IMPLICATIONS OF CLIMATE CHANGE FOR WATER MANAGEMENT IN CANTERBURY

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1 Introduction

On the dry east coast of New Zealand's South Island, the Canterbury region is at the sustainability limits of water availability (Jenkins 2007a). The region's agricultural economy is highly dependent on irrigation water which represents 89% of consumptive use (Morgan et al. 2002). Agriculture is the dominant source of greenhouse gas emissions in New Zealand contributing 47% of the country's emission profile (Ministry for the Environment 2013). Therefore, there is a need for adaptation and opportunities for mitigation to address climate change.

The paper sets out New Zealand's greenhouse gas emission profile and then summarises the climate change projections for temperature, seasonal rainfall, snowfall and potential evapotranspiration deficit. The hydrology of the Canterbury region is outlined so that the broad implications of climate change projections for water management in Canterbury can be identified. Two case studies of the changes to two rivers, the Waimakariri and the Rangitata are summarised. Adaptations for freshwater management are described and examples of offsets and agricultural emission mitigation measures are provided.

2. Implications of Climate Change

New Zealand's Greenhouse Gas Emission Profile

Based on the official annual report of all human-caused emissions of greenhouse gases in New Zealand (Ministry for the Environment 2013) in 2001, New Zealand's total greenhouse gas emissions were 72.8 million tonnes of carbon dioxide equivalent (Mt CO_2-e) and net removal associated with forestry was 16.8 Mt CO_2-e. Unlike most developed countries, agriculture is the largest contributing sector representing 47.2% of total emissions. Typical figures for other developed countries are around 12%. This is primarily due to methane emissions from ruminant livestock and nitrous oxide emissions from the use of fertiliser. Agricultural emissions continue to increase (12.1% since 1990) particularly associated with the expansion of the dairy sector.

New Zealand's per capita rate of 16.4 t CO_2-e per person is fifth highest among the 40 Kyoto Protocol Annex 1 countries. However, its carbon dioxide only emissions (7.6 t CO_2-e per person) are relatively lower (22nd among Annex 1 countries). This reflects the high proportion of renewable generation in the electricity sector -77% - with hydro-generation producing 22,639 GWh (52.8%) of New Zealand's 42,900 GWh generated in 2012 (Ministry of Economic Development 2013).

Also New Zealand has a relatively high level of net removals from afforestation, reforestation and deforestation at 13.5 Mt CO_2-e (18.5% of total emissions). However net removals from forestry have decreased due to increased harvesting of plantation forests as a larger proportion of the estate reaches harvest age, and forest being converted to pasture. Between 2003 and 2012, New Zealand's planted forest has declined from 1,827,333 ha to 1,719,501 ha (6% decline), while in Canterbury the planted forest has declined from 122,773 ha to 110,055 ha (10% decline) (Ministry of Agriculture and Forestry 2004) (Ministry for Primary Industries 2013). Deforestation intention surveys indicate 86% conversion from forestry to dairying (Manly 2013).

In relation to water management and New Zealand's emissions profile, there are the following significant linkages:

- The role of hydro-generation in reducing carbon dioxide emissions from the electricity sector: this is particularly significant for Canterbury with 65% of the country's hydro capacity;
- The role of agriculture, particularly dairying, in increasing methane and nitrous oxide emissions: this is also significant for Canterbury where the major growth in dairy conversions is occurring: 40% of the increase in cow numbers in New Zealand between 2007/8 and 2012/3 occurred in Canterbury (Livestock Improvement Corporation 2008) (DairyNZ 2013).
- The decreasing role of afforestation/deforestation in reducing New Zealand's net emissions: this is also significant in Canterbury where there has substantial conversion of forest blocks to pasture for dairying (12,700 ha between 2003 and 2012).

Projected Temperature Change

There has been a long-term increase in the average temperature for New Zealand of about 0.6°C between 1920 and 2000. Figure 1 shows the annual average temperature from 1850 compared to the 1971-2000 average with blue bars showing the deviation below that average and the red bars showing above average deviations.

Fig.1 New Zealand average surface temperature (°C) NIWA data (O'Donnell 2007)

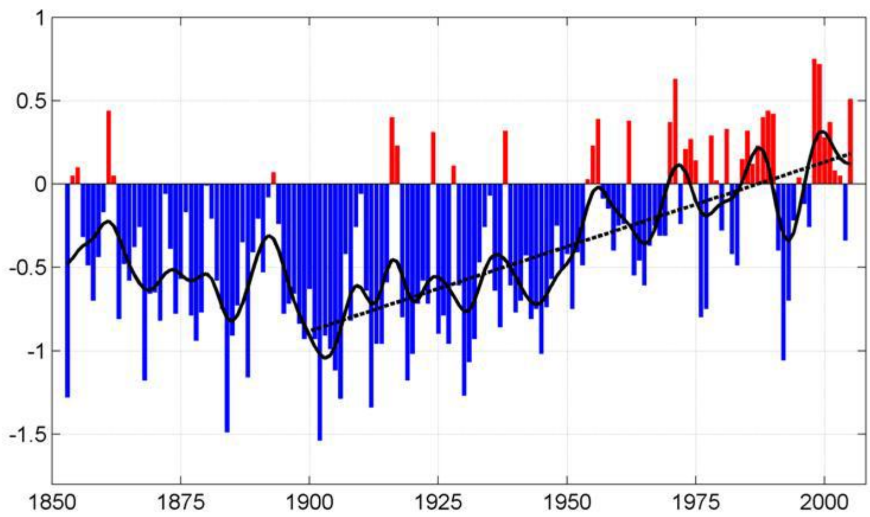
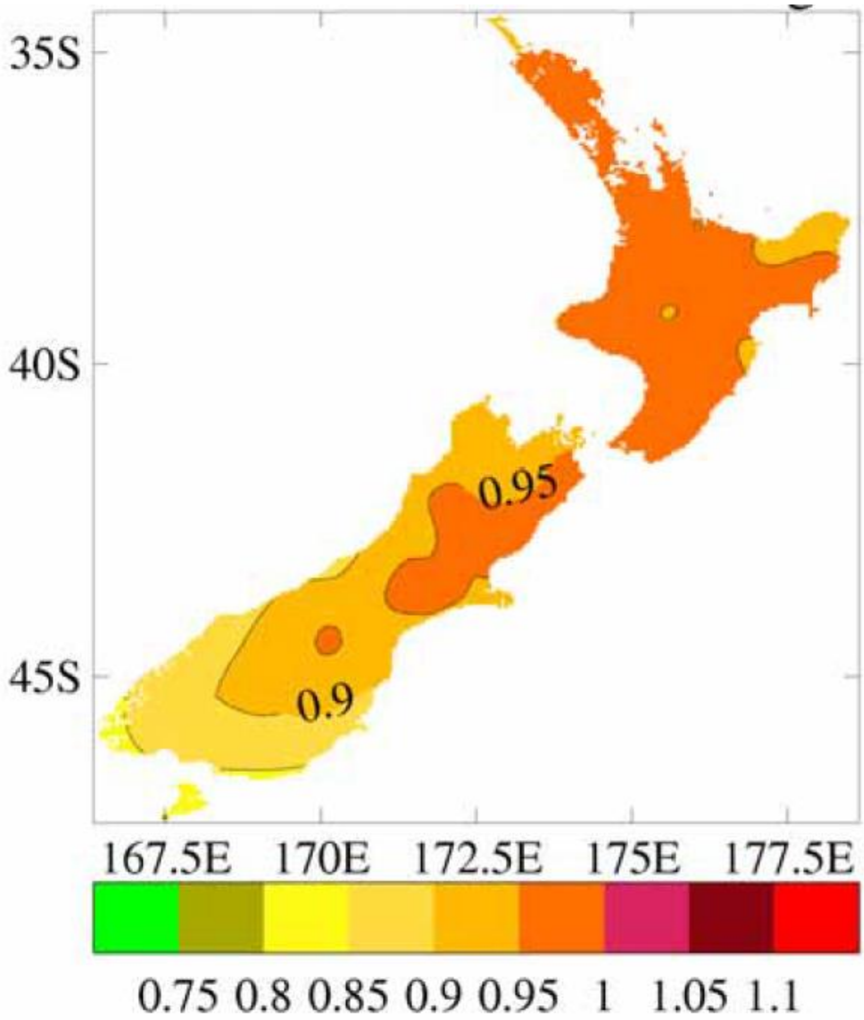


