Projected Effects of Climate Change on Water Supply Reliability in Mid-Canterbury

MAF Technical Paper No: 2011/12

Prepared for the Ministry of Agriculture and Forestry
by Aqualinc Research Limited
CC MAF POL_2008-20 (127-3)
Climate Change – Plan of Action Research Programme 2007/08
Adaptation Vulnerability and Impacts of Climate Change on
New Zealand's Pastoral Systems

ISBN No: 978-0-478-37571-8 (online)
ISSN No: 2230-2794 (online)

March 2011

Ministry of Agriculture and Forestry
Te Manatū Ahuwhenua, Ngāherehere

BIOSECURITY NEW ZEALAND

NEW ZEALAND FOOD SAFETY AUTHORITY

Disclaimer

Requests for further copies should be directed to:

Publication Adviser
MAF Information Bureau
P O Box 2526
WELLINGTON

Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the MAF website at
www.maf.govt.nz/news-resources/publications.aspx

Quality Control				
Client:	Ministry of Agriculture and Forestry			
Report reference:	Title: Projected Effects of Climate Change on Water Supply Reliability in Mid-Canterbury			No: C08120/1
Prepared by:	John Bright, Helen Rutter, James Dommisse, Ross Woods, Andrew Tait, Brett Mullan, Jordy Hendrikx and Jani Diettrich.			
Reviewed by:	IMc	Approved for issue by:		
Date issued:	December 2008	Project No:	C08120/1	

Document History			
Version: 1	Status: Draft	Author: JCB	Reviewer:
Date: 30-9-2008	Doc ID:	Typist: KW	Approver:
Version: 2	Status: Final	Author: JCB	Reviewer: IMc
Date: 15-12-2008	Doc ID: MAFccReport-C08120-15dec08	Typist: KW	Approver: IMc

Contents

Page

Executive Summary

This project report provides estimates of the potential effects of climate change on weather elements (e.g. daily rain, temperature), mean daily river flows, irrigation water demand and water supply reliability for one catchment and associated irrigated area (Rangitata River in Canterbury).

The changes in climate are based on the average of 12 global climate models used for the recent Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. The climate change data for 2040 have been produced by statistically downscaling global climate model output to the grid of New Zealand's Virtual Climate Network, thus providing data every day and approximately every 5km in the study area. More than 35 years of daily climate data and river flow data (at one location) were synthesised. These data cover both current climate and a future climate (A1B emissions scenario for 2040).

Climate change projections for 2040 within the study area indicate:

- Annual average temperatures about one degree warmer than the average for 1980–99.
- Changes in annual average precipitation range from increases of up to 400mm/year in the Rangitata headwaters to little change on the Canterbury Plains.
- Changes in annual average potential evaporation for 2040 range from increases of 60mm/year on the Canterbury Plains, to small decreases in the headwaters of the Rangitata.
- In terms of seasonal changes, the largest projected increases in precipitation for the headwaters are in winter and spring, while small changes in seasonal rainfall patterns on the Plains are projected to occur. Seasonal warming is least in spring and early summer; otherwise the warming is uniformly distributed through the year. The increases in potential evaporation are largest in spring and summer on the plains.

Daily river flow time series are provided by using a Topnet model for the Rangitata catchment upstream of the Klondyke gauging station.

The main differences between modelled flows for the current and 2040 climate are:

- Mean flows for 2040 are projected to be about 8 m^3/s larger than under the current climate (about an 8% increase in mean flow)
- The monthly mean flow is projected to increase or stay the same in 10 months of the year, and to reduce by 1–2 m^3/s in December and January
- The months with greatest projected absolute increase in flow are August, September and October (each increased by ~18 m^3/s compared to the model flows for the current climate)

The projected effect of climate change under the A1B 2040's scenario is a reduction in groundwater recharge from the land-surface of about 10%.

The main changes projected for irrigation, drainage and water supply reliability are:

- Average annual irrigation water use is projected to increase by about 6%
- Average annual drainage from un-irrigated land is projected to decrease by about 10%
- Average annual drainage from irrigated land is projected to decrease by about 3%
- Water supply reliability from surface water and groundwater sources is projected to reduce. This conclusion is the opposite of that reached in the LE (2001) analysis.

Under current allocation policies, the area of land able to be irrigated would be reduced by 10%. If the groundwater allocation zone is already fully allocated, or within 10% of being fully allocated, the existing irrigators would, in theory, face a reduction in their allocations of up to 10%. At present the process for making such a reduction is highly contentious for many reasons. New Zealand is ill prepared for this issue.

Where surface water is used for irrigation it substantially mitigates the effects of climate change on groundwater recharge.

The lack of a sufficiently reliable source of surface water for irrigation will limit the size of both the groundwater supplied irrigation area and the surface water supplied area, to a total area well short of the potentially irrigable area on the Canterbury Plains.

Using stored surface water to provide a reliable surface water supply also provides for a reliable groundwater supply on the lower plains.

Storing surface water is a critically important climate change adaptation measure.

The main source of the projected increase in flow for 2040 is the projected increase in precipitation for July, August, September, and October. This is the main source of uncertainty in the river flow projections. This uncertainty is compounded by the snow sub-model of Topnet, which could not be directly validated because there are no systematic measurements of snow storage in the catchment.

The methodology and tools tested in this project are sufficiently robust, notwithstanding the sources of uncertainty noted above, to be applied throughout Canterbury and other drought prone areas that increasingly depend on irrigation to maintain the profitability of agriculture.

Future assessments of climate change impacts might be enhanced by use of new methods for downscaling climate data, such as Regional Climate Modelling, and improvements to Topnet that will result from systematic data on seasonal snow, considered as a water resource. The analysis of other scenarios (e.g. A1FI and B2) and other times (e.g. 2090) are desirable to provide a fuller picture of the uncertainty surrounding any assessment of the potential effects of climate change.

1 Introduction

1.1 RESEARCH GOAL

The research goal was to test new methodology for quantifying the potential impact of climate change on the capacity of groundwater and surface water resources to meet agriculture's current and foreseeable water needs, by applying it to one catchment and associated irrigated area (Rangitata River in Canterbury).

An outcome of the testing was new understanding of the projected effects of climate change on irrigation water use, groundwater recharge and water supply reliability in the project area.

1.2 BACKGROUND

Intensification of pastoral systems is increasingly dependent on water supply reliability for stock water and irrigation. Water supply reliability is a function of both water availability and water demand. Climate change potentially impacts both. Changes in natural water flows (in rivers and aquifers) and agricultural water demand, in combination with current Regional Council water allocation rules, may render current levels of groundwater use unsustainable. The knock-on effect of this would be greater pressure on surface water flows and to provide stored surface water. At this stage it is not known if current levels of groundwater and surface water supply reliability can be sustained. Recent work (Aqualinc, 2008) indicates that the number of regions for which supply reliability will be a critical issue is growing rapidly as the number of catchments which are deemed to be fully allocated grows.

A strategic approach to quantifying the water supply and demand balance under historical climates has been successfully applied in several regions to identify upcoming water management issues and to plan how to meet future water demand (Morgan et al, 2001). When an early version of this approach was used in 2001 with the climate change scenarios available at that time, it exposed significant shortcomings in some of the models used (LE,2001a). Furthermore the scope of that work was limited to surface water availability. Significant progress has been made since then on improvements to the overall methodology and the associated tools, and climate change scenarios have been updated. A strategic approach to water management needs to anticipate the potential effects of climate change – the aim of this project is to test whether New Zealand now has the tools to do this.

1.3 OVERALL APPROACH

The methodology for this project is to (i) extract current climate data and downscale climate change information for the future scenario, (ii) run a river flow simulation model under the current and future climates, and (iii) run an irrigated farm simulation model under the current and future climates. Differences between modelled river flow, irrigation water use and drainage volume information from the two model runs are interpreted as the potential impact of the climate change scenario. This interpretation is subject to the assumptions of those models and the uncertainties of the climate scenario.

While the results presented here are specific to the Rangitata area, the methodology is a generic one which can be applied to other parts of New Zealand. New Zealand catchments studied with this approach include the Tukituki, Motueka and Rangitata catchments (Lincoln Environmental 2001, Mullan et al. 2001), the Oreti (Lincoln Environmental 2003, Mullan et al. 2003) and elsewhere in New Zealand for water supply purposes.

1.4 STUDY AREA

The study area is the Rangitata River catchment and associated irrigation areas. These are illustrated in Figure 1-1.

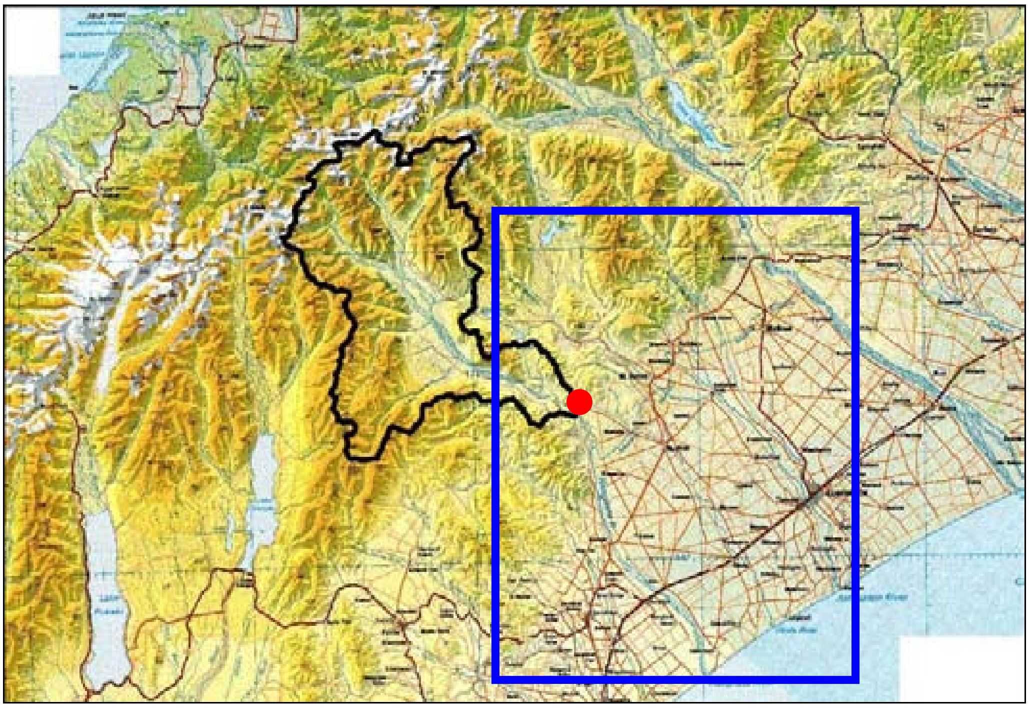

Figure 1-1: Study area, showing irrigation area (blue rectangle), river flow recorder for Rangitata River at Klondyke (red dot), and catchment boundary above flow recorder (black).

2 Future Climate Scenario and Benchmark Climate

Climate information was required for the current climate, and for one future scenario, referred to in this report as the 2040 scenario. The weather elements required are listed in Table 2-1.

2.1 OBSERVATIONAL WEATHER; THE BENCHMARK CLIMATE

A set of high-resolution daily climate maps exists for New Zealand: these are described in Tait et al. (2006), Tait and Woods (2007) and Tait (in press). For each day over the last 35 years or more, a daily map is created by interpolating between climate observations on that day. Each map has interpolated data on a grid of 0.05 degrees, that is, about 5km by 5km. The rainfall grids begin in 1960, while grids for most other weather elements in Table 2-1 are available from 1972. They continue to be automatically updated daily, as an adjunct to NIWA's Climate Database. This set of data form the Virtual Climate Network (VCN).

Table 2-1: Weather elements in this study

Symbol	Description	Units
RAIN	24-hour rainfall total from 9am local day	(mm)
TMAX	Maximum temperature over 24 hours from 9am local day	(°C)
TMIN	Minimum temperature over 24 hours from 9am local day	(°C)
TMEAN	Calculated from (TMAX + TMIN)/2	(°C)
SVP	Calculated saturated vapour pressure corresponding to TMEAN	(hPa)
VP	Vapour pressure at 9am local day [assume here that this is constant over whole day]	(hPa)
RH	Relative Humidity calculated as VP/SVP * 100	(%)
TDEW	Dewpoint temperature calculated from RH [assuming dry bulb temperature is TMEAN]	(°C)
RAD	24-hour global solar radiation total from midnight local day	(MJ/m2)
WIND	Average wind speed at 10m above ground level over 24 hours from midnight local day	(m/s)
MSLP	Mean sea level pressure at 9am local day	(hPa)
PET	24-hour PET total (Penman) from 9am local day	(mm)

From these maps of the VCN we extracted the points lying within the study area, from 1 January 1972 to 31 December 2007. These were used as the data for the current climate for this study.

For each grid point within the irrigation study area, a record of daily weather (all 12 items in Table 2-1) was extracted for the complete 36 years.

2.2 FUTURE CLIMATE – SCENARIO AND TIME-FRAME SELECTION

Global climate models used for the IPCC Fourth Assessment Report formed the basis of a recently revised set of climate change projections for New Zealand, which are described in a guidance manual for local government (Ministry for the Environment 2008). Only a brief sketch is given here, and the guidance manual should be consulted for full details.

Climate change projections for New Zealand are derived from the results of global climate models which have been used in the IPCC's Fourth Assessment Report to simulate future climate. These global models have been run with a range of possible future greenhouse gas emissions, and the results of the models are sensitive to the choice of emissions scenario.

Given the limitations and scope of this study, a single climate change scenario was assumed for this study, that is, a particular emissions scenario, A1B, is adopted. See Appendix A1 of (Ministry for the Environment 2008) for a discussion of emissions scenarios. A1B can be described as a "middle of the road" emissions scenario relative to other IPCC scenarios, neither particularly high nor particularly low.

2.3 GENERATING WEATHER SEQUENCES FOR THE STUDY AREA – DOWNSCALING

The output of a global climate model is generally at too coarse a spatial resolution to be directly applied within New Zealand. Thus, the global model output has been statistically downscaled to the same 0.05 degree (~5km) grid used for the VCN (see above).

The methodology for downscaling temperature and precipitation to the Virtual Climate Network grid is described in Ministry for the Environment (2008). The methodology for downscaling the potential evaporation is described in Mullan et al (2005), but we have used the most recent climate change projections as input to the Mullan et al (2005) downscaling equations.

From the IPCC Fourth Assessment Report, results are available for 17 different global models. The scenario adopted for this study is based on the average result of downscaling the 12 most appropriate models. All 12 have been shown to perform acceptably in simulating the past climate of New Zealand and the South Pacific. Given sufficient resources, the downscaled scenarios from each of the 12 models should be used individually as input to the water resources simulation models (rather than just using their average), so that a better appreciation of climate scenario uncertainty can be obtained. The downscaled global models do sometimes differ significantly from one another (see Appendix A3 in Ministry for the Environment (2008)).The scenario assumed for this study is the 12-model average for 2040 (actually 2030–2049), based on the A1B emissions scenario.

2.3.1 Application to this study

Statistically downscaled change projections were developed on the ~5km Virtual Climate Network grid mentioned above. The directly downscaled changes were for monthly mean values of temperature, rainfall, and potential evaporation. The change referred to is the difference between the period 2030–2049 (midpoint reference year = 2040), when compared with the base period 1980–1999 (midpoint reference year = 1990).

From the downscaled rainfall and temperature changes, and knowledge of correlations between weather elements, change projections for 2040 were developed for all 12 weather elements as shown in Table 2-2. Four secondary weather elements were assumed not to change under this climate scenario: Relative Humidity, Global Solar Radiation, Average Wind Speed, and Mean Sea Level Pressure. In addition, we have assumed that the number of days with rain does not change.

Table 2-2: Methods for computing climate change projections for each weather element. The symbols for the weather elements are defined in Table 2-1.

Symbol	Method used to Produce Daily Series of Future Climate
RAIN	Downscaled monthly rainfall change is divided evenly amongst current days with rain. Days with zero rain in current climate are not changed in future climate.
TMAX	Downscaled monthly temperature change is added to current TMAX
TMIN	Downscaled monthly temperature change is added to current TMIN
TMEAN	Calculated from changed (TMAX + TMIN)/2
SVP	Calculated saturated vapour pressure corresponding to changed TMEAN [SVP = 6.11*exp((17.3.*TMEAN)./(237.3+TMEAN))]
VP	Changed SVP multiplied by RH
RH	No change
TDEW	Calculated from changed VP [TDEW = (116.91+237.3.*log(VP))./(16.78.*log(VP))]
RAD	No change
WIND	No change
MSLP	No change
PET	Downscaled monthly change in PET is added to all days

In all cases the detailed future climate was developed by applying the downscaled changes to the current high-resolution daily climate data from the Virtual Climate Network.

