Waikato Regional Climate Impacts Report Applying CMIP6 Data

26 November 2021

Drs Yinpeng Li and Peter Urich
with
Johnny Yu and Hannah Rogers

File history	
Oct 2021	First draft
Nov 2021	First revision
March 2022	Added CMIP5 & CMIP comparison section

Table of Contents

Acronyms

ANN – Annual

ARI – Average Recurrence Interval

CMIP6 - Coupled Model Intercomparison Project Sixth Report

DJF – December, January, February

JJA – June, July, August

Kph – Kilometres per hour

MAM – March, April, May

MEC – Modified Employment Counts

m/s – metres per second

mm/day – millimetres per day

SON – September, October, November

SSP – Shared Socioeconomic Pathway

PED – Potential Evapotranspiration Deficit

Q5 – 1 in 5-year 7 day low flow

Executive Summary

(1) This report investigates nine essential climate and two socioeconomic variables for the Waikato Region, using historical and CMIP6 GCM SSP2-4.5 and SSP5-8.5 scenario data. Trends in average seasonal and annual mean, maximum and minimum temperature are explored. Patterns in average seasonal and annual precipitation, runoff, wind speed, daily extreme precipitation, daily extreme wind speed, and annual potential evapotranspiration deficit are also analysed. And in terms of socio-economic variables, historical water take statistics are examined.

(2) Historical annual mean temperature changes indicate a warming trend in the Waikato region. The average annual mean temperature of the Waikato Region is expected to rise over the examined time slices of 2050, 2070 and 2090, increasing 3.2°C in 2090 applying the SSP5-8.5 50th percentile scenario compared to the baseline (2005 is the central year of 1985-2014 set in the IPCC AR6 report). Seasonally, the average temperature of the summer months is predicted to increase more rapidly than other seasons.

(3) Under both scenarios, the maximum temperature of the Waikato Region, relative to the baseline, is shown to increase out to 2090. Again, the data suggests that the summer months (DJF) will experience the most significant temperature rise, with 3.4°C increase by 2090 under SSP5-8.5. The greatest temperature increases occur in southeast districts (such as Taupō), decreasing towards the northwest corner.

(4) The minimum temperature analysis predicts an annual increase across both SSP2-4.5 (1.53°C) and SSP5-8.5 (3.06°C) scenarios by 2090. Seasonally, the summer months show the greatest increase in temperatures, followed by autumn. As with the maximum temperature analysis, the changes in minimum temperature are most noticeable in the south-eastern corner of the region and lowest in the north, including the Coromandel and Waikato districts.

(5) Based on the precipitation data from 1972 to 2020, the annual mean precipitation in the Waikato region shows a declining linear trend, at around 20 mm per decade. The interannual variabilities need to be considered, especially in recent years, as precipitation has experienced historical lows in parts of the Waikato region. The annual mean? Precipitation of the Waikato Region could continue the historical trends under both scenarios out to 2090. However, these changes are predicted to be relatively minor (0.5% reduction). While autumn and spring months exhibit a declining trend, the summer and winter months show a small increase in precipitation (X%). The districts with the most significant predicted increase in precipitation are around the southern edges of the region, notably the Waitomo and Taupō Districts. In the northeast, predictions suggest a decline in precipitation in the Hauraki, Coromandel and Waikato Districts, at least for later analysis periods.

(6) Annual runoff is expected to decline in 2050 and gradually increase to 2090 under SSP2-4.5. For the SSP5-8.5 scenario, runoff is likely to increase out to 2090. Concerning the seasons for both scenarios, runoff most distinctly declines in the spring months. Generally, the north-western region is expected to receive the greatest increase in runoff, while the eastern edge may experience minor changes. Interestingly, the baseline runoff map displays an irregularly high runoff value over Hamilton City. This elevation is likely the result of the anthropogenic effect of a densely populated district and associated impervious areas, on the runoff.

(7) The historical annual mean wind speed in the Waikato region is 3.23 m/sec, it is 11.62 km/hr, and the seasonal variations are not significant. Higher wind speeds occur in Coromandel and West Coast areas. Based on the VCSN data 1997 to 2020, the average wind speed shows a weak decreasing trend,

0.093m/sec (0.335 kph) per decade. The average annual wind speed of the Waikato Region decreases across both scenarios into 2090, compared to the baseline. Seasonally, while the wind speed declines for the summer and autumn months, it could increase slightly over the winter and spring months for both SSP scenarios. The districts predicted to experience the most significant increases in wind speed are primarily the Waitomo and Taupō Districts.

(8) The historical daily extreme precipitation data is obtained from HIRDSv4. Average Return Intervals (ARI) of 10-, 20-, 50-, 100-, and 250-year data was analysed for the historical period. The highest extreme precipitation occurs in the Coromandel area, where events can reach more than 600mm for a 1 in 250-year return event. The areal average of 100-year return daily extreme precipitation is 197 mm. Daily extreme precipitation is predicted to increase out to 2090 across all ARIs and for both SSP scenarios for the Waikato Region. The rate of change increases over time between 2050, 2070, and 2090. The most extreme precipitation intensity tends to occur in the Coromandel District.

(9) Station specific analysis was applied for the 31 stations which have relatively long records of hourly wind speed data. Extreme wind speed generally increases out to 2090 across most districts of the Waikato region. Some of the districts which may experience the greatest increase in extreme wind speed include Waitomo and Taupō districts which could increase by 4.9% in 2090, compared to their baseline. It should be noted that South Waikato does not have adequate data for the extreme wind speed analysis.

(10) PED increases into 2090 for both SSP2-4.5 and SSP5-8.5 scenarios. As expected, the probability of the PED exceeds 200 mm is far greater than that exceeding 400 mm. Districts with the highest probability with a PED larger than 200 mm and 400 mm include the Hauraki and Waikato districts.

(11) Based on data provided by WRC, almost 600 million m^3 of water is taken per annum under consent in the Waikato region. Of this volume, 479 million m^3 comes from surface water, and 119 million m^3 from groundwater. Across the whole region, municipal supply is the largest proportion, taking more than 310 million m^3 or 51% of the total volume. In contrast, industrial activities consume just less than a quarter of the volume. Despite only utilising 7% of the total volume of water, stock water takes required almost 2500 consents, whereas municipal supply takes only resulted in 196 consents. While surface water take was also predominantly utilised by town supply activities, groundwater was predominantly used for industrial activities (35%).

(12) The economic index analysis for the Waikato Region suggests that the modified employment count (MEC) is likely to increase into 2090 for industrial, 'town supply' and the 'other' sectors. Furthermore, while agriculture experienced a decline in MEC between 2018 and 2020 of 1.2%, it is likely to recover by 2030 and continues to increase by more than 10% by 2060. The value-added statistics demonstrate the same trends as the MECs.

(13) Finally, from a population of about 475,600 in 2018, the Waikato Region grew by 3.56% in 2020. The population will likely grow by more than 20% by 2040 and more than 35% in 2060, relative to the baseline. More details regarding water supply and demand trends and projections can be found in the accompanying "Climate Change Impacts on Water Resources and Water Demand Trends in the Waikato Region Report.

(14) The water availability and demand issues across the Waikato region was investigated using historical and CMIP6 GCM scenario data. In addition, statistical results of potential changes in precipitation and PET were analysed for the integrated water management zones and aquifers as identified by WRC.

(15) Historical variability and changes in the trend of precipitation were analysed over the Waikato region. Recent low precipitation years have raised general awareness of water supply and demand issues. However, there is no clear signal of annual precipitation decrease at the historical decadal scale.

(16) Precipitation changes in CMIP6 model data have indicated a median model annual ensemble signal of less than a possible 1.0 % decrease in annual precipitation. However, sub-annually the median model ensemble signaled a potential 5.0 % decrease over the spring and summer seasons by 2090. This signal was not in CMIP5 GCM ensemble median ensemble projections. Notably, the intermodal variability range across the ensemble of 45 CMIP6 models, in reference to the CMIP5 models, depicts greater decreases and increases, and underscores the uncertainties across the projections.

(17) Notably, historical PET has increased significantly at approximately 100 mm over recent decades across many of the region's territorial authorities. Under the modelled scenarios, the continued increase in temperature under CMIP6 modeling could increase PET, from 4% to 5% under SSP2-4.5 2050, and up to 12 to 15% under SSP5-8.5 in 2090 in ensemble median. However, the median increase may be conservative, given observed PET increases of about 10% over the last few decades.

(18) Historical runoff data were investigated using NOAA reanalysis data. Runoff changes show a similar yet stronger decreasing signal in the spring and summer seasons. Therefore, the future runoff is projected to decrease in both SSP scenarios applied. The decrease of precipitation and runoff and the increase of PET will likely lead to a reduction in surface water and groundwater resources, plus lead to drier soil conditions, especially during late spring and summer, particularly for the northern part of the Waikato region.

(19) Historical surface water variabilities were investigated using streamflow data from 29 gauges across the Waikato region. Q5 low flow, defined as the threshold of allocable surface water, was calculated for each decade. In recent decades many of the stations have shown a decline in Q5 flow. Thus, the allocable surface water resources are diminishing.

(20) The allocable amount of surface water has been either fully or over-allocated in several catchments. A total of 53% of surface water has been allocated across the Waikato region. At the same time, 6% of the groundwater of the mapped reserves of the Waikato region is allocated.

(21) Groundwater availability was investigated using 28 aquifer areas. The WRC's documented precipitation recharge fraction approaches were applied. Thus, groundwater recharge represents a relatively small proportion of the annual mean precipitation.

(22) Future water demand was projected for population and economic activities applying the WISE (2018 baseline) projections. By 2050 the medium projection of regional population could increase by 28.5% (with a modelled range of between 13.3% and 43.8%) and 35.5% (between 14.4% and 56.77%) in 2060. These changes are in part driven by higher population increases in Hamilton City and the Waikato District rather than evenly across the other Districts.

(23) The increase in population and economic activities, barring technological changes, will likely increase the region-wide demand for water. With water demand in proportion to population, all the allocable surface water could be allocated between 2050 and 2060 under the high population projection.

(24) Currently, low stream flows occur widely in March and April. For example, the lower Waikato River is on average only 50% of the high flow that has been historically reached in August. The seasonal variabilities of streamflow are already resulting in noticeable water allocation tensions. Under both modelled climate change scenarios, stream flows during the drier spring and summer seasons are projected to decrease due to increasing temperatures and evapotranspiration and the concomitant potential for a decrease in annual and more pronounced seasonal precipitation.

(25) In order to provide the best and cross-validated climate change information for the WRC decision-making process, a comparison of the latest CLIMsystems projections (CMIP5 and CMIP6) and the MfE 2018 projections (CMIP5) for the Waikato region, plus wildfire risk, which is a newly identified risk for Waikato region.

(26) The CMIP6 mean temperature projections for 2090 are very close to the MfE 2018 report. On the other hand, the CMIP5 mean temperature results based on GCMs results are slightly lower than the MfE report due to their model selection and dynamical downscaling. Mean temperature change projection in model selection is varied; however, the envelope of the scenarios and intermodal variability is larger.

(27) The MfE 2018 report examined monthly precipitation with all the available GCMs. Therefore, the GCM numbers are different for each RCP. The CLIMsystems Waikato region report applied a pattern scaling approach using all the available GCMs, percentage change per degree of global temperature change, to obtain consistent climate change signals. Although the MfE 2018 seasonal and annual precipitation changes are very close to the Waikato regional report, all the reports have less than 5% percent annual precipitation and a decrease signal in spring, with substantial model uncertainties. Hamilton (Ruakura) and Taupo are separately presented for consistency with the MfE 2018 report. Taupo has a stronger annual precipitation signal than Hamilton.

(28) MfE applied the unified extreme precipitation change factors for New Zealand using RCM data. WRC 2022 applied all the available GCMs, for the Waikato region only. However, MfE 2018 and WRC 2022 have consistent results; with the increase of ARI (average recurrence intervals), the change factor will increase; with the increase of duration, from hours to days, the change factor decreases. Therefore, due to the differences in model data and selection, the CMIP5 extreme precipitation projections for Waikato are consistently smaller than the MfE projections.

(29) Hot days and cold nights were not analysed in the original WRC 2022 report. Therefore, the same periods of historical data were applied for the comparison. As a result, the CMIP6 SSP5-8.5 results predict more hot days and fewer cold nights.

(30) There are national PED projection maps and descriptions in the MfE 2018 report but no dedicated numbers for the Waikato region. WRC 2022 provided a different analysis, with exact numbers of the region. WRC 2022 reported the change in probability (percentage) of annual PED>200mm and PED>400mm, while MfE 2018 reported the increase of PED in millimetres. The MfE 2018 and WRC 2022 reports have a consistent change trend based on the maps and descriptions. Both reports identified an increasing trend of PED in the Waikato region.

(31) The MfE 2018 report applied the 99^{th} percentile daily mean wind speed, and the WRC report applied daily maximum wind speed and extreme value analysis. The WRC 2022 report found a weak, increasing signal (75th percentile) of extreme wind speed with a wide uncertainty envelope. This analysis provided historical observation data and 5 to 90th percentile confidence intervals. The MfE 2018 report provides a map displaying the weak increase to decrease trend.

(32) There is no specific analysis for mean wind speed analysis in the MfE 2018 report. However, the WRC 2022 report indicated a slight decrease in mean wind speed.

(33) Wildfire is a risk recently identified in the wildfire output in the MfE 2018 and WRC 2022 reports. The wildfire risk is increasing based on the KBDI fire danger index. The moderate risk category will be widespread in 2090, and the high-risk category will be extended to Waipa, Hauraki, and Coromandel.

(34) The comparison results conclude that the differences between CLIMsystems WRC reports are consistent with the MfE 2018 report, provided the same climate change signal with minimal differences, which falls in the uncertain envelopes and will not complicate the decision-making process. Furthermore, the WRC 2022 report provides detailed district-level analysis and numbers, allowing actionable planning.

1: Background – Here's Why – The Climate Action Roadmap

The Waikato region is already experiencing the effects of our changing climate. The changes present risks to our economy, our people, our property and our environment.

Drought and extreme storm events are increasingly affecting the primary sector, upon which the Waikato economy depends.

Dairying and agricultural biotechnology are key drivers of our regional economy, with aquaculture, forestry and horticulture also important. The changes that affect primary production will impact on the city and towns that have grown around these industries. Town and country need each other. There is a clear interdependency between the primary sector and those working in manufacturing, retail, transport, research, and professional and trade services.

Many communities are already feeling the effect of water restrictions on their business and domestic use, and many will face increased fire risk. Low water flows during times of drought impact the ability to generate power through our hydro schemes and the health of our river ecosystems.

More frequent and increasingly extreme storms, increased rainfall events and rising tides will test our coastal communities, infrastructure, roads, rail and communications networks. Our native animals and plants will become increasingly vulnerable, particularly if rates of change are faster than they can adapt.

Collectively, we need to adapt to these changes so we can continue to thrive economically and socially. But more importantly, we need to tackle the root cause of the problem – we need to reduce our greenhouse gas emissions. **We're all in this together – he waka eke noa.**

This project addresses the need for science-based knowledge to support decision making for operationalising the Roadmap. This first phase of analysis provides an update on the previous two climate impact assessment reports commissioned by WRC (CMIP3 (not published); and CMIP5 by Wang, M. *et al.* 2015) through the application of the latest IPCC model data known as CMIP6 (Coupled Model Intercomparison Project).

2: An Overview of Our Approach

Working with raw CMIP6 GCM data, the project focused on the generation of climate outputs broadly comparable with previous reports. Given the volume of data and best practice approaches, the results have been broken down into individual reports in four categories as described in Table 1 (Regional, District, Catchment, and Special Reports).

Table 1: List of individual reports in support of the objectives of the project

Regional	District/City	Water Management Areas	Special
Waikato Regional Report	Hamilton City	Central Waikato	Tongariro Power Scheme
Waikato regional water supply and demand	Hauraki	Coromandel	Summary of Tables
	Matamata-Piako	Lake Taupō	
	Otorohanga	Lower Waikato	
	Rotorua	Tongariro	
	South Waikato	Upper Waikato	
	Taupō	Waihou-Piako	
	Thames-Coromandel	Waipa	
	Waikato	West Coast	
	Waipa		
	Waitomo		

Figures 1 shows the information flows needed to undertake a regional climate change assessment in the Waikato region. CLIMsystems has applied the latest CMIP6 data (see a list of general circulation models in Appendix 1), and two SSPs (Shared Socioeconomic Pathways) to generate climate change scenarios in conjunction with other modelling approaches and a range of data sourced from National bodies such as NIWA and Waikato Regional Council and private industry. The data types and methods are detailed in Appendix 2.

Figure 2 depicts how previous analysis using CMIP5 data and RCPs 4.5 and 8.5 has been linked with the shared socioeconomic pathway scenarios currently being applied under CMIP6 (Lee, *et al.* 2021). To maintain general comparability from previous analysis, SPPs 2-4.5 and 5-8.5 were applied in the current analysis.

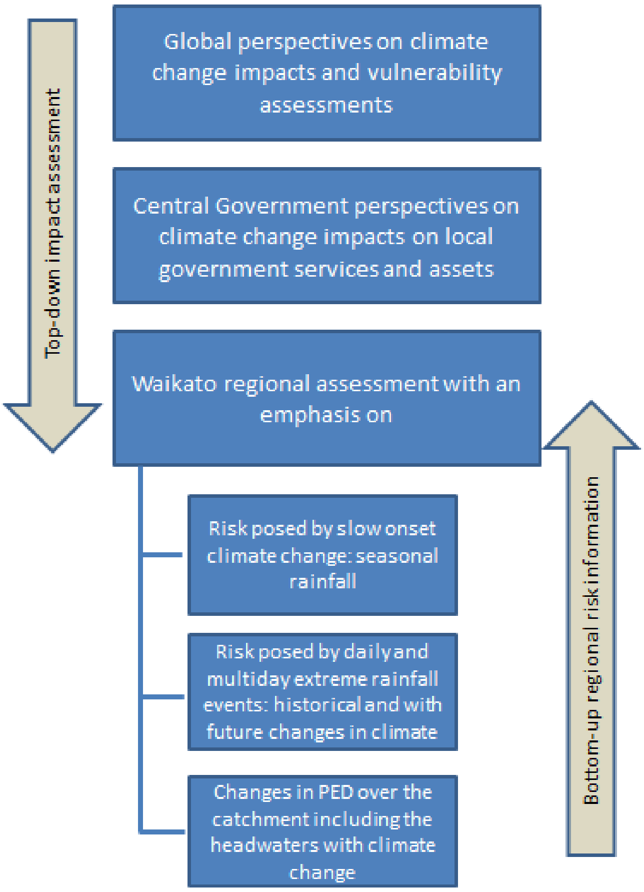


Figure 1: Information and knowledge flows for a regional climate change assessment in the Waikato region

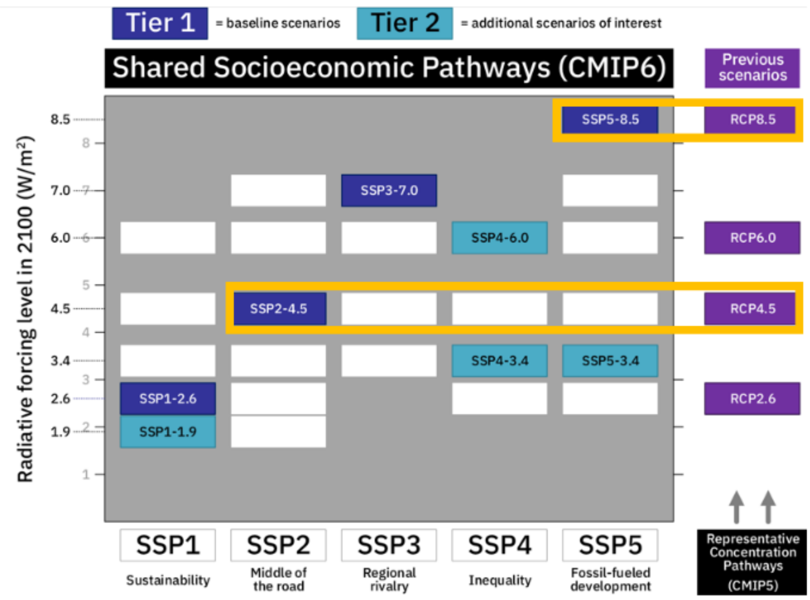


Figure 2: Overview of CMIP6 shared socioeconomic pathways (SSPs) compared with CMIP5 representative concentration pathways (RCPs) (Rojeli *et al*. 2018)

Figure 3 includes a summary of the variables addressed in the project. It reflects the updating of many of the variables addressed in the CMIP3 and CMIP5 reports produced for WRC. As there has been an expressed need to focus more clearly on water supply and demand issues across the entire Waikato region, the previous stream flow variable found in the two early reports has been expanded considerably to provide insights across the region as to potential changes in drought, runoff and surface and groundwater demand. Given the limited budget and time for delivering this third report, a high-level supply and demand analysis underpins further work on allocation and other water resources such as groundwater and rainwater catchment. As these additional parameters include considerable human dimensions that are influenced by regulatory considerations, historical practice (on the allocation of water take permits, for example), technological change/innovation and behavioural change (water metering), these, and undoubtedly other issues will need to be considered in subsequent analyses.

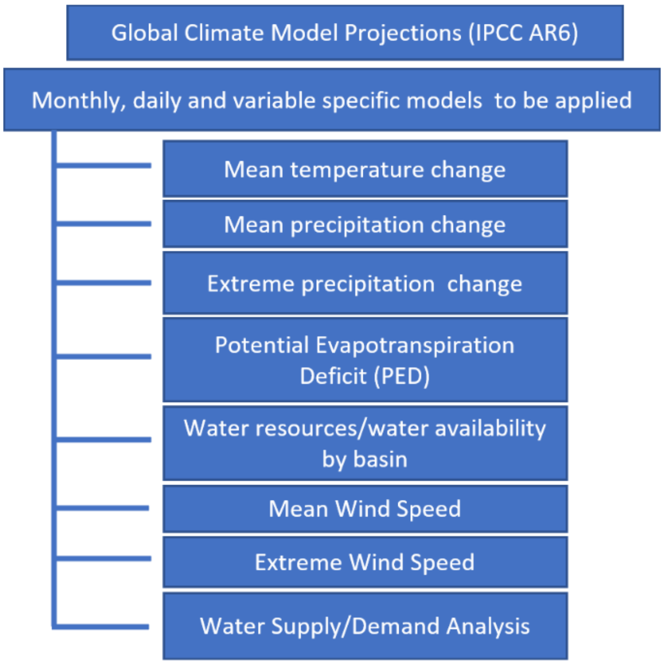


Figure 3: CMIP6 analysis undertaken for the Waikato region

The project's primary aim was to undertake a regional assessment of the impacts of climate change in the Waikato region applying the most recently available CMIP6 climate model data. The assessment indicates where the impacts warrant further research and response in terms of adaptation to climate change in relation to regional resource management and projects future change scenarios over short (2050), medium (2070) and long (2090) timeframes.

3: Overview of the Sixth Assessment Report

The Sixth Assessment Report (AR6) of the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) had its first planning meeting in 2013. This led to the publishing in 2016 of an overview of the design and organisational structure. This progressed in 2018 to the endorsement of 23 Model Intercomparison Projects (MIPs) involving 33 modeling groups in 16 countries. Four primary reports are scheduled for release:

- AR6 Climate Change 2021: The Physical Science Basis (released in August 2021)
- AR6 Climate Change 2022: Impacts, Adaptation and Vulnerability (scheduled for release February 2022)
- AR6 Climate Change 2022: Mitigation of Climate Change (scheduled for release March 2022)
- AR6 Synthesis Report: Climate Change 2022 (scheduled for release September 2022)

After its 1990 release, the FAR (First Assessment Report) exposed the need for international cooperation and spurred creation of the UN Framework Convention on Climate Change (UNFCCC), the key international treaty to guide greenhouse gas (GHG) reduction (referred to as climate change mitigation) and provide a framework for managing consequences of nonreduction (referred to as climate-change adaptation). Since 1995 regular assessments have been released along with a number of special scientific reports. The previous report (AR4) was released in 2007. The AR5 report was released in three instalments over the course of 2013 and 2014.

These assessment reports and related updated scientific publications assist national governments in their communications with the UNFCCC and help them review their GHG emissions and plans for mitigation, potential impacts, and adaptation.

Recently released and forthcoming AR6 reports will contain more extensive information on climate change's socioeconomic impacts and thus its role in sustainable development.

Differences Between AR5 and AR6

The previous CMIP5 report on the Waikato Region applied the Representative Concentration Pathways (RCPs) 4.5 and 8.5. The current report followed a similar approach however, the nomenclature has changed under CMIP6 to Share Socioeconomic Pathways (SSPs). In the current report SSP 2-4.5 and SSP5-8.5 have been applied. The SSPs 2-4.5 and 5-8.5 are further explained in the dialogue box as per the key underlying assumptions.

SSP2 Middle of the Road (Medium challenges to mitigation and adaptation) The world follows a path where social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceed unevenly, with some countries making relatively good progress while others fall short of expectations. Global and national institutions work toward but make slow progress in achieving sustainable development goals. Environmental systems experience degradation, although there are some improvements and overall, the intensity of resource and energy use declines. Global population growth is moderate and levels off in the second half of the century. Income inequality persists or improves only slowly, and challenges to reducing vulnerability to societal and environmental changes remain.

SSP5 Fossil-fuelled Development – Taking the Highway (High challenges to mitigation, low challenges to adaptation). This world places increasing faith in competitive markets, innovation, and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated. There are also strong investments in health, education, and institutions to enhance human and social capital. At the same time, the push for economic and social development is coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy-intensive lifestyles around the world. All these factors lead to rapid growth of the global economy, while global population peaks and declines in the 21stcentury. Local environmental problems like air pollution are successfully managed. There is faith in the ability to effectively manage social and ecological systems, including by geo-engineering if necessary.

CMIP6 consists of the "runs" from around 100 distinct climate models being produced across 49 different modelling groups. These models are running several new and updated emission pathways that explore a much more comprehensive range of possible future outcomes than were included in CMIP5. While the results from 44 monthly CMIP6 models have been published at the time of the analysis undertaken for this report. In general, it is evident that a number of models have a notably higher climate sensitivity than models in CMIP5 (Zelinka *et al.* 2020). This higher sensitivity contributes to projections of greater warming this century – around 0.4C warmer than similar scenarios run in CMIP5 – though these warming projections may change as more models become available. Specifically, a set of scenarios were chosen to provide a range of distinct end-of-century climate change outcomes. The IPCC AR5 featured four Representative Concentration Pathways (RCPs) that examined different possible future greenhouse gas emissions. These scenarios – RCP2.6, RCP4.5, RCP6.0, and RCP8.5 –have new versions in CMIP6. These updated scenarios are called SSP1-2.6, SSP2-4.5, SSP4-6.0, and SSP5-8.5, each of which result in similar 2100 radiative forcing levels as their predecessor in AR5.

Several new scenarios are also being used for CMIP6 to give scientists a wider selection of futures to simulate. These scenarios are included in the chart below (figure 4), shows the radiative forcing levels to 2100. The new scenarios that can be applied for risk and vulnerability assessments are limited to the following five in contrast to the eight shown the SSP figure above: SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5.

As with CMIP5 there are a range of models available for application with CMIP6 depending on the variable being applied. This is important when applying methods for variables such as wind and for extreme analysis for rainfall that require sub-monthly data. Historically, such as with CMIP3 only monthly rainfall patterns were available. With CMIP4 daily patterns were released, leading to a revolution in extreme event analysis. It became apparent that extreme daily rainfall could increase in intensity with climate change while monthly and annual rainfall could decrease. CMIP5 models were run for 6 and 3 hourly rainfall, which permitted higher temporal resolution analysis and led to even greater evidence that short-term extreme rainfall events could increase in intensity while monthly and annual rainfall could vary little over time or decrease.

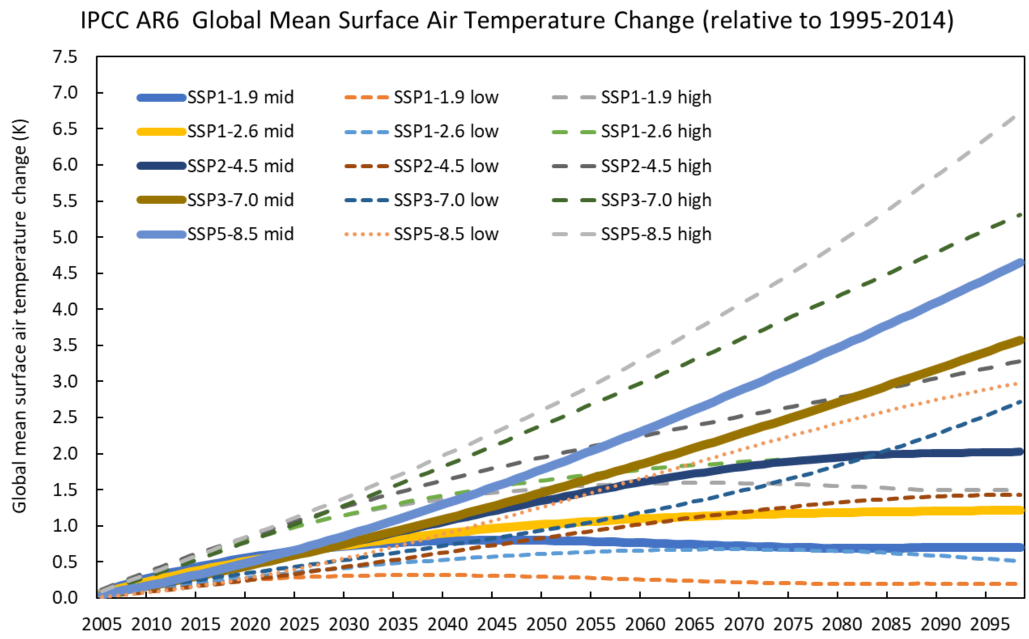


Figure 4: IPCC AR6 global mean surface air temperature changes (relative to 1996-2014) for different scenarios

Summary of the methodologies

To produce the baseline and future climate projections for the Waikato region several important considerations need to be made, as they relate to assessing the impacts, risks, and adaptation to climate change (Jones, 2010; and Benestad, 2002, Li and Ye, 2011):

- The spatial scale at which climate information is provided, to assess risks and appropriate adaptation actions;
- There is a need for regionalised projections of climate change;
- Local climates may exhibit gradual trends and non-linear changes in response to global warming, usually not resolved in General Circulation Models (GCMs).

The climate change scenarios produced in this Assessment are based on CMIP6 General Circulation Model (GCM) outputs.

For monthly precipitation, temperature, solar radiation, wind speed, extreme precipitation, pattern scaling approach was applied. For all the available CMIP6 GCM monthly outputs for these variables were processed to produce climate patterns for global coverage (0.5°*0.5°) (see Appendix 1 for a full description of this method), and then regridded to 500m resolution for the Waikato region.

Pattern scaling has a higher degree of confidence for temperature-related impacts, while less confidence for precipitation-related impacts of climate change can be expected. This is because attributes of climate variability and anthropogenic change are often unresolved due to large variability in precipitation patterns. As a result, systems affected by multiple variables including extreme climatic variables (for instance, agricultural cropping systems, livestock production systems and natural ecosystems), usually face higher uncertainty with respect to climate change related impacts.

For runoff and extreme wind speed which are not suitable for the application of the pattern scaling approach, a change factor approach was applied, which is to directly derive the change factors for the original GCM outputs between historical simulation and scenario simulation. Therefore, the change factors may be not linearly according the global temperature change and scenarios.

Ensembles of up to 45 GCMs were used to generate the future scenarios, by providing the range of ensemble member values per variable. The spatial scenarios and statistics produced are presented using ensemble statistics, that is, the Low (5th percentile), Median (50th percentile), and High (95th percentile) values of the ensemble. For different variables, according to the availability of GCM data, the ensemble members are different. Details of the GCMs used for producing the future scenarios of specific variables are provided in Appendix 1.

The following steps were undertaken to produce the results contained in this Assessment (and further details of the steps are provided in Appendix 1):

- Temperature and precipitation patterns were normalised, using the global mean temperature change of the corresponding period and GCM; and
- Spatial and statistical analyses were undertaken based on the ensemble results, for:
- The historical period (1972-2020, from Virtual Climate Station Network (VCSN) daily data with 0.05-degree spatial resolution; climate grid data with 500m spatial resolution; HIRDSv4 extreme precipitation data; meteorological station wind speed data. All the historical data we obtained from NIWA
- and three future time periods: 2050, 2070 and 2090 under SSP2-4.5 and SSP5-8.5.

The global mean temperature change for the selected year and scenario were list below (5th and 95th percentile of the projections is in the brackets)

	SSP1-19	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
2050	0.80 (0.30, 1.50)	1.00 (0.60, 1.60)	1.30 (0.80, 1.90)	1.40 (0.90, 2.30)	1.70 (1.20, 2.50)
2070	0.73 (0.23, 1.59)	1.14 (0.67, 1.87)	1.78 (1.16, 2.47)	2.21 (1.43, 3.48)	2.78 (1.99, 3.94)
2090	0.70 (0.20, 1.50)	1.20 (0.60, 2.00)	2.00 (1.40, 3.00)	3.10 (2.20, 4.70)	4.00 (2.70, 5.70)

In this project a range of CMIP6 model data has been applied with various numbers of models available. It is noted that not all model groups produce all the variable outputs made available for public use. The range of models applied are itemised in Appendix 1.

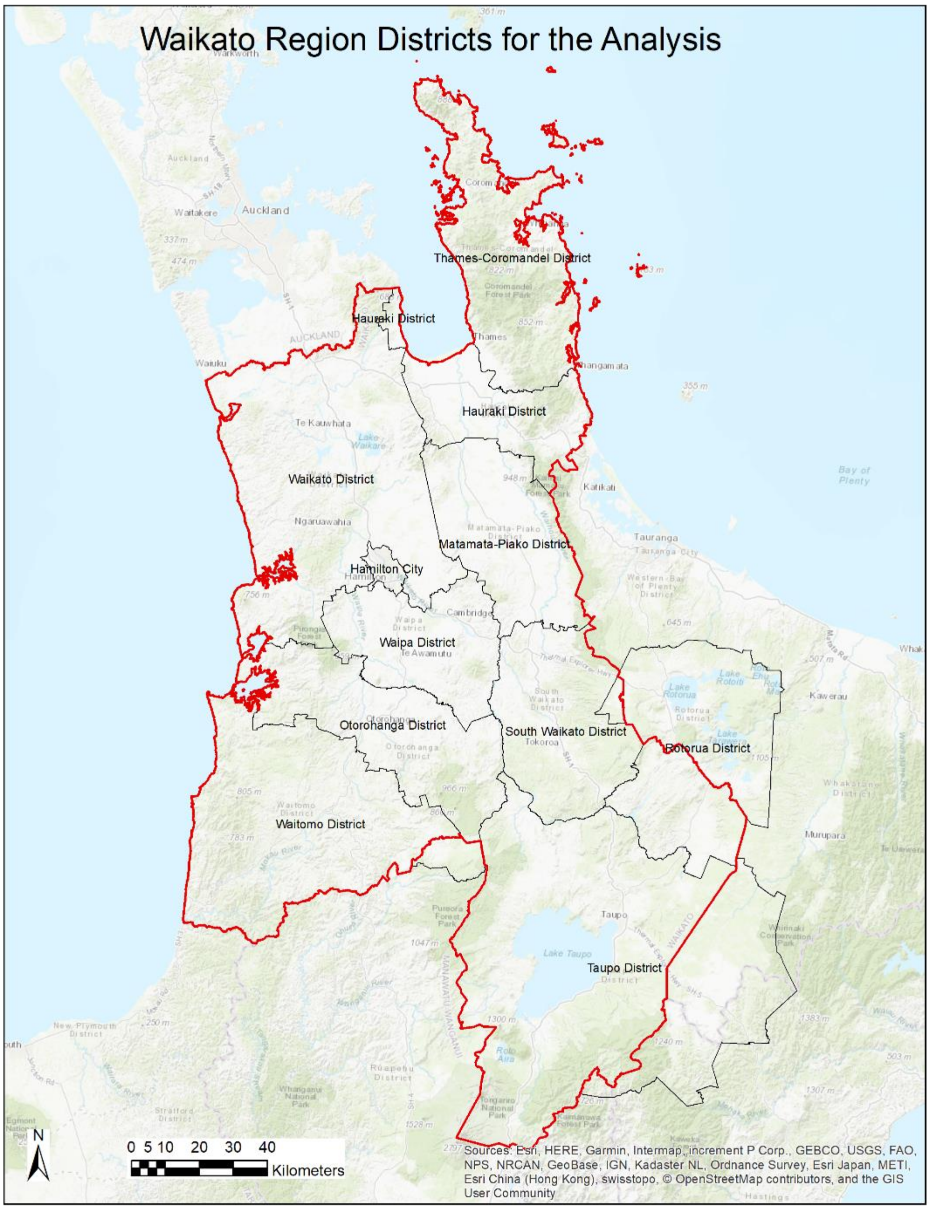
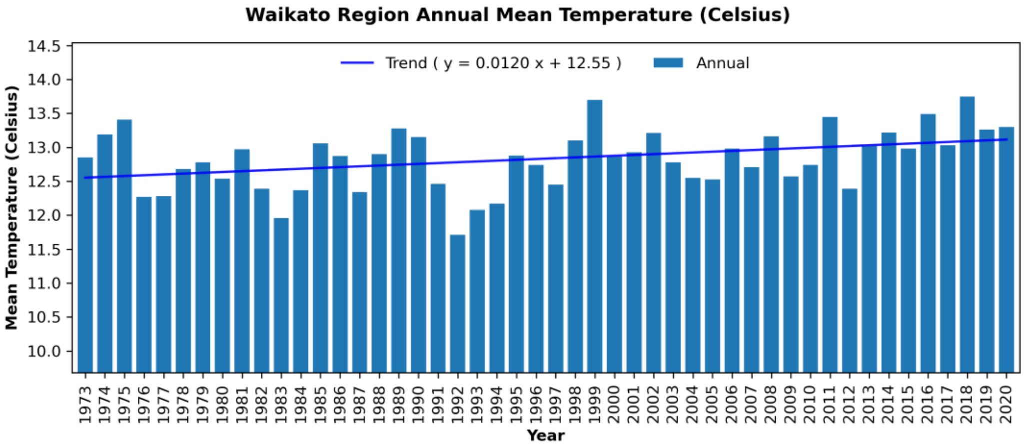


Figure 5: The Waikato region and territorial authorities included in this project.

4: Average Seasonal and Annual Mean Temperature

The historical areal average of annual mean temperature for Waikato region (1973-2020) is 12.9°C, with 17.2°C during summer months (DJF), and 8.5°C during winter months (JJA) (Table 2). Over the period 1973-2020, annual mean temperature has shown an increasing linear trend of 0.12°C per decade (Fig. 4). May, June, and July show the strongest warming trends.



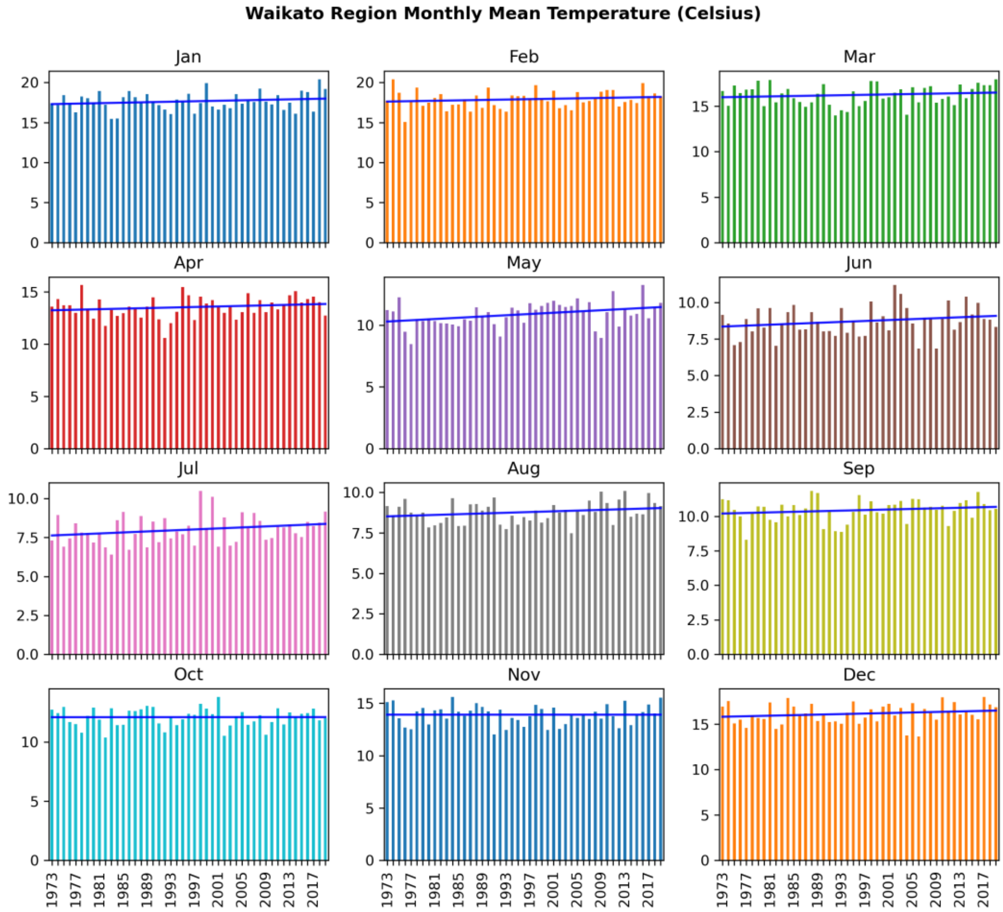


Figure 6: Waikato Region, Annual and Monthly Mean Temperature Historical (Celsius).

The average seasonal and annual mean temperature of the Waikato Region is expected to rise until 2090, relative to the baseline The annual mean temperature for SSP2-4.5 is expected to increase by more than 1.6°C by 2090. Seasonally, the average mean temperature for SSP2-4.5 most noticeably rises over the summer months of December, January and February by 1.1°C in 2050 and 1.7°C in 2090. The SSP5-8.5 results are more extreme, with the average annual mean temperature expected to be 2.2°C warmer in 2070 and 3.1°C in 2090. The seasonal shifts for SSP5-8.5 also suggest warmer mean temperature during the summer months with a rise from 1.4°C higher in 2050 to 3.4°C higher in 2090.

The maps of historical and future mean temperature distribution and change, as shown in figure 6-8. The annual mean temperature of in Waikato, Hauraki, and Matamata-Piako districts are higher than other districts, because of their low elevation and latitude, while southern districts have lower annual mean temperature, especial in the Taupō District. The annual mean temperature changes in the future for different districts would not range very much from 1.3-1.4°C in SSP2-4.5 2050, and 2.1-2.2°C in SSP5-8.5 2070. The Waikato region is relatively small, comparing to the large grid cells of GCMs and it is reasonable that the Waikato region is in the same climate type.

The whisker figure 9 shows the inter-model variabilities and the uncertainties, which also shows in the table 2. such under SSP5-8.5. the 50th percentile of mean temperature increase of 3.1°C with 2.3°C in 5th percentile and 4.8°C for 95th percentiles. The 25th and 75th of the ensemble percentiles are also displayed. Even given the large uncertainties ranges, the temperature projections are clearly increasing even in the 5th percentile of the ensemble.

Table 2: Waikato Region, Average Seasonal and Annual Mean Temperature Baseline (Celsius) and Changes (Celsius) - 50th Percentile (Brackets 5th and 95th Percentile).

Season	Year	SSP2-4.5	SSP5-8.5
DJF	Baseline	17.22	17.22
DJF	2050	1.09 (0.84, 1.50)	1.43 (1.10, 1.97)
DJF	2070	1.49 (1.15, 2.06)	2.33 (1.79, 3.22)
DJF	2090	1.68 (1.29, 2.31)	3.36 (2.58, 4.63)
MAM	Baseline	13.55	13.55
MAM	2050	1.06 (0.78, 1.44)	1.39 (1.02, 1.89)
MAM	2070	1.45 (1.07, 1.98)	2.26 (1.67, 3.08)
MAM	2090	1.63 (1.20, 2.22)	3.26 (2.40, 4.44)
JJA	Baseline	8.50	8.50
JJA	2050	0.96 (0.73, 1.34)	1.26 (0.96, 1.75)
JJA	2070	1.32 (1.00, 1.83)	2.06 (1.57, 2.86)
JJA	2090	1.49 (1.13, 2.06)	2.97 (2.25, 4.12)
SON	Baseline	12.17	12.17
SON	2050	0.92 (0.69, 1.28)	1.21 (0.90, 1.67)
SON	2070	1.27 (0.94, 1.75)	1.97 (1.47, 2.74)
SON	2090	1.42 (1.06, 1.97)	2.84 (2.11, 3.93)
ANN	Baseline	12.86	12.86
ANN	2050	1.01 (0.76, 1.39)	1.32 (0.99, 1.82)

ANN	2070	1.38 (1.04, 1.91)	2.16 (1.62, 2.97)
ANN	2090	1.55 (1.17, 2.14)	3.11 (2.34, 4.28)

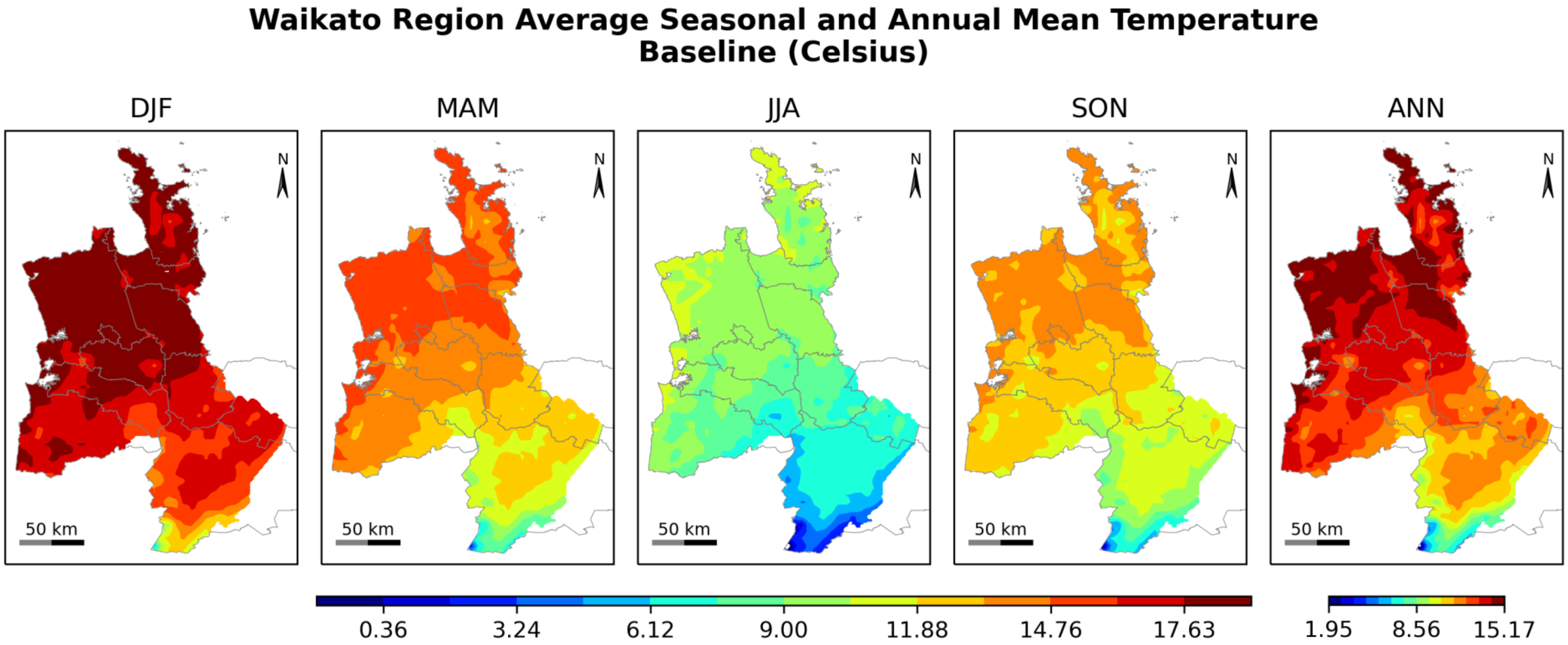


Figure 7: Waikato Region Average Seasonal and Annual Mean Temperature Baseline (1972-2020) (Celsius) and Changes (Celsius)

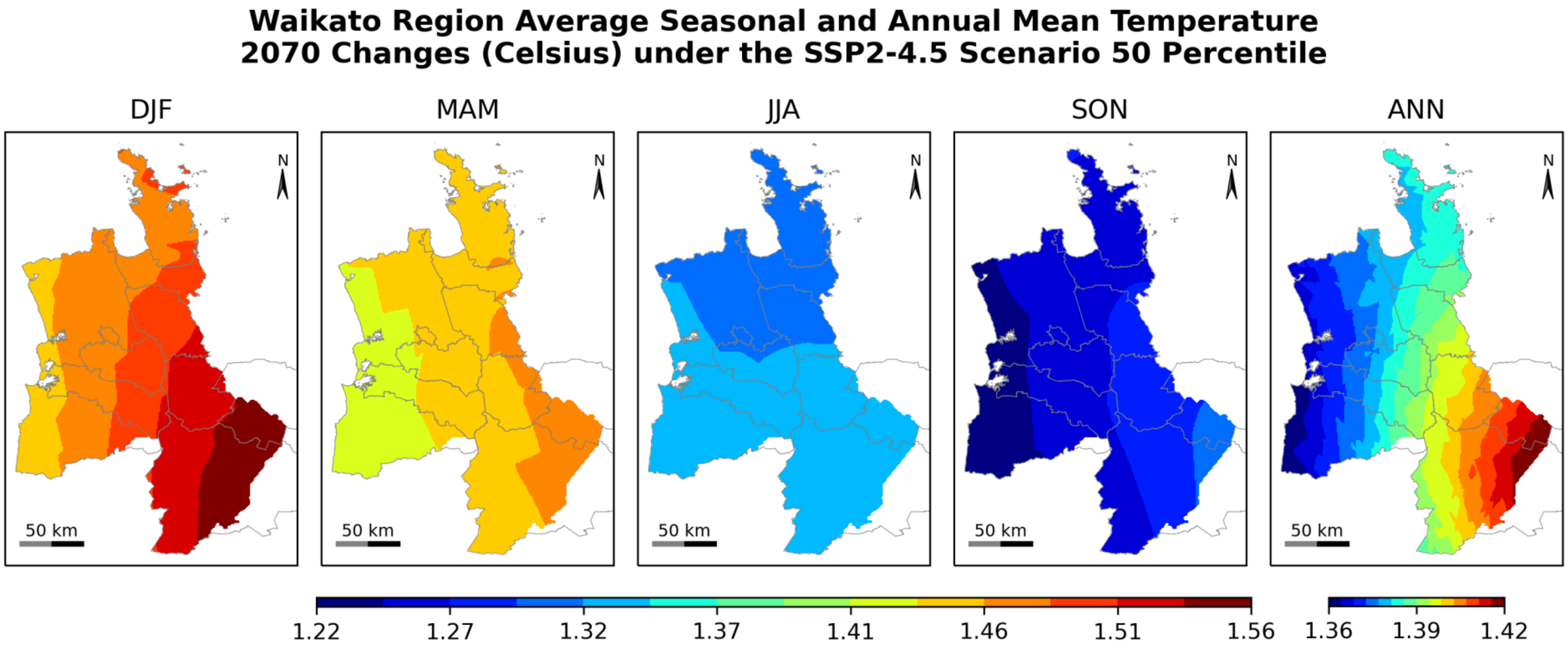


Figure 8: Waikato Region Average Seasonal and Annual Mean Temperature Changes (Celsius).

