Costs and Benefits of Climate Change and Adaptation to Climate Change in New Zealand Agriculture: What do we know so far?

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Executive Summary

Temperature increases and changes in the amount and regional distribution of rainfall are expected to occur over New Zealand during the coming century, as a result of projected global increases of greenhouse gas concentrations from human activity. In addition drought risk will increase in some currently drought-prone areas of New Zealand. Agricultural productivity in at least some regions, and hence national gross domestic product (GDP), might be affected by these projected climatic changes.

This report presents a summary and review of past research on the economic effects of climate on agriculture in New Zealand. These estimated effects are then compared with some new estimates that have been compiled specifically for this report.

The report has three distinct parts:

1. Future climate scenarios and projections of resulting changes in agricultural productivity
2. Literature review of the economic effects of climate change on New Zealand agriculture
3. Orders of magnitude of economic costs and benefits of climate change on agriculture in 2030s and 2080s

Part 1 outlines the development of New Zealand climate change scenarios for the 2030s and 2080s, corresponding to global temperature changes 25% and 75% of the way between the lower and upper bounds of the scenarios in the Intergovernmental Panel on Climate Change (IPCC) 2001 Third Assessment Report (TAR). These scenarios of climate changes across New Zealand take account of the effect of local topography and geography on climate. They are obtained from broad regional changes projected by global climate models through a process called statistical downscaling. Some preliminary projections based on the IPCC 2007 Fourth Assessment Report (AR4) are also discussed.

Some of the key findings are as follow:

- Projected dairy and sheep/beef production in the driest “scenario years” in the periods 2020–2049 and 2070–2099 is worse than in the driest year in the 1972–2002 period.

- For the TAR climate scenarios considered, average year production and worst year production are both projected to decline for east coast locations (Wellington, Hawke’s Bay, Canterbury, Bay of Plenty, Gisborne), and also Northland. Improvements in production are projected in Southland and the West Coast – regions which are projected to remain moist while warming. These results apply to both dairy production and sheep/beef production. Similar patterns of change are described based on the AR4 climate scenarios considered, with the exception of production in Gisborne and northern Hawke’s Bay which is projected to stay the same or increase.

- For average years, the new projections show no strong trend during the coming century in production when accumulated over the whole country. Projected national dairy production ranges from 96–101% of the 1972–2002 average, and projected sheep/beef production from 91–96% of the 1972–2002 average.

The methodology cannot predict possible changes due to increased carbon dioxide concentrations in the atmosphere. For concentrations of 475–650 ppm, plausible estimates for direct CO_2 fertilization effects alone (i.e. in the absence of parallel changes in climate) on

grazed New Zealand pastures range from no effect, to an increase in production of around 15%.

In Part 2 we review six comprehensive studies on the effects of climate on agriculture. The studies use different approaches, cover different historical time periods, regions and agricultural sub-sectors, and differ in the extent to which they allow for second round effects. Nevertheless there is a high degree of consistency. Broadly speaking, for a change of one standard deviation in the number of days of soil moisture deficit (DSMD), reductions in agricultural gross output are usually less than 5%. The consequential effect on the nation's GDP is around 0.1%. However, the effects are non-linear. A change of three standard deviations in DSMD reduces national GDP by around 1%. Of course the effects are larger in regions that are more reliant on agriculture.

Long term climate trends may include a trend in the average value of an indicator (such as DSMD), and may also include a trend of the variance of an indicator. The two are not unrelated. An increase in the frequency and severity of droughts – as expected for New Zealand under climate change – could raise both the variance of DSMD and its average value.

Assessing the costs of floods and storms is rather different than assessing the costs of gradual climate change. The documents on flood events that we have reviewed focus exclusively on tangible costs, but even then the estimates are shaky. Most reports quote only estimated loss and damage costs for assets, or the value of insurance claims. Cost impacts on agriculture are not at all well covered and depend not only on the climate, but also on the socio-economic scenarios describing population density, housing types, land-use and so on. It is not possible to reliably estimate economic loss from these indicators.

