasting models	Derraik and Calisher 2004; EPIDEMIA ; Hales et al 1999; Jacups et al 2008; Liu et al 2015

Risk	Mitigation/Adaptation Options	Direct Benefit	Reference
Inability to control diseases (outbreaks)	• Being informed of the latest control technique suitable control/eradication methods in the event of exotic mosquito incursion • Close monitoring of new biological control agents and other novel solutions eg, Wolbachia and ovillanta[36], genetically modified mosquitoes	• Preparedness in the event of an outbreak • Reduced risk to the environment from alternative (non-chemical) control	Adalja et al 2016; Aliota et al 2016; DeGennaro et al 2013; Hammond et al 2016; Kramer et al 2011b; Matchar 2016; McMichael et al 2003; National Academies of Sciences 2016; Portier et al 2010; Tompkins et al 2013; Tong et al 2004; USGCRP 2016

Reduced national capability of disease vector identification	• Ensure national expertise in:
	  • disease
	  • vector control
	  • surveillance
	
	• Evaluate emergency response capabilities, serological and clinical surveillance for vector-borne diseases are initiated in key localities, and public and professional education
		• Enhancement pathogen/vector control infrastructure including vector and host identification.	Kelly-Hope et al 2002

[36] Wolbachia is a bacteria that naturally infects insects including mosquitoes. It is thought that Wolbachia infection of mosquitoes will reduce their ability to become infected with pathogens. Ovillanta is a low cost mosquito trap designed to collect and dispose of their eggs and larvae.

Risk	Mitigation/Adaptation Options	Direct Benefit	Reference
Potential spill-over of animal disease to humans via vectors	• Development of an integrated approach to epidemiological, entomological and environmental data collection and analysis. • Combining human and animal health disease surveillance activities through enhanced co-operation and exchange of knowledge	• Maximises synergy and avoids duplication	CEC 2009; Institute of Medicine (US) Forum on Microbial Threats 2008

6.5 CONCLUSIONS

Under more extreme climate change scenarios, it is possible that some areas of New Zealand may become more favourable for the establishment of exotic vectors (medium to longer-term (25-75 years[37])). The transmission of vector borne diseases will be limited by the rates at which pathogens transmitted by those vectors are able to develop, replicate and survive, and subsequently infect humans. The maintenance of surveillance systems and the effectiveness of response systems remain key tools to exclude competent vectors in New Zealand from establishing.

The research gaps identified that are of particular relevance to New Zealand include:

- Knowledge of shortening of pathogen incubation periods, and disruption and relocation of large human populations.
- Further research into vector-borne disease controls at the regional level including genetic modification of vectors and biological controls and preventive education to manage incursion risk
- Studies to determine the role of climate change on the competence and potential risk from non-mosquito vectors such as blackflies, fleas and ticks.

[37] It should be noted that will be some uncertainty associated with predicting the extent of climate change. See Tompkins D, Brock A, Jones G et al. 2012. *Modelling the Impacts of Climate Change On Infectious Diseases in New Zealand*, ESR Limited for the uncertainty of parameters.

7. TOXIN PRODUCING ORGANISMS

7.1 INTRODUCTION

This section reviews the effect climate change may have on human exposure to toxin producing organisms. Toxin producing organisms that deliver a toxin as a bite or sting are termed venomous, whereas those that indirectly deliver toxins such as through touch (eg, secretion of harmful chemicals through skin) or ingestion are termed poisonous.

New Zealand has very few toxin producing organisms of concern with aquatic species and spiders being the most important in terms of environmental health risks. Naturally, there is a risk that new species could be introduced through travel, trade and accidentally via the air or ocean. Very few studies exist on the risk from existing toxin producing organisms and how these might impact health in the future due to environmental change.

7.2 CLIMATE CHANGE AND TOXIN PRODUCING ORGANISMS

7.2.1 Algae and cyanobacteria

Cyanobacteria, are naturally present in freshwater (eg, lakes and rivers) or marine environments. Some freshwater and marine algae produce chemicals (called cyanotoxins) that have adverse human health effects following exposure to them at high enough concentrations (Funari and Testai 2008). In New Zealand, these “algae” are most likely to be cyanobacteria, or blue-green algae, which are a type of bacteria. Extreme precipitation events and subsequent increases in runoff can increase nutrient loading in freshwater reservoirs, estuarine and coastal environmeents, which in turn increases the likelihood of harmful cyanobacterial bloom occurrence (Delpla et al 2009; Mosley 2015). Similarly, low river levels caused by droughts may concentrate nutrient levels, thereby increasing the likelihood of algal blooms. Where cyanobacteria bloom in water bodies, their concentrations may increase to levels toxic to humans (Moore et al 2008; NZCPHM 2013) (Figure 15). Exposure can occur by breathing in the toxins that have become aerosolised, direct skin contact, accidental ingestion during recreational water-related activities (Pilotto et al 1997), eating shellfish that have been living in water containing toxins or consumption of inadequately treated drinking water containing toxins. Specific health effects may include liver damage, dermatologic, gastrointestinal, respiratory, and neurologic symptoms (Hilborn et al 2014).

Freshwater cyanobacteria may bloom (grow rapidly) when water temperatures are warm enough, and sufficient nutrients are available to sustain their growth. In the ocean, blooms usually occur when wind and water currents are favourable although other causes include slow water circulation or unusually high water temperatures (Ministry for Primary Industries 2017). Blooms are also known to occur following extreme events such as after a cyclone. Warmer water temperatures are also likely to increase the severity of cyanobacterial blooms in surface waters (PMCSA 2017).

An apparent increase in toxic blooms globally has been partially associated with climate change (Anderson 2012; Chapra et al 2017). Toxic blooms are also reportedly increasing in variety, frequency and intensity (Cressey 2017; Paul et al 2008). Quantifying the relationship between changing climate and the increase in toxic blooms alone is difficult due to a number of other simultaneous anthropogenic changes (increased run-off, nutrient input, population etc.) (Hallegraeff 1993, Wood et al 2017).

Scientists predict that cyanobacteria blooms will increase in the future, because of higher water temperatures, altered precipitation patterns, enhanced vertical stratification, increased atmospheric CO_2 and changes to nutrient composition in fresh and marine waters (eg, from fertiliser run off) (Carey et al 2012; Paerl and Paul 2012; Paerl and Otten 2013; Vermeulen et al 2012). The timing of the seasonal window of growth is also projected to change in algal blooms studied overseas (Fu et al 2012; Kouzminov et al 2007; Parsons et al 2012).

Areas undergoing rapid warming are likely to be among the most vulnerable (Tirado et al 2010), and the shift of warmer waters to the poles is also likely to lead to the spread of toxic cyanobacteria species normally suited to milder waters (O'Neil et al 2012; Vincent and Quesada 2012).

However, other human-related activities remain important factors in encouraging bloom development. For example, taking water from rivers with low flow, further decreases flow and leads to increased nutrient concentration. Run-off of nutrients from agricultural activities into waterways increases nutrient concentrations, and removal of riparian vegetation increases run-off rates and allows more light into waters to sustain bloom development.

Algal and cyanobacterial blooms can also interfere with water treatment processes if there are large numbers in the untreated water, which may lead to substandard drinking quality (EPA 2014).

Some key factors (Paerl et al 2011), affecting cyanobacterial growth include:

- Freshwater run-off (increasing nutrient delivery, availability, salinity (in estuaries), water residence time and vertical density stratification
- surface water warming
- light
- alkalinity and pH
- stratification and low oxygen
- population stability (of the algae).