Note: The fine colour categories of the map were based on calculated values, they are not indications of the significant variations. This note applies to other spatial maps in this report.

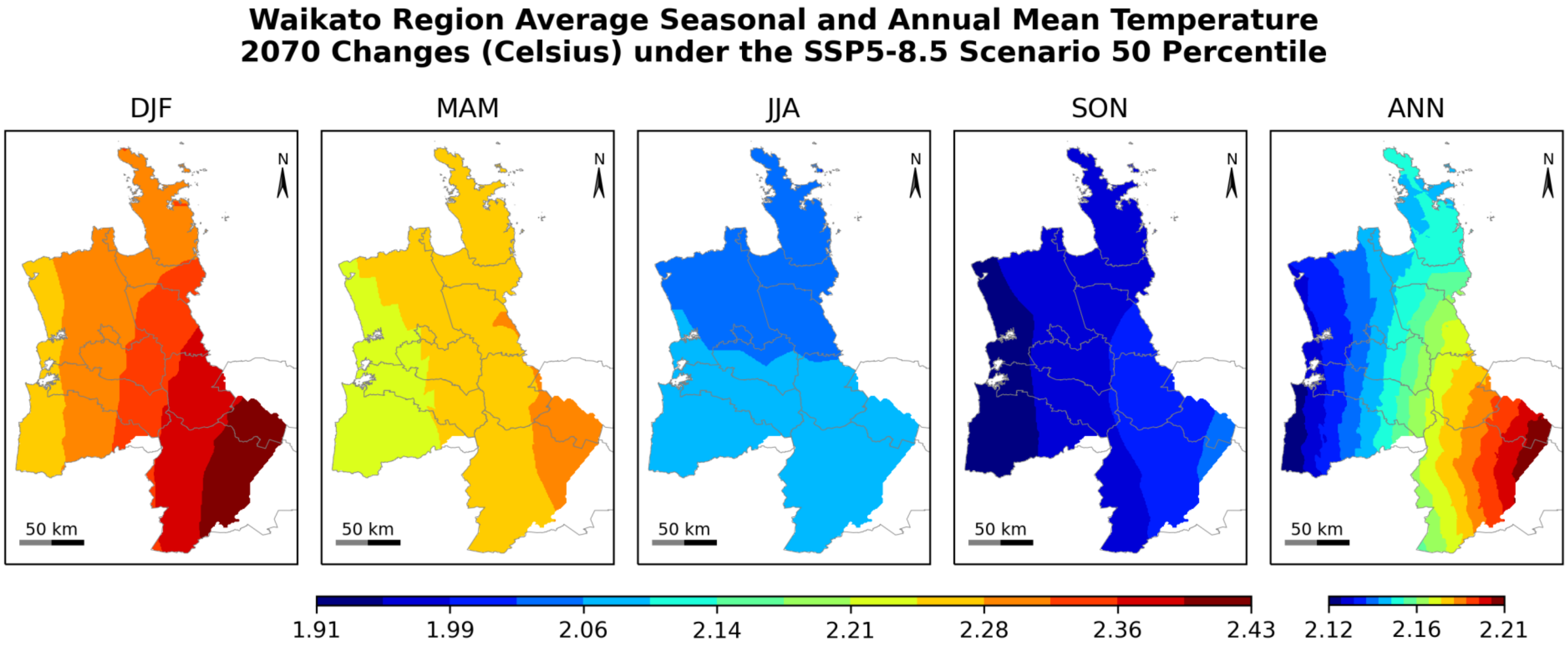


Figure 9: Waikato Region Average Seasonal and Annual Mean Temperature Changes (Celsius)

10a

10b

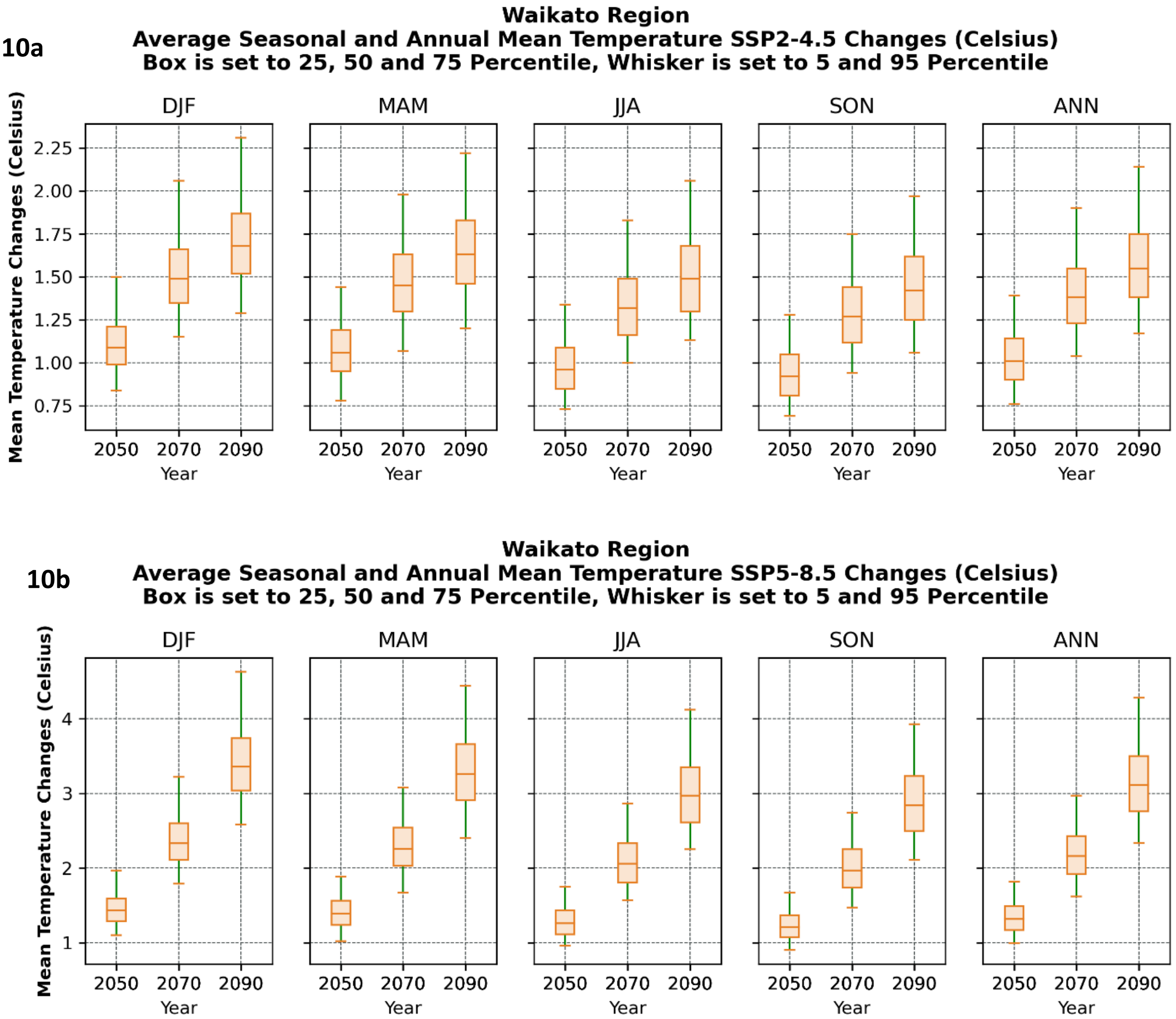


Figure 10: Waikato Region Average Seasonal and Annual Mean Temperature Changes (Celsius) for Scenario SSP2-4.5 (10a) and SSP5-8.5 (10b)

5: Average Seasonal and Annual Maximum Temperature

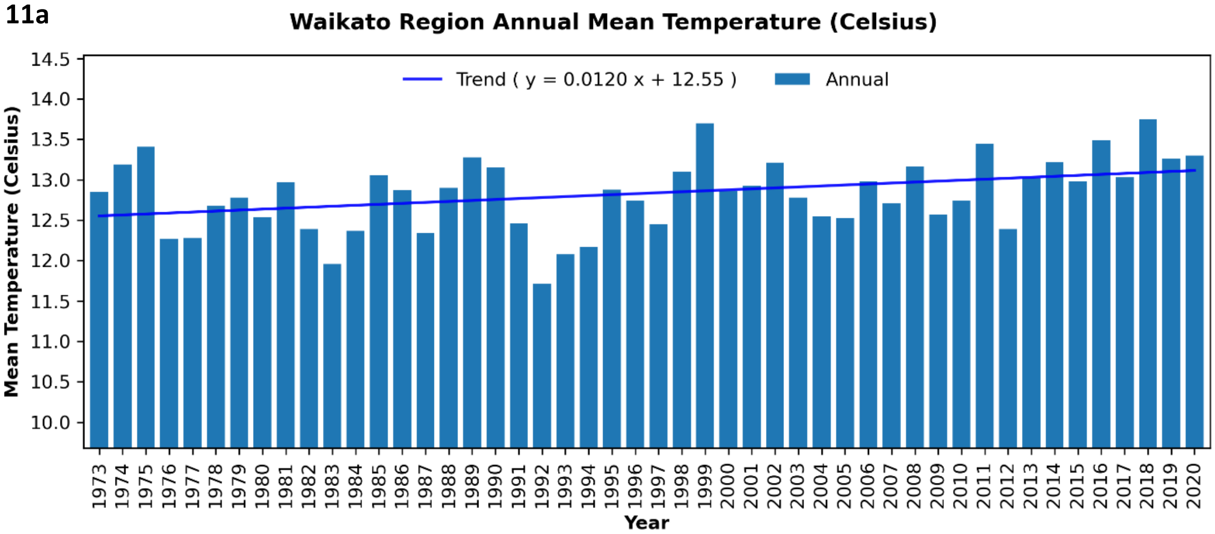
The areal average of annual maximum temperature for Waikato region is 17.6°C, with 22.9°C during summer months (DJF), and 12.7°C during winter months (JJA), The historical average annual mean temperature is showing an increasing trend as shown in Figure 10a, the linear trend is 0.13°C per decade, with cooler months (May-Aug) showing the strongest warming trends (Fig. 10b)..

The average seasonal and annual maximum temperature of the Waikato Region is expected to rise until 2090, relative to the baseline The annual maximum temperature for SSP2-4.5 is expected to increase by more than 1.5°C by 2090. Seasonally, the average maximum temperature for SSP2-4.5 most noticeably rises over the summer months of December, January, and February by 1.1°C in 2050 and 1.7°C in 2090. The SSP5-8.5 results are more extreme, with the average annual maximum temperature expected to be more than 2°C warmer in 2070 and 3°C in 2090. The seasonal shifts for SSP5-8.5 also suggest warmer maximum temperature summer months with a rise from 1.5°C higher in 2050 to 3.4°C higher in 2090.

Table 3: Waikato Region Average Seasonal and Annual Maximum Temperature Baseline (Celsius) and Changes (Celsius)

Season	Year	SSP2-4.5 (05Pth, 95Pth)	SSP5-8.5 (05Pth, 95Pth)
DJF	Baseline	22.38	22.38
DJF	2050	1.11 (0.84, 2.08)	1.45 (1.10, 2.72)
DJF	2070	1.52 (1.16, 2.85)	2.37 (1.81, 4.44)
DJF	2090	1.71 (1.30, 3.20)	3.41 (2.59, 6.39)
MAM	Baseline	18.46	18.46
MAM	2050	1.08 (0.85, 1.73)	1.42 (1.11, 2.26)
MAM	2070	1.48 (1.16, 2.37)	2.31 (1.82, 3.70)
MAM	2090	1.66 (1.31, 2.66)	3.33 (2.62, 5.33)
JJA	Baseline	12.74	12.74
JJA	2050	0.98 (0.74, 1.47)	1.28 (0.97, 1.93)
JJA	2070	1.34 (1.01, 2.02)	2.08 (1.59, 3.15)
JJA	2090	1.50 (1.14, 2.27)	2.99 (2.28, 4.54)
SON	Baseline	16.66	16.66
SON	2050	0.94 (0.72, 1.70)	1.23 (0.95, 2.23)
SON	2070	1.29 (0.99, 2.34)	2.02 (1.55, 3.65)
SON	2090	1.45 (1.11, 2.62)	2.90 (2.23, 5.25)
ANN	Baseline	17.56	17.56
ANN	2050	1.03 (0.79, 1.75)	1.34 (1.03, 2.28)
ANN	2070	1.41 (1.08, 2.39)	2.20 (1.69, 3.74)
ANN	2090	1.58 (1.21, 2.69)	3.16 (2.43, 5.37)

11a



11b

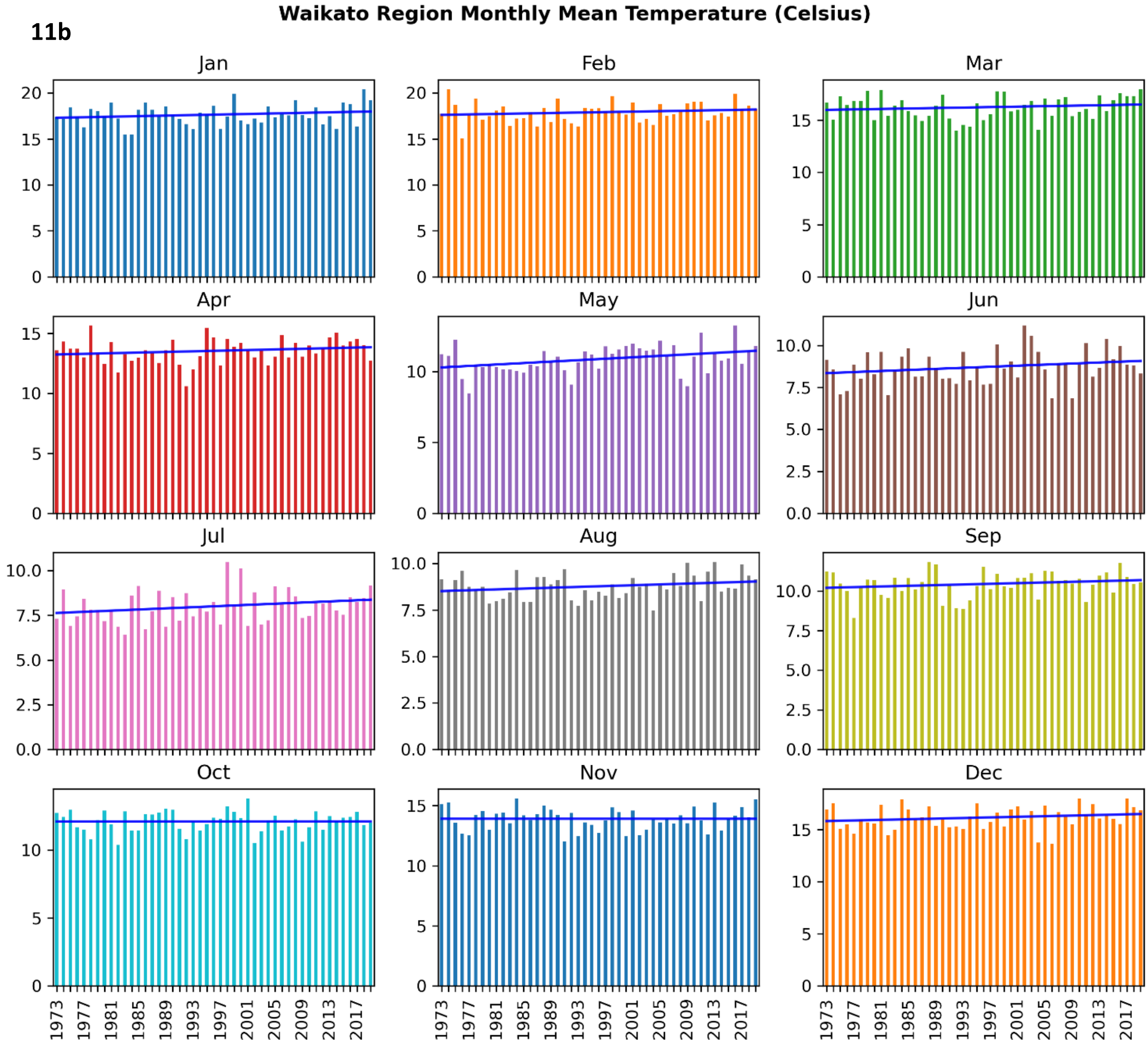


Figure 11: Waikato Region Annual (11a) and Monthly (11b) Maximum Temperature (Celsius)

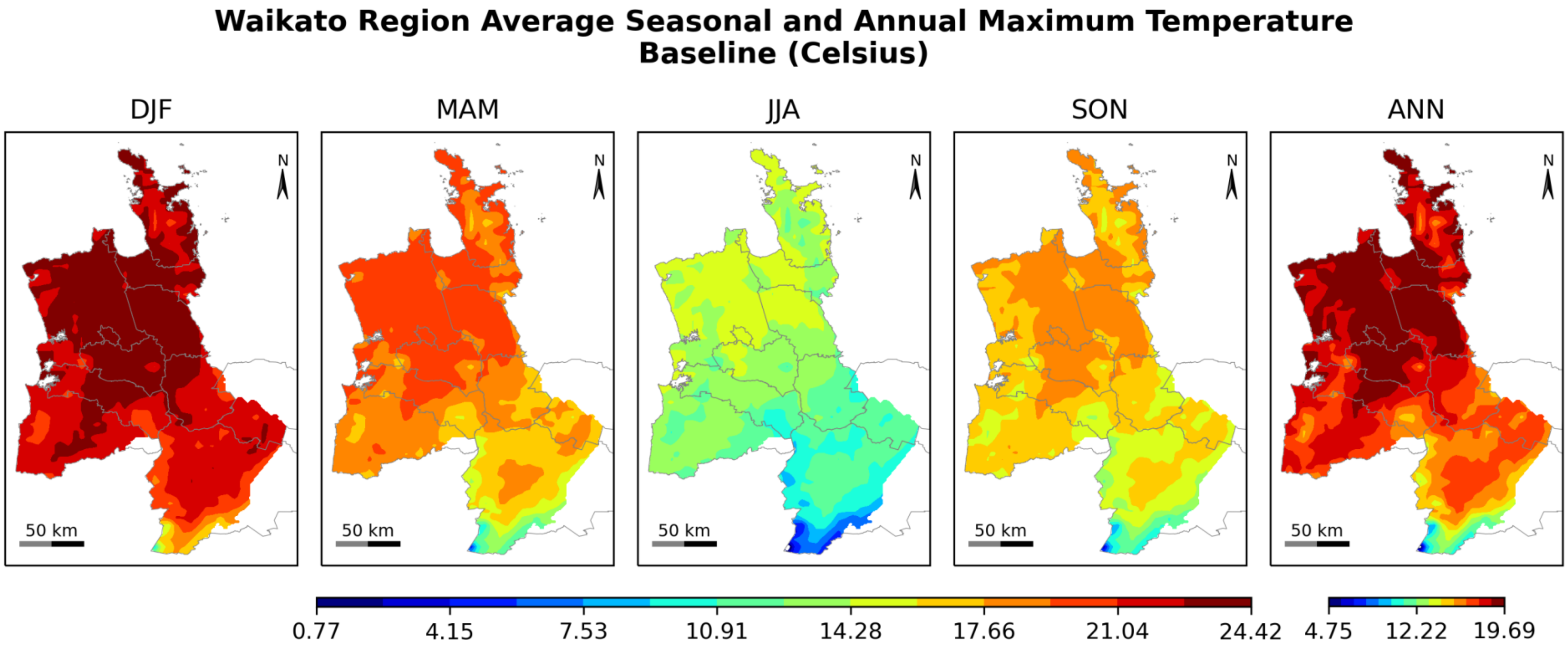


Figure 12: Waikato Region Average Seasonal and Annual Maximum Temperature Baseline (Celsius) and Changes (Celsius)

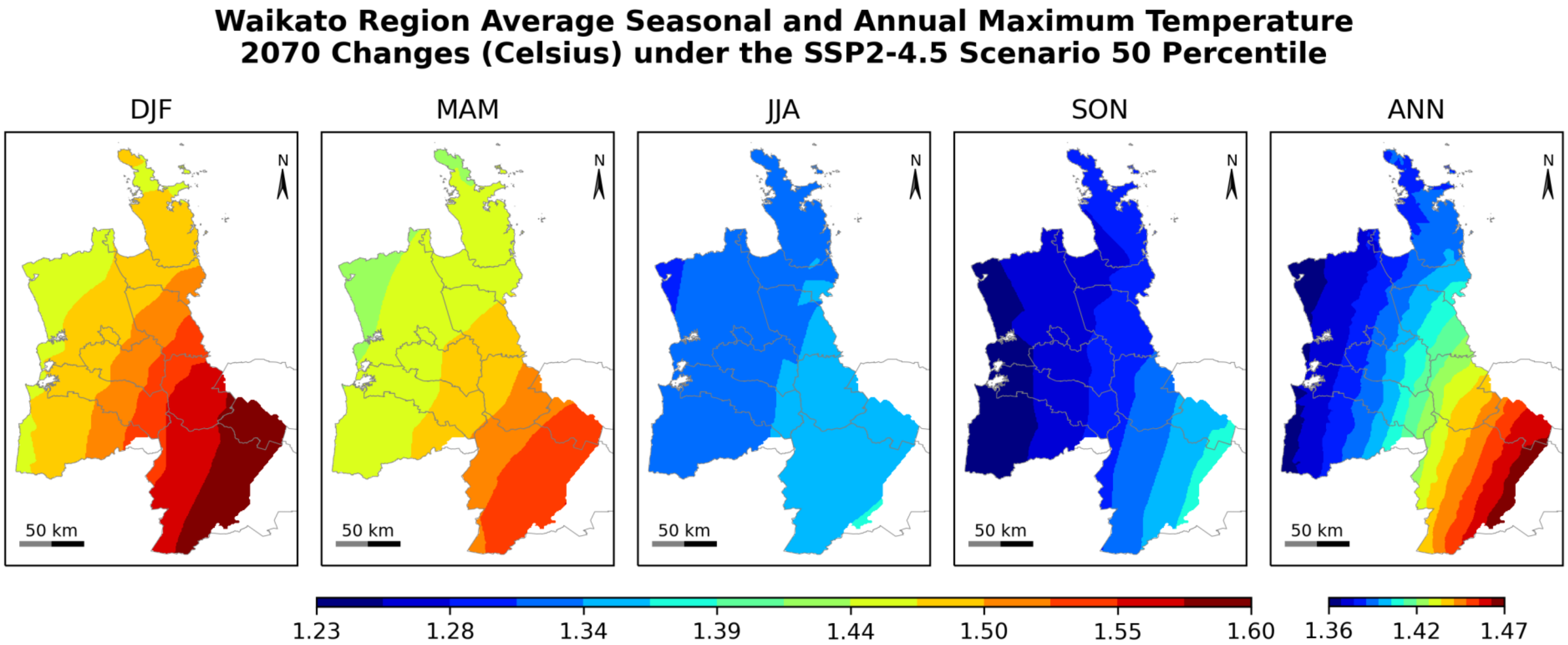


Figure 13: Waikato Region Average Seasonal and Annual Maximum Temperature Changes (Celsius)

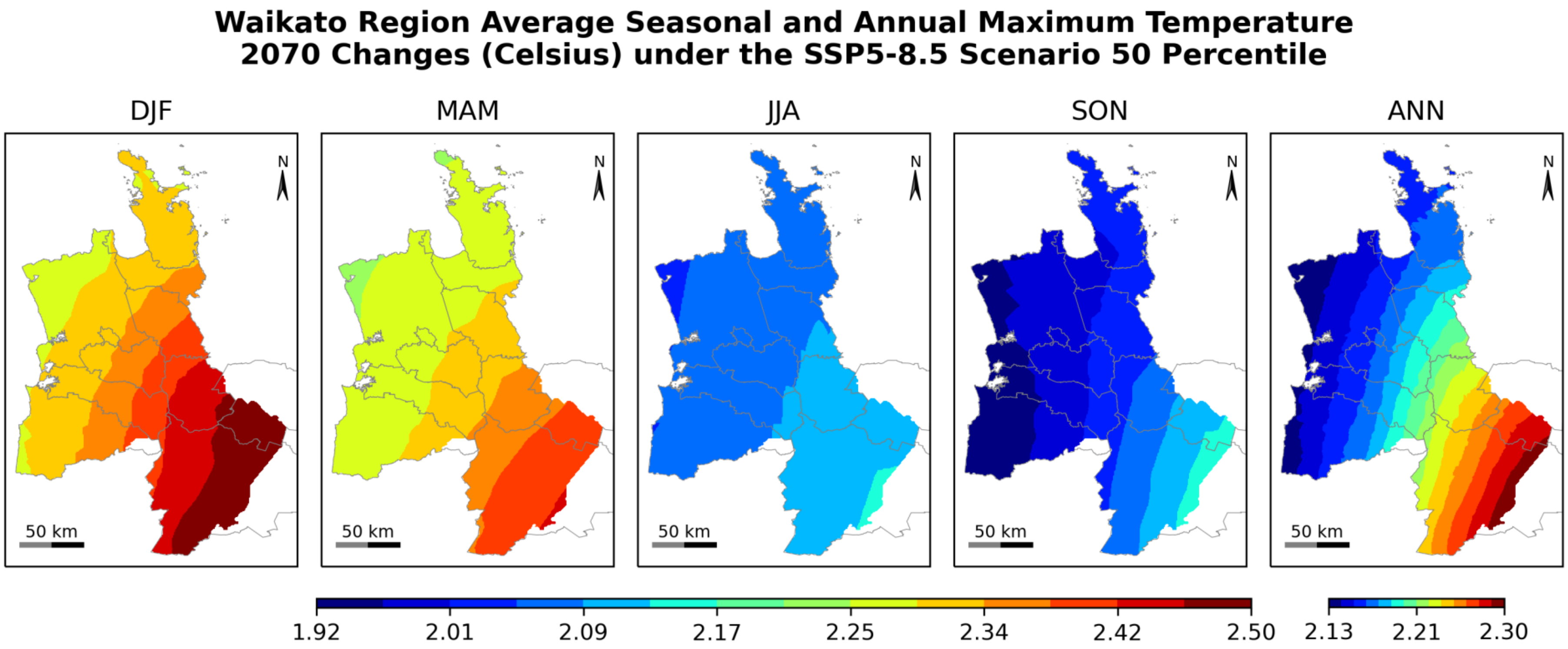
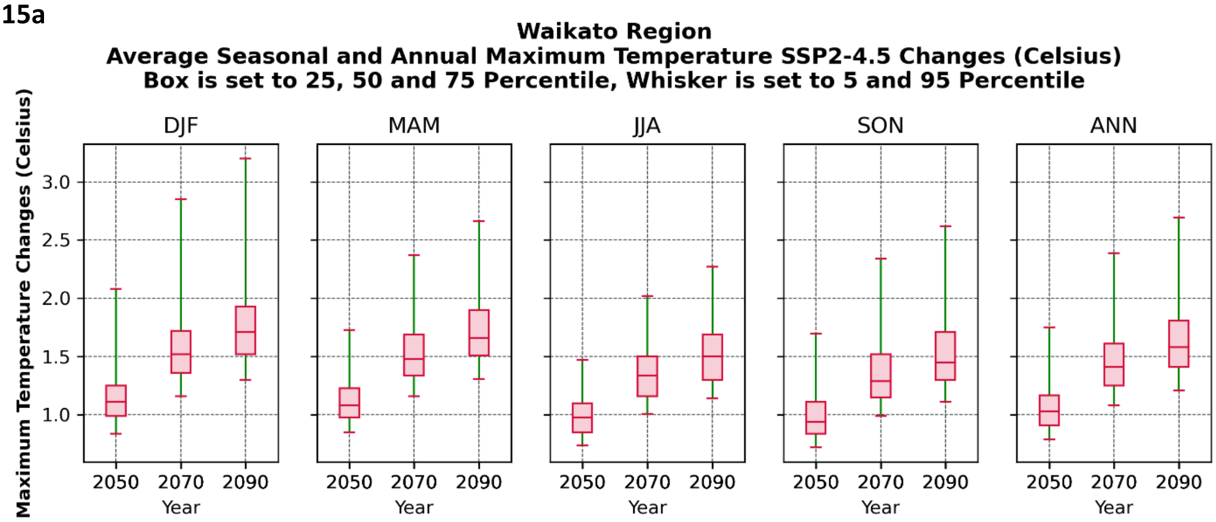


Figure 14: Waikato Region Average Seasonal and Annual Maximum Temperature Changes (Celsius)

15a



15b

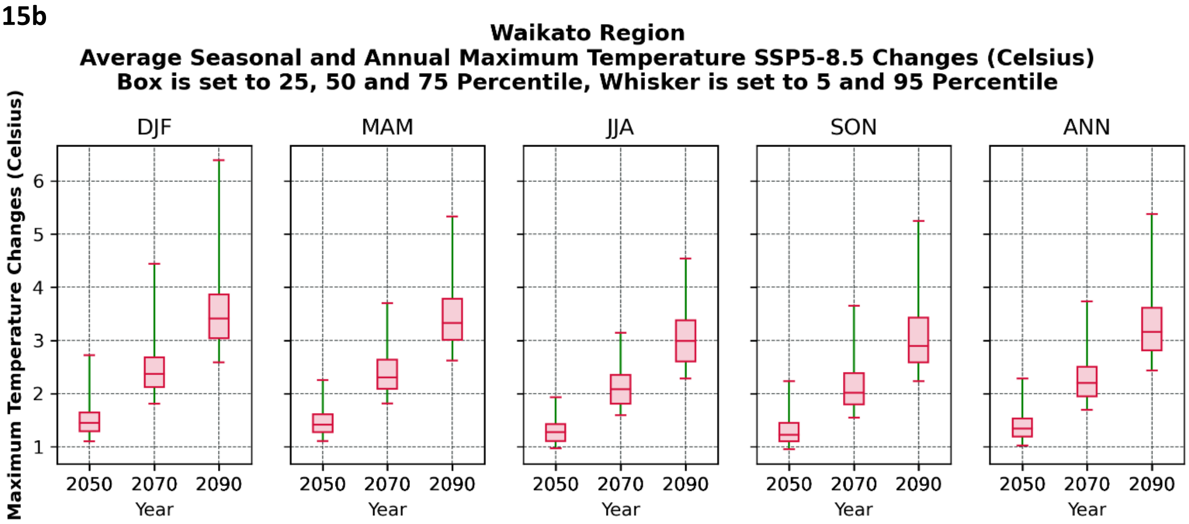


Figure 15: Waikato Region Average Seasonal and Annual Maximum Temperature Changes (Celsius) for Scenario SSP2-4.5 (15a) and SSP5-8.5 (15b).

6: Average Seasonal and Annual Minimum Temperature

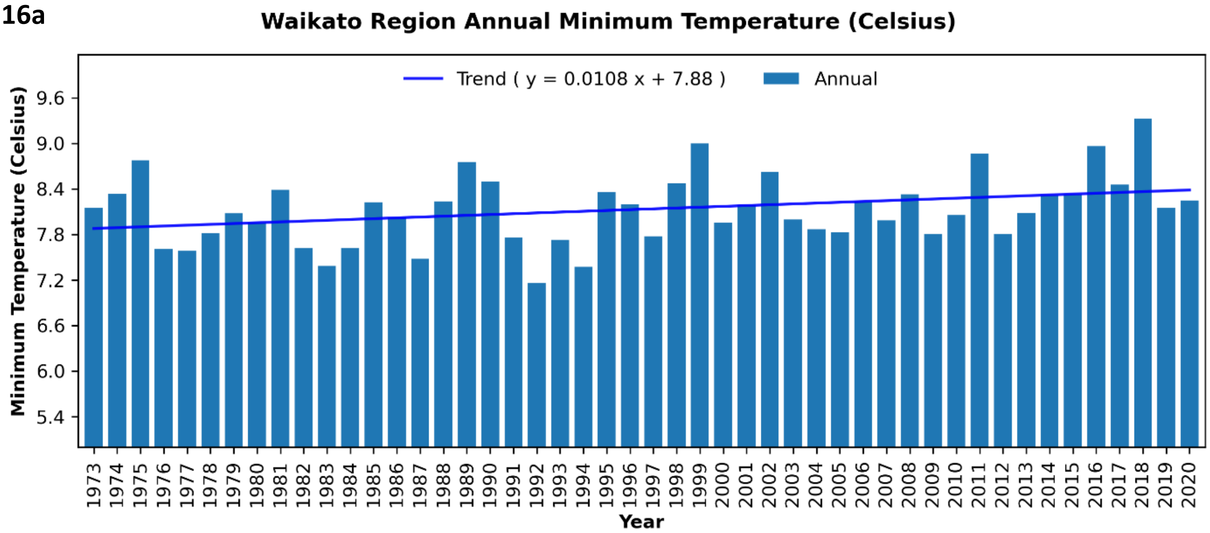
The areal average of annual mean temperature for Waikato region is 8.2°C, with 12.1°C during summer months (DJF), and 4.3°C during winter months (JJA), The historical average annual mean temperature is showing an increase trend (Figure 14a), with a linear trend of 0.11°C per decade. Colder months tend to show the greatest warming trend.

The average seasonal and annual minimum temperature of the Waikato Region is expected to rise out to 2090 (and beyond), relative to the baseline year of 2005. Under SSP2-4.5, the annual minimum temperature is expected to increase by more than 1.5°C by 2090. Seasonally, the average minimum temperature for SSP2-4.5 most clearly rises over the summer months of December, January and February by 1.1°C in 2050 and 1.6°C in 2090. The SSP5-8.5 results are more severe, with the average annual minimum temperature expected to be more than 2°C warmer in 2070 and 3°C in 2090, compared to the baseline. Furthermore, the seasonal shifts for SSP5-8.5 predict warmer maximum temperature summer months relative to the baseline, with a rise of 1.4°C in 2050 and 3.3°C in 2090 (Table 3).

Table 4: Waikato Region Average Seasonal and Annual Minimum Temperature Baseline (Celsius) and Changes (Celsius)

Season	Year	SSP2-4.5 (05Pth, 95Pth)	SSP5-8.5 (05Pth, 95Pth)
DJF	Baseline	12.06	12.06
DJF	2050	1.07 (0.81, 1.53)	1.40 (1.07, 2.00)
DJF	2070	1.46 (1.11, 2.09)	2.29 (1.74, 3.27)
DJF	2090	1.64 (1.25, 2.35)	3.29 (2.51, 4.71)
MAM	Baseline	8.63	8.63
MAM	2050	1.06 (0.81, 1.48)	1.39 (1.07, 1.94)
MAM	2070	1.45 (1.12, 2.02)	2.27 (1.75, 3.17)
MAM	2090	1.63 (1.26, 2.28)	3.26 (2.51, 4.56)
JJA	Baseline	4.26	4.26
JJA	2050	0.95 (0.74, 1.31)	1.24 (0.96, 1.72)
JJA	2070	1.30 (1.01, 1.80)	2.03 (1.57, 2.81)
JJA	2090	1.46 (1.13, 2.02)	2.91 (2.26, 4.04)
SON	Baseline	7.67	7.67
SON	2050	0.90 (0.68, 1.29)	1.18 (0.89, 1.69)
SON	2070	1.23 (0.93, 1.77)	1.92 (1.45, 2.76)
SON	2090	1.38 (1.05, 1.99)	2.76 (2.09, 3.98)
ANN	Baseline	8.16	8.16
ANN	2050	0.99 (0.76, 1.40)	1.30 (1.00, 1.84)
ANN	2070	1.36 (1.04, 1.92)	2.13 (1.63, 3.00)
ANN	2090	1.53 (1.17, 2.16)	3.06 (2.34, 4.32)

16a



16b

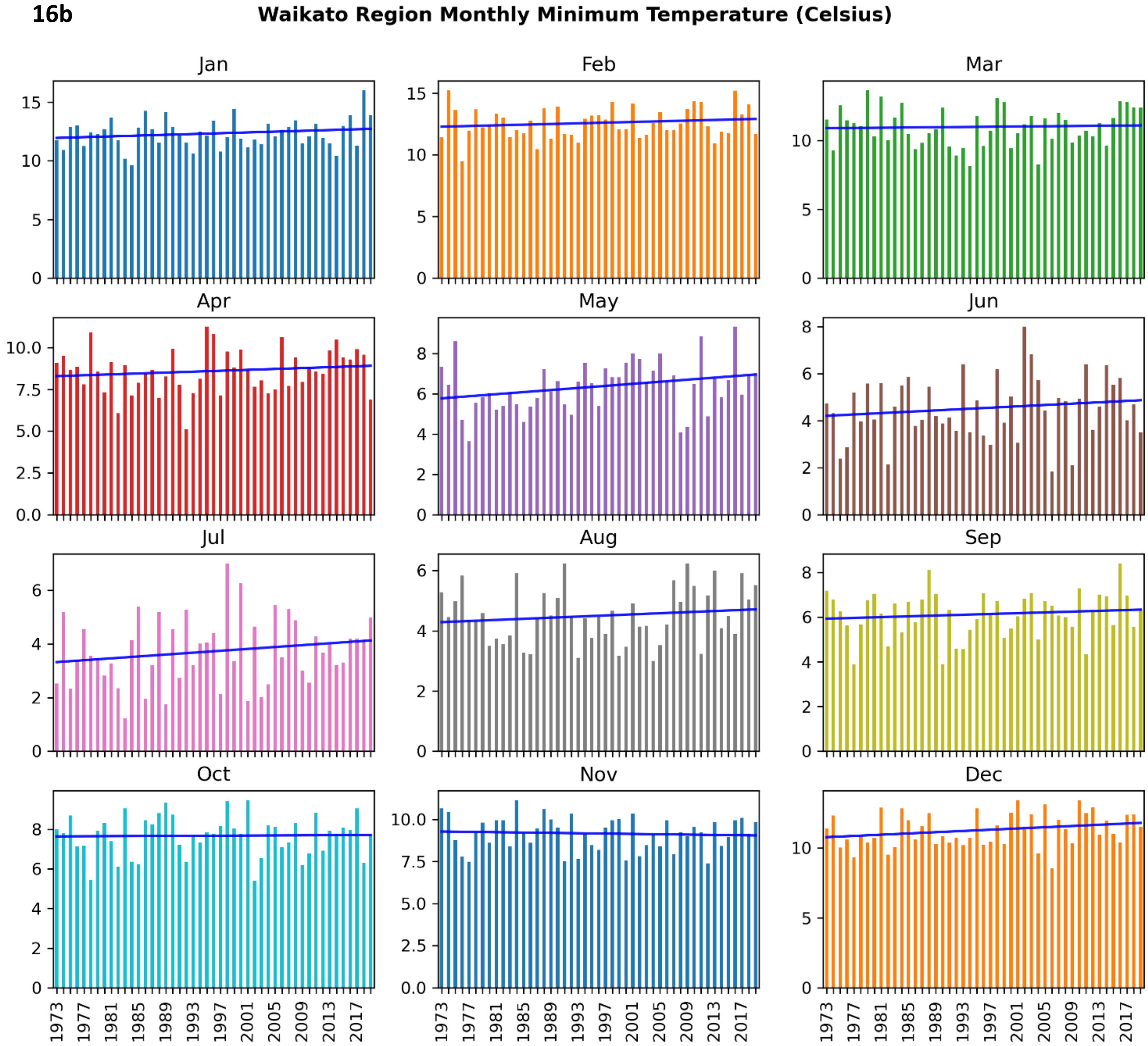


Figure 16: Waikato Region Annual (16a) and Monthly (16b) Minimum Temperature (Celsius)

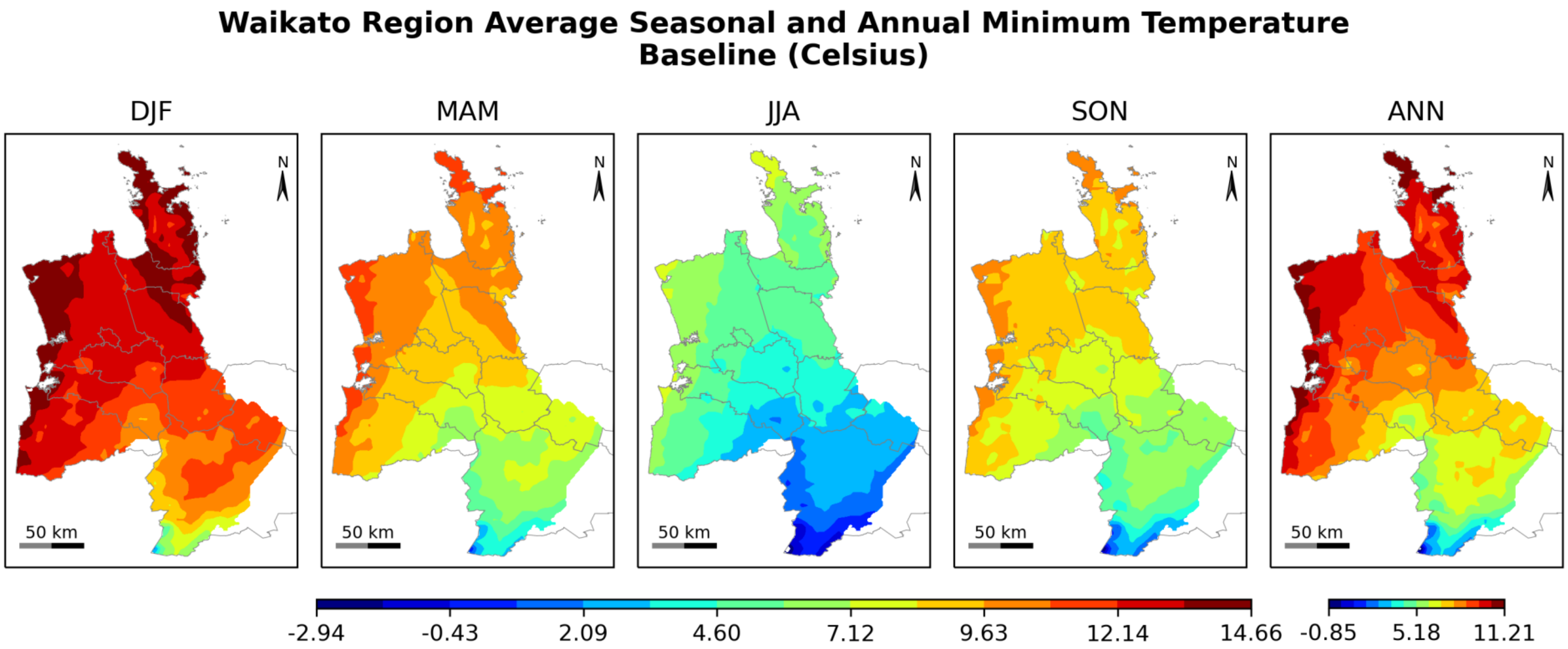


Figure 17: Waikato Region Average Seasonal and Annual Minimum Temperature Baseline (Celsius) and Changes (Celsius)

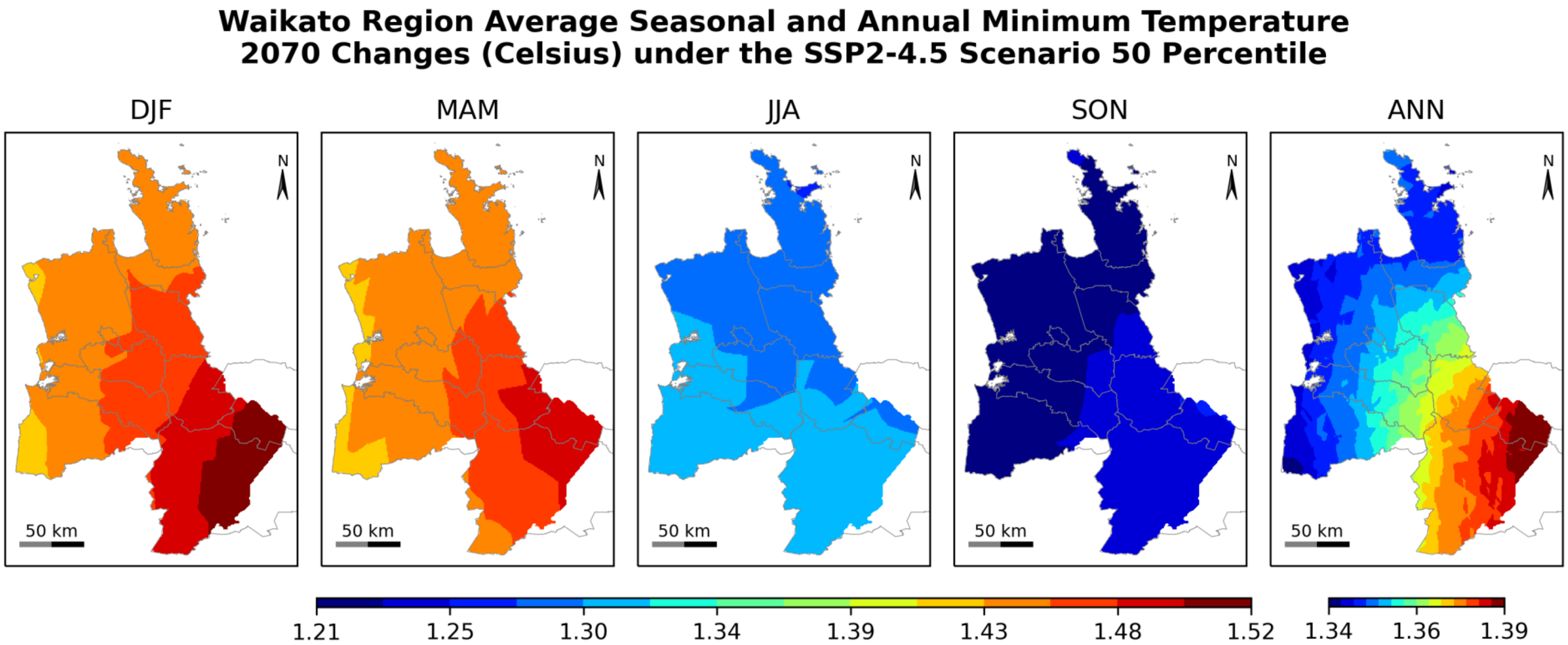


Figure 18: Waikato Region Average Seasonal and Annual Minimum Temperature Baseline (Celsius) and Changes (Celsius)

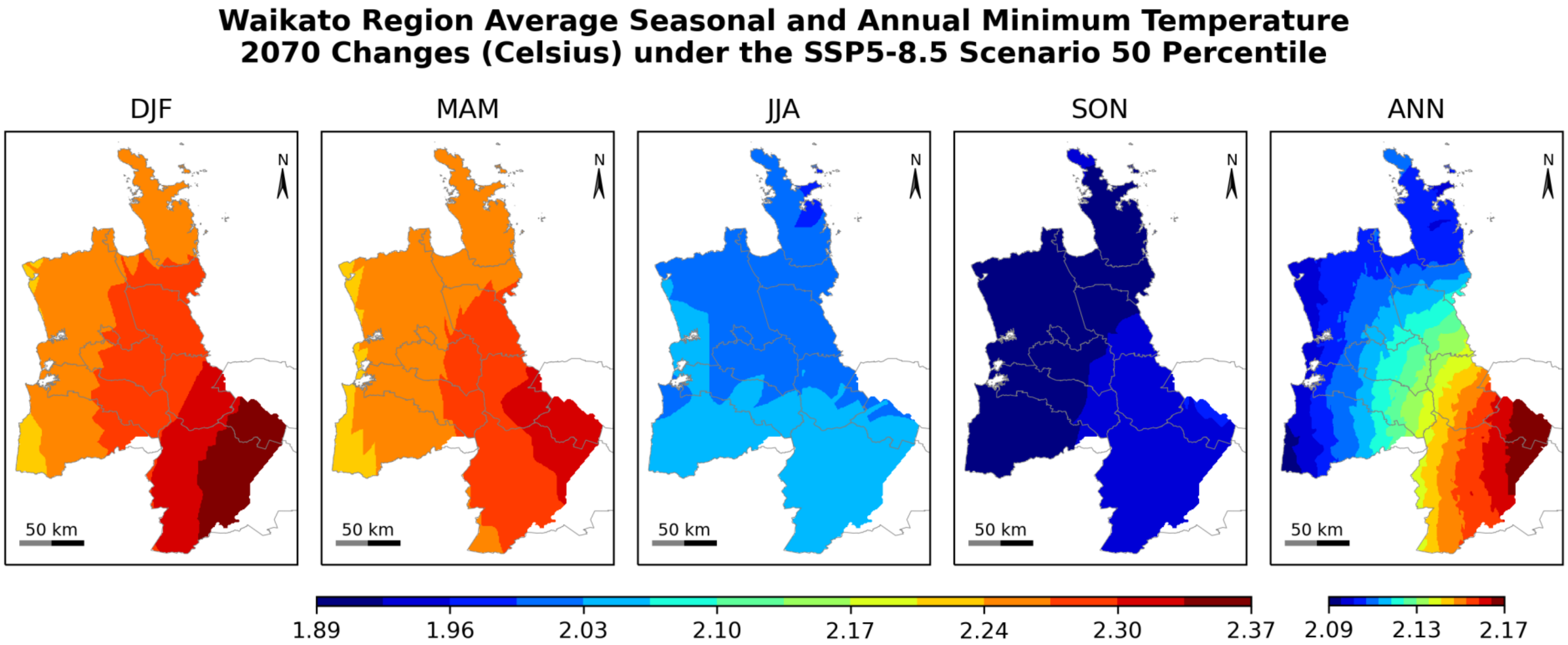
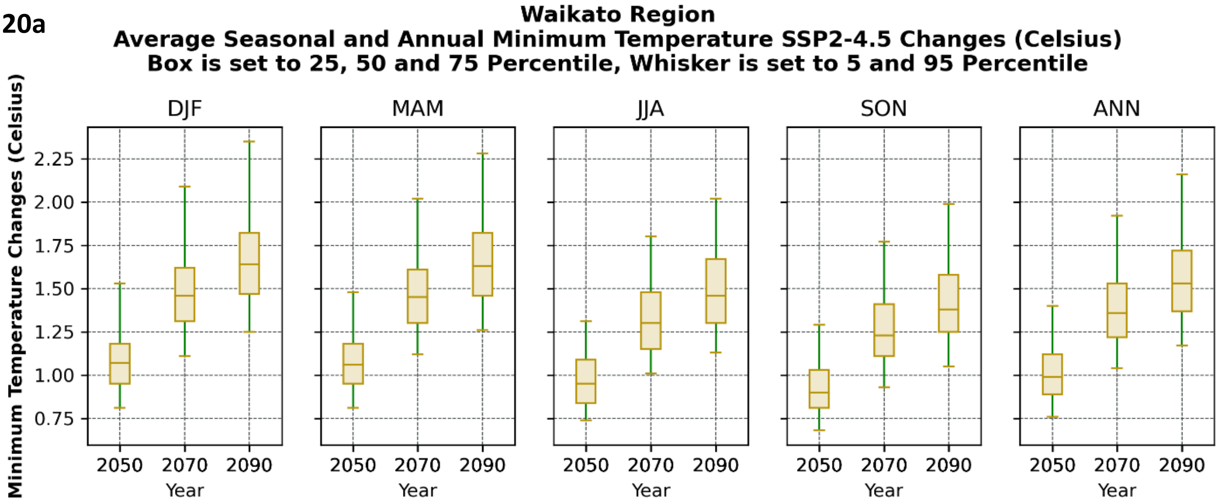


Figure 19: Waikato Region Average Seasonal and Annual Minimum Temperature Changes (Celsius)

20a



20b

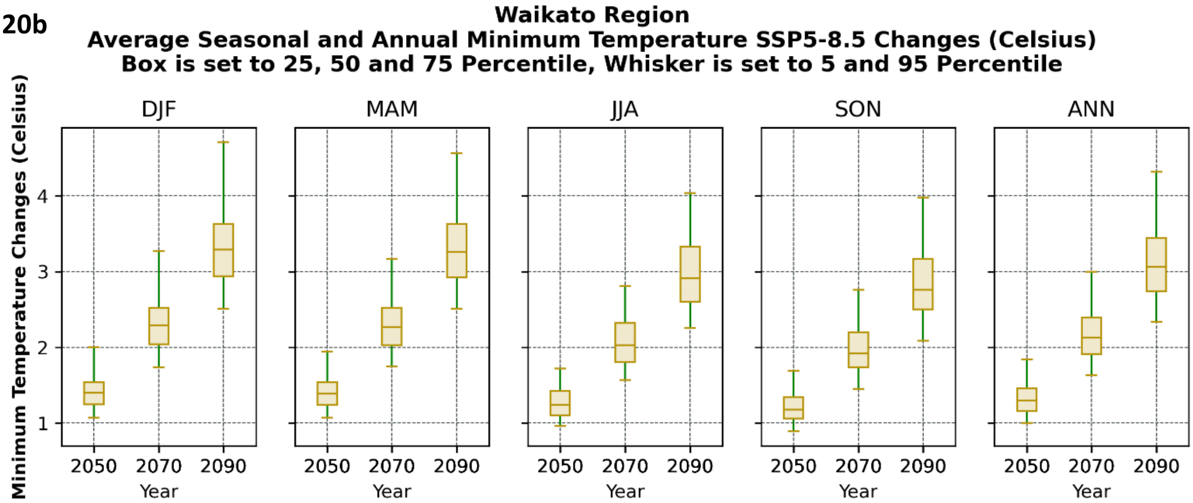


Figure 20: Waikato Region Average Seasonal and Annual Minimum Temperature Changes (Celsius) for Scenario SSP2-4.5 (20a) and SSP5-8.5 (20b)

7: Average Seasonal and Annual Precipitation

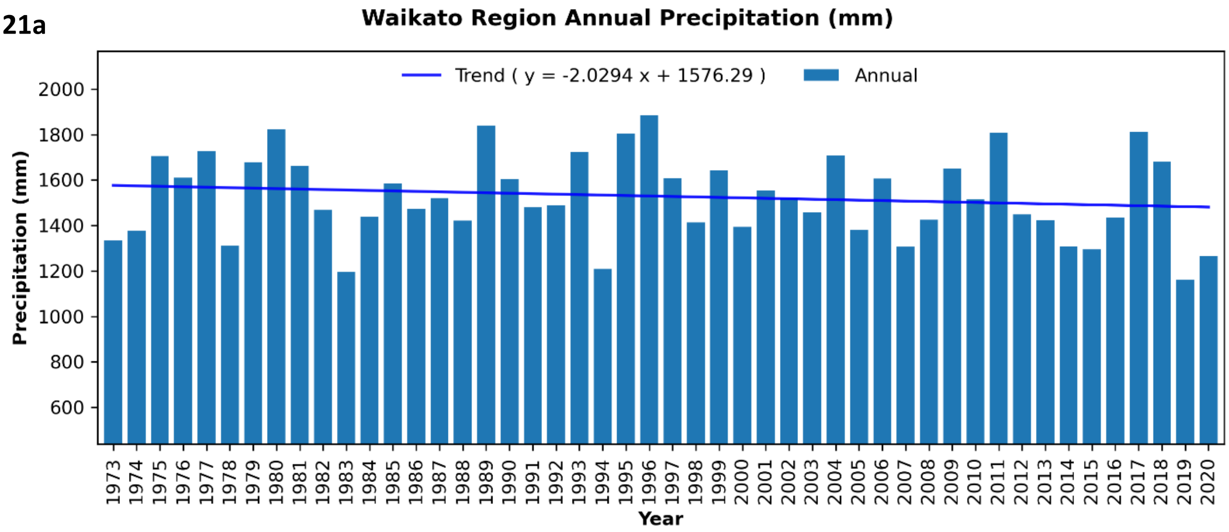
Based on the precipitation data from the baseline 1973 to 2020, the annual mean precipitation in Waikato region has a decreasing linear trend of 20.3 mm per decade. The interannual variabilities need to be considered, especially in recent years, the precipitation hit the historical low in Waikato region. The regional areal average annual precipitation is 1493 mm, with winter months (JJA) receiving 473 mm, and summer months (DJF) only 297 mm as the summer dry season.