Part 3 compares the results from Parts 1 (the analysis of TAR-based scenarios only) and 2. Overall the consistency of results is quite remarkable, given the vastly different methodologies employed. The objective of each methodology is identical: to estimate the effect of climate change (changes in DSMD) on agricultural output. One approach uses spatial data in a largely agronomic model, while the other uses (stationary) time series data to determine an ex post relationship between DSMD and production.

Theoretically the agronomy model should be a better guide to the effects of permanent differences in the climate on production, as the time series models know about only temporary climatic variation. In so far as the historical variability in the climate (or at least in DSMD) has been around a reasonably flat trend (in terms of both mean and variance), historical econometric studies will usually overstate the negative effects of climate change on agricultural output and on the economy in general. This is because past reactions by farmers (in particular) are based on certain 'stationary' expectations about the climate.

On the other hand, there may be positive bias by the accessibility of temporary assistance such as greater irrigation or the importation of animal feed from neighbouring regions. These options may not be available under a permanently drier climate.

Other responses can be expected at a sectoral level – for example the loss of dairy output in an unexpected dry year might not occur if expectations of a drier climate lead to a more suitable pattern of land use.

More fundamentally, for the purpose of projecting changes in agricultural production under a 'worst year' scenario, what is the appropriate definition of a 'departure from normal' with respect to climate indicators? Over 75 years one might reasonably assume that the configuration of farming capital stock and management practices would have adjusted to match a different climate. Then departures from normal should be measured with respect to what is normal at that future time. For animals and plants, however, full adaptation to a different climate is unlikely. As discussed in Part 1, different regions have permanent differences in net primary productivity. In that case departures from normal in a 'worst year' might be better measured with respect to historical averages. In fact this leads to greater alignment between the projections of the two methodologies, perhaps implying that the physiological limitations to adapting to a different climate cannot be fully offset by changes in farm management practices. On the other hand, the alignment may just reflect the calibration of the agronomy model to historical spatial climatic differences.

Hence we are still far from understanding what the economic impacts of climate change will be on New Zealand agriculture. The following additional research is essential to combating our ignorance:

- National and regional projections of future pastoral-based productivity for a wider range of scenarios are required. We suggest this could be usefully done with climate projections downscaled from the latest set of global model runs undertaken for the IPCC AR4, considering both statistical downscaling (as used in this study) and physical downscaling using regional climate models (i.e. expanding on the preliminary work presented in Section 8 of Part 1).

- It would be desirable to use bio-physical models to predict future changes in pasture growth due both to changes in climate including irrigation water availability and changes in carbon dioxide concentrations (CO_2 'fertilization' effects), coupled to nutrient availability, aboveground/belowground allocation, herbage digestibility and ruminant physiology. From a detailed process model analysis, it is likely that simple analyses such as the present study can be extended to be better targeted and calibrated to yield more robust results across a range of agronomic, soil and climate conditions.

- Models that lead to an understanding of how pasture growth varies with climate are just part of the adjustment process. An understanding of changes in land use in response to different pasture productivity is also required.

- No account has been taken of any changes in the prices of inputs or outputs that may be caused by shortages or surpluses of product – whether local or international, or by policy responses to such shortages/surpluses. Price changes have the potential to change agricultural incomes in the opposite direction to changes in physical production. Taking account of price change is critical to determining the allocative efficiency effects that arise from a permanently different climate.

- Further work could focus on identifying climate impacts on production in New Zealand in three categories – (1) impacts where New Zealand is "in sync" with the rest of the world (such as CO_2 fertilization) and therefore little impact on export economics is likely; (2) impacts where New Zealand is potentially out of sync with other areas globally and likely to be affected strongly economically; and (3) strongly localised impacts within New Zealand likely to require adaptation responses (e.g. increased drought in some areas, changes in growing season).

