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Impact of Climate Change on the Manuherikia Irrigation Scheme

Prepared for Manuherikia Catchment Water Strategy Group

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List of Abbreviations

C	Centigrade
CO_2	Carbon dioxide
ET_o	reference evapotranspiration
m	metre
MAR	mean annual rainfall
mm	millimetre
PAW	plant available water
PED	potential evapotranspiration deficit
PET	potential evapotranspiration
GCM	Global Climate Model
IPCC	The Intergovernmental Panel on Climate Change
MfE	The Ministry for the Environment
NIWA	National Institute of Water and Atmosphere

EXECUTIVE SUMMARY

The purpose of this report is to summarise the current knowledge of climate change and its potential impact on the proposed Manuherikia Irrigation Scheme. The weather within the Manuherikia catchment is variable and it will continue to experience natural climate variations between seasons. However, due to greenhouse effects (primarily increased concentrations in atmospheric CO_2) and global warming it is likely that the frequency of extremes weather events, both droughts and floods, will increase.

Impact of climate change on agriculture will be both positive and negative. Warmer weather will lengthen growing seasons (particularly in cold regions) and increased concentrations in atmospheric CO_2 will act as an ‘atmospheric fertilisation’. However, it is likely that average summer rainfall will reduce and potential evapotranspiration deficit will increase. The reduced water availability due to low summer rainfall and higher irrigation demand will increase pressure on the water resources.

Climate change is a highly complex phenomenon that depends on interactions between many natural processes in atmosphere, land and ocean, and activities by mankind. It is difficult to predict the full-scale impacts of climate change in advance, in part because future human activities cannot be accurately predicted.

The Intergovernmental Panel on Climate Change (IPCC) have developed a range of possible climate change scenarios. NIWA considers that the most possible climate change scenario for New Zealand, out of many IPCC scenarios, is the intermediate scenario (i.e., not the extreme low or high scenarios). There are also a number of global climate models (GCM) have been developed to project the impact on climate change. However, the spatial resolutions of these models are very low. Therefore, the models need to be downscaled to meaningfully be used for variable topography such as New Zealand to identify impacts at a regional scale.

The accuracy of most GCMs has been impeded by uncertainties associated with initial conditions, and flux imbalances (of energy, momentum or fresh water). The long-term predictions between models tend to vary due to the uncertainties. To counter the uncertainties of models, it is the general practice to use more than one model to capture the range of climate possibilities.

NIWA has produced predictions for New Zealand by using IPCC temperature change projections and GCMs. The key potential climate change projections for the Manuherikia area are:

- The mean annual temperature would increase by 0.9 and 2°C relative to 1990 (i.e., the average of 1980-1999) by 2040 and 2090, respectively.
- The mean annual precipitation would increase by up to 5% and 10% relative to 1990 by 2040 and 2090, respectively.
- However, most of the precipitation increase would occur in winter and the average summer rainfall would reduce.
- Low summer rainfall will increase the crop-water deficit, increasing irrigation requirements.

- It is likely that current 1-in-20 year droughts would occur approximately three times more frequently by 2090.
- Occurrence of extreme climate events such as floods, severe droughts, and warmer days would increase.

While there is high uncertainty associated with the scale of potential climate change, projections under all GCMs indicate that the crop-water deficit will be higher in the future. Thus higher irrigation system capacities, both irrigation system and convey systems, will be required in the future.

The reduction in summer rainfall and increased irrigation requirements means if Falls Dam is not raised reliability to existing Manuherikia irrigators will reduce. Without additional storage, the additional winter rainfall cannot be ultilised. In contrast, if Falls Dam is raised the full 27 m, additional winter rainfall would be able to be captured and used in summer.

The increase in drought frequency will significantly impact on dryland production. An increase in the water available for irrigation will be necessary to off-set this reduction in dryland production, if current production levels are to be maintained.

Raising Falls Dam 27 m will provide security of reliable irrigation water which will be critical to realising the economic benefits from agriculture and horticulture. The well design and future proofed irrigation schemes will make the district more resilient to climate change.

1 INTRODUCTION

A larger part of the Manuherikia River catchment has been developed for agriculture and horticulture. The sustainability and future growth of these land uses is closely linked to reliable water supply for irrigation, stock water and associated requirements. The climate in the catchment is semi-arid and exhibits a continental type of climate with larger seasonal temperature variations than is common elsewhere in New Zealand. Climate and its potential future changes directly affect the water requirements for crops and stocks.

This reports summaries how future climate change would affect the agriculture and horticulture in the Manuherikia River catchment. This report was produced by reviewing current literature and reports. No new modelling has been carried out.

2 CLIMATE AND WEATHER

Local temperatures fluctuate naturally. However, measured data shows the average global temperature has increased at the fastest rate in recorded history over the past 50 years, as shown in Figure 2-1. Statistical analysis of global observations shows that there have been changes in climate (i.e. a shift in the average weather) over the past few decades (IPCC, 2007).

