The Implications of Future Climate Change on the Wairoa District

A report prepared for the Wairoa District Council

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Table of Contents

Executive Summary

The objectives of this report are:

- To provide a general overview of anthropogenic climate change, the global observational trends and future predictions.
- Focus on regional scale predictions for the Wairoa district under various emission scenarios.
- Look at the potential impact this would have on the district and provide recommendations on how to mitigate this.

Future climate predictions are as follows:

- Anthropogenic climate change is occurring. There is overwhelming observational data which shows trends that occur outside natural variation. These include increases in atmospheric temperature, sea level rise, melting land ice and glaciers, and ocean acidification.
- For New Zealand increased temperature is modelled to be between 0.7 and 3°C dependant on future carbon emissions.
- Sea-level rise is close to the global average, which range from 0.26-0.55m to 0.52-0.9m for RCP2.6 and RCP8.5 respectively (lowest and highest emission pathways).
- The magnitude of changes in precipitation increases with time and emissions. Annually rainfall in Wairoa is projected to decrease, in spite of an anticipated rise summer precipitation due to a reduction in westerlies. However there is considerable variability in between models and predicted rainfall remains uncertain.
- Future climate extremes will vary. Heavy rainfall may decrease in agreement with a predicted reduction in winter precipitation. Future storminess is uncertain, however wind intensity is likely to increase. Dry conditions will become more prevalent, with an estimated 10% more time spent under drought by the middle of this century.

The potential impacts this will have on the Wairoa District are as follows:

- Increased coastal inundation and erosion, which at this stage is difficult to quantify due to the lack of study. Only Mahia has been looked into and the coastal erosion zones are based on out of date sea level projections, so need revising. Research is being planned for the coastline by Hawke's Bay Regional Council and any plans regarding land use should remain flexible to this new information. Soft options such as managed retreat are advised to maintain the coastlines natural beauty and ecosystems.

- Wairoa is prone to inland flooding from the Wairoa River. Currently the community has been reluctant to implement flood defences due to the high cost and negative aesthetic impact. With the potential reduction in heavy rainfall there will be no new incentive to invest in inland flood defences. However as rainfall predictions are uncertain the district should make sure that any improved model projections are considered. Due to the potential for extend periods of drought, conditions for high run off in the event of heavy rainfall may persist, increasing the likelihood of a large flood event regardless of any change in precipitation patterns.
- In the short to medium term the agricultural sector could benefit from longer growing seasons and increased summer precipitation. This may be offset however by the introduction of new pests and diseases, the correct response to which requires further research.
- The negative impacts of drought will become more commonplace over the coming century. This report outlines strategies from small adaptive changes, to the future need to consider drought tolerant grass species and irrigation. Uncertainties in regional climatic predictions makes long term planning difficult. A strategy will require consideration of a range of issues such as biodiversity, land degradation and water use. Further research will be required to secure the long term future of the sector.
- Conditions will become more favourable for wildfire, with an estimated 20-40 day increase in time where there is an extreme or very high fire risk. Fire danger is as much effected by changes in human behaviour or policies towards fire management as it is by changes in climatic drivers. This report therefore recommends improvements to prevention and communication, rather than any land use changes.

1. Introduction

The climate is changing. The overwhelming consensus by climate scientists is that recent trends in atmospheric warming are predominately the result of human activity (IPCC, 2014), with this agreement going up with the level of scientific expertise (Cook, et al., 2016). But what does this mean for future generations? Generally human activity works within an environment well-adjusted to mean climatic conditions. There is a band of tolerance in which human systems reliant on the environment is well adapted. Outside this band the ability to respond to changes, without stress or damage, decreases as climatic conditions become more extreme (Salinger, et al., 1995). It is therefore imperative that policy makers have the most up to date information to reduce the social, economic and environmental impacts of climate change.

This report will focus on what predicted atmospheric warming will mean for the district of Wairoa. This is an area covering 405 000 hectares, made up of hilly country and 130 km of coastline in Northern Hawke's Bay. The population of the district is approximately 8000, with just over half the residents situated in the town of Wairoa. Within the area there is a high dependency on the environment to support the local economy. Agriculture, forestry and fishing are the biggest industries, with pastoral farming representing the largest economic output. The area is also much more socio-economically deprived than the country as a whole (Salmond , et al., 2006). Therefore any deviation from current environmental conditions is vital to mitigate the social and economic implications for the district.

Along with the most up to date information, this report will make suggestions to assist policy makers and make recommendations for any further research required. Changes in the climate can never be predicted with absolute confidence, and uncertainty in predictions made by climate models will be addressed, so this can be conveyed correctly to the wider community.

2. Global Climate Change

2.1 Causes of anthropogenic climate change

Before addressing the issues at a more local level, it is important to understand the causes of anthropogenic climate change and its global impacts.

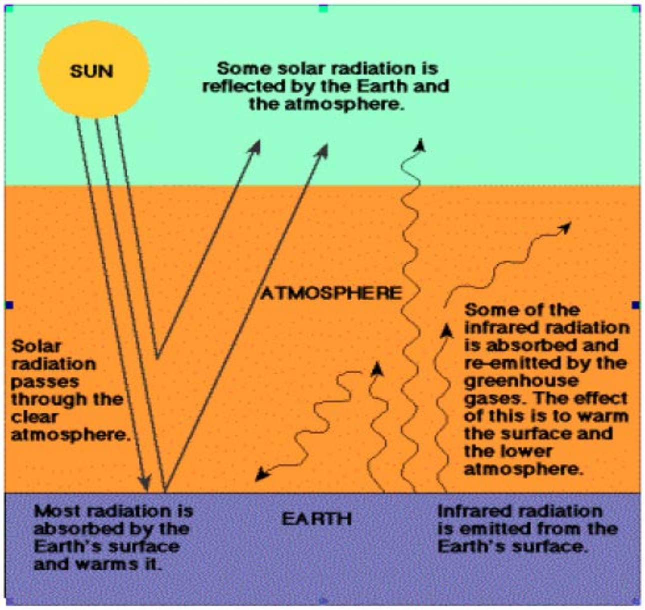

Figure 1 *– Simplified diagram illustrating the equilibrium reached between incoming shortwave radiation emitted from the sun and outgoing longwave radiation emitted from the Earth's surface* (Watt, et al., 2008).

The warming of the Earth's surface and the lower atmosphere is controlled by a natural greenhouse effect. Gases such as water vapour and carbon dioxide allow shortwave radiation emitted from the sun to reach the ground, but subsequently absorb the longwave infra-red radiation released by the Earth's surface as it warms. An equilibrium is reached between the infra-red radiation emitted back into space, in addition to the reflected shortwave radiation, and the energy absorbed from the sun (figure 1). This creates a global average surface temperature of approximately 15°C. (Cubasch , et al., 2013).

Since the pre-industrial era human activity has led to concentrations of greenhouse gases such as carbon dioxide (CO_2), methane and nitrous oxide to increase to levels not seen in the past 800 000 years. Between 1750 and 2011 cumulative anthropogenic CO_2 emissions released into the atmosphere were 2040 ± 310 gigatonnes (IPCC, 2014), with about 40% remaining in the atmosphere. This rate of increase is currently accelerating (see figure 2c and 2d), with half the anthropogenic $C0_2$ emitted occurring in the last 40 years. The largest absolute increases were between 2000 and 2010, despite the efforts of climate mitigation policies. This rise in greenhouse gases increases the amount of infra-red radiation absorbed in the lower atmosphere, causing atmospheric warming.

2.2 Observed Global Trends

Even in the absence of external forcing the climate system exhibits a great deal of natural variation. Despite this there are many indicators of human induced climate change that lay outside the range of these fluctuations. These include responses in surface temperature, sea level, sea and land ice, glaciers and ocean acidification.

2.2.1 Temperature

Studies have demonstrated a near linear relationship between cumulative carbon emissions and temperature (Goodwin, et al., 2014). As the concentration of CO_2 has steadily increased, the observational

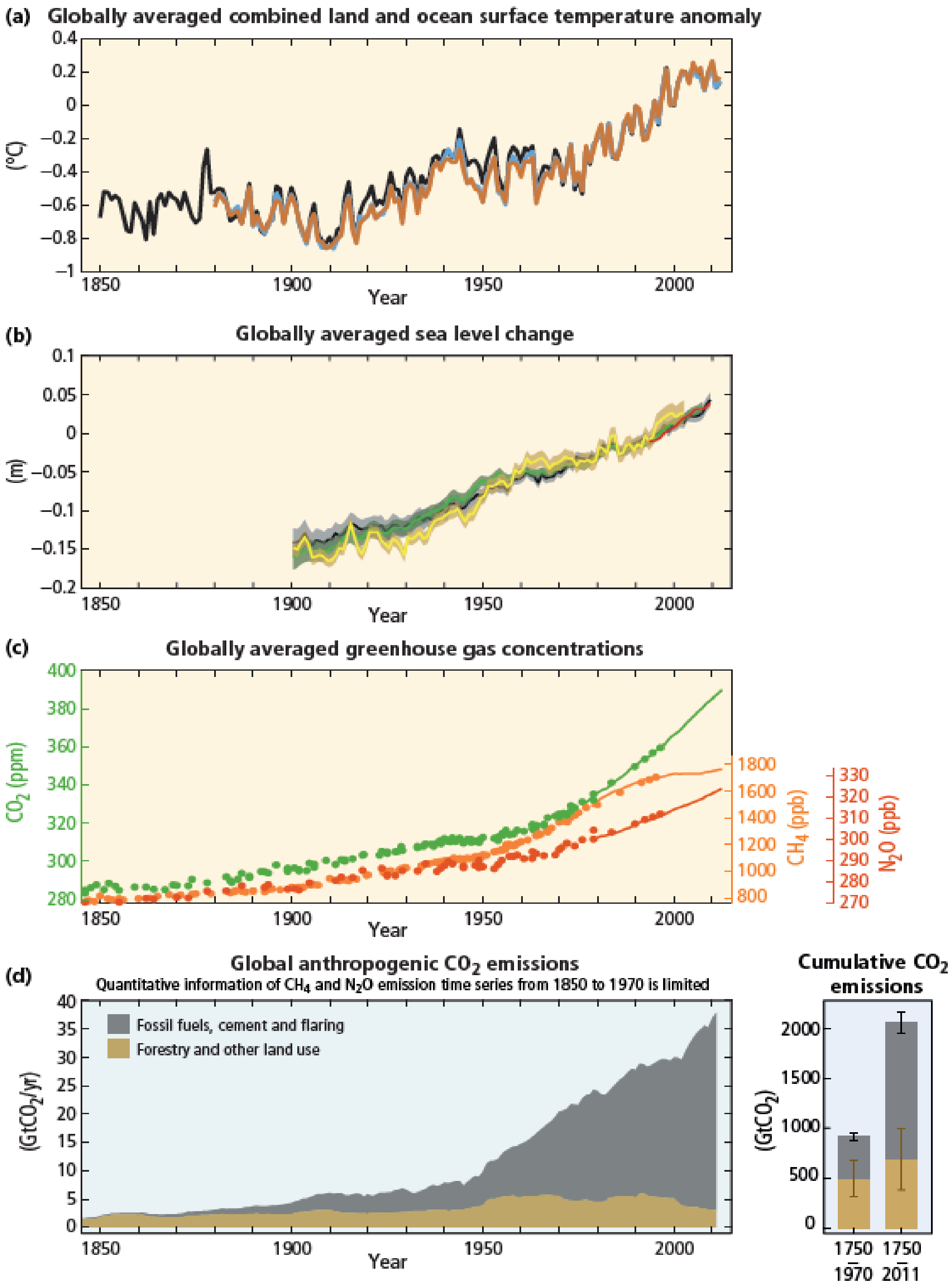

Figure 2 *– Four graphs showing the relationship between observations (a, b, c) and anthropogenic $C0_2$ emissions (d) to highlight the indicators of human induced climate change:* ***(a)*** *Globally averaged combined land and ocean surface temperature anomalies relative to an average calculated from 1986 – 2005.* ***(b)*** *Globally averaged sea level change relative to an average calculated over the period 1986 – 2005.* ***(c)*** *Atmospheric concentrations of greenhouse gases (CO_2, green), Methane (CH_4, orange) and nitrous oxide (N_2O, red).* ***(d)*** *Global anthropogenic CO_2 emissions from fossil fuels, forestry and other land use* (IPCC, 2014).

temperature record has seen a rise in globally averaged temperature of approximately 0.85°C (Jones , et al., 2012). In keeping with more recent accelerated CO_2 emissions, the last 3 decades have seen the warmest 30 year period in 1400 years over the Northern Hemisphere (see figure 2a), where such a calculation was possible (IPCC, 2014).