Figure 15: (A) A non-toxic bloom of *Anabaena planktonic* observed in lower Karori reservoir, Wellington, (B) shoreline scum of toxic *Microcystis* species, Lake Winitoa, Levin, (C) shoreline scum of toxic *Microcystis panniformis*, Lake Rotoehu, Rotorua.

Source: Ministry for the Environment and Ministry of Health (2009)

To assess and manage the risk of toxic cyanobacteria in drinking-water supplies, the Ministry of Health have developed national criteria and guidance for assessing and managing the risk of toxic cyanobacteria in drinking-water supplies (Kouzminov et al 2007). Increases in cyanobacteria can have significant economic effects that result from increased water supply treatment costs for human drinking, irrigation water supplies, fisheries and recreational resources (Paerl and Paul 2012). Moreover, increased degradation of water quality can also result in loss of confidence in the quality of treated water (Kouzminov et al 2007).

7.2.2 Spiders

There are only two spider species of concern for human health in New Zealand. They are the katipo and the Australian red back (Ministry of Health 2015d). Both deliver venom through biting. There has been little work undertaken on how climate may impact these species. Vink et al (2011), modelled potential global distribution of the Australian red back spider, based on current climate, and overlaid areas of suitable climate in New Zealand. A number of areas the species could establish, including urban habitats were identified.

7.2.3 Marine Organisms

In marine environments, some species of jellyfish, stingray, and fish contain toxin or venom (de Cook 2010; Ministry of Health 2014c). In North Shore, Auckland and the Coromandel area, the grey sided sea slug (*Pleurobranchaea maculata*) has been found to contain the toxin tetrodotoxin but it is currently unknown whether the toxin is produced by the organism itself or through ingestion or production of the toxin through some other mechanism (NIWA, 2017b). The grey sided sea slug has been associated with a number of dog deaths in Auckland (McNabb et al 2009) and it is thought that the level of toxin may increase at warmer temperatures. Sea water temperatures are expected to increase in the future, and therefore toxicity of these organisms may also increase (Devonport-Takapuna Local Board, 2015). However, unless the sea slug is ingested by humans the human health risk is low. There have also been some sightings of sea snakes and kraits, and these are known to arrive here naturally via ocean currents. The reporting of sea snakes has increased recently and one or two live snakes have been reported from beaches in Northland.

Examination of the physical oceanography of the currents surrounding New Zealand over the last 20 to 30 years do not suggest any strengthening or significant change (Fernandez et al 2017, in prep). Sea-surface temperature trends could not be determined for New Zealand's oceanic, subtropical, and subantarctic waters and the Tasman Sea for 1993 to 2016 (at the 95% confidence level) (Ministry for the Environment and Stats New Zealand 2017). Sea surface temperature is projected to increase by around 2.5°C by the end of the century (compared with the period 1986-2005). These projections are based on RCP8.5 and the average from several global climate models (Law, 2016).

7.3 MITIGATION AND ADAPTATION

Surveillance of existing and potentially new toxin-producing organisms will be important to monitor environmental health risks in the future (see Section 8 for further discussion relating to cyanotoxins). Education will be an important tool for minimising the risk of health-related effects from toxin-producing organisms.

7.4 CONCLUSIONS

The key research gap for toxin-producing organisms is understanding how the abundance and distribution of toxin-producing organisms may change in New Zealand as a result of a modified climate.

8. OTHER ENVIRONMENTAL HEALTH RISKS

8.1 INTRODUCTION

Other environmental health risks related to climate change but not covered in the previous sections are described here. They include risks associated with:

- water treatment and management
- water security
- social change and migration to New Zealand
- antimicrobial resistant bacteria and
- emerging and re-emerging infectious disease

8.2 WATER TREATMENT AND MANAGEMENT

A safe, reliable, affordable, and easily accessible water supply is essential for good health.

Higher water temperature and more frequent and intense heavy rain events can result in increased concentrations of pathogens in drinking-water sources. These pathogens can be introduced from run-off or storm water/sewage inflows, or might already be present in the water or sediment. Increased amounts of organic matter, washed into source waters during heavier rainfall or storm events, can pose a challenge for the removal of pathogenic organisms in water treatment plants (Gaffield et al 2003). Small communities, private groundwater wells, rainwater collection systems or other water collection structures for drinking-water that do not treat, or minimally treat, the collected water, are more susceptible to waterborne infections (Kozlica et al 2010).

Extreme precipitation events resulting in increased turbidity (cloudiness) of treated drinking-water have been statistically linked to increased levels of gastrointestinal illness and the presence of protozoan pathogens. Children and older people were identified as groups that were particularly vulnerable to infections from waterborne protozoa (Duncanson et al 2000; Gaffield et al 2003; Mann et al 2007; Uejio et al 2014).

Climate change projections show that western parts of New Zealand will experience an increase in the frequency of heavy rainfall (increased winter rainfall, increased number of extreme wet days and increased flash flooding) (Ministry for the Environment 2016b; Reisinger et al 2014). More frequent and/or intense heavy rainfall is likely to result in an increase in microbial and sediment loading. This can lead to difficulties in water treatment processing, and contaminated drinking water without adequate management. This in turn may lead to potable water shortages and further challenge communities already dealing with the aftermath of flood events.

8.2.1 Biofilms

Biofilms are a community of one or more types of microorganism such as bacteria, fungi and protists (eg, protozoans, certain algae and slime moulds). In water supplies, such communities can be found growing on the inside of network structures and lead to a wide range of water quality and operational problems (Ministry of Health 2017b).

Biofilms can pose a health risk as they are able to act as environmental reservoirs for pathogenic microorganisms (Brown et al 1999). A study by Wingender and Flemming (2011) suggested that biofilms should be included in risk assessments applied to water-related pathogens.

Under a changing climate, issues associated with biofilm growth may result in challenges for water supply operations. Further research is required to understand those specific changes and their relation to environmental health risks.

8.3 WATER SECURITY

UN-water proposed the definition for water security as "*The capacity of a population to safeguard sustainable access to adequate quantities of and acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability*." (UN-water, 2013).

Changing patterns of rainfall will affect water security. Drinking-water security and safety are of primary concern in every country reviewed. In Europe, a number of countries have conducted assessments of the risks to drinking-water supply, and the potential health impacts to those sources from climate change (Semenza et al 2012b). In New Zealand, communities that do not have reticulated water are at risk of water insecurity. Many of those populations rely largely on rainwater roof collection for drinking-water. During periods of low rainfall even communities receiving reticulated water may have to manage their water carefully to ensure an adequate supply of water.

Climate change projections for New Zealand (Ministry for the Environment 2016a; Reisinger et al 2014) report an increased number of dry days across the North Island and inland South Island with up to a 5% increase for RCP8.5[38] by 2090. A reduction

[38]For the 5th assessment IPCC report, there are four Representative Concentration Pathways (RCP): RCP8.5, RCP6, RCP4.5, and RCP2.6. The numbers refer to radiative forcing (global energy imbalances), measured in watts per square metre, by the year 2100. RCP8.5 is a worst-case scenario in which by 2100, atmospheric concentrations of CO_2 are projected to be three to four times higher than pre-industrial levels.

in soil moisture and therefore an increased need for water for irrigation will increase the demand on freshwater resources. The potential impact on health may occur where water resources are heavily utilised; highly urbanised areas and agricultural lands, but also in areas that rely on non-reticulated supply that is replenished seasonally. Increased demand for water can also lead to an overall reduction in secure water available in some communities with associated risks from decreased hygiene (Bennett et al 2014).

