The impacts and implications of climate change for the Clutha District

Griffin, C. & Goldsmith, M., GHC Consulting Report 2020/03, April 2020

BIBLIOGRAPHIC REFERENCE

Griffin, C.E. & Goldsmith, M.J., 2020. The impacts and implications of climate change for the Clutha District, *GHC Consulting Report* 2020/03, April 2020.

ACKNOWLEDGEMENTS

The authors would like to thank the valuable GIS support provided by David Rowe at the Clutha District Council for producing the maps shown in this report. We would also like to acknowledge NIWA for openly sharing their climate projection and coastal flooding datasets with us. Without these datasets, this report would not have been possible. Finally, we would like to thank all of the local informants living in the Clutha District who so generously provided their time and knowledge.

CONTENTS

FIGURES

TABLES

APPENDICES

EXECUTIVE SUMMARY

The Clutha District will face a range of new challenges and opportunities in a future and changing climate. Drawing on the best available data, this report summarises the impacts and implications of climate change for the Clutha District. We have sourced knowledge through local consultation, historic rainfall and temperature records, and future climate and hydrological projections produced by the National Institute of Water and Atmospheric Research (NIWA), to describe the local impacts of climate change.

The findings reveal that overall, the Clutha District will become warmer and wetter in the future, with more water likely flowing through the Clutha River. These changes may bring opportunities, such as improved winter pasture growth; however, they may also bring challenges such as a potential increase in flood frequency and severity. Understanding the nature of the changes that have occurred to date, and those that are predicted for the future, will allow the Clutha District to prepare for, and adapt to, the impacts of climate change.

The findings of this work can be summarised into the following key points:

1. Temperature is expected to warm across the Clutha District by 0.5°C to 3°C between the years of 1995 to 2090. Temperature extremes are predicted to increase, and up to 20 more hot days (days >30°C), and up to 50 fewer frost days (days <0°C), may be expected by 2090. The highest increases in temperature are predicted for West Otago.
2. Mean annual rainfall is expected to increase by as much as 20% by 2090, with the towns of Milton and Waihola and surrounding areas expected to experience the largest increases. Heavy rain days (where >25 mm of rain falls) are expected to increase (by 0 to 5 days), with the largest increases in The Catlins and over the Old Man Range by 2090.
3. The number of dry days (or no rain days) that occur each year will increase in some areas, while decreasing in others. By the end of the century, The Catlins may experience up to four additional dry days per year, while the Clutha Valley, Milton and Waihola areas are likely to experience fewer dry days and overall wetter conditions.
4. The Clutha River is expected to experience an overall increase in river flow, especially during the winter and spring months, due to more precipitation in the upper catchment.
5. Rainfall totals during high intensity events are predicted to increase across the district, potentially leading to more frequent localised flooding.
6. Sea level is expected to continue to rise. When combined with an increased likelihood of extreme sea level events, low-lying coastal settlements and the infrastructure that supports them will, over time, become increasingly susceptible to inundation. This includes low-lying parts of the Taieri Mouth, Toko Mouth, Kaitangata, Kaka Point, Pounawea and Jacks Bay settlements. Rural areas such as Molyneux Bay may also be affected.
7. The agricultural and forestry sectors may face new challenges in terms of flood and water management, yet they may also benefit from improved winter pasture growth and new cropping opportunities. Tourism (particularly in The Catlins) may benefit from overall warmer weather; however, wildlife and coastal landforms such as the Cathedral Caves may be affected by sea level rise and erosion.
8. NIWA's scientific predictions are consistent with local experiences, and some residents are already experiencing, and have begun the process of adapting, to a changing climate.

1.0 INTRODUCTION

> 'We used to get like a run of frosts, like sort of a week and everything would freeze, all the water would freeze and everything. We haven't had that for a few years now…. they talk about the frosts killing everything, all the pests and things in the soil but you don't get that now' (Local Milton resident [1]).

> 'I think the king tides are getting higher (*followed by agreement from others in the room*)…. They are cutting off the road, out to Jacks Bay it's over the road in several spots out there, it's right up around the Hina Hina Falls Road now. So yeah I think they are higher, quite a lot higher.' (Participant of a climate change discussion, Papatowai fire station, 9 Sept, 2019 [2]).

The quotes above demonstrate that the impacts of climate change are already being experienced locally within the Clutha District. Globally, our atmosphere has already warmed by about 1°C above pre-industrial levels, and this pattern of warming is attributed to increasing concentrations of greenhouse gas in our atmosphere [3][4]. New Zealand has warmed by around 1°C over the last century or so, and is predicted to continue warming by between 0.5 and 5°C by 2110 [3]. Alongside this warming, precipitation is predicted to increase, particularly in winter and spring for most parts of New Zealand's South Island [3]. These changes will have significant impacts on our natural and built environments, and the livelihoods (including sheep and dairy farming systems, forestry, and tourism) that depend on them.

The Clutha District Council (CDC) is committed to better understanding, and preparing for, changes to our local climate, and this report presents a first assessment of the impacts and implications of climate change for the Clutha District. This work draws on a range of data sources, primarily historic temperature and precipitation data obtained from NIWA weather stations, future climate projections (temperature, precipitation, wind speed) also modelled by NIWA, alongside knowledge sourced through detailed conversations with local residents. This work is the first of CDC's efforts to ensure that the Clutha District is informed and ready to adapt to the challenges and opportunities that will arise in a changing climate. Subsequent stages will aim to improve our understanding of the risk associated with the impacts of climate change, and how CDC (and the community as a whole) can respond.

1.1 GEOGRAPHIC AREAS WITHIN THE CLUTHA DISTRICT

In general, New Zealand is expected to experience warmer and (for some areas) wetter conditions in the future. However, rates of changes will vary geographically across the country. Similarly, at the Clutha District scale, there will be local variations in the amount of change experienced - some areas will warm more, while others will experience higher increases in precipitation. For this reason, we have divided the Clutha District into four distinct areas in order to summarise localised climate change impacts (Figure 1-1). These areas were devised in consultation with CDC, by combining the district's wards that experience similar climatic conditions, or contain similar geographic features, into the following:

- **Coastal and Eastern Clutha:** This area includes a large section of Clutha's coastline from Port Molyneux to Taieri Mouth, and the Clutha delta. It incorporates the Balclutha, Kaitangata and Bruce wards, and the towns of Balclutha, Milton and Waihola. This area is agriculturally dominated, has extensive low-lying areas, and can be prone to floods.

- **The Catlins:** This sparsely populated coastal area includes The Catlins ward, from Chaslands and the Catlins conservation park in the south, to Kaka Point in the north. It is the Clutha District's wettest environment, boasting native forests, stunning coastal landforms, and agriculture in the fertile hinterland.

- **Central Clutha:** This area includes the fertile Clutha Valley, the Clutha River, and its tributary, the Pomahaka. It incorporates the Clinton, Clutha Valley and Lawrence-Tuapeka wards, extending from the town of Clinton in the southwest to Lawrence and Waipori in the northeast.

- **West Otago:** This area includes the West Otago ward and the towns of Tapanui, Heriot and Edievale. The terrain comprises steep high country, rolling hills, and broad floodplain areas. This area also experiences the greatest temperature extremes; it can be the warmest part of the Clutha District in summer, but also the coolest in winter.

Produced by Clutha District Council's GIS Section

Contains data sourced from Land Information New Zealand under Creative Commons Attribution 4.0 NZ licence

Figure 1-1 The Clutha District, separated into four distinct geographic and climatic areas for the purposes of this report.

1.2 AN OVERVIEW OF THE CLIMATE DATA SOURCED FOR THIS REPORT

This report draws on a range of data sources to describe the past, present and future climate of the Clutha District. These data sources are summarised in Table 1-1 and are described below.

1.2.1 Local knowledge

Local residents of the Clutha are the first to observe and respond to changes in local climatic conditions. In recognition of this knowledge, we have integrated scientific information with important local insights on past and present weather conditions, and the localised impacts of climate change. Local sources of knowledge were identified through consultation with CDC staff and other members of the community. In total 13 interviews were held with local residents, predominantly farmers who have an in-depth understanding of local weather systems. We met with informants across the district, including farmers or their families, DOC workers, and emergency management personnel from Balclutha, Milton, Toko Mouth, Chaslands, Owaka, Clydevale, Tuapeka West, Waitahuna, Lawrence, Heriot, and Waipahi. A community discussion was also held with local residents at the Papatowai Fire Station. These interviews and community discussions obtained information about:

1. *Past and present weather patterns and reflections on long-term trends,*
2. *How weather extremes are prepared for, and responded to, and,*
3. *The impact climate change may have on the functioning of local livelihoods (mostly agricultural and forestry related).*

These interviews provided important, locally relevant context to the broader-scale scientific assessments conducted by NIWA that are discussed below.

1.2.2 Historic temperature and precipitation data

To better understand the local climate, and how it may change under different climate scenarios, we obtained historic temperature and precipitation data for various weather stations within the Clutha District (available through NIWA's Cliflo database [5]). We used as many sites as possible, where a recording period of at least 14 years was available. In many cases, the available data was insufficiently long enough to statistically present a long-term trend.[a] However, they still provide an overview of local conditions and allow us to infer how these relate to the projected climate trends that have been modelled by NIWA. The following climatic variables were extracted and graphed at different locations within the Clutha District:

- *Mean annual air temperature,*
- *Hot days (days where temperatures reached or exceeded 25°C in a 24-hour period),*
- *Cold nights or frosty mornings (days where temperatures reached or dropped below 0°C in a 24-hour period),*
- *Mean annual rainfall (total precipitation in any given year), and*
- *Heavy rainfall (days where greater than 25 mm of rain falls in a 24-hour period).*

While all attempts were made to select the most comprehensive records, there are some limitations to this historic data. Some years are missing from the records and where this has

[a] For example, the Tuapeka Mouth rainfall station is only 14 years (1990 to 2004).

occurred, we have made a note of the missing years on the graph. It is also likely that historic data recorded by hand was rounded to the nearest decimal point, while newer records have maintained greater detail due to modern recording practices.

In this report, we use 25°C as an indicator for a hot day, as opposed to NIWA's future climate change projections, which use 30°C. Trawling through the historic data we found very few days on record that reached or exceeded 30°C, and so we lowered this value to 25°C. This allowed us to better understand historic trends. Furthermore, in most parts of the Clutha District, 25°C is still considered a 'hot day'.

1.2.3 Future temperature and precipitation models

To understand what the Clutha District's future climate may look like, a series of computational models developed by NIWA have been used to inform this report. These models make predictions about future temperature and precipitation patterns by the years 2040 and 2090, relative to present day conditions. They are based on dynamical downscaling[b] of global climate models produced by the Intergovernmental Panel on Climate Change (IPCC), and are presented as a 5 by 5 km grid over all of New Zealand [4]. The climate projections are produced as two 20-year averages relative to a baseline period of 1986 to 2005. This means that predictions for 2040 represent the modelled average for the period between 2031 and 2050. Likewise, 2090 represents the modelled average for the period 2081 to 2100 [3]. A full discussion of the methodology employed by NIWA and the IPCC can be found elsewhere [3][4][6].

Within this report, we rely on climate projection data from NIWA's recent work for the Otago Regional Council titled, 'Climate change projections for the Otago region' [6]. For simplicity, but also to demonstrate that there is uncertainty around future greenhouse gas emissions at the global scale, we have reported on just two emissions scenarios. These include the 'low-mid range' emissions scenario (RCP 4.5), and the high-range emissions scenario (RCP 8.5).[c] This approach is consistent with previous work commissioned by the Otago Regional Council [6].

GIS raster files were obtained from NIWA, and GIS staff at CDC clipped these outputs to the Clutha District boundary and produced maps for the two RCP scenarios and two timeframes (2040 for RCP 4.5 and 8.5, and 2090 for RCP 4.5 and 8.5). We have restricted our analysis to annual rates of change in order to simply and clearly communicate future change; however, seasonal changes have also been modelled by NIWA (and are available at the Otago scale [6]).

There are of course some limitations to NIWA's climate models that are presented in this report. Firstly, it is difficult to absolutely predict future rates of global greenhouse emissions. To overcome this, the IPCC have developed a range of likely future emissions scenarios (as discussed in section 1.3 below); however, it is possible that actual emissions may be more or less than these scenarios indicate. Secondly, natural variability in future climate trends related to large-scale climate oscillations (the El Nino Southern Oscillation, the Interdecadal Pacific Oscillation and the Southern Annual Mode) introduces some uncertainty into the models [6]. While at times these climatic oscillations may offset or contribute to projected climate trends, by the end of the century the anthropogenic influence is predicted to become the dominant factor determining climatic conditions (for a full discussion see [6]).

---

[b] the process of applying large global climate models, to a regional scale.

[c] section 1.3 provides more detail on representative concentration pathways

1.2.4 Extreme sea level

The Clutha District contains a large stretch of coastline that is likely to be impacted by sea level rise in the future. To understand which areas are most susceptible to combined storm and sea level inundation, this report draws on recent work completed by NIWA titled, 'Coastal flooding exposure under future sea-level rise for New Zealand' [7]. NIWA have modelled the combination of extreme sea level with various increments of sea level rise that may occur in the future. Extreme sea level is considered a large and rare event (with a 1% probability of occurring in any given year), which combines high tide, storm surge, sea level anomaly and wave set up. Within this report, extreme sea level combined with both 50 cm and 100 cm of sea level rise has been mapped. These rates of sea level rise represent what we might expect for 2075 (50 cm) and 2115 (100 cm) under a high range emission scenario (RCP 8.5) (see appendix 1 for a full list of scenarios) [8]. We obtained the GIS files from NIWA and mapped extreme sea level scenarios for Taieri Mouth, Bull Creek, Kaitangata, the Clutha Delta, Kaka Point, Willsher Bay, Newhaven, Pounawea, Jacks Bay, the Catlins River, Papatowai to McLennan, and the southern end of Tautuku beach.

While the extreme sea level models produced by NIWA are good indications of what may happen, there are some important uncertainties associated with the data. The methodology used is commonly called a 'bathtub approach' and generally leads to the overestimation of inundation extents [7]. The output from these models (i.e. mapped 'inundation extents') do not necessarily show the impact of locally important factors such as the depth and duration of inundation, tidal influences, sediment processes, and velocity of water flow. Furthermore, sea level is treated as static over time, when in reality storm surge events only last one to three hours [7]. However, these models still allow us to identify which areas are most susceptible to future inundation and represent the latest modelling, from a reputable source.

1.2.5 Hydrological projections

Future changes to temperature and precipitation patterns will also impact hydrological processes and flood hazard within the Clutha District. To better understand these changes, we have drawn on hydrological models of river flow as well as modelled high intensity rainfall projections. Data on future flow rates for the Clutha River were taken from a NIWA report titled, 'Hydrological projections for New Zealand rivers under climate change' [9]. This work applied a hydrological model called TopNet to predict future hydrological conditions under different emissions scenarios. The parameters from this work included in this report include: mean annual flow, mean annual low flow, mean annual flood, and high flow.

While the IPCC recognise that the increased frequency and intensity of rainfall for many parts of New Zealand is very likely to contribute to an increase in flood hazard [3], uncertainties around precipitation patterns and how they relate to flood exist. It is important to note that the parameters listed above (from NIWA [9]), such as mean annual flood, do not necessarily translate to an increase in flood hazard. For this reason, we have also drawn on data available through NIWA's High Intensity Rainfall Design System (HIRDS) [10]. This tool generates future predictions of rainfall depths during high intensity rainfall periods. For this report, we have chosen to report rainfall depths for 2090 (an average of the years 2081-2100) under a high range emissions scenario (RCP 8.5). This tool tells us what a future 24-hour rainfall event with a 1 in 50-year change of occurring may look like in the future.[d]

[d] for a full explanation of the HIRDS methodology see https://www.niwa.co.nz/information- services/hirds/help

Table 1-1 The various data sources that were used to describe the impacts of climate change in the Clutha District.

Data Type	Description	Available at:
Local knowledge of weather and climate extremes	13 interviews with local farmers or their families, DOC workers, and emergency management personnel from Balclutha, Milton, Toko Mouth, Chaslands, Owaka, Clydevale, Tuapeka West, Heriot, Waipahi and Waitahuna.	n/a
Historic temperature and precipitation data	Variables included: mean annual air temperature, hot days (≥25°C), cold nights or frosty mornings (≤0°C), mean annual rainfall, and heavy rain days (>25 mm of rain). Stations included Nugget Point, Owaka, Finegand, Milton, Waihola, Mahinerangi, Tuapeka Mouth, Tapanui, and Moa Flat.	https://cliflo.niwa.co.nz/
Future temperature, precipitation and wind projections	Data from NIWA's climate models presented in a report titled 'Climate change projections for the Otago region'. Mean annual temperature, hot days (>30°C), cold days (<0°C), mean annual precipitation, heavy rain days (>25 mm), dry days, and extreme winds (top 99% of windy days) have been mapped at the Clutha scale.	https://www.orc.govt.nz/media/7591/niwa_climatechangereport_2019_final.pdf
Extreme sea level	Projections of extreme sea level taken from a NIWA report titled, 'Coastal flooding exposure under future sea-level rise for New Zealand'. Extreme sea level is considered a large and rare event (with a 1% probability of occurring in any given year), which combines high tide, storm surge, sea level anomaly and wave set up. Extreme sea level, combined with both 50 cm and 100 cm of sea level rise has been mapped for various locations within the Clutha District.	https://www.deepsouthchallenge.co.nz/news-updates/new-reports-highlight-flood-risk-under-climate-change
Hydrological projections of the Clutha River	Data on future flow rates for the Clutha River taken from a NIWA report titled, 'Hydrological projections for New Zealand rivers under climate change'.	https://www.mfe.govt.nz/publications/climate-change/hydrological-projections-new-zealand-rivers-under-climate-change
High intensity rainfall	Future depths of high intensity rainfall events: Rainfall totals under a high range emissions scenario (RCP 8.5) to understand what a 24-hour rainfall event with a 1 in 50-year chance of reoccurring may look like in 2090.	https://hirds.niwa.co.nz/

1.3 UNDERSTANDING EMISSIONS SCENARIOS

The information presented in this report draws on greenhouse gas emission scenarios agreed on by the IPCC. Generally, climate models are produced for a range of different emission scenarios, termed 'representative concentration pathways' (RCP). Representative concentration pathways are used to make projections on what the future climate will look like. The IPCC have agreed on four predictive emissions pathways that consider factors such as future population size, economic activity, lifestyle, energy use, land use patterns, technology and the implementation of climate policy [3]. Within this document we report on results from the 'low-mid' stabilisation pathway (RCP 4.5) and the 'business as usual' or high range scenario (RCP 8.5). While actual changes in climate or precipitation may in fact be higher or lower than either of these scenarios, they provide a reasonable indication of the range of possible climate 'outcomes' for the Clutha District. The four representative concentration pathways are outlined below, and while we focus our discussion around the RCP 4.5 and RCP 8.5 scenarios, an analysis of each pathway at the New Zealand scale can be found elsewhere [4].

- ***Best case scenario (RCP 2.6):*** *This is a mitigation scenario and assumes that changes in energy use and climate policy will lead to considerable removal of current levels of* CO_2 *from the atmosphere.*

- ***Low-mid stabilisation pathway (RCP 4.5):*** *This scenario assumes that greenhouse gas concentrations will continue to rise until approximately 2040 after which time concentrations will begin to decline.*

- ***Mid-high stabilisation pathway (RCP 6.0):*** *This scenario assumes that greenhouse gas concentrations will continue to rise until approximately 2080 after which time concentrations will begin to decline.*

- ***High range scenario (RCP 8.5):*** *This is a business as usual scenario and assumes that greenhouse gas concentrations will continue to grow at the current rate, assuming an uninhibited supply of fossil fuels. Under this scenario, the concentration of greenhouse gases in the atmosphere will continue to increase beyond 2100 [10].*

With our approach and methodology now explained, the following chapter will describe the patterns and rates of temperature and precipitation changes that can be expected with climate change in the Clutha District (assuming a low-mid range RCP 4.5, and high range RCP 8.5 scenario).

1.4 CHAPTER 1 REFERENCES

[1] Personal communication with Clutha District Council employee and sheep farmer, Milton, 10 September 2019.

[2] Personal communication with participants of a community level discussion held in the Papatowai Fire Station, 9 September 2019.

[3] Intergovernmental Panel on Climate Change (IPCC) (2013). *Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Stocker, TF, Qin, D, Plattner, GK, Tignor, M, Allen, SK, Boschung, J, ... Midgley, PM (Eds), Cambridge and New York: Cambridge University Press.

[4] Ministry for the Environment (2018). *Climate Change Projections for New Zealand: Atmosphere Projections Based on Simulations from the IPCC Fifth Assessment, 2nd Edition*. Report prepared by

National Institute of Water and Atmospheric Research Ltd (NIWA) for the Ministry for the Environment, Wellington.

[5] Cliflo National Climate Database, National Institute of Water and Atmospheric Research (NIWA) Ltd. Available at http://cliflo.niwa.co.nz/

[6] National Institute of Water and Atmospheric Research Ltd (NIWA) (2019). *Climate change projections for the Otago Region.* Report prepared for the Otago Regional Council. Macara, G., Woolley, J-M, Zammit, C., Pearce, P., Stuart, S., Wadhwa, S., Sood, A. & Collins, D.

[7] National Institute of Water and Atmospheric Research Ltd (NIWA) (2019). *Coastal flooding exposure under future sea-level rise in New Zealand*. Report prepared for the Deep South Challenge. Paulik, R., Stephens, S. Wadhwa, S., Bell, R., Popovich, B & Robinson, B.

[8] Ministry for the Environment (2017). *Coastal Hazards and Climate Change: Guidance for local government.* Bell, R., Lawrence, J., Allan, S. Blackett, P. and Stephens, S. New Zealand Government.

[9] National Institute of Water and Atmospheric Research Ltd (NIWA) (2018). *Hydrological projections for New Zealand rivers under climate change*. Report prepared for the Ministry for the Environment by Collins, D., Montgomery, K. & Zammit, C. NIWA, Christchurch.

[10] High Intensity Rainfall Design System (HIRDS), National Institute of Water and Atmospheric Research (NIWA) Ltd. Available at: https://hirds.niwa.co.nz/.

[11] Meinshausen, M., Smith, S.J., Calvin, K., Daniel, J.S., Kainuma, M.L.T., Lamarque, J-F., Matsumoto, K., Montzka, S.A., Raper, S.C.B., Raihi, K., Thomson, A., Velderm G.J.M. & van Vuuren, D.P.P. (2011). The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. *Climatic Change,* 109: 213-241.

2.0 CLUTHA DISTRICT OVERVIEW

This chapter presents an overview of future climate projections for the Clutha District. Climate predictions are drawn from NIWA's work at the national [1] and regional scale [2], which models temperature, precipitation, and wind conditions under future climate change scenarios. This chapter also draws on other work to provide an overview of predicted changes in our oceans, particularly in regard to sea level rise, temperature and acidity.

Before we describe these predictions at the Clutha scale, we'll first briefly discuss the kinds of climate trends we may expect across New Zealand more generally. Overall, NIWA's predictions demonstrate that the entire country will experience warmer conditions, an increase in extreme hot temperatures, and a decrease in extreme cold temperatures (snow and frost days) [1]. Within New Zealand, there is a discernible pattern in the rates of change from north to south, and slightly lower rates of warming are predicted for the south of the South Island [1]. Furthermore, warming is weaker in coastal areas due to the tempering effect of cool ocean water, while it is higher in more elevated regions due to a loss of snow cover [1]. Precipitation patterns are more variable, and a decrease in rainfall is expected for the north and east of the North Island, with an overall increase in rainfall expected elsewhere [1].

Importantly, when we compare New Zealand's overall climate trends to predictions for the Clutha District, we find Clutha is expected to warm slightly less than the remainder of the country. In addition, some substantial increases in rainfall are predicted for the Clutha District under some scenarios; however, these are less significant than in some parts of the South Island – for example the Southern Alps and upper reaches of the Clutha catchment. Within the Clutha District, patterns of change will differ from place to place, and these predicted changes are described below.

2.1 TEMPERATURE PREDICTIONS

The Clutha District is predicted to experience overall warmer conditions in the future [2]. This will be experienced as an overall increase in mean annual temperature, increase in the number of hot days (those greater than 30°C), and a decrease in frost and snow days. As will be discussed in the following chapters, these predictions are consistent with the observations made by local residents who broadly agree that winters in particular are already becoming milder, and that frost and snow days are becoming fewer and farther between.

2.1.1 Mean annual air temperature

At present, the mean annual air temperature in the Clutha District ranges from about 8°C to 12°C [2]. By 2040, mean annual air temperature is expected to increase by 0.5 to 1°C under both the low-mid and high range emission scenarios (Figure 2-1). By 2090, rates of change become more spatially variable, and the Clutha District may warm by 0.5 to 3°C, depending on location and emission scenario.

By 2090, the largest increases in mean annual air temperature are expected over the Umbrella Mountains/Old Man Range in West Otago, where temperatures are predicted to increase by up to 3°C under a high range emission scenario. The lowest increases are predicted in the south-eastern part of the District, including Papatowai, Owaka, Kaka point and Kaitangata (Figure 2-1).

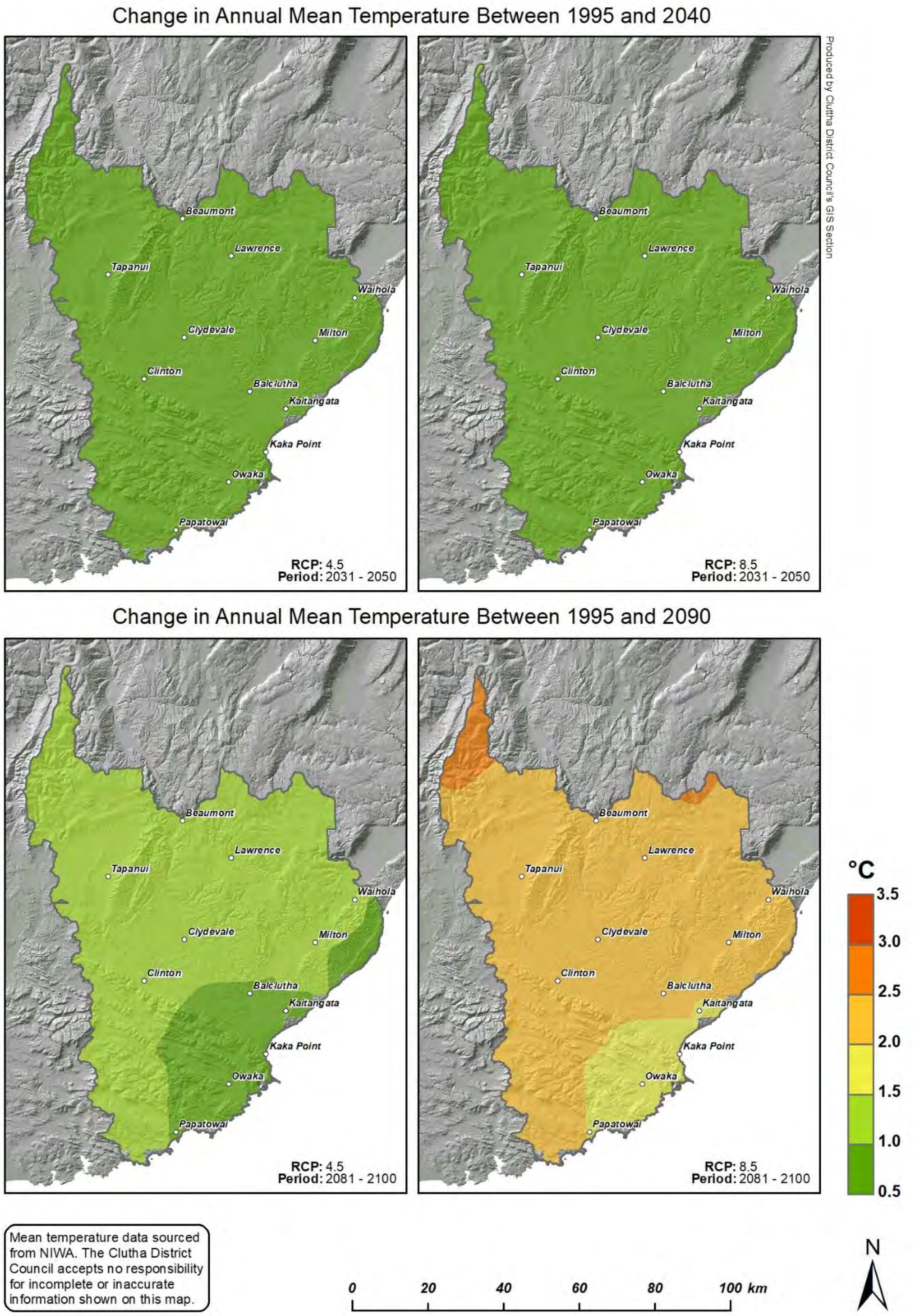


Figure 2-1 Change in mean annual temperature predicted in the Clutha District under two climate change scenarios. The top two images show the expected increase in mean annual temperature (in °C) by 2040 under a low-mid (left) and high range (right) emission scenario. The bottom two images show the expected increase by 2090, under a low-mid (left) and high range (right) emission scenario.

2.1.2 Temperature extremes

Climatic changes are often most noticeable when we look at temperature extremes, such as very hot or very cold days. To better understand this trend, NIWA have modelled changes in the number of extreme hot days (those greater than 30°C) and the number of frost days (those less than 0°C) that may occur under future climate change scenarios.

***Extreme hot days*[e]**

In this report, an extreme hot day is considered to occur when the maximum temperature is above 30°C. At present, most of the Clutha District experiences very few extreme hot days (less than 1 per year) [2]. However, the number of extreme hot days in Clutha is predicted to increase by between zero and two days per year by 2040, with larger increases possible in the north of the district (Figure 2-2). More significant change is predicted by 2090, when the district may experience up to six additional extreme hot days under a low-mid range scenario (RCP 4.5), or up to 20 days assuming a high range scenario (RCP 8.5).

Northern parts of the district are expected to experience the largest increases, particularly the Umbrella Mountains/Old Man Range, and townships of Beaumont and Waipori. While we have only included the annual change in the number of extreme hot days in this report, the predicted changes do have a seasonal trend and the majority of these will occur in summer [2].

Frost days

The climate projection modelling supplied by NIWA [2] defines a frost day as when the modelled daily minimum temperature falls below 0°C. Anecdotal evidence and historical records (as summarised in chapters 3 to 6) suggest that there has already been a reduction in the frequency of frosts in parts of the Clutha District, and Figure 2-3 shows that further decreases are predicted into the future.[f]

Presently, the Clutha District experiences between 10 and 100 frost days each year, with more frosts occurring further inland and in higher altitude locations [2]. By 2040, the district may expect between one and 20 fewer frost days each year. By 2090 this increases to between five and 50 fewer frost days each year, depending on the emission scenario (Figure 2-3).

As with extreme hot days, the largest changes are expected for northern and inland parts of the district, with substantial decreases predicted for the Umbrella Ranges/Old Man Range in West Otago, Lawrence and Waipori. While we have only included annual change in frost days in this report, the number of frost days has a seasonal trend and the majority of these will likely occur in the winter months [2].

---

[e] As noted in section 1.2.2, this measurement differs from that used to describe previous changes in the number of hot days. The dataset provided by NIWA to describe future changes in climate uses 30°C as an indicator for hot days, rather than 25°C.

[f] Note that the NIWA climate models are calculated on 5 x 5 km grids and that the actual occurrence of frosts is influenced by finer local topographic and landscape features [2].

