NIWA
Taihoro Nukurangi

Updated climate change scenarios for the Kapiti Coast

NIWA Client Report: AKL-2007-091
November 2007

NIWA Project: KDC08301

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Prepared for

Kapiti Coast District Council

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Contents

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Executive Summary

This report, prepared for the Kapiti Coast District Council, is an update of the climate change guidance prepared by NIWA in 2005 (Gray et al., 2005).The report describes the background information on the climate of Kapiti Coast Region and discusses several elements of the expected climate changes during the 21st century in the Region, including changes in large scale circulation, winds and pressure patterns, and implications for average climate of the Region: temperature rise; frequency and intensity of rainfall; sea level rise. The projections of extreme rainfall intensities in the Kapiti Coast Region for years 2030, 2040, 2090 are also presented in this report for several sites in the Region.

Parts of the Kapiti Coast Region are located near sea level, and are vulnerable to the impacts of climate change as has been experienced in the last few years when a conspicuous number of extreme storm events occurred, the worst being in 2004.

Based upon global climate model output as used in the IPCC 4th Assessment Report published in 2007, a downscaling to New Zealand conditions has been completed, showing that temperatures are expected to increase everywhere. However, mean projected rainfall varies around the country, and with season. Other expected changes at the national scale are: decreased frost risk, increased risk of high temperatures, and increased frequency of extreme daily rainfalls, decreased seasonal snow cover, and a possible increase in strong winds.

Climate change projections at the Kapiti Coast Region scale suggest an increase in the 21st century in mean temperature and annual rainfall with a significant increase in the frequency and intensity of storm surge events, and an increase in mean sea level. Three scenarios were used to provide average temperature increases for the Kapiti Coast Region, showing average temperature increases for the 2030 to range from 0.2 to 1.7°C (with a mean rise of 0.7°C), and for the 2090 from 0.6 to 5.1°C (with a mean rise of 2.1°C). If Kapiti mean temperatures increased by 2.1°C, the result would be a climate warmer than Taranaki and Waikato at present.

At the same time there is projected to be an increase in westerly circulation over New Zealand. Changes in annual mean rainfall range from -2 to +8% for the 2030, and -7 to +14% for the 2090. The scenarios provide multiplicative factors indicating how much high intensity design rainfall are likely to increase by. These give increases in the intensity of design storm events for the 2030, 2040, and 2090. Larger increases in intensity are expected to occur for high rainfall events of short duration (.i.e. less than 6 hours), compared to those of longer duration. These represent significant increases in design rain storm intensities as the 21st century progresses.

With increases in the annual rainfall, and in the frequency and intensity of heavy rain periods, these will imply an increase in the risk of ponding and an impact on ground water in the Region.

Concerning sea level, the possible effect that future sea-level rise may have on how often present day high tide levels may be exceeded is discussed in this report. Given that sea-level rise has presently been tracking close to the upper levels of the IPCC sea-level projections it is likely that high-tide levels that are only exceeded once or twice a year at present will be exceeded on most tides by the end of the century.

1. Introduction

Global warming is expected to continue during the 21st century, and to enhance already observed changes in regional climate. The global scale projections presented in the IPCC 4th Assessment Report published in 2007 include a global average surface warming of 1.1°C to 6.4°C, an increases in mean annual rainfall in some regions and decreases in others, a contraction of snow cover, and a global mean sea-level rise ranging from 0.18 to 0.59 m (with a caveat of a further 0.1–0.2 m in the upper ranges if the major ice sheets melt faster than 1993–2003 rate due to rising temperatures). The range of likely temperature increases and other changes is related to uncertainties about the future levels of greenhouse gases emitted into the atmosphere, and to differences between different climate model projections of future climate.

Based upon global climate model output as used in the IPCC 4th Assessment Report, a downscaling to New Zealand conditions has been completed, based largely upon statistical models, but some use has been made of dynamical downscaling using the NIWA regional climate model.

The most likely changes out to 2100 for New Zealand include increases in average temperature of between 0.5 and 5.5°C. As temperature increases, the water holding capacity of the atmosphere increases. With this the intensities of design rainfall extremes increase for a particular duration. For a specific rainfall intensity, the recurrence interval (return period) reduces.

In this report, which is an update of the climate change guidance prepared by NIWA for Kapiti Coast District Council in 2005 (Gray et al., 2005), several elements will be discussed of the expected climate changes in the Kapiti Coast Region, including: changes in large scale circulation, winds and pressure patterns, and implications for average climate of the Kapiti Coast region; temperature rise; frequency and intensity of rainfall; and sea-level rise.

Information on changes in high-intensity rainfalls and other extremes have been drawn from the NIWA regional climate model runs, carried out with only one GCM (the UK Met. Office Unified Model) rather than the suite of twelve models used in statistical downscaling. It will be possible to make only general statements about ground-water and ponding, as in the previous report.

The timeframe for projections is 40, 50 and 100 years into the future, by comparing the 20-year periods 1980-1999 (referred to as "1990") with future 20-year periods; 2020-2039 ("2030"), 2030-2049 ("2040") and 2080-2099 ("2090").

Scientific information on climate variability and change based on the 4th IPCC Assessment Report will help to assess its impacts on groundwater and ponding in the Kapiti Coast Region and it will enable the Kapiti District to better face those issues, and foresee a longer term planning.

2. Background

2.1 Climate change and variability

Since 1990 the IPCC has produced three more assessment reports on Climate Change with the Fourth Assessment Reports being released in 2007 (IPCC, 2007a). There have been very significant improvements in our understanding of climate change science, with major improvements in the details of climate change, from observations to producing climate change scenarios, and then to modelling and downscaling projections of change to smaller areas such as New Zealand. At the same time the understanding of how sea level will rise during the 21st century and its projections has become much more sophisticated. This, with the development of supercomputers has provided climate scientists with much enhanced tools for the evaluation of climate change scenarios, the development of rainfall patterns and long term sea-level rise projections. As well, there has been development of much improved understanding of how natural climate variability impacts on regional and local climate patterns around New Zealand, through such factors as the El Niño-Southern Oscillation (ENSO), and the Interdecadal Pacific Oscillation (IPO).

There are two key natural cycles that operate over timescales of years (El Niño-Southern Oscillation, ENSO) and decades (Interdecadal Pacific Oscillation, IPO). The most significant impacts of these natural phenomena on climate are confined largely to the Pacific Ocean, but there is evidence that sea temperature conditions elsewhere, such as in the Indian Ocean, can also affect New Zealand climate at some times of year. The future climate in New Zealand will arise from a combination of natural climate variation, and from anthropogenic origins as a result of increases in greenhouse gas emissions.

2.2 The El Niño-Southern Oscillation (ENSO)

El Niño is a natural feature of the climate system. The term was originally used by fishermen for the occasional warming of waters along the Peruvian coast, which they observed as it became strongest around Christmas in some years. The warming extends out along the Equator from the South American coast to the central Pacific. It is accompanied by large changes in the tropical atmosphere, lowering pressures in the east and raising them in the west, in what is known as the "Southern Oscillation". In the late 1960's and early 1970's, scientists realised that El Niño and the Southern Oscillation were linked, with one component in the ocean and the other in the atmosphere. This became known as ENSO. A convenient way of measuring ENSO is in terms of the east-west pressure difference, the Southern Oscillation Index, or SOI, which is a scaled form of the difference in mean sea-level pressure between Tahiti and Darwin. A graph of the SOI is shown in Figure 1.

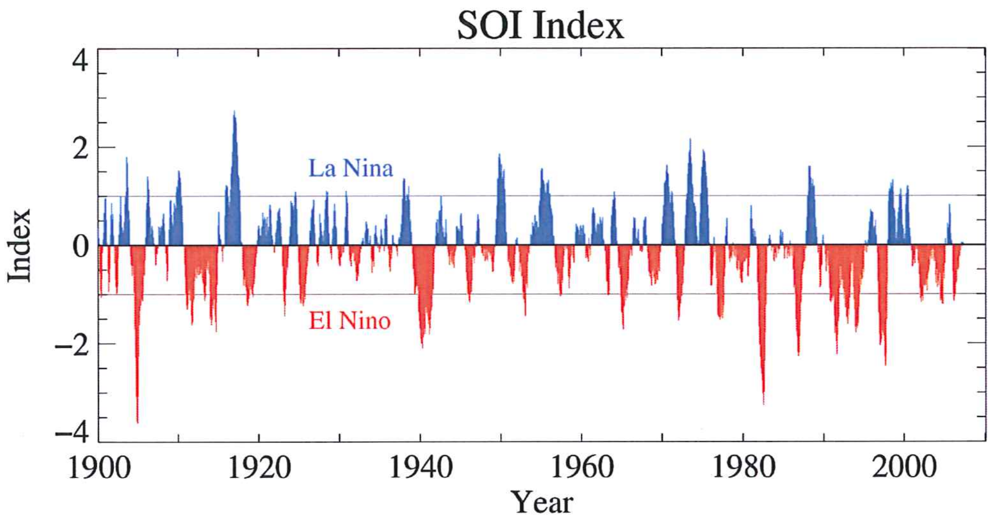

Figure 1. **The Southern Oscillation Index (SOI) over the period 1900 - 2007. Negative excursions (red) indicate El Niño events, and positive excursions (blue) indicate La Niña events. The irregular nature of ENSO events is evident in the time sequence. © NIWA.**

ENSO may be thought in terms of a slopping back and forth of warm surface water across the equatorial Pacific Ocean. The trade winds, blowing from the east towards the west, normally help to draw up cool water in the east and to keep the warmest water in the western Pacific. This encourages low air pressures in the west and high pressures in the east. An El Niño event is when the warm water "spills out" eastwards across the Pacific, the trade winds weaken, pressures rise in the west and fall in the east. Eventually, the warm water retreats to the west again and "normality" is restored. The movements of water can also swing too far the other way and waters become unusually cool near South America, resulting in what is termed a "La Niña", where the trade winds are unusually strong while pressures are unusually low over northern Australia.

El Niño events occur irregularly, about 3 to 7 years apart, typically becoming established around April or May and persisting for about a year thereafter. The ENSO cycle is an example of a positive feedback system, where a small change in the trade winds can change equatorial sea temperatures to encourage a larger change in the trade winds that changes sea temperatures even more, and so on, into a full-blown El Niño or La Niña.

New Zealand does not lie directly in any of the high-impact regions in the Pacific, but its climate is significantly affected by changes in the atmospheric circulation (winds). (Figure 2) In general, El Niño conditions, indicated by persistently negative values for the SOI, give more westerly and southwesterly wind than usual over the country. Annual mean sea levels around the North Island are generally depressed below normal. Conversely, La Niña conditions, indicated by persistently positive SOI values, typically give more northeasterly wind than usual over the country. Annual mean sea levels around the North Island are generally increased above normal (up to 0.1–0.12 m in larger La Niña events). In the centre of the country the climate effects are muted for most seasons and no clear ENSO influence is identifiable against the natural variability of climate.

As shown in the 2005 Report (Gray et al, 2005), no clear pattern of difference is apparent in the Kapiti Coast Region between the ENSO states, although some organisation of the data can be noticed with drier conditions more likely in La Niña conditions and wetter conditions more likely in neutral or El Niño conditions.

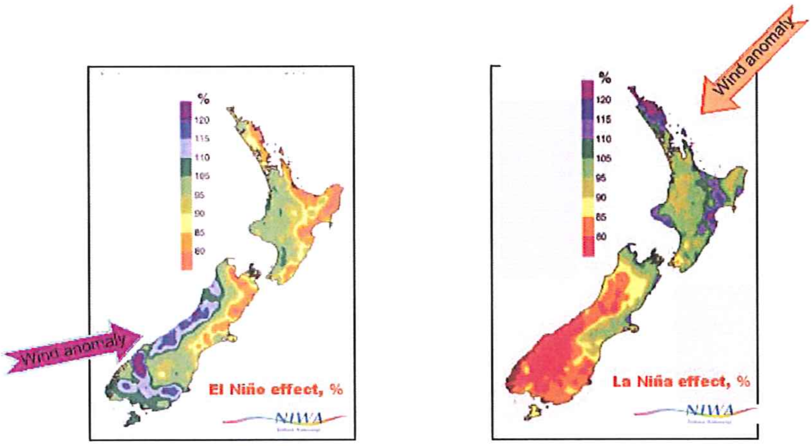

Figure 2. Average summer rainfall anomaly (percent) for El Niño and La Niña seasons. © NIWA.

2.3 Interdecadal Pacific Oscillation (IPO)

The Interdecadal Pacific Oscillation, or IPO, is a Pacific-wide natural fluctuation in the climate, which causes abrupt "shifts" in Pacific circulation patterns that persist for decades.

The IPO also affects New Zealand's climate, and affects temperature and rainfall averages in each phase. The IPO is strongest in the North Pacific, but sea temperatures in the eastern equatorial Pacific (the "home" of El Niño) are also influenced. Current research in Australia and New Zealand is showing that when the IPO changes phase, there are changes in the way the El Niño-Southern Oscillation affects Australasia. Thus, a "shift" can not only change the average climate, but can also mean that different forecasting relationships are needed to predict monthly and seasonal variations.