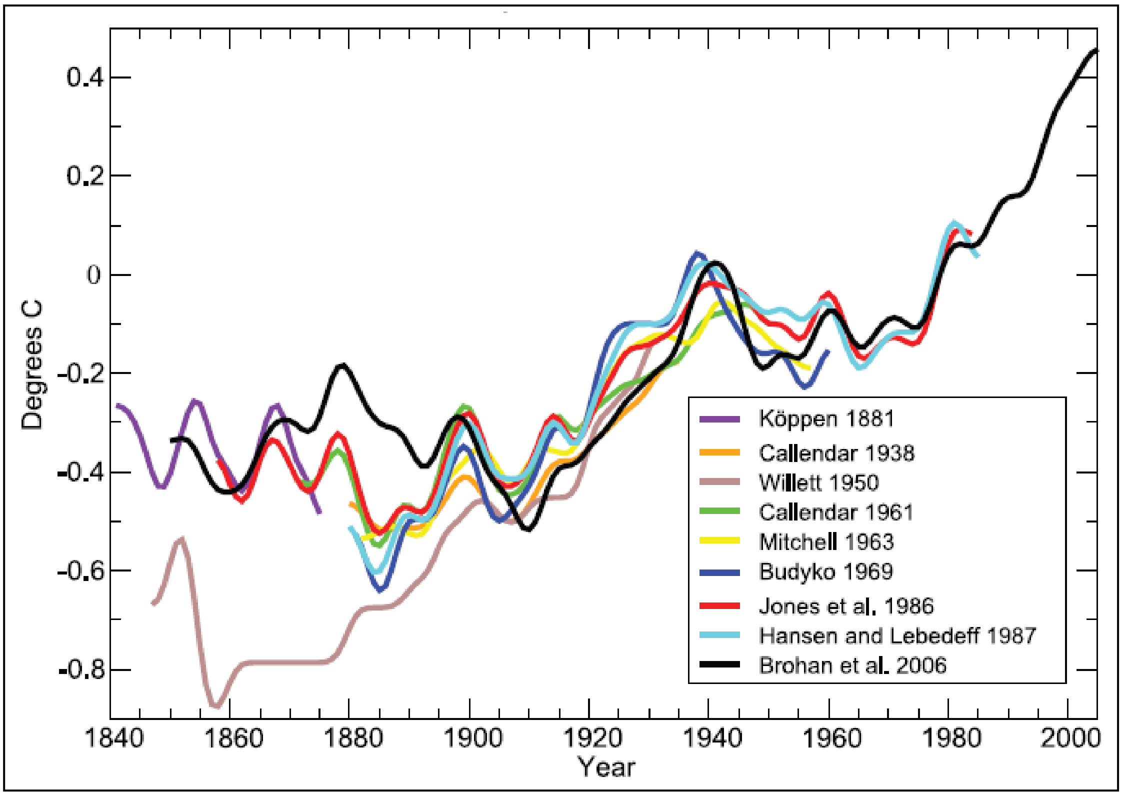

Figure 2-1: Published records of surface temperature change over large regions (Source: IPCC (2007))

2.1 Greenhouse Effect

The amount of energy reaching from the Sun to the Earth's surface and atmosphere need to be balanced by the Earth itself by radiating, on average, the same amount of energy back to space. The concentration of greenhouse gasses presence on Earth's atmosphere acts as a partial blanket and determines the amount of radiation back to space. While these greenhouse help to maintain the Earth's mean surface temperature around 14°C, higher greenhouse concentration do increase the temperature and adversely affect the environmental balance (IPCC, 2007). The most important greenhouse gases for this phenomenon are water vapour and carbon dioxide (CO_2). Nitrogen (78%) and oxygen (21%) make up a large proportion of gases in the atmosphere; however, they do not exert a greenhouse effect (IPCC, 2007).

Adding more CO_2 to the atmosphere intensifies the greenhouse effect, warming Earth's climate. Figure 2-2 shows the greenhouse gas concentrations has increased at a higher rate over the last two centuries. However, the effect of greenhouse concentration in the atmosphere varies between different regions. Adding a small amount of CO_2 or water vapour has only a small greenhouse effect in the regions closer to the equator where humidity is high and there is so much water vapour in the air. However, the effect can be greater in dry and cold regions. The amount of water vapour in the atmosphere increases due to increased temperature, which further intensifies the greenhouse effect.

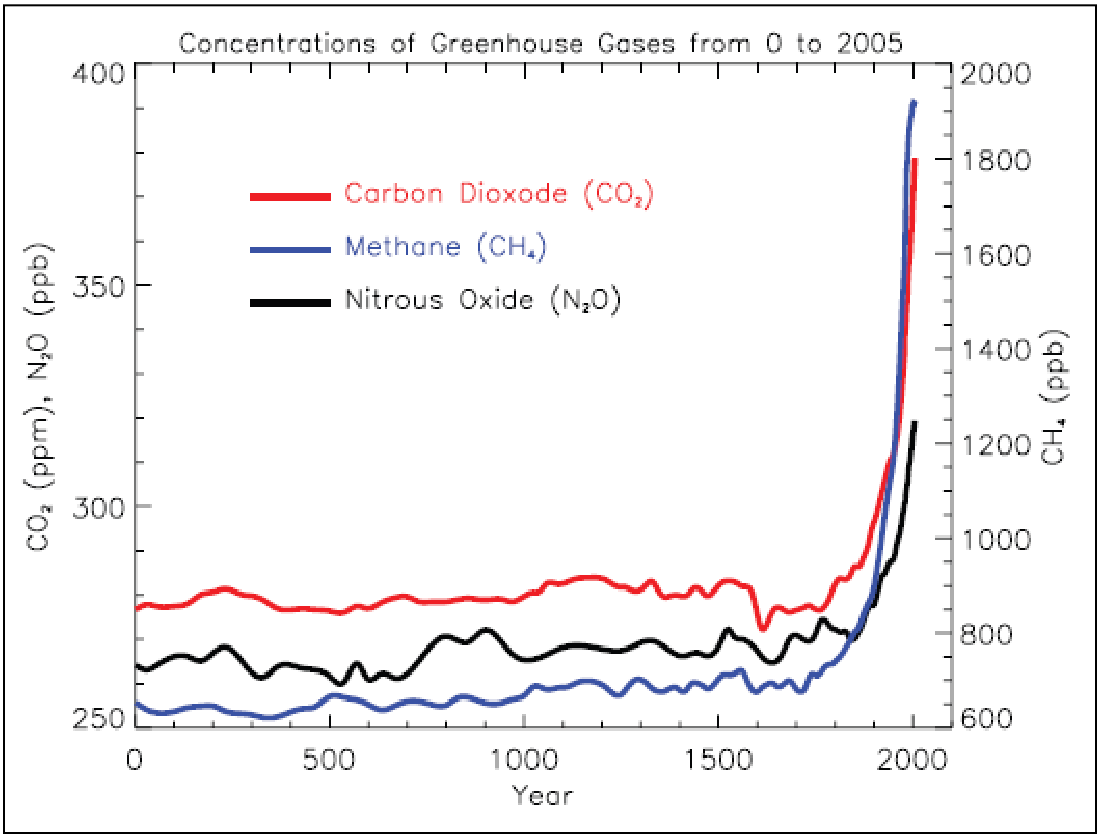

Figure 2-2: Atmospheric concentrations of greenhouse gasses (Source: IPCC (2007))

The temperature measurements show that global temperature at the Earth's surface has risen globally over the last 150 years. This temperature rise coincides with the greenhouse effect. As shown in Figure 2-3 (data covers up to end of 2006), the average global surface temperatures have risen by approximately 0.74^{0}C over the past century. The most interesting observations can be seen from these records are the rapid temperature increase of 0.44^{0}C since 1980, and 11 of the 12 warmest years occurred between 1995 and 2006. The data has also shown that warming has generally been greater over land than over the oceans primarily since the 1970s (IPCC, 2007).

