REPORT

IMPACT OF CLIMATE CYCLES AND TRENDS ON COUNCIL ASSETS 2023 Update

PREPARED FOR

Selwyn District Council

WL23041

07/09/2023

PREPARED BY
Nick Dudley Ward
Ayaka Kashima
Ross Hector
Greg Hatley
Olivia Cranney

aqualinc.com

Disclaimer

This document has been prepared solely for the benefit of Selwyn District Council. No liability is accepted by Aqualinc Research Ltd or any employee or sub-consultant of this Company with respect to its use by any other person.

This disclaimer shall apply notwithstanding that the document may be made available to other persons for an application for permission or approval or to fulfil a legal requirement.

Quality Control

Client	Selwyn District Council
Document Title	Impact of Climate Cycles and Trends on Council Assets - 2023 Update
Document Number	WL23041-1
Authors	Nick Dudley Ward, Ayaka Kashima, Ross Hector, Greg Hatley, Olivia Cranney
Reviewed By	Andrew Dark
Approved By	Andrew Dark
Date Issued	07/09/2023
Project Number	WL23041
Document Status	Final
File Name	WL23041_report_final

For more information regarding this document please contact

Andrew Dark
Business Manager Research and Development
Aqualinc Research Limited
(03) 964 6521
a.dark @aqualinc.co.nz

The preferred citation for this document is:

Dudley Ward, N; Kashima, A; Hector, R; Hatley, G. Cranney, O. (2023): Impact of Climate Cycles and Trends on Council Assets - 2023 Update. Selwyn District Council, Aqualinc Report WL23041-1. Aqualinc Research Ltd.

DOCUMENT CONTROL

Version Number	Date	Name
1	30 June 2023	Draft for SDC comment
2	7 September 2023	Final

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Aqualinc has produced two previous reports for Selwyn District Council on the impact of climate cycles and trends on water infrastructure: *Impacts of Climate Cycles and Trends on Selwyn District Water Assets*. The first report was completed in 2016, and an update was completed in 2020.

These previous reports compared future climate projections to 2050 with historical data, which aligned with the timeframe for SDC's Long Term Plan (LTP). Furthermore, they focused solely on SDC's Five Waters assets (water supply, wastewater, stormwater, land drainage and water races).

This report is an update of the previous two reports, with historical climate data extended to 2023. It differs from the previous reports in the following significant ways:

- expansion of the range of SDC assets considered to include roading, facilities and open spaces,
- consideration of risks from non-SDC assets,
- extension of the analysis timeframe for climate future projections to 2100, and
- places greater focus on climate projections than historic data.

Since the 2020 report, several important international and national reports have been published, with the most notable being Assessment Report 6 (AR6) which is the most detailed synthesis of climate change science. While broadly consistent with AR5 (published in 2013/2014), its conclusions are expressed with significantly greater confidence and sense of urgency. The main message from this report is that climate futures are highly dependent on emissions scenarios, and therefore highly uncertain. Under all scenarios, climate change means more volatility in weather patterns with a greater incidence of extreme events.

Assessments of climate impacts and their associated risks on SDC assets are summarised in Table 1 and Table 2. There levels of risk have been assigned ('low', 'medium' and 'high'). There is inevitably a high degree of subjectivity in the assignment of risk level, which has been carried out in consultation with SDC staff. Most environmental factors assessed as high risk relate to the occurrence of extreme events like extreme rainfall, drought, or high wind. Of substantially greater importance than the assignment of absolute risk is the relative risk between different asset classes and different environmental factors.

This assessment should be compared with Tonkin and Taylor's *Canterbury Climate Change Risk Assessment.* This report differs substantially from the T+T report for several reasons including:

- difference of spatial scale – the T+T report covers all of Canterbury and includes all stakeholder and asset owner interests. This report is focused solely on the Selwyn District and the council's assets.
- granularity – Selwyn district is partitioned into three zones (high country, plains and low plains/coastal) and an assessment of risks to assets has been given for each zone.

The T+T report has four risk levels ('low', 'moderate', 'high' and 'extreme') instead of three. As an example of the difference between the current report and the T+T report, risk to groundwater availability due to sea level rise is assessed as 'extreme' for all climate futures in the T+T report whereas we have assessed it to be low / medium (but with substantial uncertainties). Sea level rise (SLR) poses a significant risk to shallow coastal groundwater systems but since SDC groundwater is sourced from relatively deep bores our assessment is that (moderate) SLR will not significantly impact SDC's potable water supply, projecting to 2050.

Zone	Environmental factor	Water	Wastewater	Stormwater	Land drainage	Water races
All zones	Temperature (excl. ET impacts)	Medium	Medium	Medium	Medium	High
	Annual rainfall	Low	Low	Low	Low	Low
	Drought	High	Low	Low	Low	Medium
	Evapotranspiration (ET)	Medium	Low	Low	Low	Low
	Wind (excluding ET impacts)	Medium	Medium	Low	Low	Low
	Alpine river flows	Medium	Low	Low	Low	High
Alpine, hills and high-Country	Extreme rainfall events (foothills and alpine)	High	High	High	High	High
	Foothills-sourced river flows	High	Low	Low	Low	High
	Snow levels and ice	Low	Low	Low	Low	Low
Plains	Extreme rainfall events (Plains)	Low	High	High	High	High
	Snow levels and ice	Low	Low	Low	Low	Low
	Ground water levels (upper /mid plains)	Medium	Low	Low	Low	Low
Coastal and lower plains	Sea Level rise	Low	Medium	Medium	High	Low
	Extreme rainfall events (Coastal)	High	High	High	High	Medium
	Groundwater levels (Lower Plains)	Low	Low	low	Medium	Low

Table 1. Summary risk assessment of climate change impacts on SDC water assets projecting to 2050.

Zone	Environmental factor	Transportation	Community facilities	Developed open spaces	Natural open spaces
All zones	Temperature (excl. ET impacts)	High	High	High	Medium
	Annual rainfall	Low	Low	Low	Low
	Drought	Low	Low	High	Medium
	Evapotranspiration (ET)	Low	Low	Medium	Low
	Wind (excluding ET impacts)	Low	High	High	High
	Alpine river flows	Medium	Low	Medium	Medium
Alpine, hills and high-Country	Extreme rainfall events (foothills and alpine)	High	High	High	High
	Foothills-sourced river flows	High	High	High	Medium
	Snow levels and ice	Low	Low	Low	Low
Plains	Extreme rainfall events (Plains)	High	High	High	High
	Snow levels and ice	Low	Low	Low	Low
	Ground water levels (upper /mid plains)	Low	Low	Low	Low
Coastal and lower plains	Sea Level rise	Medium	Medium	High	Medium
	Extreme rainfall events (Coastal)	High	High	High	High
	Groundwater levels (Lower Plains)	Low	Low	Medium	Low

Table 2. Summary risk assessment of climate change impacts on SDC transportation, community, and open space assets projecting to 2050.

The key messages of this report are summarised below:

Temperature

- Over the last 100 years New Zealand has warmed by an average of 1°C.
- Future annual average warming in Canterbury spans a wide range: 0.5-1.5 °C by 2040, and 0.5-3.5°C by 2090, depending on the greenhouse gas emission scenario.
- By 2040, seasonal mean temperatures across much of Canterbury are projected to increase by 0.5-1.5°C under RCP4.5. By 2090 they are projected to increase by 1.5-3.0°C under RCP8.5, with increases of 3.0-4.0°C for westernmost pasts of Canterbury.

- The number of hot days is projected to increase by 10-20 days by 2040 for the Selwyn District under both RCP4.5 and 8.5. By 2090 the number of hot days is projected to increase by 10-60 days.
- The number of frost days is projected to decrease by 10-30 frost days per year for inland parts of the region. By 2090 the number of frost days is projected to decrease by 20-50 days for inland areas of Canterbury.

Evapotranspiration

- By 2040, both RCP4.5 and RCP8.5 project an accumulated potential evapotranspiration deficit (PED) of 50-100 per year for most eastern parts of Canterbury.
- By 2090 under RCP8.5 5, PED is projected to increase by 100-200 mm per year for many inland areas of the Selwyn District.
- Historical PET records suggest that rates have not changed significantly over the period 1960-2023.

Annual rainfall

- Annual rainfall is projected to change by between ±5% for most of Canterbury by 2040 and 2090.
- Winter rainfall is projected to increase considerably by 2090 under RCP8.5 in many eastern, western and southern parts, with 15-40% more rainfall projected.

Dry days

- By 2040, under RCP4.5 the annual number of dry days is projected to decrease by up to 5 days for eastern parts of the District and the Plains, while increasing by a smiliar amount elsewhere.
- By 2090, under RCP8.5 this is projected to change by up to ±15 days.

Extreme rainfall

- Extreme rainfall events are expected to increase everywhere in New Zealand.
- With 2°C warming, projections of the increase in 50-year Rx1 day and Rx5 day events for New Zealand are inconsistent.
- With 4°C warming, models project a median increase in the intensity and frequency of heavy precipitation of more than 15% in the 50-year Rx1 day and Rx5 day events compared to the 1°C warming level.

Snow and windspeed

- The number of snow days is projected to decrease throughout the district, with the largest reductions of the order of 10-25 days in higher elevation areas.
- Annual mean wind speed is projected to increase 2-10% for much of the district under RCP8.5.

Groundwater

- Groundwater levels in bores drilled into deeper aquifers are projected to decrease, with a greater frequency of lower water levels.
- Groundwater levels in shallow coastal bores are projected to increase slightly due to sea level rise (SLR).
- SLR will lead to a greater risk of saline intrusion near the coast, but the extent and magnitude has a high degree of uncertainty.

River flows

- Historical river flow data in the Selwyn District does not indicate any long-term trends.
- Mean annual flows in the alpine rivers (Waimakariri and Rakaia) are projected to increase by 3% by the 2040's, as a result of increased alpine precipitation. The greatest increases are likely to occur in winter.
- Foothill river flows may slightly decrease over the next 30 years, due to a small increase in evapotranspiration.
- Towards 2100, the annual cycle of river flows may be significantly modified and is highly dependent on climate future.

Sea level rise

- In the last 60 years, sea levels have risen by 2.44 mm per year (0.14 m total). If global emissions remain high, sea levels will increase by a further 0.21 m by 2040 and 0.67 m by 2090 (MfE, 2020).
- Sea levels are projected to rise by up to 0.90 m by 2100 under RCP8.5.
- ESL (extreme sea level) events that are historically rare will become common by 2100 under all emissions scenarios.
- With SLR, saltwater intrusion into coastal and surface waters and soils is expected to be more frequent and enter farther inwards.
- Sea level rise (SLR) may result in Te Waihora / Lake Ellesmere needing to be opened more often or managed under a new operating range. If global emissions remain high, and without any change in lake management, lake levels are projected to rise by 0.21 m by 2040 and 0.67 m by 2090.

Risk assessment of SDC assets

Summary tables of risk assessments for SDC assets are given in Tables 1 and 2. The following comments apply to all asset classes:

- Projecting to 2050, environmental factors assessed as high risk of impacting SDC assets relate to the occurrence of more extreme weather events.
- Projecting to 2100, climate change impacts on SDC assets are highly dependent on emissions scenario.
- In all emissions scenarios, the occurrence of extreme weather events is likely to increase.

Comments specific to asset classes are given below:

Potable water supply

- Based on current projections, significant longer-term impacts on environmental factors like groundwater levels up to mid-century may be relatively small.

Wastewater

- Higher alpine rainfall and flood flows will likely result in an increase of stormwater inflows for the Arthurs Pass, Castle Hill and Lake Coleridge wastewater systems.
- An increase in sea level rise of ~0.21 m may impact Upper Selwyn Huts and Rakaia Huts wastewater systems.
- Projecting to 2100, climate change impacts on SDC wastewater assets are highly dependent on emissions scenario.

Stormwater

- Higher alpine rainfall and extreme rainfall events may result in an increase in occurrence of surface flooding at Arthurs Pass, Castle Hill and Lake Coleridge.
- An increase in sea level rise of ~0.21 m may impact the efficacy of the stormwater system during coastal storm events at Rakaia Huts.

Land drainage

- Higher alpine rainfall and extreme rainfall events may result in an increase in occurrence of surface flooding in the Arthurs Pass land drainage (flood protection) systems.
- An increase in sea level rise of ~0.21 m will impact Te Waihora /Lake Ellesmere levels and parts of the land drainage network.

Water races

- An increase in alpine flood flows could result in an increase in flood damage to intakes. Conversely, higher alpine flows would improve reliability of water supply.
- A potential minor reduction in flows in the Kowai River may impact supply reliability.

Transportation assets

- Under all emissions scenarios, the incidence of extreme events is expected to increase resulting in more frequent road closures.
- Flood events previously categorised as 1 in 100 year events may become 1 in 10 year events

Facilities and open spaces

- Under all emissions scenarios, the incidence of extreme events is expected to increase resulting in more frequent inundation of areas.
- More frequent occurrence of extreme events will impact on building envelopes and systems, and the accessibility and usability of facilities that are required as part of emergency response.

Recommendations and limitations

This report reviewed many information and data sources. Projected climate futures were used to assess risks to SDC assets as defined in the scope of this report. The aim of this exercise is to help SDC asset managers and planners prioritise resilience planning. This report provides a high-level assessment of climate change impacts that is meant as a guide for this moment in time. Projected climate futures may not be how the future climate eventuates, and recent collective global experience suggests that impacts may be accelerating. We therefore recommend a review and rescoping of this work within two years, with a significant focus on adaptation.

Projecting even into the near future, the biggest uncertainty is groundwater. This is because groundwater systems are hidden from sight, and it is difficult to monitor effects.

The impact of sea level rise on (especially) shallow coastal groundwater systems is a very significant uncertainty. Given that large-scale saline contamination and soil degradation through salination is likely to be effectively irreversible, we recommend further investigation on the Selwyn District's coastal groundwater and sea level rise. The purpose of this is to provide recommendations to better monitor the state of shallow coastal groundwater systems, to enable early warning of severe impacts and more robust decision-making in the future.

1 INTRODUCTION

This section provides summaries of:

- **Previous reports and revised scope for present report,**
- **Recent national and international reports on Climate Change,**
- **Risk assessments of SDC assets, and**
- **Document structure.**

Aqualinc has produced two previous reports for Selwyn District Council on the impact of climate cycles and trends on water infrastructure: *Impacts of Climate Cycles and Trends on Selwyn District Water Assets*. The first report was completed in 2016 while an update was completed in 2020.

These reports compared future climate projections to 2050 with historical data, which aligned with the timeframe for SDC's Long Term Plan (LTP). Furthermore, they focused solely on SDC's Five Waters assets (water supply, wastewater, stormwater, land drainage and water races).

This report is an update of the previous two reports, with historical climate data extended to 2023. It differs from them in the following significant ways:

- expansion of the range of SDC assets considered to include roading, facilities and open spaces,
- consideration of risks from non-SDC assets,
- extension of the analysis timeframe for future projections to 2100,
- and places greater focus on climate projections than historic data.

Since the 2020 report, several important international and national reports have been published:

- In 2021-2023 the International Panel on Climate Change (IPCC) published Assessment Report 6 (AR6) which is the most detailed synthesis of climate change science. While broadly consistent with AR5 (published in 2013/2014), its conclusions are expressed with significantly greater confidence and sense of urgency, as will be discussed in the next section.

- Furthermore, the Ministry for the Environment published *National Climate Change Risk Assessment for New Zealand* (MfE, 2020) which is an important point of reference for the current report.

- Given that downscaled climate change projections for New Zealand using AR6 have not yet been made available, the MfE has also issued *Aotearoa New Zealand climate change projections guidance* (MfE, 2022), which provides a distilled summary and interpretation of the AR6 findings that are relevant to New Zealand. This report states that *'overall future regional projections using CMIP6 [Coupled Model Intercomparison Project Phase 6] global projections over New Zealand, excluding extremes, are expected to be similar to previous versions, but perhaps with areas of improved confidence and clarity'*. This report uses a combination of information from assessment reports based on AR5 and AR6.

- We also reference extensively NIWA's 2020 report *Climate change projections for the Canterbury Region,* based on a downscaling of AR5.

While it is important to understand climate change impacts in the context of historical climate, the planet is undergoing unprecedented and rapid climate and environmental changes that are not reflected in the last 100 years of historical data. So, while a particular extreme weather event may be comparable in magnitude to previous observed events, extreme weather events are projected to become more frequent. For example, events which were regarded as 1 in 100-year events will, in time, become closer to 1 in 10-year events. This important uncertainty ('in time') is a critical factor in risk management. Table 3 and Table 4 provide an overall risk assessment for SDC water, transportation, community facility and open space assets, categorised by zone (hills and high country, plains and coastal) and environmental factor. Most factors assessed as high risk relate to the (projected) increased occurrence of extreme weather events and to sea level rise.

Zone	Environmental factor	Water	Wastewater	Stormwater	Land drainage	Water races
All zones	Temperature (excl. ET impacts)	Medium	Medium	Medium	Medium	High
	Annual rainfall	Low	Low	Low	Low	Low
	Drought	High	Low	Low	Low	Medium
	Evapotranspiration (ET)	Medium	Low	Low	Low	Low
	Wind (excluding ET impacts)	Medium	Medium	Low	Low	Low
	Alpine river flows	Medium	Low	Low	Low	High
Alpine, hills and high-Country	Extreme rainfall events (foothills and alpine)	High	High	High	High	High
	Foothills-sourced river flows	High	Low	Low	Low	High
	Snow levels and ice	Low	Low	Low	Low	Low
Plains	Extreme rainfall events (Plains)	Low	High	High	High	High
	Snow levels and ice	Low	Low	Low	Low	Low
	Ground water levels (upper /mid plains)	Medium	Low	Low	Low	Low
Coastal and lower plains	Sea Level rise	Low	Medium	Medium	High	Low
	Extreme rainfall events (Coastal)	High	High	High	High	Medium
	Groundwater levels (Lower Plains)	Low	Low	low	Medium	Low

Table 3. Summary risk assessment of climate change impacts on SDC water assets projecting to 2050.

Zone	Environmental factor	Transportation	Community facilities	Developed open spaces	Natural open spaces
All zones	Temperature (excl. ET impacts)	High	High	High	Medium
	Annual rainfall	Low	Low	Low	Low
	Drought	Low	Low	High	Medium
	Evapotranspiration (ET)	Low	Low	Medium	Low
	Wind (excluding ET impacts)	Low	High	High	High
	Alpine river flows	Medium	Low	Medium	Medium
Alpine, hills and high-Country	Extreme rainfall events (foothills and alpine)	High	High	High	High
	Foothills-sourced river flows	High	High	High	Medium
	Snow levels and ice	Low	Low	Low	Low
Plains	Extreme rainfall events (Plains)	High	High	High	High
	Snow levels and ice	Low	Low	Low	Low
	Ground water levels (upper /mid plains)	Low	Low	Low	Low
Coastal and lower plains	Sea Level rise	Medium	Medium	High	Medium
	Extreme rainfall events (Coastal)	High	High	High	High
	Groundwater levels (Lower Plains)	Low	Low	Medium	Low

Table 4. Summary risk assessment of climate change impacts on SDC transportation, community, and open space assets projecting to 2050.

An overview of the document structure is given in Table 5. Each section begins with a short summary or key messages with sections being largely self-contained.

Report Section No.	Topic	Purpose
1	Introduction	Previous reports, purpose, summary risk matrices.
2	Climate Change Science and AR6	Overview of AR6 and related reports.
3	Climate Cycles and Variability	Overview of climate patterns.
4	Historical Data	Sources of historical data.
5	Temperature	Summaries of historical data and projected climate futures.
6	Evapotranspiration	
7	Rainfall	
8	Other Climate Variables	
9	Groundwater	Modelled groundwater system responses to climate change futures and irrigation.
10	River Flows	Summaries of historical data and projected climate futures.
11	Sea Level Rise	Sea level rise (SLR) and secondary impacts.
12	Te Waihora/Lake Ellesmere	
13	Rakaia Mouth	
14	Rakaia Huts	
15	Groundwater and Sea Level	
16	Potable Water Supply	Projected impacts of climate change on SDC assets and risk assessments.
17	Wastewater	
18	Stormwater	
19	Land Drainage	
20	Water Races	
21	Transportation Assets	
22	Facilities and Open Spaces	
23	Non-SDC assets	
24	Recommendations and limitations	
25	References	
	Appendix A	IrriCalc model.
	Appendix B	Groundwater model calibration.

Table 5. Report structure.

2 CLIMATE CHANGE SCIENCE AND AR6

2.1 International and national reports

The basis of the 2020 *Impacts of Climate Cycles and Trends* report was the International Panel on Climate Change (IPCC) assessment report AR5 (2013/2014) and a Ministry for Environment report *Climate Change Projections for New Zealand* (2016) based on AR5.

In 2021-2023 the IPCC published updated AR6 synthesis reports. The overall conclusions of AR5 and AR6 remain the same: the world is warming with human activities being the primary cause, but at a rate faster than previously estimated and with a higher incidence of extreme events. However, conclusions are expressed with significantly greater confidence in AR6, with many conclusions strengthened. Additionally, projections and estimates of temperature increase are slightly higher than in AR5. For example, AR6 concludes that the world has already warmed by 1.1°C since pre-industrial times, compared to 0.85°C in AR5.

AR6 states that *'it is unequivocal that human influence has warmed the atmosphere, ocean, and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred*'. Notably, AR6 observes that each of the last four decades has been successively warmer than any decade that preceded it since 1850.

The biggest driver of climate change is the increase in atmospheric concentrations of greenhouse gases, primarily carbon dioxide (CO_2), that result from human activities, such as burning fossil fuels for energy (coal, oil, and natural gas), deforestation, and industrial processes. These greenhouse gases trap heat in the atmosphere, causing the Earth's temperature to rise and leading to a range of impacts including sea level rise, more frequent and intense heatwaves, more severe storms, and changes in precipitation patterns.

To estimate impacts of Climate Change in the future, AR5 used four Representative Concentration Pathways (RCPs). These are standardised scenarios which model different trajectories of greenhouse gas emissions and their potential impacts on the climate system:

- **RCP2.6**: This is the most optimistic scenario, in which greenhouse gas emissions peak around the year 2020 and then decline rapidly, leading to a world in which global warming is limited to below 2°C above pre-industrial levels by the end of the century.

- **RCP4.5**: This scenario assumes that greenhouse gas emissions continue to rise until around mid-century, and then gradually decline due to a combination of technological change, policy measures, and behavioural changes. It assumes that the world will warm by about 2°C above pre-industrial levels by the end of the century, but that this warming will be limited to below 2°C if additional measures are taken.

- **RCP6.0**: This scenario assumes a more moderate level of greenhouse gas emissions, with emissions continuing to rise until around mid-century and then declining more slowly than in RCP4.5. It assumes that the world will warm by about 3°C above pre-industrial levels by the end of the century, but that this warming could be limited to below 2°C if aggressive mitigation measures are taken.

- **RCP8.5**: This is the most pessimistic scenario, in which greenhouse gas emissions continue to rise throughout the 21st century, largely driven by a reliance on fossil fuels and limited mitigation efforts. It assumes that the world will warm by about 4°C above pre-industrial levels by the end of the century, with significant impacts on ecosystems, food production, and human health.

RCP4.5 and RCP8.5 were considered in the 2020 report. In 2020 the RCPs were replaced by Shared Socioeconomic Pathways (SSPs) and include five scenarios: SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5. The principal difference is that the SSPs consider broader socioeconomic and political trends that could affect the trajectory of emissions, for example, future demographic trends, economic development, energy use, land use, and technological change. Broadly speaking the conclusions drawn from the SSPs are consistent with those from AR5.

The 2022 Ministry for the Environment report *Aotearoa New Zealand climate change projections guidance* provides a summary and interpretation of AR6 relevant to New Zealand. Table 6 shows the difference between projected global mean warming between AR5 and AR6. Note that the 'envelopes of uncertainty' in brackets are slightly smaller in AR6 than in AR5, while the level of confidence expressed has also increased in AR6 ('likely range' to 'very likely range'). Table 7 shows projected changes in New Zealand temperatures for mid-century and end of century under a range of SSPs. The report notes that *'New Zealand regional air temperature* *is projected to increase slightly less than the global mean, reflecting the large oceanic influence on New Zealand climate*'.

Table 6. Projected global mean warming in 2081-2100, relative to 1850-1900, in AR5 and AR6. The AR5 values are originally relative to the mean temperature of 1986-2005. Following AR5, 0.6°C has been added to represent warming between 1850-1900 and 1986-2005. 'SPM' refers to the WG1 Summary for Policymakers reports for AR5 and AR6. (Table 1 from MfE, 2022).

End-of-century nominal radiative forcing (W m^{-2})	Warming in 2081-2100 (°C) under RCP scenarios (likely range; AR5 table SPM.2)	Warming in 2081-2100 (°C) under SSP scenarios (very likely range; AR6 table SPM table B.1.2)
1.9		1.4 (1.0-1.8)
2.6	1.6 (0.9-2.3)	1.8 (1.3-2.4)
4.5	2.4 (1.7-3.2)	2.7 (2.1-3.5)
7.0		3.6 (2.8-4.6)
8.5	4.3 (3.2-5.4)	4.4 (3.3-5.7)

Table 7: Projected New Zealand region annual mean air temperature change (over land and sea) relative to 1995-2014 average. Values in parentheses indicate the 10-90 percentile range spanned by the ensemble of CMIP6 models. (Table 2 from MfE, 2022).

NZ region	Mid century	End of century
SSP1-2.6	+0.75°C (0.39 to 1.06°C)	+0.8°C (0.47 to 1.46°C)
SSP2-4.5	+1.0°C (0.60 to 1.32°C)	+1.6°C (1.03 to 2.26°C)
SSP5-8.5	+1.3°C (0.91 to 1.66°C)	+3.1°C (2.20 to 4.05°C)

2.2 Regional reports

In their 2020 report *Climate change projections for the Canterbury Region*, the National Institute of Water & Atmospheric Research (NIWA) presented future climate predictions for Canterbury at a 5 km x 5 km resolution, based on downscaling global climate model simulations using representative RCPs from AR5. The general picture is of a shift upwards of daily temperatures, along with an increase in the range of likely temperatures, leading to a higher incidence of extreme events: more heat waves, coastal flooding and changing seasonality (MfE, 2020).

Some of the most noteworthy conclusions of the NIWA report are:

- Diurnal temperature range (the difference between minimum and maximum daily temperatures) is expected to increase over time with increasing greenhouse gas concentrations.
- The average number of hot days (≥25°C) is projected to increase over time and emission scenario. The number of hot days in some inland areas of Canterbury are projected to increase by 60-85 days per year by 2090 under the most extreme scenario RCP8.5, while the number of frost days (<0°C) are expected to decrease, with largest decreases in inland areas.
- Projected changes to rainfall show considerable variability across the region with small changes of ±5% in annual rainfall projected by 2040 and 2090. The largest changes are expected during winter with 15-40% more rainfall projected in many eastern, western and southern parts by 2090 under RCP8.5.
- Projected increase in potential evapotranspiration deficit (PED) leading to increased drought potential.
- Floods are expected to become larger for many parts of Canterbury.

Tonkin + Taylor published *Canterbury Climate Change Risk Assessment* in 2022. This was the result of extensive consultation and assessed a very broad range of risks for all stakeholder and asset owner interests. This risk assessment differs from ours in terms of scope and detail. The T+T report is global in terms of stakeholders and risks. The current report focuses entirely on SDC assets and our assessment of risk is relative to these assets and consequently differs from the T+T assessment. For further details we refer to section 15.

3 CLIMATE CYCLES AND VARIABILITY

3.1 Climate and weather patterns

The terms ‘climate’ and ‘weather’ are often used interchangeably but differ significantly in their scope and duration. Weather refers to atmospheric conditions in a particular place at a specific time and includes short-term variations (on a daily or hourly timescale) in precipitation, humidity, wind speed, cloud cover and atmospheric pressure.

Climate, on the other hand, refers to long-term patterns and variability of atmospheric conditions observed over a significant a period, typically 30 years or more.

While much of the variation in New Zealand’s climate is random and lasts only for short periods, our climate is heavily influenced by three large-scale oscillations:

- El Niño-Southern Oscillation (ENSO),
- Interdecadal Pacific Oscillation (IPO), and
- Southern Annular Mode (SAM)

These processes have substantial quasi-cyclic impacts on our climate and weather patterns. The year-to-year climate of New Zealand will continue to be impacted by this natural variability in the future. Consequently, those engaged in planning and managing climate-sensitive infrastructure and activities in the Canterbury region will have to manage and adapt to the combined effects of both human-induced changes and natural variability. It is therefore helpful to review historical data in combination with projected climate futures.

3.2 Climate change

Climate change refers to long-term shifts in global or regional climate patterns, primarily caused by human activities such as the burning of fossil fuels, deforestation, and industrial processes which has resulted in observed global warming since pre-industrial times. As a result of global warming, temperature, precipitation, and wind patterns, as well as other aspects of the Earth's climate system have changed and continue to change.

While climate models and standardised scenarios (like the RCPs or SSPs) provide valuable information on climate futures, there remains considerable uncertainty especially when projecting to the end of the 21st century. This is shown, for instance, by the envelopes of uncertainty of mean annual temperatures shown in Table 6 and Table 7. There is compounding uncertainty about the higher incidence and magnitude of extreme events like floods and droughts which are associated with global warming. This makes assessing the impact of climate futures 30 years and 70 years ahead in the Selwyn District and the management of assets very challenging.

Although an increasing trend in annual mean temperature is observed in the Canterbury region, and New Zealand generally, since the start of records, the natural variability of climate variables like temperature, together with the problem of extrapolation into the future, make it impossible to attribute individual recent extreme events to climate change using current data. Furthermore, climate change is about a change in the statistical distribution of events and while, on a global and national scale, we are observing more extreme events like floods and droughts, there is considerable uncertainty about the likely distribution of extreme events for climate futures in 2050, and even more in 2100. For these climate futures we need to rely on climate model projections and, while downscaled projections for New Zealand based on AR6 have not yet been released, it has already been noted above that the conclusions of AR5 and AR6 are broadly consistent. In the following sections we will therefore refer extensively to the NIWA report *Climate change projections for the Canterbury Region* which, as mentioned above, is based on AR5.

A useful way to visualise the impacts of climate change is shown in Figure 1. The blue curve represents the distribution of current daily temperatures, while the red curve represents the distribution for a climate future in which the planet is warmer by, say, 1.5°C. The most important thing to note is that along with the shift towards hotter temperatures, the red curve has been stretched out. Thus, there is a bigger range of temperatures - more hot days and fewer cold days. In short, we can expect more volatility in weather patterns.

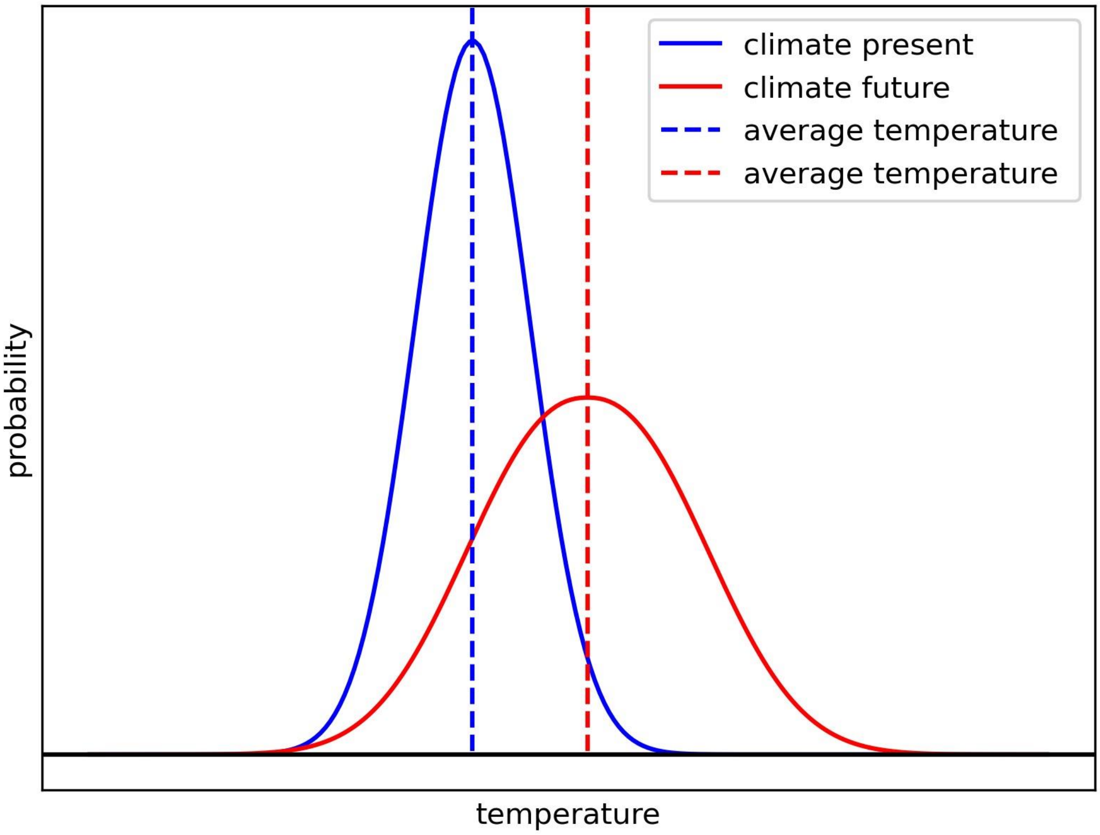


Figure 1. Climate change in a nutshell (From: N. Dudley Ward, Water Sketches: Climate Challenges, Calamities and Adaptations.).

4 HISTORICAL DATA

This section gives a summary of

- **Historical time series data sources, and**
- **Data extension methodologies.**

Historical data sources are shown in Table 8.

Table 8. Summary of data and sources.