Planning for the consequences of drought and fluctuating rainfall is necessary. This may include the implementation of mitigation and prevention steps, such as the harvesting and storage of rainwater. Water shortage and consequent reduced irrigation may indirectly lead to food shortages. Poor basic hygiene, because of water shortage, may increase the likelihood of infectious diseases and disease outbreaks. A water supply vulnerability tool for New Zealand has been developed that guides small communities in assessing their vulnerability to climate change effects, including being without drinking water, and identifying possible adaptations to meet these challenges (Nokes 2012; see also https://haifa.esr.cri.nz/assessing-climate-change-vulnerability-in-water-supplies/).

A contentious issue that relates to water security is the allocation of water and the potential impending costs, security and quality of water sources, such as groundwater. Indirect health impacts may occur where families save money for water and pay for water, potentially leading to hygiene problems. These changes will increase financial and health burdens on poorer communities, particularly Māori and Pacific peoples (Marriot and Sim 2014; McKerchar et al 2015).

8.4 SOCIAL CHANGE AND MIGRATION TO NEW ZEALAND

The Pacific is a vital part of New Zealand's identity. In 2013, there were over 340,000 Pacific islanders forming part of our diverse population. The Pacific ethnic group population in New Zealand is projected to increase from 340,000 in 2013 to 530,000 to 650,000 by 2038 (Stats NZ, 2017). New Zealand has close historical, cultural, sporting and economic ties with our Pacific neighbours as well as constitutional obligations to the Cook Islands, Tokelau and Niue, and a Treaty of Friendship with Samoa. Pacific leaders generally turn to New Zealand in times of need, particularly in response to natural disasters. The Pacific Forum for Economic Ministers have identified climate change as the greatest threat to livelihoods, security and well-being of the people of the Pacific, and climate change finance is an important issue.

The effects of climate change will be dramatic on our Pacific island neighbours. The three most climate-vulnerable Pacific Islands (Kiribati, Tuvalu and Tokelau) have a combined population of more than 250,000 people (Health Promotion Forum 2010).

The Royal New Zealand College of General Practice's position statement on climate change, health and general practice in Aotearoa New Zealand and the Pacific also reinforce an important issue. The connection between the Pacific and New Zealand must also be factored in when considering the health impacts of climate change (The

Royal New Zealand College of General practitioners 2016). Rising sea level and increased extreme events will leave many people displaced and those that can afford to leave are likely to increase migration pressure on New Zealand (Community and Public Health 2017; Pene et al 2009; Regional Public Health 2015). Increased migration can result in pressures on medical equipment, medicines and general health system support structure. Increased housing pressures can lead to overcrowding in state and low-income housing, and increase the risk of infectious diseases such as tuberculosis (Baker et al 2012; Ministry of Health 2009; Howden-Chapman et al 2010). In addition, pressures on housing stock may overflow into existing vulnerable populations, new migrants and older people.

8.5 ANTIMICROBIAL RESISTANT BACTERIA

There has been an increased interest in the presence of antimicrobial resistant bacteria (AMR) in the environment (Turgeon et al 2011), and how flooding may impact the distribution of antibiotic resistant genes (Garner et al 2016). The study by Garner et al (2016), examined the abundance of certain antibiotic resistance genes (ARG), before, after, and 10 months post flood in the Cache La Poudre River, Colorado. The study found that the total abundance of ARG decreased after the flood and returned to pre-flood levels 10 months after the flood. However, the type of ARG before the flood and ten months post-flood was different. It was suggested that this was a result of selective pressures due to the presence of certain antibiotics and heavy metals in the river after the flood. Climate variability was considered, amongst other variables, as a possible contributor to antibiotic use/misuse and resistance development in a study in India (Sahoo et al 2010).

8.6 EMERGING AND RE-EMERGING INFECTIOUS DISEASE

Emerging infectious diseases (EID) are infections that have occurred recently within a population or are those that already exist but are rapidly increasing in incidence or geographic range (Morse 1995). In New Zealand, EIDs were the third highest communicable disease reported of any cause from acute hospital admissions in a 2012 study (Baker et al 2012). From a global environmental health perspective, the increase in EID has been linked with increased international travel, climate change, and trade with livestock and plants (Anderson et al 2004; Cunningham et al 2003; Weiss and McMichael 2004). Globally, EID events are dominated by zoonoses (animal to human infection), and it is estimated that 30-50% of these events are caused by bacteria (Jones et al 2008; Lindahl and Grace 2015). However social and demographic drivers (including population aging, social inequality, and lifestyle); environmental and ecological factors and public health system drivers (eg, vaccine preventable diseases) can also play an important role (Jones et al 2008). Fungal and fungal like diseases have been associated with socioeconomics, climate and latitude. It is thought that global warming will increase the prevalence and distribution of fungal diseases in mammals. This will be a result from temperature gradients between mammals and the environment decreasing, the spread of fungi to other geographic regions and increased pressure on fungal pathogens that opening new niche possibilities but also closing others (Bebber et al 2014; Fisher et al 2011; Taylor and Gurr 2014).

In New Zealand, EIDs of concern include those related to travel (zika fever, chikungunya, and dengue fever), some sexually transmitted diseases (gonorrhoea) and new strains of pathogenic organisms including those that have developed genetic resistance to antibiotics (eg, Methicillin-resistant *Staphylococcus aureus* (MRSA)). Other emerging infectious diseases of interest to New Zealand have been modelled as part of the HAIFA project (Tomkins et al 2012). They include (campylobacteriosis, cryptosporidiosis, Neisseria meningococcal infectious disease, influenza, Ross River and dengue fevers).

8.7 MITIGATION OF, AND ADAPTATION TO, OTHER ENVIRONMENTAL HEALTH RISKS

The mitigation and adaptation options for other environmental health risks not considered in previous sections are presented in Table 10. In summary they include:

- Ensuring that communities at risk from water shortages in the future, have adequate and safe drinking-water management plans, and improved water security.
- Prevention of cyanobacteria blooms.
- Future policy and decisions consider the health impacts from increased migration to New Zealand from a health and well-being perspective.
- Surveillance programs and environmental monitoring for antimicrobial resistance and emerging and re-emerging diseases will help to anticipate and address new and emerging risks.