There are two phases, the **positive** and **negative** phase of the IPO. In the positive phase, westerly quarter winds over the country and anticyclones in the north Tasman are more prevalent, with generally drier conditions in the north and east

Phase changes of the IPO are shown in Figure 3. The IPO exhibits phase reversals once every 20-30 years. Previous phase reversals of the IPO occurred around 1922, 1945, and 1977. The latest diagnosis of the IPO index from global sea surface temperatures (Figure 3) indicates a recent reversal in 1999/2000. This current negative phase would be expected to encourage more La Niña activity in the tropical Pacific, and a higher frequency of northeasterlies over the country.

Climate in the Kapiti Coast region is not markedly affected by El Niño and IPO, however fluctuation in background sea levels for short periods in some years or seasons can be attributed to El Niño and to the IPO.

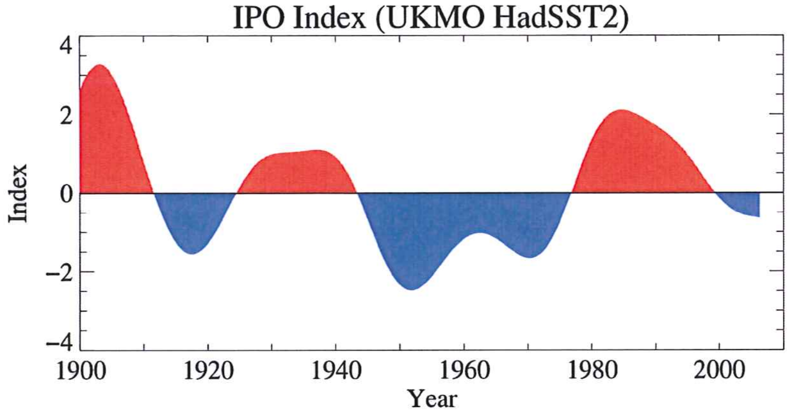

Figure 3. Phases of the Interdecadal Pacific Oscillation. Positive values indicate periods when stronger westerlies occur over New Zealand, and more anticyclones over the northern New Zealand. Negative values indicate periods with more north-easterlies to northern regions. Data courtesy of the Hadley Centre, UK Meteorological Office. © NIWA.

2.4 Present climate in the Kapiti Region

The Kapiti coast is exposed to disturbed weather systems originating from the Tasman Sea, producing a relatively windy climate, with a generally medium level of rainfall relative to other areas of New Zealand, and few temperature extremes.

2.4.1 Rainfall

Normal (1971-2000) annual rainfall is between 1,000 mm and 1,100 mm near sea level along the Kapiti Coast (Figure 4). However annual rainfall increases with altitude (approx. 330 mm per 100 m), being noticeably higher on the coastal hills and in the inland catchment areas of the Tararua Range (over 2,000 mm), a situation which can, in moist onshore air flow, at times contribute to a significant volume of storm water runoff.

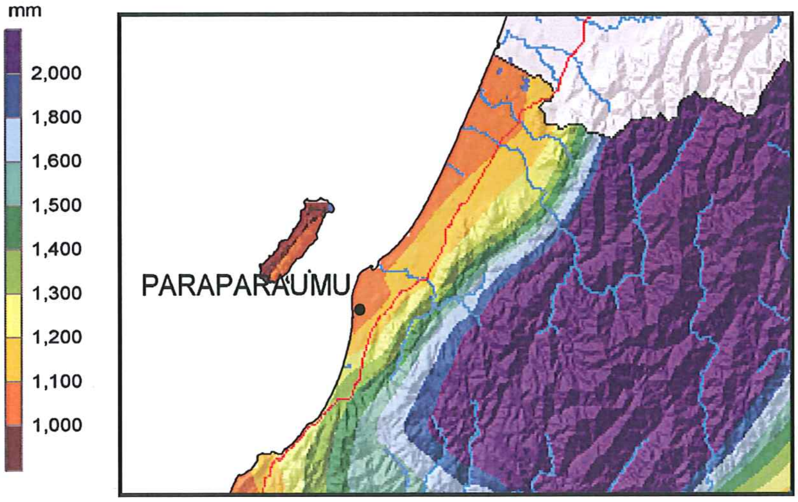

Figure 4. Kapiti Coast District median annual average rainfall (1971-2000). © NIWA.

The most settled weather (with longer dry periods) usually occurs during mid to late summer and early autumn, while winter and spring are often the most unsettled (wettest) times of year. However, large variations can occasionally occur, e.g. the extremely wet February of 2004 (Figure 5).

Table 1. Annual rainfall normals, mm (1971-2000).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Te Horo, Longcroft	77	69	95	87	113	119	114	107	98	124	103	110	1,216
Waikanae Waterworks	79	69	92	85	117	123	123	108	99	127	99	105	1,224
Reikorangi	114	93	128	118	154	166	168	151	144	180	142	153	1,712
Paraparaumu Airport	70	56	75	78	100	105	101	90	84	105	82	85	1,031
Kapiti Island	71	57	87	93	115	119	106	101	87	113	92	87	1,128
Paekakariki Hill	89	72	103	100	125	141	137	121	106	128	99	107	1,328

On the coast, days with light or moderate rainfall (less than 25 mm in 24 hours [9am-9am]) are on average more frequent between May and December. However, there is no seasonal tendency for larger rainfall events – which can occur at any time of the year. Days with (9am-9am) rainfall totalling more than 50 mm (which can often be associated with surface flooding) occur on average a few times each year near sea level (Table 2), but are more frequent in hill country catchment areas over 300 m above mean sea level.

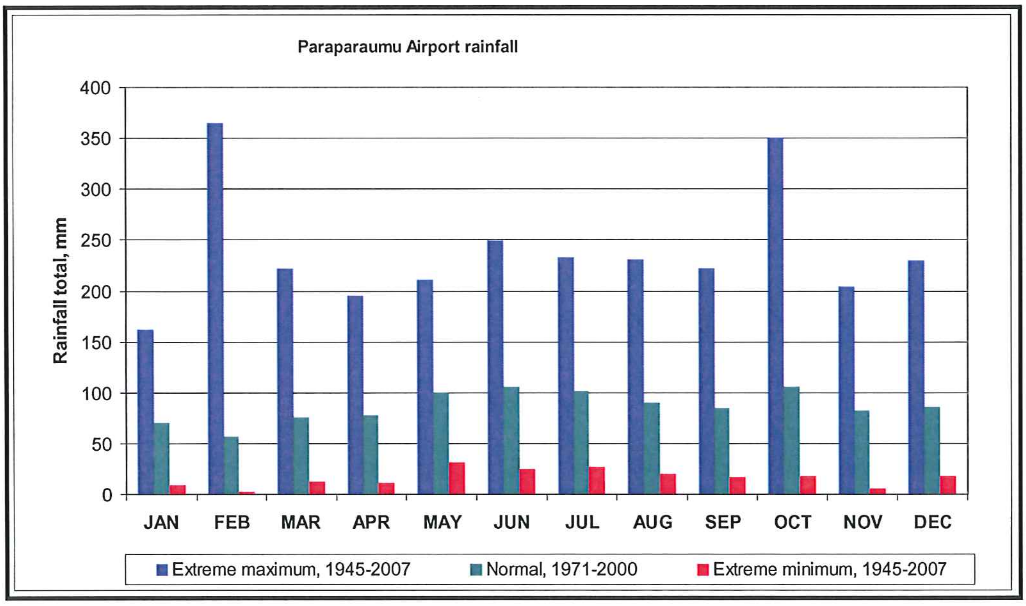

Figure 5. Paraparaumu Airport monthly rainfall.

Table 2. Mean annual days with rainfall over selected thresholds (1971-2000).

Station	>1 mm	>10 mm	>25 mm	>30 mm	>40 mm	> 50 mm	>75 mm	>100 mm
Te Horo, Longcroft	116	39	11	7	3	2	0.4	0.1
Waikanae Waterworks	114	39	11	7	4	2	0.4	0.1
Reikorangi	134	53	17	13	7	4	0.9	0.2
Paraparaumu Airport	109	33	8	6	3	1	0.1	0.0
Paekakariki Hill	117	42	12	9	4	2	0.7	0.1
Estimate at 350 m	173	74	26	19	10	5	1.6	0.8

2.4.2 Temperature

The annual mean temperature at Paraparaumu Airport is 13.0°C (1971-2000), which is similar to estimates for the whole of the coastal area from Paekakariki to Otaki. Mean temperatures decrease with increasing altitude (approx. 0.65° C per 100 m), so are noticeably lower in and towards the Tararua Range (Figure 6).

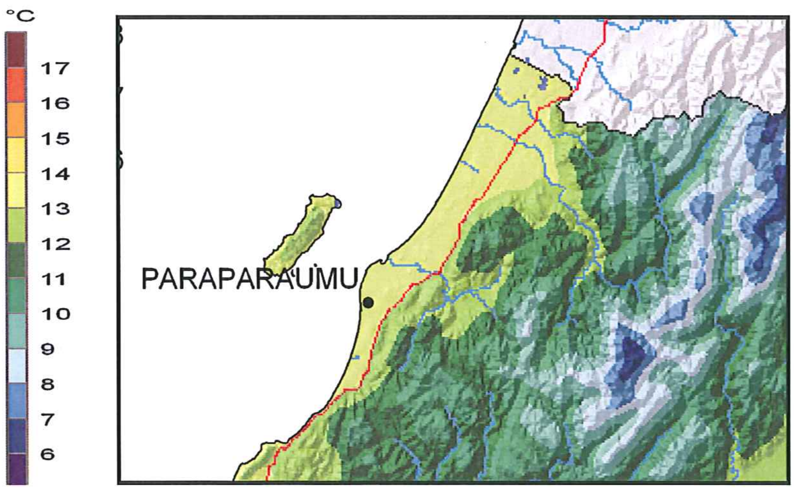

Figure 6. Kapiti Coast District median annual average air temperature (1971-2000). © NIWA.

Summer conditions are often mild to warm. Typical summer daytime maximum air temperatures at Paraparaumu Airport average about 21°C (Figure 7), and on a few days may occasionally exceed 25°C. Mean daily minima during summer average

13°C. The highest temperature on record at the Airport is 29.6 °C, while 30.3 °C has been recorded on Kapiti Island.

Winters are cool. Typical winter daytime maximum air temperatures at the Airport average about 13°C, with variations depending on cloud cover and the speed and direction of the wind. In winter, frosts may occur on clear, calm, cold nights. The lowest temperature on record at Paraparaumu Airport is -4.8 °C. Mean daily minima during winter average 5°C.

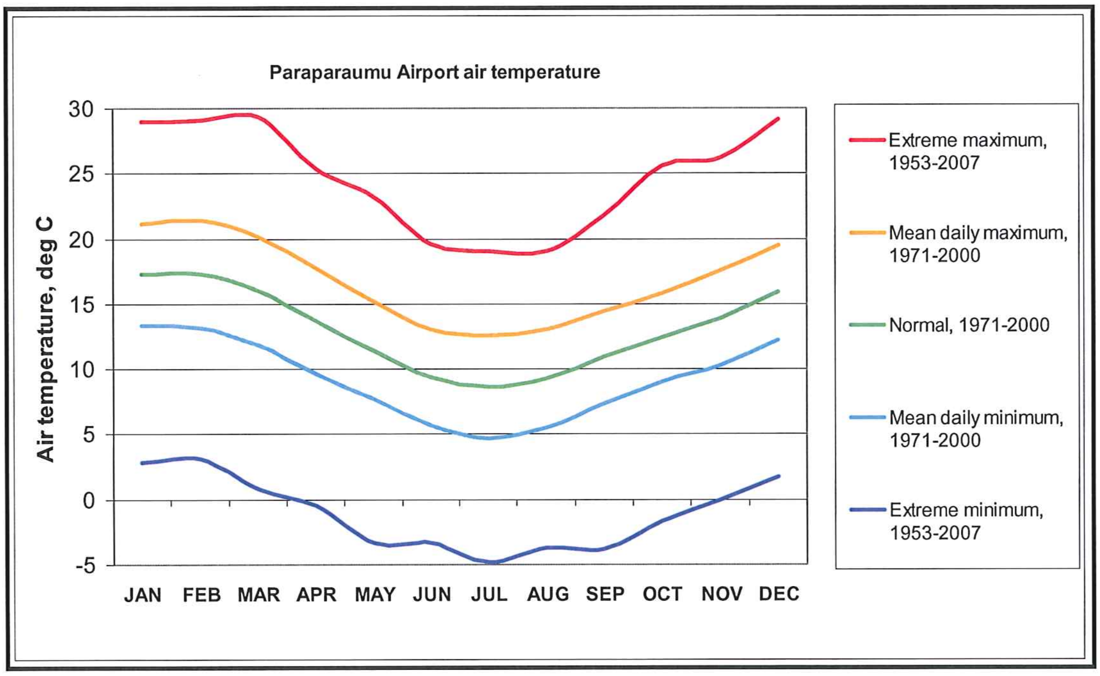

Figure 7. Paraparaumu Airport monthly air temperature.