List of Acronyms used in this report

ANPP	Above-ground Net Primary Production
AR4	Fourth Assessment Report of the IPCC
CSIRO	Australia's Commonwealth Scientific and Industrial Research Organisation
D	Digestibility
DSMD	Days of Soil Moisture Deficit
ENSO	El Niño – Southern Oscillation
EQC	Earthquake Commission
FACE	Free-Air Carbon Dioxide Enrichment
GDD	Growing Degree Days
GDP	Gross Domestic Product
GE	General Equilibrium (Model)
GIS	Geographic Information System
ICNZ	Insurance Council of New Zealand
IPCC	Intergovernmental Panel on Climate Change
LRIS	Land Resource Information System
LURNZ	Land Use in Rural New Zealand
MAF	Ministry of Agriculture and Forestry
ME	Metabolisable Energy
MfE	Ministry for the Environment
MPG	Metabolisable Pasture Growth
NIWA	National Institute of Water and Atmospheric Research Ltd
NPP	Net Primary Production
NZIER	New Zealand Institute for Economic Research
OECD	Organisation for Economic Co-operation and Development
PED	Potential Evapotranspiration Deficit
PET	Potential Evapotranspiration
PSRM	Pastoral Supply Response Model
QVNZ	Quotable Value New Zealand
RMSE	Root Mean Square Error
SMD	Soil Moisture Deficit
SRES	Special Report on Emission Scenarios
TAR	Third Assessment Report of the IPCC
VAR	Vector Autoregressive (Model)

Contents

Executive Summary 2
List of Acronyms used in this report 5

PART 1 Climate Change and New Zealand Agriculture – Future Climate Scenarios and Projections of Resulting Changes in Agricultural Productivity 8
Executive Summary 8
1. Introduction 12
1.1 Background 12
2. Climate Scenarios Projected for the 2030s and 2080s 14
2.1 Climate scenarios for the quantitative agricultural production modelling undertaken in this report 16
3. Current and likely future constraints and demands on water usage and storage for agriculture.. 20
3.1 Demand for water 20
3.1.1 Current demand 21
3.1.2 Future Prospects for Demand 21
3.2 Availability of water 23
3.2.1 Future prospects for availability of water 24
3.2.2 Current water shortages 24
4. Changing risks of significant drought occurring over two adjacent agricultural years. 26
5. Present Spatial Land-Use Patterns and Productivity for Various Agricultural Land Uses 29
6. Past work on impacts of climate change on growing locations and productivity for New Zealand agriculture 32
6.1 Pastoral Agriculture 33
6.2 Wheat Production 34
6.3 Apples 34
6.4 Kiwifruit 34
6.5 Grapes 34
6.6 Maize and Sweetcorn 35
7. New Projections of Changes in Pastoral Production for the 2030s and 2080s due to Changes in Growing Degree Days and Soil Moisture 36
7.1 Methods Used for Calculating Climate Impacts on Pasture Production 37
7.2 Results: Projected impacts on dairy production and sheep/beef production 39
7.2.1 Dairy Production 43
7.2.2 Sheep and Beef Production 44
7.3 Assumptions Underlying the New Pastoral Production Estimates 44
8. Preliminary Results from an Analysis of IPCC Fourth Assessment Report Climate Models 48
8.1 Climate Scenarios Projected for 2040 and 2090 48
8.2 Projections of Changes in Growing Degree Days and Soil Moisture for 2030–2049 and 2080–2099 52
8.3 Projections of Changes in Pastoral Production for 2030–2049 and 2080–2099 due to Changes in Growing Degree Days and Soil Moisture 55
9. Discussion and Conclusions 59
10. References 61

PART 2 Literature Review of the Economic Effects of Climate Change on New Zealand Agriculture 64
1. Metrics for Measuring the Effects of Climate Change 64
1.1 Measuring the Loss in GDP 65
1.2 Extreme climate change events 65
1.3 Gradual climate change 66
1.4 Caveats 67
2. Literature Review – Dry Periods 69
3. Literature Review – Floods and Storms 85
4. References 115