Data type	Source	Frequency
Rainfall	cliflo.niwa.co.nz	Daily
Maximum temperature	cliflo.niwa.co.nz	Daily
Minimum temperature	cliflo.niwa.co.nz	Daily
Potential evapotranspiration (Penman)	cliflo.niwa.co.nz	Daily
Ground water levels	data.ecan.govt.nz	Daily
River flows	data.ecan.govt.nz, hydrowebportal.niwa.co.nz ECan (Tony Gray)	Daily
Sea level (at Lyttelton)	LINZ Data Service	Annual
Te Waihora Lake Ellesmere Water Level	ECan (Tony Gray)	Daily

Evapotranspiration is not directly measured, but may be estimated empirically from radiation, temperature, wind, and vapour pressure measurements, typically using the Penman-Monteith method.

The source data in Table 8 was processed to generate extended time-series for the period 1910-2023. Aqualinc's Climate Time Series Extension (CTSE) software was used to gap fill and extend daily time-series for rain, temperature and potential evapotranspiration (PET). CTSE identifies weather observation data for sites that are highly correlated, and fills gaps based on the correlation. An outline of the CTSE software is provided in Brown *et al*. (2016).

A daily time-series of PET for the 1910-2023 period was generated using the McGuiness-Bordne method, which estimates PET as a function of daily mean temperatures and latitude (Guo *et al*. 2016). This method was used due to a lack of radiation records (which are required by the Penman-Monteith method) prior to 1960. These estimates were then compared to the 1960 - 2023 extended PET data estimated using the Penman-Monteith method and were found to be broadly consistent.

Groundwater level time-series for the climate futures considered in this report were obtained by simulating groundwater movement using extended rainfall and PET time series as inputs (see Section 9). Rainfall and PET were used to estimate daily land surface recharge and water demand using Aqualinc's IrriCalc model (Bright 2009).

Table 9. Data extension processes

Data type	Process	Period
Rainfall	Extended and gap filled with CTSE software	1892-2023
Minimum and maximum temperature	Extended and gap filled with CTSE software	1905-2023
Potential evapotranspiration (Penman-Monteith)	Extended and gap filled with CTSE software	1960-2023
Potential Evapotranspiration (McGuiness-Bordne)	Generated from temperature data	1910-2023
Groundwater level	Modelled using rainfall and potential evapotranspiration input and calibrated to post-earthquake observed groundwater levels.	1910-2023

5 TEMPERATURE

The key messages for this section are:

- **Over the last 100 years New Zealand has warmed by an average of 1°C.**
- **Future annual average warming in Canterbury spans a wide range: 0.5-1.5 °C by 2040 and 0.5-3.5°C by 2090 depending on the greenhouse gas emission scenario.**
- **By 2040, seasonal mean temperatures across much of Canterbury are projected to increase by 0.5-1.5°C under RCP4.5. By 2090 they are projected to increase by 1.5-3.0°C under RCP8.5, with increases of 3.0-4.0°C for westernmost pasts of Canterbury.**
- **The number of hot days is projected to increase by 10-20 days by 2040 for Selwyn District under both RCP4.5 and 8.5. By 2090 the number of hot days is projected to increase by 10-60 days.**
- **The number of frost days is projected to decrease by 10-30 frost days per year for inland parts of the region. By 2090 the number of frost days is projected to decrease by 20-50 days for inland areas of Canterbury.**

According to the British Meteorological Office, global surface temperatures have warmed by about 1°C on average since the late 19th century. New Zealand has also warmed by this amount between 1908 and 2018 according to MfE (2020).

This section is largely based on the 2020 NIWA report *Climate change projections for the Canterbury Region.* Over the historic period 1986-2005 considered by NIWA, mean temperatures range between 10-14°C for most coastal and inland low-elevation locations of Canterbury, as shown in Figure 2. By 2040 annual mean temperature is projected to increase by 0.5-1.5°C by 2040 under RCP4.5 and RCP8.5, while by 2090 increases of the order of 0.5-2.0°C (RCP4.5) and 1.5-3.5°C (RCP8.5) are projected for most of the region, as shown in Figure 3. Greater temperature increases are projected for inland areas. This may be due to the moderating effect of the sea for coastal and plains areas.

The NIWA report also contains graphical representations of projections of changes in seasonal mean, maximum and minimum temperatures which, for the Selwyn District, are broadly consistent with Figure 3.

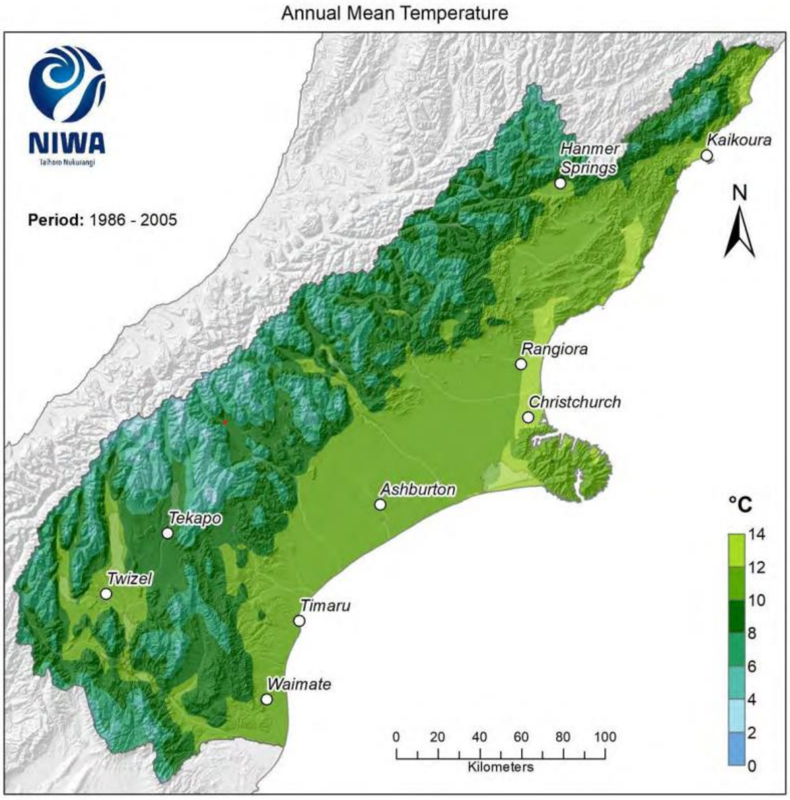


Figure 2. Modelled annual mean temperature, average over 1986-2005 (NIWA, 2020)

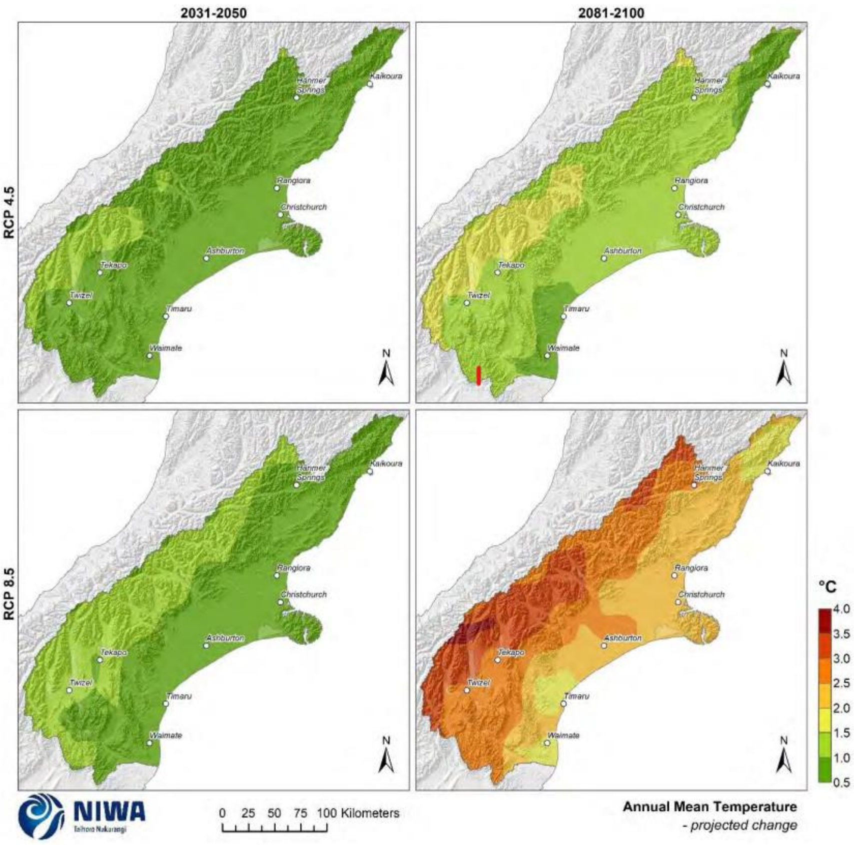


Figure 3. Projected annual mean temperature changes by 2040 and 2090, under RCP4.5 and RCP8.5, (NIWA, 2020).

The NIWA projections are based on taking the average of 6 dynamically downscaled climate models and therefore give one possible trajectory for a climate future: a kind of 'best estimate'. However, each climate model predicts a different climate future. While there is broad consistency between different model projections (all models project warming for RCPs 4.5 and 8.5, with higher greenhouse concentrations generally leading to more warming) the actual degree of warming is much less certain especially when projecting to 2090. This is reflected, for example, by the wide envelopes of uncertainty shown, for example, in Table 6. We refer also to Figure 4.9 in NIWA (2020), which shows the variability between different models.

Nevertheless, of far greater consequence to managers and decision-makers than the actual numerical values of annual and seasonal warming are projected physical consequences of warming; that is, changes to the patterns of seasonal and daily temperatures and impacts on the hydrological cycle, especially precipitation patterns and the incidence of hot days (≥25°C) and frost days (≤0°C). Broadly speaking, annual and seasonal minimum and maximum temperatures are projected to increase under all emission scenarios. However, projected increases in minimum temperatures are projected to be less than projected increases in maximum temperatures, leading to an increase in the diurnal temperature range.

5.1 Hot days

The number of hot days observed in Canterbury is projected to increase under all emissions scenarios. Currently Selwyn District experiences an average of 30-40 hot days per year, as shown in Figure 4. This is projected to increase by 10-20 days by 2040 for Selwyn District under both RCP4.5 and 8.5. By 2090 the annual number of hot days is projected to increase by 10-60 days, depending on the emissions scenario, as shown in Figure 5.

Historically, hot days occur most frequently during summer months, with 10-30 hot days observed in most low-elevation areas of Canterbury. With warming the increased frequency of hot days observed in summer months is projected to spill over into spring and autumn, lengthening the traditional summer season.

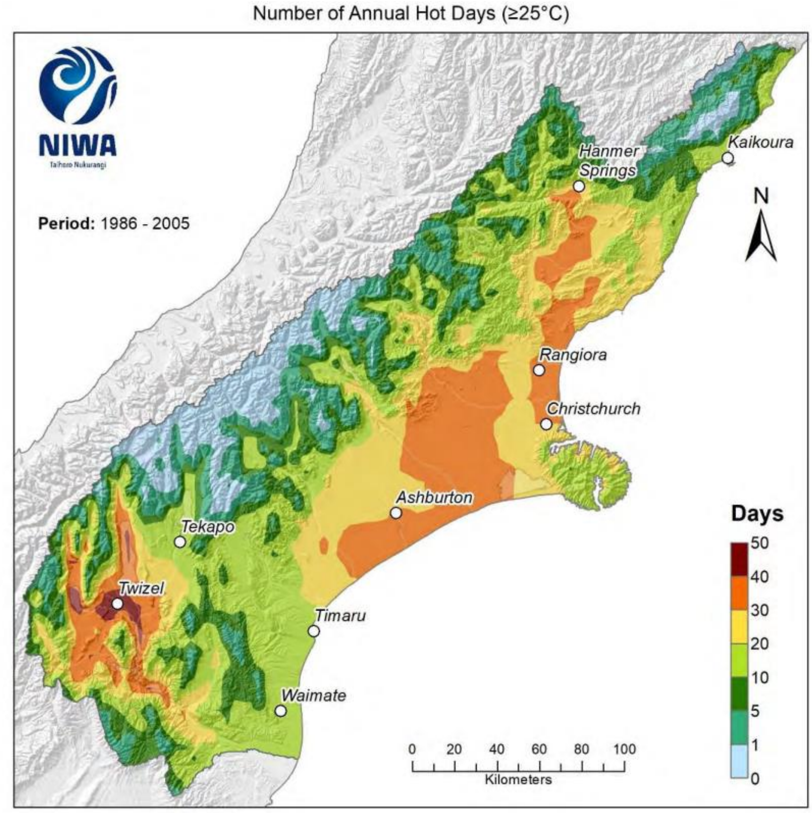


Figure 4. Modelled annual number of hot days (days with maximum temperature ≥25°C), average over 1986-2005, (NIWA 2020).

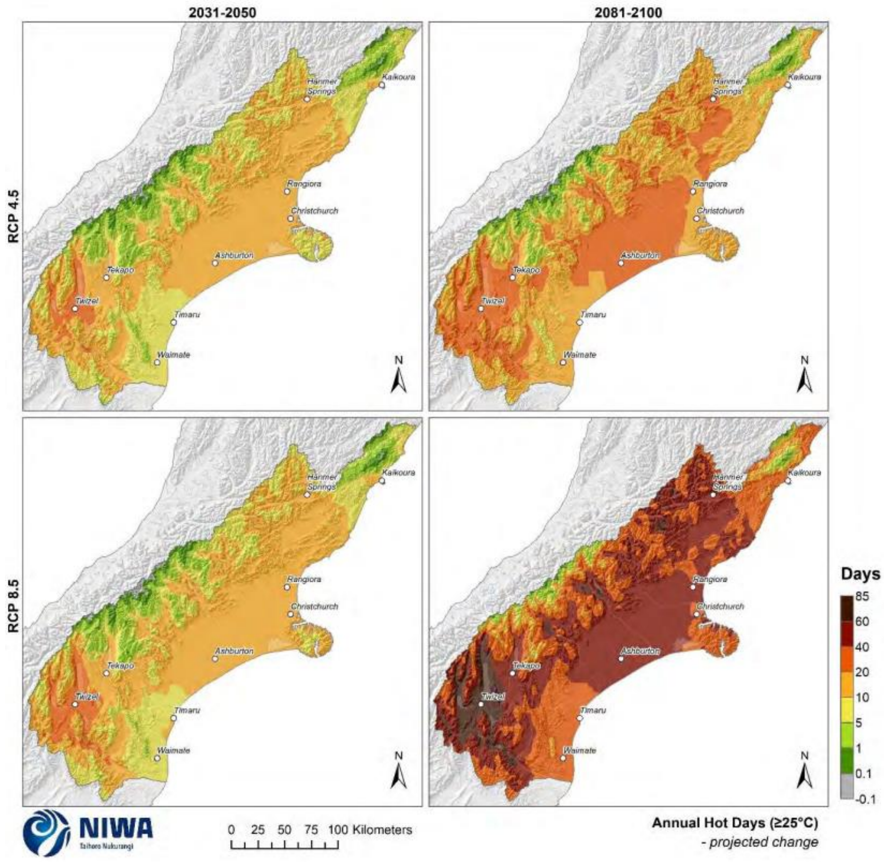


Figure 5. Projected annual hot day (days with maximum temperature ≥25°C) changes by 2040 and 2090, under RCP4.5 and RCP8.5 , (NIWA 2020).

5.2 Frost days

The annual number of frost days is projected to decrease throughout the Canterbury region, with larger reductions further inland and at higher elevations. Currently much of Selwyn District experiences between 10-50 frost days a year, as shown in Figure 6, with most frost days occurring during winter months. With warming the duration of the 'frost season' is projected to decrease.

By 2090 much of Canterbury is projected to experience a reduction of between 5-20 days under RCP4.5 and 10-50 days under RCP8.5 as shown in Figure 7, with the greatest reduction experienced in the high-country areas. Note that while the projected reduction is the same as the current number of frost days, this does not imply that there will be no frosts in the Selwyn District under future climates.

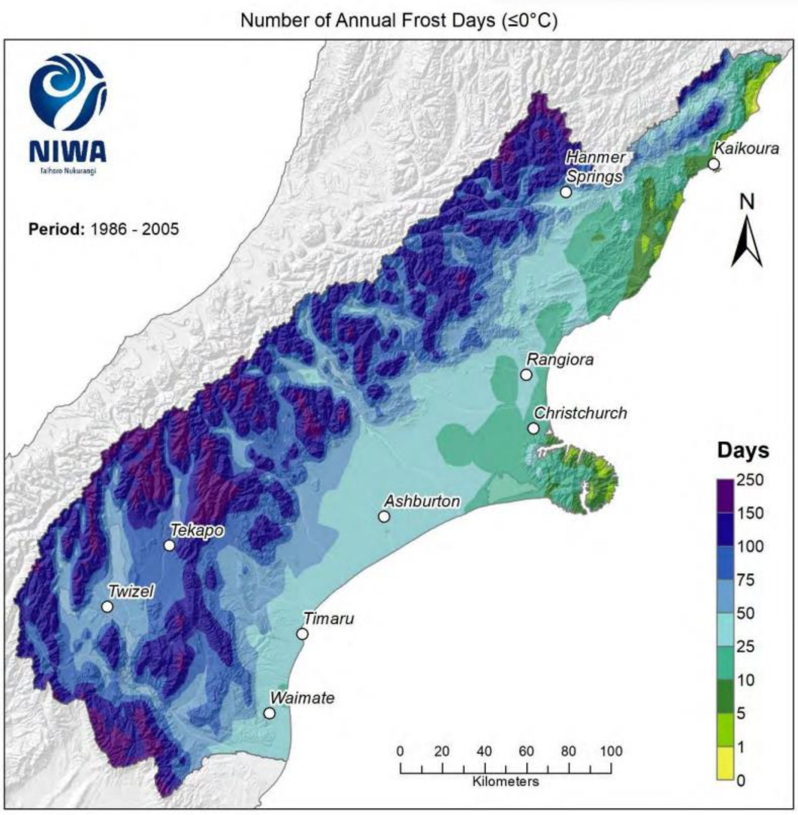


Figure 6. Modelled annual number of frost days (days with minimum temperature ≤0°C), average over 1986-2005.

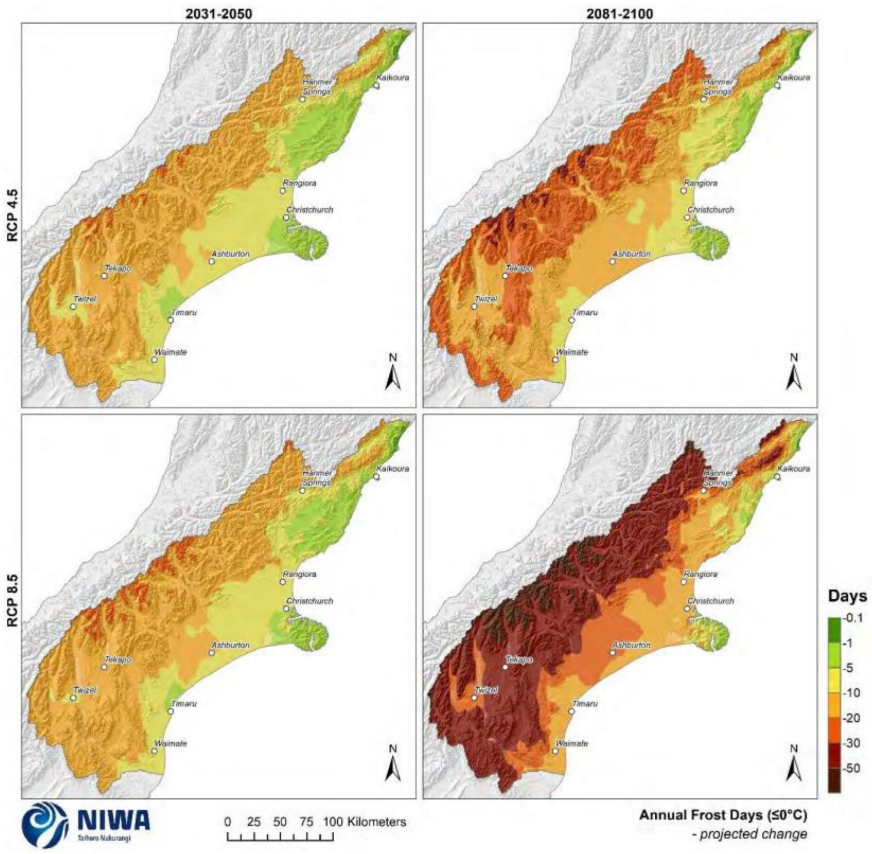


Figure 7. Projected annual frost day (days with minimum temperature ≤0°C) changes by 2040 and 2090, under RCP4.5 and RCP8.5.

5.3 Summary

The information in this section gives a broad and simplified summary of projected future temperatures for the Selwyn District. There are significant uncertainties about our climate future as shown by the envelopes of uncertainty quoted above and by the large disparities between projections based on RCP4.5 and RCP8.5. Although climate scientists are increasingly confident about the causes of global warming and climate change impacts, almost all statements in the IPCC reports are qualified with statements of uncertainty. Inevitably, envelopes of uncertainty increase significantly with distance into the future. Furthermore, the 2020 *National Climate Change Risk Assessment for New Zealand* cautions against the use of static measures like minimum flood levels, routinely used in planning. The report further states that '*failure to account for uncertainty in decision-making increases the likelihood that an action will be maladaptive*' and encourages flexible planning and design that consider the inevitable uncertainties associated with climate change. Perhaps the best picture of future changes to the Selwyn District's temperatures to keep in mind is Figure 1. This effectively summarises the contents of Section 5. Increasing temperature is the fundamental driver of climate change which influences all of the other climate variables considered in this report.

6 EVAPOTRANSPIRATION

The key messages for this section are:

- **By 2040, both RCP4.5 and RCP8.5 project an accumulated PED of 50-100 per year for most eastern parts of Canterbury.**
- **By 2090 under RCP8.5 5, PED is projected to increase by 100-200 mm per year for many inland areas of the Selwyn District.**
- **Historical PET records suggest that rates have not changed significantly over the period 1960-2023.**

Evapotranspiration is the process by which water is transferred from the Earth’s surface to the atmosphere through a combination of direct evaporation and transpiration from plants. The ‘potential evaporation’ (PET) is the rate of evaporation that would occur if there were a sufficient water source available. As the growing season progresses, the rate of water loss through evapotranspiration usually surpasses the amount of rainfall received, leading to an increase in soil moisture deficit. This limits the availability of moisture for pasture production, and evapotranspiration becomes insufficient to meet the water demand from the atmosphere. This leads to ‘potential evapotranspiration deficit’ (PED), which is the difference between the atmospheric demand and the actual evapotranspiration. This deficit is the amount of water required by irrigation to maintain plant growth without being constrained by water scarcity.

The PED provides a measure of drought intensity and duration, with higher PED values corresponding to drier soils.

Figure 8 shows estimated PET between 1960 and 2023 for three long-term climate stations in the Selwyn District. While each station has a very small decreasing trend in PET, it is very small with respect to the year-to-year variability. The very low values of PET in recent years highlight short-term variability that will continue to be a factor of future climate.

By contrast, the 2020 NIWA report concludes that PED is projected to increase across much of Canterbury, increasing drought potential. Over the period 1986-2005 the Selwyn District experienced 200-400 mm PED per year. By 2040 under RCP 4.5 and 8.5, most eastern parts of the region are projected to experience an increase in PED of 50-100 mm per year, while by 2090 under RCP8.5 PED is projected to increase by 100- 200 mm per year for many inland areas of the Selwyn District.

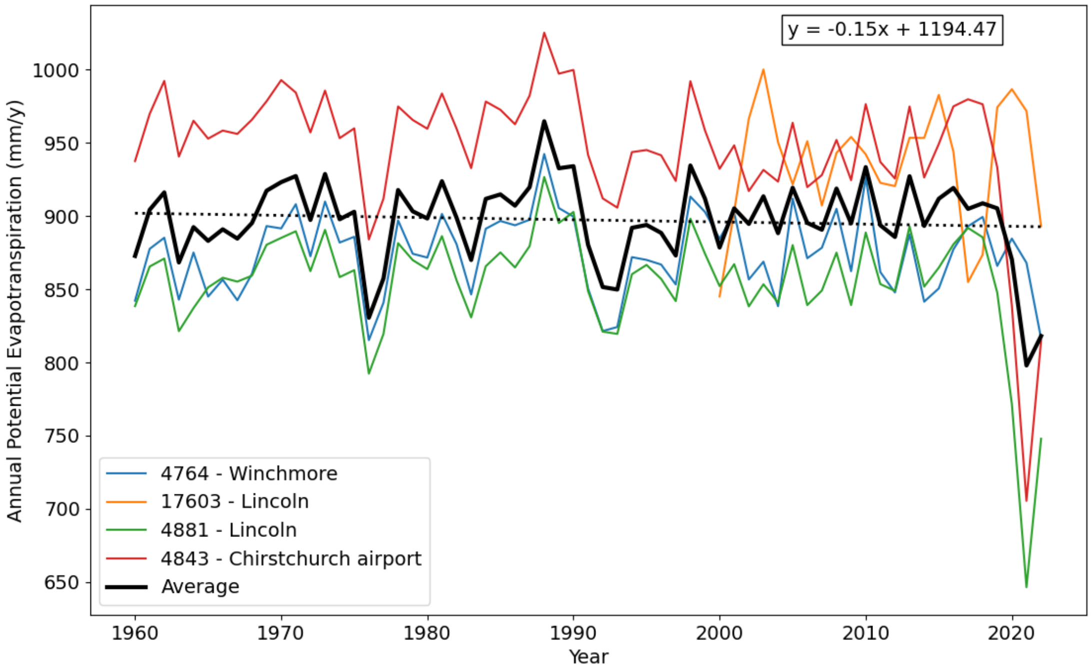


Figure 8. Measured PET from 1960 to 2023 for three locations in the Selwyn District.

7 RAINFALL

7.1 Annual Rainfall

The key messages of this section are:

- **Annual rainfall is projected to change by between ±5% for most of Canterbury by 2040 and 2090.**
- **Winter rainfall is projected to increase considerably by 2090 under RCP8.5 in many eastern, western and southern parts, with 15-40% more rainfall projected.**

Over the historic period 1986-2005, for eastern parts of Canterbury average rainfall ranges from 500-800 mm, as shown in Figure 9, with winter the driest season of the year. For much of the region under both RCP4.5 and RCP 8.5 annual rainfall is projected to change by up to ±5% for much of Canterbury, as shown in Figure 10. By 2090 the disparity between climate futures based on RCP4.5 and 8.5 on a seasonal scale is significantly greater with winter rainfall projected to increase significantly in many eastern, western and southern parts of Canterbury (including the Selwyn District), with 15-40% more rainfall projected.

It is interesting to compare climate future projections with historical data. Rainfall data from 6 sites across the Canterbury Plains is shown in Figure 11. Annual rainfall for the three long-term stations on the lower Central Canterbury Plains is shown in Figure 12, while Figure 13 shows annual rainfall for three long-term stations on the upper Central Canterbury Plains. There are no evident long-term trends in the measured data which is consistent with the small projected changes projecting to 2050.

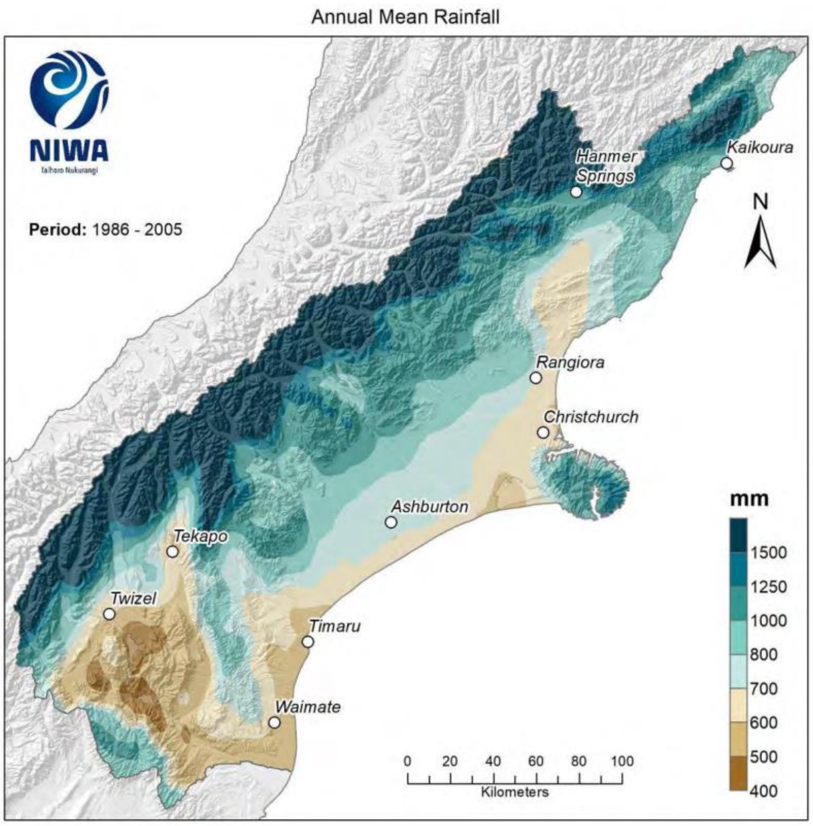


Figure 9. Modelled annual mean rainfall (mm), average over 1986-2005 (NIWA, 2020).

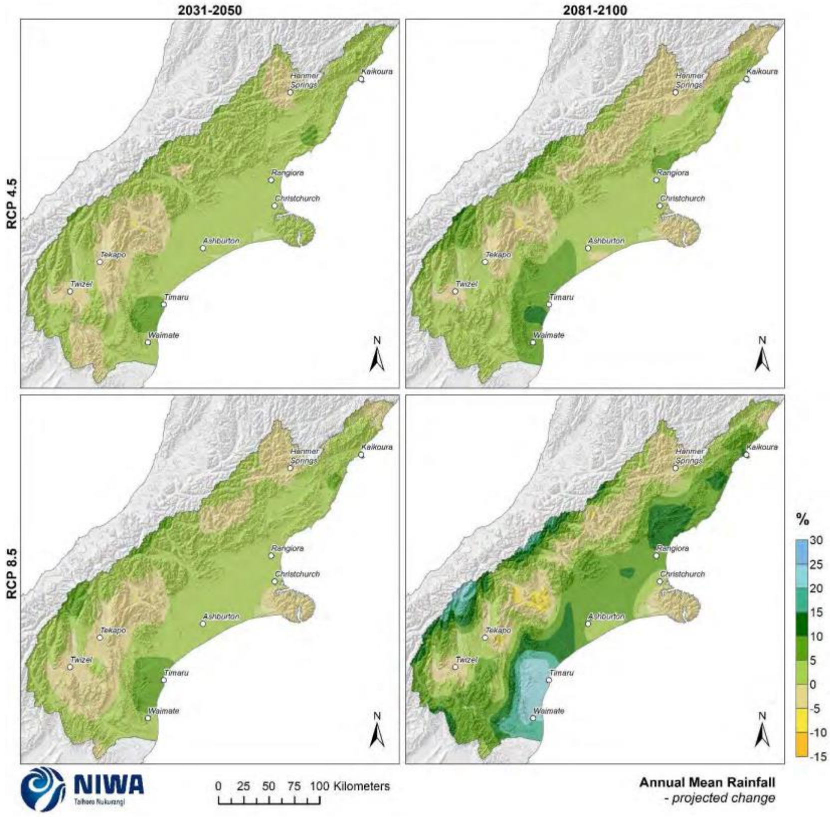


Figure 10. Projected annual mean rainfall changes by 2040 and 2090, under RCP4.5 and RCP8.5 (NIWA, 2020).

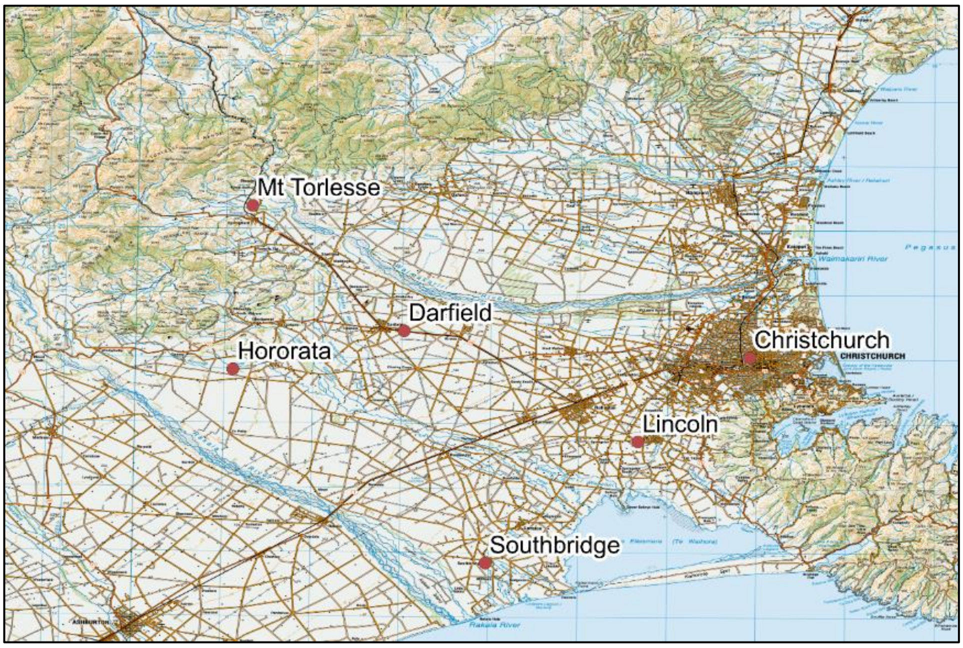


Figure 11. Locations of rainfall stations.