2.5 Sea-level rise

2.5.1 An overview of coastal hazard drivers

Coastal hazards, such as inundation and coastal erosion, tend to be caused by a range of inter-relating factors or "drivers" which can be both natural and caused or exacerbated by human actions. Besides earthquakes and underwater landslides (which can cause a tsunami or coastal subsidence), the main natural causes of coastal hazards arise from a combination of ocean tides and extremes in weather such as storms. Variability in climate, such as seasonal, El Niño/Southern Oscillation (ENSO) or Interdecadal Pacific Oscillation (IPO) cycles also play an important role through influencing the background sea levels and the occurrence and characteristics of storm conditions. It is these weather and climate-related factors that will be altered most by climate change arising from global warming, and will mostly exacerbate coastal hazard problems within developed coastal margins.

This section focuses primarily on the effect of climate change on sea-level rise on the Kapiti coast based on the conclusions of the latest IPCC Fourth Assessment Report.

2.5.2 Components of sea level

Sea levels are important along the Kapiti coastline for two primary reasons:

a) the range swept by all high tides governs the likelihood of coastal inundation and potential for coastal erosion, especially when combined with storm surge or where stormwater or river and stream network levels back up during high intensity rainfall; and

b) sea-levels also determine the degree to which waves may be depth-limited at the coastline and hence is an important factor in determining factors such as the magnitude of wave run-up and overtopping of coastal defences, and the potential for structural damage to coastal defences.

The main component of sea level is the astronomical tide, which can be predicted accurately many years in advance. However, actual sea level can be elevated (or lowered) due to a number of ocean and weather factors including:

- Seasonal (annual), El Niño/Southern Oscillation (3–7 year), and Interdecadal Pacific Oscillation (20–30 year) timescales which in total can cause fluctuations of up to about ±0.25 m in background sea levels for short periods in some years or seasons. For example during El Niño phases, sea levels tend to be depressed, and during La Niña phases, sea levels tend to be higher. The IPO in its negative phase (as it currently is) tends to increase sea levels around the North Island by around 0.05 m above the background sea-level rise;

- Storm surge: the temporary increase in sea level over 1–3 days due to a reduction in atmospheric pressure (inverse barometer effect) and influence of wind on the sea surface. In a New Zealand context, maximum storm surge on the open coast is unlikely to be greater than about 1 m but can be higher in estuarine and harbour settings. The combination of astronomic tide (+ effects of any long-term climate fluctuation effects) and storm surge is usually referred to as the storm tide.

Wave conditions also affect localised water levels where inshore of the wave breaker zone, water levels are set-up. This is a localised phenomenon and can be highly variable along even a short stretch of coastline, being dependent on the wave conditions and configurations of offshore sand bars and beach slope.

2.6 Climate change

The growth in anthropogenic greenhouse gas concentrations in the atmosphere is expected to be the most important factor causing climate to change during the 21st century. In the atmosphere there are naturally occurring greenhouse gases, but various human activities have boosted the concentration of many of these gases to levels unprecedented for at least the last 650,000 years. The principal greenhouse gas is carbon dioxide (CO_2), and others include ozone (O_3), methane (CH_4) and nitrous oxide (N_2O). Water vapour, together with cloud effects, has a stronger greenhouse effect than CO_2, but it represents a natural feedback in the climate system rather than an emitted greenhouse gas. These gases are largely transparent to incoming solar radiation (short wave) from the sun, while at the same time they also act to trap outgoing radiation (long wave) that is re-radiated by the Earth back to space. By preventing some of this heat from escaping the atmosphere, greenhouse gases ensure Earth temperatures are kept at levels necessary to support life. This is known as the *natural greenhouse effect* and has operated in the Earth's atmosphere for billions of years due to naturally occurring greenhouse gases (IPCC 2007a). Relatively recent changes in the concentrations of these greenhouse gases, however, have changed the efficiency with which the Earth cools to space. That is, as concentrations of greenhouse gases have increased the atmosphere has been absorbing more of the outgoing heat radiation (infrared) from the surface of the Earth. This has resulted in a general warming of the climate system, which includes the lower atmosphere and the Earth's surface. This is widely referred to as the *enhanced greenhouse effect.*

Over the last 20 million years, the natural concentration of carbon dioxide in the atmosphere has ranged from approximately 190 parts per million (ppm) to 280 ppm. Careful studies of the relationship between CO_2 concentrations and temperature have shown that as concentrations of CO_2 increase so too do temperatures and vice versa. By 2005, CO_2 concentrations had reached nearly 380 ppm (IPCC 2007a). By 2100, the atmospheric concentration of CO_2 is expected to be at least twice, and possibly almost four times, the pre-industrial level (of 280 ppm), unless major international efforts are undertaken to substantially reduce emissions. Other greenhouse gases besides carbon dioxide are also well above pre-industrial levels (Hennessey et al, 2007). These are likely to increase Auckland temperatures by +0.3 to 4.0°C by the 2080s (IPCC 2007b).

As far as extreme precipitation goes, a warmer atmosphere can hold more moisture (about 8% more for every 1°C increase in temperature), so the likelihood of heavier extreme rainfall in a warmer world is high (IPCC, 2001). An early study of extreme rainfall for the Australasian region (Whetton *et al.* 1996) suggested there could be a reduction in the return period of heavy rainfall events. In other words, heavy rainfall events are likely to become more common. Thus by 2030, "no change through to a halving of the return period of heavy rainfall events" was expected, and by 2070 "no change through to a fourfold reduction in the return period" was expected. Subsequent analyses that give guidance for the New Zealand region (Semenov and Bengtsson 2002; MfE 2004) support this earlier finding.

2.7 Climate Change in Kapiti Region

The Intergovernmental Panel on Climate Change (IPCC) has published updated climate change assessments during 2007 (IPCC, 2007a,b). NIWA has used climate model data from the IPCC Fourth Assessment to update the climate change scenarios for New Zealand. These are described in a guidance manual prepared for the Ministry for the Environment (Mullan et al., 2007), and supersedes the earlier scenarios (MfE, 2004).

This report draws on the new scenario information. The IPCC presented projections for six emissions scenarios to cover a wide range of possible future economic, political and social developments during the 21st century. In this report, we show maps of projected climate changes under the mid-range IPCC emissions scenario known as A1B. For the purpose of sensitivity analysis, we also consider the lowest IPCC emissions scenarios (known as B1), and the highest emission scenario (A1FI). Mullan et al. (2007) discusses these IPCC scenarios, and the downscaling methodology used to derive detailed changes at the regional and district council scale.

Figure 8 indicates the range of global temperature increases likely out to 2100. There is a wide spread range in projected warming. The range encompasses not only the range of plausible emissions scenarios, but also the uncertainty in the climate response as represented by a number of global climate models. The temperature increase at 2100, relative to the average over 1980-1999, varies from +1.1°C (least sensitive model combined with the lowest emission scenario B1) to +6.4°C (most sensitive model with the highest emission scenario A1FI). The multi-model average, or IPCC 'best estimate', of the temperature increase for the mid-range A1B scenario is +2.8°C.

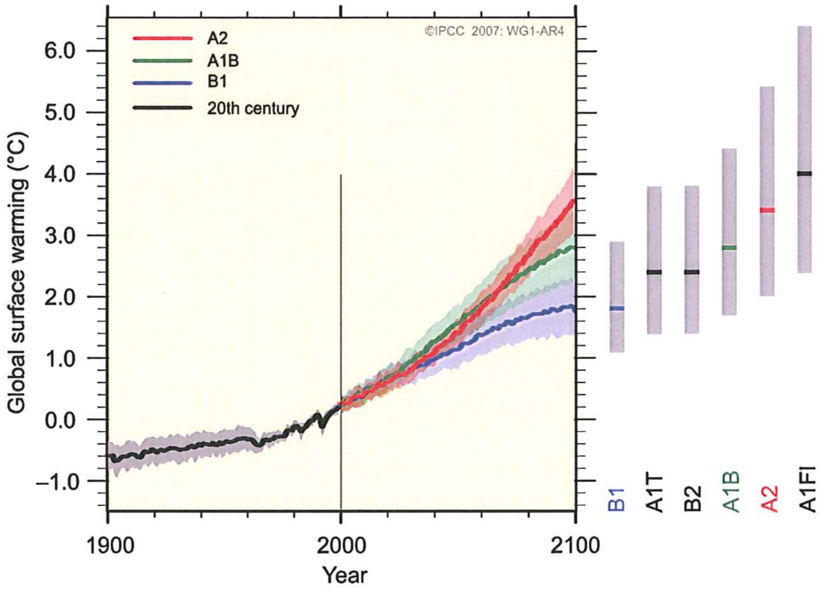

Figure 8. **IPCC projections of global temperature increase. Solid coloured lines are multi-model global averages of surface warming (relative to 1980-1999) for emission scenarios B1, A1B and A2, shown as continuations of the 20th century simulations (black line). The coloured shading denotes the ±1 standard deviation range of individual model annual averages. The grey bars at right indicate the best estimate (solid horizontal line within each grey bar) and the 'likely range' across 6 scenarios that span the full range of all IPCC emission scenarios. (Adapted from Figure SPM-5, IPCC 2007).**

3. Climate change projections for Kapiti District

3.1 Historical data

3.1.1 Sites

Annual maximum rainfalls for the durations from 10 minutes to 72 hours have been extracted for four sites in the Kapiti district (Table 3) from NIWA's nationally significant data bases – the Climate Database and Water Resources Archive – together with rainfall data provided by regional councils. These data have been collected for a revision to NIWA's design rainfall software HIRDS, and contain data up to 2005.

Table 3. Details of sites for extreme value analysis.

Location	Latitude °S	Longitude °E	Height (asl)	Comment
Paekakariki Hill	41 1' S	174 59' E	190 m	Hill site
Paraparaumu Air	40 54' S	174 59' E	5 m	
Waikanae Waterworks	40 53' S	175 4' E	30 m	
Reikorangi	40 54' S	175 7' E	125 m	Hill site

3.2 Changes in large scale circulation, wind and pressure patterns

The circulation patterns for a 12-model average for the A1B emission scenarios for the 2090 show an increase in mean sea level pressure over the country, with decreases to the south. Thus the subtropical ridge intensifies over northern New Zealand, concurrent with an increase in the strength of the westerly circulation to the south. The resultant flow is an increase in the mean westerly wind component across New Zealand this century, and Mullan et al (2001) suggest an increase of 10% in the westerly wind component over the next 50 years. Increases in the strength of the westerly wind flow over New Zealand are most prominent in winter, while in summer there is little change projected, or even a slight decrease in the westerlies.

3.3 Mean Temperature projection

Temperature projections show little spatial variation across New Zealand, but the magnitude of the change will vary with the emission scenario and also with the climate model used. Figure 9 shows the seasonal patterns of temperature increase over the lower North Island at 2040 for the A1B emission scenario, where the temperature changes of 12 global climate models have been averaged together. Figure 10 shows corresponding patterns for 2090. These nominal years represent the mid-points of bi-decadal periods: 2040 is the average over 2030-2049, and 2090 the average over 2080-2099, relative to the baseline climate of 1980-1999 (denoted as 1990 for short). Changes at 2030, can be approximated as 80% of the 2040 changes.

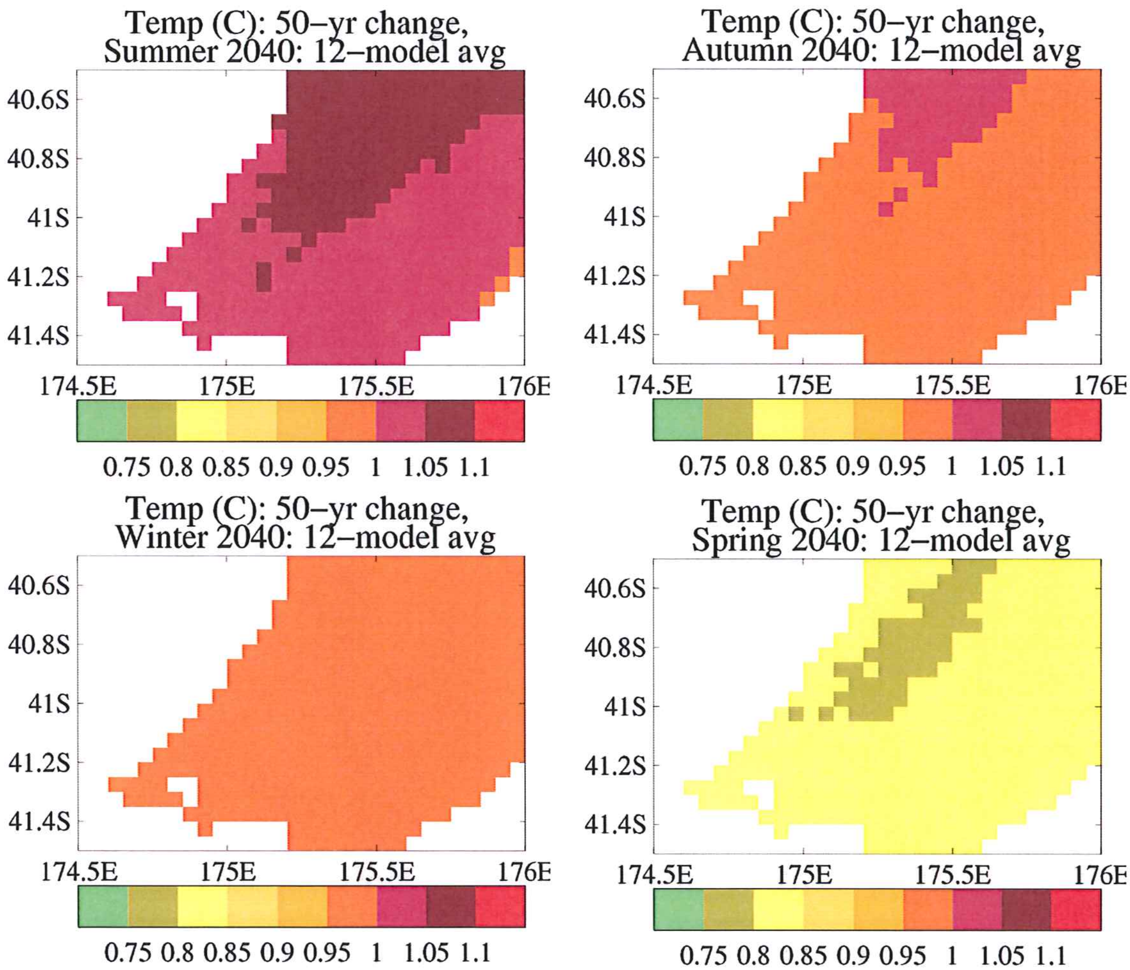

Figure 9. **Projected seasonal temperature changes at 2040 (2030-2049 average), relative to 1990 (1980-1999), for the IPCC A1B emission scenario, averaged over 12 climate models.**

[Note: The contour colours used here, and in subsequent similar figures, are the same as in the Ministry for the Environment Guidance Manual, and are chosen to cover the projected changes over the whole of New Zealand, which is a slightly broader range than for the lower North Island alone.]