2.4 CHANGES IN KEY WEATHER ELEMENTS BETWEEN THE BENCHMARK CLIMATE AND THE 2040 CLIMATE SCENARIO

Figure 2-1 shows the projected average annual changes in rainfall, temperature and potential evaporation. These projections are derived from the average of 12 downscaled global model projections, assuming the A1B emissions scenario.

The regional changes in the long term mean are illustrated in Figure 2-1, and the seasonal patterns in the projected change are illustrated in Figure 2-2.

Broadly speaking, climate change projections for 2040 within the study area indicate annual average temperatures about one degree warmer than the average for 1980–99. Changes in annual average precipitation range from increases of up to 400mm/year in the headwaters to little change on the plains. Changes in annual average potential evaporation for 2040 range from increases of 60mm/year on the plains, to small decreases in the headwaters of the Rangitata.

In terms of seasonal changes, the largest projected increases in precipitation for the headwaters are in winter and spring, while seasonal rainfall patterns on the plains are not projected to change. Seasonal warming is least in spring and early summer; otherwise the warming is uniformly distributed through the year. The increases in potential evaporation are largest in spring and summer on the plains.

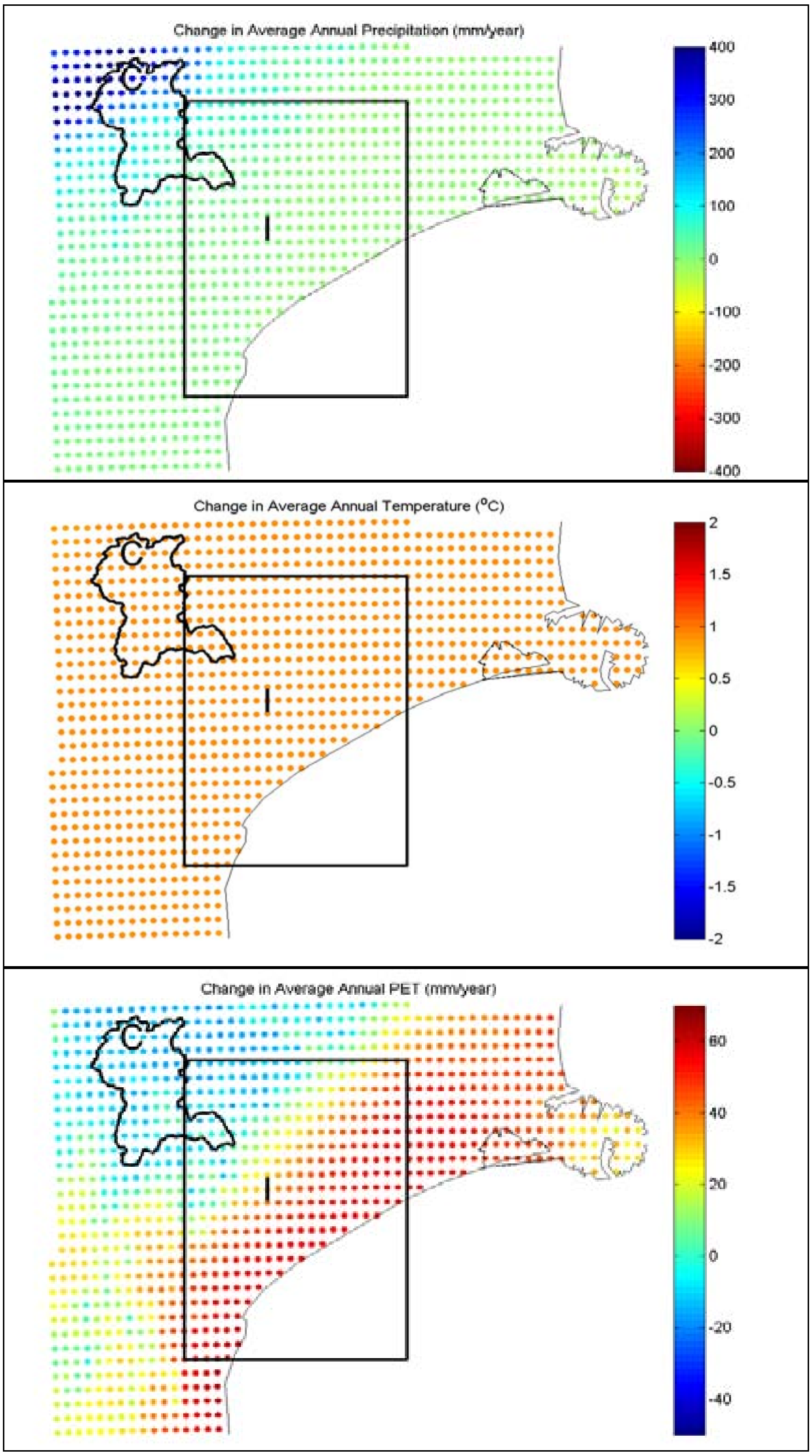

Figure 2-1: Maps of changes (2040's relative to 1990's) in the average annual precipitation, temperature, and potential evaporation. The catchment and irrigation areas are indicated.

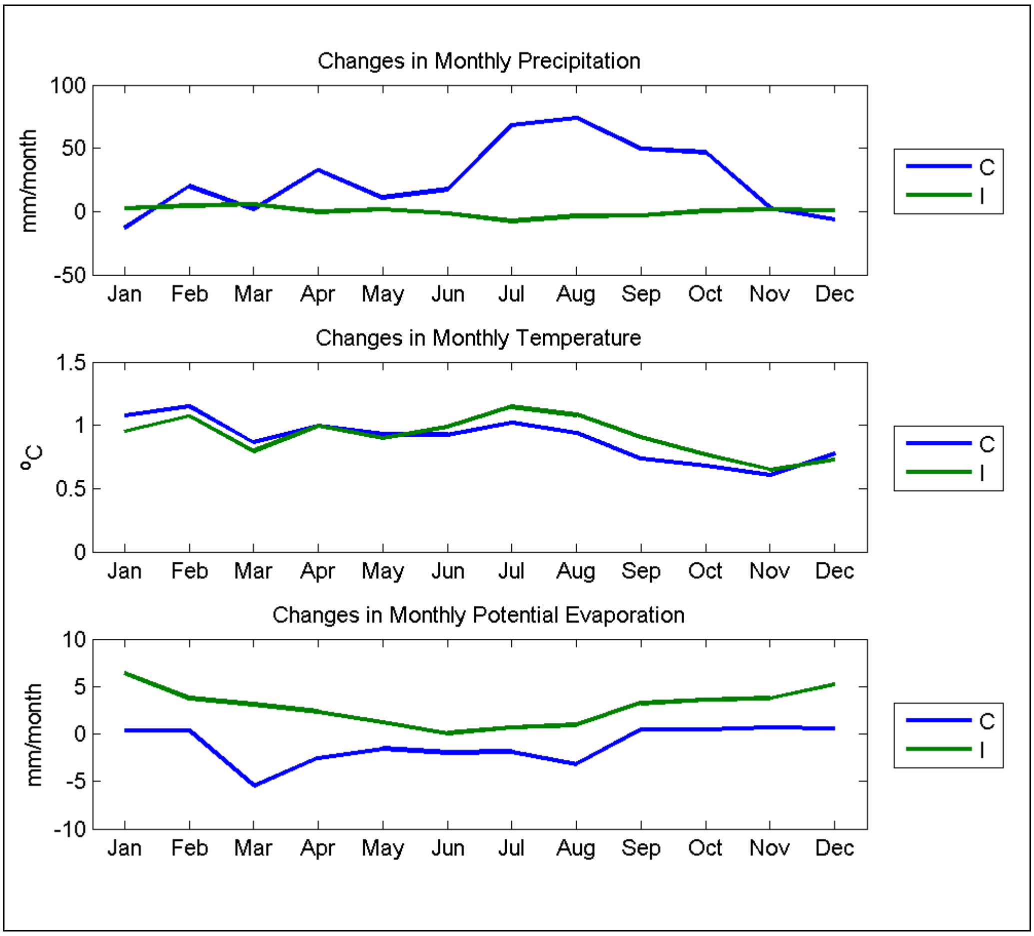

Figure 2-2: Seasonal patterns of changes (2040 relative to 1980-1999) in the average annual temperature, precipitation and potential evaporation, for example locations in the catchment (C) and irrigation (I) areas.

Limitations of the climate change projections are discussed in Ministry for the Environment (2008); see especially the discussion of uncertainty of downscaling in Appendix A.3.1 of that report and the discussion of differences between global models in Appendix A3.2 of that report.

3 River Flow

3.1 OVERALL APPROACH

Daily river flow time series were generated by using a Topnet model for the Rangitata catchment above Klondyke. Topnet is the catchment model which has been used for the surface water component of the National Water Accounts (Henderson et al. 2007). Improved climate data sources (Tait et al. 2006) and recent Topnet developments (Clark et al. 2008) have improved the simulation of dry weather river flows relative to those used for previous estimates of water supply reliability (Mullan et al. 2001, Mullan et al. 2003).

Topnet is a spatially distributed, time-stepping model of water balance. It is driven by time series of rainfall and temperature data, and of additional weather elements where available. Topnet simulates water storage in the snowpack, plant canopy, rooting zone, shallow subsurface, lakes and rivers. It produces time series of modelled river flow throughout the modelled river network, as well as evaporation. A detailed description of the model equations is published in Clark et al. (2008).

A critical element of the project was successfully validating a Topnet model for the Rangitata catchment above the Klondyke flow recorder site. A validated model is essential for developing mean daily flow series from the baseline climate dataset and the projected 2040's climate dataset.

3.1.1 Data

For this study the climate information used for Topnet is as described in the Climate section of this report. Topnet also makes use of spatially distributed information on topography, soils, vegetation and climate. The main sources of spatial data used for New Zealand applications of Topnet are the New Zealand River Environment Classification (Snelder & Biggs (2002), supplemented with additional analyses of topographic data), the Land Resources Inventory (Newsome et al. 2000), and the New Zealand Land Cover Data Base (Willoughby et al., 2001).

3.2 CALIBRATING THE TOPNET RIVER FLOW SIMULATOR

For many applications of Topnet, the estimation of model parameter values currently requires calibration, usually using measured streamflow. The parameters requiring this type of estimation are generally associated with soil hydraulic properties (hydraulic conductivity and water holding capacity of soils). However, careful review of data quality (e.g. rainfall, temperature and streamflow) is a wise first step, before calibration. For example, in this study, the relationship between rainfall and river flow is observed to change in the late 1980s. Calibration to the river flow data before this time produces results which are not useful for the majority of the flow record.

The model calibration reported here used data from 1987-90 as the calibration period.
The time series of observed and modelled river flow for the calibration period are shown in Figure 3-1. They show three years, beginning on 1 May (after the irrigation season ends, but before major snow accumulation). Flow rates above 300 m3/s are not displayed since they are not easily exploitable as water resources – however the model also does an adequate job of simulating flood flows.

In examining Figure 3-1, when we consider the applicability of the model for water resource availability we observe that the availability of water is typically constrained during periods of low river flow, and so the accuracy of the model during recessions is important. The model is well calibrated during flow recessions from September through to April. Two cases where the model does less well are around the start of February 1989, when the model is too low, and in February 1990, when the model does not recede far enough. The model also misses the small peak in mid-March 1990, but follows the recession accurately.

Aside from recession performance, the other criterion for calibration were the monthly flow regime, and the probability distribution of daily flows. The overall model performance on these aspects is shown below in the validation plots, and discussed there.

Time series of observed and modelled flows are shown in
Figure 3-2 for 3 validation years, starting 2003-2005. No adjustment was made to the model parameters from the calibration. The complete set of plots of observed and modelled flow time series for all years studied are reported in Woods et al (2008).

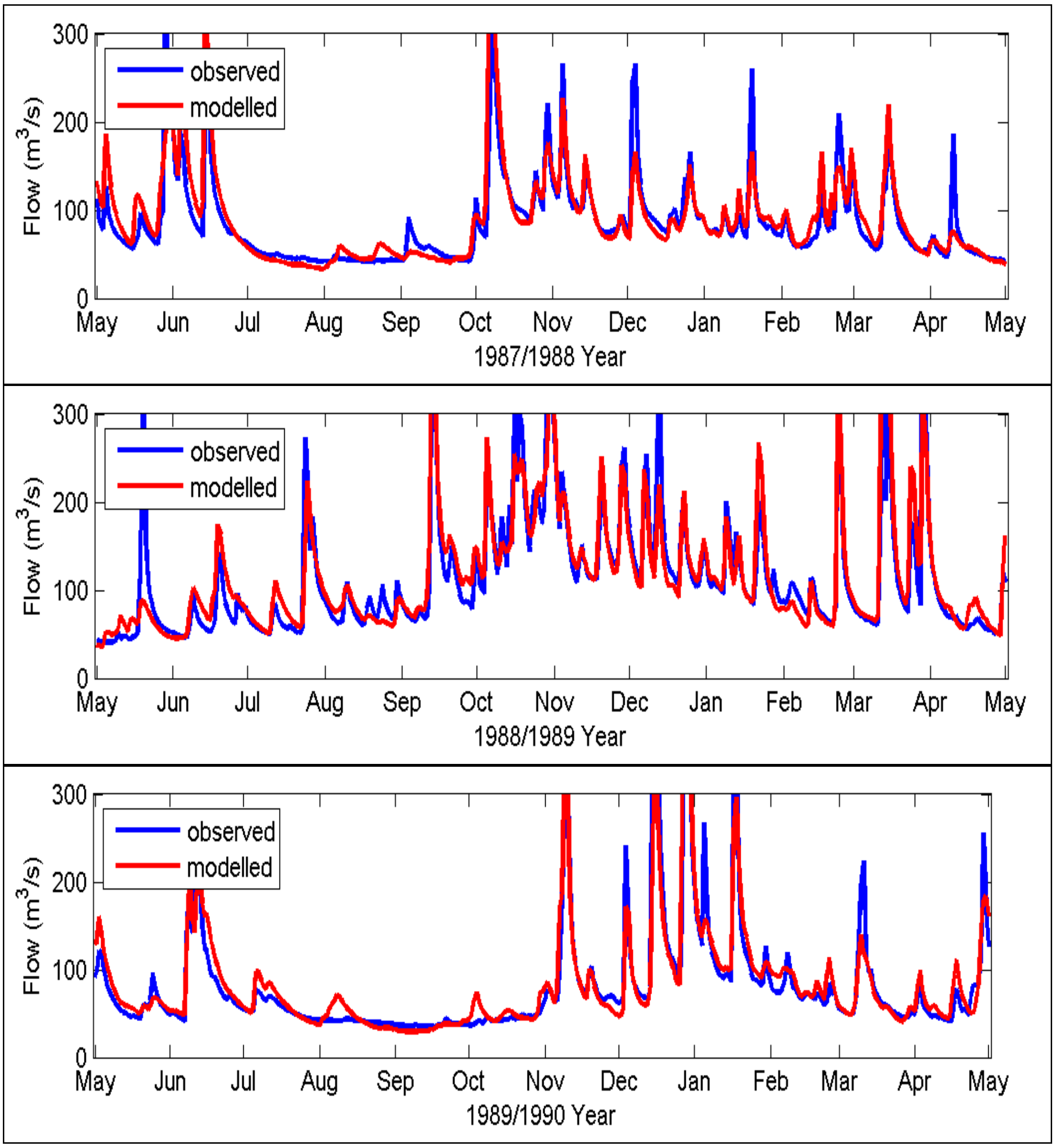

Figure 3-1: Calibration plots of flow time series for years starting 1987, 1988 and 1989, showing the extent to which the model mimics the observed river flow records. Observations are in blue, model in red. Tick marks on the time axis indicate start of month.

From the upper plot in
Figure 3-3, we can see that the Topnet model output mimics the general outline of the observed mean monthly flow, with the lowest flows typically in winter. The model overestimates observed flow by 3-5 m3/s in autumn and early winter, and underestimates flow in December by 12 m3/s. Overall for the year, the mean difference between observed and modelled flow is 0.5 m3/s, well within the uncertainties of both the modelling and the measurements.

