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IMPACT OF CLIMATE CYCLES AND TRENDS ON SELWYN DISTRICT WATER ASSETS: 2020 UPDATE

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Selwyn District Council (SDC) is committed to the sustainable management of the district's five water assets: potable water, wastewater, stormwater, land drainage, and water races. Good asset management requires robust and defendable scientific evidence. SDC has engaged Aqualinc Research Ltd to assess the impact of climate trends and cycles on these assets. Our assessment looks out 30 years to 2050, as requested by SDC.

The purpose of this report is to consider projected changes in climate in the light of historically observed climate cycles and trends and to assess what the impact of those changes could be on Selwyn District Council's water assets.

When assessing the impacts, a core philosophy to our approach is that a thorough understanding of local historical climate is an important foundation for understanding future climate. A robust analysis of long term historical climate (100 years+) allows climate projections to be placed in context. Our approach invests considerable effort in understanding the past because our experience for New Zealand is that for certain climate variables, natural variability is often much greater than climate change effects , particularly for a 30 year horizon.

The study is a high level risk assessment, to identify the assets that are most likely to be affected by climate change. Priority areas were guided by a risk matrix that we developed in consultation with SDC at the outset of the study. The environmental factors that were identified as having the greatest impact were:

- Groundwater levels;
- Annual rainfall;
- Extreme rainfall;
- Alpine and foothill river flows (floods and low flows);
- Evapotranspiration; and
- Sea level rise;

The key conclusions were:

Temperature

- Average temperatures across New Zealand have increased 1°C over the last 100 years.
- By 2050 temperatures are projected to be 1.3°C warmer (on average) compared with the last 20 years (1998 to 2018).
- There will be fewer frost days (daily minimum temperature < 0°C) and an increase in the number of days with a maximum temperature > 25°C, by 2050.

Evapotranspiration

- Evapotranspiration rates are expected to increase by about 5% by 2050.

Annual rainfall

- There is no long term trend observed in annual rainfall on the Canterbury Plains and no change in the annual rainfall is expected on the Canterbury Plains by 2050.
- Alpine rainfall is projected to increase by 5% by 2050.

Extreme rainfall

- There is no observed long term trend in extreme rainfall events on the Canterbury Plains.

- Very wet[1] rainfall days are not projected to be any wetter by 2050.
- Castle Hill basin is projected to have an additional 10 dry days per year by 2050 compared to the last 20 years.
- Extreme rainfall events[2] are projected to increase by 4-12% by 2050.

Other climate variables

- Climate change will have a relatively minor impact on the overall amount of snow in the high mountains of the Southern Alps and snow frequency on the Canterbury Plains.
- Average wind on the Canterbury Plains will remain relatively unchanged, while the wind speed on very windy days is projected to increase by 5% by 2050.

Groundwater

- We expect climate change will have only a minor impact on groundwater levels over the next 30 years.
- Central Plains Irrigation has a much greater impact than climate change and will increase groundwater levels.
- Record low groundwater levels in 2016 are due to a combination of below average rainfall and increased pumping of groundwater for irrigation.

River flows

- Mean annual flows in the alpine rivers (e.g. Waimakariri and Rakaia) could increase by about 3% by mid-century, as a result of increased precipitation.
- Foothill river flows may slightly decrease over the next 30 years, due to a small increase in evapotranspiration.
- We expect climate change will only have a minor impact on flows in lowland streams and drains.

Sea level rise

- Local sea levels have risen 0.27 m since 1900.
- Sea levels could rise by between 0.09 m and 0.28 m by 2050.
- Sea level rise will result in either the Te Waihora/Lake Ellesmere mouth needing to be opened more frequently and/or an increase in lake levels. Without any change in lake management, lake levels may rise by 0.09 m to 0.28 m by 2050.
- Sea level rise may result in a minor increase in flooding frequency at Rakaia Huts.
- Sea level rise could have a minor impact on groundwater levels at the coast. Impacts quickly diminish and are very small beyond about 1 km inland.

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[1] Very wet days were taken as those in the top 99th percentile.
[2] Represented by the maximum 5 day annual rainfall.

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Potable water supply

- Climate change will likely have a minor impact on most aspects of SDC potable assets over the next 30 years.

- Higher evapotranspiration may mean 1-2% higher peak water demands.

- Higher alpine flood flows may have some impact on Arthurs Pass, Castle Hill and Lake Coleridge water supply intakes.

Wastewater

- Climate change will probably have only a minor impact on most aspects of SDC wastewater assets over the next 30 years.

- Higher alpine rainfall and flood flows may result in an increase in stormwater inflows for the Arthurs Pass, Castle Hill and Lake Coleridge wastewater systems.

- An increase in sea level of up to 0.28 m may have an impact on Upper Selwyn Huts, Rakaia Huts and Lakeside wastewater systems.

Stormwater

- Climate change will probably have only a minor impact on most aspects of SDC stormwater assets over the next 30 years.

- Higher alpine rainfall and flood flows may result in an increased occurrence of surface flooding at Arthurs Pass, Castle Hill and Lake Coleridge.

- An increase in sea level of up to 0.28 m may have a minor impact on stormwater drainage systems at Rakaia Huts.

Land drainage

- An increase in sea level of up to 0.28 m may impact on Lake Ellesmere/Te Waihora levels and parts of the land drainage network.

- A projected 6-8% increase in flood flows may impact on Arthurs Pass Bealey River flood protection systems.

- Other aspects of climate change will probably have only a minor impact on land drainage systems over the next 30 years.

Water races

- Climate change will probably have only a minor impact on most aspects of the SDC water race system.

- An increase in alpine flood flows could result in a small increase in flood damage to intakes. Conversely higher alpine flows would improve reliability of supply.

- A potential minor reduction in flows in the Kowai River might have a small impact on reliability.

1 INTRODUCTION

This chapter provides:

- The background of why this project was undertaken;
- The general study approach;
- An overview of asset sensitivity to changes in environmental factors; and
- An overview of the document structure and data flow processes.

Selwyn District Council (SDC) is committed to the sustainable management of the district's five water assets: potable water, wastewater, stormwater, water races, and land drainage. Good asset management requires robust and defendable scientific evidence. SDC have requested Aqualinc Research Ltd (Aqualinc) to assess the impact of climate trends and cycles on these assets. The assessment is an update on a similar 2016 report and looks out 30 years to 2050 as requested by SDC.

The purpose of this report is to consider projected changes in climate in the light of historically observed climate cycles and trends and to assess what the impact of those changes could be on Council's water assets.

When assessing the impacts a core philosophy to our approach is that a thorough understanding of local historical climate is an important foundation for understanding future climate. A robust analysis of long term historical climate (ideally 100 years+) allows climate projections to be placed in context. Note that we use the word *projection* rather than forecast or prediction as the outcome is dependent on assumptions of future greenhouse gases. Our approach invests considerable effort in understanding the past because our experience for New Zealand is that for certain climate variables, natural variability is often much greater than any likely climate change effect, particularly for a 30 year horizon.

Our approach was to focus our time and resources primarily on the areas where climate cycles and trends pose the greatest risk to SDC water assets. This allowed us to go into greater quantitative detail for issues that matter most. For example, because groundwater level variations potentially pose significant risk to a number of SDC assets we undertook more in-depth analysis in this area, including modelling multiple locations on the plains for a simulation period of over 100 years.

The study is a high level risk assessment, to identify the assets that are most likely to be affected by climate change. Priority areas were guided by a risk matrix that we developed in consultation with SDC at the outset of the 2016 study (Table 1). Whether or not an asset is affected depends both on the asset's sensitivity to change, and the scale of change. The asset sensitivities were combined with projected changes (Chapters 4 to 14), to give the expected impacts of climate change on assets (Chapters 15 to 19).

Where vulnerabilities have been identified we recommend more detailed analysis should be undertaken to better quantify the risks.

Table 1: Asset sensitivity to changes in environmental factors.

Environmental factor	Water	Wastewater	Stormwater	Land drainage	Water races
Ground water levels (upper plains)	High	Minor	Minor	Minor	Minor
Ground water levels (lower plains)	Low	High	High	High	Low
Annual rainfall	Moderate	Minor	Minor	Minor	Moderate
Extreme rainfall (Plains)	Moderate	High	High	High	Moderate
Extreme rainfall (foothills and alpine)	High	High	High	High	Moderate
Alpine river flows	Moderate	Minor	Minor	Minor	High
Foothill and lowland river flows	Moderate	Minor	Minor	Minor	High
Evapotranspiration (ET)	High	Minor	Minor	Minor	Minor
Sea Level rise <0.23 m	Minor	Low	Low	High	Minor
Snow and ice (excl. alpine river flows impacts)	Minor	Minor	Minor	Minor	Low positive
Temperature (excl. ET impacts)	Minor	Minor	Minor	Minor	Minor
Wind (excluding ET impacts)	Moderate	Moderate	Minor	Minor	Minor

Table 2 provides an overview of the document structure. Each chapter begins with a short summary of either the purpose or key conclusions for that chapter. Chapters are largely self-contained, so it is not necessary to read the report from cover to cover to get the key messages. The document structure is intended to make it easier to find relevant information.

Table 2: Report structure overview.

No.	Topic	Purpose
1	Introduction	Background, study approach, report layout, data flows.
2	Historical Data	Available and sources of historical data.
3	Climate Cycles	Overview of different climate indices.
4	Temperature	Measured historical trends, and projected future changes for the different climate parameters.
5	Evapotranspiration	
6	Mean Annual Rainfall	
7	Extreme Rainfall	
8	Other Climate Variables	
9	Land Surface Recharge	Modelled groundwater response to climate change and irrigation (including Central Plains Water).
10	Groundwater	
11	River Flows	Measured historical trends, and projected future changes in river flows.
12	Sea Level Rise	Sea level rise and secondary impacts.
13	Te Waihora/Lake Ellesmere	
14	Rakaia Mouth	
15	Groundwater and Sea Level	
16	Potable Water Supply	Impact of climate change on SDC assets.
17	Wastewater	
18	Stormwater	
19	Land Drainage	
20	Water Races	
21	References	

An overview of the main data flow processes is shown in Figure 1.
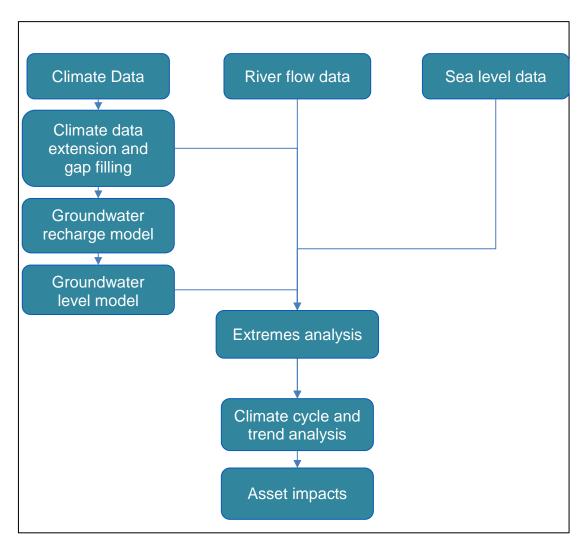
Figure 1 Data flow process diagram

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This chapter provides:

- Historical time series data sources; and
- Data extension methodologies.

Historical data sources are summarised in Table 3.

Table 3. Data descriptions

Data type	Source	Frequency	Comments
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	Derived product
Ground water levels	data.ecan.govt.nz	Daily	
River flows	data.ecan.govt.nz, hydrowebportal.niwa.co.nz Tony Gray, ECan.	Daily	
Sea level (at Lyttelton)	John Hannah, Emeritus Professor, School of Surveying, University of Otago	Annual	
Te Waihora Lake Ellesmere Water Level	ECan Tony Gray	Daily	

Evapotranspiration data is not a direct measurement, but is a derived product calculated from radiation, temperature, wind, and vapour pressure measurements.

The source data were processed in a variety of ways (see Table 4) to provide extended time series for climate cycle and trend analysis.

We used Aqualinc's Climate Time Series Extension (CTSE) software to gap fill and extend daily time series for rain, temperature and potential evapotranspiration (PET). An outline of the CTSE software is provided in Brown et al. (2016). In summary, the software identifies weather observation data for sites that are highly correlated, and fills gaps based on the correlation.

To extend PET estimates back to 1910, we used a two-step process. An estimate of PET for the 1910-2019 period was generated with the McGuiness-Bordne method that uses daily minimum and maximum temperatures (Guo et al. 2016). We used the McGuiness-Bordne method (which only uses temperature to estimate PET) because of the lack of radiation records prior to 1960. These estimates were then compared to the 1960 – 2019 extended PET data estimated using the Penman method. The Penman method is more accurate, but requires radiation, wind, vapour pressure and temperature data. The relationship between the McGuiness-Bordne and Penman estimates was then used to adjust the entire McGuiness-Bordne series.

Groundwater level time series were extended through modelling the groundwater using the extended rainfall and PET as the primary inputs. Rainfall and PET were converted to estimates of daily land surface recharge using Aqualinc's IrriCalc model (Bright 2009).

Table 4. Data extension methodologies

Data type	Process	Period
Rainfall	Extended and gap filled with CTSE software	1892-2019
Minimum and maximum temperature	Extended and gap filled with CTSE software	1905-2019
Potential evapotranspiration (Penman)	Extended and gap filled with CTSE software	1960-2019
Potential Evapotranspiration (McGuiness-Bordne)	Generated from temperature and calibrated to NIWA Penman estimates	1909-2019
Groundwater	Modelled from rainfall and potential evapotranspiration and calibrated to post-earthquake observed groundwater levels.	1909-2019

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The key conclusions for this section are:

- Climate is affected by both cycles and long term trends;
- The words "climate change", "climate", and "weather" have three very different meanings;
- Three known climate cycles are investigated for causes of local climate variation.

3.1   Overview

An analysis of a long historic period is necessary to separate trends from multi-decadal cycles. For example some multi-decadal cycles show up as trends if only the last 40 years of historical data is analysed. This impacts on the accuracy of future climate predictions.
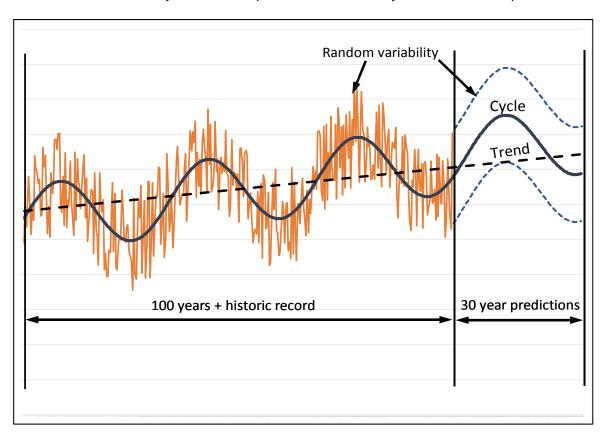
Figure 2: Schematic illustrating Trends, cycles and random variability

Some of the variation in climate may be attributable to different large scale climate cycles. Relationships between observed Selwyn District environmental data and four different climate characteristics were assessed. These climate characteristics were:

1. Climate change
2. El Niño - Southern Oscillation (ENSO),
3. Interdecadal Pacific Oscillation (IPO),
4. Southern Annular Mode (SAM)

A description of each climate characteristic is provided below. Further details are provided in Appendix A of Brown et al. (2016).

3.2   Climate change

The terms "weather", "climate", and "climate change" have three very different meanings. The difference between weather and climate is a measure of time. "Weather" is conditions of the atmosphere over a short period of time, and "climate" is the average condition of the atmosphere over decades. Weather can change from minute-to-minute, hour-to-hour, day-to-day, and season-to-season. In contrast climate encompasses all these continual changes (i.e. variability) including the highs, lows, and extreme events. Weather forecasts and weather events do not directly relate to *climate change*. For example the drought of 2014/15, the El Nino event in 2015/16, and the very low groundwater levels of 2016 are all examples of individual weather events, because the scale of events is days to months.

"Climate change" means that there has been a long term shift in the climate characteristics. For example a single drought in isolation is not climate change, but a long term increase in the frequency or severity of droughts would indicate the climate has shifted. Similarly a single flood or extreme rain event is not climate change, but a long term increase in the frequency or magnitude of extreme events is climate change.

In this study we are focused on assessing the impact of *climate change*, not climate. The purpose is not to identify assets that may be susceptible to natural climate variability, but rather to assess where climate change may result in a change in the vulnerability of an asset to individual weather events. For example, climate change impacts might be where an asset was previously designed to accommodate a 1 in 50 year rainfall event, but a long-term shift in climate now means that that design event occurs on average every 10 years.

Climate change assessments also require that non-climate influences be removed. For example groundwater levels are affected not only by climate, but also by pumping, irrigation schemes, irrigation practices, and land use. A long term shift to lower or higher groundwater levels may be due a change in a non-climatic factor.