Climate models have been tested relative to observations to show that these trends are indeed due to increases in greenhouse gas emissions, rather than variation in solar radiation. Observations show increases in tropospheric temperature and decreases in stratospheric temperature, consistent with the impact of rising greenhouse gases found in models. Climate models testing only changes in solar variability show that both the troposphere and the stratosphere would respond with the same sign (IPCC, 2014).

2.2.2 Sea Level

There has been numerous reports of observed sea level rise (Church , et al., 2008; Holgate , 2007) that indicate a positive trend in global mean sea level in the order of 1.7±2 mmyr^{-1} (figure 2b). This has amounted to an approximate increase of 0.19 m between 1901 and 2010 (IPCC, 2014). Recent satellite altimetry data suggests that sea level over the last decade has increased at a much faster rate (Bindoff, et al., 2007).

Sea level rise is caused by two processes, thermal expansion and the melting of glaciers and land ice. Due to its scale and properties the ocean absorbs around 90% of accumulated heat (Abraham , et al., 2013). This has led to a rise in upper ocean temperature, defined as the surface down to 75m, of 0.11°C (Glecker , et al., 2012). As the ocean warms it becomes less dense and expands. The resultant change in sea surface height is termed thermosteric sea level rise, and this has accounted for 0.33 mmyr^{-1} of global sea level rise from 1955 to 2003 (Antonov , et al., 2005).

The second contributor is due to the loss of mass of glaciers and land ice. Between 1992 and 2011 both Greenland and Antarctic Ice Sheets have been losing mass (Lenaerts , et al., 2012), and glaciers have been shrinking globally (Marzeion , et al., 2012). It is also likely that this trend has been increasing since the 21st century (IPCC, 2014).

2.2.3 Sea-Ice Melt

Between 1979 and 2012 Arctic sea-ice has decreased in every season, and in every successive decade (Stammerjohn, et al., 2012). This has amounted to decadal decreases in the range of 3.5 to 4.1%. Annual mean Antarctic sea-ice has also reduced, between 1.2% and 1.8% per decade, within that time frame (IPCC, 2014).

2.2.4 Ocean Acidification

The ocean absorbs approximately 30% of the anthropogenic CO_2 emitted into the atmosphere every year (Sabine , et al., 2007). Annual rates are seen to be increasing over time, due to the ever growing concentration of atmospheric carbon (Le Quéré , et al., 2009). After entering the ocean the disassociation of carbon into various carbonate species leads to the release of hydrogen ions in the water which determines pH. Various work has shown a global ocean average reduction in pH of 0.1, corresponding to a 26% increase in hydrogen ions (Feely , et al., 2009; Orr , et al., 2005).

2.3 Global Projections

2.3.1 Representative Concentration Pathways

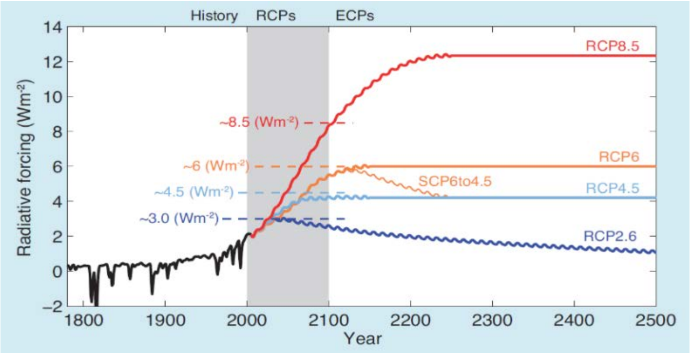

Figure 3 *– Total radiative forcing for RCP's for RCP26, RCP4.5, RCP6, RCP8.5 through time. Total forcing (Wm^{-2}) at the year 2100 labelled for each pathway. Past variation due to volcanic forcing. Included throughout is 11 year cyclical cycle representing fluctuation in solar forcing, apart from at times of stabilisation (IPCC, 2014)*

A definitive quantitative prediction for any climatic parameter is not feasible. As has been shown from current observations, the behaviour of the climate system is linked to the amount of greenhouse gases released, with accelerated trends in atmospheric warming occurring in conjunction with the greatest release of greenhouse gases. Therefore long term projections require assumptions regarding our future emissions. These are dependent on future global social, economic and environmental policies. Therefore defined scenarios are used to cover a range of plausible outcomes. These are known as Representative Emission Pathways (RCP). These cover plausible increases in radiative forcing (Wm^{-2}) by the year 2100, compared to pre-industrial values. They represent a wide range of future anthropogenic greenhouse gas emissions, with RCP2.6 requiring some of the CO_2 presently in the atmosphere to be removed, and RCP8.5 representing very high greenhouse gas concentrations (figure 3). With this range of possible outcomes defined future trends in physical climate parameters can be determined.

2.3.2 Temperature

Apart from RCP2.5, all scenarios discussed above would likely see global surface temperature exceed 1.5°C by 2100, relative to an average taken from between 1850 to 1900. For the higher emission pathways temperature is seen to pass the 2°C threshold before the turn of the century. For the RCP8.5 scenario average temperatures globally will rise to 3.7°C. Nearer term projections predict an increase of 0.3 to 0.7°C between present day and 2035, compared to observations recorded from 1986 and 2005 (IPCC, 2014).

What can be said to be virtually certain (99-100% probability) is that there will be much more frequent hot temperature extremes over most land areas. Heat waves will occur more frequently and last longer than those seen presently (IPCC, 2014).

2.3.3 Sea Level

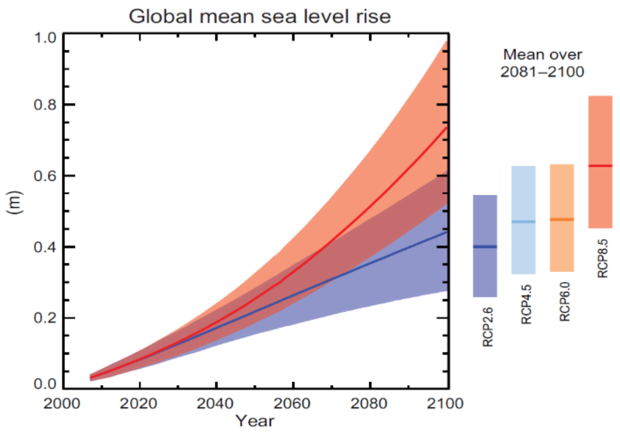

***Figure 4** – Projections of global mean sea level rise up to the year 2100, relative to 1986-2005 for RCP scenarios RCP2.6, RCP4.5, RCP6, RCP 8.5. Likely range (66-100%) for each pathway shown as shaded band (IPCC, 2014).*

Figure 4 shows the large range of plausible outcomes for global mean sea level rise. Projections range from 0.26-0.55m to 0.52-0.9m for RCP2.6 and RCP8.5 respectively. Thermal expansion will be the largest driver in this change, accounting for 30-55% of any increase. While glaciers will contribute approximately 15-35% (IPCC, 2014).

Sea level rise will not be uniform. However by the end of the century 95% of the world's oceans are shown to increase in height. Risks associated with a rise in the sea surface are along the coast. Around 70% of the world's coastlines are projected to experience a rise in sea level within 20% of global mean sea level change (IPCC, 2014).

2.3.4 Precipitation

A gradual increase global precipitation is modelled with future atmospheric warming. Over the 21st century change exceeds $0.05mmd^{-1}$ (approximately 2% of global precipitation) and $0.15mmd^{-1}$ (approximately 5% of global precipitation) by 2100, for RCP2.6 and RCP8.5 respectively (IPCC, 2014).

2.3.5 Extreme Events

The impacts of climate change are often manifested through extremes in weather, such as storms or extended periods of drought. A single extreme event cannot, at present, be associated with anthropogenic forcing. Although work has been done which shows a change in the likelihood of some events, attributed to changes in the climate (Zwiers, et al., 2011). Looking forward, there is likely to be a shift towards more intense storms, over wet tropical regions and mid-latitude land masses (Kharin, et al., 2013; Sorojini, et al., 2012). While in dry regions agricultural drought is projected with median confidence for higher concentration pathways (Koster, et al., 2009).

3. Regional Climate Change

Any forecasts throughout this section are based on the findings of the Intergovernmental Panel on Climate Change (IPCC) 5th assessment report. Here in New Zealand NIWA scientists used statistical and dynamical downscaling of 41 global climate models (Mullan, et al., 2001) to produce projections specific to New Zealand at a 5km resolution. The assumption is that the average of all these model ensembles will provide the most likely outcome in an attempt to consolidate considerable variation in model projections. Whether this assumption is reasonable is up for debate. The upper and lower projections may deserve more attention in assessing the overall vulnerability to an area.

3.1 Temperature

3.1.1 Observed

The observational record in New Zealand, made up of a seven station series (Mullan, et al., 2010), has shown increases by about 1°C over the last 100 years, with an average incremental rise of approximately 0.12°C per decade (Salinger, et al., 1995). At least part of this trend can be attributed to natural variability (Salinger & Mullan, 1999; Mullan, et al., 2010), but a large contribution to the warming is due to anthropogenic forcing (Dean & Stott, 2009). Natural variability in the system is most commonly due to El Nino, a weakening of the trade winds in the Pacific, and a Pacific wide fluctuation which reverses phase every 20-30 years. Longer term warming trends are super-imposed onto the large natural variability found in New Zealand. This trend has persisted despite more frequent El Nino events bringing cooler conditions.