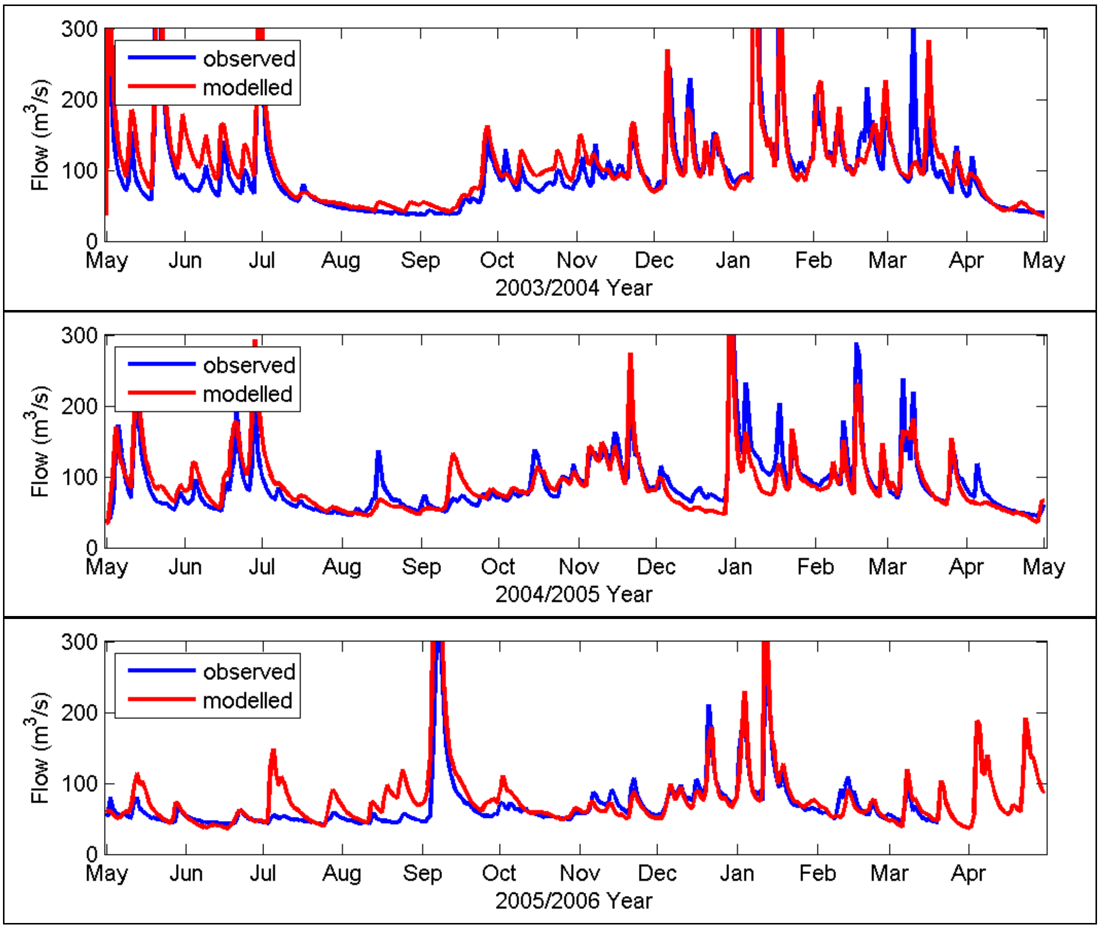

Figure 3-2: Validation plots of flow time series for 3 validation years, starting 2003-2005, showing the extent to which the model mimics the observed river flow records. Observations are in blue, model in red. Tick marks on the time axis indicate start of month.

The lower plot in
Figure 3-3, a flow duration curve, shows the fraction of time the river spends above each flow of interest, for both the model and the observations. For example, observed flow is less than 80 m3/s about 52% of the time, while modelled flow is less than 80 m3/s about 49% of the time. The observed and modelled curves are quite similar except at the lowest flows. During low flow periods (in winter), the model occasionally produces flows which are too low by about 10 m3/s. This happens in a small number of winter precipitation events where the model erroneously interprets the precipitation as snowfall and merely adds it to the snowpack, whereas it presumably fell as rain and caused river flow to rise. This error may be occurring because of the simplistic model of the rain-snow threshold in equation (2). New FRST-funded research is underway on this topic.

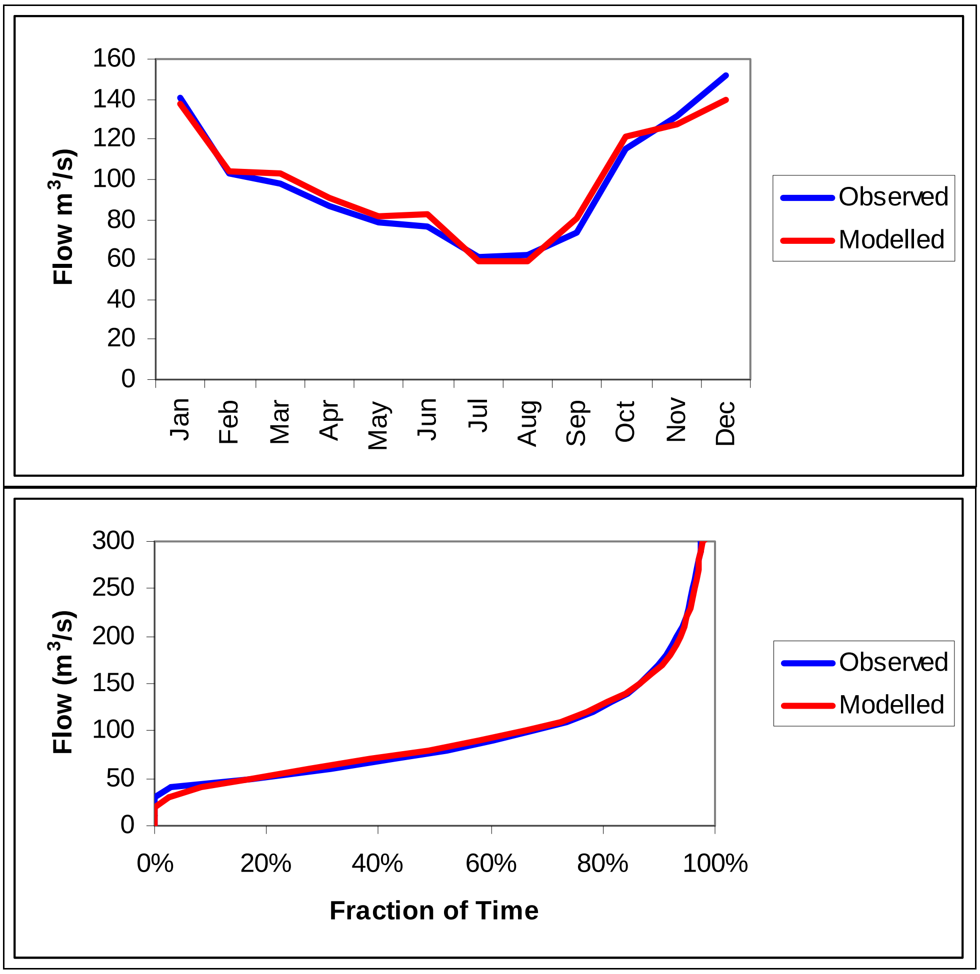

Figure 3-3: Validation plots of mean monthly flow regime and flow duration curve showing the extent to which the model mimics the observed river flow records. Here the validation is done on the entire period of flow record. Observations are in blue, model in red.

The validations in
Figure 3-3 show whether the model is doing well in two senses: how accurate is the model for average month–to–month variations, and for the total range of flows. In Figure 3-4 we also examine whether the model reliably simulates the range of flows in each month of the year. The red and blue lines marked 95% in Figure 3-4 show the 95th percentile flows for each month from the model and the observations. Selected other percentiles are also indicated on the figure: the 50th percentile is the median flow for the month. So for example, looking at the 50% lines in December, the observed median flow was 104 m3/s, while the modelled median was 96 m3/s. The model does surprisingly well in simulating the unusually high flows such as the 95th percentile. The poorer simulation of unusually low flows in winter may be due to the rain-snow identification problem described above. It should not have any serious consequences for the current project, but needs addressing in future.

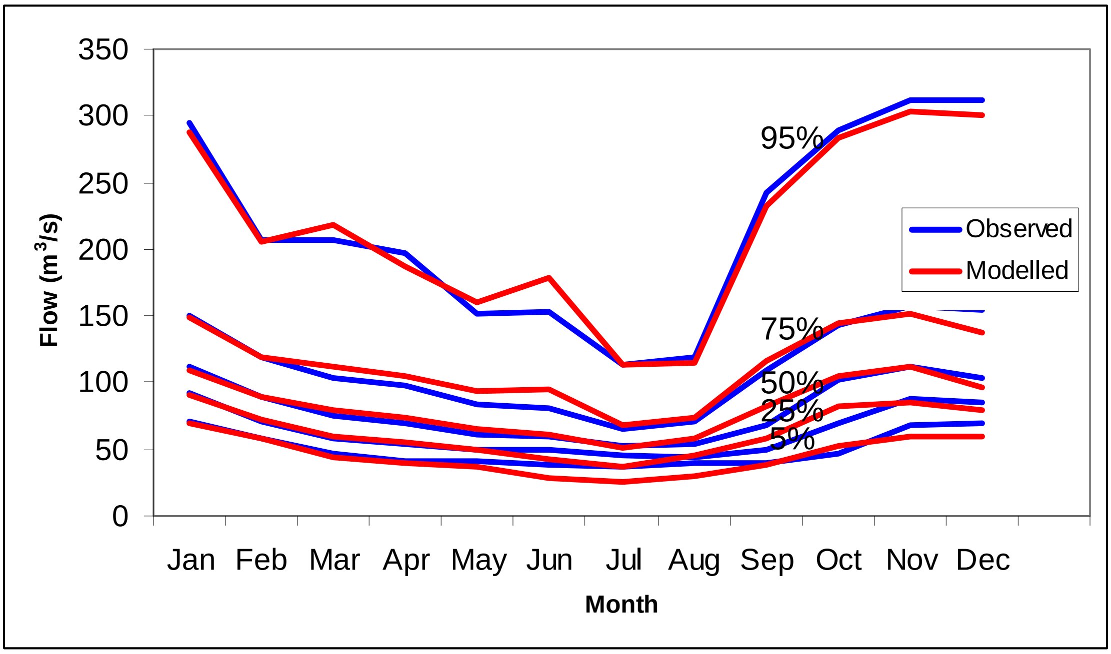

Figure 3-4: Validation plots of quantiles of flows in each month, showing the extent to which the model mimics the observed river flow records. The percentage figures are explained in the text. Here the validation is done on the entire period of flow record. Observations are in blue, model in red.

3.3 CHANGES IN RIVER FLOW UNDER CLIMATE CHANGE SCENARIO A1B (2040)

The Topnet model of the catchment was run for both the current and 2040 climates. Simulation modelling runs were done using a one-hour timestep, and results were aggregated to daily timescales before being delivered to the client in electronic form.

The main differences between modelled flows for the current and 2040 climate are:

- Mean flows for 2040 are projected to be about 8 m3/s larger than under the current climate (about an 8% increase in mean flow)
- The monthly mean flow is projected to increase or stay the same in 10 months of the year, and to reduce by 1–2 m3/s in December and January
- The months with greatest projected absolute increase in flow are August, September and October (each increased by ~18 m3/s compared to the model flows for the current climate)

3.3.1 Discussion of river flow projections

The main source of the projected increase in flow for 2040 is the projected increase in precipitation for July, August, September, and October (see

Figure 2-2). At the example location C in the headwaters of the Rangitata, these increases are 50–70 mm in each of those 4 months.

The predicted increase in temperature means that there is no significant additional modelled snowmelt in summer from the increased spring precipitation. This is because the hydrology model calculates that much of the extra precipitation is expected to either fall as rain and thus be discharged as river flow in spring, or to melt relatively quickly.

The reliability of the flow projections is most strongly dependent on the reliability of the projected increases in precipitation in July–October. To assess this reliability, we investigated the level of agreement amongst the global models used to create the 12-model average precipitation used in this study. This showed that no more than 2 of the 12 models predict a decrease in alpine rainfall for 2040. Thus the 12-model average we have used is based on models which generally agree that spring precipitation will increase by 2040 relative to 1980-99.

It is unclear whether the statistical downscaling method has a significant effect on the projections. Recent assessments indicate that it explains 40–60% of the variation in winter precipitation (Ministry for the Environment 2008, Fig A3.1). Further research is underway on the use of dynamical downscaling techniques, such as Regional Climate Modelling, which may lead to improved results.

There is strong agreement among global models for an increase in annual average temperature by 2040, so this is less of a source of uncertainty. However, a sensitivity test revealed that seasonal timing of flows is sensitive to this ~1 degree temperature change. To summarise the results of that test very crudely, every half degree of warming shortens the melt season by about a month. This result is not transferable to other basins, as it depends on the specific basin elevations, temperature and precipitation patterns of the Rangitata.

The second most important factor in determining the reliability of the flow projections is the modelling of the seasonal snowpack. Because of the absence of systematic measurements of snow in the catchment (and in other seasonal snowfields of New Zealand), the snow submodel in Topnet has not been tested directly. The modelling of the snow had to be inferred from the delays between precipitation and measured streamflow. The results are not inconsistent with the general understanding of seasonal snow in New Zealand. A more direct evaluation of the snow model is needed in future studies. New research is in progress to develop a national snow and ice monitoring network, and to make best use of remote sensing of snow covered areas (made challenging by extensive cloud cover). Improved data are needed to support further progress in snow sub-model development: Clark et al. (submitted) gives an example of this research.

In the scenario modelling we have assumed that no hydrologically significant changes take place in (i) catchment vegetation (ii) diversion or abstraction of river water (iii) sub-daily distribution of rainfall. The first two assumptions could be addressed if they were relevant to the problem and scenario information was available.

The third point above is more problematic, since detailed scenarios for changes in sub-daily rainfall are not yet available. It is expected that extreme rainfalls will increase with the projected temperature increases for 2040. This is independent of changes in seasonal or long-term mean precipitation, and is expected because a warmer atmosphere can hold (and therefore produce as rainfall) more moisture (e.g., for every 1 °C increase in temperature there is an approximate 8% increase in the 24-hour 100-year average recurrence interval rainfall amount). See Ministry for the Environment (2008) for details and quantitative guidance on extreme rainfall, especially for other durations and average recurrence intervals. The climate change scenarios used here do not include this increase in rainfall intensity, because methods still need to be developed to appropriately link changes in extreme rainfall into long daily rainfall series. In the meantime, since catchments produce more river flow per unit rainfall in more intense rainfall events, this effect might be expected to slightly increase the mean flow of the river, though the extent of this potential effect is not quantified here.

3.4 SUMMARY

The Topnet model was able to be well validated for the Rangitata catchment above Klondyke. This represents a significant step forward on the work reported in LE (2001a).

The effect of climate change on climate and river flow in the Rangitata catchment and associated irrigation areas was estimated. Only one climate change scenario was considered, a "middle of the road" A1B emissions scenario for 2040. The outputs from 12 global models of the IPCC Fourth Assessment were downscaled to provide appropriate spatial detail, and then averaged to provide a single projection.

Broadly speaking, climate change projections for 2040 within the study area indicate annual average temperatures about one degree warmer than the average for 1980–99. Changes in annual average precipitation range from increases of up to 400mm/year in the headwaters to little change on the plains. Changes in annual average potential evaporation for 2040 range from increases of 60mm/year on the plains, to small decreases in the headwaters of the Rangitata. In terms of seasonal changes, the largest projected increases in precipitation for the headwaters are in winter and spring, while seasonal rainfall patterns on the plains are not projected to change. Seasonal warming is least in spring and early summer; otherwise the warming is uniformly distributed through the year. The increases in potential evaporation are largest in spring and summer on the plains.