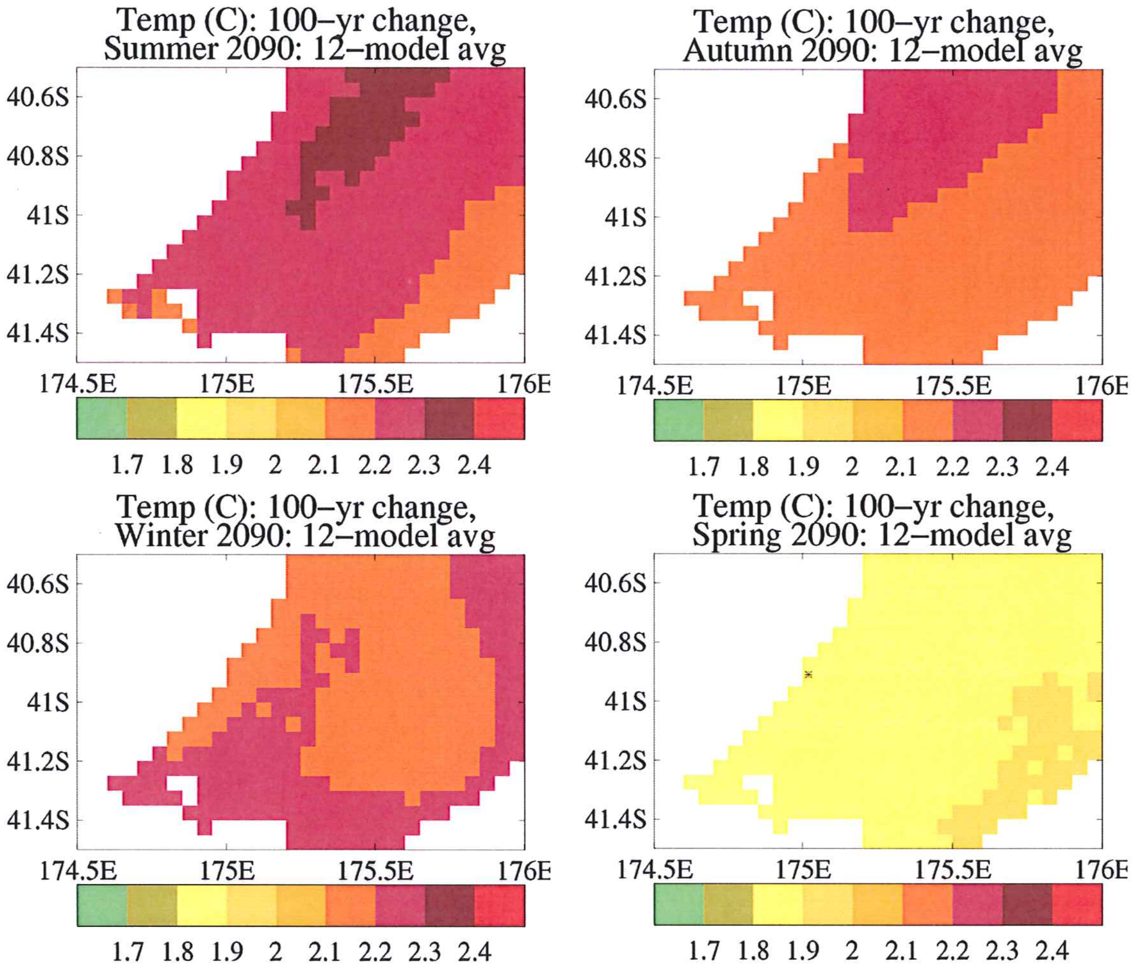

Figure 10. Projected seasonal temperature changes at 2090 (2080-2099 average), relative to 1990 (1980-1999), for the IPCC A1B emission scenario, averaged over 12 climate models. The black star in the panel for spring 2090 marks the location of the Paraparaumu grid-point in the 0.05 degree data set used for downscaling. Note that contour values are the same for each season, to allow easy inter-comparison, but are different from those used for the 2040 figure.

Figures 9 and 10 show future warming in the Kapiti district of approximately 0.2°C per decade for the A1B emissions scenarios, when averaged over the 12 global climate models analysed by NIWA. There is a slight acceleration in warming in the second 50 years of the 21st century compared to the first 50 years. Some models give less warming and others a faster rate of warming (Mullan et al., 2007). The full range of model-projected warming is given in Table 1 for three future periods. The temperature changes are relative to the baseline period 1980-1999 (as used by IPCC), denoted for short as "1990". Hence, the changes at 2030, 2040 and 2090 should be thought of as 40-year, 50-year, and 100-year trends.

The "best estimate" in Table 4 is the temperature increase averaged over all 12 global climate models analysed by NIWA, and also averaged over the six illustrative emissions scenarios used by IPCC. The lower limit to warming is set by the climate model with the lowest climate sensitivity (i.e., least warming) run under the lowest emissions scenario (B1). The upper limit is set by the most sensitive climate model under the highest emissions scenario (A1FI).

Table 4. Projected changes in seasonal and annual mean temperature (in °C) for the Kapiti region for three time periods: 2030, 2040 and 2090. The first number is the "best estimate", with the bracketed numbers giving the lower and upper limits.

Period	Summer	Autumn	Winter	Spring	Annual
2030	0.8 [0.2, 1.7]	0.8 [0.2, 2.0]	0.8 [0.1, 1.7]	0.6 [0.0, 1.5]	0.7 [0.2, 1.7]
2040	1.0 [0.2, 2.2]	1.0 [0.2, 2.5]	1.0 [0.2, 2.1]	0.8 [0.0, 1.9]	0.9 [0.2, 2.2]
2090	2.2 [0.8, 5.6]	2.1 [0.6, 5.1]	2.1 [0.6, 5.0]	1.8 [0.3, 4.8]	2.1 [0.6, 5.1]

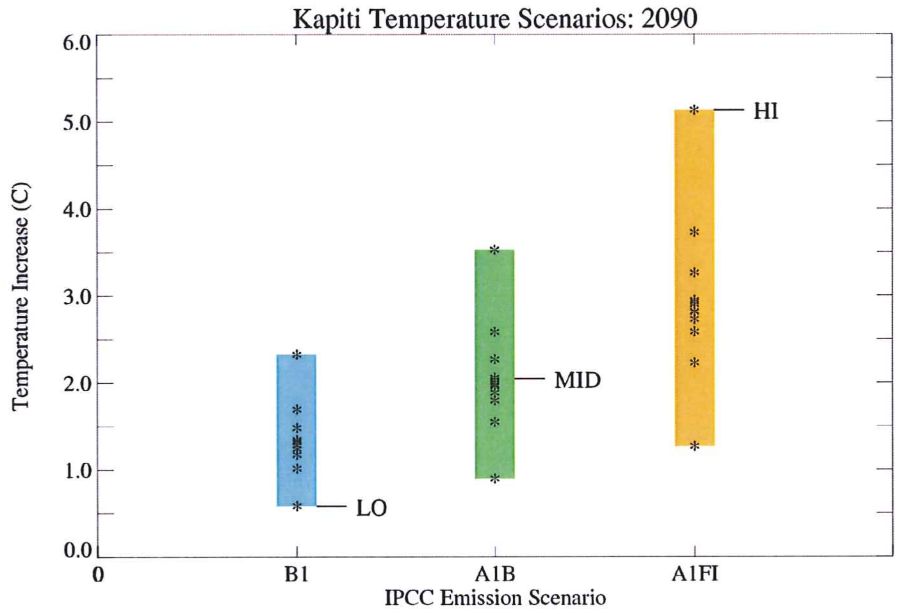

Figure 11. IPCC projections of temperature change for 2090, downscaled to the Kapiti region. Vertical coloured bars show the range across 12 climate models for the three emission scenarios known as B1, A1B and A1FI. Stars mark the individual model values. Short horizontal lines mark the positions of the low, middle and high temperature scenarios used in this report. Note that the upper star is well separated from the second most sensitive climate model.

Figure 11 shows the range of annual warming at 2090 for the 12 climate models, and for the 3 emissions scenarios B1 (lowest), A1B (Mid-range) and A1FI (highest). These ranges are the Kapiti region equivalent to the global temperature ranges in Figure 4. The temperature extremes (labelled "LO" and "HI"), and the mid-point ("MID"), are used in the sensitivity analysis for changes in extreme rainfall, and are also shown in Table 5.

The IPCC is reluctant to state whether any of their emissions scenarios are more likely to eventuate than others. However, observed emissions are already increasing faster than the lowest B1 scenario, and the slowest temperature increase to 2100 projected from the B1 scenario is less than the linear extrapolation of the observed New Zealand temperature increase over the 20th century. Thus, it is the opinion of NIWA scientists that the actual temperature increase in New Zealand this century is very likely to be more than the 'low' scenario given here. Under the mid-range scenario for 2090, an increase in mean temperature of 2.05^{o}C, would represent a warmer climate in Kapiti in 2090 than presently exists in Taranaki and Waikato.

Table 5. Kapiti temperature change scenarios used to calculate changes in extreme rainfall. Changes are relative to 1980-1999, and are shown for the 3 future periods of 2030, 2040 and 2090. The low, middle and high scenarios, shown graphically in Fig 4 for 2090, relate respectively to: the smallest warming for the lowest IPCC emissions scenario B1, the average warming over 12 climate models for the mid-range emission scenario A1B, and the greatest warming for highest IPCC emissions scenario A1FI.

Period	Low	Middle	High
2030	0.19	0.74	1.74
2040	0.24	0.92	2.18
2090	0.58	2.05	5.13

3.4 Mean Precipitation scenarios

Precipitation projections show much more spatial variation than the temperature projections. Again, the magnitude of the change will scale up or down with the emission scenario, and also be quite different for different climate models. Figures 12 and 13 shows the seasonal patterns of precipitation change over the lower North Island at 2040 and 2090 for the A1B emission scenario. As with Figures 9 and 10, the changes of 12 global climate models have been averaged together.