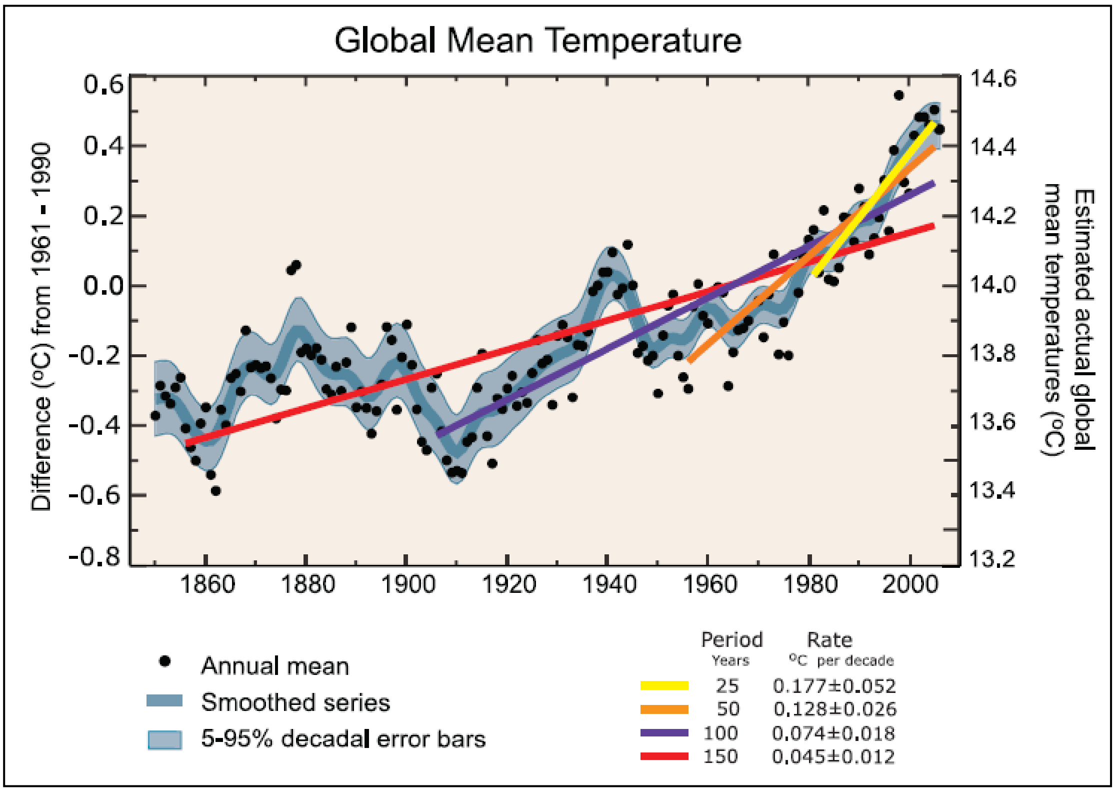

Figure 2-3: Annual global mean temperature (Source: IPCC (2007))

The recorded data shows that there are changes in amount, intensity, frequency and type of precipitation (rainfall and snowfall) over the last 100 years. Such changes generally demonstrate large natural variability, and El Niño and changes in atmospheric circulation patterns (IPCC, 2007).

2.2 Extreme Climate Events

The global data shows that the number if extreme climate events, which exceed up to 10% variation of long term records, have increased since 1950. While the annual occurrence of cold nights has significantly decreased, the annual occurrence of warm nights has considerably increased. These warm extremes entail an increased frequency of heat waves (IPCC, 2007). Although mean precipitation amounts are not generally increasing, a number of extremes has increased indicating increased extremely wet periods and increased drought frequency.

The number of strong hurricanes has increased significantly with the number of category 4 and 5 hurricanes increased by about 75% since 1970. The El Niño-Southern Oscillation affects the location and intensity of tropical storms around the world (IPCC, 2007). It is likely that the wind patterns and its strength will change in New Zealand due global phenomenon such as the El Niño.

3 CLIMATE IN THE STUDY AREA

Mean annual rainfall for the Manuherikia catchment is approximately 630 mm/year. Rainfall patterns vary within the catchment. The north-eastern end of the catchment receives higher rainfall; up to 1,200 mm/year. At the other end of the catchment, Alexandra only receives 350 mm/year on average. We estimate that mean annual reference evapotranspiration (ET_o) ranges between 750 – 950 mm/year within the Manuherikia irrigation scheme area. Further details on the Manuherikia catchment climate is given “Manuherikia Catchment Study: Stage 1 (Land)” (Aqualinc 2012a).

Data shows that temperatures are low over winter, early spring and late autumn months. These low temperatures limit the crop growing season.

4 EFFECT OF CLIMATE CHANGE ON CROPS

The effect of global warming on crops can be both positive and negative. Increased concentrations in atmospheric CO_2 have a positive effect on crops due to ‘atmospheric fertilisation’ as greater concentrations will lead to greater rates in photosynthesis[1] (Howell, 2009). Kimball (1983) showed that doubling CO_2 concentrations, average biomass productivity can be increased by 33% in plants. Over time, plants adapt to elevated CO_2 levels, therefore the long term increase in biomass productivity are less.

Aqualinc (2012b), using a field based study, showed that higher ambient temperature and solar radiation increase the pasture dry matter (DM) production. This finding agrees with previous research (DNZ, 2011; Fitzgerald, 1978).

Warrick *et al*. (2001) reported that some climate change models have shown that 1 to 3^0C increase in temperatures would result in an increase in annual pasture yields, with likely increases of 20-50% at 3^0C temperature rise (Warrick *et al*., 2001).