The main differences between modelled flows for the current and 2040 climate are:

- Mean flows for 2040 are projected to be about 8 m3/s larger than under the current climate (about an 8% increase in mean flow)
- The monthly mean flow is projected to increase or stay the same in 10 months of the year, and to reduce by 1–2 m3/s in December and January
- The months with greatest projected absolute increase in flow are August, September and October (each increased by ~18 m3/s compared to the model flows for the current climate)

The main source of the projected increase in flow for 2040 is the projected increase in precipitation for July, August, September, and October. This is the main source of uncertainty in the river flow projections. The precipitation projection used in this study is based on 12 models which generally agree that spring precipitation will increase by 2040 relative to 1980-99. The second most important source of uncertainty is the snow sub-model of Topnet, which could not be directly validated because there are no systematic measurements of snow storage in the catchment.

Future assessments of climate change impacts could be enhanced by use of new methods for downscaling climate data, such as Regional Climate Modelling, and improvements to Topnet that will result from systematic data on seasonal snow, considered as a water resource.

4 Effects of Climate Change on Irrigation Water Use and Groundwater Recharge

4.1 OVERALL APPROACH

The aims of this section of work were twofold:

1. Develop daily time series of irrigation water use for a representative farm located in each VCN grid square for historical and 2040's climate regimes as key inputs to the water supply reliability analyses described in Section 5.
2. Provide summary statistics of the effects of the 2040's climate projections on irrigation requirements and drainage volumes at a farm scale.

The daily time series of irrigation water use was derived for a representative pasture-based farm system from daily climate data time series, and other parameters, by computer simulating the operation of the farm's irrigation system.

Two irrigation water use time series were derived for each of the main soil types present in each VCN grid square – one based on climate parameters measured over the base period 1972 - 2007 and the other based on climate parameters projected to occur in the 2040's under climate change scenario A1B.

Changes in irrigation water use and in drainage attributable to a change in climate between the base period and the 2040's were quantified and summary statistics derived.

This section describes the irrigation simulation model and its validation, the primary inputs to the model and their source. It concludes by presenting the summary statistics that describe the changes in irrigation system water use and drainage that are projected to occur.

4.2 THE FARM IRRIGATION SIMULATION MODEL

At the project planning phase it was intended that FarmSim, a model for simulating water and nitrogen dynamics on a daily time-step at paddock and farm scale, be validated and used in this project. Unfortunately this model was not available in time for calibration and validation for this project. An alternative model, IrriCalc-FS, was used.

IrriCalc-FS is a model for simulating irrigation water use for each of the many paddocks that make a farm and is based on a single-layer soil water balance model as described in Bright (1986). It is a farm-scale version of IrriCalc, a single paddock irrigation water use simulator. The irrigation management options that were modelled using IrriCalc-FS are rule-based and are equivalent to those built into FarmSim.

The primary difference between FarmSim and IrriCalc-FS that is relevant to this project is the way in which plant growth is simulated.

The plant growth component in FarmSim calculates biomass production daily, based in radiation inputs and the current green leaf area index. If the plant comes under soil moisture stress, which it frequently does under non-irrigated conditions in the project area, biomass production is adversely impacted meaning that leaf area does not develop as fast and to the extent that it would under irrigated conditions. This means plant water use is less than for fully irrigated conditions and drainage is greater.

The plant model component in IrriCalc-FS assumes that green leaf area index follows the same pattern each year. This pattern has been calibrated to data obtained under fully irrigated conditions. Crop water use and drainage have been shown to be well estimated for irrigated conditions. However the lack of response to soil moisture stress means that this model will underestimate drainage under non-irrigated conditions.

In terms of estimating water supply reliability, the use of IrriCalc-FS has no significant impact on the results – the groundwater recharge estimates required are all based on the assumption of irrigated conditions.

4.2.1 Validation of the Irrigation Simulation Model

IrriCalc has been validated using data from an Environment Canterbury drainage lysimeter site near Dunsandel that is representative of irrigated intensive pastoral farms. The validation was undertaken as part of work for Irrigation New Zealand to develop and test a method for estimating seasonal irrigation water use.

Measured rainfall, irrigation, drainage and soil moisture data were able to be obtained for this site. This meant that actual evapotranspiration, the only unknown, was able to be calculated directly from measured data.

IrriCalc uses a crop factor, which is the ratio of actual evapotranspiration to the potential evapotranspiration of a reference crop, to capture the effects of plant canopy height, structure and resistances to water loss on plant water use. A time series of actual evapotranspiration divided by potential evapotranspiration (estimated by NIWA using data from the Lincoln climate station) was calculated for the period 1 July 1999 to 30 June 2001. This is referred to as the calibration period. This two year time series was split into two single years, referenced to 1 July, and averaged to provide a daily crop factor time series for irrigated pasture. This is shown in Figure 4-1. The resulting crop factor time series was simplified a little by smoothing out some of the variability.

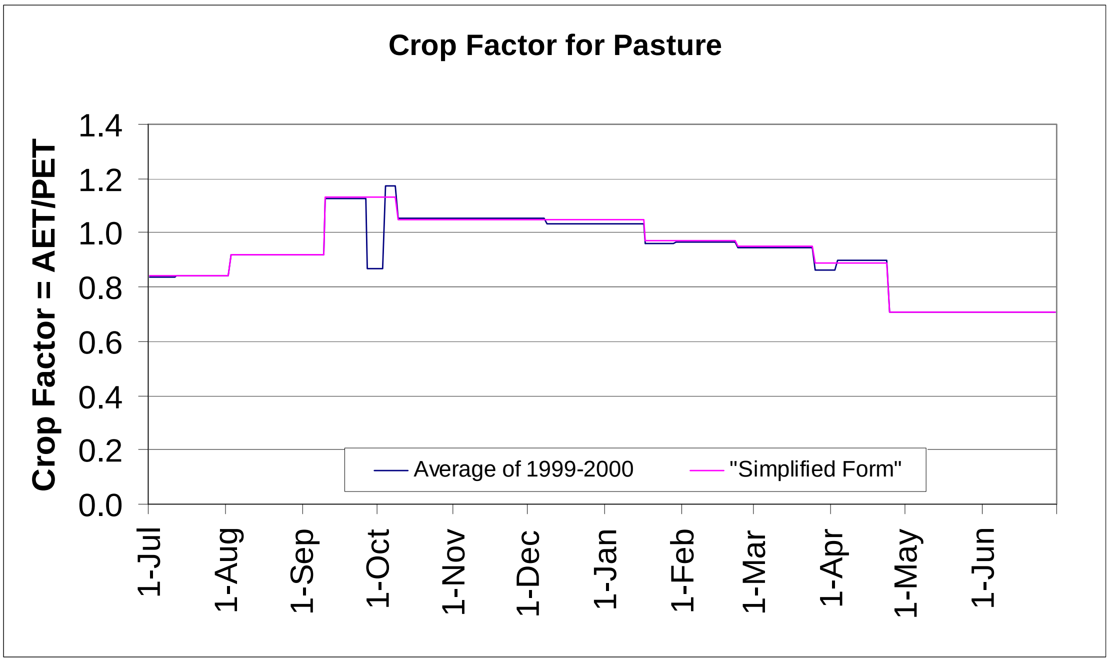

Figure 4-1: Crop Factor for Pasture

The measured inputs of rainfall and irrigation, along with potential evapotranspiration (PET) derived from the Lincoln climate station and the derived daily crop factor time series were then used as inputs to Irricalc.

The programme was run for the calibration period to produce a modelled drainage time series, which was then compared to the measured lysimeter drainage time series. The results of doing so are shown in the graphs that follow. The purpose of this comparison was simply to check the accuracy of the calculated crop factor and the effects of averaging and smoothing the crop factor.

The results of this comparison are shown in Figures 4-2, 4-3 and 4-4.

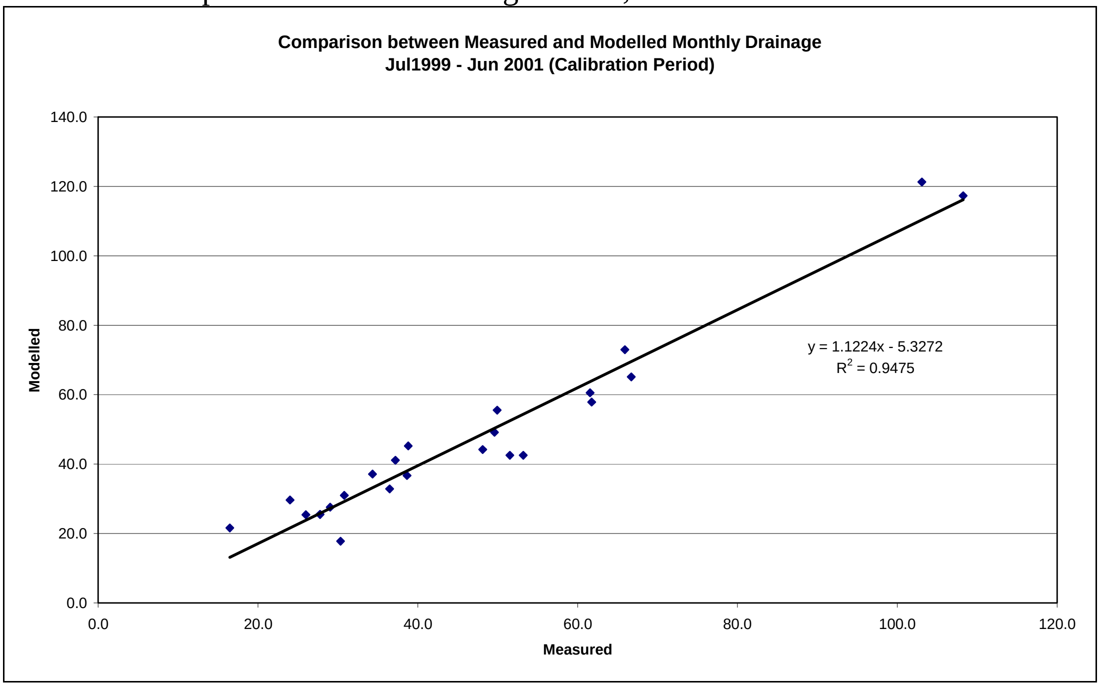

Figure 4-2: Comparison of Modelled and Measured Drainage over the “Calibration Period”

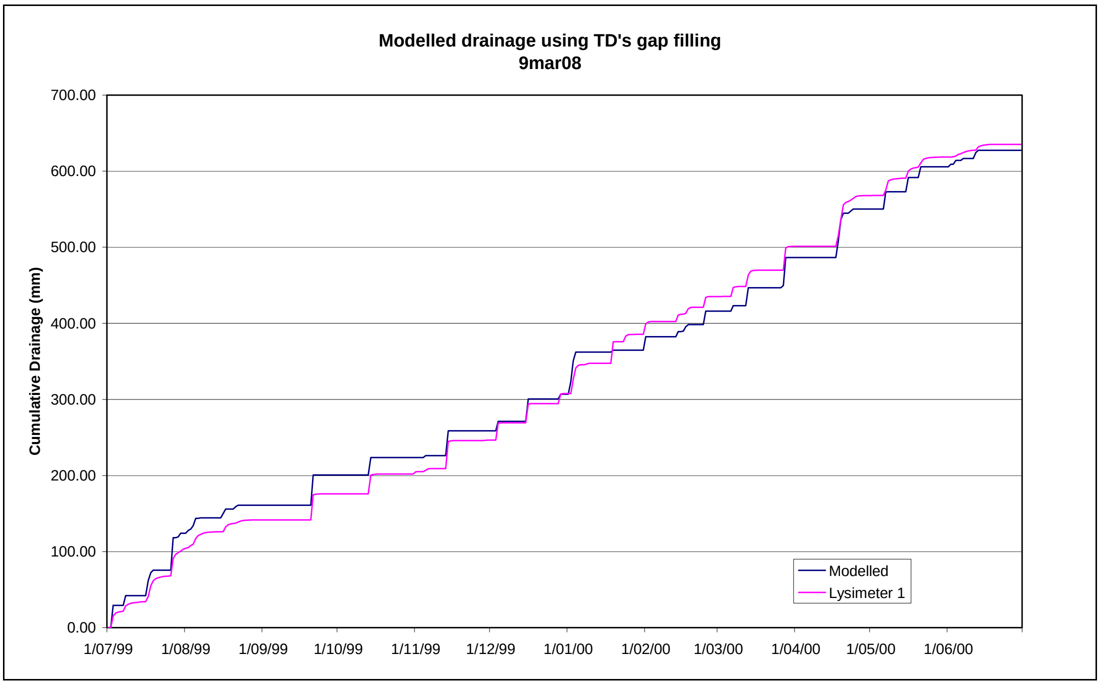

Figure 4-3: Comparison of Modelled and Measured Cumulative Drainage for 1999/2000

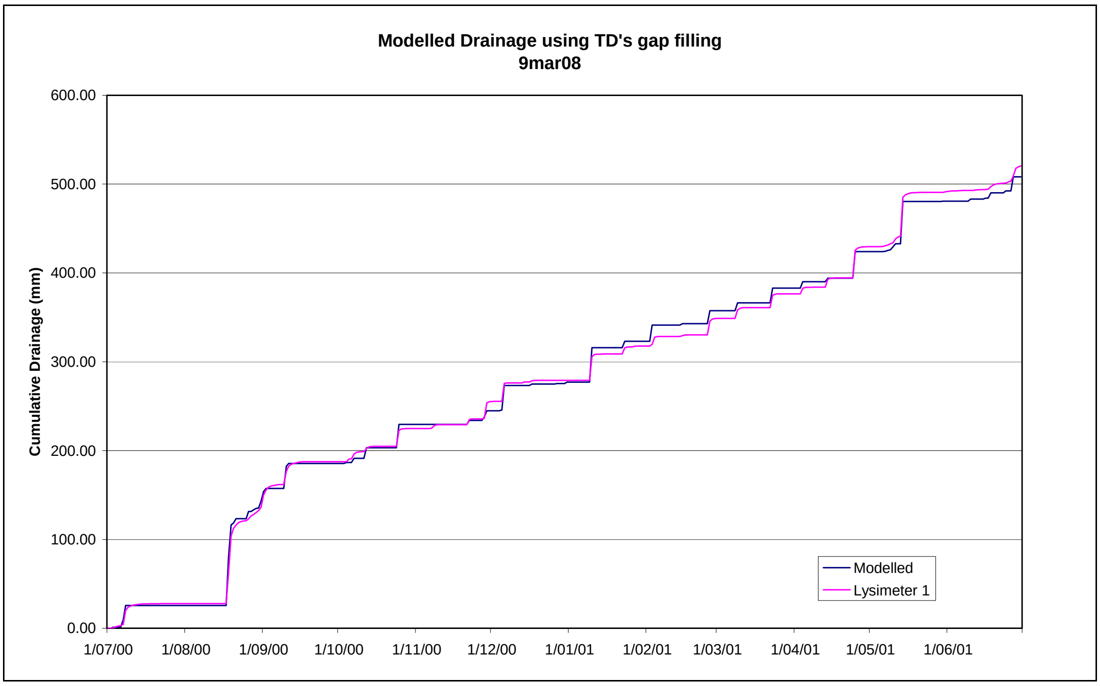

Figure 4-4: Comparison of Modelled and Measured Cumulative Drainage for 2000/2001

The 1998/99 year was not used for calculating the crop factor so has been used as a validation season. Comparison of the measured and modelled drainage for this year are shown in Figures 4-5 and 4-6.