Figure 2 indicates the projected change in annual average temperature across New Zealand over 50 years (1990-2040). For Canterbury this is 0.9°C with a range across six scenarios of 0.2-1.9°C. The increase is slightly higher in winter (1°C) and lower in spring (0.7°C).

Fig. 2 Projected Changes in Annual Mean Temperatures (in °C) in 2040 relative to 1990 average over 12 climate models for A1B emission scenario (Ministry for the Environment 2008)



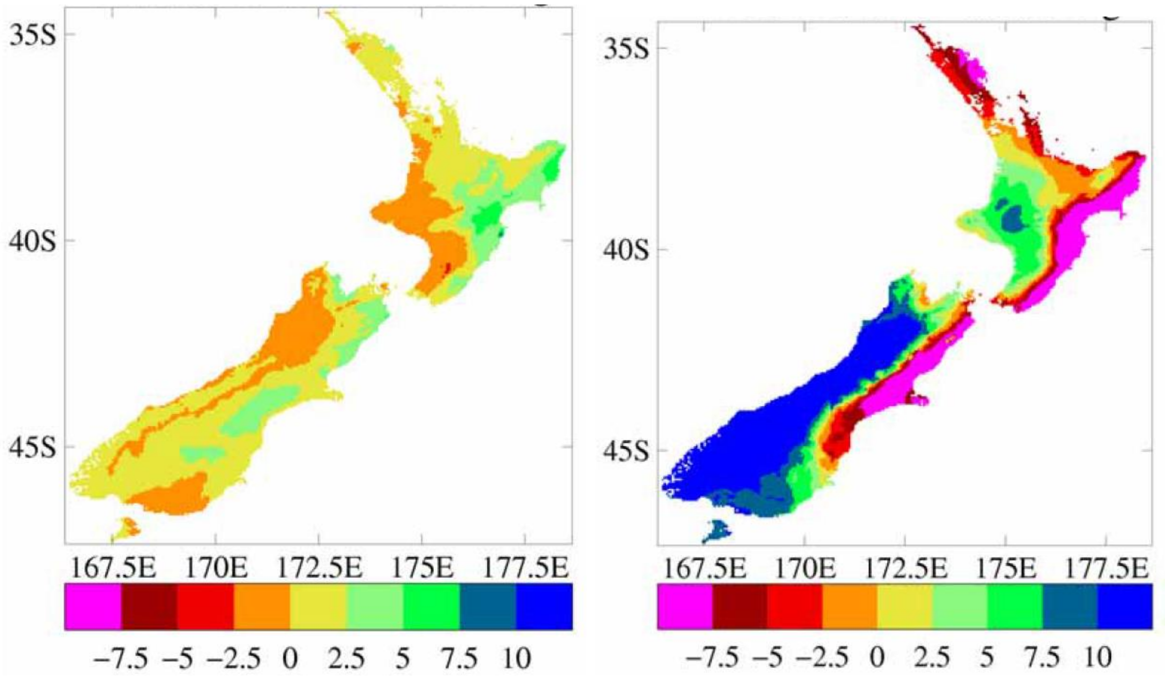
Projected Changes in Seasonal Rainfall

The projections for rainfall are more variable for the different climate models. There is also greater spatial and seasonal variability. Figure 3 shows the projected changes in summer and winter rainfall (in percentages) for 2040 relative to 1990. It is based on the average of the 12 climate models for the A1B emission scenario. (Note that the A1B scenario is one of the Special Report on Emission Scenarios (Nakicenovic and Swart 2000). It assumes rapid economic growth and global population that peaks mid-century and declines thereafter, rapid introduction of new and more efficient technologies and a balance of fossil and non-fossil energy sources. This assumes a doubling of global emissions from 1990 to 2050 and declining thereafter.)

For the country, the general pattern is in summer for small increases on the east coast (2.5-5%) and marginally drier conditions on the west coast (0-2.5%). While in winter there are more significant changes projected with decreases on the east coast (7.5-10%) and increases on the west coast (5-12.5%).

For Canterbury, lower winter rainfall on the Canterbury Plains means reduced aquifer recharge and lower flows in foothill rivers. However for the major alpine rivers there is increased rainfall in the upper catchments in the Southern Alps.

Fig. 3 Projected changes in seasonal mean rainfall (in %) for 2040 relative to 1990: average over 12 climate models for A1B emission scenario (Ministry for the Environment 2008)



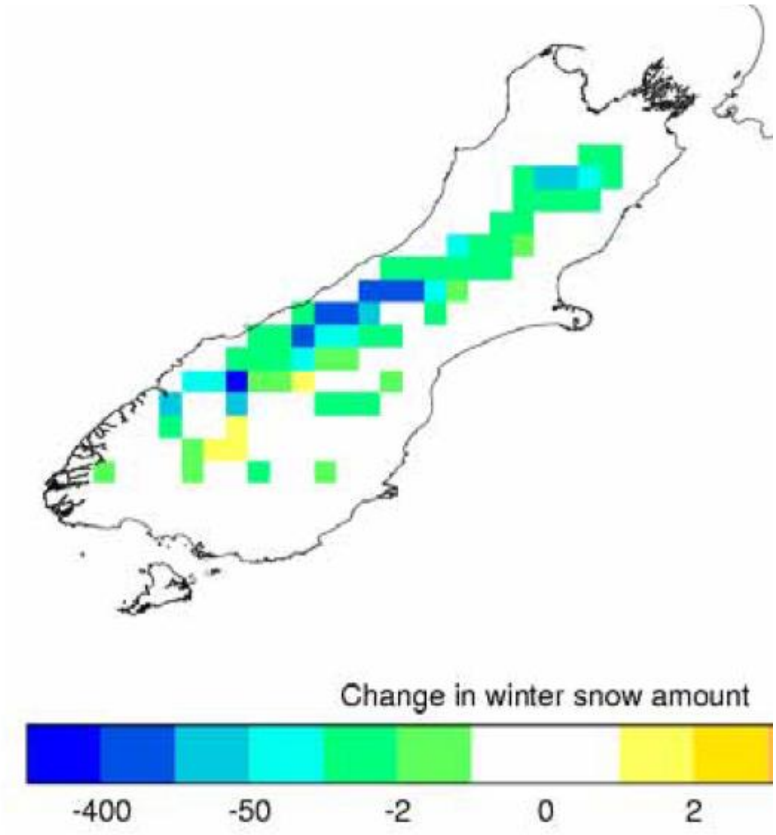
Projected Changes in Snowfall

Chinn investigated 127 glaciers in the Southern Alps (Chinn 1996). He found that on average glaciers had shortened by 38% and lost 25% in area. The upward shift of glacier mean elevation from 1890 to 1995 of 94m is approximately equivalent to a temperature rise of 0.6°C.