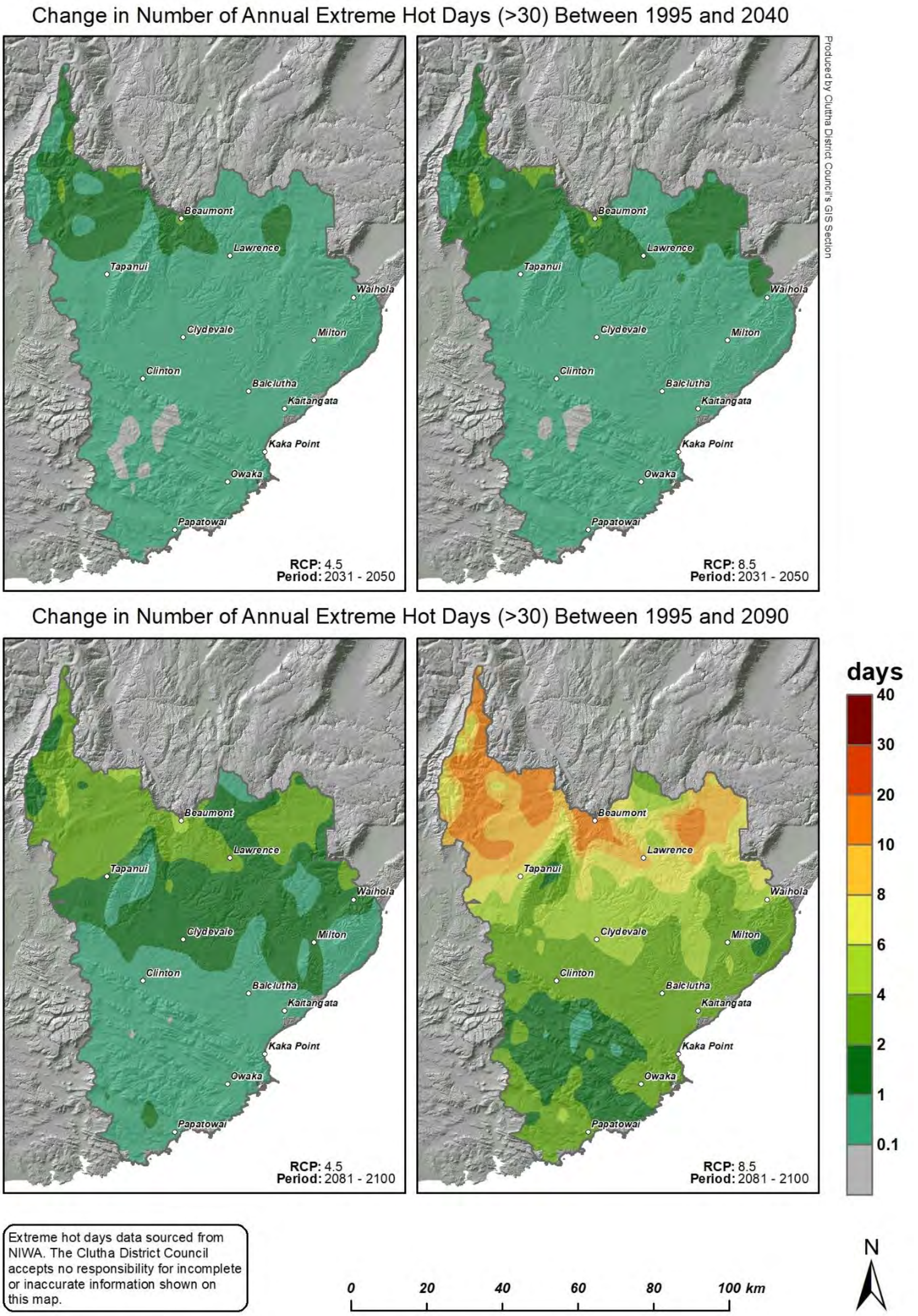


Figure 2-2 The change in number of extreme hot days predicted for the Clutha District under two climate change scenarios. The top two images show the increase in number of hot days by 2040 under a low-mid (left) and high range (right) emission scenario. The bottom two images show the expected increase by 2090 under a low-mid (left) and high range (right) emission scenario.

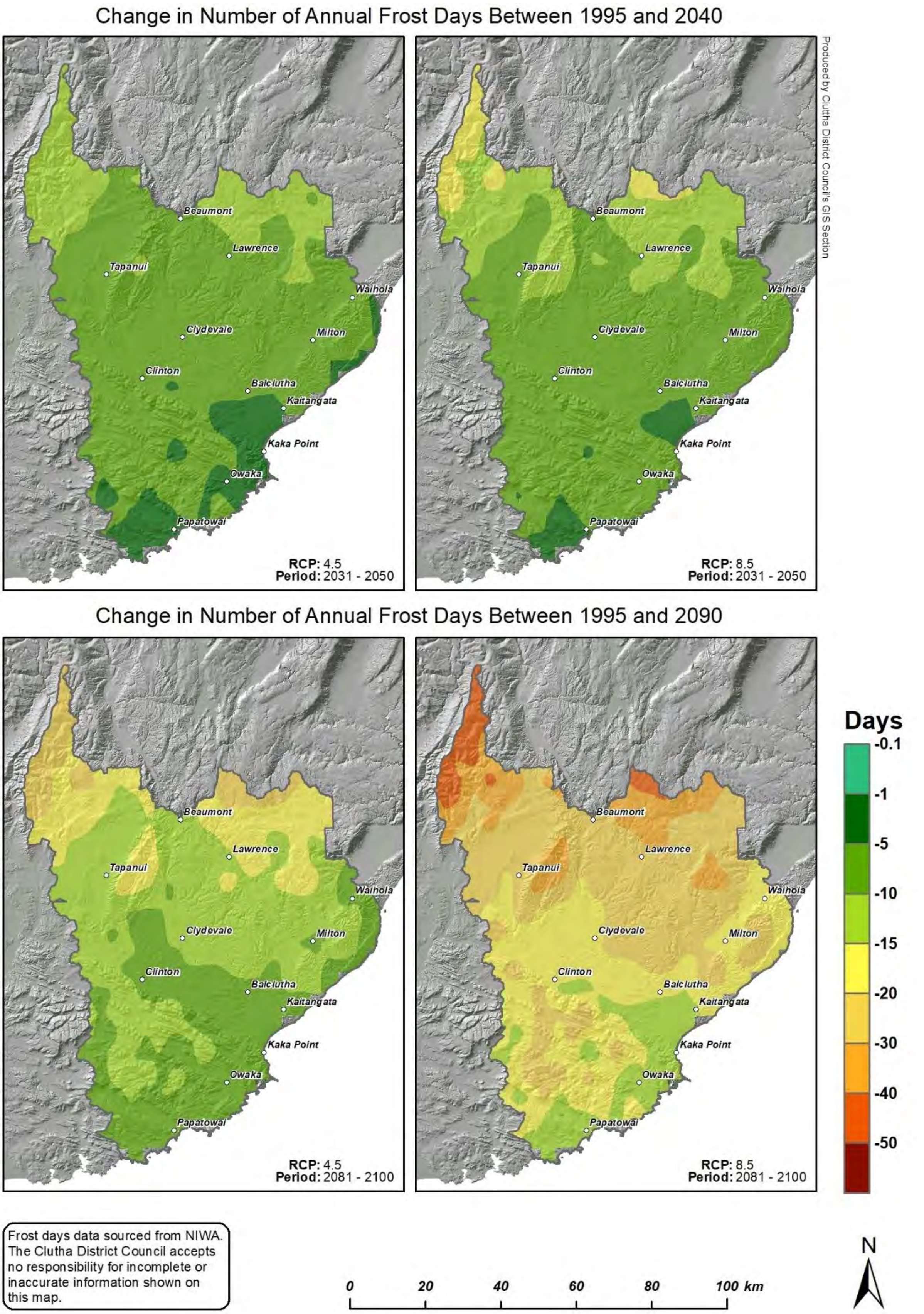


Figure 2-3 Changes in the number frost days predicted for the Clutha District under two climate change scenarios. The top two images show the decrease in the number of frost days by 2040 under a low-mid (left), and high range (right) emission scenario. The bottom two images show the expected decrease by 2090, under a low-mid (left) and high range (right) emission scenario.

2.1.3 Snow days

The NIWA modelling [2] used to inform this report defines a snow day as a "precipitation day where the mean temperature was below freezing point". NIWA acknowledge that this approach likely underestimates the current number of snow days, particularly for low elevation elevations where snowfall often occurs when the ambient temperature is at or above 0°C. However, this measure does provide a reference against which future changes can be compared.

NIWA's modelling at the Otago scale shows that the largest reduction in snow days occurs in cold mountainous areas, where there are a relatively large number of snow days in the present climate [2]. Within the Clutha District, the models also show that the largest reductions in the number of snow days occur at high altitudes, such as the Umbrella Mountains/Old Man Range (which may experience up to five fewer snow days per year by 2090). However, even low-lying parts of the Clutha District can experience several snow days per year under current conditions, and it seems likely that these will also become less frequent, given NIWA's predictions for the rest of the region.[2]

It is noted that some changes have already observed by local farmers, who commented that the snow line has already begun retreating to higher altitudes.

2.2 PRECIPITATION CHANGES

As a warmer atmosphere can hold more moisture [2], rainfall patterns will also change in the future. While future precipitation patterns are variable, an overall shift towards more and heavier rainfall is expected for the Clutha District. These changes are reflected in models of mean annual precipitation, heavy rain days, high intensity rainfall events, and dry days, as outlined below.

2.2.1 Mean annual precipitation

The Clutha District is predicted to experience an overall increase in mean annual precipitation, with increases felt especially during the spring and winter months [2]. Currently, annual precipitation for the Clutha District ranges from between 600 and 1500 mm [2]. By 2040, most of the district can expect a 0 to 5% increase in annual precipitation, while the area from Milton out to the coast is predicted to experience a 5 to 10% increase (Figure 2-4). By 2090, rates of increase vary depending on emission scenario, and the greatest increases are predicted for the Clutha Valley, the towns of Milton and Waihola and their surrounds. These areas may experience an increase in annual precipitation of up to 20% by the end of the century (for a high range emission scenario, RCP 8.5).[g]

[g] Note that the direction of change for rainfall predictions is less certain compared to temperature owing to the fact that the models project both increases and decreases in rainfall within the same scenario. While mean annual rainfall for the Clutha District shows an overall increase, when this variable is broken into seasons, it can show decreases (e.g. a decrease in rainfall during winter is predicted for parts of West Otago for 2040 (RCP 4.5 & 8.5) and 2090 (RCP 4.5) [2].

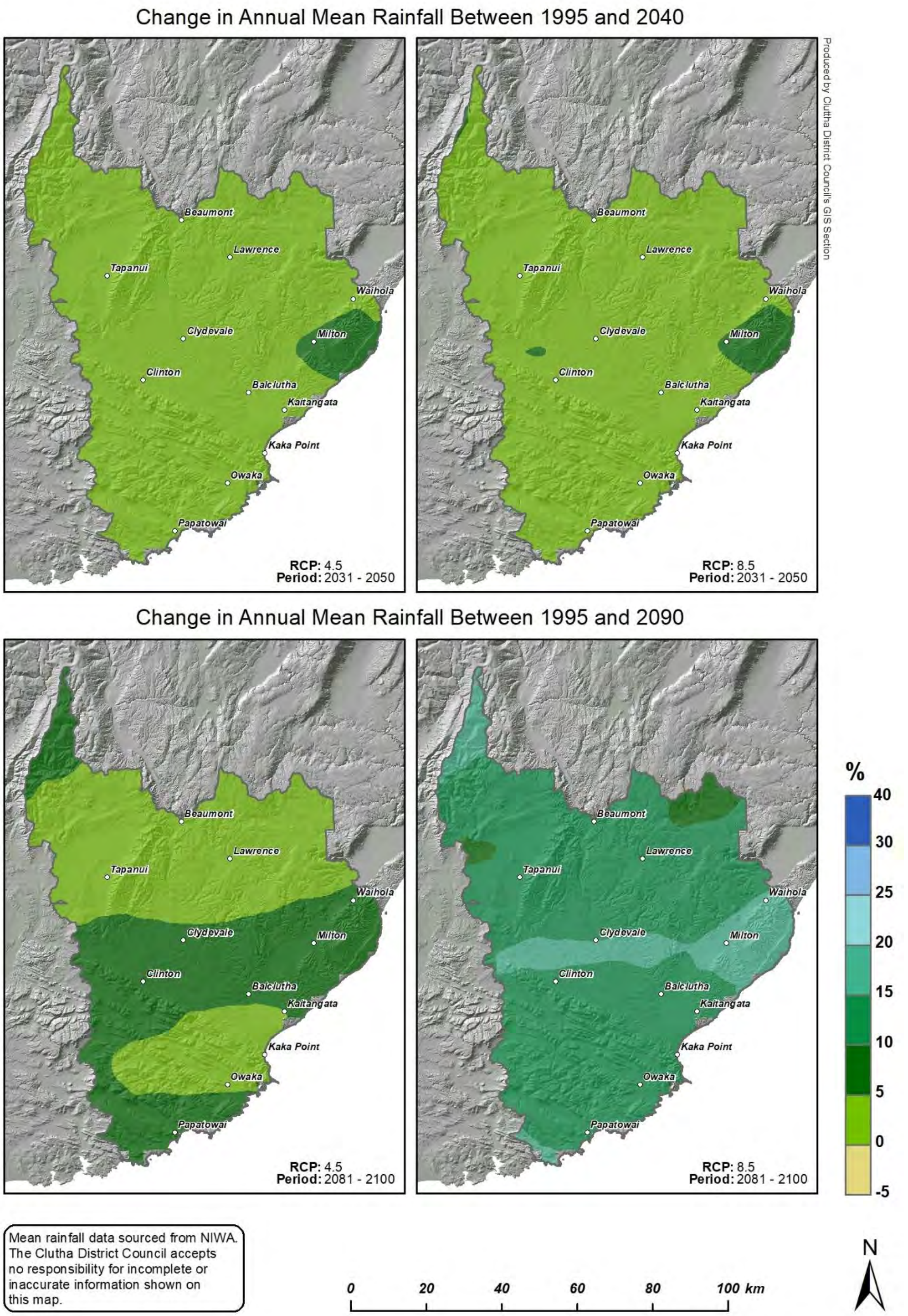


Figure 2-4 Percentage change in mean annual precipitation, as predicted for the Clutha District under two climate change scenarios. The top two images show percentage increase in mean annual precipitation by 2040 under a low-mid (left) and high range (right) emission scenario. The bottom two images show the percentage increase by 2090, under a low-mid (left) and high range (right) emission scenario.

2.2.2 Number of heavy rain days

Alongside increases in annual precipitation, the Clutha District is also predicted to experience a relatively small increase in the number of heavy rain days (those with greater than 25 mm of rain). At present, between one and six heavy rain days can be expected across the Clutha District each year, with the highest number occurring in The Catlins and the fewest in West Otago [2].

By 2040, most of the district is predicted to experience an increase of up to one extra heavy rain day per year, with up to two extra rain days in The Catlins, to the west of Papatowai (Figure 2-5). By 2090, the district may experience between zero and five extra heavy rain days, with the greatest increases generally predicted to occur in The Catlins and West Otago areas. River catchments located in these areas (and therefore more likely to be affected by additional heavy rain days) include:

- The upper reaches of the Pomahaka River (above Leithen Glen),
- The southern part of the Blue Mountains, including Whisky Gully (above Tapanui) and the Rankle Burn,
- The mid-section of the Pomahaka catchment (above Burkes Ford),
- The Catlins and Tahakopa rivers in The Catlins, and
- The upper reaches of the Waiwera River near Clinton.

2.2.3 Magnitude of high intensity rainfall events

In addition to the district-wide climate models described above, work was undertaken to understand likely changes in the magnitude of high intensity rainfall events at certain locations. The scenario chosen to achieve this was a 24-hour rainfall event, with an estimated return period of 1 in 50-years. A range of other scenarios could have been modelled, using different duration events, and different return periods. However, storms lasting approximately one day are reasonably common in coastal Otago, and have previously resulted in significant flooding in many parts of the Clutha District (see for example [4] and [5]).

The 'High Intensity Rainfall Design System' (HIRDS) [2] was used to determine the current rainfall total expected from a 1 in 50-year, 24-hour event at selected towns across the district. In addition, the rainfall expected from such an event under two climate change scenarios at the end of this century was also modelled. The results are shown in Table 2-1 and Figure 2-6.

Compared to the current situation, such an event will bring an additional 6 - 8 mm of rain, depending on location and emission scenario. The potential impact of increased rainfall intensities (as illustrated in Table 2-1) are discussed in chapters 3 to 6.

Table 2-1 Rainfall totals (mm) during a 1 in 50-year rainfall event lasting 24 hours, for various locations across the Clutha District. Data obtained from HIRDS [3].

	Balclutha	**Milton**	**Lawrence**	**Tapanui**	**Clinton**	**Owaka**
Current estimate	93.6	108	103	98.9	97.7	107
2090 (low-mid scenario, RCP 4.5)	99.4 (+5.8)	114 (+6)	110 (+7)	105 (+6.1)	104 (+6.3)	114 (+7)
2090 (high scenario, RCP 8.5)	100 (+6.4)	115 (+7)	111 (+8)	106 (+7.1)	105 (+7.3)	115 (+8)

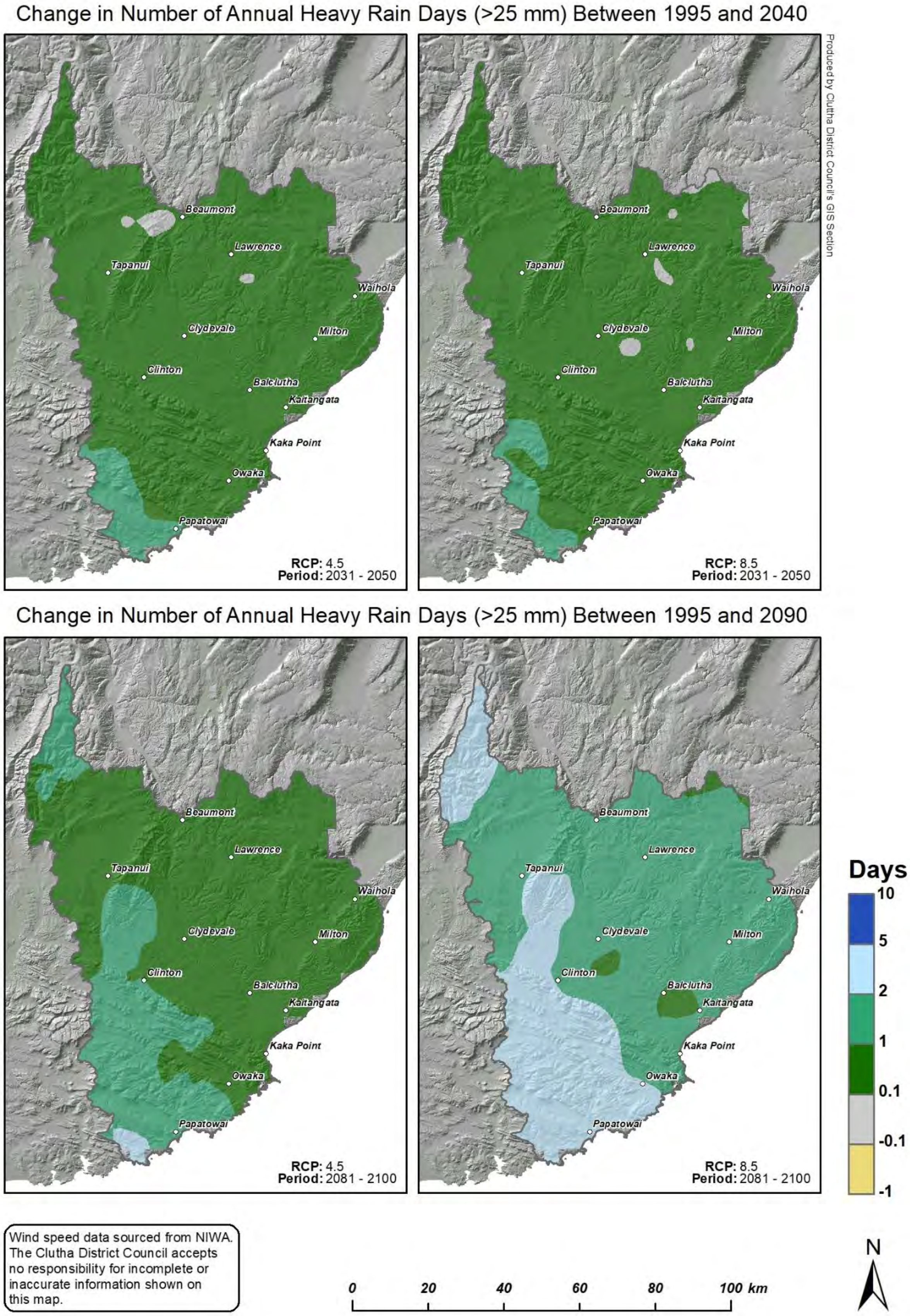


Figure 2-5 Changes in the number of heavy rain days predicted for the Clutha District under two climate change scenarios. The top two images show predicted changes in the number of heavy rain days by 2040 under a low-mid (left) and high range (right) emission scenario. The bottom two images show the predicted changes by 2090 under a low-mid (left) and high range (right) emission scenario.

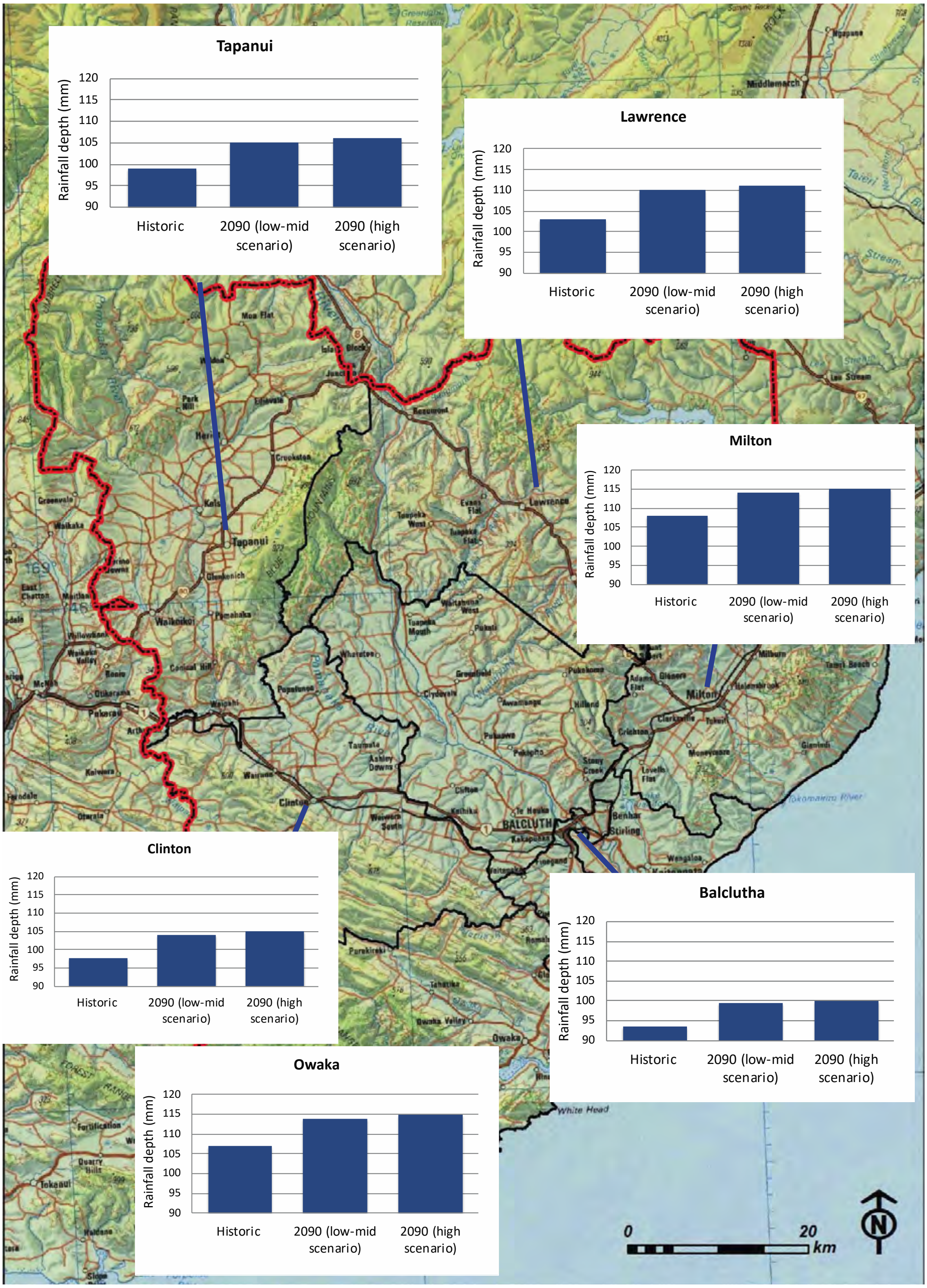


Figure 2-6 Predicted increase in rainfall totals during a high intensity rainfall event for various locations across the Clutha District. This Figure shows the magnitude of a 1 in 50-year rainfall event lasting 24 hours in 2090 (under low-mid range (RCP 4.5) and high range (RCP 8.5) scenarios). The current estimate for such an event, based on historical data, is also shown (data sourced from NIWA's HIRDS [3]).

2.2.4 Dry days

With more rainfall predicted, it is reasonable to assume fewer dry days; however, this isn't the case throughout all of the Clutha District. Presently, the Clutha District experiences between 150 and 250 dry days per year [2], depending on topography and location. NIWA's predictions show that the number of dry days (those where less than 1 mm of rain is recorded) that occur each year will increase in some areas, while decreasing in others. The modelling results in Figure 2-7 show a 'band' stretching from west to east through the centre of the Clutha District (from approximately Waipahi to Akatore Creek) which will, as a result of climate change, generally experience fewer dry days compared to the rest of the district.

In general, the eastern end of this band (Milton and the surrounding area) will experience the largest decrease in the number of dry days. This pattern is stronger under the high range (RCP 8.5) scenario, for both timeframes (2040 and 2090). The Catlins, and to a lesser extent West Otago, see an increase in the number of dry days, under most of the scenarios shown in Figure 2-7.

It is noted that while only annual maps are presented in this report, the number of dry days does have a seasonal pattern, and generally the largest decreases are expected for the winter months, and the largest increases are projected for the summer months [2].

2.2.5 Extreme wind

Changes in air temperature will also impact local wind conditions and NIWA have modelled changes in extremely windy days. Extreme wind is defined here as the top 99th percentile of daily wind speeds, which roughly equates to the top three windiest days that are experienced each year [2]. Overall, extreme daily wind speed is predicted to undergo little change in the eastern part of the Clutha District, with more noticeable increases further inland, particularly in proximity to the Old Man Range in West Otago. Little change is expected for much of the district by 2040, except for West Otago which is predicted to experience increases of up to 6%. By 2090, extreme daily wind speed is expected to increase by up to 8% in West Otago, with an increase of between 0 and 4% expected elsewhere (Figure 2-8).

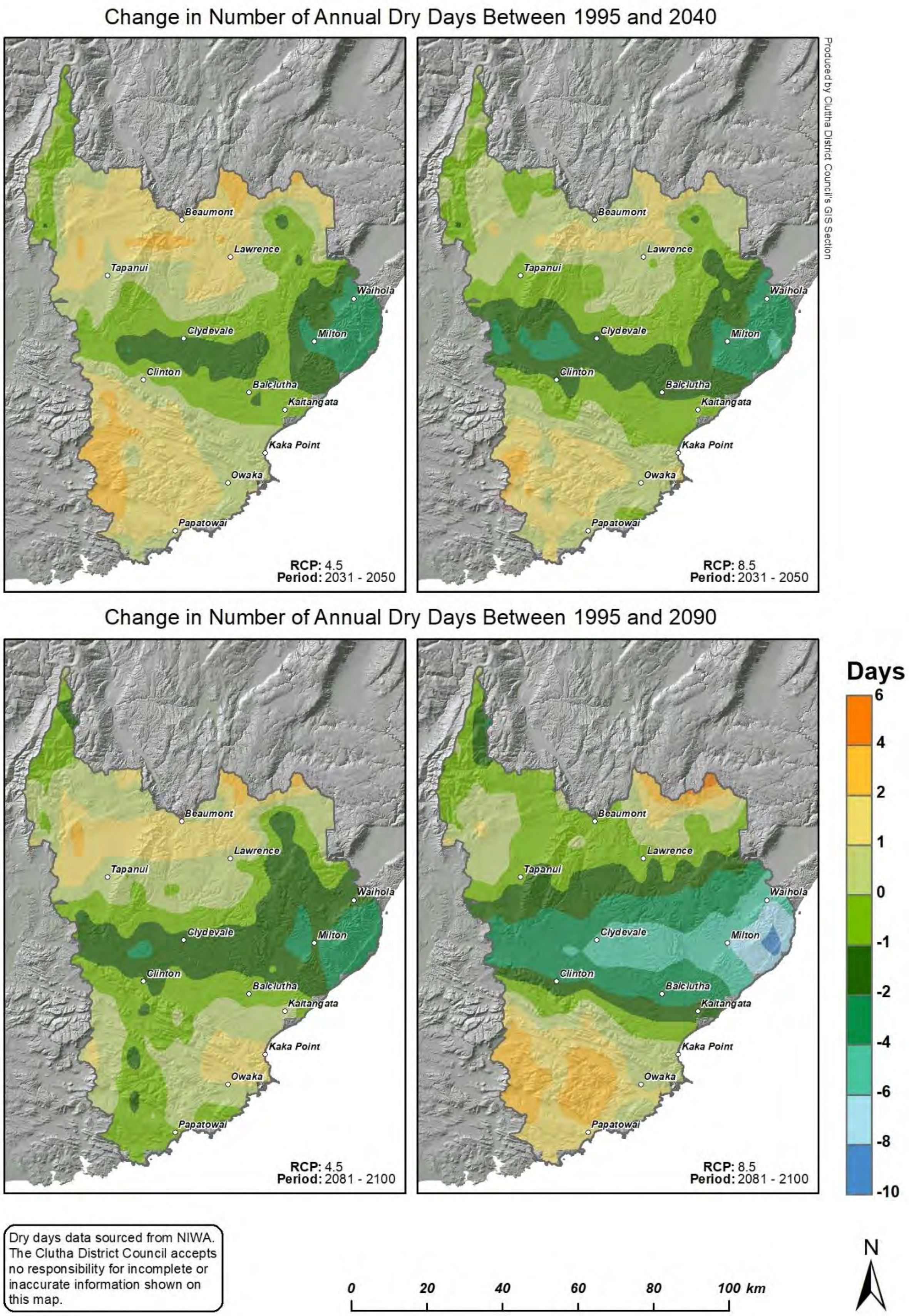


Figure 2-7 Predicted changes in the number of dry days in the Clutha District under two climate change scenarios. The top two images show changes in the number of dry days by 2040 under a low-mid (left) and high range (right) emissions scenario. The bottom two mages show changes in the number of dry days by 2090 under a low-mid (left) and high range (right) emissions scenario.

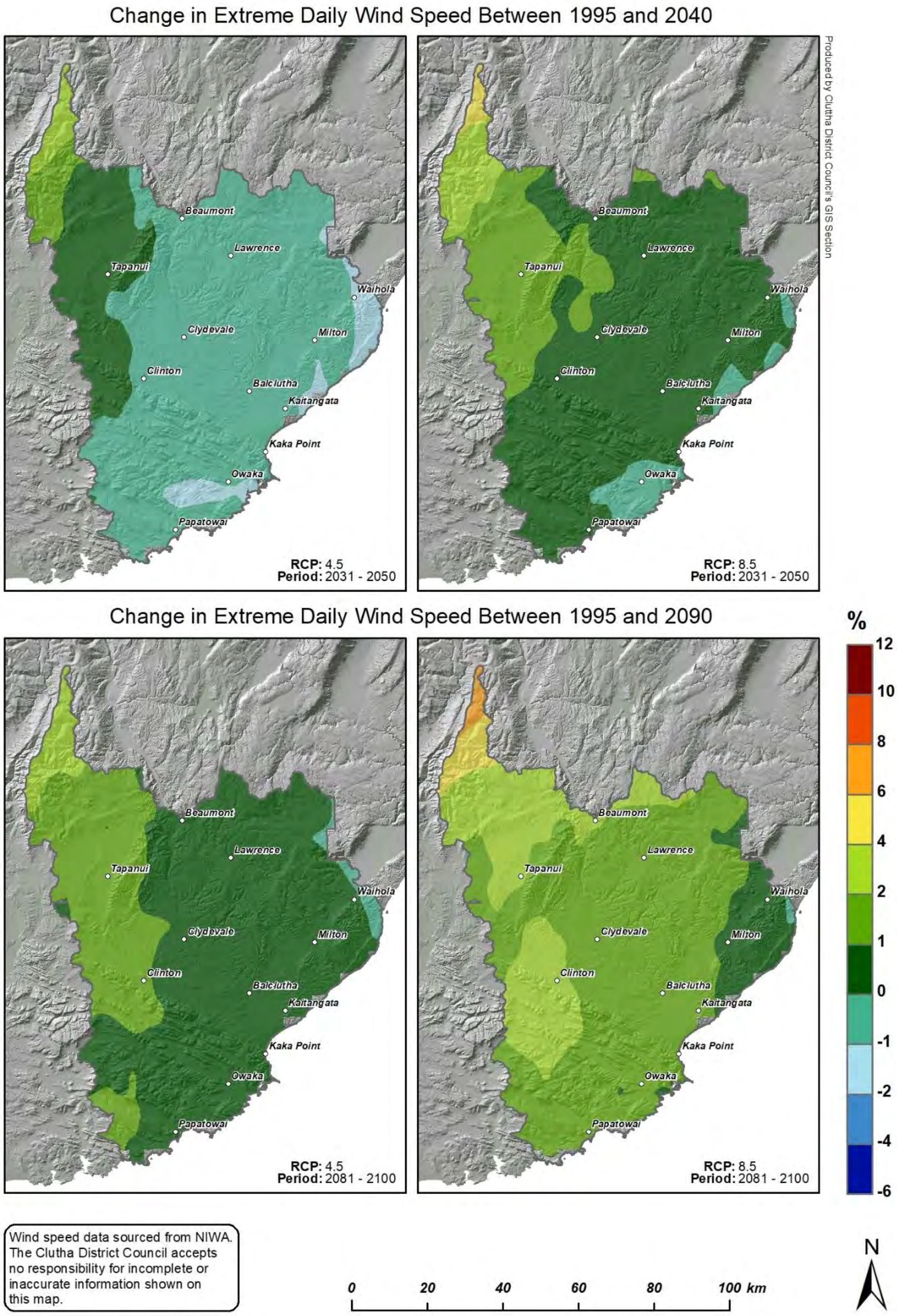


Figure 2-8 Changes in extreme daily wind speeds (as a percentage) for the Clutha District under two climate change scenarios. The top two images show changes in extreme daily wind speed percentages by 2040 under a low-mid (left) and high range (right) emission scenario. The bottom two images show changes in extreme daily wind speed percentages by 2090 under a low-mid (left) and high range (right) emission scenario.