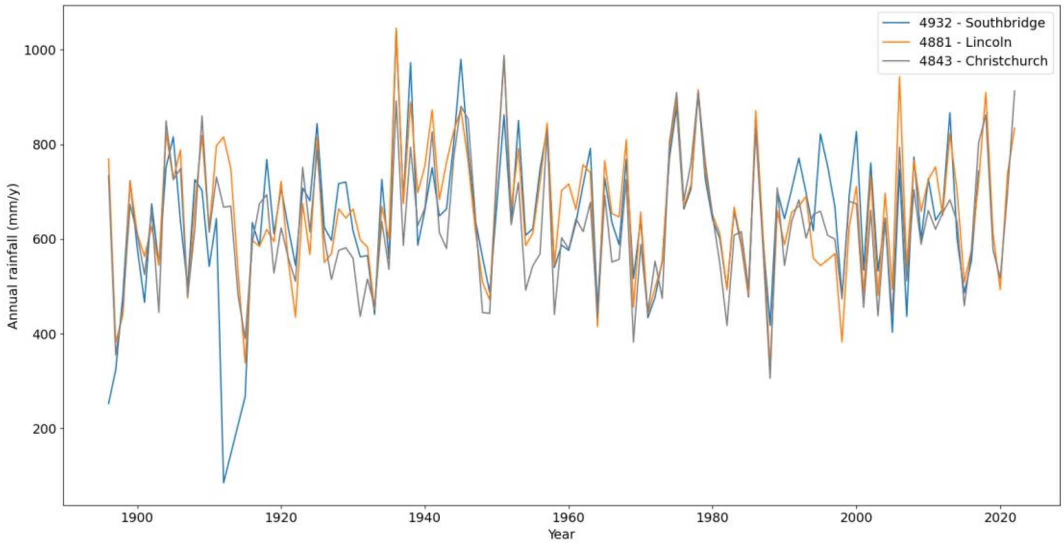


Figure 12. Annual rainfall for three sites on the lower Central Canterbury Plains 1892-2023.

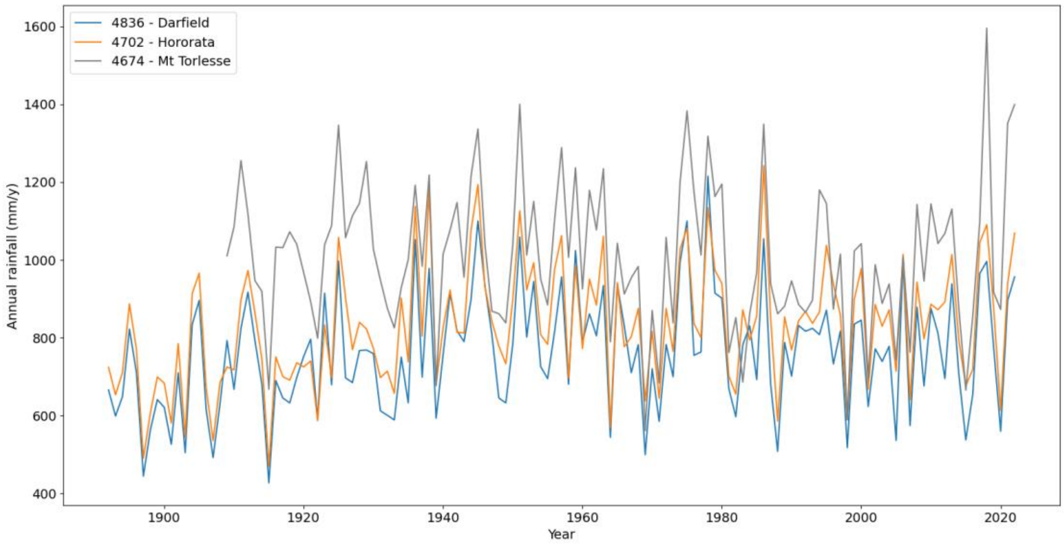


Figure 13. Annual rainfall for three sites on the upper Central Canterbury Plains 1892-2023.

7.2 Dry days

The key messages for this section are:

- **By 2040 under RCP4.5 the annual number of dry days is projected to decrease by up to 5 days for eastern parts of Canterbury and around the Canterbury Plains, while increasing by the same amount elsewhere.**
- **By 2090 under RCP8.5 this is projected to change by up to ±15 days.**

A day is called 'dry' if there is less than 1 mm rainfall on that day. As shown in Figure 14, Selwyn District averages around 200-300 dry days per year. In all emissions scenarios the number of dry days is projected to decrease in eastern parts of Canterbury and in the Canterbury Plains, while increasing in other parts of Canterbury, as shown in Figure 15. By 2040 under RCP4.5 the change in the number of dry days is small and of the order of ±5 days, while by 2090 under RCP8.5 the changes are projected to be of the order of ±15 days per year.

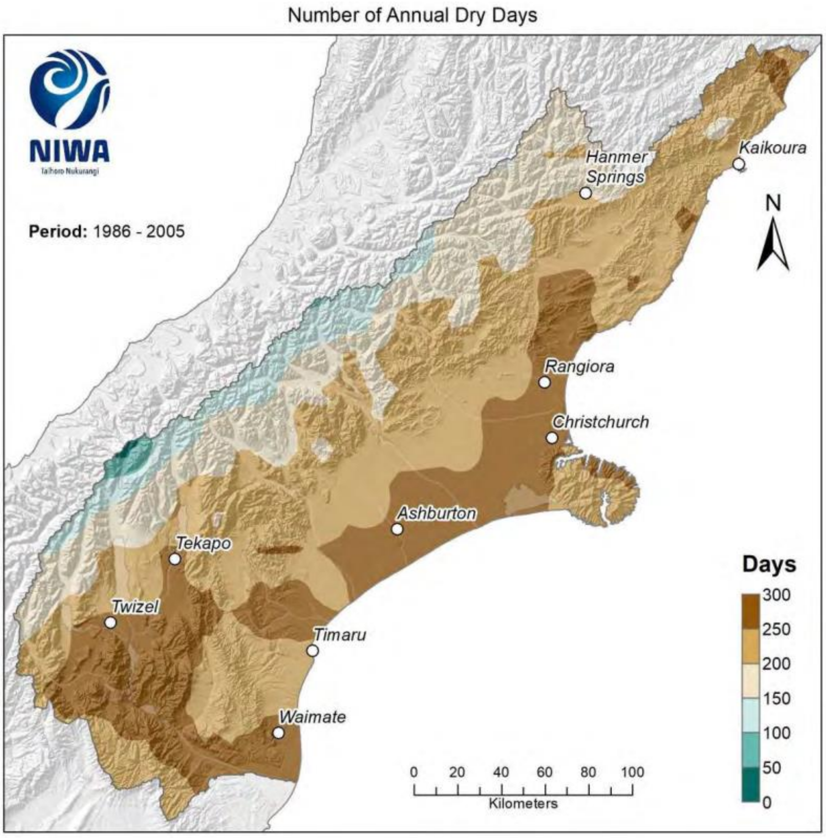


Figure 14. Modelled annual number of dry days (daily rainfall <1mm), average over 1986-2005.

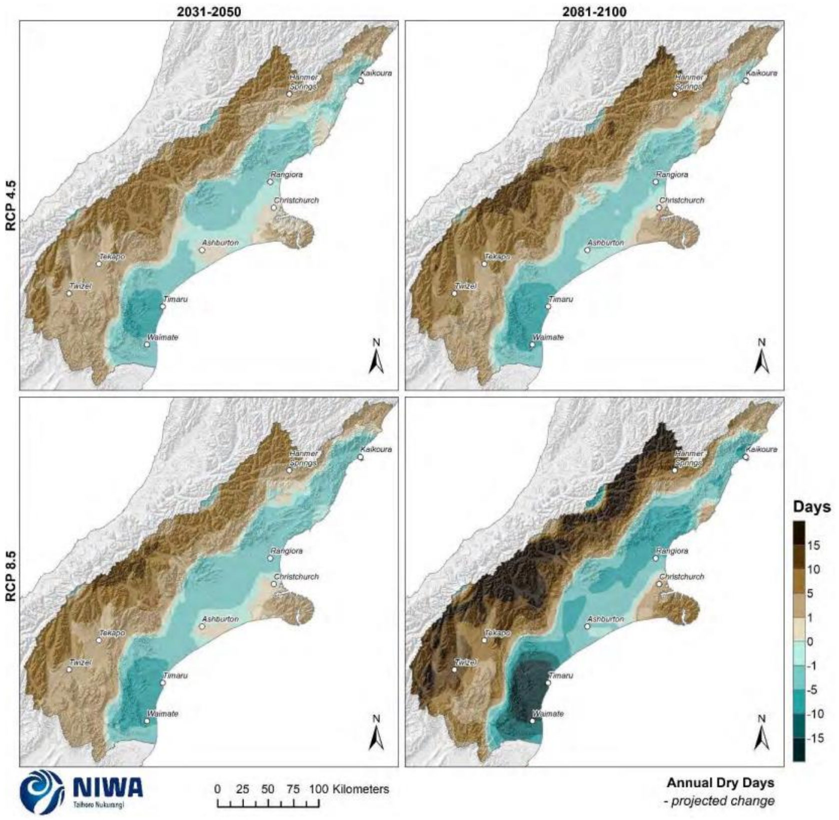


Figure 15. Projected annual number of dry day (daily rainfall <1mm) changes by 2040 and 2090, under RCP4.5 and RCP8.5.

7.3 Extreme rainfall

The key messages for this section are:

- **Extreme rainfall events are expected to increase everywhere in New Zealand.**
- **With 2°C warming, projections of the increase in 50-year Rx1[1]day and Rx5 day events for New Zealand are inconsistent.**
- **With 4°C warming models project a median increase in the intensity and frequency of heavy precipitation of more than 15% in the 50-year Rx1 day and Rx5 day events compared to the 1°C warming level.**

NIWA's 2020 report *Climate change projections for the Canterbury Region* does not contain quantitative information on projected changes to extreme rainfall events. However, it states that '*along with increases in global mean temperature, mid-latitude and wet tropical regions will experience more intense and more frequent extreme rainfall events by the end of the 21st century*'. Similarly, the Ministry for the Environment 2018 report *Climate Change Projections for New Zealand* states that '*very extreme rainfall is likely to increase in all areas with increases more pronounced for shorter duration events*'.

Estimates of projected high-intensity rainfall events to the end of century for a range of RCPs including RCP4.5 and RCP8.5 have been generated by NIWA's High Intensity Rainfall Design System (HIRDS). Table 10 shows estimated rainfall depths for 1 in 10 year and 1 in 100 year rainfall events for three representative locations in the Selwyn District.

[1] Rx1 and Rx5 are the maximum daily and 5 daily precipitation amounts, respectively.

Table 10. Estimated rainfall depths (mm) for different climate futures and representative locations in the Selwyn District.

		Historical		2050 RCP4.5		2100 RCP4.5		2100 RCP8.5	
		1 in 10	1 in 100	1 in 10	1 in 100	1 in 10	1 in 100	1 in 10	1 in 100
Castle Hill	1 hr	19.9	32.7	21.8	36	23.1	38.1	26.6	44.2
	1 day	108	172	115	182	119	189	131	210
	5 day	156	242	162	253	166	260	178	280
Darfield	1 hr	17.6	31.8	19.4	35	20.4	37	23.6	42.9
	1 day	89.9	150	95.3	159	98.8	165	109	183
	5 day	162	260	169	271	174	279	186	300
Leeston	1 hr	17.6	31.3	19.3	34.5	20.4	36.5	23.6	42.3
	1 day	85.3	142	90.4	151	93.7	156	103	173
	5 day	137	220	143	230	147	237	158	255

AR6 provides limited information on increase and intensity of heavy precipitation events in Table 11.11 (IPCC, Climate Change 2021, The Physical Science Basis). For 1.5 and 2°C warming, CPIM6 climate models project inconsistent changes in the region. However, for 4°C warming models project a median increase in the intensity and frequency of heavy precipitation of more than 15% in the 50-year Rx1day and Rx5 day events compared to the 1°C warming level.

In practical terms extreme rainfall events that were traditionally assessed to be 1 in 10-year or 1 in 100-year events will become more frequent.

It is interesting to compare projections with historical rainfall data. Figure 16 shows the average of the five-day maximum of four stations shown in Figure 17. This data as well as the individual station data show.no significant long-term trends. Comparing the historical data summarised in Figure 16 with the projected data in Table 10, it is evident that the 1 in 10 year 5 days events for all climate futures in Table 10 are consistent with the range of historically observed rainfall events. However, the 1 in 100 year high-intensity events lie significantly outside this range which highlights the wide uncertainty associated with events with a 1 in 100 return period.

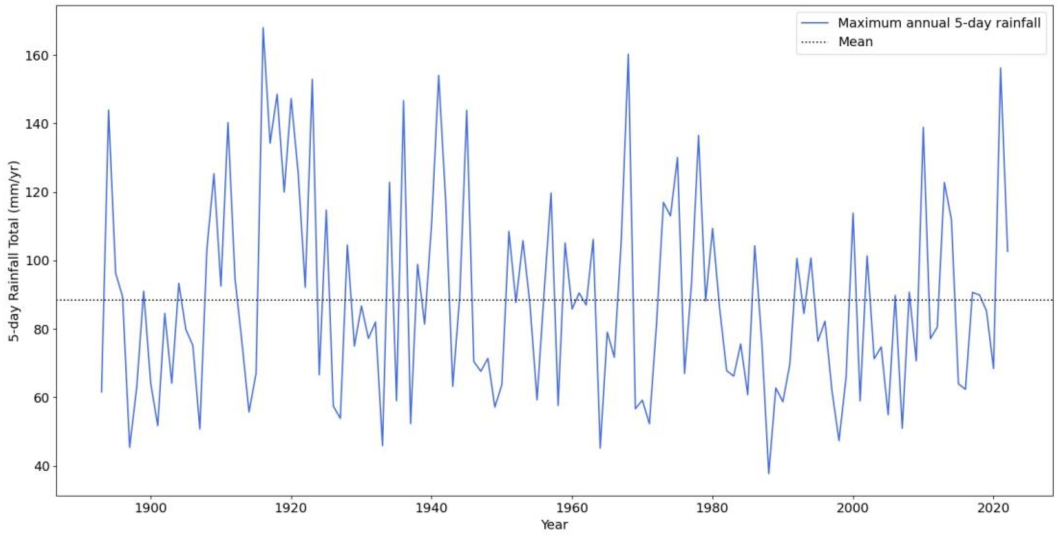


Figure 16. Annual maximum 5 day rainfall for the mean of four long term stations (Southbridge, Lincoln, Hororata and Christchurch Gardens).

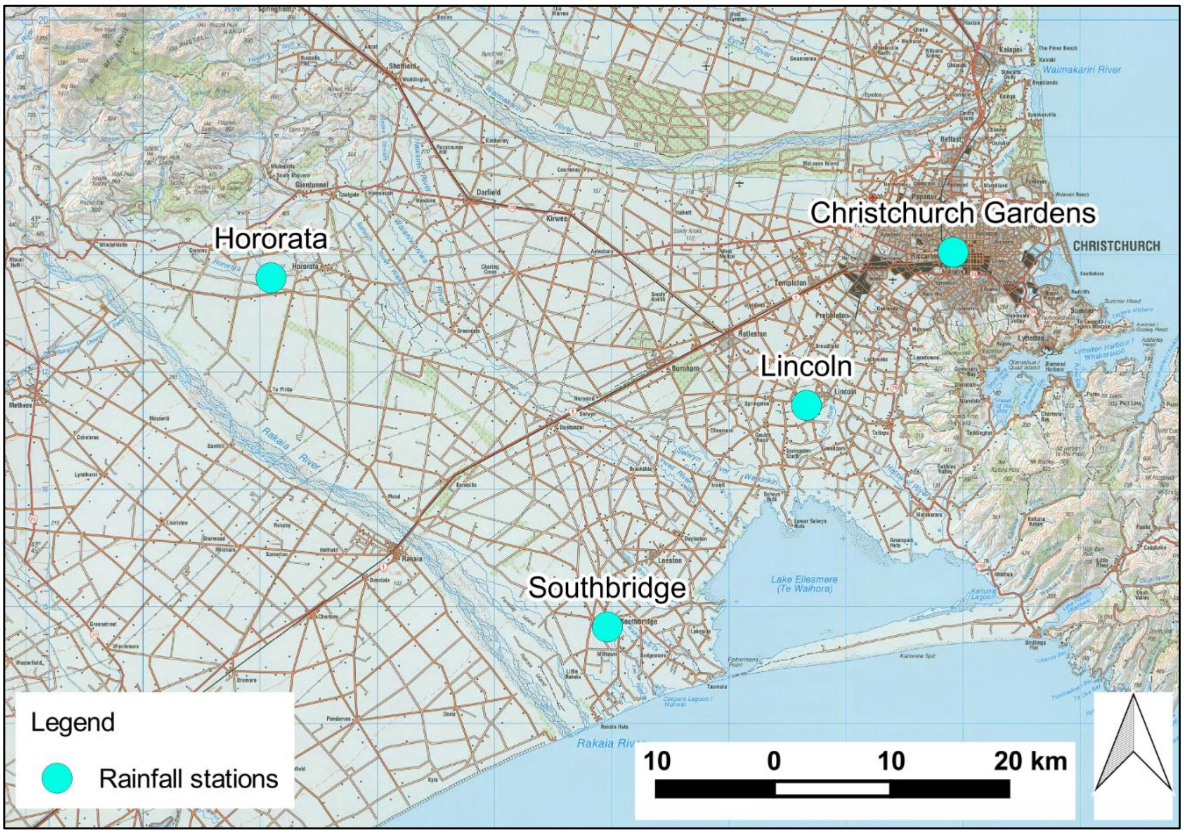


Figure 17. Four long term rainfall stations with records from at least 1893.

8 OTHER CLIMATE VARIABLES

The key messages for this section are:

- **The number of snow days is projected to decrease everywhere in Canterbury, with the largest reductions of the order of 10-25 days in higher elevation regions.**
- **Annual mean wind speed is projected to increase 2-10% for much of Canterbury under RCP8.5.**

8.1 Snow

The number of snow days is projected to reduce everywhere, with the largest reductions in the coldest mountainous areas. In the higher-elevation alpine regions, the number of snow days (days with recorded precipitation and temperatures less than 1°C) varies between 25-100 annually, with the largest reduction of the order of 10-25 days in higher elevation alpine regions (NIWA, 2020).

8.2 Wind

NIWA (2020) projects increases in annual mean wind speed of the order of 2-10% for much of Canterbury by 2090 under RCP8.5, with the largest changes projected to occur during winter and spring months.

9 GROUNDWATER

In the Selwyn District groundwater accounts for approximately two-thirds of the water used for irrigation. Therefore, potential adverse impacts on groundwater systems and dependent infrastructure resulting from changing climate patterns constitute a major issue for the district. Furthermore, the Intergovernmental Panel on Climate Change (IPCC 2021) assessment report AR6 acknowledges a high level of uncertainty of climate related changes to groundwater.

Different climate futures will lead to changes in irrigation demand, groundwater pumping and land surface recharge. To assess the potential impacts on groundwater systems in the Selwyn District we have modelled several climate future scenarios.

The 2020 *Impacts of Climate Cycles and Trends* report compared a climate future in 2050 with the historical case and found insignificant changes to groundwater levels mid-century. In this report we consider climate futures in both 2050 and 2100, which requires estimating pumping and land surface recharge over the simulation period. For 2050 we follow the same method as in the 2020 report, in which modified PET time series is generated based on a 1.5°C increase in mean temperature (consistent with climate futures corresponding to RCP4.5 and 8.5 mid-century). Aqualinc's crop-soil water balance model (IrriCalc) was used to estimate land surface drainage and water demand for the different scenarios. One-dimensional groundwater models calibrated to historical data were then used to simulate groundwater levels at various locations in Selwyn District.

It is clear from the preceding sections that by the end of century we can expect considerably more uncertainty, especially with precipitation patterns especially when considering the broad disparities in climate futures between RCP4.5 and RCP8.5. We have therefore taken a different approach for 2100 and have used simulated rainfall and PET data from NIWA, generated from their regional climate model, to drive the groundwater simulations.

9.1 Land surface recharge

Aqualinc's crop-soil water balance model (IrriCalc) (Bright, 2009) was used to generate time-series of land surface drainage and water demand. The model estimates soil water content as a function of crops and soil types, climate, and irrigation strategies. An overview of the model is given in Appendix A.

IrriCalc requires the following data inputs:

- Land use, specifically the distribution of
    - Irrigated pasture, and
    - Dryland pasture.
- Potential evapotranspiration (PET),
- Rainfall,
- Soil plant available water (PAW) estimated from S-Map, and
- Irrigation parameters.

For the groundwater modelling the aquifer was divided into 7 zones, shown in Figure 18. Representative climate data for each of these zones from the stations shown in Figure 18 are listed in Table 11.

The identification of irrigated areas for each groundwater zone was determined by mapping conducted by Aqualinc. All irrigation water was assumed to be sourced from groundwater. Furthermore, spray irrigation was assumed for all areas, with an equivalent 80% (approximately) water use efficiency. Model parameters are summarised in Table 12.

As noted in Section 4, evaporation transpiration data for the period 1910-2023 was estimated using the McGuinness-Bordne method.

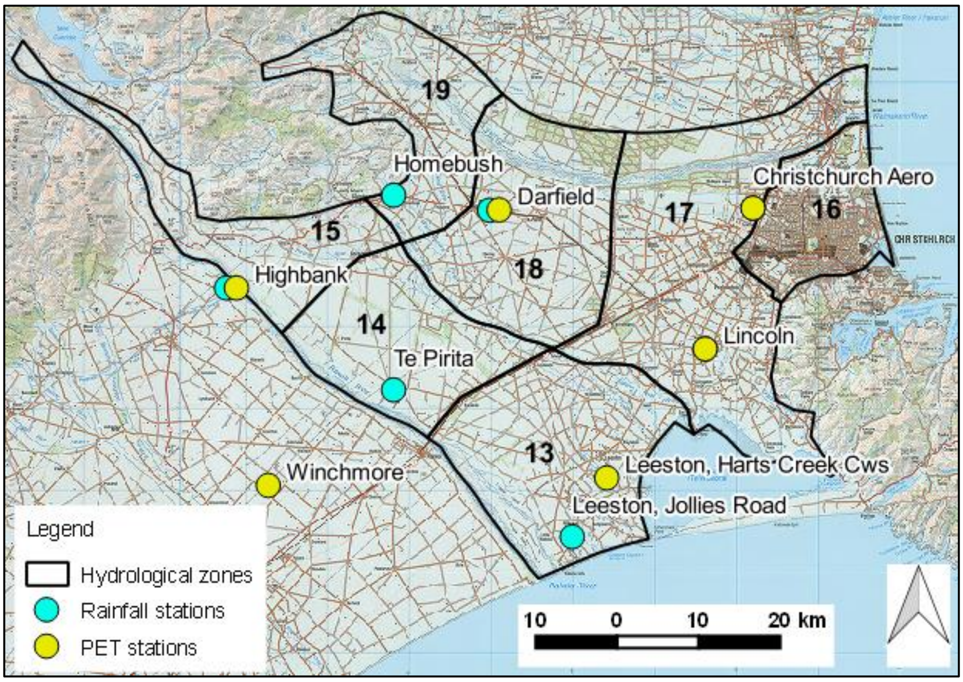


Figure 18. Groundwater model zones.

Table 11. Climate stations used for each groundwater model zone.

Ground water model zone	Climate Variable	
	Rain	Potential evapotranspiration
13	Leeston	Leeston
14	Te Pirita	Winchmore
15	Highbank	Highbank
16	CHCH Aero	CHCH Aero
17	Lincoln	Lincoln
18	Darfield	Darfield
19	Homebush	Darfield

Table 12. Soil and irrigation parameters used in IrriCalc modelling.

Model zone	Average PAW (mm)	Application depth (mm)	System capacity (mm/d)
Leeston	83	60	4.3
Te Pirita	67	43	4.3
Hororata	70	43	4.3
Christchurch City	99	0 (Dryland only)	0 (Dryland only)
Lincoln	84	60	4.3
Darfield	74	43	4.3
Homebush	74	43	4.3

9.2 Groundwater modelling scenarios

Groundwater modelling scenarios are listed in Table 13.

Table 13. Groundwater modelling scenarios

Scenario	PET	Irrigation
Historic	Estimated from temperature data	Current land-use and water sources.
Climate Change 2050	Estimated from temperature data	
Climate Change 2100, RCP4.5	NIWA projected data	
Climate Change 2100, RCP8.5	NIWA projected data	

Description of scenarios:

- **Historic:** The simulation period 1910-2023 assumed post-earthquake land use, groundwater pumping and irrigation. Land surface recharge was derived from the extended time series of rainfall and PET.
- **Climate Change 2050, RCP4.5 and RCP8.5:** In this case PET data was generated from temperature data assuming a 1.5°C increase in temperature.
- **Climate Change 2100, RCP4.5:** NIWA projected data for RCP4.5 has been used to simulate groundwater responses at end of century.
- **Climate Change 2100, RCP8.5:** NIWA projected data for RCP8.5 has been used to simulate groundwater responses at end of century.

9.3 Groundwater modelling

To simulate groundwater level responses resulting from changes in land surface recharge and pumping, one-dimensional eigenmodels (Bidwell and Burbery, 2011) were fit to historical data from representative wells in the Selwyn District. These simplified bulk-parameter compartment groundwater models are useful for capturing the dynamic response of wells and rapidly exploring scenarios.

The catchment was divided into three slices along which groundwater flow is approximately unidirectional, Figure 20. Each slice was divided into three zones (inland, mid-plains and coastal) and eigenmodels were calibrated to the six representative wells also shown in Figure 19.

9.4 Selected wells

Calibration wells were selected to provide spatial coverage, while including a mix of shallow and deep wells and are summarised in Table 14. These wells were also selected since they have long-term water level data and are broadly representative of SDC well assets.

Well number	Depth (m)	Location	Eigen model slice	Representation
M35/1000	48.8	West Melton	1	Moderately deep groundwater supply
M35/1080	30	Christchurch-West Melton	1	Shallow groundwater supply
M36/0217	41	Rolleston	1	Shallow groundwater supply
L36/0092 & BX22/0003	61 & 93	Charing Cross	2	Deep groundwater supply
M36/0599	9	Lincoln	2	Shallow groundwater levels & drainage
L36/0124	35	Bankside-Dunsandel	3	Shallow groundwater supply
L36/1226	109	Te Pirita-Hororata	3	Deep groundwater supply
M36/0424	13	Doyleston	3	Shallow groundwater levels & drainage
L35/0180	8	Darfield (north)	4	Shallow groundwater supply

Table 14. Description of selected wells.

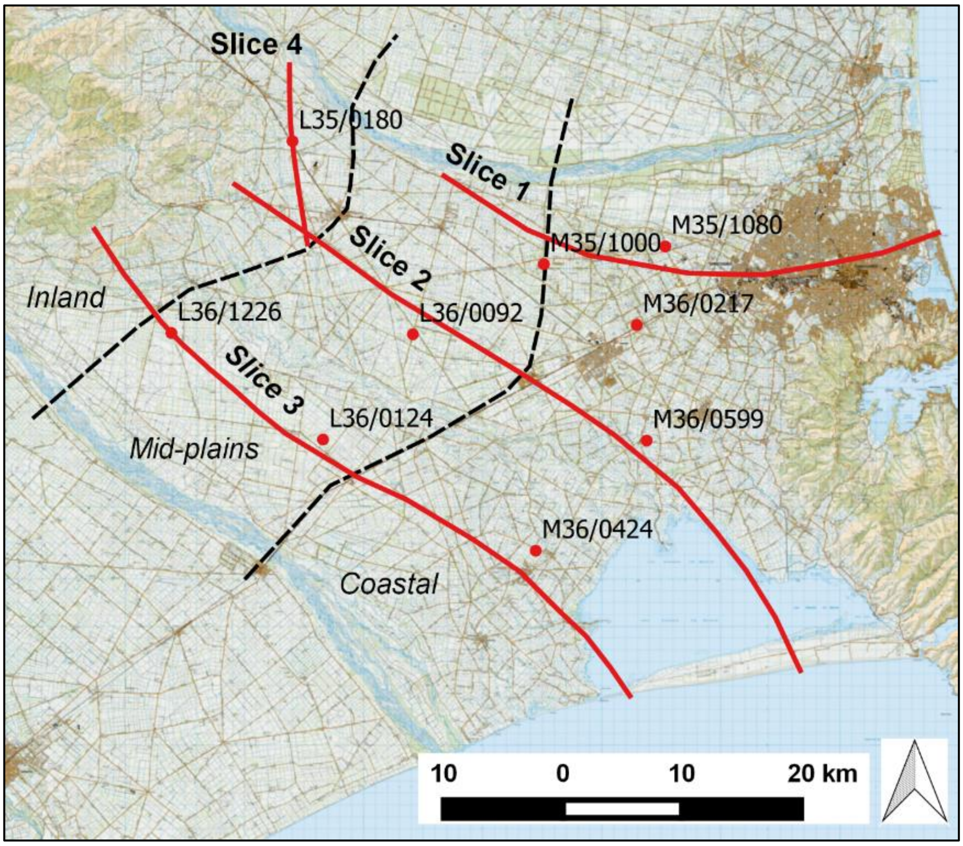


Figure 19. Calibration well locations and conceptual groundwater model slices.

9.5 Model calibration

Each eigenmodel ran from January 1910 to April 2023 with monthly stress periods. Models were calibrated to measured groundwater levels, estimated pumping and land surface recharge over the period August 2011 to December 2014. This period was chosen because:

- model inputs (pumping rates and drainage) assume current water use and land use intensification, and
- to avoid earthquake responses and subsequent changes to groundwater levels that occurred in some wells (Cox *et al*. 2012; Dudley Ward, 2015).

Figure 20 shows the simulated dynamic response of well L36/0092 over the period. Responses for the other wells are given in Appendix B.

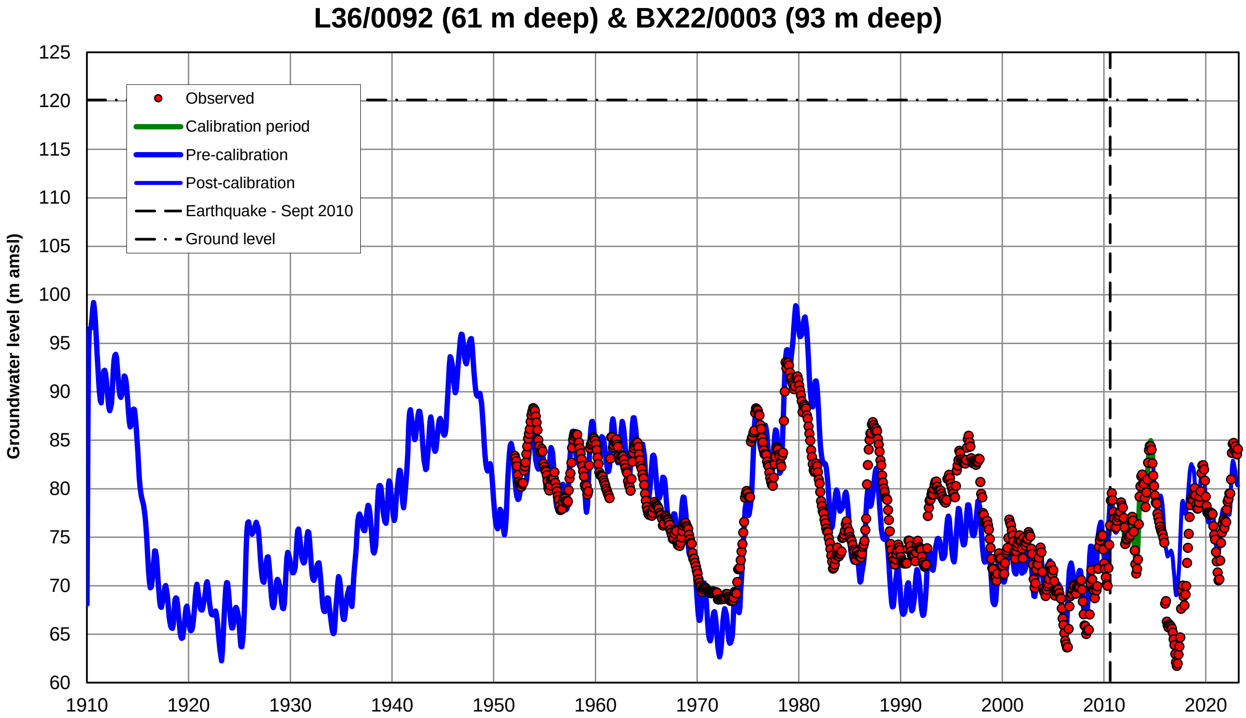


Figure 20. Simulated dynamic response of well L36/0092.

9.6 Results and recommendations – 2050 climate futures

Summary statistics for the historic and 2050 climate future periods for the modelled bores are shown in Table 15 and Table 16. Five out of the nine wells indicate small or insignificant reductions to groundwater levels. However, the other four deeper wells (viz. L36/0092, L36/0124, L36/1226 and M35/1000) show more significant reductions in water levels. These are most pronounced in the summary data on low groundwater levels. Given the possibility of lower groundwater occurring at some stage in the future, we recommend investigation of the following questions:

- can existing physical infrastructure such as pump placement and well hydraulics effectively handle lower projected groundwater levels?
- If not, what emergency operating regime should be implemented to ensure partial water supply?