In the climate projections with higher winter temperatures, it is expected that snow cover will decrease and snowlines rise (Ministry for the Environment 2008). Figure 4 shows a projection of snow amount changes from the NIWA climate model for the A2 emissions scenario for the 100 years from 1980-1999 to 2080-2099. A2 scenario assumes a heterogeneous world, increasing global population, regionally oriented economic development and slower technological change compared to other scenarios. This assumes a doubling of emissions from 1990 to 2040 and ongoing increases to 2100 (Nakicenovic and Swart 2000).

A decrease in winter snowfall and an earlier spring melt can cause marked changes in the annual pattern of river flow with higher flows in winter and early spring and lower flows in summer at the height of the irrigation season.

Fig. 4 Change in winter snow (in kg/m^2) between 1980-1999 and 2080-2099 under scenario A2 (Ministry for the Environment 2008)



Note: The contour intervals are not equally spaced. The snow amount is that lying on the ground averaged over the season. 1 kg/m^2 is equivalent to 1mm rainfall.

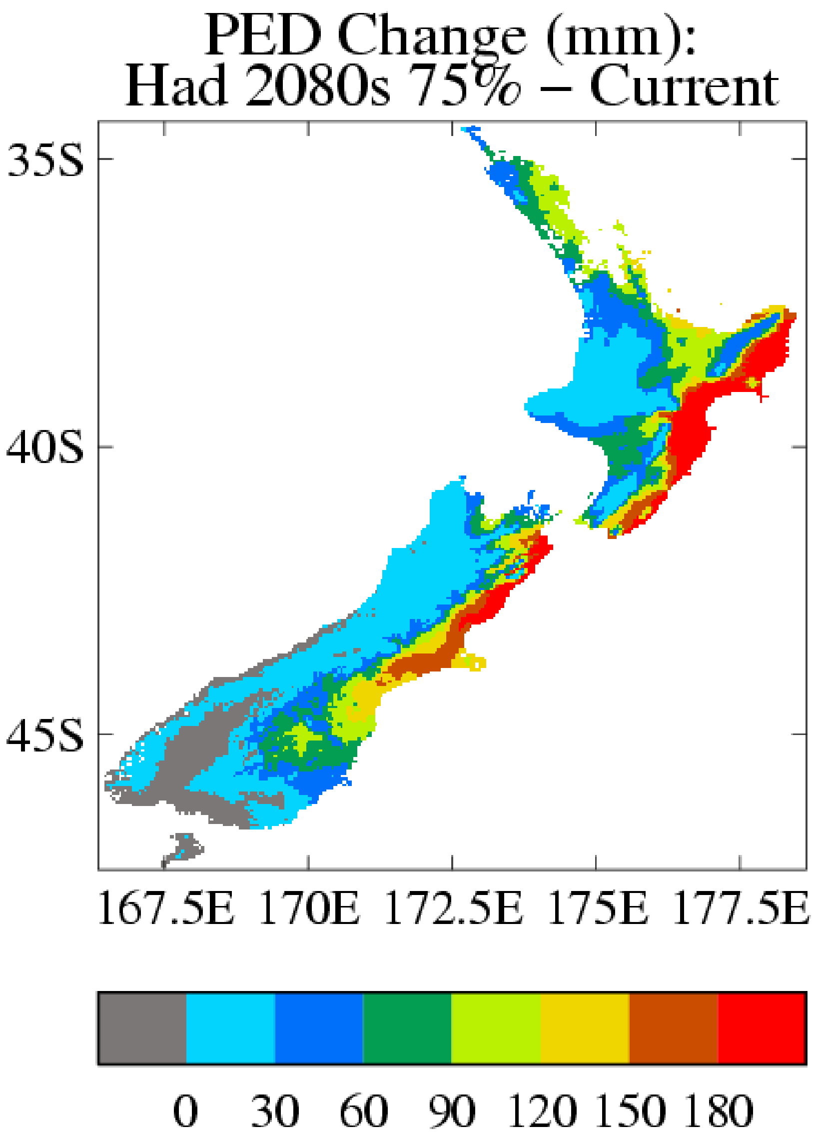
Potential Evapotranspiration Deficit

Accumulated Potential Evapotranspiration Deficit (PED) is the amount of water that would need to be added to a crop over a year to prevent loss of production due to water shortage. PED can be used as an indicator of drought risk and as an indicator of irrigation demand. For unirrigated pastures, an increase in PED of 30mm corresponds to approximately one week more of pasture moisture deficit and reduced grass growth (Mullen et al. 2005).

NIWA investigated four climate change projections from two global climate models (Hadley and CSIRO) downscaled to take account of New Zealand's local climate. This provided a range of projections from 25% ('low-medium') to 75% ('medium-high') of the projected global temperature range. 'Current' climate was based on data from 1972-2003, and projections were for '2030s' (2020-2049) and '2080s' (2070-2099).

The modelling indicated an increase in drought in the eastern regions of New Zealand with the frequency of the current 1-in-20 year drought increasing between two and more than fourfold depending on the scenario. For Canterbury, which already has a high annual average PED of 322mm, climate projections indicate this will increase with some areas with PED increases of over 180mm in 2080s with the medium-high projection (see Figure 5).

Fig.5 Average Change in Annual Accumulated PED (mm) between Current Climatology and Projected Climatology for 2080s Using Hadley Model Scaled to IPCC 75% Global Warming (Mullen et al. 2005)



3. Outline of Canterbury Hydrology

Types of River Systems

In Canterbury there are three main types of river systems. Firstly, there are the alpine rivers with their upper reaches in the Southern Alps so that they are snow-fed with summer peak flows. Secondly, there are the foothill rivers with rain-fed catchments and winter peak flows. Thirdly, there are lowland streams that are fed from groundwater. Refer Figure 6.