2.3 OUR OCEAN

The ocean is often the first indicator of global change, and there is evidence that sea levels are rising, and that the ocean is becoming warmer and more acidic due to the effects of climate change [6]. Global sea level data indicates that from the late 19th century to the early 20th century, rates of sea level rise began to accelerate, reflecting a trend of global warming due to the expansion and melting of polar ice sheets [6]. From 1961, the global rate of sea level rise has been, on average, 1.9 ± 0.4 mm per year [6] [7]. However, sea level rise is not globally uniform, and the average rate of sea level rise in New Zealand up to 2000 was 1.7mm ± 0.1 mm per year, as determined from four long-term, and six shorter sites across the country. [8]

In more recent times, a sea level monitoring recorder on Green Island, offshore from Dunedin was installed in 2002 (Figure 2-9). Although this monitoring site has a record which is still too short for deriving long-term trends, the data is of high quality, with a frequent (1 minute) recording interval, and an instrument accuracy of ± 1 mm. The average level of the sea at Green Island has increased at a reasonably consistent rate of 3.3 mm/year since 2002 [9]. While we don't yet know the precise rate of rise currently occurring along the Clutha District coastline, it is likely be similar to that observed at Green Island which lies approximately 18 km from Taieri Mouth, and 66 km from Kaka Point.

Figure 2-9 Green Island, off the coast of Dunedin. The red arrow shows the location of the sea level recorder (inset). Source: [9]

Sea level is projected to continue to rise throughout the 21st century, with a global rate of 3.7 mm per year modelled for the beginning of the century [7]. Under RCP 4.5, this current rate of increase would remain reasonably steady. However, under RCP 8.5, it would likely accelerate over time (Figure 2-10).

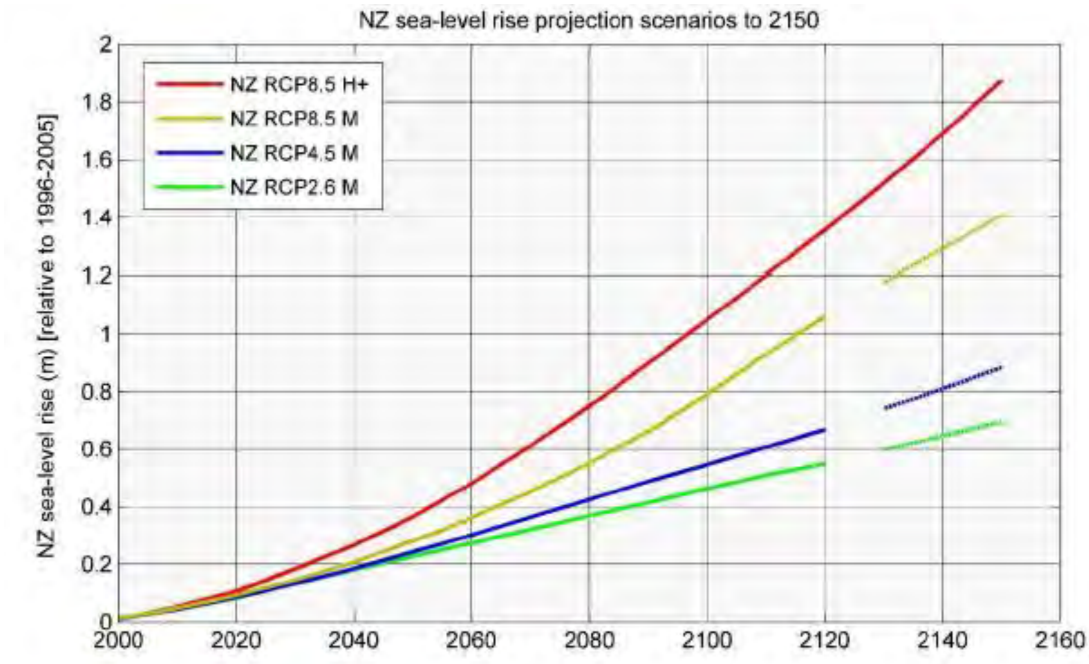


Figure 2-10 Four scenarios of New Zealand-wide regional sea-level rise projections, with extensions to 2150. The scenarios used in this report are RCP 8.5 (yellow line) and RCP 4.5 (blue line). Source: [14]

The Ministry for Environment [10] recommend a planning period of 100 years for coastal assets, and by 2120 it is predicted that New Zealand's mean sea level will have risen by 0.67 m assuming a low to mid-range emission scenario (RCP 4.5), or by 1.06 m for a high range emission scenario (RCP 8.5) [10].[h]

However, it is important to note that as mean sea level steadily increases over time, the likelihood of important coastal assets being inundated during storm surge and extreme high tide events will also increase [11]. In this report, extreme sea level is defined as a large and rare event (with a 1% probability of occurring in any given year – i.e. a '1 in 100-year event'), which combines high tide, storm surge, sea level anomaly and wave set up. Drawing on NIWA models, extreme sea level combined with both 50 cm and 100 cm of sea level rise has been mapped. According to Figure 2-10 above:

- 50 cm of sea level rise could be reached by 2075 under RCP 8.5, or by 2090 under RCP 4.5.
- 100 cm of sea level rise could be reached by 2115 under RCP 8.5, or by 2170 under RCP 4.5 [10].

While these increments of sea level rise may pose a hazard in and of themselves, their greatest impact will be felt during an extreme sea level event. These impacts are discussed at the local level in chapters three and four.

Alongside rising sea levels, global trends indicate that the ocean is also becoming warmer and more acidic. While New Zealand's data does not reveal this same warming trend, it is likely due to a short recording period [6]. However, the acidity of New Zealand's Subantarctic waters has decreased by 0.0015 units as measured from 1998 [6]. While this may not seem like much, the pH scale is logarithmic and a decrease of 0.1 pH units is equivalent to a 26% increase in

[h] These values will vary locally depending on vertical land movements, and may in fact be greater in areas of active subsidence and less in areas of uplift [9] [10].

acidity [12]. While we don't yet understand the extent or impact of this at the Clutha scale, it is noted here to help demonstrate the broad spectrum of climate change impacts.

2.4 SUMMARY

The climate models presented above (representing a selection of NIWA's most up to date modelling), demonstrate that the Clutha District is predicted to become warmer and wetter by the end of the century. Notably, there will be fewer frosts, more hot days, and heavier rainfall. Yet, within the Clutha District, patterns of change will vary, and West Otago for example, will warm more than The Catlins coast. Ongoing sea level rise (along with other oceanic changes) may also cause challenges for coastal communities within the Clutha District.

These distinct patterns of change mean that various wards within the district will experience their own set of issues associated with climate change. The following chapters have grouped wards by geographic and climatic features to discuss the unique challenges and opportunities that each area may face with predicted changes in climate and sea level.

2.5 CHAPTER 2 REFERENCES

[1] Ministry for the Environment (2018). *Climate Change Projections for New Zealand: Atmosphere Projections Based on Simulations from the IPCC Fifth Assessment, 2nd Edition*. Report prepared by National Institute of Water and Atmospheric Research Ltd (NIWA) for the Ministry for the Environment, Wellington.

[2] National Institute of Water and Atmospheric Research Ltd (NIWA) (2019). *Climate change projections for the Otago Region.* Report prepared for the Otago Regional Council. Macara, G., Woolley, J-M, Zammit, C., Pearce, P., Stuart, S., Wadhwa, S., Sood, A. & Collins, D.

[3] High Intensity Rainfall Design System (HIRDS), National Institute of Water and Atmospheric Research (NIWA) Ltd. Available at: https://hirds.niwa.co.nz/.

[4] Otago Regional Council and Clutha District Council, (2012). Flood risk management strategy for Milton and Tokomairiro Plain. Prepared by Goldsmith, M. & Brass M.

[5] Otago Regional Council, (2015). *Coastal Otago flood event 3 June 2015.* Prepared by Goldsmith, M., Payan, J.L., Morris, R., Valentine, C., MacLean, S., Xiaofeng, L., Vaitupu, N., and Mackey, B. October 2015.

[6] Ministry for the Environment & Statistics New Zealand (2016). *New Zealand's Environmental Reporting Series: Our marine environment 2016.* Available from www.mfe.govt.nz and www.stats.govt.nz

[7] Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan (2013). Sea Level Change. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* Eds Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[8] Hannah & Bell (2012). Regional sea level trends in New Zealand. *Journal of Geophysical Research*, 117, 1-7.

[9] Otago Regional Council (2016). *The Natural Hazards of South Dunedin*. Prepared by Goldsmith M. & Hornblow, S. July 2016.

[10] Ministry for the Environment (2017). Coastal Hazards and Climate Change: Guidance for local government Bell, R., Lawrence, J., Allan, S. Blackett, P. and Stephens, S. New Zealand Government.

[11] National Institute of Water and Atmospheric Research Ltd (NIWA) (2019). *Coastal flooding exposure under future sea-level rise in New Zealand*. Report prepared for the Deep South Challenge. Paulik, R., Stephens, S. Wadhwa, S., Bell, R., Popovich, B & Robinson, B.

[12] Intergovernmental Panel on Climate Change (IPCC) (2013). Summary for policymakers. In Stocker, TF, Qin, D, Plattner, GK, Tignor, M, Allen, SK, Boschung, J, ... Midgley, PM (Eds), *Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge and New York: Cambridge University Press.

3.0 COASTAL AND EASTERN CLUTHA

Figure 3-1 View of farmland and forestry blocks to the north of Balclutha with Lake Tuakitoto in the distance (source: GHC).

3.1 INTRODUCTION

Coastal and Eastern Clutha is a diverse geographical area, incorporating the extensive Clutha Delta, the regional centre of Balclutha, and a series of smaller settlements located at the mouth of, or along, major river systems (including the Clutha, Taieri and Tokomairiro rivers). The area encompasses the Balclutha, Kaitangata and Bruce wards, and extends from Lake Waihola in the north to Molyneux Bay in the south.

Much of the area can be affected during flood events, particularly the Tokomairiro and lower Clutha floodplains, and the towns of Milton and Balclutha. With important forestry, agricultural and manufacturing industries, the Coastal and Eastern Clutha area will experience its own unique set of challenges and opportunities in a changing climate.

3.1.1 Key findings:

- By 2090, mean annual temperature in Coastal and Eastern Clutha is expected to increase by between 0.5° C and 2.5° C, relative to 1995 [1].
- The Clutha River is expected to undergo an increase in mean river flow due to increased precipitation along the Southern Alps [2].
- Predicted increases in the magnitude of heavy rainfall events may result in increased flood risk for towns and rural Coastal and Eastern Clutha.
- Sea level is expected to continue to rise, and low-lying coastal settlements and infrastructure (such as Taieri Mouth, Toko Mouth, Kaitangata, and Molyneux Bay) may become increasingly susceptible to inundation during extreme sea level events.
- The agricultural and forestry sectors may face new challenges in terms of flood and water management, yet they may also benefit from more winter pasture growth and new cropping opportunities.

- While climate change will present new challenges for Coastal and Eastern Clutha, through informed planning, and innovative adaptation, these future challenges can be faced and overcome.

Contains data sourced from Land Information New Zealand under Creative Commons Attribution 4.0 NZ licence

Figure 3-2 The Coastal and Eastern Clutha boundary, encompassing the Balclutha, Kaitangata and Bruce wards.

3.2 UNDERSTANDING THE PAST AND PRESENT CLIMATE

Presently, the Coastal and Eastern Clutha area experiences a reasonably mild maritime climate, with mean annual temperatures of 8°C to 12°C [1]. Average maximum temperatures during the summer months lie between 18°C and 20°C, while average minimum winter temperatures lie between 0°C and 4°C [1]. The area experiences regular frosts in winter, with very few days exceeding 30°C [1]. Annual rainfalls range from 600 to 1000 mm, with the town of Milton generally receiving the most rainfall [1].

3.2.1 Air temperature

Past records tell us that New Zealand's air temperatures have increased by about 1°C over the past century [3], a trend that is also supported by local weather observations within Coastal and Eastern Clutha. Temperature records taken from Finegand (to the south of Balclutha) for the period of 1965 to 2017 suggest there has been a slight increase in mean annual temperature over time (Figure 3-3 a, however note the substantial periods of missing years in this record). Historic temperature records from this station also suggest that the total number of hot days (those with temperatures greater than 25°C) per year is increasing, and 2018 contained the largest number of hot days on record (29 days in total) (Figure 3-3 b).

While warmer weather often means fewer frosts, this trend is less discernible at the Finegand station (Figure 3-3 c). Anecdotal observations made by local farmers in Milton however, broadly agreed that frost days are becoming fewer and further between, especially when present day conditions are compared with the weather they remember from their youth [4][5].

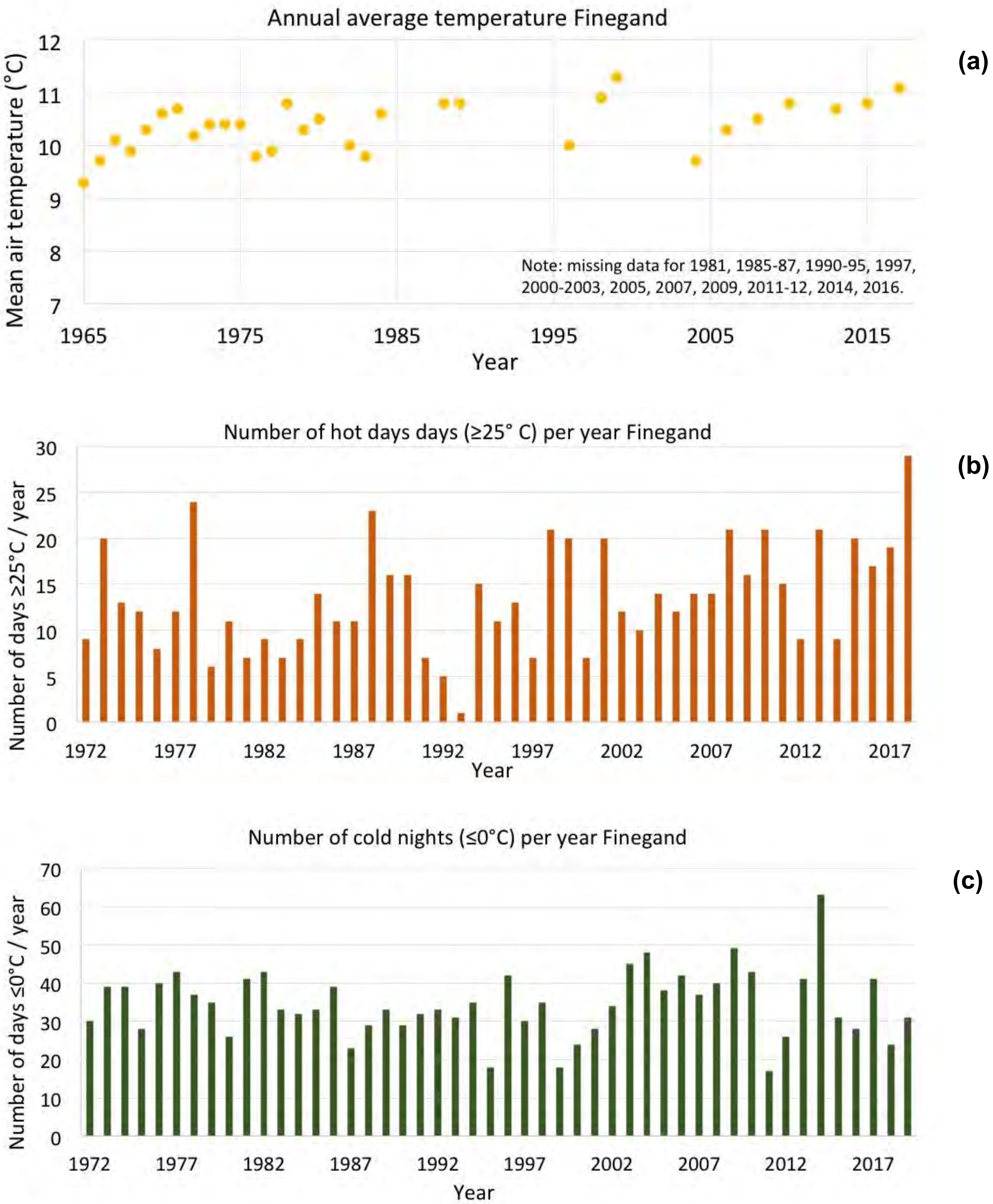


Figure 3-3 Historic temperature data from Finegand obtained from the NIWA climate database; a) mean average temperature, b) number of hot days (greater than 25° C), and c) number of frost days or nights (where temperatures dropped below 0° C) [6].

3.2.2 Rainfall

There is little variation in annual rainfall totals across most of the Coastal and Eastern Clutha area, although the coastal hills to the east of Milton typically receive more rain than lower-lying areas to the west. (Figure 3-4). At Milton, records show that annual rainfall totals generally fluctuated between 600 mm and 900 mm between 1930 and 1984 (Figure 3-5 a); while further north at Waihola they fluctuated between 470 mm and 980 mm for the period 1963 to 2000 (Figure 3-5 c).

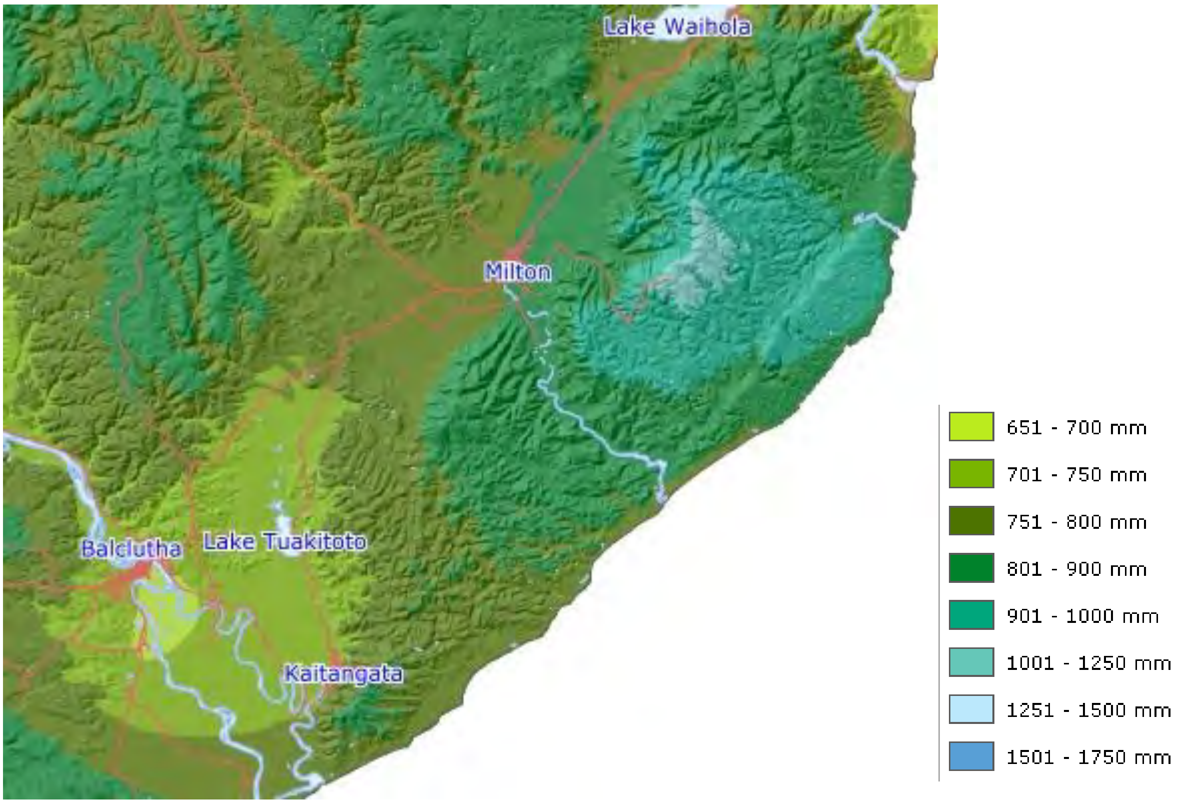


Figure 3-4 Median annual rainfall in the Coastal and Eastern Clutha area. Modelled by NIWA for the GrowOtago project.

The Coastal and Eastern Clutha area is known for heavy rainfall events that can contribute to localised flooding. While the intensity of such events has increased over time in nearby Dunedin [7], and annual precipitation has actually decreased at some Dunedin sites [8], records taken within the Coastal and Eastern Clutha area are more variable and do not clearly reflect these long-term trends.

Notably however, both annual precipitation and the number of heavy rain days (>25 mm in a 24-hour period) in Milton increased during the late 1970's and early 1980's in line with the heavy flooding events experienced during this time (Figure 3-5 b). Consultation with local farmers indicated that rainfall has remained variable over time, and a long-term pattern was not discernible. Furthermore, farmers from Balclutha and Milton agreed that the floods of the late 1970s and early 1980s remain the worst they have faced, in line with the rainfall data presented below [4][5][9].

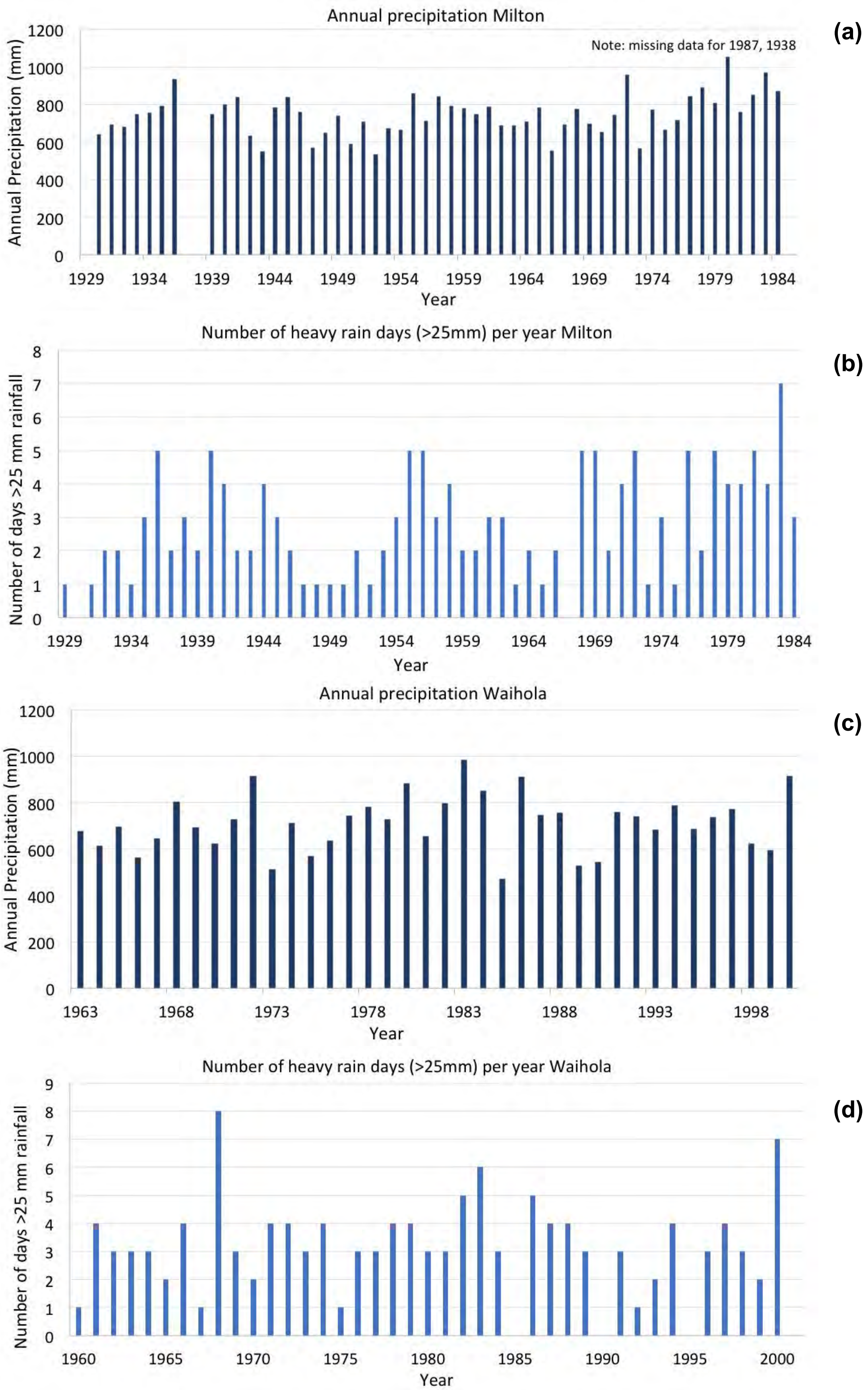


Figure 3-5 Historic precipitation data within Coastal and Eastern Clutha obtained from the NIWA climate database; a) annual precipitation in mm at Milton, b) number of heavy rain days where precipitation was greater than 25 mm in a 24 hour period in Milton, c) annual precipitation in mm at Waihola and d) number of heavy rain days in Waihola [6].

Figure 3-6 Flooding of SH1, near Milton in 1987 (source: Hocken Snapshot collection, University of Otago).

3.3 WHAT DO FUTURE CLIMATE PREDICTIONS TELL US?

With the past and present climate summarised above, we can now draw on scientific models to understand the range of climatic change that is predicted to occur in the future. The changes outlined below reflect the output of downscaled global climate models produced by NIWA [1]. These models aim to predict how temperature and rainfall patterns will change, depending on different estimates of how much greenhouse gas we will emit in the future. Within this report we present two emission scenarios, from a low to mid-range or 'stabilisation pathway' (RCP 4.5) to a high range 'business as usual' scenario (RCP 8.5) (see section 1.3 for more information). While they are predictive, in that they will not tell us exactly how much things will change, they still provide a very useful tool for understanding the range of likely future climatic conditions.

3.3.1. Air temperature

Warming of air temperatures within the Coastal and Eastern Clutha area is predicted to continue into the future. By 2040, mean annual air temperature is predicted to increase by 0.5°C to 1°C for both emissions scenarios (RCP 4.5 & 8.5) (Figure 2-1) [1]. This pattern of warming continues towards the end of the century, and by 2090 mean annual air temperature is predicted to increase by 0.5°C to 1.5°C for RCP 4.5, and by 1.5°C to 2.5°C for RCP 8.5. Regionally, the towns of Waihola and Milton are expected to warm slightly more than coastal areas and Balclutha (Figure 2-1). As mean annual temperatures increase, the number of extreme hot days will also increase slightly (by one to four extra days by 2090 depending on the emission scenario) (Figure 2-2). Frosts are predicted to decrease, and by 2090, Milton and Balclutha are expected to experience up to 18 and 17 fewer frost days each year respectively[i] (Figure 2-3) [1].

[i] Or between 6 (RCP 4.5) and 6.5 (RCP 8.5) fewer frost days by 2040, and between 10 (RCP 4.5) and 18 (RCP 8.5) fewer frost days by 2090 at Milton, and between 5.5 (RCP 4.5) and 6 (RCP 8.5) fewer frost days by 2040, and between 9 (RCP 4.5) and 17 (RCP 8.5) fewer frost days by 2090 at Balclutha.

3.3.2. Rainfall

Precipitation patterns are also predicted to change under future climate change scenarios, and precipitation totals in Coastal and Eastern Clutha will likely increase, especially during the spring and winter months [1]. Average annual rainfall is expected to increase by 5 - 10% by 2040, and by 10 - 20% by 2090 (Figure 2-4). Overall, this modelled increase in annual precipitation is expected to be highest in the town of Milton (Table 3-1, Figure 2-4). A slight increase in the total number of very wet days (>25 mm) is also expected across this area, and by 2090 an additional one to two days where rainfall is greater than 25 mm may be experienced annually (Figure 2-5).

3.3.3. Other atmospheric changes

Along with the temperature and rainfall changes outlined above, climate change will also contribute to other shifts in atmospheric processes, such as wind speed and direction. During winter, strengthened westerlies are predicted for the south of the South Island, with more north-easterly airflow expected during the summer months [3]. By 2040, daily extreme wind[j] is predicted to decrease slightly in coastal regions [1]. By 2090 however, these wind extremes are predicted to increase by up to 2% in inland areas [1].

[j] Defined as changes in the 99th percentile daily wind speeds, or the top three windiest days each year.

Table 3-1 Seasonal changes in annual precipitation at Milton and Balclutha for 2040 and 2090 under the RCP 4.5 and RCP 8.5 emission scenarios (Source: NIWA [1])

Locality	Emission Scenario	Summer	Autumn	Winter	Spring	Annual
Milton						
2040	Low-mid (RCP 4.5)	+ 3%	+ 4%	+ 7%	+ 8%	+ 6%
	High (RCP 8.5)	+ 1%	+ 8%	+ 5%	+ 8%	+ 5%
2090	Low-mid (RCP 4.5)	+ 2%	+ 13%	+ 5%	+ 8%	+ 7%
	High (RCP 8.5)	+ 5%	+ 19%	+ 25%	+ 18%	+ 17%
Balclutha						
2040	Low-mid (RCP 4.5)	+ 5%	+ 3%	+ 4%	+ 6%	+ 4%
	High (RCP 8.5)	No change	+ 7%	+ 2%	+ 6%	+ 4%
2090	Low-mid (RCP 4.5)	+ 2%	+ 10%	+ 3%	+ 7%	+ 5%
	High (RCP 8.5)	+ 2%	+ 15%	+ 23%	+ 16%	+ 14%

3.4 CLIMATE CHANGE IMPLICATIONS FOR PEOPLE, INFRASTRUCTURE AND INDUSTRY IN COASTAL AND EASTERN CLUTHA

The information above has provided an overview of past climate trends and future projections, but what does this mean for people, infrastructure and industry in Coastal and Eastern Clutha? This section identifies some of the potential socio-economic impacts that may accompany climate change, covering an increase in flood risk, coastal inundation of low-lying settlements, to some of the implications facing agriculture and forestry in the area.

3.4.1 Changes in flood risk

The Coastal and Eastern Clutha area has experienced a range of significant flood events in the past, and it is likely that future floods will be influenced by changes in regional precipitation patterns. Currently, the Clutha Delta and townships of Balclutha, Milton and Waihola are particularly susceptible to flood inundation, and it is likely that periods of flooding will continue, and possibly increase, into the future.