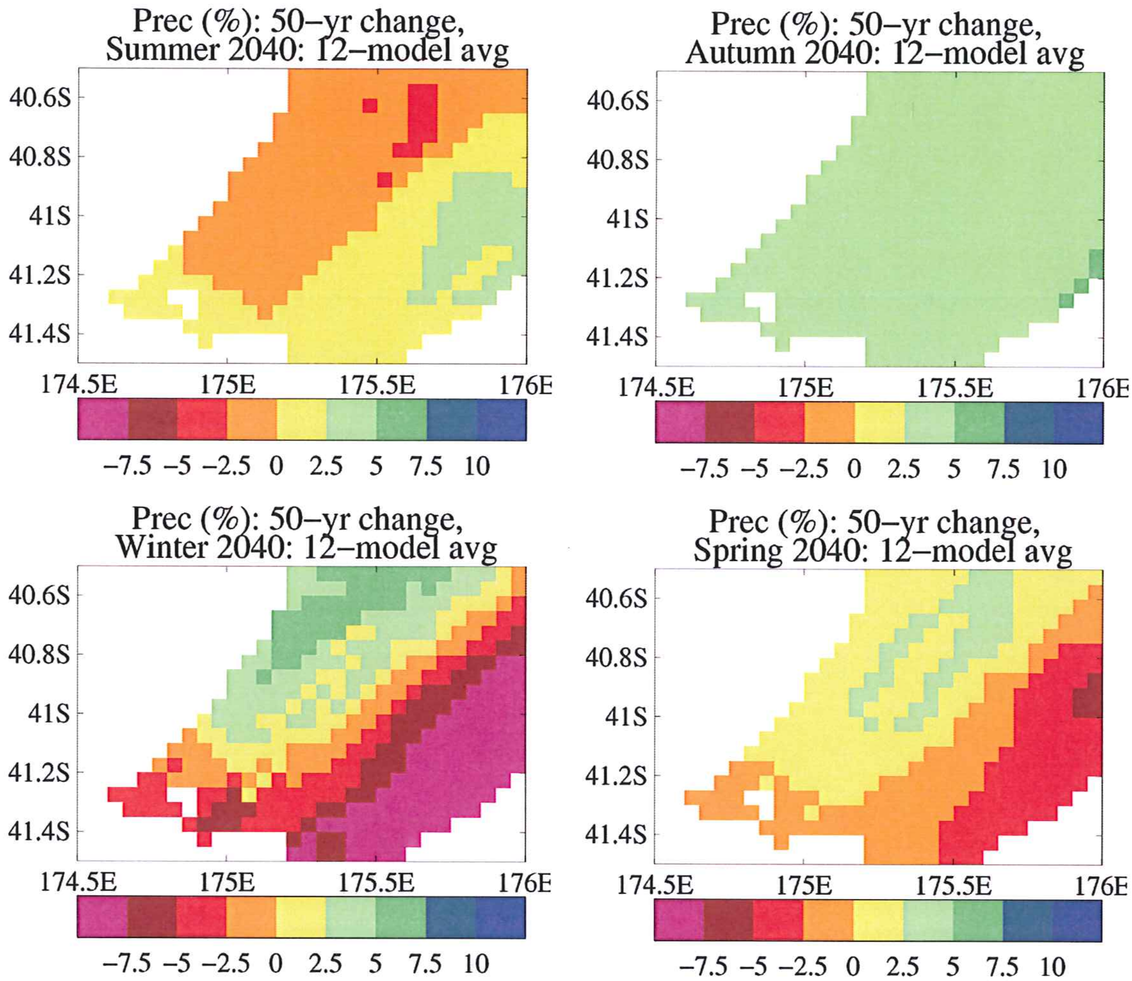

Figure 12. **Projected seasonal precipitation changes (in %) at 2040 (2030-2049 average), relative to 1990 (1980-1999), for the IPCC A1B emission scenario, averaged over 12 climate models.**

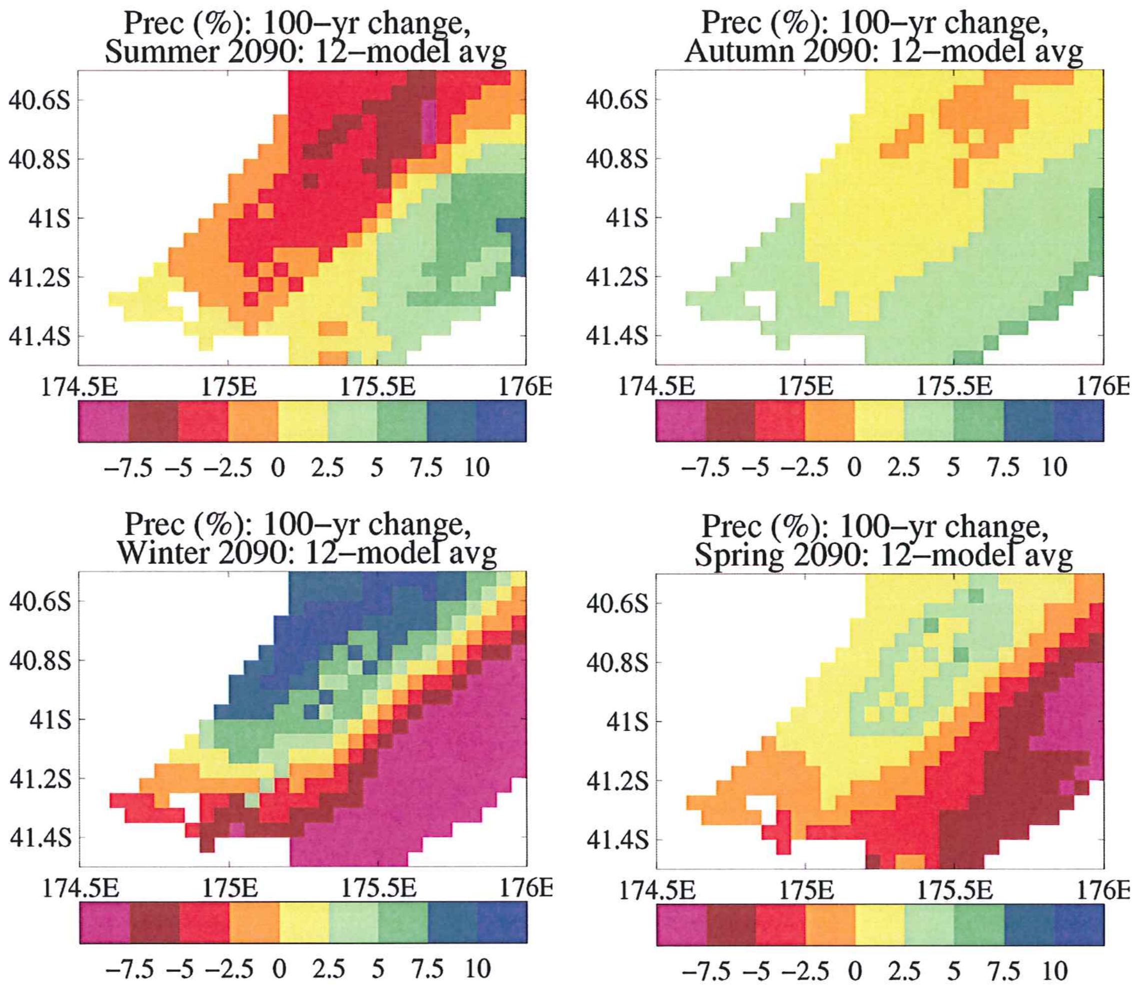

Figure 13. Projected seasonal precipitation changes (in %) at 2090 (2080-2099 average), relative to 1990 (1980-1999), for the IPCC A1B emission scenario, averaged over 12 climate models.

The 12-model average projections indicate slightly less rainfall in summer but slightly wetter conditions in the other seasons, especially in winter. The seasonality of these changes fits with the seasonality of expected changes in westerly winds, as discussed in section 3.2. Table 6 show numerical values for the Paraparaumu grid-point from the NIWA down-scaled analysis. The average picture can be slightly misleading since there is much disagreement between the climate models on the rainfall changes. Figure 14 show seasonal rainfall projections from all the models individually for 2090. Note that there is one model very much drier than the other 11 in summer. However, all 12 models indicate rainfall increases in the winter season. Hence, an increase in winter rainfall for the Kapiti region is highly likely, whereas either increase or decreases appear almost equally likely for the other seasons of the year.

Table 6. **Projected changes in seasonal and annual mean rainfall (in %) for Paraparaumu for three time periods: 2030, 2040 and 2090. The first number is the "best estimate", with the bracketed numbers giving the lower and upper limits.**

Period	Summer	Autumn	Winter	Spring	Annual
2030	0 [-17, +10]	+3 [-2, +11]	+3 [-1, +10]	+1 [-4, +11]	+2 [-2, +8]
2040	0 [-21, +13]	+4 [-3, +14]	+4 [-1, +13]	+2 [-5, +14]	+2 [-3, +10]
2090	-1 [-38, +16]	+2 [-12, +14]	+9 [0, +26]	+2 [-15, +26]	+3 [-7, +14]

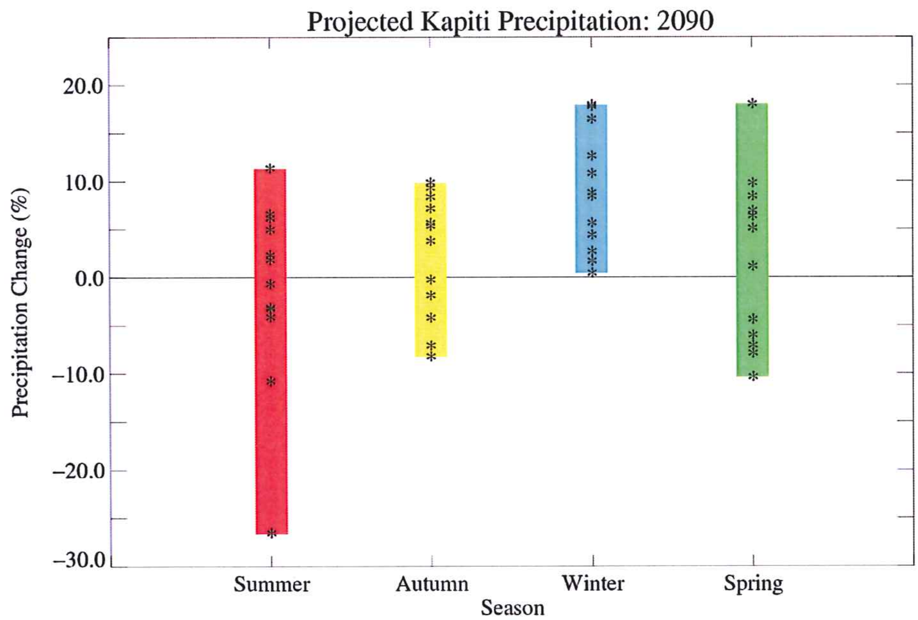

Figure 14. **Projected seasonal precipitation changes by 2090 for Kapiti (Paraparaumu grid-point). The vertical coloured bars show the range over all 12 climate models used, and stars the changes for each model individually.**

3.5 Scenarios for changes in extreme rainfall

3.5.1 HIRDS rainfall depth-duration frequency tables

For historical rainfall data, single-site analyses of extreme rainfalls were undertaken for a number of sites in the Kapiti district. A regional frequency analysis approach was also taken, using the NIWA software package HIRDS (High Intensity Rainfall Design System). HIRDS (Thompson, 2002) is an acronym standing for High Intensity Rainfall Design System. It is a generalised procedure developed by experts at the National Institute of Water and Atmospheric Research to obtain reliable, spatially and temporally consistent depth-duration frequency design rainfalls for New Zealand. HIRDS allows a quick and consistent determination of high intensity design rainfall depths in millimeters (along with associated standard errors) over mainland New Zealand, by simply supplying geographical coordinates. HIRDS incorporates data from archives held by NIWA and local territorial Authorities, and uses robust estimation techniques associated with regional frequency analysis. In producing this report HIRDS V2.0 was used to calculate design rainfall depths for selected time intervals ranging from 10 minutes to 72 hours, with average recurrence intervals (ARI, also known as return periods) ranging from 2 to 100 years (Table 3).

3.5.2 Calculating rainfall depth-duration frequencies

The *HIRDS V2.0* procedure to determine high intensity design rainfalls involved a number of steps, being:

1. Estimates were made of rainfall for various ARI from a large number of New Zealand stations (at a spatial resolution of 10 km) with real annual maximum rainfall data from 10 minutes to 72 hours.

2. A generalised isohyet map of New Zealand, for a specified duration and ARI was produced, based on previously computed point estimates. These maps provide a means for spatial interpolation between sites.

3. Empirical procedures, enabling interpolation to be made between rainfall durations and between recurrence intervals were then applied. Thus, estimates of rainfall depths corresponding to any duration and average recurrence interval could be calculated from the base isohyet map. *HIRDS V2.0* estimates for most locations have an error of ±10 percent or less, the worst-case situation is estimated at +/- 15 percent.

3.5.3 Augmentation factors for future scenarios

Table 7 list augmentation factors that have been derived for use in deriving changes in extreme rainfall for preliminary scenario studies. The values within the body of the table are percentage increases per degree warming, as a function of return period

(ARI) and duration of heavy rainfall. This table is a reproduction of Table 5.2 in Mullan et al (2007), and the guidance manual should be consulted for the caveats discussed there.

Table 7. Augmentation factors (percentage increases per degree warming) used in deriving changes in extreme rainfall for preliminary scenario studies.

	ARI						
Duration	**2 yrs**	**5 yrs**	**10 yrs**	**20 yrs**	**30 yrs**	**50 yrs**	**100 yrs**
10 minutes	8.0	8.0	8.0	8.0	8.0	8.0	8.0
30 minutes	7.2	7.4	7.6	7.8	8.0	8.0	8.0
1 hour	6.7	7.1	7.4	7.7	8.0	8.0	8.0
2 hours	6.2	6.7	7.2	7.6	8.0	8.0	8.0
6 hours	5.3	6.1	6.8	7.4	8.0	8.0	8.0
12 hours	4.8	5.8	6.5	7.3	8.0	8.0	8.0
24 hours	4.3	5.4	6.3	7.2	8.0	8.0	8.0
48 hours	3.8	5.0	6.1	7.1	7.8	8.0	8.0
72 hours	3.5	4.8	5.9	7.0	7.7	8.0	8.0

[Note In preparing these tables, all reasonable skill and care was exercised using best available methods and data. Nevertheless, NIWA does not accept any liability, whether direct, indirect or consequential, arising out of their use.]