Table 10: Summary of mitigation and adaptation options from various international and local studies

Risk	Mitigation/Adaptation Options	Direct Health Benefit	Reference
Increased pressures on drinking water systems from heavy rainfall or flooding events	• Improved filtration and chemical treatment where necessary (eg, chlorination) • Improved maintenance of potable water systems • Increase buffer zones eg, riparian planting • Reducing nutrient inputs • Removing sediment input (eg, dredging) • Upgrading of water treatment plants	• Decreased risk in water security • Maintenance of safe drinking-water quality • Reduced pollutants and pathogens in drinking-water • Reduced requirement to implement water shortage and boil water notices • Increased biodiversity • Reduced potential for water quality charges	Clark et al 2008; Fassman et al 2010; Gaffield et al 2003; Hoeger et al 2005; Rosa et al 2014; Simcock 2007; PCE 2012

Risk	Mitigation/Adaptation Options	Direct Health Benefit	Reference
Increases in toxic cyanobacteria in surface fresh waters and marine waters	• Reduction of nutrient input • Reduction of non-point source loadings of nutrients (agricultural fertilizer and waste, urban storm water runoff) • Studies examining the potential increase of toxic cyanobacteria in New Zealand and the limiting factors involved • Examination of technological solutions (physical, chemical, biological) to remove toxic cyanobacteria from water bodies and treatment facilities • Monitor drinking-water sources that may contain cyanotoxins.	• Reduction in toxic cyanobacteria in drinking water sources and recreational water • Improved wellbeing from increased use of recreational waters	Dyble et al 2008; Erdner et al 2008; Fu et al 2012; Hoeger et al 2005; Moore et al 2008; Nokes 2014; Paerl and Ustach 1982; Seebens et al 2016; Van Dolah 2000; Wells et al 2015; Wong et al 2007
Increased pollution from storm water runoff	• Health risk assessments to examine whether treatment is required prior to use for non-potable purposes (re-cycled water for irrigation for example) • Changes to urban design eg, green roofs, shifting guttering • Increase buffer zones eg, riparian planting • Reducing nutrient inputs • Upgrading of water treatment plants	• Lower direct and indirect health impacts from contamination • Reduced pollutant and pathogens in drinking-water • Reduction of soil erosion and run-off • Reduced potential for water quality charges	Gaffield et al 2003; Voyde et al 2010; Yao et al 2013

Risk	Mitigation/Adaptation Options	Direct Health Benefit	Reference
Reduction in water availability/ water security	• Desalination of seawater pumping water in from greater distances resulting in large reticulation • Use of smart technology to maximise water-use efficiency and to prevent and reduce leaks • Improvements to existing water treatment and maintenance • Develop policy to ensure that households have a right to a minimum amount of water at no charge	• Improved water security prevents usage of alternative sources that may not be safe • Decreased financial stress • Reduced need to recycle water	Berst 2010; Ministry for Health 2016a; Howden-Chapman et al 2010b; Willis et al 2013
Increased illness in vulnerable populations from waterborne pathogens	• Mitigations noted in relation to heavy rainfall, above • Improving community awareness to reduce adverse exposures • Developing early warning and emergency response plans • Improving infrastructure capacity	• Self-empowerment of communities • Improved water security and water quality • Less financial stress • Reduced waterborne related illness	Kouzminov et al 2007a; Wang and McAllister 2011
Emerging infectious disease	• Use of risk assessment tools eg, DAISY	• Improved preparedness and response to emerging infectious disease	Adlam 2012

8.8 CONCLUSIONS

The main environmental health risks related to climate change in this section include:

- Increases in sediment loading and pathogens in source water that may impact on water treatment facilities
- Removal of toxins from drinking-water or preventing their entry
- Water security in some parts of the country
- Areas with no water treatment are at higher risk of pathogen contamination.
- Unknown risks from AMR and emerging and re-emerging infectious disease

The research gaps identified from this review and of particular importance to New Zealand include:

- modelling to predict the occurrence of toxic levels for public notifications
- establishing measures to prevent toxic cyanobacterial blooms
- climate change impacts on antimicrobial resistance
- climate change impacts on emerging infectious diseases and
- environmental health impacts from changes to water sources during times of drought.

9. MITIGATION AND ADAPTATION

This section briefly summarises the mitigation and adaptation options for New Zealand with a focus on mitigation in the health care sector.

The terms ‘mitigation’ and ‘adaptation’ refer to two different paths for confronting climate change and are common throughout the literature. Mitigation addresses the causes of climate change ie, heat-trapping gas emissions, and is aimed at reducing those human-made effects on the climate system eg, reducing atmospheric emissions of heat-trapping gases from anthropogenic sources, deforestation and livestock farming.

In contrast, adaptation revolves around making changes to prepare and negate the effects of climate change or those projected to occur, thereby reducing the vulnerability of communities and ecosystems. By adapting to cope with the effects of climate change, communities, enterprises and health care institutions can build up their climate change resilience.

Climate resilience can have many meanings. The IPCC defined it as “*the ability of a system to absorb disturbances while retaining the same basic structure, ways of functioning and self-organisation*” (IPCC, 2007). Another interpretation could be the way that a system[39] is able to minimise its vulnerability by using adaptation strategies.

In a health context, climate resilience may refer to the capacity of a health system, health-related systems and structures to cope with and manage health risks in a way that the essential functions, identity and structure of health systems are maintained (WHO, 2015a).

The [climate] system can be defined as an interactive system consisting of five major components: atmosphere, biosphere, cryosphere (sea ice, ice sheets, and glaciers), hydrosphere (rivers, lakes, and ocean) and land surface, Baede et al 2001, 1. The Climate System: an Overview Contents in Climate Change 2001: The Scientific Basis pp 87-98 https://www.ipcc.ch/ipccreports/tar/wg1/pdf/TAR-01.PDF

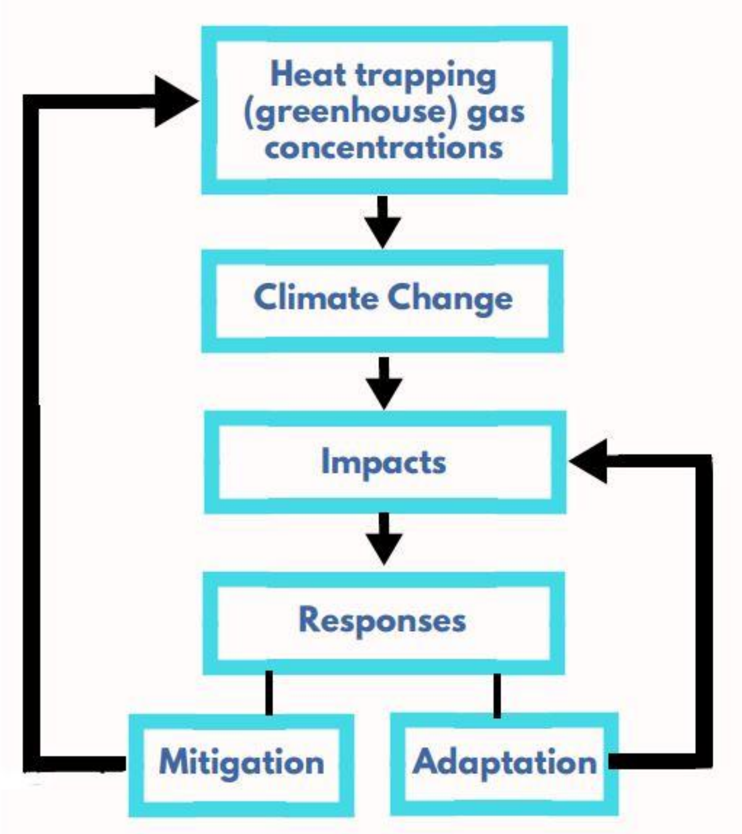

Figure 16: The relationship between mitigation and adaptation

Climate change mitigation and adaptation[40] are not mutually exclusive but are key partners (Figure 16). Effective mitigation can restrict climate change and its impacts and in doing so, can also reduce the level of adaptation required. However, there is a significant time lag between mitigation activities and their effects on climate change reduction that must be accounted for.