PART 3 Orders of magnitude of economic costs and benefits of climate change on agriculture in 2030s and 2080s 116
1. Gradual Climate Change 116

1.1 Average years ... 117
1.2 Worst years ... 117
1.3 Discussion ... 118
2. Storms and Floods ... 119
2.1 Slips ... 119
2.2 Flooding ... 119
3. References ... 121

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PART 1
Climate Change and New Zealand Agriculture – Future Climate Scenarios and Projections of Resulting Changes in Agricultural Productivity

Executive Summary

Temperature increases and changes in the amount and regional distribution of rainfall are expected to occur over New Zealand during the coming century, as a result of projected global increases of greenhouse gas concentrations from human activity. Work undertaken recently by NIWA also suggests that, for a range of climate change scenarios, drought risk will increase in some currently drought-prone areas of New Zealand. Agricultural productivity in at least some regions, and hence national gross domestic product (GDP), might be affected by these projected climatic changes. This report documents the first part of a project to quantify some effects of projected climate changes on New Zealand agriculture and to estimate resulting economic impacts.

The report outlines climate change scenarios projected for the periods 2020–2049 ("the 2030s"), and 2070–2099 ("the 2080s"), discusses possible changes in water demand and supply for irrigation, and documents present spatial land-use patterns and productivity. Previous research on potential impacts of climate changes on New Zealand agricultural productivity is reviewed. New estimates for changes in pastoral productivity are provided, under selected climate scenarios for the 2030s and 2080s.

The work discussed above was undertaken before the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) was completed, and is based on downscaling to New Zealand from global climate models run for the IPCC Third Assessment Report (TAR) in 2001. However, preliminary projections for pastoral productivity based on downscaling from some of the AR4 global model runs were prepared in late 2007, and a section has been added to this report which discusses these.

Methods Used

For the main part of the report, New Zealand climate change scenarios for the 2030s and 2080s are developed corresponding to global temperature changes 25% and 75% of the way between the lower and upper bounds of the scenarios in the IPCC TAR. These scenarios of climate changes across New Zealand take account of the effect of local topography and geography on climate. They are obtained from broad regional changes projected by global climate models through a process called statistical downscaling. We use data from runs of the 'HadCM2' global model undertaken for the TAR. These model runs lead to downscaled New Zealand scenarios which have a significant increase in the west-to-east rainfall gradient across the country (wetter in the west, drier in the east).

We label the downscaled scenarios based on the HadCM2 model corresponding to the global temperatures 25% and 75% across the IPCC range the "h25" and "h75" scenarios. These scenarios are used to develop projections for future regionally-varying changes in Growing Degree Days (GDD; an index of annual heat accumulation above a daily base temperature – in this case 5°C) and an index of Soil Moisture Deficit (SMD), which are then

used to project future changes in agricultural productivity. Expected changes in water availability for irrigation are examined (based partly on climate change scenario work) and results developed for the NIWA drought study are used to analyse possible future changes in the frequency with which droughts occur for two years running.

Our review of past work on impacts on agricultural productivity from projected climate changes focuses mainly on results from the ‘CLIMPACTS’ project. Our new estimates of regional changes in pastoral productivity under various climate change scenarios use relationships derived between present spatially varying climate parameters and spatially varying data on pasture dry matter production. These relationships are applied to changes in GDD and in a SMD index under the 2030s and 2080s climate scenarios, to project resulting changes in pasture growth.

The IPCC released the AR4 in 2007. Climate model output from 12 updated AR4 global models, driven by the middle-of-the-road emissions scenario known as ‘SRES A1B’, are downscaled to produce changes of temperature and precipitation over New Zealand for the two future periods 2030–2049 and 2080–2099. In section 8 of this report, the 12-model average projections are used to evaluate changes in pastoral production which then are compared with the TAR-based results.