3.6 Climate change impacts on sea-level rise

The Intergovernmental Panel for Climate Change (IPCC) released its Fourth Assessment Report (AR4) in April 2007. It found that "*Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice,* ***and rising global mean sea level***" [emphasis added]. This section provides an overview of the climate change impacts on sea levels. It is based on guidance provided in the soon to be published *Coastal Hazards and Climate Change: A Guidance Manual for Local Government in New Zealand* (MfE, 2007) where further information can be obtained.

Increasing global sea levels are a well established consequence of global climate change. Measurements of sea-level changes over the last two centuries have primarily come from long-term measurements by tide gauges mounted on land, supplemented since around 1993 by measurements made by satellites. The longest records suggest that the rate of rise of global sea levels began to increase from around the early to mid-1800s compared with a relatively stable sea level in the preceding century.

Over the 20th century global sea levels have increased by on average 0.17 m ±0.05 m over the 100-year period. In New Zealand, tide gauge records from our four main ports average out to a linear rise in relative mean sea level with respect to the land surface of 1.6 mm/yr (or 0.16 m per century) over the 20th century, (Hannah, 2004, and updated to 2006 by NIWA).

Sea levels will continue to rise over the 21st century and beyond primarily because of thermal expansion within the oceans and loss of ice sheets and glaciers on land. The basic range of projected global sea-level rise estimated in the AR4 is for a rise of 0.18 m to 0.59 m by the decade 2090-2099 (mid 2090s) relative to the average sea level over the period 1980 to 1999, Figure 15. This is based on projections from 17 different Global Climate Models (GCMs) for six different future emission scenarios. The ranges for each emission scenario are 5 to 95% intervals characterising the spread of GCM results (bars on the right-hand side of Figure 15). However, these projections exclude uncertainties in carbon-cycle feedbacks[1] and the possibility of faster ice melt from Greenland and West Antarctic Ice Sheets.

[1] Feedback where warming of atmosphere reduces ocean uptake of atmospheric CO_2 increasing the fraction of anthropogenic emissions remaining in the atmosphere.

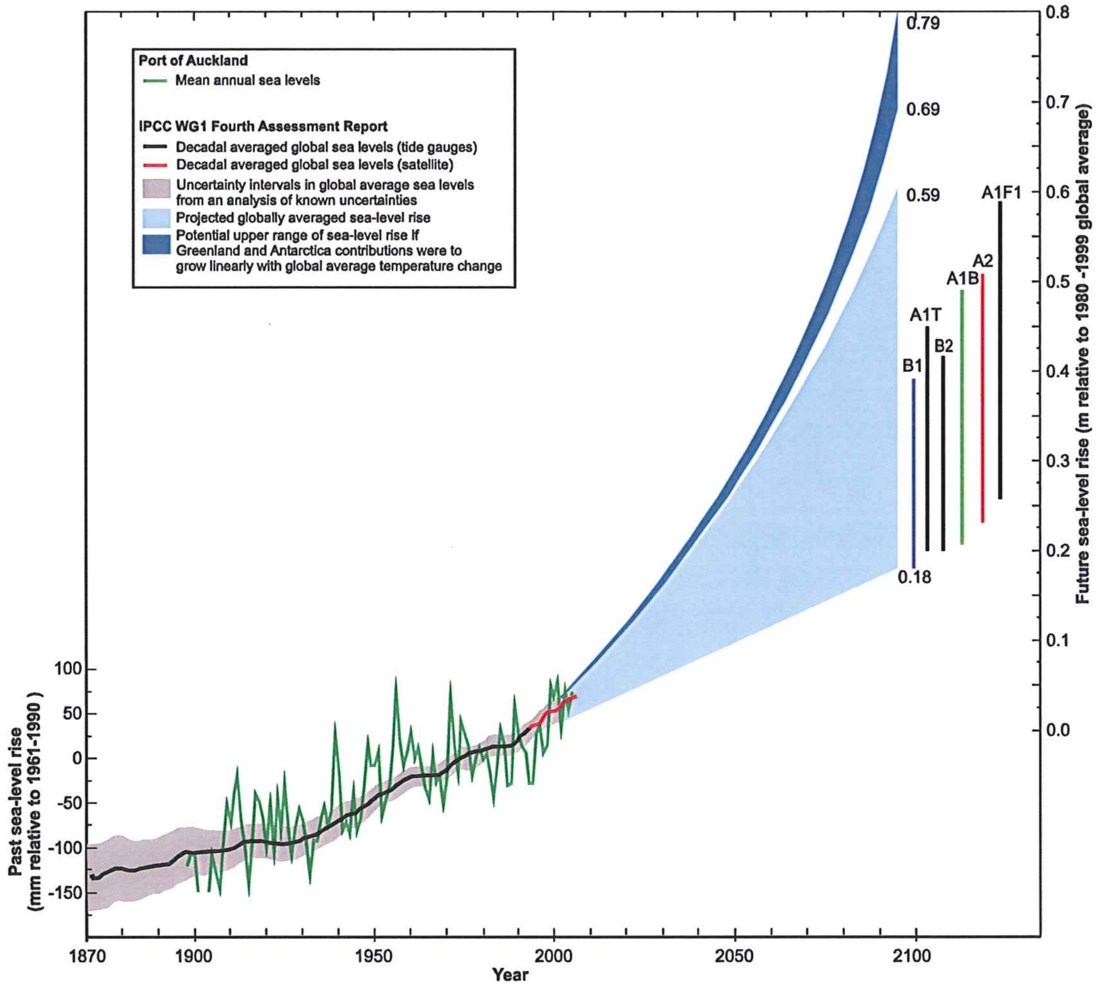

Figure 15. **Global mean sea-level rise projections to the mid 2090s in the context of historical sea-level measurements back to 1870. The black line and grey shading on the left hand side show the decadal-averaged global sea levels and associated uncertainty respectively, as measured by tide gauges throughout the world. The red line is the decadal averaged sea levels as measured by satellites since 1993. The green line is the mean annual relative sea level as measured at the Port of Auckland since 1899 (New Zealand's longest tide gauge record). The light blue shading shows the range in projected mean sea level out to the 2090s. The dark blue line shows the potential additional contribution from Greenland and West Antarctic Ice Sheets if contributions to sea-level rise were to grow linearly with global average temperature change. The vertical colour lines on the right-hand side show the range in projections from the various GCMs for six emission scenarios.**

The basic set of projections (light blue shading in Figure 15) include sea-level contributions due to ice flow from Greenland and West Antarctic Ice Sheets at the rates observed between 1993 to 2003 but it is expected that these rates will increase in the future particularly if greenhouse gas emissions are not reduced. An additional 0.1 to 0.2 m rise in the upper ranges of the emission scenario projections (dark blue shading) would be expected if these ice sheet contributions were to grow linearly with global temperature change. An even larger contribution from these ice sheets, especially from Greenland, over this century cannot be ruled out.

It is important to note that the range of uncertainty in future sea-level rise projections is largely related to different future scenarios of greenhouse gas emissions (based on scenarios of different future socio-economic profiles, energy use, population growth etc) and the differences in projections from the various climate models used for each emission scenario.

The MfE (2007) Guidance Manual on coastal hazards and climate change concludes that for New Zealand, there is good argument to continue to adopt the global projections provide by the IPCC AR4. Draft guidance on sea-level rise allowances for New Zealand includes:

1. For planning and decision timeframes out to the 2090s (2090–2099) that a minimum sea-level rise of **0.5 m relative to the 1980-1999 average**[2] is used along with an assessment of the sensitivity to a possible higher sea-level of up to **0.8 m relative to the 1980-1999 average** (to account for a possible high emission scenario and uncertainties associated with increased contribution from Greenland and West Antarctic Ice sheets, and possible differences from the global average sea-level rise in the New Zealand region).

2. For planning and decision timeframes beyond 2100 where, as a result of the particular decision, future adaptation options will be limited, an allowance for sea-level rise of **10 mm/year beyond 2100** is recommended (in addition to the above recommendation).

These projections are for mean sea levels. Less information is available on how extreme storm sea levels will change with climate change but will largely depend on changes in frequency, intensity and/or tracking of atmospheric low-pressure systems, and occurrence of stronger winds (see below), but there remains uncertainty as to how climate change will influence such extreme events. As such it is assumed that storm tide elevation will rise at the same rate as mean sea-level rise until future projections of changes in storminess become more certain.

[2] Note: Assuming an average rate of mean annual sea-level rise of 1.6 mm/yr, sea levels will have already risen by about 0.024 m between the mid point of this timeframe (1990) and 2006.

3.6.1 Effect of sea-level rise on high tide frequency

Sea levels are measured by a NIWA sea-level gauge located on Kapiti Island. Based on the data collected at this location we have derived a high-tide exceedance curve from predictions of all high tides over the next 100 years. These exceedance curves provide the frequency at which a given high tide is exceeded over this time period (but excluding sea-level rise and climate / meteorological variability). Figure 16 shows the high tide exceedance curve for the Kapiti Island gauge for the present day relative to Mean Level of the Sea (MLOS) (black curve in the figure). The range covered by all high tides is around 1 m.

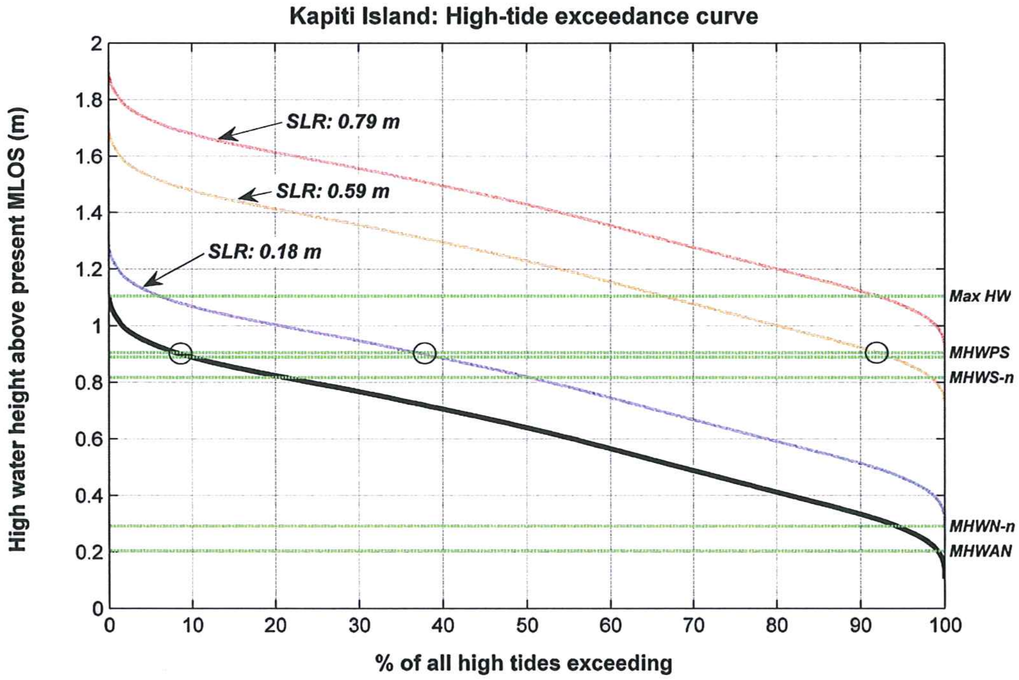

Figure 16. High tide exceedance curves based on a simulation of 100 years of tides at the Kapiti Island sea level gauge for the present day relative to MLOS (black line) and for a 0.18 m, (blue line) 0.59 m (orange line) and 0.79 m (red line) rise in sea level. Also shown are the present day tide levels for Mean High Water Neap (MHWN-n), Mean High Water Spring (MHWS-n), Mean High Water Perigean Spring (MHWPS) and Maximum Astronomical Tide levels (horizontal green lines).

The exceedance curve is provided in terms of high tide height above the actual Mean Level of the Sea (MLOS). This means the high-tide exceedance curve (heavy black line in Figure 16) can be used for several decades, with the only requirement to update the MLOS level to the particular year or if there has been sufficient change in MLOS due to long-term climate cycles or sea-level rise (and ADD it on to the y-axis values in Figure 16). The Kapiti Island gauge has not been surveyed into the LINZ Vertical

Datum, so at present we are not able to relate present-day MLOS on the Kapiti Coast to the regional Wellington Vertical Datum–1953. Some indication can be gleaned from the Queens Wharf gauge in Wellington Harbour, where MLOS is presently around 0.165 m above Wellington Vertical Datum–1953, or from Port Taranaki, where MLOS is presently about 0.145 m above Taranaki Vertical Datum–1970 (based on "MSL" values published by LINZ: http://www.hydro.linz.govt.nz/tides/stdport-info/tidal-levels/index.asp).