Climate change will likely have a negative impact on water resources. Water is a key driver of agricultural production. The study area has a continental type of climate with larger seasonal temperature variations than other parts of New Zealand (Aqualinc, 2012a). Water for irrigation is an integral part of current farming systems. The impact of climate change will lead to an intensification of extremes of the global hydrological cycle and could have major impacts on water resources. Changes in the total amount of precipitation and in its frequency and intensity directly affect the magnitude and frequency of floods and droughts.

The increase in drought frequency will significantly impact on dryland production. An increase in the water available for irrigation will be necessary to off-set this reduction in dryland production, if current production levels are to be maintained.

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[1] Photosynthesis is a process used by plants and other organisms to convert the light energy captured from the sun into chemical energy that can be used to fuel the organism's activities. In plants, photosynthesis uses CO_2 and water, releasing oxygen as a waste product.

5 CLIMATE FORECASTS

The future climate predictions are carried out using global climate model or general circulation model (both abbreviated as GCM). These models generally use the same equations of motion as a numerical weather prediction (NWP) models. However, NWP models are used to predict the short-term weather (1-3 days) and medium (4-10 days). GCMs are run for much longer periods, generally for years, to learn about the climate in a statistical sense (i.e. the means and variability).

It is important to include all the boundary conditions such as solar constant, and different mediums such as atmosphere, land and ocean in these GCM models. A large number of coupled models have been developed. These models include global representations of the atmosphere, oceans and land surface. Due to highly complex nature of the models, they are limited in resolution to a 0.5° latitude by 0.5° longitude grid. The resolution of the GCM is coarse. Thus, they take account the average effect of New Zealand's topography, and do not represent the local effects. The local changes are inferred from the coarser-scale information of the GCMs by a statistical technique known as 'downscaling'. Typically, GCMs have a resolution of 150-300 km by 150-300 km. Many impacts models require information at scales of less than 20 km. Statistical downscaling first derives statistical relationships between observed small-scale (often station level) variables and larger (GCM) scale variables, using either analogue methods, regression analysis, or neural network methods. Future values of the large-scale variables obtained from GCM projections of future climate are then used to drive the statistical relationships and so estimate the smaller-scale details of future climate.

The accuracy of most GCM models has been impeded by uncertainties associated with initial conditions, and flux imbalances (of energy, momentum or fresh water) (IPCC, 2007). The long-term predictions between models tend to vary due to the uncertainties. To counter the uncertainties of models, it is the general practice to use more than one model to capture the range of climate possibilities. In preparation to the "Climate Change Effects and Impacts Assessment: A Guidance Manual for Local Government in New Zealand", MfE (2008) used 12 GCM models to statistical downscale and develop six scenarios of greenhouse gas emissions. The predictions were given for 2040 (2030–2049 average), and for 2090 (2080–2099 average), relative to the climate of 1990 (1980–1999 average) (MfE, 2008). NIWA's "Changes in drought risk with climate change" (NIWA, 2005), which may be more relevant to the Manuherikia Irrigation Scheme, also used statistical downscale techniques to develop four 'potential evapotranspiration deficit' (PED) scenarios for New Zealand.

Warrick *et al*. (2001) found that New Zealand climate has warmed at a rate averaging between 0.1 and 0.2°C per decade since 1940. They found that future predictions are difficult as available daily data sites across the country are limited. Using downscaled GCM scenario modelling they estimated that for the mid-range scenario the number of frost days in the South Island would reduce by 10 and 20 fewer days compared to 1990 by 2050 and 2100, respectively. The implications for the Manuherikia area are that a reduction in frosts can be expected.

Mullan *et al*. (2001) predicted climate change would increase drought risk, especially in the drought-prone eastern regions of the country.

6 POTENTIAL IMPACT ON MANUHERIKIA IRRIGATION SCHEME

MWH (2010) investigated the impact of climate change on rural water infrastructures in New Zealand. This investigation included five case studies of irrigation schemes. One of the schemes studied was the existing Manuherikia Irrigation Scheme. Section 6.1 presents a summary of MWH (2010) findings.

A summary of the study on potential changes in drought risk with climate change (NIWA, 2005) is presented in Section 6.2. This study has given the climate predictions for Ranfurly, which is reasonably close to the Manuherikia Irrigation Scheme (distance between the eastern boundary of the proposed scheme and Ranfurly is approximately 17 km).

NIWA’s recent projection (NIWA, 2008) on climate change is summarised in Section 6.3.

6.1 MWH Study

MWH (2010) investigated the potential impact of climate change on rural water infrastructures. They assessed the impacts on New Zealand’s rural water infrastructure using five irrigation schemes and seven rural stock water supply schemes. One of the irrigation schemes assessed was the existing Manuherikia Irrigation Scheme.

MWH (2010) used MfE ‘Climate Change Effects and Impacts Assessment’ (MfE, 2008) for their assessment. As noted in Section 5, MfE (2008) has scaled down 12 GCM models to show climate change effects for New Zealand.

The key findings of the MWH (2010) for the Manuherikia Irrigation Scheme are:

- The mean annual rainfall is projected to increase across all seasons, with up to 20% over the winter months by 2090.
- The frequency of extreme rainfall events will increase.
- Temperatures are projected to increase by 0.9°C above current levels by 2040 and 2.0°C by 2090.
- The number of very hot days (over 25°C) will increase and number of frost events will decrease.
- The number of drought days will increase markedly.

6.2 Changes in Drought Risk (NIWA, 2005)

NIWA (2005) developed four potential scenarios of changes in drought risk for New Zealand due to climate change. This study used the Intergovernmental Panel on Climate Change (IPCC) 3rd Assessment (IPCC, 2001). Note that the latest IPCC 4th Assessment (IPCC, 2007) was not available at the time of investigation.

NIWA (2005) has identified that it is difficult to predict exactly how much New Zealand's climate will change. Therefore, they have developed a range of plausible scenarios to response to the question 'How will climate change affect future drought risk?', rather than attempt to develop "a scenario".