3.3   El Niño Southern Oscillation (ENSO)

ENSO is a climate characteristic related to the sea surface temperature in the eastern equatorial Pacific (commonly known as El Niño) and the atmospheric pressure difference across the equatorial Pacific (known as the Southern Oscillation). ENSO has been shown to relate to weather conditions throughout the world and has multi-month persistence that enables seasonal forecasting in some locations. The physical explanation for the variations are a subject of considerable research, with positive feedback of ocean-climate interactions playing a large part.

The strength of the El Niño, the Southern Oscillation, or a combination of the two may be measured in a variety of different ways. We have selected the Coupled ENSO Index (CEI) as our measure (Figure 3) as it covers the time span that the data are available for, and combines the sea surface temperature and atmospheric pressure measurements that constitute the ENSO phenomena.

The variation in the CEI over time is shown in Figure 3. For the CEI, a negative index indicates an El Niño event while a positive value indicates a La Niña event. The recent extreme El Niño years of 1982-83, 1997-98 and 2015-16 show as extreme low points with this index.

The Southern Oscillation Index is projected to increase by 2050 (see Figure 65 of MfE, 2016) but the increase is small with large uncertainty.
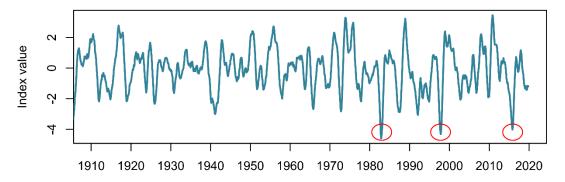
Figure 3. ENSO variation represented by the Coupled ENSO Index (CEI).

3.4   Interdecadal Pacific Oscillation (IPO)

Pacific sea surface temperatures show variation on a multi-decadal timescale often referred to as the Interdecadal Pacific Oscillation (IPO). The multi-decadal variation has been observed in weather throughout the Pacific and in the strength of the ENSO oscillations. The physical explanation of the variation is not well understood. There are three different measures that may be used to describe this variation. It is common to consider these measures in terms of their "phase", as in "the positive phase from the late 1970's to early 2000's", rather than the actual values. A smoothed version of the three measures are shown in Figure 4. Over the last century the measures are mainly positive from 1922 to1944, negative from 1946 to 1977, positive from 1979 to 1998, and negative from 2000 to 2018.
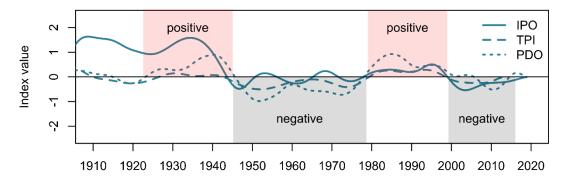
Figure 4. 13 year filtered indices of Pacific sea surface temperature. IPO is the Interdecadal Pacific Oscillation index, TPI is the Tripole Index for the Interdecadal Pacific Oscillation, and PDO is the Pacific Decadal Oscillation index.

3.5   Southern Annular Mode (SAM)

The SAM is a description of the strength and position of the westerly winds around the mid-latitudes of the Southern Hemisphere. SAM is measured by the SAM Index. A positive SAM index indicates the westerly winds have moved closer to Antarctica. A negative SAM index indicates the westerly winds have moved closer to the equator.

Locally the SAM is expressed as the strength, frequency and location of the westerly winds across the South Island. The higher the SAM index, the weaker the westerly winds over the South Island.

The SAM index is shown in Figure 5. SAM changes at a weekly timescale and can be used for short term forecasting. There is a long term trend in the SAM towards higher values indicating that climate change is leading to less frequent and weaker westerly winds over the South Island.
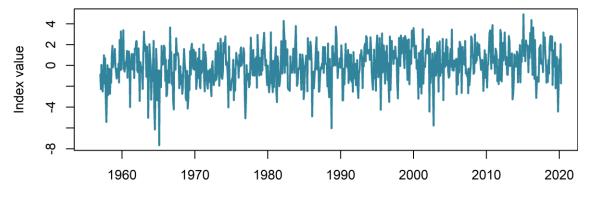
Figure 5. Southern Annual Mode (SAM)

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The key conclusions for this section are:

- Average temperatures across New Zealand have increased at a rate of 0.01°C/y, over the last 100 years.

- Temperatures by 2050 are projected to be 1.3°C warmer (on average) compared with the 1998 to 2018 period.

- There will be fewer frost days (daily minimum temperature < 0°C) and an increase in the number of days with a maximum temperature > 25°C, by 2050.

The global climate is undergoing a long-term change. Evidence of this change in New Zealand is provided by a composite of temperature data from the NIWA "7 station" series (Mullan *et al.* 2010) shown in Figure 6. For these 7 stations, temperatures have increased by 1.1°C over the last 109 years, or 0.01 °C/y (on average).

The most recent projections of New Zealand climate change (MfE 2016) indicate that by 2050, temperatures will be 1.3°C warmer (on average), compared with the period from 1986 to 2005 (MfE, 2016). This is 1.1°C warmer (on average) compared with the recent 1998 to 2018 period. The projected rate of temperature increase out to 2050 is 0.024°C/y. This is about twice the historic rate. The temperature projections are uncertain and depend on projections of global greenhouse gases. The projections used here assume that the greenhouse gases continue to increase at the current rate.

The climate change projections for Canterbury (MfE 2016) indicate that from the 1990's to the 2040's there will be an increase of 10 days per year (from 27 to 37) with a maximum temperature > 25°C. Over the same time period a decrease of frost days (daily minimum temperature < 0°C) by 19 days (from 47 to 28) is expected. This is a 37% increase in the days with highs above >25°C and a 40% decrease in the number of frost days each year, by the 2040's.
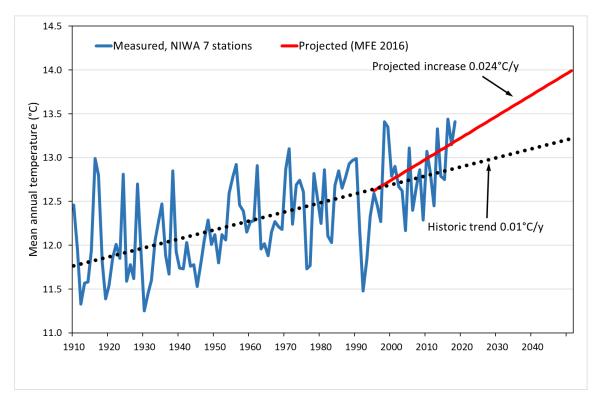
Figure 6: Measured and projected temperature for New Zealand: 1910-2050

5   EVAPOTRANSPIRATION

The key conclusions for this section are:

- PET is projected to increase by 5-6% by 2050.

- Historical PET records suggest rates have not changed significantly from 1960 to 2020.

Potential Evapotranspiration (PET) is the water that evaporates from the land surface and transpires from plants, under conditions of sufficient soil moisture content, such that plant stress does not occur. It is one of the important inputs for estimates of groundwater recharge. Changes in PET rates with climate change could change water demands and groundwater levels. PET rates are driven by several factors including solar radiation (i.e. sunshine and cloudiness), humidity, wind speed, and temperature. As temperature increases, generally so do PET rates.

One method for estimating the change in PET is to use the Penman Monteith[3] equation to test how a 1.3° temperature change (the projected change by 2050 relative to the period 1998 to 2018) affects PET rates. We did this analysis using Lincoln climate data. If wind speed, radiation and relative humidity remain constant, increasing the temperature by 1.3°C resulted in a 5% increase in mean annual PET.

MfE (2016) project a 60 mm increase in annual Potential Evapotranspiration Deficit (PED) for the Canterbury Plains from 1995 to 2040. This is a 6% increase. For the Canterbury Plains, a change in PED may be considered the equivalent to a change in Potential Evapotranspiration as rainfall is not projected to change. However, Collins and Zammit (2016)

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[3] The Food and Agricultural Organisation recommend using the Penman Monteith equation for estimating PET while the Penman method is NIWAs default approach. The two methods give similar estimates.

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found a decrease in the equivalent soil moisture deficit for inland Canterbury. The MfE (2016) analysis is based on climate data, whereas the Collins and Zammit (2016) assessment includes additional consideration of soil moisture holding capacity. Whether the additional complexity leads to an improved result or not is not possible to say. For planning purposes, use of the MfE (2016) projections is the safest option.

Figure 7 illustrates how recorded PET rates, for the three long term climate stations on the Canterbury Plains, have changed from 1960 to present. For each of these stations we filled gaps and where necessary extended the record length using Aqualinc's CTSE software. For all three stations there is a slightly decreasing trend in PET rates. The trend is small relative to the year-to-year variability, and below the level that would indicate a statistically significant change. The lack of any trend is also observed if the same analysis is repeated for all New Zealand long term PET records.
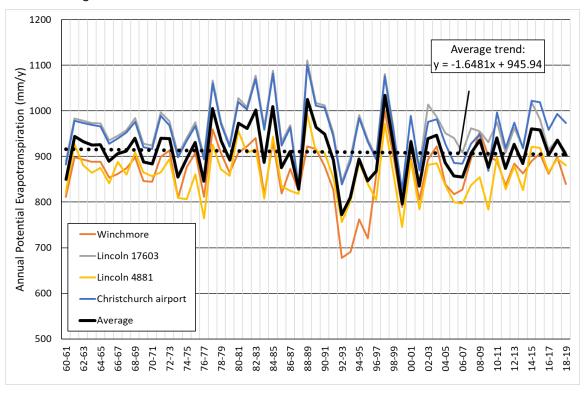
Figure 7: Measured change in PET 1960 to 2020 for three locations

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The key conclusions for this section are:

- There is no long term trend in the measured annual rainfall on the Canterbury Plains.

- The annual rainfall on the Canterbury Plains is not projected to change by 2050.

- Alpine rainfall is projected to increase by over 5% by 2050.

Annual rainfall is a useful rainfall statistic for identifying droughts and years of low and high groundwater recharge.

We analysed observed rainfall data from 6 sites across the Canterbury Plains to investigate whether there has been any long term trends. Where possible, we extended the rainfall records back to 1892 using Aqualinc's CTSE software. The locations of the stations used in the analysis are illustrated in Figure 8.

Figure 9 illustrates the measured annual rainfall for the three long term stations on the lower Central Canterbury Plains, and Figure 10 illustrates the three long term stations on the upper Central Canterbury Plains. No trends were apparent in any of the data that could not be explained by chance.
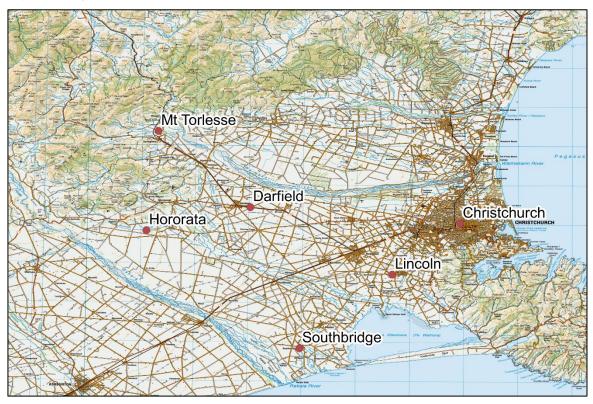
Figure 8: Rainfall stations used in annual rainfall analysis
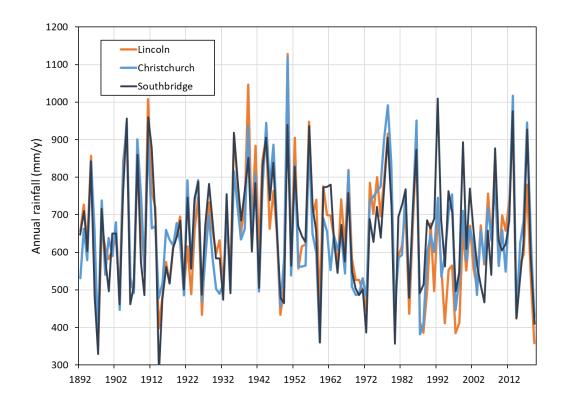
Figure 9: Annual rainfall for three sites on the lower Central Canterbury Plains 1892-2020
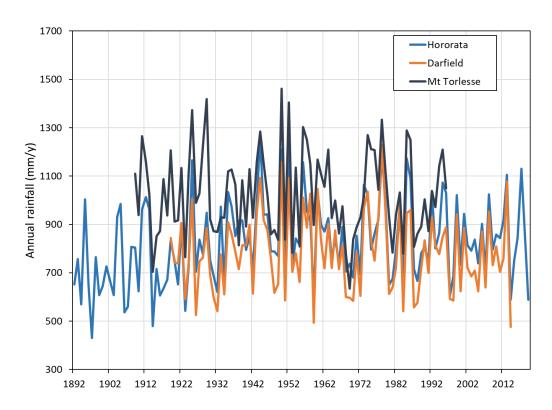
Figure 10: Annual rainfall for three sites on the upper Central Canterbury Plains 1892-2020

Annual rainfall is not projected to increase by the 2040s for Christchurch or Hanmer (MfE, 2016). Hanmer may be considered representative of a Canterbury foothills site. The projection for Tekapo (representative of Castle Hill Basin) is an increase of 6%. The projection for Hokitika (representative of Arthur's Pass) is an increase of 5%. For all of three projections there is at least 5% uncertainty. A projected change of less than 10% is not considered significant (MfE, 2016). By the 2090s the projections are similar for Christchurch and Hanmer, but Tekapo and Hokitika have increased to 11%, though the uncertainty has also increased to 10% in all cases. Seasonally, the increase in precipitation inland is projected to mainly occur in winter time. On the Canterbury plains the winter precipitation is projected to decrease in the winter, though this is offset by an increase in the summer. Maps of the projected percentage change in seasonal precipitation between the 1990s and the 2040s are shown in Figure 11[4].
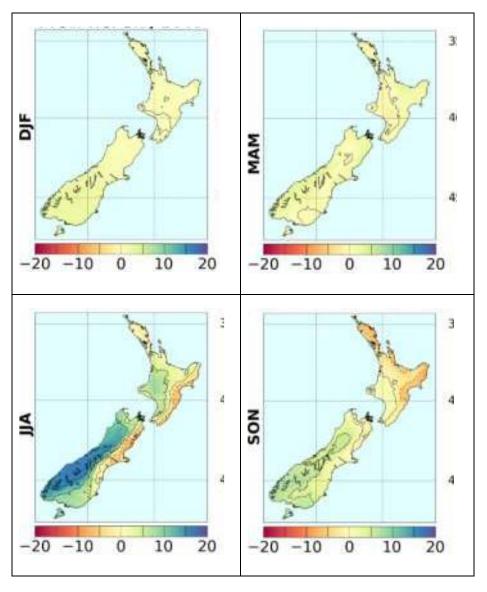
Figure 11: Projected percentage change in seasonal precipitation between the 1990s and the 2040s based on statistical downscaling of global climate models (from MfE, 2016 Figure 39).

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[4] The labels on the figure refer to seasonal quarters – e.g. DJF is December-January-February.

The key conclusions for this section are:

- There is no measurable long term trend in extreme rainfall events on the Canterbury Plains;

- The rainfall amount on very wet days is not projected to increase significantly;

- The number of dry days per year is not projected to increase on the plains but is projected to increase in Castle Hill basin by 10 days per year by the 2040s compared with the 1990s.

- Extreme rainfall events are projected to increase from between 4% and 12% by 2050 depending on the event duration and recurrence interval.

We analysed data from 4 rainfall stations on the Canterbury Plains to investigate whether there has been a change in extreme rainfall as represented by the maximum 5 day annual rainfall. The stations used in our analysis are illustrated in Figure 12. The average five-day-maximum for all four stations is shown in Figure 13. The data show no significant long term trend. Analysis of the annual frequency of moderate rainfall events (>95 percentile) within the Selwyn District by Brown et al. (2016) found no statistically significant long term trends, or statistically significant correlations with the three main climate cycle indices (ENSO, IPO and SAM).

Other researchers have also concluded that there is no obvious trend in extreme rainfall events on the Central Canterbury Plains. Rainfall data at Christchurch has been analysed for long term trends by Griffiths (2013). For the 1962 to 2011 period, no statistically significant (p < 0.05) trend was found for mean annual rainfall, number of days per year with more than 25 mm of rain, annual maximum daily rainfall, annual maximum 5 day rainfall, annual total rainfall from the top 4 events per year, or annual maximum consecutive rain days. This result was in agreement with previous work carried out for the 1950 to 2004 period (Griffiths 2007).