Based on the ensemble median, the model scenario shows less than 1% decrease for annual precipitation, with very wide bounds from -33.9% to 40.0%. Therefore there is no clear signal detected in annual precipitation. The seasonal trends vary, with marginal increases in the summer and winter but more prominent declines in precipitation over the autumn and spring months. Under SSP2-4.5, the annual precipitation is expected to decline by 0.23% in 2090, relative to the baseline. The SSP5-8.5 results are more extreme, with more significant seasonal shifts, compared to the baseline year. For example, the spring months of September, October and November are expected to experience a decline in precipitation of more than 2% in 2050 and nearly 5% by 2090.

Table 5: Waikato Region Average Seasonal and Annual Precipitation Baseline (mm) and Changes (%)

Season	Year	SSP2-4.5 (05Pth, 95Pth)	SSP5-8.5 (05Pth, 95Pth)
DJF	Baseline	297.21	297.21
DJF	2050	0.06 (-11.89, 15.83)	0.08 (-15.54, 20.70)
DJF	2070	0.08 (-16.27, 21.67)	0.13 (-25.42, 33.85)
DJF	2090	0.09 (-18.28, 24.35)	0.19 (-36.57, 48.71)
MAM	Baseline	350.11	350.11
MAM	2050	-0.24 (-10.70, 15.96)	-0.31 (-13.99, 20.87)
MAM	2070	-0.32 (-14.65, 21.85)	-0.51 (-22.87, 34.13)
MAM	2090	-0.37 (-16.45, 24.56)	-0.73 (-32.91, 49.11)
JJA	Baseline	472.63	472.63
JJA	2050	1.18 (-7.86, 11.23)	1.55 (-10.28, 14.69)
JJA	2070	1.62 (-10.76, 15.38)	2.53 (-16.81, 24.02)
JJA	2090	1.82 (-12.09, 17.28)	3.64 (-24.18, 34.56)
SON	Baseline	373.45	373.45
SON	2050	-1.59 (-13.68, 8.92)	-2.08 (-17.89, 11.66)
SON	2070	-2.18 (-18.73, 12.20)	-3.40 (-29.26, 19.06)
SON	2090	-2.45 (-21.05, 13.71)	-4.89 (-42.10, 27.43)
ANN	Baseline	1493.40	1493.40
ANN	2050	-0.15 (-11.03, 12.99)	-0.19 (-14.43, 16.98)
ANN	2070	-0.20 (-15.10, 17.78)	-0.31 (-23.59, 27.77)
ANN	2090	-0.23 (-16.97, 19.98)	-0.45 (-33.94, 39.95)

21a



21b

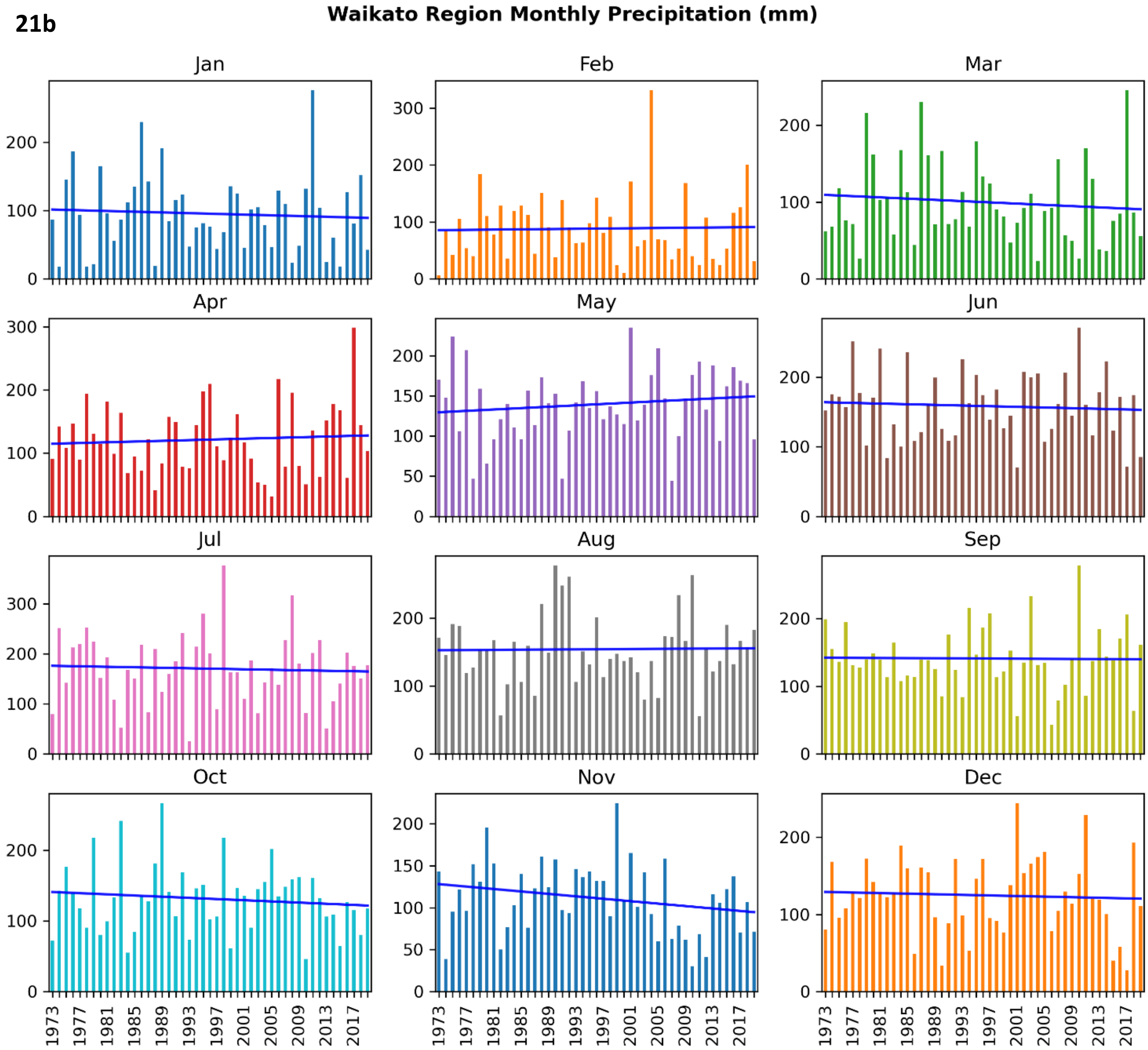


Figure 21: Waikato Region Annual (21a) and Monthly (21b) Precipitation (mm)

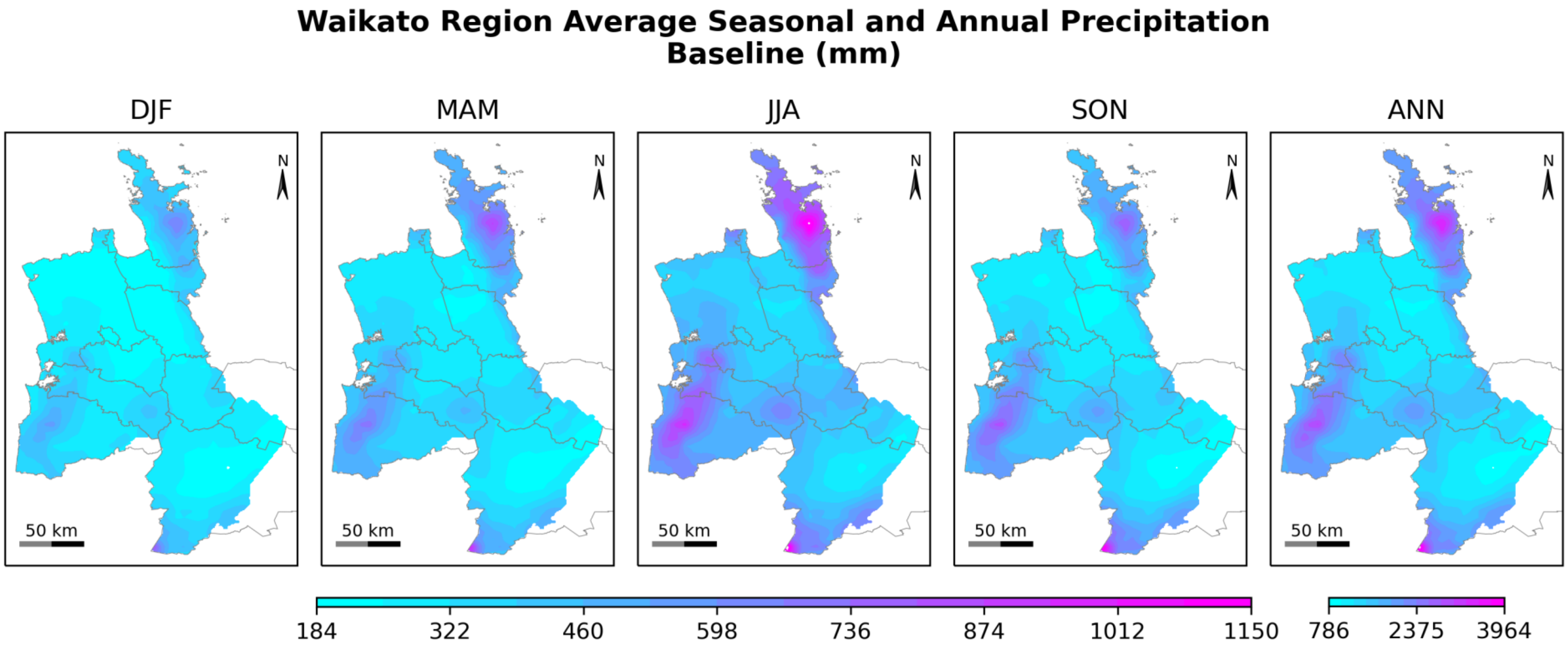


Figure 22: Waikato Region Average Seasonal and Annual Precipitation Baseline (mm)

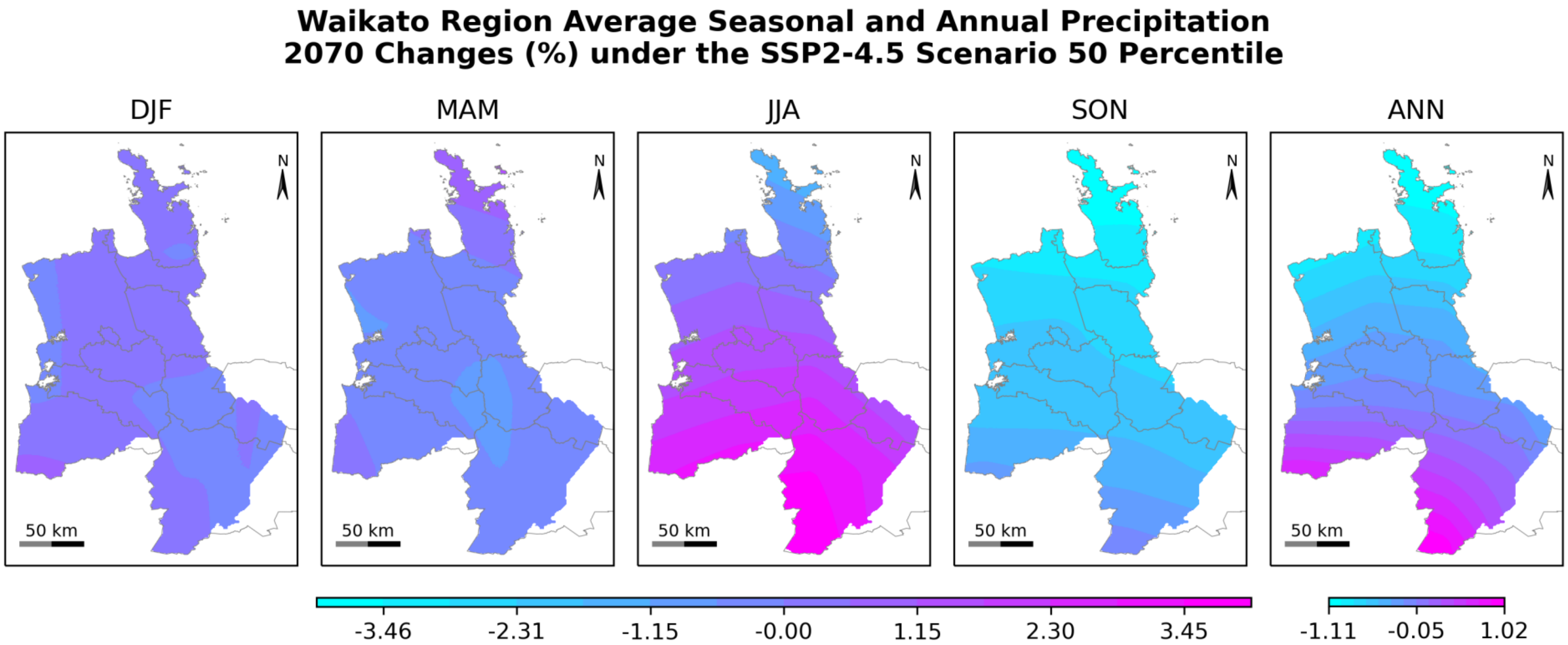


Figure 23: Waikato Region Average Seasonal and Annual Precipitation Changes (%)

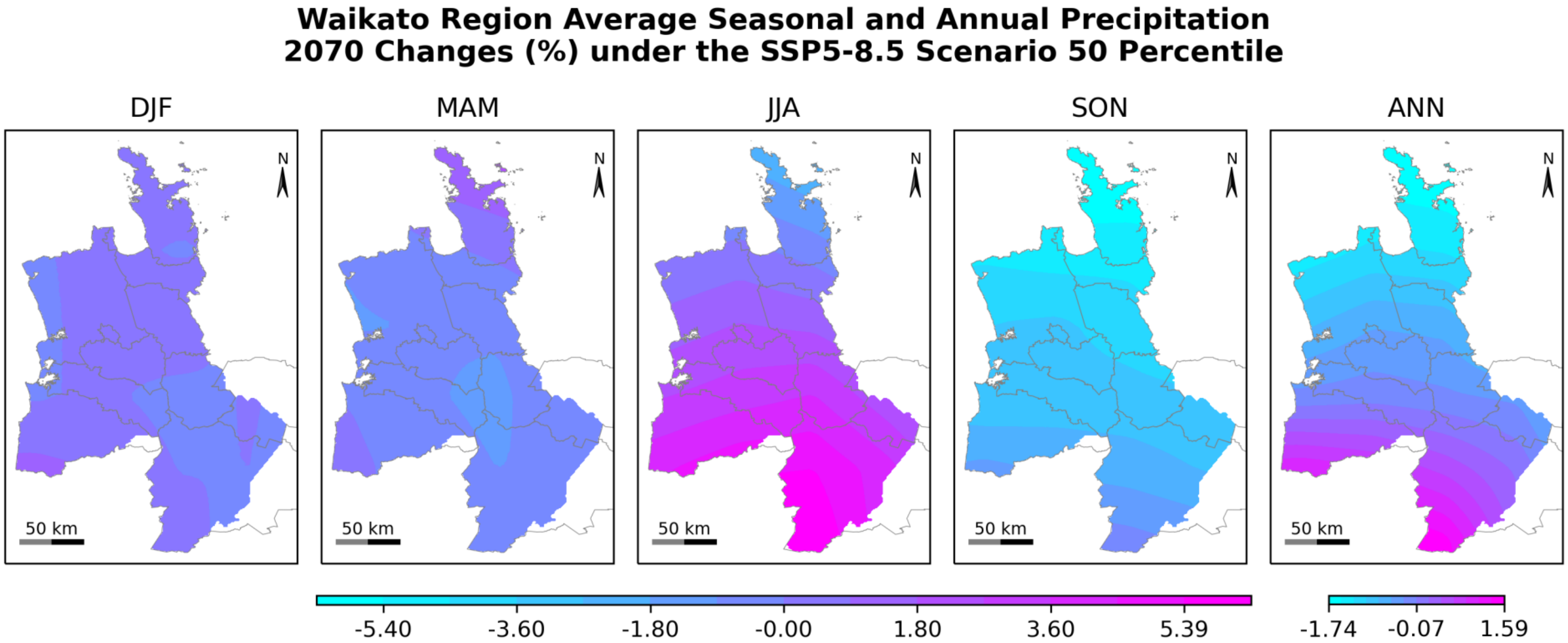
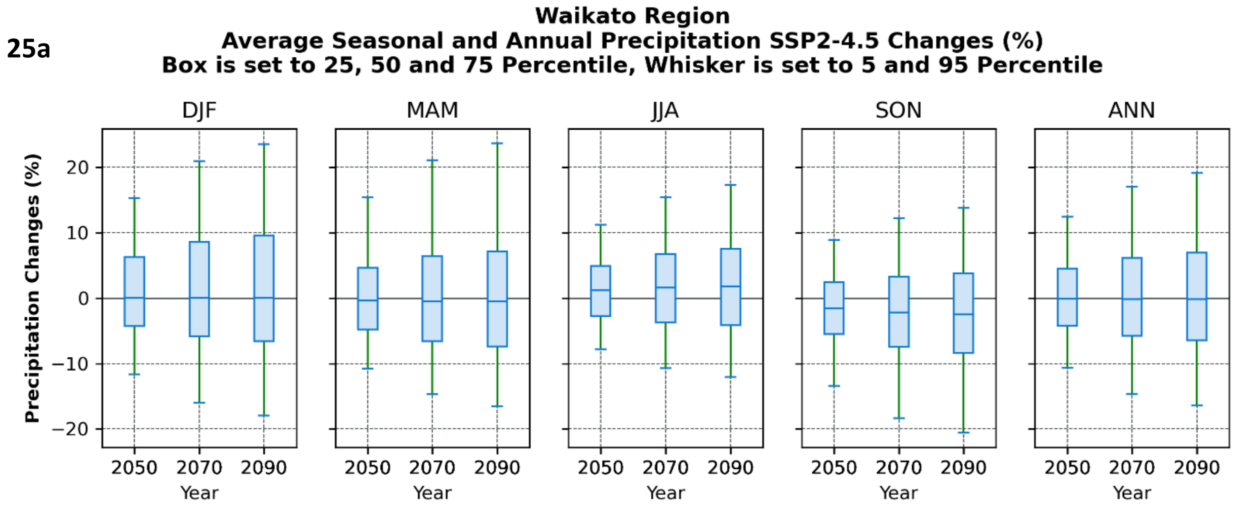


Figure 24: Waikato Region Average Seasonal and Annual Precipitation Changes (%)



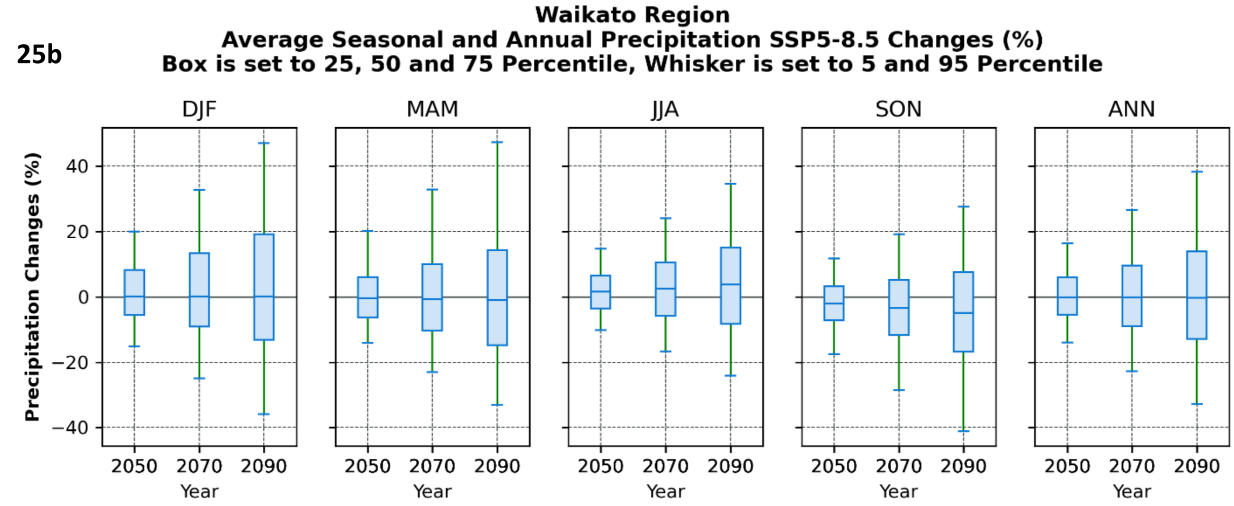


Figure 25: Waikato Region Average Seasonal and Annual Precipitation Changes (%) for Scenario SSP2-4.5 (25a) and SSP5-8.5 (25b)

8: Average Seasonal and Annual Runoff

The historical runoff data applied in this study is NOAH modelling data. In this report we applied the annual and seasonal long term mean as the baseline (1981-2020), and the future change factors were derived from GCM runoff outputs, which is an indicator of potential changes in future surface water resources. The change factors are not the results of pattern scaling but reflect the direct differences between historical and scenarios simulation of GCMs, therefore, it shows the increase or decrease, in nonlinear change signals with temperature change.

Under SSP2-4.5, the average annual runoff of the Waikato Region is expected to decline in 2050 and 2070 but then increase in 2090, relative to the baseline. Comparably, under SSP5-8.5, the average annual runoff of the Waikato Region is predicted to increase by 0.39% in 2050 and more than 7 % in 2090. Across both SSPs, there are no clear seasonal trends. For example, during the summer months under SSP2-4.5, the runoff decreases by 3.92% in 2050 to nearly 66% in 2090. Nevertheless, during the summer months under SSP5-8.5, the runoff declines by 1.59% in 2050 but increases by more than 13.60 % in 2090 relative to the baseline.

Changes are small and there is no consistent pattern (there are increases and decreases in runoff). Largest decreases are (as a median of model ensemble predictions) on the order of -6% (DJF SSP2-4.5 2090), whereas the largest increase was 16% (MAM SSP5-8.5 2090).

Table 6: Waikato Region Average Seasonal and Annual Runoff Baseline (mm) and Changes (%)

Season	Year	SSP2-4.5 (05Pth, 95Pth)	SSP5-8.5 (05Pth, 95Pth)
DJF	Baseline	36.56	36.56
DJF	2050	-3.92 (-42.98, 59.69)	-1.59 (-38.17, 57.23)
DJF	2070	-3.51 (-52.87, 54.73)	2.66 (-39.44, 65.74)
DJF	2090	-5.99 (-62.15, 65.96)	13.60 (-32.31, 81.81)
MAM	Baseline	26.71	26.71
MAM	2050	-3.83 (-42.95, 76.86)	2.09 (-42.35, 81.58)
MAM	2070	-1.17 (-45.50, 68.62)	7.57 (-36.13, 91.40)
MAM	2090	5.25 (-74.99, 71.90)	16.10 (-32.62, 94.35)
JJA	Baseline	60.13	60.13
JJA	2050	-1.22 (-28.87, 31.33)	3.70 (-31.91, 48.39)
JJA	2070	3.53 (-40.71, 40.68)	3.12 (-22.85, 52.02)
JJA	2090	5.28 (-53.81, 45.58)	4.97 (-29.32, 55.81)
SON	Baseline	65.19	65.19
SON	2050	-5.10 (-33.47, 37.91)	-2.63 (-35.31, 38.98)
SON	2070	-4.46 (-43.92, 30.21)	-2.65 (-36.19, 39.95)
SON	2090	-4.10 (-53.29, 47.76)	-5.45 (-37.69, 48.19)
ANN	Baseline	188.58	188.58
ANN	2050	-3.52 (-37.07, 51.45)	0.39 (-36.94, 56.55)
ANN	2070	-1.40 (-45.75, 48.56)	2.67 (-33.65, 62.27)
ANN	2090	0.11 (-61.06, 57.80)	7.30 (-32.99, 70.04)

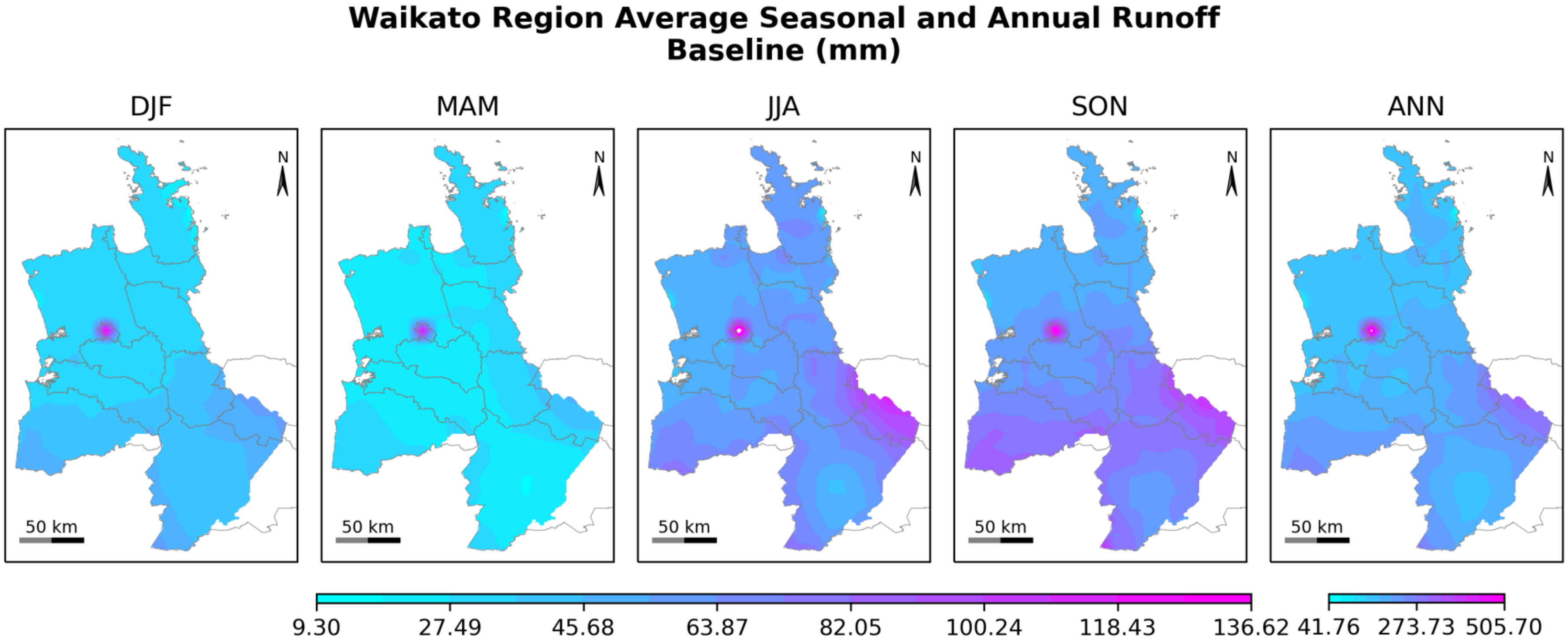


Figure 26: Waikato Region Average Seasonal and Annual Runoff Baseline (mm)

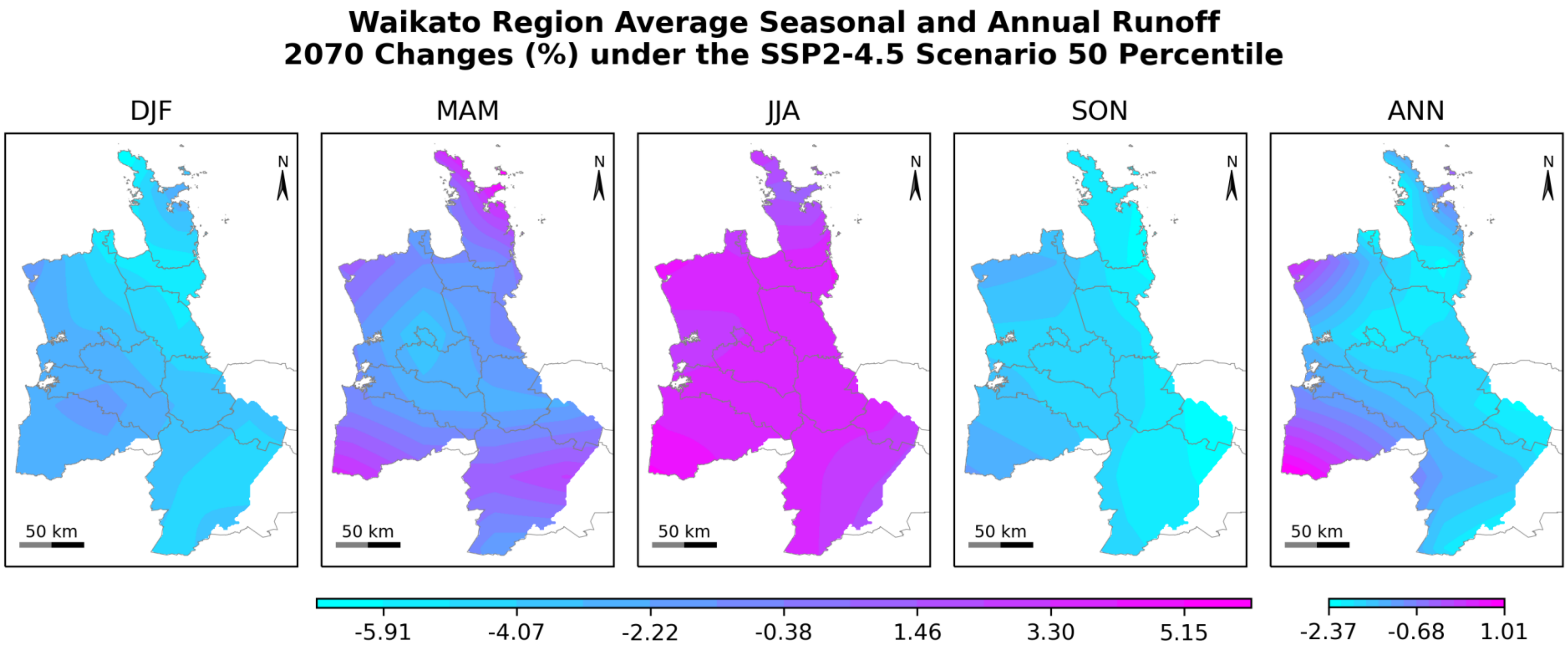


Figure 27: Waikato Region Average Seasonal and Annual Runoff 2070 (mm) and Changes (%) SSP5-8.5

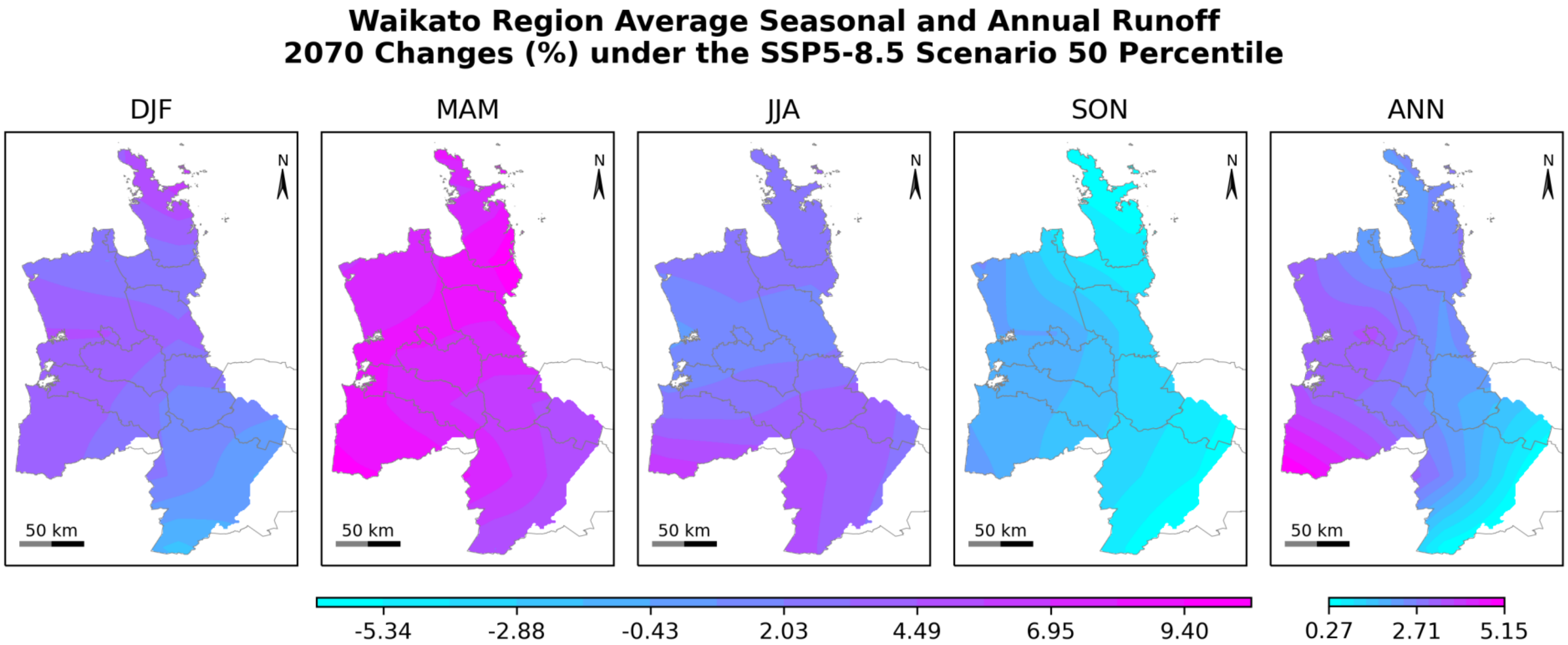
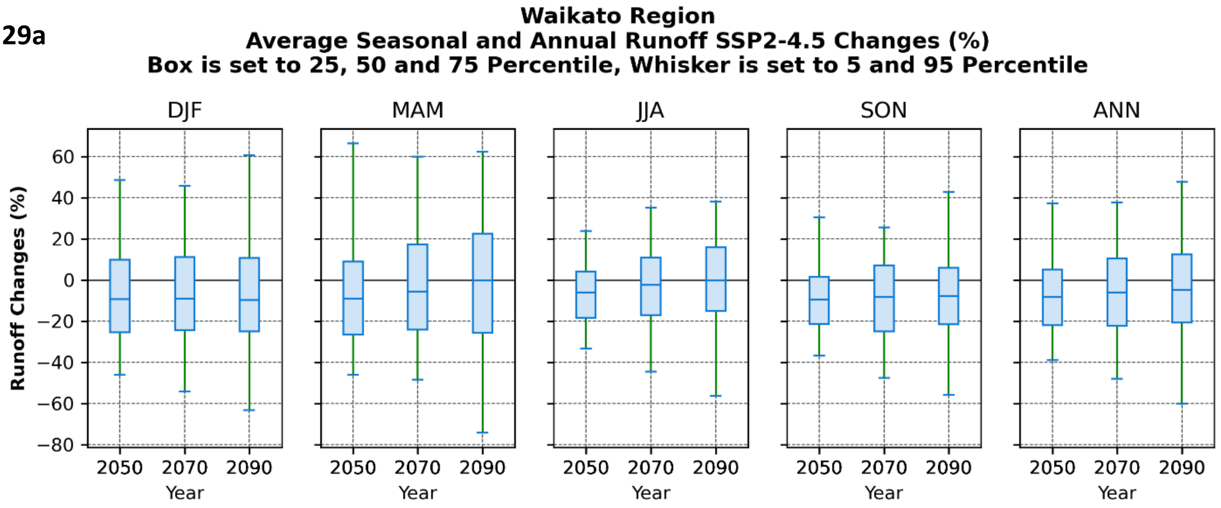


Figure 28: Waikato Region Average Seasonal and Annual Runoff 2070 (mm) and Changes (%) SSP2-4.5

29a



29b

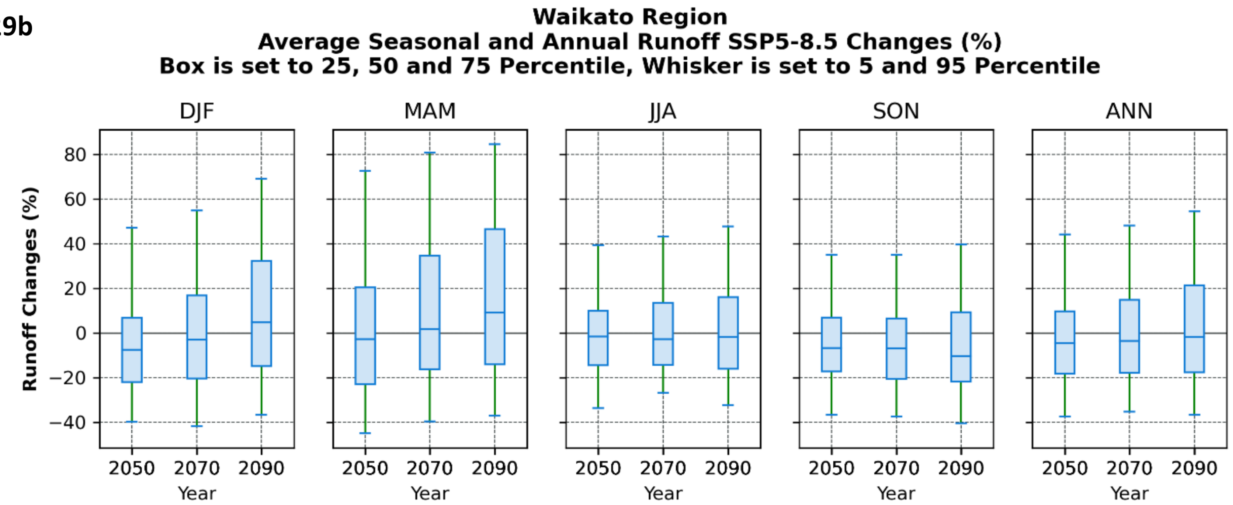


Figure 29: Waikato Region Average Seasonal and Annual Runoff Baseline (mm) and Changes (%) for Scenario SSP2-4.5 (29a) and SSP5-8.5 (29b)

9: Average Seasonal and Annual Wind Speed

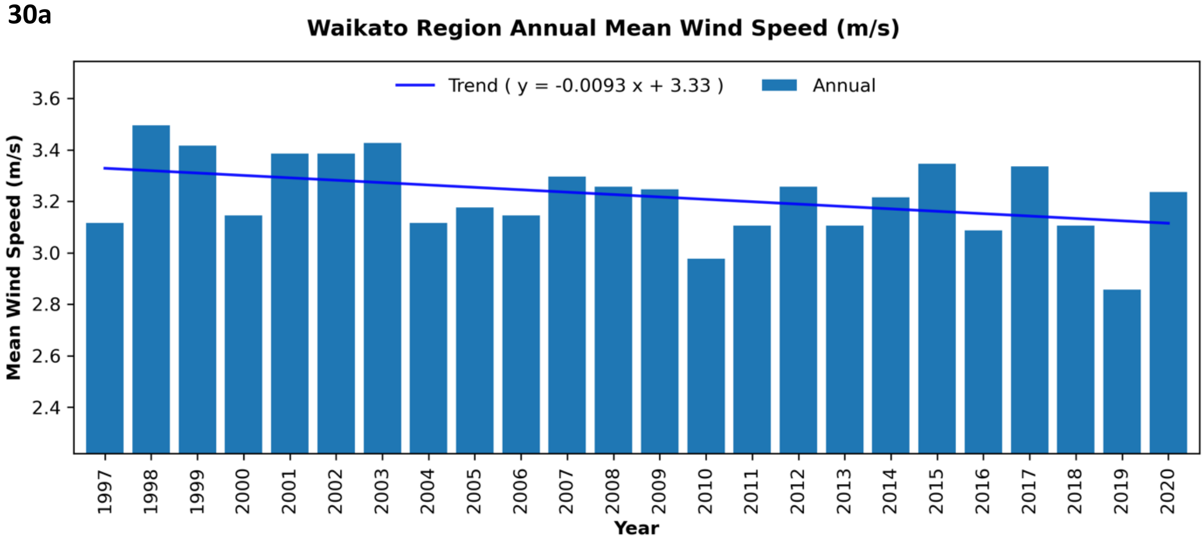
The historical annual mean wind speed in Waikato region 3.23 m/sec, or 11.62 km/hr, and the seasonal variations are not significant. Higher wind speeds occur in the Coromandel and West Coast areas. Based on the VCSN data 1997-2020, the average wind speed has a weak decreasing trend, 0.093 m/sec (0.335 kph) per decade.

Predicted changes for average annual and seasonal wind speed across the Waikato Region are relatively small (largest changes are on the order of 10%, with most changes <5%). Predicted changes are consistently negative for the DJF, MAM and ANN periods, whereas JJA and SON are close to zero.