Specifically looking at the climate over Hawke's Bay, temperatures are higher than those found in other areas of New Zealand. Due to the sheltering by western high country from the prevailing winds Hawke's

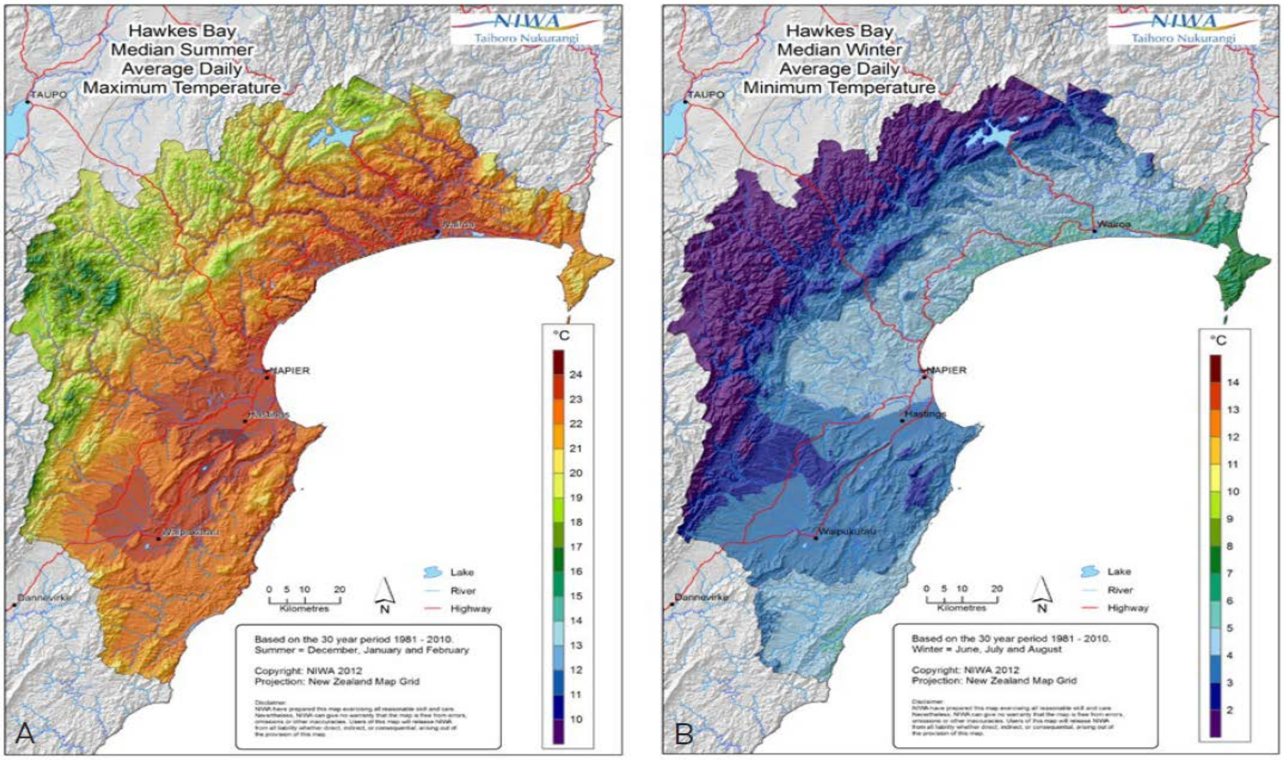

***Figure 5** – **(a)** Left: Hawke's Bay median summer average daily temperature. **(b)** Right: Hawke's Bay median winter average daily minimum temperature (Chappell, 2012).*

Bay is a very sunny region. Figure 5 shows the median average daily maximum temperature for summer and winter. Focusing on Wairoa, average maximum temperatures can exceed 24°C in summer, with 50 days a year experiencing temperatures that surpass 25°C. Coastal areas of the district have comparatively milder winter average maximum temperatures. Figure 5 also shows how on the peninsula average daytime temperatures reach 7°C, much greater than coastal areas to the south. This is reflected in the number of frost days which are lower in the Wairoa district than any other area of Hawke's Bay (Chappell, 2012).

3.1.2 Predicted

Evidence suggests that the warming trend in New Zealand will be less than for globally averaged air temperature. However the probability of future warming in the district is virtually certain (99-100% probability). By 2040 temperatures in New Zealand are projected to increase by between 0.7°C (RCP2.6) and 1°C (RCP8.5), going up to 0.7°C (RCP2.6) and 3°C (RCP8.5) by 2090. Again this illustrates how critical future emission paths are in determining warming over New Zealand. Spatial patterns over the country show a stronger signal over the North Eastern side of the North Island, where Wairoa is situated.

Seasonally, apart from under the smallest emission pathway warming is not seen to vary greatly in Hawke's Bay (Mullan, et al., 2016).

Maximum and minimum temperature projections are positive, with trends in maximum temperature larger than minimum trends. This creates an increase in diurnal temperature range which is predicted to be greater over the eastern North Island.

3.2 Precipitation

3.2.1 Observed

New Zealand weather is dominated by prevailing westerlies (Salinger, et al., 2004) causing the greatest amount of precipitation to fall along the west coast, declining eastwards. Yearly natural variation is dominated by the El Nino Southern Oscillation, where the east-west pattern of precipitation is heightened during El Nino years and weakened during La Nina (Salinger & Mullan, 1999; Hay , et al., 1993). There is also longer term natural variability that influences precipitation. Since 1977 the north east of the North Island has gotten 10% drier, coinciding with a switch in a natural oscillation in the Pacific (Mantuna , et al., 1997). It is difficult to distinguish a signal due to anthropogenic forcing with such large natural variability. Observational record needs to be longer to discern if a trend is occurring beyond fluctuations caused by the processes described.

Weather systems that cause rain in Hawke's Bay are irregular, resulting in high temporal and spatial variability. Within Hawke's Bay Wairoa receives comparatively higher rainfall than other districts. Annual rainfall exceeds 1200mm compared to areas such as Napier and Ngatarawa, where yearly rainfall is 823 and 707 mm respectively. Dry spells, periods of 15 days or more with less than 1mm of rain, are also more infrequent in Wairoa. On average 3.5 dry spells occur in Napier compared to 1.7 in Wairoa. Seasonally winter brings with it the greatest rainfall, reaching on average 140mm in July, whereas December reaches only half this figure (Chappell, 2012).

3.2.2 Predicted

Table 1 shows predicted percentage change in seasonal and annual rainfall for years 2040 and 2090, compared present day observations averaged between 1986 and 2005. Due to local variation, such as discussed above, precipitation has not been averaged over regional council areas, instead calculated at specific sites. For Hawke's Bay NIWA projections have focused on Napier. While results for Wairoa will inevitability deviate from this location, it provides enough evidence to draw general conclusions. There is

Region	Season				
Hawkes's Bay - Napier	Summer	Autumn	Winter	Spring	Annual
RCP8.5	0 (-23,13)	2 (-11,13)	-6 (-21,5)	-5 (-17,7)	-2 (12,5)
RCP6.0	6 (-12,29)	3 (-16,14)	-4 (-18,8)	-2 (-15,11)	0 (-10,12)
RCP4.5	1 (-11,17)	2 (-8,14)	-6 (-18,9)	-2 (-16,16)	-1 (-8,6)
RCP2.6	4 (-10,17)	0 (-10,10)	-2 (-18,13)	-3 (-17,9)	-1 (-8,7)

Region	Season				
Hawkes's Bay - Napier	Summer	Autumn	Winter	Spring	Annual
RCP8.5	16 (-3,43)	7 (-7,19)	-17 (-39,2)	-13 (-33,1)	-3 (15,13)
RCP6.0	3 (-106,30)	1 (-48, 19)	-12 (-70, 8)	-9 (-72,9)	-5 (-72,10)
RCP4.5	4 (-13,21)	2 (-14,17)	-7 (-29,9)	-5 (-16,7)	-2 (-18,5)
RCP2.6	-4 (-19,10)	1 (-10,11)	-2 (-11,9)	-2 (-14,9)	-2 (-9,4)

***Table 1** – Projected changes in seasonal and annual rainfall (%) in Napier, Hawke's Bay. **Top Table** represents the change modelled rainfall between the 1986-2005 mean and the 2031-2050 mean. **Bottom Table** again shows difference in rainfall but extends the prediction to between 2081-2100. Results are calculated from statistical downscaling and an ensemble average of multiple models. Both tables shows changes with respect to RCP2.6, RCP4.5, RCP6 and RCP8.5* (Mullan, et al., 2016).

a large degree of spatial variation for future rainfall over New Zealand, and the results in table 1 currently provide the most accurate representation of changes expected in the Wairoa District.

What is true for all locations is the magnitude of change generally increases with time, and the strength of the radiative forcing. Precipitation signals in 2040 are generally not large enough to be defined above modelled natural variation, while in 2090 there is a clear signal above the noise. For Napier there is a clear seasonal trend. Summer sees greater rainfall due to the decreased frequency of westerly conditions, while in winter there will likely be a reduction, corresponding to a strengthening of westerly winds. This pattern is most prominent for RCP8.5 where in 2090 precipitation changes are 16 and -17% for summer and winter respectively. These magnitudes become less pronounced as the radiative forcing decreases, particularly in the summer months between RCP8.5 and RCP6, where the result drops 13%. Annually rainfall is predicted to reduce, becoming drier over time. This is in keeping with most of the North Island where the frequency of dry days is set to increase (Mullan, et al., 2010). The greater uncertainty in predictions compared to temperature should be noted. The averages in table 1 have a large range of possible values within the 5th and 95th percentile, as there is a significant amount of inter-modal variability.

3.3 Sea Level

3.3.1 Observed

20th century rise in sea level has been well documented in New Zealand, based on tide gauge measurements with long observational records (Hannah, 1990; Hannah, 2004). A similar study has been done for Hawke's Bay that shows an increase of 2 mmyr^{-1} (Komar & Harris , 2014). However this result can only be viewed as approximate due to the length of the record and significant scatter in the data. Despite the uncertainty the result is consistent with global trends, and other locations in New Zealand.

3.3.2 Predicted

Model predictions (Meehl, et al., 2007) indicate that New Zealand will experience sea level rise similar to the global average (see section 2.3.3).

3.3.3 Relative Sea Level

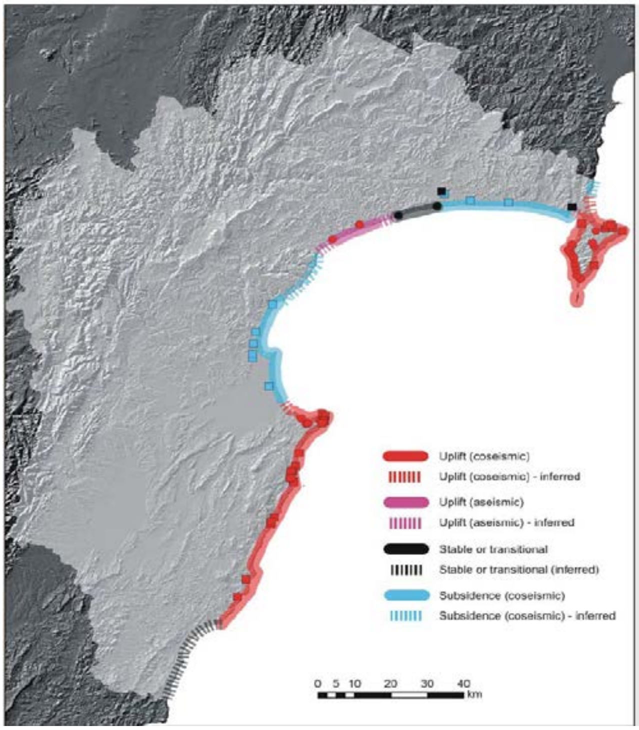

***Figure 6** – Estimates of geological land elevation along the coastline of Hawke's Bay. Squares and circles represent locations where there is the availability of long term data (Beavan & Litchfield , 2009)*

For the purposes of planning it is important to look at changes in sea level relative to adjustments in land elevation. This is known as relative sea level change. Hawke's Bay is effected by both long term tectonic motion, and displacements associated with earthquakes. A great example of this is the coastal uplift associated with the earthquake in Napier in 1931. This caused a rise in elevation exceeding a metre along the coastline in a region where the long-term net movement is subsistence (Hull, 1990). Another large event such as this in the next 100 years has a low probability, although is always possible. Due to its high impact it should be factored into all long term planning by the district council. However for the purposes of this report, only consistent annual elevation changes associated with isostatic adjustment and plate tectonics have been considered in conjunction with rising sea level.