Table 15. Groundwater modelling summary - Part A

Bore M35/1080 Christchurch-West Melton (GL 60.7m amsl)							
Scenario	Average	High GW levels (m amsl)			Low GW levels (m amsl)		
	(m amsl)	1 y in 10	1 y in 25	1 y in 100	1 y in 10	1 y in 25	1 y in 100
Historic	45.68	49.53	51.28	52.52	42.57	42.28	41.84
2050	44.09	47.89	49.18	51.28	41.21	40.87	40.49
Bore M36/0217 Rolleston (GL 52.9m amsl)							
Scenario	Average	High GW levels (m amsl)			Low GW levels (m amsl)		
	(m amsl)	1 y in 10	1 y in 25	1 y in 100	1 y in 10	1 y in 25	1 y in 100
Historic	35.96	41.84	44.23	45.65	31.12	30.76	29.55
2050	34.51	40.14	42.96	43.90	29.98	29.61	28.81
Bore L36/0092 Charing Cross (GL 120.1m amsl)							
Scenario	Average	High GW levels (m amsl)			Low GW levels (m amsl)		
	(m amsl)	1 y in 10	1 y in 25	1 y in 100	1 y in 10	1 y in 25	1 y in 100
Historic	77.29	92.85	95.67	99.15	65.62	64.20	62.32
2050	70.32	85.88	88.42	93.58	58.88	57.52	55.17
Bore M36/0599 Lincoln (GL 14.7m amsl)							
Scenario	Average	High GW levels (m amsl)			Low GW levels (m amsl)		
	(m amsl)	1 y in 10	1 y in 25	1 y in 100	1 y in 10	1 y in 25	1 y in 100
Historic	13.01	13.90	14.11	14.43	12.43	12.37	12.28
2050	12.83	13.70	13.93	14.22	12.28	12.23	12.13

Table 16. Groundwater modelling summary - Part B

Bore L36/0124 Bankside-Dunsandel (GL 112.3m amsl)							
Scenario	Average (m amsl)	High GW levels (m amsl)			Low GW levels (m amsl)		
		1 y in 10	1 y in 25	1 y in 100	1 y in 10	1 y in 25	1 y in 100
Historic	86.72	93.54	95.22	98.14	80.48	79.32	78.03
2050	83.39	90.42	92.25	95.15	76.96	75.89	74.73
Bore L36/1226 Te Pirita-Hororata (GL 198.3m amsl)							
Scenario	Average (m amsl)	High GW levels (m amsl)			Low GW levels (m amsl)		
		1 y in 10	1 y in 25	1 y in 100	1 y in 10	1 y in 25	1 y in 100
Historic	107.35	118.88	121.78	125.47	95.76	94.63	93.24
2050	100.23	116.81	120.60	128.87	88.76	87.13	85.79
Bore M36/0424 Doyleston (GL 21.4m amsl)							
Scenario	Average (m amsl)	High GW levels (m amsl)			Low GW levels (m amsl)		
		1 y in 10	1 y in 25	1 y in 100	1 y in 10	1 y in 25	1 y in 100
Historic	20.36	21.09	21.28	21.66	19.68	19.61	19.48
2050	20.10	20.86	21.06	21.32	19.41	19.34	19.20
Bore L35/0180 Darfield (north) (GL 255.2m amsl)							
Scenario	Average (m amsl)	High GW levels (m amsl)			Low GW levels (m amsl)		
		1 y in 10	1 y in 25	1 y in 100	1 y in 10	1 y in 25	1 y in 100
Historic	249.93	250.94	251.17	251.65	249.24	249.19	249.13
2050	249.96	251.01	251.29	251.76	249.32	249.22	249.16
Bore M35/1000 West Melton (GL 105.2m amsl)							
Scenario	Average (m amsl)	High GW levels (m amsl)			Low GW levels (m amsl)		
		1 y in 10	1 y in 25	1 y in 100	1 y in 10	1 y in 25	1 y in 100
Historic	68.04	82.06	84.96	89.29	56.85	54.81	54.46
2050	59.88	73.49	77.45	83.67	49.42	47.32	46.33

9.7 Results – 2100 climate futures

The results of this section are based on NIWA's modelled climate data for the 21st century for RCP4.5 and RCP8.5. Summary statistics for the difference between historic and projected levels are given in Table 17 for well L36/0092. The broad picture is of reduced groundwater levels with relatively little difference between RCP4.5 and RCP8.5 at end-of-century. When interpreting these results, it is very important to temper them with the very significant uncertainties when projecting to the end of the 21st century. Furthermore, with little doubt, the next 70 years will also see substantial changes to land-use and irrigation demand; our assessment is unable to take this into account. The main message to take on board is that groundwater levels are projected to get lower on average with more frequent occurrence of 'extreme events' (i.e. lower water levels).

Table 17. Groundwater modelling summary of the differences between historic and projected levels in 2100 for RCP4.5 and RCP8.5 using NIWA projected climate data.

Bore L36/0092 Charing Cross (GL 120.1m amsl)							
Scenario	Average (m amsl)	High GW levels (m amsl)			Low GW levels (m amsl)		
		1 y in 10	1 y in 25	1 y in 100	1 y in 10	1 y in 25	1 y in 100
2050 RCP4.5	11.68	15.12	16.76	15.3	8.16	7.51	7.55
2050 RCP8.5	11.45	15.01	16.65	15.16	7.55	8.01	7.75
2100 RCP4.5	10.96	15.02	17.47	13.44	6.86	7.03	7.56
2100 RCP8.5	11.24	16.08	18.14	13.25	7.16	6.65	8.13

10 RIVER FLOWS

The key messages for this section are:

- **Historical river flow data in the Selwyn District does not indicate any long-term trends.**
- **Mean annual flows in the alpine rivers (Waimakariri and Rakaia) are projected to increase by 3% by the 2040's, as a result of increased alpine precipitation. Greatest increases are likely to occur in winter.**
- **Foothill river flows may slightly decrease over the next 30 years, due to a small increase in evapotranspiration.**
- **Towards 2100 the annual cycle of river flows may be significantly modified and is highly dependent on climate future.**

Historical time series of flows for the Rakaia River, Waimakariri River, Selwyn River and Doyleston Drain are shown in Figure 21. No long-term trends are evident daily river flows or in the number of days with high flows.

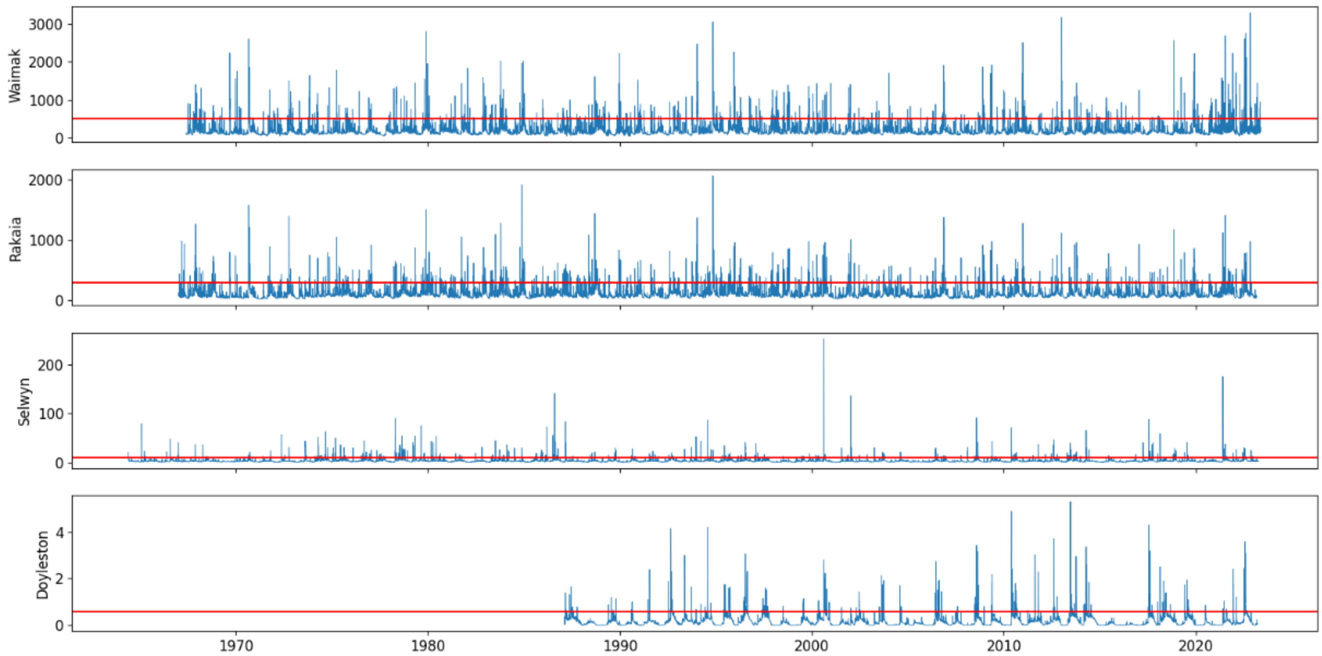


Figure 21. River flow time-series. The red lines are the 95th percentile for daily flows.

McKerchar and Henderson (2003) investigated Rakaia and Waimakariri flows for changes between the IPO phases for the 1947 and 1999 period. They found an increased annual flood levels for the Rakaia River for the positive phase of the IPO, but could not distinguish a change for the Waimakariri River.

Projections of river flows by mid-century (2031 to 2050) for the Rakaia River indicate an increase in mean flow of 3% mostly due to a 14% increase in winter flows, (Collins *et al*. 2018). Low flows are not projected to have any significant change, but the mean annual flood flow is projected to increase by 18%.

Climate change projections of stream flows between 2036-2056 in agricultural land across Canterbury indicate changes to average flow, low flows, the timing of when low flows occurred, flow reliability, and mean annual flood, (Collins and Zammit, 2018). The only variable that showed any significant changes for the Selwyn district was the mean annual floods, which were projected to increase in the upper Canterbury Plains and foothills areas by 20 to 40%.

Foothill river flows (e.g. Selwyn and Kowai River) may decline over the next seventy years. This is a result of a small increase in evapotranspiration (Section 6). Overall, projecting to mid-century, any decrease in flow may be expected to be small compared to natural year to year variability of river flow.

Lowland drains, such as Doyleston Drain, are fed predominately from groundwater. Climate change futures in 2050 project a reduction in groundwater levels (Section 9) with a relatively minor impact on drain flows.

Beyond 2050 the uncertainty increases significantly and is highly dependent on climate future: with the projected increase in volatility of extreme rainfall events noted in section 7, it is reasonable to expect increased volatility in river flows. This means that infrastructure like bridges and stopbanks may become more susceptible to damage.

Furthermore, with the projected decrease in snowfall and shortening winter season, receding snowline and snow cover duration especially at lower elevations, the annual cycle of river flows in the Canterbury region may be significantly modified over time. For example, areas which traditionally experienced snow cover over winter months are projected to experience higher rainfall over these months increasing the chance of larger winter floods.

11 SEA LEVEL RISE

The key messages for this section are:

- **In the last 60 years, sea levels have risen by 2.44 mm per year (0.14 m). If global emissions remain high, sea levels will increase by a further 0.21 m by 2040 and 0.67 m by 2090 (MfE, 2020).**
- **Sea levels are projected to rise by up to 0.90 m by 2100 under RCP8.5.**
- **ESL (extreme sea level) events that are historically rare will become common by 2100 under all emissions scenarios.**
- **With SLR saltwater intrusion into coastal and surface waters and soils is expected to be more frequent and enter farther inwards.**

The 2020 *National Climate Change Risk Assessment* observes that sea levels around New Zealand have risen by 2.44 mm per year over the last 60 years or 0.14 m over this period. It also states that if global emissions remain high then sea levels will increase by a further 0.21 m by 2040, and 0.67 m by 2090. By comparison, if sea level follows the historical trend it would rise by 0.17 m by 2090.

Figure 22 shows measured and projected changes in mean annual sea level at Lyttleton (the closest sea level measurement to the Selwyn District's coastline) based on these estimates. The large disparity in projections indicates the considerable uncertainty associated with sea level rise (SLR).

Apart from having a potentially significant impact on ecosystems and available land for primary industries, shallow coastal groundwater systems become increasingly vulnerable to saltwater contamination with SLR (see section 14). The 2022 IPCC *Special Report on Ocean and Cryosphere in a Changing Climate* states that '*with rising sea levels, saline water intrusion into coastal aquifers and surface waters and soils is expected to be more frequent and enter farther landwards. Salinisation of groundwater, surface water and soil resources also increases with land-based drought events, decreasing river discharges in combination with water extraction and SLR (high confidence)*'.

To give a general picture of SLR futures, the IPCC report further states that '*sea level is rising and accelerating over time and will continue to rise throughout the 21st century and for centuries beyond' and that 'ESL [extreme sea level] events that are historically rare, will become common by 2100 under all emissions scenarios, leading to severe flooding in the absence of ambitious adaptation efforts (high confidence)*'.

In a presentation 'Future projections of sea level rise and the implications for our coasts: IPCC perspective' given in November 2022 in Sydney[2], the speaker and IPCC author Professor Nathan Bindhoff observed that '*SLR greater than 15 m cannot be ruled out'*. He further notes that '*small changes [in SLR] can be critical to sea level [and the incidence of extreme sea level (ESL) events]*'. This means that the consequences of even small projected changes in SLR given under certain emissions scenarios should not be underplayed in planning.

The *National Climate Change Risk Assessment* states that '*Many Māori communities are concentrated around coastal areas, which are particularly vulnerable to rising sea levels'*. We note that while it is not SDC infrastructure, Taumutu Rūnanga's marae, Te Pa o Moki, is close to the coast and may be impacted by SLR and ESL.

[2] https://nesp2climate.com.au/national-adaptation-forum-22

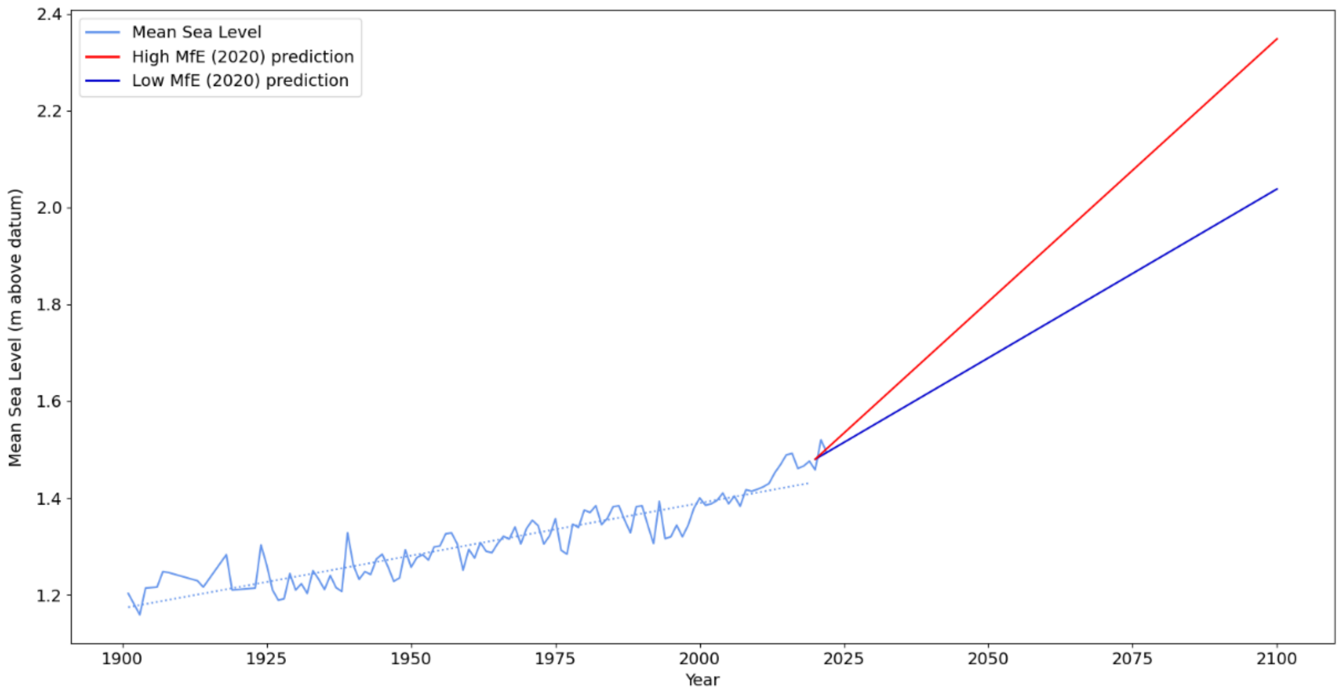


Figure 22. Measured and projected changes in mean annual sea level at Lyttelton: 1901-2050.

12 TE WAIHORA/LAKE ELLESMERE

The key messages for this section are:

- **Te Waihora / Lake Ellesmere is artificially managed to maintain a water level well below the lake's natural operating range.**
- **95% of the time lake levels are between 0.4 m to 1.2 m amsl (above mean sea level), although in an extreme rainfall event levels have been up to 1.8 m amsl.**
- **Sea level rise (SLR) may result in the lake needing to be opened more often or managed under a new operating range. If global emissions remain high, and without any change in lake management, lake levels are projected to rise by 0.21 m by 2040 and 0.67 m by 2090.**
- **Under RCP8.5 lake levels are projected to rise by up to 0.90 m by 2100.**
- **A higher lake level would result in more frequent flooding of areas around the lake (including lower Selwyn Huts) and would reduce the effectiveness of SDC's land drainage network.**
- **The installation of an outlet weir would allow lake levels to be maintained over a narrower range, which could alleviate some of the flooding problems that have occurred historically and offset a projected rise in sea levels.**

12.1 Lake water level management

The water level of Te Waihora has been artificially managed through creating a connection from the lake to the sea since at least 1860. Environment Canterbury estimate that without human intervention the lake level would rise to a range of 2.7 m to 3.6 m amsl before the opening was naturally breached. Environment Canterbury has been involved with Te Waihora openings through the former North Canterbury Catchment Board since 1947 (ECan, 2016). The lake level is managed relative to mean sea level. The National Water Conservation (Te Waihora / Lake Ellesmere) prescribes the levels at which the lake can be opened.

The method currently used to open the lake is to excavate a channel through the gravel beach using excavators, a dragline and bulldozers (Figure 23). This may take from a few days to weeks to complete, depending on the volume of gravel built up on the beach. Once the lake is opened, there is very limited ability to control how long it remains open. The duration of the opening is determined by weather and sea conditions and how quickly gravel is deposited by the sea to close the cut. The ability to successfully open the lake depends heavily on weather and sea conditions, particularly southerlies. Unfavourable weather conditions can cause significant delays in opening the lake (ECan, 2016).

Figure 23. Te Waihora Lake Opening Location

Over the last 30 year,s lake levels have been in the range of 0.4 to 1.2 m amsl 95% of the time. At the extremes, levels have been as low as 0.2 m amsl and as high as 1.8 m amsl. Historic levels are illustrated in Figure 24 and Figure 25. The area of inundation on 30 June 2013, when lake levels were at the highest recorded level of 1.81 m amsl, is shown in Figure 26.

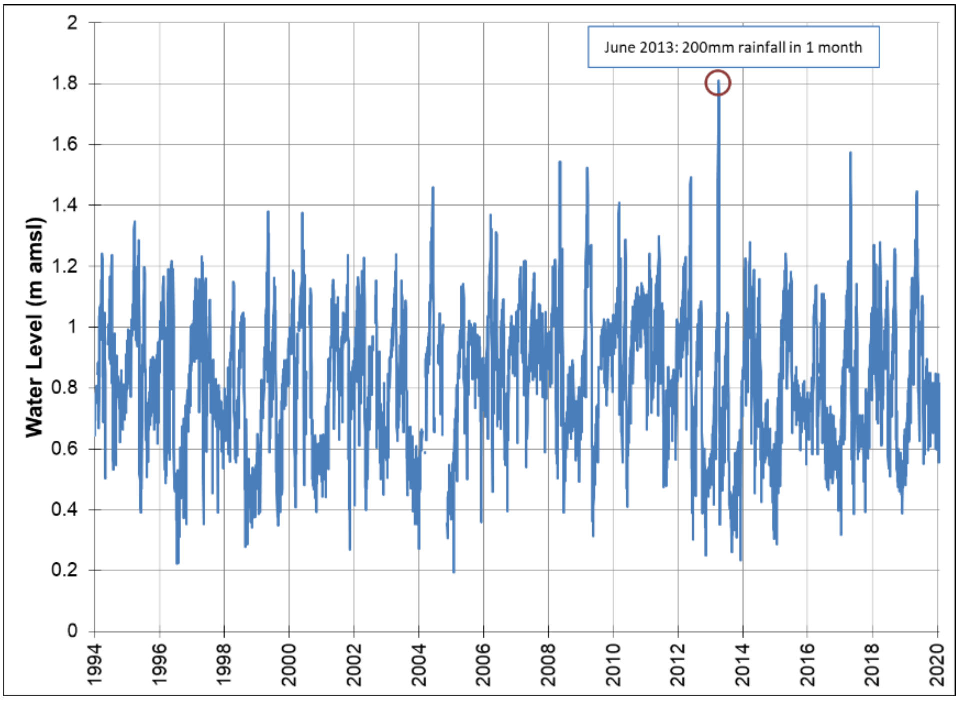


Figure 24. Te Waihora water levels 1994 to 2020.

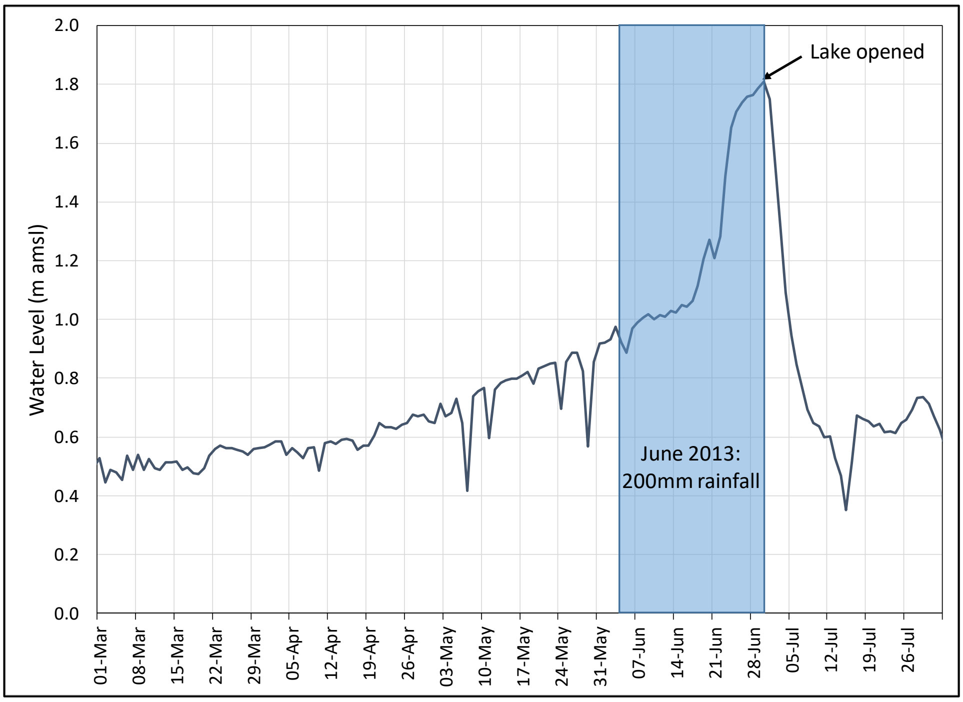


Figure 25. Te Waihora water levels Mar-Jul 2013.

Figure 26. Area inundated due to high lake levels: 30 June 2013.

Higher sea levels will affect Te Waihora/Lake Ellesmere water levels. Sea level rise will make it more difficult to achieve a successful lake opening, and may result in a higher mean lake level. Without any change in lake management, lake levels may rise by 0.21 m by 2050, with respect to the 1999-2019 levels, due to the level differential required to generate flow through the opening.

A higher lake level would result in more frequent flooding of areas around the lake and would reduce the effectiveness of SDC’s land drainage network.

Lake levels could be maintained in a narrower range if infrastructure such as an outlet weir was installed, which could alleviate some of the flooding problems that have occurred historically. However, building any such infrastructure in the coastal environment is likely to be incredibly challenging.

12.2 Selwyn Huts

A higher lake level in Te Waihora would result in more frequent flooding of lower Selwyn Huts and may reduce the effectiveness of the Upper Selwyn Huts wastewater system.

The lower Selwyn Huts are already prone to flooding. Figure 28 shows that the settlement was entirely under water on 30 June 2013, when lake levels rose to 1.8 m amsl. Sea level rise has the potential to increase the frequency and magnitude of flooding.

The upper Selwyn Huts (settlement is approximately 2.5 m amsl) are less prone to flooding than the lower huts. However, the current wastewater system uses border dyke irrigation for effluent disposal.

Conditions of the resource consent for the wastewater system include:

- Disposal of wastewater will not result in runoff from the area.
- Disposal of wastewater will not result in discharge to areas where there is standing water, including ponded rainwater or ponded discharge. Also, it cannot occur under circumstances where the discharge is likely to cause ponding for longer than 24 hours.

Given these conditions, shallow groundwater levels are likely to be a concern. M36/0768 is a 27m deep well approximately 2 km to the northwest of the site. This has a long water level record (shown in Figure 27), which shows groundwater levels fluctuating between around 2m and 0.3m bgl. Although this may not be fully representative of shallow groundwater, one-off measurements in shallow bores in the area also show very shallow groundwater levels (from 0.1m to 1m bgl).

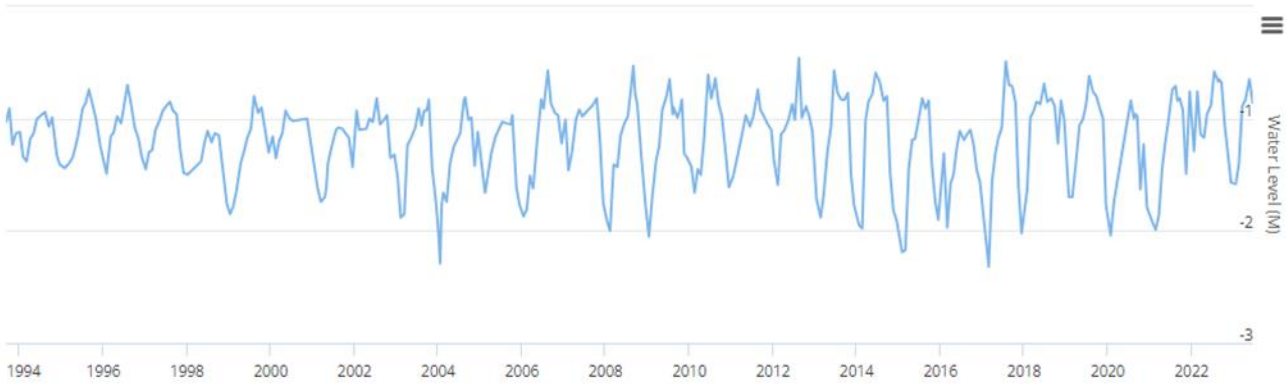


Figure 27. Water level record from bore M36/0768, 2km from Selwyn Huts.

Any factors that affect shallow groundwater are of concern in terms of not causing ponding or runoff. Shallow groundwater is likely to be affected by sea level rise, rising lake levels and increasing extreme events in this area. A long-term increase in sea/lake level will result in an increase in the long term average groundwater level. In addition to this, increasing extreme events are likely to cause short-term peaks in groundwater level that impact on the discharge of treated effluent over shorter time periods.

When lake levels are high irrigation cannot occur. SDC's preferred option at present is to pipe wastewater away from the site, replacing the current disposal system.

Figure 29 and Figure 30 show the difference that a 0.23 m rise in lake level would have had on the 30 June 2013 event. A 0.23 m rise was the maximum sea level rise predicted in the MfE (2008) report, which has now been updated with the MfE (2017) report with a more recent sea level rise prediction of 0.17-0.28 m amsl by 2050, relative to a 1999-2019 baseline (MfE 2017). As noted in the previous section, current estimates of sea level rise are of the order of 0.21 m by 2040 if global emissions remain high. Inundation maps have therefore not been updated since the 2016 climate change report for SDC (Brown *et al*, 2016). Actual impacts may differ because of the wide range of sea level rise scenarios.

Figure 28. Lower Selwyn Huts with a water level of 1.8 m amsl

Figure 29. Upper Selwyn Huts with a water level of 1.8 m amsl.

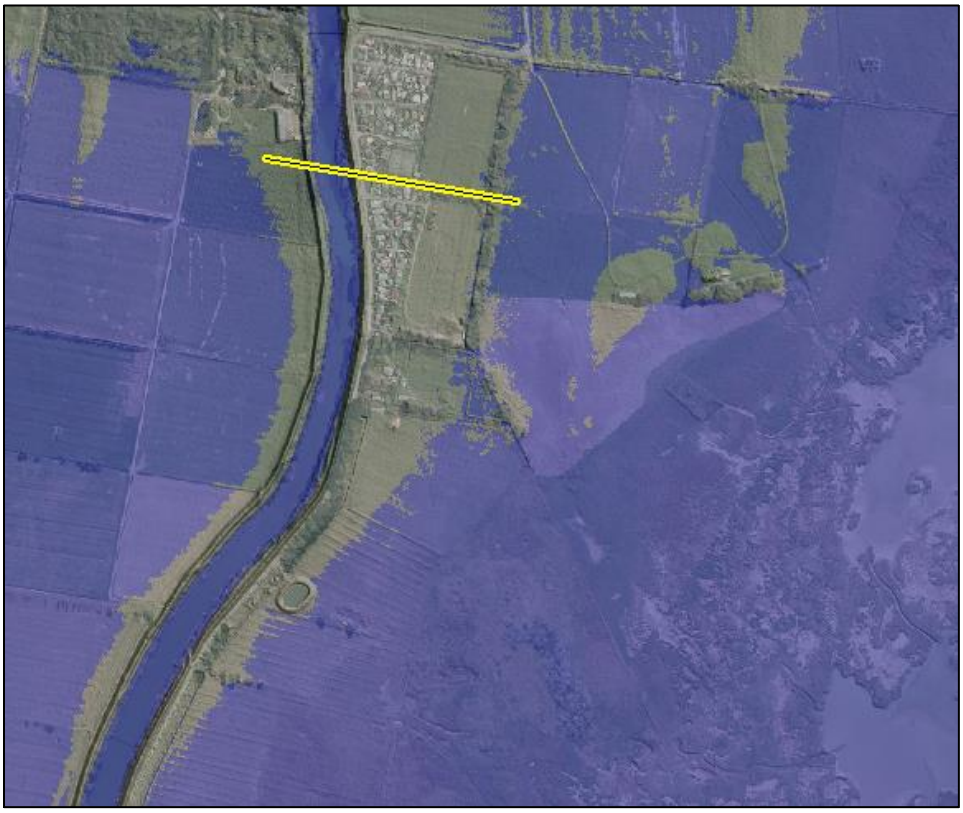


Figure 30. Upper Selwyn Huts with a water level of 2.03 m amsl.

12.3 Land drainage network

A rise in Te Waihora water levels (see Section 12.1) would reduce the effectiveness and flood capacity of SDC's land drainage network. A higher lake level both floods the land in the immediate vicinity of the lake, and increases the lengths of races that are affected by backwater effects. Backwater effects may occur when a rise in water levels at the end of a drain propagates back up the drain, resulting in reduced flow and drainage capacity. For example, Figure 31 shows that for the Ararira / LII drainage network, during a moderate flood, backwater effects can increase water levels in the drains, up to 1.0 m above the level of the Te Waihora lake level (from Samad 2007, Figure 6-17).

During an extreme event, such as on 30 June 2013, lake levels may rise up to 1.8 m above sea level. Allowing for 1 m of backwater effects, and given a typical drain depth of 1 m, this means lake levels can affect land drainage up to an elevation of about 3.8 m amsl (1.8+1.0+1.0). Figure 32 and Figure 33 provide a coarse assessment of the difference that an additional 0.23 m increase in lake water level would make on the affected drainage area. These figures show that there is little difference between the affected areas because there is a reasonable slope on the Canterbury Plains above an elevation of about 2.0 m amsl. Because of this slope, the updated sea level rise maximum prediction of 0.21 m amsl by 2050 (relative to a 1999-2019 baseline) would also show little difference in the affected areas.

Higher water levels in the Ararira / LII drainage network summer, further away from Te Waihora where backwater effects are not significant, are a result of macrophyte growth, and can be addressed via maintenance practices.

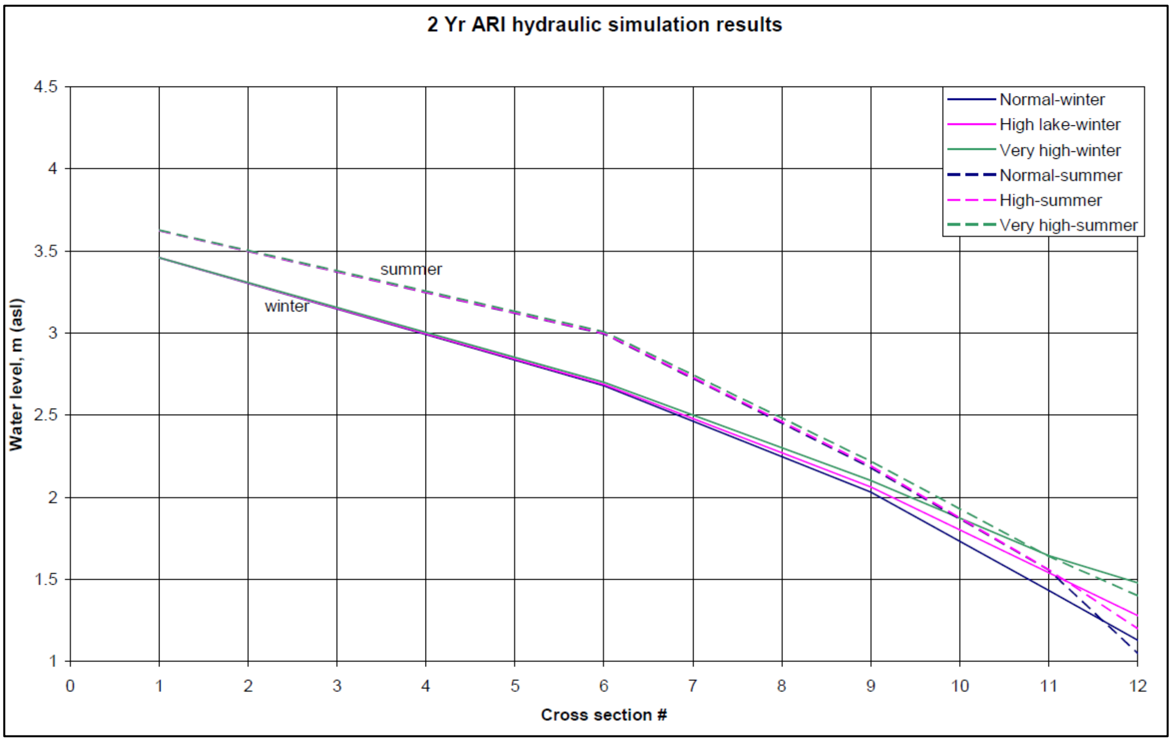


Figure 31. Backwater impacts in Ararira / LII drainage network during a moderate storm event.