Balclutha and the Clutha Delta

The Clutha River is New Zealand's largest river by volume and catchment area, and experienced significant flood events in 1878, 1978 and 1999 [16]. The river originates in the Southern Alps, and is fed by the Kawarau and Upper Clutha Rivers and other smaller tributaries, before entering the ocean at Molyneux Bay via the Koau and Matau branches (ORC, 2016). Deposition of sediment during historic flood events has created a highly fertile plain on the Clutha Delta, which is now largely used for dairying and meat production. The town of Balclutha lies at the upper end of the delta.

Changes in rainfall patterns under future climate change scenarios are likely to increase the volume of water that enters and flows through the Clutha River. These changes are largely driven by increased precipitation along the Southern Alps [17][18], meaning more water will reach the Clutha River, particularly during the winter and spring months [18]. The increase in winter and spring streamflow is a combination of increased precipitation from June to October, and a decrease in snow accumulation, causing more precipitation to run off directly [17].

According to climate and hydrological modelling,[18] it is projected that the Clutha River will experience increases in both mean annual flow and mean annual low flow.[k] Of more relevance to flood risk however, are predicted changes in the frequency and magnitude of high flows, which have potential to impact on Balclutha and low-lying rural areas.

Table 3-2 shows that by the late 21st century, 'high flows' at the mouth of the Clutha River are predicted to increase by 6% under RCP 4.5, or by 9% under RCP 8.5.[l] A significant increase is also predicted for the magnitude of the mean annual flood under the RCP 8.5 emission scenario.[m]

Table 3-2 Projected increases in 2 hydrological variables (as a %) for the Clutha River at the mouth between a baseline period (1986-2005) and the late 21st century (2080-2099). The changes are given for two RCPs (4.5 & 8.5) and are sourced from NIWA, 2018 [2]

Emission Scenario	Mean Annual Flood (MAF)	The flow exceeded 5% of the time
High range scenario (RCP 8.5)	+51%	+9%
Mid to low range scenario (RCP 4.5)	+1%	+6%

The calculated high and mean annual flood flow values for the baseline period are shown in Table 3-3, along with an estimated value for 2090, calculated by applying the predictions shown in Table 3-2 to the current value. It is noted that the estimates shown in Table 3-3 apply to the Clutha River at Balclutha monitoring site, and will vary for other locations on the lower Clutha River. However, they are a useful guide for helping to understand what changes in upper catchment rainfall patterns might mean for the flood risk of Balclutha and the Clutha Delta.

Table 3-3 Projected changes in four hydrological variables (in m^3/s) for the Clutha River at Balclutha between a baseline period (1986-2005) and the late 21st century (2080-2099). Current estimates sourced from Otago Regional Council data.

Emission Scenario	Mean Annual Flood (MAF)	The flow exceeded 5% of the time
Current value	1,710	1,024
High range scenario (RCP 8.5)	2,582	1,116
Mid to low range scenario (RCP 4.5)	1,727	1,085

The impact of climate change on flood hazard at Balclutha and on the Clutha Delta will be influenced by the level of protection provided by the Lower Clutha Flood Protection and Drainage Scheme. Previous work by the Otago Regional Council describes how the current flood hazard varies across the Clutha Delta [16].

[k] Mean annual flow is the mean discharge over the analysis period, while mean annual low flow is the mean of the series of each year's lowest 7-day discharge.

[l] High flow: for the purposes of this report, this value is the baseline flow exceeded 5 % of the time

[m] Mean annual flood: the mean of the series of each year's highest daily flow. Such a flow can be expected to have a recurrence interval of once every 2 to 3 years, and would generally not be considered a major hazard in the lower Clutha River (assuming that the current level of flood protection was still in place). NIWA [2] note that changes in MAF alone cannot be used to infer overall changes in flood hazard

There are five different levels of flood protection provided by the scheme to various areas behind the flood banks, which are up to 5.5 m in height at some locations. However, it is important to acknowledge that a residual flood risk still remains for all of those areas, in relation to their design flood standard.[n] Flood protection levels for the Lower Clutha Flood Protection Scheme are summarised in Table 3-4.

Table 3-4 Flood protection levels for the Lower Clutha Flood Protection Scheme (source: [16])

Area	**Flood protection level**	
	Flow	**Current assessment of return period (approximate)**
Balclutha and Finegand Freezing Works	5,600 m^3/s	1 in 200-year flood
Rural areas downstream of Balclutha, including Inch Clutha	4,000 m^3/s	1 in 40-year flood
Area inside Mosley Road Loop (true right bank of Matau Branch)	3,200 m^3/s	1 in 20-year flood
Barnego Flats	2,850 m^3/s	1 in 10-year flood
Lower Clutha Floodway	1900 – 2000 m^3/s	Less than a 1 in 5-year flood

The overall increase in flow projected for the Clutha River, alongside projected increases in annual precipitation and high intensity rainfall events[o] will likely impact future flood hazard. Additional research would be required to understand likely changes in the magnitude, frequency and consequences of extreme Clutha River floods as a result of climate change. This additional work would provide a better understanding of the risk associated with rare, but potentially highly destructive floods (such as the 1878, 1978 and 1999 events) for Balclutha and the wider Clutha Delta.

[n] Residual risk is the risk that remains after mitigation.
[o] in the upper catchment, as well as locally.

(a)

(b)

Figure 3-7 The Clutha River showing a) a flood bank breach on the Clutha Delta in flood in 1957 (source: Hocken Snapshot, University of Otago), and b) the river in flood at Balclutha on 4 February 2020 (source: GHC).

Milton and the Tokomairiro Plain

The town of Milton and parts of the Tokomairiro Plain have also historically been at risk from flooding. Flood events in coastal catchments such as the Tokomairiro are generally caused by persistent rain-bearing easterlies, with continual rainfall over several days saturating the soil, leading to rapid runoff.

Milton's location means it is exposed to flooding from a number of sources. The town is located in the lower reaches of the Tokomairiro basin, with the upstream catchment consisting of extensive hill country and broad floodplain areas. The main tributaries of the Tokomairiro River and a number of overland flow paths converge at this point, before draining to the Pacific Ocean through a narrow gorge [21].

Modelling shows that an increase in mean annual precipitation is predicted in Milton and its surrounds over the 21st century (Figure 2-4). This may not necessarily result in an increase in flood risk, if that rainfall is spread reasonably evenly throughout the year. However, while modelling provided by NIWA (Figure 2-5) also does not show a significant increase in the number of heavy rainfall days, it does show an increase in rainfall totals during high intensity rainfall events (Figure 2-6), which may result in additional flood risk.

Previous records show that, for some reason flood events often occur in 'clusters' as occurred in the 1970's, and again in the mid 2000's [21]. The cumulative effect of a series of major flood events can result in severe disruption for the community, particularly where the impacts are significant – this can include flooding of residential, commercial and industrial properties, and damage or inundation of key access roads (including SH1). Additional industrial development planned for the northern end of the Tokomairiro Plain may also result in additional stormwater runoff during heavy rainfall events.

The Milton 2060 Flood Risk Management Strategy (2012) addresses flood risk in Milton and the Tokomairiro Plain [21]. This joint strategy prepared by the Clutha District Council and Otago Regional Council, is intended to evolve in response to improvements in our understanding of flood hazard, including as a result of climate change. Although this strategy is an example of a comprehensive attempt to reduce flood risk over the long term, this community will continue to have some exposure to flooding due to its physical and built environment, and it is possible that the impacts of climate change (warmer temperatures, more intense rainfall) may contribute to flood risk.

Waihola

High lake levels in Lake Waihola can occur as a result of coastal storm events (as described for the Tokomairiro Plain), and also due to high inflows from the Taieri and Waipori rivers which stretch further inland to the northwest. Although it lies some 15 km from the sea, Lake Waihola is tidally influenced, and any increase in mean sea level would likely result in an overall increase in average lake level. Much of Waihola township, and other infrastructure in this area is located on ground which is sufficiently elevated to avoid the worst effects of flooding. Further research[p] would provide a better understanding of flood risk in Waihola under climate change scenarios.

3.4.2 Hazards faced by low-lying coastal settlements

Climate change is also likely to exacerbate coastal hazards along Clutha's coastline. The topography and other natural features of the shoreline in this area[q] mean that it is already exposed to hazards such as coastal erosion and shoreline retreat. The combination of slow yet persistent sea level rise and extreme sea level events may increase the likelihood of direct coastal inundation of low-lying land, and also exacerbate existing coastal erosion issues in some areas, as discussed below.

[p] such as modelling the interactions between higher sea level, conditions at the mouth of the Taieri River, and increased rainfall totals during high intensity rainfall events.

[q] i.e. between Port Molyneux and Taieri Mouth (Figure 3-2).

Figure 3-8 View out to sea over the Toko Mouth settlement, located on an old beach ridge at the north-eastern end of Measly Beach. Source: GHC.

Coastal erosion

Coastal erosion may occur due to a combination of sea level rise, increased storminess and changed sediment processes as a result of climate change. Sand is naturally cycled along beaches and near shore environments, with periods of accretion (the increased deposition of sand) often followed by periods of erosion during storm events. However, with predicted strengthened westerlies in winter, and more north-easterlies in summer [3], it is possible that these sediment processes and budgets will change. When combined with sea level rise, we may see erosional activity outweigh any periods of accretion, resulting in long-term shoreline retreat in some areas.

Past studies of this stretch of coast reveal significant erosion is currently occurring along the south end of the Clutha Delta, from the Koau Mouth of the Clutha River to Kaka Point [22]. If this pattern of erosion is to continue, or possibly intensify, into the future, the impact of sea level rise (as discussed below) may be exacerbated in this area. Similarly, it is possible that areas which currently show net accretion on the coast (such as Measly and Chrystalls beaches) [22] may switch to a sediment deficit, resulting in long-term shoreline retreat.

Coastal inundation

Coastal inundation associated with extreme sea level conditions may also impact assets and infrastructure along Clutha's coastline. Models of extreme sea level produced by NIWA show properties and infrastructure (including roads and bridges) at Taieri Mouth, Toko Mouth, Kaitangata, and the Clutha delta are potentially at risk of inundation [15]. At Taieri Mouth for example, properties located behind the fore dunes are at risk of inundation during a future severe storm event, assuming both 50 cm and 100 cm of sea level rise (Appendix 2 and Figure 3-9 respectively).

Further south, the small settlement of Bull Creek, situated between Taieri Mouth and Toko Mouth, shows limited inundation under both the 50 cm and 100 cm extreme sea level scenarios, and no apparent risk to properties (Appendix 2). Conversely, at Toko Mouth, Toko Mouth Domain Road, and adjacent properties, as well as those backing Toko Mouth beach are at risk of inundation during a severe storm, particularly after 100 cm of sea level rise (Figure 3-10).

Although it is located about 5 km from the coast, parts of Kaitangata are still low-lying, with many properties on Clyde Terrace and in the area between Water Street and Eddystone Street being less than 3 m above mean sea level [28]. Together with nearby low-lying farmland, these properties may be affected by coastal inundation during an extreme storm event. However, the extent of inundation due to elevated sea levels in the Kaitangata area will be influenced by the Lower Clutha Flood Protection and Drainage Scheme (assuming that this remains in place and intact). Widespread inundation could still occur if the flood banks were breached or overtopped during a high magnitude event, and Figure 3-11 shows the potential extent of inundation in this area during a 1:100 year extreme sea level event, with an increase of 100 cm in mean sea level.

The most extensive area at risk of coastal inundation in Coastal and Eastern Clutha is the low-lying Clutha Delta (Figure 3-12). Much of this area is offered an element of protection by coastal sand dunes, and an extensive network of flood banks designed to protect against Clutha River floods of up to 4,000 m^3/s [16] [28]. Generally, the flood bank crest in the Clutha Delta area is 3 m higher than the surrounding land. These flood banks also offer a level of protection against tsunami and extreme sea level events. However, a high magnitude event may result in sections of flood bank being overtopped, weakened or breached [28]. As noted above, sea-level rise and shoreline erosion may reduce the effectiveness of flood banks on the Clutha Delta.

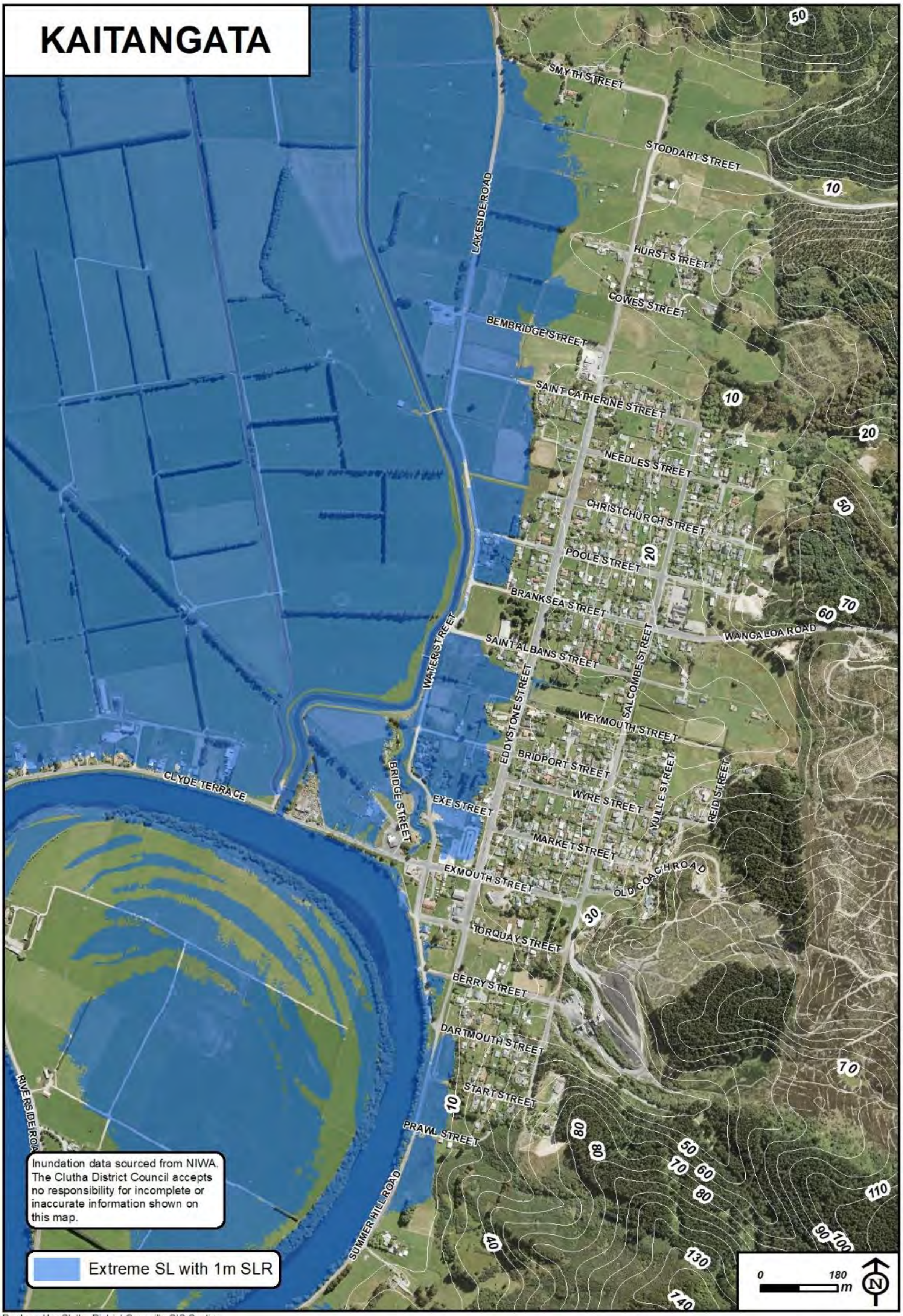
Figure 3-12 shows areas of the Clutha Delta that are potentially exposed to inundation, under the 100 cm sea level rise scenario, assuming that direct inundation from the sea was able to occur (i.e. no flood protection was in place). Areas at risk include Port Molyneux in the south, Paretai, Otanomomo, Matau, Benhar, and Lovells Flat in the north. Areas which have limited, or no flood bank protection include farmland alongside the Puerua River as far inland as the Owaka Highway, and sections of Kaka Point Road [28].

While potential inundation of this delta is expansive, during local discussions with farmers it was noted that floods are a fairly regular occurrence in this area and adaptation methods, such as evacuating livestock early, are already well established [23].

Figure 3-9 Land which is potentially exposed to coastal inundation at Taieri Mouth (shaded blue), during a 1:100-year extreme sea level event, together with 100 cm of sea level rise. Smaller increments of sea level rise may also have an impact on this settlement, and a 50 cm SLR scenario is shown in Appendix 2.

Produced by Clutha District Council's GIS Section.

Figure 3-10 Land which is potentially exposed to coastal inundation at Toko Mouth (shaded blue), during a 1:100-year extreme sea level event, together with 100 cm of sea level rise. Smaller increments of sea level rise may also have an impact on this settlement, and a 50 cm SLR scenario is shown in Appendix 2.



Produced by Clutha District Council's GIS Section

Figure 3-11 Areas which are potentially exposed to coastal inundation in and around Kaitangata, during a 1:100-year extreme sea level event, together with 100 cm of sea level rise. Smaller increments of sea level rise may also have an impact on this area, and a 50 cm SLR scenario is shown in Appendix 2.

Figure 3-12 Land which is potentially exposed to coastal inundation on the Clutha Delta (shaded blue), during a 1:100-year extreme sea level event, together with 100 cm of sea level rise. Smaller increments of sea level rise may also have an impact on this area, and a 50 cm SLR scenario is shown in Appendix 2.

Another potential issue affecting coastal communities in this area iso the risk of saltwater intrusion into groundwater aquifers [14]. To date, no observed or scientific predictions of saltwater intrusion into freshwater aquifers are available, and we do not know if this is likely to become a significant issue for farms and people living along the Clutha coast. However, during community level discussions, we did not find any anecdotal evidence of this process already occurring.[r]

3.4.3 Agriculture

Climate change will also pose new issues and opportunities for agriculture within the Coastal and Eastern Clutha area. Importantly, by warming less than New Zealand's average and maintaining a wetter environment than expected elsewhere, new agricultural opportunities may arise. However, we may also see an increase in flood risk if high precipitation patterns and more intense rainfall events eventuate. Dairy, sheep and beef farming systems, many of which are located on low-lying flood-prone ground, are common throughout the Coastal and Eastern Clutha area.

Under climate change scenarios it is possible that this pasture and grazing land will experience more regular periods of flood inundation. Alongside risk to livestock, floods may exacerbate erosion and water contamination issues, particularly on dairy farms [24]. During local consultation, farmers on the Clutha Delta, around Milton and Toko Mouth noted that they are used to responding to floods and have systems in place to evacuate livestock early and safely [4][23][25]. These adaptation measures will become increasingly important if farmers are to face worsening flood conditions.

The warmer and wetter weather predicted for Coastal and Eastern Clutha may also improve winter pasture growth and provide the opportunity to diversify into new crops with a lengthened growing season [24]. Currently, some local farmers grow grains (oats, wheat, barley) and potatoes, and these crops may become increasingly important, or alternative crops sought if the right conditions arise. However, overall warmer weather may contribute to livestock heat stress and increase on-farm water demands [26].

[r] Note that when this issue was discussed, one local dairy farmer from the Clutha Delta mentioned that if ground waters were to become salinised, dairy cows would likely do well with the extra iodine [23].

Figure 3-13 Land use patterns along the Tokomairiro River, towards Toko Mouth, showing dairy farming in the foreground and pine plantations on the hills in the background.

3.4.4 Forestry

The Coastal and Eastern Clutha area has substantial forestry operations and it is likely that farm forestry will become an increasingly attractive option for landholders in the future. The conversion of pasture land to forest to earn carbon credits is a process already occurring within Coastal and Eastern Clutha, and notable stretches of forestry are situated along the Tokomairiro River and at Toko Mouth (Figure 3-13). Farm forestry allows carbon credits to be earned by transitioning pasture to forest (predominantly radiata pine), often grown on steep hill country. As the market for carbon credits increases, it is possible that the Coastal and Eastern Clutha are may see more conversion of land to forestry [27]. This industry may also benefit from wetter and warmer conditions, and the fertilisation effects of higher levels of CO_2 in the atmosphere, which are predicted to favour the growth of radiata pine [26].

3.5 SUMMARY: WHERE TO FROM HERE?

Climate change will present new and unique challenges to the Coastal and Eastern Clutha area. Overall, the region is expected to warm between 0.5°C to 2.5°C by 2090, and is predicted to experience an increase in annual precipitation, more intense rainfall, and increased flows in the Clutha River, which may lead to increased flood risk on the Clutha Delta and in Balclutha. Sea level rise is predicted to make low-lying settlements (Taieri Mouth, Toko Mouth, Kaitangata and the Clutha Delta) more susceptible to inundation during large storm events. The agricultural and forestry sectors may face new challenges in terms of flood and water management, yet gains in productivity may be realised with a lengthened growing season, and the potential for crop diversification. Likewise, the forestry sector may face new opportunities in terms of production and market demand. Overall, while climate change will pose new challenges to Coastal and Eastern Clutha, it may also bring new opportunities. Through informed planning and continued adaptation, these challenges may be faced and overcome.

3.6 CHAPTER 3 REFERENCES

[1] National Institute of Water and Atmospheric Research Ltd (NIWA) (2019). *Climate change projections for the Otago Region*. Report prepared for the Otago Regional Council. Macara, G., Woolley, J-M., Zammit, C., Pearce, P., Stuart, S., Wadhwa, S., Sood, A. & Collins, D.

[2] National Institute of Water and Atmospheric Research Ltd (NIWA) (2018). *Hydrological projections for New Zealand rivers under climate change*. Report prepared for the Ministry for the Environment by Collins, D., Montgomery, K. & Zammit, C. NIWA, Christchurch.

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

[4] Personal communication with sheep farmer, Milton, 16 September 2019.

[5] Personal communication with Clutha District Council employee, Milton, 10 September 2019.

[6] Data extracted from the National Climate Database, National Institute of Water and Atmospheric Research Ltd. Available at http://cliflo.niwa.co.nz/

[7] Fitzharris, B. (2010). *Climate change impacts on Dunedin*. Report prepared for the Dunedin City Council. University of Otago, Dunedin, March 2010.

[8] Bodeker Scientific (2016). *Precipitation trends for the Otago region over the 21st century.* Report prepared for the Otago Regional Council by Cameron, C., Lewis, J. and Hanson, M. Alexandra.

[9] Personal communication with dairy farmer from Clutha Delta, Balclutha, 9 September 2019.

[10] Ministry for the Environment & Statistics New Zealand (2016). *New Zealand's Environmental Reporting Series: Our marine environment 2016.* Available from www.mfe.govt.nz and www.stats.govt.nz

[11] Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan (2013). Sea Level Change. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* Eds Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[12] Hannah & Bell (2012). Regional sea level trends in New Zealand. *Journal of Geophysical Research*, 117, 1-7.

[13] Intergovernmental Panel on Climate Change (IPCC) (2013). Summary for policymakers. In Stocker, TF, Qin, D, Plattner, GK, Tignor, M, Allen, SK, Boschung, J, ... Midgley, PM (Eds), *Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge and New York: Cambridge University Press.

[14] Ministry for the Environment (2017). Coastal Hazards and Climate Change: Guidance for local government Bell, R., Lawrence, J., Allan, S. Blackett, P. and Stephens, S. New Zealand Government.

[15] National Institute of Water and Atmospheric Research Ltd (NIWA) (2019). *Coastal flooding exposure under future sea-level rise in New Zealand*. Report prepared for the Deep South Challenge. Paulik, R., Stephens, S. Wadhwa, S., Bell, R., Popovich, B & Robinson, B.

[16] Otago Regional Council (2016). *Natural hazards on the Clutha delta, Otago.* Prepared by Hornblow, S., Payan, J-L., Sims, A. & O'Sullivan K. May 2016, Dunedin.

[17] Poyck, S., Hendrikx, J., McMillan, H., Hreinsson, E.O. & Woods, R. (2011). Combined snow and streamflow modelling to estimate impacts of climate change on water resources in the Clutha River, New Zealand. *Journal of Hydrology*, 50(2), 293-312.

[18] Jobst, A.M., Kingston, D.G., Cullen, N.J., and Schmid, J. (2018). Intercomparison of different uncertainty sources in hydrological climate change projections for an alpine catchment (upper Clutha River, New Zealand). *Hydrology and Earth System Sciences*, 22, 3125–3142, doi.org/10.5194/hess-22-3125-2018, 2018.

[19] High Intensity Rainfall Design System (HIRDS), National Institute of Water and Atmospheric Research (NIWA) Ltd. Available at: https://hirds.niwa.co.nz/.

[20] Otago Regional Council (2020). Infrastructure committee meeting minutes, update on February 2020 flooding. Dunedin 11 March 2020. Available at: https://www.orc.govt.nz/media/8275/infrastructure-committee-agenda-20200311.pdf

[21] Otago Regional Council and Clutha District Council, (2012*). Flood risk management strategy for Milton and Tokomairiro Plain.* Prepared by Goldsmith, M & Brass M.

[22] Otago Regional Council (2014). *Coastal Morphology of South Otago: Nugget Point to Chrystalls Beach*. Williams, J. & Goldsmith, M. September 2014, Dunedin.

[23] Personal communication with dairy farmer from Clutha Delta, Balclutha, 9 September 2019.

[24] Ministry for Agricultural and Forestry (2008). *Climate Change: A guide for land managers.* Regional summary, effects and impacts: Otago and Southland. Wellington.

[25] Personal communication with sheep farmer from Toko Mouth, Milton, 16 September 2019.

[26] Ministry for Primary Industries (2013). *Four Degrees of Global Warming: Effects on the New Zealand Primary Sector.* MPI Technical Information Paper No. 2013/49. Wellington.

[27] Adams, T. & Turner, J.A. (2012). An investigation into the effects of an emissions trading scheme on forest management and land use in New Zealand. *Forest Policy and Economics*, 15, 78-90.

[28] Otago Regional Council (2012). *Community vulnerability to elevated sea level and coastal tsunami events.* Goldsmith, M. July 2012, Dunedin.

4.0 THE CATLINS

Figure 4-1 Tautuku Beach as viewed from Florence Hill lookout (Source: GHC).

4.1 INTRODUCTION

Situated at the southern tip of the South Island and the Otago region,[s] The Catlins boasts a unique environment with exposed rocky headlands, native forests perched on sandy dune systems, and an agricultural hinterland. Farming, forestry and eco-tourism are the main industries and these will face their own set of challenges, and opportunities, in a changing climate.

4.1.1 Key findings:

- By 2090, mean annual temperature in The Catlins is expected to increase by between 0.5°C and 2.5°C, relative to 1995 [1].
- Although mean annual precipitation is expected to increase, there may also be more dry periods between rainfall events [1].
- Sea level is expected to continue to rise, and low-lying coastal settlements and infrastructure (such as Kaka Point, Willsher Bay, Pounawea, Jacks Bay and Maclennan) may become susceptible to inundation, particularly during extreme sea level events.
- Warmer weather may attract more visitors, and may also impact the regions unique wildlife and coastal landforms.
- The agricultural and forestry sectors may face new challenges in terms of water management, pest control and general land management, yet they may also benefit from the creation of new market opportunities.

[s] Although 'The Catlins' also extends into Southland, this report only refers to the section within the Clutha District.

- While climate change will present new challenges for The Catlins, through informed planning, and innovative adaptation, these future challenges can be faced and overcome.

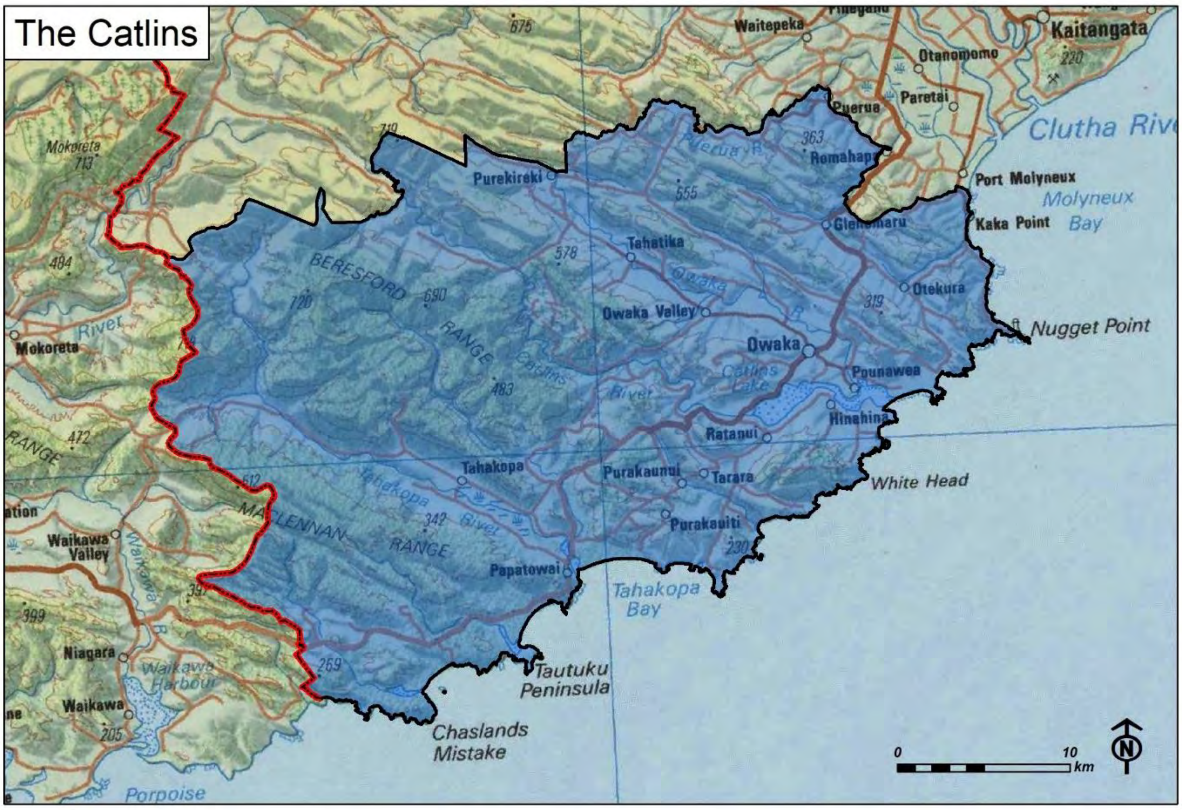


Figure 4-2 The Catlins ward. The red line shows the boundary between the Clutha and Southland districts.

4.2 UNDERSTANDING THE PAST AND PRESENT CLIMATE

The Catlins has a temperate maritime climate that is strongly influenced by the Pacific Ocean, and is generally cooler and wetter than other coastal areas in eastern Otago. Winds can reach considerable strengths, especially on the exposed coast, and annual rainfall ranges from about 800 to 1,300 mm. Maximum summer temperatures range from 16°C to 20°C, with average winter minimums of between 0°C and 4°C [1]. This section provides a brief summary of climate data from The Catlins, and discusses any trends that may be evident.

4.2.1 Air temperature

Past records tell us that New Zealand's air temperatures have increased by about 1°C over the past century [3], a trend that is also supported by the limited local weather observations taken within The Catlins. Temperature recordings from Nugget Point lighthouse for the period 1983 to 2018 suggest there has been a slight increase in mean annual temperature over time (Figure 4-3 a).

While warmer annual temperatures can be accompanied by more hot days (defined here as those above or equal to 25°C), this trend is not noticeable at Nugget Point. At this location, generally up to seven hot days have been experienced each year, although the unusually warm El Nino years of 1998-1999 contained 13 and 16 days respectively (Figure 4-3 b). The number of frost days however, where temperatures reached or dropped below 0°C, suggests a slight decline between 1983 and 2018 (Figure 4-3 c). These records are consistent with observations made by local residents, who broadly agreed that frost days in The Catlins are becoming fewer and further between [4].