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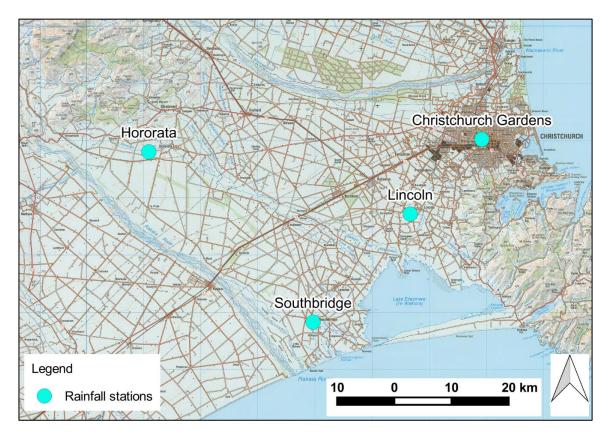
Figure 12: Four long term rainfall stations with records from at least 1893
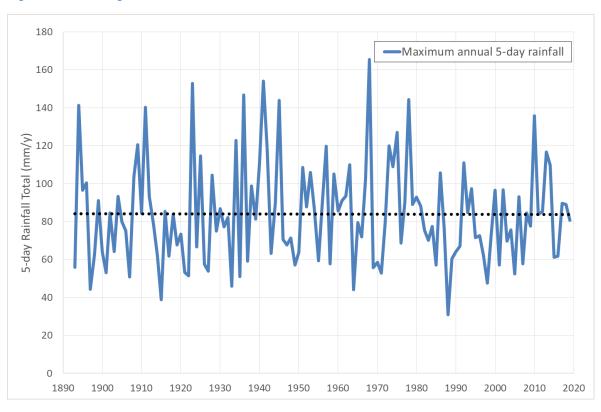
Figure 13: Annual maximum 5 day rainfall for the mean of four long term stations (Southbridge, Lincoln, Hororata and Christchurch Gardens)

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MfE (2016) projected the change in the number of dry days per year, and the change in the amount of rain on very wet days[5] for the 2040s. Their projections were provided as maps and are reproduced in Figure 14. For the Canterbury Plains no significant change in either the number of dry days, or the magnitude of the rain on very wet days. For the Castle Hill Basin and the alpine regions an additional 10 dry days per year are projected, but no significant change in the magnitude of the rain on very wet days.

The New Zealand High Intensity Rainfall Design System (HIRDS, hirds.niwa.co.nz Carey-smith *et al.*, 2018) estimates extreme rainfall magnitudes throughout New Zealand and includes consideration of climate change. The climate change projections are based on relationships between extreme rain intensities and projected temperature change as determined from atmospheric modelling. For the Canterbury area, high intensity rain in 2050 is projected to increase from 4% for 120 hour events that occur once every two years on average, to 11.5% for 1 hour events that occur once every 100 years.

Assessment of the relationship between high intensity 1 hour rain events and temperature for historical Christchurch rainfall data found that 99th percentile events (events that would occur on average 3 times a year) increased by less than 3% per degree C. (Kerr, 2017). This is considerably less than HIRDS' projected climate change increase of 12% per degree C. for 1 hour rainfall occurring once every 2 years. It is hard to resolve the difference even considering the different return intervals. There is a growing body of evidence that indicates that temperature affects rainfall processes that are not well represented at the scale of atmospheric model (27 km) used to estimate the HIRDs climate change projections.

While the conservative approach would be to adopt the HIRDS climate change projections, if this may lead to considerable increase in investment, site specific modelling of climate change impacts should be used to determine any likely change in extreme rainfall.
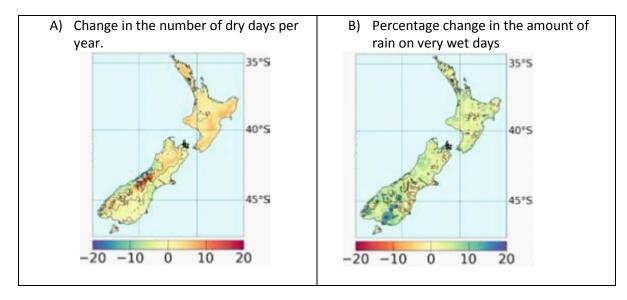
Figure 14. Projected changes between 1990s and 1940s of A) the number of dry days per year and B) percentage change in the high (99th percentile) daily rain amounts.

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[5] Very wet days were taken as those in the top 99th percentile. On average there would be 3 events per year of this magnitude.

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The key conclusions for this section are:

- Climate change will have a relatively minor impact on the overall amount of snow in the high mountains of the Southern Alps and snow frequency on the Canterbury Plains; and

- Wind speed on very windy days is projected to increase by 5% by 2050.

8.1   Snow

Estimates of future climate change effects on snow to 2040s indicate elevated seasonal snow lines with little change in the overall amount of snow in the high mountains of the Southern Alps where increased precipitation is projected to offset increased temperature (Hendrikx et al. 2012). The inter-montane basins (Castle Hill and Coleridge regions) are projected to have less snow by the 2040s by about 20%, but the headwater catchments are projected to have increased snow at higher and western regions. The number of days with snow falling is projected to decrease by 10 days (MfE, 2016).

The frequency of low elevation snow events are unlikely to noticeably change in the next 30 years as they are usually a result of particular weather events (southerly flows colliding with a depression moving south eastward across the South Island) which are largely unrelated to changes in the "average" condition.

8.2   Wind

MfE (2016) project a 5% increase in wind speed on windy days[6] across the Canterbury plains by the 2040s. Our analysis of historical data shows no trend over time. Historical trends in wind are less reliable than other climate parameters because of the relatively small number of stations and the difficulty in maintaining stable sites (i.e. without changes in sheltering) over long periods.

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[6] Windy days were taken as 99th percentile of daily mean wind speed. On average there would be 3 days a year at or above this level.

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The key messages for this section are:

- Land surface recharge estimates are used in groundwater modelling; and

- We modelled five scenarios including climate change, Central Plains Irrigation, and no irrigation.

We used Aqualinc's in-house crop-soil water balance model (IrriCalc) (Bright, 2009) to generate time series of land surface drainage. The crop-soil water balance model simulates the variable use of water in agriculture with differing crops, agricultural soil types, climate, and irrigation strategies. The basis of the model is a daily soil moisture balance with an irrigation scheduling component. An overview of the model is provided in Appendix A.

Data inputs to the IrriCalc model were:

- Land use, simplified into the following two categories:
  - Irrigated pasture
  - Dryland pasture
- Potential evapotranspiration (PET);
- Rainfall;
- Soil plant available water estimated from S-Map; and
- Irrigation parameters.

The groundwater modelling divided the aquifer area into 7 zones (Figure 15). For each of these zones climate data was prepared from available observed data. The sites used for each zone and each climate parameter are listed in Table 5.

Table 5: 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

Irrigated areas were derived from mapping undertaken by Aqualinc. This was used to assign the proportion of irrigated and dryland area for each groundwater zone. We assumed that all irrigation (except for the CPW scenario) was sourced from groundwater. We also assumed that all irrigation was spray with an equivalent 80% (approximately) water use efficiency. Both the irrigated and dryland scenarios were considered for the model zones except for the Christchurch City zone where no irrigation was assumed to occur. Model parameters are summarised in Table 6.

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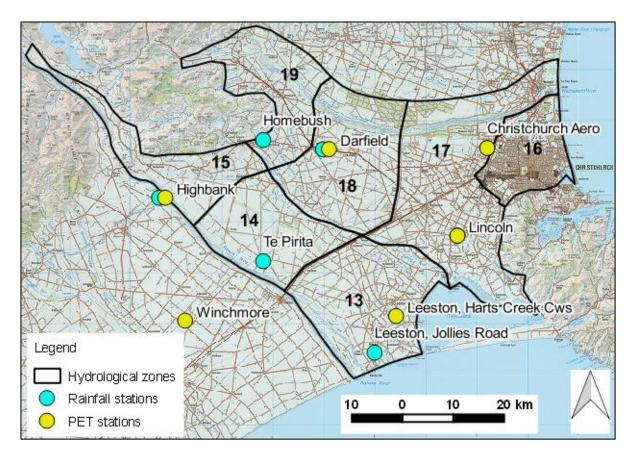
Figure 15: Groundwater model zones

Table 6: 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)	0.0 (Dryland only)
Lincoln	84	60	4.3
Darfield	74	43	4.3
Homebush	74	43	4.3

The long time series evapotranspiration data used in this work is derived solely from observed temperature data using the McGuiness-Bordne method (see Chapter 2). While a more precise calculation of evapotranspiration may be obtained from consideration of temperature, humidity, wind speed and solar radiation, there are few long time series of these additional environmental parameters. In addition, difficulties with site changes, particularly with respect to radiation and wind speed, means they are less reliable for trend analysis. Daily time series of land surface recharge were generated for each of the zones shown in Figure 15. We modelled five different groundwater scenarios (Table 7)

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Table 7: Groundwater modelling scenarios

Scenario	PET	Irrigation	Groundwater Pumping
Historic	Extended	Post-earthquake	Post-earthquake
Current	De-trended	Post-earthquake	Post-earthquake
Climate Change	De-trended	Post-earthquake	Post-earthquake
CPW	De-trended	Post-earthquake + 42,000 ha additional within CPW command area	Post-earthquake less 18,000 ha irrigation within CPW command area
No Irrigation	De-trended	0	0

Historic: The historic groundwater scenario is the 1910-2016 groundwater model output using post-earthquake land use, groundwater pumping and irrigation. The land surface recharge is derived from the extended time series of rainfall and PET.

Current: This is the same as the "Historic" scenario, except the PET data used to drive the model has had any long term trends removed[7]. Rainfall was not changed as no trend was observed.

Climate Change: This is the same as the "Current" scenario except that the de-trended PET has been adjusted for the estimated climate change effects to 2050 using the values from MfE (2016). The rainfall was not adjusted as the climate change scenario shows no change to 2048.

CPW: This is the same as the "Current" scenario except the irrigation ratios and groundwater pumping have been changed across the scheme command area to reflect the amounts anticipated from the CPW scheme. The irrigated area of 60,000 ha was assumed to be evenly distributed across the command area with 70% new irrigation and 30% converted from groundwater takes.

No Irrigation: This is the same as "Current" scenario except with no irrigation (i.e. dryland recharge everywhere) and no groundwater pumping.

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[7] Removing historic trends from the observed time-series gives a long-term time-series that reflects the current state of the climate. This ensures that when climate change scenarios are considered, the results are due to the projected change, rather than historic trends in the observations.

The key conclusions for this section are:

- Long term climate change is expected to have only a minor impact on groundwater levels.

- Central Plains Irrigation will have a much greater impact than climate change and will increase groundwater levels.

10.1   Method Overview

For SDC's catchment, groundwater eigen models have been used to simulate the response in groundwater levels as a result of changes in land surface recharge and pumping. Bidwell & Burbery (2011) describe groundwater eigen models as follows:

- They present a 1-dimensional representation of the aquifer system.

- They are a simplification compared to real aquifers, but are adequate for situations for which dynamic response is the primary interest.

- They are useful where there is a clear dynamic response between groundwater inflows (river recharge and/or land surface recharge), outflows (pumping and spring flows) and groundwater levels.

- They are particularly helpful in situations where the aquifer system is not known in sufficient detail to construct a more detailed numerical model, or where this is prevented by time and budgetary constraints.

Groundwater eigen models incorporate bulk aquifer parameters which are calibrated to match the measured groundwater level response at specific wells (Figure 16). Spatial variation down the catchment is accommodated by the inclusion of zones (Figure 16; inland, mid-plains and coastal) of differing aquifer stresses (land surface recharge (LSR) and pumping). Each well is assumed to lie along a slice (Figure 16), along which, the differing time series of LSR and pumping are applied as the slice passes through each zone. Each well along each slice has the same LSR and pumping time series applied as other wells along the same slice. However, different slices have different time series. The location of each well along the slice differs.

River recharge is assumed to be constant and results in a constant 'base' groundwater level as supported by the rivers. LSR provides the transient response on top of this base groundwater level.

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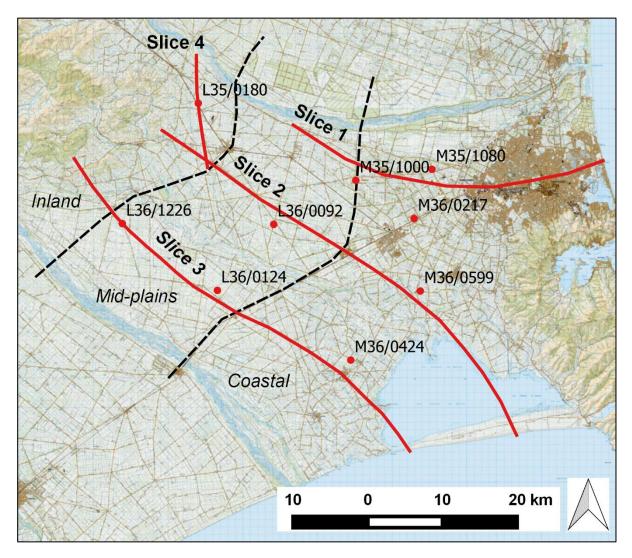
Figure 16: Well locations and conceptual groundwater model slices

10.2   Selected Wells

Table 8 presents an overview of the wells chosen to represent SDC's infrastructure. Wells were chosen to provide spatial coverage over the catchment and to provide a mixture of both shallow and deep wells, and various locations to represent key SDC infrastructure (main towns etc.).

Table 8: Well selection rationale

Well number	Depth (m)	Location	Eigen model slice	Representation
M35/1000	48.8	West Melton	1	Shallow 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

10.3   Model Development and Calibration

Each groundwater eigen model is constructed to run from June 1910 through to June 2019 with monthly stress periods. The models are calibrated to measured groundwater levels from 1 January 2012 to May 2015, for two reasons:

- Inputs have been generated assuming current water use and land use intensification. Hence, they do not represent aquifer stresses prior to about 2012; and

- To avoid and earthquake responses and the subsequent sustained changes in groundwater levels (Cox et al, 2012) (this is particularly obvious in well L36/1226).

Figure 17 demonstrates for bore L36/0092 both the model calibration (shown by the green line from 2012 to 2015) and the prediction over the 1910-2019 period assuming current water takes and land use (the blue line prior to 2012 and post 2015). This long-term prediction provides an indication of the groundwater level response if the well had been in place for the same period under current land and water use intensification, plus there had been no earthquake-related changes. A full set of calibration graphs for all eight bores is included in Appendix B.

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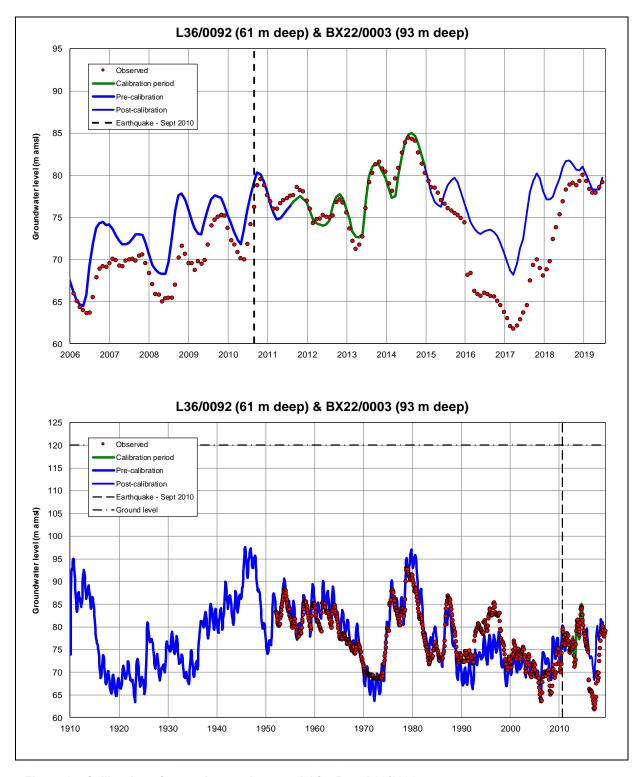
Figure 17: Calibration of groundwater eigen model for Bore L36/0092

10.5   Results

The outputs from the modelling were used to estimate groundwater levels for various return intervals under each scenario. Groundwater modelling results are summarised in Table 9, Tabe 10 and Table 11. Scenario time series graphs for the period 1970 to 1980 are included in Appendix C. The 1970 to 1980 period includes both times of very high and very low groundwater levels.

Results in Table 9 show that groundwater level variations are primarily due to the year to year variability in rainfall. The next biggest influence is existing irrigators pumping from groundwater. Climate trends will probably only result in a minor reduction in groundwater levels. The lack of any significant projected impact is primarily because we do not expect a change in annual rainfall characteristics on the Canterbury Plains over the next 30 years. A slight reduction in levels due to climate change is due to the projected increase in evapotranspiration. The projected increase in levels due to Central Plains Irrigation is typically three times the projected reduction due to climate change.

The very low groundwater levels in 2016 are the result of very low groundwater recharge over the last 20 months combined with two consecutive seasons of high irrigation demand. Past periods of low rainfall recharge (e.g. early 1970's) did not have this added stress of irrigation pumping.

Our groundwater trend and cycles analysis is included in Appendix D. We did not detect any statistically significant correlations with the three main climate cycle indices (IPO, ENSO and SAM).

Table 9: Environmental impacts on groundwater levels

Factor	Average water level change (% of status quo water level range)
Climate change	-3%
Central Plains Irrigation	+13%
Existing irrigation from groundwater	-20%
Annual rainfall variability	±40%

Tabe 10: Groundwater bore modelling results - Part A.