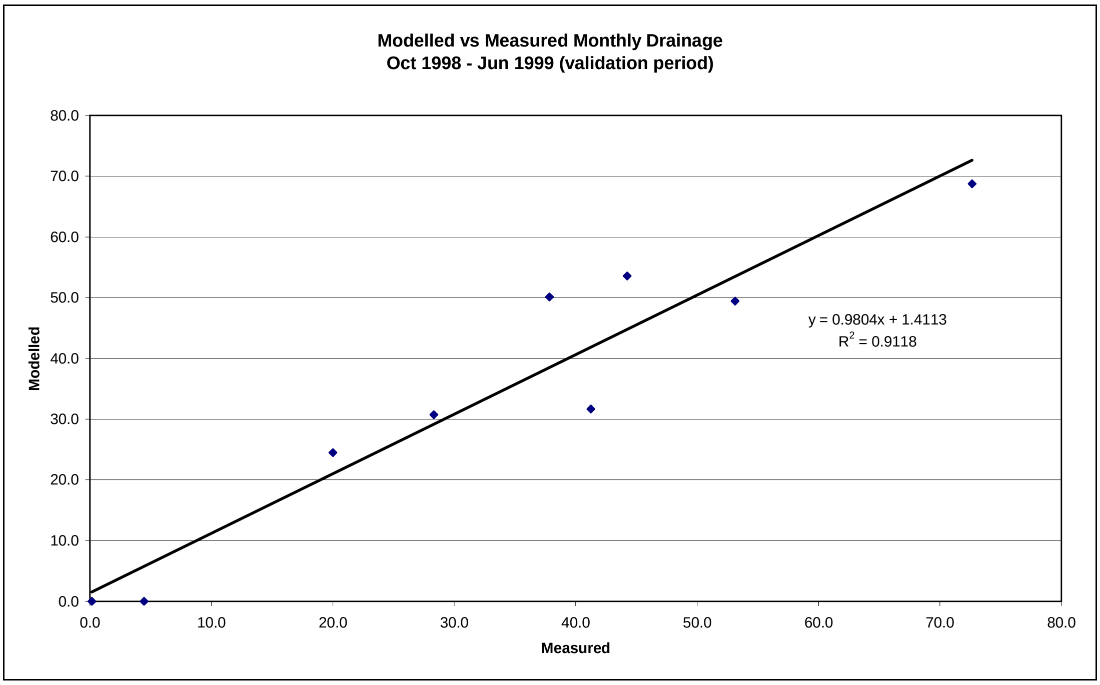

Figure 4-5: Comparison between Measured and Modelled Drainage for Validation Period

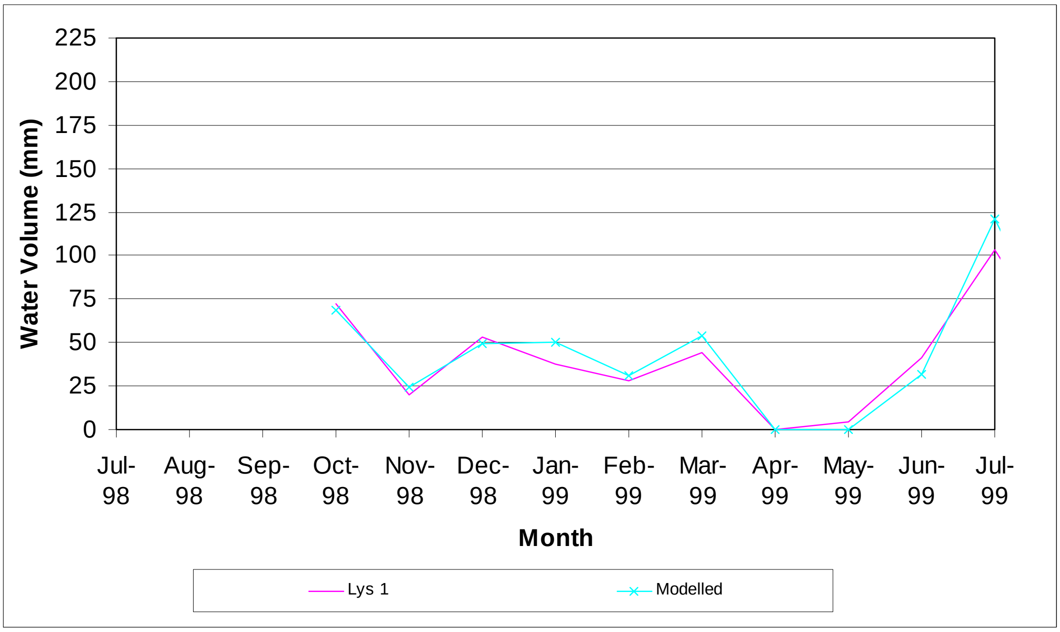

Figure 4-6: Comparison between Measured and Modelled Drainage Depths for 1998/99 Irrigation Season

These comparisons show that both the calibration and the validation are very good and give confidence in the use of the model for estimating irrigation water use and drainage to groundwater for irrigated pasture grazed by dairy cows.

4.3 GENERATING IRRIGATION WATER USE AND GROUNDWATER RECHARGE SERIES

4.3.1 Irrigable Area

The irrigable area was determined to be all of the area bounded by the Rangitata and Ashburton Rivers, the coastline and the foothills, that has a slope of less than fifteen degrees. This area is shown in Figure 4-7, overlaid by the NIWA VCN grid.

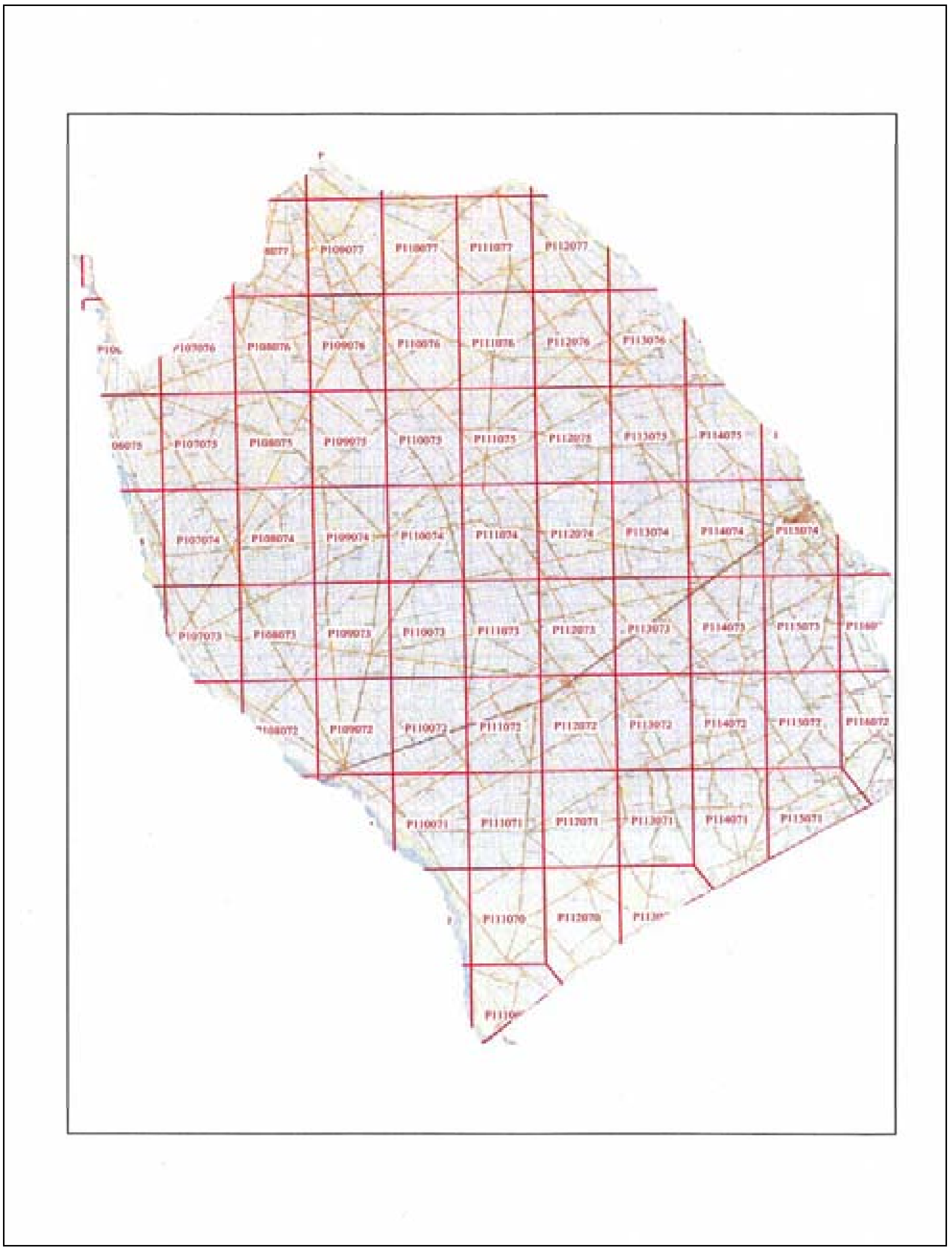

Figure 4-7: Area Assumed to be Irrigable

4.3.2 Land-use

For the purposes of this study it was assumed that all of the study area was in irrigated pasture. This assumption leads to greater estimates of irrigation water use and lower estimates of drainage than would currently occur because some of the land-use is arable and not all of the area is irrigated. Providing sufficient, reliable, water is made available, it is reasonable to assume that all of this area will be irrigated. The balance between intensive pastoral and arable farming will fluctuate in response to changes in financial returns.

4.3.3 Soil Characteristics

The key soil characteristic required by the IrriCalc model is the quantity of plant available water in the root zone, between the soil's full point (or field capacity) and wilting point. This information was obtained from LandCare Research's soils database. For the study area the following levels of plant available water were used: 50, 62, and 124 mm.

4.3.4 Irrigation equipment and its management

Key characteristics of the irrigation equipment and its management are the average depth of water applied during an irrigation event, the uniformity with which that water is applied, and the criteria applied to determine when to irrigate.

The irrigation rules that are able to applied in IrriCalc that determine the timing and amount of irrigation are summarized in the following table:

Table 4-1: Outline of IrriCalc Irrigation Rules

		When to Irrigate		
		Never	Fixed Return Period	Soil Water Trigger, providing days since last irrigation > return period
Application Depth	Fixed depth: User defined	x	x	x
	Variable Depth: Return Soil Water to a set point	x	x	x

4.3.4.1 Average application depth.

The average application depth depends on the design of the irrigator and the willingness of the operator to adjust the average application depth from one irrigation event to another. For the purpose of this study it was assumed that a RotoRainer would be used, this being the most prevalent type of travelling irrigator, and that the application depth would not be adjusted from one event to the next. A fixed average application depth of 50mm was assumed, this being a typical RotoRainer setup.

4.3.4.2 Application Uniformity

The spatial uniformity of application is specified in terms of Christiansen's Uniformity Coefficient.

This factor is used, along with the average application depth and the soil water status at the time of irrigation, to determine how much of each irrigation event drains beyond the root zone. Implicit in this calculation is the assumption that the spatial distribution of application depth can be represented by the Normal distribution.

In the simulations conducted for this project a uniformity coefficient of 70% has been used. This value is based on the results of tests of travelling irrigators conducted by NZAEI in the 1980's.

Irrigation application efficiency typically varies from application event to application event, and is an output of IrriCalc simulations.

4.3.4.3 Deciding when to irrigate

Irrigation was initiated if two criteria were satisfied:

- The soil water content in the root zone was less than or equal to 50% of the difference between the full point (field capacity) and wilting point, and
- More than ten days had passed since the paddock was last irrigated.

4.3.4.4 Other factors of significance

It was assumed for this project that the farm water supply rate was 0.8 litres/second/hectare irrigated. This was sufficient to allow about 20 hectares to be irrigated each day, if necessary, which would be achievable with four RotoRainers in operation.

4.3.5 Climate

The baseline climate and the 2040's climate scenario are described in Section 2.

4.4 CHANGES IN IRRIGATION DEMAND UNDER CLIMATE CHANGE SCENARIO A1B (2040)

The monthly mean irrigation water use, assuming no supply restrictions, is shown for the 1990's and the 2040 scenario in Figure 4-1. Irrigation water use is projected to increase in most months. The absolute change in the monthly mean irrigation water use is greatest in January, September and December.

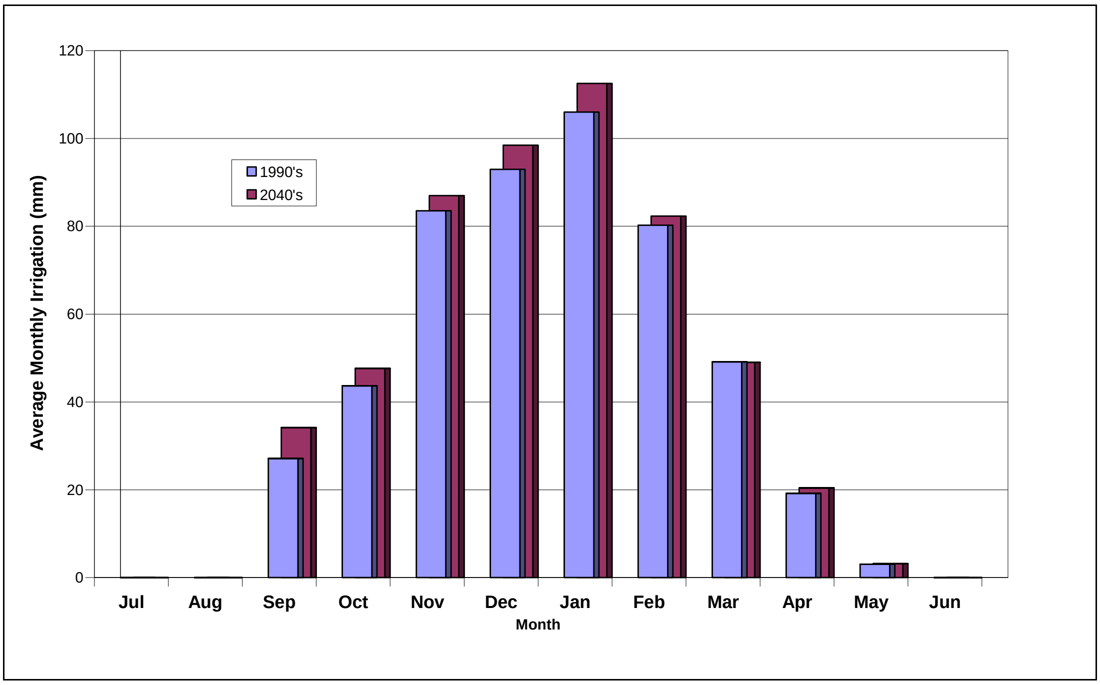

Figure 4-8: Monthly mean irrigation water use for the 1990's and the 2040 climate scenario.

In terms of the relative change in irrigation water use, the greatest increases are projected to occur at the start and end of the irrigation season – "the shoulders of the season". This can be seen in Figure 4-2. It should be noted that irrigation water use in September and May in the base period is low so small absolute increases in water use translate to large relative changes.

The increase in irrigation water use through spring and summer is consistent with the projected increase in potential evapotranspiration rate over this period, and minimal change in rainfall. From February through to June the projected increase in potential evapotranspiration gradually declines to a minimal increase in June.

The average increase in total irrigation season water use is projected to be 6%.

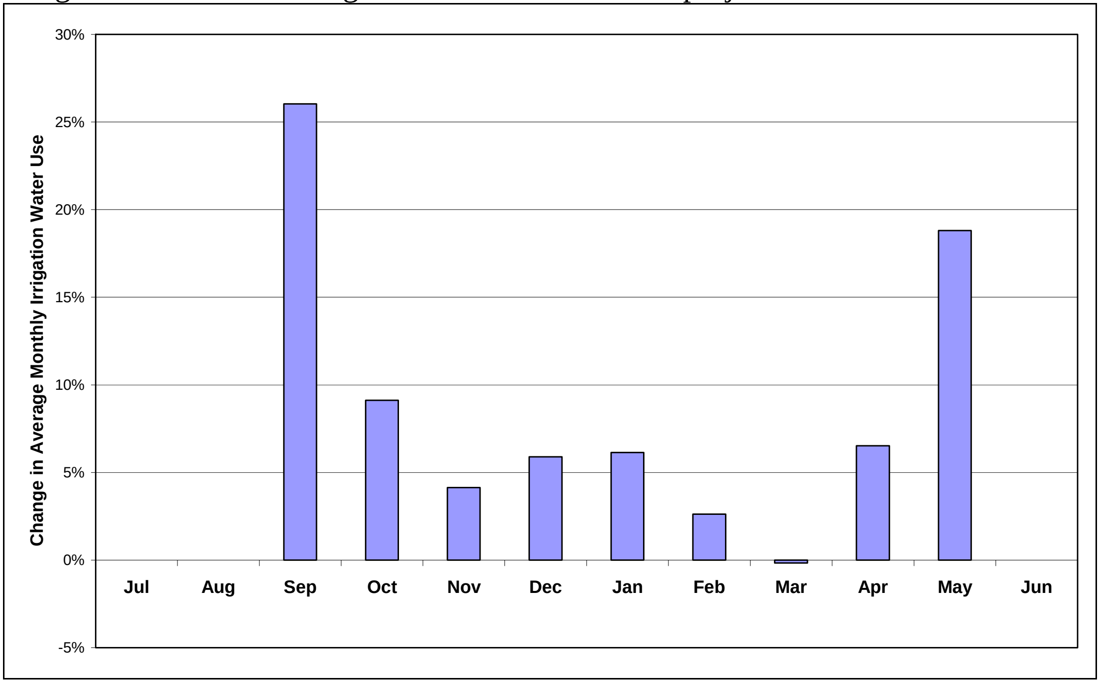

Figure 4-9: Change in mean monthly irrigation water use as a proportion of the water use over the base period.