Fig 6 River Types Within Canterbury

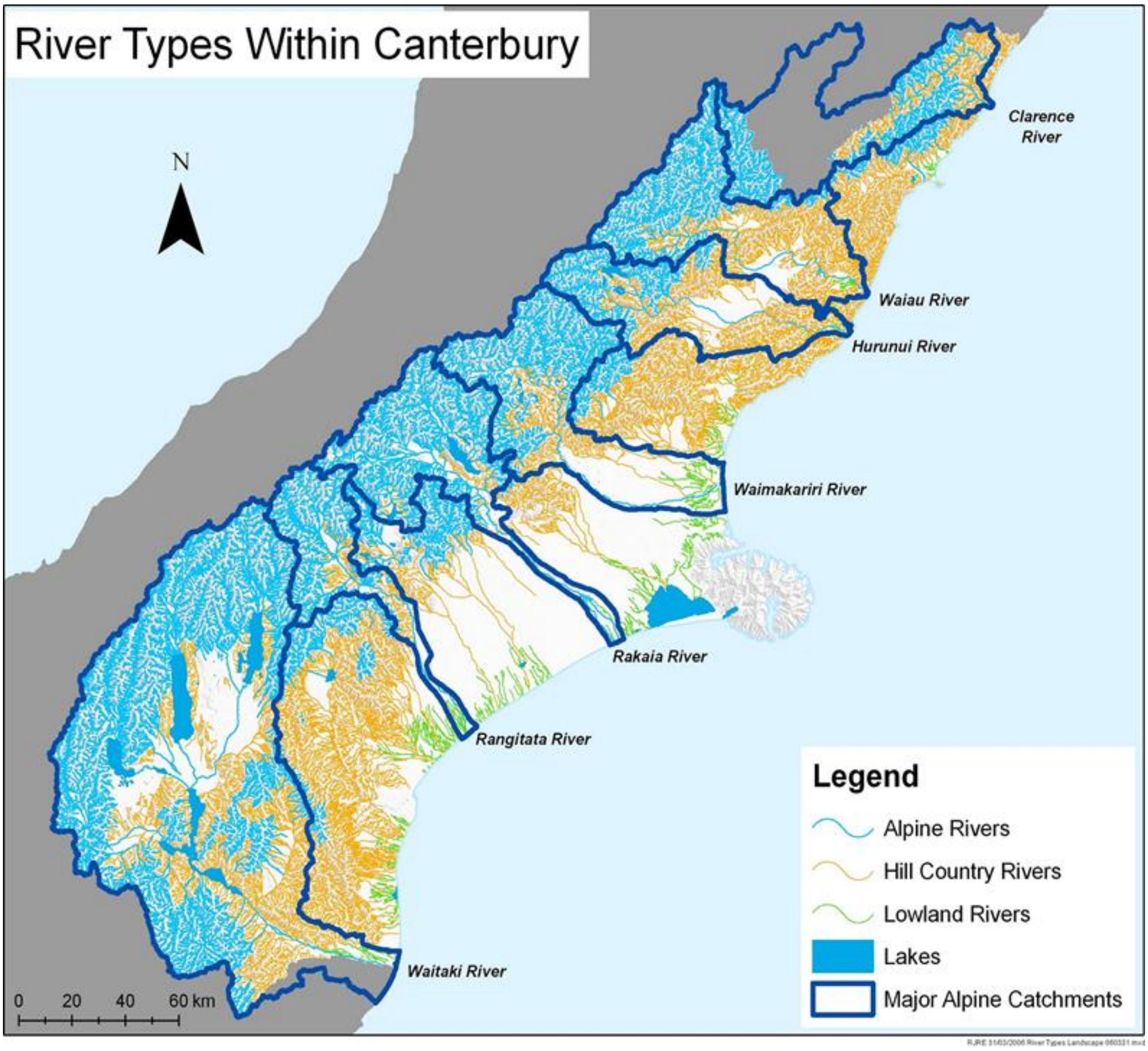


Table 1 sets out the mean flows in the major Canterbury rivers. The seven alpine rivers contribute 88% of the flow and are an order of magnitude greater in volume compared to the foothill rivers. Lowland streams are even smaller in flow.

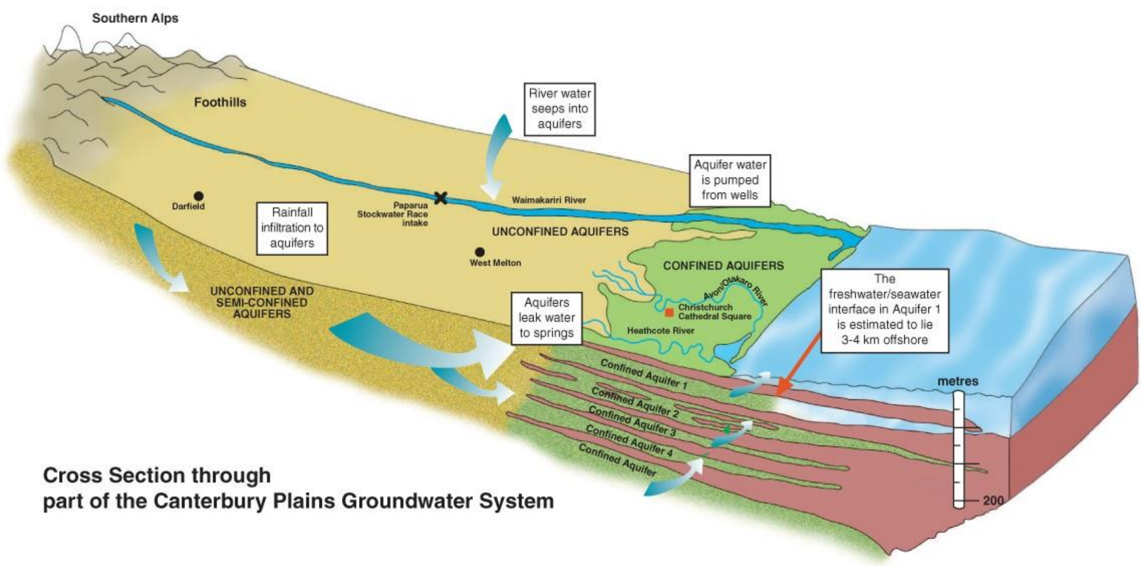
Table 1 Mean Flows (m^3/s) for Major Canterbury Rivers (Morgan et al. 2002)

Alpine Rivers		Other Major Rivers	
Waitaki	373	Ashburton	15
Rakaia	221	Ashley	13
Waimakariri	120	Orari	11
Waiau	116	Opuha	10
Rangitata	100	Opihi	5
Hurunui	72	Waihao	4
Clarence	72	Pareora	4
		Waipara	3

Groundwater in the Canterbury Plains

Thorpe describes the geological setting of the Canterbury Plains which defines the groundwater system in the Waimakariri catchment (Thorpe 1992). The Canterbury Plains were built up from coalescing alluvial fans of gravel originating in the Southern Alps. In the interglacial periods when sea level rose, marine silts and clays were deposited over gravels on the coastal margins. The final result is for an unconfined aquifer on the plains while near the coast is a sequence of gravel aquifers separated by fine-grained marine deposits that form confining layers so that much of the coastal city of Christchurch sits on at least four aquifers Figure 7.

Fig. 7 Cross Section through the Canterbury Plains



Recharge to groundwater is primarily from rain infiltrating through the soil when the soil is saturated. This is predominantly in winter. Aquifers are also hydraulically connected to rivers with gaining and losing reaches along alpine and foothill rivers, and with lowland streams being groundwater fed.

4. Implications of Climate Change Projections for Water Management in Canterbury

Broad Implications for Canterbury

The projections of climate change have significant implications for the management of freshwater in Canterbury. The most important changes are:

- The increase in PED which will generate increased irrigation demand
- The decrease in winter rainfall on the Canterbury Plains reducing aquifer recharge and groundwater levels thereby reducing flows in groundwater-fed lowland streams

- The drier east coast will lead to lower flows in foothill rivers
- The wetter west coast and warmer winters leading to reduced snow and increased winter flows but reduced summer flows in alpine rivers.

Two case studies are described below which demonstrate the varied implications across the region. The first is the changes projected for the Waimakariri catchment in central Canterbury, one of the region's alpine rivers. The second is in South Canterbury for the Rangitata catchment also an alpine river but with substantial groundwater use in the area.