NIWA (2005) has developed four scenarios for climate change (Table 6-1). They have used two different future global-average temperature projections with two different global climate models. The two projections for future global temperatures are approximately 25% and 75% of the way between the lowest and the highest temperature projections developed by the IPCC (2001). The lower projection is referred as "25% scaling" and the higher projection as "75% scaling". The two GCMs used are the CSIRO model and the Hadley model from the UK Met Office Hadley Centre.

Table 6-1: Four scenarios modelled by NIWA (2005)

Model	**Global temperature projection**	
	25% IPCC	**75% IPCC**
CSIRO	2030s, 2080s 'low-medium'	2030s, 2080s
Hadley	2030s, 2080s	2030s, 2080s 'medium-high'

As described in Section 5 the GCM predictions are generally for course scales and do not take account of the effect of New Zealand's topography on the local climate. Therefore, NIWA (2005) has statistically downscaled the GCMs to produce more relevant climate patterns for New Zealand. The grid size of the downscaled model is approximately 5 km by 4 km.

NIWA (2005) developed the 'potential evapotranspiration deficit' (PED) (i.e., the amount of water that would need to be added to a crop over a year to prevent loss of production due to water shortage) under each scenario.

Table 6-2 lists the NIWA (2005) projection of drought risk characteristics for Ranfurly. The key findings are:

1. Drought risk is expected to increase during this century in all areas that are currently already drought-prone, under all the scenarios.
2. It is predicted that droughts (i.e., current 1-in-20 year drought) would occur at least twice as often as currently in the inland and northern parts of Otago, by the 2080s under the 'low-medium' scenario.
3. Water deficit in an average year is projected to increase by between about 55 mm and 80 mm PED in Ranfurly by the 2080s for low-medium and medium-high scenarios, respectively.
4. The current 1-in-20 droughts in Ranfurly would predict to occur on average every 8.5 and 6.5 years by the 2080 under low-medium and medium-high scenarios, respectively.
5. The projected increased PED accumulation over the year would probably produce an expansion of droughts into the spring and autumn months.

Table 6-2: Drought estimates for Ranfurly (NIWA, 2005)

Present PED (mm) 1-in-20 year drought	2080s, low-med scenario. PED (mm), 1-in-20 year drought	2080s, med-high scenario. PED (mm), 1-in-20 year drought	2080s, low-med scenario. Average return interval (yrs) for current 1-in-20 year drought	2080s, med-high scenario. Average return interval (yrs) for current 1-in-20 year drought
645	700	725	8.5	6.5

6.3 Climate Change Projections (NIWA, 2008)

This section summarises NIWA's recent climate change projections (NIWA, 2008). These projections were carried out using 12 GCMs and IPCC 4th Assessment's (IPCC, 2007) intermediate scenario of global warming, also known as "A1B". IPCC (2007) indicates a range of possible future global temperatures, which reflect the range of plausible emissions scenarios and the range of GCM predictions for given scenarios. The scenario labelled "A1B", which gives an intermediate level of warming by the end of the century, has more GCM output data available than any other scenario. Therefore, the "A1B" scenario derives most of the projections for New Zealand. NIWA (2008) states that uncertainty associated with climate modelling is high that reads as follows:

> *"Given our current knowledge and modelling technology, there are uncertainties in each of these steps. For example, emission predictions depend on the difficult task of predicting human behaviour, such as changes in population, economic growth, technology, energy availability and national and international policies, including predicting the results of international negotiations on constraining greenhouse gas emissions. Our understanding of the carbon cycle and of sources and sinks of non-carbon dioxide greenhouse gases is still incomplete. As discussed in NIWA's climate modelling web page, there are significant uncertainties in current global climate model predictions – particularly at the regional level".*

The 12 GCMs have been downscaled using similar approach described in Section 6.2. The climate projections have again given for 2040 (i.e., 2030-2049) and 2090 (2080-2099). This modelling has contributed to producing MfE's "Guidance Manual" of climate change.

The key general findings for New Zealand and the maps of climate change projections produced by NIWA (2008) are presented in Appendix A. The climate extremes (i.e., floods, droughts, frosts, strong winds, tropical cyclones and storm surges) are more difficult to predict than the mean climate conditions. It is likely that the number of days above 25°C will increase in the future.

There is much more spatial structure in the rainfall changes than in the temperature changes, and also a larger spread between GCMs. The models show that the potential for heavier rainfall event would increase as a warmer atmosphere can hold more moisture (about 8% more for every 1°C increase in temperature). While intensities of rainfalls remains uncertain to project, the mid-range and high temperature change scenarios indicate that an extreme rainfall in the current climate might occur twice and up to four times as often, respectively, by the end of the 21st Century.

NIWA (2008) also predicts that precipitations as snow at high altitudes will increase as warmer air hold more moisture. However, snow cover will melt more quickly and the snowline would rise as the climate warms. This will probably reducing spring and early summer river flows.

IPCC (2007) indicates that New Zealand will experience a strong seasonality in the wind changes. The westerly in the winter and spring seasons will increase, and summer and autumn will see decreased westerly winds. In spring the mean westerly flow increases by about 10% by 2040 and 20% by 2090.

With predicted seasonal changes in weather (i.e., rainfall, wind and temperature) and their magnitudes and intensities, it is difficult use the historical weather data and river flow records to accurately determine irrigation water demand for the future. Therefore, analysis for the future should be conservative.

The projections for the Manuherikia area are:

- The mean annual temperature in 2040 is projected to increase in by 0.9 °C relative to 1990 with a range of 0.2 and 2 °C.
- The mean annual temperature in 2090 is projected to increase in by 2 °C relative to 1990 with a range of 1.2 and 3.2 °C.
- The projected mean annual precipitation increase for the period from 1990 to 2040 can range between 2.5 to 5%.
- The projected mean annual precipitation increase for the period from 1990 to 2090 can range between 7.5 to 10%.

7 IMPACTS ON IRRIGATION SCHEME INFRASTRUCTURE

The climate change research in New Zealand (NIWA, 2005; NIWA, 2008) shows that while mean annual rainfall (precipitation in general) will increase for the Manuherikia area, the likelihood of droughts will also increase. This mainly occurs as some of the precipitation events are extreme events and inflict floods. In other words, temporal distribution of rainfall will change; there would be a few high rainfall events (mostly in the winter months) and longer periods without sufficient rainfall to increase soil-moisture that is available for crop growth. The warmer climates will also increase the evapotranspiration. Therefore, water demand for irrigation will increase.