Bore M35/1080 Christchurch-West Melton (GL 60.7m 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	45.9	50.5	51.9	54.4	43	42.8	42.1
Current	46	50.8	52	53.8	43.3	43.1	42.5
Climate change	45.8	50.5	51.7	53.5	43.1	42.9	42.3
CPW	46.6	51.2	52.5	54.3	44	43.8	43.2
Dryland	47.1	51.5	53	54.8	44.9	44.6	44.4

Bore M36/0217 Rolleston (GL 52.9m 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	35	40.7	43	44.5	30.3	29.8	29
Current	35.4	41.3	42.8	45	30.8	30.5	29.7
Climate change	34.8	40.6	42	44.2	30.4	30	29.3
CPW	36.6	42.4	43.8	45.7	32.2	31.9	31.1
Dryland	37.9	43.4	44.8	46.8	34	33.6	33

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
Historic	77.8	90	95.6	97.6	66.7	65.1	63.3
Current	79.1	91.1	96.1	97.9	68.3	66.8	64.9
Climate change	77	89.2	93.6	95.5	66.3	64.9	62.9
CPW	86.8	97.9	102.7	104.7	76.5	75.1	73.9
Dryland	88.3	99.6	104.1	105.8	78.4	76.6	71.1

Bore M36/0599 Lincoln (GL 14.7m 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	13	13.8	13.9	14.3	12.4	12.3	12.3
Current	13	13.8	13.9	14.3	12.5	12.4	12.3
Climate change	12.9	13.7	13.9	14.2	12.4	12.4	12.3
CPW	13.2	14	14.1	14.4	12.7	12.6	12.5
Dryland	13.2	14	14.1	14.4	12.8	12.8	12.7

Table 11: Groundwater bore modelling results - Part B.

Scenario	Average (m amsl)	High GW levels (m amsl)			Low GW levels (m amsl)		
Bore L36/0124 Bankside-Dunsandel (GL 112.3m 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	86.2	93.4	94.8	99.1	79.7	78.7	77.2
Current	86.7	93.4	94.8	99.7	80.4	79.6	78.9
Climate change	85.9	92.7	94	98.9	79.6	79	77.4
CPW	88.5	94.8	96.4	100.6	82.7	81.9	81.2
Dryland	90.7	95.9	97.4	101.8	86.4	86.3	85.2
Bore L36/1226 Te Pirita-Hororata (GL 198.3m 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	108.6	116.8	120.1	124.6	99.5	98.7	97.4
Current	109.5	117.8	120.1	124	101.1	100.2	99.2
Climate change	108.2	116.4	119.1	122.7	99.5	98.7	97.7
CPW	113.2	120.6	122.9	126.3	105.4	104.6	103.8
Dryland	116.6	123.6	124.7	128.7	110.9	110	109.6
Bore M36/0424 Doyleston (GL 21.4m 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	20.3	21.2	21.3	21.9	19.5	19.4	19.2
Current	20.3	21.2	21.3	22.1	19.5	19.5	19.3
Climate change	20.3	21.1	21.3	22	19.5	19.4	19.4
CPW	20.4	21.2	21.4	22.1	19.7	19.6	19.4
Dryland	20.6	21.2	21.3	22.2	20.2	20.2	20.1
Bore L35/0180 Darfield (north) (GL 255.2m 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	249.7	251.1	251.3	252.1	248.8	248.8	248.7
Current	249.8	251.1	251.3	252.1	248.9	248.8	248.7
Climate change	249.7	251.1	251.3	252.1	248.9	248.8	248.7
CPW	250	251.2	251.5	252.1	249.4	249.3	249.3
Dryland	250	251.2	251.4	252.1	249.3	249.3	249.2
Bore M35/1000 West Melton (GL 105.2m 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	65.2	81.1	85.2	92.6	53.1	51.2	49.7
Current	68.6	83.6	88.4	91.9	55.9	54.5	52.8
Climate change	66.3	81	85.8	88.9	53.9	52.3	50.6
CPW	73.7	88.6	93.2	96	61.5	60.3	59
Dryland	78.9	91.5	97.5	100.7	68	66	60.8

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The key conclusions for this section are:

- River flow data does not show any long term trend.

- Mean annual flows in the alpine rivers (e.g. Waimakariri and Rakaia) are projected to increase by 3% by the 2040's, as a result of increased alpine precipitation.

- Foothill river flows may slightly decrease over the next 30 years, due to a small increase in evapotranspiration.

Long term river flow series for the Rakaia River, Waimakariri River, Selwyn River and Doyleston Drain were analysed for historic trends. No long term trends were identified in the daily river flows and no trends were identified in the number of days with high flows[8]. Graphs of the daily data are shown in Figure 18 together with the 95th percentile line used to calculate the number of days with high flows each year. The flow data was also compared with time series of climate indices to determine if there were any relationships. Of the four sites, only the Rakaia shows a difference in the number of high flow days between IPO phases. For positive IPO years there was an average of 22.3 days a year with high flows, and IPO negative years averaged 15.8 days. This difference was large enough that there is less than a 5% chance that it could be observed by random chance. This finding supports the work of McKerchar and Henderson (2003) who investigated Rakaia and Waimakariri flows for changes between the IPO phases for the 1947 and 1999 period. They found 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) have been prepared for the Rakaia River (Collins et al. 2018). The mean flows are projected to increase by 3% mostly from a 14% increase in winter flows. The low flows are not projected to have any significant change, but the mean annual flood flow is projected to increase by 18%.

Other alpine rivers including the Rangitata and Waimakariri will likely also see a similar increases.

Climate change projections to 2036-2056 of stream flows in agricultural land across Canterbury have been prepared by Collins and Zammit (2016). They projected changes in the average flow, the low flows, the timing of when low flows occurred, flow reliability, and mean annual flood. 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 slightly decline over the next thirty years. This is a result of a small increase in evapotranspiration (Chapter 5). MfE (2016) states that that precipitation will remain relatively unchanged (Chapter 6). Overall we would expect any decrease to be small compared with the rivers' natural year to year variability.

Lowland drains, such as Doyleston Drain, are fed predominately from groundwater. Climate change will result in a minor reduction in groundwater levels (Chapter 10) which will impact on drain flows. The development of Central Plains Irrigation should more than offset any reduction in flows due to climate change.

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[8] High flows were taken as the 95th percentile flows. On average four days a year will have flows above the 95th percentile level.
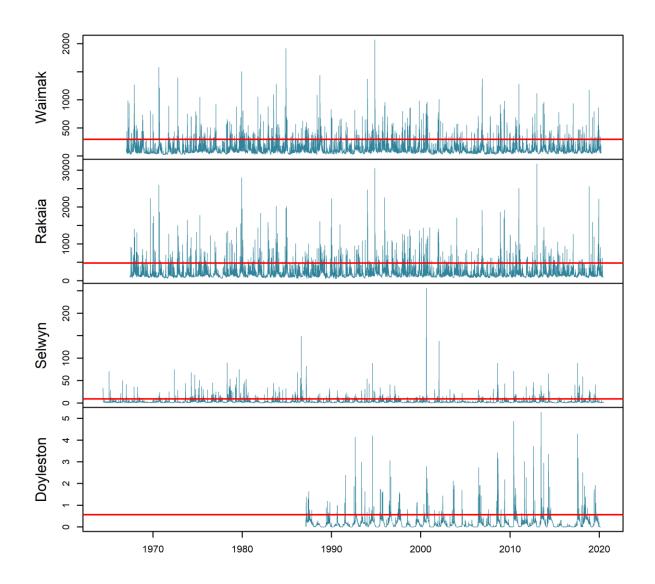
Figure 18. River flow time series. The red lines represent the 95th percentile for daily flows.

12   SEA LEVEL RISE

The key messages for this section are:

- Local sea levels have risen at a rate of 2.3 mm/y over the last 118 years.

- MfE recommend allowing for a sea level rise of between 0.17 and 0.28 m by 2050, relative to the period 1999-2019.

- If the historic trend continues the sea level will rise 0.09 m by 2050.

MfE (2017) projects an average future rate of sea level rise over the next 100 years of between one and three times the historic rate (Figure 19). This wide range of estimates is because of the uncertainty in sea level rise models. Because of the uncertainty, MfE

recommends a conservative approach by allowing for a 0.23 to 0.37 m rise by the 2050's relative to the period 1986-2005 (MfE, 2017, Table 10). This is an increase of 0.17 to 0.28 m relative to the period 1999-2019 (last 20yrs). If, however, sea level rise follows the historical trajectory, the rise in levels would be limited to 0.09 m by 2050, relative to the period 1999-2019.

Figure 19: Measured and projected change in mean annual sea level at Lyttelton: 1901-2050

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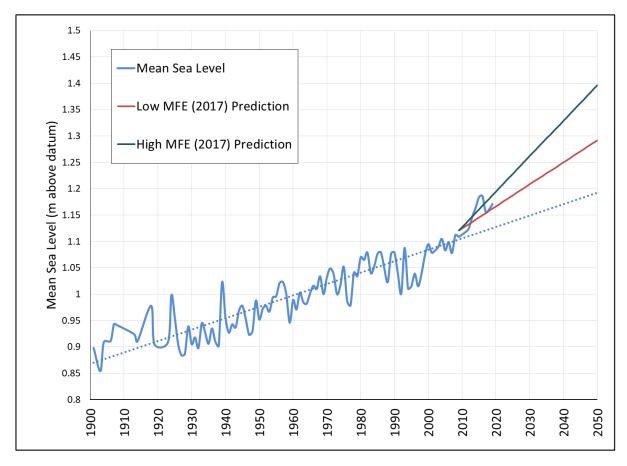The key conclusions for this section are:

- Te Waihora 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 will result in either the lake needing to be opened more frequently and/or an increase in lake levels. Without any change in lake management, lake levels would rise by 0.09 m to 0.28 m by 2050.

- 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.

- If an outlet weir is installed, lake levels could be maintained in a narrower range, which could alleviate some of the flooding problems that have occurred historically. This could more than offset a predicted rise in sea levels of up to 0.28 m by 2050.

13.1   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 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 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 20). This process may take a number of 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 the lake 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 20: Te Waihora Lake Opening Location

Over the last 26 years lake levels have been in the range of 0.4 to 1.2 m amsl 95 percent 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 21 and Figure 22. The area of inundation on 30 June 2013, when lake levels were at the highest recorded level of 1.81 m amsl, are illustrated in Figure 23.
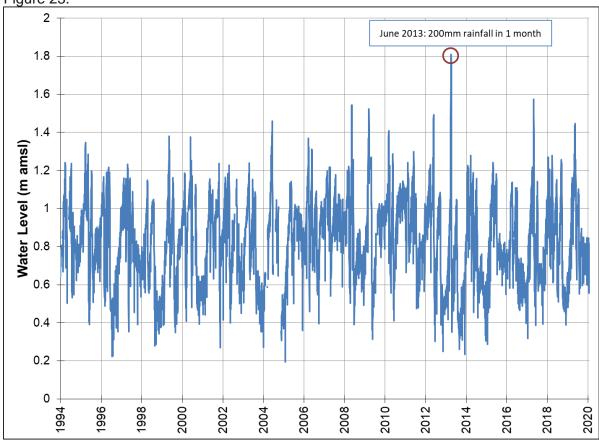
Figure 21: Te Waihora water levels 1994 to 2020

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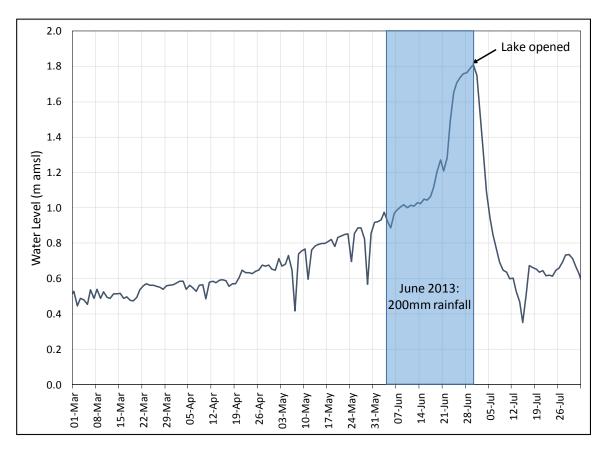© Aqualinc Research Ltd.

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Figure 22: Te Waihora water levels Mar-Jul 2013
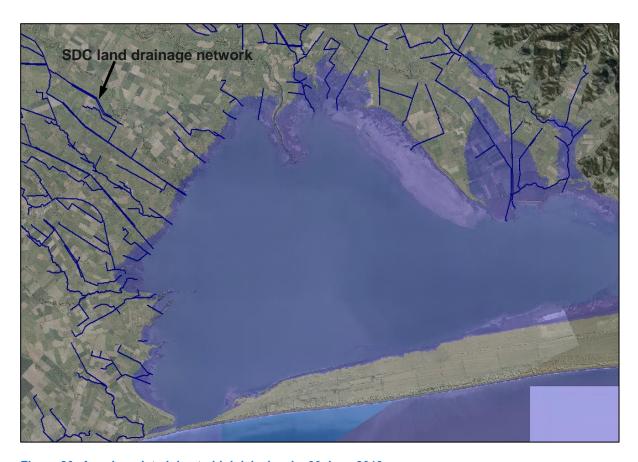
Figure 23: Area inundated due to high lake levels: 30 June 2013

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Higher sea levels will affect Te Waihora/Lake Ellesmere water levels. Sea level rise will result in either the lake needing to be opened more frequently and/or an increase in lake levels. Without any change in lake management lake levels would rise by 0.09 m to 0.28 m by 2050, with respect to the 1999-2019 levels.

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.

If however an outlet weir is installed, lake levels could be maintained in a narrower range, which could alleviate some of the flooding problems that have occurred historically. This potentially could more than offset a rise in sea levels of up to 0.28 m by 2050. An outlet weir has been under discussion.

13.2   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 24 illustrates 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. When lake levels are high irrigation cannot occur. This wastewater system is currently being upgraded so that waste water is treated then disposed of onto raised beds, which should make it less vulnerable to flooding in the future. Figure 25 and Figure 26 illustrate 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).

Inundation maps have not been updated since the 2016 climate change report for SDC (Brown *et al*, 2016), with the updated sea level rise maximum of 0.28 m amsl, as this was not included in the scope of the current project. Actual impacts may differ because of the wide range of sea level rise scenarios.

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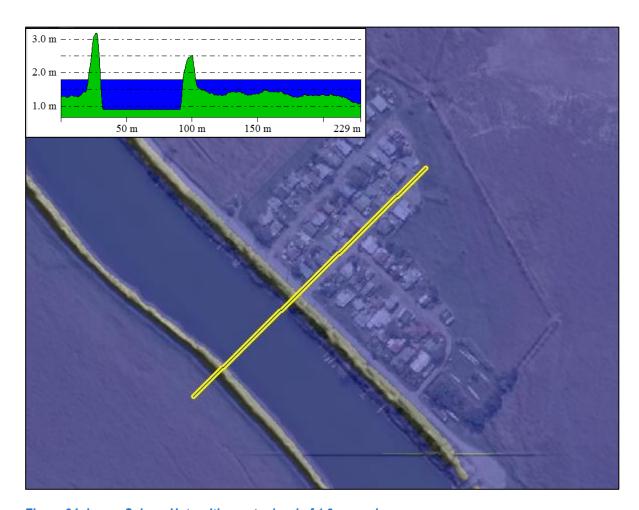© Aqualinc Research Ltd.

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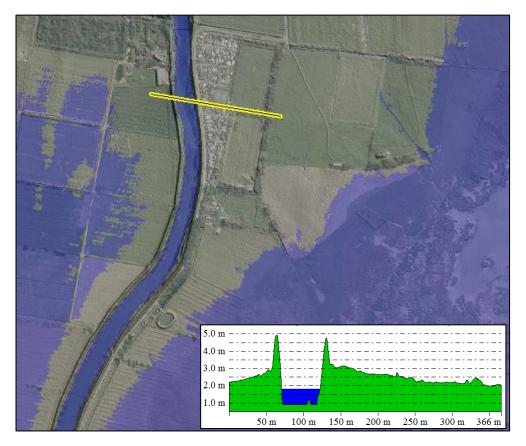*Figure 24: Lower Selwyn Huts with a water level of 1.8 m amsl*

Figure 25: Upper Selwyn Huts with a water level of 1.8 m amsl
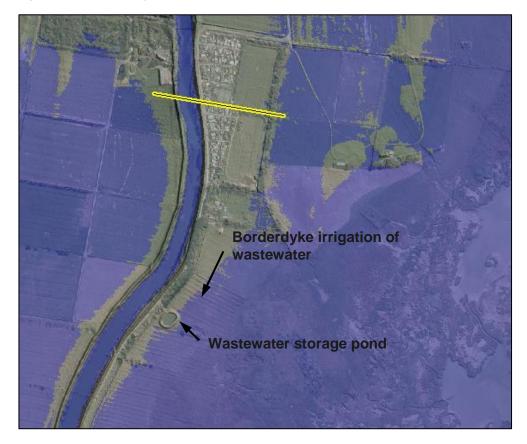

Figure 26: Upper Selwyn Huts with a water level of 2.03 m amsl

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13.3   Land drainage network

A rise in Te Waihora water levels would reduce the effectiveness 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 are where a rise in water levels at the end of a drain can propagate back up the drain, resulting in reduced flow and drainage capacity. For example Figure 27 illustrates that for the L2 drain, during a moderate flood, backwater effects can increase water levels in the drain, 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 can 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 28 and Figure 29 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 0.28 m amsl by 2050 (relative to a 1999-2019 baseline) would also show little difference in the affected areas. Actual sea level rise by 2050 and corresponding impacts may be significantly less than the inundation shown in Figure 28 and Figure 29.