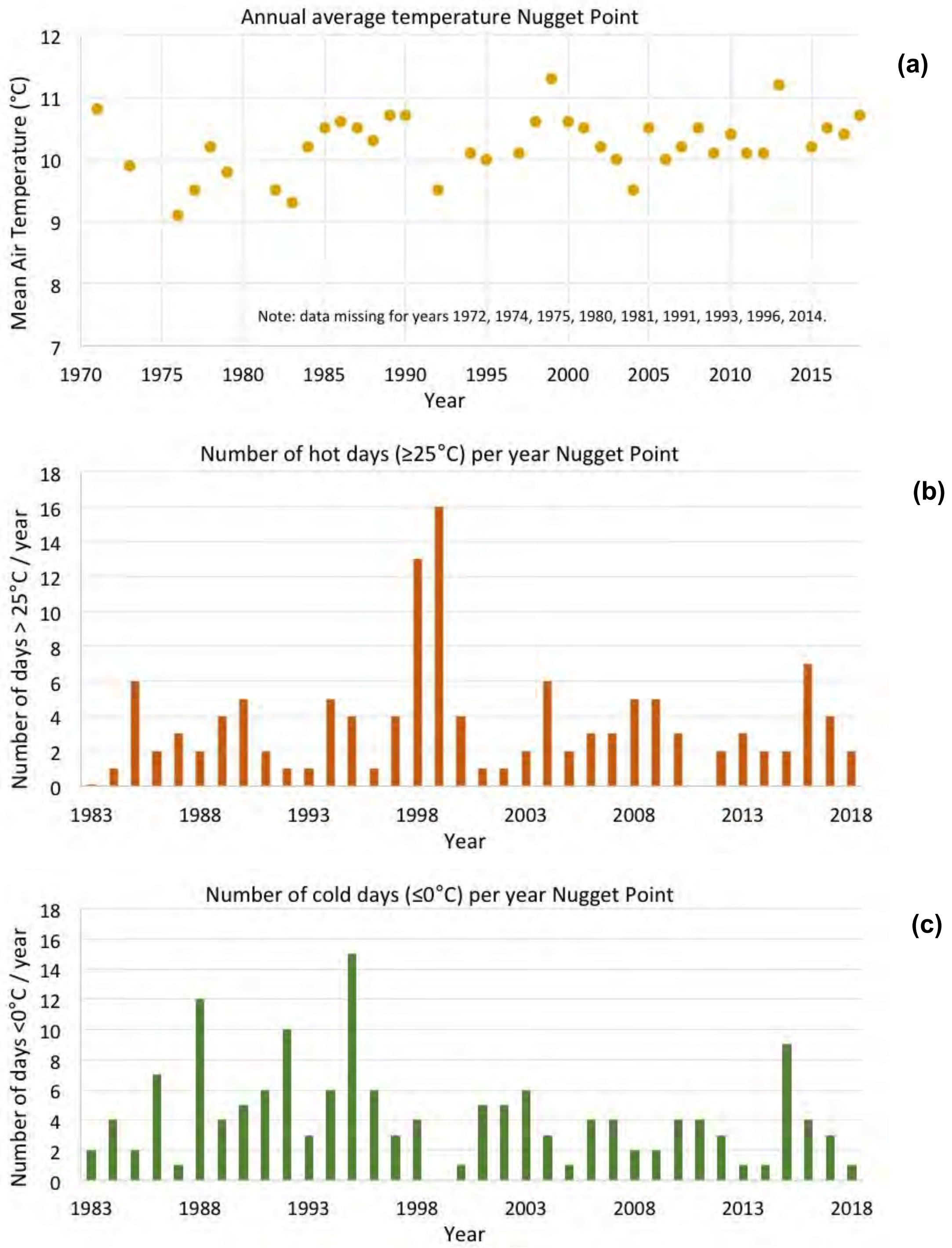


Figure 4-3 Historic temperature data from Nugget Point Lighthouse obtained from NIWA's climate database, a) mean average temperature (note that the recording station at Nugget Point was upgraded to an AWS in 1986), b) number of hot days (greater than or equal to 25°C), and c) number of frost days or nights (where temperatures reached or dropped below 0°C) [5].

4.2.2 Rainfall

Previous modelling work by NIWA (Figure 4-4) shows that rainfall within The Catlins is variable and dependent on local topographic features, with higher annual totals in the west and at higher elevation in the Maclennan and Beresford ranges. Records from two rainfall monitoring sites in The Catlins are shown in Figure 4-5.[t] The relatively short record from Nugget Point (1997 to 2016) shows annual rainfall typically varies between 600 mm and 850 mm, while the much longer Owaka record (1914 to 1987) shows a typical range of 800 to 1000 mm. The Owaka site does show a slight increase in average rainfall over that period,[u] from about 850 mm to 890 mm, although this trend is masked to some extent by a number of very wet or very dry years.

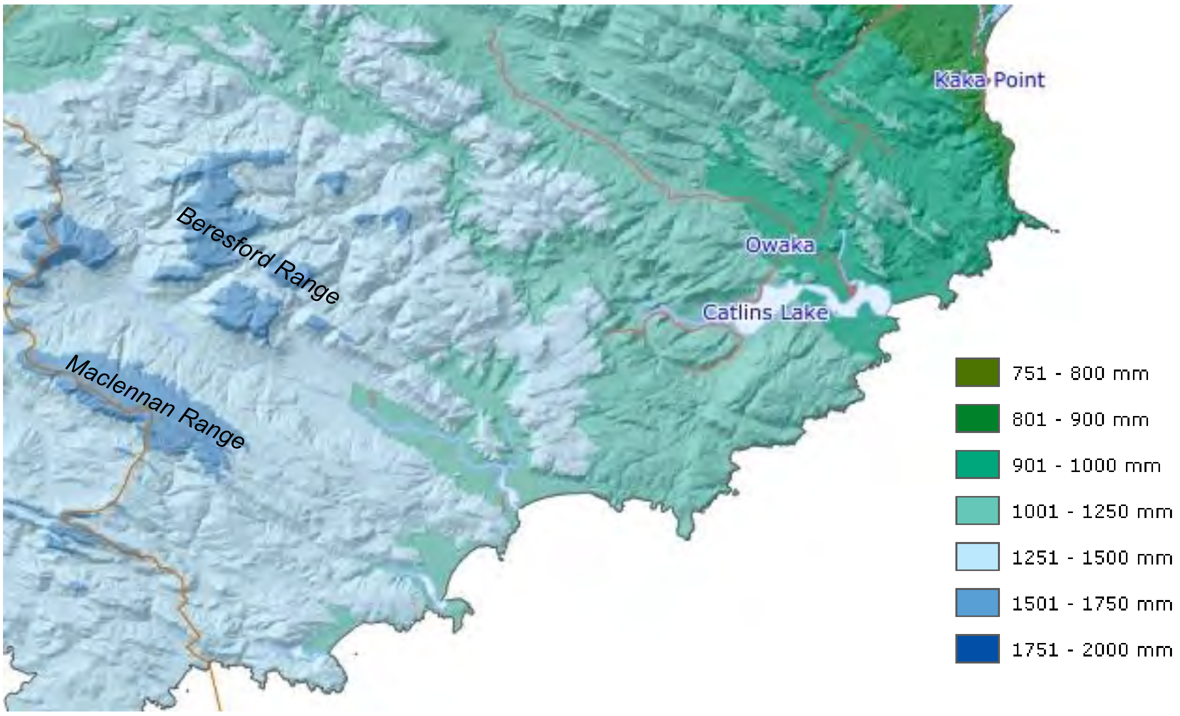


Figure 4-4 Median annual rainfall in The Catlins area. Modelled by NIWA for the **GrowOtago** project

There is insufficient data to determine if there have been changes in the frequency or intensity of heavy rainfall in The Catlins. Figure 4-5 (c) shows that Nugget Point can experience up to five heavy rain days (>25 mm in a 24-hour period) in a year, although the short record does not show any discernible historic trends in heavy rainfall patterns.

During discussions with local residents it was noted that the misty and drizzly rain that would last for days, and that people remember from their past, has been replaced with heavier rain which is shorter in duration [4]. While these anecdotal observations correlate with findings recorded for eastern New Zealand [6][7] they do not necessarily represent the whole of The Catlins, and some residents explained how they have also dealt with more frequent water shortages in recent years [4].

[t] A short, but more up-to-date rainfall record from Katea in the Owaka Valley is shown in Appendix 4.

[u] As determined by a simple linear trend line.

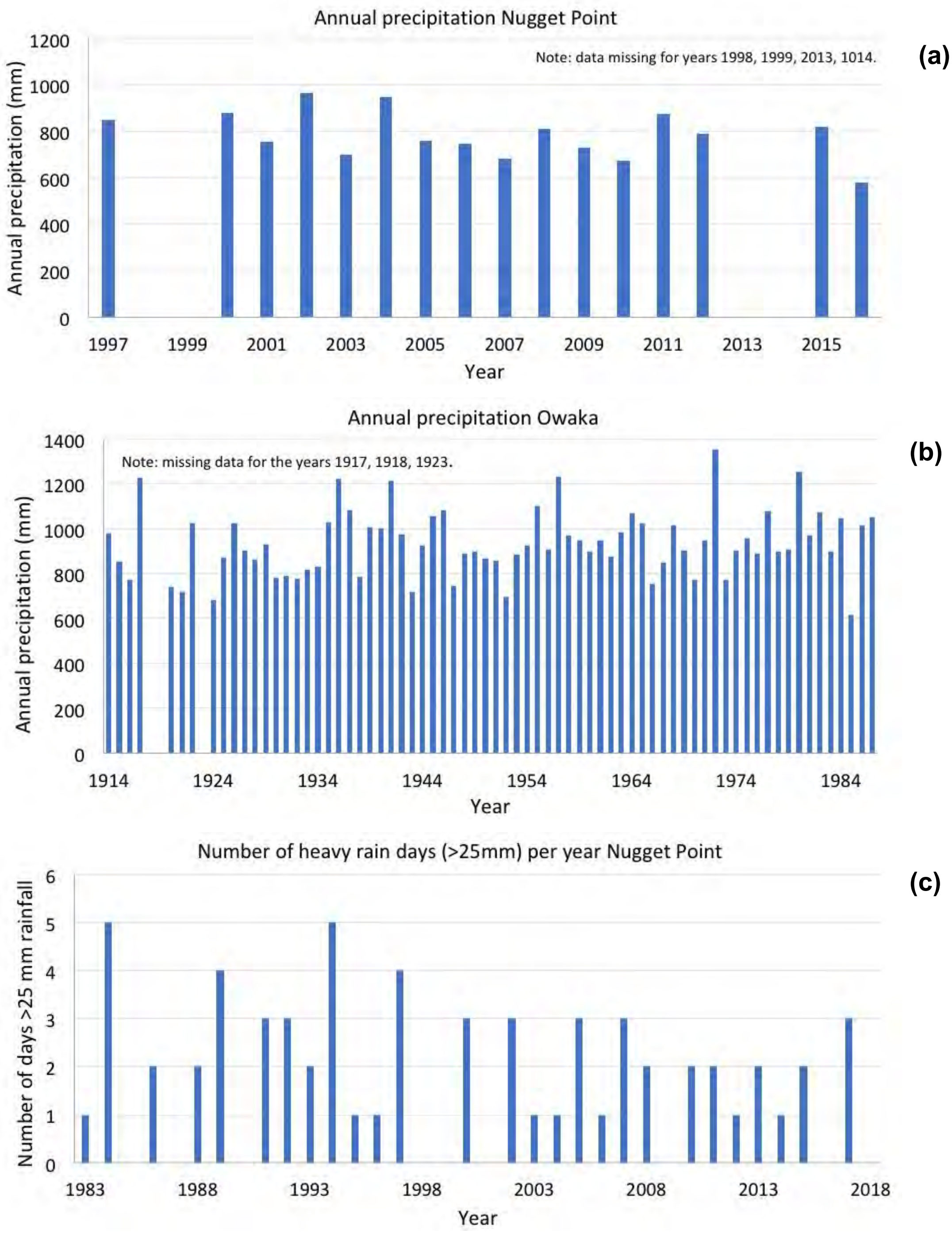


Figure 4-5 Historic precipitation data from Nugget Point Lighthouse obtained from the NIWA climate database, a) shows annual precipitation at Nugget Point in mm, b) annual precipitation at Owaka in mm, and c) number of heavy rain days where precipitation was greater than 25 mm in a 24-hour period [5].

4.3 WHAT DO FUTURE CLIMATE PREDICTIONS TELL US?

With the past and present climate outlined above, we can now draw on scientific models to understand the range of climatic change that is predicted to occur in the future. The changes outlined below reflect the output of downscaled global climate models produced by NIWA [1]. These models aim to predict how temperature and rainfall patterns will change, depending on different estimates of how much greenhouse gas we will emit in the future. Within this report we present two emission scenarios, from a low to mid-range or ‘stabilisation pathway’ (RCP 4.5), to a high range ‘business as usual’ scenario (RCP 8.5) (see section 1.3 for more information). While they are predictive, in that they will not tell us exactly how much things will change, they still provide a very useful tool for understanding the range of likely future climatic conditions.

4.3.1 Air temperature

Average air temperatures in The Catlins are predicted to warm into the future. By 2040 mean annual air temperature is predicted to increase by 0.5°C to 1.0°C for both the low to mid and high-level emissions scenarios (RCP 4.5 and 8.5 respectively) (Figure 2-1). This pattern of warming continues towards the end of the century, and by 2090 mean annual air temperature is predicted to increase by 0.5°C to 1.5°C under RCP 4.5, or 1.5°C to 2.5°C under RCP 8.5. These temperature changes will contribute to a slight increase in the number of hot days (>30°C) (Figure 2-2), and a slight decrease in the number of snow days by 2090 [1].

More noticeable however, is that rising air temperatures are expected to lead to a decrease in the total number of cold nights and frosty mornings (<0°C). It is expected that by 2090, frost days will decrease by five to 15 days under RCP 4.5, or by 10 to 30 days under RCP 8.5 (Figure 2-3). More elevated areas are likely to see the greatest reduction in frost days.

4.3.2 Rainfall

As noted in section 4.2.2, rainfall patterns already vary spatially within The Catlins. Precipitation patterns are also predicted to change under future climate change scenarios, and any future trends may be expected to vary across this area as well. This section provides an assessment of predicted changes, based on the best information currently available.

Mean annual rainfall is expected to increase by up to 5% by 2040, and by as much as 15% in some areas (south of Papatowai) by 2090 (Figure 2-4). An increase in the number of very wet days is also predicted, and by 2090 an additional one to two days with rainfall greater than 25 mm is expected annually (Figure 2-5).

Rainfall intensities are also expected to increase, meaning more rain will fall during high rainfall periods. For example in Owaka, the depth of rain that falls during what is currently considered a ‘1 in 50-year, 24-hour event’ will increase by approximately 7-8 mm. Presently, such an event leads to about 107 mm of rain; however by 2090 this may increase to 114 or 115 mm (depending on the emissions scenario) (Source: HIRDS [12]).

Despite these overall increases in rainfall, The Catlins may also experience more dry days between rainfall events, depending on the emission scenario. Assuming a high range scenario (RCP 8.5) by 2090, The Catlins may expect up to four additional days with no rainfall each year (Figure 2-7).

4.3.3 Other atmospheric changes

The temperature and rainfall changes outlined above will also contribute to other shifts in atmospheric processes, such as wind speed and direction. During winter, strengthened westerlies are predicted for the south of the South Island, with more north-easterly airflow predicted during the summer months [3]. Furthermore, by 2090, daily wind extremes (modelled as changes in the 99th percentile daily wind speeds, or the top three windiest days each year) are predicted to increase by up to 2% (Figure 2-8).

4.4 CLIMATE CHANGE IMPLICATIONS FOR PEOPLE, INFRASTRUCTURE AND INDUSTRY IN THE CATLINS

The information above has provided an overview of past climate trends and future projections, but what does this mean for people, infrastructure and industry in The Catlins? This section identifies some of the potential socio-economic impacts that may accompany climate change, spanning the unique issues facing low-lying coastal settlements, infrastructure, tourism and wildlife, to agriculture and forestry.

4.4.1 Hazards faced by low-lying coastal settlements

Climate change is likely to exacerbate coastal hazards along The Catlins coastline. Local consultation in this area indicates that a number of low-lying areas are already experiencing some impact from rising sea level, and that coastal hazards are a key concern for some residents [4]. The combination of slow yet persistent sea level rise and extreme sea level events may contribute to coastal erosion, and increase the likelihood of coastal inundation affecting low-lying land within The Catlins, as discussed below.

Figure 4-6 The seawall at Pounawea, looking towards the Catlins Lake and Hina Hina Road in the background.

Coastal erosion

Coastal erosion is a process that may occur due to the combination of sea level rise, increased storminess and changed sediment processes as a result of climate change. Sand is naturally cycled along beaches and near shore environments, with periods of accretion (the increased deposition of sand) often followed by periods of erosion during storm events. However, with predicted strengthened westerlies in winter, and more north-easterlies in summer [3], it is possible that sediment processes and budgets will change. When combined with sea level rise, we may see changes in shoreline position and dune systems on The Catlins coast.

While past records of shoreline change are not available for the full stretch of this coast, bank erosion has previously been a threat at New Haven,[v] and this hazard may be exacerbated by sea level rise. Elsewhere, a series of beach transects measured over time from The Nuggets to Kaka Point show a net trend of accretion between 2004 and 2013 [15]. During community discussions we heard local accounts that other areas are eroding, observed specifically through the formation of steep erosion scarps in dunes backing Surat and Cannibal Bay and the northern end of Waipati Beach [16] [17].

Coastal inundation

Coastal inundation associated with extreme sea level conditions may also impact landscapes, assets and infrastructure along The Catlins coastline. Models of extreme sea level[w] with future sea level rise projections show potential inundation of properties and infrastructure (including roads and bridges) at Kaka Point, Willsher Bay, Pounawea, Jacks Bay and Maclennan.[14] The Esplanade at Kaka Point, for example, is susceptible to storm inundation, especially with 100 cm of sea level rise (Figure 4-8). Likewise, various properties, and the Nuggets Road that passes behind the dune system at Willsher Bay to the south, are also at risk of inundation, for both 50 cm (Appendix 2) and 100 cm of sea level rise (Figure 4-9).

Pounawea at the mouth of the Catlins River is particularly susceptible to inundation, and much of the northern end of the town would be affected by an extreme sea level event, under both the 50 cm (Appendix 2) and 100 cm (Figure 4-10) sea level rise scenarios. Low-lying parts of Pounawea can already be affected by elevated sea levels, as shown during a storm event in April 2006 [23]. The nearby settlement of New Haven is more elevated, and is unlikely to be affected by an extreme sea level event (Figure 4-11).

To the south of the Catlins River, the Hina Hina area is at risk of inundation (Figure 4-11), as is the foreshore at Jacks Bay (Figure 4-12). While Papatowai appears to be at minimal risk of inundation due to sea level rise, much of the road connecting Papatowai and Maclennan will be affected, under both the 50 cm and 100 cm of sea level rise scenarios (Figure 4-13).

Extreme sea level events have the potential to have a significant impact on local communities, as illustrated during an event in April 2020, when wave runup at Jacks Bay affected a number of properties, and inundated the access road. The approximate extent of wave runup is shown in Figure 4-7.

Impact of sea level rise on roading

Some low-lying roads in The Catlins are already susceptible to inundation and can be partly or fully submerged during king tides. This issue was noted during discussions with local residents as part of this work. Roads which people noted as being affected included Nugget Point Road, The Esplanade (Kaka Point to Willsher Bay), Hina Hina Road and Jacks Bay Road [4]). In addition, an extensive community consultation program took place in this area as part of the 'Our Place Catlins' project in 2019. When asked which services are particularly vulnerable to the effects of climate change, many respondents stated that low-lying roads, water supplies, and Council's sewage scheme were at risk. Maintaining a resilient road network through The

[v] https://www.odt.co.nz/regions/south-otago/joint-effort-strengthens-wall

[w] a combination of high tide, storm surge, sea level anomaly and wave set up

Catlins is necessary for the sustainability of this area, and this will be an ongoing challenge as sea level continues to rise throughout the 21st century (Figure 2-10).

Figure 4-7 Debris marks at Jacks Bay showing the maximum extent of inundation (dashed line), following an elevated sea level event on 15 April 2020. (Source: B. Smith, Emergency Management Otago).

Figure 4-8 Land which is potentially exposed to coastal inundation at Kaka Point (shaded blue), during a 1:100-year extreme sea level event, together with 100 cm of sea level rise. Smaller increments of sea level rise may also have an impact on this area, and a 50 cm SLR scenario is shown in Appendix 2.

Figure 4-9 Land which is potentially exposed to coastal inundation at Willsher Bay (shaded blue), during a 1:100-year extreme sea level event, together with 100 cm of sea level rise. Smaller increments of sea level rise may also have an impact on this area, and a 50 cm SLR scenario is shown in Appendix 2.

Figure 4-10 Land which is potentially exposed to coastal inundation at Pounawea (shaded blue), during a 1:100-year extreme sea level event, together with 100 cm of sea level rise. Smaller increments of sea level rise may also have an impact on this settlement, and a 50 cm SLR scenario is shown in Appendix 2.

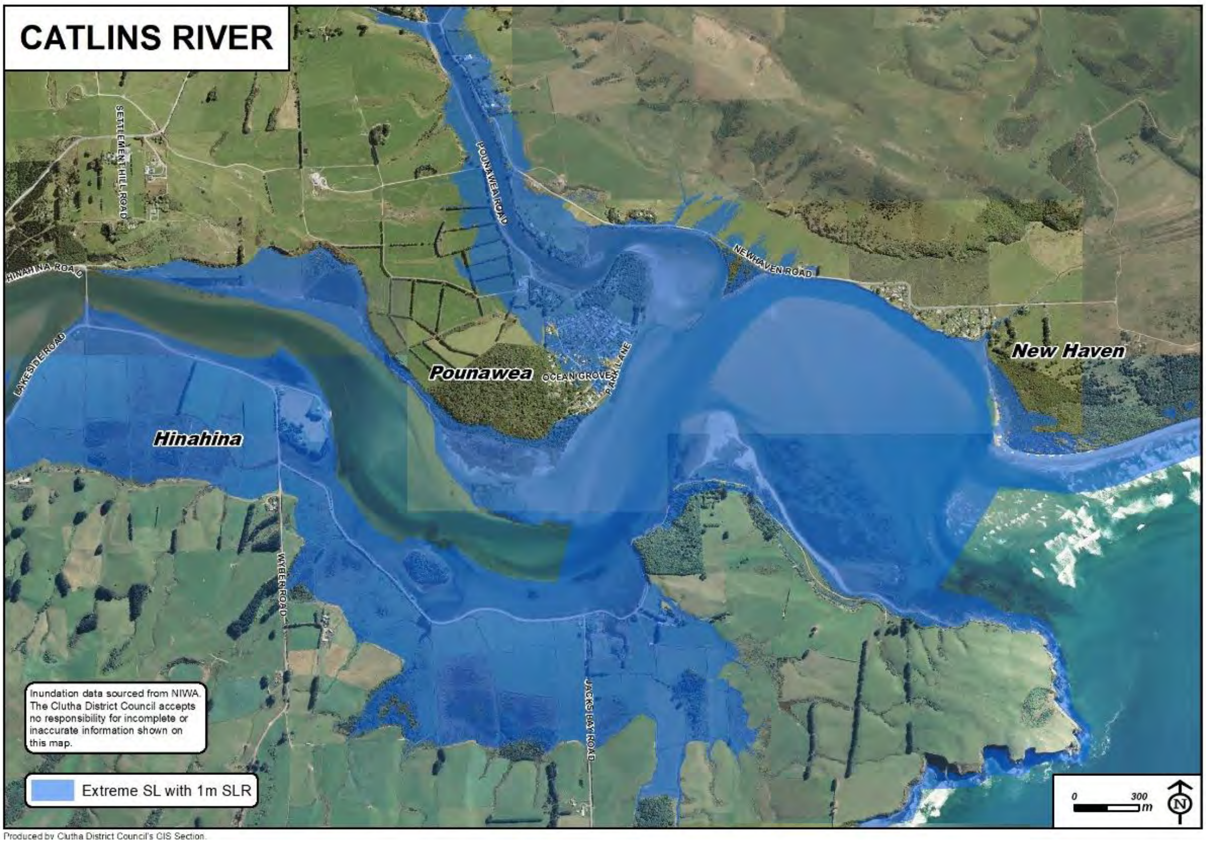


Figure 4-11 Land which is potentially exposed to coastal inundation on the margins of the lower Catlins and Owaka rivers (shaded blue), during a 1:100-year extreme sea level event, together with 100 cm of sea level rise. Smaller increments of sea level rise may also have an impact on this area, and a 50 cm SLR scenario is shown in Appendix 2.

Figure 4-12 Land which is potentially exposed to coastal inundation at Jacks Bay (shaded blue), during a 1:100-year extreme sea level event, together with 100 cm of sea level rise. Smaller increments of sea level rise may also have an impact on this settlement, and a 50 cm SLR scenario is shown in Appendix 2.

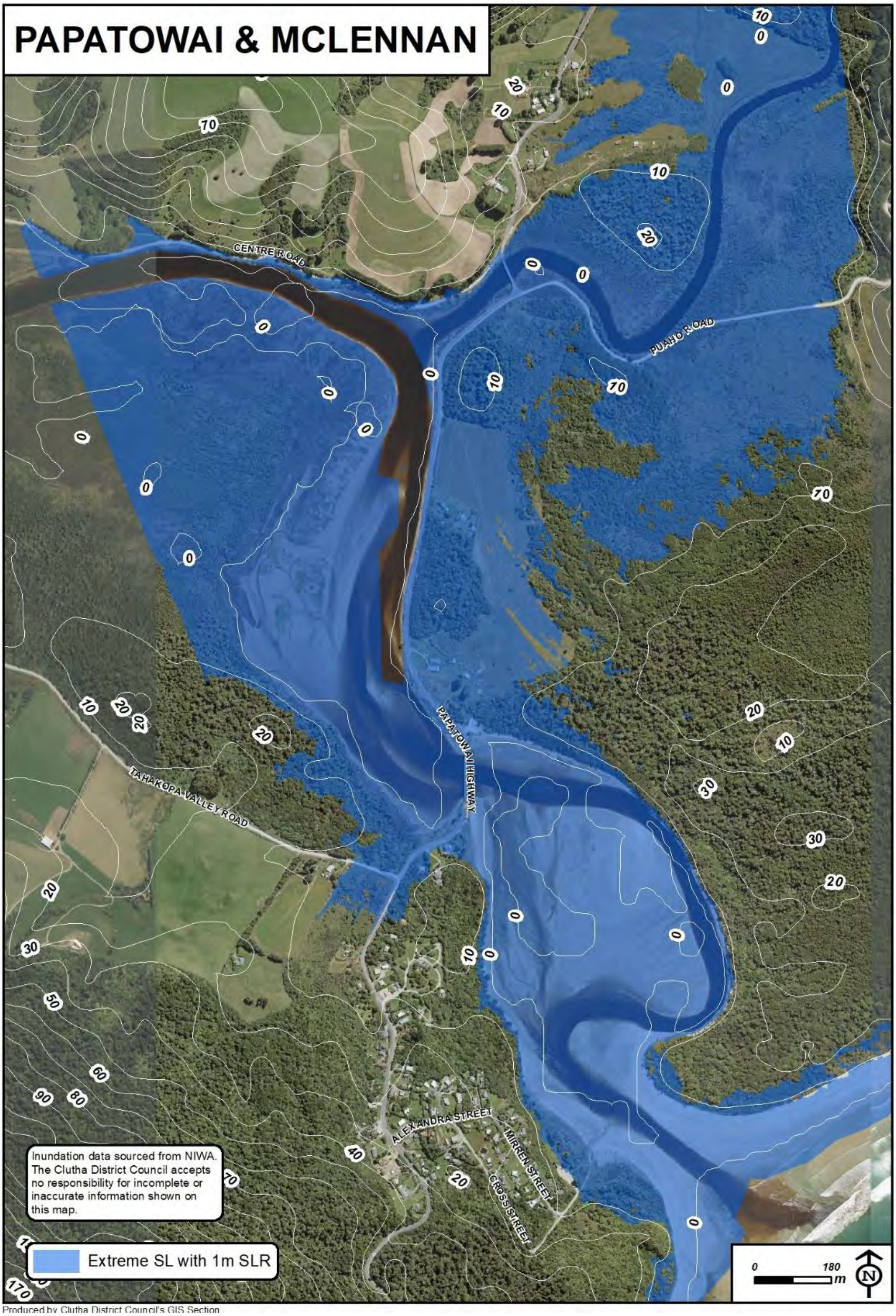


Figure 4-13 Land which is potentially exposed to coastal inundation at Papatowai and Maclennan (shaded blue), during a 1:100-year extreme sea level event, together with 100 cm of sea level rise. Smaller increments of sea level rise may also have an impact on this area, and a 50 cm SLR scenario is shown in Appendix 2.

4.4.2 Tourism

With stunning coastal landforms, rainforest, and abundant wildlife, the Catlins coast is steadily gaining popularity as an ecotourism destination, a trend that is likely to continue into the future. As raised during a community level discussion, warmer weather will likely attract more summer visitors to the region [4]. However, as outlined above, sea level rise may place some of the infrastructure needed to service this influx of people at risk, with some noticeable concerns including the access roads to Kaka Point and Jacks Bay, the road connecting Papatowai to Maclennan, and the settlement of Pounawea.

Combined with sea level rise, a shift in coastal sediment processes may affect access to some of the regions coastal landforms that draw tourists in. Already only accessible at low tide during certain times of the year, the Cathedral Caves is a large tourist attraction, and access may become further restricted if sea levels rise and sediment regimes change. Local consultation suggests that the beach is receding at the eastern end of Waipati Beach, near Cathedral Caves, a situation that may possibly worsen and further endanger access to the cave [17]. And while beyond the extent of the Clutha District, the Jurassic era fossilised forests at Curio Bay, may become more frequently submerged with higher tides, the flow on effects in terms of tourist numbers also possibly affecting the northern and central Catlins areas. Tourism within The Catlins is also dependent on the areas unique and abundant wildlife, and the impacts facing some of these marine species is described below.

4.4.3 Wildlife

While more research is needed to better understand the impact climate change will have on marine and coastal flora and fauna in The Catlins, a predicted southward shift in the range of marine species is expected [18]. Marine species such as the hectors dolphin, hoiho (or yellow eyed penguin), New Zealand fur seal, sea lion, elephant seal, and a vast array of shorebird species may experience changes in their habitat and food supply chains. Indeed, local recreational fisherman have already recorded the presence of marine species such as kingfish, which were previously considered to only inhabit waters further north [17]. Furthermore, Department of Conservation (DOC) employees monitoring the hoiho population have observed changes in the kinds of fish species that parents feed their young, turning to larger species such as blue cod in the absence of smaller and more energy rich fish varieties [16]. As a result, they are recording higher levels of starvation in the population.[x] Alongside this shift in the food chain, warmer springs followed by wet summers is believed to have encouraged the introduction of avian malaria into the hoiho population, a disease that was previously considered to only affect higher latitude populations [16].

Many marine species live among The Catlins sandy beach systems, and the shape of these dynamic environments will continue to change in the future, most likely affecting shore birds that nest in the fore dunes, and sea lions that laze on beaches and in dunes during the day. DOC employees have noticed that the naturally occurring erosion and accretion cycles are becoming more pronounced, leading to the formation of steep erosion scarps along Surat and Cannibal Bay, which in the past have been a popular location for sea lion [16]. To find more accessible dune systems, the sea lions have shifted into Purakaunui and Jacks Bay, and they have even intermittently taken up residence inside Cathedral Cave. This shift in habitat to areas used for recreational purposes has contributed to the rise of encounters between people and

[x] It is unclear what contribution anthropogenic climate change verse deep sea trawling plays in this observed change.

sea lions, a process that will likely continue and need to be managed in the future as the shoreline continues to change.

4.4.4 Agriculture

Climate change will also pose new issues and opportunities for agriculture within The Catlins area. Importantly, by warming less than New Zealand's average and maintaining a wetter environment than expected elsewhere, new agricultural opportunities may arise. During community discussions, local farmers noted that they couldn't foresee the introduction or expansion of new crops given the regions wet conditions. Instead they thought it was more likely that sheep and cattle farming [4] [17], and dairying in some of the valleys would continue [4] [17].

Sheep and cattle farming, alongside dairying, is projected to increase in Southland and some parts of Otago due to more winter pasture growth under future climate change scenarios [19], and this may provide opportunities for The Catlins. Yet, despite this increase in expected production, it is predicted that The Catlins will experience slightly more dry days each year (Figure 2-7), and these may adversely impact production and create water supply issues [20]. Furthermore, fewer frost days will make it harder to eradicate pests and invasive species such as gorse [16] [17].