Figure 16 also shows an example of the possible effect that future sea-level rise may have on how often present day high tide levels may be exceeded. Considering present day Mean High Water Perigean Spring (MHWPS) tide level[3] this is presently exceeded by 8% of all high tides (marked by a circle at the intersection between the exceedance curve – black line, and the MHWPS line). For the lower limit of the IPCC sea-level projection of 0.18 m, by the 2090s, this level would be exceeded by 37% of all high tides (intersection of the blue line and MHWPS level). If sea-level rise was 0.59 m, such a level would be exceeded by 92% of all high tides, and with a 0.79 m rise, by essentially 100% of all high tides would exceed this level. Given that sea-level rise has presently been tracking close to the upper levels of the IPCC projections it is likely that high-tide levels that are only exceeded once or twice a year at present will be exceeded on most tides by the end of the century.

3.7 Climate change impacts on other coastal hazard drivers

There has been little progress, both globally and in New Zealand since the IPCC Third Assessment Report in 2001, in understanding the effects climate change is having, and will have, on the other drivers of coastal hazards, such as tides in shallow waters, storms, waves, swell and coastal sediment supply (MfE, 2007).

Whilst it is expected that the intensity of severe storms may increase, there is still much uncertainty associated with how future climate change will influence the frequency, intensity and tracking of tropical cyclones (in the Pacific tropics), ex-tropical cyclones, which track down to the temperate regions such as New Zealand), mid-latitude extra tropical cyclones and low-latitude storms.

[3] *MHWPS*: An upper level MHWS related to higher perigean-spring tides that occur in clusters for a few months, peaking at approximately 7-month periods when Full of New Moon coincide closely with the Moon's perigee (sometimes called "king tides"). In the upper North Island such a tide height is exceeded by between 4% to 9% of all high tides. These tides are listed as red-alert days at: http://www.niwa.co.nz/rc/hazards/dates

There is a reasonable level of confidence that winter atmospheric pressure gradients will increase over the South Island implying an increase in mean westerly-wind component of flows across New Zealand expected by 2090s (and hence changes in wave climate on west facing coastlines). Climate model downscaling to New Zealand shows this shift in bias to winds more often coming from a westerly direction but overall wind speeds in all directions may not change significantly.

3.8 Consideration of ground water and ponding

Despite some variability, future rainfall scenarios at 2040 and 2090 as discussed in this report both indicate potential decreases in summer rainfall in the Kapiti district. Drier summers will have an impact on the quality and availability of ground water resources, as water supplies decrease and irrigation requirements are strained during extended periods of low rainfall.

Ponding, being water lying during and after an initial storm event, can contribute toward potential health problems for both humans and animals. The future climate scenarios discussed in this report, suggest that it is very likely that ponding and related surface water problems will become more frequent in the Kapiti district due to the expected increase in the frequency and intensity of extreme rainfall events. This could be a particular problem in the winter season.

4. High intensity rainfall changes at Paraparaumu Airport

Interpretation of the HIRDSV2 rainfall depths for Paraparaumu Airport (Tables 8a & b) shows that an accumulated rainfall total of 204 millimetres (bold) in a 72-hour period would have an average recurrence interval (ARI) of 100 years under the current climate, with a standard error of ±15.1 mm. For the same 72-hour period recurrence interval the amount increases to 216 mm, 218 mm, and 237 mm respectively for the mid-range temperature warming scenarios for the 2030, 2040, and 2090 respectively.

Table 8a. Current climate Depth-Duration-Frequency table (mm) for Paraparaumu Airport.

	Duration								
ARI (yrs)	**10min**	**30min**	**1h**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	7	12	17	24	38	52	71	84	93
10	10	17	24	32	53	72	99	116	127
20	12	20	27	37	61	83	114	133	145
30	13	22	30	40	66	91	124	144	158
50	15	24	33	45	74	101	139	161	175
100	18	28	38	52	87	119	163	187	**204**

Table 8b. Current climate Depth-Duration-Frequency table of standard errors (mm) for Paraparaumu Airport.

	Standard errors (mm)								
ARI (yrs)	**10m**	**30m**	**1h**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	0.6	1	1.4	1.9	3	4	4.9	5.9	6.3
10	1	1.5	2.1	2.8	4.5	5.9	7.7	9.3	9.7
20	1.1	1.8	2.4	3.2	5.2	6.7	8.9	10.8	11.2
30	1.3	1.9	2.6	3.4	5.6	7.3	9.7	11.7	12.1
50	1.4	2.1	2.9	3.7	6.1	7.9	10.8	13	13.3
100	1.7	2.5	3.3	4.2	7	9	12.5	14.9	15.1

Table 9. Low, mid-range and high temperature scenarios for 2030: Depth-Duration-Frequency table (mm) for Paraparaumu Airport

2030 – Low Range			Duration						
ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	7	12	18	24	39	53	71	85	94
10	10	17	24	33	54	73	100	117	129
20	12	20	28	38	62	84	115	135	147
30	13	22	30	41	67	92	126	146	160
50	15	24	33	46	75	103	141	163	178
100	18	29	39	53	88	120	165	190	207

2030 – Mid Range		Duration							
ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	7	13	18	25	40	54	73	87	96
10	11	18	25	34	56	76	103	121	133
20	12	21	29	39	64	88	120	140	153
30	14	23	31	43	70	96	131	153	167
50	16	26	35	48	78	107	147	170	185
100	19	30	40	56	92	126	172	198	**216**

2030 – High Range		Duration							
ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	8	14	19	26	42	56	76	90	99
10	12	19	27	36	59	80	109	128	140
20	13	22	31	42	69	94	128	149	163
30	15	24	34	46	75	103	141	164	179
50	17	27	37	51	84	115	158	183	199
100	20	32	44	60	99	135	185	213	232

Table 10. Low, mid-range and high temperature scenarios for 2040: Depth-Duration-Frequency table (mm) for Paraparaumu Airport

2040 – Low Range		Duration							
ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	7	12	18	24	39	53	72	85	94
10	10	17	24	33	54	73	100	117	129
20	12	20	28	38	62	85	116	135	148
30	13	22	30	41	67	92	126	147	161
50	15	25	33	46	75	103	141	164	178
100	18	29	39	53	88	121	166	191	207

2040 – Mid Range		Duration							
ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	8	13	18	25	40	54	74	87	96
10	11	18	25	35	56	77	104	122	134
20	13	21	29	40	65	89	121	141	155
30	14	23	32	43	71	97	133	155	169
50	16	26	35	48	79	109	149	172	188
100	19	30	41	56	93	127	175	201	**218**

2040 – High Range		Duration							
ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	8	14	20	27	43	58	78	91	101
10	12	20	28	37	61	83	112	131	144
20	14	23	32	43	71	96	131	153	168
30	15	25	35	47	78	106	145	169	184
50	17	28	39	53	87	119	163	189	206
100	21	33	45	62	102	139	191	220	239

An alternative way of thinking about these changes in extreme rainfall is in terms of a reduction in return period (or ARI). The tables show that the current 100-year ARI extreme rainfall amounts could become 50-year ARI events in future – by 2090 under a mid-range warming scenario, or by 2040 under a high-range warming scenario.

Table 11. Low, mid-range and high temperature scenarios for 2090: Depth-Duration-Frequency table (mm) for Paraparaumu Airport

2090 – Low Range		**Duration**							
ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	7	13	18	24	40	54	73	87	95
10	11	18	25	34	55	75	102	119	131
20	12	21	28	39	63	86	118	138	151
30	14	22	31	42	69	94	129	150	164
50	15	25	34	47	77	106	145	168	183
100	18	30	40	55	91	124	170	196	213

2090 – Mid Range		**Duration**							
ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	8	14	20	26	42	57	77	91	100
10	12	20	27	37	60	82	111	130	143
20	14	23	31	43	70	96	130	152	166
30	15	25	34	47	77	105	144	167	182
50	17	28	38	52	86	118	161	187	204
100	20	33	44	61	101	138	189	218	**237**

2090 – High Range		**Duration**							
ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	10	17	23	31	49	65	87	101	110
10	14	24	33	44	71	96	130	152	166
20	17	28	38	52	84	114	156	181	198
30	18	30	42	57	93	128	175	202	220
50	21	34	46	63	104	143	195	227	247
100	25	40	54	74	122	167	229	264	287

5. Conclusions

Global warming is expected to continue during the 21st century, and enhance already observed changes in regional climate. The most likely changes out to 2100 for New Zealand include increases in average temperature of between 0.5 and 5.5°C. As temperature increases, the water holding capacity of the atmosphere increases. With this the intensities of design rainfall extremes increase for a particular duration. For a specific rainfall intensity, the recurrence interval (return period) reduces.

For the Kapiti District, climate models project average temperature increase for the 2030 to range from 0.2 to 1.7°C, and for the 2090 from 0.6 to 5.1°C. At the same time there is an increase in westerly circulation over New Zealand, notably in winter. Changes in annual mean rainfall range from -2 to +8% for the 2030, and -7 to +14% for the 2090. The scenarios provide multiplicative factors by which high intensity design rainfall are likely to increase by. Future climate change depends on future emissions of greenhouse gases and aerosols, which are dependent on future changes in population, economic growth, technology, energy availability and policies to reduce greenhouse gas emissions. Three scenarios were used to provide average temperature increases.

These give increases in the intensity of design storm events for the 2030, 2040, and 2090. Larger increases in intensity occurred for the shorter duration rainfalls, compared to the longer duration. These represent significant increases in design storm intensities as the 21st century progresses.

Little information is available on how extreme storm sea levels will change with climate change but will largely depend on changes in frequency, intensity and/or tracking of atmospheric low-pressure systems, and occurrence of stronger winds, but there remains uncertainty as to how climate change will influence such extreme events. However, a high-tide exceedance curve has been derived from predictions of all high tides over the next 100 years. This curve also shows an example of the possible effect that future sea-level rise may have on how often present day high tide levels may be exceeded. Considering present day MHWPS tide level this is presently exceeded by 8% of all high tides, and it will be exceeded much more often in the next 100 years accordingly to the IPCC sea-level projection. Given that sea-level rise has presently been tracking close to the upper levels of the IPCC projections it is likely that high-tide levels that are only exceeded once or twice a year at present will be exceeded on most tides by the end of the century.

6. References

Chen, Z. M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller, (Eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Available at http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Pub_SPM-v2.pdf

Gray W., A. McKerchar, J. Renwick, S. Burgess, 2005: Kapiti Coast ground water and ponding. NIWA Client Report WLG2005-53 for Kapiti Coast District Council.

IPCC. 2007a. Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., D. Qin, M. Manning

IPCC. 2007b. Summary for Policymakers. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J..P. Palutikof, P.J. van der Linden and C.E. Hanson (Eds.), Cambridge University Press, Cambridge, UK, 7-22. Available at http://www.gtp89.dial.pipex.com/spm.pdf

Hannah, J., 2004. An updated analysis of long-term sea level change in New Zealand. Geophysical Research Letters Vol. 31 L03307; doi:10.1029/2003GL019166.

Kidson, J. W. and J. A. Renwick, 2002a: Patterns of convection in the tropical Pacific and their influence on New Zealand weather. International Journal of Climatology, 22, 151-174.

Kidson, J. W. and J. A. Renwick, 2002b: The Southern Hemisphere evolution of ENSO during 1981-1999. Journal of Climate, 15, 847-863.

Ministry for the Environment. 2004. Climate Change Effects and Impacts Assessment: A Guidance Manual for Local Government in New Zealand. Prepared by D. Wratt, B. Mullan and J. Salinger (NIWA), S. Allen and T. Morgan (MWH New Zealand Ltd), and G. Kenny (Earthwise Consulting). Ministry for the Environment Report ME 513, Wellington, 153p. (Available from website: http://www.climatechange.govt.nz/resources/local-govt/effects-impacts-may04/index.html).

Ministry for the Environment, 2007. Coastal Hazards and Climate Change. A Guidance Manual for Local Government in New Zealand. 2nd edition. Prepared by Ramsay, D., & Bell, R., Draft report for the Ministry for the Environment.

Mullan, B., D. Wratt, S. Dean, M. Hollis, S. Allan, T. Williams, G. Kenny, 2007. Climate Change Effects and Impacts Assessment: A Guidance Manual for Local Government in New Zealand, updated 2007. NIWA Client Report WLG2007/62 for Ministry for the Environment (in draft as of Nov 2007).

Mullan AB, D.S. Wratt, and J.A. Renwick, 2001. Transient model scenarios of climate changes for New Zealand. Weather and Climate 21: 3–34.

Semenov V.A. and L. Bengtsson, 2002. Secular trends in daily precipitation characteristics: greenhouse gas simulation with a coupled AOGCM. Climate Dynamics 19: 123–140.

Thompson, CS, 2002. The High Intensity Rainfall Design System: HIRDS. Proceedings International Conference on Flood Estimation, March 2002, Berne, Switzerland. International Commission for the Hydrology of the Rhine Basin, CHR Report II-17, 273 – 282.

Thompson, CS, 2007. Decadal climate variability of extreme rainfalls in New Zealand. Weather and Climate, 26, 3 – 20.

Appendix A

A1 Current Climate: Rainfall Depth (mm) – Duration (hours) – Frequency (years)

Depth-Duration-Frequency information for the four sites in Kapiti region for current climate is given in the following tables.