Changes in Irrigation Reliability in the Waimakariri Catchment under Climate Change Scenarios

The impact of a range of climate change scenarios on the irrigation reliability of the main irrigation scheme that extracts water from the Waimakariri River – the Waimakariri Irrigation Limited (WIL) – was undertaken (Srinivasan et al. 2011). WIL supports 18,000 ha of irrigated land. The investigations covered the three 20-year periods: 1980-99 ('1990 condition'), 2030-49 ('2040 scenario'), and 2080-99 ('2090 scenario'); and three climate scenarios: B1 (low emission), A1B (medium emissions), and A1F1 (high emissions).

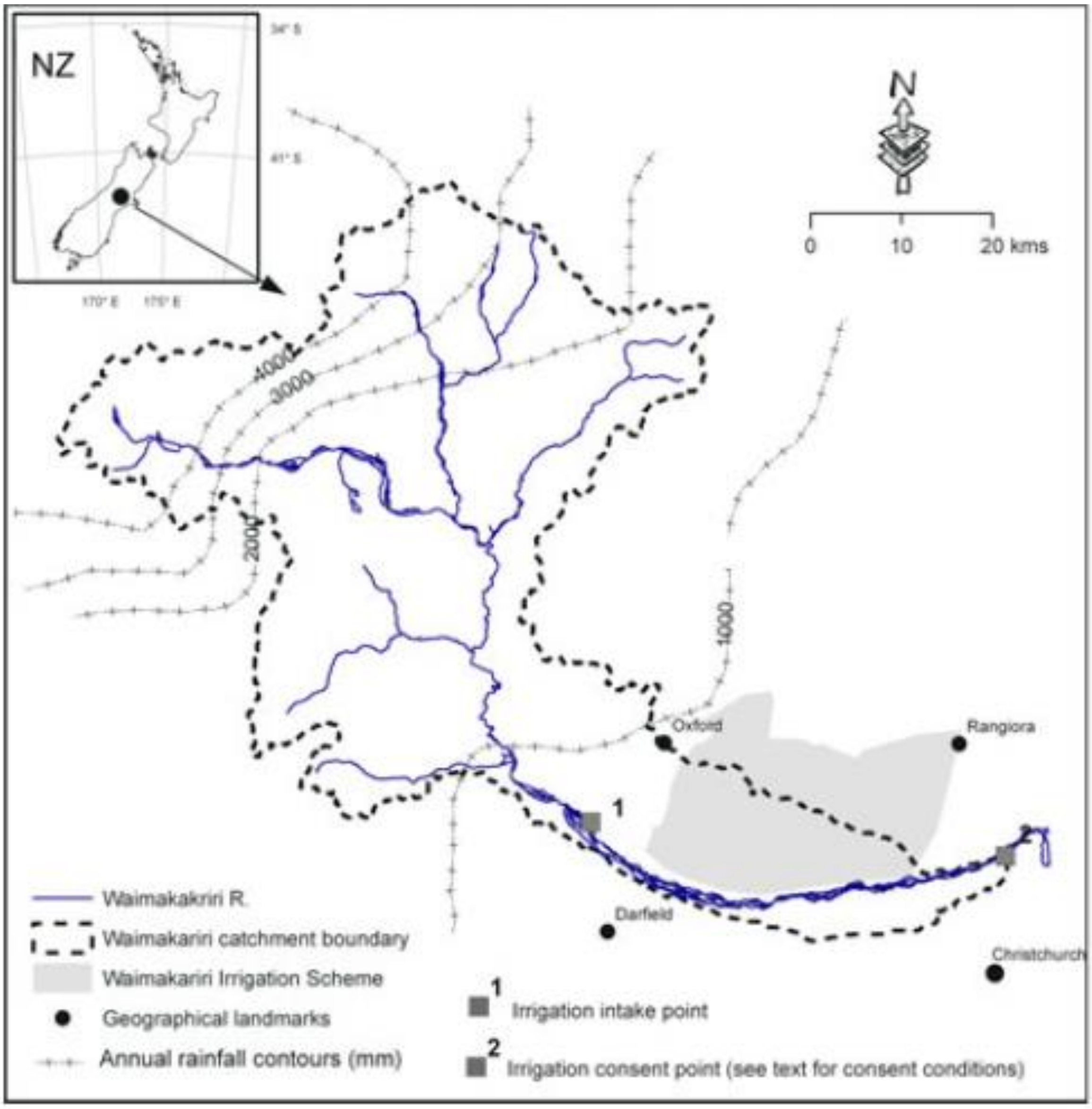
WIL is consented to abstract 10.5 m^3/s from the river during the irrigation season but the consent conditions mean the take can be restricted by the flow in the river. This is to protect the environmental flow requirements for the river. No abstraction is permitted when the river flow is below 41 m^3/s (full restriction); between 41 and 63 m^3/s a proportion of the consented take can be abstracted (partial restriction); and above 63 m^3/s the full consented take can be abstracted (no restriction). Previous studies concluded that low river flows limit irrigation supplies 11% of the time between September and December, and 48% of the time between January and April (Srinivasan and Duncan 2012).

Typical of Canterbury's alpine rivers, the Waimakariri has high rainfall in its headwaters in the Southern Alps (2000-5000mm), moderate rainfall in the foothills (1000-2000mm) and low rainfall on the plains (less than 1000mm) – see Figure 8. The change in rainfall pattern projected by climate change was consistent across the scenarios (although varying in amount). The high rainfall upper catchment increased in rainfall particularly in the May-August period, there was a smaller increase in the foothills and the plains had a decrease in May-August. The projections for A1B scenario in 2040 is shown in Table 2.

Table 2 Projected Precipitation in A1B 2040 scenario (in mm) and percentage change from 1990 condition (Srinivasan et al. 2011)

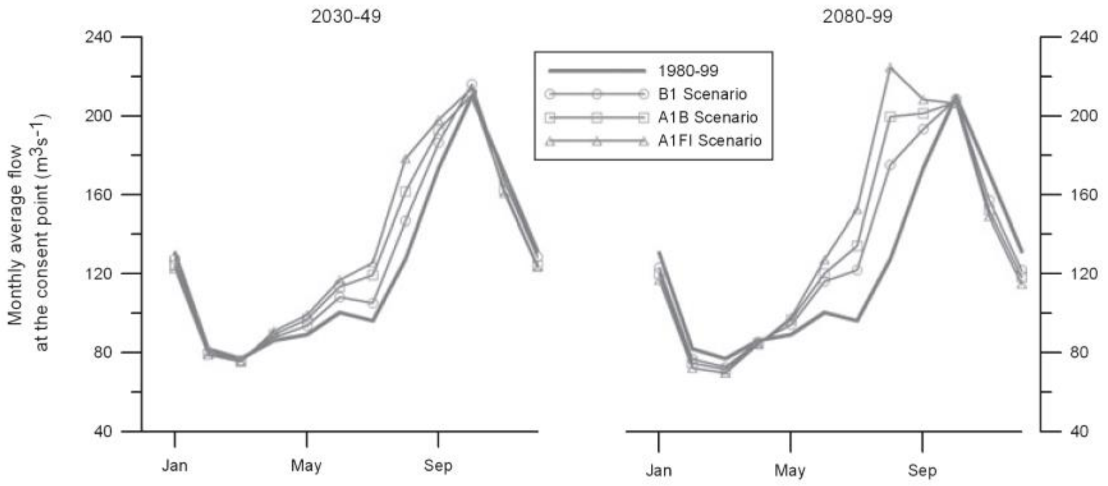
PERIOD	Upper catchment (above 2000mm)	Foothills (1000-2000mm)	Plains (less than 1000mm)
Annual	3995 (+5%)	1310 (+4%)	799 (-1%)
Jan-Apr	1551 (+1%)	357 (+2%)	262 (+4%)
May-Aug	1301 (+11%)	478 (+5%)	274 (-6%)
Sep-Dec	1549 (+5%)	474 (+4%)	263 (<-1%)

Fig. 8 Waimakariri Catchment Rainfall Zones (Srinivasan et al. 2011)



The increased precipitation leads to increased mean annual flow, e.g. a 7% increase for the 2040 A1B scenario (Zammit and Woods 2011). However, the change in flow varies throughout the year. Figure 9 presents the average monthly flows for the different scenarios. There are large flow increases from May to September, but little change and even slight decreases between September and April (the southern hemisphere irrigation season). This is attributed to the increased temperature associated with climate change scenarios resulting in more rainfall and less snowfall and an earlier snowmelt.