9.1 THE HEALTH CARE SECTOR'S ROLE IN CLIMATE CHANGE MITIGATION AND ADAPTATION

Prevention is the best course of action, and mitigation of global heat-trapping gas emissions should remain a top priority. The actions and strategies that are effective in reducing heat-trapping gas emissions will also reduce the likely threats to human health and well-being.

However, due to the slow response times of the oceans and ice sheets, there is a certain amount of climate change in the future that cannot be avoided, even if heat-trapping gas emissions ceased today. This means that there will still be some sea level rise (a rise of approximately 50 cm more is expected over the next 200 years) and an increase in global temperatures above pre-industrial levels that will continue for some

[40] in http://www.actiononclimate.today/act-on-information/mitigation-adaptation-and-resilience-climate-terminology-explained/

centuries (IPCC 2013; The Royal Society of New Zealand 2016). Anticipating and addressing the adverse effects of climate change will become increasingly more important to prevent or minimise any environmental health impacts.

From an environmental health perspective, adaptation options need to address current and future climate sensitive burden of disease (Thomas et al 2012). Adaptation options also need to remain flexible and favour “no-regret” or “win-win” strategies that yield benefits even in absence of climate change (Hallegatte 2009; Wardekker et al 2012; Wilby and Dessai 2010). Actions that reduce heat-trapping gas emissions and improve the environment, which also bring co-health benefits such as a reduction in obesity, increased physical activity, and/or decreased housing-related illness and cancers, are considered by many to be sufficient motivation to act (Norman et al 2013) . In fact, many ‘climate’ actions should be recommended solely on a health basis. Any options considered also need to have specific objectives and expected outcomes that have some measurable gain, eg, reduced heat-trapping gases, lower mortality, lower disability-adjusted life years (DALYs), savings to health care, lower A&E admissions etc.

As adopted in the Paris (COP21) agreement (United Nations / Framework Convention on Climate Change 2015), actions should also respect, promote and consider the respective obligations on human rights, the right to health, the rights of indigenous peoples, local communities, migrants, children, persons with disabilities and people in vulnerable situations including the right to development, as well as gender equality, empowerment of women and intergenerational equity[41].

The Ministry of Health’s new Health Strategy recognises that climate change has health and social consequences as a global challenge.

Health officials are leading measures to mitigate and adapt to these potential impacts of climate change in the health sector by:

- funding DHB public health units to detect exotic mosquitoes of public health significance and take measures to ensure any exotic mosquitoes intercepted are not able to establish in New Zealand
- maintain aircraft disinfection to prevent exotic mosquitoes (and other insect pests) arriving in New Zealand
- supporting the Ministry for Primary Industries to implement standards for risk goods including the fumigation of all imported used tyres
- planning for extreme weather events including droughts and floods, and ensuring DHBs also include these risks in their emergency and business continuity plans

[41] https://unfccc.int/resource/docs/2015/cop21/eng/l09.pdf

- commissioning a review of drinking-water safety plans to check if water suppliers are including the impact of extreme weather events in their water supply risk management planning
- reviewing the National Health Emergency Plan and Business Continuity Plan and
- encouraging the integration of renewable energy sources into health sector plans.

The Ministry of Health is also undertaking surveillance to detect and gather evidence on potential effects of climate change. The Ministry has funded the development of environmental health indicators on climate change which include hot days (the numbers of days reaching temperatures of 25°C or above) and soil moisture. Health officials are also observing the incidence of diseases like salmonellosis and cryptosporidiosis, as health experts believe that we will see higher rates of these diseases as conditions get warmer.

The health sector also has an obligation to reduce its carbon footprint. Although the literature search did not reveal any information regarding heat-trapping gas emissions from the NZ health sector, a global study estimated that health-related emissions in England and the United States, accounted for 3% and 8% of total national emissions, respectively (Brown et al 2012). The latter is now thought to be much higher when the total footprint is considered, including vehicle emissions, anaesthetic gas use and waste management (Eckelman and Sherman 2016; Holmner et al 2012). Moreover, Brown et al (2012) estimated 470,000 DALYs from pollution-related disease, or 405,000 DALYs when adjusted for recent shifts in power generation sector emissions.

New Zealand's emissions profile is unusual compared to other OECD countries as the majority of emissions originate from the agricultural sector (approximately 49%) (OECD 2017), with the remaining emissions from energy, industrial processes and product use (IPPU) (Figure 17) (Ministry for the Environment 2016d). Some examples of mitigation pathways to reduce heat-trapping gas emissions from within the health sector are shown in Table 11. Some of those actions will bring co-health benefits such as reduction in air pollutants, as discussed by health professionals in a joint call for action[42] and the WHO (WHO 2015b).

[42] http://www.hauora.co.nz/health-professionals-call-for-action-on-climate-change-and-health.html#sthash.BdpEzrK9.9MN5S3aP.dpuf. Accessed 14/6/2016

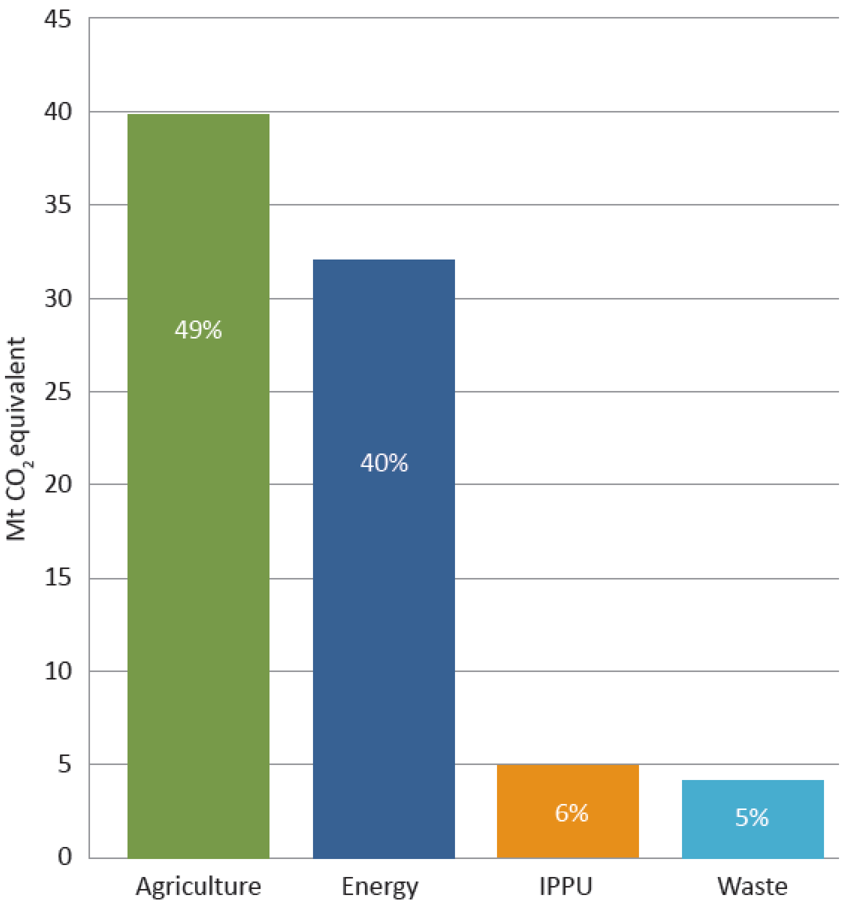

Figure 17: New Zealand's gross greenhouse (heat-trapping) gas emissions by sector[43] in 2014

Source: Ministry for the Environment (2016d). Mt refers to the unit, million tonnes.