4.5 CHANGES IN GROUNDWATER RECHARGE UNDER CLIMATE CHANGE SCENARIO A1B (2040)

4.5.1 Changes for Un-irrigated Farms

The monthly mean drainage from the root zone, assuming no irrigation occurs, is shown for the 1990’s and the 2040 scenario in Figure 4-3. Drainage is projected to decrease in almost all months. The absolute change in the monthly mean drainage is greatest in July, August and September. The slight increase in drainage in March is probably due to the projected decrease in potential evapotranspiration in March and a slight increase in rainfall.

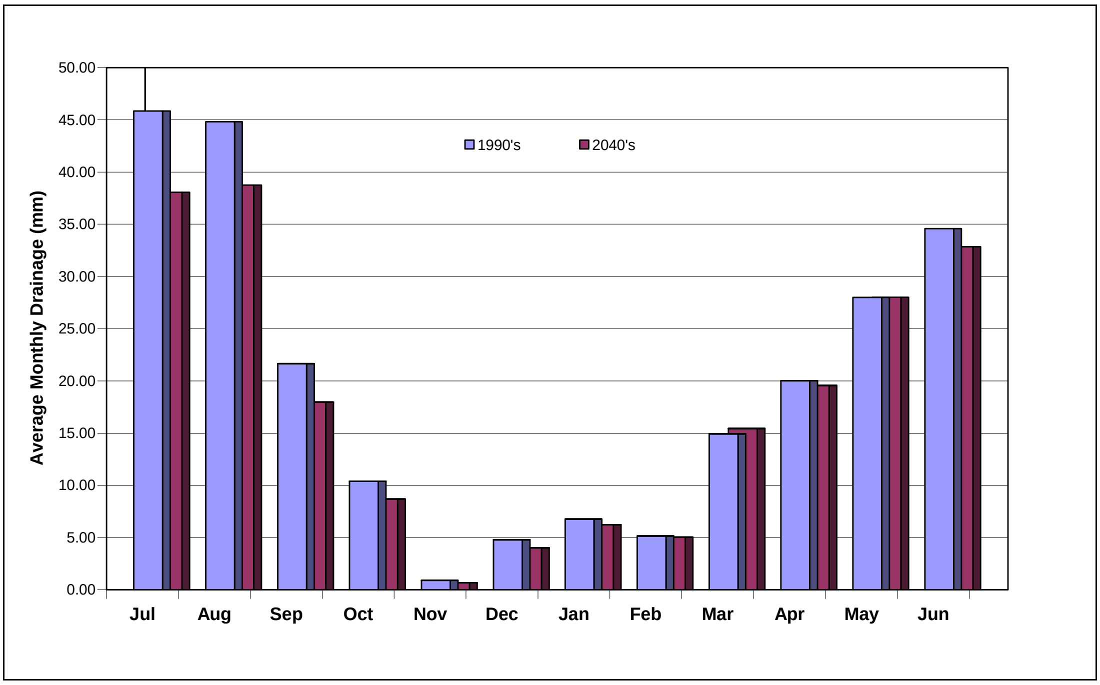

Figure 4-10: Monthly mean drainage for the 1990’s and the 2040 climate scenario, for un-irrigated pastoral farms.

In terms of the relative change in drainage, the greatest decreases are projected to occur in the July to January period. This can be seen in Figure 4-4.

The decrease in drainage over this period is consistent with the projected increase in potential evapotranspiration rate over this period, and minimal change in rainfall.

The average decrease in the annual drainage volume is projected to be 10%.

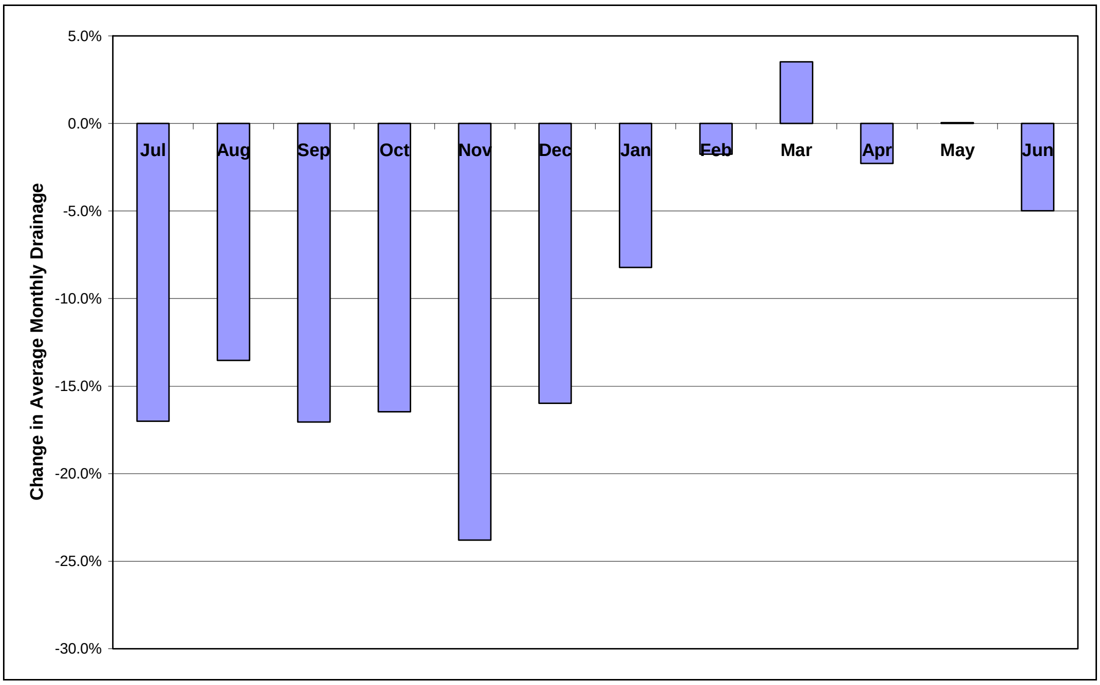

Figure 4-11: Change in mean monthly drainage from un-irrigated land as a proportion of the drainage over the base period.

4.5.2 Changes for Irrigated Farms

The monthly mean drainage from the root zone of irrigated pastoral farms is shown for the 1990's and the 2040 scenario in Figure 4-5. Drainage is projected to decrease in June, July, August and September. The absolute change in the monthly mean drainage is greatest in July and August.

In terms of the relative change in drainage, the greatest decreases are projected to occur in the July and August. This can be seen in Figure 4-6.

Irrigation using equipment such as rotary boom irrigators on generally light soils significantly modifies the temporal distribution of drainage, compared to the un-irrigated situation. Maintaining higher soil water levels during the summer period increases the proportion of rainfall that drains through the soil profile. While this has the effect of reducing the impact of climate change on drainage during the bulk of the irrigation season, it also increases the risk of nitrate leaching.

The average decrease in the annual drainage volume is projected to be 3%, significantly less than from un-irrigated farms.

A consequence of irrigation is a reduction in the impact of climate change on drainage volumes, providing the irrigation water source is a river.

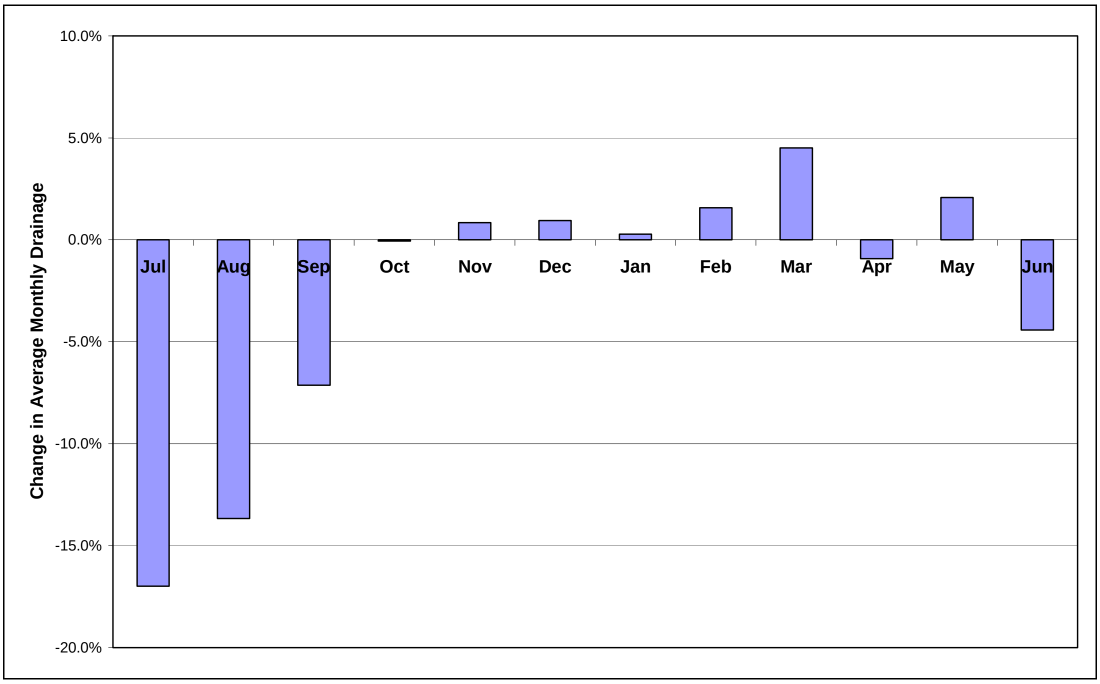

Figure 4-12: Change in mean monthly drainage from irrigated land as a proportion of the drainage over the base period.

4.6 SUMMARY

The model used to simulate irrigation water use and drainage validated well against drainage lysimeter data from Environment Canterbury.

An analysis of the daily time series of irrigation water use and drainage, computer simulated using climate data for the base period and climate data synthesised for the 2040's and based on climate change scenario A1B has shown that:

- On an average annual basis irrigation water use increases by 6%
- In absolute terms, the largest increases in mean monthly irrigation water use are projected to be in mid-season (December and January)
- In relative terms, the largest increases are in the shoulders of the irrigation season.
- On an average annual basis, drainage from un-irrigated land reduces by 10% and from irrigated land by 3%.
- Irrigation, from surface water sources, mitigates the effects of climate change on an important source of groundwater recharge.

5 Water Supply Reliability under Climate Change Scenario A1B (2040)

5.1 OVERALL APPROACH

This section assesses whether or not the projected change in climate improves or reduces water supply reliability, relative to that of the baseline climate. To do this it brings together the Rangitata River mean daily flow series estimated in the manner described in Section 3 with the irrigation water use and drainage time series estimated in the manner described in Section 4.

Water supply reliability is quantified in this work by first calculating a daily time series of the ratio of water supply rate to irrigation demand rate. When this ratio is less than one a supply shortfall exists. If there is no irrigation demand on a particular day, the ratio is not calculated. This time series is then analysed to determine the magnitude and frequency of occurrence of shortfalls to gain an understanding of the reliability of the water supply – its capacity to meet demand.

The magnitude of supply shortfalls has been characterised as “noticeable”, “moderate”, and “severe”. A noticeable shortfall is said to have occurred if the supply to demand ratio was less than or equal to 0.95 for more than 20% of the irrigation season. A moderate shortfall occurred if the ratio was less than or equal to 0.80, and a severe shortfall occurred if the ratio was less than or equal to 0.5, for more than 20% of the irrigation season.

To gauge the effect of projected climate change, the frequency of occurrence of noticeable, moderate and severe shortfalls in each month were quantified for the baseline climate and the 2040’s. This enabled a judgment to be formed about whether projected climate change could be expected to improve or reduce water supply reliability, and provided information about whether the change in reliability was the result of a change in demand, a change in supply, or a combination of both.

In an irrigated catchment, groundwater supply reliability, irrigation water use and surface water supply reliability are interdependent because of flowpath linkages and feedback loops. Limitations in the current suite of modelling tools mean that surface water supply reliability and groundwater supply reliability must be assessed sequentially, not simultaneously.

Groundwater supply reliability was assessed by assuming that if the extra volume of recharge from surface-water supplied irrigation equalled or exceeded the net use of groundwater for irrigation, on an average annual basis, then the groundwater balance would remain in its natural state (or better) on average and groundwater would remain accessible. If the surface-water supplied irrigation was then reliable enough to meet the irrigation reliability criteria, both surface-water and groundwater supplies would be considered reliable. If the surface-water supplied irrigation delivered the average annual groundwater recharge but did not meet irrigation reliability criteria, the groundwater might still be reliable. However to establish whether this is so requires computer simulation runs using a model such as Aqualinc’s Canterbury Groundwater Model. This was beyond the scope of this project.

5.2 MAINTAINING THE GROUNDWATER BALANCE

If the groundwater balance is maintained on an average annual basis by providing sufficient extra recharge via surface-water supplied irrigation to offset the net use of groundwater, spring-fed stream-flow and subsurface coastal discharges are maintained in their natural state, at least on average. On going use of groundwater on this basis should meet sustainability criteria and not be subject to restrictions.

5.2.1 Area of surface-water supplied irrigation required to balance groundwater use under baseline climate

Each hectare of land irrigated from groundwater results in, under the baseline climate, an average annual net use of 2790 cubic metres of water. Under the baseline climate, each hectare of land irrigated from surface water results in a 2260 cubic metre increase in the average annual groundwater recharge.

To maintain the groundwater balance on an average annual basis under the baseline climate, the area of surface-water supplied irrigation must equal 1.235 times the area of groundwater supplied irrigation (2790 / 2260).

The total irrigable area in the study area is 113,820 hectares. The optimum area of the groundwater supplied zone, based on the baseline climate is therefore about 51,000 hectares (113,820 / (1+1.235). If there is sufficient, reliable, surface water to irrigate the balance of the study area (62,820 hectares) then both the surface water and groundwater could be considered reliable water sources.

5.2.2 Area of surface-water supplied irrigation required to balance groundwater use under 2040's climate

Each hectare of land irrigated from groundwater results in, under the 2040's climate, an average annual net use of 3000 cubic metres of water. Under the 2040's climate, each hectare of land irrigated from surface water results in a 2350 cubic metre increase in the average annual groundwater recharge.

To maintain the groundwater balance under the projected 2040's climate, the area of surface-water supplied irrigation must equal 1.277 times the area of groundwater supplied irrigation

The total irrigable area in the study area is 113,820 hectares. The optimum area of the groundwater supplied zone in 2040 is therefore about 50,000 hectares (113,820 / (1+1.277). If there is sufficient, reliable, surface water to irrigate the balance of the study area (63,820 hectares) then both the surface water and groundwater could be considered reliable water sources.

5.3 SURFACE WATER SUPPLY RELIABILITY

For the purposes of this project a water source was considered to be reliable if there were "noticeable" restrictions for no more than 2 years in 5 or "severe" restrictions for no more than 1 year in 10. A noticeable restriction was considered to have occurred when a greater than 5% restriction level was imposed for more than 20% of the irrigation season. A severe restriction was considered to have occurred when a greater than 50% restriction level was imposed for more than 20% of the irrigation season.

This benchmark is similar (slightly simplified) to reliability option 3 in LE (2001).

The irrigation demand time-series modelled for each of the VCN squares as described in Section 4 were aggregated and then scaled to provide irrigation demand time series for a surface water supplied irrigation scheme of 62,820 hectares (for baseline climate) and 63,820 (for 2040's climate). These irrigation scheme demand time-series were matched to water availability from the Rangitata River for the surface water supplied scheme area between the Rangitata and Ashburton Rivers.

Water availability from the Rangitata River was calculated from the mean daily flow time series estimated as described in Section 3 by applying to them the current consent conditions for the RDR take from the Rangitata River.

The water available each day from the Rangitata River was assumed to be split between the Rangitata to Ashburton area and the Ashburton to Rakaia area on the same basis as it is currently.

The daily time series of supply to demand ratio were summarised in terms of the average number of days per month that the supply to demand ratio was less than 0.95, 0.80 and 0.50. The following sections present these summary results.