Fig. 9 Monthly Average Flows for Scenarios (Srinivasan et al. 2011)



The modelled amount of water stored as snow for the different scenarios is shown in Table 3. The table indicates the average of the maximum snow storage for the year over the 20 year period for each scenario. The table shows the decline from the 1990 condition where the annual average of the snow storage over the 20-year period (1980-99) of 155mm to 109mm in 2040 for A1B scenario (medium emissions) and a further decline to 69mm in 2090. There are greater declines for the high emission scenarios (A1F1) and lesser declines for the low emission scenarios (B1).

Table 3 Modelled Water Stored as Snow (mm): Average over 20-Year Period (Srinivasan et al. 2011)

SCENARIO	ANNUAL AVERAGE OF MAXIMUM SNOW STORAGE OVER 20-YEAR PERIOD (mm)
1990 Condition (1980-99)	155
2040 Scenarios (2030-49)	
B1	134
A1B	109
A1F1	97
2090 Scenarios (2080-99)	
B1	90
A1B	69
A1F1	40

So despite higher precipitation overall in the catchment with the reduction in snowmelt in spring there are more projected irrigation restrictions between September and December. One key summary indicator is average duration of the longest continuous restriction over the 20-year period. Table 3 shows the increased length of restriction with projected climate change and the greater proportion of full restrictions as part of the continuous restriction. For the 1990 condition the average duration is 27 days with 6 of those on full restriction. This can be compared to 29 days for the A1B 2040 scenario with 7 days of full restriction increasing to 33 days for A1B 2090 scenario with 10 of those days on full restriction.

Table 3 Average Duration (days) of longest continuous restriction over 20-year period (Srinivasan et al. 2011)

SCENARIO	Duration (days)	Full Restriction (100%)	Partial Restriction (50-99%)	Partial Restriction (1-49%)
1990 Condition (1980-99)	27	6	11	10
2040 Scenarios (2030-49)				
B1	28	6	13	9
A1B	29	7	13	9
A1F1	30	8	13	9
2090 Scenarios (2080-99)				
B1	32	8	14	10
A1B	33	10	14	9
A1F1	34	12	14	8

Climate Change Effects in Mid-Canterbury

A second example of projecting climate change effects was undertaken for mid Canterbury (Ministry of Agriculture and Forestry 2011). This considered another alpine river, the Rangitata, and the irrigated area between the Rangitata River and the Ashburton River on the Canterbury Plains – an area of 113,820 ha (Figure 10). Irrigation is from run-of-river diversions from the Rangitata River and from unconfined groundwater which underlies the Canterbury Plains. The climate change projections were for the A1B 2040 scenario.

In relation to rainfall there is a projected increase of about 400mm in the headwaters of the Rangitata River in winter and spring, mainly in July and August. The projected increase in temperature results in increased PED of 60 mm/y on the plains in the study area with the largest increase in spring and summer. In addition for the characteristics of the Rangitata headwaters every 0.5°C of warming shortens the melt season by a month.

The implications for river flow are for an increase of $8m^3/s$ in mean annual flow (8% increase). Monthly mean flows are projected to increase for 10 months of the year with August, September and October projected to have the largest increase of $18m^3/s$. Flows in December and January are projected to decrease by $1\text{-}2m^3/s$.

Fig. 10 Mid-Canterbury Study Area showing irrigation area (blue rectangle), flow measuring site (red dot) and catchment above flow recorder (black line) (Ministry of Agriculture and Forestry 2011)

The study addressed the change in irrigation demand. With increased PED irrigation water use would need to increase overall by 6% with the greatest increase in December and January (Figure 11). There are also reductions in recharge to groundwater. For unirrigated land the reduction is estimated to be 10% (Figure 12) and for irrigated land 3%.

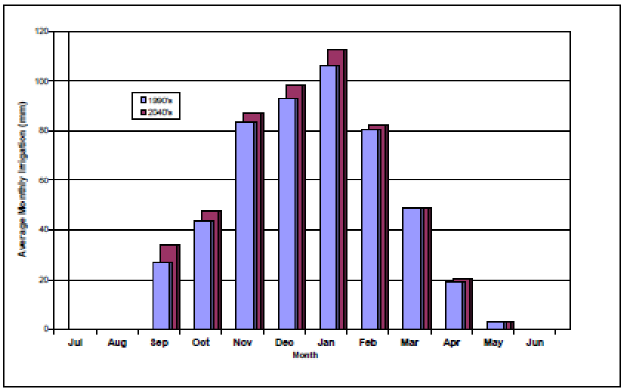


Fig. 11 Monthly mean irrigation water use for the 1990 and 2040 climate scenarios (Ministry of Agriculture and Forestry 2011)

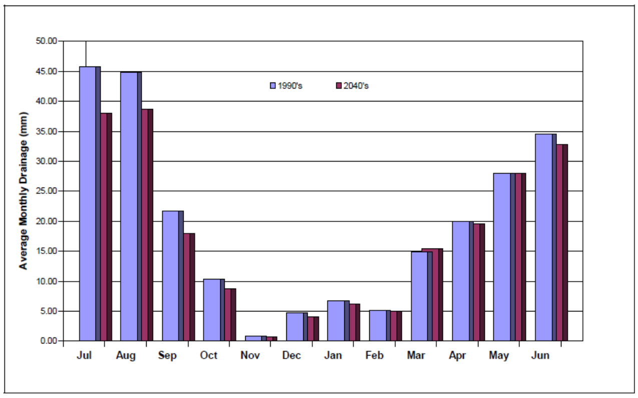


Fig. 12 Monthly mean drainage for 1990 and 2040 climate scenarios for unirrigated pastoral farms (Ministry of Agriculture and Forestry 2011)

To assess the implications for irrigation reliability it was assumed that if the groundwater balance was maintained then the spring-fed streamflow would be maintained in order to meet sustainability criteria. It was further assumed that this balance could be achieved by providing sufficient extra recharge by surface irrigation to offset the net use of groundwater.

An analysis was made of three grades of irrigation restriction: ‘noticeable’ where the supply to demand ratio was less than 0.95 for 20% of the time; ‘moderate’ where the supply to demand ratio was less than 0.80 for 20% of the time; and, ‘severe’ where the supply to demand ratio was less than 0.50 for 20% of the time. All grades of restriction increased. The results for the frequency of severe supply shortfalls are shown in Figure 13. The increase in severe restrictions with climate change is attributed to the increase in irrigation demand. However the frequency of severe water shortages increases substantially more in December and January with the added effect of reduced river flow.