The increased mean rainfall will primarily increase flows in winter, but not in summer. The reduction in summer rainfall and increased irrigation requirements means if Falls Dam is not raised reliability to existing Manuherikia irrigators will reduce. Without additional storage, the additional winter rainfall cannot be ultilised. In contrast, if Falls Dam is raised the full 27 m, additional winter rainfall would be able to be captured and used in summer.

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Appendix A: Climate projections (NIWA, 2008)

This Appendix presents the climate projections and associated maps produced by NIWA (2008).

Table A1: Main features of New Zealand climate change projections for 2040 and 2090 (NIWA, 2008)

Climate variable	Direction of change	Magnitude of change	Spatial and seasonal variation
Mean temperature	Increase	All-scenario average 0.9°C by 2040, 2.1°C by 2090	Least warming in spring season
Daily temperature extremes (frosts, hot days)	Fewer cold temperatures and frosts, more high temperature episodes	Whole frequency distribution moves right (see MfE, 2008)	See MfE, 2008
Mean rainfall	Varies around country, and with season. Increases in annual mean expected for Tasman, West Coast, Otago, Southland and Chathams; decreases in annual mean in Northland, Auckland, Gisborne and Hawke's Bay	Substantial variation around the country and with season (see MfE, 2008)	Tendency to increase in south and west in the winter and spring. Tendency to decrease in the western North Island, and increase in Gisborne and Hawke's Bay, in summer and autumn
Extreme rainfall	Heavier and/or more frequent extreme rainfalls, especially where mean rainfall increase predicted	No change through to halving of heavy rainfall return period by 2040; no change through to fourfold reduction in return period by 2090	Increases in heavy rainfall most likely in areas where mean rainfall is projected to increase
Snow	Shortened duration of seasonal snow lying, Rise in snowline, Decrease in snowfall events		
Wind (average)	Increase in the annual mean westerly component of windflow across New Zealand	About a 10% increase in annual mean westerly component of flow by 2040 and beyond	By 2090, increased mean westerly in winter (>50%) and spring (20%), and decreased westerly in summer and autumn (20%)
Strong winds	Increase in severe wind risk possible	Up to a 10% increase in the strong winds (>10m/s, top 1 percentile) by 2090	
Storms	More storminess possible, but little information available for New Zealand		