5.3.1 Supply reliability during the baseline period

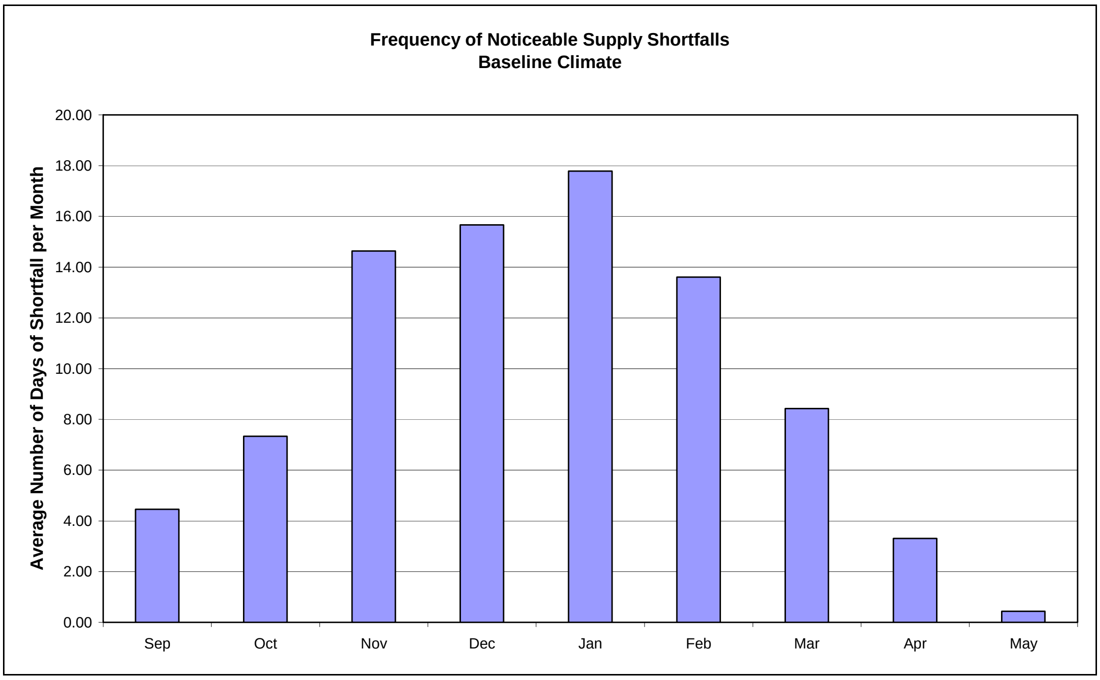

Figure 5-1: Frequency of Noticeable Supply Shortfalls during the baseline climate, based on optimum groundwater supply zone

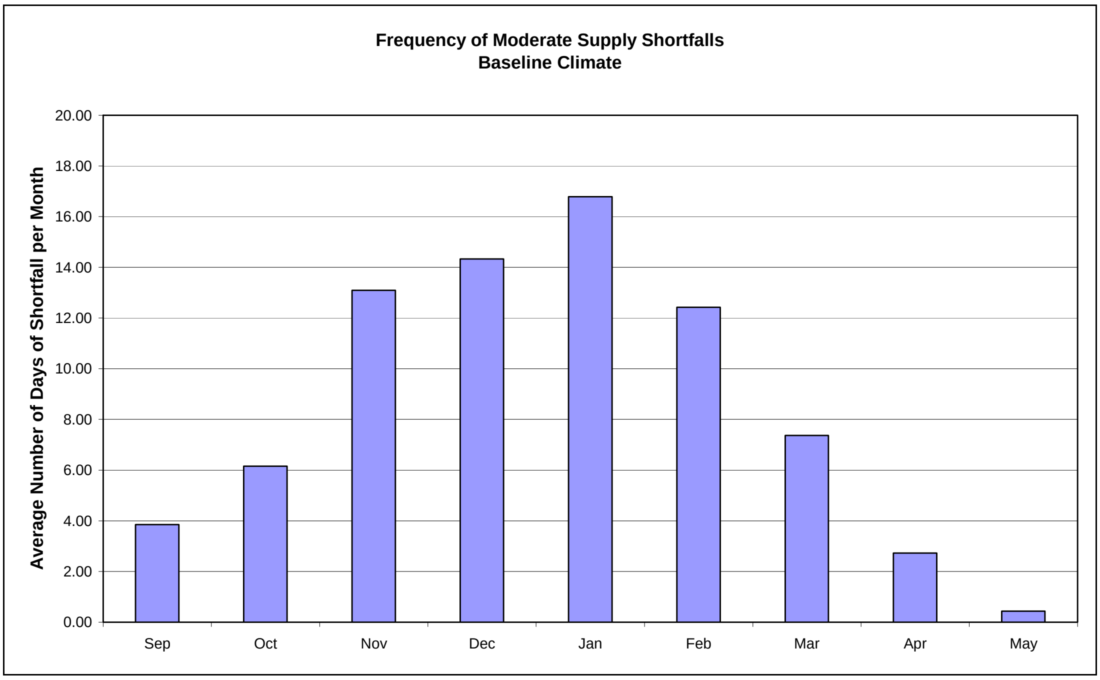

Figure 5-2: Frequency of Moderate Supply Shortfalls during the baseline climate, based on optimum groundwater supply zone

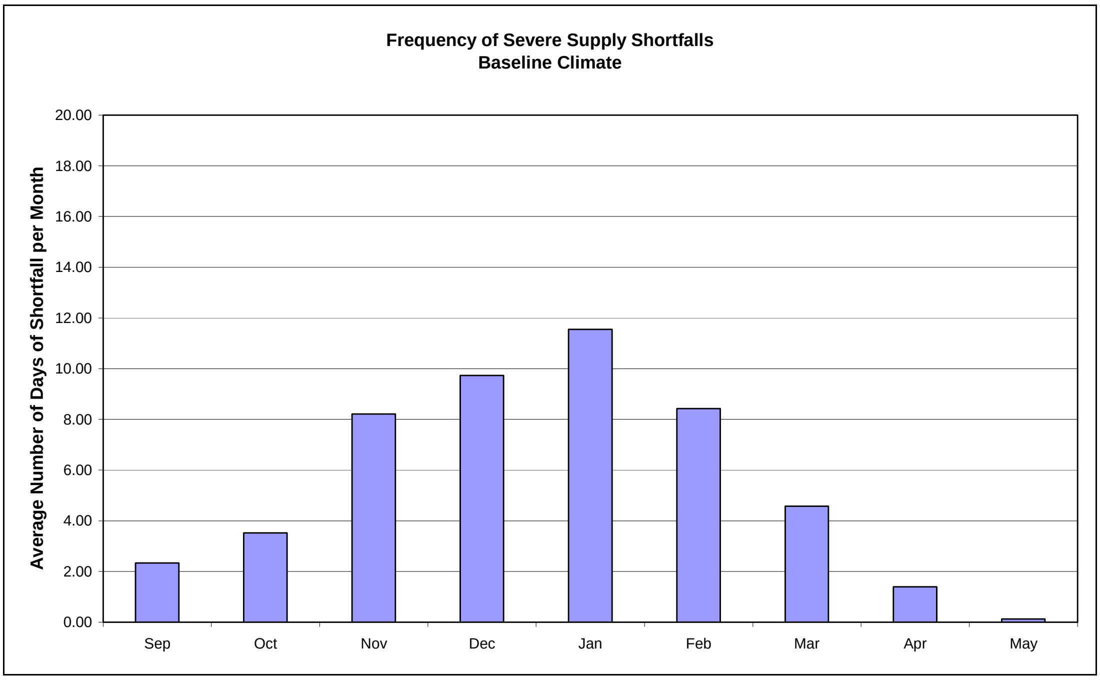

Figure 5-3 Frequency of Severe Supply Shortfalls during the baseline climate, based on optimum groundwater supply zone

5.3.2 Change in reliability under the 2040's scenario

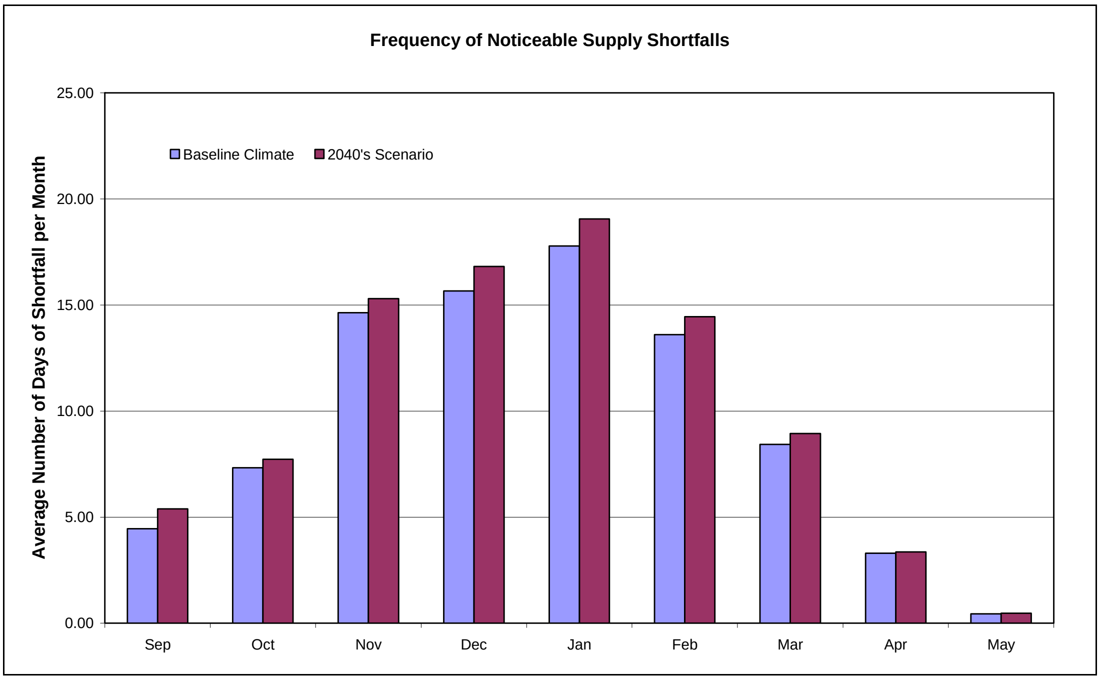

Figure 5-4: Change in the Frequency of Noticeable Supply Shortfalls, based on optimum groundwater supply zone

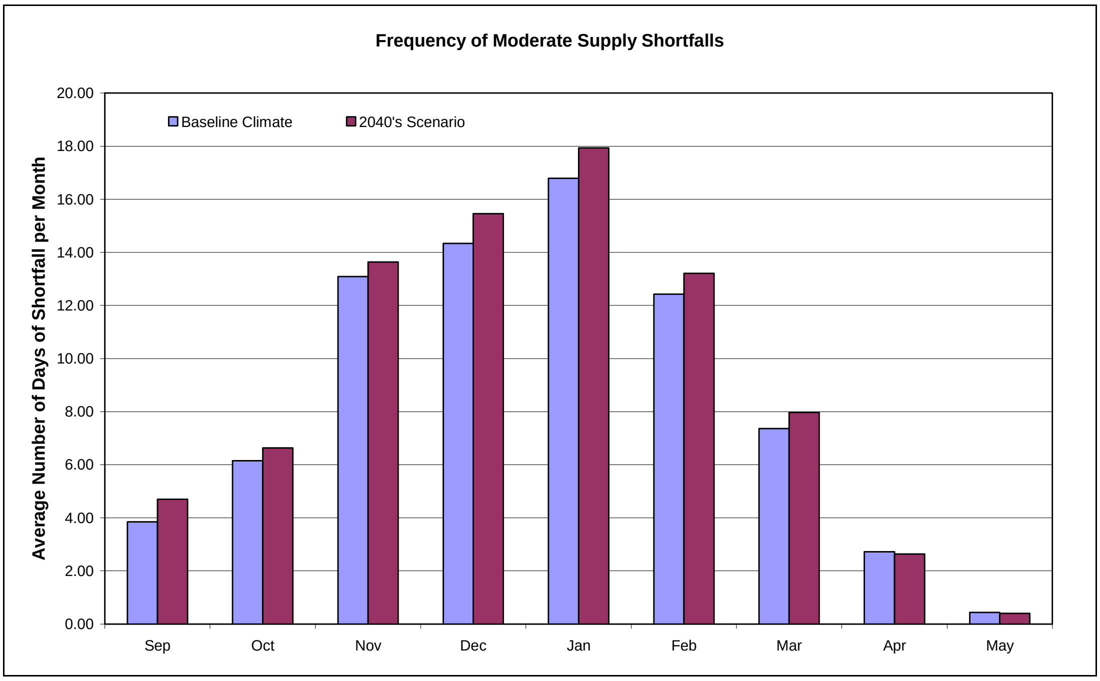

Figure 5-5: Change in the Frequency of Moderate Supply Shortfalls, based on optimum groundwater supply zone

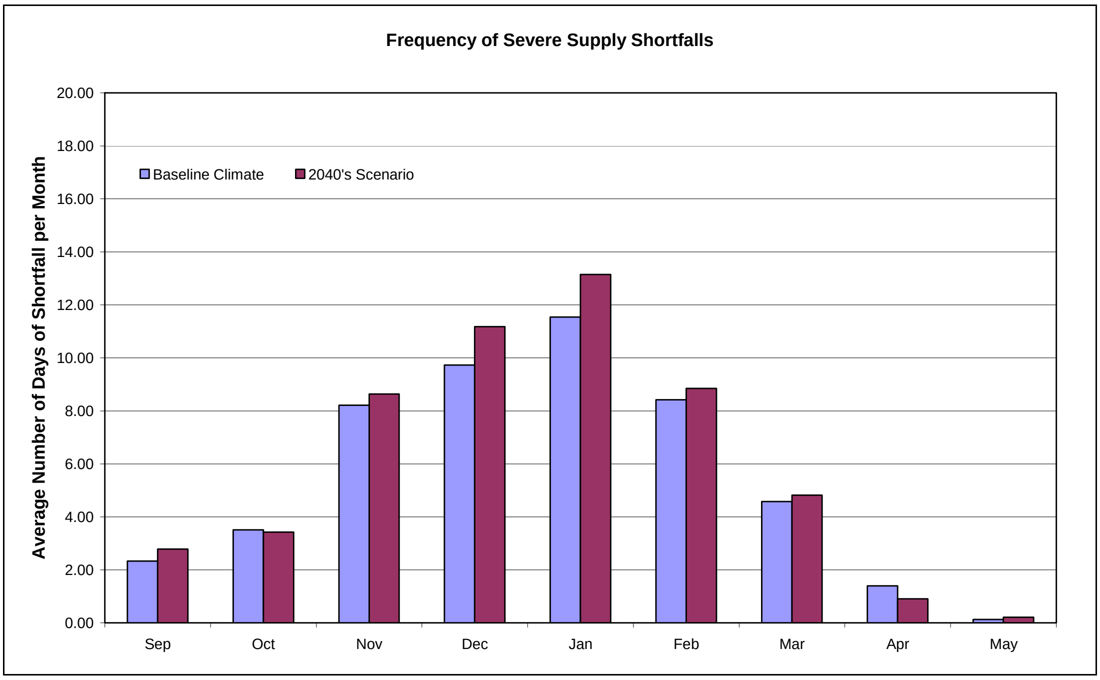

Figure 5-6: Change in the Frequency of Severe Supply Shortfalls, based on optimum groundwater supply zone

5.4 SUMMARY

This section set out to quantify the effects of projected climate change on water supply reliability by integrating the effects of climate change on irrigation demand, river flow and groundwater recharge from the land-surface.

The surface water supply during the baseline period of record would not have reliably irrigated the area of land required to balance the use of groundwater for irrigating 50,000 hectares, this being the optimum size of the groundwater zone. This was expected because the area irrigated is larger than is currently irrigated. On this basis the supply of groundwater to the 50,000 hectares could not be considered reliable unless more detailed analysis using a model such as the Canterbury Groundwater Model showed otherwise.

The projected 2040’s climate significantly increases the flow rate in the Rangitata River during some months, and reduces it in others. It also increases irrigation demand.

The overall effect of these climate driven changes is to reduce surface-water supply reliability, compared to the baseline reliability. This is the opposite conclusion to that reached in the 2001 analyses of the potential effects of climate change (LE, 2001).

The frequency of noticeable water shortages increases during the bulk of the irrigation season by about the same amount as does irrigation demand. However the frequency of severe water shortages increases substantially more during December and January than does irrigation demand, because of the combined effects of a decrease in water availability and an increase in irrigation demand.