Figure 6 shows how the coastline around the Wairoa district is subsiding, apart from along Mahia Peninsula where there is tectonic uplift. This is highest at the northern end of the peninsula, recording a rate of +2.5 $mmyr^{-1}$ (Beavan & Litchfield , 2009). A projected sea level rise of 3 $mmyr^{-1}$ means no area along the peninsula will balance future increases in sea surface height. Areas of subsistence will exaggerate the coastal impacts associated with a rising sea levels.

3.4 Extremes

Climate change is expected to have a significant impact on extremes. Small changes in mean conditions can lead to a large increase in their frequency (Katz & Brown, 1992). Globally, where sufficient data has been provided, significant trends have occurred in the 20th century (Nicholls , et al., 1995). The greatest socio-economic implications of climate change for Wairoa will be from extremes in climate. Therefore any predictions for the increased occurrence of extreme events should be considered carefully.

3.4.1 Temperature

Extremes in temperature for New Zealand are days where it exceeds 25°C, or is equal to or below 0°C. This is a complex issue. Projected changes in minimum and maximum temperature are effected by a number of parameters. It is noted in the literature that further work will be required to test the robustness of predictions (Ackerley, et al., 2012), although very clear trends are evident.

Results from NIWA climate models show a positive trend in maximum temperature, with the largest increase in days surpassing 25°C occurring in Gisborne and Hawke's Bay. For Hawke's Bay the present day average for 'hot days' per year is 27.5. These become more common over time, with model output for the year 2090 ranging from 36.1 to 78.1 days for RCP2.6 and RCP8.5 respectively (Mullan, et al., 2016). Wairoa has more 'hot days' annually than the Hawke's Bay average (section 3.1.1). While a prediction more specific to Wairoa can't be attain from these results, the number of days exceeding 25°C will increase, and it can be assumed that this will be greater than the number predicted more generally for Hawke's Bay.

Conversely the number of 'cold nights' decreases under all scenarios. Hawke's Bay experiences a reduction in nights where the temperature drops below freezing from 16, to 10.4 and 1.2 for RCP2.6 and

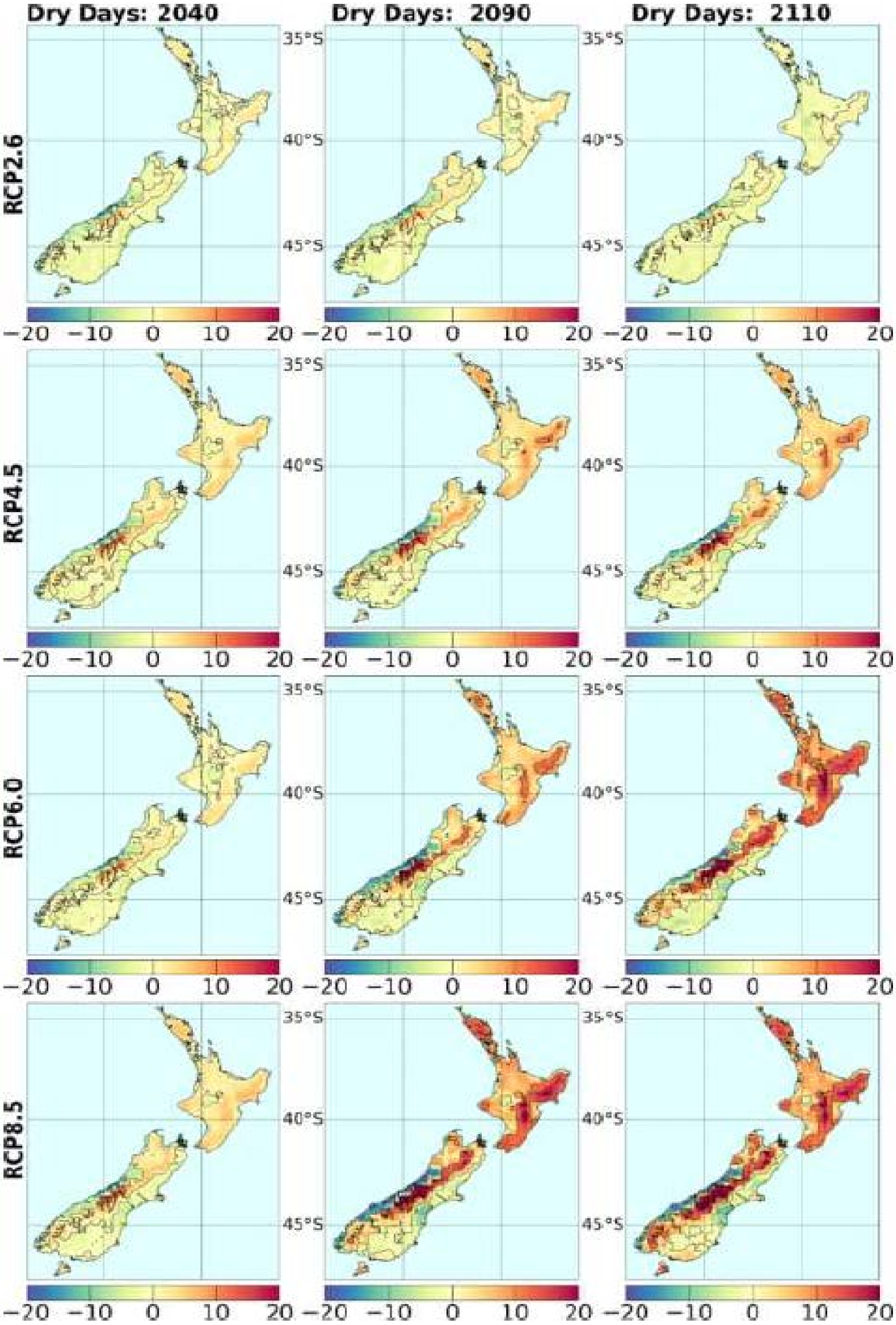

Figure 7 *– Projected changes in the number of dry days (precipitation less than 1 mmd^{-1}), compared to a 1995 baseline period. Projections are made using four RCP scenarios and are the result of averages taken from 6 regional climate models (Mullan, et al., 2016).*

RCP8.0 for respectively (Mullan, et al., 2016). Again the average number of 'cold nights' in the Wairoa district is less than the Hawke's Bay average and may see further decreases below these values.

3.4.2 Precipitation

Current rainfall indices in New Zealand show no increase in intensity and frequency as forecast by global climate models. Instead the opposite has been found, with significant decreases in both frequency and intensity at certain locations between 1951 and 1996 (Salinger & Griffiths , 2001). Regional model predictions are also far from conclusive. A systematic increase in precipitation extremes is seen in the South Island, while results in the North Island are small and erratic (Mullan, et al., 2016). For the year 2090 under RCP8.5 all models actually showed a decrease in daily extreme rainfall in Hawke's Bay coinciding with the reduction in winter rainfall (section 3.2.2). The figure is likely underestimated however as the climate models used do not have the resolution to correctly simulate tropical cyclones. The results therefore, are far from conclusive, and close attention will have to be paid to future research as predictions become more robust.

Figure 7 shows the frequency of dry days, where precipitation is less than 1 mmd^{-1}, increasing significantly over the east coast of the North Island (Mullan, et al., 2016). This is expected given the trend in mean annual rainfall.

3.4.3 Storminess

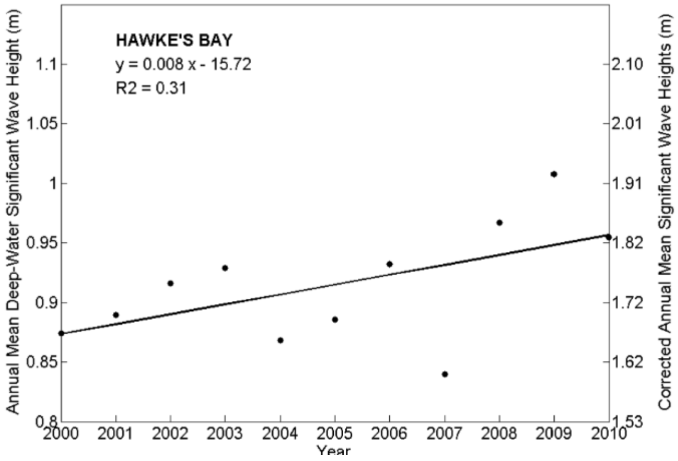

***Figure 8**– Regression trend of annual average deep water significant wave height from 2000 to 2010 (Komar & Harris , 2014).*

There is considerable concern about the impact of anthropogenic climate change on coastal areas, particularly in relation to extreme high water levels. A major determinant of these short term extremes is the relationship between the atmosphere and the sea surface. This can be divided into the effect of pressure and storminess, the interaction between the wind and the sea surface. As the air passes over the sea there is a transfer of momentum which creates a surge. There is periodic variation in wind speed and direction caused by the El Nino Southern Oscillation (Gomez, et al., 2004). The latest IPCC report notes that this oscillation will remain the dominant natural mode of climate variability in the region over the 21st century (IPCC, 2014). Any anthropogenic signal will be on top of this natural deviation, and will not replace it. It is therefore hard to pick out clear anthropogenic signal without a longer record. Waves measured by a Port of Napier's buoy between 2000 and 2010 show a rise in significant wave height of 0.008 $mmyr^{-1}$, representing a 6% increase over the 11 years (Komar & Harris , 2014). This quantitative analysis is inconclusive however due to the length of the data set, yet alongside concurrent work showing an increase in extreme wind speed (Young, et al., 2011), it has been concluded that sufficient evidence is present to warrant enhanced storminess in future hazard assessments for Hawke's Bay (Komar & Harris , 2014). Looking to the future, globally it is likely (66-100%) storminess will increase, however there is a low confidence in region-specific projections. Yet evidence presented by Mullan (2011) suggests wind intensity is likely to continue to increase in New Zealand. To determine the magnitude of any increase in wave height a much longer record is required.

3.4.4 Drought

Droughts are common in New Zealand, and frequently have a detrimental impact on the rural economy (Pearson & Henderson , 2004). It is defined as occurring when there is a severe moisture deficit below a certain threshold that restricts some type of activity (Wilhite , et al., 2007). The water balance is determined by precipitation and temperature, which controls rates of evaporation and plant transpiration. Rainfall deficits that last over a period of one or two months are called 'agricultural droughts' and impact crop and pastoral production. In Wairoa these occurs more frequently during El Nino years (Salinger, et al., 2004).