It is important to note that the analysis indicating reduced reliability is contrary to earlier expectation that because flows in rivers fed from the Southern Alps in Canterbury and Otago are expected to increase (on average) under most climate change scenarios that water supply reliability from irrigation systems fed from this source may increase (Ministry of Agriculture and Forestry 2005).

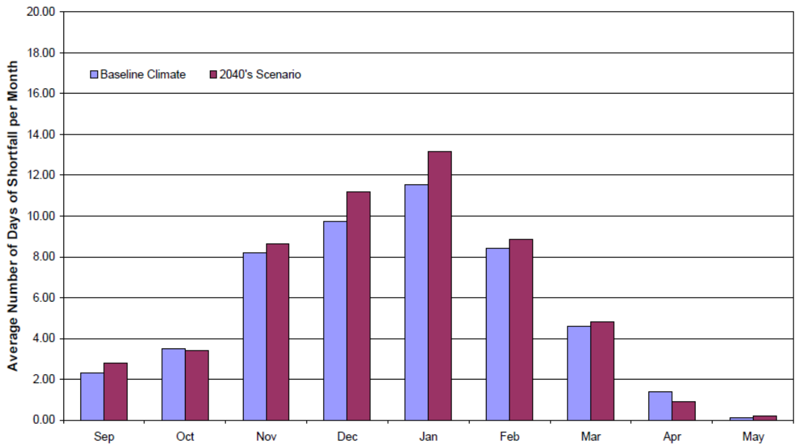


Fig. 13 Change in Frequency of Severe Supply Shortfalls between 1990 and 2040 climate scenarios (Ministry of Agriculture and Forestry 2011)

4 Climate Change Response

Freshwater Adaptations

For Canterbury there will be an increased demand for water (with increased potential evapotranspiration) but reduced availability for run-of-river abstraction (with reduced flows during the irrigation season) and groundwater withdrawal (with reduced rainfall recharge).

One of the findings of the Canterbury Water Management Strategy was that there was the opportunity for significant improvements in water use efficiency (Canterbury Water 2009). It was found that the cheapest additional water is water currently allocated but used inefficiently. In particular there were inefficiencies in:

- Irrigation methods, such as border dyke (or flood) irrigation
- High application rates leading to macropore flow
- Low reliability of supply which led irrigators to use water when it was available rather than when it was needed
- Leakage from canal distribution systems
- Spatial application of surface and groundwater (Jenkins 2012).

There was a potential role for storage and inter-basin transfers so long as the storage was sustainable. Storages on the main stems of alpine rivers have led to significant adverse effects, such as, reductions in braided character, algal blooms, deoxygenation in reservoirs, reduced sediment transport and increased coastal erosion (Jenkins 2007b). An example of a more sustainable solution is the harvesting of increased winter flows for off-river storage for summer irrigation use. This is occurring on the Rangitata River at Arundel (Figure 14).

Fig. 14 Off-River Storage on the Rangitata River at Arundel

Managed aquifer recharge could maintain groundwater levels for abstraction and lowland stream flow as well as dilute groundwater contamination from land use intensification. It also avoids the evaporative losses and loss of land associated with surface storage. Analyses for the Canterbury Water Management Strategy demonstrated that managed aquifer recharge was only two thirds of the cost of equivalent surface water storage.

More can be done through integrated surface and groundwater management. Integrated approaches would involve a predominant use of surface water when river flows allow, and a predominant use of groundwater when river flows are restricted. Also the greater use of surface water for irrigation in the upper reaches of groundwater zones would enhance recharge and enable greater use of groundwater for irrigation in the lower reaches.

Offsets

One possible sustainability strategy to address the increase in greenhouse gas emissions due to dairy conversions and forestry clearance in Canterbury (and elsewhere in New Zealand) is the requirement for offsets. The greenhouse gas emissions from dairy farms are variable: Ledgard examined 26 dairy farms in Rotorua and estimated an average of 9,067 $kgCO_2$-e per ha with a range from 4,504 to 12,198 $kgCO_2$-e per ha (Ledgard et al. 2010). Smeaton modelled a base dairy farm model of 9,300 $kgCO_2$-e per ha compared to a sheep and beef farm of 3,400 $kgCO_2$-e per ha (Smeaton et al. 2011). Thus for a conversion from a sheep and beef farm to a dairy farm would require an offset of about 5,900 $kgCO_2$-e per ha.

Mason and Ledgard are developing a calculator for making farms greenhouse neutral based on the number of hectares of radiate pine plantation which would be required for each 30 year period of farming, assuming a hectare of pine plantation can absorb 11,800 $kgCO_2$-e, allowing for harvesting (Mason and Ledgard 2013). Thus for a dairy farm to be greenhouse gas neutral would require about 0.8ha of pine plantation for each hectare of dairy farm, or, as an offset for a dairy conversion from a sheep and beef farm, about 0.5ha of pine plantation for each hectare of dairy farm.

Another avenue for offsets is the generation of hydroelectricity as a component of irrigation storage (e.g. Opuha Dam) or tail race discharged (e.g. Rangitata Diversion Race (RDR)). The Highbank and Montalto power stations, associated with the 64,380ha RDR scheme, generated 98 GWhr in 2011. In terms of fossil fuel emissions avoided (about 513 tCO_2-e per GWhr), the Highbank/Montalto generation would counterbalance about 5,500ha of dairy farm emissions (assuming 9.3 tCO_2-e per ha), or, offset the conversion of 8,500ha of sheep/beef farms to dairy farms (based on 5.9 tCO_2-e per ha differential emission rates).

Nitrification Inhibitors

The concept of the nitrification inhibitors is designed to intervene in the nitrogen cycle in the soil profile. Nitrogen as ammonia percolates into the soil profile from urine patches, nitrogen fertilisers and nitrogen fixation by plants. The nitrification process converts the insoluble ammonia into nitrite and nitrate which leaches into the groundwater or volatilises as nitrogen gases, including nitrous oxide, into the atmosphere. The nitrification inhibitor, DCD, slows down the rate of nitrate production and thus reduces the nitrate leaching loss to groundwater and nitrous oxide loss to atmosphere. Figure 15 shows the nitrogen cycle in the soil profile and the point of intervention of the nitrification inhibitor in that cycle.

The effectiveness of the approach has been confirmed in experimental and field trials. Experiments involving two Canterbury soils and two North island soils showed that the application of a fine particle suspension of DCD to grazed pasture was very effective in reducing nitrous oxide emissions with an average of 70% reduction (Di et al. 2007). Figure 16 shows the results of for a Canterbury Templeton soil indicating the daily flux of nitrous oxide for a urine rate of 1000kgN per ha with and without DCD (as well as controls).