Table 11: Examples of mitigation avenues to reduce heat-trapping gas emissions from health-related sectors

Sector	Examples	Refs/Source
Agriculture	• changing the food in hospitals to those that use less energy and water, particularly meat, and replacing with more nutrient rich foods	Harm 2016

[43] Agriculture includes emissions from nitrous oxide from fertiliser, methane from livestock digestive systems and manure, energy includes road transport and electricity production, industrial processes and product use (IPPU) includes metals, minerals and chemicals and waste includes landfill management practices, solid waste disposal and industrial and domestic wastewater handling.

Sector	Examples	Refs/Source
Energy	• reduction in heat-trapping gases from transport eg, replace vehicle fleet with electric vehicles, encourage staff to carpool, walk, cycle and use public transport • shifts in energy production from fossil fuels to renewable energy sources • energy conservation • improved building design divest investment funds out of fossil fuels	Bambrick et al 2011; Bennett et al 2015; Brown et al 2012; Jonas et al 2007; Lloyd et al 2008; Macmillan et al 2014; O'Connell et al 2010
Waste	• reduce waste including medical waste	Eckelman and Sherman 2016

In 2015, Ministry of Health officials briefed DHB medical officers of health on the Government's measures to support New Zealand to mitigate and adapt to climate change. Health officials provided medical officers of health with a suite of actions that public health leaders can take at a DHB, public health unit and individual level including:

- use carbonzero (or equivalent) providers and renewable energy generators
- reduce energy use - look at energy stars when buying new appliances, set up microgeneration
- use clean heat, improve insulation
- use public transport where feasible
- reduce air travel – use teleconferencing and videoconferencing
- reduce waste (unpackaged goods, reusable bags)
- use of the 5 R's: refuse, reduce, reuse, recycle, replant
- advocate to others in workplace and among friends
- support initiatives in the community to set up carbon banks or establish renewable energy and
- offset carbon emissions.

The NZ climate and health council have also produced resources on how to make the health sector more sustainable and climate-friendly. They include carbon reductions, promoting green hospitals and divestment from fossil fuels (Orataiao 2017; Bennett et al 2015). The mitigation measures suggested here, also align with the recent global report published in March 2017 which examines options towards achieving domestic emissions neutrality in the second half of the century (Kazaglis et al 2017).

9.2 CONCLUSIONS

The costs of setting future reduction in heat-trapping gas emission targets should account for the risks that inaction on climate change poses not only to our health but to our economic, social and environmental wellbeing. Some positive examples of mitigation and adaptation in the health sector are provided in this section, in particular ways to reduce heat-trapping gas emissions and monitoring those changes at all levels. There are still ways to improve climate-related action that will benefit the health sector. Importantly, there will be positive health benefits for everyone if appropriate mitigation and adaptation strategies are implemented sooner rather than later.

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10. GLOSSARY

Adaptation
In a climate change context, adaptation is the capacity and potential for humans to adapt. Adaptive capacity will be different across regions and populations, and is also closely linked to the social and economic development of individual countries.

Anthropocene
A term used to describe the current geological age, where human activity has been the dominant influence on climate and the environment.

Anthropogenic Climate Change
Changes to climate as a result of human (anthropogenic) activities on Earth.

Catastrophic climate change
Describes a situation that, due to climate change results in change to climate with catastrophic consequences. An example is the disintegration of the West Antarctic Ice Sheet resulting in a sea level rise of 4-6 metres over several centuries.

Cognitive illness
A disease or medical illness affecting a persons learning, memory, perception, and problem solving abilities.

Consequence
In risk assessment terms, consequence is the outcome of an event that has an effect (positive or negative) on people and/or assets.

Deficiency
A lack or shortage.

Greenhouse Gas (see Heat-trapping Gas)
A gas that contributes to the greenhouse effect by absorbing infrared radiation. Examples are carbon dioxide and methane.

Heat-trapping Gas
As per *Greenhouse Gas.* An alternative term that acknowledges that not all countries will be familiar with a "greenhouse".

Environmental Health
Is the field of science that studies how the environment influences human health and disease.

Exposure
People, property, systems, or other assets present in hazard zones or exposed to hazards that are thereby subject to potential losses.

Exotic disease
A disease which does not normally occur within a particular area.

Event
An event could be one occurrence, several occurrences, or even a nonoccurrence (when something doesn't happen that was supposed to happen). It can also be a change in circumstances. Events are sometimes referred to as incidents or accidents.

Faecal
The solid waste passed out of the body of a human or animal through the bowels.

Hazard
An intrinsic capacity to cause harm. A hazard can be an event, entity, phenomenon or human activity, and can be single, sequential or combined with other hazards in its origin and effects. Each hazard is characterised by its timing, location, intensity and probability. The origin of hazards can be natural (geological, hydro-meteorological and biological) or induced by human activity (environmental degradation and technological hazards), and include latent conditions or trends that may represent future threats.

Hemisphere
One half of the earth, usually as divided into northern and southern halves by the equator, or into western and eastern halves by an imaginary line passing through the pole.

Humidity
The amount of water vapor in the air. Absolute humidity refers to the percentage of water vapour actually present in the air whereas relative humidity is the absolute humidity divided by the amount of water that could be present in the air.

Insufficiency/insufficient
Not enough; inadequate.

Mitigation
The action of reducing or preventing the severity or seriousness of an issue eg. The emission of heat-trapping gases.

Modelling
Methods to simulate (climate) interactions.

Montreal Protocol
A global agreement to protect the stratospheric ozone layer by phasing out the production and consumption of ozone-depleting substances (ODS).

Morbidity
Refers to having a disease or a symptom of disease, or to the amount of disease within a population.

Mortality
The relative frequency of deaths in a specific population; death rate.

Intervention measures
A measure designed to improve health or alter the course of disease.

Pathogen
A bacterium, virus, or other microorganism that can cause disease.

Photochemical air pollution
Pollution caused by the reaction of unsaturated and saturated hydrocarbons, aromatics and aldehydes (emitted owing to the incomplete combustion of fuels) with light.

Precipitation
Rainfall

Premature mortality
Refers to deaths that occur at a younger age than a selected cut-off.

Public Health
The health of the population as a whole.

Relative Concentration Pathway
In the IPCC 5th assessment report are a new set of four scenarios known as representative concentration pathways (RCPs). These pathways are identified by their approximate total radiative forcing at 2100 relative to 1750:

- 2.6 W m^{-2} for RCP2.6
- 4.5 W m^{-2} for RCP4.5
- 6.0 W m^{-2} for RCP6.0
- 8.5 W m^{-2} for RCP8.5.

These RCPs include one mitigation pathway (RCP2.6, which requires removal of some of the CO_2 presently in the atmosphere), two stabilisation pathways (RCP4.5 and RCP6.0) and one pathway with very high heat-trapping gas concentrations (RCP8.5).

Reticulated water
A system which carries water for domestic purpose.

Risk
Risk is defined as the likelihood and consequences of a hazard. Risk can also be described as the effect of uncertainty on objectives (Risk Management Standard ISO31000).

Risk assessment
The process of evaluating the likelihood and consequence of a hazardous event. Risk assessment involves hazard identification, risk characterization, likelihood/probability estimation, and consequence analysis.

Risk reduction
Risk reduction refers to efforts to decrease in risk through risk avoidance, risk control, or risk transfer – this can be accomplished by reducing vulnerability and/or consequences.