4.4.5 Forestry

The Catlins has a long history of forestry operations, and many sawmills for native trees were once scattered throughout the area. While sawmills began their decline in the 1960s and farming subsequently became the main industry [2], the introduction of New Zealand's emissions trading scheme means that exotic forestry is becoming an increasingly attractive option for land owners. Farm forestry allows carbon credits to be earned by transitioning pasture to forest (predominantly radiata pine), often grown on steeper hill country. As the market for carbon credits increases, it is possible that The Catlins may see more conversion of land to forestry [20][21]. This industry may also benefit from wetter and warmer conditions, and the fertilisation effects of higher levels of CO_2 in the atmosphere, which are predicted to favour the growth of radiata pine [20].

However, when we discussed these changes in land use patterns with local farmers, concerns about losing the aesthetic and cultural values associated with farmland were raised [4]. Despite these concerns, it is very possible that farm forestry will become an increasingly important part of The Catlins economy, especially in a changing climate.

Figure 4-14 Typical land use patterns in the central Catlins, looking towards the Tahakopa Valley. Note the mix of native forests to the left, exotic forestry in the background, and farmland in the valley.

4.5 SUMMARY: WHERE TO FROM HERE?

Climate change will present new and unique challenges to The Catlins. Overall, the area is expected to warm between 0.5°C and 2.5°C by 2090, and is predicted to experience a slight increase in heavy rainfall events with some dry spells in between. Sea level rise will expose low-lying settlements (Kaka Point, Willsher Bay, Jacks Bay, Pounawea and Maclennan), as well as their service roads, to inundation during extreme sea level events. While warmer weather is expected to bring more tourists, these changes may also impact the regions unique wildlife and endanger access to coastal landforms.

The agricultural and forestry sectors may face new challenges in terms of water management and pest control, yet forestry operations may benefit from the creation of new market opportunities if the demand for carbon credits increases. Overall, while climate change will pose new challenges to The Catlins, it may also bring new opportunities. Through informed planning and continued adaptation, these challenges may be faced and overcome.

4.6 CHAPTER 4 REFERENCES

[1] National Institute of Water and Atmospheric Research Ltd (NIWA) (2019). Climate change projections for the Otago Region. Report prepared for the Otago Regional Council. Macara, G., Woolley, J-M., Zammit, C., Pearce, P., Stuart, S., Wadhwa, S., Sood, A. & Collins, D.

[2] The Official Website of the Catlins, available at: www.catlins.org.nz

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

[4] Personal communication with participants of a community level discussion held in the Papatowai Fire Station, 9 September 2019.

[5] Data extracted from the National Climate Database, National Institute of Water and Atmospheric Research Ltd. Available at http://cliflo.niwa.co.nz/

[6] Fitzharris, B. (2010). Climate change impacts on Dunedin. Report prepared for the Dunedin City Council. University of Otago, Dunedin, March 2010.

[7] Salinger, M.J. and Griffiths, G.M (2001). Trends in New Zealand Daily Temperature and Rainfall Extremes. *International Journal of Climatology*, 21, 1437-1452.

[8] Ministry for the Environment & Statistics New Zealand (2016). *New Zealand's Environmental Reporting Series: Our marine environment 2016.* Available from www.mfe.govt.nz and www.stats.govt.nz

[9] Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan (2013). Sea Level Change. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Chang.e* Eds Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[10] Hannah & Bell (2012). Regional sea level trends in New Zealand. *Journal of Geophysical Research*, 117, 1-7.

[11] Intergovernmental Panel on Climate Change (IPCC) (2013). Summary for policymakers. In Stocker, TF, Qin, D, Plattner, GK, Tignor, M, Allen, SK, Boschung, J, ... Midgley, PM (Eds), Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge and New York: Cambridge University Press.

[12] High Intensity Rainfall Design System (HIRDS), National Institute of Water and Atmospheric Research (NIWA) Ltd. Available at: https://hirds.niwa.co.nz/.

[13] Ministry for the Environment (2017). Coastal Hazards and Climate Change: Guidance for local government. Bell, R., Lawrence, J., Allan, S. Blackett, P. and Stephens, S. New Zealand Government.

[14] National Institute of Water and Atmospheric Research Ltd (NIWA) (2019). *Coastal flooding exposure under future sea-level rise in New Zealand*. Report prepared for the Deep South Challenge. Paulik, R., Stephens, S. Wadhwa, S., Bell, R., Popovich, B & Robinson, B.

[15] Otago Regional Council (2014). *Coastal Morphology of South Otago: Nugget Point to Chrystalls Beach*. Williams, J. & Goldsmith, M. September 214, Dunedin.

[16] Personal communication with Department of Conservation employee, Owaka, 9 September 2019.

[17] Personal communication with sheep farmer, Chaslands, 14 September 2019.

[18] National Institute of Water and Atmospheric Research Ltd (NIWA) (2007). *Climate change and the New Zealand marine environment.* NIWA Client Report: NEL2007-025. Wellington, October 2007.

[19] Ministry of Agriculture and Forestry (2008). *The costs and benefits of climate change and climate change adaptation: What do we know so far?* Ecoclimate: Integrated research on the economics of climate change impacts adaptation and mitigation.

[20] Ministry for Primary Industries (2013). *Four Degrees of Global Warming: Effects on the New Zealand Primary Sector.* MPI Technical Information Paper No. 2013/49. Wellington.

[21] Adams, T. & Turner, J.A. (2012). An investigation into the effects of an emissions trading scheme on forest management and land use in New Zealand. *Forest Policy and Economics*, 15, 78-90.

[22] Otago Regional Council (2016). *Natural hazards on the Clutha delta, Otago.* Prepared by Hornblow, S., Payan, J-L., Sims, A. & O'Sullivan K. May 2016, Dunedin.

[23] Otago Regional Council (2012). *Community vulnerability to elevated sea level and coastal tsunami events.* Report plus supporting map book. Prepared by Goldsmith, M. July 2012, Dunedin.

5.0 CENTRAL CLUTHA

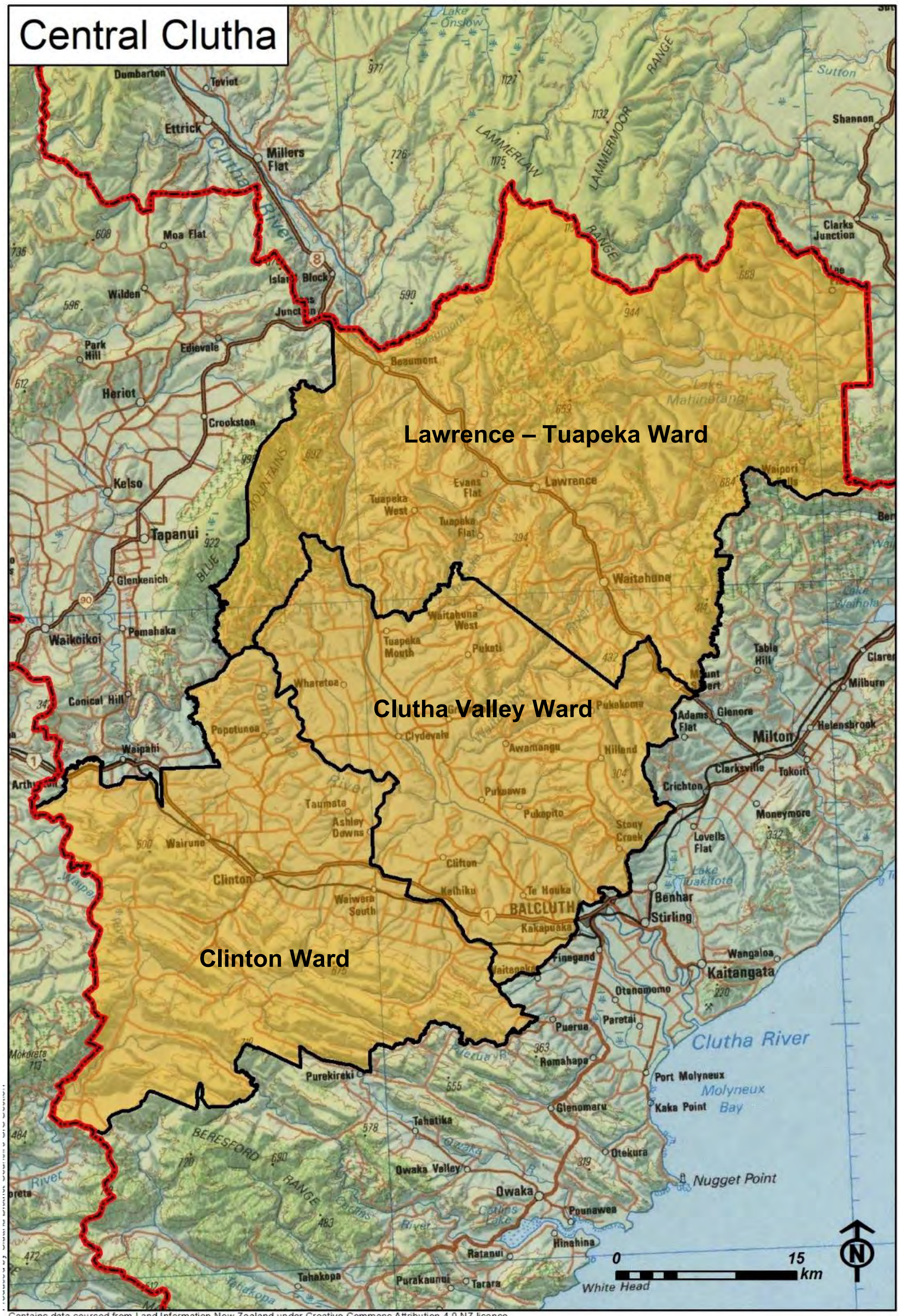
Figure 5-1 Rural outlook, near Lawrence (Source: GHC).

5.1 INTRODUCTION

Central Clutha is a fertile agricultural landscape that incorporates the Clinton, Clutha Valley and Lawrence-Tuapeka wards (Figure 5-2). The landscape features broad floodplain areas, rolling hill country, and rugged terrain in the upper catchment, with the Clutha River flowing past the town of Clydevale in its central valley. Central Clutha stretches from the town of Clinton in the south, to the Clutha Valley in the centre, and the towns of Lawrence and Waipori in the north. With important agricultural and forestry activities, Central Clutha will experience its own unique set of challenges and opportunities in a changing climate.

5.1.1 Key findings:

- By 2090, mean annual temperature in the Central Clutha area is expected to increase by between 0.5°C and 2.5°C, relative to 1995 [1].
- Annual average rainfall is predicted to increase over time across this area, with fewer annual dry days expected, especially within the Clutha Valley [1].
- Increased precipitation and high intensity heavy rainfall events may contribute to the risk of floods on low-lying farmland and townships such as Lawrence.
- The agricultural and forestry sectors may face new challenges in terms of flood and water management, yet they may also benefit from more winter pasture growth.
- While climate change will present new challenges for Central Clutha, through informed planning, and innovative adaptation, these future challenges can be faced and overcome.



Contains data sourced from Land Information New Zealand under Creative Commons Attribution 4.0 NZ licence

Figure 5-2 The Central Clutha boundary, encompassing the Lawrence-Tuapeka, Clutha Valley and Clinton wards.

5.2 UNDERSTANDING THE PAST AND PRESENT CLIMATE

The Central Clutha area experiences a cool climate that can reflect either coastal or inland weather systems. At times, weather patterns mimic Central Otago, with warm still days in summer and some snowfall in winter. The area can also experience coastal weather systems and cool southerlies. Annual average temperatures range between 8°C and 12°C, with the occasional very hot day in summer, and regular frosts in winter [1]. Average annual rainfalls of between 600 and 900 mm have been recorded at Tuapeka Mouth [2], with rainfall across the whole area spanning the range of 650 to 1000 mm (Figure 5-3) [1].

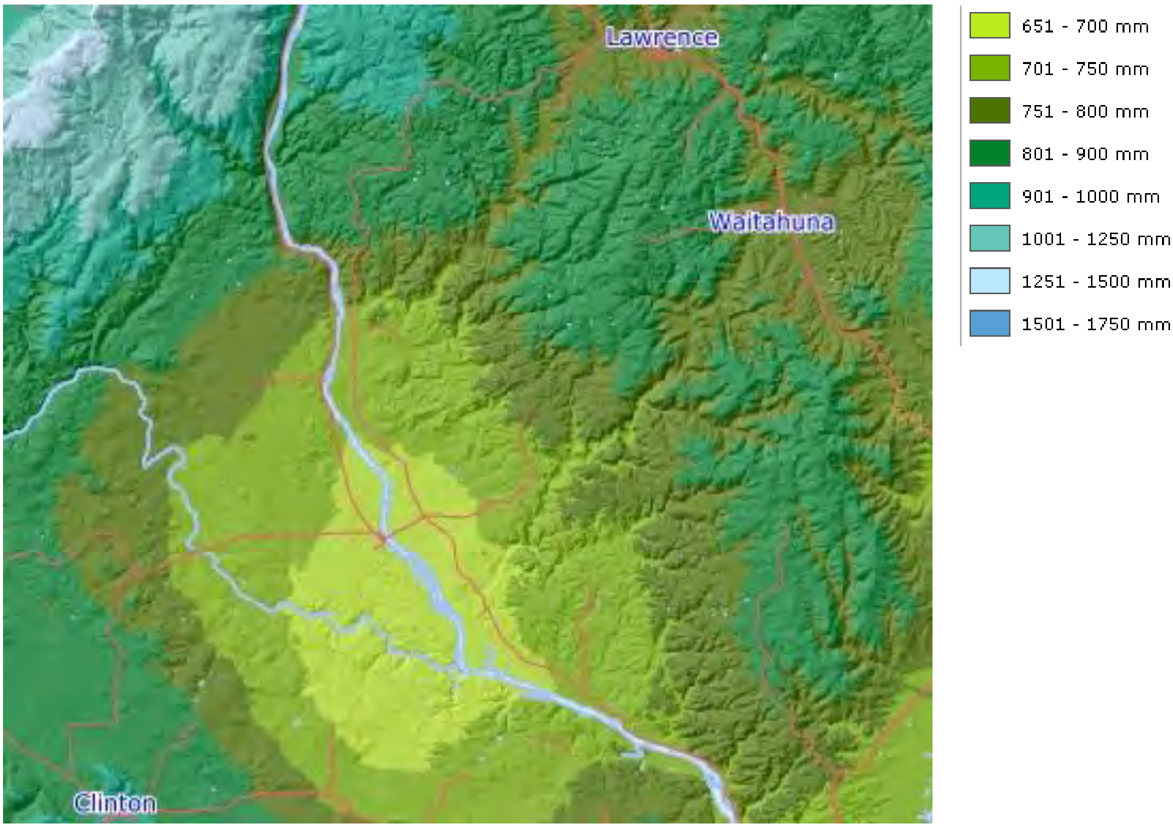


Figure 5-3 Median annual rainfall in the area from Clinton to Lawrence / Waitahuna. Modelled by NIWA for the GrowOtago project

5.2.1 Air temperature

While historical records tell us that New Zealand's air temperatures have increased by about 1°C over the past century (MfE, 2018) [3], there is insufficient long-term temperature data to verify whether this trend is also occurring in the Central Clutha area. The longest temperature records available are from Lake Mahinerangi near Waipori, and these extend from 1966 to 1988/89. During this period, mean annual air temperature fluctuated between 7.9 and 9.3°C (Figure 5-4 a). The number of hot days (with a maximum temperature of 25°C or above) fluctuated between one and 12 per year, and a long-term trend is not discernible (Figure 5-4 b). In this same period, the number of frost days (with temperatures <0°C) ranged from 98 to 44 days per year, with a slight decrease over time observed (Figure 5-4 c).

Alongside recordings from weather stations, anecdotal observations made by local farmers in Tuapeka West and Waitahuna were that frost and snow days are becoming fewer and further between, especially when present day conditions are compared with the weather they remember from their youth [4][5].

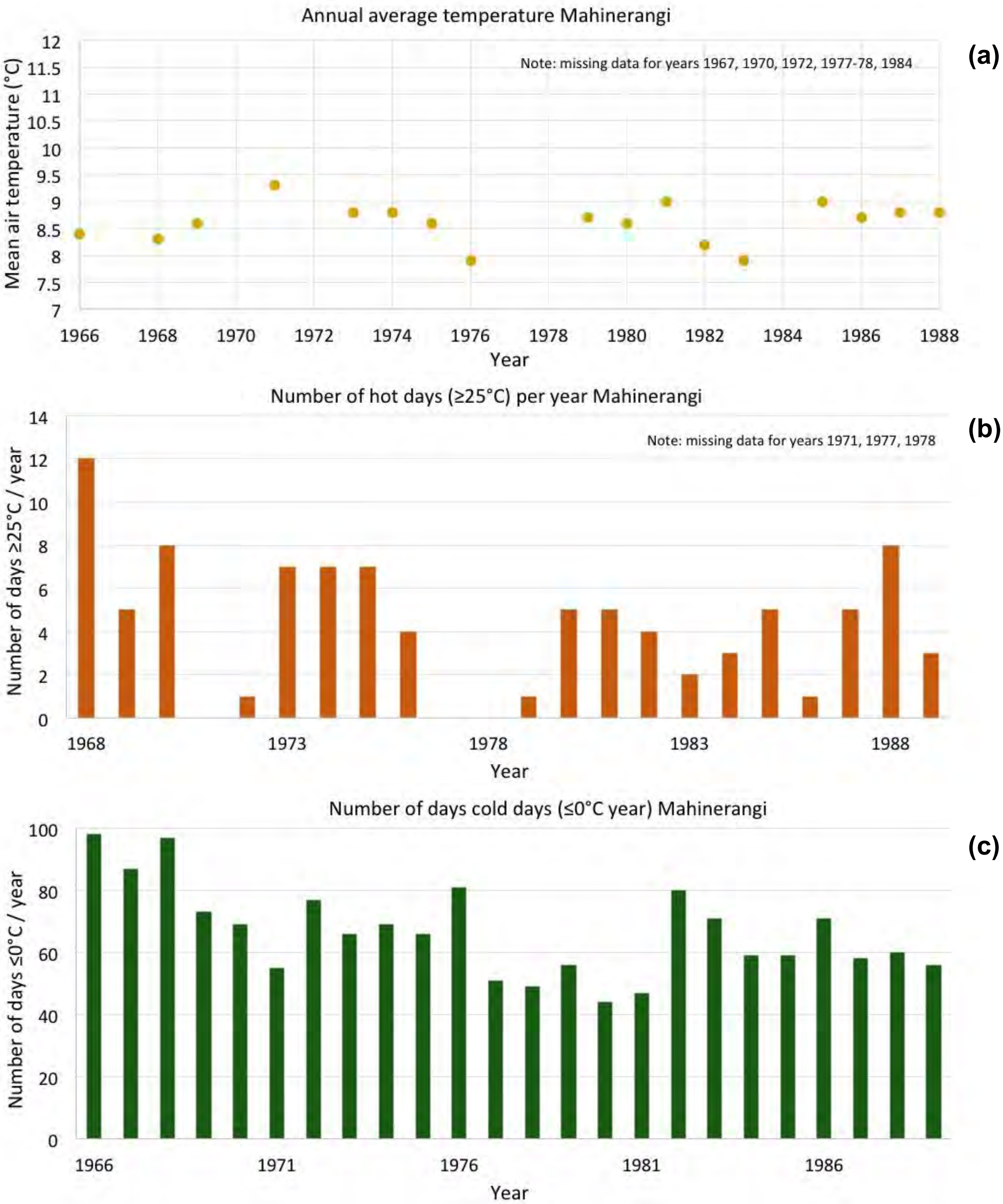


Figure 5-4 Historic temperature data from Mahinerangi obtained from the NIWA climate database; a) mean average temperature, b) number of hot days (greater than or equal to 25°C), and c) number of frost days or nights (temperatures of 0°C or below) [2].

5.2.2 Rainfall

Presently, Central Clutha experiences moderate precipitation with annual averages of 600 to 800 mm within the Clutha Valley, rising to between 800 and 1,000 mm towards Clinton in the south and Waipori to the north [1]. As for the temperature data discussed above, precipitation data for Central Clutha is insufficiently long to reveal long-term trends. However, observations from Tuapeka Mouth reveal that annual rainfall values ranged from 580 mm to 910 mm between 1990 and 2004. At this site, the number of heavy rain days (where greater than 25 mm falls in a 24-hour period) ranged from one to seven per year (Figure 5-5 b).

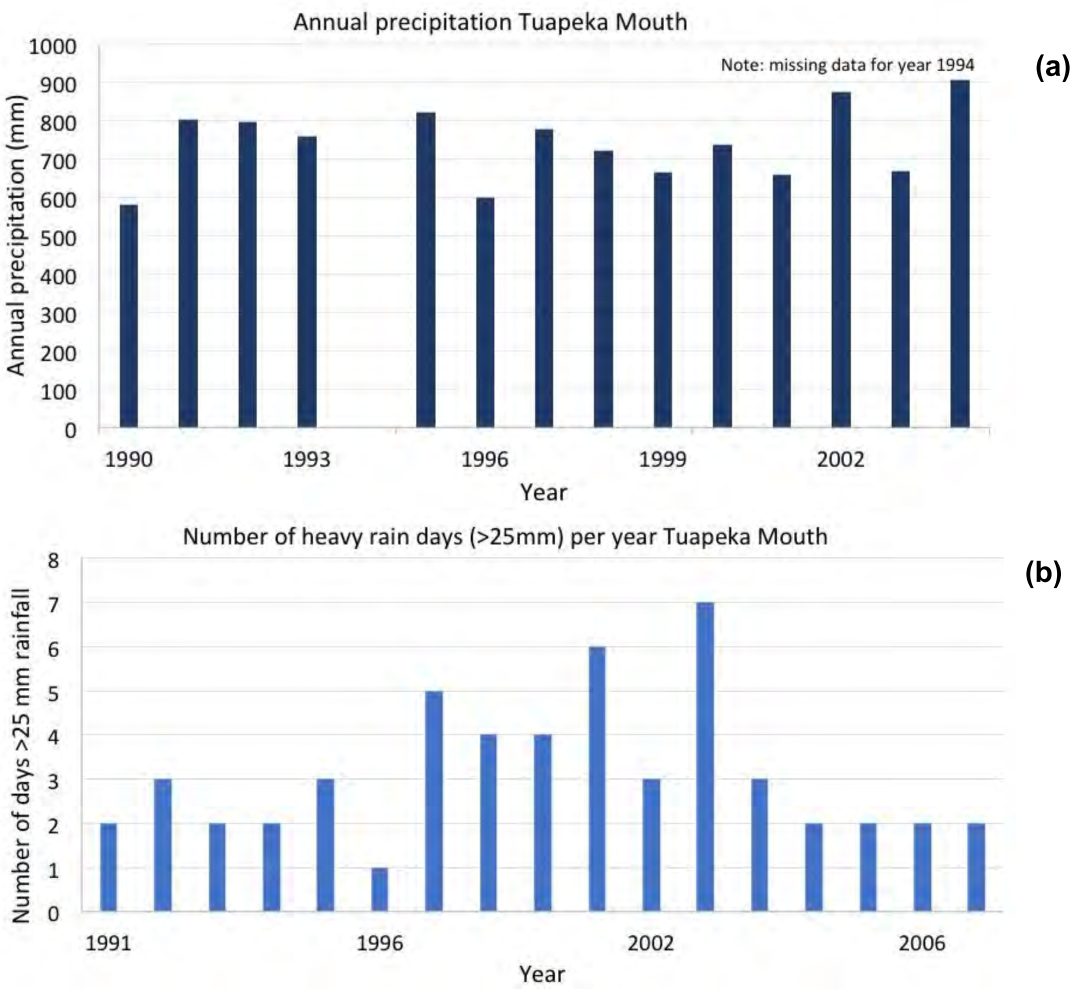


Figure 5-5 Historic precipitation data at Tuapeka Mouth obtained from the NIWA climate database; a) shows annual precipitation in mm, and b) number of heavy rain days where precipitation was greater than 25 mm in a 24- hour period [2].

5.3 WHAT DO FUTURE CLIMATE PREDICTIONS TELL US?

With the past and present climate outlined above, we can now draw on scientific models to understand the extent of climatic change that is predicted to occur in the future. The changes outlined below reflect the output of downscaled global climate models produced by NIWA [1]. These models aim to predict how temperature and rainfall patterns will change, depending on different estimates of how much greenhouse gas we will emit in the future. Within this report we present two emission scenarios, from a low to mid-range or 'stabilisation pathway' (RCP 4.5) to a high range 'business as usual' scenario (RCP 8.5) (see section 1.3 for more information). While they are predictive, in that they will not tell us exactly how much things will change, they still provide a very useful tool for understanding the range of likely future climatic conditions.

5.3.1 Air temperature

Average air temperatures are predicted to warm into the future, with rates of change in Central Clutha likely to be slightly higher than what is projected for Clutha's coastal areas. By 2040 mean annual air temperature is predicted to increase by 0.5°C to 1°C for both the low-mid and high range emission scenarios (RCP 4.5 and 8.5 respectively) (Figure 2-1) [1]. This pattern of warming continues towards the end of the century, and by 2090 Central Clutha is predicted to warm by 1°C to 1.5°C under RCP 4.5, or by 2°C to 2.5°C under RCP 8.5 [1]. These rates of warming are regionally consistent throughout Central Clutha (except for the lower reaches of the Clutha Valley near Balclutha, which is predicted to warm slightly less under RCP 4.5).

While minimal increases in the number of hot days (those greater than 30°C) are expected by 2040 under both emission scenarios, by 2090 the Central Clutha area may experience up to six extra hot days per year under RCP 4.5, or up to 20 extra hot days under RCP 8.5 (Figure 2-2) [1]. The highest increases in the number of hot days by 2090 are expected in Beaumont and Waipori,[y] followed by Lawrence[z] (Figure 2-2).

The number of frost days (where temperatures drop below 0°C) is also expected to decrease, and by 2040, between five and 20 fewer frost days are expected (Figure 2-3) [1]. This trend continues through to the end of the century, and by 2090 somewhere between five and 40 fewer frosts days are predicted, with the largest reductions for the northern reaches of the Central Clutha area (Figure 2-3).

5.3.2 Rainfall

Precipitation patterns are predicted to change due to climate change; with annual precipitation likely to increase, especially during the spring and winter months [1]. Annual rainfall is expected to increase by up to 5% by 2040, and by up to 20% by 2090 (Figure 2-4). Overall, this modelled increase in precipitation is expected to be highest in the Clutha Valley and Clydevale.

A slight increase in the total number of very wet days (>25 mm) is also expected in this area, and by 2090 up to five additional heavy rain days may be expected per year, with the greatest increase in heavy rain days predicted to the south of Clinton (Figure 2-5). While up to six fewer dry days are predicted each year for Clydevale and the Clutha Valley, the towns of Lawrence and Beaumont are expected to experience little change in the average number of dry days each year (Figure 2-7).

5.3.3 Wind speed and direction

Along with the temperature and rainfall changes outlined above, climate change will also contribute to other shifts in atmospheric processes, such as wind speed and direction. During winter, strengthened westerlies are predicted for the south of the South Island, with more north-easterly airflow expected during the summer months [3]. Within the Central Clutha area, minimal changes in extreme daily wind speeds[aa] are expected by 2040. However, by 2090 extreme windy days may increase by 1 - 4% assuming a high range emissions scenario, with the towns of Clinton and Beaumont predicted to experience the largest increases (Figure 2-8).

5.4 CLIMATE CHANGE IMPLICATIONS FOR PEOPLE, INFRASTRUCTURE AND INDUSTRY IN CENTRAL CLUTHA

The information above has provided an overview of past climate trends and future projections, but what does this mean for people, infrastructure and industry in Central Clutha? This section identifies some of the potential socio-economic impacts that may accompany climate change,

[y] Beaumont and Waipori are both predicted to experience 10-20 additional hot days (>30°C) for a high range emission scenario (RCP 8.5) (Figure 2-2).

[z] Lawrence is predicted to experience 8-10 additional hot days (>30°C) for a high range emission scenario (RCP 8.5) (Figure 2-2).

[aa] defined as changes in the 99th percentile daily wind speeds, or the top three windiest days each year

covering an increase in flood risk, to some of the implications facing agriculture and forestry in the area.

5.4.1 Changes in flood risk

Central Clutha has experienced a range of significant floods in the past, and it is possible that such events will intensify into the future. The area contains a number of small to mid-sized catchments, including the Waipori, Waitahuna and Tuapeka rivers to the north, and the Waiwera, Waipahi and lower Pomahaka rivers to the south. In addition, the Clutha River passes through Central Clutha, passing Beaumont, Tuapeka Mouth and Clydevale along the way (Figure 5-2).

Central Clutha's topography includes extensive areas of rolling hill country, with some fairly rugged terrain in upper catchment areas. There are only a few broad floodplain areas, located on the margins of the Clutha River (downstream of Tuapeka Mouth), in certain sections of the lower Pomahaka catchment, and near Waipahi. Smaller floodplain areas do exist alongside smaller tributaries, for example in the Waitahuna catchment near SH8 (Figure 5-6). Land use is predominantly rural, with a number of small towns (including Lawrence, Clinton and Clydevale), and some industrial sites (e.g. Danone in the Clutha Valley).

Figure 5-6 View of floodplain area at Waitahuna, from the SH8 Bridge. Source: GHC.

Given previous experience of flood events and limited demand for development, land use in this area generally reflects existing flood hazard. Industrial, residential and commercial development is typically located outside of the worst affected areas, while farming and other lower-risk activities continue to take place on more flood-prone land.[bb]

There are some notable exceptions however, including parts of Lawrence (Figure 5-8) and Waitahuna, as well as bridges, roads and other infrastructure where these cross floodplains or rivers (Figure 5-9). The impact of floods in urban areas can be quite severe, as occurred in Lawrence in June 2017 when flooding caused significant damage to businesses located along Lawrence's main street, Ross Place, and forced one café to close for a period of nine months due to flood damage [7]. Effects on rural land can include damage to fences and access tracks, extensive ponding on floodplain areas, and sedimentation due to river bank erosion (Figure 5-10) or landslip activity.

Any change in flood risk will be dependent on local precipitation patterns (particularly as a result of storms from the east and south), as well as rainfall and inflows from the upper Clutha

[bb] Noting that farms can still be badly affected by large flood events, with loss of livestock, balage etc.

catchment. As described in chapter three, the mean flow of the Clutha River is predicted to increase, due to more precipitation in the upper catchment and Southern Alps. The frequency and magnitude of high flows in the Clutha may also increase (Table 3-2), with potential impacts on flood-prone areas adjacent to the Clutha River, particularly downstream of Tuapeka Mouth (Figure 5-7).

Figure 5-7 View of infrastructure and farm land on the true left bank of the Clutha River at Clydevale. Source: Google Street View

Precipitation patterns within the Central Clutha area are also predicted to change, as outlined in chapter two. It is anticipated that by the end of this century, there will be one to two additional days per year with rainfall totals greater than 25mm across most of this area, with up to five additional days to the southeast of Clinton (Figure 2-5). The amount of precipitation during high intensity rainfall events is also predicted to increase.[cc] As a result, the frequency of rainfall events which are large enough to potentially cause damage to infrastructure and other assets may increase.

As noted above, the areas where flooding can cause issues for local communities are generally well known, and it is these areas which are most likely to be affected by changes in climate. However, any new development or change in activity should also consider the potential impacts of changes in rainfall patterns and flood hazard.

[cc] For example, the depth of rain that falls in 24 hours at Lawrence, during what is currently considered a ‘1 in 50-year’ event is predicted to increase by about 7 mm by the end of the century, from 103 mm to 110 mm. See Table 2-1 for other heavy rainfall scenarios.

Figure 5-8 Top: Looking west down Ross Place, Lawrence during a flood event in 1904 (Source: Hocken Library). Bottom: The same view in 2010 (Google Street View).

Figure 5-9 Road inundation, due to flooding in the Waitahuna River, January 1966 (source: ORC).

Figure 5-10 October 1978 Hunt Road Creek, Lawrence, showing streambank erosion. Source: ORC.

5.4.2 Agriculture

Climate change will also pose new issues and opportunities for agriculture within the Central Clutha area. By warming less than New Zealand's average and maintaining a wetter environment than expected elsewhere, new agricultural opportunities may arise. Warmer conditions, fewer frosts and increases in precipitation may see improved winter pasture growth that will support sheep and beef and dairy farming systems [9]. However, we may also see an increase in flood risk if there are more or larger heavy rainfall events. Dairy, and sheep and beef farming systems, many of which are located on low-lying ground, prone to flooding, are prevalent throughout the Central Clutha area. Under climate change scenarios it is possible that pasture and grazing land will experience more regular periods of flood inundation. Alongside risk to livestock and reduced calving rates [6], floods may exacerbate erosion and water contamination issues, particularly on dairy farms [9]. Indeed, one farmer noted that they have never seen their effluent ponds fill like they did during the recent floods of February 2020 [6].