Fig. 15 Nitrification Inhibitor: Point of Intervention in Nitrogen Cycle in Soil Profile (McLaren and Cameron 1996)

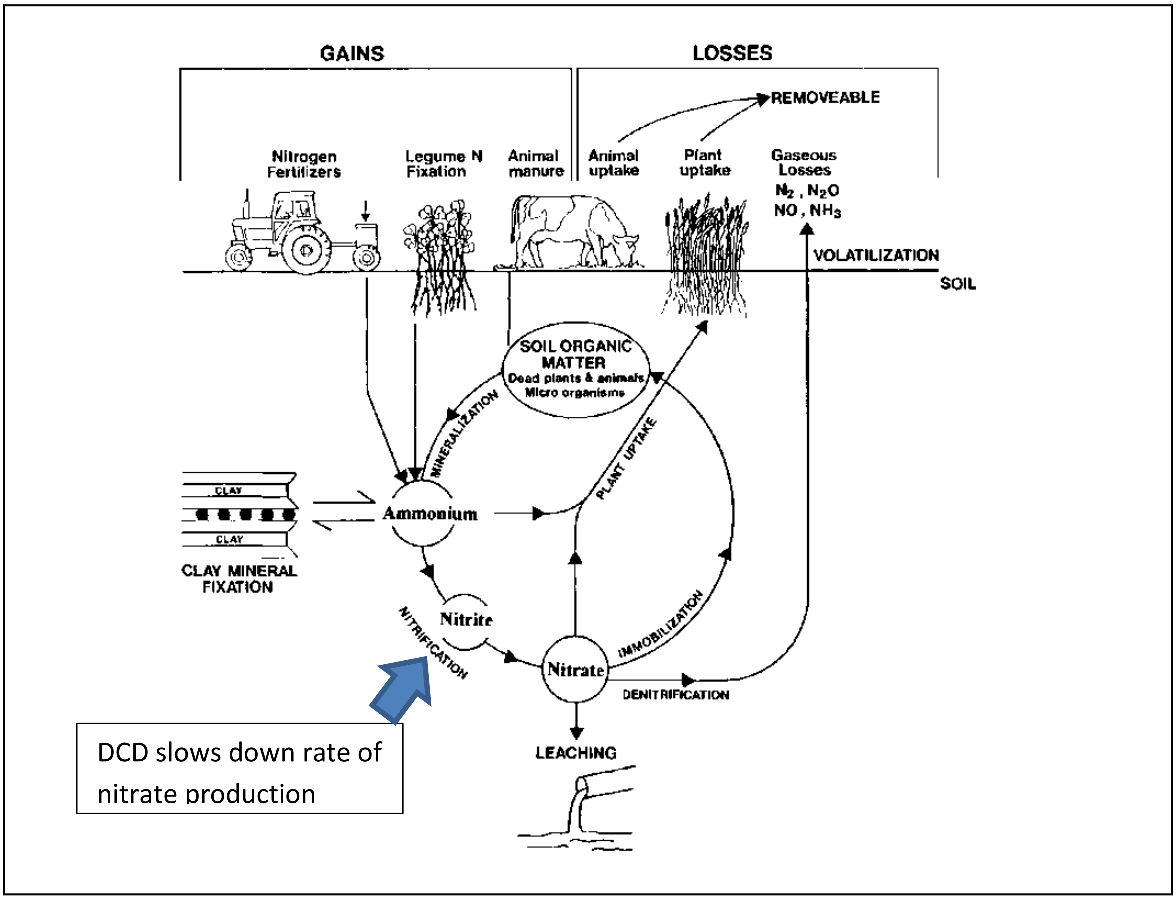
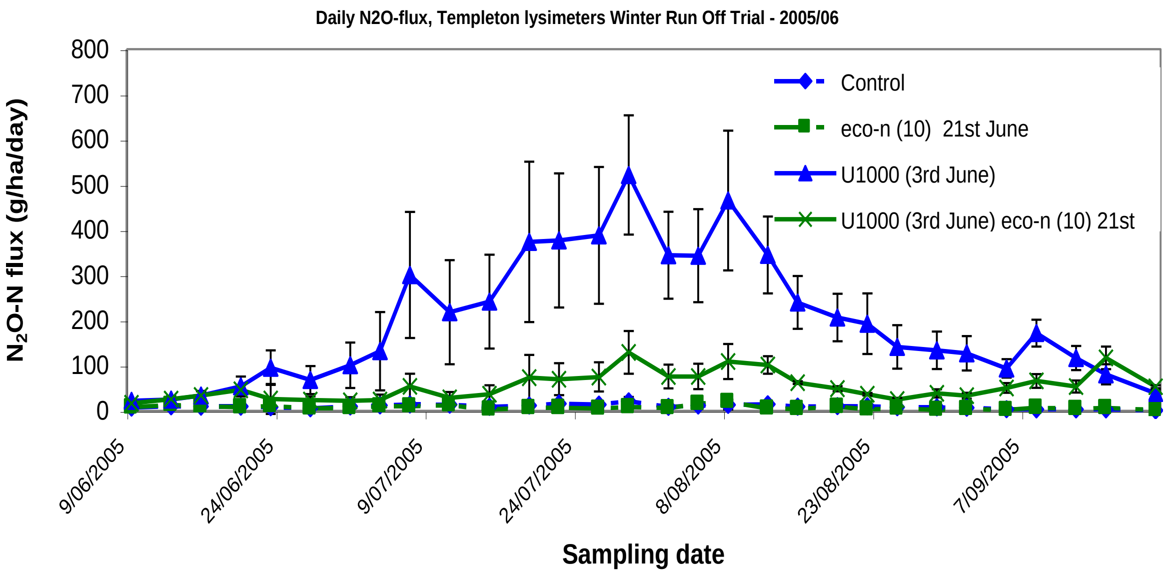


Fig. 16 Nitrous Oxide flux reduction due to Nitrification Inhibitor (Di et al. 2007)



5. Conclusion

New Zealand's greenhouse gas emission profile is different from other developed countries because agriculture is the largest contributing sector with 47.2% of the country's emissions. This results mainly from methane emissions from ruminant livestock and nitrous oxide from fertiliser use. Emissions from the sector are increasing because of the expansion of dairying particularly in Canterbury. Forest clearance for conversions to dairying is also reducing greenhouse sinks.

Climate projections indicate an increase in temperature: about 1°C in the next 50 years which is double the historical rate (1°C in the last 100 years). For Canterbury on the dry east coast of the South Island, this will result in an increased potential evapotranspiration deficit of around 120-180 mm per year. Rainfall projections for Canterbury are for a small summer increase (2.5-5%) and a winter decrease (7.5-10%). Whereas the west coast is projected to have lower summer rain (0-2.5%) and increased winter rain (5-12.5%). With higher winter temperatures it is projected that snow cover in the Southern Alps will decrease and snow lines rise.

These climate change projections have significant implications for Canterbury where 89% of consumptive use is for irrigation of agriculture. The increase in potential evapotranspiration will increase irrigation demand. The decrease in winter rainfall on the Canterbury Plains will reduce groundwater recharge while lowered groundwater levels will reduce flows in groundwater-fed lowland streams. Drier winters will also lead to lower flow in foothill rivers. For alpine rivers with their catchments extending into the Southern Alps, there will be an increase in annual flows from increased winter rain on the west coast. However the reduced snow will lead to increased winter flows but reduced summer flows. More detailed analysis of monthly flows in two alpine rivers, the Waimakariri and the Rangitata, indicate reduced reliability of supply for run-of-river irrigation schemes.

There is therefore a need for adaptation to the climate change projections but also an opportunity for greenhouse gas emission mitigation because of the significance of agricultural emissions. Strategic investigations highlight that improved water use efficiency can increase water availability. While there are concerns about storage on the main stems of alpine rivers, sustainable options exist for off-river or aquifer storage of projected increased winter flows for use in the irrigation season.

There is also the potential for offsets of agricultural emissions through forestry plantings and incorporation of hydro electricity generation in association with irrigation schemes. Reductions in nitrous oxide emissions can be achieved by the application of nitrification inhibiters.

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