Key Findings

- For the “h75” downscaled New Zealand scenarios based on the HadCM2 model runs from the IPCC TAR, a drying corresponding to an increase in the annual SMD index of 100–200 mm for the 2080s (compared to 1990) is projected for some eastern parts of Marlborough and the Wairarapa, much of Hawke’s Bay and Gisborne, and parts of the Bay of Plenty and Northland. Greater drying, corresponding to increases of over 200 mm in SMD, is projected for substantial parts of Hawke’s Bay and Gisborne. For comparison, average SMD can exceed 400mm in some eastern areas of the country under the current climate.
- This is consistent with the NIWA drought report, which also projects that soil conditions will become drier in the east of New Zealand later this century. These eastern regions contain most of the currently water–short areas of New Zealand. Drier conditions are expected to increase the demand for water.
- Our analysis of these HadCM2-based results suggests that Hawke’s Bay and Gisborne could be particularly vulnerable to increased frequency of successive dry years in the future. However, details of projected changes in successive dry years are likely to depend on the particular climate model used in the downscaling assessment. The subsequent modelling we undertook based on the IPCC AR4 models indicated less vulnerability for Gisborne. Such changes will also depend on whether the frequency of El Niño conditions changes in future – a topic on which there is not yet a clear scientific consensus.
- Given that flows in the rivers fed from the Southern Alps in Canterbury and Otago are expected to increase (on average) under most climate change scenarios, one might expect increased water supply reliability from irrigation systems fed from this source. However it has not yet been determined whether the likely increase in water supply from these Alps-fed rivers will fully compensate for the likely increase in demand.
- Agricultural regions in eastern New Zealand which do not have Alps-fed rivers are likely to face greater shortages of water in future: this would include Northland, Hawke’s Bay, and parts of Tasman and Marlborough.
- The “h75” downscaled New Zealand scenarios developed from the HadCM2 model runs indicate an increase of 500–800 GDD (base 5°C) in the 2080s compared to 1990 for most of the North Island, and for some northern and eastern parts of the South Island

(from South Canterbury north). For comparison, average GDD can exceed 3000 in warmer parts of the North Island under the current climate.

- Work published in 2001 from the CLIMPACTS study predicted an 8–10% increase in pasture dry matter production in 2020 averaged across five sites in different parts of New Zealand (compared to 1990), for a mid-range IPCC scenario, for all seasons. Averaged across the same sites, CLIMPACTS projections of seasonal changes in dry matter production for 2050 ranged from a 19% increase in spring to a 27% increase in winter.
- The first part of this report provides new projections covering the whole country, of the effects of changes in SMD and GDD on pastoral production over the coming century for the New Zealand climate scenarios already described. The projections are suitable for risk assessment of changes in production which could occur under plausible climate scenarios exhibiting significant increases in the west-to-east rainfall gradient across the country (wetter in the west, drier in the east).
- Projected dairy and sheep/beef production in the driest “scenario years” in the periods 2020–2049 and 2070–2099 is worse than in the driest year in the 1972–2002 period.
- For the climate scenarios considered, average year production and worst year production are both projected to decline for east coast locations (parts of Wellington, Hawke’s Bay, Canterbury, Bay of Plenty, Gisborne), and also Northland. Improvements in production are projected in Southland and the West Coast – regions which are projected to remain moist while warming. These results apply to both dairy production and sheep/beef production.
- For average years, the new projections show no strong trend during the coming century in production when accumulated over the whole country. Projected national dairy production ranges from 96–101% of the 1972–2002 average, and projected sheep/beef production from 91–96% of the 1972–2002 average.
- The methodology used for these new pastoral productivity projections cannot predict possible changes due to increased carbon dioxide concentrations in the atmosphere. For concentrations of 475–650 ppm, plausible estimates for direct CO_2 fertilization effects alone (i.e. in the absence of parallel changes in climate) on grazed New Zealand pastures range from no effect, to an increase in production of around 15%.
- For the scenarios considered in this report, it is likely that as the century progresses the drying of pasture in spring may begin earlier than at present. Also, the projected increase in temperatures and growing degree days may give rise to an earlier start to pasture growth in the late winter or spring. Farmers might choose to bring forward some of their operations to fit such changes, perhaps resulting (for example) in lambs being ready for the works earlier than at present.
- The preliminary work based on the IPCC AR4 models supports the conclusions bulleted above, with the exception of the impact projected for the east coast region north of Napier. While some AR4 models still indicate decreased summer rainfall in this area, the average of 12 AR4 model rainfall projections indicates increased summer rainfall (by as much as +10% by 2090), which is a marked departure from the HadCM2 projections which indicate a decline in summer rainfall in this region (by as much as -10% by the 2080s). The result of this projected increase in summer rainfall in this area is the AR4 12-model average net primary production (NPP) for the future period median years now show similar or increased productivity compared with the reference period.