Table 7: Waikato Region Average Seasonal and Annual Mean Wind Speed Baseline (m/s) and Changes (%)

Season	Year	SSP2-4.5 (05Pth, 95Pth)	SSP5-8.5 (05Pth, 95Pth)
DJF	Baseline	3.23	3.23
DJF	2050	-2.80 (-13.21, 9.18)	-3.65 (-17.27, 12.00)
DJF	2070	-3.83 (-18.08, 12.57)	-5.98 (-28.25, 19.63)
DJF	2090	-4.30 (-20.32, 14.12)	-8.61 (-40.64, 28.25)
MAM	Baseline	2.90	2.90
MAM	2050	-3.37 (-12.98, 9.44)	-4.41 (-16.98, 12.34)
MAM	2070	-4.62 (-17.77, 12.92)	-7.21 (-27.76, 20.19)
MAM	2090	-5.19 (-19.97, 14.52)	-10.37 (-39.94, 29.04)
JJA	Baseline	3.12	3.12
JJA	2050	0.32 (-12.32, 17.51)	0.42 (-16.11, 22.90)
JJA	2070	0.44 (-16.87, 23.98)	0.69 (-26.35, 37.45)
JJA	2090	0.50 (-18.95, 26.94)	1.00 (-37.91, 53.88)
SON	Baseline	3.66	3.66
SON	2050	0.62 (-9.89, 13.04)	0.81 (-12.93, 17.06)
SON	2070	0.84 (-13.54, 17.86)	1.32 (-21.15, 27.89)
SON	2090	0.95 (-15.21, 20.07)	1.90 (-30.42, 40.14)
ANN	Baseline	3.23	3.23
ANN	2050	-1.31 (-12.10, 12.29)	-1.71 (-15.82, 16.08)
ANN	2070	-1.79 (-16.57, 16.83)	-2.79 (-25.87, 26.29)
ANN	2090	-2.01 (-18.61, 18.91)	-4.02 (-37.23, 37.83)

30a



30b

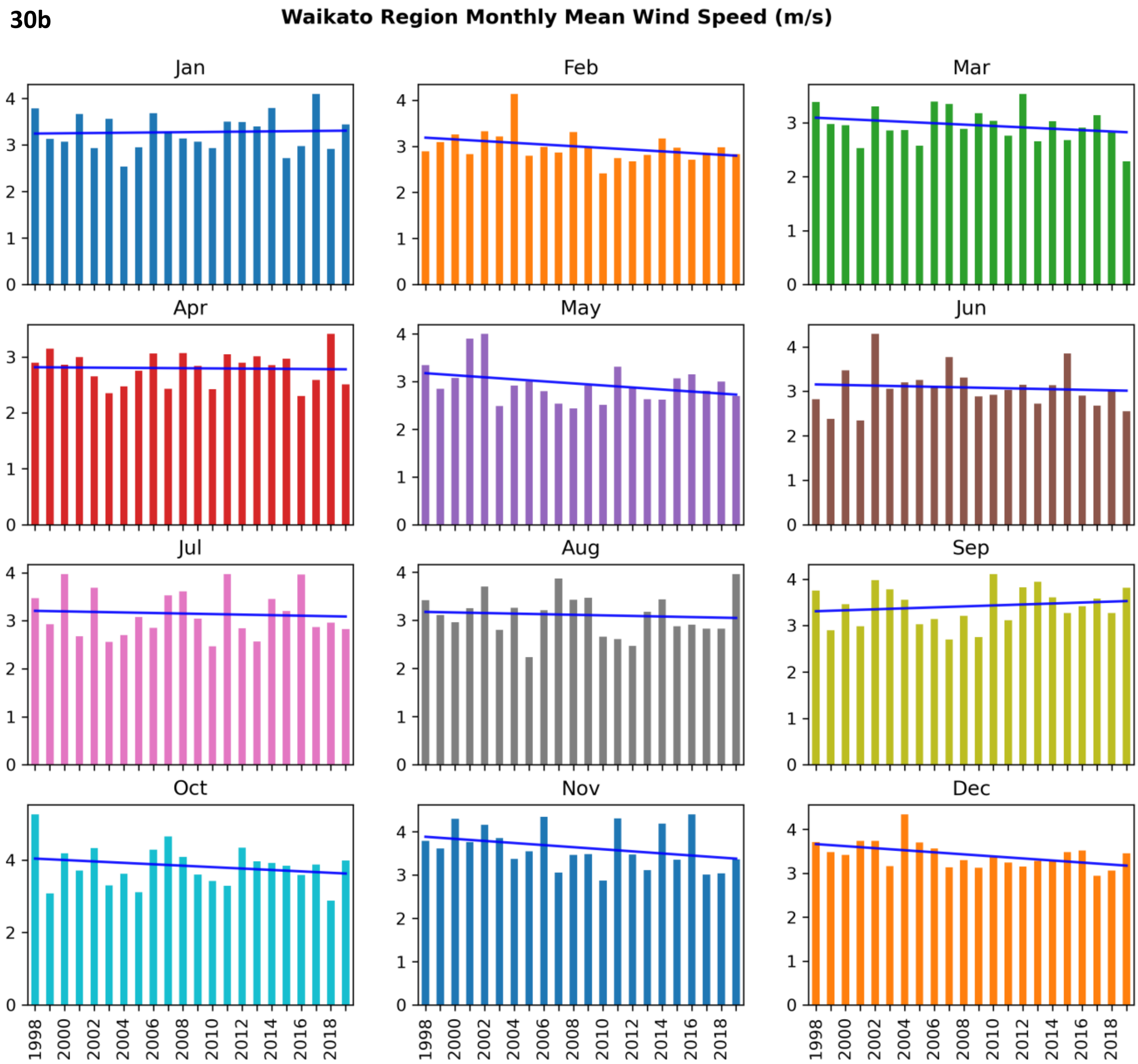


Figure 30: Waikato Region Annual (30a) and Monthly (30b) Mean Wind Speed (m/s)

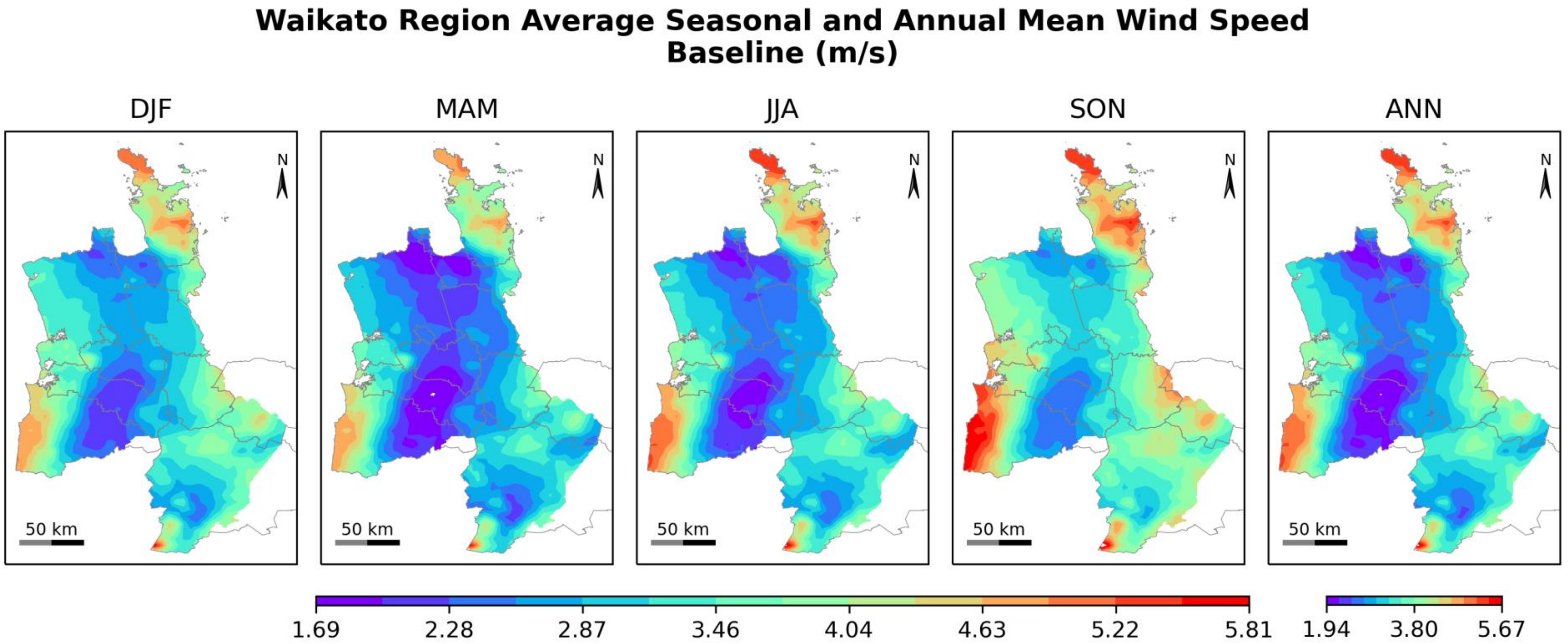


Figure 31: Waikato Region Average Seasonal and Annual Mean Wind Speed Baseline (m/s)

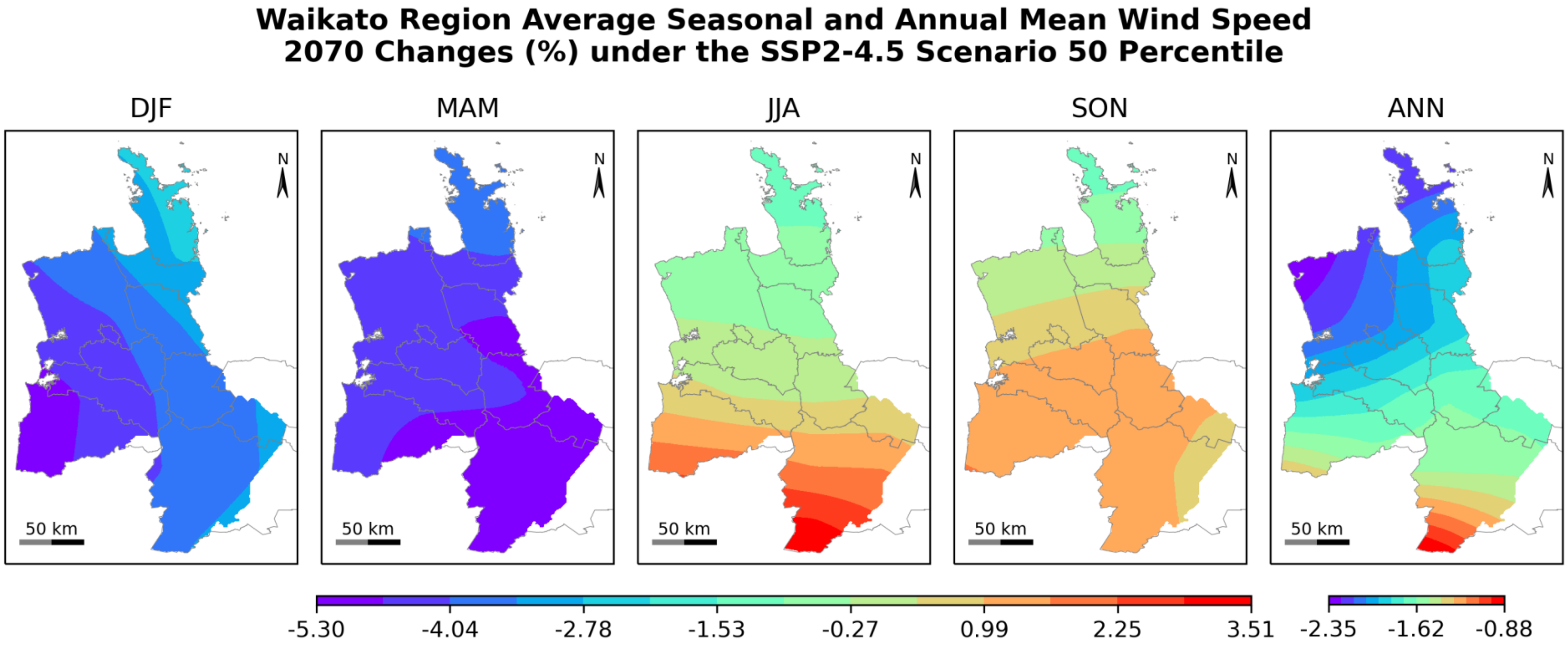


Figure 32: Waikato Region Average Seasonal and Annual Mean Wind Speed Changes (%)

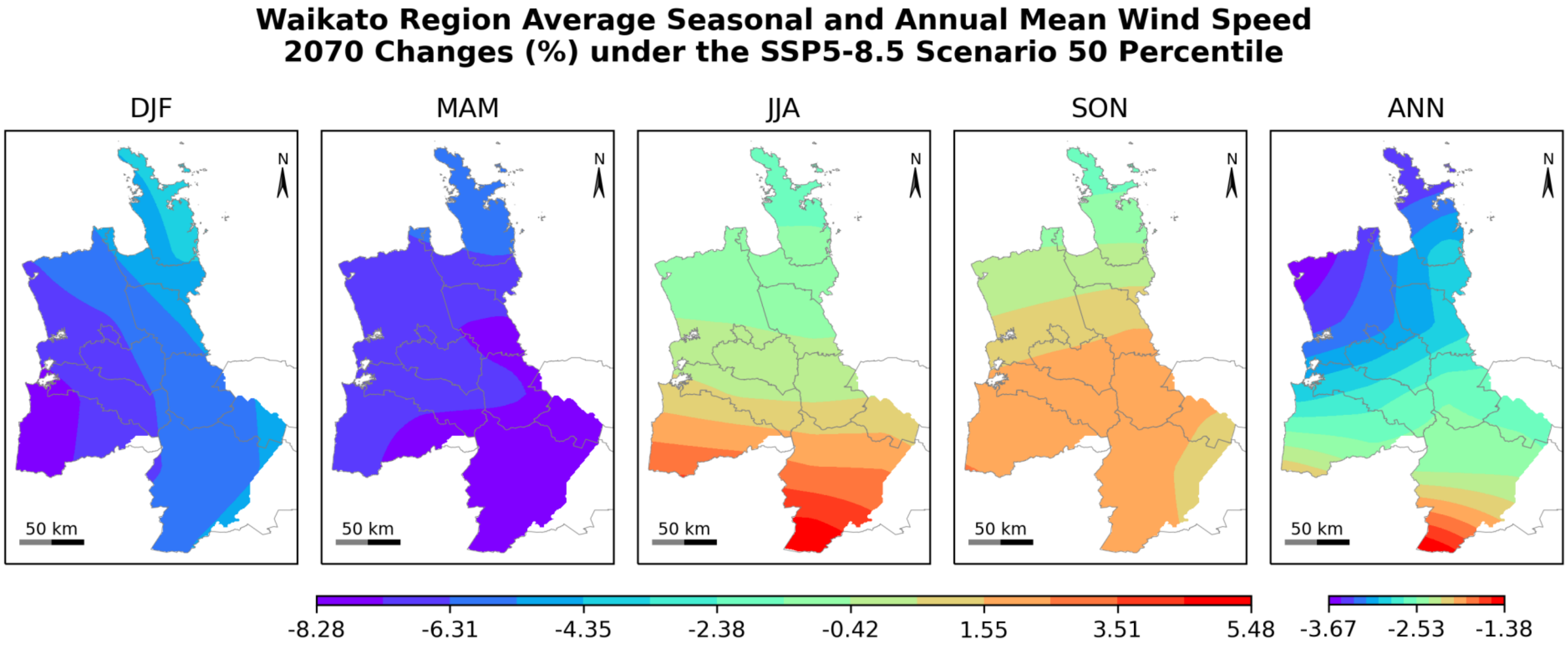
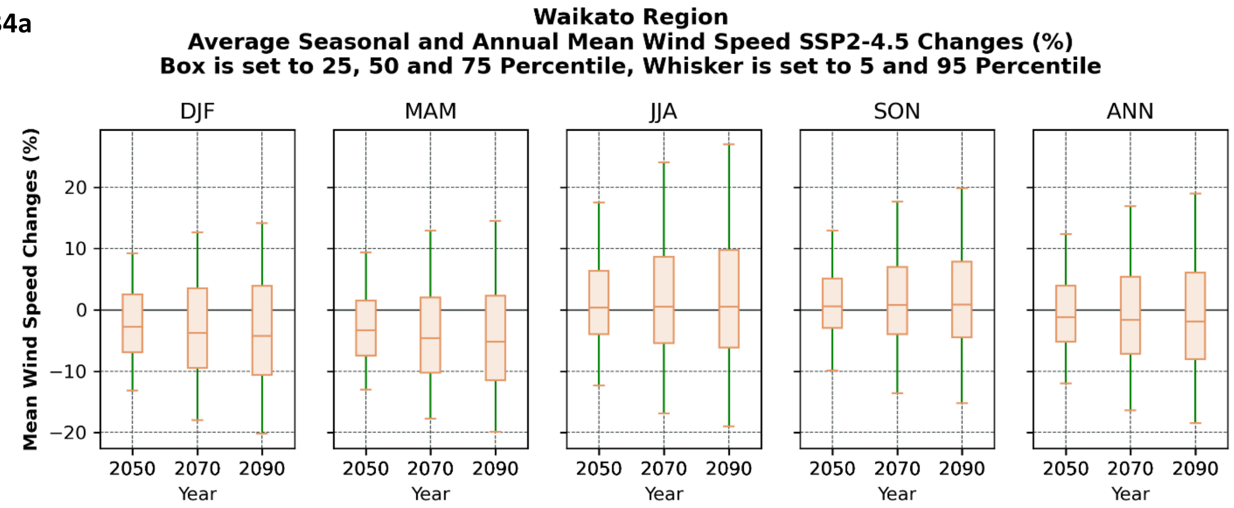


Figure 33: Waikato Region Average Seasonal and Annual Mean Wind Speed Changes (%)

34a



34b

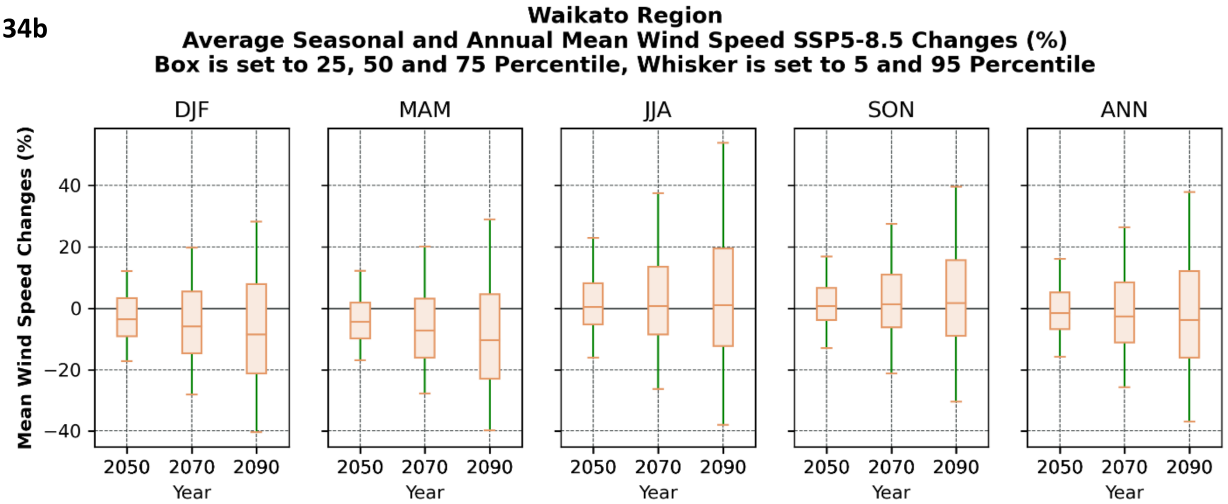


Figure 34: Waikato Region Average Seasonal and Annual Mean Wind Speed Changes (%) for Scenario SSP2-4.5 (34a) and SSP5-8.5 (34b)

10: Daily Extreme Precipitation

The historical daily extreme precipitation data is obtained from HIRDSv4. Average Return Interval (ARI) of 10, 20-, 50-, 100-, and 250-year data was analysed for the historical period. HIRDSv4 applied the historical precipitation records from the meteorological station setup up to earlier than 2016 (NIWA, High Intensity Rainfall Design System Version 4, 2018). In Waikato region, the highest extreme precipitation occurred in the Coromandel area, at more than 600 mm, representing a 250-year return period event, and low (as shown in the figures). The areal average of 100-year return daily extreme precipitation is 197 mm. The detailed statistics are presented in the district level reports.

Under the SSP2-4.5 scenario, the average daily extreme precipitation of the Waikato Region is expected to increase out to 2090 with greater changes as the average return intervals (ARIs) increase, compared to the baseline. Under the average return interval of 10 years, the average daily extreme precipitation increases by 9.1% in 2050 and 14.1% in 2090. This increasing trend is even more pronounced for the 250-year return interval, where daily extreme precipitation increases by 15.4% in 2050 and 23.7% by 2090.

In contrast to the no clear change in signal in annual total precipitation changes, there is stronger evidence of increasing extreme precipitation in all ARIs. Higher ARIs have large percentages of increase, that indicates rare events are getting more severe. The 5-95 percentile is ranged from -9.7% to 65.1% in 2090 ARI 250, and narrower in the lower ARIs.

Table 8: Waikato Region, Average Extreme Precipitation Baseline (mm/day) and Changes (%) under the SSP2-4.5 Scenario - 50th Percentile (Brackets 5th and 95th Percentile).

Year	ARI010	ARI020	ARI050	ARI100	ARI250
Baseline	129.13	148.56	175.64	197.07	226.25
2050	9.13 (2.06, 17.00)	9.68 (1.62, 18.87)	11.12 (-1.32, 26.14)	12.53 (-3.24, 31.58)	15.40 (-6.33, 42.34)
2070	12.50 (2.82, 23.28)	13.25 (2.21, 25.83)	15.22 (-1.80, 35.79)	17.16 (-4.43, 43.23)	21.08 (-8.66, 57.97)
2090	14.05 (3.17, 26.16)	14.89 (2.49, 29.03)	17.11 (-2.03, 40.21)	19.28 (-4.98, 48.58)	23.69 (-9.73, 65.13)

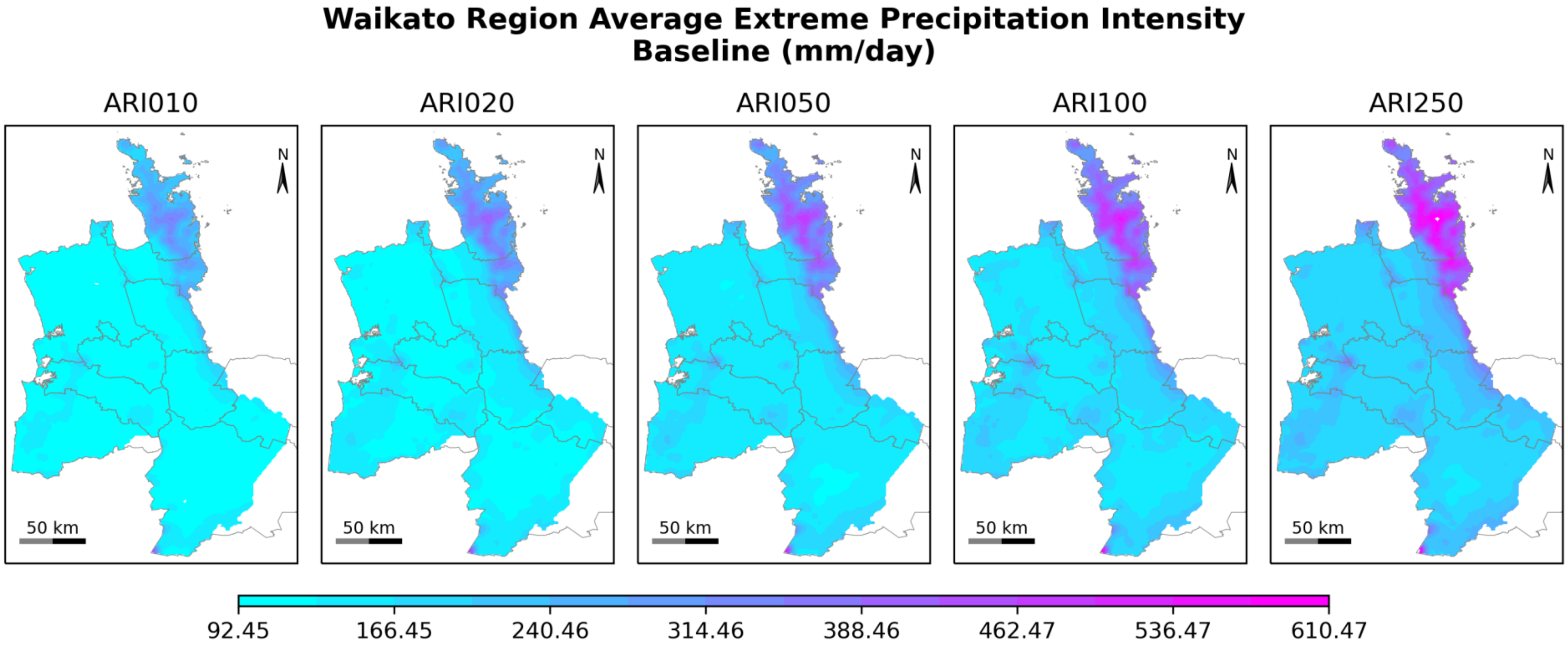


Figure 35: Waikato Region Average Daily Extreme Precipitation Intensity Baseline (mm/day) and under the SSP2-4.5 Scenario, 50 Percentile

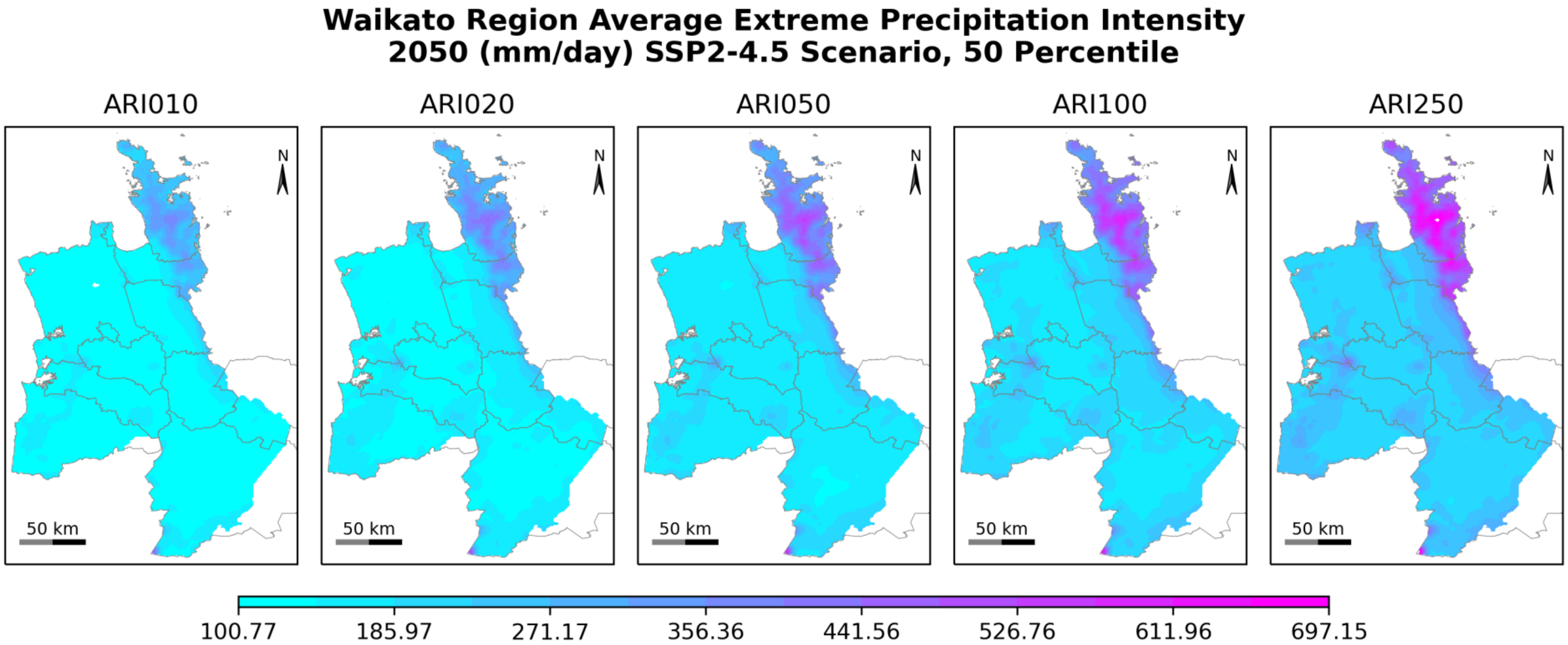


Figure 36: Waikato Region Average Daily Extreme Precipitation Changes (%) under the SSP2-4.5 Scenario

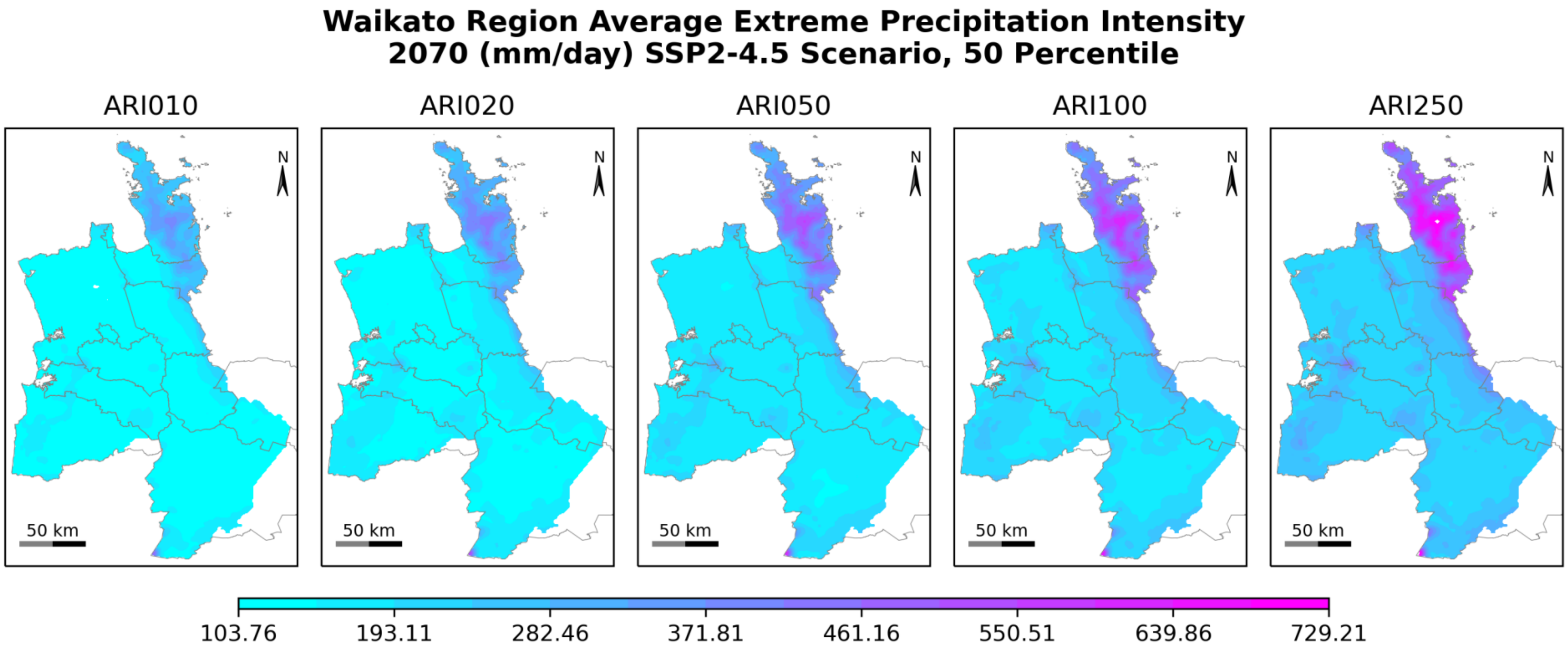


Figure 37: Waikato Region Average Daily Extreme Precipitation Intensity Baseline (mm/day) under the SSP2-4.5 Scenario, 50 Percentile

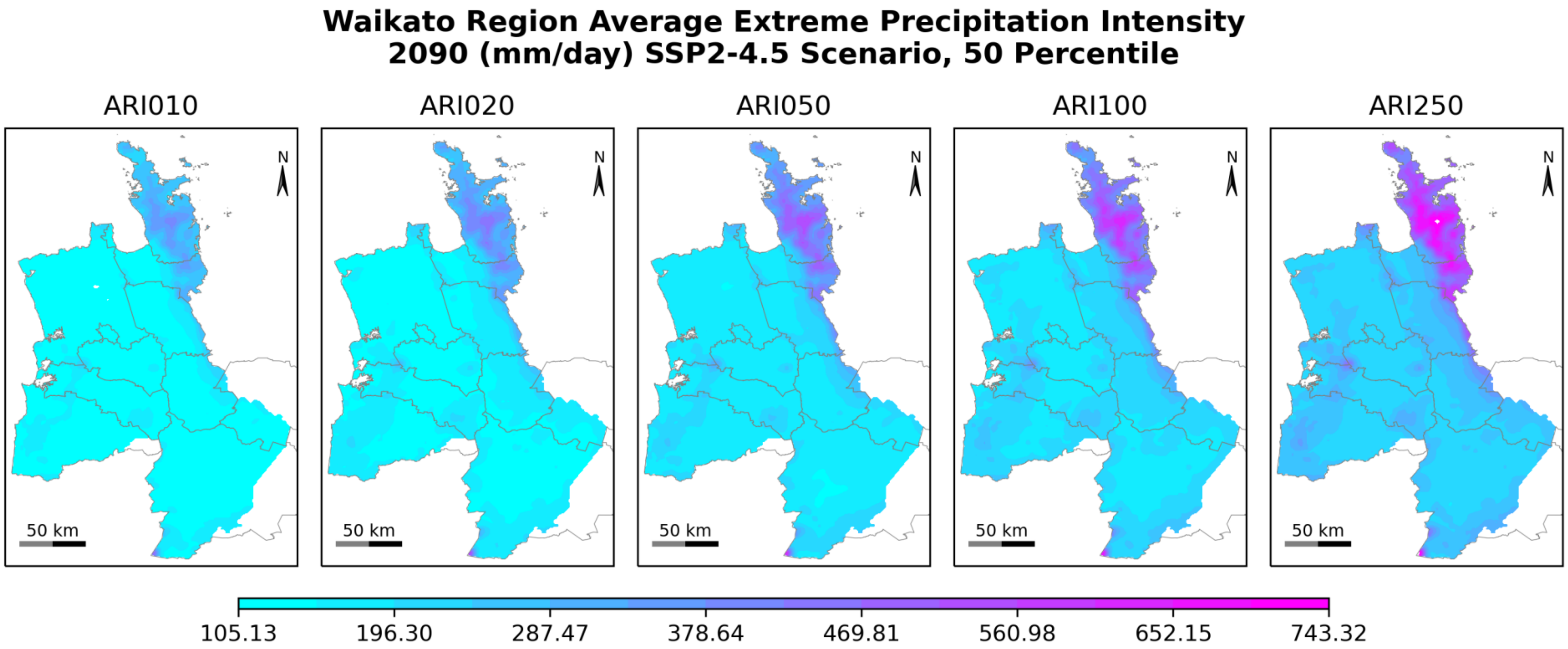


Figure 38: Waikato Region Average Daily Extreme Precipitation Intensity Baseline (mm/day) under the SSP2-4.5 Scenario, 50 Percentile

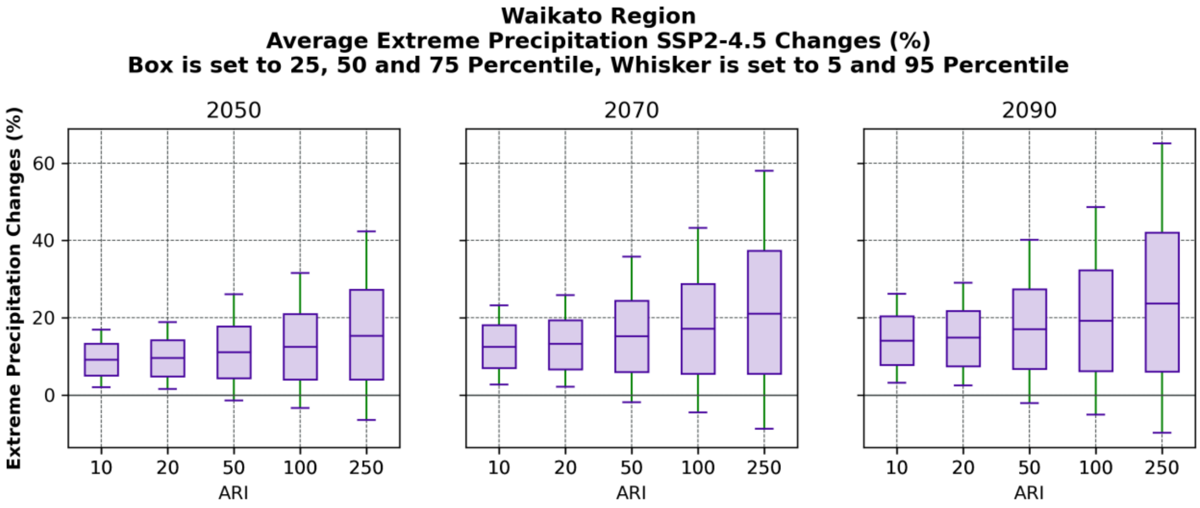


Figure 39: Waikato Region Average Daily Extreme Precipitation Intensity Baseline (mm/day) and under the SSP2-4.5 Scenario, 50 Percentile

Under the SSP5-8.5 scenario, the average daily extreme precipitation of the Waikato Region is expected to increase until 2090 with greater changes as the average return intervals (ARIs) increase, compared to the baseline year of 2005. Under the average return interval of 10 years, the average daily extreme precipitation increases by 11.0% in 2050 and 31.2% in 2090. This increasing trend is relatively consistent until the average return interval of 250 years, where daily extreme precipitation increases by more than 20% in 2050 and 47% in 2090.

Table 9: Waikato Region, Average Extreme Precipitation Baseline (mm/day) and Changes (%) under the SSP5-8.5 Scenario - 50th Percentile (Brackets 5th and 95th Percentile).

Year	ARI010	ARI020	ARI050	ARI100	ARI250
Baseline	129.13	148.56	175.64	197.07	226.25
2050	11.94 (2.70, 22.24)	12.66 (2.11, 24.67)	14.54 (-1.72, 34.18)	16.39 (-4.23, 41.29)	20.14 (-8.27, 55.36)
2070	19.53 (4.41, 36.36)	20.70 (3.45, 40.35)	23.78 (-2.82, 55.89)	26.80 (-6.92, 67.52)	32.93 (-13.53, 90.53)
2090	28.10 (6.35, 52.32)	29.78 (4.97, 58.05)	34.21 (-4.05, 80.42)	38.57 (-9.96, 97.16)	47.38 (-19.47, 130.27)

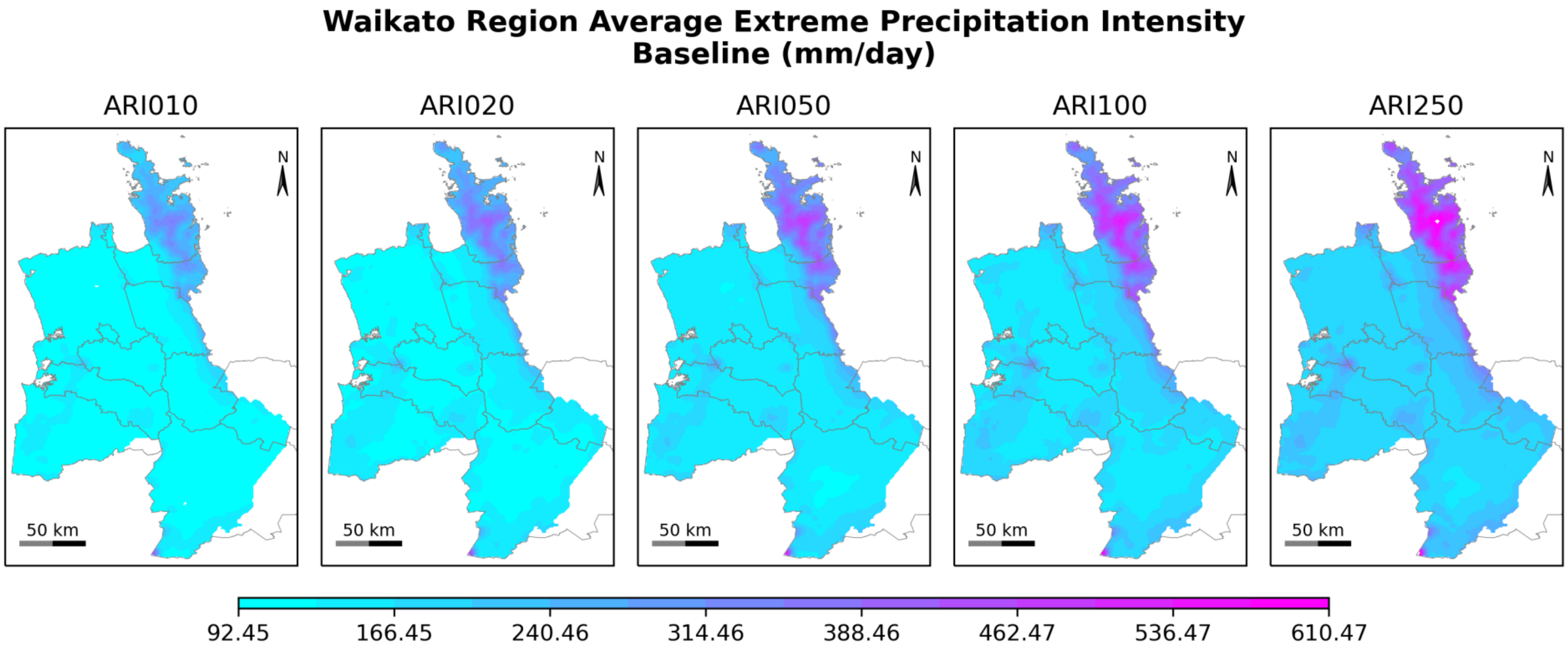


Figure 40: Waikato Region Average Daily Extreme Precipitation Intensity Baseline (mm/day)

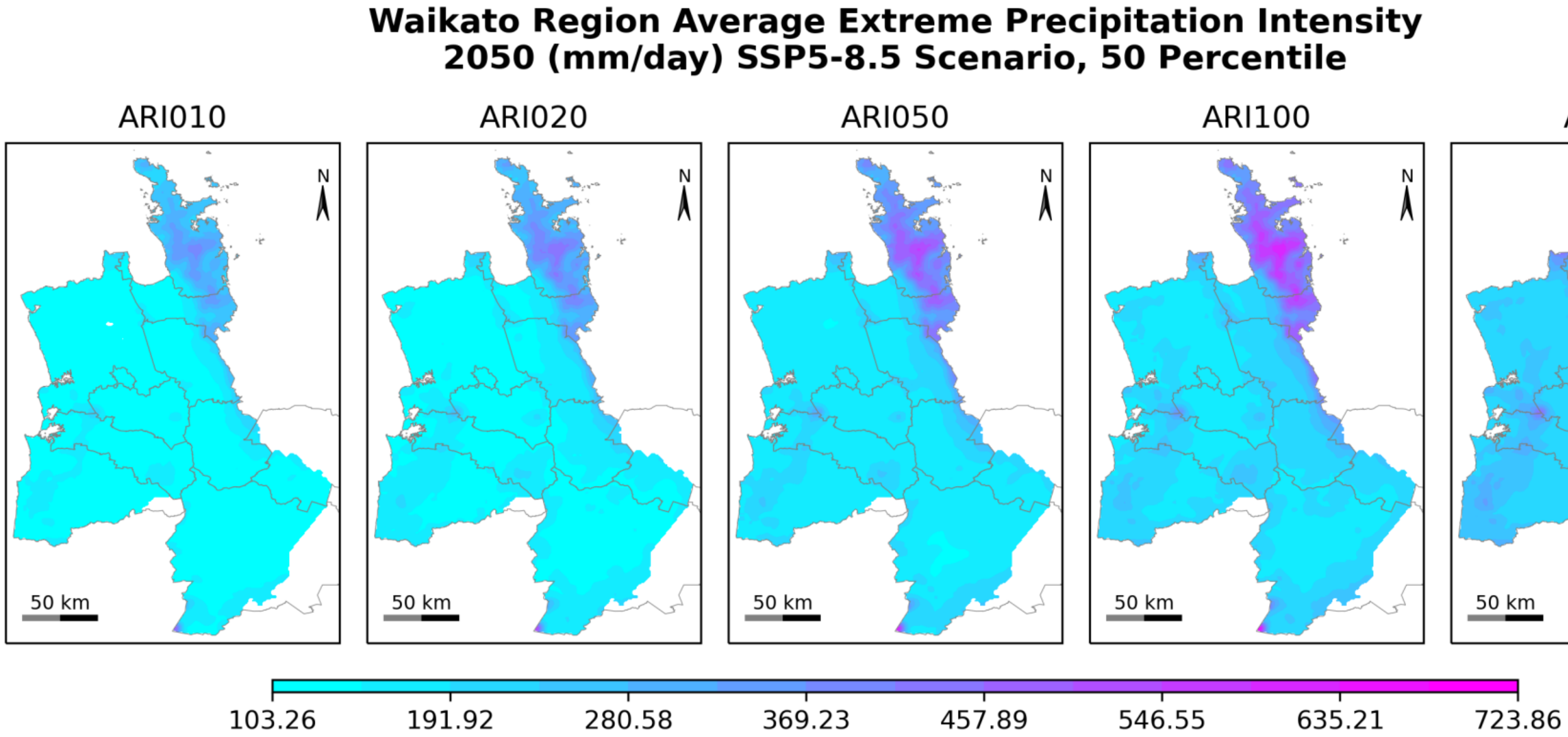


Figure 41: Waikato Region Average Daily Extreme Precipitation Intensity 2050 in (mm/day) under the SSP5-8.5 Scenario, 50 Percentile

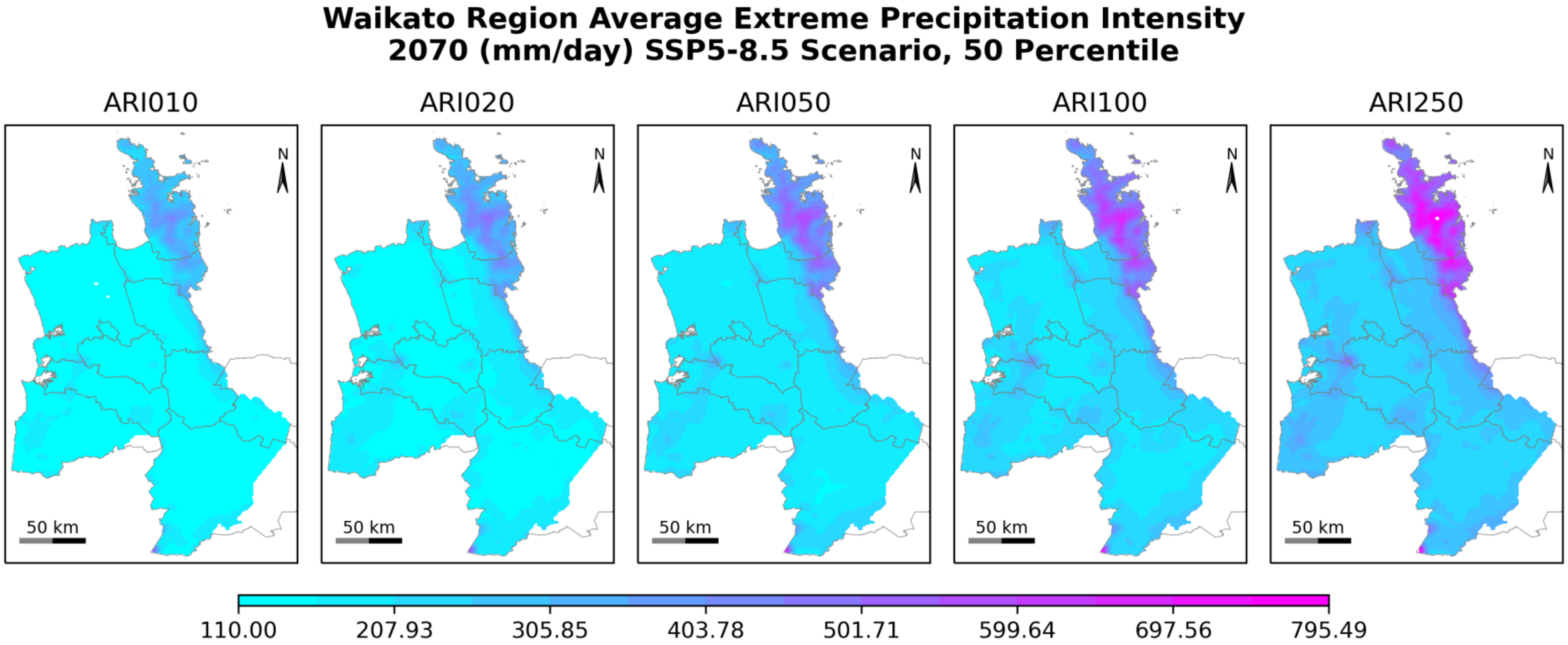


Figure 42: Waikato Region Average Daily Extreme Precipitation Intensity 2070 in (mm/day) under the SSP5-8.5 Scenario, 50 Percentile

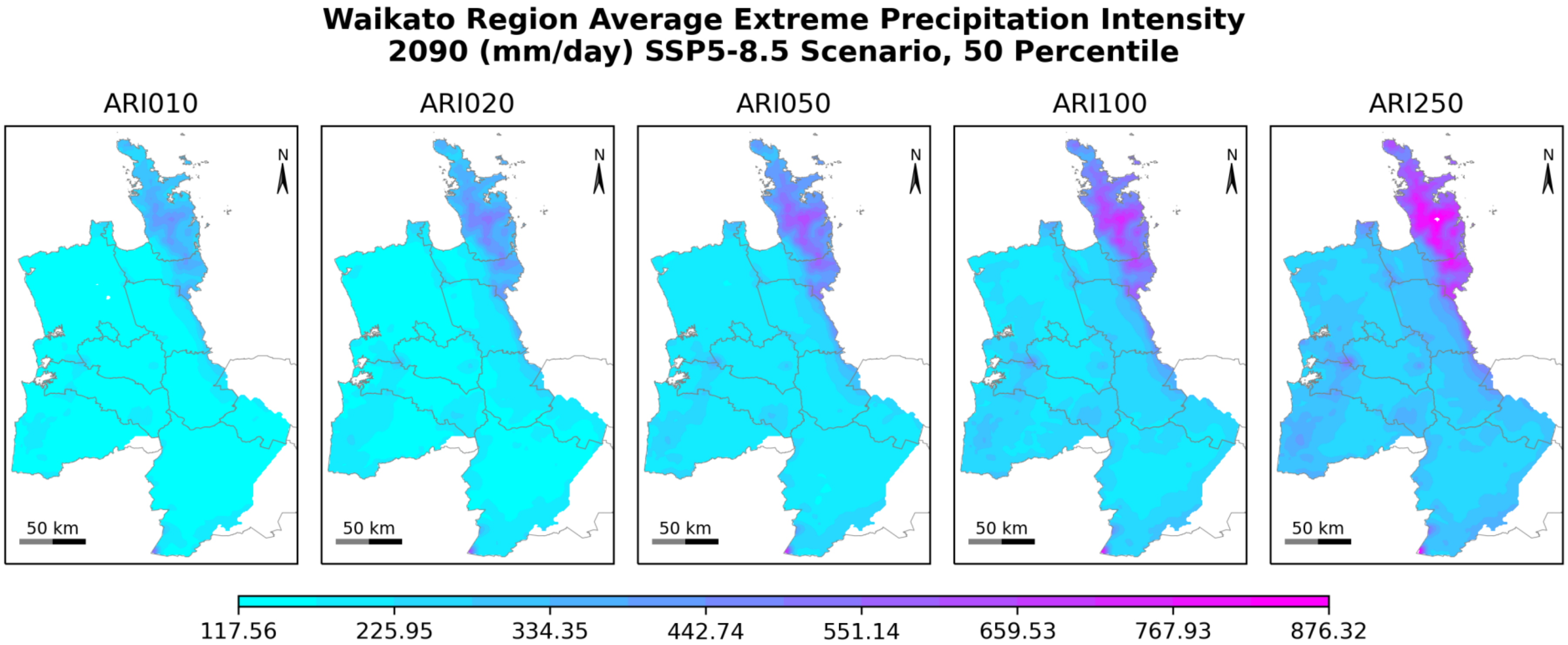


Figure 43: Waikato Region Average Daily Extreme Precipitation Intensity 2090 in (mm/day) under the SSP5-8.5 Scenario, 50 Percentile

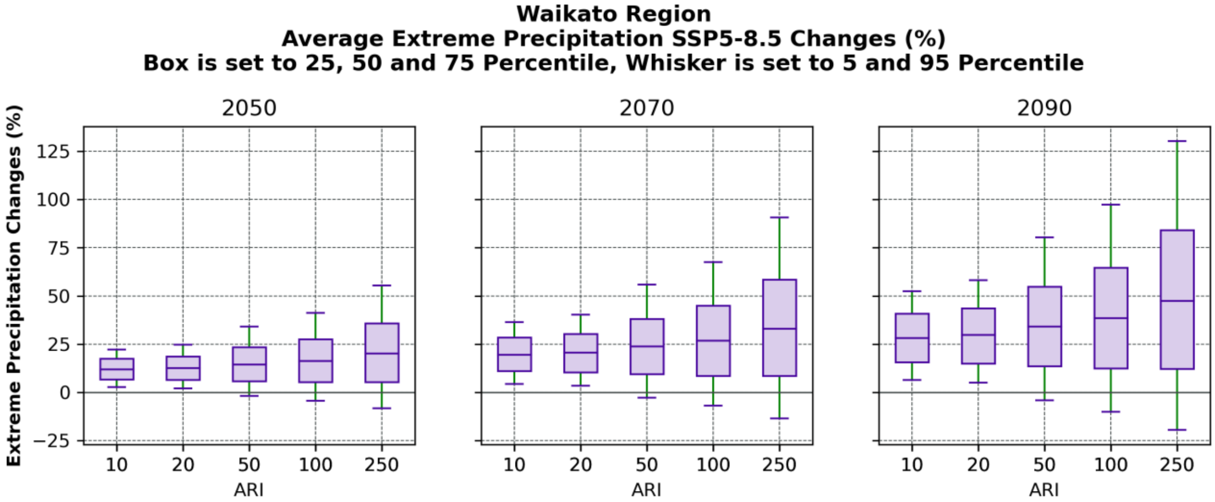


Figure 44: Waikato Region Average Daily extreme precipitation Changes (%) under the SSP5-8.5 Scenario

11: Extreme Wind Speed

Since historical gridded extreme wind speed data is unavailable, station-specific analysis was applied for the 31 stations which have more than 15 years of hourly wind speed data. Among the stations, – Cape Colville Aws in Thames-Coromandel District experienced the highest wind speed, 211.9 km/hr (kph), representing a 1 in100 year return event, while Te Kuiti Ews in Waitomo District experienced a 71.8 kph extreme wind speed for same return period. Hamilton Ruakura Ews experienced a 93.7 kph extreme wind speed as its historical 100-year return period event.