Analysis is commonly based on the Philip & McGregor index (Philips & McGregor, 1998) which looks at soil moisture content. The Potential Evapotranspiration Deficit (PED) is used as a drought indicator because it specifically measures drought in relation to agricultural production, defined as the amount of water required to support optimum crop growth. In Wairoa this can commonly exceed 200 mm in a year so farmers have mitigation techniques in place (Mullen, et al., 2005). However it is important to know if these will remain adequate in the future.

As of 2011 the preceding 7 years had seen a marked increase in drought frequency (Clark, et al., 2011). If this can be attributed to anthropogenic forcing or can be explained purely by natural variation is unknown. Going forward figure 9 shows the greatest increase in PED is over the eastern side of the North Island, covering the Wairoa district. Looking at Wairoa it is predicted to see less of an increase than other parts

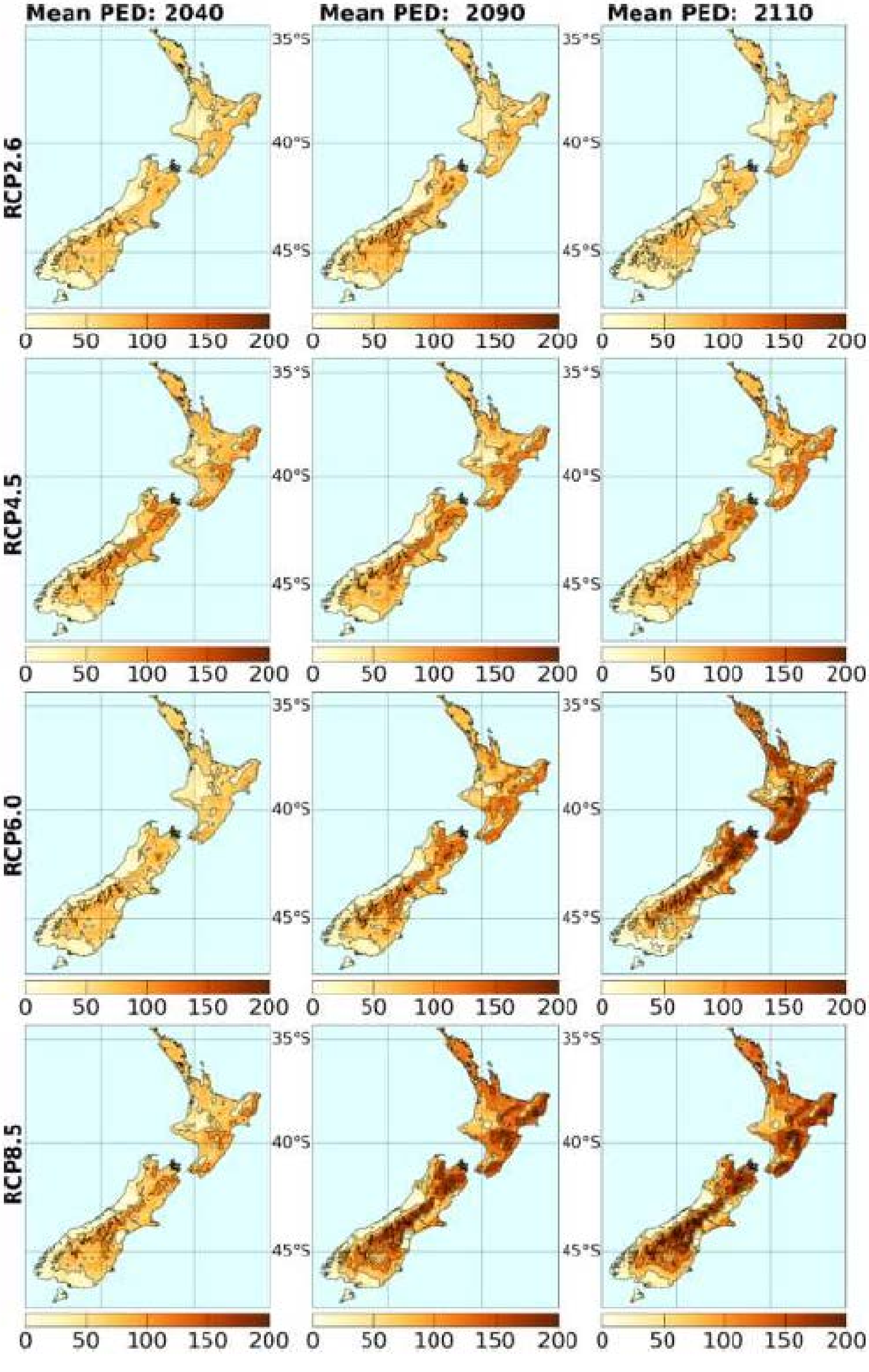

Figure 9 *– Potential Evapotranspiration Deficit (PED) in millimetres over a year, compared to 1995 baseline. Regional climate model results are over three future time periods (2040, 2090 and 2110) for four RCP scenarios (Mullan, et al., 2016).*

of Hawke's Bay, in agreement with the higher rainfall observed (see section 3.2.1). Generally in Hawke's Bay an increase in anomaly of 200 mm is seen for higher emission scenarios around the turn of the century, double the magnitude of an extreme 2012/13 drought seen over the North Island (Porteous & Mullan, 2013). The anomaly for Wairoa is markedly lower, although the results are still significant (Mullan, et al., 2016). In general eastern areas of the North Island should expect 10% more time spent in drought conditions under higher emission scenarios by the middle of the century (Clark, et al., 2011). Moreover because of the trend in atmospheric warming, they are likely to concur with higher temperatures. Even a small increase in average temperature can have a major impact on drought intensity. It not only increases evapotranspiration rates (Breshears, et al., 2013), but also imposes greater physiologic stress on plants, reducing growth rate and causing death under extreme stress (Allen, et al., 2015).

3.4.5 Uncertainty

When it comes to predicting the climate uncertainty comes from two sources: Not having a complete understanding of how the climate system works and how it best be represented in numerical models, and from the future actions of human beings, determined by policy decisions and technological advancements. While there can be very little uncertainty as to whether human activity is causing the Earth to warm, more specific questions about when and where impacts will occur holds unknowns. Decisions at a local level require more detailed information relating to the region, timescales and variables. In such cases understanding the sources of uncertainty is very important.

As a communicator it is critical to convey to the wider community scientific uncertainty, that being the extent to which scientists can agree upon a specific question, and uncertainty that comes from deciding how best to respond to this information. Model outputs provide us with a large range of plausible scenarios. Having a range of possible outcomes should not been seen as a case for inaction, rather as an incentive to put in place measures to mitigate the impact of future climate perturbations, while remaining open to more up to date forecasts in the future. The message should focus on risk instead of uncertainty i.e. the losses that might happen if no action is taken. An open line of communication between the providers and users of any climate information is key. An effective an honest conversation can only happen if the future risks of climate change are transparent and understood by all.

4. Impact on Wairoa

But what does all this mean for the district? And is there sufficient scientific evidence to provide the basis for changes in policy? This section of the report will focus on what the consequences are of climate change in Wairoa. Recommendations will be provided based on the information at hand, and if insufficient, suggestions of necessary research will be outlined.

4.1 Coastline

The coastline of the Mahia Peninsula is made up of steep cliffs and marine terraces on the west, and sandy beaches and lagoons on the east. West of the peninsula leading to Wairoa River there is rock beach barrier for most of the coastline, where a series of lagoons and wetlands have formed. Beyond the river the coast is characterised by steep slopes that emerge straight from the sea, and beaches consisting of dark gravels and coarse sands.

4.1.1 Inundation

Work by de Lange (1996) found storm surge elevations with a return period of 100 years in New Zealand are between 0.8 and 1.0 metre. Generally 0.9 m is the height used for potential surges with a 1% probability of occurring each year. Even if storm frequency and intensity stayed at present day levels any rise in sea level is super-imposed onto the current risk, increasing this probability. The potential for coastal inundation will also be effected by coastal erosion (section 4.2.2). Natural coastal defences like the beach barriers present along the Wairoa coastline may be lost, exposing areas further inland to coastal flooding.

Future coastal flood risk in the area has not been assessed, nor is there any data looking at historic flooding along the districts coast. This is due to the lack of settlements and steep slopes adjacent to the coastline, which make it a low priority compared to other more densely populated areas of Hawke's Bay to the south. The present difficultly providing quantitative regional estimates for future extreme high water, and the lack of current data on inundation, make assessments of future impacts difficult.

4.1.2 Erosion

The Hawke's Bay coastline is susceptible to erosion due tp its soft rock structure. Pettinga (1980) carried out an extensive study of southern Hawke's Bay and found actively eroding coastal catchments, as well as tectonically induced slide failures. For Wairoa the vulnerability of its cliffs in certain areas are somewhat protected due to the sandy and gravel beaches acting as a buffer (Tonkin & Taylor LTD, 2004). This may result in less wave erosion, however this has yet to be quantified.

Predicting the shoreline response to climate change is complex. Conceptual models based on sea level rise alone will provide little information. Any quantitative analysis into how beaches will respond to anthropogenic climate forcing in Hawke's Bay (Komar & Harris , 2014) has been undertaken in the south.

A specific beaches response is dependent on factors such as sediment supply, movement, wave behaviour and storm frequency. Due to the variety of parameters that influence shoreline movement assumptions cannot be made for Wairoa. What can be said however is that areas that historically have seen erosion will see exacerbation of these trends under climate change.

Somewhat offsetting this lack of study, observational data has been collated for beach profiles through a monitoring programme undertaken by the regional council (Gibb, 1996). The majority of data series in Southern Hawke's Bay date back to the mid 70's, with some records going as far back as 1916. For the Wairoa coastline however monitoring did not start until 1998. This shorter timeframe makes it difficult to distinguish the effect of climate change in such a complex system. A greater amount of work has been done along the Mahia Peninsula, with rates of erosion and accretion attained (Daykin, 2013). As such the Mahia Peninsula has erosion zones for 2060 and 2100.

4.1.3 Response

Going forward a comprehensive analysis of the Wairoa coastline is required to determine the correct response to changes in mean sea level and the intensity and frequency of storms. General estimates of coastal erosion can be inferred by looking at past erosion rates, the beach profile and at the difference between past and future predictions of relative sea level. Ideally a more robust consideration of the inherent uncertainties accompanying this method is required to more accurately set erosion risk lines. Examples of such uncertainties are as follows:

- Insufficient monitoring data
- Modelling assumptions
- Future emissions
- The dynamic response of coastal drivers to a change in climate

Increased monitoring needs to take place to correctly assess the effect of rising sea levels. The potentially more detrimental impact of storm surges also needs to be analysed. Surveys need to be taken immediately after a major storm to ascertain the extent of morphological changes compared to the maximum water levels reached by the swash.

Encouragingly upcoming research for northern Hawke's Bay has been proposed (Becker, et al., 2015) and current uncertainties will also be addressed. Future projects by Hawke's Bay Regional Council will incorporate new storm surge projections, undertaken by the NIWA, with multiple hazard drivers to improve inundation projections. There is also national and regional attention regarding coastal erosion. Current software used to assess natural hazards doesn't deal with the issue of coastal erosion, and a concerted effort will be made in the near future to model loss from coastal hazards.