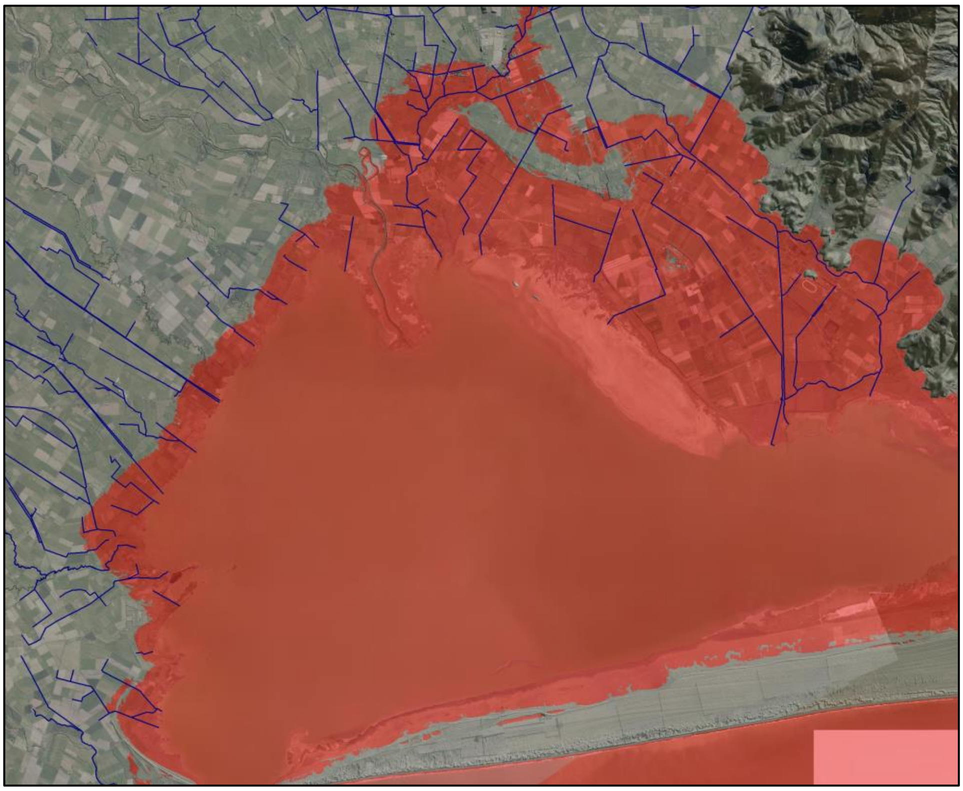


Figure 32. Maximum extent that lake levels affect land drainage (3.80 m amsl).

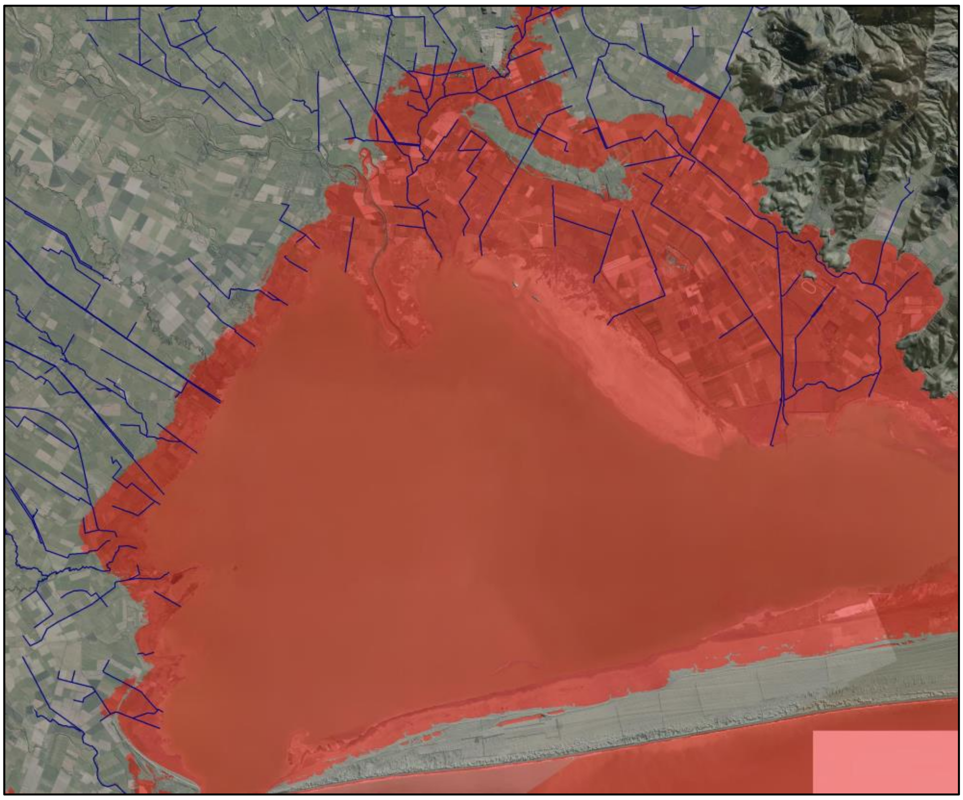


Figure 33. Maximum extent that lake levels affect drainage (4.03 m amsl).

13 RAKAIA MOUTH

The key messages for this section are:

- **Projected increase in SLR of 0.21 m by 2050 may increase the frequency of ‘normal’ flooding at Rakaia Huts.**
- **Furthermore, the projected increase in frequency of extreme sea level (ESL) means that the Rakaia Huts will be more exposed to catastrophic flooding.**

The lowest point at Rakaia Huts is about 3.5 m amsl. The huts are protected from the sea by a sand bar, and periodically flood when the Rakaia Mouth is closed. The balance between deposition and erosion at the river mouth and coast is highly dynamic due to river floods and coastal erosion/deposition.

Figure 34 and Figure 35 show the impact of a 0.21 m sea level rise could have on flooding, which is minor. However, the projected increase in frequency of extreme sea level (ESL) means that the Rakaia Huts will be more exposed to extreme flooding events. This needs to be taken in combination with the impacts of coastal and river processes, noting that the single biggest factor that currently controls flooding is whether the river mouth is open.

Projecting to 2100, the magnitude of impacts is highly dependent on emissions scenario.

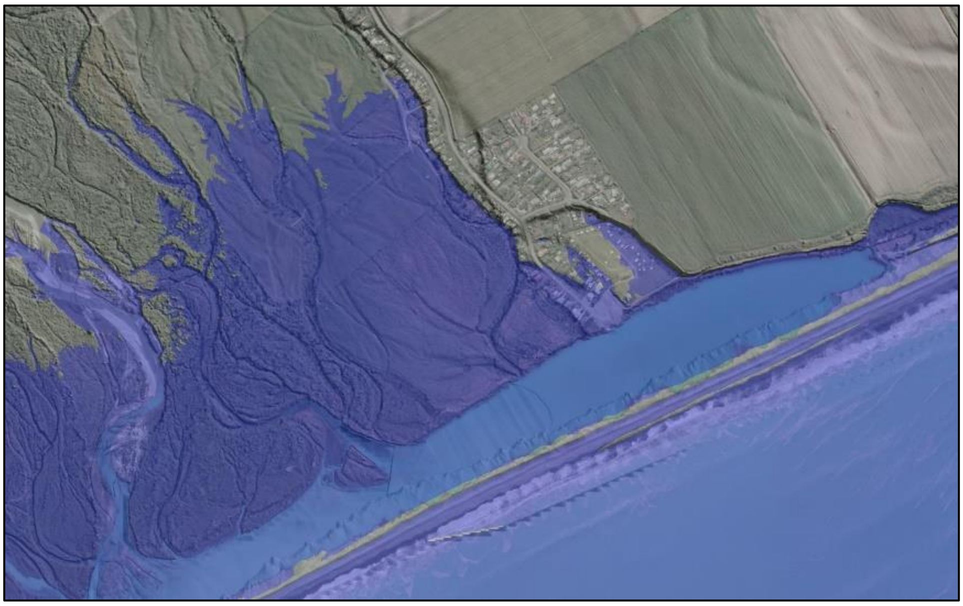


Figure 34. Rakaia Huts with a flood water level of 4.00 m amsl.

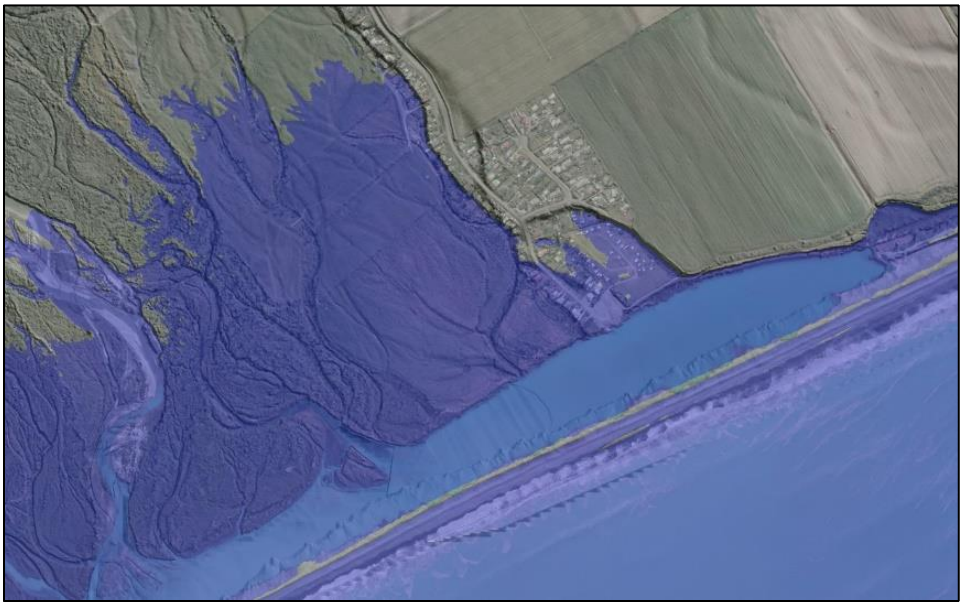


Figure 35. Rakaia Huts with a water level of 4.21 m amsl.

13.1 Rakaia Huts – Culturally Significant Area

Rakaia Huts is a small seaside settlement located on the northern side of the Rakaia River mouth. This was traditionally an early area of occupation and food gathering for local Māori which now holds a high cultural and archaeological significance, particularly to Te Taumutu Rūnanga and Te Rūnanga o Ngai Tahu. This is one of the earliest dated sites in Canterbury so holds regional significance, and with very few (if any) sites of this type, it is also nationally significant. The close proximity of this area to the sea and river, creates the risk of damage or partial loss from natural processes influenced by climate change and more specifically, flooding and sea-level rise. SDC has developed the Rakaia Huts Conservation Plan (2009), that addresses threats to the significant cultural value of the area and inform future management.

The Rakaia River is a braided river with many constantly shifting channels. At the sea entrance the river has created a bar to the east with a lagoon extending behind it. The size and location of the river entrance, bar and lagoon are ever changing by the erosional and depositional processes occurring at the river mouth. Rakaia huts is located on the landward side at the eastern end of the lagoon. The areas of cultural significance from Māori inhabitance were associated with moa and moa hunting, with evidence of hundreds of ovens, some middens, and several house sites, found on the upper and middle terraces. These areas have been mapped by archaeologists and include the foreshore, Rakaia Huts settlement, camping ground, and some surrounding agricultural land (Figure 36).

Figure 36. Figure from Rakaia Conservation Plan (2009), showing areas of Rakaia Huts with Maori artefacts and their management zones.

Climate change over the next 100 years has the potential to cause erosion or damage to the culturally significant areas at Rakaia Huts. A coastal hazard assessment of the north Rakaia Huts settlement has been conducted by Cope (2019) to identify future coastal hazard risk and vulnerability to this small coastal settlement.

A detailed study into the area by Cope (2019) indicates there is an erosion risk to the archaeological area. An eroding archaeological oven can be seen in the road edge at Rakaia Huts along the front of the lagoon (Rakaia Huts Conservation Plan, 2009). The archaeological areas on the higher plains surrounding the huts will be less prone to erosion as they are not as steep as the road cutting, are further from the sea and are more protected from the elements. We note that SDC are not specifically responsible for preserving the archaeological sites.

Cope (2019) also identifies flooding as a primary risk to the township and identified several factors that have contributed to past flooding events; river channel outlet position, gravel beach barrier height, river freshes that don't breach the coastal barrier, and storm waves overtopping the beach barrier. Cope (2019) used a conservative 'bathtub' approach (assumes the inland area will be inundated to the equivalent static sea level as the open coast/lagoon) and the MfE (2017) guidance of a sea level rise with the RCP8.5H+ scenario, to predict a potential future floodable area of all land in this area below 5.8 m, over the next 100 years. Figure 36 shows potential inundation of part of the 'Middle Terrace built up area' historical management area identified in the Rakaia Huts Conservation Plan (2007). In the archaeological investigation conducted as part of the Rakaia Huts Conservation Plan (2007) this residential area is considered a moderate to high potential for containing archaeological material, therefore inundation or flooding of this area may damage archaeological artefacts.

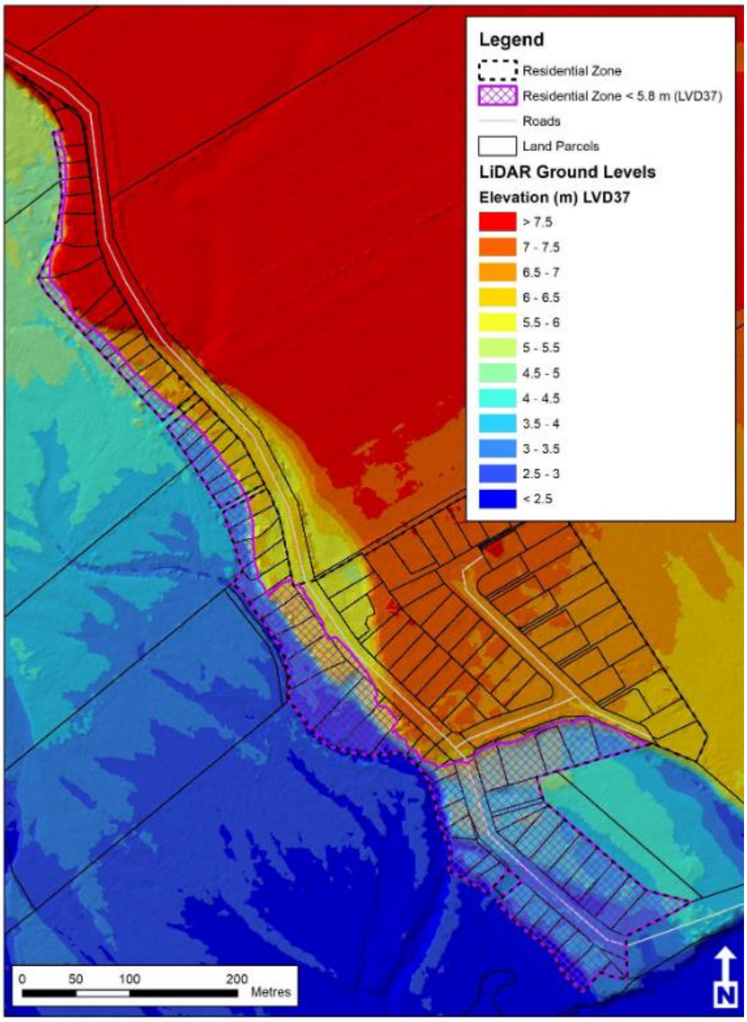


Figure 36: Figure from Cope (2019) showing potential floodable area within the residential zone, based on ground elevation and the MfE 2017 sea level rise prediction.

Coastal erosion was identified as another main risk to the township in the assessment conducted by Cope (2019). Figure 37 shows approximately 30 m of shoreline migration where the bank top is likely to erode into the lagoon over the next 100 years (based on MfE (2017) sea level rise prediction). This area encompasses the foreshore area, and the coastal road where artefacts have been recorded in the road cutting (Rakaia Huts Conservation Plan (2009)), but no residential or council owned land.

Figure 37: Figure from Cope (2019) showing the potential shoreline (bank-top) and the coastal erosion predicted in 100 years.

Based on previous studies of the cultural significance of the area surrounding Rakaia Huts, and coastal risks to the settlement, it is obvious that the risk to a significant cultural area is high. The foreshore area is expected to be the most impacted by coastal erosion and the management area the 'middle terrace built up area' is expected to be inundated or flooded in 100 years. The 'upper terrace' areas will likely avoid significant erosion or flooding in the next 100 years, and the camping ground area may potentially lose a small amount of land to erosion.

A large majority of the Māori artefacts associated with this site remain buried (Rakaia Huts Conservation Plan (2009)) at present.

Although the inundation and erosion estimates from Cope (2019) give an indication to what is likely expected over the next 100 years, it is noted that coastal and river-mouth processes are complex and interconnected and therefore difficult to predict the impact they may have on surrounding sediments. Artificial infilling or protection works along this stretch of coast may be useful to slow the rate of erosion and preserve the culturally significant area but would need to be well-planned and prevent damaging the soils surrounding this area that may also contain artefacts.

14 GROUNDWATER AND SEA LEVEL RISE

The key messages for this section are:

- **SLR level rise of ~0.21 m would lead to a moderate increase in the phreatic surface (water table) near the coast.**
- **Moderate SLR and the increased occurrence of ESL events will mostly impact groundwater and soil quality.**
- **Projecting to 2100 the impacts of SLR on coastal aquifers are highly dependent on emissions scenario.**
- **To prepare for impacts of future SLR on coastal aquifers we recommend a special study on SDC's coastal groundwater.**

Sea level rise (SLR) will lead to higher groundwater levels (jn the shallow aquifer) and saline intrusion near the coast. While SLR of ~0.21 m would lead to a moderate increase in the height of the phreatic surface (water table) near the coast, the impact of SLR on saline intrusion is much less clear. Projecting to end of century, SLR, and hence the impacts on coastal aquifers, could be significantly greater and is highly dependent on the emissions scenario.

Perhaps of greater concern to asset managers when considering the impacts of SLR on coastal aquifers and soil quality are extreme sea level events (ESLs). The 2022 IPCC special report[3] on the cryosphere notes that '*events which are currently rare (e.g., with an average return period of 100 years), will occur annually or more frequently at most available locations for RCP8.5 by the end of the century (high confidence*)'.

The special report considers that SLR will '*mostly impact groundwater quality and in turn exacerbate salination induced by marine flooding events'*. SLR may also lead to soil degradation through salination.

The report notes the importance of improving observational systems for preparing for future SLR. Given the large uncertainties associated with coastal groundwater, we emphasise the need to improve observational systems to improve our understanding of the impacts of SLR on coastal aquifers. These range from direct measurements of groundwater quality to geophysical imaging techniques.

Groundwater, generally, is characterised by large uncertainties due mainly to the sparsity of measurements. Given that large-scale groundwater contamination and soil degradation through salination is likely to be irreversible, we recommend a special study on SDC's coastal groundwater and sea level rise.

[3] section 4.2.3.4.1

15 RISK ASSESSMENT FRAMEWORK

The following sections contain our risk assessment for the following SDC assets:

- Potable water supply,
- Wastewater,
- Stormwater,
- Land drainage
- Water races
- Transportation assets
- Facilities and open spaces
  - Community facilities
  - Developed open spaces.

The district has been divided into three zones (alpine hills and high country, plains, coastal and lower plains), see Figure 37. Environmental factors (e.g. 'temperature' or 'rainfall') are partitioned by zone (e.g. 'extreme rainfall' occurs in all 3 zones) while 'sea level rise' only occurs in the coastal and lower plains zone. Global factors like 'temperature' with similar asset impacts in all zones are grouped together in 'All zones'.

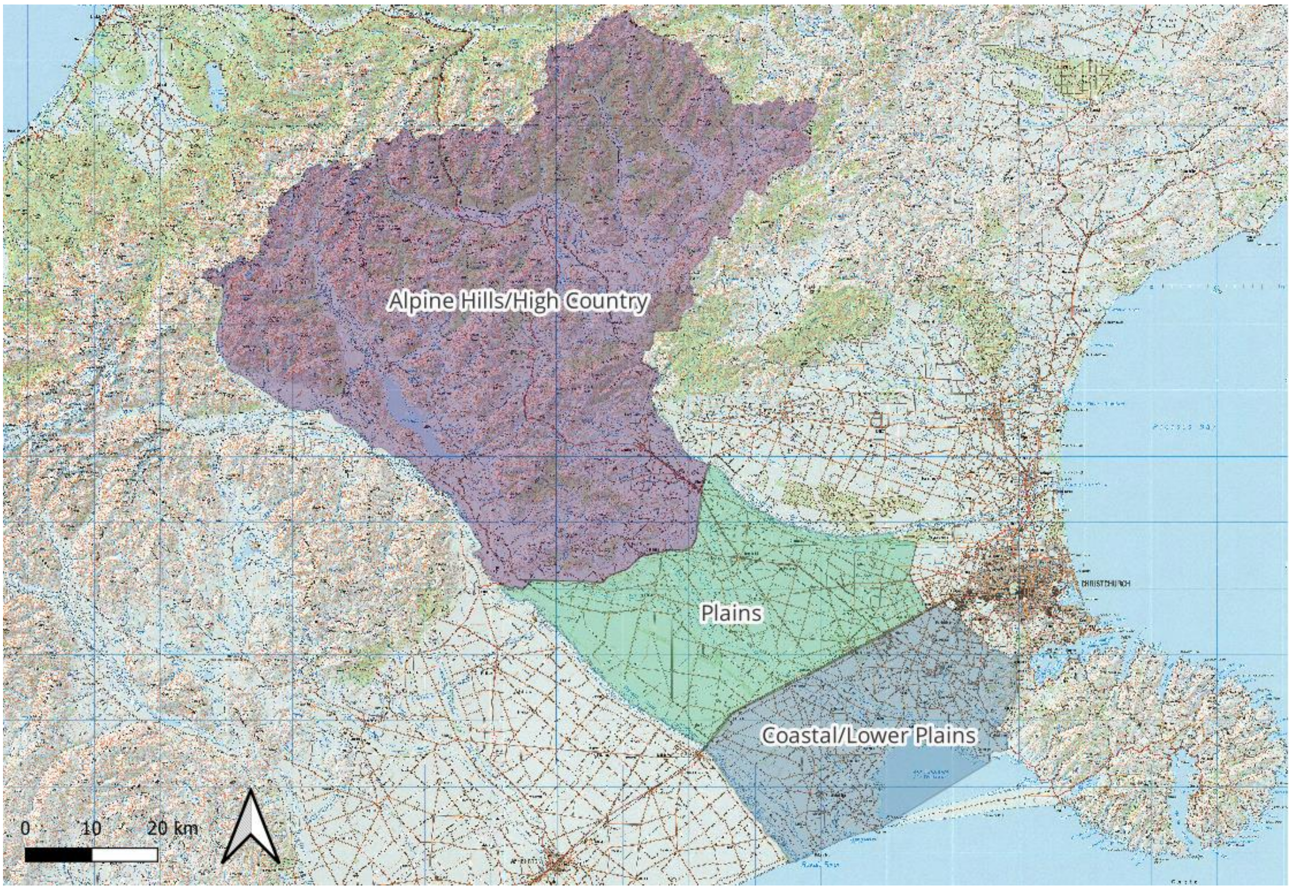


Figure 37. Zone map for Selwyn District

The 'asset impacts' column contains a summary of impacts that result from a projected change to an environmental factor like temperature or river flow. The term 'None' means that there is no obvious impact resulting from a projected climate change future to 2050. Actual impacts may different significantly if the climate turns out worse than projected climate change futures.

We have confined our risk assessment to projecting to 2050 since projected climate futures to 2100 are highly dependent on emissions scenario, and consequently the envelope of uncertainty projecting to 2100 is large. For simplicity we have assigned three levels of risk (‘low’, ‘medium’, and ‘high’) which are a function of the assessed vulnerability (consequence) and the likelihood of impact. Note that these levels are relative to the asset class considered.

There is inevitably a large degree of subjectivity in assigning levels of risk to individual asset classes. In the main we have assigned ‘high risk’ to extreme weather events like extreme rainfall which impacts all assets classes negatively, while we have assessed certain extreme events like drought to impact portability water availability more severely than wastewater or stormwater, for example. Of more relevance to decision makers/planners than the absolute level of assigned risk (which is subjective) are the relative differences between different asset classes and different environmental factors.

Our assessment should be compared with Tonkin and Taylor’s *Canterbury Climate Change Risk Assessment (T+T, 2022).* This report differs substantially from the Tonkin and Taylor report for several reasons including:

- difference of spatial scale – the T+T report covers all of Canterbury and includes all stakeholder and asset owner interests. This report is focused solely on the Selwyn District and the council’s assets.
- granularity – Selwyn district is portioned into three zones (high country. plains and low plains/coastal) and an assessment of risks to assets has been given for each zone

The T+T report has four risk levels (‘low’, ‘moderate’, ‘high’ and ‘extreme’) instead of three. As an example of the difference between the current report and the T+T report, risk to groundwater availability due to sea level rise is assessed as ‘extreme’ for all climate futures in the T+T report whereas we have assessed it to be low (but with substantial uncertainties, refer section 14). SLR poses a significant risk to shallow coastal groundwater systems but since SDC groundwater is sourced from relatively deep bores our assessment is that (moderate) SLR will not significantly impact SDC’s potable water supply projecting to 2050. We also think that effects may be different on shallow and deeper coastal aquifers; while water levels of shallow coastal groundwater systems may increase due to SLR, water levels in deeper wells are projected to decrease on average. Thus, low groundwater levels in deeper bores may impact supply reliability while shallow aquifers may show a moderate increase in the water table.

16 POTABLE WATER SUPPLY

The key conclusions for this section are:

- **Projecting to 2050, environmental factors impacting potable water supply assessed as high risk relate to the occurrence of more extreme weather events.**
- **Based on current projections, significant longer-term impacts on environmental factors like groundwater levels up to mid-century may be relatively small.**
- **Projecting to 2100, climate change impacts on potable water supplies are highly dependent on emissions scenario.**
- **In all emissions scenarios the occurrence of extreme weather events is likely to increase.**

SDC manages 26 potable water supplies. These supplies service 80% of the residential properties within the district. Maps of the schemes are shown in Figure 38 and Figure 39.

Estimated climate change impacts and risk assessment are summarized in Table 18. Environmental factors assessed as high risk mainly relate to the occurrence of more extreme events, like extreme rainfall. These will likely increase under all emissions scenarios. It is impossible to predict the probability of catastrophic failure given the rapidly changing environment; however, recent countrywide experience supports a strategic review of SDC potable water supply assets and the development of an emergency plan focused on emergency water supply.

Based on current projections, significant longer-term impacts on environmental factors like groundwater levels up to mid-century may be relatively small. However, this does not mean that potential impacts should be ignored. A general message of the IPCC special report on the cryosphere is the need to improve observational data.

Evapotranspiration is likely to increase in all scenarios. With the projected higher incidence of longer periods of drought, peak water demand will increase. Combined with lower groundwater levels this may impact supply reliability during summer months.

SDC have three potable water supplies near the coast: Rakaia Huts (consent CRC991055, Bore L37/0545), Taumutu (consent CRC010894, Bore M37/0106) and Upper Selwyn Huts (consent CRC146688, Bore M36/0529).

The Rakaia Huts bore is 23 m deep. It is a high-yielding well with a take of 12 l/s and a specific capacity of 27 l/s/m. The bore has a static water level of about 5.4 m amsl and is located 1.3 km from the coast.

The Taumutu bore is 73 m deep and 600 m inland from the coast. The consented take from this bore is less than 1 l/s averaged over a day. The bore is flowing artesian. Saltwater intrusion is expected to pose minimal risk to this bore due to its depth and artesian pressure.

The Upper Selwyn Huts bore is 67 m deep and 800 m from Te Waihora. Saltwater intrusion is expected to pose minimal risk to this bore due to its depth and artesian pressure.

While sea level rise of 0.23 m is expected to increase the risk of saltwater intrusion only slightly, long-term future monitoring of the salinity of coastal water supply assets is a prudent step.

Beyond 2050 there is much less certainty about impacts on SDC's potable water supply which is highly dependent on emissions scenario. To close the data gap, we recommend further investigation and strategic review of climate change impacts and risks on SDC groundwater assets, particularly in the lower plains and coastal area, considering the interactions between the groundwater system and sea level rise.

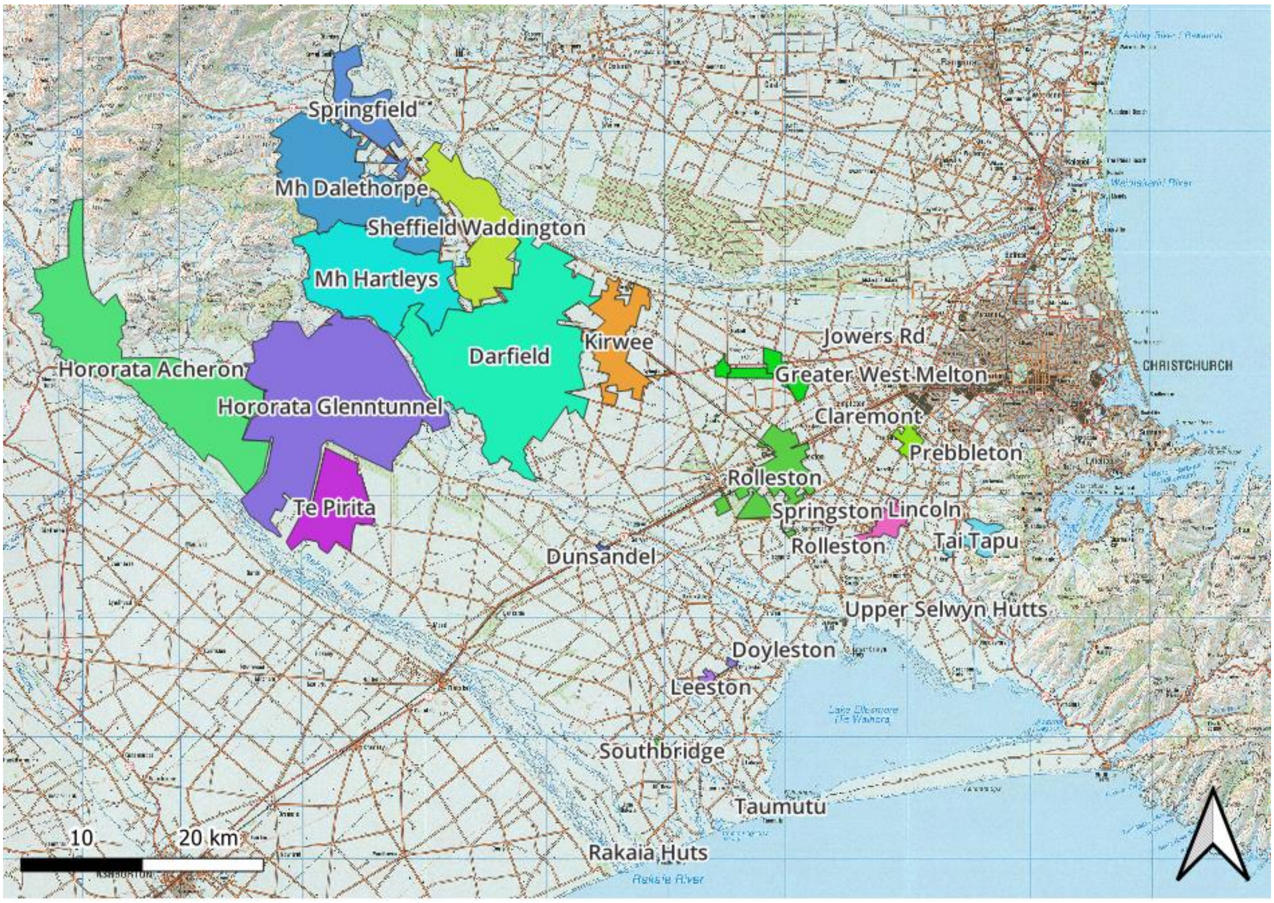


Figure 38. SDC potable water supply schemes – Canterbury Plains.