The variabilities of extreme wind change signals derived from GCMs are varied from -10% to 10% as the 5 and 95 percentile bounds, and a weakly decreasing signal in the 50th percentiles. Based on the precautionary principle, we listed the 75th percentiles of extreme wind speed, which could be the recommendation for decision-making. The extreme wind speed analysis suggests a mostly positive trend across the districts, following the 75th percentile. Data were collected from several stations of each district, except for South Waikato, which was not available. Most districts are expected to experience an increase in wind speed by 2090. Some of the most significant changes include an increase of 4.9% by 2090 compared to the Waitomo and Taupō District baseline. It is important to note the small variability in change (%) across most districts, suggesting similar changes in extreme wind speed.

Weather Stations Applied for Extreme Wind Speed Analysis
for Waikato Region

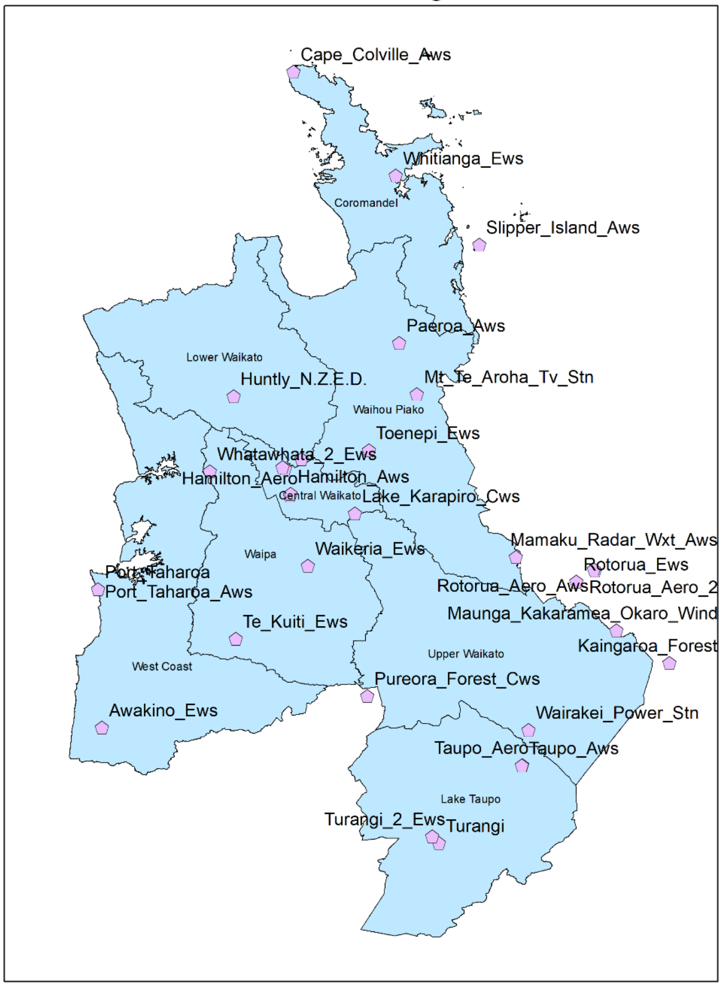


Figure 45: Weather station applied for the extreme wind analysis.

Table 10: Waikato Region Site-Specific Annual 100-year ARI Extreme Wind Speed Statistics in kph and Future Change – 75th Percentile (brackets 5th, 50th and 95th percentile)

Station Name	Baseline kph	SSP2-4.5 2050 Changes (%)	SSP2-4.5 2070 Changes (%)	SSP2-4.5 2090 Changes (%)	SSP25-8.5 2050 Changes (%)	SSP25-8.5 2070 Changes (%)	SSP25-8.5 2090 Changes (%)
Thames-Coromandel District - Cape_Colville_Aws	211.9	1.17 (-9.05, -0.86, 5.75)	1.78 (-8.52, -1.37, 6.50)	0.34 (-9.54, -3.39, 5.65)	1.04 (-6.61, -1.68, 4.20)	1.43 (-9.69, -1.32, 6.80)	3.00 (-6.43, -0.10, 11.38)
Thames-Coromandel District - Slipper_Island_Aws	167.2	1.92 (-7.74, -1.07, 5.43)	1.94 (-8.13, -1.01, 7.74)	0.31 (-7.47, -2.17, 4.83)	1.74 (-6.19, -1.90, 4.80)	0.75 (-6.93, -0.80, 8.04)	3.61 (-6.18, 0.56, 11.27)
Thames-Coromandel District - Whitianga_Ews	90.9	1.58 (-8.49, -0.50, 5.50)	1.34 (-8.90, -1.07, 7.10)	0.51 (-8.81, -3.04, 5.44)	1.39 (-5.98, -2.18, 5.05)	0.99 (-7.83, -1.29, 7.78)	4.06 (-6.03, 0.20, 12.00)
Hauraki District - Paeroa_Aws	120.9	1.92 (-7.74, -1.07, 5.43)	1.94 (-8.13, -1.01, 7.74)	0.31 (-7.47, -2.17, 4.83)	1.74 (-6.19, -1.90, 4.80)	0.75 (-6.93, -0.80, 8.04)	3.61 (-6.18, 0.56, 11.27)
Waikato District - Huntly_N.Z.E.D.	110.6	1.38 (-8.00, 0.01, 6.22)	2.54 (-7.36, 0.13, 8.43)	0.52 (-6.00, -1.47, 5.19)	2.05 (-6.30, -0.24, 6.25)	2.48 (-5.44, -0.78, 8.96)	4.82 (-5.34, 2.06, 12.03)
Waikato District - Whatawhata_2_Ews	106.8	1.38 (-8.00, 0.01, 6.22)	2.54 (-7.36, 0.13, 8.43)	0.52 (-6.00, -1.47, 5.19)	2.05 (-6.30, -0.24, 6.25)	2.48 (-5.44, -0.78, 8.96)	4.82 (-5.34, 2.06, 12.03)
Waikato District - Holland_Road_Hamilton_Cws	77.4	1.38 (-8.00, 0.01, 6.22)	2.54 (-7.36, 0.13, 8.43)	0.52 (-6.00, -1.47, 5.19)	2.05 (-6.30, -0.24, 6.25)	2.48 (-5.44, -0.78, 8.96)	4.82 (-5.34, 2.06, 12.03)
Matamata-Piako District - Mt_Te_Aroha_Tv_Stn	172.4	1.65 (-7.94, -1.27, 5.02)	1.82 (-6.89, -0.53, 7.94)	-0.08 (-6.55, -0.96, 4.97)	1.49 (-6.43, -1.20, 5.68)	2.15 (-6.12, -2.07, 8.06)	4.15 (-6.00, 0.77, 11.61)
Matamata-Piako District - Toenepi_Ews	113.2	1.65 (-7.94, -1.27, 5.02)	1.82 (-6.89, -0.53, 7.94)	-0.08 (-6.55, -0.96, 4.97)	1.49 (-6.43, -1.20, 5.68)	2.15 (-6.12, -2.07, 8.06)	4.15 (-6.00, 0.77, 11.61)
Hamilton City - Hamilton_Ruakura_Ews	93.7	1.38 (-8.00, 0.01, 6.22)	2.54 (-7.36, 0.13, 8.43)	0.52 (-6.00, -1.47, 5.19)	2.05 (-6.30, -0.24, 6.25)	2.48 (-5.44, -0.78, 8.96)	4.82 (-5.34, 2.06, 12.03)
Hamilton City - Hamilton_Ruakura_2_Ews	86.7	1.38 (-8.00, 0.01, 6.22)	2.54 (-7.36, 0.13, 8.43)	0.52 (-6.00, -1.47, 5.19)	2.05 (-6.30, -0.24, 6.25)	2.48 (-5.44, -0.78, 8.96)	4.82 (-5.34, 2.06, 12.03)
Waipa District - Hamilton_Aero	122.8	1.38 (-8.00, 0.01, 6.22)	2.54 (-7.36, 0.13, 8.43)	0.52 (-6.00, -1.47, 5.19)	2.05 (-6.30, -0.24, 6.25)	2.48 (-5.44, -0.78, 8.96)	4.82 (-5.34, 2.06, 12.03)
Waipa District - Hamilton_Aws	116.2	1.38 (-8.00, 0.01, 6.22)	2.54 (-7.36, 0.13, 8.43)	0.52 (-6.00, -1.47, 5.19)	2.05 (-6.30, -0.24, 6.25)	2.48 (-5.44, -0.78, 8.96)	4.82 (-5.34, 2.06, 12.03)
Waipa District - Lake_Karapiro_Cws	92.0	1.65 (-7.94, -1.27, 5.02)	1.82 (-6.89, -0.53, 7.94)	-0.08 (-6.55, -0.96, 4.97)	1.49 (-6.43, -1.20, 5.68)	2.15 (-6.12, -2.07, 8.06)	4.15 (-6.00, 0.77, 11.61)
Otorohanga District - Waikeria_Ews	82.5	1.67 (-8.14, -0.35, 5.61)	3.36 (-6.41, 0.18, 8.12)	0.35 (-4.42, -1.41, 3.70)	1.68 (-6.38, -0.85, 5.70)	3.82 (-5.55, -0.68, 7.35)	4.26 (-4.83, 1.98, 13.17)
Waitomo District - Port_Taharoa	245.7	2.11 (-7.83, 0.02, 5.82)	4.07 (-6.66, 1.56, 8.42)	1.86 (-4.29, -1.13, 4.01)	1.62 (-5.72, -0.50, 6.96)	3.27 (-4.62, -0.40, 7.84)	3.99 (-4.65, 2.65, 13.47)

Waitomo District - Port_Taharoa_Aws	147.1	2.11 (-7.83, 0.02, 5.82)	4.07 (-6.66, 1.56, 8.42)	1.86 (-4.29, -1.13, 4.01)	1.62 (-5.72, -0.50, 6.96)	3.27 (-4.62, -0.40, 7.84)	3.99 (-4.65, 2.65, 13.47)
Waitomo District - Te_Kuiti_Ews	71.8	1.67 (-8.14, -0.35, 5.61)	3.36 (-6.41, 0.18, 8.12)	0.35 (-4.42, -1.41, 3.70)	1.68 (-6.38, -0.85, 5.70)	3.82 (-5.55, -0.68, 7.35)	4.26 (-4.83, 1.98, 13.17)
Waitomo District - Awakino_Ews	193.6	1.50 (-7.62, 0.45, 6.26)	4.27 (-6.11, 1.38, 8.41)	1.68 (-3.69, -1.03, 4.08)	2.68 (-4.64, -0.15, 7.45)	3.64 (-4.49, 0.51, 6.67)	4.10 (-4.64, 1.67, 12.26)
Waitomo District - Pureora_Forest_Cws	146.6	1.47 (-7.63, -0.52, 4.90)	2.60 (-6.27, -0.34, 7.79)	-0.26 (-5.88, -1.18, 4.05)	1.90 (-6.88, -0.84, 4.56)	3.53 (-7.37, 0.21, 7.66)	4.90 (-5.84, 0.91, 12.29)
Taupō District - Wairakei_Power_Stn	128.3	1.46 (-6.12, -1.68, 4.52)	2.26 (-8.41, -1.37, 7.33)	0.05 (-6.90, -1.70, 4.42)	1.77 (-7.58, -2.10, 4.61)	3.92 (-8.94, -0.54, 7.47)	4.44 (-4.88, 0.45, 12.31)
Taupō District - Taupō_Aero	128.6	1.46 (-6.12, -1.68, 4.52)	2.26 (-8.41, -1.37, 7.33)	0.05 (-6.90, -1.70, 4.42)	1.77 (-7.58, -2.10, 4.61)	3.92 (-8.94, -0.54, 7.47)	4.44 (-4.88, 0.45, 12.31)
Taupō District - Taupō_Aws	102.9	1.46 (-6.12, -1.68, 4.52)	2.26 (-8.41, -1.37, 7.33)	0.05 (-6.90, -1.70, 4.42)	1.77 (-7.58, -2.10, 4.61)	3.92 (-8.94, -0.54, 7.47)	4.44 (-4.88, 0.45, 12.31)
Taupō District - Turangi	114.9	1.47 (-7.63, -0.52, 4.90)	2.60 (-6.27, -0.34, 7.79)	-0.26 (-5.88, -1.18, 4.05)	1.90 (-6.88, -0.84, 4.56)	3.53 (-7.37, 0.21, 7.66)	4.90 (-5.84, 0.91, 12.29)
Taupō District - Turangi_2_Ews	112.0	1.47 (-7.63, -0.52, 4.90)	2.60 (-6.27, -0.34, 7.79)	-0.26 (-5.88, -1.18, 4.05)	1.90 (-6.88, -0.84, 4.56)	3.53 (-7.37, 0.21, 7.66)	4.90 (-5.84, 0.91, 12.29)
Rotorua District - Rotorua_Aero_2	120.5	1.21 (-6.97, -1.29, 4.20)	2.70 (-7.55, -0.28, 7.29)	-0.03 (-6.69, -1.96, 4.16)	1.32 (-7.07, -2.01, 4.64)	2.84 (-8.10, -1.25, 7.75)	4.19 (-4.94, -0.85, 11.45)
Rotorua District - Rotorua_Aero_Aws	110.2	1.21 (-6.97, -1.29, 4.20)	2.70 (-7.55, -0.28, 7.29)	-0.03 (-6.69, -1.96, 4.16)	1.32 (-7.07, -2.01, 4.64)	2.84 (-8.10, -1.25, 7.75)	4.19 (-4.94, -0.85, 11.45)
Rotorua District - Kaingaroa_Forest	134.3	1.16 (-5.26, -1.63, 3.99)	2.49 (-9.49, -0.26, 7.75)	1.28 (-6.77, -2.19, 5.15)	1.27 (-6.87, -2.18, 4.14)	2.66 (-8.19, -1.12, 6.60)	4.39 (-5.66, -0.76, 10.99)
Rotorua District - Mamaku_Radar_Wxt_Aws	158.9	1.21 (-6.97, -1.29, 4.20)	2.70 (-7.55, -0.28, 7.29)	-0.03 (-6.69, -1.96, 4.16)	1.32 (-7.07, -2.01, 4.64)	2.84 (-8.10, -1.25, 7.75)	4.19 (-4.94, -0.85, 11.45)
Rotorua District - Rotorua_Ews	90.0	1.21 (-6.97, -1.29, 4.20)	2.70 (-7.55, -0.28, 7.29)	-0.03 (-6.69, -1.96, 4.16)	1.32 (-7.07, -2.01, 4.64)	2.84 (-8.10, -1.25, 7.75)	4.19 (-4.94, -0.85, 11.45)
Rotorua District - Maunga_Kakaramea_Okaro_Wind	109.7	1.21 (-6.97, -1.29, 4.20)	2.70 (-7.55, -0.28, 7.29)	-0.03 (-6.69, -1.96, 4.16)	1.32 (-7.07, -2.01, 4.64)	2.84 (-8.10, -1.25, 7.75)	4.19 (-4.94, -0.85, 11.45)

12: Potential Evapotranspiration Deficit

During the historical period, the probability of PED>200mm is 25.8%, and PED>400mm was only 2.2%. The potential evapotranspiration deficit (PED) increases across all areas with greater average annual PED of 200 and 400 mm, with more significant rises under the SSP5-8.5 scenario. Under the SSP2-4.5 scenario, the regional average probability of accumulated annual exceeding 200mm increases to more than 34% by 2050 and almost 37% by 2090. Comparably, in the SSP5-8.5 scenario, the probability of PED exceeding 200mm will reach more than 35% in 2050 and nearly 46% in 2090. The probability of receiving an annual accumulated PED over 400mm demonstrates the same overall trend.

As displayed on the maps, the Waikato, Hauraki, and Matamata-Piako Districts and portions of northern Taupō and Rotorua have the highest annual PED>200mm probability in some areas that exceed 90%. The high probability PED>400mm area is mainly in Hauraki and the northern part of Matamata-Piako District, while the southern part of Rotorua is another PED>400mm hotspot.

Table 11: Regional Average Probability of Annual Accumulated PED will Exceed 200mm and 400mm (%) During Baseline and Scenarios in Waikato Region - 50th Percentile (Brackets 5th and 95th Percentile).

Limit	Year	SSP2-4.5	SSP5-8.5
PED>200mm	Baseline	25.78	25.78
PED>200mm	2050	33.86 (21.42, 54.37)	35.24 (20.58, 59.04)
PED>200mm	2070	35.80 (20.10, 60.60)	39.79 (18.45, 75.17)
PED>200mm	2090	36.93 (20.04, 65.31)	45.80 (16.47, 87.61)
PED>400mm	Baseline	2.21	2.21
PED>400mm	2050	3.10 (0.69, 11.62)	3.67 (0.66, 14.63)
PED>400mm	2070	3.87 (0.62, 15.76)	5.55 (0.50, 30.59)
PED>400mm	2090	4.28 (0.64, 19.76)	8.49 (0.37, 50.95)

*The High (95th percentile of the ensemble) PED was calculated using the future scenarios for a combination of the High (95th percentile of the ensemble) of global temperature change and a Low (5th percentile of the ensemble) of global precipitation change.

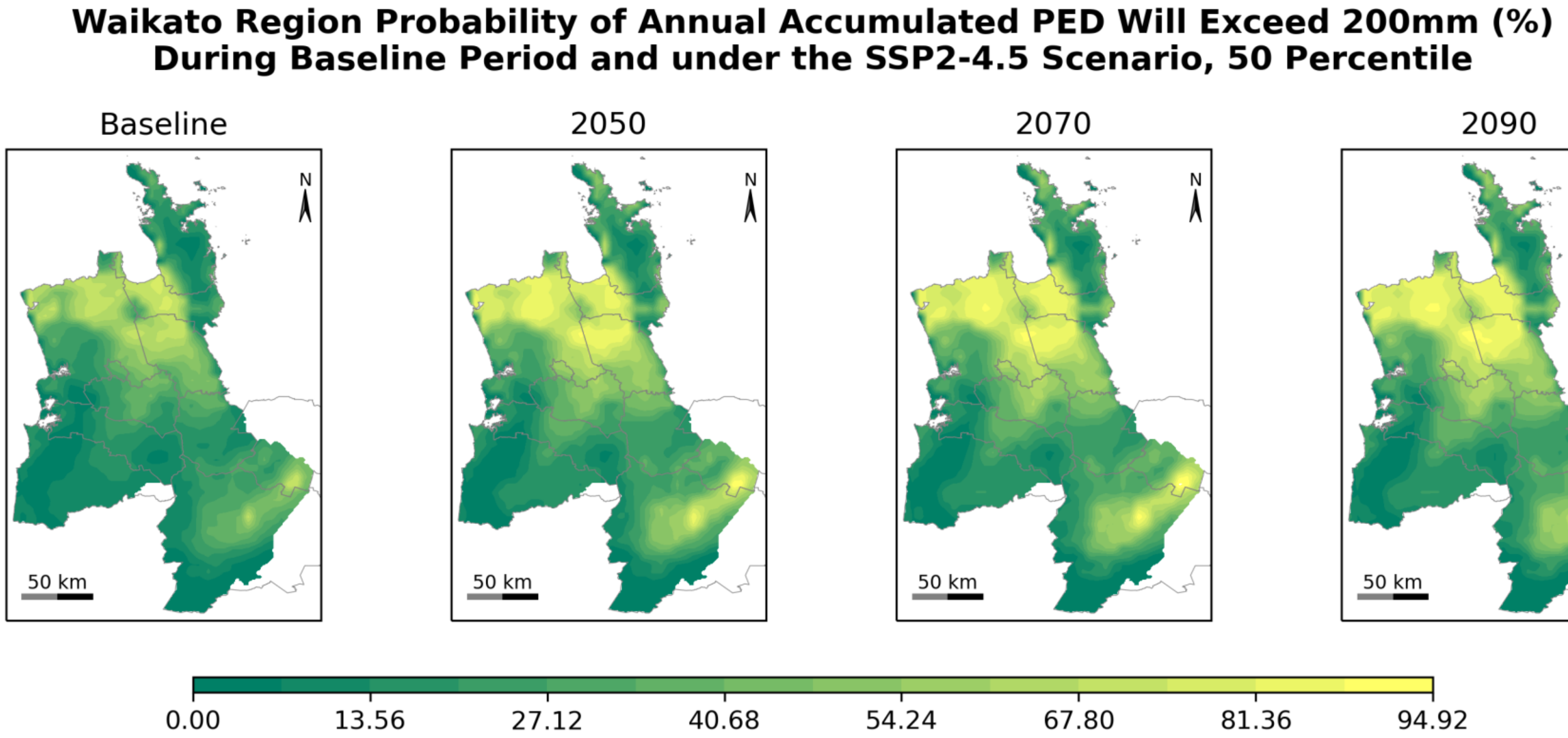


Figure 46: Probability of Annual Accumulated PED Will Exceed 200mm (%) During Baseline Period and under the SSP2-4.5 Scenario, 50 Percentile in Waikato Region.

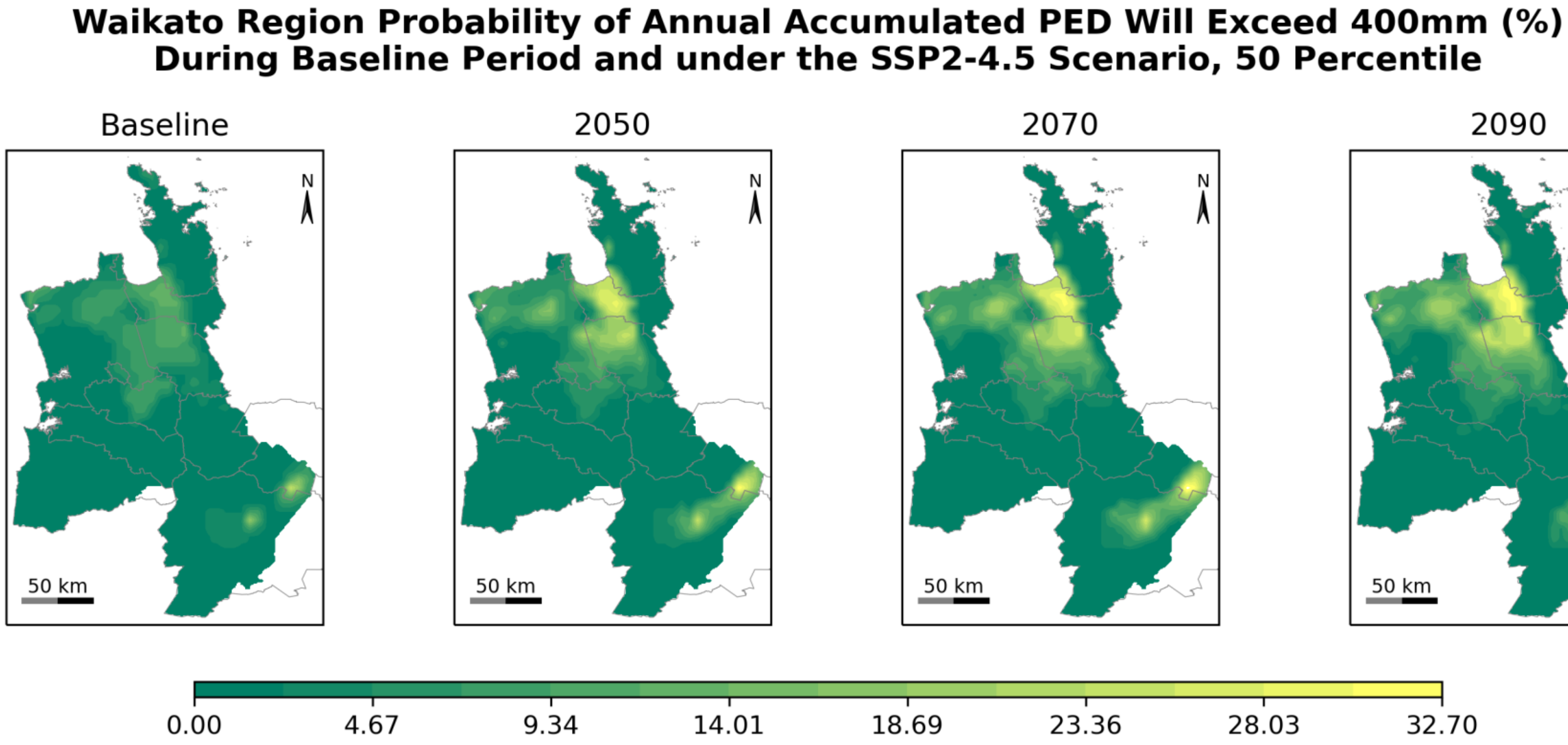


Figure 47: Probability of Annual Accumulated PED Will Exceed 200mm (%) During Baseline Period and under the SSP2-4.5 Scenario, 50 Percentile in Waikato Region.

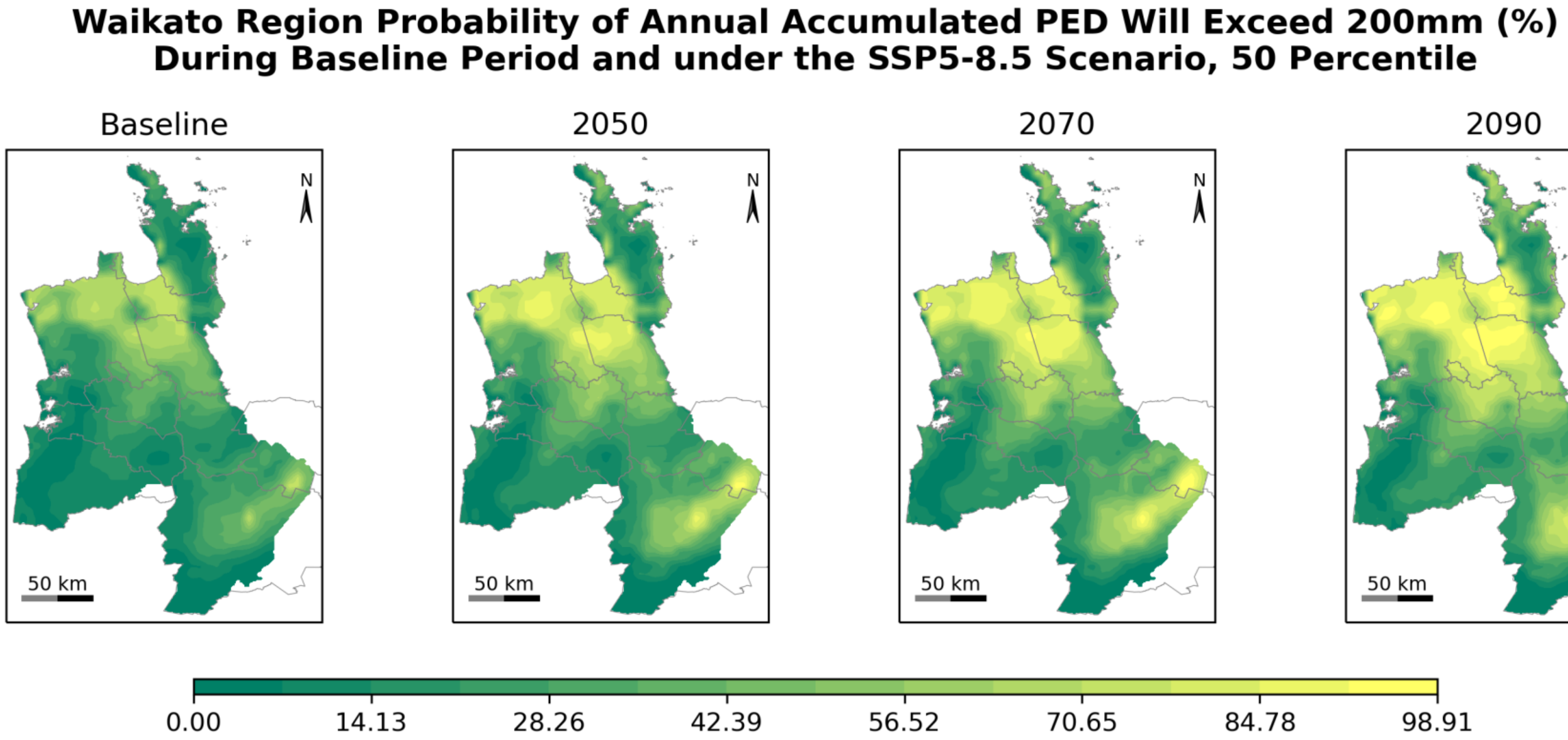


Figure 48: Probability of Annual Accumulated PED Will Exceed 200mm (%) During Baseline Period and under the SSP5-8.5 Scenario, 50 Percentile in Waikato Region.

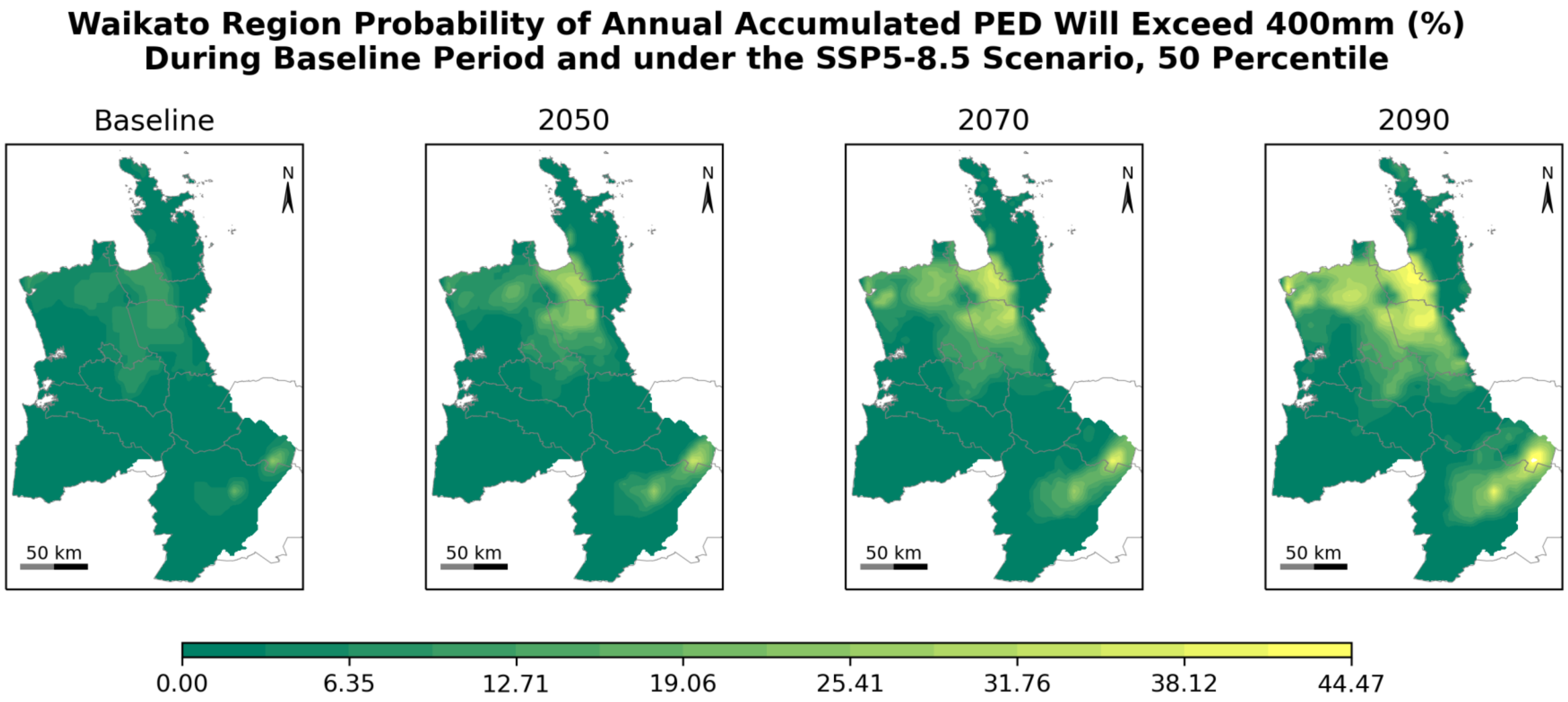
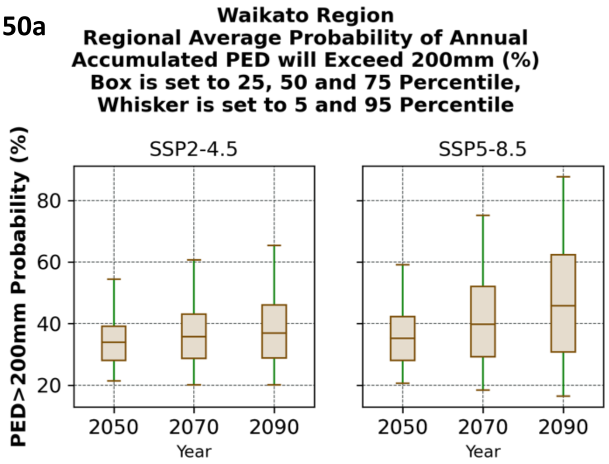


Figure 49: Probability of Annual Accumulated PED Will Exceed 400mm (%) During Baseline Period and under the SSP5-8.5 Scenario, 50 Percentile in Waikato Region.

50a



50b

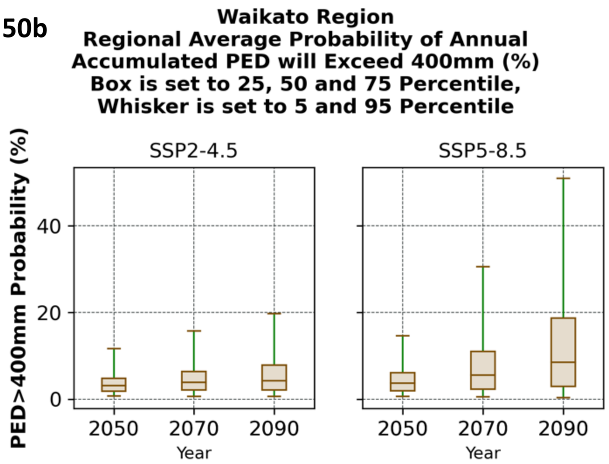


Figure 50: Waikato Region, Regional Average Probability of Annual Accumulated PED will Exceed 200mm and 400mm (%) (50a) and 400mm (50b) and under the SSP5-8.5 Scenario, 50 Percentile in Waikato Region

13: Water Take Consent Statistics

There are more than 16,000 km of rivers and streams in the Waikato region. There are also several large lakes and wetlands and a myriad of smaller water bodies. Water is one of the main forces shaping the region, as can be seen in the Waikato River's historical pathways that have left remnant peat lakes, river terraces, and rich soil deposits of the Waikato basin and Huka Falls. Perhaps more than any other part of New Zealand, Waikato is a watery landscape. The Waikato River is the country’s longest river at 425 km, and Taupō is the largest lake at 622 km^2.

In addition, the region has 80% of the country’s geothermal systems, important wetlands (Whangamarino and Kopuatai) and major springs feeding rivers like the Waihou.

The Waikato River Authority (2019) stated in their Vision and Strategy: Our vision is for a future where a healthy Waikato River sustains abundant life and prosperous communities who, in turn, are all responsible for restoring and protecting the health and wellbeing of the Waikato River and all it embraces for generations to come. This Vision and Strategy is Te Ture Whaimana o Te Awa o Waikato.

Several of the strategies will be influenced by a change in the climate and policies on water allocations:

- ✓ Encourage and foster a ‘whole of river’ approach to the restoration and protection of the Waikato River, including the development, recognition, and promotion of best practice methods for restoring and protecting the health and wellbeing of the Waikato River.
- ✓ Ensure that cumulative adverse effects on the Waikato River of activities are appropriately managed in statutory planning documents at the time of their review.
- ✓ Ensure appropriate public access to the Waikato River while protecting and enhancing the health and wellbeing of the Waikato River.

There are many conflicting demands placed upon the region’s waterways. The Waikato’s rivers are used for hydroelectricity, water supply, waste treatment, irrigated crop and livestock agriculture, flood control and recreation such as fishing and boating. These activities can take a toll on the aquatic environment, often reflected by a decrease in water quality. This can have consequences for the health of people, plants and animals that rely on the resource for food and habitats.

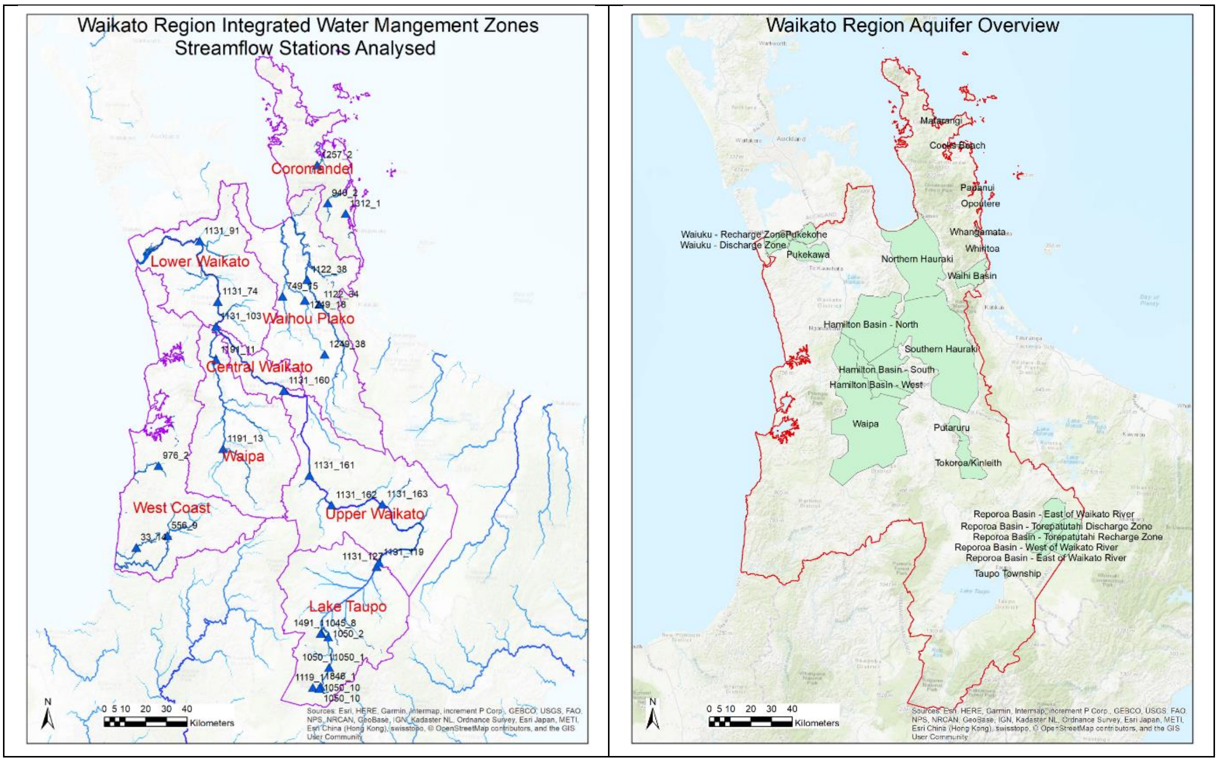


Figure 51: WRC defined water management zones and aquifer areas considered in this report, including the locations of the 29 stream and river flow data sets applied (Sources: WRC 2021).

Table 12: WRC defined integrated catchment zones by area, including the Tongariro Power Scheme (Source: WRC 2021).

Integrated Catchment Zone	Area (square kms)
Lower Waikato	2911.72
West Coast	4249.11
Waipa	3067.39
Central Waikato	636.25
Upper Waikato	4327.78
Waihou Piako	3945.10
Lake Taupō	3495.96
Coromandel	1957.23
Tongariro Power Scheme	662.67
Total Land Area	25253.22

Almost 600 million m^3 of water is collected with consent in the Waikato region. More than half (52%) of this water is collected for town supply. Otherwise, a quarter (25%) is utilised for industrial purposes, 16% is collected for irrigation, 7% is for stock and <1% of this volume is utilised for other activities. Regarding the number of consents made to access these volumes of water, most (more than 2,400) are made for stock purposes. In comparison, there have only been 406 consents for irrigation, 254 consents made for industrial purposes, 196 for town supply and 113 for other consents. Hence, the volume of water requested by each consent is highly variable. For example, town supply uses more than half of the water volume and only had 196 consents. In comparison, stock activity required more than 2,400 consents for 7% of the total water volume used in the Waikato region.

Water allocation means water that is allocated via either a resource consent or in accordance with section 14(3) of the Resource Management Act 1991 (for example, permitted in a regional plan, or reasonable needs for an individual's domestic needs, or a person's animals for stock drinking water, or geothermal water taken for either tikanga Māori purposes or firefighting).

Limit is defined under the National Policy Statement Freshwater Management 2020 as the maximum amount of resource use available, which allows a freshwater objective to be met. Instream minimum flow for surface water is defined in the Regional Policy Statement as being the flow of water in a river or stream necessary to sustain aquatic life, water quality, recreational use, outstanding natural features or Māori cultural values. It is the flow rate at which non-essential abstractions should stop.

Table 13: Water availability, consented and % by type (Source: https://www.lawa.org.nz/explore-data/waikato-region/water-quantity/)

Source	The amount available to consent	Volume consented	Consented as a % of available
Surface Water	1.13 billion m^3	0.6 billion m^3	53%
Groundwater	2.18 billion m^3	0.13 billion m^3	6%
Total	**3.32 billion m^3**	**0.73 billion m^3**	**22%**

Groundwater management (Waikato Region Plans, Water Module)

d) Classifying as a discretionary activity any supplementary take or temporary take which might otherwise be a permitted activity when the take, assessed in combination with all other existing authorised water takes within the same aquifer, is for a rate greater than 100 % of the **Sustainable Yield identified in Table 3-6**.

e) Using **Management Levels** to indicate when there is increasing demand from an aquifer.

f) Classifying as a discretionary activity all applications for domestic or municipal supply takes for groundwater where a water management plan which meets the requirements of Method 8.1.2.2 has been provided.

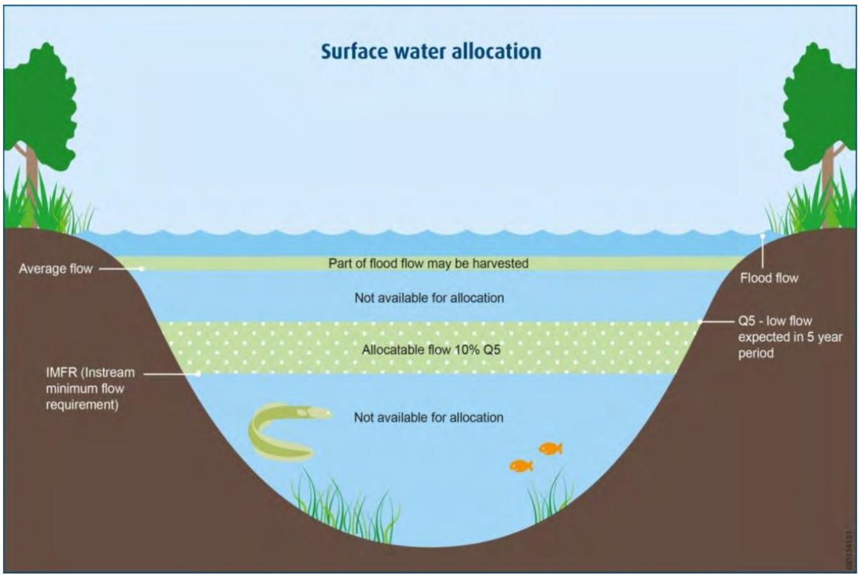


Figure 52: Illustration of the operative regional water and land plan method used to allocate surface water (Source: BoP, 2016).

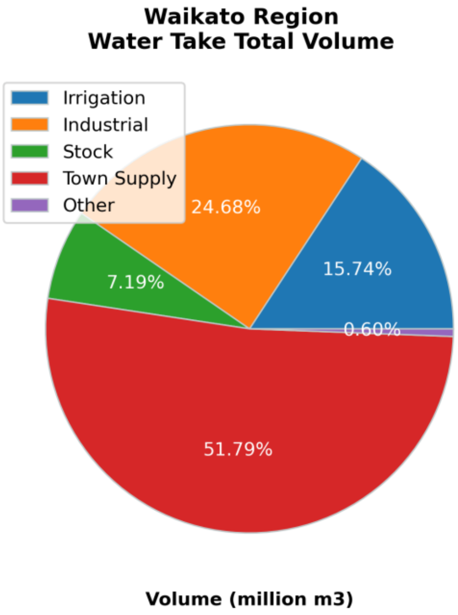
According to WRC's water consent statistical data, by the end of 2020, the annual total active allocated surface water is 479.2 Mm^3. Town supply takes 61.3% of the total allocated surface water, industrial use water is 107.3 Mm^3, and irrigation water takes 14.9%.

341 stock use consents are recorded in the Regional Council's dataset, the highest consent number, with relatively small water volume per consent. This demand is followed by the number of irrigation consents at 193, further defined as agriculture water use.

For groundwater allocation in the Waikato region, the total water volume is 119.91 Mm^3. Industrial water use takes the largest share, 41.5 Mm^3, 34.6%, stock takes the second place of 37.5 Mm^3, and most of the consents 2132. The total number of consents was 2648 by the end of 2020.

Table 14: Waikato Region Water Take Consents Statistics

Activity	Waikato region Volume (million m3)	Waikato region Percentage (%)	Waikato region Consents (number)
Irrigation	94.31	15.74	406
Industrial	147.87	24.68	254
Stock	43.08	7.19	2473
Town Supply	310.29	51.79	196
Other	3.57	0.60	113
Total	599.13	100.00	3442



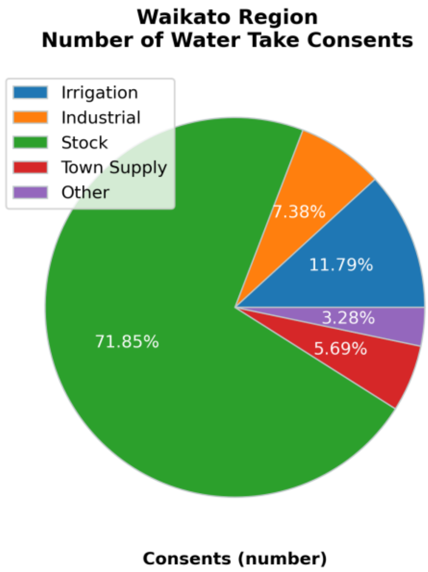


Figure 53: Waikato Region Authorised Water Take Statistics

The town supply activities used more than 60% of the total volume based on the surface water take consent statistics. The sector with the second greatest demand on water take was the industrial sector (22.19%). Despite taking the greatest volume of water, town supply activities have only had 97 consents, compared to industrial having had 114 consents.