For most of the regions coastline priority is focused on the protection of natural systems rather than increased development (Beca Carter Hollings & Ferner LTD, 2004). Sub-division in inappropriate locations can worsen adverse environmental effects, as well as have social and economic implications for the community. In an area such as Wairoa the promotion of sustainable management to retain the areas natural beauty is key. Options such as managed retreat are advised. Future developments on vulnerable coastlines should be limited, and the sea allowed to progressively shape the landscape. As such providing up to date coastal erosion lines is crucial and current zones in Mahia need revising. The estimates used are from 2005 and use a predicted sea level rise of 0.5 m by 2100, taken from the IPCC report written in 2001 (Tonkin & Taylor LTD, 2004). More recent reports for Hawke's Bay consider a greater increase in sea surface height based on more recent projections (Komar & Harris , 2014), and estimates for Mahia should be amended to agree with these current predictions.

As has been shown the impact of future erosion and flooding has a great deal of uncertainty. However gradual improvements in the accuracy of forecasts are forthcoming. Management practices need to be flexible, amending to future projections as uncertainties are reduced. It is imperative that decisions are made on the most up to date scientific information to provide the best response to increased sea level and storm intensity.

4.2 Inland Flooding

4.2.1 Impacts

Potential for flooding from the Wairoa River is great, with high run-off occurring for a number of reasons. The area has the highest variation in rainfall in New Zealand, where heavy rain occurs after long hot dry spells, resulting in rapid runoff. Another contributing factor is the short, steep catchment, made up of shallow soils underlain by impermeable mudstone sub-strata. With increases in dry days expected for Wairoa, conditions could be more favourable for flooding in the district. Any large flood in the district will have a major effect on the community, damaging the environmental and economic infrastructure. Figure

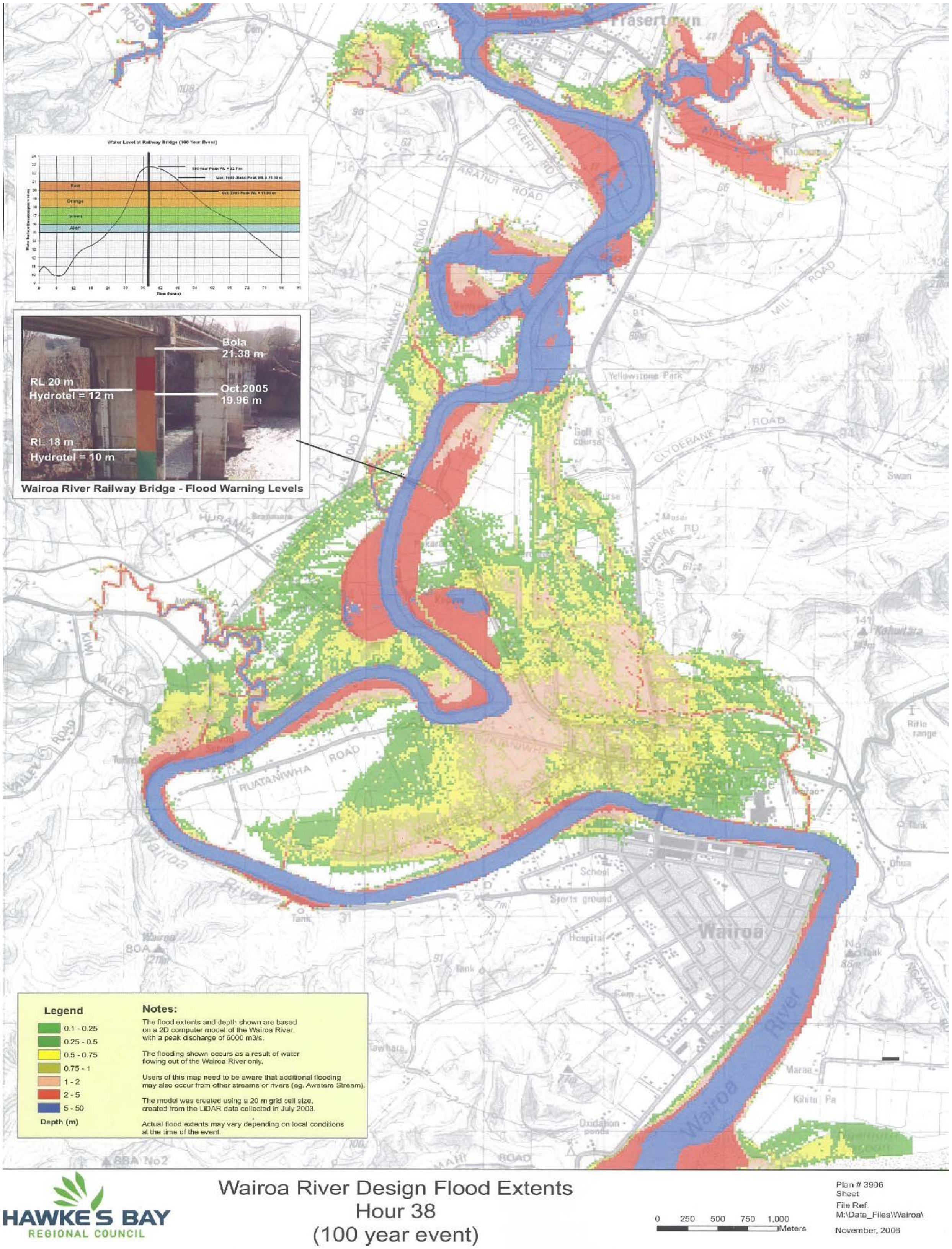

Figure 10 *– Map showing extent of flooding from a 1 in 100 year flood event at peak water surface elevation. Legend included to show range of flood levels that would be experienced (Goodier, 2006)*

10 shows the extent of flooding from the Wairoa River modelled for a 1 in 100 year storm event (Goodier, 2006). Floodwater inundation is extensive, covering large areas of agricultural land, the airport and the small residential settlement of North Clyde. The town of Wairoa remains largely intact, however floodwaters of up to 0.5 m extend just beyond the river, reaching the community centre, supermarket and residential areas. Evidence presented in section 3.4.2 suggest that heavy rainfall would decrease, coinciding with a reduction in precipitation in winter. However uncertainty remains in the models and future results should be monitored closely.

Widespread erosion occurs on the steep slopes of the Wairoa District as forests have been cleared to make way for pastoral farms. Reid and Page (2002) concluded that there was a 25 fold increase in area landslides on pasture land in comparison to areas of tall wooded vegetation, under a large storm event. Soil slip erosion can cause dramatic reductions in pasture production (Lambert, et al., 1984; Trustrum, et al., 1984a), with recent soil slip scars producing only 35% of the yield provided on older scars pre-dating 1942 (Douglas & Trustrum, 1986). Therefore any change in the intensity and frequency of heavy rainfall will have a significant impact on erosion and pastoral productivity.

4.2.2 Responses

At present there is little protection from inland flooding. The only existing approach is to open the Wairoa River bar, by mechanically excavating the beach barrier to create a new outlet. Under the Soil Conservation and Rivers Control Act 1941 there has been considerable effort by the Hawke's Bay Regional Council to assess all options that would mitigate the impacts of flooding. Early warning systems have been implemented which act to minimise personal injury, however the proposal of physical options have been deemed technically difficult, and beyond what the community could reasonably afford. Options such as stopbanks and river mouth training groins have been concluded unlikely to gain public approval due to their cost and negative impact aesthetically.

It is important that communities determine what risks are acceptable. This can only be achieved though continuous education about future flood risk. Presently current evidence would not be sufficient to change public opinion. However this does not mean that Wairoa is not at risk of a large inland flood. Results of future localised flooding are uncertain, and results for Hawke's Bay are not district averages but specific to Napier, not Wairoa. A decision not to act should be flexible, open to new evidence provided by further research. The implementation of physical defences as a preventative measure is much less detrimental to the local economy than any decision made as a direct response to a devastating flood. Therefore providing the most up to date information, is key in this preventative approach.

The most effect method of erosion control would be the consideration of land use change from pastoral to woodland. A report by Blaschke (2008) showed how afforestation can reduce erosion by up to 50%, as well improve water quality, protect biodiversity and retain nutrients in the soil. Such changes have been proposed in the neighbouring district of Gisborne (Barry, et al., 2012) on marginal lands, and were concluded to not to be viable. The uncertainty surrounding extreme rainfall, and the lack of quantitative evidence regarding the impact of soil slips in the region suggests that similar conclusions in Wairoa would be drawn. Instead in the future it may become economically viable to use techniques such as fencing, reseeding with legumes and using additional fertiliser to reduce rates of erosion (Litherland, 2004).

4.3 Agriculture

Compared to other areas of Hawke's Bay in Wairoa there is a high dependency on agriculture for the local economy. Approximately 25% of employment is within the agriculture, forestry and fishing sector. 60% of the total land use is productive, with 48% cleared for pasture. Any change in agricultural production under climate change could have far reaching implications for the region.

4.3.1 Temperature

For pasture, climate change will effect overall productivity and alter species composition. Higher temperatures and atmospheric carbon have been shown to increase annual pasture yields by 10 to 20% (Warrick, et al., 2001), however this may be offset by the increased risk of drought (section 3.4.4). The productivity of forest plantation growth is also been shown to positively correlate with rising temperature (Leith, 1973). For Radiata Pine, the predominant planted forest, this is principally driven by a lengthening of the growing season (Kerkhoff, et al., 2005).

Pasture composition may change in response to a warmer climate, more likely in drought prone eastern regions (Kenny , 2001). The potential spread of low quality sub-tropical grasses is a concern, although they are more resistant to drought and would provide feed during periods of low soil moisture. It may also lead to the increase of invasive weed species such as *Melaleuca quinquenervia* (broad-leaved paperback) and the *Pueraria montana* (Kudzu). The effect of changing temperature on growth rate is complicated by optimum temperatures for growth changing with CO_2 concentration for many species. However the lengthening of the growing season is expected to increase the production of weeds (Watt, et al., 2008). A rise in atmospheric CO_2 is also likely to increase growth rate independent of any temperature rise (Ziska, 1983).

There is little knowledge about the effect climate change will have on forest insects (Watt, et al., 2008), making it hard to assess how their abundance and distribution may change. However there is concern about the introduction of new species from sub-tropical or warm temperate regions due to warmer winters. Assessment of the potential impacts on plantation productivity require further study.

Another factor to consider is the spread of disease. In planted forests these are caused by fungal plant pathogens, influenced by the interaction between the pathogen, host and their environment (Tainter & Baker, 1996; Agrios, 2005). Despite these complexities *Phaeocryptopus gaeumanni*, the most widespread disease for Radiata Pine, is strongly correlated with winter temperature (Stone, et al., 2007), thus can be expected to increase under New Zealand temperature projections. Again work is needed to quantify the influence this will have on productivity.