Higher water levels in L2 during summer, further away from Te Waihora where backwater effects are not significant, are a result of weed growth.
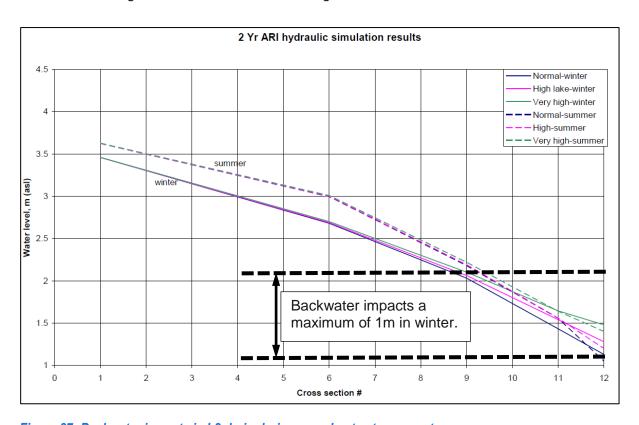
Figure 27: Backwater impacts in L2 drain during a moderate storm event.

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Figure 28: Maximum extent that lake levels affect land drainage (3.80 m amsl)

Figure 29: Maximum extent that lake levels affect drainage (4.03 m amsl)

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14   RAKAIA MOUTH

The key conclusions for this section are:

- Sea level rise could indirectly increase flooding frequency at Rakaia Huts; and

- Because flooding at the Huts is primarily the result of the Rakaia River Mouth dynamics we expect the sea level rise impacts by 2050 will be minor compared with coastal and river process impacts.

The lowest point at Rakaia Huts is about 3.5 m amsl. The huts are protected from the sea by a sand bar, and are not at risk of flooding directly as a result of sea level rise. The huts do, however, flood from time to time, when the Rakaia Mouth is closed.   The balance between deposition and erosion at the river mouth and coast is highly dynamic, both as a result of river floods and coastal erosion and deposition.

A rise in sea level of between 0.09 m to 0.28 m might result in a small increase in the frequency and magnitude of flooding at Rakaia Huts. Any flooding increase would be less than the rise in sea level, since sea levels are only one of the factors that affect water levels at the river mouth. The single biggest factor that affects flooding is whether or not the river mouth is open. Figure 30 and Figure 31 illustrate the difference a 0.23 m sea level rise could have on flooding. Actual impacts may be slightly larger or much smaller than this.

The *difference* due to sea level rise (illustrated by showing how a 4.00 m amsl flood could increase to 4.23 m amsl) is not the same as the worst case flooding scenario. A worst case flood may be more than a 4.00 m amsl water level. Quantifying current flood frequency and magnitude is a separate issue not directly related to sea level rise.

Overall, we think it is likely that that sea level rise risk will have only a relatively minor impact on the flooding frequency at Rakai Huts. The geological dynamics of coastal and river processes are likely to be more significant factors. More detailed analysis, including modelling of coastal and river processes would be necessary if a refined estimate of the change in the flooding risk at Rakaia Huts is required. This is beyond the scope of this study.
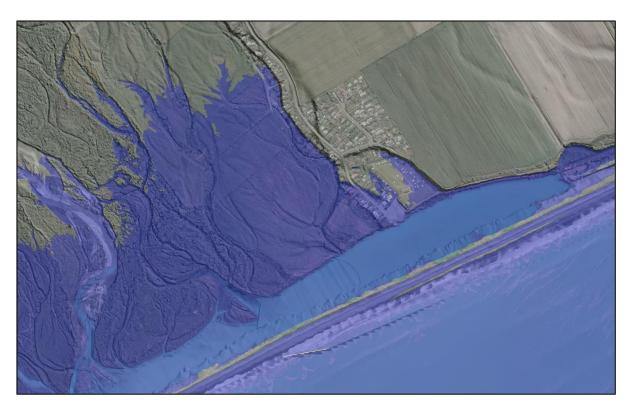
Figure 30: Rakaia Huts with a water level of 4.00 m amsl
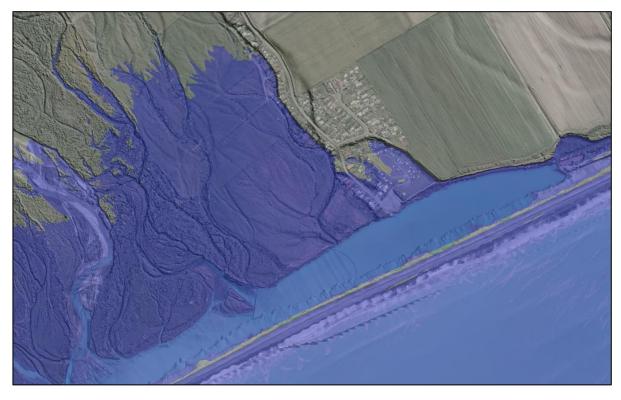

Figure 31: Rakaia Huts with a water level of 4.23 m amsl

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15   GROUNDWATER AND SEA LEVEL RISE

The key conclusions for this section are:

- Sea level rise could have a minor impact on groundwater levels at the coast; and

- Impacts quickly diminish and are very small beyond about 1 km inland.

The effects on groundwater levels as a result of sea level rise are expected to be greatest at the ocean boundary. The change in groundwater levels at this interface would be equal to, or less than, the sea level rise. Hence, for a projected rise in average sea level of 0.09-0.28 m, groundwater levels would be expected to rise no more than this amount at the coast. At increasing distances inland from the coast, the rise reduces until, at sufficient distance from the coast, there is no noticeable effect on groundwater levels from a sea level rise.

Specific modelling of groundwater level rise as a result of sea level rise has not been conducted for this study. However, various lines of evidence can be used to estimate the possible impact. A simulation was completed by Aqualinc for the Motueka-Riwaka coastal plains area where a sea level rise of 1 m was applied to the costal boundary of the groundwater model. A 0.2 m groundwater level rise from this 1 m coastal sea level rise (i.e. 20% of the total rise) was predicted to occur approximately 3 km inland. Like Canterbury, the Motueka-Riwaka Plains aquifer system is highly transmissive and has a similar hydraulic gradient. Consequently, we expect a similar scale of effect, proportional to the projected sea level rise. That is, an effect of no more than ~0.06 m (20% of 0.28 m maximum rise) might propagate approximately 0.8[9] km inland from the coastal boundary.

Aqualinc have conducted numerous aquifer tests in the Canterbury region where we have measured tidal responses in groundwater levels (those located relatively close to the coast). From these tests, groundwater levels in deep wells have varied by up to 0.25 m at a distance of less than 1 km from the coast as a result of tidal amplitude changes of 1.4-3.8 m. The tidal response in groundwater levels reduces at increasing distance from the coast, and no measurable tidal effect has been observed in tests conducted more than approximately 5 km from the coast. Comparing these observations to the projected sea level rise of 0.09-0.28 m, then the additional effects of sea level rise would be expected to propagate no further than approximately 0.5-1.0 km from the coast, which is similar to the conclusions from the Motueka-Riwaka modelling work.

In addition, Aqualinc has participated in research to investigate the effects on shallow groundwater from tidal changes in water levels in the Avon River. As part of this research, the propagation of increased groundwater level associated with the Avon River was monitored via a series of groundwater sensors located in a line perpendicular to the river direction. This work concluded that tidal variations in the river stage propagated through the groundwater system no more than approximately 1 km inland from the river's edge. While it was not possible to assess how far a longer-term change would propagate, it was considered that a permanent shift would propagate further than the tidal response observed.

The above assessment assumes that the location of the coast remains where it currently is (i.e. there is a simple vertical shift in the level). However, should the coast move inland as a result of the rise in sea level, then the rise in groundwater levels would also propagate further inland (by the same amount of horizontal shift). The scale of effects discussed above are substantially less than natural variations in groundwater levels, particularly for deeper wells where groundwater levels typically vary more than shallower wells.

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[9] The length that sea level rise impacts propagate inland is proportion to the ratio of the sea level rise **and** the groundwater gradient. Since the groundwater gradient is largely fixed, the distance impacts propagate inland is proportional to the sea level rise. 3km×0.28/1.0 = 840m.

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Any sea level rise or coastal horizontal shift in the boundary will result in the saltwater-freshwater interface moving landward. Therefore, suitable caution should be placed on groundwater takes located nearer the coast to mitigate the increased salt water intrusion risk (particularly shallow wells).

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The key conclusions for this section are:

- Climate change will likely have only a minor impact on most aspects of SDC potable assets over the next 30 years;

- Higher evapotranspiration may mean 1-2% higher water demands; and

- Higher alpine rainfall and extreme rainfall may have some impact on Arthurs Pass, Castle Hill and Lake Coleridge water supply intakes.

SDC manages 29 potable water supplies. These supplies service 75% of the residential properties within the district. A map of the schemes is shown in Figure 32 and Figure 33. Projected climate change impacts are summarized in Table 12. The table includes an estimate of how large the projected climate change effect is, relative to the historic range. For example, the projected drop in ground water levels in the upper plains is about 7% of the historic range due to normal climate variability.
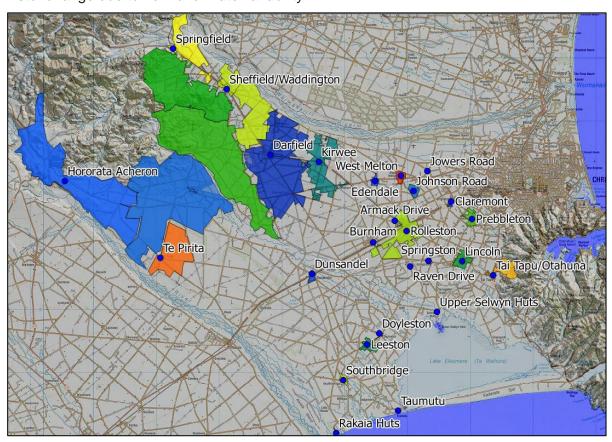

Figure 32: SDC potable water supply schemes – Canterbury Plains
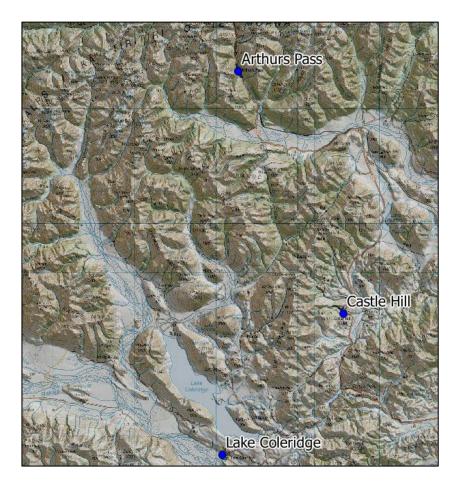
Figure 33: SDC potable water supply schemes – Alpine

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Table 12: Impact of climate change on SDC potable water supplies

Environmental factor	Asset vulnerability	Issues	Projected climate change	Asset impact[1]	Climate change /Historic range
Ground water levels (upper plains)	High	Low GW levels. Supply reliability.	Minor	Minor	1% lower[2]
Ground water levels (lower plains)	Low	Low GW levels. Supply reliability.	Minor	Minor	7% higher[3]
Annual rainfall Canterbury Plains	Moderate	Peak summer water demand.	Minor	Minor	Small[4]
Extreme rainfall events (Plains)	Moderate	Water quality.	4-12% increase	Minor	2-7% higher[5]
Extreme rainfall events (foothills and alpine)	High	Intake damage and water quality	4-12% increase	Minor	Small[6]
Alpine river flows	Moderate	Low flows. Supply reliability.	3% increase	Minor positive	5% higher[7]
Foothill and lowland river flows	Moderate	Low flows. Supply reliability.	Low	Low negative	Small[8]
Evapotranspiration (ET)	High	Summer water demand.	6% increase	Low negative	10% higher[9]
Sea level rise	Minor		0.09-0.28m increase	Minor	+50 to 150%[10]
Snow and ice (excl. alpine river flows impacts)	Minor	Asset access in winter.	Minor	Minor	20% less[11] (Castle Hill snow)
Temperature (excl. ET impacts)	Minor		1.1°C increase	Minor	56% higher[12]
Wind (excluding ET impacts)	Moderate	Wind damage to assets in a storm.	Low	Low negative	Small

(1) Asset impact is the lesser of the asset vulnerability and the predicted climate change.
(2) Based on L36/0092 (Charing Cross). (63.3-62.9) / (97.6 – 63.3)= 1%. Refer Tabe 10.
(3) Based on M36/0424 (Doyleston). (19.2-19.4) / (21.9 – 19.2)= -7%. Refer Table 11.
(4) No change in annual rainfall on the Canterbury plains is discernable in historic data, and no change is expected by 2050 in response to climate change (refer Chapter 6).
(5) No change in extreme rainfall events is discernible in historical data, in response to climate change. 4-12% increase based on the NIWA High Intensity Rainfall Design System, but recommend site specific analysis where these projections will have a significant impact on investment. Climate change ÷ range in maximum 5 day rainfall average at Canterbury Plains rainfall stations from 1890-2020 (refer Figure 13)= 4-12% x 82/ (165-31) = 2-7%
(6) No change in extreme rainfall events is discernible in historical data, in response to climate change. 4-12% increase based on the NIWA High Intensity Rainfall Design System, but recommend site specific analysis where these projections will have a significant impact on investment.
(7) Climate change ÷ range in mean annual flow for Rakaia at Fighting Hill from 1967 to 2020 = 3%×207/(282-129)=5%
(8) Climate change projection is small decrease in flow as a result of higher PET vs high natural annual variability.
(9) For Lincoln site 4881, mean annual PET for 1960-2020 has ranged from 429 to 956mm with an average of 848mm (refer Figure 7). 6%x848/(956-429)=9.7%
(10) Average annual range over last 30 years at Lyttleton Port is 0.19m (refer Figure 19). (0.09 to 0.28)/(0.19)=0.47 to 1.47.
(11) This is an estimate based on a 36 year simulation for the Opuha Catchment, which we consider to be an analogy for the Selwyn District Castle Hill and Lake Coleridge regions.
(12) 1.1°C÷average annual temperature range over the last 30 years = 1.1/(13.4-11.48)=56% (refer Figure 6).

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Climate change will probably have only a minor impact on most aspects of SDC potable assets over the next 30 years. This is because on the Canterbury Plains where SDC have most of their assets, climate change is projected to only have a minor impact on environmental factors that affect asset vulnerability.

The main environmental factor that is projected to change on the plains is the evapotranspiration rate. A significant portion of the water used in summer is for residential gardens. The increase in evapotranspiration rates of 6%, as described in Chapter 5, has the potential to increase this summer peak. While evapotranspiration will likely increase, we do not expect rainfall to change. The net impact of PET increasing, but no change in rainfall, will probably be a 1 to 2% increase in the water demand. This impact may mean that residents are subject to slightly longer and more frequent periods of water restrictions.

In alpine areas, climate change is projected to have a more significant impact. The main projected change that impacts on SDC assets is the increase in mean annual rainfall and flood flows. Higher alpine rainfall and flood flows may have some impact on Arthurs Pass, Castle Hill and Lake Coleridge water supplies. The exact impact will depend on the individual vulnerability of the sources to floods.

MFE (2016) predict a 5% increase in wind speed on 'windy days' (Chapter 8). This may result in a very small increase in the frequency of wind damage during storms.

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 20 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 inland from the coast. We expect a sea level rise of 0.28 m should result in only a minor increased risk of saltwater intrusion.

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 artesian (i.e. flows without pumping). Saltwater intrusion should 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 should pose minimal risk to this bore due to its depth and artesian pressure.

The key conclusions for this section are:

- Climate change will probably have only a minor impact on most aspects of SDC wastewater assets over the next 30 years;

- Higher alpine rainfall and flood flows may result in an increase in stormwater inflows for the Arthurs Pass, Castle Hill and Lake Coleridge wastewater systems; and

- An increase in sea level rise of up to 0.28 m may have an impact on Upper Selwyn Huts, Rakaia Huts and Lakeside wastewater systems.

- At Leeston, the wastewater treatment plant groundwater levels have exceeded the 900 mm below land surface threshold approximately once each year, altering the normal discharge to land procedure. On the basis of this work, it appears that the predicted minor changes in groundwater levels over the next 30 years should not significantly increase exceedances to this threshold, though it is recommended that more detailed, site specific, modelling is carried out to ensure that this conclusion is correct.