Table 15: Waikato Region Surface Water Take Consents Statistics

Activity	Waikato region Volume (million m3)	Waikato region Percentage (%)	Waikato region Consents (number)
Irrigation	71.51	14.92	193
Industrial	106.33	22.19	114
Stock	5.62	1.17	341
Town Supply	293.87	61.32	97
Other	1.90	0.40	49
Total	479.22	100.00	794

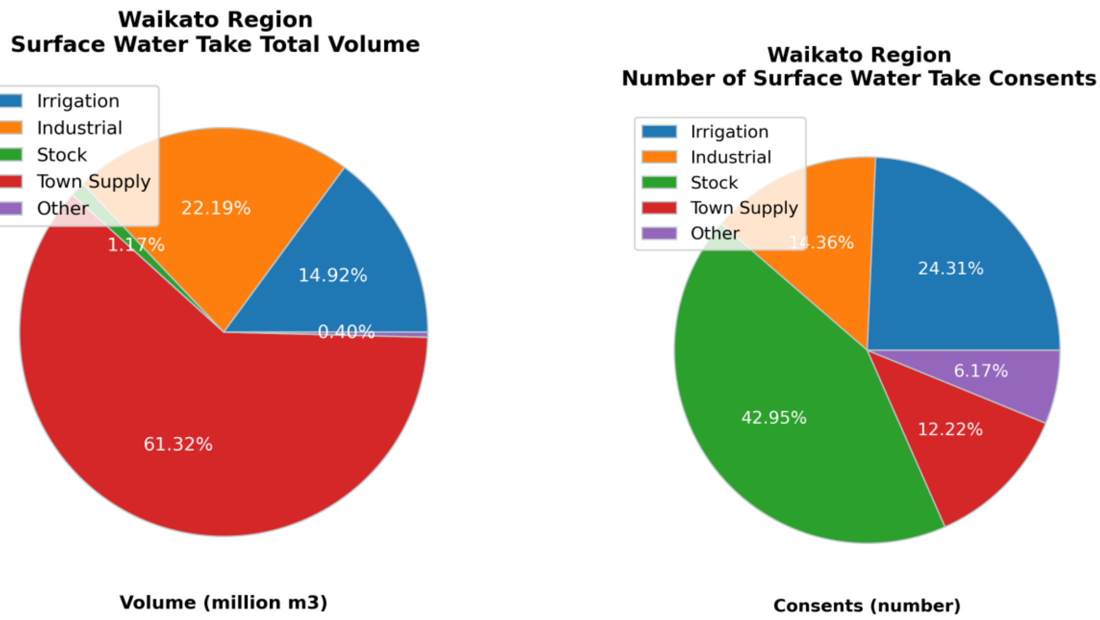


Figure 54: Waikato Region Authorised Surface Water Take Statistics

Regarding the groundwater take consent statistics, industrial activities have used the greatest volume (41.55 million m^3). Next, stock activities have consumed more than 37 million m^3, while town supply has only used 16.42 million m^3 of groundwater. In this case, stock activities, which utilise the second-largest volume of groundwater, have submitted far more consents than the other activities (2132).

Table 16: Waikato Region Groundwater Take Consents Statistics (Source: WRC 2021)

Activity	Waikato region Volume (million m3)	Waikato region Percentage (%)	Waikato region Consents (number)
Irrigation	22.80	19.02	213
Industrial	41.55	34.65	140
Stock	37.46	31.24	2132
Town Supply	16.42	13.70	99
Other	1.68	1.40	64
Total	119.91	100.00	2648

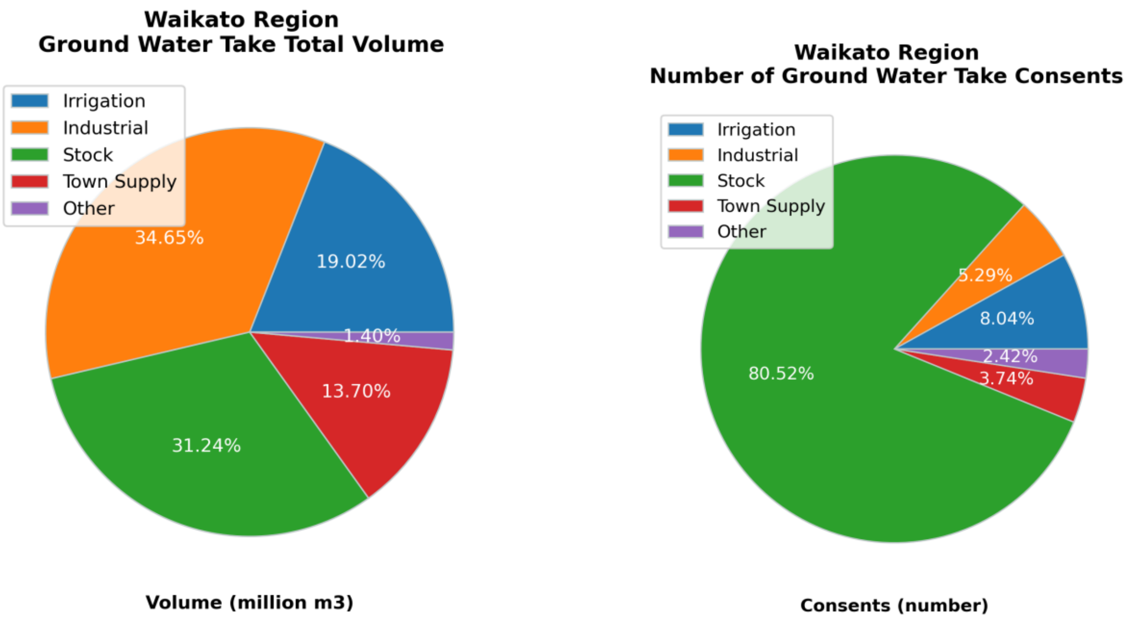


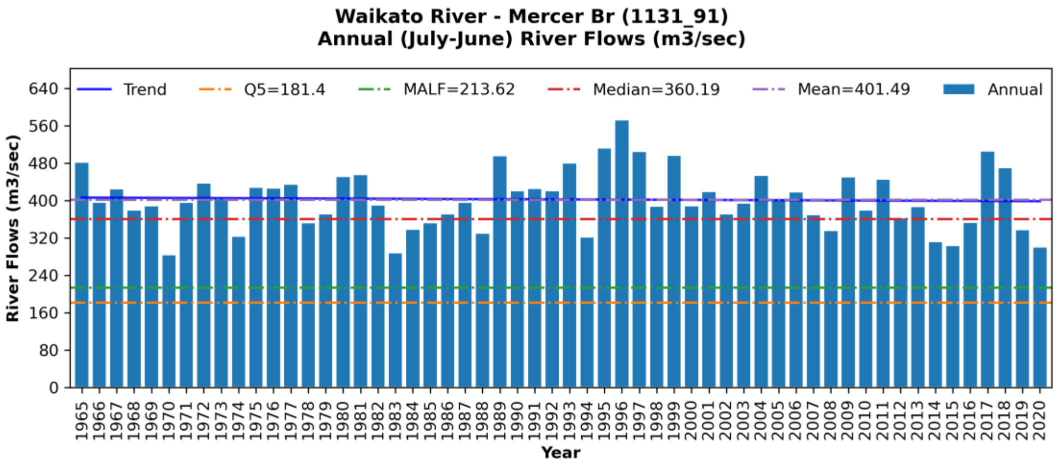
Figure 55: Waikato Region Authorised Groundwater Take Statistics

14: Historical Surface Water Status in the Waikato Region

Historical surface water variabilities were investigated using streamflow data from 29 gauges across the Waikato region. Taking the Mercer Bridge as an example, as shown in Figure 6 and Table 17, we have not found a significant trend of annual mean flow from the historical streamflow data. However, most river gauges have a decreasing trend over the spring and summer seasons.

Figure 7 illustrates the seasonal variabilities of the streamflow of the Waikato River. In April, the mean flow at the Mercer Bridge on the Waikato river is 284.16m^3/sec, only 50.6% of the historical August flow value. The river flow variations are still notable for water allocation, quality, and regulated ecosystem services requirements.

Table 18 presents the statistics of the flow gauges across the region, including Q5, mean, median, low, and high flow. Q5 low flow (20th percentile of low annual flow based on seven-day moving average), has been defined by WRC as the threshold of allocable surface water and was calculated for each decade. In recent decades many of the stations show a decline in Q5 flow. Thus the allocable surface water resources are diminishing. Table 19 shows the decadal variabilities and trend of Q5 in the flow statistics of 29 gauges. Of these 29 gauges, 17 show a decrease in the Q5 signal.



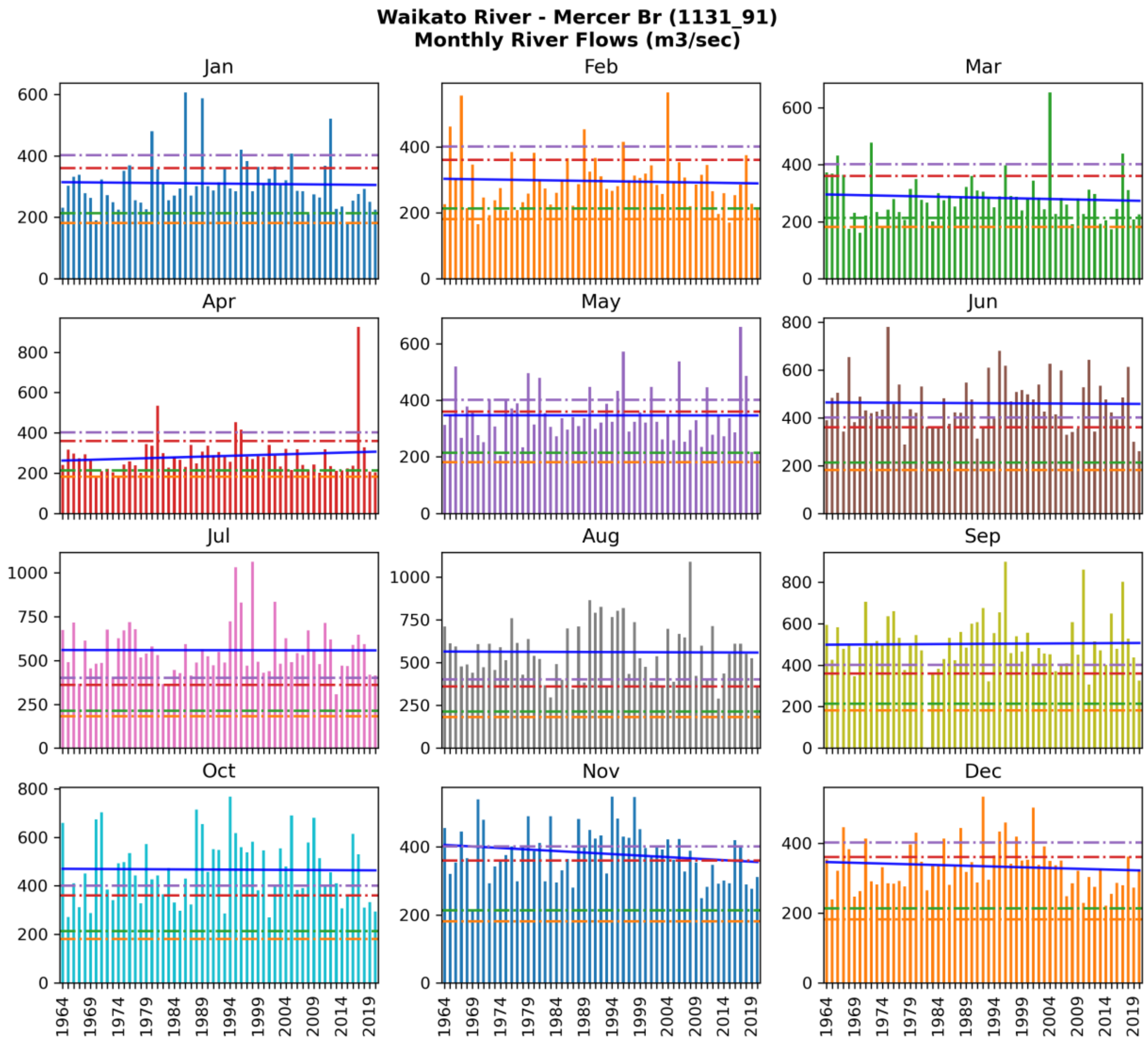


Figure 56: Lower Waikato - Waikato River - Mercer Br (1131_91), Annual and Monthly Water Yield

Table 17: Lower Waikato - Waikato River - Mercer Br (1131_91), Average Monthly (July-June) River Flows (m3/sec)

Month	Mean	50Pth (05Pth, 95Pth)
Jul	559.09	530.94 (367.12, 832.69)
Aug	561.41	**539.14 (350.99, 819.92)**
Sep	502.60	486.10 (325.53, 724.03)
Oct	466.95	451.17 (287.38, 692.00)
Nov	380.73	387.54 (279.56, 500.45)
Dec	334.01	330.98 (244.99, 448.70)
Jan	309.59	292.43 (221.41, 488.43)

Feb	296.25	285.63 (195.68, 454.92)
Mar	284.51	280.98 (178.04, 434.05)
Apr	284.16	266.28 (200.89, 423.44)
May	346.45	323.90 (230.80, 522.16)
Jun	461.55	436.90 (310.87, 644.78)

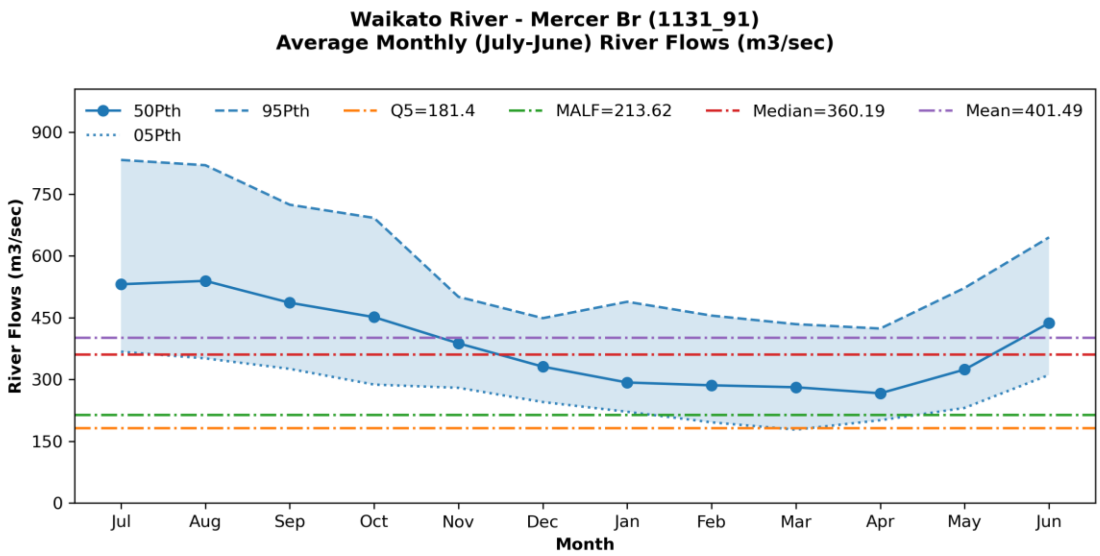


Figure 57: Lower Waikato - Waikato River - Mercer Br (1131_91), Average Monthly (July-June) River Flows (m3/sec)

Table 18: Annual streamflow statistics for the Waikato Region (Source: WRC 2021)

Zone Name	Agent No.	Site Name	Station Name	Record Period	Q5_WRC (m3/sec)	Q5 (m3/sec)	MALF (m3/sec)	Median (m3/sec)	Mean (m3/sec)
Central Waikato	1131_103	1131-Waikato River	103-Ngaruawahia Cableway	1959 - 2020	173.90	167.07	190.20	306.91	336.91
Central Waikato	1131_160	1131-Waikato River	160-Karapiro Dam Total	1950 - 2020	-	142.02	155.42	225.06	234.87
Coromandel	1257_2	1257-Waiwawa River	2-Rangihau Rd Ford	1993 - 2020	0.79	0.73	0.92	3.89	7.94
Coromandel	1312_1	1312-Wharekawa River	1-Adams Farm Br	1993 - 2020	0.27	0.25	0.32	0.93	1.82
Coromandel	940_2	940-Tairua River	2-Broken Hills	1977 - 2020	0.68	0.68	0.90	3.17	5.81
Lake Taupō	1050_1	1050-Tongariro River	1-Poutu Intake On Tongariro River	1961 - 2020	-	2.61	5.26	10.98	12.86
Lake Taupō	1050_10	1050-Tongariro River	10-Upper Dam (NIWA/Genesis)	1961 - 2020	2.96	2.94	3.49	9.41	11.78
Lake Taupō	1050_2	1050-Tongariro River	2-Turangi Cableway	1958 - 2020	22.09	22.12	25.25	30.35	37.64
Lake Taupō	1119_1	1119-Waihohonu Stm	1-SH1 Rangipo	1964 - 2010	3.35	3.35	4.02	5.96	6.38
Lake Taupō	1131_127	1131-Waikato River	127-Taupō Control Gates	1950 - 2020	-	44.10	64.97	136.08	143.60
Lower Waikato	1131_74	1131-Waikato River	74-Huntly Power Station	1985 - 2020	-	180.57	203.32	324.36	362.31
Lower Waikato	1131_91	1131-Waikato River	91-Mercer Br	1965 - 2020	185.30	181.40	213.62	360.19	401.49
Tongariro	1045_8	1045-Tokaanu Stm	8-Tokaanu Power House (NIWA)	1980 - 2008	-	3.49	11.34	48.17	49.03
Tongariro	1050_1	1050-Tongariro River	1-Poutu Intake On Tongariro River	1961 - 2020	-	2.61	5.26	10.98	12.86
Tongariro	1050_10	1050-Tongariro River	10-Upper Dam (NIWA/Genesis)	1961 - 2020	2.96	2.94	3.49	9.41	11.78
Tongariro	1491_1	1491-Tokaanu Power Station Tailrace Canal	1-SH41 Bridge Over Canal	2002 - 2020	-	1.60	7.10	46.22	47.16
Tongariro	1846_1	1846-Tongariro Power Development (TPD)	1-TPD Total Diversion	1981 - 2019	-	58.24	60.81	62.24	63.80

Upper Waikato	1131_119	1131-Waikato River	119-Reids Farm	1972 - 2020	61.35	57.93	69.57	145.11	151.45
Upper Waikato	1131_161	1131-Waikato River	161-Waipapa Dam Total	1963 - 2020	-	122.73	134.67	204.75	213.60
Upper Waikato	1131_162	1131-Waikato River	162-Whakamaru Dam Total	1958 - 2020	99.60	100.92	113.24	177.18	184.96
Upper Waikato	1131_163	1131-Waikato River	163-Ohakuri Dam Total	1963 - 2020	78.50	84.29	95.76	162.29	169.60
Waihou Piako	1122_34	1122-Waihou River	34-Te Aroha	1967 - 2020	20.24	20.13	22.25	32.09	37.49
Waihou Piako	1122_38	1122-Waihou River	38-Tirohia	1971 - 2020	20.35	21.65	23.93	33.64	39.60
Waihou Piako	1249_18	1249-Waitoa River	18-Mellon Rd Recorder	1988 - 2020	1.10	0.80	1.04	3.05	4.94
Waihou Piako	1249_38	1249-Waitoa River	38-Waharoa Control	1986 - 2020	0.23	0.16	0.22	0.85	1.52
Waihou Piako	749_15	749-Piako River	15-Paeroa-Tahuna Rd Br	1973 - 2020	0.72	0.45	0.66	3.28	7.12
Waipa	1191_11	1191-Waipa River	11-SH23 Br Whatawhata	1974 - 2020	15.01	13.27	19.22	62.78	85.32
Waipa	1191_13	1191-Waipa River	13-SH31 Br Otorohanga	1981 - 2020	4.13	3.92	5.49	21.04	29.07
West Coast	33_14	33-Awakino River	14-SH 3 Gorge (NIWA)	1981 - 2020	1.70	1.10	1.79	8.90	12.94
West Coast	556_9	556-Mokau River	9-Totoro Rd Recorder	1981 - 2020	3.98	3.86	5.21	24.55	35.60
West Coast	976_2	976-Tawarau River	2-Speedies Rd	1981 - 2011	1.92	2.05	2.35	4.97	6.30

Table 19: Stream flow Q5 decadal statistics in the Waikato region. Red figures symbolise values below the Q5 level (Source: WRC 2021)

Agent No.	1950 (m3/sec)	1960 (m3/sec)	1970 (m3/sec)	1980 (m3/sec)	1990 (m3/sec)	2000 (m3/sec)	2010 (m3/sec)	2020 (m3/sec)	Q5 (m3/sec)
1045_8	-	-	-	-	-	10.55	5.23	-	3.49
1050_1	-	-	2.67	2.39	3.45	3.6	3.22	13.83	2.61
1050_10	-	-	2.67	2.39	3.45	3.61	3.05	2.68	2.94
1050_2	-	24.99	27.08	23.42	25.32	23.56	20.97	18.98	22.12
1119_1	-	-	-	5.14	3.87	3.61	3.86	-	3.35
1122_34	-	-	20.94	21.66	18.91	21.45	20.85	19.17	20.13
1122_38	-	-	-	30.96	20.77	22.41	21.43	22.04	21.65
1131_103	-	183.84	162.49	160.14	178.45	189.02	176.5	165.65	167.07
1131_119	-	-	-	71.68	66.16	61.01	65.16	61.59	57.93
1131_127	23.43	31.06	30.11	59.86	77.64	70.23	53.09	64.41	44.1

1131_160	146.49	136.87	127.73	143.88	152.3	158.61	149.87	145.91	142.02
1131_161	-	-	93.86	120.34	131.93	125.57	126.37	123.52	122.73
1131_162	-	117.35	86.06	99.88	113.96	107.18	101.14	109.4	100.92
1131_163	-	-	61.51	78.61	98.79	89.59	83.09	95.87	84.29
1131_74	-	-	-	-	243.51	195.45	181.28	171.76	180.57
1131_91	-	-	148.82	169.58	203.08	237.74	190.55	178.06	181.4
1191_11	-	-	-	42.04	18.98	14.75	12.27	12.33	13.27
1191_13	-	-	-	-	5.94	4.61	3.93	3.02	3.92
1249_18	-	-	-	-	1.01	0.85	0.94	0.77	0.8
1249_38	-	-	-	-	0.22	0.19	0.19	0.12	0.16
1257_2	-	-	-	-	-	1.09	0.72	0.69	0.73
1312_1	-	-	-	-	-	0.33	0.25	0.27	0.25
1491_1	-	-	-	-	-	-	8.63	1.94	1.6
1846_1	-	-	-	-	61.96	61.55	57.95	58.69	58.24
33_14	-	-	-	-	1.6	2.01	1.6	1.25	1.1
556_9	-	-	-	-	5.24	4.43	4.11	2.76	3.86
749_15	-	-	-	1.17	0.51	0.53	0.58	0.34	0.45
940_2	-	-	-	1.2	0.73	0.79	0.74	0.63	0.68
976_2	-	-	-	-	2.45	2.36	2.2	2.63	2.05

15: Historical Groundwater Status in the Waikato Region's Aquifers

Based on Environment Waikato documentation (EW 2008), the annual daily average of available groundwater was estimated using the following equation:

A = (RR x Pr x Ga x Ra) / 365 days

A = annual daily average of groundwater availability – cubic metres per day (m3/day).

RR = average annual rainfall over the aquifer – metres per year (m/year).

Pr = estimate of rainfall recharge to groundwater as a fraction of the average annual rainfall over the aquifer. This will usually range from 0.22 (22%) to 0.4 (40%) in the Waikato region.

Ga = groundwater recharge available for allocation. This is estimated to be 50% (0.5 in the equation), allowing the remaining 50% of recharge to be lost via springs and submarine discharges.

RA = the size (area) of the aquifer – square metres (m2). The size of the aquifers is in line with the aquifers listed in Table 3-6 of Variation 6 (Water Allocation chapter) of the Waikato Regional Plan.

Refer to water allocation maps 'Management Level – Assessed Aquifers', as directed by the relevant map and catchment numbers in Table 3-6.

• In Table 3-6 of the WRC report where N/A appears in the column relating to Sustainable Yield, the necessary evaluation of sustainable yield has yet to be undertaken. When a Sustainable Yield is set it supersedes the Management Level.

• The determination of Sustainable Yields may result in the inclusion of more refined information. This may include delineation of aquifers laterally and with depth and improved mapping of aquifer extents.

Table 20 presents all the parameters applied in the groundwater calculations. A comparison was made of the rainfall data used in the WRC database and the rainfall data in NIWA VCSN data. The differences are across aquifers, however, the overall averages are close to each other.

Table 21 displays the decadal variations of annual precipitation, which is critical for determining groundwater resources. In the last decade, 2011 to 2020, across the 28 aquifers with data, 17 received less precipitation than the previous 2000 to 2010 decade, and some of the aquifer areas are lower than the long term average values.

Table 22 illustrates the increase of PET during the past several decades. For some areas, an increase in PET of between 50 and 100mm is evident. This translates to a decrease in soil moisture and total water recharge to the aquifer. Finally, Table 24 is applied to check the consistency of the trend of mean temperature increase over the aquifers—the temperature increases over the same period range between 0.2 and 0.8 degrees Celsius.

Table 20: Historical aquifer groundwater estimation for the Waikato region (Source: WRC 2021, the source of rainfall values (RA) the Rain and RAIN_BC were calculated from NIWA VCSN 1973-2020 data)

Aquifer	Ga	Pr	RA (m2)	RR(m per year)	Sustainable Yield km3 per year	RAIN	RAIN_BC
Cooks Beach	0.5	0.4	1353659	1.62	438.6	1.88	2.31
Hahei	0.5	0.25	378277	1.563	73.9	1.84	2.27
Kuaotunu West	0.5	0.4	230803	1.763	81.4	1.15	1.11
Matarangi	0.5	0.4	3659042	1.884	1378.8	1.16	1.12
Opoutere	0.5	0.4	1701253	1.934	658.1	1.18	1.17
Pauanui	0.5	0.4	2583986	1.753	905.8	1.66	1.96
Whangamata - Moana Point	0.5	0.25	1386034	2.25	389.7	1.78	2.08
Whangamata	0.5	0.25	4338967	2.236	1212.6	1.18	1.13
Whangapoua	0.5	0.4	461089	1.916	176.7	1.84	2.16
Whiritoa	0.5	0.4	855949	2.128	364.3	1.92	2.49
Hamilton basin – North	0.5	0.3	601874574	1.165	105193.6	1.34	1.22
Hamilton basin – South	0.5	0.3	244550933	1.148	42129.9	1.31	1.21
Hamilton basin - West	0.5	0.3	206271473	1.21	37431.2	1.39	1.29
Northern Hauraki	0.5	0.38	741228730	1.179	166052.5	1.32	1.10
Southern Hauraki	0.5	0.38	1365357655	1.294	335604.8	1.12	0.88
Pukekawa	0.5	0.22	141484490	1.338	20830.6	1.16	0.93
Pukekohe	0.5	0.22	79250436	1.354	11805.9	1.24	1.06
Waiuku - Discharge zone	0.5	0.22	60102787	1.402	9271.2	1.22	1.19
Waiuku - Recharge zone	0.5	0.22	36511858	1.392	5590.2	1.04	0.82
Reporoa Basin - East of Waikato River	0.5	0.3	227691861	1.136	38808.4	1.50	1.48
Reporoa Basin - Torepatutahi recharge zone	0.1	0.3	155188112	1.085	5051.4	1.93	1.76
Reporoa Basin - Torepatutahi discharge zone	0.5	0.3	55776605	1.097	9178.2	1.39	1.36
Reporoa Basin - West of Waikato river	0.5	0.3	93193792	1.188	16602.2	1.38	1.22
Putaruru	0.5	0.22	59471034	1.353	8850.7	1.35	1.22
Tokoroa/Kinleith	0.5	0.22	157528161	1.416	24533	1.57	1.63
Taupō Township	0.5	0.3	7363776	1.036	1144	1.82	1.89
Waihi Basin	0.5	0.05	126084995	1.962	6184.6	1.88	2.16
Waipa	0.5	0.3	1418213251	1.504	319879.4	2.03	2.00

Table 21: Historical (1973 to 2020) annual mean precipitation by decade (mm) for the Waikato region aquifer areas (Source: NIWA VCSN data). The red figures indicate that the 2011-2020 level is lower than 2001-2010

Aquifer Name	1973 - 1980	1981 - 1990	1991 - 2000	2001 - 2010	2011 - 2020	Long term
Cooks Beach	1882.60	1798.17	1826.58	1959.11	1927.77	1878.85
Hahei	1848.15	1751.33	1790.31	1919.68	1893.46	1840.59
Hamilton Basin - North	1262.03	1135.09	1168.85	1081.97	1143.53	1158.29
Hamilton Basin - South	1250.34	1136.85	1184.98	1086.46	1146.40	1161.01
Hamilton Basin - West	1244.99	1146.15	1226.69	1131.10	1182.11	1186.21
Kuaotunu West	1613.72	1527.71	1652.52	1763.88	1731.09	1657.78
Matarangi	1752.43	1689.85	1770.23	1890.33	1809.29	1782.43
Northern Hauraki	1247.84	1236.99	1174.50	1120.99	1133.80	1182.82
Opoutere	1922.54	1802.42	1763.34	1858.26	1847.12	1838.74
Pauanui	2023.91	1929.91	1832.25	1936.88	1915.42	1927.67
Pukekawa	1399.34	1301.27	1382.60	1283.81	1346.90	1342.79
Pukekohe	1346.43	1263.08	1373.00	1265.51	1331.77	1315.96
Putaruru	1523.94	1404.43	1424.12	1309.21	1297.38	1391.82
Reporoa Basin - East of Waikato River	1361.92	1326.25	1371.10	1305.70	1233.45	1319.68
Reporoa Basin - Torepatutahi Discharge Zone	1143.69	1117.64	1193.41	1106.03	1034.08	1118.97
Reporoa Basin - Torepatutahi Recharge Zone	1207.98	1173.64	1223.73	1133.88	1050.83	1158.01
Reporoa Basin - West of Waikato River	1263.95	1254.00	1303.28	1227.48	1151.49	1240.04
Southern Hauraki	1338.58	1275.47	1249.73	1133.34	1146.78	1228.78
Taupō Township	1050.37	1021.64	1093.14	1037.23	1014.61	1043.40
Tokoroa/Kinleith	1634.05	1505.81	1548.37	1469.65	1371.18	1505.81
Waihi Basin	2005.51	1919.81	1841.81	1964.39	1925.12	1931.33
Waipa	1416.57	1358.36	1475.79	1351.76	1357.26	1391.95
Waiuku - Discharge Zone	1424.17	1316.18	1443.31	1330.77	1388.20	1380.53
Waiuku - Recharge Zone	1390.47	1283.55	1410.95	1304.12	1369.61	1351.74
Whangamata	1637.72	1516.48	1510.08	1616.77	1593.15	1574.84
Whangamata - Moana Point	1913.96	1814.44	1750.00	1826.44	1810.67	1823.10
Whangapoua	1866.95	1858.64	1864.98	1987.03	1828.56	1881.23
Whiritoa	2139.42	2049.04	1963.85	2011.40	1996.60	2032.06

Table 22: Waikato region annual aquifer PET decadal statistics (Source: NIWA, VCSN data)

Aquifer Name	**1971 - 1980**	**1981 - 1990**	**1991 - 2000**	**2001 - 2010**	**2011 - 2020**	**Mean PET (mm)**
Cooks Beach	1024.72	914.88	913.16	983.49	1019.07	971.06
Hahei	1039.12	920.07	924.77	993.79	1026.20	980.79
Hamilton Basin - North	899.29	858.88	854.35	906.62	943.83	892.60
Hamilton Basin - South	876.83	838.30	829.89	884.56	921.09	870.13
Hamilton Basin - West	881.02	836.44	825.57	881.93	915.27	868.05
Kuaotunu West	1032.74	921.84	916.60	988.78	1022.40	976.47
Matarangi	1020.14	920.00	908.71	980.12	1017.16	969.22
Northern Hauraki	952.60	890.85	896.16	944.28	984.82	933.74
Opoutere	970.71	883.40	895.00	957.77	1005.97	942.57
Pauanui	1017.17	907.46	920.20	983.86	1021.06	969.95
Pukekawa	934.51	901.40	891.61	927.75	977.43	926.54
Pukekohe	964.60	923.58	915.77	945.99	992.99	948.59
Putaruru	870.03	831.46	814.18	861.67	903.47	856.16
Reporoa Basin - East of Waikato River	883.90	850.94	789.94	847.00	885.84	851.52
Reporoa Basin - Torepatutahi Discharge Zone	893.87	859.23	796.78	853.92	889.35	858.63
Reporoa Basin - Torepatutahi Recharge Zone	833.66	830.62	751.91	818.05	868.93	820.63
Reporoa Basin - West of Waikato River	873.71	843.59	784.28	840.45	877.98	844.00
Southern Hauraki	901.09	860.92	864.71	908.98	952.08	897.56
Taupō Township	830.32	808.72	752.84	811.17	853.14	811.24
Tokoroa/Kinleith	818.27	798.62	762.10	815.93	867.77	812.54
Waihi Basin	905.39	860.54	876.21	924.85	984.21	910.24
Waipa	880.56	820.19	**802.33**	**861.18**	**890.63**	850.98
Waiuku - Discharge Zone	986.86	941.42	937.18	958.47	1003.61	965.51
Waiuku - Recharge Zone	991.62	946.53	941.73	961.51	1007.47	969.77
Whangamata	986.65	895.70	919.66	972.23	1015.79	958.01
Whangamata - Moana Point	967.05	886.10	904.89	959.27	1006.87	944.84
Whangapoua	992.76	911.44	891.31	962.91	1007.58	953.20
Whiritoa	943.73	874.78	894.11	946.91	1000.26	931.96

Table 23: Waikato historical decadal climatological temperature changes (not changes these are absolute temperatures) by aquifer region (Source: NIWA VCSN data)

Aquifer Name	**1973 - 1980**	**1981 - 1990**	**1991 - 2000**	**2001 - 2010**	**2011 - 2020**	**1971- 2020**
Cooks Beach	14.61	14.66	14.38	14.67	14.96	14.65
Hahei	14.79	14.83	14.57	14.88	15.19	14.85
Hamilton Basin - North	14.00	14.05	14.00	14.20	14.52	14.15
Hamilton Basin - South	13.68	13.74	13.60	13.79	14.30	13.82
Hamilton Basin - West	13.69	13.74	13.65	13.86	14.32	13.85
Kuaotunu West	14.59	14.70	14.42	14.68	14.98	14.67
Matarangi	14.45	14.59	14.32	14.55	14.85	14.55
Northern Hauraki	14.53	14.47	14.49	14.70	14.94	14.63
Opoutere	14.24	14.25	14.16	14.48	14.86	14.40
Pauanui	14.70	14.71	14.55	14.88	15.24	14.82
Pukekawa	14.03	14.04	14.20	14.39	14.73	14.28
Pukekohe	14.23	14.24	14.46	14.61	14.99	14.51
Putaruru	13.31	13.32	12.91	13.07	13.53	13.23
Reporoa Basin - East of Waikato River	11.91	12.10	12.03	12.21	12.86	12.22
Reporoa Basin - Torepatutahi Discharge Zone	11.87	12.10	12.11	12.29	12.95	12.26
Reporoa Basin - Torepatutahi Recharge Zone	10.97	11.21	11.31	11.47	12.09	11.41
Reporoa Basin - West of Waikato River	11.90	12.07	12.00	12.16	12.90	12.21
Southern Hauraki	14.09	14.10	13.86	14.01	14.40	14.09
Taupō Township	11.85	11.82	11.68	11.80	12.57	11.94
Tokoroa/Kinleith	12.32	12.38	11.98	12.16	12.62	12.29
Waihi Basin	13.92	14.02	13.94	14.14	14.56	14.12
Waipa	13.55	13.56	13.50	13.74	14.11	13.69
Waiuku - Discharge Zone	14.70	14.84	14.89	15.05	15.39	14.98
Waiuku - Recharge Zone	14.69	14.83	14.90	15.05	15.40	14.97
Whangamata	14.56	14.62	14.59	14.88	15.30	14.79
Whangamata - Moana Point	14.37	14.42	14.38	14.66	15.07	14.58
Whangapoua	14.12	14.32	14.08	14.25	14.56	14.27
Whiritoa	14.13	14.21	14.18	14.44	14.87	14.37

16: Climate Change Impact on Precipitation, Runoff and PET

The red values in Table 24 highlight the decreasing signal of precipitation and runoff in other months. The slight decrease in the signal is highlighted in eight months and the annual mean value for precipitation, although they are less than 5%. Table 25 illustrates the changes from a spatial distribution perspective. Only the Lake Taupō and Tongariro areas show a possible increase in the precipitation signal.

Table 27 indicates an increase in PET with the rise in temperatures across all areas. PET increases of between 5 and 6% are possible under SSP5-8.5 by 2050 and could reach between 12 and 14% by 2090. Given the historical data of PET increasing, these values could reach 95% of the GCM ensemble projections, which could reach 10% for the SSP5-8.5 scenario by 2050, and 20% for SSP 5-8.5 2090.

Table 24: Waikato region 2050 monthly changes in temperature, precipitation, runoff, and mean wind speed under the SSP5-8.5 Scenario, median with the 5th and 95th percentile range. The red figures show the decrease signal in precipitation and runoff in ensemble median changes

Month	Mean Temperature (Celsius)	Maximum Temperature (Celsius)	Minimum Temperature (Celsius)	Precipitation (%)	Runoff (%)	Mean Wind Speed (%)
Jan	1.46 (1.21, 2.09)	1.50 (1.20, 2.95)	1.45 (1.16, 2.10)	**1.96 (-17.45, 23.85)**	-3.98 (-37.00, 64.69)	-4.09 (-20.87, 13.97)
Feb	1.50 (1.11, 2.03)	1.49 (1.15, 2.68)	1.46 (1.12, 2.20)	**-1.26 (-16.47, 23.65)**	4.17 (-46.10, 61.90)	-4.44 (-17.94, 10.83)
Mar	1.46 (1.09, 1.98)	1.49 (1.17, 2.64)	1.46 (1.14, 2.15)	**0.75 (-12.63, 28.35)**	-1.60 (-49.51, 85.63)	-3.73 (-16.36, 13.16)
Apr	1.38 (1.07, 1.81)	1.39 (1.16, 2.14)	1.38 (1.10, 1.83)	**-0.24 (-15.52, 19.04)**	5.60 (-40.72, 82.39)	-4.93 (-18.71, 15.48)
May	1.32 (0.90, 1.87)	1.37 (1.00, 2.00)	1.32 (0.96, 1.83)	**-1.44 (-13.82, 15.23)**	2.21 (-35.96, 77.15)	-4.56 (-15.84, 8.39)
Jun	1.27 (0.98, 1.78)	1.28 (0.99, 1.92)	1.25 (1.00, 1.74)	**-0.09 (-10.94, 13.65)**	4.74 (-39.67, 62.16)	-2.34 (-16.70, 17.44)
Jul	1.27 (0.97, 1.73)	1.28 (0.96, 1.88)	1.27 (0.95, 1.74)	**2.88 (-8.47, 16.12)**	3.01 (-25.77, 44.39)	0.33 (-19.96, 24.99)
Aug	1.24 (0.92, 1.74)	1.27 (0.96, 1.99)	1.20 (0.94, 1.68)	**1.85 (-11.42, 14.29)**	3.15 (-30.16, 38.17)	3.28 (-11.66, 26.27)
Sep	1.18 (0.92, 1.68)	1.21 (0.97, 2.13)	1.15 (0.92, 1.63)	**-1.01 (-12.59, 15.09)**	2.81 (-28.86, 49.68)	3.78 (-11.61, 23.95)
Oct	1.20 (0.92, 1.66)	1.20 (0.98, 2.24)	1.18 (0.91, 1.64)	**-3.32 (-18.43, 7.53)**	-3.04 (-32.08, 38.84)	1.37 (-13.32, 14.60)
Nov	1.24 (0.86, 1.67)	1.29 (0.89, 2.32)	1.20 (0.84, 1.81)	**-1.91 (-22.65, 12.35)**	-7.82 (-44.49, 28.21)	-2.73 (-13.86, 12.62)
Dec	1.32 (0.97, 1.78)	1.36 (0.95, 2.52)	1.28 (0.92, 1.70)	**-0.46 (-12.71, 14.61)**	-4.91 (-31.11, 45.25)	-2.43 (-13.01, 11.21)
Annual	**1.32 (0.99, 1.82)**	**1.34 (1.03, 2.28)**	**1.30 (1.00, 1.84)**	-0.19 (-14.43, 16.98)	**0.36 (-36.79, 56.54)**	**-1.71 (-15.82, 16.08)**

Table 25: Waikato Water Management 2070 Changes under the SSP5-8.5 Scenario, Median with the 5 and 95 Percentile Range. The red figures show the decrease in signal in precipitation and runoff in ensemble median changes

Zone Name	Mean Temperature (Celsius)	Maximum Temperature (Celsius)	Minimum Temperature (Celsius)	Precipitation (%)	Runoff (%)	Mean Wind Speed (%)
Lower Waikato	2.14 (1.61, 2.92)	2.15 (1.67, 3.26)	2.11 (1.63, 2.93)	-1.05 (-25.04, 28.18)	3.19 (-34.36, 66.64)	-3.39 (-26.47, 25.19)
West Coast	2.13 (1.60, 2.91)	2.15 (1.65, 3.28)	2.11 (1.63, 2.92)	-0.03 (-22.71, 27.77)	3.86 (-33.58, 60.25)	-2.83 (-25.72, 27.39)
Waipa	2.15 (1.61, 2.95)	2.17 (1.67, 3.46)	2.12 (1.64, 2.97)	-0.25 (-23.24, 27.56)	3.31 (-34.30, 59.41)	-2.86 (-25.96, 26.65)
Central Waikato	2.15 (1.62, 2.95)	2.18 (1.67, 3.46)	2.12 (1.64, 2.97)	-0.52 (-24.23, 27.53)	2.81 (-35.20, 61.84)	-3.10 (-26.23, 25.65)
Upper Waikato	2.19 (1.64, 3.03)	2.25 (1.72, 4.23)	2.15 (1.63, 3.09)	-0.16 (-23.22, 27.36)	1.96 (-32.20, 56.83)	-2.56 (-25.60, 25.94)
Waihou Piako	2.16 (1.63, 2.98)	2.19 (1.70, 3.73)	2.12 (1.63, 3.01)	-0.87 (-24.89, 27.85)	2.52 (-34.27, 64.28)	-2.99 (-26.24, 25.13)
Lake Taupō	2.18 (1.64, 3.05)	2.26 (1.72, 4.29)	2.15 (1.62, 3.09)	0.68 (-22.10, 27.73)	1.02 (-29.53, 56.31)	-2.15 (-25.29, 27.71)
Coromandel	2.15 (1.63, 2.95)	2.16 (1.69, 3.78)	2.11 (1.63, 3.00)	-1.51 (-25.59, 28.50)	2.32 (-33.27, 69.21)	-3.26 (-26.28, 24.63)
Tongariro	2.17 (1.63, 3.04)	2.25 (1.71, 4.17)	2.14 (1.62, 3.06)	1.35 (-21.70, 28.00)	1.52 (-28.73, 60.53)	-1.56 (-24.89, 28.85)

Table 26: Waikato Water Management 2090 Changes under the SSP5-8.5 Scenario, Median with the 5th and 95th Percentile Range

Zone Name	Mean Temperature (Celsius)	Maximum Temperature (Celsius)	Minimum Temperature (Celsius)	Precipitation (%)	Runoff (%)	Mean Wind Speed (%)
Lower Waikato	3.08 (2.32, 4.20)	3.09 (2.40, 4.70)	3.03 (2.35, 4.22)	-1.51 (-36.02, 40.54)	7.16 (-34.24, 74.50)	-4.88 (-38.09, 36.25)
West Coast	3.07 (2.30, 4.19)	3.09 (2.38, 4.72)	3.03 (2.35, 4.21)	-0.04 (-32.67, 39.96)	9.80 (-32.80, 68.96)	-4.07 (-37.01, 39.41)
Waipa	3.09 (2.32, 4.25)	3.13 (2.40, 4.98)	3.05 (2.36, 4.27)	-0.35 (-33.44, 39.65)	8.97 (-32.50, 66.86)	-4.12 (-37.35, 38.35)
Central Waikato	3.10 (2.33, 4.25)	3.13 (2.40, 4.99)	3.05 (2.35, 4.28)	-0.75 (-34.86, 39.61)	7.98 (-32.62, 68.97)	-4.46 (-37.75, 36.91)
Upper Waikato	3.15 (2.37, 4.36)	3.24 (2.48, 6.08)	3.09 (2.34, 4.44)	-0.22 (-33.41, 39.37)	6.15 (-31.63, 64.25)	-3.68 (-36.83, 37.32)
Waihou Piako	3.11 (2.34, 4.29)	3.15 (2.44, 5.36)	3.05 (2.35, 4.33)	-1.25 (-35.82, 40.07)	7.08 (-32.21, 71.89)	-4.31 (-37.76, 36.15)
Lake Taupō	3.14 (2.36, 4.38)	3.25 (2.47, 6.17)	3.10 (2.33, 4.44)	0.98 (-31.80, 39.89)	6.21 (-30.84, 65.19)	-3.09 (-36.39, 39.88)

Coromandel	3.10 (2.34, 4.25)	3.12 (2.44, 5.43)	3.03 (2.34, 4.31)	-2.17 (-36.83, 41.00)	6.54 (-35.34, 77.69)	-4.69 (-37.82, 35.43)
Tongariro	3.12 (2.35, 4.37)	3.24 (2.46, 6.00)	3.08 (2.33, 4.41)	1.94 (-31.22, 40.28)	8.05 (-29.88, 70.21)	-2.25 (-35.81, 41.51)

Table 27: Waikato region aquifer annual PET baseline (mm) and (%) climate changes for SSP 2-4.5 and SSP5-8.5 for 2050, 2070 and 2090 statistics, median with the 5th and 95th percentile range

Aquifer Name	Baseline Annual Mean PET (mm)	SSP245 2050 Changes (%)	SSP245 2070 Changes (%)	SSP245 2090 Changes (%)	SSP585 2050 Changes (%)	SSP585 2070 Changes (%)	SSP585 2090 Changes (%)
Cooks Beach	971.06	4.21 (2.79, 8.12)	5.69 (3.44, 9.52)	6.74 (4.36, 10.93)	5.15 (3.33, 9.10)	8.75 (6.10, 14.03)	12.66 (8.51, 17.67)
Hahei	980.79	4.21 (2.76, 8.19)	5.69 (3.42, 9.58)	6.72 (4.34, 11.00)	5.15 (3.31, 9.17)	8.73 (6.07, 14.08)	12.63 (8.49, 17.69)
Hamilton Basin - North	892.60	4.20 (2.87, 6.65)	5.69 (3.53, 8.47)	6.71 (4.51, 10.07)	5.15 (3.51, 7.95)	8.75 (6.39, 13.19)	12.80 (8.87, 17.23)
Hamilton Basin - South	870.13	4.27 (2.92, 7.18)	5.80 (3.59, 9.01)	6.83 (4.61, 10.64)	5.30 (3.63, 8.49)	8.93 (6.61, 13.86)	13.15 (9.22, 17.65)
Hamilton Basin - West	868.05	4.23 (2.91, 6.86)	5.76 (3.58, 8.69)	6.78 (4.61, 10.32)	5.23 (3.60, 8.18)	8.86 (6.59, 13.47)	13.03 (9.12, 17.38)
Kuaotunu West	976.47	4.23 (2.77, 8.16)	5.70 (3.42, 9.52)	6.76 (4.33, 10.90)	5.14 (3.28, 9.13)	8.74 (6.04, 14.00)	12.64 (8.38, 17.62)
Matarangi	969.22	4.25 (2.79, 8.09)	5.71 (3.44, 9.46)	6.78 (4.35, 10.82)	5.13 (3.30, 9.07)	8.76 (6.04, 13.95)	12.66 (8.39, 17.58)
Northern Hauraki	933.74	4.20 (2.83, 7.36)	5.68 (3.48, 9.07)	6.69 (4.42, 10.56)	5.19 (3.46, 8.54)	8.76 (6.24, 13.78)	12.79 (8.84, 17.66)
Opoutere	942.57	4.21 (2.81, 8.19)	5.72 (3.52, 9.74)	6.73 (4.44, 11.19)	5.23 (3.47, 9.25)	8.84 (6.25, 14.31)	12.83 (8.88, 17.95)
Pauanui	969.95	4.18 (2.81, 8.11)	5.67 (3.49, 9.59)	6.68 (4.40, 11.02)	5.16 (3.41, 9.12)	8.74 (6.17, 14.09)	12.66 (8.71, 17.67)
Pukekawa	926.54	4.12 (2.92, 5.80)	5.54 (3.52, 7.54)	6.64 (4.49, 8.82)	4.98 (3.40, 7.09)	8.54 (6.08, 12.10)	12.41 (8.27, 16.48)
Pukekohe	948.59	4.11 (2.91, 5.81)	5.53 (3.50, 7.53)	6.62 (4.45, 8.79)	4.96 (3.36, 7.09)	8.52 (6.00, 12.07)	12.37 (8.19, 16.46)
Putaruru	856.16	4.52 (3.03, 8.98)	6.14 (3.77, 10.75)	7.16 (4.78, 12.31)	5.71 (3.87, 10.22)	9.49 (6.99, 15.82)	14.11 (9.98, 19.25)
Reporoa Basin - East of Waikato River	851.52	4.87 (3.16, 11.35)	6.71 (4.13, 12.93)	7.64 (5.18, 14.52)	6.21 (4.30, 12.41)	10.29 (7.26, 18.22)	15.36 (11.03, 21.21)
Reporoa Basin - Torepatutahi Discharge Zone	858.63	4.87 (3.14, 11.47)	6.72 (4.11, 13.02)	7.63 (5.18, 14.60)	6.22 (4.28, 12.49)	10.29 (7.23, 18.25)	15.38 (11.01, 21.25)
Reporoa Basin - Torepatutahi Recharge Zone	820.63	4.95 (3.20, 11.74)	6.82 (4.21, 13.28)	7.76 (5.30, 14.90)	6.32 (4.39, 12.72)	10.47 (7.37, 18.52)	15.64 (11.26, 21.57)

Reporoa Basin - West of Waikato River	844.00	4.89 (3.17, 11.27)	6.73 (4.14, 12.88)	7.61 (5.19, 14.39)	6.23 (4.29, 12.38)	10.29 (7.28, 18.14)	15.41 (11.03, 21.17)
Southern Hauraki	897.56	4.34 (2.87, 8.16)	5.90 (3.57, 9.96)	6.91 (4.56, 11.56)	5.45 (3.66, 9.41)	9.10 (6.60, 14.95)	13.42 (9.40, 18.40)
Taupō Township	811.24	4.88 (3.22, 10.96)	6.70 (4.15, 12.62)	7.52 (5.18, 14.02)	6.23 (4.28, 12.14)	10.23 (7.35, 17.81)	15.39 (11.05, 20.98)
Tokoroa/Kinleith	812.54	4.65 (3.13, 9.51)	6.33 (3.94, 11.25)	7.35 (4.95, 12.80)	5.88 (4.03, 10.74)	9.78 (7.22, 16.38)	14.56 (10.39, 19.83)
Waihi Basin	910.24	4.28 (2.84, 8.34)	5.83 (3.57, 10.06)	6.83 (4.51, 11.58)	5.38 (3.60, 9.50)	9.03 (6.45, 14.84)	13.20 (9.26, 18.39)
Waipa	850.98	4.21 (2.92, 6.86)	5.75 (3.59, 8.66)	6.79 (4.66, 10.25)	5.26 (3.64, 8.17)	8.85 (6.65, 13.43)	13.07 (9.19, 17.29)
Waiuku - Discharge Zone	965.51	4.06 (2.89, 5.49)	5.48 (3.47, 7.21)	6.60 (4.44, 8.40)	4.90 (3.32, 6.81)	8.44 (5.93, 11.69)	12.25 (7.94, 16.18)
Waiuku - Recharge Zone	969.77	4.08 (2.88, 5.55)	5.50 (3.45, 7.28)	6.63 (4.43, 8.47)	4.91 (3.31, 6.88)	8.47 (5.91, 11.78)	12.30 (7.93, 16.30)
Whangamata	958.01	4.18 (2.76, 8.21)	5.70 (3.49, 9.85)	6.69 (4.40, 11.29)	5.24 (3.48, 9.30)	8.84 (6.25, 14.41)	12.85 (8.93, 18.08)
Whangamata - Moana Point	944.84	4.20 (2.80, 8.15)	5.71 (3.52, 9.79)	6.70 (4.43, 11.24)	5.25 (3.50, 9.25)	8.85 (6.29, 14.38)	12.88 (8.98, 18.08)
Whangapoua	953.20	4.27 (2.83, 8.04)	5.74 (3.47, 9.43)	6.82 (4.38, 10.77)	5.14 (3.32, 9.05)	8.80 (6.07, 13.93)	12.72 (8.42, 17.57)
Whiritoa	931.96	4.22 (2.82, 8.23)	5.75 (3.56, 9.90)	6.74 (4.48, 11.37)	5.29 (3.56, 9.35)	8.92 (6.37, 14.52)	12.97 (9.12, 18.17)

17: Population and Economic Projections for the Waikato Region Based on WISE data

The Waikato Integrated Scenario Explorer (WISE) is an Integrated Spatial Decision Support System (ISDSS) designed specifically for New Zealand, which focuses on the Waikato region. (http://www.creatingfutures.org.nz/waikato-projections-demographic-and-economic/)
The Waikato Projections for 2018-2068 are based on the 2018 census data and were completed at the end of March 2021. The Waikato projections represent data at a territorial authority level for several parameters. Further modelling work generated outputs for the key parameters down to a Statistical Area 2 unit level (SA2).