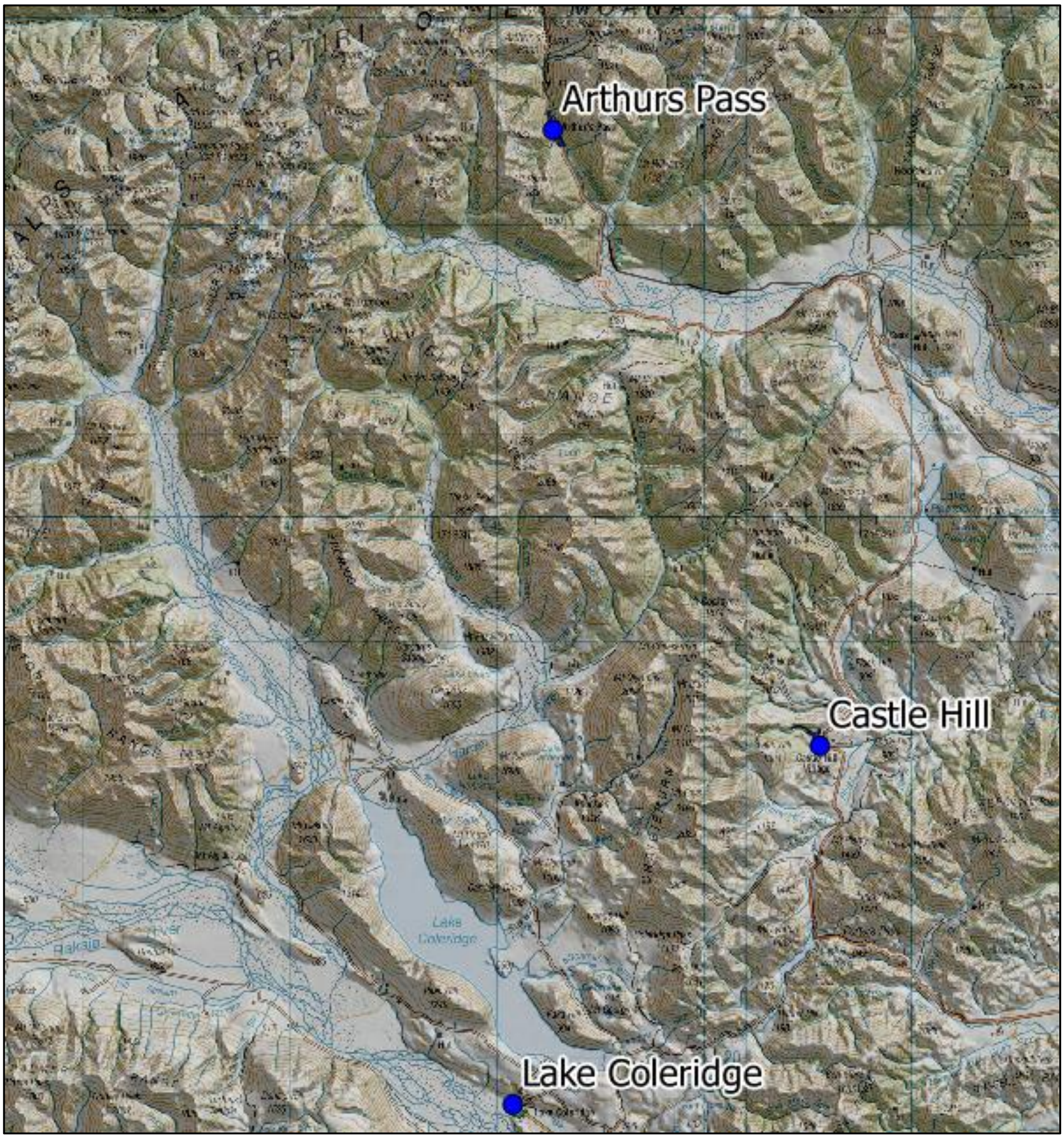


Figure 39. SDC potable water supply schemes – Alpine.

Zone	Environmental factor	Vulnerability (Consequence)	Asset impacts	Summary of projected changes	Projected change (Likelihood of impact)	Impact (Risk)
All zones	Temperature (excl. ET impacts)	Minor	Increased peak summer water demand	1.5 °C average increase, 10-20 more hot days , 5-10 fewer frost days	High	Medium
	Annual rainfall	Moderate	Reduced supply reliability; increased water demand	±5% change in average annual rainfall	Low	Low
	Drought	High	Increased peak summer water demand; reduced supply reliability (SW takes)	±5 change in number of dry days	Medium	High
	Evapotranspiration (ET)	Moderate	Increased summer water demand; reduced supply reliability	PED increase of 50-100 mm per year	Medium	Medium
	Wind (excluding ET impacts)	Moderate	Wind damage to assets in a storm	Increase in average wind speed 2-10%	Medium	Medium
	Alpine river flows	Moderate	Reduced supply reliability; increased flood damage to intakes	3% increase in alpine river mean flows, biggest increases in winter	Medium	Medium
Alpine, hills and high-Country	Extreme rainfall events (foothills and alpine)	High	Intake damage from floods; turbidity.	Increased incidence of high-intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Foothills-sourced river flows	High	Supply reliability - low flows. (e.g. Kowai)	3% increase in alpine river flows, biggest increases in winter	Medium	High
	Snow levels and ice	Minor	Harder access in winter	Reduction in number of average annual snow days by 10-25 days	Low	Low
Plains	Extreme rainfall events (Plains)	Minor	None	Increased incidence of high intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	Low
	Snow levels and ice	Minor	Asset damage in extreme snowfall events (potential benefit)	Reduction in extreme snowfall and elevation in snowline	Low	Low
	Ground water levels (upper /mid plains)	High	Low GW levels, supply reliability	Reduced groundwater levels, possibly significant in deeper aquifers towards 2050.	Low	Medium
Coastal and lower plains	Sea Level rise	Minor	Saltwater contamination	Mean sea level increase ~0.21 m; increased frequency of extreme sea-level events, unquantified impacts on saltwater intrusion	Medium	Low
	Extreme rainfall events (Coastal)	Moderate	Water quality (wellhead security) (e.g. Upper Selwyn Huts)	Increased incidence of high intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Groundwater levels (Lower Plains)	Minor	Low gw levels, supply reliability. (Note links to SLR)	Generally moderately reduced groundwater levels; unquanitifed interactions with SLR.	Low	Low

Table 18. Estimated climate change impacts and risk assessment on SDC potable water supplies projecting to 2050

17 WASTEWATER

The key conclusions for this section are:

- **Projecting to 2050, environmental factors impacting SDC wastewater assessed as high risk relate to the occurrence of more extreme weather events.**
- **Based on current projections, significant longer-term impacts on environmental factors like groundwater levels up to mid-century may be relatively small.**
- **Higher alpine rainfall and flood flows will likely result in an increase of stormwater inflows for the Arthurs Pass, Castle Hill and Lake Coleridge wastewater systems.**
- **An increase in sea level rise of ~0.21 m may impact Upper Selwyn Huts and Rakaia Huts wastewater systems.**
- **Projecting to 2100, climate change impacts on SDC wastewater assets are highly dependent on emissions scenario.**
- **In all emissions scenarios the occurrence of extreme weather events is likely to increase.**

SDC manages 15 reticulated wastewater systems that service 67% of properties within the district. A map of the schemes is shown in Figure 40 and Figure 41. Estimated climate change impacts and risk assessment are summarized in Table 19.

Environmental factors assessed as high risk on SDC's wastewater assets mainly relate to the occurrence of more extreme events, like extreme rainfall. These will likely increase under all emissions scenarios.

Sea level rise (SLR) may impact the Upper Selwyn Huts border-dyke wastewater disposal system (Section 12.2) and the risk of flooding at Rakaia Huts (Section 13). SLR may also impact the Lakeside wastewater system, which has not been assessed in this report.

Under current projections climate change is likely to have a more significant impact in alpine areas. The projected increase in mean annual rainfall and flood flows which may impact Arthurs Pass, Castle Hill, Lake Coleridge and Springfield wastewater systems.

NIWA (2020) project increases in annual mean wind speed of the order of 2-10% for much of Canterbury by 2090 under RCP8.5 (Section 8.2). This may result in an increase in the frequency of wind damage during storms.

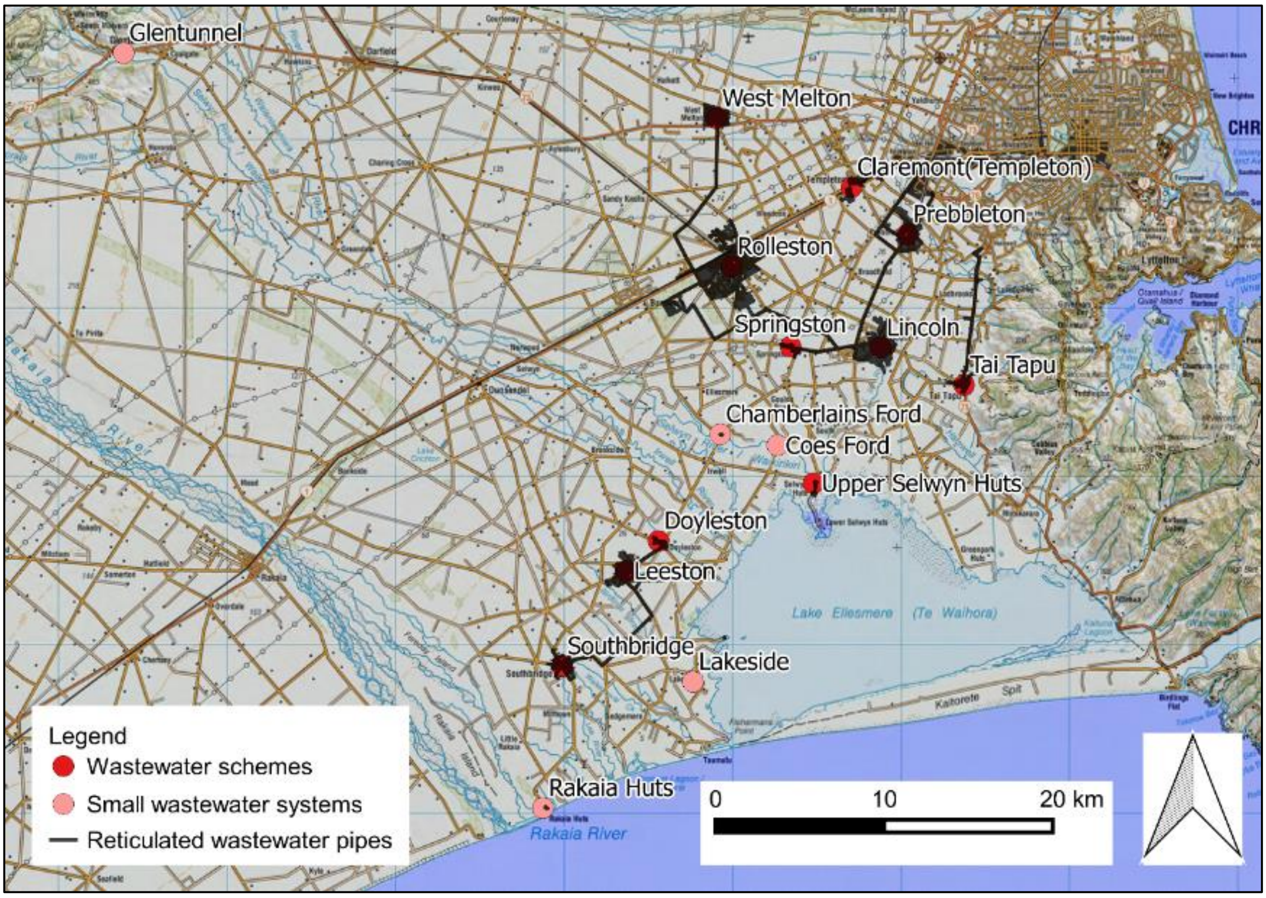


Figure 40. SDC wastewater schemes – Canterbury Plains.

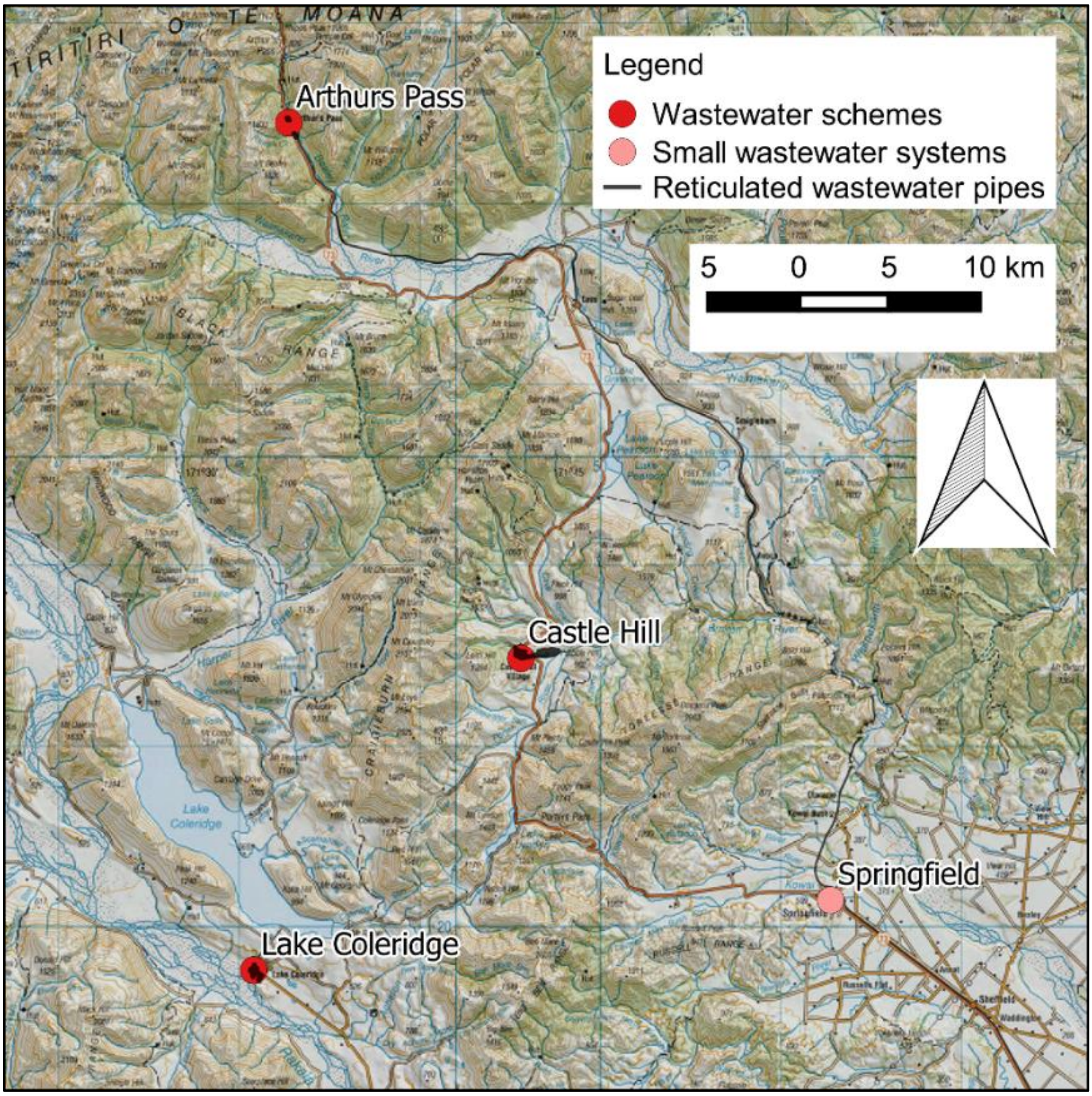


Figure 41. SDC wastewater schemes – Alpine and foothill.

Zone	Environmental factor	Vulnerability (Consequence)	Asset impacts	Summary of projected changes	Projected change (Likelihood of impact)	Impact (Risk)
All zones	Temperature (excl. ET impacts)	Minor	Efficiency of treatment processes and sludge drying (potential benefit). Odour issues. Algal blooms on ponds.	1.5 °C average increase, 10-20 more hot days , 5-10 fewer frost days	High	Medium
	Annual rainfall	Moderate	Ability to discharge treated WW to land (potential benefit)	±5% change in average annual rainfall	Low	Low
	Drought	Minor	Ability to discharge treated WW to land (potential benefit)	±5 change in number of dry days	Medium	Low
	Evapotranspiration (ET)	Minor	Ability to discharge treated WW to land (potential benefit)	PED increase of 50-100 mm per year	Medium	Low
	Wind (excluding ET impacts)	Moderate	Wind damage to assets in a storm	Increase in average wind speed 2-10%	Medium	Medium
	Alpine river flows	Minor	None	3% increase in alpine river mean flows, biggest increases in winter	Medium	Low
Alpine, hills and high-Country	Extreme rainfall events (foothills and alpine)	Moderate	Inflow.	Increased incidence of high-intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Foothills-sourced river flows	Minor	None	3% increase in alpine river flows, biggest increases in winter	Medium	Low
	Snow levels and ice	Moderate	Ability to discharge to land (potential benefit)	Reduction in number of average annual snow days by 10-25 days	Low	Low
Plains	Extreme rainfall events (Plains)	Moderate	Inflow.	Increased incidence of high intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Snow levels and ice	Minor	Asset damage in extreme snowfall events (potential benefit)	Reduction in extreme snowfall and elevation in snowline	Low	Low
	Ground water levels (upper /mid plains)	Minor	Reduced infiltration (potential benefit)	Reduced groundwater levels, possibly significant in deeper aquifers towards 2050.	Low	Low
Coastal and lower plains	Sea Level rise	Moderate	Ability to discharge -e.g. Selwyn Huts. Inflow and Infiltration.	Mean sea level increase ~0.21 m; increased frequency of extreme sea-level events, unquantified impacts on saltwater intrusion	Medium	Medium
	Extreme rainfall events (Coastal)	Moderate	Inflow.	Increased incidence of high intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Groundwater levels (Lower Plains)	Moderate	Ability to discharge -e.g. Selwyn Huts. Infiltration (higher GW levels - note links to SLR).	Generally moderately reduced groundwater levels; unquantified interactions with SLR.	Low	Low

Table 19. Estimated climate change impacts and risk assessment on SDC wastewater assets projecting to 2050.

18 STORMWATER

The key conclusions for this section are:

- **Projecting to 2050, environmental factors impacting SDC stormwater assessed as high risk relate to the occurrence of more extreme weather events.**
- **Based on current projections, significant longer-term impacts on environmental factors like groundwater levels up to mid-century may be relatively small.**
- **Higher alpine rainfall and extreme rainfall events may result in an increase in occurrence of surface flooding at Arthurs Pass, Castle Hill and Lake Coleridge.**
- **An increase in sea level rise of ~0.21 m may impact the efficacy of the stormwater system during coastal storm events at Rakaia Huts.**
- **Projecting to 2100, climate change impacts on SDC stormwater assets are highly dependent on emissions scenario.**
- **In all emissions scenarios the occurrence of extreme weather events is likely to increase.**

SDC manages 22 stormwater management areas within the Selwyn District. These are all urban in nature and have infrastructure in place to collect, convey and dispose of surface water. Many areas also manage stormwater in terms of water quality and quantity. A map of the management areas is shown in Figure 42 and Figure 43. Estimated climate change impacts and risk assessment are summarized in Table 20.

Environmental factors assessed as high risk on SDC's stormwater assets mainly relate to the occurrence of more extreme events, like extreme rainfall. These will likely increase under all emissions scenarios.

Under current projections climate change is likely to have a more significant impact in alpine areas. The projected increase in mean annual rainfall and flood flows which may impact Arthurs Pass, Castle Hill, Lake Coleridge and Springfield stormwater systems.

Sea level rise (SLR) increases the risk of the stormwater system at Rakaia huts being inundated during coastal storm events.

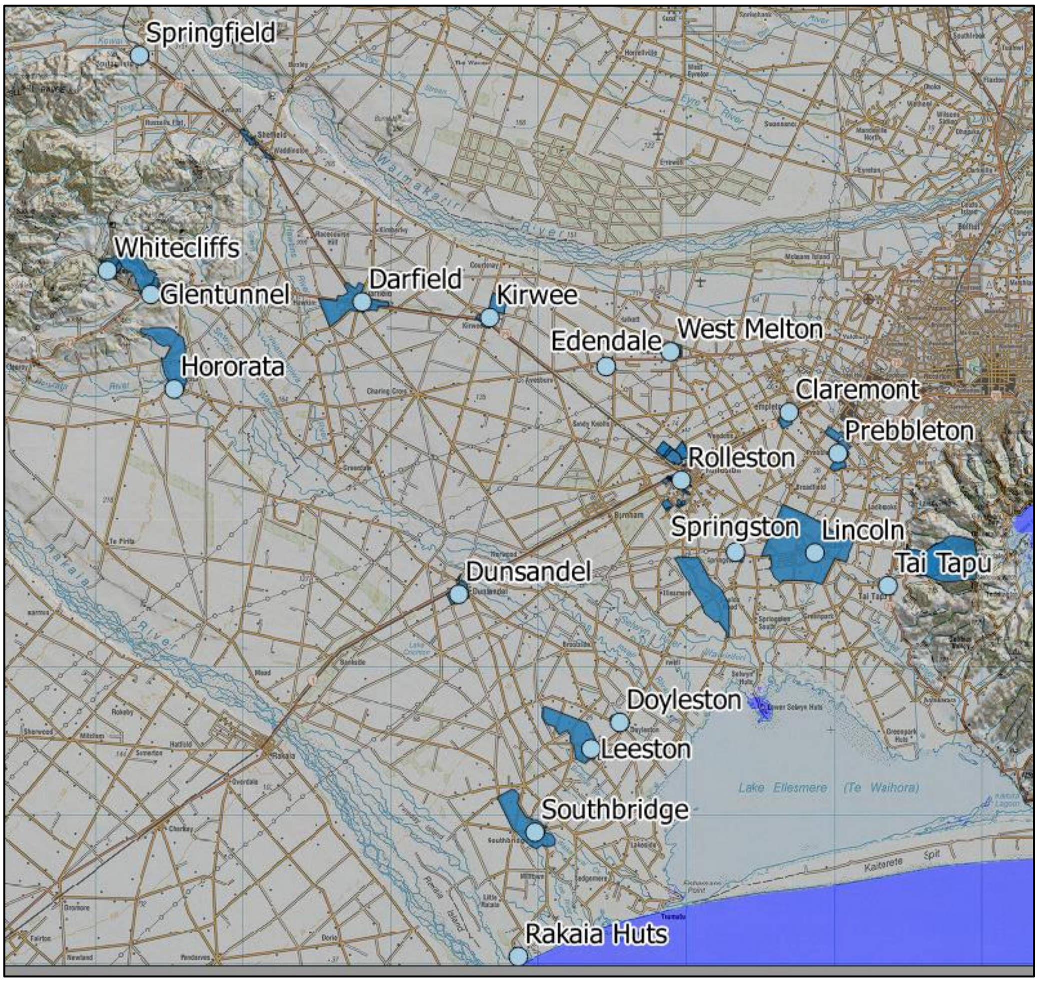


Figure 42. SDC stormwater schemes – Canterbury Plains.

Figure 43. SDC stormwater schemes – Alpine.

Zone	Environmental factor	Vulnerability (Consequence)	Asset impacts	Summary of projected changes	Projected change (Likelihood of impact)	Impact (Risk)
All zones	Temperature (excl. ET impacts)	Minor	Ecological impacts (wetlands).	1.5 °C average increase, 10-20 more hot days , 5-10 fewer frost days	High	Medium
	Annual rainfall	Minor	None	±5% change in average annual rainfall	Low	Low
	Drought	Minor	Lower inflows (potential benefit). Soil desiccation / hydrophobicity (reduced infitration). Wetland plant mortality.	±5 change in number of dry days	Medium	Low
	Evapotranspiration (ET)	Minor	None	PED increase of 50-100 mm per year	Medium	Low
	Wind (excluding ET impacts)	Minor	None	Increase in average wind speed 2-10%	Medium	Low
	Alpine river flows	Minor	None	3% increase in alpine river mean flows, biggest increases in winter	Medium	Low
Alpine, hills and high-Country	Extreme rainfall events (foothills and alpine)	High	Surface flooding; network capacity. Erosion of channels / swales.	Increased incidence of high-intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Foothills-sourced river flows	Minor	None	3% increase in alpine river flows, biggest increases in winter	Medium	Low
	Snow levels and ice	Minor	Reduced meltwater (potential benefit)	Reduction in number of average annual snow days by 10-25 days	Low	Low
Plains	Extreme rainfall events (Plains)	High	Surface flooding; network capacity. Erosion of channels / swales.	Increased incidence of high intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Snow levels and ice	Minor	None	Reduction in extreme snowfall and elevation in snowline	Low	Low
	Ground water levels (upper /mid plains)	Minor	None	Reduced groundwater levels, possibly significant in deeper aquifers towards 2050.	Low	Low
Coastal and lower plains	Sea Level rise	Moderate	Infiltration capacity e.g. Rakaia Huts	Mean sea level increase ~0.21 m; increased frequency of extreme sea-level events, unquantified impacts on saltwater intrusion	Medium	Medium
	Extreme rainfall events (Coastal)	High	Surface flooding; network capacity. Erosion of channels / swales.	Increased incidence of high intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Groundwater levels (Lower Plains)	Moderate	Infiltration capacity (high GW levels) e.g. Rakaia Huts. Note interaction with land drainage network.	Generally moderately reduced groundwater levels; unquantified interactions with SLR.	Low	low

Table 20. Estimated climate change impacts and risk assessment on SDC stormwater assets projecting to 2050.

19 LAND DRAINAGE

The key conclusions for this section are:

- **Projecting to 2050, environmental factors impacting SDC land drainage network assessed as high risk relate to the occurrence of more extreme weather events.**
- **Based on current projections, significant longer-term impacts on environmental factors like groundwater levels up to mid-century may be relatively small.**
- **Higher alpine rainfall and extreme rainfall events may result in an increase in occurrence of surface flooding at Arthurs Pass land drainage systems.**
- **An increase in sea level rise of ~0.21 m will impact Te Waihora /Lake Ellesmere levels and parts of the land drainage network.**
- **Projecting to 2100, climate change impacts on SDC land drainage network are highly dependent on emissions scenario.**
- **In all emissions scenarios the occurrence of extreme weather events is likely to increase.**

SDC manages 9 drainage schemes covering 25,332 ha within the Selwyn District. Seven of these schemes are in place primarily to drain groundwater, but have a secondary stormwater function. The other two schemes are primarily for river protection. The primary purpose of Arthurs Pass drainage scheme is flood protection from the Bealey River, while the primary purpose of the Hororata River drainage is erosion protection management for a section of the Hororata River. A map of the management areas is shown in Figure 44 and Figure 45. Estimated climate change impacts and risk assessment are summarized in Table 21.

Environmental factors assessed as high risk on SDC's land drainage assets mainly relate to the occurrence of more extreme events, like extreme rainfall. These will likely increase under all emissions scenarios.

Under current projections climate change is expected to have a more significant impact in alpine areas. The projected increase in mean annual rainfall and flood flows which may impact Arthur's Pass river protection scheme and Hororata erosion protection works.

Sea level rise (SLR) of ~0.21 m will increase Te Waihora levels and impact coastal sections of land drainage network. These impacts will depend on how the Te Waihora mouth is managed in the future. If Te Waihora lake levels rise, the impact on the drains is estimated to extend around 1 m above the lake level because of backwater effects, see Section 12.

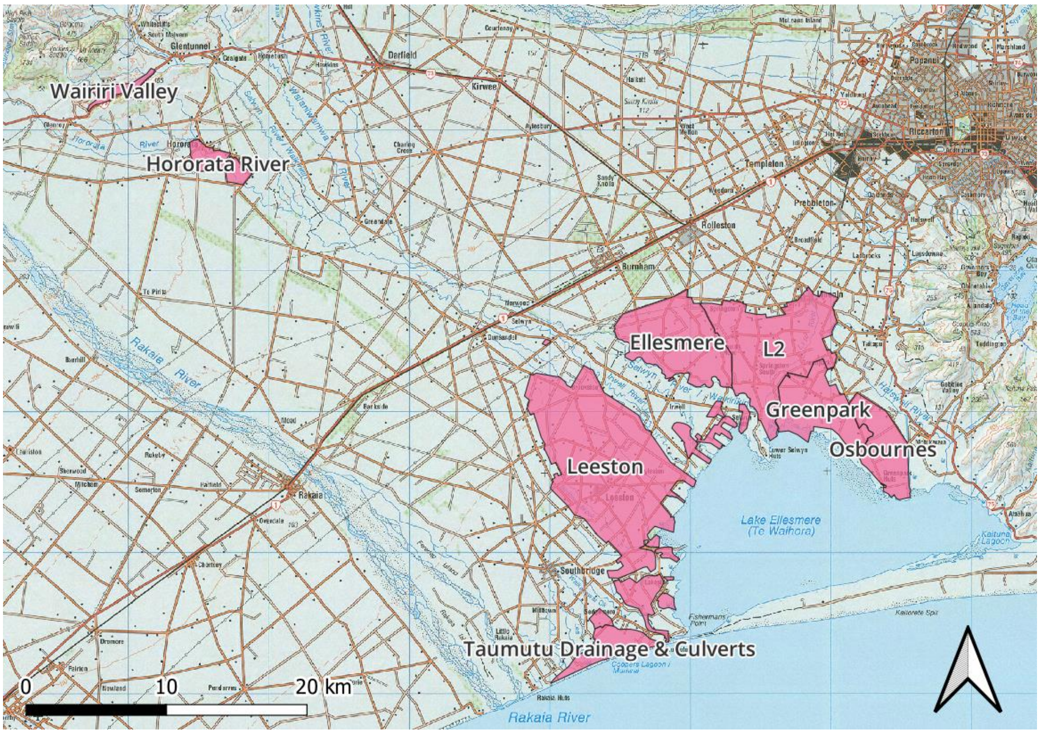


Figure 44. SDC land drainage schemes – Canterbury Plains.

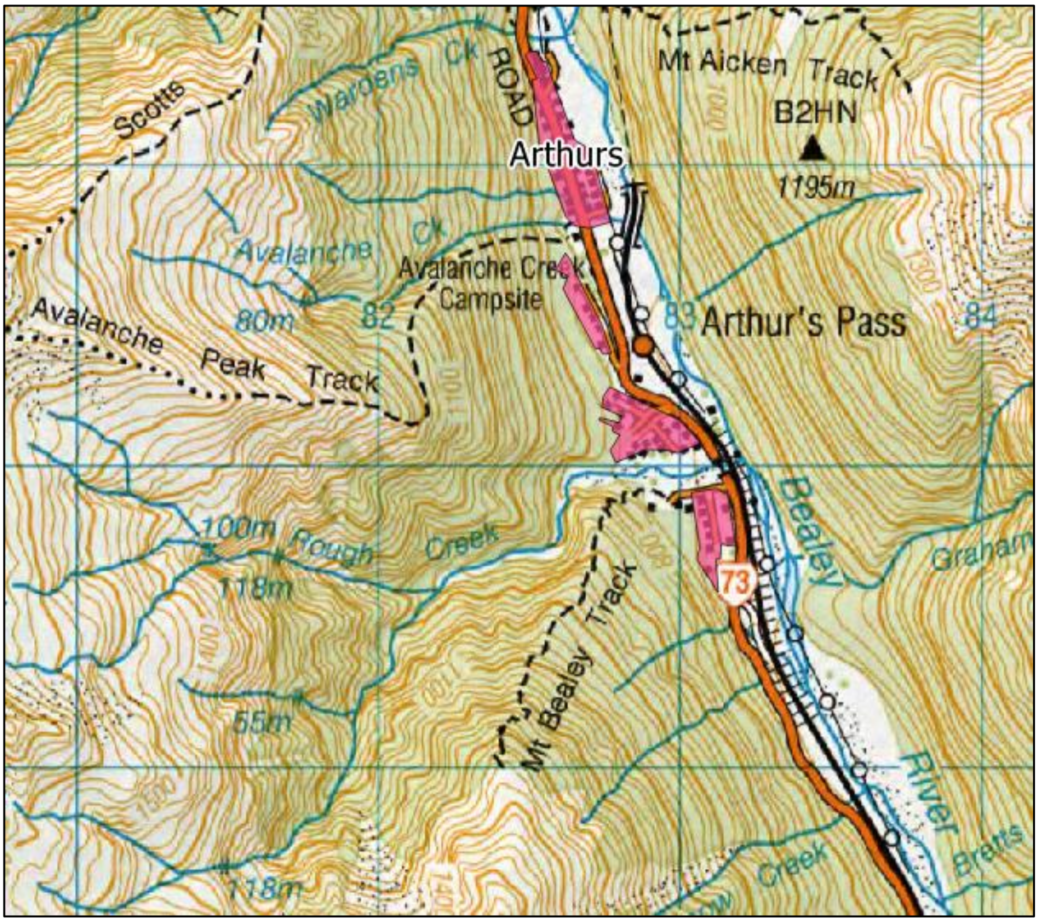


Figure 45. SDC land drainage schemes – Alpine.

Zone	Environmental factor	Vulnerability (Consequence)	Asset impacts	Summary of projected changes	Projected change (Likelihood of impact)	Impact (Risk)
All zones	Temperature (excl. ET impacts)	Minor	Ecological impacts.	1.5 °C average increase, 10-20 more hot days , 5-10 fewer frost days	High	Medium
	Annual rainfall	Minor	None	±5% change in average annual rainfall	Low	Low
	Drought	Minor	Potential benefit for maintenance: can spray dry drains.	±5 change in number of dry days	Medium	Low
	Evapotranspiration (ET)	Minor	None	PED increase of 50-100 mm per year	Medium	Low
	Wind (excluding ET impacts)	Minor	None	Increase in average wind speed 2-10%	Medium	Low
	Alpine river flows	Minor	None	3% increase in alpine river mean flows, biggest increases in winter	Medium	Low
Alpine, hills and high-Country	Extreme rainfall events (foothills and alpine)	High	Surface flooding; network capacity (Wairiri Valley, Hororata and Arthurs Pass)	Increased incidence of high-intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Foothills-sourced river flows	Minor	None	3% increase in alpine river flows, biggest increases in winter	Medium	Low
	Snow levels and ice	Moderate	Reduced meltwater (potential benefit)	Reduction in number of average annual snow days by 10-25 days	Low	Low
Plains	Extreme rainfall events (Plains)	High	Increased inflow via interconnection with stockwater and urban stormwater networks.	Increased incidence of high intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Snow levels and ice	Minor	None	Reduction in extreme snowfall and elevation in snowline	Low	Low
	Ground water levels (upper /mid plains)	Minor	None	Reduced groundwater levels, possibly significant in deeper aquifers towards 2050.	Low	Low
Coastal and lower plains	Sea Level rise	High	Backwater effects - note interaction with Te Waihora opening; coastal inundation and gravel deposition (lower Leeston network and Taumutu Culverts).	Mean sea level increase ~0.21 m; increased frequency of extreme sea-level events, unquantified impacts on saltwater intrusion	Medium	High
	Extreme rainfall events (Coastal)	High	Surface flooding; network capacity (lowland drainage networks)	Increased incidence of high intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Groundwater levels (Lower Plains)	High	Increased network inflows (high GW levels)	Generally moderately reduced groundwater levels in deeper aquifers; unquantified interactions with SLR.	Low	Medium

Table 21. Estimated climate change impacts and risk assessment on SDC land drainage systems projecting to 2050.