SDC manages 16 reticulated wastewater systems that service 55% of properties within the district. A map of the schemes is shown in Figure 34 and Figure 35. Predicted climate change impacts are summarised in Table 13.
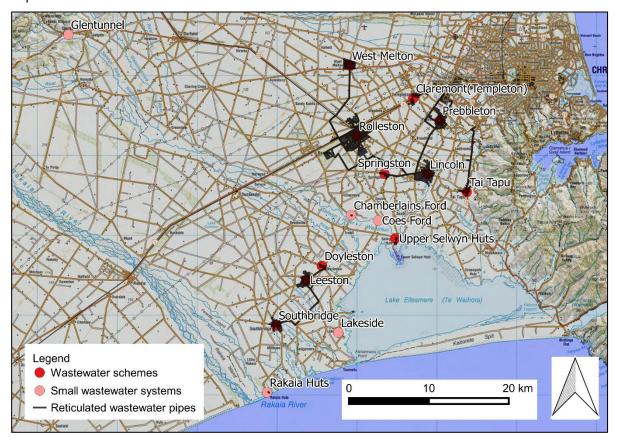

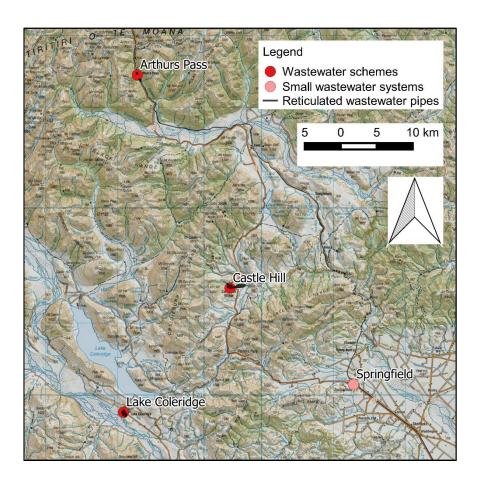*Figure 34: SDC wastewater schemes – Canterbury Plains*

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Figure 35: SDC wastewater schemes – Alpine and foothill

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Table 13: Impact of climate change on SDC wastewater systems

Environmental factor	Asset vulnerability	Issues	Projected climate change	Asset impact	Climate change /Historic range[1]
Ground water levels (upper plains)	Minor		Minor	Minor	1% lower
Ground water levels (lower plains)	High	GW infiltration into sewer system	Minor	Minor	7% higher
Annual rainfall	Minor		Minor	Minor	Small
Extreme rainfall events (Plains)	High	Inflow and infiltration	4-12% increase	Minor	2-7% higher
Extreme rainfall events (foothills and alpine)	High	Inflow	4-12% increase	Minor	Small
Alpine river flows	Minor		3% increase	Minor	5% higher
Foothill and lowland river flows	Minor		Minor	Minor	Small
Evapotranspiration (ET)	Minor		6% increase	Minor	10% higher
Sea level rise <0.23 m	Low	Upper Selwyn Huts	0.09-0.28 m increase	Low negative	+50% to 150%
Snow and ice (excl. alpine river flows impacts)	Minor		Minor	Minor	20% less (Castle Hill snow)
Temperature (excl. ET impacts)	Minor		1.1 °C increase	Minor	56% higher
Wind (excluding ET impacts)	Moderate	Wind damage to assets in a storm	Low	Low negative	Small
(1) Refer Table 12 for details.					

Climate change will probably have only a minor impact on most aspects of SDC wastewater assets over the next 30 years. This is because on the Canterbury Plains where SDC have most of their assets, climate change is projected to only have a minor impact on environmental factors that affect asset vulnerability.

The main environmental factor that is projected to change on the plains is sea level rise. This has the potential to impact on the Upper Selwyn Huts borderdyke wastewater disposal system (Chapter 13) and to a lesser extent the risk of flooding at Rakaia Huts (Chapter 14). Sea level rise also has the potential to impact on the Lakeside wastewater system; we are not familiar with the details of the Lakeside system and have not assessed the impacts.

In alpine areas, climate change is projected to have a more significant impact. The main projected change that impacts on SDC assets is the increase in both mean annual rainfall and flood flows which may have some impact on Arthurs Pass, Castle Hill, Lake Coleridge and Springfield wastewater systems. The exact impact will depend on the individual vulnerability of these assets to floods and high rainfall events.

MFE (2016) predict a 5% increase in wind speed on 'windy days' (Chapter 8). This may result in a very small increase in the frequency of wind damage during storms.

The Leeston waste water treatment plant (WWTP) has a current consent (expires July 2029) for treated wastewater to be discharged if the groundwater level in the monitoring bore on Beethams Rd (M36/4083), is higher than 900 mm below the land surface. During these periods wastewater is discharged into specialised infiltration basins. While using the infiltration basins for discharge, groundwater is pumped from below the basins to ensure

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groundwater level stays below 900 mm in four monitoring bores surrounding the infiltration basins. Six groundwater pumps below the basins are used to extract the groundwater which is then discharged as surface water into Tramway Reserve drain that drains into Te Waihora.

Figure 36 shows that between April 2017 and April 2020, there were only two occasions where groundwater level in the WWTP monitoring bore M36/4083 was higher than 900 mm bgl, in July and August 2017. Groundwater levels were close to the 900 mm threshold (between 1000 and 900 mm), in the winter of 2018 and 2019, for several days.

To understand local ground water levels over a longer time frame than the last 3 years, data from the WWTP monitoring bore was compared to a Doyleston bore (M36/0424), which has several decades of data and is 2.3 km from the WWTP monitoring bore. Our analysis shows the Doyleston bore data minus 500 mm approximates the WWTP monitoring bore reasonably well over the last 3 years (Figure 37), so can be used as a surrogate to approximate groundwater levels over the last several decades. Based on the "surrogate Doyleston bore – 500 mm" data set, there are likely to be exceedances of the 900 mm threshold, roughly every year, with each having a duration of approximately 4 or 5 days/year, but up to a maximum of 12 days/year (based on the last 20 years (Figure 31)). Regional groundwater levels in 2015/16 were unusually low, so this period should not be considered representative of normal groundwater levels in the SDC monitoring bore.

Although the "Doyleston – 500 mm surrogate" does look to be a reasonable representative for the WWTP bore, it may under-represent high groundwater levels, at least for the 2017 high ground water level period. For this reason, it should be used with caution as it may under-represent earlier high ground water levels as well. On the basis of the available data, Leeston WWTP would be expected to not be able to discharge to land because of high groundwater, approximately once a year, for short durations.

Since the Leeston WWTP is 4 km from the lake and 15.9 m amsl, lake management will likely have more impact in the medium term, than sea level rise, on ground water levels. Even so, the sea level rise expected in the next 30 years would likely only impact ground water levels up to 1 km inland (Chapter 15), and it is reasonable to assume that changing lake levels would have a similar effect.

The effects of CPW have been incorporated within the eigen modelling, which suggests that they are minimal. Backwater effects from the lake were also assessed as they may influence drainage of pumped surface water to Te Waihora. In this case, this influence is expected to be minor because even in large storm events, reduced land drainage would be expected to occur at up to approximately 3.8 m amsl (Chapter 13). The Leeston WWTP is 15.9 m amsl, so even in extreme events the Tramway drain is unlikely to be affected to the extent that it poses an issue to the WWTP. We have not considered the discharge flow rate into Tramway drain, and the effects this may have.

In summary, based on this data, groundwater levels are expected to exceed the 900 mm below land surface threshold, approximately once each year, restricting discharge to land for a short duration of a few days at a time. Groundwater levels are expected to decrease slightly as a result of climate change, however a minor increase is expected from CPW effects, resulting in relatively stable ground water levels over the next 30 years. However, it should be noted that the eigen modelling is a relatively simple approach, with attendant uncertainties and limitations. If the future of operations at the WWTP are to be assessed with more confidence, we would recommend further, more specific modelling of the site, including the impacts of CPW.
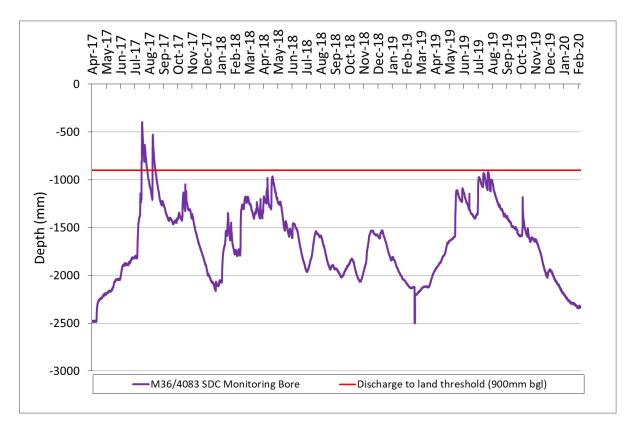
Figure 36: Ground water level of monitoring bore M36/4083 at Leeston waste water treatment plant
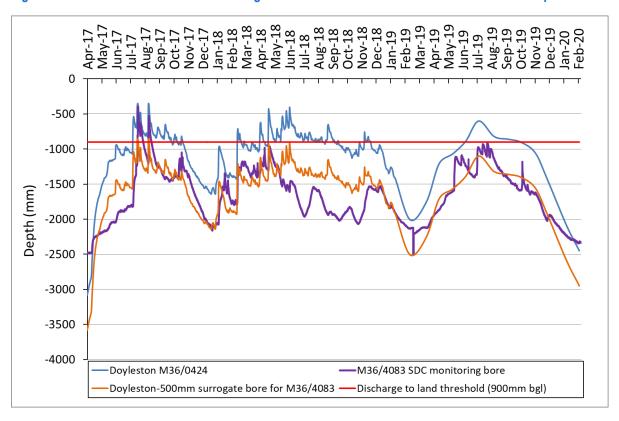

Figure 37: Ground water level over the last 3 years from the Doyleston bore M36/0424, the SDC monitoring bore M36/4083, and an adjusted data set that approximates water levels in the M36/4083.

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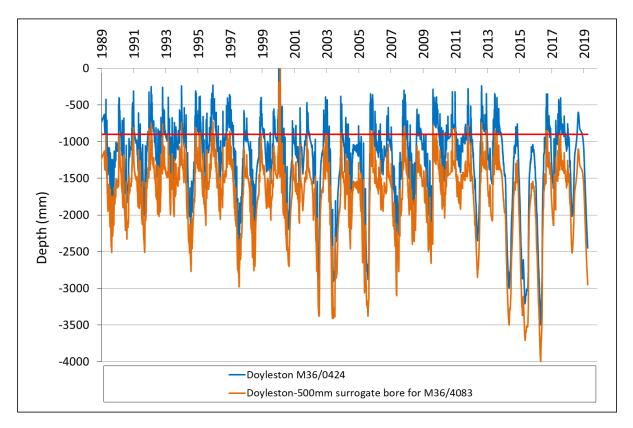
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Figure 38: Ground water level data since 1989 for the Doyleston bore M36/0424, and the altered dataset 'Doyleston-500mm', which approximates water level in the SDC monitoring bore.

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The key conclusions for this section are:

- Climate change will probably have only a minor impact on most aspects of SDC stormwater assets over the next 30 years.

- 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 up to 0.28 m might have a very small impact on stormwater drainage systems at Rakaia Huts.

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 39 and Figure 40. Projected climate change impacts are summarised in Table 14.
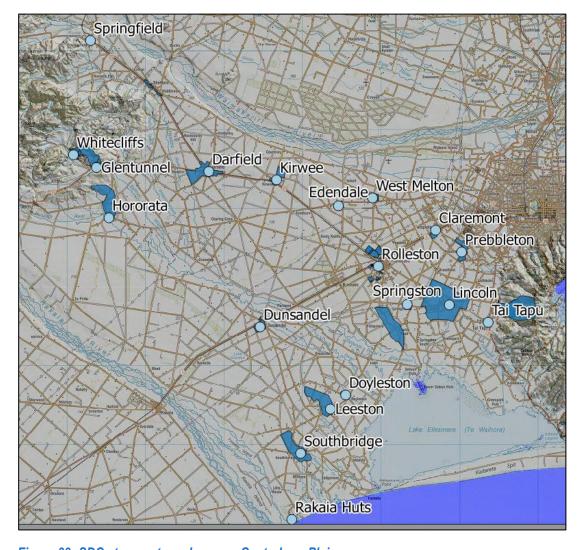

Figure 39: SDC stormwater schemes – Canterbury Plains

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Figure 40: SDC stormwater schemes – Alpine

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Table 14: Impact of climate change on SDC stormwater systems

Environmental factor	Asset vulnerability	Issues	Projected climate change	Asset impact	Climate change /Historic range[1]
Ground water levels (upper plains)	Minor		Minor	Minor	1% lower
Ground water levels (lower plains)	High	Flooding / drainage issues	Minor	Minor	7% higher
Annual rainfall	Minor		Minor	Minor	Small
Extreme rainfall events (Plains)	High	Surface flooding	4-12% increase	Minor	2-7% higher
Extreme rainfall events (foothills and alpine)	High	Surface flooding	4-12% increase	Moderate	Small
Alpine river flows	Minor		3% increase	Minor	5% higher
Foothill and lowland river flows	Minor		Minor	Minor	Small
Evapotranspiration (ET)	Minor		6% increase	Minor	10% higher
Sea Level rise <0.23 m	Low	Rakaia Huts	0.09-0.28 m increase	Low	+50% to 150%
Snow and ice (excl. alpine river flows impacts)	Minor		Minor	Minor	20% less (Castle Hill snow)
Temperature (excl. ET impacts)	Minor		1.1°C increase	Minor	56% higher
Wind (excluding ET impacts)	Minor	Wind damage to assets in a storm	Minor	Minor	Small
(1) Refer Table 12 for details.					

Climate change will probably have only a minor impact on most aspects of SDC stormwater assets over the next 30 years. This is because on the Canterbury Plains, where SDC have most of their assets, climate change is projected to only have a minor impact on environmental factors that affect asset vulnerability.

In alpine areas, where climate change is projected to have a more significant impact, the main projected change is the increase in both mean annual rainfall and flood flows. Higher alpine rainfall and flood flows may have some impact on Arthurs Pass, Castle Hill, Lake Coleridge and Springfield stormwater systems. The exact impact will depend on the individual vulnerability of these assets to floods and high rainfall events.

An increase in sea level rise of to 0.28 m might have a very small impact on stormwater drainage systems at Rakaia Huts.

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The key conclusions for this section are:

- An increase in sea level rise of up to 0.28 m may impact on Te Waihora /Lake Ellesmere levels and parts of the land drainage network.

- An increase in flood flows may impact on Arthurs Pass river protection systems.

- Other aspects of climate change will probably have only a minor impact on land drainage systems over the next 30 years.

SDC manages 11 drainage schemes covering 20,800 ha within the Selwyn District. Nine 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 Arthurs Pass drainage scheme's primary purpose is flood protection from the Bealey River, while the Hororata River drainage scheme's primary purpose is erosion protection management for a section of the Hororata River. A map of the management areas is shown in Figure 41 and Figure 42. Projected climate change impacts are summarised in Table 15.
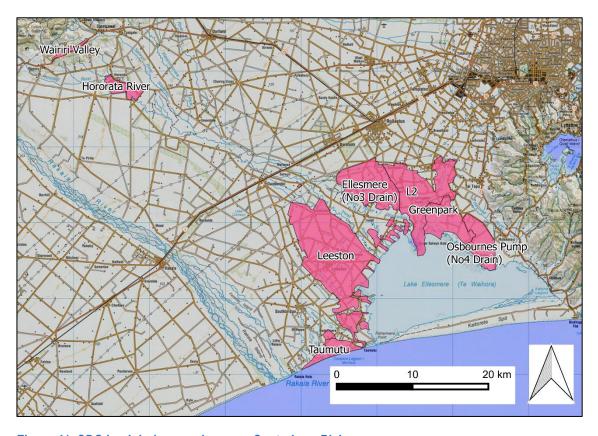
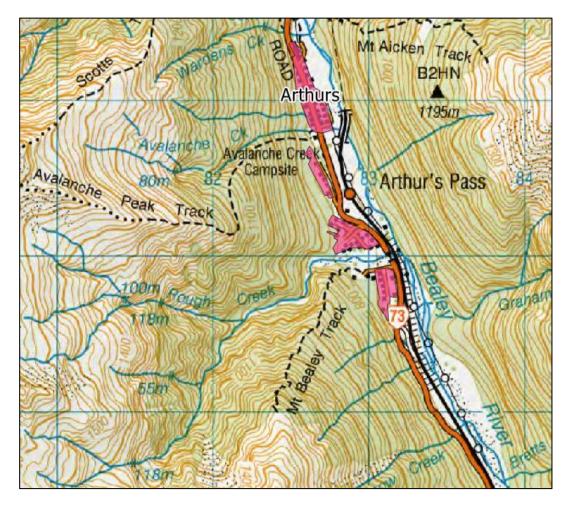*Figure 41: SDC land drainage schemes – Canterbury Plains*

Figure 42: SDC land drainage schemes – Alpine

Table 15: Impact of climate change on SDC land drainage systems

Environmental factor	Asset vulnerability	Issues	Projected climate change	Asset impact	Climate change /Historic range[1]
Ground water levels (upper plains)	Minor		Minor	Minor	1% lower
Ground water levels (lower plains)	High	Groundwater drainage	Minor	Minor	7% higher
Annual rainfall	Minor		Minor	Minor	Small
Extreme rainfall events (Plains)	High	Surface flooding	4-12 % increase	Minor	2-7% increase
Extreme rainfall events (foothills and alpine)	High	Bealey River flooding	4-12 % increase	Minor	Small
Alpine river flows	Minor		3% increase	Minor	5% higher
Foothill and lowland river flows	Minor		Minor	Minor	Small
Evapotranspiration (ET)	Minor		6% increase	Minor	10% higher
Sea Level rise <0.23 m	High	Drain backwater impacts	0.09-0.28 m increase	Moderate to high	+50% to 150%
Snow and ice (excl. alpine river flows impacts)	Minor		Minor	Minor	20% less (Castle Hill snow)
Temperature (excl. ET impacts)	Minor		1.1°C increase	Minor	56% higher
Wind (excluding ET impacts)	Minor		Minor	Minor	Small

(1) Refer Table 12 for details.