Tables 28 to 30 represent the data derived from WISE projections. They were focusing on the value-added in 2050, 34.4% increase in agriculture, 46.8 in industry, other 45.9% in other sectors, and 47.4% in town water supply. The development of the economy will likely increase the water demand. However, the relationship between growth and water demand may not be proportionally linked since many factors can impact water consumption rates and economic activities.

Based on international experience, water consumption is usually linearly related to the population increase, even globally.

In 2018, the total population of the Waikato region was 475,601. Hamilton's population was 168,600, and the Waikato District was 78,200, representing two of the most populated areas. The overall population of the Waikato region is projected to increase by a median projection of 28.5% (low 13.8% and high 43.87% projections) by2050. Across the region, Hamilton is projected to have the most significant increase with a median growth of 41.1% (low 24.8% and high 57.6% projections). Considering that 53% of surface water has already been allocated, the current water demand and supply tensions are likely to be an increasingly contentious issue.

Table 28: Waikato region economic index - value-added baseline and changes (%) (Source: WISE 2018)

Year	Agriculture - Value Added ($2018m) (05Pth, 95Pth)	Industrial - Value Added ($2018m) (05Pth, 95Pth)	Other - Value Added ($2018m) (05Pth, 95Pth)	Town Supply - Value Added ($2018m) (05Pth, 95Pth)
2018	2808.3	5156.43	410.85	11833.57
2020	-1.03 (-4.61, 3.31)	0.5 (-5.45, 8.44)	1.8 (-1.38, 7.07)	2.93 (0.08, 6.41)
2030	10.18 (6.48, 16.63)	16.39 (2.78, 32.38)	17.92 (9.01, 28.7)	19.11 (10.91, 27.87)
2040	22.41 (16.97, 30.95)	31.53 (12.85, 52.98)	32.39 (18.68, 48.5)	33.82 (20.71, 47.93)
2050	**34.37 (26.93, 44.96)**	**46.78 (23.58, 72.38)**	**45.89 (27.34, 67.19)**	**47.44 (29.37, 66.92)**
2060	45.86 (36.23, 58.58)	62.12 (34.52, 90.81)	58.88 (35.22, 85.3)	60.55 (37.22, 85.47)

Table 29: Waikato region economic index - employment baseline and changes (%) (Source: WISE 2018)

Year	Agriculture - Employment (MECs) (05Pth, 95Pth)	Industrial - Employment (MECs) (05Pth, 95Pth)	Other - Employment (MECs) (05Pth, 95Pth)	Town Supply - Employment (MECs) (05Pth, 95Pth)
2018	25372.4	56026.2	7883.3	137773.2
2020	-1.18 (-3.53, 3.69)	0.22 (-6.46, 8.14)	1.49 (-1.67, 6.75)	2.56 (0.11, 5.82)
2030	4.61 (0.45, 11.62)	11.09 (-3.52, 26.1)	15.81 (7.06, 26.4)	13.48 (6.48, 21.8)
2040	8.36 (2.56, 17.1)	20.41 (1.26, 39.12)	28.09 (14.82, 43.68)	22.22 (11.11, 35.39)
2050	**10.22 (2.85, 20.42)**	**29.03 (6.3, 49.73)**	**39.05 (21.36, 59.35)**	**29.24 (14.21, 46.91)**
2060	10.56 (1.72, 22.18)	37.05 (11.22, 58.57)	49.17 (26.96, 73.98)	35.19 (16.31, 57.08)

Table 30: Waikato population growth projections (05Pth, 95Pth) statistics for each district and Hamilton City. The red values highlight the area where the population increase is relatively fast

District Name	2018 Baseline	2020 Changes (%)	2030 Changes (%)	2040 Changes (%)	2050 Changes (%)	2060 Changes (%)
Thames-Coromandel District	30700.00	1.65 (0.68, 2.62)	2.21 (-1.99, 6.43)	3.17 (-5.28, 11.67)	5.20 (-7.64, 18.14)	8.11 (-9.23, 25.62)
Hauraki District	20600.00	2.16 (1.18, 3.15)	4.73 (0.40, 9.09)	8.06 (-0.76, 16.95)	13.20 (-0.43, 26.93)	18.24 (-0.44, 37.12)
Waikato District	78200.00	4.74 (3.75, 5.74)	18.16 (13.42, 22.91)	29.18 (19.09, 39.32)	39.56 (23.57, 55.63)	48.14 (25.86, 70.54)
Matamata-Piako District	35300.00	2.34 (1.35, 3.32)	7.35 (2.93, 11.79)	12.48 (3.28, 21.75)	17.62 (3.22, 32.16)	22.63 (2.73, 42.81)
Hamilton City	**168600.00**	**4.79 (3.73, 5.84)**	**18.47 (13.63, 23.32)**	**30.48 (20.16, 40.85)**	**41.09 (24.75, 57.55)**	**50.29 (27.47, 73.29)**
Waipa District	**55000.00**	**3.56 (2.57, 4.54)**	**12.94 (8.36, 17.53)**	**20.87 (11.14, 30.65)**	**28.31 (12.92, 43.84)**	**35.06 (13.62, 56.76)**
Otorohanga District	10500.00	2.46 (1.48, 3.44)	7.85 (3.44, 12.27)	14.87 (5.62, 24.18)	21.72 (7.14, 36.43)	27.63 (7.35, 48.17)
South Waikato District	24900.00	0.71 (-0.27, 1.69)	-0.60 (-4.77, 3.58)	1.44 (-7.00, 9.95)	5.73 (-7.36, 19.00)	10.43 (-7.67, 28.86)
Waitomo District	9580.05	0.33 (-0.65, 1.31)	-2.37 (-6.42, 1.69)	-2.29 (-10.31, 5.79)	0.07 (-12.18, 12.46)	3.89 (-12.90, 20.95)
Taupō District	38399.90	2.24 (1.26, 3.23)	5.61 (1.23, 10.00)	8.92 (-0.10, 18.00)	12.37 (-1.59, 26.51)	15.94 (-3.23, 35.43)
Rotorua District	3821.53	1.83 (0.84, 2.81)	5.29 (0.92, 9.68)	10.04 (1.03, 19.13)	15.35 (1.31, 29.55)	20.98 (1.55, 40.71)

Whole Waikato Region	**475601.48**	**3.56 (2.55, 4.56)**	**12.51 (7.91, 17.12)**	**20.65 (10.99, 30.37)**	**28.46 (13.28, 43.77)**	**35.48 (14.41, 56.77)**

18: Review and Discussions

Evidence points toward a changing climate across the Waikato region. Trends in precipitation and temperature and related seasonal changes are likely to become more pronounced as shown by applying the latest CMIP6 climate models under the two SSP projections.

When combined with wind and other GCM data on PET, the relationship between temperature and precipitation depicts a reasonable likelihood that water supplies will become increasingly constrained, particularly in the spring and summer months.

Many consequences relate to the changes already seen and to be seen as climate change continues in the decades to come. While beyond the current project brief, we believe this project's findings behoves those concerned with water supply and demand at the local, regional and national level to consider the following sectoral issues systemically. These will need to be addressed sooner rather than later. Conditions are likely to change increasingly quickly as demands conflict with supplies across the diversity of applications in the Waikato region.

Water consumption and demand and a changing climate

Assuming behaviours about water use do not change, more water will be required to support projected growth. This is significant in itself, but the population of the Auckland region is also expanding (http://www.stats.govt.nz/browse_for_stats/population/estimates_and_projections.aspx#projection) and will exert an additional demand on Waikato-derived water supplies. This has been factored into the application by Watercare for an additional 200,000m^3 of water per day from the Waikato River at Tuakau.

Industrial water use

Potential demand for industrial development also continues to grow in Waikato. The region is well placed to absorb this industrial growth, assuming it can provide water to support businesses. The region has excellent transport links and is well endowed with zoned and serviced industrial land. The inland port development that is well underway will likely lead to increased interest for industrial and logistics companies to consider the Waikato as a place they need to be established as a critical hub, and with the implications this could have on water demand

Agriculture water use

There may be more pressure on farmers for animal welfare reasons to provide shelter/shade to stock instead of allowing access to waterways during times of heat stress. This may extend to more off-stream access for drinking water and may require advancing the practice of spraying dairy cows with water as they wait for their turn to be milked. Conversely, water demand may decrease in some situations with land-use change to less water demanding species (livestock or forage species).

Water demand can also be expected to change with a changing climate. This may initially be in the form of businesses seeking to re-establish historical rainfall patterns through make-up irrigation.

Town supply increase with population increase

Domestic water supplies for large urban and smaller rural communities are the largest consumptive water-user of surface and groundwater across the region. Auckland's use of the Waikato River resource is the most significant individual abstraction in the region. Regionally, use is set to increase as greater demands are placed on surface and groundwater supplies by urban/industrial users in Taupō, Hamilton, Cambridge, and now Te Awamutu drawing water from the Waikato River catchment, for example.

Water quality issues

Warming of surface waterways will reduce the ability of these water bodies to assimilate the contaminants from point and non-point discharges in the future. As water temperature increases, the ability to hold dissolved gasses such as oxygen decreases. Dissolved oxygen is vital for the breakdown of pollutants and sustaining aquatic life. Any reduction in dissolved oxygen concentration will increase the demand for water for this function, thus rendering it less available for abstractive uses.

A key responsibility will be the need to shade waterways to retain dissolved gasses, especially oxygen, in the water body.

In many areas, groundwater quality is declining due to:

- An increase in the amount of wastewater discharged onto land – to about 460,000 m^3/day.
- Increased use of nitrogen fertiliser
- A doubling of stocking rates over the last forty years - animal waste from intensive farming contaminates groundwater with nitrate.
- The nutrients present in groundwater affect the plants and animals that live in the rivers and streams.

Water transfer schemes

Interbasin water transfer schemes will likely become more closely negotiated at the top end of the Waikato catchment through the Tongariro scheme and at the bottom end with transfers out of the Waikato catchment to the Auckland region.

19: Comparing MfE Projections (CMIP5) with CLIMsystems Waikato Region Projections (CMIP5 and CMIP6)

Waikato Regional Council (WRC) is in the final stages of preparing a Climate Change Adaption Guideline (CCG) for the Waikato region. The purpose of this CCG is to assist WRC staff and external stakeholders in planning for climate change adaptation and to encourage a consistent approach to climate adaptation across the region. The draft CCG is available to view on OneDrive here (not to be shared).

The CCG includes a brief section on 'potential impacts of climate change on the Waikato region' (2.1) and a more detailed section on 'modelling and scenario testing' (5), including 'climate change scenarios (RCP scenarios)' (5.1), 'climate change projections for the Waikato region' (5.2) and 'hydrological and hydraulic modelling' (5.3). Currently, the information in these sections is sourced from the latest MfE Guidance (based on CMIP5).

Advice from a MfE staff member recommends that we continue to use (and advocate the use of) the MfE projections and the RCP scenarios for climate change-related modelling and other assessments until the CMIP6 work has been downscaled for New Zealand and the guidance updated. This is to encourage national consistency, as it would be a lot of work to provide the extra guidance needed to use the CMIP6 projections and scenarios. However, they suggest that when describing climate change projections/potential impacts on the Waikato region, it would be sensible to use CLIMsystems' recently completed work.

We (WRC) are happy in principle to follow the recommendations from MfE. However, we want to provide the best information possible to our staff and stakeholders. Therefore, we consider comparing the latest CLIMsystems projections alongside the MfE projections. To decide which approach would be most appropriate, we would like a comparison of the latest CLIMsystems projections (CMIP6) and the MfE projections (CMIP5) for the Waikato region. If the difference is minimal, providing both projections will not provide meaningful value and would likely complicate the decision-making process. However, if the difference is significant, both would need to be considered. It may also be helpful to compare CLIMsystems' CMIP5 and CMIP6 projections. As such, we are requesting the work outlined below.

Work brief

First, please provide a time and cost estimate for the following comparisons (detailed below):

1. Comparison of the latest MfE projections (CMIP5) with the latest CLIMsystems projections for the Waikato region (CMIP6)
2. Comparison of the CLIMsystems CMIP6 projections with the CLIMsystems CMIP5 projections

Then, for item 1 and potentially item 2 above, provide a simple comparison (likely in table form) for the scenarios/timescales/projections in the table below.

Please provide the projections for the 50th percentile/mean and the 5th and 95th percentiles.

Some of the MfE projections for the Waikato region have been included in section 5 of the draft CCG (taken from Climate Change Projections for New Zealand: Atmosphere Projections Based on Simulations from the IPCC Fifth Assessment, 2nd Edition (MfE, 2018).

Table 31: Working scope defined by WRC

Time Slice	RCP / SSP	Projections
2090	RCP4.5 / SSP2-4.5	Mean temperature
	RCP8.5/RCP6.0 / SSP5-8.5	Mean precipitation
		High-intensity precipitation/daily extreme precipitation
		PED (PED, CMIP6)
		Mean wind speed
		Extremely windy days/extreme wind speed
		Hot days (>25 degrees C) *Frost days (<0 degrees C)*
		Wildfire

19.1 Comparison of Mean Temperature Changes

Comments:

(1) The CMIP6 mean temperature projections for 2090 are very close to the MfE 2018 report.
(2) The CMIP5 mean temperature based on GCMs results predicted a slightly lower rise in temperature than the MfE report due to differences in model selection and dynamical downscaling.
(3) The mean temperature change projection in model selection is varied; however, the envelope of the scenarios and intermodal variability is larger.

Table 32: Waikato Region, 2090 Average Seasonal and Annual Mean Temperature Changes (Celsius) – 50th Percentile (Brackets 5th and 95th Percentile)

2090	DJF	MAM	JJA	SON	ANN
SSP2-4.5	1.68 (1.19, 2.52)	1.56 (1.13, 2.46)	1.44 (1.1, 2.21)	1.42 (1.04, 2.19)	**1.55 (1.14, 2.36)**
SSP3-7.0	2.6 (1.84, 3.9)	2.42 (1.76, 3.81)	2.24 (1.7, 3.43)	2.19 (1.62, 3.39)	**2.38 (1.75, 3.65)**
SSP5-8.5	3.35 (2.37, 5.03)	3.13 (2.27, 4.91)	2.88 (2.19, 4.42)	2.83 (2.08, 4.37)	**3.07 (2.25, 4.71)**
RCP4.5	1.29 (0.71, 1.98)	1.29 (0.78, 1.82)	1.22 (0.73, 1.79)	1.15 (0.66, 1.62)	1.26 (0.74, 1.82)
RCP6.0	1.57 (0.86, 2.41)	1.57 (0.95, 2.22)	1.49 (0.89, 2.18)	1.4 (0.81, 1.98)	1.53 (0.9, 2.22)
RCP8.5	2.73 (1.49, 4.2)	2.75 (1.66, 3.88)	2.6 (1.55, 3.81)	2.45 (1.41, 3.46)	2.65 (1.55, 3.86)
RCP4.5 (6 GCMs)	1.43 (0.96, 1.79)	1.42 (1.11, 1.66)	1.2 (0.93, 1.47)	1.14 (0.69, 1.38)	1.32 (0.94, 1.6)
RCP6.0 (6 GCMs)	1.75 (1.16, 2.18)	1.74 (1.35, 2.03)	1.47 (1.13, 1.79)	1.4 (0.85, 1.68)	1.61 (1.14, 1.94)
RCP8.5 (6 GCMs)	3.04 (2.02, 3.8)	3.04 (2.36, 3.55)	2.56 (1.98, 3.13)	2.44 (1.48, 2.95)	2.79 (1.98, 3.38)
RCP4.5 (MfE) (6 RCMs)	1.5 (0.7, 2.7)	1.5 (0.8, 2.2)	1.5 (0.9, 2.0)	1.3 (0.8, 1.8)	**1.4 (0.9, 2.1)**
RCP6.0 (MfE) (6 RCMs)	2.0 (1.2, 3.6)	1.9 (1.1, 2.8)	1.9 (1.2, 2.6)	1.7 (1.0, 2.3)	**1.9 (1.2, 2.9)**
RCP8.5 (MfE) (6 RCMs)	3.3 (2.2, 5.3)	3.2 (2.3, 4.5)	3.1 (2.4, 4.0)	2.7 (2.0, 3.5)	**3.1 (2.3, 4.4)**

19.2 Comparison of Mean Precipitation Changes

Comments:

(1) The MfE 2018 report examined monthly precipitation using all available GCMs. The GCM numbers are different for each RCP (please refer to Table 2 of MfE 2018 report)
(2) The CLIMsystems Waikato region report applied a pattern scaling approach using all available GCMs, which is percentage change per degree global temperature change, to obtain consistent climate change signals.
(3) The MfE 2018 seasonal and annual precipitation changes are similar to the Waikato regional report. However, all the reports have less than a 5% per cent increase in annual precipitation and a decreased signal in spring, with substantial model uncertainties.
(4) Hamilton (Ruakura) and Taupo are separately presented to provide consistency with the MfE 2018 report. Taupo has a stronger precipitation signal than Hamilton in annual precipitation.

Table 33: Hamilton City, 2090 Average Seasonal and Annual Precipitation Changes (%) - 50th Percentile (Brackets 5th and 95th Percentile)

2009	**DJF**	**MAM**	**JJA**	**SON**	**ANN**
SSP2-4.5	1.28 (-16.06, 24.64)	0.03 (-15.41, 31.11)	1.96 (-12.08, 17.98)	-1.85 (-17.89, 11.3)	0.4 (-15.14, 20.66)
SSP3-7.0	1.99 (-24.89, 38.2)	0.05 (-23.89, 48.22)	3.04 (-18.73, 27.87)	-2.86 (-27.73, 17.51)	0.63 (-23.47, 32.02)
SSP5-8.5	2.57 (-32.11, 49.28)	0.06 (-30.83, 62.22)	3.92 (-24.16, 35.96)	-3.69 (-35.79, 22.59)	0.81 (-30.29, 41.31)
RCP4.5	3.36 (-20.82, 30.72)	4.65 (-16.02, 32.82)	1.03 (-13.96, 19.01)	-1.46 (-17.59, 21.74)	1.7 (-16.76, 25.28)
RCP6.0	4.11 (-25.42, 37.52)	5.67 (-19.57, 40.08)	1.26 (-17.05, 23.22)	-1.79 (-21.49, 26.56)	2.08 (-20.47, 30.87)
RCP8.5	7.18 (-44.44, 65.57)	9.92 (-34.2, 70.05)	2.2 (-29.8, 40.58)	-3.13 (-37.56, 46.42)	3.63 (-35.77, 53.95)
RCP4.5 (MfE)	2 (-13, 15)	-3 (-16, 9)	4 (-7, 16)	-6 (-20, 4)	1 (-4, 6)
RCP6.0 (MfE)	4 (-18, 24)	2 (-13, 36)	8 (-10, 35)	-1 (-7, 5)	3 (-10, 26)
RCP8.5 (MfE)	3 (-16, 23)	1 (-8, 10)	5 (-10, 17)	-2 (-11, 6)	0 (-11, 7)

Table 34: Taupo District, 2090 Average Seasonal and Annual Precipitation Changes (%) - 50th Percentile (Brackets 5th and 95th Percentile)

2009	**DJF**	**MAM**	**JJA**	**SON**	**ANN**
SSP2-4.5	0.27 (-16.51, 24.02)	0.89 (-16.55, 31.02)	2.79 (-12.31, 17.35)	-0.49 (-15.41, 12.23)	0.93 (-15.02, 20.52)
SSP3-7.0	0.41 (-25.59, 37.23)	1.37 (-25.66, 48.08)	4.33 (-19.08, 26.89)	-0.76 (-23.89, 18.96)	1.44 (-23.28, 31.8)
SSP5-8.5	0.53 (-33.02, 48.04)	1.77 (-33.1, 62.04)	5.58 (-24.62, 34.7)	-0.98 (-30.82, 24.46)	1.85 (-30.03, 41.03)
RCP4.5	2.95 (-22.17, 26.7)	5.08 (-15.25, 27.47)	2.36 (-12.42, 20.29)	-0.62 (-16.22, 20.21)	2.3 (-16.23, 23.3)
RCP6.0	3.61 (-27.07, 32.61)	6.21 (-18.62, 33.55)	2.88 (-15.17, 24.79)	-0.76 (-19.81, 24.69)	2.81 (-19.83, 28.46)
RCP8.5	6.3 (-47.32, 56.99)	10.85 (-32.54, 58.63)	5.04 (-26.52, 43.32)	-1.32 (-34.62, 43.15)	4.91 (-34.65, 49.74)
RCP4.5 (MfE)	2 (-4, 13)	1 (-13, 11)	4 (-8, 13)	-2 (-9, 6)	2 (-7, 10)
RCP6.0 (MfE)	2 (-20, 22)	3 (-8, 13)	7 (-9, 23)	-3 (-12, 5)	2 (-7, 12)
RCP8.5 (MfE)	8 (-4, 26)	1 (-13, 11)	6 (-7, 18)	-6 (-20, 4)	2 (-4, 7)

19.3 Comparison of Extreme Precipitation Changes

Comments:

(1) MfE applied the unified extreme precipitation change factors for all of New Zealand using RCM data.
(2) The Waikato regional report only applied all the available GCMs for the Waikato region.
(3) However, the MfE 2018 and WRC 2022 reports have consistent results. With the increase of ARI (average recurrence intervals), the change factor will increase; with the increase of duration, from hours to days, the change factor gets small.
(4) The WRC CMIP5 extreme precipitation is consistently less than the MfE 2018 assessment because of model data and selection differences.

Table 35: Waikato Region, **CMIP5** Average Extreme Precipitation Percentage Change Factors (%) - 50th Percentile (Brackets 5th and 95th Percentile)

2090	ARI002	ARI005	ARI010	ARI020	ARI030	ARI050	ARI100
3	2.93 (-6.12, 9.79)	3.33 (-7.31, 13.01)	4.58 (-7.54, 15.14)	5.65 (-7.72, 18.73)	6.35 (-7.91, 21.75)	7.15 (-8.29, 25.95)	8.19 (-9.10, 31.16)
6	3.23 (-5.68, 8.04)	3.49 (-5.93, 11.27)	4.42 (-6.04, 14.20)	5.38 (-6.14, 17.43)	5.90 (-6.20, 19.10)	6.51 (-6.33, 21.94)	7.60 (-6.62, 26.08)
12	2.88 (-5.82, 8.18)	3.19 (-6.37, 10.74)	4.16 (-6.98, 13.78)	5.08 (-7.34, 17.17)	6.09 (-7.44, 19.14)	6.95 (-7.49, 21.98)	7.86 (-7.41, 25.35)
24	3.03 (-6.99, 8.39)	3.96 (-9.04, 10.64)	4.61 (-10.37, 12.86)	4.91 (-11.26, 14.82)	5.27 (-11.67, 16.74)	6.23 (-12.10, 19.63)	7.60 (-12.54, 24.14)
48	2.75 (-5.90, 10.35)	2.74 (-7.96, 13.21)	2.86 (-9.57, 15.42)	3.27 (-11.03, 18.88)	3.45 (-11.87, 21.41)	3.85 (-12.90, 24.71)	4.58 (-14.25, 29.58)
72	2.57 (-6.86, 10.44)	2.23 (-8.55, 14.85)	nan (-10.79, 17.23)	2.72 (-11.71, 20.28)	2.92 (-12.06, 22.40)	3.35 (-12.43, 25.18)	3.79 (-12.91, 29.24)
96	2.28 (-6.90, 11.27)	2.39 (-8.26, 15.26)	2.77 (-9.10, 18.23)	3.13 (-9.19, 21.12)	3.06 (-9.26, 23.10)	2.98 (-9.27, 25.77)	3.56 (-9.16, 30.01)
120	2.15 (-6.89, 10.99)	3.12 (-9.33, 14.74)	3.64 (-9.85, 17.48)	4.16 (-9.77, 20.32)	4.51 (-9.68, 21.97)	4.70 (-9.69, 24.15)	5.02 (nan, 27.65)

144	2.39 (-6.67, 10.36)	2.86 (-8.39, 13.35)	3.28 (-9.77, 15.79)	3.22 (-9.52, 18.80)	3.41 (-9.23, 20.42)	3.83 (-8.83, 22.48)	4.46 (-8.29, 25.48)
168	2.42 (-5.76, 8.68)	2.66 (-8.57, 12.59)	2.77 (-10.33, 15.31)	3.29 (-11.06, 18.26)	3.54 (-11.41, 20.18)	4.02 (-11.78, 22.73)	5.28 (-12.21, 26.67)

Table 36: Waikato Region, **CMIP6** Average Extreme Precipitation Percentage Change Factors (%) - 50th Percentile (Brackets 5th and 95th Percentile)

2090	ARI002	ARI005	ARI010	ARI015	ARI025	ARI050	ARI100
3	6.98 (0.49, 11.47)	7.60 (0.15, 13.23)	8.15 (-0.25, 14.90)	8.39 (-0.56, 15.96)	8.90 (-0.88, 17.98)	9.54 (-1.47, 22.05)	10.46 (-2.25, 27.45)
6	6.71 (1.24, 11.98)	7.33 (0.62, 13.37)	7.66 (0.09, 14.83)	7.85 (-0.14, 16.34)	8.03 (-0.49, 18.70)	8.36 (-1.34, 22.68)	8.90 (-2.38, 27.47)
12	5.86 (0.27, 10.60)	7.18 (0.38, 12.07)	7.84 (0.28, 14.73)	8.09 (0.09, 16.92)	8.10 (-0.14, 19.71)	8.37 (-0.88, 23.95)	8.94 (-1.98, 28.80)
24	**5.31 (0.81, 9.52)**	**6.40 (1.58, 11.33)**	**7.00 (1.77, 13.09)**	**7.51 (1.46, 14.48)**	**7.92 (0.52, 16.53)**	**8.75 (-0.86, 19.77)**	**9.92 (-2.27, 23.79)**
48	3.99 (0.08, 8.13)	5.70 (0.29, 9.51)	6.82 (0.12, 11.27)	7.42 (-0.12, 12.63)	8.28 (-0.79, 14.89)	9.82 (-2.06, 18.79)	11.74 (-3.08, 23.63)
72	3.48 (-0.14, 8.48)	4.79 (-0.45, 10.83)	5.41 (-0.69, 12.89)	5.71 (-0.88, 14.48)	6.10 (-1.23, 17.21)	6.52 (-2.05, 21.29)	7.20 (-3.09, 26.04)
96	3.47 (-0.49, 7.74)	4.52 (-0.37, 9.38)	5.47 (nan, 11.01)	6.12 (-1.01, 12.90)	6.67 (-1.66, 15.71)	7.93 (-2.37, 20.17)	9.46 (-3.10, 25.24)
120	3.27 (-1.11, 7.43)	4.41 (-1.54, 9.14)	4.89 (-2.45, 10.14)	5.16 (-2.78, 11.75)	5.61 (-3.06, 14.55)	6.28 (-4.14, 19.05)	7.19 (-5.43, 24.47)
144	3.12 (-0.84, 7.19)	4.20 (-1.23, 9.78)	4.83 (-1.99, 12.02)	5.25 (-2.55, 13.66)	5.51 (-3.48, 16.04)	6.55 (-4.99, 20.03)	8.25 (-6.70, 24.73)
168	2.53 (-0.17, 6.01)	4.07 (-0.54, 9.03)	4.94 (-1.60, 11.90)	5.63 (-2.38, 13.77)	6.54 (-3.47, 16.56)	7.64 (-4.97, 21.04)	8.69 (-6.47, 26.37)

Table 13: Percentage change factors to estimate the increase in rainfall depth that is expected to result from a 1 degree increase in temperature.

ARI: Duration	2 yr	5 yr	10 yr	20 yr	30 yr	50 yr	100 yr
1 hour	12.2 9.8 – 17.5	12.8 10.6 – 18.1	13.1 10.7 – 18.5	13.3 10.7 – 18.8	13.4 10.7 – 18.9	13.5 10.7 – 19.1	13.6 10.7 – 19.4
2 hours	11.7 9.2 – 18.0	12.3 9.9 – 18.4	12.6 10.0 – 18.7	12.8 10.1 – 19.0	12.9 10.1 – 19.1	13.0 10.1 – 19.3	13.1 10.1 – 19.6
6 hours	9.8 7.5 – 14.9	10.5 8.0 – 15.4	10.8 8.3 – 15.9	11.1 8.4 – 16.4	11.2 8.5 – 16.6	11.3 8.5 – 17.0	11.5 8.5 – 17.4
12 hours	8.5 5.7 – 13.5	9.2 6.5 – 13.9	9.5 6.8 – 14.2	9.7 7.1 – 14.5	9.8 7.2 – 14.8	9.9 7.3 – 15.1	10.1 7.3 – 15.4
24 hours	7.2 4.0 – 11.9	7.8 4.6 – 12.0	8.1 4.8 – 12.1	8.2 4.9 – 12.2	8.3 5.0 – 12.3	8.4 5.1 – 12.5	8.6 5.2 – 12.8
48 hours	6.1 2.6 – 11.0	6.7 3.1 – 11.1	7.0 3.3 – 11.2	7.2 3.4 – 11.3	7.3 3.4 – 11.3	7.4 3.4 – 11.4	7.5 3.5 – 11.5
72 hours	5.5 2.1 – 10.5	6.2 2.6 – 10.6	6.5 2.7 – 10.8	6.6 2.8 – 10.9	6.7 2.9 – 11.0	6.8 2.9 – 11.1	6.9 2.9 – 11.2
96 hours	5.1 1.7 – 10.0	5.7 2.2 – 10.2	6.0 2.4 – 10.5	6.2 2.5 – 10.7	6.3 2.6 – 10.9	6.4 2.6 – 11.0	6.5 2.7 – 11.2
120 hours	4.8 1.3 – 9.6	5.4 1.9 – 9.7	5.7 2.1 – 10.0	5.8 2.3 – 10.2	5.9 2.3 – 10.4	6.0 2.4 – 10.5	6.1 2.4 – 10.7

The most likely percentage change is shown on the top of each row and the range provided below it shows the variability that could be expected across New Zealand based on the RCM results. To obtain change factors for a temperature change that is not 1 degree, the values in this table should be multiplied by the projected temperature change.

Table 14: New Zealand land-average temperature increase, in degrees, relative to 1986—2005 for four future emissions scenarios to be used with percentage change factors for extreme rainfall

	2031—2050	2081—2100	2101—2120
RCP 2.6	0.59	0.59	0.59 (4 model avg)
RCP 4.5	0.74	1.21	1.44 (5 model avg)
RCP 6.0	0.68	1.63	2.31 (CESM1-CAM5 only)
RCP 8.5	0.85	2.58	3.13 (3 model avg)

The mid- and late-21st century projections result from the average of six RCM model simulations (driven by different global climate models). The early 22nd century projections are based only on the subset of models that were available and so should be used with caution. These projected temperature changes are different to those provided in Tables 5, 6 and 7 as they are derived from the RCM simulations and because they represent changes over all of New Zealand rather than selected locations or the seven station series.

100 Climate Change Projections for New Zealand: Atmosphere projections based on simulations form the IPCC Fifth Assessment

Figure 58: Screen capture: MfE 2018 report (page 100)

19.4 Comparison of Hot Days and Cold Nights

Comments:

(1) Hot days and cold nights were not assessed in the original WRC 2022 report. Instead, the same historical data time slices were applied for comparison with the MfE 2018 report.
(2) The CMIP6 SSP5-8.5 results demonstrate more hot days and fewer cold nights than the MfE outputs.

Table 37: Waikato Region, Average Hot Days (Tmax >= 25degC) - 50th Percentile

	Baseline	**RCP4.5-2090**	**RCP6.0-2090**	**RCP8.5-2090**	**SSP2-4.5-2090**	**SSP3-7.0-2090**	**SSP5-8.5-2090**
Waikato region	21.54	40.81	46.26	69.69	47.49	64.86	80.31
(MfE) 6 RCM	23.6	47.8	57.7	84			

Table 38: Waikato Region, Average Cold Nights (Tmin <= 0degC) - 50th Percentile

	Baseline	**RCP4.5-2090**	**RCP6.0-2090**	**RCP8.5-2090**	**SSP2-4.5-2090**	**SSP3-7.0-2090**	**SSP5-8.5-2090**
Waikato region	14.27	6.78	5.62	2.07	5.99	3.24	1.68
(MfE)	15.2	6.5	5.0	1.9			

19.5 Comparison of PED Analyses

Comments:

(1) There are national PED projection maps and descriptions in the MfE 2018 report but they do not provide specific outputs for the Waikato region.
(2) The WRC 2022 report provided exact numbers of the region; hence, the analysis provided different outputs. The WRC 2022 report provided the change in probability (percentage) of annual PED>200mm and PED>400mm, while the MfE 2018 report delivered the increase of PED in mm.
(3) Based on the maps and descriptions, MfE predicts a similar trend in PED as the WRC 2022 report.
(4) Both reports identified the increasing trend of PED in the Waikato region.

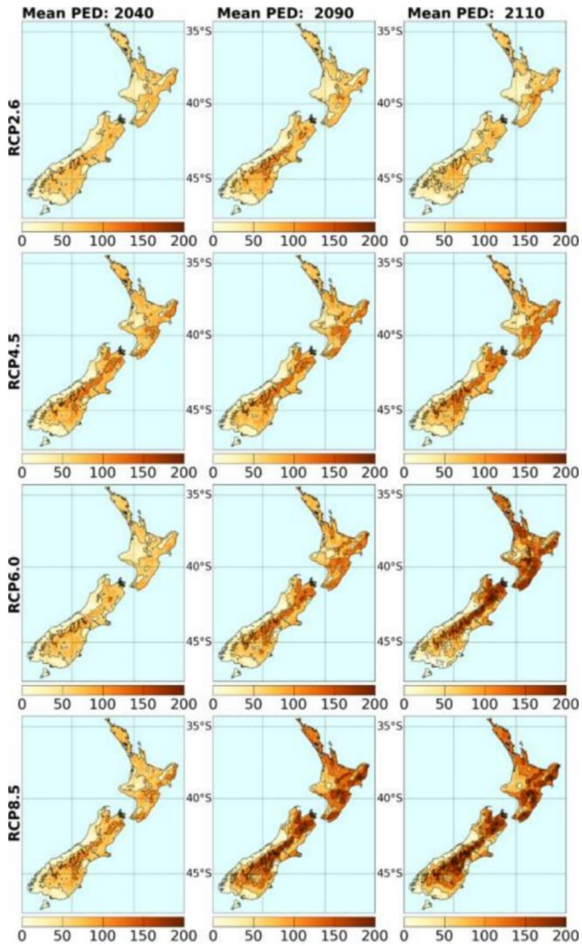


Figure 55: RCM-projected changes in potential evapotranspiration deficit (PED) (in millimetres accumulation over the July–June 'water year'), with respect to the baseline 1995 period, for all four RCPs and three future time periods

Figure 59: National maps of changes in potential evapotranspiration deficit (PED drought index) are presented in Figure 55. A consistent increase in PED of more than 50 millimetres is seen over much of the North Island, with greatest changes over northern and eastern regions, and north-eastern and central South Island east of the main divide indicating long-term drying of these regions (MfE 2018; page108. RCM results)

Excerpts from CLIMsystems WRC AR6 report, using CMIP6 models) (Similar PED increase conclusion, with detailed numbers, and regional maps

During the historical period, the probability of PED>200mm is 25.8%, and PED>400mm is only 2.2%. The potential evapotranspiration deficit (PED) increases across all areas with greater average annual PED of 200 and 400 mm, with more significant rises under the SSP5-8.5 scenario. Under the SSP2-4.5 scenario, a regional average probability of more than 34% accumulated annual PED will exceed 200mm by 2050 and almost 37% by 2090. Comparably, under the SSP5-8.5 scenario, there is a probability greater than 35% of PED exceeding 200mm by 2050 and nearly 46% by 2090. The probability of the annual accumulated PED exceeding 400mm displays the same overall trend.

As displayed on the maps, the Waikato, Hauraki, and Matamata-Piako Districts and portions of northern Taupō and Rotorua have the highest probabilities of annual PED>200mm, some areas exceed 90%. The high probability PED>400mm area is mainly in Hauraki and the northern part of Matamata-Piako District, while the southern part of Rotorua is another PED>400mm hotspot.

Table 39: Regional Average Probability of Annual Accumulated PED will Exceed 200mm and 400mm (%) During Baseline and Scenarios in Waikato Region - 50th Percentile (Brackets 5th and 95th Percentile)

Limit	Year	SSP2-4.5	SSP5-8.5
PED>200mm	Baseline	25.78	25.78
PED>200mm	2050	33.86 (21.42, 54.37)	35.24 (20.58, 59.04)
PED>200mm	2070	35.80 (20.10, 60.60)	39.79 (18.45, 75.17)
PED>200mm	2090	36.93 (20.04, 65.31)	45.80 (16.47, 87.61)
PED>400mm	Baseline	2.21	2.21
PED>400mm	2050	3.10 (0.69, 11.62)	3.67 (0.66, 14.63)
PED>400mm	2070	3.87 (0.62, 15.76)	5.55 (0.50, 30.59)
PED>400mm	2090	4.28 (0.64, 19.76)	8.49 (0.37, 50.95)

*The High (95th percentile of the ensemble) PED was calculated using the future scenarios for a combination of the High (95th percentile of the ensemble) of global temperature change and a Low (5th percentile of the ensemble) of global precipitation change.

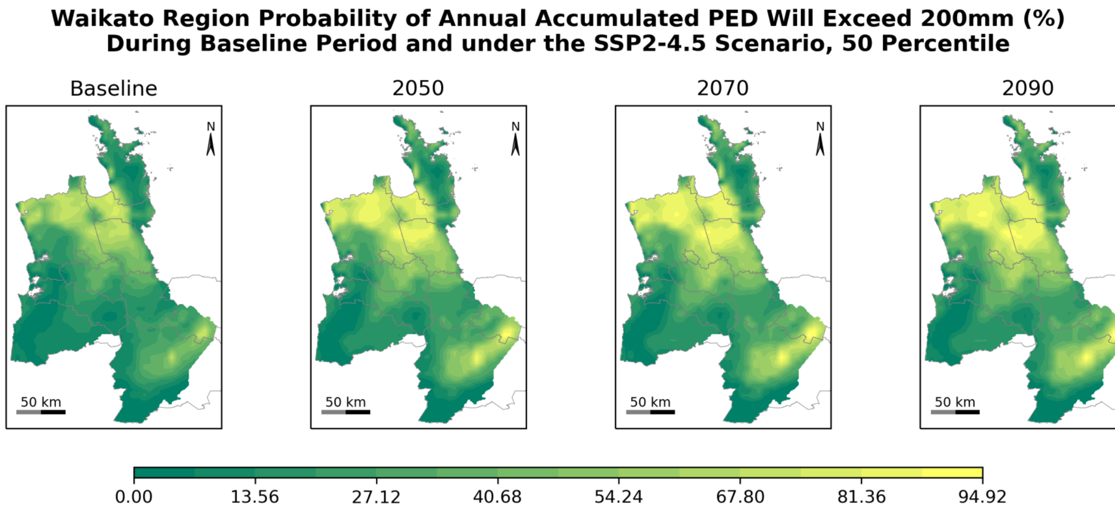


Figure 60: Probability of Annual Accumulated PED Will Exceed 200mm (%) During Baseline Period an under the SSP2-4.5 Scenario, 50 Percentile in Waikato Region

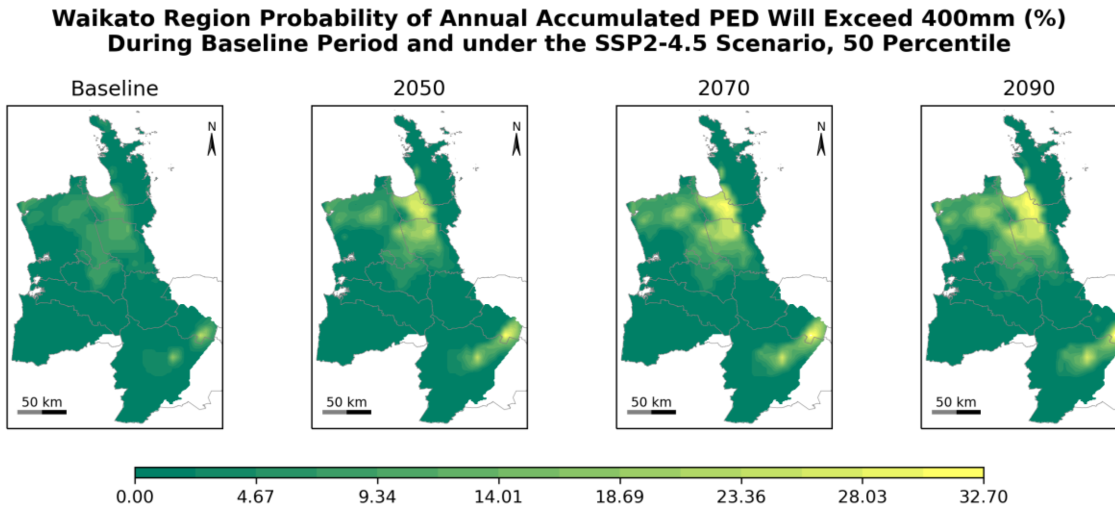


Figure 61: Probability of Annual Accumulated PED Will Exceed 200mm (%) During Baseline Period and under the SSP2-4.5 Scenario, 50 Percentile in Waikato Region

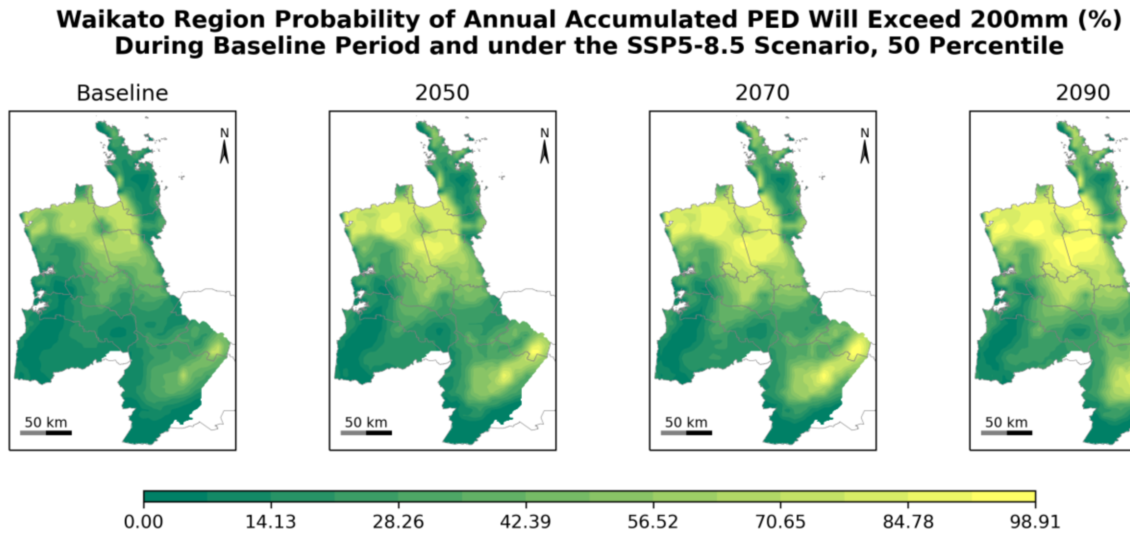


Figure 62: Probability of Annual Accumulated PED Will Exceed 200mm (%) During Baseline Period and under the SSP5-8.5 Scenario, 50 Percentile in Waikato Region

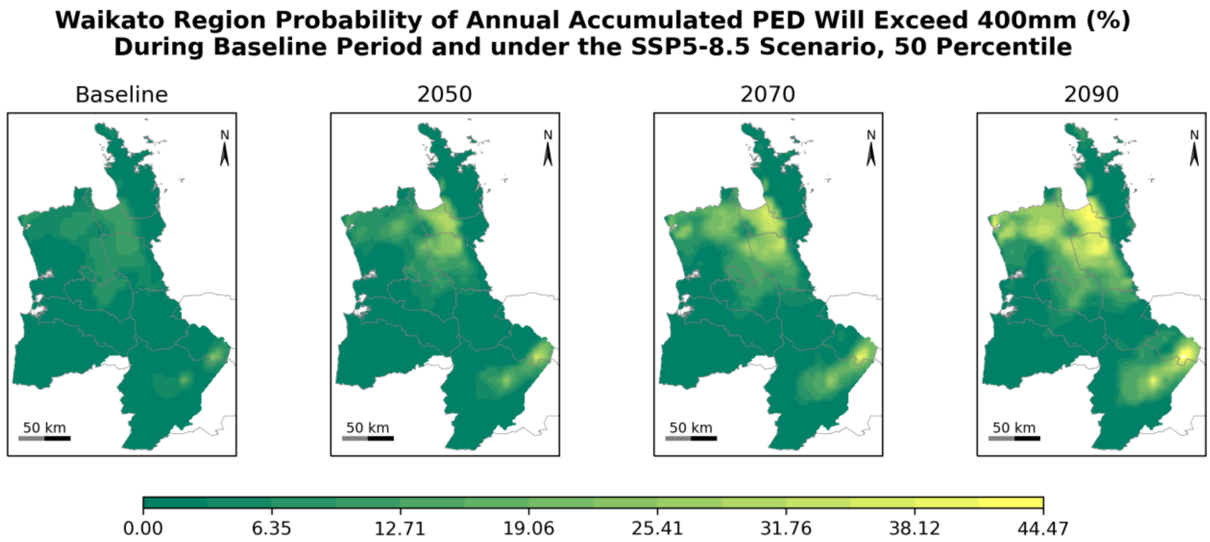


Figure 63: Probability of Annual Accumulated PED Will Exceed 400mm (%) During Baseline Period and under the SSP5-8.5 Scenario, 50 Percentile in Waikato Region

19.6 Comparison of Extreme Wind Speed

Comments:

(1) The MfE 2018 report applied the 99th percentile daily mean wind speed while the WRC report used daily maximum wind speed and extreme value analysis.
(2) The WRC 2022 report found a weak increase signal (75th percentile) of extreme wind speed with a wide uncertainty envelope. The report presented historical observations and 5 to 90th percentile confidence intervals.
(3) The MfE 2018 report presented a map displaying a weak increase to decrease in extreme wind speed.