Resilience
Resilience means being shock-ready, and having the ability to resist, survive, adapt and/or even thrive in response to shocks and stresses. Resilience can be defined in terms of societal, economic, infrastructure, environmental, cultural capital, social capital, and/or governance components.

Shock
The term 'shock' is used to denote a sudden, disruptive event with an important and often negative impact on a system/s and its assets.

Stress
A stress is a long term, chronic issue with an important and often negative impact on a system/s and its parts.

Surveillance systems
Continuous, systematic collection, analysis and interpretation of health-related data needed for the planning, implementation, and evaluation of public health practice.

System
A system is defined as set of things working together as parts of an interconnecting network; a complex whole eg, society (individual, community, nation), the environment and physical entities (eg, infrastructure).

Threat
A threat is a potentially damaging physical event, phenomenon or activity of an intentional/malicious character. It is a man-made occurrence, individual, entity, or action that has the potential to harm life, information, operations, the environment, and/or property.

Variability
Lack of consistency or fixed pattern; liability to vary or change.

Venomous
Secretion of venom; capable of injecting venom by means of a bite or sting.

Vulnerability
The characteristics and circumstances of an asset (populations, systems, communities, the built domain, the natural domain, economic activities and services, trust and reputation) that make it susceptible to, or protected from, the impacts of a hazard.

11. LIST OF ABBREVIATIONS

A&E	Accident & Emergency
AMR	Antimicrobial Resistant Bacteria
AR5	Assessment Report five (IPCC publication that presents the set of the global warming potentials for heat-trapping (greenhouse) gases known as AR5 GWPs)
ARG	Antibiotic Resistance Genes
BFV	Barmah Forest virus
CE	Common era
CH_4	Methane
CFC	Chlorofluorocarbon
CMIP5	Coupled Model Intercomparison Project Phase 5
CO	Carbon monoxide
COP21	Conference of Parties
COPD	Chronic Obstructive Pulmonary Disease
CO2	Carbon dioxide
CPHR	Centre for Public Health Research
DALY	Disability-adjusted life year
DEET	N, N-Diethyl-meta-toluamide
DHB	District Health Board
DO	Dissolved Oxygen
ECDC	The European Centre for Disease Prevention and Control
EID	Emerging Infectious Disease
ENSO	El Niño – Southern Oscillation
EPA	Environmental Protection Agency
ESM	Earth System Model
ESR	Institute for Environmental Science and Research
EU	European Union
GHG	Greenhouse Gas(es)
GIS	Geographical Information System
HAB	Harmful Algal Blooms
HAIFA	The Health Analysis & Information for Action
HAPINZ	Health and Air Pollution in New Zealand
HFC	Hydrofluorocarbon
IPCC	Intergovernmental Panel on Climate Change
IPO	Interdecadal Pacific Oscillation
IPPU	Industrial Processes and Product Use
N_2O	Nitrous oxide
NASA	National Aeronautics and Space Administration
NIWA	National Institute for Water and Atmospheric Sciences
NOAA	National Oceanic and Atmospheric Administration
NO_x	Nitrogen oxides (other than nitrous oxide)
NZ	New Zealand
NZAGRC	New Zealand Agricultural Greenhouse GasResearch Centre
NZCPH	New Zealand College of Public Health

OECD	Organisation for Economic Co-operation and Development
PCE	Parliamentary Commisioner for the Environment
pH	Potential of hydrogen
PM	Particulate Matter
RCP	Relative Concentration Pathway
RRV	Ross River Virus
RSNZ	The Royal Society of New Zealand
SCION	New Zealand Forest Research Institute Limited
SO_2	Sulfur Dioxide
UNFCCC	United Nations Framework Convention on Climate Change
US	United States (of America)
USGCRP	The U.S. Global Change Research Program
UV	Ultraviolet
UVI	Ultraviolet Index
UVR	Ultraviolet Radiation
VBD	Vector-borne Disease
VH + E	Very high and Extreme
VOC	Volatile Organic Compounds
WHO	World Health Organisation

12. APPENDIX A: Summary of climate change projections for New Zealand

A1 Summary of main features of New Zealand climate change projections

Climate Change Impacts	Main Points	Spatial and seasonal variation
Agriculture	• Shifts in agricultural production in relation to increased temperature and shifts in rainfall • Increased erosion	Rainfall changes and rising temperatures will shift agricultural production zones Some native species will suffer from range contractions Some species may face local or even global extinction
Biodiversity and ecosystems	• Threats from invasive pests and weeds • Habitat loss • Risk of increased spread of disease to plants and animals • Warmer temperature will reduce areas in which some plants and animals can survive	Summer droughts will lead to increased stress in areas of dry lowland forest Earlier springs and longer frost free seasons could affect when birds lay their eggs, when flowering plants first emerge and first flowering, health of leafing and flowering plants
Built environment	• Higher temperatures will cause discomfort for people in domestic, commercial, public buildings leading to disruption in business.	Increased average summer temperatures Increased extreme hot days Decreased extreme cold days
Business and Finance	• Insurance cover could become challenging in areas that are flood prone • Businesses in agriculture may find insurance expensive for weather related damage	

	• Potential opportunities for business in risk management	
Changes in average rainfall patterns	• Low river flow in summer • High river flow in winter • Variable changes in rainfall across the country	Annual increases of rain in the west and south of New Zealand (Nelson, West Coast, Otago, Southland) in winter and decreases in north (Auckland, Northland and Bay of Plenty in spring) and east (Waikato, Gisborne, Hawke's Bay and Canterbury) in winter.
Drought (prolonged dry weather)	• Increase in severity and frequency	Increases occur where dry conditions currently exist.
Energy	• Changes in demand for energy seasonally	Less demand for heating in winter Potential increased demand for cooling in summer
Extreme wind speed	• Increase	Up to 10% increase in southern half of North Island, and throughout the South Island
Forestry	• Increased growth in cooler regions with correct nutrients and rainfall	Reduced disease in central North Island Increased disease in South Island
Health implications	• **Increased water- and foodborne diseases** • **Fewer cold related deaths** • **Increased potential for vector diseases** • **Increased mental health issues**	**Increased number of deaths and medical admissions due to increased summer heat** **Reduced number of deaths related to colds and flu due to warmer winters**
Higher average temperatures	• Higher air and land temperatures for all RCPs • RCP2.6 is the only scenario to showa peak and then a decline	Warming highest in elevated areas Greater warming during summer autumn and least during winter/spring