During local consultation, farmers felt that dairy and sheep farming would continue in the area under climate change scenarios and that due to the current profitability associated with this land use activity, additional crops would only be grown to support livestock and milk production [6]. Furthermore, local responses to climate change are already being considered. One dairy farmers in the Clydevale area explained how he plans to provide a covered facility to hold livestock during heavy rains in order to protect paddocks, and to ensure that adequate feed has been stored and is ready for when cows are in the sheds, or for when paddocks become excessively dry [6]. Additionally, on land in the Waitahuna and Lawrence areas, some sheep farmers are focusing their response towards farm forestry systems, as discussed below.

5.4.3 Forestry

Parts of Central Clutha are used for farm forestry activities, and it is likely that this land use pattern will continue into the future, particularly if the market for carbon credit increases. Significant stretches of exotic forest (mainly radiata pine) are found around Lawrence, Waitahuna and along the Clutha River. As the market for carbon credits increases, it is possible that the Central Clutha area may see more conversion of land to forestry [10]. This industry may also benefit from wetter and warmer conditions, and the fertilisation effects of higher levels of CO_2 in the atmosphere, which are predicted to favour the growth of radiata pine [11]. Yet, notably within this area local consultation revealed that not all farmers growing trees are registered for carbon credits, and some prefer the freedom to grow trees without the condition to replant [12].

Figure 5-11 An example of land use patterns in the Central Clutha area, alongside the Clutha River. Note the dairy cows in the foreground and exotic forestry in the background (Source: GHC).

5.5 SUMMARY: WHERE TO FROM HERE?

Climate change will present new and unique challenges to the Central Clutha area. Overall, the region is expected to warm by between 0.5°C and 2.5°C by 2090, and is predicted to experience an increase in annual precipitation and high intensity rainfall events, which may increase the risk of floods in areas such as Lawrence. The agricultural and forestry sectors may face new challenges in terms of flood and water management, yet gains in productivity may be realised with a lengthened growing season and fewer dry days. Likewise, the forestry sector may face new opportunities in terms of production and market demand. Overall, while climate change will pose new challenges to Central Clutha, it may also bring new opportunities. Through informed planning and continued adaptation, these challenges may be faced and overcome.

5.6 CHAPTER 5 REFERENCES

[1] National Institute of Water and Atmospheric Research Ltd (NIWA) (2019). Climate change projections for the Otago Region. Report prepared for the Otago Regional Council. Macara, G., Woolley, J-M., Zammit, C., Pearce, P., Stuart, S., Wadhwa, S., Sood, A. & Collins, D.

[2] Data extracted from the National Climate Database, National Institute of Water and Atmospheric Research Ltd. Available at http://cliflo.niwa.co.nz/

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

[4] Personal communication with sheep farmer, Waitahuna, 12 March 2020.

[5] Personal communication with local Tuapeka West resident, 4 March, 2020.

[6] Personal communication with dairy farmer, Clydevale, 21 February, 2020.

[7] Personal communication with local business owner, Lawrence, 4 March 2020.

[8] High Intensity Rainfall Design System (HIRDS), National Institute of Water and Atmospheric Research (NIWA) Ltd. Available at: https://hirds.niwa.co.nz/.

[9] Ministry for Agricultural and Forestry (2008). *Climate Change: A guide for land managers.* Regional summary, effects and impacts: Otago and Southland. Wellington.

[10] Adams, T. & Turner, J.A. (2012). An investigation into the effects of an emissions trading scheme on forest management and land use in New Zealand. *Forest Policy and Economics*, 15, 78-90.

[11] Ministry for Primary Industries (2013). *Four Degrees of Global Warming: Effects on the New Zealand Primary Sector.* MPI Technical Information Paper No. 2013/49. Wellington.

[12] Personal communication with Clutha District Council employee and farmer, Lawrence, 4 March 2020.

6.0 WEST OTAGO

Figure 6-1 Sheep farm along the Tapanui Raes Junction Road, with the Blue Mountains in the background (source: GHC).

6.1 INTRODUCTION

West Otago is the most western and inland ward in the Clutha District, encompassing the townships of Tapanui, Edievale and Heriot. This area is bordered by the Blue Mountains Forest Conservation Area to the southeast, by Central Otago to the north, and Southland to the west. With a climate which is often more similar to that of Central Otago than Clutha, and important agricultural and forestry industries, West Otago will experience its own unique set of challenges and opportunities in a changing climate.

6.1.1 Key findings

- By 2090, mean annual temperature in the West Otago area is expected to increase by between 0.5°C and 3°C, relative to 1995 [1].
- West Otago is predicted to experience the largest increases in mean annual air temperature and the number of extremely hot days in the Clutha District. Similarly, it is predicted to experience the largest reductions in frost days, compared to other parts of the Clutha District.
- Although mean annual precipitation is expected to increase, in the short to medium term (2040) there may also be more dry periods or drought, between periods of rainfall [1].
- Increased precipitation and high intensity rainfall events may contribute to the risk of floods along the Pomahaka River, especially in the vicinity of the former township of Kelso.
- The agricultural and forestry sectors may face new challenges in terms of flood and water management, yet they may also benefit from improved winter pasture growth and new cropping opportunities.

- While climate change will present new challenges for West Otago, through informed planning, and innovative adaptation, these future challenges can be faced and overcome.

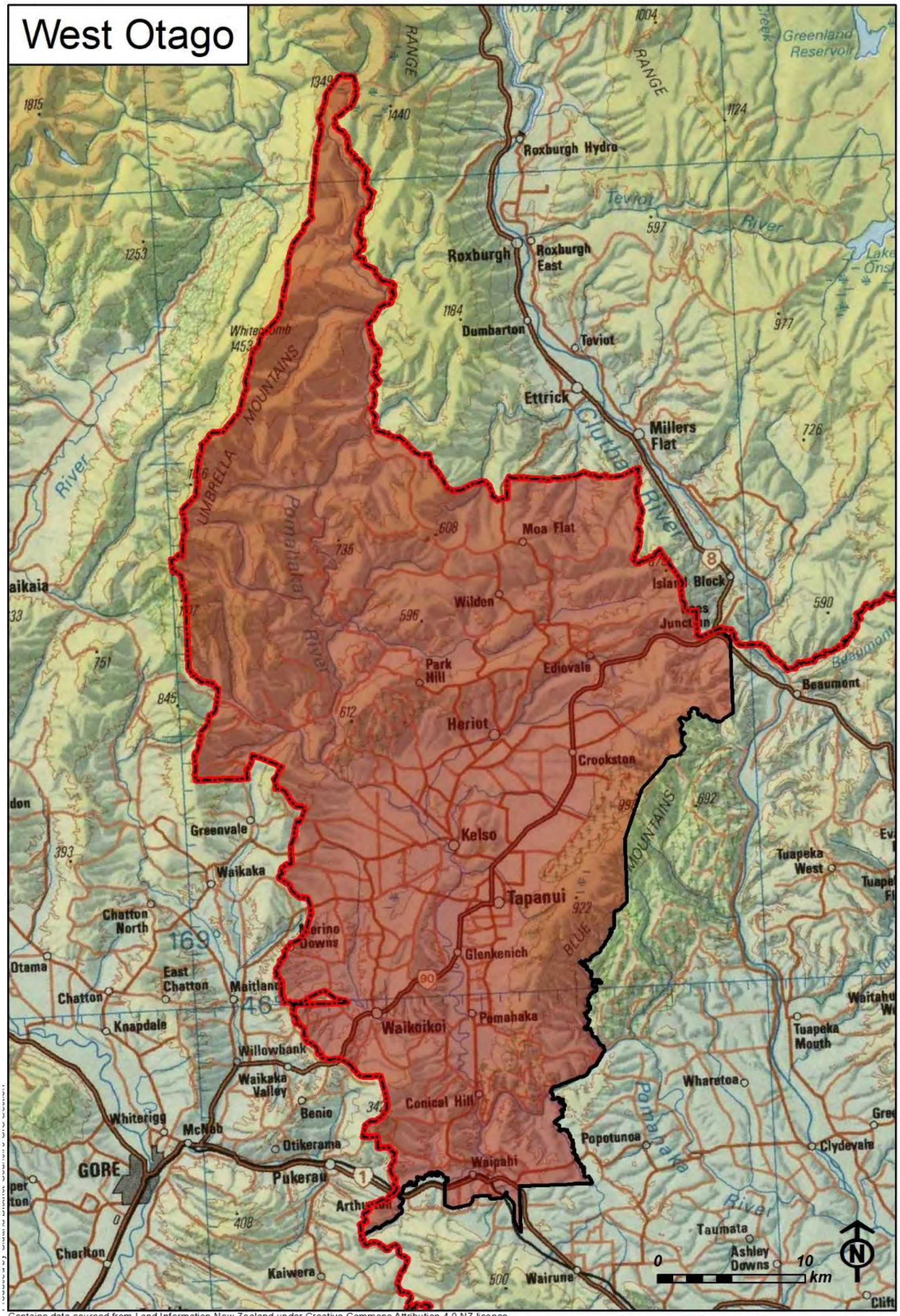


Figure 6-2 The West Otago boundary, encompassing the West Otago ward.

6.2 UNDERSTANDING THE PAST AND PRESENT CLIMATE

Presently, the West Otago area experiences the highest summer temperatures, and lowest winter temperatures, within the Clutha District. Average maximum summer temperatures range from between 18°C to 22°C, while average minimum winter temperatures range from -2°C to 2°C [1]. The area experiences regular frosts, and some snow days, with annual precipitation values fluctuating between 600 and 1000 mm [1].

6.2.1 Air temperature

West Otago contains few records of mean air temperature, and there are no long-term records of temperature extremes (hot days and frosty mornings). Records taken at Moa Flat over a 28-year period from 1951 to 1979, show mean annual temperature varied between 8.2 and 9.7°C, with 1971 the hottest year on record (Figure 6-3 b). In the nearby settlement of Ettrick in the Central Otago District, approximately 10 km from Moa Flat, 28 years of records show that mean annual temperatures vary between 9.8 and 11.5°C, and an upwards trend in temperatures is noticeable (Figure 6-3 a). Anecdotal observations made by local farmers in Heriot and Waipahi suggest that the weather is becoming warmer and that frosts are becoming fewer and farther between [2][3].

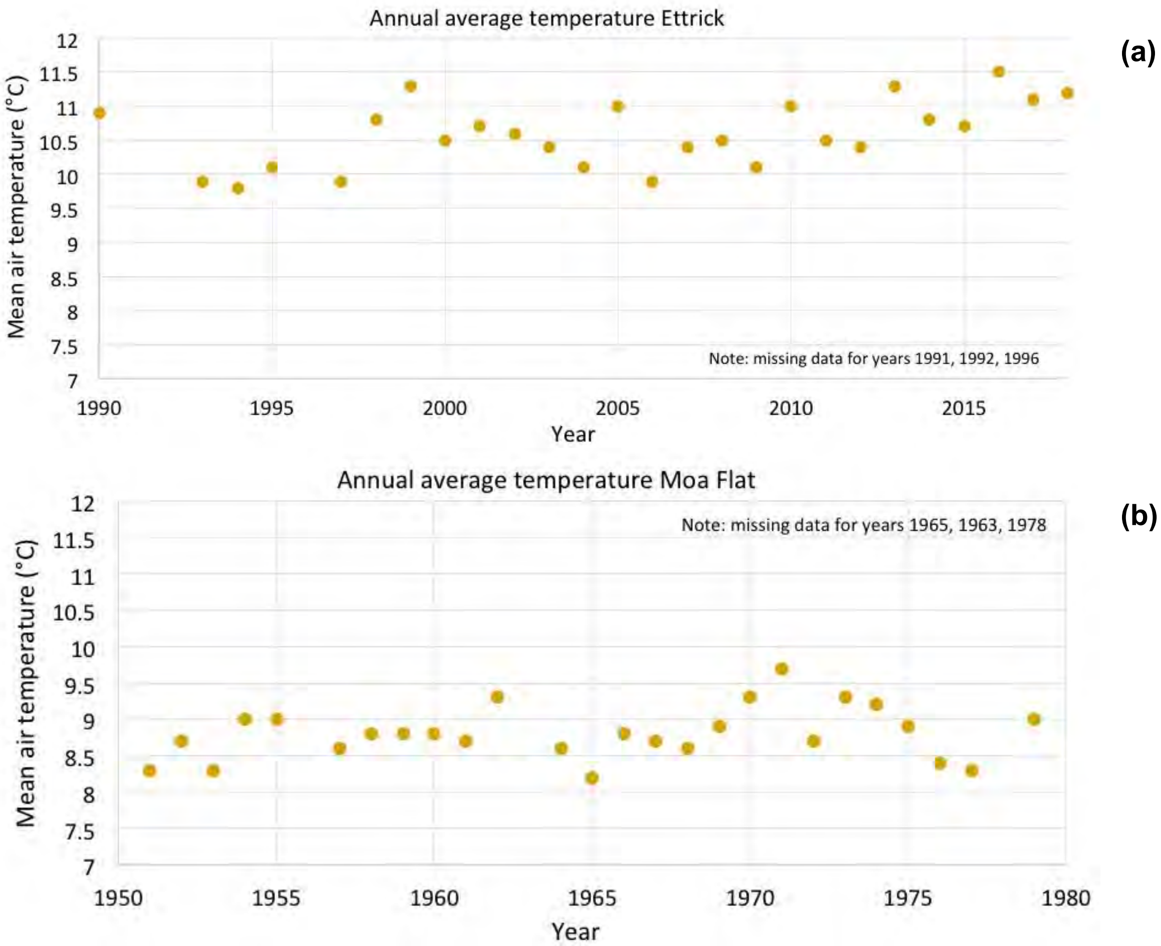


Figure 6-3 Historic temperature data from Ettrick and Moa Flat obtained from the NIWA climate database showing; a) mean annual temperature at Ettrick, and b) mean annual temperature at Moa Flat [4].

6.2.2 Rainfall

Rainfall records at Tapanui from 1990 to 2018 show that annual precipitation generally ranges from 620 to 900 mm per year (Figure 6-5 a). Annual rainfall varies considerably across West Otago area however, and Figure 6-4 shows median annual totals of more than 1000 mm in the upper Pomahaka catchment, with lower rainfall totals further east towards the Clutha River.

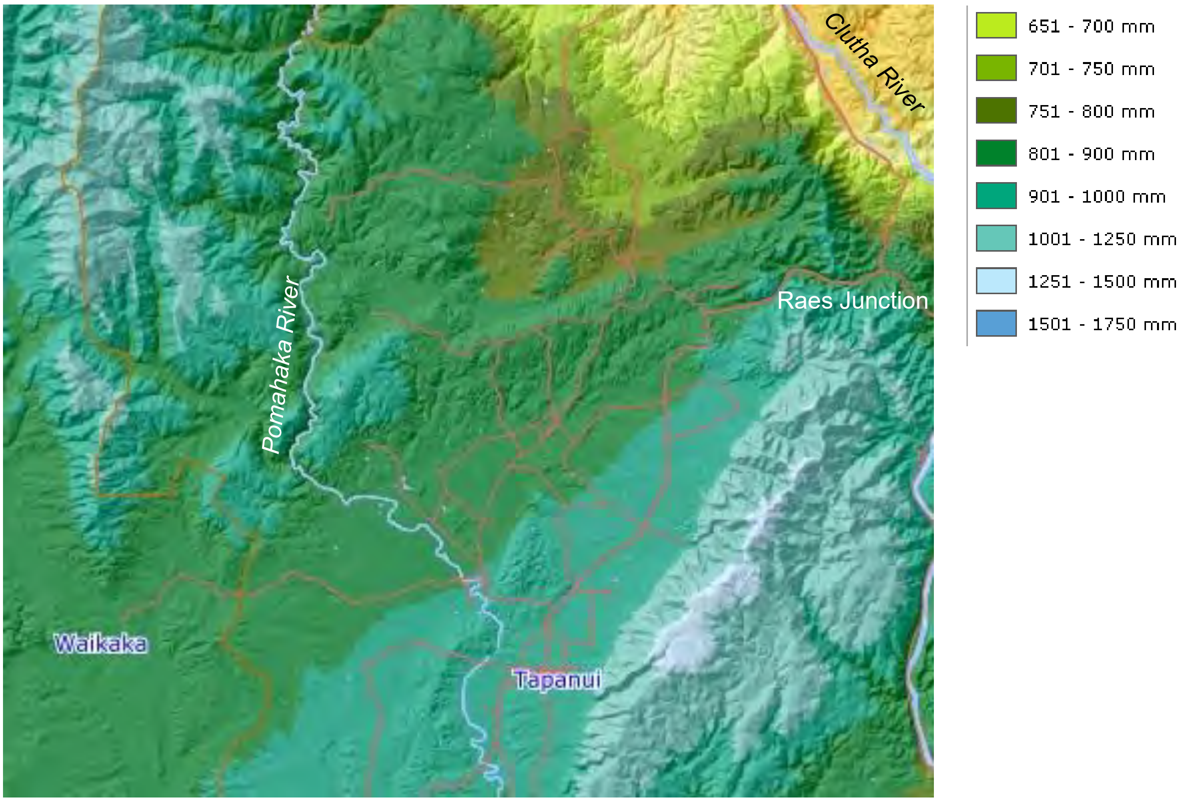


Figure 6-4 Median annual rainfall in the West Otago area. Modelled by NIWA for the GrowOtago project

Tapanui typically experiences between one and five heavy rainfall events (>25 mm in a 24-hour period) each year (Figure 6-5 b). The exception was 1994, when there were eight such events - this was also one of the wettest years on record. While the historical rainfall records from West Otago are insufficient to reveal any long-term trends, consultation with local farmers indicated that rainfall is becoming heavier and more frequent, especially during the spring and summer months, and these local observations are in line with the climate predictions that are described below [2].

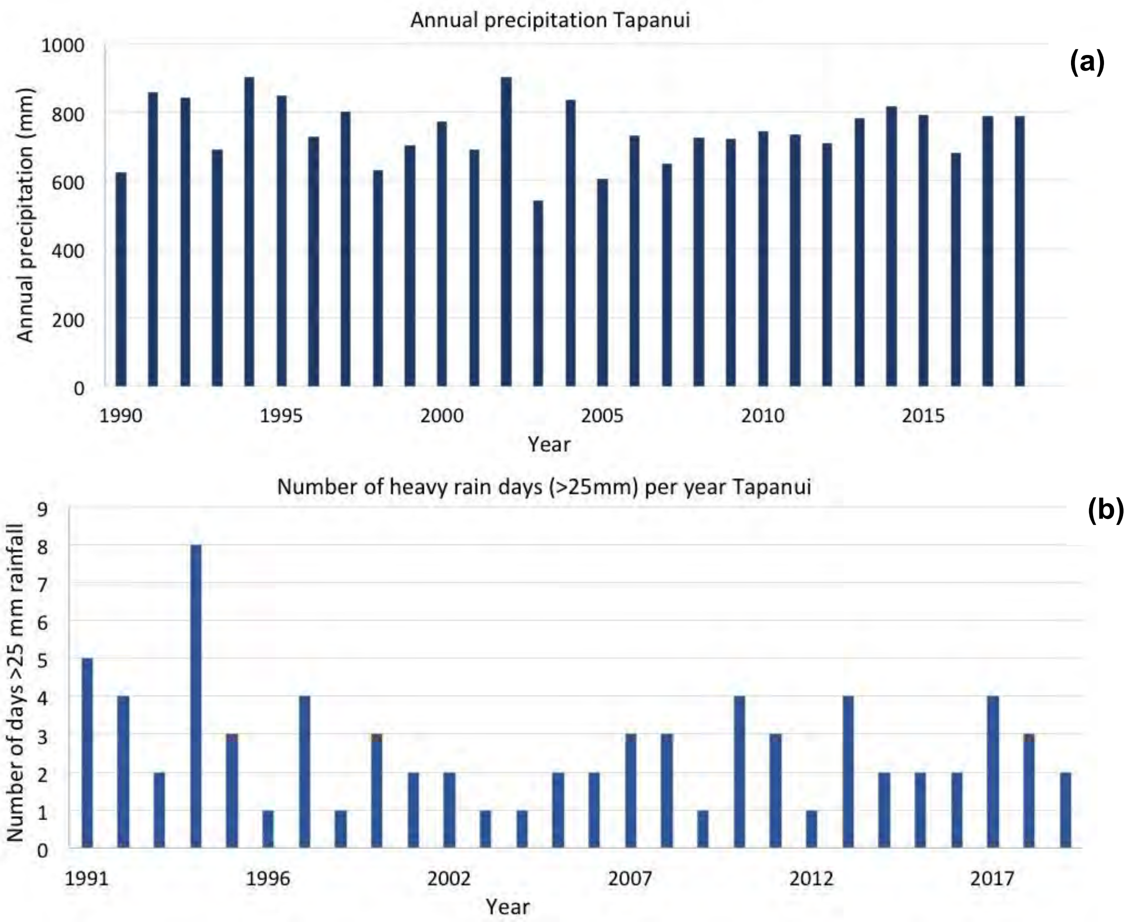


Figure 6-5 Historic precipitation data from Tapanui obtained from the NIWA climate database; a) annual precipitation in mm, and b) number of heavy rain days with precipitation greater than 25 mm in a 24-hour period [4].

6.3 WHAT DO FUTURE CLIMATE PREDICTIONS TELL US?

With the past and present climate outlined above, we can now draw on scientific models to understand the range of climatic change that is predicted to occur in the future. The changes outlined below reflect the output of downscaled global climate models produced by NIWA [1]. These models aim to predict how temperature and rainfall patterns will change, depending on different estimates of how much greenhouse gas we will emit in the future. Within this report we present two emission scenarios, from a low to mid-range or ‘stabilisation pathway’ (RCP 4.5) to a high range ‘business as usual’ scenario (RCP 8.5) (see section 1.3 for more information). While they are predictive, in that they will not tell us exactly how much things will change, they still provide a very useful tool for understanding the range of likely future climatic conditions.

6.3.1 Air temperature

Although air temperatures are predicted to increase across all of Clutha, the increases modelled for the West Otago area are slightly higher than elsewhere in the district. By 2040 mean annual air temperature is predicted to increase by 0.5°C to 1°C, and this is consistent with what is expected for the rest of the Clutha District (Figure 2-1) [1]. However, by the end of the century, the West Otago area is predicted to warm by 1°C to 1.5°C under RCP 4.5, or by 2°C to 3°C under the RCP 8.5 scenario. The largest increases in mean annual temperature are predicted for the more elevated parts of West Otago, in the headwaters of the Pomahaka River (Figure 2-1).

Along with increases in mean annual air temperature, the number of extreme hot days in West Otago is also expected to increase by the end of century (Figure 2-2). Under the highest emissions scenario (RCP 8.5), between four and 20 additional extreme hot days (>30° C) per year are possible by 2090. Much smaller increases are predicted under RCP 4.5 however (up to 6 additional days per year) [1]. West Otago is also expected to experience the largest reduction in frost days, and by 2090 the area can expect between 10 and 50 fewer frost days per year depending on location and emission scenario (Figure 2-3).

By 2090 under a high range emissions scenario, the town of Tapanui may also expect up to one less snow day per year, while the Umbrella Mountains/Old Man Range may expect up to five fewer snow days under the higher emission scenario (RCP 8.5).

6.3.2 Rainfall

Precipitation patterns are predicted to change under future climate change scenarios, and annual precipitation will likely increase, especially during the spring and winter months [1]. As for most of the district, annual rainfall in West Otago is expected to increase by 0 - 5% by 2040. By the end of the century however, the change in annual rainfall will be increasingly dependent on emission scenario (Figure 2-4). Under RCP 4.5 the increase is expected to remain at about 5%, while under RCP 8.5 the increase may be as high as 20% in the upper Pomahaka catchment, and between 10 and 15% elsewhere in West Otago.

An increase in the number of very wet days is also expected across the area, and by 2090 up to five additional days where rainfall exceeds 25 mm may be expected (Figure 2-5). The largest increase in heavy rain days would occur under RCP 8.5, and would include the area south of Tapanui and in the north over the Umbrella Mountains/Old Man Range. Rainfall intensities are also expected to increase, meaning more rain will fall during high rainfall periods.[dd]

While West Otago may experience an increase of up to four additional dry days in the short term (2040), this effect diminishes by the end of the century (2090) (Figure 2-7).

6.3.3 Wind speed and direction

Along with the temperature and rainfall changes outlined above, climate change will also contribute to other shifts in atmospheric processes, such as wind speed and direction. During winter, strengthened westerlies are predicted for the south of the South Island, with more north-easterly airflow expected during the summer months [5]. Minimal changes in extreme daily wind speeds are expected by 2040 (modelled as changes in the 99th percentile daily wind speeds, or the top 3 windiest days each year); however, by 2090 extremes winds may increase by 1 - 8% assuming a high range emissions scenario, with the Umbrella Mountains/Old Man Range predicted to experience the largest increases in extreme daily wind speed (Figure 2-8).

6.4 CLIMATE CHANGE IMPLICATIONS FOR PEOPLE, INFRASTRUCTURE AND INDUSTRY IN WEST OTAGO

The information above has provided an overview of past climate trends and future projections, but what does this mean for people, infrastructure and industry in West Otago? This section

[dd] In Tapanui for example, the depth of rain that falls during what is currently considered a '1 in 50-year, 24-hour event' will increase by approximately 6-7 mm (Figure 2-6). Presently, such an event leads to about 99 mm of rain, however by 2090 this may increase to 105 or 106 mm (depending on emissions scenario).

identifies some of the potential socio-economic impacts that may accompany climate change, including the implications of warmer weather on agriculture and forestry in the area.

6.4.1 Changes in flood risk

The West Otago ward experiences large flood events on a reasonably regular basis, and it is possible that the frequency of these events, and their associated impacts on infrastructure, communities and the environment may increase due to climate change.

The most significant flood hazard in this area is associated with the Pomahaka River. Flood events in the Pomahaka catchment are generally caused by heavy rain over a day or longer, due to persistent south-easterly conditions that can be coupled with snow melt in the spring and early summer [13]. The Pomahaka River and its tributaries (including the Waipahi River, Heriot Burn, Flodden Creek, and Leithen Burn) can rise rapidly, and carry large flows during flood events. Average velocities in the main river channels can be reasonably high in places, given the steep gradient of the catchment.

The Pomahaka River also has extensive flood hazard areas, which can extend across the flood plain for several kilometres in places. Land use on the flood-plain areas is generally high intensity dairy farming, and this activity can be impacted for days to weeks as a result of large flood events, due to channel erosion, sedimentation and extensive ponding of water. Large flood events can also cause damage to roads and bridges, both on rural flood-plain areas, and in the townships of Tapanui and Heriot (due to stormwater and high flows in tributary creeks). A recent example of flood events impacting roading was in February 2020, when high flows in the Pomahaka River at Conical Hill resulted in inundation of the Pomahaka-West Otago Road. [3] [6].

Section 6.3 shows the changes in the characteristics of heavy rainfall events which are predicted for the West Otago ward - this includes additional heavy rain days, and an increase in rainfall intensities during major storms. As a result, the frequency of rainfall events which are large enough to potentially cause damage to infrastructure and other assets may increase.

The natural, social and built environment in the West Otago area has already been modified significantly in order to reduce the impacts of flooding. Some examples include the retreat from Kelso[ee] (Box 1), a comprehensive flood warning system, and the placement of valuable infrastructure (such as milking sheds and other buildings) on higher ground. Therefore, the impact of more regular flood events on this community may not be as significant as elsewhere. However, the potential impacts of major floods, and how their impacts may increase under climate change scenarios, should still be carefully considered by Council and the community, when managing or investing in key infrastructure or other assets.

[ee] A view expressed during local consultation was that clearing of the tussock grass around the former Kelso township has contributed to greater rain water runoff, and a shortened lag time between heavy rain and rising waters [2].

Box 1. Flooding at Kelso

A series of major flood events in the Pomahaka catchment caused significant damage to the township of Kelso, which was located in the lower reaches of the floodplain, upstream of the Kelso Gorge. Repeat flood events eventually resulted in the abandonment of Kelso in the early 1980's. The images below show the Pomahaka River in flood on 17 January 1980 (top), and land use patterns today (bottom). Both images are looking south, downstream towards Kelso. Source: ORC (top) and Google Earth (bottom).

6.4.2 Agriculture

Climate change will also pose new issues and also create opportunities for agriculture in West Otago. Warmer conditions, fewer frosts and snow days, alongside increases in precipitation may see improved winter pasture growth that will support sheep and beef and dairy farming systems [8]. However, we may also see longer dry spells between rain events, which may contribute to temporary water supply issues, and may require continued investment into feed storage techniques. Warmer weather overall may also contribute to livestock heat stress and increase on-farm water demands [9]. In addition, opportunities to diversify into alternate crops may arise, and the Ministry for Primary Industries have identified that the future climate of vast areas of Otago, including the West Otago area, may become more suitable for kiwi fruit and viticulture [10].

We may also see an increase in flood risk if extreme precipitation patterns eventuate. Alongside risk to livestock, floods may exacerbate erosion and water contamination issues, particularly on dairy farms [8]. The recent floods of February 2020, which inundated large areas of dairy farm around the relic township of Kelso, stranding stock and damaging winter feed crops [11] demonstrates the impact of floods on agriculture in West Otago.

6.4.3 Forestry

West Otago, particularly land surrounding the Blue Mountains, has long been used for forestry activities. While this industry once focused on native forests, planting of exotic forest increased from the 1920's. New Zealand's emission trading scheme has encouraged the further expansion of radiata pine plantations throughout much of Otago, where it is planted on rougher hill country less suited to livestock, often to earn carbon credits. As the market for carbon credits increases, it is possible that West Otago may see more conversion of land to forestry [12]. The local forestry industry may also benefit from wetter and warmer conditions, and the fertilisation effects of higher levels of CO_2 in the atmosphere, which are predicted to favour the growth of radiata pine [10].

Figure 6-6 An example of land use patterns in West Otago, with sheep in the foreground, exotic forestry to the left, and the Blue Mountains in the distance (Source: GHC).

6.5 SUMMARY: WHERE TO FROM HERE?

Climate change will present new challenges and opportunities for West Otago. Overall, the area is expected to warm by between 0.5°C and 3°C by 2090, and is predicted to experience the largest increase in mean annual temperature and the greatest increase in the number of extreme hot days within the Clutha District. Increased precipitation and high intensity rainfall events may contribute to the risk associated with flooding in the Pomahaka catchment, especially where valuable assets or infrastructure are located close to waterways. The agricultural and forestry sectors may face new challenges in terms of flood and water management, yet gains in productivity may also be realised with a lengthened growing season, more winter rainfall and overall warmer conditions. Likewise, the forestry sector may face new opportunities in terms of production and market demand. Overall, while climate change will pose new challenges to West Otago, it may also bring new opportunities. Through informed planning and continued adaptation, these challenges may be faced and overcome.

6.6 CHAPTER 6 REFERENCES

[1] National Institute of Water and Atmospheric Research Ltd (NIWA) (2019). *Climate change projections for the Otago Region.* Report prepared for the Otago Regional Council. Macara, G., Woolley, J-M., Zammit, C., Pearce, P., Stuart, S., Wadhwa, S., Sood, A. & Collins, D.

[2] Personal communication with sheep farmer, Heriot, 21 March 2020.

[3] Personal communication with wife of sheep farmer and Clutha District Council employee, Tapanui, 21 March 2020.

[4] Data extracted from the National Climate Database, National Institute of Water and Atmospheric Research Ltd. Available at http://cliflo.niwa.co.nz/

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

[6] Otago Regional Council (2020).

[7] Data extracted from the High Intensity Rainfall Design System, National Institute of Water and Atmospheric Research Ltd. Available at https://hirds.niwa.co.nz/

[8] Ministry for Agricultural and Forestry (2008). *Climate Change: A guide for land managers.* Regional summary, effects and impacts: Otago and Southland. Wellington.

[9] Ministry of Agriculture and Forestry (2008). *The costs and benefits of climate change and climate change adaptation: What do we know so far?* Ecoclimate: Integrated research on the economics of climate change impacts adaptation and mitigation.

[10] Ministry for Primary Industries (2013). *Four Degrees of Global Warming: Effects on the New Zealand Primary Sector.* MPI Technical Information Paper No. 2013/49. Wellington.