6 Principal Sources of Uncertainty

Water supply reliability is about when, how frequent, how long and how bad are the mismatches between water availability and water-take needs.

For run-of-river takes the magnitude of future water-take needs relative to current allocation limits, and the day-to-day pattern of river flow about the flow thresholds at which water availability gets reduced by Regional Council, are of primary interest.

The matter of primary interest for groundwater takes on the Canterbury Plains is the number of successive years in which the annual land surface recharge is lower than the long term average annual land surface recharge.

For surface water takes that are backed by significant water storage capacity, the average annual volume of water available for taking is of primary interest. In systems with limited storage the pattern of average seasonal (3 monthly) volumes will be important.

The level of uncertainty about future irrigation water-take needs is dependent on the level of uncertainty about estimated daily rainfall and potential evapotranspiration time series for the Plains. Uncertainty in estimates of future land surface recharge and thus groundwater availability depend on the level of uncertainty in rainfall and potential evapotranspiration time series also. The main source of the projected increase in river flow for 2040 is the projected increase in precipitation in the catchment headwaters for July, August, September, and October. This is the main source of uncertainty in the river flow projections. Its primary relevance is to storage-based water supply systems. The second most important source of uncertainty in the river flow projections is the snow sub-model of Topnet, which could not be directly validated because there are no systematic measurements of snow storage in the catchment. Uncertainty in river flow projections due to uncertainty in the snow sub-model is significant for run-of-river water supply reliability because it is snow melt that sustains river flows above take-restriction thresholds deep into the irrigation season. The projected reduction in mean monthly river flow in December and January, and thus in water supply reliability, is considered to be attributable to a reduction in snow-melt flow in those months.

The reliability of potential evapotranspiration projections is most strongly dependent on temperature projections, followed by net radiation and wind-run projections. Current practice is to estimate potential evapotranspiration using a correlation with daily mean temperature. Hence the reliability of potential evapotranspiration projections depends on the reliability of the temperature projection and on the strength of the correlation between temperature and potential evapotranspiration. Currently there is a high degree of confidence in the direction of change in mean temperature, moderate confidence in the size of the change, and low confidence in the spatial and seasonal variation in temperature (see Ministry for the Environment 2008 for an explanation of the terminology "moderate confidence" and " low confidence").

The reliability of the flow projections is most strongly dependent on the reliability of the projected increases in precipitation in July–October. To assess this reliability, we summarised the level of agreement amongst the global models used to create the 12-model average precipitation used in this study. Figure 6.1 indicates that no more than 2 of the 12 models predict a decrease in alpine rainfall for 2040. Thus the 12-model average we have used is based on models which generally agree that spring precipitation will increase by 2040 relative to 1980-99.

It is unclear whether the statistical downscaling method has a significant effect on the projections. Recent assessments indicate that it explains 40–60% of the variation in winter precipitation (Ministry for the Environment 2008, Fig A3.1). Further research is underway on the use of dynamical downscaling techniques, such as Regional Climate Modelling, which may lead to improved results.

There is strong agreement among global models for an increase in annual average temperature by 2040, so this is less of a source of uncertainty. However, a sensitivity test revealed that seasonal timing of flows is sensitive to this ~1 degree temperature change. To summarise the results of that test very crudely, every half degree of warming shortens the melt season by about a month. This result is not transferable to other basins, as it depends on the specific basin elevations, temperature and precipitation patterns of the Rangitata.

The second most important factor in determining the reliability of the flow projections is the modelling of the seasonal snowpack. Because of the absence of systematic measurements of snow in the catchment (and in other seasonal snowfields of New Zealand), the snow submodel in Topnet has not been tested directly. The modelling of the snow had to be inferred from the delays between precipitation and measured streamflow. The results are not inconsistent with the general understanding of seasonal snow in New Zealand. A more direct evaluation of the snow model is needed in future studies. New research is in progress to develop a national snow and ice monitoring network, and to make best use of remote sensing of snow covered areas (made challenging by extensive cloud cover). Improved data are needed to support further progress in snow sub-model development: Clark et al. (submitted) gives an example of this research.

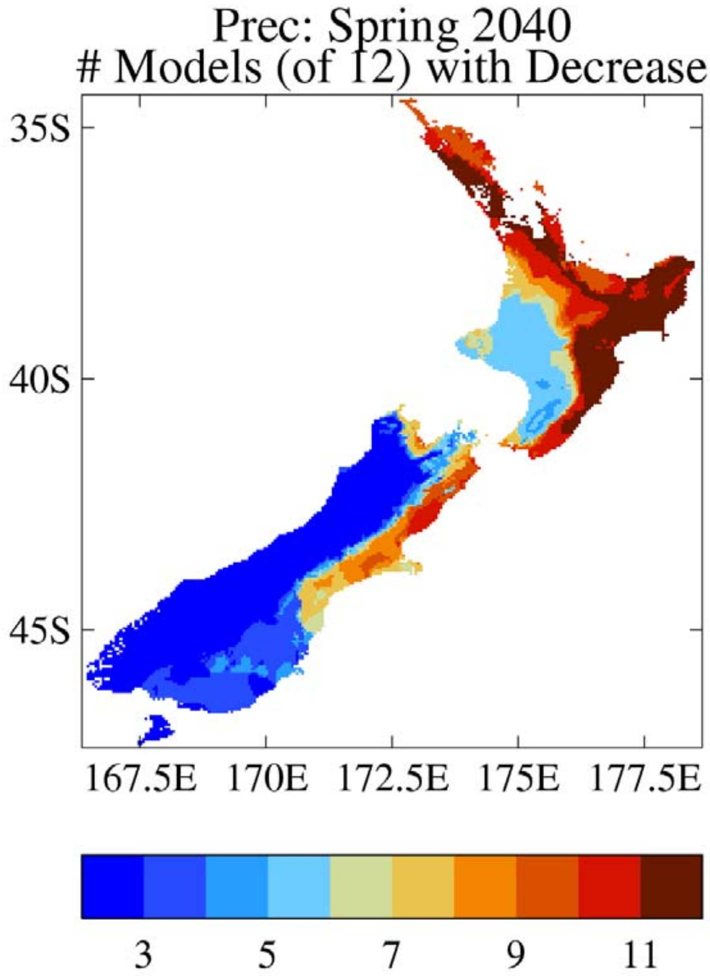

Figure 6.1: The level of agreement between global models regarding the projected change in spring precipitation for 2040 relative to 1980-1999. The map gives the number of models, out of 12, that indicate decreased precipitation in the season shown.

The Topnet model does not explicitly represent accumulation and melt from glaciers in the catchment, because they are not expected to significantly affect the hydrology. Within the version of Topnet used here, snowfall in excess of the seasonal melt simply accumulates in each model catchment, and the down-valley flow of ice is not modelled. This neglect of glaciers is partly a practical decision, given the lack of detailed hydrological knowledge of the glaciers in question, but is supported by the projections of Chinn (2001, Table 1) who assesses the effect of two climate change scenarios on Rangitata catchment glaciers, and estimates the subsequent change in mean river flow as less than 0.2 m^3/s. Glacier-climate change interactions are expected to play a somewhat larger hydrological role in other catchments, such as the Waitaki (Chinn 2001, Table 1). The appropriate integration of glacier sub-models into hydrological models is to be addressed as part of new FRST-funded research, involving NIWA and Victoria University, among others.

In the scenario modelling we have assumed that no hydrologically significant changes take place in (i) catchment vegetation (ii) diversion or abstraction of river water (iii) sub-daily distribution of rainfall. The first two assumptions could be addressed if they were relevant to the problem and scenario information was available.

The third point above is more problematic, since detailed scenarios for changes in sub-daily rainfall are not yet available. It is expected that extreme rainfalls will increase with the projected temperature increases for 2040. This is independent of changes in seasonal or long-term mean precipitation, and is expected because a warmer atmosphere can hold (and therefore produce as rainfall) more moisture (e.g., for every 1 °C increase in temperature there is an approximate 8% increase in the 24-hour 100-year average recurrence interval rainfall amount). See Ministry for the Environment (2008) for details and quantitative guidance on extreme rainfall, especially for other durations and average recurrence intervals. The climate change scenarios used here do not include this increase in rainfall intensity, because methods still need to be developed to appropriately link changes in extreme rainfall into long daily rainfall series. In the meantime, since catchments produce more river flow per unit rainfall in more intense rainfall events, this effect might be expected to slightly increase the mean flow of the river, though the extent of this potential effect is not quantified here.

The results presented in this report are based on one emissions scenario and the averaged results of 12 climate change scenarios. A better appreciation of the uncertainties in the projected effects of climate change would be gained through repeating this work with more emission scenarios and analysing each climate change scenario independently.

7 Water Resource Management Implications

The projected effect of climate change under the A1B 2040's scenario is a reduction in groundwater recharge from the land-surface of about 10%.

Under current allocation policies, the area of land able to be irrigated would be reduced by 10%. If the groundwater allocation zone is already fully allocated, or within 10% of being fully allocated, the existing irrigators would, in theory, face a reduction in their allocations of up to 10%. At present the process for making such a reduction is highly contentious for many reasons. New Zealand is ill prepared for this issue.

Where surface water is used for irrigation it substantially mitigates the effects of climate change on groundwater recharge.

The lack of a sufficiently reliable source of surface water for irrigation will limit the size of both the groundwater supplied irrigation area and the surface water supplied area, to a total area well short of the potentially irrigable area on the Canterbury Plains.

Using stored surface water to provide a reliable surface water supply also provides for a reliable groundwater supply on the lower plains.

Storing surface water is a critically important climate change adaptation measure.

8 Conclusions

A number of tools are required to quantify the effects of climate variability and projected climate change on the availability of surface and groundwater resources, irrigation water use, and water supply reliability. This project has tested several of these tools through applying them at one study area in Canterbury.

A conclusion of this project is that the tools employed for simulating river flow, drainage, and irrigation water use at paddock and farm scale from the given daily climate data sets are sufficiently robust for supply reliability analyses. Some uncertainty remains in relation to the snow sub-model of Topnet; this could not be directly validated because there are no systematic measurements of snow storage in the catchment. Interactions between irrigation demand and surface water availability are explicitly modelled in IrriCalc-FS. Interactions between irrigation demand and groundwater availability are a part of the system dynamics that are not yet modelled.

The methodology and tools tested in this project are sufficiently robust to be applied throughout Canterbury and other drought prone areas that increasingly depend on irrigation to maintain the profitability of agriculture.

The effect of climate change on climate, river flow, and water supply reliability in the Rangitata catchment and associated irrigation areas was estimated. Only one climate change scenario was considered, a "middle of the road" A1B emissions scenario for 2040.

The main differences between modelled flows for the current and 2040 climate are:

- Mean flows for 2040 are projected to be about 8 m3/s larger than under the current climate (about an 8% increase in mean flow)
- The monthly mean flow is projected to increase or stay the same in 10 months of the year, and to reduce by 1–2 m3/s in December and January
- The months with greatest projected absolute increase in flow are August, September and October (each increased by ~18 m3/s compared to the model flows for the current climate)
- Average annual irrigation water use is projected to increase by about 6%
- Average annual drainage from un-irrigated land is projected to decrease by about 10%
- Average annual drainage from irrigated land is projected to decrease by about 3%
- Water supply reliability from surface water and groundwater sources is projected to reduce. This conclusion is the opposite of that reached in the LE (2001) analysis.

Where the current level of groundwater allocation is within 10% of full allocation, projected changes in water flows (in rivers and aquifers) and agricultural water demand, in combination with current Regional Council water allocation rules, would render current levels of groundwater use unsustainable. The knock-on effect of this would be greater pressure on surface water flows, and to provide stored surface water.

If the area of land currently irrigated is to continue to receive the same degree of supply reliability the development of storage will be necessary.

If the area of reliably irrigated land is to increase it is essential that storage be developed.

9 References

Bright, JC; Rout, R; Rouse, H; Harris, S; Skilton, D; Reid, K. (2008) **Error! Style not defined. Error! Style not defined.**. Aqualinc **Error! Style not defined.**, prepared for the New Zealand Business Council for Sustainable Development.

Bright, J.C. (1986) Optimal control of irrigation systems. PhD Thesis. University of Canterbury 1986.

Chinn, T.J. (2001). Distribution of the glacial water resources of New Zealand. *Journal of Hydrology (NZ) 40(2)*: 139-187.

Clark, M.P.; Hendrikx, J.; Slater, A.G.; Hreinsson, E.Ö.; Kerr, T.; Owens, I.F.; Cullen, N. (submitted). Use of field data to design distributed snow models. *Water Resources Research*.

Clark, M.P.; Woods, R.A.; Zheng, X.; Ibbitt, R.P.; Slater, A.G.; Rupp, D.E.; Schmidt, J.; Uddstrom, M.J. (2008). Hydrological data assimilation with the Ensemble Kalman Filter: use of streamflow observations to update states in a distributed hydrological model. *Advances in Water Resources: doi: 10.1016/j.advwatres.2008.1006.1005.*

Henderson, R.D.; Woods, R.A.; Tait, A.B. (2007). Surface water components of New Zealand's National Water Accounts, 1995-2005. *NIWA Client Report No.* CHC2007-046, see http://www.stats.govt.nz/NR/rdonlyres/E06933DE-6ABD-4BE3-B2A6-3D3367906E52/0/WaterPhysicalStockAccountfinal.pdf. 42 p.

Hock, R. (2003). Temperature index melt modelling in mountain areas. *Journal of Hydrology 282(1-4)*: 104-115.

Lincoln Environmental (2001a). Impacts of Climate Change on Agricultural Water Usage and Water Availability, prepared for the Ministry of Agriculture and Forestry. *Lincoln Environmental Report No.* 4461/1. p.

Lincoln Environmental (2003). Southland Water Demand Strategy, Prepared for Venture Southland. *Lincoln Environmental Report No.* 4597/2. p.

Morgan (2001). Canterbury Strategic Water Study: Stage 1. *Lincoln Environmental Report No.* 4597/2. p.

Ministry for the Environment (2008). Climate Change Effects and Impacts Assessment. A Guidance Manual for Local Government in New Zealand. 2nd Edition. Prepared by Mullan, B; Wratt, D; Dean, S; Hollis, M. (NIWA); Allan, S; Williams, T. (MWH NZ Ltd), and Kenny, G. (Earthwise Consulting Ltd), in consultation with Ministry for the Environment. *NIWA Client Report No.* WLG2007/62. 156 p.

Mullan, A.B.; Thompson, C.S.; Woods, R.A. (2001). Future climate and river flow scenarios. *NIWA Client Report No.* WLG 2001/26. 46 p.

Mullan, A.B.; Thompson, C.S.; Woods, R.A. (2003). Future climate and river flow scenarios. *NIWA Client Report No.* CHC2003-019. 34 p.

Mullan, A.B.; Porteous, A.; Wratt, D.; Hollis, M. (2005). Changes in drought risk with climate change, produced for Ministry for the Environment and Ministry of Agriculture and Forestry. *NIWA Client Report No.* WLG2005-23. 58 p.

Newsome, P.F.J.; Wilde, R.H.; Willoughby, E.J. (2000). Land Resource Information System Spatial Data Layers. *Landcare Research Technical Report No.* p.

Snelder, T.H.; Biggs, B.J.F. (2002). Multi-Scale River Environment Classification for Water Resources Management. *Journal of the American Water Resources Association 38*: 1225–1240.

Tait, A.; Henderson, R.D.; Turner, R.; Zheng, X. (2006). Thin plate smoothing spline interpolation of daily rainfall for New Zealand using a climatological rainfall surface. *International Journal of Climatology 26(14)*: 2097-2115.

Tait, A.; Woods, R.A. (2007). Spatial interpolation of daily potential evapotranspiration for New Zealand using a spline model. *Journal of Hydrometeorology 8(3)*: 430-438.

Tait, A.B. (in press). Future projections of growing degree days and frost in New Zealand and some implications for grape growing. *Weather and Climate*.

Walter, K.M. (2000). Index to hydrological recording sites in New Zealand. *NIWA Science and Technology Series 17.* National Institute of Water and Atmosphere, Christchurch. 152p.

Willoughby, E.J.; Wilde, R.H.; McLeod, M.; Hewitt, A.E.; Webb, T.H., (2001). National soils database audit: a document describing Landcare Research soils data. Landcare Research unpublished report.