Increased extreme weather events	• Increased winter rainfall • Increased flash flooding • Increased damage from wildfires • Increased extreme hot days (>25 °C) • Increased extreme high winds • Decrease in cold night • Increased extreme dry days • Increased extreme wet days • Decreased extreme wet days	Warming highest in elevated areas Decreased number of days of frost in coldest regions. More dry days across the North Island and inland South Island. Up to 5% increase for RCP8.5 in 2090. Increase in western regions and south of South Island Decreased extremes in parts of north and east North Island
Increased pressure on freshwater resources	• Reduced soiled moisture • Reduced groundwater reservoir	Changes to water quality in summer and winter Increased water demand in the summer
Māori	• Susceptibility of climate sensitive primary industries, fisheries and tourism • Māori, Pacific, vulnerable, and lower socioeconomic populations are at risk of disproportionate health impacts from climate change	
Minimum and maximum temperature	• Progressive increase with concentration (RCP)	Maximum temperature increase faster than minimum. Warming highest in elevated areas Esp. at maximum temperatures.
Oceans and fisheries	• Ocean acidification • Stronger East Auckland current could bring in new species and potentially affect wild fisheries and aquaculture	
Relative humidity	• Decrease	Largest decrease in south Island in spring

		and summer (5% by 2090 [RCP8.5].
Sea level rise	• Increased flooding and erosion	
Snow	• Decrease	Large decreases at high altitude or southern regions of the South Island. Up to 30 or more snow days lost per year by 2090 for RCP8.5
Solar radiation	• Varies around the country but changes between -5 and +5%	West coast shows the largest changes in the summer (5%) and a winter decrease (5%) for RCP8.5
Storms	• Likely poleward shift of mid-latitude cyclones and possibly a small reduction in the frequency	More analysis required
Tourism	• Decreased snowlines (see Snow)	Ski fields in North Island potentially affected by decreased snowline
Transport	• Infrastructure damage could cause major disruption	Higher temperatures in the summer could damage infrastructure (railway lines, rutted roads)
Wind	• Varies with season	More NE airflow in the summer. Stronger westerlies in the winter.

13. APPENDIX B: Unwanted organisms

Table B1: Organisms declated to be unwanted by the Chief Technical Officer (Health)

Date	***Organism***	***Common name***	***Public health significance***	***MAF advised***	***Record kept***
08.01.99	*Aedes camptorhynchus*	Southern saltmarsh mosquito	Ross River virus, possibly Murray Valley encephalitis virus	Yes	Yes
23.06.99	*Culex annulirostris*	[No common name]	Ross River virus, Barmah Forest virus, Japanese encephalitis virus, Kunjin virus (a subtype of West Nile virus), Murray Valley encephalitis virus	Yes	Yes
7.11.99	*Aedes albopictus*	Asian tiger mosquito	Chikungunya fever, Dengue fever, Eastern equine encephalitis virus, Japanese encephalitis virus, LaCrosse encephalitis virus, Ross River virus, St Louis encephalitis virus, Western equine encephalitis virus, West Nile virus, Yellow fever	Yes	Yes
7.11.99	*Aedes japonicus*	[No common name]	Japanese encephalitis virus, La Crosse encephalitis virus, West Nile virus	Yes	Yes
7.11.99	*Aedes aegypti*	Yellow fever mosquito	Chikungunya fever, Dengue fever, Murray Valley encephalitis virus,	Yes	Yes

			Ross River virus. Yellow fever		
7.11.99	*Aedes polynesiensis*	[No common name]	Bancroftian filariasis, Dengue fever, Ross River virus	Yes	Yes
7.11.99	*Aedes vigilax*	Northern saltmarsh mosquito	Bancroftian filariasis, Barmah Forest virus, Japanese encephalitis virus, Kunjin virus, Murray Valley encephalitis virus, Ross River virus	Yes	Yes
	All mosquitoes of the genus Anopheles	Malarial mosquitoes	Malaria, may transmit Bancroftian filariasis and several viral diseases	Yes	Yes
08.09.00	*Culex gelidus*	Frosty mosquito	Japanese encephalitis virus	Yes	Yes
26.10.01	*Culex pipiens*	Northern house mosquito	Bancroftian filariasis, St Louis encephalitis virus, West Nile virus	Yes	Yes
25.02.05	*Aedes scutellaris*	[No common name]	Dengue fever	Yes	Yes
25.02.05	*Culex sitiens*	[No common name]	Japanese encephalitis virus, Ross River virus	Yes	Yes
25.02.05	*Ochlerotatus atropalpus*	Rock pool mosquito	Eastern equine encephalitis virus, LaCrosse encephalitis virus, possibly West Nile virus	Yes	Yes
25.02.05	*Ochlerotatus sierrensis*	Western tree hole mosquito	Western equine encephalitis virus	Yes	Yes
22.02.08	*Aedes togoi*		*Brugia malayi, Wuchereria bancrofti, Dilofilaria*	Yes	Yes

			immitis Japanese encephalitis		

Note: *Aedes aegypti, Aedes albopictus, Aedes polynesiensis*, *Ochlerotatus japonicus* and *Ochletrotatus vigilax* have been intercepted at New Zealand's borders and are confirmed or probable vectors for two or more of the following: Bancroftian filariasis, Barmah Forest virus, Chikungunya virus, Dengue fever, Eastern equine encephalitis virus, Japanese encephalitis virus, Kunjin virus (a subtype of West Nile virus), Murray Valley encephalitis virus, Ross River virus, Western equine encephalitis virus, West Nile virus and yellow fever (Hearndon *et al.* 1999, MoH June 1997, http://www.mosquito-va.org/disease.html). *Aedes aegypti* is the primary vector of dengue and yellow fever. Similarly, *Aedes albopictus* is a vector of dengue and yellow fever in the wild. However, under laboratory conditions it is also known to vector Eastern and Western equine encephalitis, West Nile, chikungunya and Japanese encephalitis viruses.

Note: Anopheline mosquitoes have rarely been intercepted at New Zealand's border (MAF March 2003) but are found in temperate areas as well as being common in tropical and subtropical regions. Anopheline mosquitoes are the exclusive vectors of malaria and also may transmit Bancroftian filariasis and several viral diseases (MoH June 1997).

Note: *Culex gelidus* is an exotic mosquito which has only been intercepted once at New Zealand's border but has the potential to survive and become established in New Zealand. There is evidence to suggest that it may be a vector for human diseases such as Japanese encephalitis (Whelan *et al*. July 2000).

Note: *Culex pipiens (*ssp. *pallens)* is a mosquito that has been intercepted at New Zealand's border and there is documented evidence to show that it may be a vector for human diseases such as Bancroftian filariasis, St Louise encephalitis (http://www.cdc.ncidod/arbor/slefact.htm) and West Nile virus encephalitis (http://www.mosquito-va.org/disease.html).

Note: *Culex annulorostris* is a mosquito that has been intercepted at New Zealand's border and there is documented evidence to show that it may be a vector for Ross River virus, Barmah Forest virus, Japanese encephalitis virus, Kunjin virus (a subtype of West Nile virus) and Murray Valley encephalitis virus (AMCA, 1998).

Note: *Ochlerotatus camptorhynchus* is a mosquito that has been intercepted at New Zealand's border on one occasion. However, it was somehow introduced and found to have established as a number of relatively isolated infestations, mostly in the North Island. Eradication programmes have been successfully completed or are in progress (Frampton 2004). *Ochlerotatus camptorhynchus* is an important coastal vector of Ross River virus in Australia.

(http://www.arbovirus.health.nsw.gov.au/areas/arbovirus/mosquit/mosquitoes.htm)

Note: *Aedes scutellaris, Culex sitiens, Ochlerotatus atropalpus, Ochlerotatus sierrensis* are mosquito species that have not necessarily been intercepted at New Zealand' border. However, most of these species have come to the attention of quarantine inspectors and/or health officials in recent times in association with imported goods or emerging disease (e.g. West Nile virus in the United States) (Frampton 2004, Russell and Kay 2004).

Note: *Aedes togoi* is a mosquito that has been intercepted in New Zealand and there is documented evidence to show that it may be a vector for human diseases such as *Brugia malayi, Wuchereria bancrofti, Dilofilaria immitis* and Japanese encephalitis (Tanaka, Mizusawa and Saugstad, 1979).

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