4.3.2 Precipitation

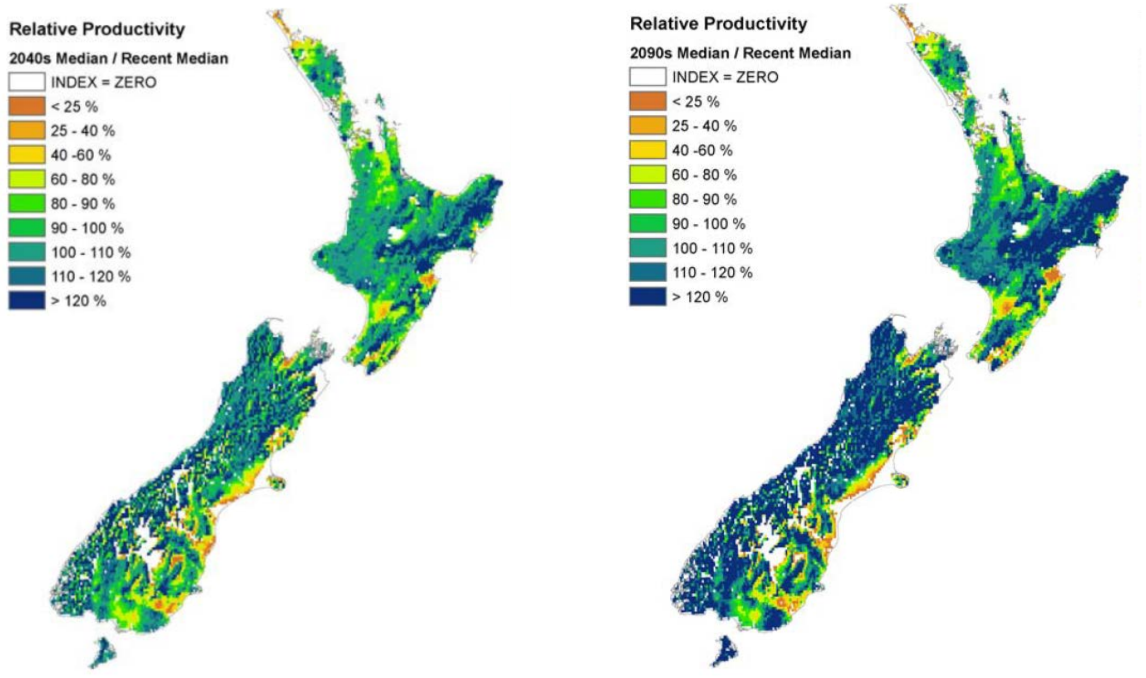

Figure 11 *– Nationwide relative productivity in 2090 compared to 1989/1990 baseline. Based on IPCC AR4 Models and metabolisable pasture growth estimates (Balsden, et al., 2008).*

Annually Wairoa is expected to become drier, however summers are predicted to become wetter resulting from reduced westerlies. Some models still indicate a decrease in rainfall, but the average of all model forecasts is for an increase in precipitation by as much as 15% (table 1). Resultantly in the future, under normal years, pasture production is expected to increase (Balsden, et al., 2008). Figure 1 shows the magnitude of this change as a function of time, with relative productivity 20% greater when compared to a present day baseline. A consideration should be given to the uncertainty surrounding future precipitation in the region. This result is based on an ensemble model average, about which there is a great deal of variability.

4.3.3 Drought

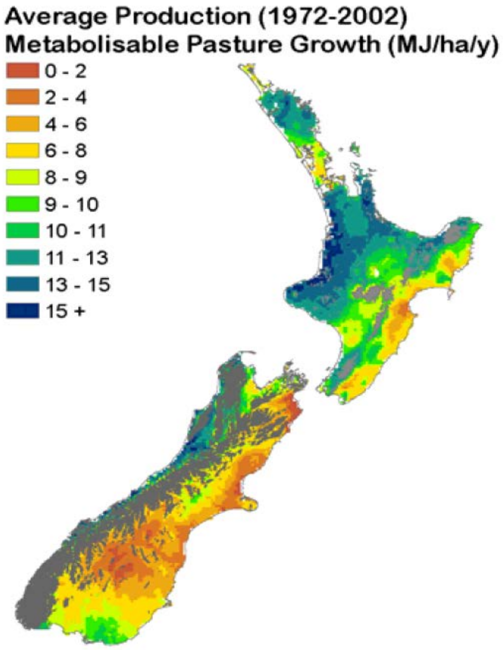

Figure 11 *– Estimates of average pasture production between 1972 and 2002. Defined by both dry matter production and the digestibility of herbage for ruminant animals. Areas shown in grey are unsuitable for pasture* (Balsden, et al., 2008).

As the previous two sections show under normal years the longer growing season and greater summer rainfall will provide better growing conditions, increasing agricultural output. However this may be offset by the negative effects of prolonged periods of drought. New Zealand is already familiar with the impacts of serve drought. A widespread rainfall deficit in 2007/2008 cost the national economy an estimated $2.8 billion (MAF, 2009), largely from reduced agricultural output. This risk will only be exacerbated by further increases in atmospheric temperature (Breshears, et al., 2013). Currently the climate in the Wairoa district is favourable for pastoral growth. Figure 11 shows how average production inland is markedly higher than the majority of arable land along the east coast (Balsden, et al., 2008). Pasture growth can exceed 10 MJ per hectare every year, while areas of Hawke’s Bay to the south, for example, see a quarter of this output. This is in agreement with the pattern of precipitation in the bay (section 3.2.2). However the availability of water under increased Potential Evapotranspiration Deficit will increasingly become an issue for the east coast of the North Island, having a detrimental effect on the pastoral output in Wairoa.

Year	Region	Dairy Production (%)	Sheep and Beef Production (%)
	Hawke's Bay	Worst Years	Worst Years
2030	**Low - Medium**	63	40
	Medium - High	44	25
2080	**Low - Medium**	44	36
	Medium - High	19	15

***Table 2** – Worst year production under future climate scenarios. An average year is defined as the normal number of growing degree days and soil moisture. Worst year is a departure from that normal measured with respect to historical averages. Temperature projections are 'Low-Medium' and 'Medium-High' which represent a temperature change between the lowest and the highest IPCC estimates of 25% and 75% respectively. Results describe the export revenue of dairy, sheep and beef in 2030 and 2080 as a percentage of the average revenue between 1972 and 2002* (Balsden, et al., 2008).

A sensitivity study looking at pastoral farming under climate change was conducted by Balsden (2008). They found that nationally under the yearly average number of growing days and soil moisture, there is no strong trend in production. However about the mean there is a great deal of variation (see figure 12 and 13) and a strong signal along the east coast of New Zealand. Table 2 shows how in Hawke's Bay when drought conditions persist, denoted as 'worst years', export falls. The magnitude of change is a function of both time and temperature change, with greatest decreases in production occurring under higher emission scenarios in 2080. In drought years export revenue is projected to be 19% and 15% compared to the current average, for dairy and sheep/beef respectively. Figure 12 shows how along Hawke's Bay there is still considerable spatial variation. Decreases in 'worst' years are less severe in the Wairoa District, although still significant in both the near and long term. For the higher temperature scenario, under 'worst' conditions export is 40-60% of the current average. Also worth noting is these results don't take into account increased growth due to 'CO_2 fertilisation' which will positively impact the growth rate. Although the reduction in agricultural export is less than other areas of the east coast, its importance should not be understated considering Wairoa's high dependency on pastoral farming.

For Radiata Pine the soil water balance is a major determinant of growth at sites where there are annual water deficits (Arneth, et al., 1998; Watt, et al., 2008). Many factors influence the water deficit of Radiata Pine. Although evapotranspiration strongly correlated to temperature, other effects such as stomatal closure under increased atmosphere CO_2 can mitigate the effect of rises in temperature on rates of transpiration (Watt, et al., 2008). Water use becomes more efficient as the concentration of CO_2 increases, which could compensate for any loss in water availability. A full quantitative assessment is required to fully assess the impacts of drought on planted forests.

4.3.4 Fires

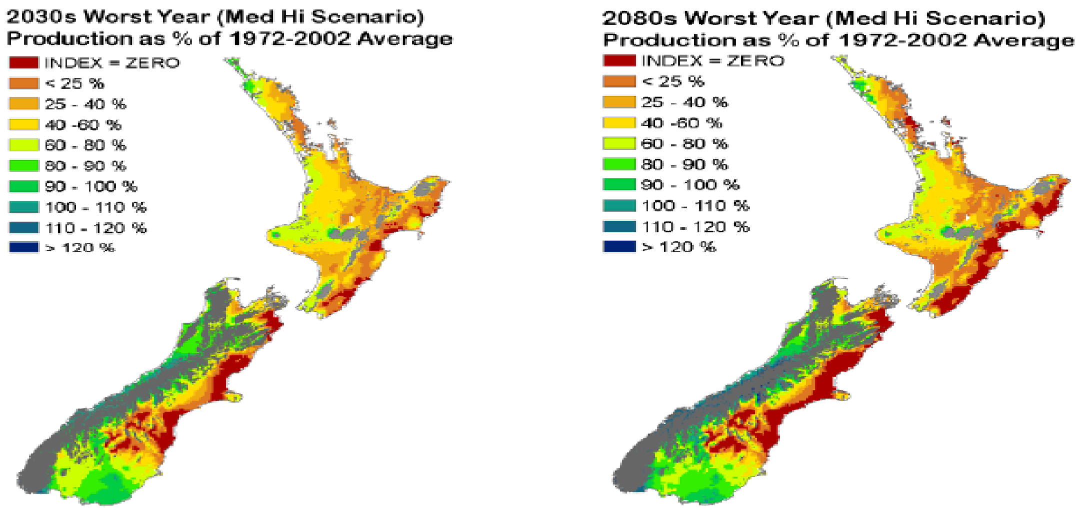

***Figure 12** – Pasture production estimates (%) for 2030 and 2080 compared to a 1972 to 2002 average for a 'worst year' where conditions are usually dry. Temperature projections are 'Medium-High' which represent a temperature change between the lowest and the highest IPCC estimates of 75%* (Balsden. et al.. 2008).

Wildfires occur after long periods of hot, dry weather, coinciding with a build-up of flammable vegetation. The Wairoa district council Rural Fire Authority protects an area of land consisting of 203 122 hectares, with the fire season starting on 1st October running through to the 30th April. Nationally there has been an increase in wildfires in recent years (Anderson, et al., 2008), although this may be due to improved reporting. The east coast is a high risk area, where extreme or very high forest fire danger occurs on more than 30 days annually (Pearce & Clifford, 2008). Conditions are set to become more favourable for wildfire during the coming century. The district has the potential for a decrease in annual rainfall (section 3.2.2) due to projected increases in westerly winds in winter and spring. Results of a study conducted by Pearce (2011) show that this could result in greater fire danger that carries through into summer, producing higher risk of wildfires on average in spite of any increase precipitation in summer and autumn. Figure 13 shows how the number of days where the risk is extreme or very high is predicted to increase under all model scenarios. The average of all simulations (figure 13a) displays an increase of between 20 and 40 days for the region. Add to this the exacerbation caused by the greater chance of drought, which will