20 WATER RACES

The key conclusions for this section are:

- **Projecting to 2050, environmental factors impacting SDC's water race system assessed as high risk relate to the occurrence of more extreme weather events.**
- **Based on current projections, significant longer-term impacts on environmental factors like groundwater levels up to mid-century may be relatively small.**
- **Projecting to 2100, climate change impacts on SDC land drainage network are highly dependent on emissions scenario.**
- **An increase in alpine flood flows could result in an increase in flood damage to intakes. Conversely higher alpine flows would improve reliability of water supply.**
- **A potential minor reduction in flows in the Kowai River may impact supply reliability.**

SDC has been operating its water race system for about 130 years. Over recent years substantial changes have been identified which are expected to change the need for, and use of, the schemes. There are presently three water race schemes within the district: Ellesmere, Malvern and Paparua; these generally service the plains areas of the old County Councils. The Selwyn scheme with its intake on the Selwyn River was closed in 2009. A map of the management areas is shown in Figure 46.

Estimated climate change impacts and risk assessment are summarized **in** Table 22.

Environmental factors assessed as high risk on SDC's water race assets mainly relate to the occurrence of more extreme events, like extreme rainfall. These will likely increase under all emissions scenarios.

Two potential impacts are an increase in alpine flood flows, which could result in an increase in flood damage to alpine river intakes, and a potential reduction in flows in the Kowai River which might have an impact on supply reliability. A potential positive impact is that higher average alpine flows would improve the reliability of supply.

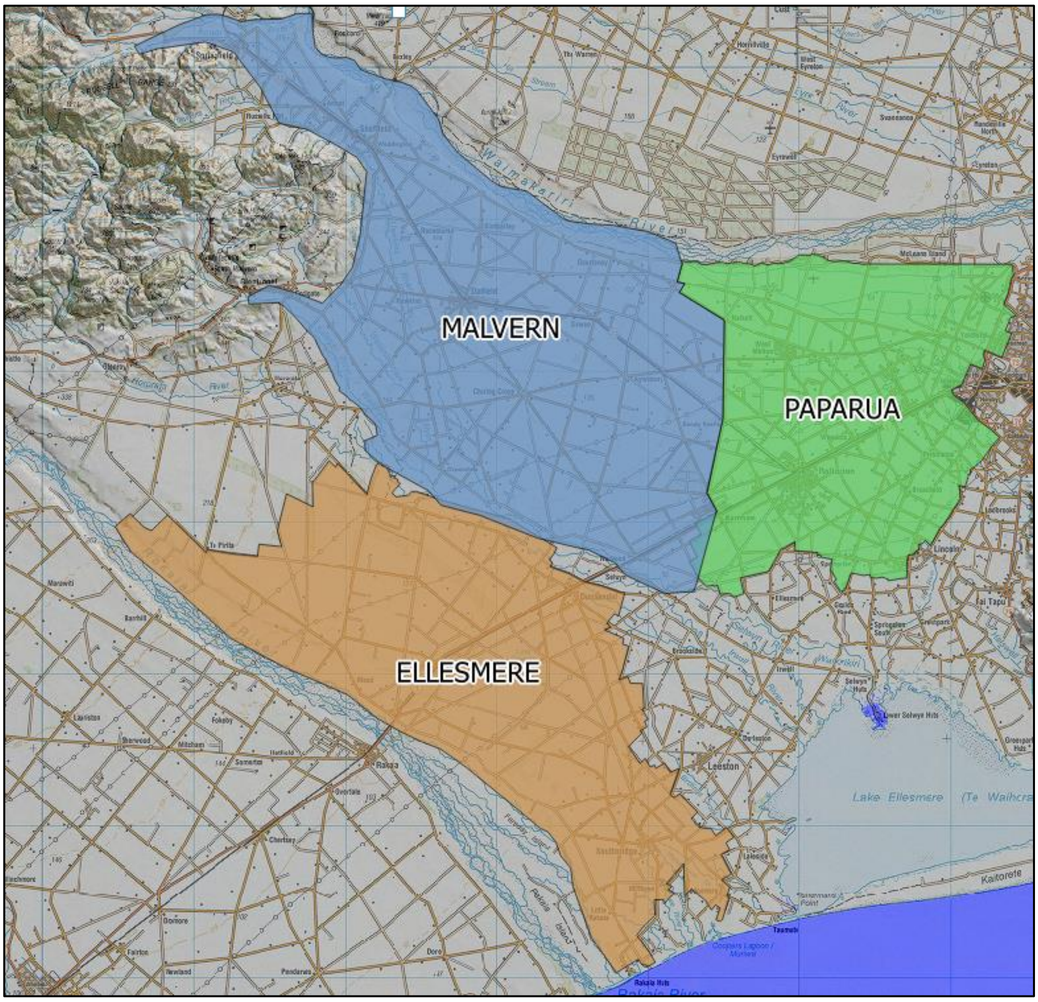


Figure 46. SDC water race networks.

Zone	Environmental factor	Vulnerability (Consequence)	Asset impacts	Summary of projected changes	Projected change (Likelihood of impact)	Impact (Risk)
All zones	Temperature (excl. ET impacts)	Moderate	Higher demand for stockwater	1.5 °C average increase, 10-20 more hot days , 5-10 fewer frost days	High	High
	Annual rainfall	Moderate	Reduced supply reliability; increased water demand	±5% change in average annual rainfall	Low	Low
	Drought	Moderate	Increased peak summer water demand; reduced supply reliability	±5 change in number of dry days	Medium	Medium
	Evapotranspiration (ET)	Minor	None	PED increase of 50-100 mm per year	Medium	Low
	Wind (excluding ET impacts)	Minor	None	Increase in average wind speed 2-10%	Medium	Low
	Alpine river flows	High	Reduced supply reliability (both low flows and flood shutdowns); increased flood damage to intakes	3% increase in alpine river mean flows, biggest increases in winter	Medium	High
Alpine, hills and high-Country	Extreme rainfall events (foothills and alpine)	High	Surface flooding; network capacity	Increased incidence of high-intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Foothills-sourced river flows	High	Supply reliability; intake damage.	3% increase in alpine river flows, biggest increases in winter	Medium	High
	Snow levels and ice	Minor	None	Reduction in number of average annual snow days by 10-25 days	Low	Low
Plains	Extreme rainfall events (Plains)	High	Surface flooding; network capacity	Increased incidence of high intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Snow levels and ice	Minor	None	Reduction in extreme snowfall and elevation in snowline	Low	Low
	Ground water levels (upper /mid plains)	Minor	None	Reduced groundwater levels, possibly significant in deeper aquifers towards 2050.	Low	Low
Coastal and lower plains	Sea Level rise	Minor	None	Mean sea level increase ~0.21 m; increased frequency of extreme sea-level events, unquantified impacts on saltwater intrusion	Medium	Low
	Extreme rainfall events (Coastal)	Minor	None	Increased incidence of high intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	Medium
	Groundwater levels (Lower Plains)	Minor	None	Generally moderately reduced groundwater levels in deeper aquifers; unquantified interactions with SLR.	Low	Low

Table 22. Estimated climate change impacts and risk assessment on SDC water race systems projecting to 2050.

21 TRANSPORTATION ASSETS

The key conclusions of this section are:

- **Projecting to 2050, environmental factors impacting SDC transportation assessed as high risk relate to the occurrence of more extreme weather events and river flooding.**
- **Projecting to 2100, climate change impacts on SDC transportation network are highly dependent on emissions scenario.**
- **Under all emissions scenarios the incidence of extreme events is expected to increase resulting in more frequent road closures.**
- **Flood events previously categorised as 1 in 100 year events may become 1 in 10 year events**

SDC's transportation assets may be categorised into three classes:

- Roads
- Fords
- Bridges

Summary data is given in Table 23.

Table 23. Summary of SDC transportation assets.

Asset		Asset	
Sealed roads	1,520 km	Unsealed Roads	1,130 km
Urban Roads	340 km	Rural Roads	2,310 km
Bridges	98 bridge structures plus large culverts		
Fords	49 approx.		
Total road network	2,650 km		

Figure 47 shows the roading network in the district in each risk assessment zone; alpine hills and high country, plains, coastal and lower plains. Estimated climate change impacts and risk assessment are summarized in Table 24.

Fords are especially vulnerable to extreme rainfall events. With more extreme events predicted under all emissions scenarios, more frequent road closures may be expected.

The extent to which extreme events may result in catastrophic failure of transportation infrastructure is highly uncertain, though the likelihood of catastrophic failure will evidently increase flood events previously categorised as 1 in 100 year events may become 1 in 10 year events.

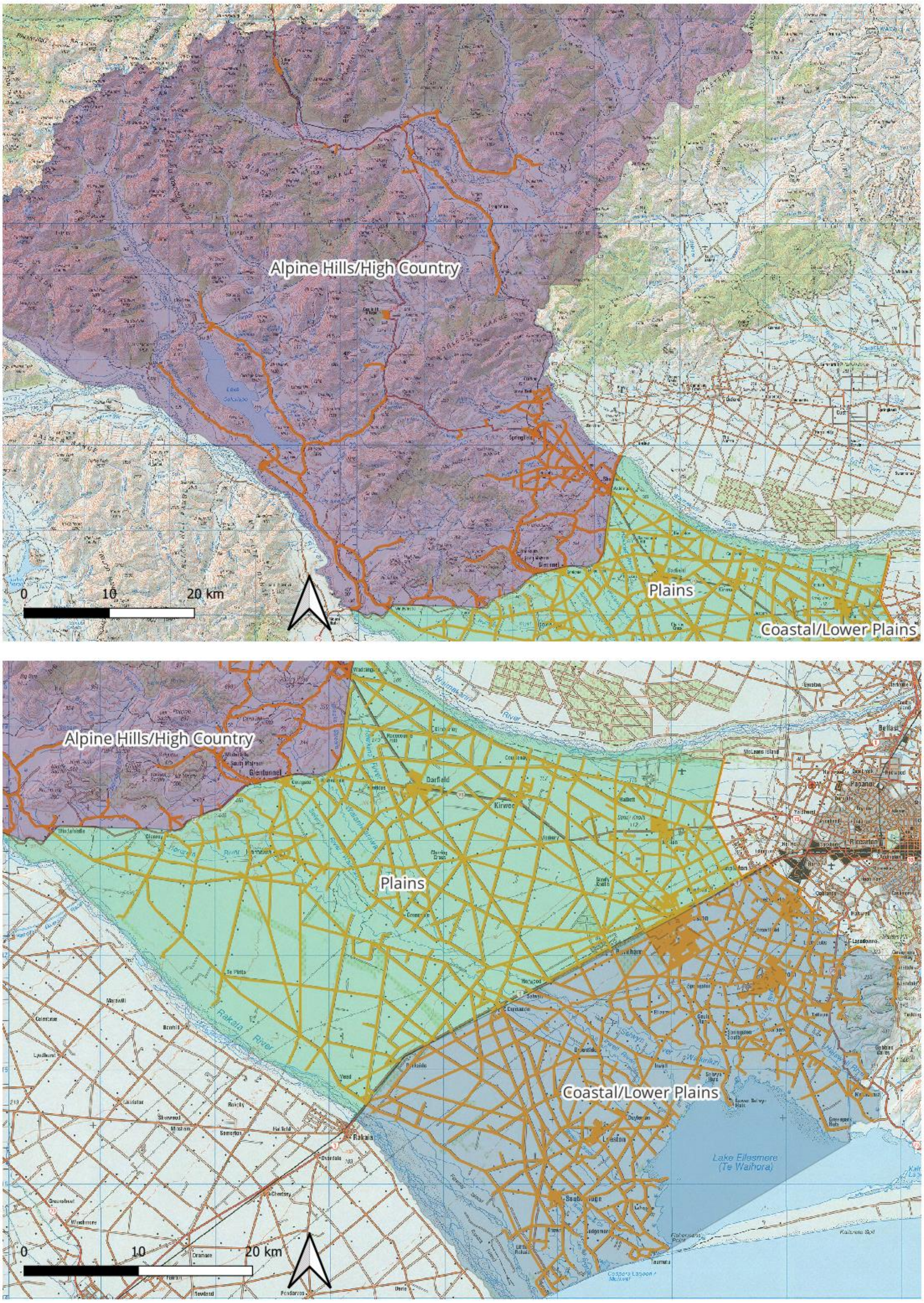


Figure 47: SDC managed roading network (orange line), including risk assessment category areas.

Zone	Environmental factor	Vulnerability (Consequence)	Asset impacts	Summary of projected changes	Projected change (Likelihood of impact)	Impact (Risk)
All zones	Temperature (excl. ET impacts)	Moderate	Road and car-park surface degradation: bitumen melting	1.5 °C average increase, 10-20 more hot days , 5-10 fewer frost days	High	High
	Annual rainfall	Minor	None	±5% change in average annual rainfall	Low	Low
	Drought	Minor	Potential benefit: increased fine weather for maintenance.	±5 change in number of dry days	Medium	Low
	Evapotranspiration (ET)	Minor	None	PED increase of 50-100 mm per year	Medium	Low
	Wind (excluding ET impacts)	Minor	Tree-fall (blocking roads)	Increase in average wind speed 2-10%	Medium	Low
	Alpine river flows	Moderate	Flooding or erosion of roads on alpine river margins; increased debris blocking culverts	3% increase in alpine river mean flows, biggest increases in winter	Medium	Medium
Alpine, hills and high-Country	Extreme rainfall events (foothills and alpine)	High	Surface flooding; road surface damage / subsidence; slips; bridge and abutment damage due to high-country stream flooding; increased debris blocking culverts	Increased incidence of high-intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Foothills-sourced river flows	High	Bridge and abutment damage due to high-country stream flooding in extreme rain events; more frequent and longer duration ford closure and damage; increased debris blocking culverts	3% increase in alpine river flows, biggest increases in winter	Medium	High
	Snow levels and ice	Moderate	Freeze-thaw effects (potential benefit of less occurrence)	Reduction in number of average annual snow days by 10-25 days	Low	Low
Plains	Extreme rainfall events (Plains)	High	Surface flooding; road surface damage / subsidence; slips; increased debris blocking culverts	Increased incidence of high intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Snow levels and ice	Minor	None	Reduction in extreme snowfall and elevation in snowline	Low	Low
	Ground water levels (upper /mid plains)	Minor	Upper plains perched shallow GW levels (e.g. Springfield and Hororata areas)	Reduced groundwater levels, possibly significant in deeper aquifers towards 2050.	Low	Low
Coastal and lower plains	Sea Level rise	Moderate	Inundation of coastal roads (limited exposure). [Note interactions with shallow GW and Te Waihora levels.]	Mean sea level increase ~0.21 m; increased frequency of extreme sea-level events, unquantified impacts on saltwater intrusion	Medium	Medium
	Extreme rainfall events (Coastal)	High	Surface flooding; road surface damage / subsidence; bridge and abutment damage due to stream flooding in extreme rain events; more frequent and longer duration ford closure and damage; increased debris blocking culverts	Increased incidence of high intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Groundwater levels (Lower Plains)	Moderate	Road surface and subgrade stability (high GW levels - note interaction with SLR)	Generally moderately reduced groundwater levels in deeper aquifers; unquantified interactions with SLR.	Low	Low

Table 24. Estimated climate change impacts and risk assessment on SDC transportation assets projecting to 2050.

22 FACILITIES AND OPEN SPACES

The key conclusions of this section are:

- **Projecting to 2050, environmental factors impacting SDC facilities and open spaces assessed as high risk relate to the occurrence of more extreme weather events and river flooding.**
- **Projecting to 2100, climate change impacts on SDC facilities and open spaces are highly dependent on emissions scenario.**
- **Under all emissions scenarios the incidence of extreme events is expected to increase resulting in more frequent road closures and inundation of areas.**
- **Flood events previously categorised as 1 in 100 year events may become 1 in 10 year events.**

Estimated climate change impacts and risk assessment for facilities, developed and natural open spaces are summarized in Table 25, Table 26 and Table 27 respectively.

Environmental factors assessed as high risk on facilities and open spaces mainly relate to the occurrence of more extreme events, like extreme rainfall and flood flows. These will likely increase under all emissions scenarios.

Figure 48 shows the location of SDC managed facilities and open spaces.

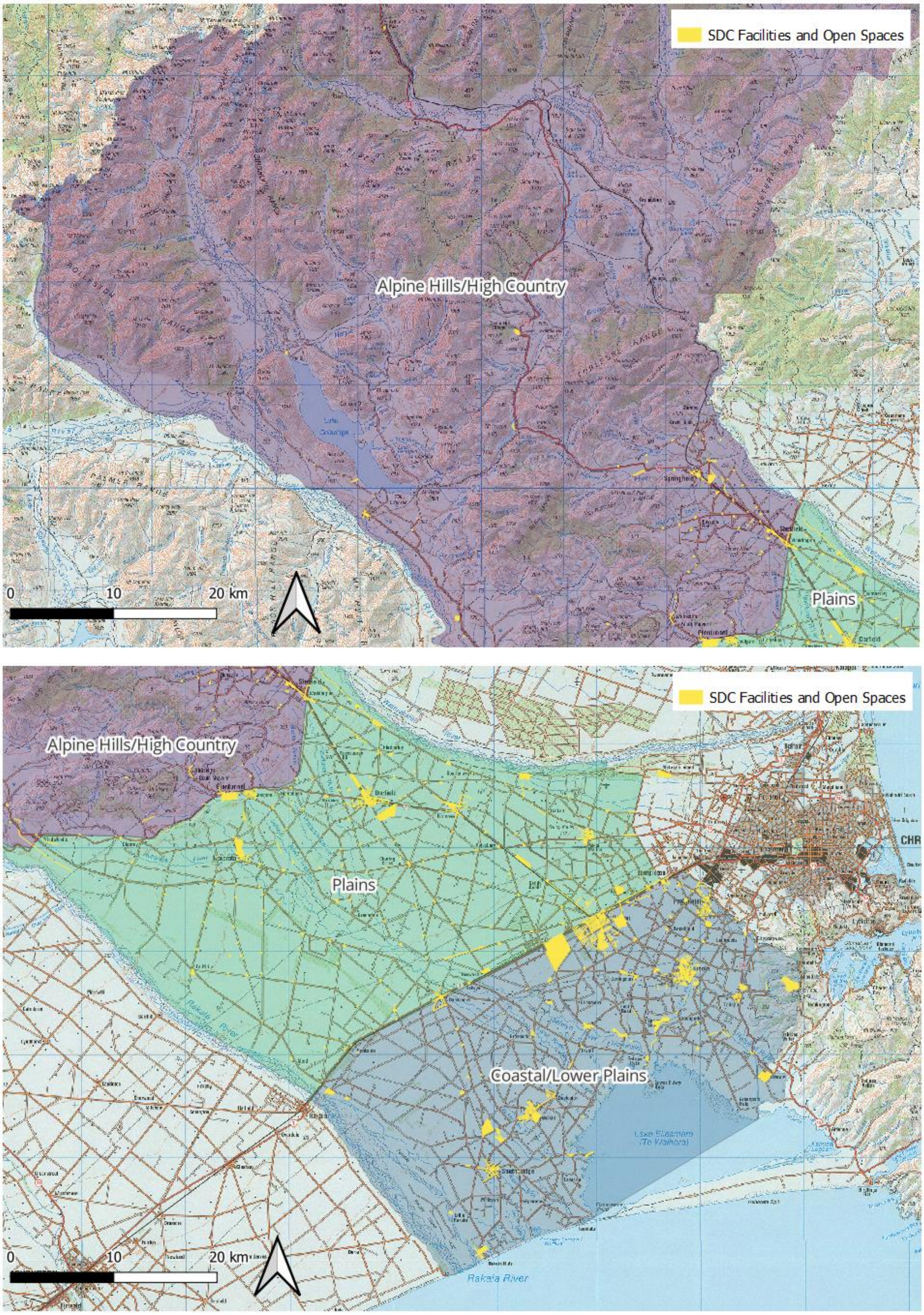


Figure 48: Location of SDC managed facilities and open spaces, including risk assessment category areas.

22.1 Community Facilities

The risk summary is shown on the next A3 page.

Zone	Environmental factor	Vulnerability (Consequence)	Asset impacts	Summary of projected changes	Projected change (Likelihood of impact)	Impact (Risk)
All zones	Temperature (excl. ET impacts)	Moderate	HVAC and air handling systems - increased demand for heating and cooling. Longevity of building envelope (coatings and claddings)	1.5 °C average increase, 10-20 more hot days , 5-10 fewer frost days	High	High
	Annual rainfall	Minor	None	±5% change in average annual rainfall	Low	Low
	Drought	Minor	Dust impacts on HVAC systems (combination of low rainfall and wind). Increased cladding / window washing.	±5 change in number of dry days	Medium	Low
	Evapotranspiration (ET)	Minor	None	PED increase of 50-100 mm per year	Medium	Low
	Wind (excluding ET impacts)	High	Wind damage to assets (roof / structure) in a storm. Impact on HVAC systems (external fans).	Increase in average wind speed 2-10%	Medium	High
	Alpine river flows	Minor	Rakaia Huts community centre.	3% increase in alpine river mean flows, biggest increases in winter	Medium	Low
Alpine, hills and high-Country	Extreme rainfall events (foothills and alpine)	High	Flooding: floodwaters entering buildings; inundation of below-ground areas; access to buildings required for emergency response. Building envelope: roof leaks; Longevity of coatings and claddings.	Increased incidence of high-intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Foothills-sourced river flows	High	Flooding of facilities close to river margins.	3% increase in alpine river flows, biggest increases in winter	Medium	High
	Snow levels and ice	Moderate	Building envelope: freeze-thaw effects, longevity of coatings and claddings (potential benefit of less occurrence)	Reduction in number of average annual snow days by 10-25 days	Low	Low
Plains	Extreme rainfall events (Plains)	High	Flooding: floodwaters entering buildings; inundation of below-ground areas; access to buildings required for emergency response. Building envelope: roof leaks; Longevity of coatings and claddings.	Increased incidence of high intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Snow levels and ice	Minor	Building envelope: reduced snow loadings on buildings. Fewer slippery surfaces. (potential benefit of less regular occurrence)	Reduction in extreme snowfall and elevation in snowline	Low	Low
	Ground water levels (upper /mid plains)	Minor	None	Reduced groundwater levels, possibly significant in deeper aquifers towards 2050.	Low	Low
Coastal and lower plains	Sea Level rise	Moderate	Inundation of facilities (particularly during storm events). Wastewater disposal for non-reticulated areas. Impact on shallow well supplies for community facilities.	Mean sea level increase ~0.21 m; increased frequency of extreme sea-level events, unquantified impacts on saltwater intrusion	Medium	Medium
	Extreme rainfall events (Coastal)	High	Flooding: floodwaters entering buildings; inundation of below-ground areas; access to buildings required for emergency response. Building envelope: roof leaks; Longevity of coatings and claddings.	Increased incidence of high intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Groundwater levels (Lower Plains)	Moderate	Wastewater disposal for non-reticulated areas (high GW levels - note interaction with SLR). Impact on shallow well supplies for community facilities.	Generally moderately reduced groundwater levels; unquantified interactions with SLR.	Low	Low

Table 25. Estimated climate change impacts and risk assessment on SDC community facilities projecting to 2050.

22.2 Developed open spaces

The risk summary is shown on the next A3 page.

Zone	Environmental factor	Vulnerability (Consequence)	Asset impacts	Summary of projected changes	Projected change (Likelihood of impact)	Impact (Risk)
All zones	Temperature (excl. ET impacts)	Moderate	Increased water demand for park and horticultural irrigation. Increased winter mowing due to fewer frosts.	1.5 °C average increase, 10-20 more hot days , 5-10 fewer frost days	High	High
	Annual rainfall	Moderate	Increased water demand for park and horticultural irrigation.	±5% change in average annual rainfall	Low	Low
	Drought	High	Increased water demand for park and horticultural irrigation. Increased fire risk. Difficulty of establishing new planting. Loss of existing tree canopy.	±5 change in number of dry days	Medium	High
	Evapotranspiration (ET)	Moderate	Increased water demand for park and horticultural irrigation	PED increase of 50-100 mm per year	Medium	Medium
	Wind (excluding ET impacts)	High	Wind damage to assets (trees, structures) in a storm	Increase in average wind speed 2-10%	Medium	High
	Alpine river flows	Moderate	Flooding of open spaces close to river margins. Safe evacuation of camping ground occupants. (Rakaia Huts)	3% increase in alpine river mean flows, biggest increases in winter	Medium	Medium
Alpine, hills and high-Country	Extreme rainfall events (foothills and alpine)	High	Surface flooding of open spaces. Slips. Damage to tracks and foot-bridges. Restricted use of playing fields. Safe evacuation of camping ground occupants. Tree fall (combination of wind and saturated ground).	Increased incidence of high-intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Foothills-sourced river flows	High	Flooding of open spaces close to river margins. Safe evacuation of camping ground occupants. (Coes Ford)	3% increase in alpine river flows, biggest increases in winter	Medium	High
	Snow levels and ice	Minor	Slight benefit (improved winter access).	Reduction in number of average annual snow days by 10-25 days	Low	Low
Plains	Extreme rainfall events (Plains)	High	Surface flooding of open spaces. Damage to tracks and foot-bridges. Safe evacuation of camping ground occupants.	Increased incidence of high intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Snow levels and ice	Minor	None	Reduction in extreme snowfall and elevation in snowline	Low	Low
	Ground water levels (upper /mid plains)	Minor	Upper plains perched shallow GW levels - impact on non-reticulated effluent systems (e.g. Springfield, Hororata)	Reduced groundwater levels, possibly significant in deeper aquifers towards 2050.	Low	Low
Coastal and lower plains	Sea Level rise	High	Inundation of open spaces (particularly during storm events). Wastewater disposal for non-reticulated areas. Salt-water intrusion for small water supplies (domains, etc).	Mean sea level increase ~0.21 m; increased frequency of extreme sea-level events, unquantified impacts on saltwater intrusion	Medium	High
	Extreme rainfall events (Coastal)	High	Surface flooding of open spaces. Damage to tracks and foot-bridges. Safe evacuation of camping ground occupants.	Increased incidence of high intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Groundwater levels (Lower Plains)	High	Surface ponding and poor drainage of parks and playing fields. Wastewater disposal for non-reticulated areas. Ability to operate cemeteries. Cemetery compliance with resource consent conditions. Uplift pressures on swimming pools. (High GW levels - note interaction with SLR).	Generally moderately reduced groundwater levels in deeper aquifers; unquantified interactions with SLR.	Low	Medium

Table 26. Estimated climate change impacts and risk assessment on developed open spaces projecting to 2050.

22.3 Natural Open Spaces.

The risk summary is shown on the next A3 page.

Zone	Environmental factor	Vulnerability (Consequence)	Asset impacts	Summary of projected changes	Projected change (Likelihood of impact)	Impact (Risk)
All zones	Temperature (excl. ET impacts)	Minor	Loss of biodiversity. Establishment of invasive weed species.	1.5 °C average increase, 10-20 more hot days , 5-10 fewer frost days	High	Medium
	Annual rainfall	Minor	None	±5% change in average annual rainfall	Low	Low
	Drought	Moderate	Increased fire risk. Difficulty of establishing new planting. Mortality of existing planting.	±5 change in number of dry days	Medium	Medium
	Evapotranspiration (ET)	Minor	None	PED increase of 50-100 mm per year	Medium	Low
	Wind (excluding ET impacts)	High	Wind-throw / damage to forest crops.	Increase in average wind speed 2-10%	Medium	High
	Alpine river flows	Moderate	Flooding of open spaces close to river margins. Safe evacuation of freedom campers and other users.	3% increase in alpine river mean flows, biggest increases in winter	Medium	Medium
Alpine, hills and high-Country	Extreme rainfall events (foothills and alpine)	Moderate	Surface flooding of open spaces. Slips. Damage to tracks and foot-bridges. Safe evacuation of freedom campers and other users.	Increased incidence of high-intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Foothills-sourced river flows	Moderate	Flooding of open spaces close to river margins. Safe evacuation of freedom campers and other users.	3% increase in alpine river flows, biggest increases in winter	Medium	Medium
	Snow levels and ice	Minor	None	Reduction in number of average annual snow days by 10-25 days	Low	Low
Plains	Extreme rainfall events (Plains)	Moderate	Surface flooding of open spaces. Damage to tracks and foot-bridges. Safe evacuation of freedom campers and other users.	Increased incidence of high intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Snow levels and ice	Minor	None	Reduction in extreme snowfall and elevation in snowline	Low	Low
	Ground water levels (upper /mid plains)	Minor	None	Reduced groundwater levels, possibly significant in deeper aquifers towards 2050.	Low	Low
Coastal and lower plains	Sea Level rise	Moderate	Inundation / wave erosion of open spaces (particularly during storm events). Salt tolerance of plant species - salinity propagating inland.	Mean sea level increase ~0.21 m; increased frequency of extreme sea-level events, unquantified impacts on saltwater intrusion	Medium	Medium
	Extreme rainfall events (Coastal)	Moderate	Surface flooding of open spaces. Damage to tracks and foot-bridges. Safe evacuation of freedom campers and other users.	Increased incidence of high intensity rainfall events, large uncertainty, highly dependent on emissions scenario	High	High
	Groundwater levels (Lower Plains)	Moderate	Surface ponding and poor drainage of open spaces. (High GW levels - note interaction with SLR).	Generally moderately reduced groundwater levels; unquantified interactions with SLR.	Low	Low

Table 27. Estimated climate change impacts and risk assessment on developed natural spaces projecting to 2050.

23 NON-SDC ASSETS

Most impacts on SDC assets assessed as high risk in previous sections related to the incidence of extreme/high-intensity weather events and SLR. However, it is important to recognise that these assessments extend to non-SDC assets, since they are exposed to the same physical risks. Notable examples of such assets include:

- Waimakariri River Stopbanks (owned and maintained by ECan),
- Central Plains Water Headrace (owned and maintained by Central Plains Water Ltd), and
- Electricity networks (owned and maintained by Orion Networks).

Damage or, in extreme cases, catastrophic failure to non-SDC assets may have a huge impact on SDC assets. For instance, failure of the electricity network managed by Orion could result in road blockages in the case of downed powerlines or prevent SDC operating critical infrastructure like pump stations in the case of power outages. Similarly, failure of non-SDC transportation assets like state highways or rail links may increase pressure on SDC transportation assets (which may themselves be compromised by damage following an extreme event).

These examples underscore the interconnectivity between various asset classes and demonstrate the cascading effects that arise from damage and failure within a particular asset class, regardless of whether it belongs to SDC or non-SDC entities. Consequently, the following elements are important in SDC's future planning and management:

- Recognition that shared risks extend beyond the boundaries of local council, and that collaboration between different stakeholders is crucial for effective climate change adaptation.
- Collaboration and coordination between relevant entities including SDC and non-SDC organisations, government agencies and infrastructure operators.
- Strengthening of infrastructure resilience.
- Investment in redundancy and backup systems. For example, redundant electricity supply systems or alternative transportation routes to ensure continuity of services.
- Enhance emergency response capability.
- Engage community in climate change resilience efforts.
- Monitoring and review of climate change impacts and adaptation/maladaptation measures.

24 RECOMMENDATIONS AND LIMITATIONS

This report reviewed a large number of information and data sources. Projected climate futures were used to assess risks to SDC assets as defined in the scope of this report. The assignment of risk levels is necessarily subjective. The aim of this exercise was to help SDC asset managers and planners prioritise resilience planning. Projected climate futures may not be how the future climate turns out and recent collective global experience suggests that impacts may be accelerating. The general message of climate change is that we need to brace ourselves to greater volatility in weather patterns with a greater incident of extreme events like extreme rainfall, wind and droughts. But the envelope of uncertainty is large, especially when projecting to end of century. This report provides a high-level assessment of climate change impacts that is meant as a guide for this moment in time. We recommend a serious revision and rescoping of this work within two years with significant refocus on adaptation.

Projecting even into the near future the biggest uncertainty is groundwater. While modelling results indicate a greater incidence of low water levels in deeper supply bores, we cannot be sure that in 10 or 20 years' time the extreme low levels may not be somewhat worse or more frequent than our results indicate. Low groundwater levels need to be monitored and observed very carefully.

Moreover, the impact of sea level rise on (especially) shallow coastal groundwater systems is a very significant uncertainty. It is frequently referenced in IPCC reports in descriptive terms but very little is known about the magnitude of impact (i.e. degree and rate of salination) on either shallow coastal aquifers and land degradation. Whereas changes in surface flows are directly observable, groundwater systems have much greater uncertainties on several accounts including:

- they are not directly observed except at sparse measurement points.
- Canterbury groundwater systems are structurally complex.
- groundwater is relatively much slower moving so cause and effect is hard to quantify.

Given the large uncertainties associated with groundwater systems and that large-scale saline contamination and soil degradation through salination is likely to be effectively irreversible, we recommend a special study on SDC's coastal groundwater and sea level rise. The purpose of this study is to provide recommendations to better monitor the state of shallow coastal groundwater systems to enable more robust decision-making in the future.

25 REFERENCES

Bidwell, V., Burbery, L., 2011. Groundwater Data Analysis - quantifying aquifer dynamics. Prepared for Envirolink Project 420-NRLC50 (No. 4110/1). Lincoln Ventures Ltd.

Bright, J., 2009. Estimation of seasonal irrigation water use - Method development (Aqualinc Report No. C08000/1). Aqualinc Research Ltd., Christchurch.

Brown P., Kerr T., Weir J., Kashima A. 2016. "Impact of Climate Cycles and Trends on Selwyn District Water Assets". Client report prepared for Selwyn District Council. Report Number C16049/1. Aqualinc Research Limited, Christchurch.

Carey-Smith, T., Henderson, R., Singh, S., 2018. High Intensity Rainfall Design System Version 4 (No. NIWA Client report No. 2018022CH). NIWA.

Collins, D., Montgomery, K., Zammit, C., 2018. Hydrological projections for New Zealand rivers under climate change (No. NIWA Client report No. 2018193CH). NIWA for the Ministry for the Environment, Christchurch.

Cope, J, 2019. North Rakaia Huts future coastal hazard assessment. Environment Canterbury. Report number R19/126.