An increase in sea level rise of 0.09 to 0.28 m may impact on Te Waihora levels and parts of the land drainage network. The exact impacts will depend on how the Te Waihora mouth is managed in the future. If Te Waihora lake levels do rise, the impact on the drains can extend up to 1 m above the lake level because of backwater effects. This is discussed in Chapter 13.

Climate change will probably have only a minor impact on most other aspects of SDC and drainage assets over the next 30 years. This is because on the Canterbury Plains where SDC have most of their assets, climate change is projected to only have a minor impact on environmental factors that affect asset vulnerability.

In alpine areas, climate change is projected to have a more significant impact. The main projected change that impacts on SDC assets is the increase in both mean annual rainfall and flood flows. Higher alpine rainfall and flood flows may have some impact on Arthurs Pass river protection system. Hororata erosion protection works may be affected to a lesser extent.

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The key conclusions for this section are:

- Climate change will probably have only a minor impact on most aspects of SDC water race system.

- An increase in alpine flood flows could result in a small 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 might have a small impact on 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 43. Projected climate change impacts are summarised in Table 16.
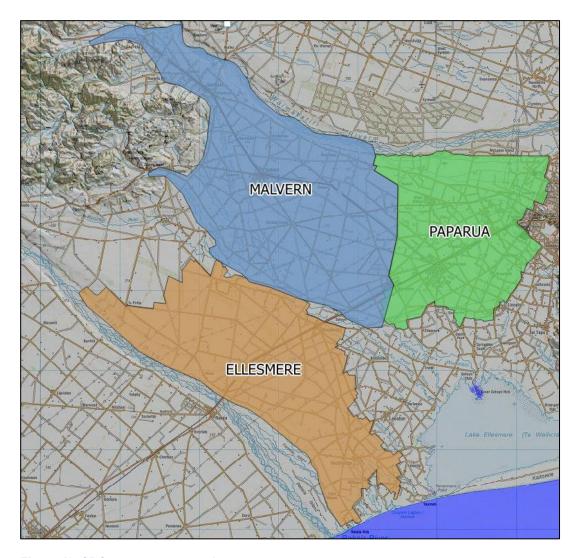
Figure 43: SDC water race networks

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Table 16: Impact of climate change on SDC water race network

Environmental factor	Asset vulnerability	Issues	Projected climate change	Asset impact	Climate change /Historic range[1]
Ground water levels (upper plains)	Minor		Minor	Minor	1% lower
Ground water levels (lower plains)	Low	Groundwater drainage	Minor	Minor	7% higher
Annual rainfall	Moderate		Minor	Minor	Small
Extreme rainfall events (Plains)	Moderate	Excess flow in races	4-12% increase	Minor	2-7% higher
Extreme rainfall events (foothills and alpine)	Moderate	Intake damage from floods	4-12% increase	Low	Small
Alpine river flows	High	Supply reliability	3% increase	Minor positive	5% higher
Foothill and lowland river flows	High	Supply reliability	Low	Low	Small
Evapotranspiration (ET)	Minor		6% increase	Minor	10% higher
Sea Level rise <0.23 m	Minor		0.09-0.28 m increase	Minor	+50% to 150%
Snow and ice (excl. alpine river flows impacts)	Low positive		Minor	Minor	20% less (Castle Hill snow)
Temperature (excl. ET impacts)	Minor		1.1°C increase	Minor	56% higher
Wind (excluding ET impacts)	Minor		Minor	Minor	Minor
(1) Refer Table 12 for details.					

Climate change will probably have only a minor impact on most aspects of SDC water race assets over the next 30 years. Two potentially minor impacts are an increase in alpine flood flows which could result in a small increase in flood damage to alpine river intakes, and a potential minor reduction in flows in the Kowai River which might have a small impact on supply reliability. A potential positive impact is higher alpine flows would improve the reliability of supply.

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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)[10]. More recently, the model has been tested by Aqualinc (2013)[11].

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.

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[10] AEI (1991): A model for assessing the impact of Regional Water Plans on irrigated agriculture. AEI Science Report, 1991; Agricultural Engineering Institute.

[11] 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.

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.

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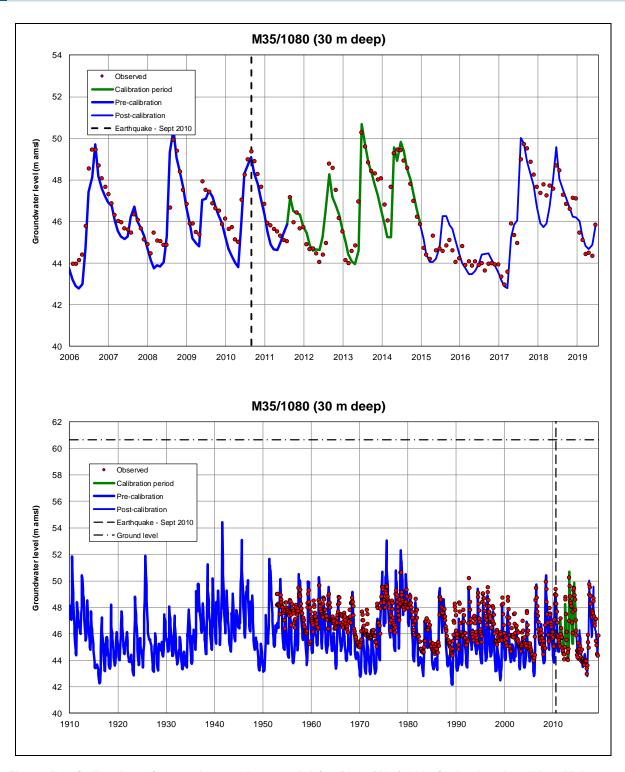
Figure B1: Calibration of groundwater eigen model for Bore M35/1080. Christchurch – West Melton. Representative of shallow groundwater supplies. GL 60.7m amsl.
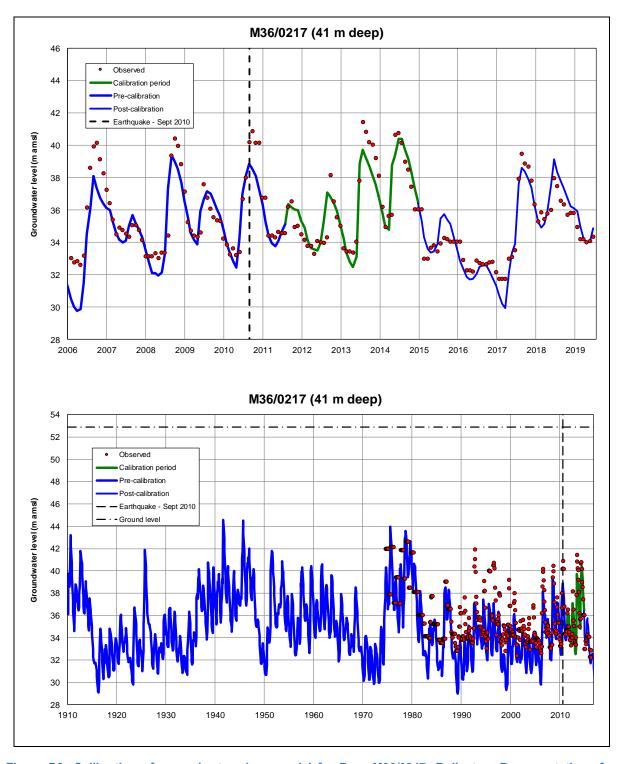
Figure B2: Calibration of groundwater eigen model for Bore M36/0217. Rolleston. Representative of shallow groundwater supplies. GL 52.9 m amsl.
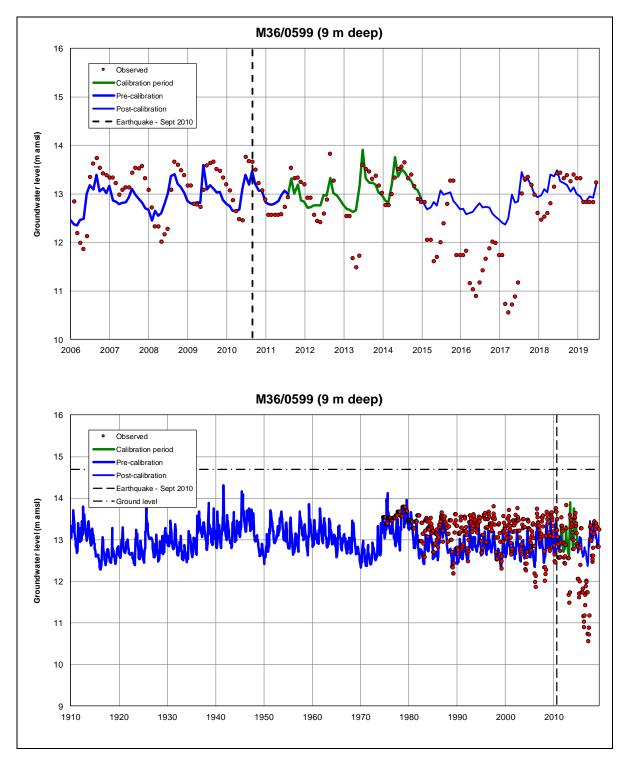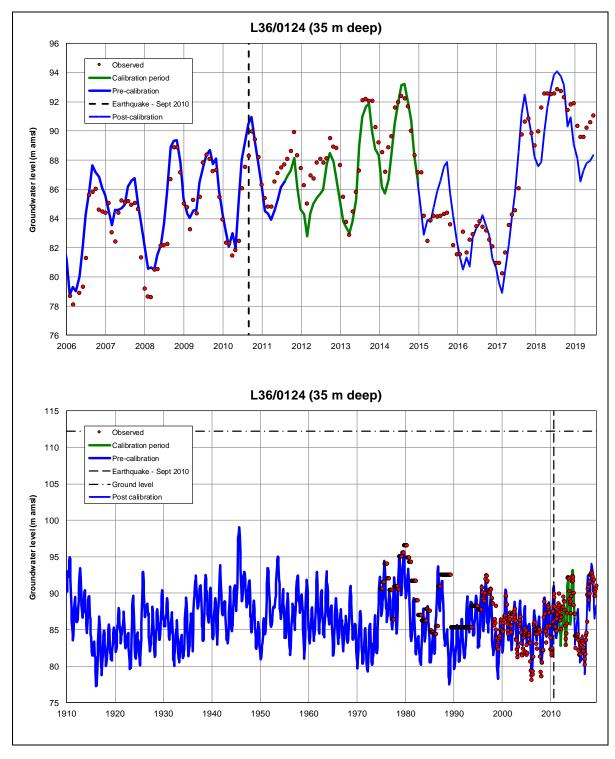
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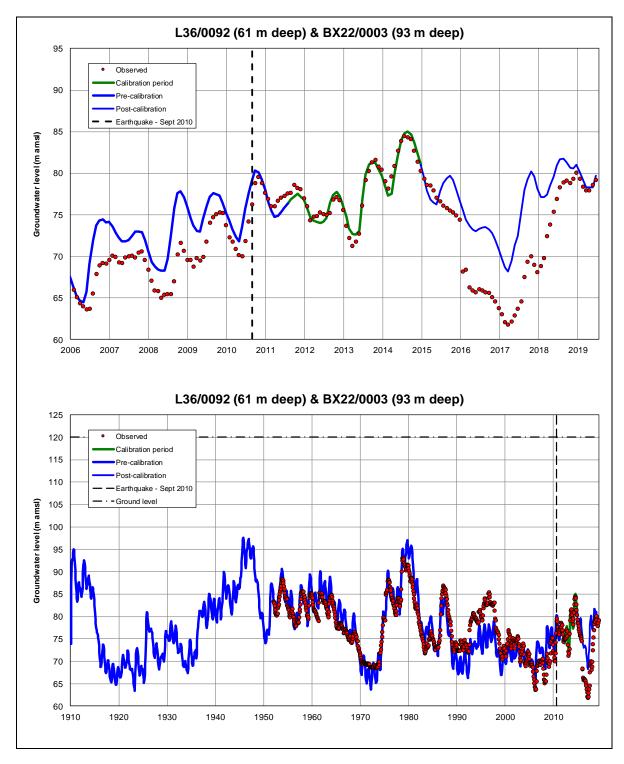
Figure B3: Calibration of groundwater eigen model for Bore L36/0092. Charing Cross. Representative of deep groundwater supplies. GL 120.1 m amsl.
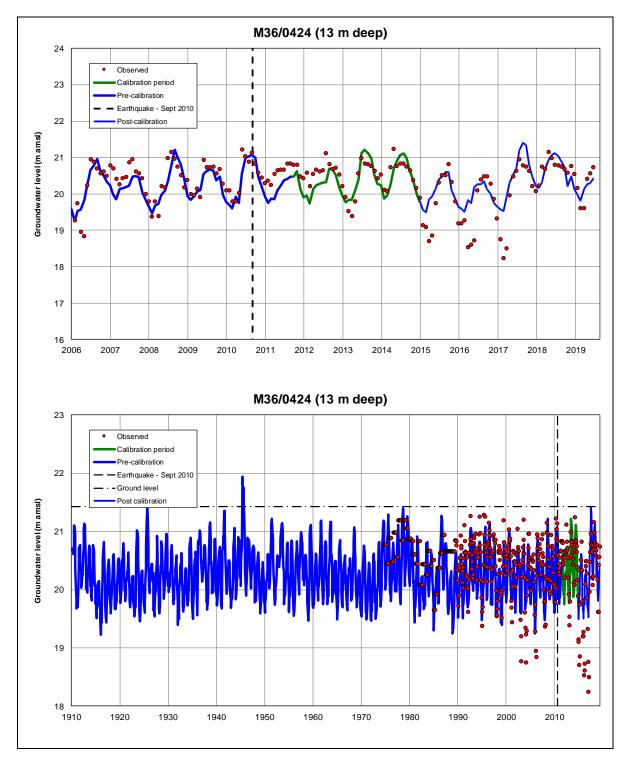
Figure B4: Calibration of groundwater eigen model for Bore M36/0599. Lincoln. Representative of shallow groundwater levels & drainage. GL 14.7 m amsl.
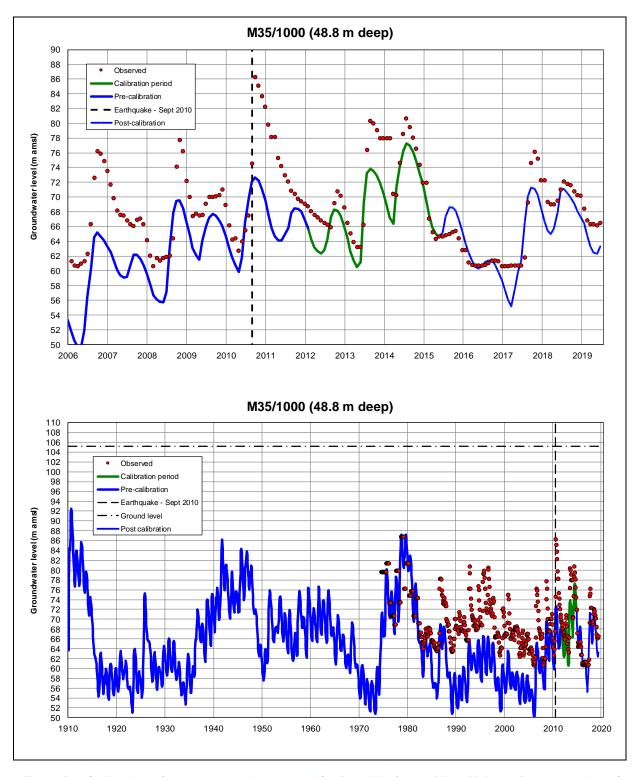
Water levels measured in bore M36/0599 between 2013 and 2016 were well below model predictions. The response is quite erratic, which would suggest the deviation (from modelled) is due to local interference. Eigen models only account for regional drivers (e.g. climate, regional groundwater pumping), not local effects such as nearby pumping.