NIWA
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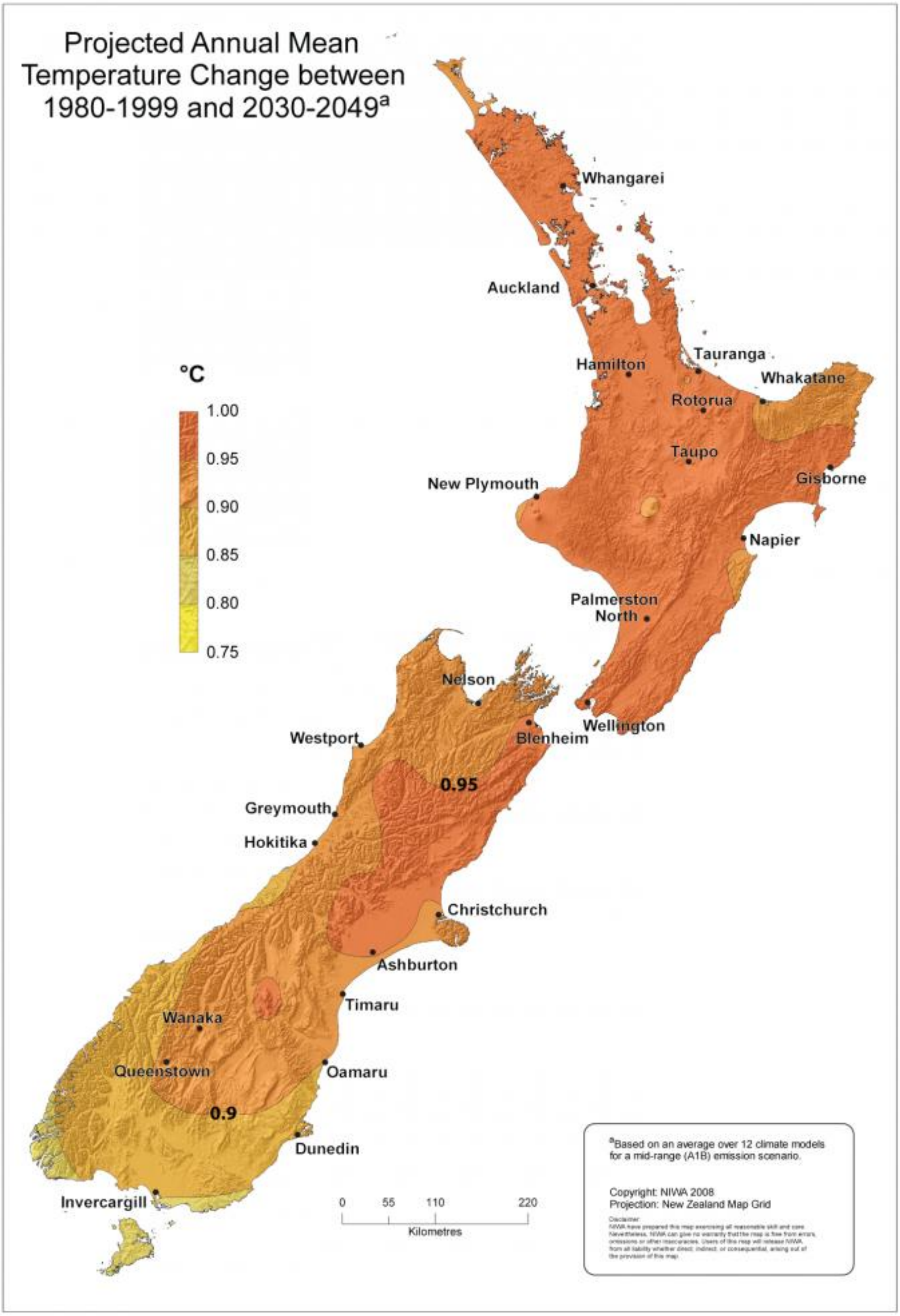
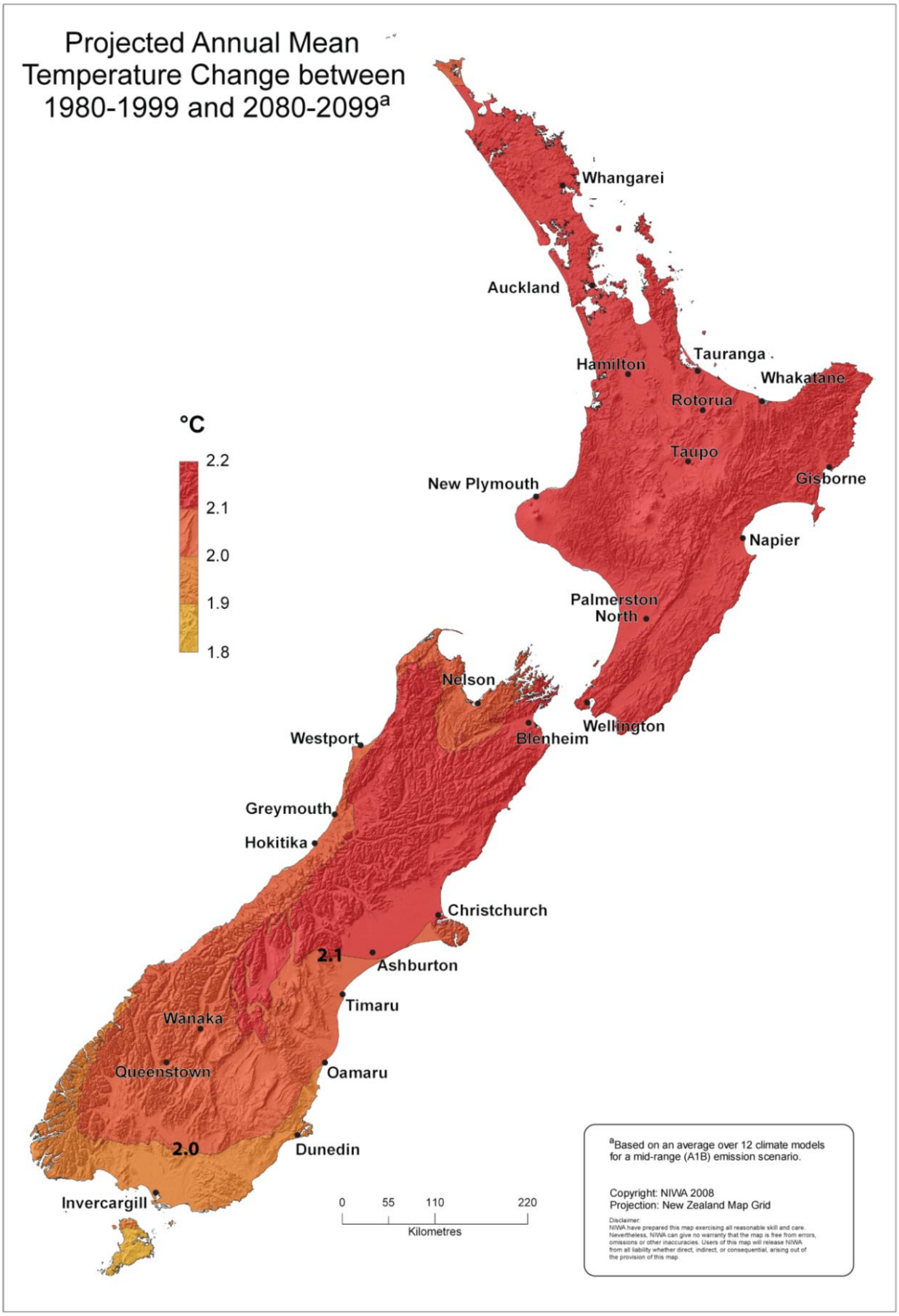


Figure A 1: Projected changes in annual mean temperature (in °C) for 2040 relative to 1990 (Source: NIWA, 2008)



[a] Based on an average over 12 climate models for a mid-range (A1B) emission scenario.

Projection: New Zealand Map Grid

Figure A 2: Projected changes in annual mean temperature (in °C) for 2090 relative to 1990 (Source: NIWA, 2008)