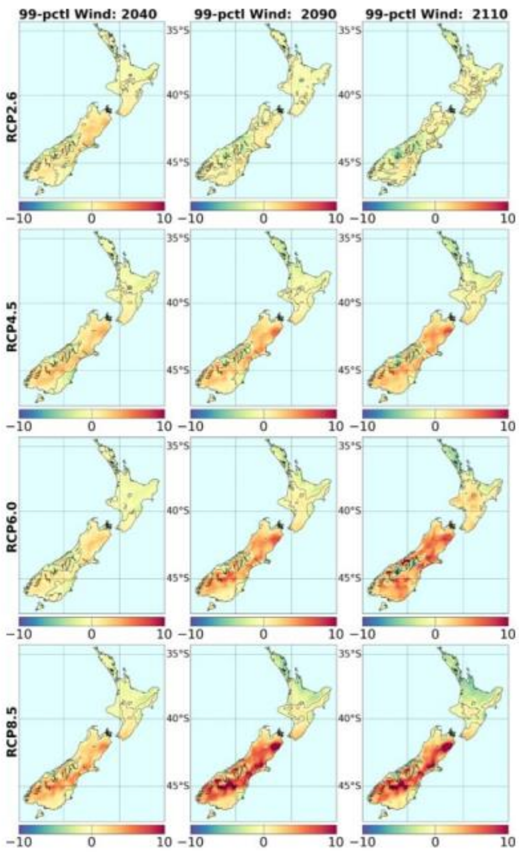


Figure 53: Change in the magnitude of the 99th percentile of daily-mean wind speed, for all four RCPs and three future time periods, relative to the daily 99th percentile in the baseline 1986–2005 period

106 Climate Change Projections for New Zealand: Atmosphere projections based on simulations form the IPCC Fifth Assessment

Figure 64: For most of the RCPs and periods, the southern half of the North Island and all the South Island are expected to have stronger extreme daily winds in the future. This is especially noticeable in the South Island, east of the Southern Alps. The regional model is able to resolve speed-up in the lee of the mountain ranges and shows increases of up to 10 per cent or greater in Marlborough and Canterbury by the end of the century under the highest RCP8.5 forcing. There is, however, a decrease in extreme winds in the North Island from Northland to the Bay of Plenty, probably because of increasing anticyclonic conditions (MfE 2018; page 106)

Excerpts from CLIMsystems WRC AR6 report for extreme wind speed.

Since historical gridded extreme wind speed data is unavailable, station-specific analysis was applied for the 31 stations with more than 15 years of hourly wind speed data. Among the stations, Cape Colville Aws in Thames-Coromandel District experienced the highest wind speed of 211.9 km/hr (kph), representing a 1 in100 year return event. The Te Kuiti Ews station in Waitomo District experienced a 71.8 kph extreme wind speed for the same return period. The Ruakura Ews station in Hamilton experienced a 93.7 kph extreme wind speed as an historical 100-year return period event.

The variabilities of extreme wind change signals derived from GCMs are varied from -10% to 10% as the 5 and 95 percentile bounds, and a weakly decreasing signal in the 50th percentiles. Based on the precautionary principle, we listed the 75th percentiles of extreme wind speed, which could be applied as best practice for decision making. The extreme wind speed analysis suggests a mostly positive trend across the districts, following the 75th percentile. Data were collected from several district stations, except for South Waikato, which was not available. Most districts are expected to experience an increase in wind speed by 2090. Some of the most significant changes include an increase of 4.9% by 2090 compared to the Waitomo and Taupō District baseline. It is important to note the small variability in change (%) across most districts, suggesting similar changes in extreme wind speed across most districts.

Table 40: Waikato Region Site-Specific Annual 100-year ARI Extreme Wind Speed Statistics in kph and Future Change – 75th Percentile (brackets 5th, 50th and 95th percentile)

Station Name	Baseline kph	SSP2-4.5 2050 Changes (%)	SSP2-4.5 2070 Changes (%)	SSP2-4.5 2090 Changes (%)	SSP25-8.5 2050 Changes (%)	SSP25-8.5 2070 Changes (%)	SSP25-8.5 2090 Changes (%)
Thames-Coromandel District - Cape_Colville_Aws	211.9	1.17 (-9.05, -0.86, 5.75)	1.78 (-8.52, -1.37, 6.50)	0.34 (-9.54, -3.39, 5.65)	1.04 (-6.61, -1.68, 4.20)	1.43 (-9.69, -1.32, 6.80)	3.00 (-6.43, -0.10, 11.38)
Thames-Coromandel District - Slipper_Island_Aws	167.2	1.92 (-7.74, -1.07, 5.43)	1.94 (-8.13, -1.01, 7.74)	0.31 (-7.47, -2.17, 4.83)	1.74 (-6.19, -1.90, 4.80)	0.75 (-6.93, -0.80, 8.04)	3.61 (-6.18, 0.56, 11.27)
Thames-Coromandel District - Whitianga_Ews	90.9	1.58 (-8.49, -0.50, 5.50)	1.34 (-8.90, -1.07, 7.10)	0.51 (-8.81, -3.04, 5.44)	1.39 (-5.98, -2.18, 5.05)	0.99 (-7.83, -1.29, 7.78)	4.06 (-6.03, 0.20, 12.00)
Hauraki District - Paeroa_Aws	120.9	1.92 (-7.74, -1.07, 5.43)	1.94 (-8.13, -1.01, 7.74)	0.31 (-7.47, -2.17, 4.83)	1.74 (-6.19, -1.90, 4.80)	0.75 (-6.93, -0.80, 8.04)	3.61 (-6.18, 0.56, 11.27)
Waikato District - Huntly_N.Z.E.D.	110.6	1.38 (-8.00, 0.01, 6.22)	2.54 (-7.36, 0.13, 8.43)	0.52 (-6.00, -1.47, 5.19)	2.05 (-6.30, -0.24, 6.25)	2.48 (-5.44, -0.78, 8.96)	4.82 (-5.34, 2.06, 12.03)
Waikato District - Whatawhata_2_Ews	106.8	1.38 (-8.00, 0.01, 6.22)	2.54 (-7.36, 0.13, 8.43)	0.52 (-6.00, -1.47, 5.19)	2.05 (-6.30, -0.24, 6.25)	2.48 (-5.44, -0.78, 8.96)	4.82 (-5.34, 2.06, 12.03)
Waikato District - Holland_Road_Hamilton_Cws	77.4	1.38 (-8.00, 0.01, 6.22)	2.54 (-7.36, 0.13, 8.43)	0.52 (-6.00, -1.47, 5.19)	2.05 (-6.30, -0.24, 6.25)	2.48 (-5.44, -0.78, 8.96)	4.82 (-5.34, 2.06, 12.03)
Matamata-Piako District - Mt_Te_Aroha_Tv_Stn	172.4	1.65 (-7.94, -1.27, 5.02)	1.82 (-6.89, -0.53, 7.94)	-0.08 (-6.55, -0.96, 4.97)	1.49 (-6.43, -1.20, 5.68)	2.15 (-6.12, -2.07, 8.06)	4.15 (-6.00, 0.77, 11.61)
Matamata-Piako District - Toenepi_Ews	113.2	1.65 (-7.94, -1.27, 5.02)	1.82 (-6.89, -0.53, 7.94)	-0.08 (-6.55, -0.96, 4.97)	1.49 (-6.43, -1.20, 5.68)	2.15 (-6.12, -2.07, 8.06)	4.15 (-6.00, 0.77, 11.61)

Hamilton City - Hamilton_Ruakura_Ews	93.7	1.38 (-8.00, 0.01, 6.22)	2.54 (-7.36, 0.13, 8.43)	0.52 (-6.00, -1.47, 5.19)	2.05 (-6.30, -0.24, 6.25)	2.48 (-5.44, -0.78, 8.96)	4.82 (-5.34, 2.06, 12.03)
Hamilton City - Hamilton_Ruakura_2_Ews	86.7	1.38 (-8.00, 0.01, 6.22)	2.54 (-7.36, 0.13, 8.43)	0.52 (-6.00, -1.47, 5.19)	2.05 (-6.30, -0.24, 6.25)	2.48 (-5.44, -0.78, 8.96)	4.82 (-5.34, 2.06, 12.03)
Waipa District - Hamilton_Aero	122.8	1.38 (-8.00, 0.01, 6.22)	2.54 (-7.36, 0.13, 8.43)	0.52 (-6.00, -1.47, 5.19)	2.05 (-6.30, -0.24, 6.25)	2.48 (-5.44, -0.78, 8.96)	4.82 (-5.34, 2.06, 12.03)
Waipa District - Hamilton_Aws	116.2	1.38 (-8.00, 0.01, 6.22)	2.54 (-7.36, 0.13, 8.43)	0.52 (-6.00, -1.47, 5.19)	2.05 (-6.30, -0.24, 6.25)	2.48 (-5.44, -0.78, 8.96)	4.82 (-5.34, 2.06, 12.03)
Waipa District - Lake_Karapiro_Cws	92.0	1.65 (-7.94, -1.27, 5.02)	1.82 (-6.89, -0.53, 7.94)	-0.08 (-6.55, -0.96, 4.97)	1.49 (-6.43, -1.20, 5.68)	2.15 (-6.12, -2.07, 8.06)	4.15 (-6.00, 0.77, 11.61)
Otorohanga District - Waikeria_Ews	82.5	1.67 (-8.14, -0.35, 5.61)	3.36 (-6.41, 0.18, 8.12)	0.35 (-4.42, -1.41, 3.70)	1.68 (-6.38, -0.85, 5.70)	3.82 (-5.55, -0.68, 7.35)	4.26 (-4.83, 1.98, 13.17)
Waitomo District - Port_Taharoa	245.7	2.11 (-7.83, 0.02, 5.82)	4.07 (-6.66, 1.56, 8.42)	1.86 (-4.29, -1.13, 4.01)	1.62 (-5.72, -0.50, 6.96)	3.27 (-4.62, -0.40, 7.84)	3.99 (-4.65, 2.65, 13.47)
Waitomo District - Port_Taharoa_Aws	147.1	2.11 (-7.83, 0.02, 5.82)	4.07 (-6.66, 1.56, 8.42)	1.86 (-4.29, -1.13, 4.01)	1.62 (-5.72, -0.50, 6.96)	3.27 (-4.62, -0.40, 7.84)	3.99 (-4.65, 2.65, 13.47)
Waitomo District - Te_Kuiti_Ews	71.8	1.67 (-8.14, -0.35, 5.61)	3.36 (-6.41, 0.18, 8.12)	0.35 (-4.42, -1.41, 3.70)	1.68 (-6.38, -0.85, 5.70)	3.82 (-5.55, -0.68, 7.35)	4.26 (-4.83, 1.98, 13.17)
Waitomo District - Awakino_Ews	193.6	1.50 (-7.62, 0.45, 6.26)	4.27 (-6.11, 1.38, 8.41)	1.68 (-3.69, -1.03, 4.08)	2.68 (-4.64, -0.15, 7.45)	3.64 (-4.49, 0.51, 6.67)	4.10 (-4.64, 1.67, 12.26)
Waitomo District - Pureora_Forest_Cws	146.6	1.47 (-7.63, -0.52, 4.90)	2.60 (-6.27, -0.34, 7.79)	-0.26 (-5.88, -1.18, 4.05)	1.90 (-6.88, -0.84, 4.56)	3.53 (-7.37, 0.21, 7.66)	4.90 (-5.84, 0.91, 12.29)
Taupō District - Wairakei_Power_Stn	128.3	1.46 (-6.12, -1.68, 4.52)	2.26 (-8.41, -1.37, 7.33)	0.05 (-6.90, -1.70, 4.42)	1.77 (-7.58, -2.10, 4.61)	3.92 (-8.94, -0.54, 7.47)	4.44 (-4.88, 0.45, 12.31)
Taupō District - Taupō_Aero	128.6	1.46 (-6.12, -1.68, 4.52)	2.26 (-8.41, -1.37, 7.33)	0.05 (-6.90, -1.70, 4.42)	1.77 (-7.58, -2.10, 4.61)	3.92 (-8.94, -0.54, 7.47)	4.44 (-4.88, 0.45, 12.31)
Taupō District - Taupō_Aws	102.9	1.46 (-6.12, -1.68, 4.52)	2.26 (-8.41, -1.37, 7.33)	0.05 (-6.90, -1.70, 4.42)	1.77 (-7.58, -2.10, 4.61)	3.92 (-8.94, -0.54, 7.47)	4.44 (-4.88, 0.45, 12.31)
Taupō District - Turangi	114.9	1.47 (-7.63, -0.52, 4.90)	2.60 (-6.27, -0.34, 7.79)	-0.26 (-5.88, -1.18, 4.05)	1.90 (-6.88, -0.84, 4.56)	3.53 (-7.37, 0.21, 7.66)	4.90 (-5.84, 0.91, 12.29)
Taupō District - Turangi_2_Ews	112.0	1.47 (-7.63, -0.52, 4.90)	2.60 (-6.27, -0.34, 7.79)	-0.26 (-5.88, -1.18, 4.05)	1.90 (-6.88, -0.84, 4.56)	3.53 (-7.37, 0.21, 7.66)	4.90 (-5.84, 0.91, 12.29)
Rotorua District - Rotorua_Aero_2	120.5	1.21 (-6.97, -1.29, 4.20)	2.70 (-7.55, -0.28, 7.29)	-0.03 (-6.69, -1.96, 4.16)	1.32 (-7.07, -2.01, 4.64)	2.84 (-8.10, -1.25, 7.75)	4.19 (-4.94, -0.85, 11.45)
Rotorua District - Rotorua_Aero_Aws	110.2	1.21 (-6.97, -1.29, 4.20)	2.70 (-7.55, -0.28, 7.29)	-0.03 (-6.69, -1.96, 4.16)	1.32 (-7.07, -2.01, 4.64)	2.84 (-8.10, -1.25, 7.75)	4.19 (-4.94, -0.85, 11.45)

Rotorua District - Kaingaroa_Forest	134.3	1.16 (-5.26, -1.63, 3.99)	2.49 (-9.49, -0.26, 7.75)	1.28 (-6.77, -2.19, 5.15)	1.27 (-6.87, -2.18, 4.14)	2.66 (-8.19, -1.12, 6.60)	4.39 (-5.66, -0.76, 10.99)
Rotorua District - Mamaku_Radar_Wxt_Aws	158.9	1.21 (-6.97, -1.29, 4.20)	2.70 (-7.55, -0.28, 7.29)	-0.03 (-6.69, -1.96, 4.16)	1.32 (-7.07, -2.01, 4.64)	2.84 (-8.10, -1.25, 7.75)	4.19 (-4.94, -0.85, 11.45)
Rotorua District - Rotorua_Ews	90.0	1.21 (-6.97, -1.29, 4.20)	2.70 (-7.55, -0.28, 7.29)	-0.03 (-6.69, -1.96, 4.16)	1.32 (-7.07, -2.01, 4.64)	2.84 (-8.10, -1.25, 7.75)	4.19 (-4.94, -0.85, 11.45)
Rotorua District - Maunga_Kakaramea_Okaro_Wind	109.7	1.21 (-6.97, -1.29, 4.20)	2.70 (-7.55, -0.28, 7.29)	-0.03 (-6.69, -1.96, 4.16)	1.32 (-7.07, -2.01, 4.64)	2.84 (-8.10, -1.25, 7.75)	4.19 (-4.94, -0.85, 11.45)

19.7 Mean Wind Speed Analysis

Comments:

(1) There is no specific mean wind speed analysis in the MfE 2018 report. However, the WRC 2022 report indicated a slight decrease in mean wind speed.

The Waikato region's historical annual mean wind speed was 3.23m/sec, or 11.62 km/hr, and the seasonal variations are not significant. Higher wind speeds occur in the Coromandel and West Coast areas. Based on the VCSN data from 1997-2020, the average wind speed demonstrated a weak decreasing trend of 0.093m/sec (0.335 kph) per decade.

The average annual and seasonal wind speed of the Waikato Region is expected to decline until 2090, relative to the baseline of 2005. Seasonally, while the wind speed drops for the summer and autumn months, it slightly increases over the winter and spring months for both SSPs. Under SSP2-4.5, the annual wind speed is expected to decline by more than 2% by 2090, compared to the baseline. The SSP5-8.5 results are more noticeable, with heightened seasonal shifts than the baseline year. For example, the average annual wind speed under SSP5-8.5 is predicted to decline by 1.71% in 2050 and more than 4% in 2090.

Table 41: Waikato Region Average Seasonal and Annual Mean Wind Speed Baseline (m/s) and Changes (%)

Season	Year	SSP2-4.5 (05Pth, 95Pth)	SSP5-8.5 (05Pth, 95Pth)
DJF	Baseline	3.23	3.23
DJF	2050	-2.80 (-13.21, 9.18)	-3.65 (-17.27, 12.00)
DJF	2070	-3.83 (-18.08, 12.57)	-5.98 (-28.25, 19.63)
DJF	2090	-4.30 (-20.32, 14.12)	-8.61 (-40.64, 28.25)
MAM	Baseline	2.90	2.90
MAM	2050	-3.37 (-12.98, 9.44)	-4.41 (-16.98, 12.34)
MAM	2070	-4.62 (-17.77, 12.92)	-7.21 (-27.76, 20.19)

MAM	2090	-5.19 (-19.97, 14.52)	-10.37 (-39.94, 29.04)
JJA	Baseline	3.12	3.12
JJA	2050	0.32 (-12.32, 17.51)	0.42 (-16.11, 22.90)
JJA	2070	0.44 (-16.87, 23.98)	0.69 (-26.35, 37.45)
JJA	2090	0.50 (-18.95, 26.94)	1.00 (-37.91, 53.88)
SON	Baseline	3.66	3.66
SON	2050	0.62 (-9.89, 13.04)	0.81 (-12.93, 17.06)
SON	2070	0.84 (-13.54, 17.86)	1.32 (-21.15, 27.89)
SON	2090	0.95 (-15.21, 20.07)	1.90 (-30.42, 40.14)
ANN	Baseline	3.23	3.23
ANN	2050	-1.31 (-12.10, 12.29)	-1.71 (-15.82, 16.08)
ANN	2070	-1.79 (-16.57, 16.83)	-2.79 (-25.87, 26.29)
ANN	2090	-2.01 (-18.61, 18.91)	-4.02 (-37.23, 37.83)

19.8 Comparison of Wildfire Risk

Comments:

(1) Wildfire is a risk recently identified in the wildfire output in the MfE 2018 and WRC 2022 reports.
(2) The wildfire risk is increasing based on the KBDI fire danger index. The moderate risk category is predicted to be widespread in 2090, and the high-risk category may extend to Waipa, Hauraki, and Coromandel districts.

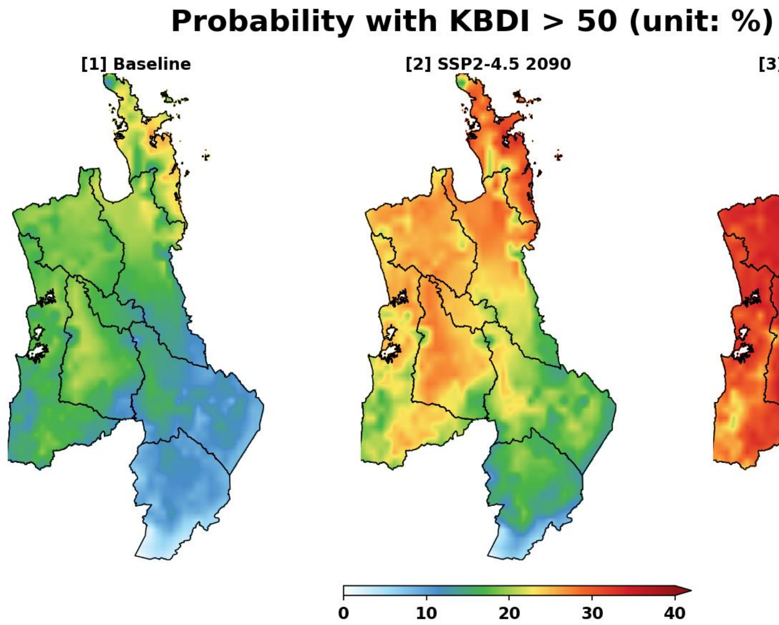
KBDI Fire Danger Index

During the calculation of FFDI, the Keetch-Byram Drought Index (KBDI) is used as the drought factor. But KBDI could also be applied to assess the fire potential (Liu et al., 2010). KBDI was created by the U.S. Department of Agriculture Forest Service fire control scientist John Keetch and physicist George Byram to link meteorological conditions to wildfire potential (Keetch and Byram, 1961). Since its inception in 1968, the agency has continually used the index employed by fire managers in the south-eastern United States and included as part of the U.S. National Fire Danger Rating System.

The KBDI scale captures heat and moisture conditions, ranging from 0 to 200 (mm), with lower scores indicating higher soil saturation levels and higher scores indicating soil moisture deficits. Historically, the KBDI is classified into eight drought stages by an increment of 100 (Keetch and Byram, 1968). However, to simplify the fire potential assessment, we followed the categories by Liu et. (2010). We combined two adjacent stages into one **fire potential level, that is, low (KBDI below 50), moderate (50–100), high (100–150), and extreme potential (above 150).**

Table 42: Waikato region KBDI based wildfire danger potential, the regional average percentage of days on each fire danger category

Fire Danger Category	Baseline	2090 SSP2-4.5 (05 ,50, 95 percentile)	2090 SSP5-8.5 P50 (05 ,50, 95 percentile)
Low (KBDI <50)	85.64	79.47 (82.30, 75.53)	72.45 (78.48, 62.85)
Moderate (KBDI 50-100)	11.37	14.77 (12.79, 17.28)	17.97 (14.56, 22.23)
High (KBDI) (KBDI 100-150)	2.95	5.43 (4.61, 6.77)	8.40 (6.10, 13.21
Extreme (KBDI>150)	0.05	0.32 (0.29, 0.41)	1.18 (0.86, 1.71)



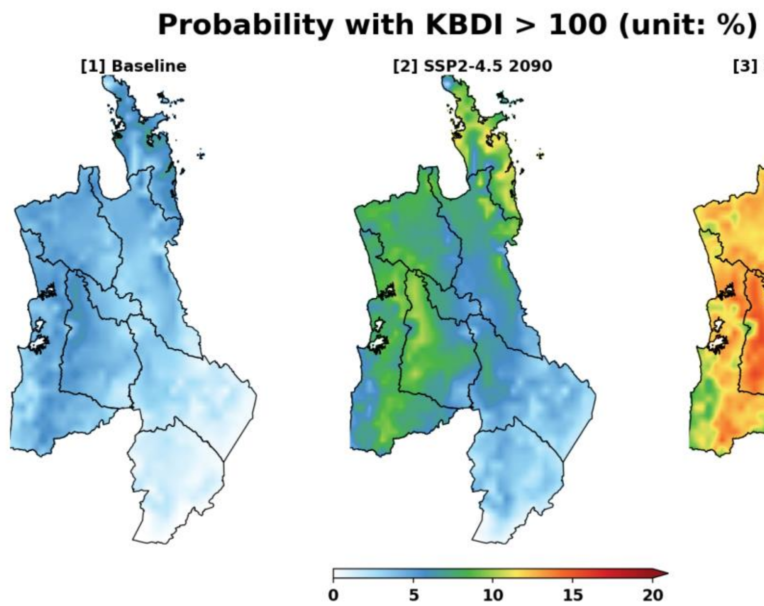


Figure 65: Waikato Region KBDI Based Wildfire Probability during baseline (1981-2020), SSP2-4.5, SSP5-8, 2090, ensemble 50percentile

20: Disclaimer - Limitations

This report was prepared by CLIMsystems ('the Consultants') in accordance with the scope of work as outlined by Waikato Regional Council ('the Recipient') and subsequent communications. The data and methods presented in this report represent the consultants' professional judgment based on information made available in the TOR and are true and correct to the best of the consultants' knowledge as at the date of the report's development.

The Consultants did not independently verify either written or oral information provided during the development of this report. While the Consultants have no reason to doubt the accuracy of the information provided, the report is complete and accurate only to the extent that the information provided was itself complete and accurate.

The Consultants take great care to ensure the climate information in this report are as correct and accurate as possible. The climate information provided is subject to the uncertainties of scientific and technical research; may not be accurate, current or complete; be subject to change without notice and is not a substitute for independent professional advice, and users should obtain any appropriate professional advice relevant to their particular circumstances. The Consultants do not guarantee the information provided and accepts no legal liability whatsoever arising from, or connected to, the use of any material contained therein.

Climate design data analytics is by its nature a dynamic and ongoing process. Therefore, it is recommended that the Recipient routinely incorporate the latest climate data into all future planning.

The Consultants recommend that the Recipient uses its skill and care concerning their use of the climatic design information, and those users carefully evaluate the accuracy, currency, completeness, and relevance of the material for their purposes. Any use of the data is solely at the Recipient's own risk. We understand that no party can rely upon the results of the assessments for planning purposes.

To the extent permitted by law, the Consultants make no representation or warranty (expressed or implied) as to merchantability or performance of the data; about the fitness of the data for the permitted use; or that the data does not infringe the intellectual property rights or any other right of any person. The Recipient indemnifies and releases the Consultants against all claims, demands, suits, liability, loss, or expense arising directly or indirectly from the Recipient's use of the data or any breach of this agreement by the Recipient. This report does not purport to give legal advice. Qualified legal advisors can only give this advice.

This data has been prepared exclusively for Waikato Regional Council and may not be relied upon by any other person or entity without CLIMsystems express written permission.

21: Appendix 1 CMIP6 GCM List

GCM list for the variables for monthly analysis

GCM	Lat	lon	ssp2-4.5	ssp5-8.5
ACCESS-CM2	144	192	ok	ok
ACCESS-ESM1-5	145	192	ok	ok
AWI-CM-1-1-MR	192	384	ok	ok
BCC-CSM2-MR	160	320	ok	ok
BCC-ESM1	64	128		
CAMS-CSM1-0	160	320	ok	ok
CAS-ESM2-0	196	360	ok	ok
CESM2	192	288	ok	ok
CESM2-WACCM	192	288	ok	ok
CIESM	192	288	ok	ok
CMCC-CM2-SR5	192	288	ok	ok
CMCC-ESM2	362	292	ok	ok
CNRM-CM6-1	128	256	ok	ok
CNRM-CM6-1-HR	360	720	ok	ok
CNRM-ESM2-1	128	256	ok	ok
CanESM5	64	128	ok	ok
CanESM5-CanOE	64	128	ok	ok
EC-Earth3	256	512	ok	ok
EC-Earth3-AerChem	256	512		
EC-Earth3-CC	256	512	ok	ok
EC-Earth3-Veg	256	512	ok	ok
EC-Earth3-Veg-LR	292	362	ok	ok
FGOALS-f3-L	180	288	ok	ok
FGOALS-g3	80	180	ok	ok
FIO-ESM-2-0	192	288	ok	ok
GFDL-CM4	180	360	ok	ok
GFDL-ESM4	180	288	ok	ok
GISS-E2-1-G	90	144	ok	ok
GISS-E2-1-H	90	144		
HadGEM3-GC31-LL	144	192	ok	ok
HadGEM3-GC31-MM	324	432		ok
IITM-ESM	94	192	ok	ok
INM-CM4-8	120	180	ok	ok
INM-CM5-0	120	180	ok	ok
IPSL-CM5A2-INCA	96	96		
IPSL-CM6A-LR	143	144	ok	ok
KACE-1-0-G	144	192	ok	ok
KIOST-ESM	96	192	ok	ok
MCM-UA-1-0	80	96	ok	ok

MIROC-ES2L	64	128	ok	ok
MIROC6	128	256	ok	ok
MPI-ESM-1-2-HAM	96	192		
MPI-ESM1-2-HR	192	384	ok	ok
MPI-ESM1-2-LR	96	192	ok	ok
MRI-ESM2-0	160	320	ok	ok
NESM3	96	192	ok	ok
NorESM2-LM	96	144	ok	ok
NorESM2-MM	192	288	ok	ok
TaiESM1	192	288	ok	ok
UKESM1-0-LL	144	192	ok	ok
Total			**44**	**45**

CMIP6 GCM list for 3 hours precipitation data

GCM	ssp2-4.5	ssp3-7.0	ssp5-8.5
ACCESS-CM2	ok	ok	ok
AWI-CM-1-1-MR	ok	ok	ok
BCC-CSM2-MR	ok	ok	ok
CanESM5	ok	ok	ok
CMCC-CM2-SR5	ok	ok	ok
CMCC-ESM2	ok	ok	ok
CNRM-CM6-1	ok	ok	ok
CNRM-CM6-1-HR	ok	ok	ok
CNRM-ESM2-1	ok	ok	ok
EC-Earth3	ok	ok	ok
EC-Earth3-Veg	ok	ok	ok
FGOALS-g3	ok	ok	ok
GFDL-ESM4	ok	ok	
HadGEM3-GC31-LL	ok		ok
HadGEM3-GC31-MM			ok
IITM-ESM	ok	ok	ok
IPSL-CM5A2-INCA		ok	
IPSL-CM6A-LR	ok	ok	ok
KACE-1-0-G	ok	ok	ok
KIOST-ESM	ok		ok
MIROC6	ok	ok	ok
MIROC-ES2L	ok	ok	ok
MPI-ESM-1-2-HAM		ok	
MPI-ESM1-2-HR	ok	ok	ok
MPI-ESM1-2-LR	ok	ok	ok
MRI-ESM2-0	ok	ok	ok
NESM3	ok		ok
TaiESM1			ok
UKESM1-0-LL	ok	ok	ok
Total	**25**	**24**	**26**

CMIP6 GCM daily maximum wind speed

GCM	ssp2-4.5	ssp3-7.0	ssp5-8.5
ACCESS-ESM1-5	ok	ok	ok
AWI-CM-1-1-MR	ok	ok	ok
BCC-CSM2-MR	ok	ok	ok
BCC-ESM1		ok	
CanESM5	ok	ok	ok
CMCC-CM2-SR5	ok	ok	ok
EC-Earth3	ok	ok	ok
EC-Earth3-AerChem		ok	
EC-Earth3-CC	ok		ok
EC-Earth3-Veg	ok	ok	ok
EC-Earth3-Veg-LR	ok	ok	ok
FGOALS-g3	ok	ok	ok
GFDL-CM4	ok		ok
GFDL-ESM4	ok	ok	
INM-CM4-8	ok	ok	ok
INM-CM5-0	ok	ok	ok
IPSL-CM6A-LR	ok	ok	ok
KACE-1-0-G	ok	ok	ok
MIROC6	ok	ok	ok
MPI-ESM-1-2-HAM		ok	
MPI-ESM1-2-HR	ok	ok	ok
MPI-ESM1-2-LR	ok	ok	ok
MRI-ESM2-0	ok	ok	ok
NESM3	ok		ok
total	**21**	**21**	**20**

22: Appendix 2 – Data and Methodologies for WRC

Data sources

Historical data:

(1) NIWA daily VCSN data, 0.05 degree 1972-2020, provided by WRC
(2) NIWA grid climate data, 500m spatial resolution, provided by WRC
(3) NIWA, HIRDSv4 data for daily extreme precipitation, 2000m spatial resolution (obtained from NIWA portal)
(4) NIWA CLIFLO wind speed data
(5) Stream flow data, provided by WRC
(6) Waikato region water allocation data provided by WRC
(7) Waikato region aquifer data provided by WRC
(8) Historical runoff reanalysis data obtained from NOAH dataset (https://disc.gsfc.nasa.gov/datasets/GLDAS_NOAH025_M_2.1/summary)

SSP2-4.5 and SSP5-8.5 climate change scenario data obtained from CMIP6 data archive obtained from CMIP6 data portal (https://esgf-node.llnl.gov/projects/cmip6/)

(1) Monthly mean, maximum, minimum temperature, precipitation, runoff, wind speed.
(2) 3 hourly precipitation data
(3) Daily maximum wind speed data

For a list of GCMs applied please see Appendix 1.

Methodologies:

Pattern Scaling Methodology for Monthly Variables

Pattern scaling approach is based on the theory that, firstly, a simple climate model can accurately represent the global responses of a GCM, even when the response is non-linear (Raper *et al*., 2001), and secondly, a wide range of climatic variables represented by a GCM are a linear function of the global annual mean temperature change represented by the same GCM at different spatial and/or temporal scales (Mitchell, 2003; Whetton *et al*., 2005). Scaling local trends by projections of global warming and comparing these to model projections will allow adaptation needs at the local and regional scale to be assessed. For example, pattern-scaled historical data can be compared with pattern scaling from GCMs.

Pattern scaling involves the following general steps (Lu and Hulme, 2002):

Step 1: Defining the 'master pattern' – a single GCM experiment run (or ideally an ensemble) with a corresponding SSP emissions scenario pattern for one climate variable, such as global mean temperature;

Step 2: Normalising the 'master pattern' - the climate change values for each individual grid cell in the 'master pattern' are normalised by subtracting the 'average' value for the global mean temperature (for that GCM experiment run) from each grid cell. This normalised pattern then represents the degree of warming in each grid cell, per degree global warming;

Step 3: Obtaining scalars – this derives the global warming values per grid cell in a climate pattern, for a time in the future for a given emissions scenario provided by IPCC AR6 report;

Step 4: Scaling the normalised pattern – the pattern of changes for the future time period can be produced by multiplying the normalised pattern in Step 2 by the respective scalar developed in Step 3.

Pattern scaling may be described as follows: for a given climate variable *V*, its anomaly ΔV^* for a particular grid cell (*i*), month (*j*) and year or period (*y*) under the scenarios of SSP2-4.5 and SSP5-8.5:

$$\Delta V^*_{yij} = \Delta T_y \cdot \Delta V'_{ij} \qquad (1)$$

ΔT being the annual global mean temperature change.

The local change pattern value ($\Delta V'_{ij}$) was calculated from the GCM simulation anomaly (ΔV_{yij}) using linear least squares regression, that is, the slope of the fitted linear line.

$$\Delta V'_{ij} = \frac{\sum_{y=1}^{m} \Delta T_y \cdot \Delta V_{yij}}{\sum_{y=1}^{m} (\Delta T_y)^2} \qquad (2)$$

where *m* is the number of future sample periods used, with a 10-year average as a period.

Pattern-scaling does not seem to be a very large source of error in constructing regional climate projections, even for extreme scenarios (Ruosteenoja *et al*., 2007). However, in applying pattern-scaling, two fundamental sources of error related to its underlying theory need to be addressed: 1) the non-linearity error: the local responses of climate variables, precipitation in particular, may not be inherently linear functions of the global mean temperature change; and 2) noise due to the internal variability of the GCM. Based on the pattern scaling theory, for a given GCM, the linear response change pattern of a climate variable to global mean temperature change represented by the GCM should be obtained from any one of its GHG emission simulation outputs.

Computation of the Potential Evapotranspiration Deficit, PED

The water balance calculation used to derive the Potential Evapotranspiration Deficit (*PED*) index assumes that the water gains and losses to the soil profile are typically in balance (Mullan *et al*., 2005). Provided that water is non-limiting, the balance for a given rainfall period can be written as:

$P = PET + Ro + D \pm \Delta S$

Where *P* is precipitation, *PET* is potential (or upper limit) evapotranspiration, *Ro* is surface runoff, *D* is drainage loss through percolation, and *ΔS* is the change in water storage. For the purposes of this study, *PET* is calibrated for pasture water use.

In principle, for each day,

$S = S_{d-1} + P - PET - Ro - D$

Where *S* is the new storage, and S_{d-1} is the water storage for the previous day.

Field capacity water storage is defined by the Available Water Capacity *(AWC)*, which was taken to be 150 mm for this study (Mullan *et al*., 2005). Rainfall in excess of field capacity is assumed to be lost to the water balance by runoff and drainage.

if $\quad S_{d-1} + P - PET > AWC$

then $\quad (S_{d-1} + P - PET) - AWC = (Ro + D)$

As *S* is reduced, it becomes increasingly difficult for plants to extract water from the soil, and water transpiration decreases. Here we have used a method for estimating constrained water use by assuming evapotranspiration (ET) continues at its potential rate until half *AWC* is depleted, following which it ceases until further rain occurs.

if $\quad S < ½(AWC)$

then $ET = 0$

The difference between the subsequent soil water-restricted evapotranspiration, *(RET),* and the atmospheric potential evapotranspiration for the period *(PET)*, is referred to here as the potential evapotranspiration deficit *(PED)* and is incremented on a daily basis.

$PED = PED_{d-1} + (PET - RET)$

In effect, *PED* is approximately equivalent to the amount of water that would need to be added by rainfall or irrigation to keep pasture growing at its daily potential rate.

PED was accumulated daily for the July to June year, beginning from zero each year. Note that the soil moisture deficit carries over from one year to the next, even though *PED* is reset at the beginning of each July-June period. The water balance calculation was initiated on 1 January 1976, so there was a potentially non-zero starting value of soil moisture deficit at the beginning of July 1976.

Extreme precipitation and depth duration frequency analysis

Several components are included in this process as depicted in Figure 56: (1) Historical observation daily or sub-daily extreme event analysis, and depth duration frequency (DDF) calculation; (2) GCM historical data extreme event analysis; (3) GCM scenarios extreme event analysis; (4) GCM extreme event DDF change factor analysis; and (5) Future DDF perturbation which is to add DDF change factors to observed historical DDF.

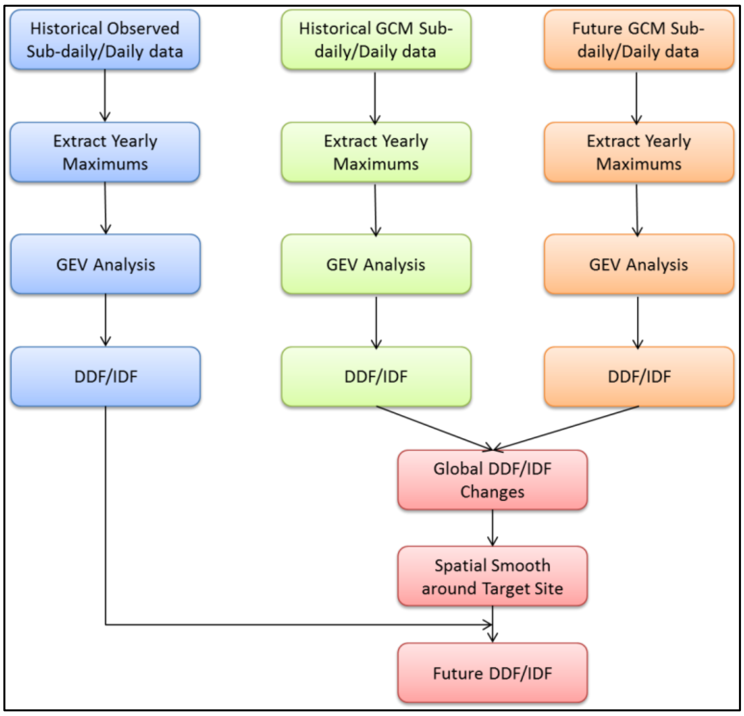


Figure 58: Equidistance quantile-matching method for generating future DDF curves under climate change

Historical Observation Depth Duration Frequency (DDF)

Step 1: Derive the rainfall intensity time series of the different durations from the historical 3 hourly data time series. The durations include 3, 6, 12, 24, 48, 72, 120, 144 and 168 hours, then select annual maxima series from the rainfall intensity series. Fit the annual maxima series for each duration to a group of probability distribution functions. Three distribution functions are tested: Generalized Logistic (GLO), Generalised Extreme Value (GEV), and Gumbel distribution. Finally, choose the method to deploy for distribution parameter estimation.

Step 2: Assess their goodness of fit with the Anderson-Darling test to follow the method of Viglione (2008). The Anderson-Darling test measures the extent of the departure, in terms of probabilities, between a hypothetical simulated distribution and the frequency distribution for consideration. If the estimated probability is greater than some defined significance level, the test fails. Explore which of the three distributions provides the best fit. For illustration, we continue with the presumption that GEV parameters are used for further analysis.

Step 3: Calculate rainfall depths for the range of return periods (including 2, 3, 5, 10, 15, 25, 50, 100, 200 and 300 years) for each storm duration using GEV distribution parameters obtained from **Step 1**. The values form the table of depth-duration-frequency (DDF). Next, the intensity-duration-frequency (IDF) table is computed directly from the DDF table by simply dividing the rainfall depths by duration in hours.

Future DDF calculation

The impacts of climate change on historical DDF are evaluated based on climate model data. In order to reduce the uncertainty of climate change simulated by GCMs, the outputs of as many GCMs as possible should be used. According to the Six Assessment Report of IPCC (AR6), there are 43 GCM models developed by various research centres worldwide. Currently, only 22 GCMs out of the 42 GCMs are validated because:

i) Not all the GCMs generate selected SSPs for future climate scenarios (i.e., SSPs 2-4.5 and 5-8.5)
ii) There are some technical issues related to downloading (such as connecting to remote servers or repositories) for some GCM models.

The basic procedure is to employ an equidistant quantile matching (EQM) method to update the DDF and IDF curves under changing climate conditions.

Step 1: GCM 3 hourly output for each grid cell is analysed using extreme value analysis (EVA) to calculate extreme rainfall amounts for the current climate (called the baseline, 1995-2014) and the future periods of interest (2050).

Step 2: DDF change factors for the range of durations (3, 6, 12, 24, 48, and 72, 120, 144 and 168 hours) and return years (2, 3, 5, 10, 15, 25, 50, 100, 200 and 300 year) for each GCM under SSP2-4.5 and SSP5-8.5 (or other SSPs) are calculated by applying a pattern scaling approach (Li and Ye, 2011).

Step 3: Interpolate the global DDF change patterns into the same spatial resolutions (0.5^o x 0.5^o) to construct a global database. Furthermore, a super ensemble method can be applied to derive ensemble statistics at different percentiles (e.g., 25th and 75th percentile of the GCM ensemble), with SSP2-4.5 and SSP5-8.5 change factors for all GCMs being applied equally without any weighting.

Step 4: Perturb the historical estimated precipitation depth/intensity values of each duration and return period using the global DDF change factors for the studied area for the selected future periods (*e.g.* 2050 SSP5-8.5). The global DDF changes show high variability around the world. There are also considerable differences among GCM members. Therefore, to further reduce natural variability's impact, change factors are averaged over the studied region.[1]

This approach is applied to perturb extreme event changes, which is crucial for stormwater management. Sørup *et al*. (2017) applied a similar DDF perturbation method, promising to create artificially perturbed precipitation time series that can represent a changing climate and be used as input in hydrologic and hydraulic models.

Special considerations for short-duration extreme precipitation events

In this study, only observed daily precipitation is reliable for extreme event analysis. Daily data are suitable for deriving extreme precipitation events for a single day (24 hours) or consecutive days (e.g., 48 or 72 hours). However, it is not enough for some projects, such as stormwater design, which require short-duration (less than 24 hours, even less than 1 hour) events as inputs. Here some approaches have been used to take such issues into special considerations.

The linearity of the moment from this study is also observed in other regions of the world. For example, Ghanmi (2014) in Tunisia (Northern of Africa) found that data from (Tunis) presented linearity, Ceresseti (2011) in France; Bara *et al.* (2009) in Slovakia; Nhat (2006) in Japan have found linearity in similar studies. In this study, the log-log linear relationship for the calculation of sub-daily precipitation intensity is applied.

First, there is the need to create the empirical statistical relationships between 3-, 6-, 12-, 18- and (24-hourly) extreme precipitation based on Multi-Source Weighted-Ensemble Precipitation data (MSWEP, 3 hourly, 0.25*0.25 latitude longitude degree spatial resolution, 1979-2015) following the steps in section 5.1 and then apply them to scale the observations to get the extreme values for durations (3, 6, 12, 18 hours) under the specified return years (e.g., 2, 3, 5, 10, 15, 25, 50, 100, 200 and 300 years).

Secondly, fit the extreme precipitation at different durations and return years into IDF curves based on an empirical mathematical relationship between the precipitation intensity (*I*), the duration (*D*), and the return period(*T*) (the annual frequency of exceedance, ARI), from which the extreme precipitation intensities can be read for other durations.

Extreme wind analysis

No pattern scaling was applied for extreme wind speed change analysis. For each GCM, the wind speed change values were derived directly from the GCM data between SSP scenario 2050, 2070, and 2090 and 1995-2014. The 75^{th} percentile of the GCM ensemble for wind speed extreme value changes was applied. For extreme value analysis methodologies, please refer to the GCM extreme precipitation analysis section of this report for more details.

23: References

Bara, M., Gaal, L., Kohnova, S., Szolgay, J., Hlavcova, K. (2009). Simple scaling extreme rainfall in Slovakia a case study. Meteorological Journal 11, 153–157.

Benestad, R.E. (2002). Empirically downscaled temperature scenarios for northern Europe based on a multi-model ensemble. Climate Research. 21(2):105-125.

BOP regional council (2016) Assessment of water availability and estimates of current allocation levels October 2016 (https://www.boprc.govt.nz/media/2866/assessment-of-water-availablity-report-rev-12.pdf)

Ceresetti D. Anquetin S., Molinié G., Leblois E., et Creutin J. D. (2011). Severity diagrams: a new approach for the multi-scale evaluation of extreme rainfall events. Weather and Forecasting.

Environment Waikato (2008) Proposed Waikato Regional Plan, Proposed Variation No. 6 – Water Allocation (Hearings Committee Recommendation Version) Analysis of alternatives, benefits and costs under section 32 of the Resource Management Act 1991 Explanation of the approach taken in the Variation, pp360.

Ghanmi, H., (2014). Estimation des courbes Intensité-Durée-AireFrequence (IDAF) de la region de Tunis dans un context multifractal. Université de Versailles Saint-Quentin-enYvelines et Université de Tunis EL Manar, à l'UVSQ-LATMOS (Guyancourt-France) Thèse de doctorat.

IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

Jones, R. N. (2010). *A risk management approach to climate change adaptation, in: New Zealand Climate Change Centre 2010.Climate change adaptation in New Zealand: Future scenarios and some sectoral perspectives.* Wellington.

Keetch JJ, Byram GM (1968) A drought index for forest fire control. USDA Forest Service, Southeastern Forest Experiment Station, Research Paper SE-38. (Asheville, NC, USA)

Lee, J. Y., J. Marotzke, G. Bala, L. Cao, S. Corti, J. P. Dunne, F. Engelbrecht, E. Fischer, J. C. Fyfe, C. Jones, A. Maycock, J. Mutemi, O. Ndiaye, S. Panickal, T. Zhou, (2021), Future Global Climate: Scenario-Based Projections and Near-Term Information. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

Li Y., and Ye W. (2011). Applicability of ensemble pattern scaling method on precipitation intensity indices at regional scale, *Hydrology and Earth System Sciences Discussion*, 8, 5227–5261, doi:10.5194/hessd-8-5227-2011.

Liu, Y., Stanturf, J., and Goodrick, S. (2010) Trends in global wildfire potential in a changing climate," Forest Ecology and Management 259, no. 4: p. 685–697, https://doi.org/10.1016/j.foreco.2009.09.002.

Lu, X., & Hulme, M. (2002). A Short Note on Scaling GCM Climate Response Patterns. Prepared for the AIACC regional study teams. June 2002. http://www.aiaccproject.org/resources/GCM/GCM.html

Ministry of Environment, (2018) Climate Change Projections for New Zealand: Atmosphere Projections Based on Simulations from the IPCC Fifth Assessment, 2nd Edition.

Mitchell, T. D. (2003). Pattern Scaling: An Examination of the Accuracy of the Technique for Describing Future Climates. *Climatic Change, 60*(3), 217-242. 10.1023/a:1026035305597

Nhat L.M., Tachikawa Y., Sayama T., Takara K. (2006). Establishment of intensity-duration-frequency curves for precipitation in monsoon area of Vietnam. Annuals of disas. Prev, Res, Inst, Kyoto Univ.

NIWA (2018). High Intensity Rainfall Design System (HIRDS) Version 4. Prepared for Envirolink. Pgs 73.

Raper, S. C. B., Gregory, J. M., & Osborn, T. J. (2001). Use of an upwelling-diffusion energy balance climate model to simulate and diagnose A/OGCM results. *Climate Dynamics, 17*(8), 601-613. 10.1007/pl00007931

Rogelj, J., Popp, A., Calvin, K.V., Luderer, G., Emmerling, J., Gernaat, D., Fujimori, S., Strefler, J., *et al*. (2018). *Scenarios towards limiting global mean temperature increase below 1.5 °C.* Nature Climate Change 8 (4) 325-332. 10.1038/s41558-018-0091-3.

Ruosteenoja, K., Tuomenvirta, H., & Jylhä, K. (2007). GCM-based regional temperature and precipitation change estimates for Europe under four SRES scenarios applying a super-ensemble pattern-scaling method. *Climatic Change, 81*(0), 193-208. 10.1007/s10584-006-9222-3

Sørup, H. J. D., Georgiadis, S., Gregersen, I. B., & Arnbjerg-Nielsen, K. (2017). Formulating and testing a method for perturbing precipitation time series to reflect anticipated climatic changes. *Hydrology and Earth System Sciences*, *21*(1), 345.

Viglione, A. (2008). Contributed R-Package: nsRFA (Non-supervised Regional Frequency Analysis). URL: http://www.r-project.org.

Waikato Regional Council: Waikato Regional Plan, Chapter 3 Water Module (https://www.waikatoregion.govt.nz/assets/WRC/Council/Policy-and-Plans/Rules-and-regulation/WRP/Chapter-3-Water-Module-Operative-WRP-to-include-NPSFM.pdf)

Waikato River Authority (2019). Annual Report.

Wang, M., Li, Y., Yin, C. (2015) . An assessment of the impcts of climate change in the Waikato region: Applying CMIP5 data. Report: TR 2015/26.

Whetton, P. H., McInnes, K. L., Jones, R. N., Hennessy, K. J., Suppiah, R., Page, C. M., *et al*. (2005). *Australian Climate Change Projections for Impact Assessment and Policy Application: A Review* : CSIRO Marine and Atmospheric Research, Aspendale, Victoria, Australia.

WISE (2018). Waikato Integrated Scenario Explorer. http://www.creatingfutures.org.nz/wise/what-is-wise/

Zelinka, M. D., Myers, T. A., McCoy, D. T., Po-Chedley, S.,Caldwell, P. M., Ceppi, P., *et al*. (2020).Causes of higher climate sensitivity inCMIP6 models.Geophysical ResearchLetters,47, e2019GL085782. https://doi.org/10.1029/2019GL085782