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Figure B5: Calibration of groundwater eigen model for Bore L36/0124. Bankside - Dunsandel. Representative of shallow groundwater supplies. GL 112.3 m amsl.
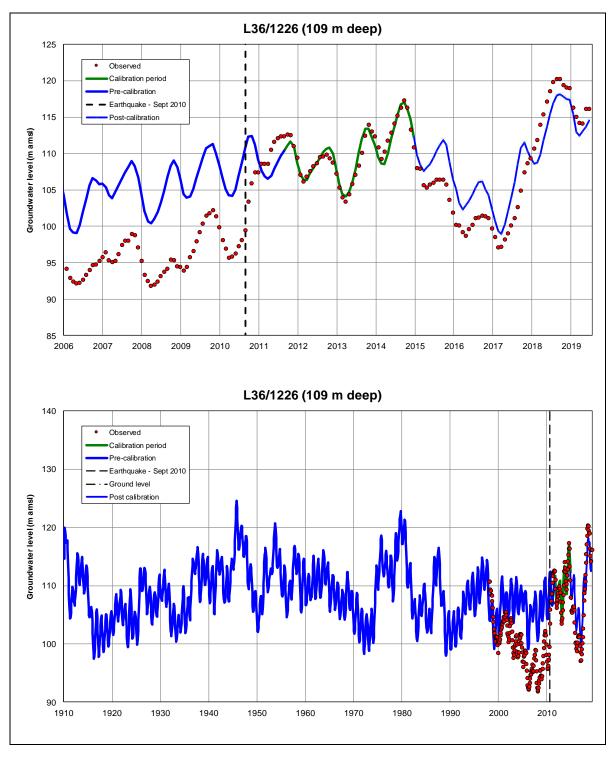
Figure B6: Calibration of groundwater eigen model for Bore L36/1226. Te Pirita - Hororata. Representative of deep groundwater supplies. GL 198.3 m amsl.

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Figure B7: Calibration of groundwater eigen model for Bore M36/0424. Doyleston. Representative of shallow groundwater levels & drainage. GL 21.4 m amsl.
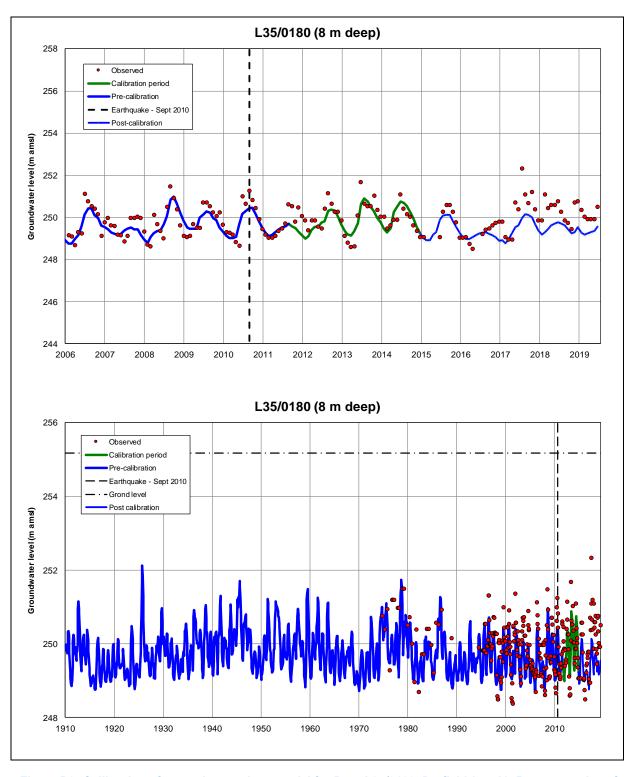
Figure B8: Calibration of groundwater eigen model for Bore L35/0180. Darfield (north). Representative of shallow groundwater supplies. GL 255.2 m amsl.

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Figure B9: Calibration of groundwater eigen model for Bore M35/1000. (West Melton). Representative of shallow groundwater supplies. GL 105.2 m amsl.
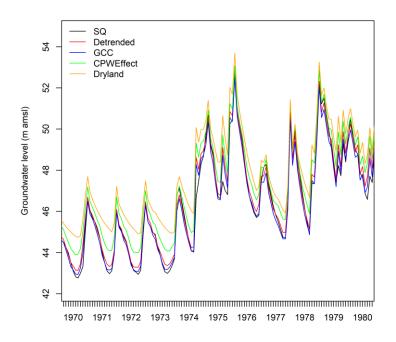
Figure C1: Modelled water levels for Bore M35/1080. Christchurch – West Melton. Representative of shallow groundwater supplies.
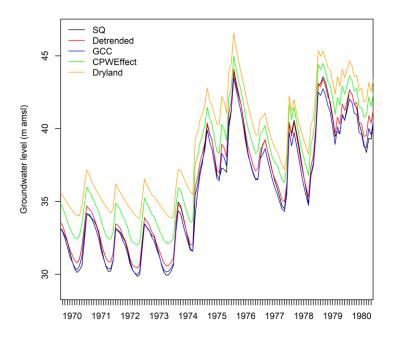
Figure C2: Modelled water levels for Bore M36/0217. Rolleston. Representative of shallow groundwater supplies.

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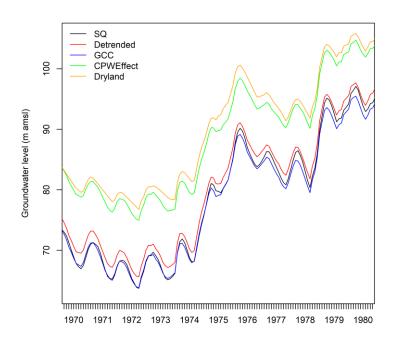
Figure C3: Modelled water levels for Bore L36/0092. Charing Cross. Representative of deep groundwater supplies.
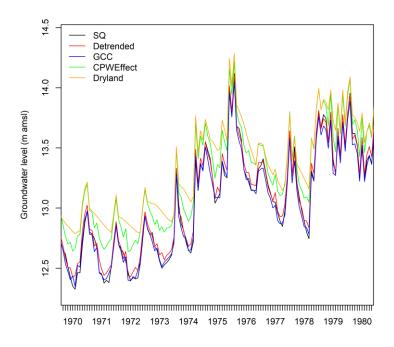
Figure C4: Modelled water levels for Bore M36/0599. Lincoln. Representative of shallow groundwater levels and drainage.
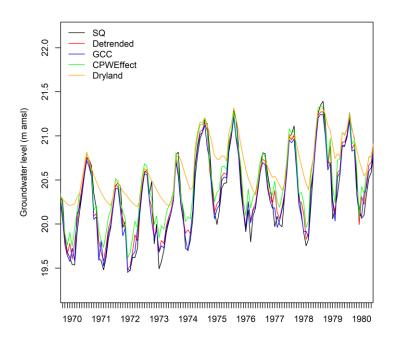
Figure C5: Modelled water levels for Bore L36/0124. Bankside - Dunsandel. Representative of shallow groundwater supplies.
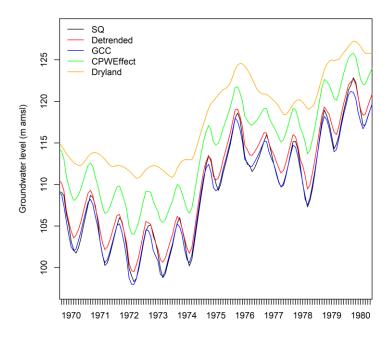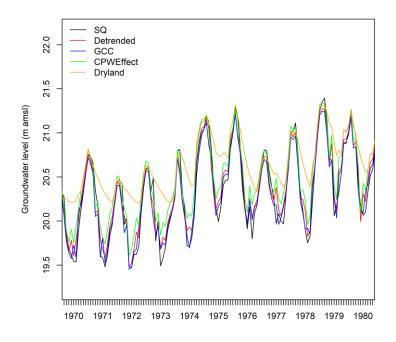

Figure C6: Modelled water levels for Bore L36/1226. Te Pirita - Hororata. Representative of deep groundwater supplies.

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Figure C7: Modelled water levels for Bore M36/0424. Doyleston. Representative of shallow groundwater levels and drainage.
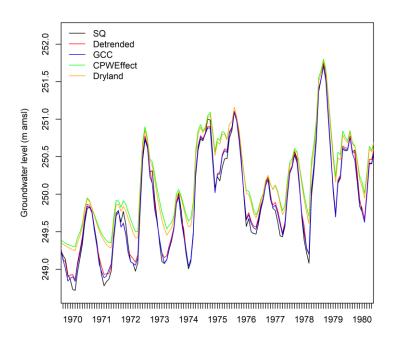
Figure C8: Modelled water levels for Bore L35/0180. Darfield (north). Representative of shallow groundwater supplies.
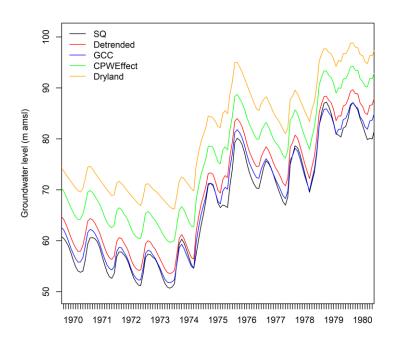
Figure C9: Modelled water levels for Bore M35/1000 West Melton. Representative of shallow groundwater supplies.

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D1. Annual low groundwater levels in the upper plains

Annual low groundwater levels were modelled for four well sites, Racecourse Hill, Hororata, Charing Cross and Bankside (Figure D1). The levels were modelled for the 1910-2015 period assuming the current state of irrigation, groundwater abstraction and land use. By doing this the variation in the modelled groundwater levels are independent of land use changes.

The time series' of the estimated annual minimum ground water level for the four groundwater sites are shown in Figure D2. These graphs show that the deep well at Racecourse Hill has much less variation than the others but that they all have similar but considerable variability from year to year. No trend was found for any of these time series that could be clearly distinguished from random variation.

Scatter plots of the annual minimum ground water level against ENSO and SAM indices are shown in Figure D3. These scatter plots indicate a poor relationship between any of the site's annual minimum ground water level and the climate indices.

The difference between the annual minimums for different IPO phases could not be shown to be different from zero (using the Welch two sample t-test).

The histograms of the "de-trended" and downscaled global climate change (GCC) annual minimum groundwater levels are shown in Figure D4. These show no clear increase in extreme low groundwater levels at any of the well sites for the GCC 2048 scenario.
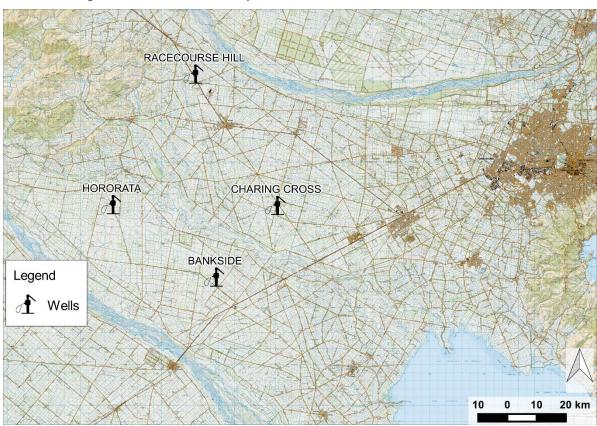

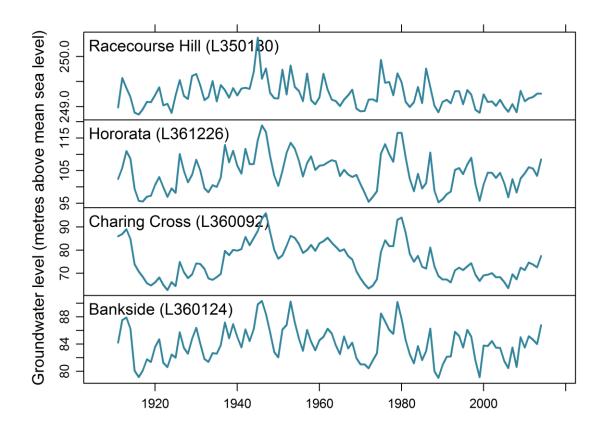*Figure D1. Ground water sites used to consider annual low levels*

Figure D2. Time series of estimated annual minimum groundwater levels. Note that the vertical scale is different for each graph.
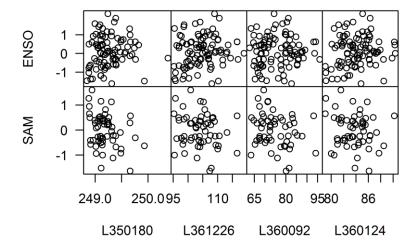

Figure D3. Scatter plots of estimated annual minimum groundwater level versus average annual climate indices

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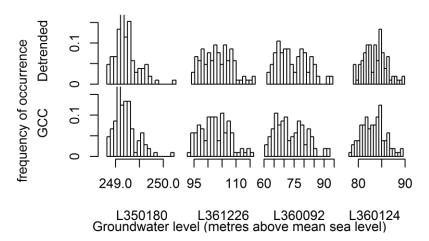
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Figure D4. Histograms of frequency of occurrence of minimum annual ground water levels. The histograms are for the different wells under a 2015 scenario (detrended) and a 2048 scenario based on downscaled middle-of-the-road Global Climate Change scenario (GCC).

D2.   Annual high groundwater levels in the lower plains

In the lower plains, the main issue concerns shallow groundwater maxima levels. Annual high groundwater levels were modelled for four well sites, Doyleston, Springston, Weedons and Templeton (Figure D5). The levels were modelled for the 1910-2015 period assuming the current state of irrigation, groundwater abstraction and land use. By doing this the variation in the modelled groundwater levels are independent of land use changes.
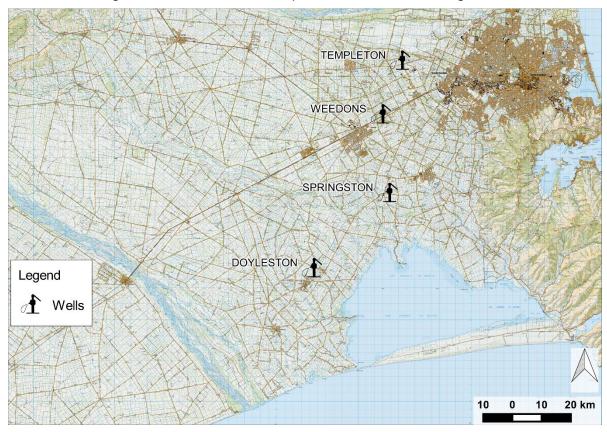

Figure D5. Ground water sites used to consider annual high levels

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The time series' of the estimated annual maximum ground water level for the four groundwater sites are shown in Figure D6. These graphs show that each well responds to similar drivers though they have different average levels and different ranges. They also show that there is considerable variability from year to year. No statistically significant trend was found for any of these time series.

Scatter plots of the annual maximum ground water level against ENSO, IPO and SAM indices are shown in Figure D7. These scatter plots indicate a poor relationship between any of the site's annual maximum ground water level and the climate indices.

The difference between the annual maximums for different IPO phases could not be shown to be different from zero (using the Welch two sample t-test).
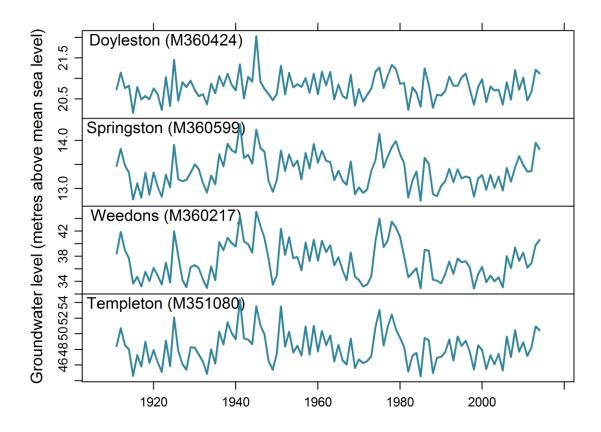

Figure D6. Time series of estimated annual maximum groundwater levels. Note that the vertical scale is different for each graph.

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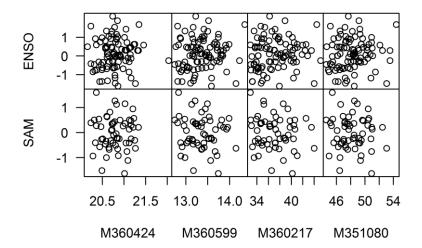© Aqualinc Research Ltd.

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Figure D7. Scatter plots of estimated annual maximum groundwater level versus average annual climate indices

The histograms of the "de-trended" and downscaled global climate change (GCC) annual maximum groundwater levels are shown in Figure D8. These show no clear increase in annual high groundwater levels at any of the well sites for the GCC 2048 scenario.
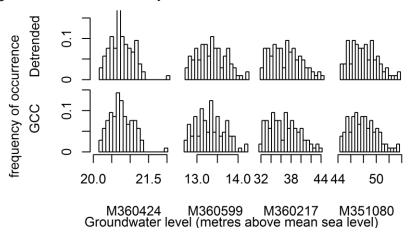

Figure D8. Histograms of frequency of occurrence of maximum annual ground water levels. The histograms are for the different wells under a 2015 scenario (detrended) and a 2048 scenario based on downscaled middle of the road Global Climate Change scenario (GCC).