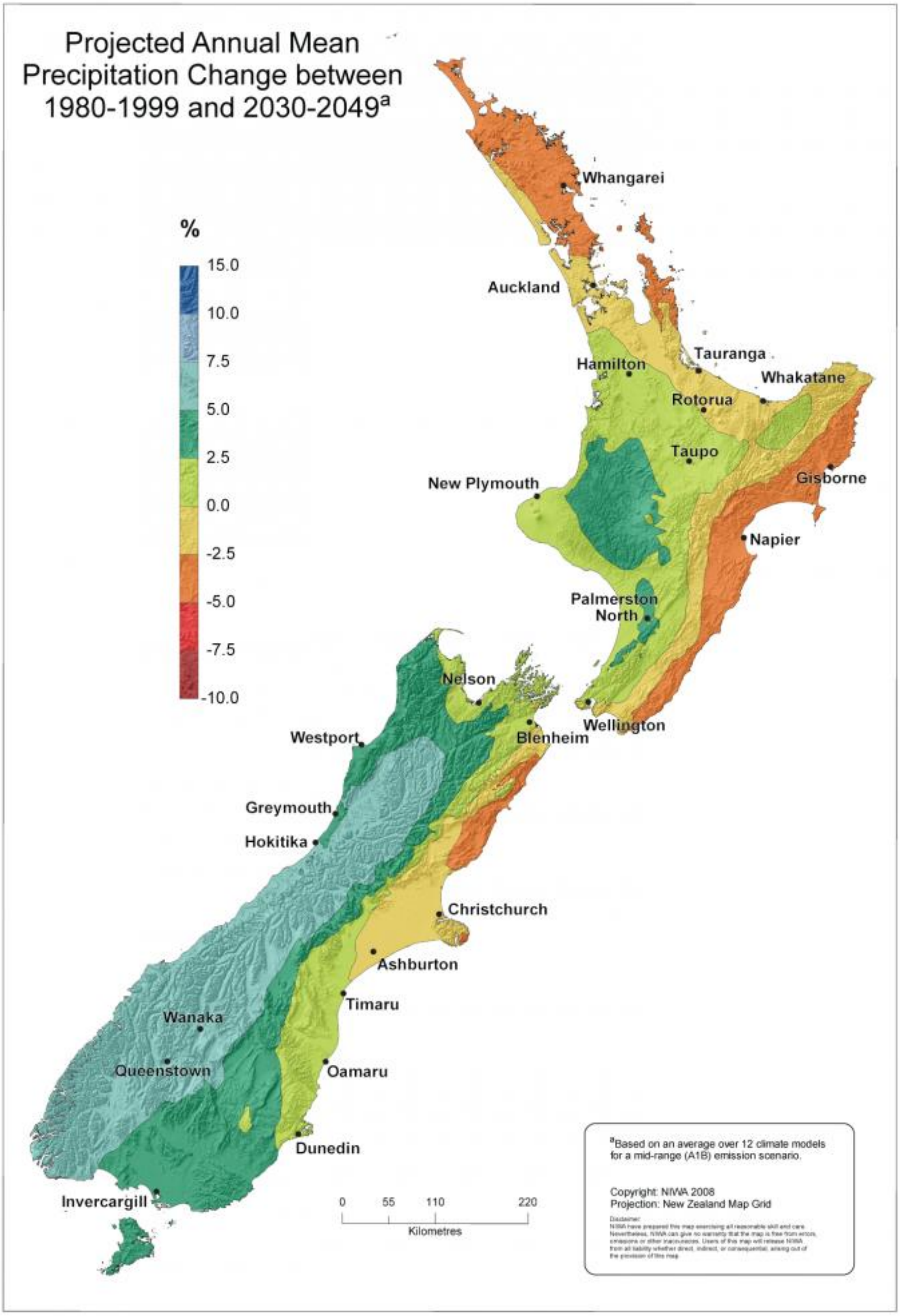


Figure A 3: Projected changes in annual mean rainfall (in %) for 2040 relative to 1990 (Source: NIWA, 2008)

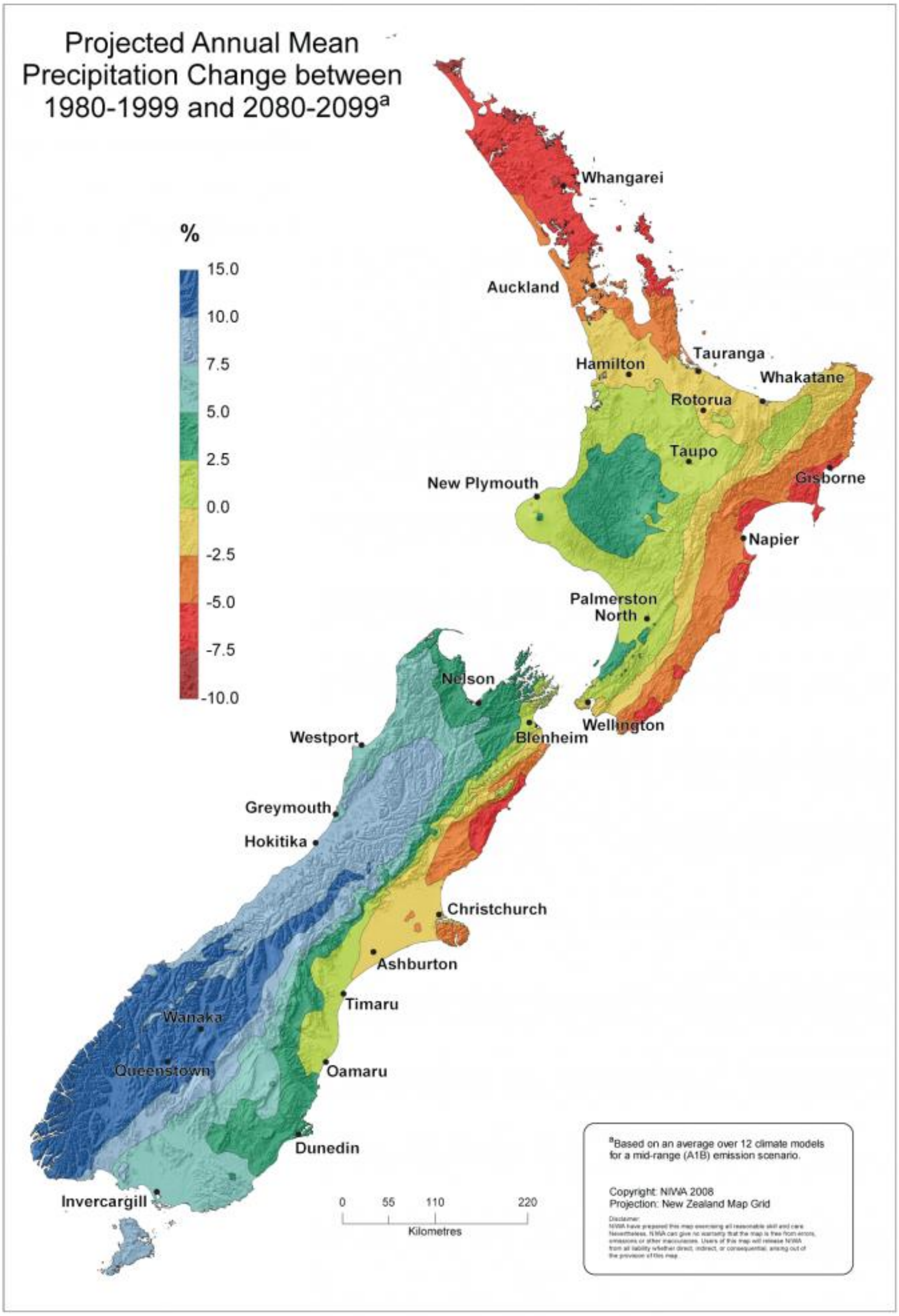


Figure A 4: Projected changes in annual mean rainfall (in %) for 2090 relative to 1990 (Source: NIWA, 2008)