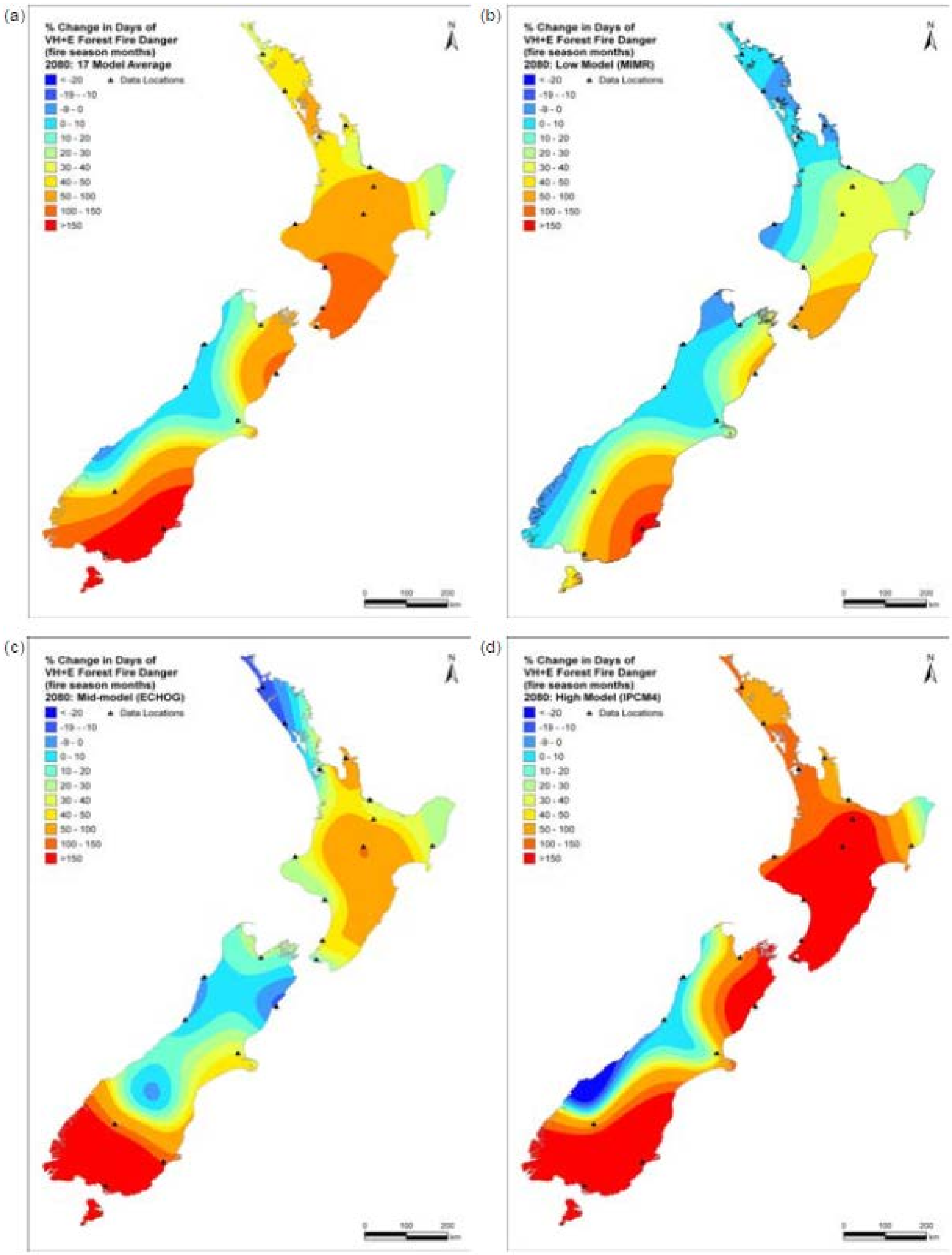

***Figure 13** – Change (%) in the number of days where fire risk is either Very High or Extreme over fire season (October-April) in 2080 compared to current climate. (a) Average of 17 models; (b) low range model; (c) mid-range model; (d) high-range model (Pearce, et al., 2011).*

provide a greater quantity of dry, flammable fuel (Mullen, et al., 2005). The increase in weeds discussed would also lead to greater fuel types.

The physical effects of a fire depend on its intensity and duration but they can be far reaching. Large costs can be associated with property loss, fire suppression, loss of income and recovery. Pinus Radiata, which is the dominant planted forest species, has a very low tolerance to fire. As well as destruction to the plantation, wildfire can be detrimental to the soil structure, leading to increased erosion (DeBano, et al., 1998) and a dependency on fertiliser for re-establishment. If there is sufficient fuel and the soil is dry enough, the fire can burn the tree roots below the soil surface. In this case fires become much harder to supress, having a greater impact and requiring a great deal more staff hours to put out (Savage, 2006).

4.3.5 Response

Likely increases in temperature and summer precipitation are advantageous for the primary sector. However the response of agriculture to future warming will be complex and there is uncertainty in future climate projections, particularly regarding precipitation. It is also likely that as the century continues extreme events such as drought will become more commonplace. Moisture availability will become an issue, exacerbated by atmospheric temperatures. There is therefore a need to provide adaptive measures to safeguard Wairoa's agricultural sector.

All future scenarios predict an increase in temperature. This will cause earlier pasture growth in late winter or early spring, and provide a later cut off in autumn or early winter. A report by Mullen (2005) points out how under high end scenarios, farmers may have to bring forward operations to fit these changes, such as earlier lambing. Other adaptive measures may include installing shade sprinklers and fans in dairy sheds. Attention also needs to be given to changes in pests and disease associated with higher temperature, although any form of quantitative study is lacking at present.

An improved resilience to drought requires careful consideration. In the short term the continued implementation of strategies currently in place will be sufficient. Nevertheless the immediate implementation of small adaptive changes would only serve to benefit the industry, such as low mowing frequency, which has been proven to provide more resistance to drought than species richness (Vogel, et al., 2012). However in the medium to long term greater changes will be required. This will be a focus on more drought tolerant species and the potential use of irrigation.

There have been many studies which outline the benefit of drought tolerant pastures. Korte & Rhodes (1993) showed how drought tolerant species, such as tall fescue and chicory, increased financial returns at a low establishment cost in drought prone regions. The introduction of Lucerne has also proved to be a great success in Marlborough where drought conditions persist. It copes well in very dry environments (Brown , et al., 2005) and is tolerant to grazing (Sewall, et al., 2011). The increased use of Willow is another option, as it has successfully been implemented in dry years previously. Irrigation of pasture under dry conditions has been experimentally shown to double pasture production (Clark, et al., 2001), although the balance between large capital cost and potential benefit to production need to be considered carefully.

In the medium to short term the sector could benefit from climate change, provided changes in soil moisture and species composition is effectively managed. Ideally a long term strategy should be implemented which encompasses a range of issues such as biodiversity, land degradation and water use. There are a range of plausible scenarios over the next 50-100 years, with uncertainties in rainfall and extreme events. This makes committing to high-cost infrastructure changes such as irrigation difficult at this stage, but it should have future consideration. Dramatic land-use changes don't look necessary, although if higher emission scenarios persist and temperatures increase dramatically, improved models may predict a longer term climatic shift.

Future fire danger is as much effected by changes in human behaviour or policies towards fire management as it is by changes in climatic drivers. Rather than a move away from at risk land zones such as planted forests, there should be a focus on improving communication and policy. Comprehensive plans for the prevention and response to wildfire are already in place (Scott, 2014) under the Forest and Rural Fires Act. Steps such as the creation of firebreaks and the removal of slash pruned from pine trees would reduce the risk further.

5. Conclusion

The New Zealand climate in a large part is controlled by natural modes such as El Nino and the Pacific Decadal Oscillation. Throughout the 20th century trends outside these modes have been attributed to anthropogenic forcing, with these set to continue over the coming century. Atmospheric temperatures are going to increase, the magnitude of which is dependent on the emission scenario. Temperature has been shown in recent studies to have a near linear relationship with cumulative carbon released into the atmosphere. Sea levels along the coast have been rising at a rate of 1-2 mmyr^{-1} and are projected to continue, with evidence signifying an acceleration of this trend with increased forcing. Precipitation predictions are more uncertain, displaying a much greater inter-model variability. Despite this results indicate that Wairoa will become drier annually, although a potential reduction in westerlies would increase summer precipitation.

The likelihood of extreme events is also difficult to quantify. Evidence suggests daily heavy rainfall may decrease, coinciding with a reduction in precipitation during winter. Storminess is likely to increase globally, but projections specific to Wairoa are low in confidence. Still due to the potential impacts along the coast it has warranted further investigation by the Hawke's Bay Regional Council. Recent studies have deemed an increase in extreme wind speed likely for New Zealand, although a greater observational data set is required to determine its relationship with wave height and its coastal impact. Drought will progressively become more of an issue for the district, with evidence suggesting a 10% rise in time spent under drought by the middle of this century.

Climate change is a gradual process, and its impacts for the district are difficult to determine due to the range of plausible emission scenarios, and uncertainty in region specific results. While this information may be difficult to translate into policy, a failure to act in the long term would be costly. The development and use of land usually brings about long term change that is difficult to reverse once the impacts of climate change manifest themselves. For example areas of coastline deemed not under threat from inundation or erosion may subsequently be at risk in the future. Sub-division of coastal land without proper consideration of the long-term implications of climate change will create significant problems for future generations. In this case, short term action may just be providing a sufficient information base for effective long term policy development through the commission of large scale studies. Treating the inherent uncertainty within climate models as justification for inaction may have little implication in the short term, but would be detrimental over longer timescales.

Careful consideration also needs to be given to the implications of climate change on agricultural output, not least because of the importance of the primary sector on the local economy. If managed correctly future climate conditions may be favourable for production. Longer growing periods and increased summer precipitation have been modelled to positively impact productivity in Wairoa. This without the increase in growth rate that will occur with greater concentrations of atmospheric CO_2. However this positive response is likely to be subject to increased periods of drought. While current evidence doesn't suggest land use change is necessary, steps should be taken to make pasture more drought resistant, through the incorporation of drought tolerant grass species and the potential instillation of irrigation systems. The severity of future extreme events on the agricultural sector is difficult to assess due to the large range of plausible scenarios and model uncertainty, though the general consensus is that over time their impact will be more detrimental. The absence of any assessment which encompasses the full range of issues, including biodiversity, land degradation and water use, prevents the formulation of a long term (50-100 years) adaptation plan. Such research will have to be undertaken to mitigate any adverse effects of climate change on the industry.

With more time spent in drought and a drier climate annually, conditions suitable for the spread of wildfires can be expected in the future. A major influence on their frequency is human behaviour and policy, and this report recommends a focus on improving these two factors, rather than any dramatic changes in land use. Practices such as removal of slash should become commonplace and the introduction of firebreaks would help mitigate the effect of wildfires increasing in frequency and magnitude.

One environmental hazard where the risk could reduce is inland flooding. With heavy rainfall predicted to decrease the likelihood of a large flood event around the Wairoa River could fall. However as mentioned precipitation predictions on this finer scale are uncertain, and regional scale extreme rainfall is again hard to fully quantify. Communities are already unwilling to implement flood defences due to the high financial cost and negative aesthetic impact. Although the information provided would not be enough of an incentive to invest in flood defences or revise land use, an area already deemed at risk of inland flooding should pay close attention to future research. Even if heavy rainfall events aren't predicted to become more frequent, future environmental conditions may be more favourable for flooding, increasing the risk.

Despite uncertainty in future long term predictions the hope is that the information provided will incentivise the district to begin formulating adaptive measures to mitigate the impacts of climate change. Often the district lacks sufficient observational data and predictive study to formulate long term policies and in the short term this should be addressed. Modelling results are based on IPCC reports that come out every few years and it is important that the district remains informed with the most up to date information. Correctly communicating any uncertainty is imperative so it is not seen as an excuse for taking no action. Although there is a large range of plausible scenarios the climate is changing, and Wairoa will have to adapt to avoid a detrimental socio-economic impact.

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