Table A1. Rainfall Depth-Duration-Frequency tables (mm).

Paraparaumu Airport

Duration

ARI (yrs)	10min	30min	1h	2h	6h	12h	24h	48h	72h
2	7	12.2	17.3	23.5	38.3	52.1	70.9	84.4	93.4
10	10.1	17	23.7	32.4	53	72.3	98.6	115.8	127.3
20	11.8	19.7	27.2	37.1	60.9	83.2	113.6	132.8	145.4
30	13	21.5	29.5	40.3	66.2	90.6	123.8	144.2	157.6
50	14.7	24.1	32.8	44.9	73.9	101.2	138.6	160.6	175.1
100	17.6	28.3	38.2	52.4	86.5	118.6	162.6	187.4	203.5

Paekakariki Hill

Duration

ARI (yrs)	10min	30min	1h	2h	6h	12h	24h	48h	72h
2	7.1	13.7	20.7	29	49.5	69.4	97.2	117.6	131.5
10	10.2	19.1	28.4	39.9	68.5	96.2	135.2	161.8	179.7
20	11.9	22.1	32.6	45.9	78.8	110.9	156	185.8	205.8
30	13.1	24.1	35.4	49.9	85.8	120.8	170.1	202	223.4
50	14.9	27	39.5	55.7	95.9	135.2	190.6	225.4	248.7
100	17.7	31.9	46.2	65.2	112.5	158.8	224.2	263.7	290

Waikanae Waterworks

Duration

ARI (yrs)	10min	30min	1h	2h	6h	12h	24h	48h	72h
2	7.1	12.8	18.6	25.6	42.5	58.4	80.4	97.1	108.4
10	10.3	18	25.6	35.3	58.7	80.9	111.6	133.1	147.6
20	12	20.8	29.3	40.5	67.5	93.1	128.6	152.5	168.5
30	13.3	22.7	31.9	44	73.4	101.4	140.1	165.6	182.7
50	15	25.5	35.5	49.1	82	113.3	156.6	184.4	202.9
100	18	30	41.5	57.4	96	132.8	183.8	215.1	235.8

Reikorangi

Duration

ARI (yrs)	10min	30min	1h	2h	6h	12h	24h	48h	72h
2	7.3	13.8	20.6	29	49.7	69.9	98.2	119.9	134.8
10	10.6	19.3	28.3	39.9	68.7	96.8	136.3	164.5	183.6
20	12.4	22.4	32.5	45.8	79	111.4	157	188.5	209.7
30	13.6	24.5	35.4	49.9	86	121.3	171	204.7	227.4
50	15.5	27.4	39.4	55.6	96.1	135.5	191.3	228	252.7
100	18.5	32.4	46.1	65.1	112.5	158.9	224.4	266	293.8

A2 Low, mid-range and high rainfall scenarios for 2030

Table A2. Low, Mid, High range Scenario for 2030: Rainfall Intensity (mm)-Duration-Frequency for Kapiti Region

Paekakariki

2030 - Low Range

ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
	Duration								
2	7	14	21	29	50	70	98	118	132
10	10	19	29	40	69	97	137	164	182
20	12	22	33	47	80	112	158	188	209
30	13	24	36	51	87	123	173	205	227
50	15	27	40	57	97	137	193	229	252
100	18	32	47	66	114	161	228	268	294

2030 - Mid Range

ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
	Duration								
2	8	14	22	30	51	72	100	121	135
10	11	20	30	42	72	101	142	169	188
20	13	23	34	48	83	117	164	196	216
30	14	26	37	53	91	128	180	214	236
50	16	29	42	59	102	143	202	239	263
100	19	34	49	69	119	168	237	279	307

2030 - High Range

ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
	Duration								
2	8	15	23	32	54	75	104	125	140
10	12	22	32	45	77	107	150	179	198
20	14	25	37	52	89	125	176	209	231
30	15	27	40	57	98	138	194	229	253
50	17	31	45	63	109	154	217	257	283
100	20	36	53	74	128	181	255	300	330

Waikanae Waterworks

2030 - Low Range

	Duration								
ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	7	13	19	26	43	59	81	98	109
10	10	18	26	36	59	82	113	135	149
20	12	21	30	41	68	94	130	155	171
30	14	23	32	45	75	103	142	168	185
50	15	26	36	50	83	115	159	187	206
100	18	30	42	58	97	135	187	218	239

2030 - Mid Range

	Duration								
ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	8	13	20	27	44	60	83	100	111
10	11	19	27	37	62	85	117	139	154
20	13	22	31	43	71	98	135	161	177
30	14	24	34	47	78	107	148	175	193
50	16	27	38	52	87	120	166	195	215
100	19	32	44	61	102	141	195	228	250

2030 - High Range

	Duration								
ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	8	14	21	28	46	63	86	104	115
10	12	20	29	40	66	90	124	147	163
20	14	24	33	46	76	105	145	171	189
30	15	26	36	50	84	116	160	188	207
50	17	29	40	56	93	129	178	210	231
100	21	34	47	65	109	151	209	245	269

Reikorangi

2030 - Low Range

	Duration								
ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	7	14	21	29	50	71	99	121	136
10	11	20	29	40	70	98	138	166	186
20	13	23	33	46	80	113	159	191	212
30	14	25	36	51	87	123	174	208	231
50	16	28	40	56	98	138	194	231	257
100	19	33	47	66	114	161	228	270	298

2030 - Mid Range

	Duration								
ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	8	15	22	30	52	72	101	123	138
10	11	20	30	42	72	101	143	172	192
20	13	24	34	48	83	117	165	198	221
30	14	26	37	53	91	128	181	217	240
50	16	29	42	59	102	144	203	241	268
100	20	34	49	69	119	168	238	282	311

2030 - High Range

	Duration								
ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	8	16	23	32	54	76	106	128	143
10	12	22	32	45	77	108	151	182	202
20	14	25	37	52	89	126	177	212	235
30	15	28	40	57	98	138	195	232	258
50	18	31	45	63	109	154	218	260	288
100	21	37	53	74	128	181	256	303	335

A3 Low, mid-range and high rainfall scenarios for 2040

Table A3. **Low, Mid, High range Scenario for 2040: Rainfall (mm) Intensity-Duration-Frequency for Kapiti Region**

Paekakariki

2040 – Low Range

ARI (yrs)	Duration								
	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	7	14	21	29	50	70	98	119	133
10	10	19	29	41	70	98	137	164	182
20	12	23	33	47	80	113	159	189	209
30	13	25	36	51	87	123	173	206	228
50	15	28	40	57	98	138	194	230	253
100	18	33	47	66	115	162	229	269	296

2040 - Mid Range

ARI (yrs)	Duration								
	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	8	15	22	31	52	72	101	122	136
10	11	20	30	43	73	102	143	171	189
20	13	24	35	49	84	118	166	198	219
30	14	26	38	54	92	130	183	216	239
50	16	29	42	60	103	145	205	242	267
100	19	34	50	70	121	170	241	283	311

2040 - High Range

ARI (yrs)	Duration								
	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	8	16	24	33	55	77	106	127	142
10	12	22	33	46	79	110	154	183	203
20	14	26	38	54	92	129	180	215	237
30	15	28	42	59	101	142	200	236	261
50	17	32	46	65	113	159	224	265	292
100	21	37	54	77	132	186	263	310	341

Waikanae Waterworks

2040 - Low Range

ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
				Duration					
2	7	13	19	26	43	59	81	98	109
10	10	18	26	36	60	82	113	135	150
20	12	21	30	41	69	95	131	155	171
30	14	23	33	45	75	103	143	169	186
50	15	26	36	50	84	115	160	188	207
100	18	31	42	59	98	135	187	219	240

2040 - Mid Range

ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
				Duration					
2	8	14	20	27	45	61	84	100	112
10	11	19	27	38	62	86	118	141	156
20	13	22	31	43	72	99	137	162	179
30	14	24	34	47	79	109	150	177	196
50	16	27	38	53	88	122	168	198	218
100	19	32	45	62	103	143	197	231	253

2040 - High Range

ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
				Duration					
2	8	15	21	29	47	65	88	105	117
10	12	21	30	41	67	92	127	151	167
20	14	24	34	47	78	108	149	176	194
30	16	27	37	52	86	119	165	194	213
50	18	30	42	58	96	133	184	217	238
100	21	35	49	67	113	156	216	253	277

Reikorangi

2040 - Low Range

Duration

ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	7	14	21	29	50	71	99	121	136
10	11	20	29	41	70	98	138	167	186
20	13	23	33	47	80	113	160	192	213
30	14	25	36	51	88	124	174	209	232
50	16	28	40	57	98	138	195	232	258
100	19	33	47	66	115	162	229	271	299

2040 - Mid Range

Duration

ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	8	15	22	31	52	73	102	124	139
10	11	21	30	43	73	103	144	174	194
20	13	24	35	49	84	119	167	201	223
30	15	26	38	54	92	130	184	219	244
50	17	29	42	60	103	145	205	245	271
100	20	35	49	70	121	171	241	286	315

2040 - High Range

Duration

ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
2	9	16	24	33	55	77	107	130	145
10	12	22	33	46	79	111	155	186	207
20	15	26	38	53	92	129	182	218	242
30	16	29	42	59	101	142	201	240	266
50	18	32	46	65	113	159	225	268	297
100	22	38	54	76	132	187	264	312	345

A4 Low, mid-range and high rainfall scenarios for 2090

Table A4: Low, Mid, High range Scenario for 2090: Rainfall (mm) Intensity-Duration-Frequency for Kapiti Region

Paekakariki Hill

2090 - Low Range

ARI (yrs)	Duration 10m	30m	1h	2h	6h	12h	24h	48h	72h
2	7	14	22	30	51	72	100	121	134
10	11	20	30	41	71	100	140	167	185
20	12	23	34	48	82	115	162	193	213
30	14	25	37	52	90	126	177	210	233
50	16	28	41	58	100	141	199	236	260
100	19	33	48	68	118	166	235	276	303

2090 - Mid Range

ARI (yrs)	Duration 10m	30m	1h	2h	6h	12h	24h	48h	72h
2	8	16	24	33	55	76	106	127	141
10	12	22	33	46	78	109	153	182	201
20	14	26	38	53	91	127	179	213	235
30	15	28	41	58	100	141	198	234	259
50	17	31	46	65	112	157	222	262	289
100	21	37	54	76	131	185	261	307	338

2090 - High Range

ARI (yrs)	Duration 10m	30m	1h	2h	6h	12h	24h	48h	72h
2	10	19	28	38	63	86	119	141	155
10	14	27	39	55	92	128	179	212	234
20	17	31	45	64	109	152	214	253	280
30	18	34	50	70	121	170	240	283	312
50	21	38	56	79	135	191	269	318	351
100	25	45	65	92	159	224	316	372	409

Waikanae Waterworks

2090 - Low Range

ARI (yrs)	Duration 10m	30m	1h	2h	6h	12h	24h	48h	72h
2	7	13	19	27	44	60	83	100	111
10	11	19	27	37	61	84	115	137	152
20	13	22	31	42	70	97	133	158	174
30	14	24	33	46	77	106	146	173	190
50	16	27	37	51	86	119	164	193	212
100	19	31	43	60	100	139	192	225	247

2090 - Mid Range

ARI (yrs)	Duration 10m	30m	1h	2h	6h	12h	24h	48h	72h
2	8	15	21	29	47	64	87	105	116
10	12	21	29	41	67	92	126	150	165
20	14	24	34	47	78	107	148	175	193
30	15	26	37	51	85	118	163	192	212
50	17	30	41	57	95	132	182	215	236
100	21	35	48	67	112	155	214	250	274

2090 - High Range

ARI (yrs)	Duration 10m	30m	1h	2h	6h	12h	24h	48h	72h
2	10	18	25	34	54	73	98	116	128
10	15	25	35	48	79	108	148	175	192
20	17	29	41	56	93	128	176	208	229
30	19	32	45	62	104	143	198	232	255
50	21	36	50	69	116	160	221	260	286
100	25	42	59	81	135	187	259	303	333

Reikorangi

2090 - Low Range

ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
				Duration					
2	8	14	21	30	51	72	101	123	138
10	11	20	29	41	71	100	141	170	189
20	13	23	34	48	82	116	163	195	217
30	14	26	37	52	90	127	178	213	237
50	16	29	41	58	101	142	200	239	264
100	19	34	48	68	118	166	235	278	307

2090 - Mid Range

ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
				Duration					
2	8	16	23	33	55	77	107	129	144
10	12	22	33	46	78	110	154	185	206
20	14	26	38	53	91	128	180	216	240
30	16	29	41	58	100	141	199	237	263
50	18	32	46	65	112	158	223	265	294
100	22	38	54	76	131	185	261	310	342

2090 - High Range

ARI (yrs)	10m	30m	1h	2h	6h	12h	24h	48h	72h
				Duration					
2	10	19	28	38	63	87	120	143	159
10	15	27	39	55	93	129	180	216	239
20	17	31	45	64	109	153	215	257	285
30	19	35	50	70	121	171	241	287	317
50	22	39	56	78	136	191	270	322	356
100	26	46	65	92	159	224	316	375	414