Cox, S., Rutter, H., Sims, A., Manga, M., Weir, J., Ezzy, T., White, P., Horton, T., Scott, D., 2012. Hydrological effects of the Mw 7.1 Darfield (Canterbury) earthquake, 4 September 2010, New Zealand. New Zealand J. of Geology and Geophysics. 55:3, 231-247.

Dudley Ward, N.F., 2015. On the mechanism of earthquake induced groundwater flow. Journal of Hydrology 530, 561-567.

ECan (2016). Managed Te Waihora/Lake Ellesmere Openings. Website address: http://ecan.govt.nz/services/environmental-planning/pages/te-waihora-openings.aspx . Last accessed 21 May 2016.

Guo, D., Westra, S., Maier, H.R., 2016. An R package for modelling actual, potential and reference evapotranspiration. Environmental Modelling & Software 78, 216–224. doi:10.1016/j.envsoft.2015.12.019

Griffiths, G.M., 2007. Changes in New Zealand daily rainfall extremes 1930 - 2004. Weather and Climate 27, 3–44.

Griffiths, G., 2011. Drivers of extreme daily rainfalls in New Zealand. Weather and Climate 31, 24–49.

Griffiths, G., 2013. New Zealand six main centre extreme rainfall trends 1962-2011. Weather and Climate 33, 76–88.

Hannah, J., 2004. An updated analysis of long-term sea level change in New Zealand. Geophys. Res. Lett. 31, L03307. doi:10.1029/2003GL019166

Hannah, J., 1990. Analysis of mean sea level data from New Zealand for the period 1899–1988. J. Geophys. Res. 95, 12399–12405. doi:10.1029/JB095iB08p12399

Hendrikx, J., Hreinsson, E., Clark, M., Mullan, A., 2012. The potential impact of climate change on seasonal snow in New Zealand: part I—an analysis using 12 GCMs. Theoretical and Applied Climatology 1–12. doi:10.1007/s00704-012-0711-1

Kerr, T., 2017. Observed relationship between high intensity rainfall and temperature, in: Filling the Knowledge Reservoir. Presented at the New Zealand Hydrological Society Annual Conference, New Zealand Hydrological Society, Napier.

Larsen, S.H., 1989. Forecasting climate change at Lincoln College, Canterbury, New Zealand. (M.Sc.). Lincoln College, University of Canterbury, Lincoln.

McKerchar, A.I., Henderson, R.D., 2003. Shifts in flood and low-flow regimes in New Zealand due to interdecadal climate variations / Variations dans les régimes de crue et de basses aux en Nouvelle-Zélande dues à des variations climatiques inter-décennales. Hydrological Sciences Journal 48, 637–654.

MfE, 2008b. Coastal Hazards and Climate Change. A guidance manual for local government in New Zealand, 2nd edition. Ministry for the Environment, Wellington.

MfE, 2016. Climate change projections for New Zealand: Atmosphere Projections based on simulations from the IPCC fifth assessment. Ministry for the Environment, Wellington.

MfE, 2017, Coastal Hazards and Climate Change – guidance for local councils. Bell, R., Lawrence, J., Allan, S., Blackett, P., Stephens, S. Ministry for the Environment, Wellington.

MfE, 2020, National Climate Change Risk Assessment for New Zealand, Ministry for the Environment, Wellington.

MfE, 2022, Aotearoa New Zealand climate change projections guidance - Interpreting the latest IPCC WG1 report findings, Ministry for the Environment, Wellington.

Mullan, A.B., Stuart, S.J., Hadfield, M.G., Smith, M.J., 2010. Report on the Review of NIWA's "Seven-Station" Temperature Series (No. NIWA Information Series No. 78). NIWA, Wellington.

NIWA, 2020, Climate change projections for the Canterbury Region. Macara, G., Woolley, J-M., Pearce, P., Wadhwa, S., Zammit, C., Sood, A., Stephens, S. National Institute of Water & Atmospheric Research Ltd.

Samad, S.S., 2007. An analysis of the impact of sea level rise on Lake Ellesmere - Te Waihora and the L2 drainage network, New Zealand.

SDC, 2009, Rakaia Huts Conservation Plan. Selwyn District Council

T+T, 2022, Canterbury Climate Change Rish Assessment. Tonkin and Taylor.

Ummenhofer, C.C., England, M.H., 2007. Interannual extremes in New Zealand precipitation linked to modes of Southern Hemisphere climate variability. Journal of Climate 20, 5418–5440.

Appendix A: IrriCalc crop-soil water balance model

To calculate the irrigation demand and subsequent land surface drainage, Aqualinc's IrriCalc water balance model was used. The model simulates how the use of water in agriculture varies with crop, soil type, representative daily climatic conditions and irrigation strategies. The basis of the model is a daily soil moisture balance and an irrigation scheduling component. These components are described in more detail below.

The model was developed by Lincoln Environmental as part of a research project funded by the Foundation for Research, Science and Technology (FRST). It has been based on New Zealand field data and was initially tested on Canterbury irrigation schemes. Further details and this testing can be found in AEI (1991)[4]. More recently, the model has been tested by Aqualinc (2013)[5].

Soil Moisture Balance Component

The model is designed to simulate a single paddock in which a specified crop is grown. The soil is treated as a reservoir, with a capacity equal to the maximum plant available water content of the soil. Soil moisture levels are calculated on a daily basis in response to daily data on climate (rainfall and potential evapotranspiration), crop uptake and irrigation using the following equation:

$$Soil\ moisture\,(day_t) = Soil\ moisture\,(day_{t-1}) + rainfall + irrigation - actual\ evapotranspiration$$

Actual evapotranspiration (AET) describes the combined effects of evaporation from the soil and transpiration by the crop. The model considers AET to be a function of the atmospheric demand for water, crop characteristics (including stage of growth) and the soil moisture content in the root zone. The atmospheric demand for water is the daily potential evapotranspiration calculated from meteorological conditions such as radiation, wind run and temperature. Crop characteristics can vary throughout a season to reflect relative ground cover, root development and the onset of crop maturity. Soil moisture influences evapotranspiration because as the soil becomes drier, it becomes increasingly difficult for more moisture to be transpired or evaporated.

Once calculated, soil moisture levels then become an input to the irrigation scheduling component of the model. The model assumes that the maximum amount of water a soil can hold is the soil's available water capacity. Water (either from rainfall or irrigation) in excess of the soil's available water capacity is assumed to drain through the root zone and into underlying substrata as land surface recharge.

Irrigation Scheduling Component

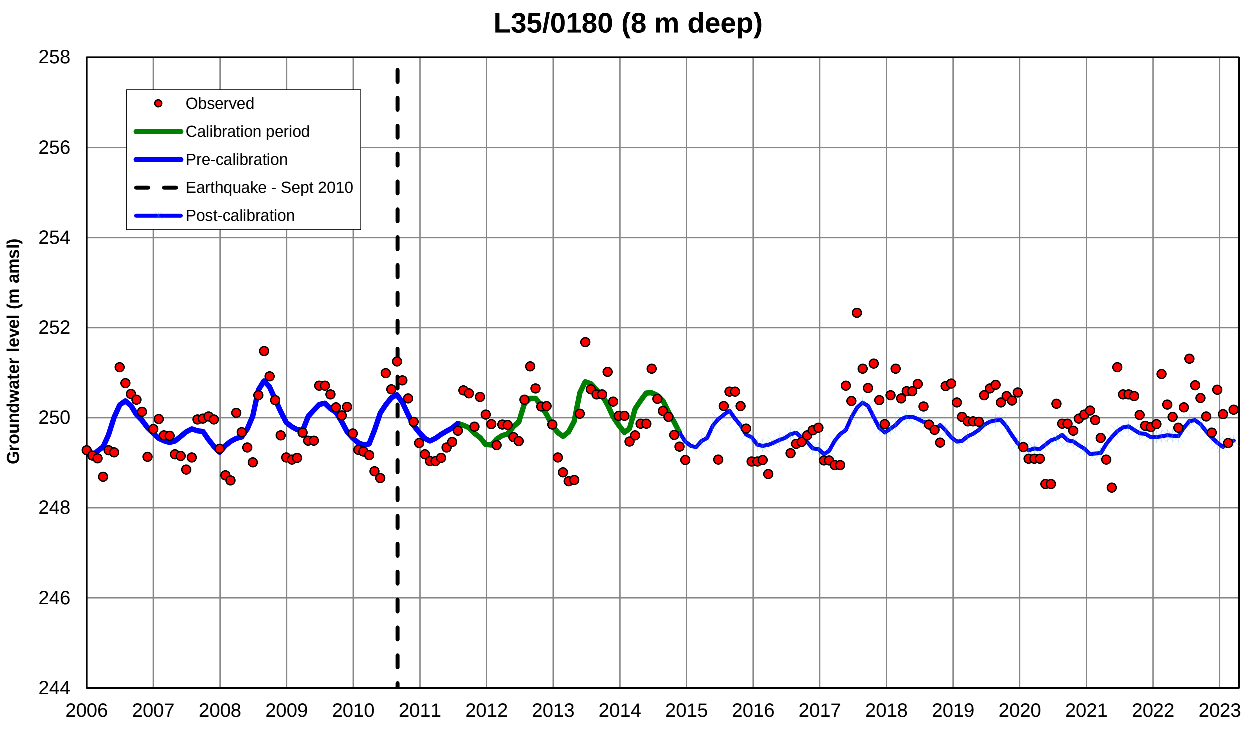
The depth of water applied and the timing of irrigation is determined by the irrigation strategy. For a given irrigation strategy, the model predicts the timing and depth of irrigation applications based on the crop type, stage of growth, and subsequent water requirements. It also accounts for the irrigation return period.

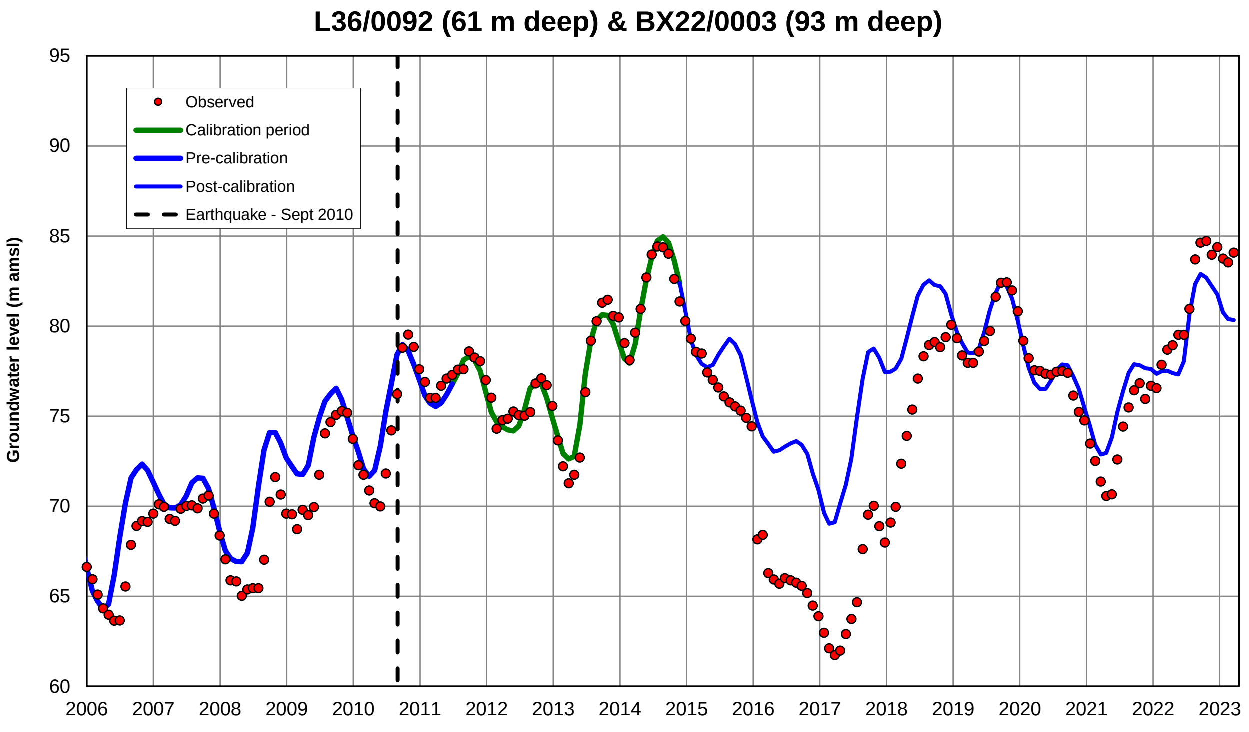
Irrigation is triggered when the soil water content is reduced below a user-defined level (e.g. 50% of the maximum available soil water). The irrigation depth can be determined in two ways. Firstly, it can be specified by the user as a fixed amount. Secondly, it can be calculated by the model as the depth required to restore the soil water content to a user defined level (e.g. field capacity).

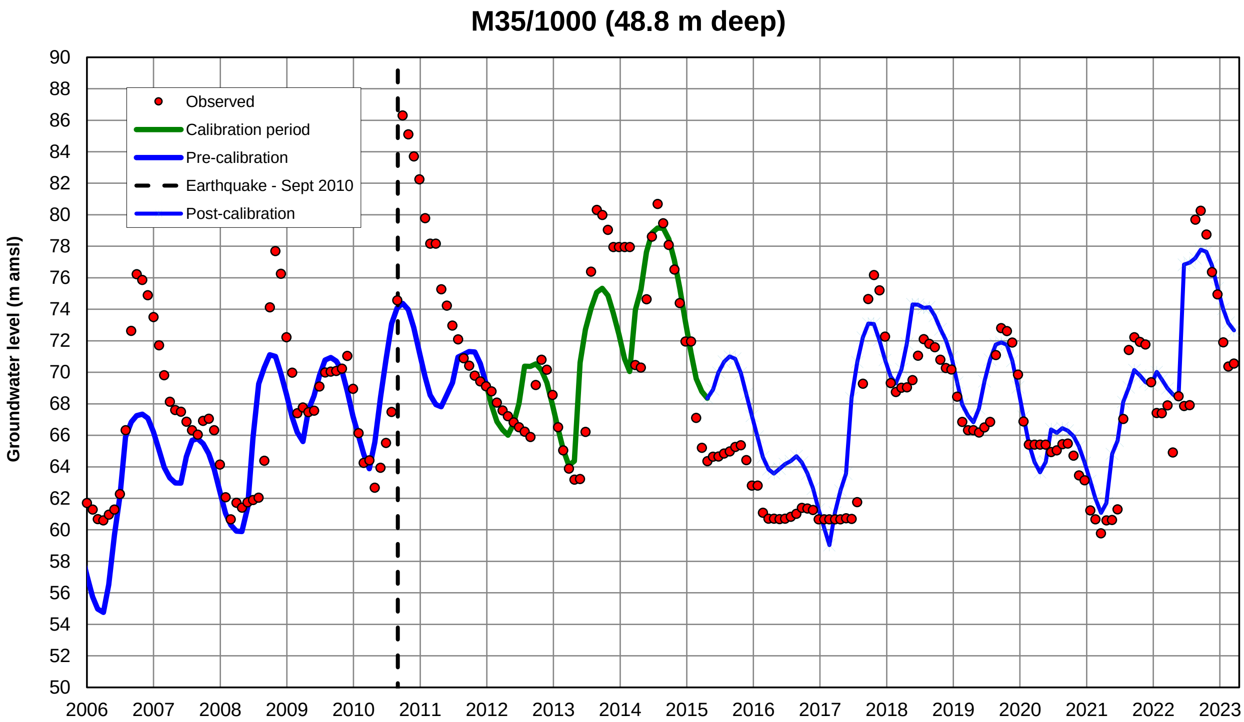
A user-defined irrigation efficiency factor is also set to allow for on-farm losses due to wind losses, surface runoff and non-uniform distribution of water.

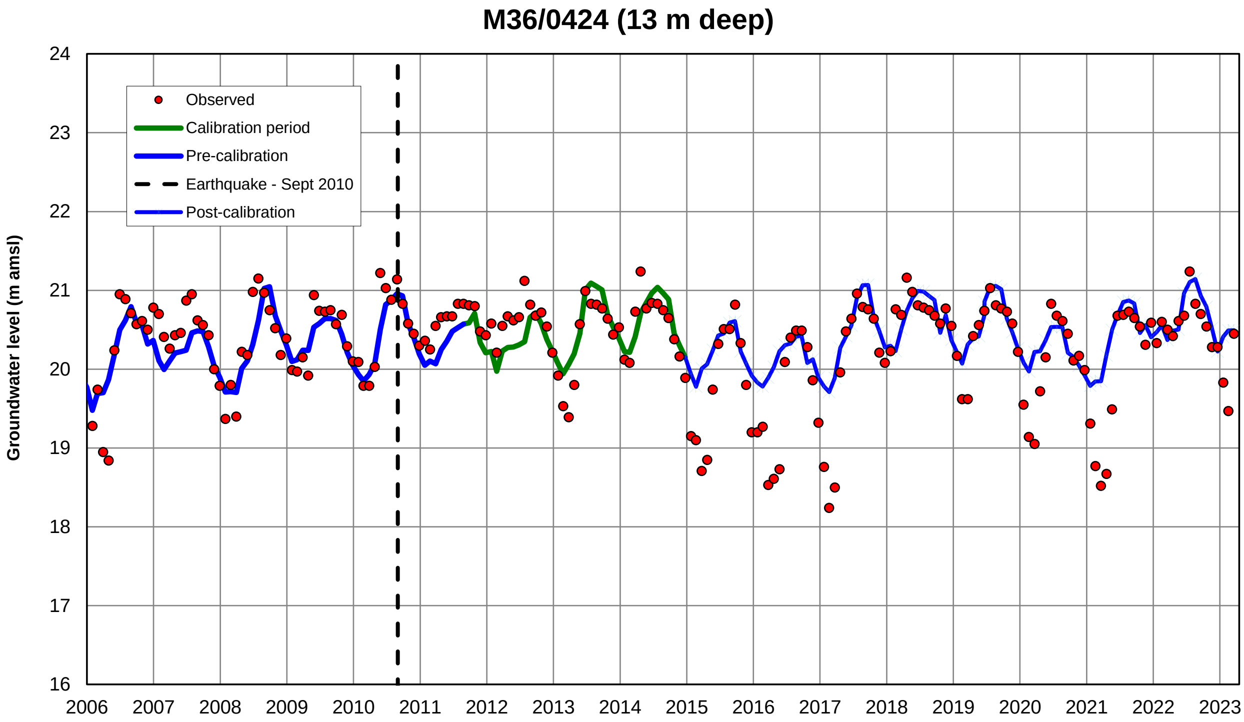
[4] AEI (1991): A model for assessing the impact of Regional Water Plans on irrigated agriculture. AEI Science Report, 1991; Agricultural Engineering Institute.
[5] Aqualinc (2013): *Field Verification of the Water Balance Model used for Development of Irrigation Guidelines for the Waikato Region*. Prepared by Aqualinc Research Ltd for Waikato Regional Council. Report No 12003/2. April 2013.

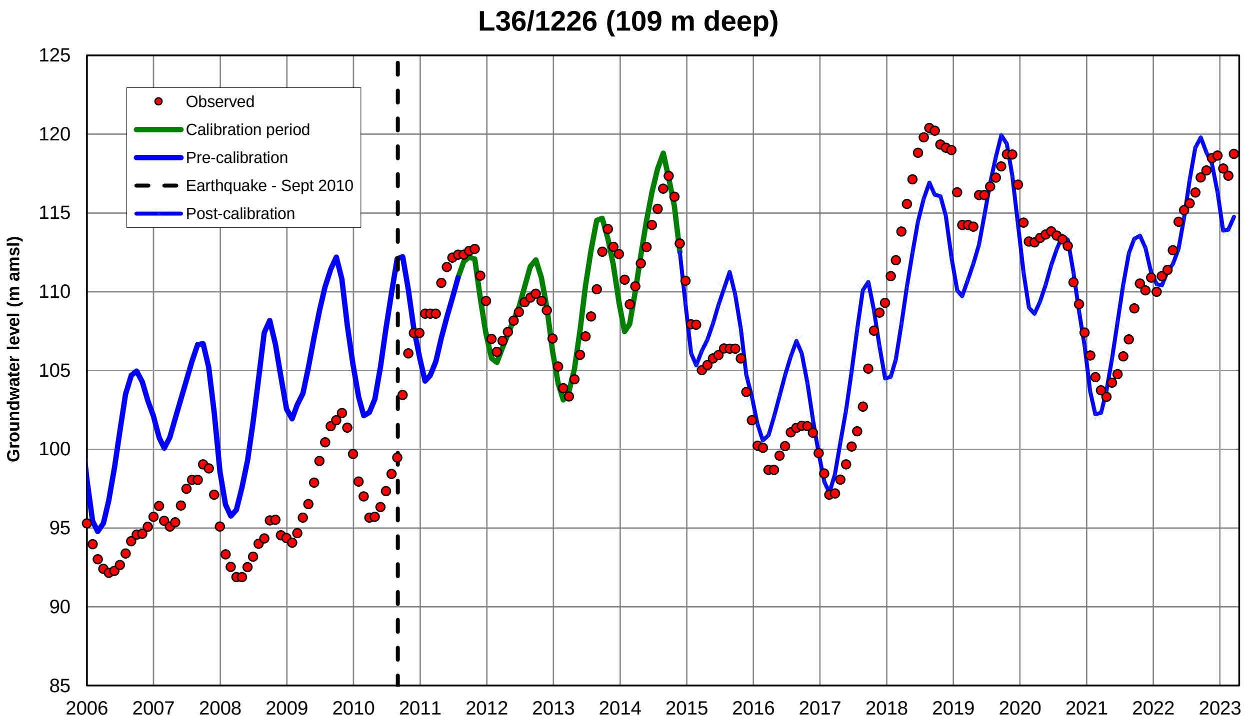
Appendix B: Groundwater model calibration

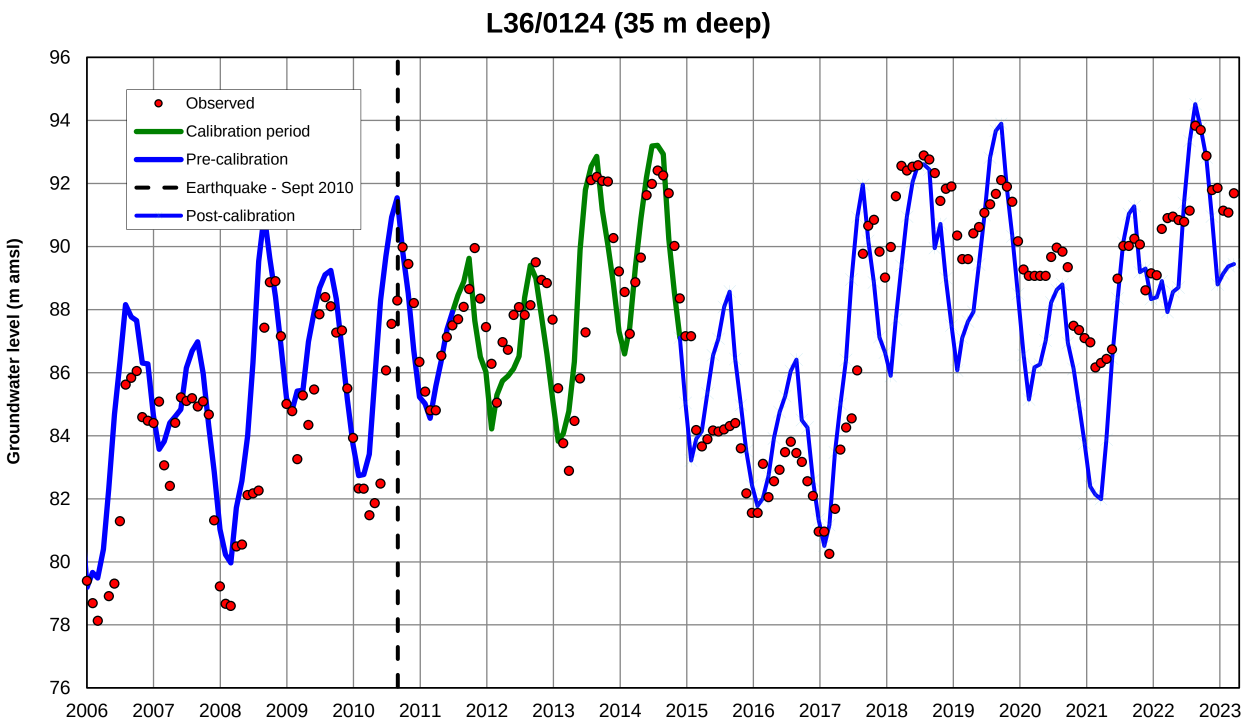




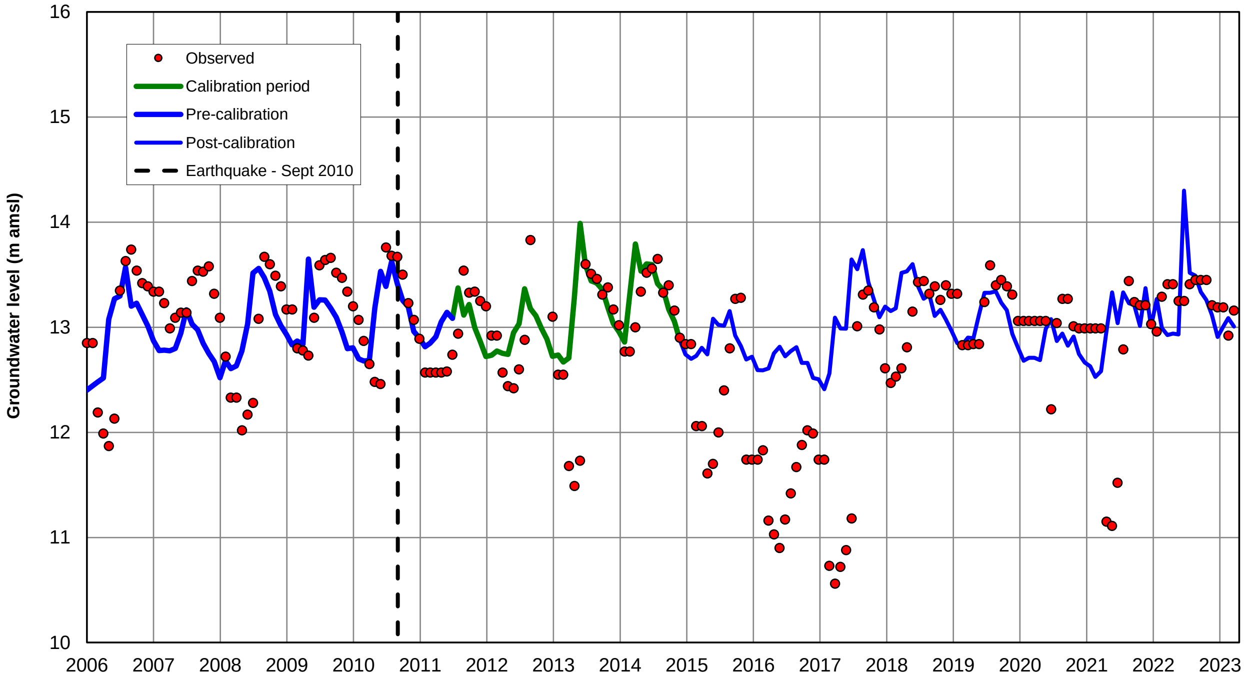

M35/1000 (48.8 m deep)
Groundwater level (m amsl)
Observed
Calibration period
Pre-calibration
Earthquake - Sept 2010
Post-calibration
90
88
86
84
82
80
78
76
74
72
70
68
66
64
62
60
58
56
54
52
50
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023


M36/0424 (13 m deep)
Groundwater level (m amsl)
Observed
Calibration period
Pre-calibration
Earthquake - Sept 2010
Post-calibration
24
23
22
21
20
19
18
17
16
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023

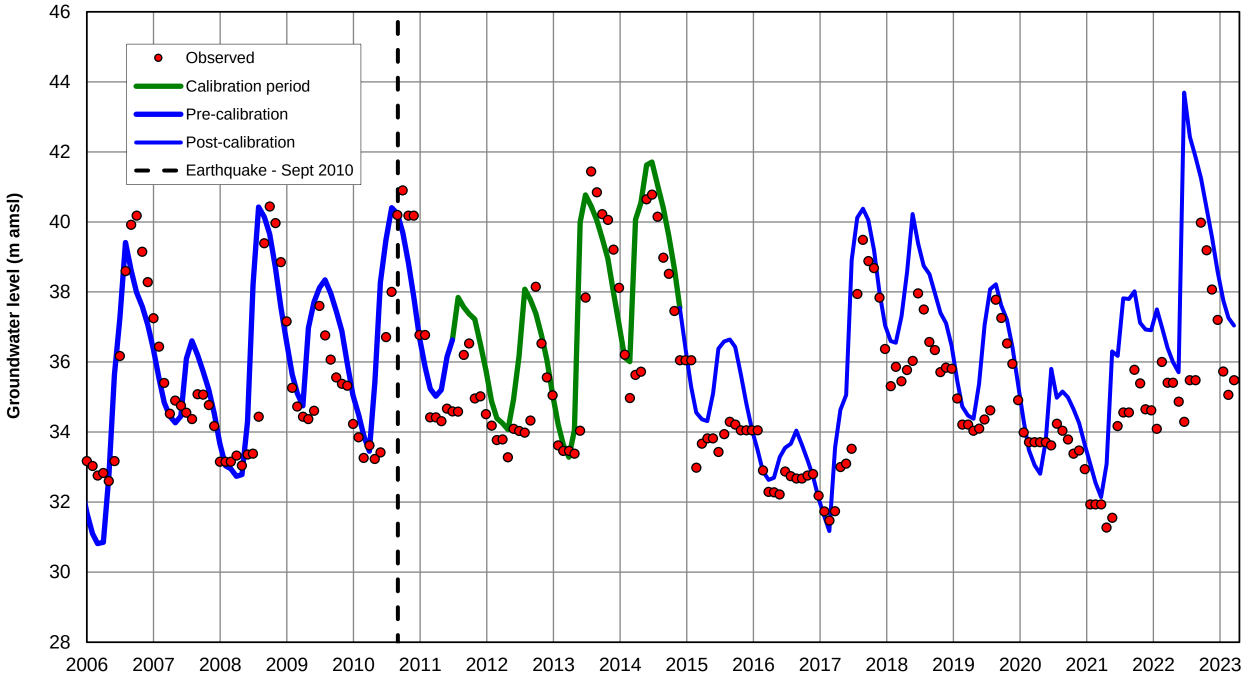

L36/1226 (109 m deep)
Observed
Calibration period
Pre-calibration
Earthquake - Sept 2010
Post-calibration
Groundwater level (m amsl)
125
120
115
110
105
100
95
90
85
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023

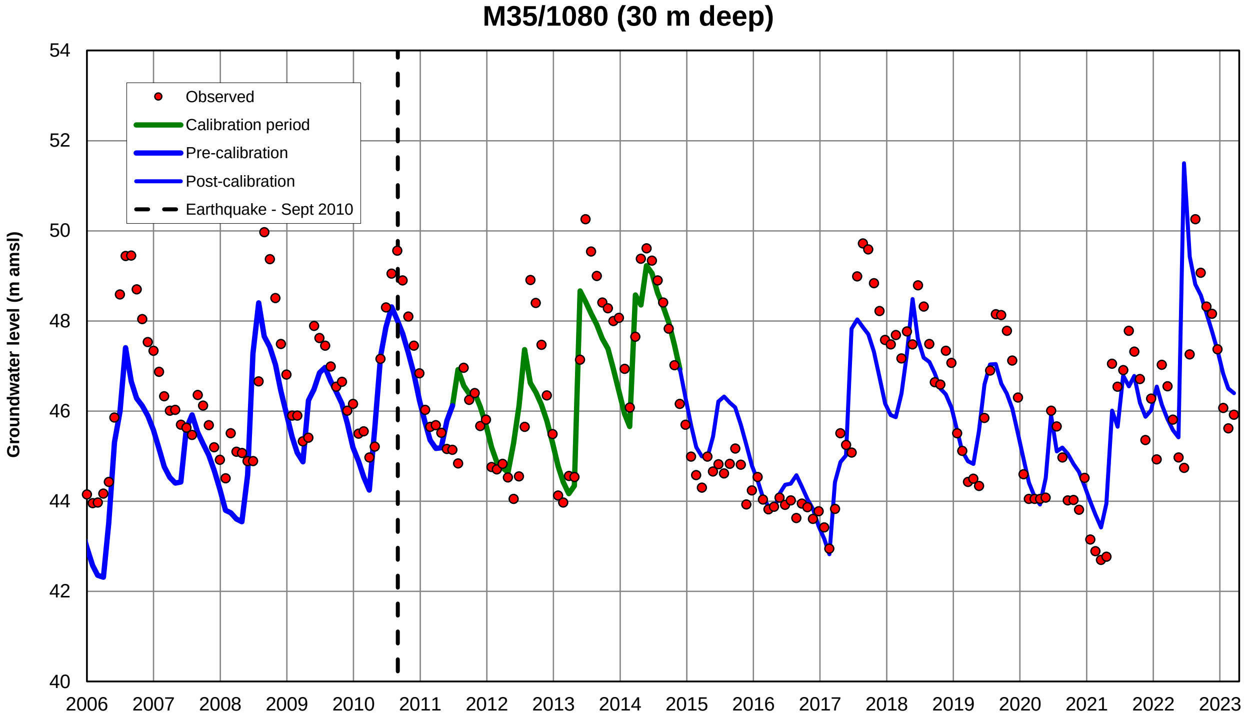

L36/0124 (35 m deep)
Observed
Calibration period
Pre-calibration
Earthquake - Sept 2010
Post-calibration
Groundwater level (m amsl)
96
94
92
90
88
86
84
82
80
78
76
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023

M36/0599 (9 m deep)



M36/0217 (41 m deep)




M35/1080 (30 m deep)
Groundwater level (m amsl)
54
52
50
48
46
44
42
40
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
Observed
Calibration period
Pre-calibration
Post-calibration
Earthquake - Sept 2010