[11] Neale Wallace, N. February 7, 2020. 'Floods follow poor conditions', Farmers Weekly available at: https://farmersweekly.co.nz/section/agribusiness/view/floods-follow-poor-conditions

[12] Adams, T. & Turner, J.A. (2012). An investigation into the effects of an emissions trading scheme on forest management and land use in New Zealand. *Forest Policy and Economics*, 15, 78-90.

[13] Otago Regional Council (2016*). Pomahaka River Morphology and Riparian Management Strategy*. J. Williams & R. Ozanne. May 2016.

7.0 CONCLUSION

A first assessment of climate change impacts and implications has been undertaken for the Clutha District Council as part of their Climate Change Leadership and Response Plan. The work program involved collating local knowledge alongside scientific assessments (provided by the National Institute of Water and Atmospheric Research - NIWA) to understand how Clutha will be impacted by changes in temperature and precipitation patterns.

The main findings conclude that the Clutha District is expected to become warmer and wetter by the end of this century. Notably, there will be fewer frosts, more extreme hot days, and heavier rainfall. The highest rates of temperature rise are expected for West Otago, and the smallest increases are expected for The Catlins. Rainfall intensities and mean annual rainfall are expected to increase across the district, with the towns of Milton and Waihola expected to experience the largest increases in annual precipitation rates. The Clutha River is expected to experience an overall increase in river flow, especially during the winter and spring months, due to more precipitation and less snowfall in the upper catchment. Sea level will continue to rise, which will increasingly impact coastal communities, particularly the towns of Taieri Mouth, Pounawea and low-lying parts of the Clutha Delta.

The changes outlined above will present challenges, alongside new opportunities, for communities, industry and infrastructure located in the Clutha District. The agricultural and forestry sectors may face new challenges in terms of flood and water management, yet they may also benefit from improved winter pasture growth and new cropping opportunities. Tourism, particularly in The Catlins, may benefit from overall warmer weather; however, wildlife, coastal landforms, and local infrastructure may be affected by sea level rise and erosion. Floods are likely to continue to pose challenges to agriculture and Council infrastructure in the Clutha District, and more work is needed to understand what is most at risk. Finally, and importantly, local residents are already experiencing, and some have begun the process of adapting to, a changing climate. This is particularly true for the district's sheep and beef, and dairy farmers, who hold in-depth knowledge of local weather patterns and are experienced in responding to weather extremes.

While the best attempts were made to source the most relevant and up to date climate data, the knowledge presented in this report will need to be revisited with time. As climate models become more detailed, and we track the actual impacts of climate change at the local level, the predictions presented in this report will improve. Updating this information is also important to understand the changing risk that climate change will pose to Council infrastructure and assets.[ff] Rather than a stand-alone and static document, it is hoped that this report will form part of an ongoing effort to understand, and respond to, climate change at the Clutha District level. [gg]

Despite the future challenges facing the Clutha District, through informed planning, and innovative adaptation, these challenges can be faced and overcome. Achieving this however, will involve a more detailed understanding of the assets and infrastructure at risk, alongside a better understanding of local adaptation measures, and the implementation of an informed and flexible planning approach.[hh]

[ff] see an excerpt from CDC's 2018-48 Infrastructure Strategy in Appendix 3

[gg] Note that NIWA's climate projection and extreme sea level rise data is now held in CDC's GIS database.

[hh] An example of this may include adoption of the dynamic adaptive pathways (DAP) planning approach, which allows decision makers to identify a range of possible adaptation options, how they are affected over time, and whether they reach a point at which they are no longer viable.

APPENDICES

A1.0 APPENDIX 1: NEW ZEALAND SEA LEVEL RISE ESTIMATES

Table A1.1 Approximate years, from possible earliest to latest, when specific sea-level rise increments (metres above 1986–2005 baseline) could be reached for various projection scenarios of sea-level rise for the wider New Zealand region (Source: MfE, 2017, NZ Coastal Policy Statement).[ii]

SLR (metres)	Year achieved for RCP 8.5 H (83 percentile)	Year achieved for RCP 8.5 (median)	Year achieved for RCP 4.5 (median)	Year achieved for RCP 2.6 (median)
0.3	2045	2050	2060	2070
0.4	2050	2065	2075	2090
0.5	2060	2075	2090	2110
0.6	2070	2085	2110	2130
0.7	2075	2090	2125	2155
0.8	2085	2100	2140	2175
0.9	2090	2110	2155	2200
1.0	2100	2115	2170	>2200
1.2	2110	2130	2200	>2200
1.5	2130	2160	>2200	>2200
1.8	2145	2180	>2200	>2200
1.9	2150	2195	>2200	>2200

[ii] Note that the year for achieving each sea level rise value has been rounded to the nearest five or 10 year value.

A2.0 APPENDIX 2: COASTAL INUNDATION MAPS, 50 CM SEA LEVEL RISE

Figure A2.1 Land which is potentially exposed to coastal inundation at Taieri Mouth (shaded blue), during a 1:100-year extreme sea level event, together with 50 cm of sea level rise.

Produced by Clutha District Council's GIS Section

Figure A2.2 Land which is potentially exposed to coastal inundation at Toko Mouth (shaded blue), during a 1:100-year extreme sea level event, together with 50 cm of sea level rise.

Produced by Clutha District Council's GIS Section

Figure A2.3 Land which is potentially exposed to coastal inundation at Bull Creek (shaded blue), during a 1:100-year extreme sea level event, together with 50 cm of sea level rise.

Produced by Clutha District Council's GIS Section.

Figure A2.4 Land which is potentially exposed to coastal inundation at Bull Creek (shaded blue), during a 1:100-year extreme sea level event, together with 100 cm of sea level rise.

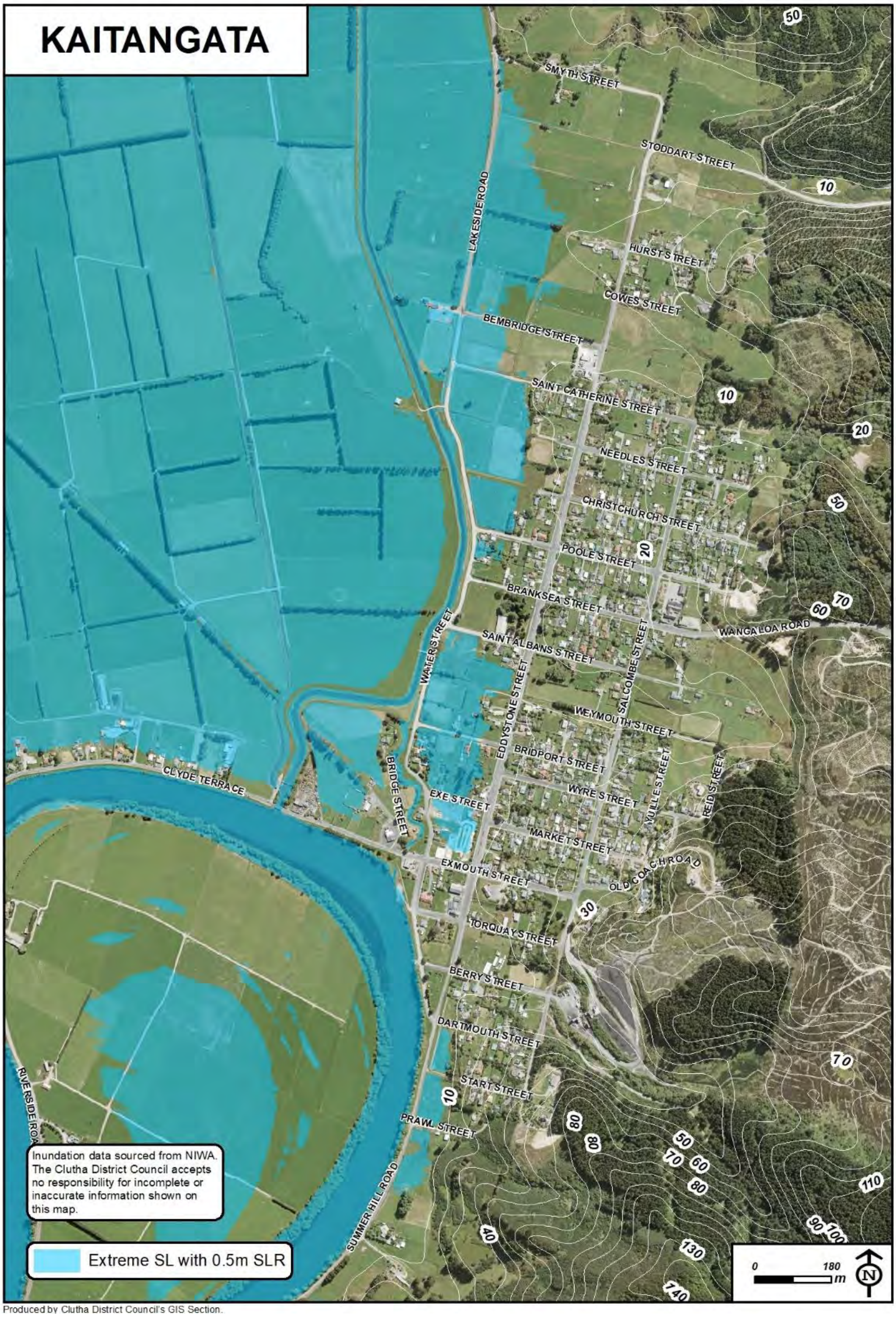


Figure A2.5 Land which is potentially exposed to coastal inundation at Kaitangata (shaded blue), during a 1:100-year extreme sea level event, together with 50 cm of sea level rise.

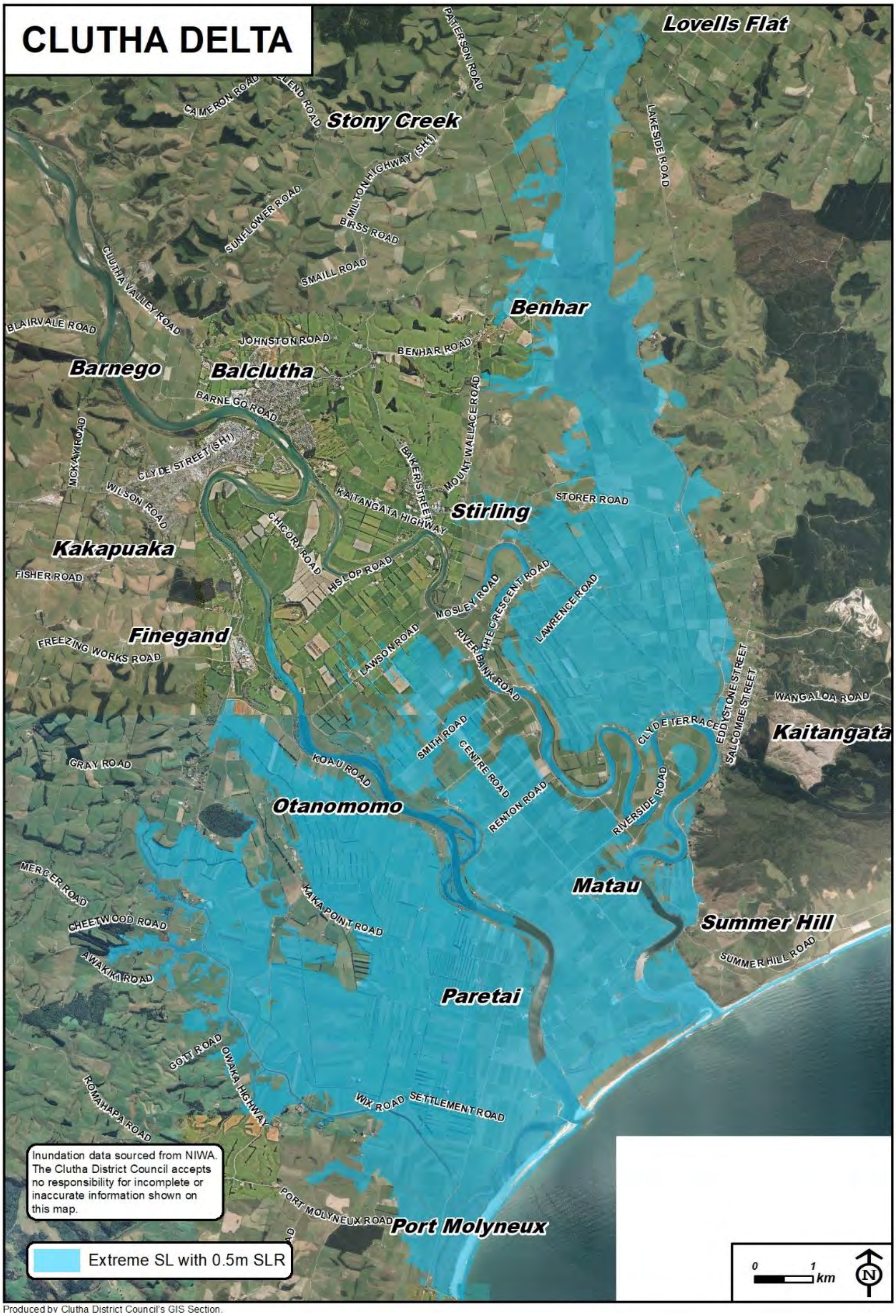


Figure A2.6 Land which is potentially exposed to coastal inundation on the Clutha Delta (shaded blue), during a 1:100-year extreme sea level event, together with 50 cm of sea level rise.

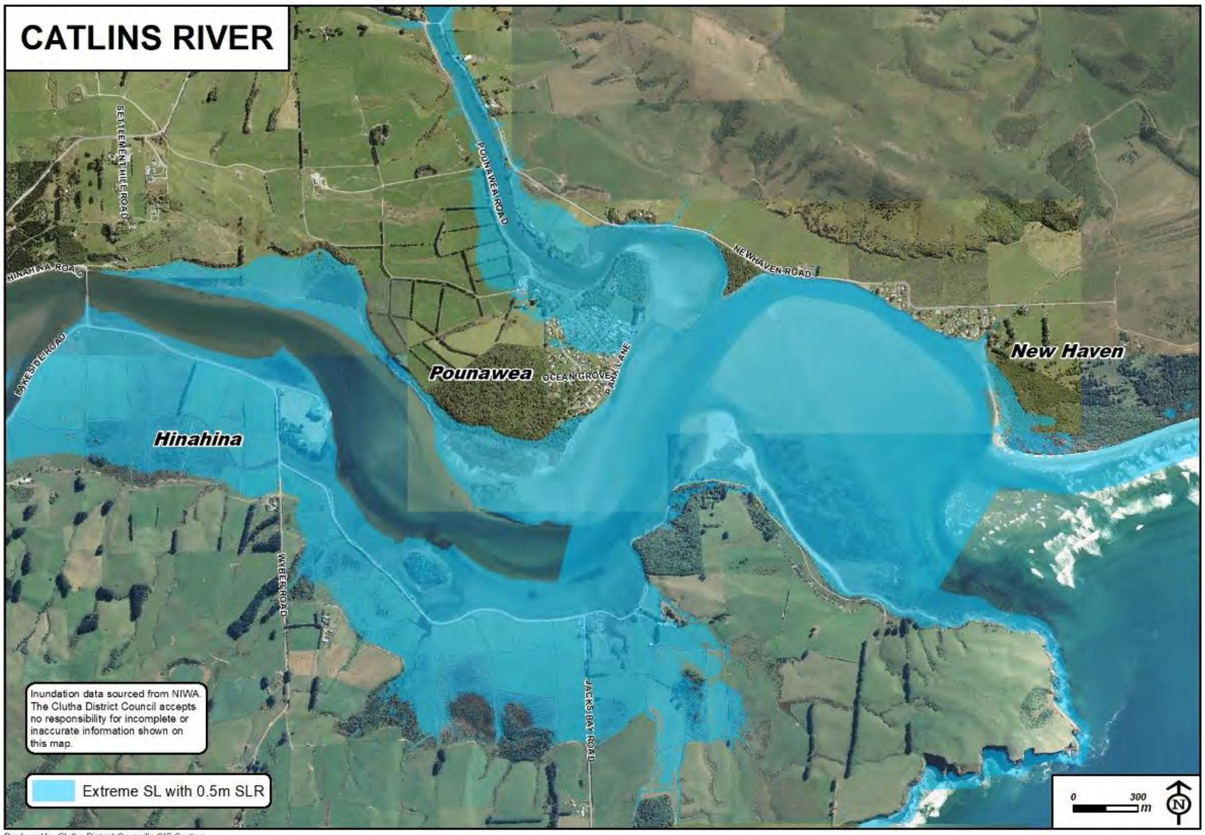
Figure A2.7 Land which is potentially exposed to coastal inundation at Kaka Point (shaded blue), during a 1:100-year extreme sea level event, together with 50 cm of sea level rise.

Produced by Clutha District Council's GIS Section

Figure A2.8 Land which is potentially exposed to coastal inundation at Willsher Bay (shaded blue), during a 1:100-year extreme sea level event, together with 50 cm of sea level rise.

Produced by Clutha District Council's GIS Section.

Figure A2.9 Land which is potentially exposed to coastal inundation at Pounawea (shaded blue), during a 1:100-year extreme sea level event, together with 50 cm of sea level rise.



Produced by Clutha District Council's GIS Section.

Figure A2.10 Land which is potentially exposed to coastal inundation on the margins of the lower Catlins and Owaka rivers (shaded blue), during a 1:100-year extreme sea level event, together with 50 cm of sea level rise.

Figure A2.11 Land which is potentially exposed to coastal inundation at Jacks Bay (shaded blue), during a 1:100-year extreme sea level event, together with 50 cm of sea level rise.

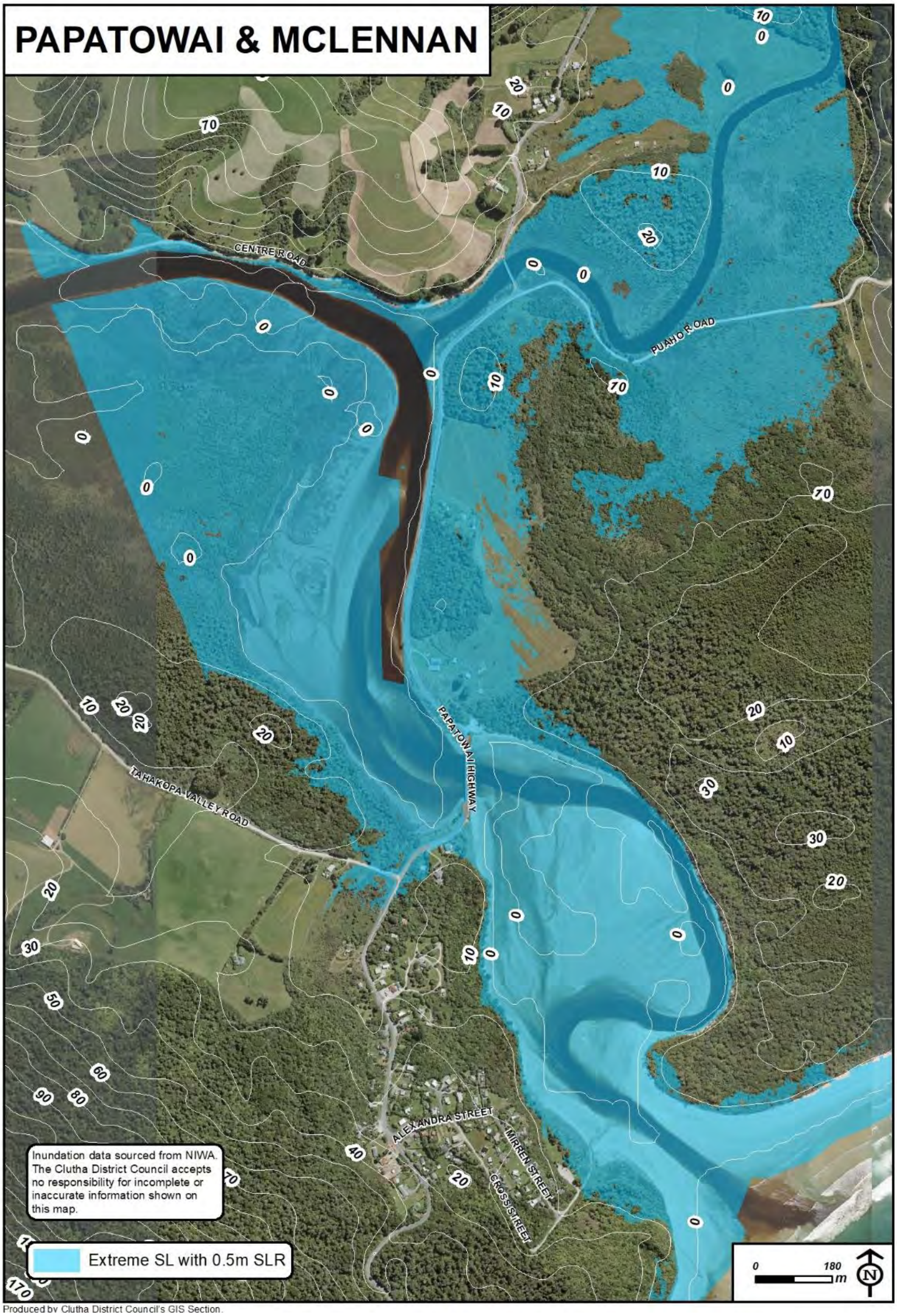


Figure A2.12 Land which is potentially exposed to coastal inundation at Papatowai and Maclennan (shaded blue), during a 1:100-year extreme sea level event, together with 50 cm of sea level rise.

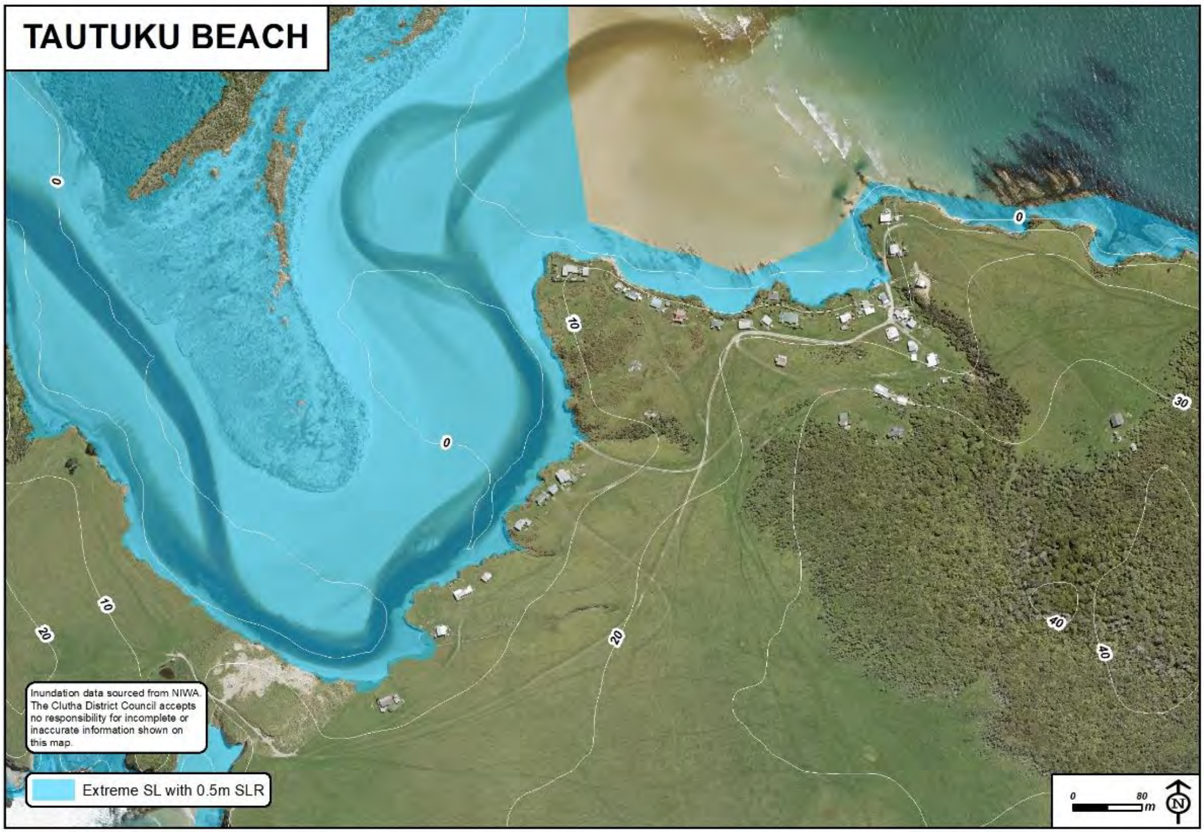


Figure A2.13 Land which is potentially exposed to coastal inundation at Tautuku Beach (shaded blue), during a 1:100-year extreme sea level event, together with 50 cm of sea level rise.

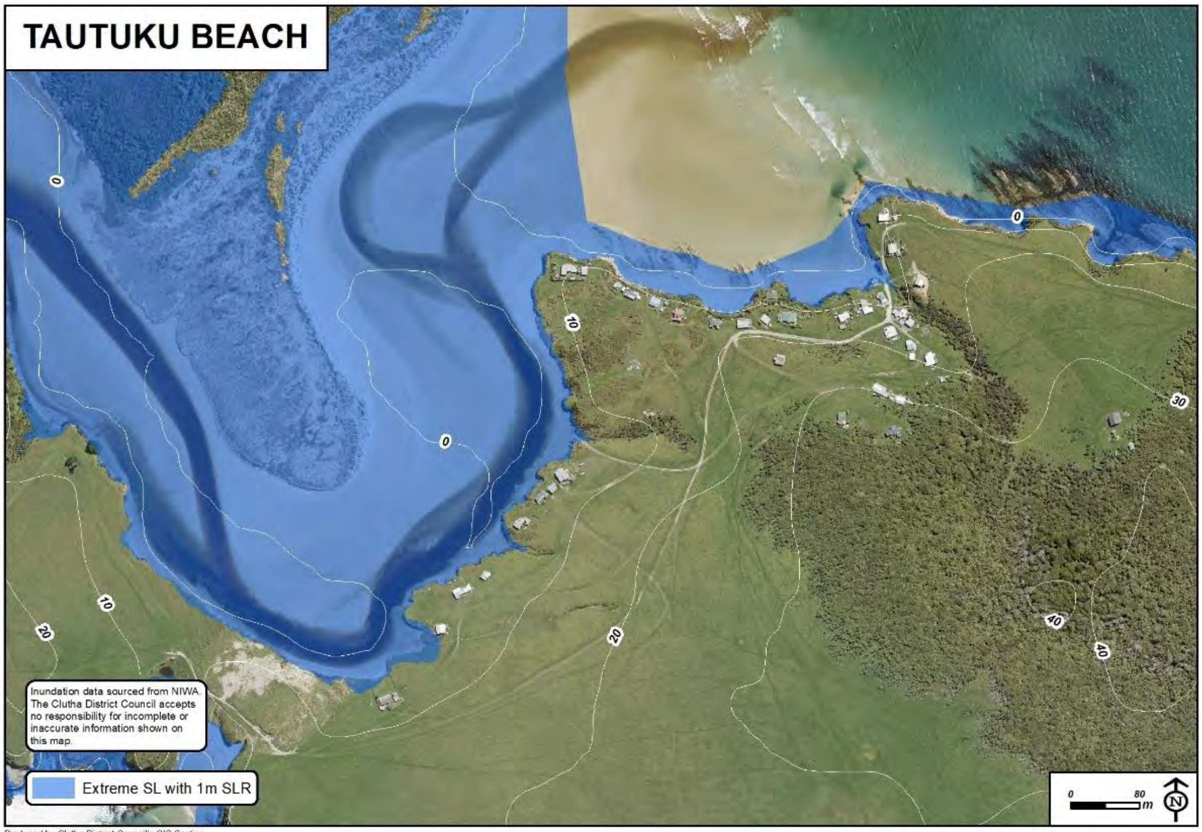


Figure A2.14 Land which is potentially exposed to coastal inundation at Tautuku Beach (shaded blue), during a 1:100-year extreme sea level event, together with 100 cm of sea level rise.

A3.0 APPENDIX 3: CDC INFRASTRUCTURE STRATEGY

The following text has been extracted from Clutha District Councils 2018-2048 Infrastructure Strategy.

The Clutha District has a varied and complex natural hazard setting, due to a combination of natural landscape-forming processes, and current land-use practices. The range of natural hazards that can be experienced include flooding, alluvial fan (debris flow) hazard, seismic activity, and coastal processes such as erosion, storm surge and tsunami. The level of risk associated with these hazards varies across the district, depending on the scale and type of each hazard and the nature and vulnerability of the features exposed to it. It is noted that the Clutha Delta and Milton areas are particularly vulnerable, given their low-lying topography and larger population centres.

Existing natural hazards may well be exacerbated by predicted changes in climate and sea-level rise. The effects of coastal erosion and inundation are increasingly likely to pose a threat to existing infrastructure and land-use. Where there is a reliance on natural or man-made features for protection, there will generally be a residual risk to residents and Council infrastructure, should the integrity or performance of those features be compromised in the future.

However, the strategy assumes that the effects of climate change will be felt gradually throughout the period of this Infrastructure Strategy, allowing Council time to plan and prepare its response options around services and infrastructure.

- *The specific impacts of long-term climate change on Council infrastructure may include: increased risk of flooding, landslides and erosion: the capacity of stormwater systems may be exceeded more frequently due to heavy rainfall events which could lead to surface flooding, damage to infrastructure and road closures.*

- *Water availability: water security is more likely to be an issue. Droughts are likely to increase in both intensity and duration over time.*

- *Coastal hazards: there is likely to be increased risk to coastal roads and infrastructure from coastal erosion and inundation, increased storm surge and sea-level rise.*

If the impacts of climate change are felt sooner than expected there may be demands on Council's budgets. Council's ability to deliver the level of service to the community may be impacted if climate change occurs faster than expected or to a greater extent. If this occurs it may require unbudgeted emergency work to be carried out and/ or create additional costs to mitigate impacts, such as improving protection of critical infrastructure or increasing maintenance.

Council's financial position allows flexibility to respond to any unexpected events or trends, through borrowing for emergency works if required. In addition, Council self-insures for underground assets to help provide for emergency work if required. To ensure that our infrastructure is resilient, Council will ensure that new assets are of sufficient standard to cater for the predicted effects of climate change, including increased rainfall intensity/duration, and sea-level rise. The full range of consequences that may arise from climate change and sea-level rise needs to be considered, along with possible interactions between multiple risk sources, and any uncertainty in terms of how people or systems will behave. Council is planning to carry out more detailed modelling around climate change impacts over the next 3 years and will continue to monitor climate change science and the response of central government, and adapt its response where required. In addition, Council will continue to support civil defence and emergency management preparations, so that communities in the Clutha District are well prepared for the effects of natural hazards.

A4.0 APPENDIX 4: ANNUAL PRECIPITATION - KATEA

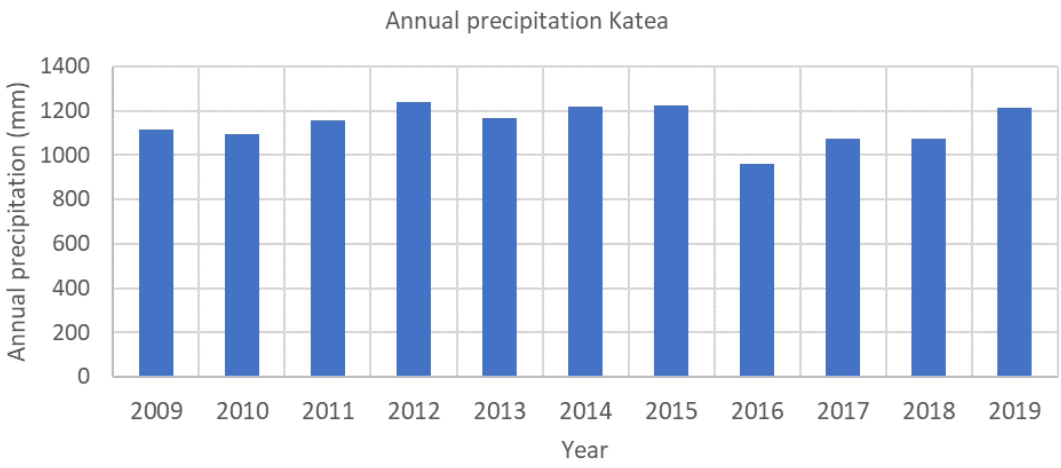


Figure A4.1 Annual precipitation totals from Katea in the Owaka Valley