The future projections from both the CLIMPACTS analyses and from our new methodology do not adequately account for irrigated agriculture. Thus our projected decreases in agricultural production in drier regions may be at least partially offset by increased irrigation in places where water availability does not become a constraint. On the other hand, in areas which presently have adequate water for irrigation but may not have in future, production could decrease. Also, our assumption that regional annual dairy and sheep / beef production are proportional to metabolisable pasture growth, does not account for response measures in dry conditions such as transport of feed from other regions, or sale of stock to farmers from other regions.

For future work we suggest:

- Producing national and regional projections of future pastoral-based productivity for a wider range of scenarios, utilising climate projections presently being downscaled from the latest set of global model runs undertaken for the IPCC AR4 (i.e. expanding on the preliminary work presented in Section 8).
- Estimating the temporal and spatial changes in river and groundwater available for irrigation under future climate scenarios, and incorporating these estimates into the estimated change in pasture growth.
- Projecting future changes in pasture growth due to both changes in climate (including water availability from irrigation) and increases in carbon dioxide concentration, using the bio-physical model being developed by AgResearch.

These suggestions form part of the research proposed under the new “Ecoclimate” collaboration, for which partial funding is presently being negotiated with the Foundation for Research, Science and Technology.

1. Introduction

This report is composed of three parts, each being prepared for the New Zealand Ministry of Agriculture and Forestry. They will document results from a project drawing together existing knowledge in order to provide a first set of estimates of likely costs of projected climate changes, and costs and benefits of adaptation. The reports are focusing particularly on pastoral agriculture.

Part 1 first outlines climate change scenarios projected for the 2030s[1] and 2080s, based on global model runs from the IPCC TAR (Houghton et al, 2001). It next describes present spatial land-use patterns and productivity. Expected changes in productivity for pastoral agriculture land uses are then estimated for selected 2030s and 2080s climate change scenarios. Finally, preliminary work on the impact of climate change on agricultural production based on models from the IPCC AR4 (IPCC, 2007) is also presented.

Part 2 will collate and analyse existing information on past costs of climatic fluctuations and adverse climatic effects, for New Zealand agriculture. The information on economic costs and benefits from Part 2 will be extrapolated and applied to the changes in land productivity projected in Part 1. The outcome is presented in Part 3 which provides “orders of magnitudes” of economic costs and benefits of climate change as it is projected to affect agriculture in the 2030s and 2080s. Part 3 will also recommend priorities for future research.

1.1 Background

A report titled “Changes in Drought Risk with Climate Change” (Mullan et al, 2005) was recently prepared by NIWA for Ministry of Agriculture and Forestry (MAF) and Ministry for the Environment (MfE). A key finding was that under a “low-medium” climate change scenario, by the 2080s severe droughts[2] are projected to occur at least twice as often as currently in the following areas: inland and northern parts of Otago, eastern parts of Canterbury and Marlborough, and parts of the Wairarapa, Hawke’s Bay, Bay of Plenty, and Northland (see Figure 1.1 for the location of these regions). Under a “medium-high” scenario the frequency of severe drought in these areas could increase even more. Even in an average year, water deficits are projected to increase significantly in many of the areas listed above.

Tait et al (2005 b) have shown that year-to-year variations in rainfall, days of soil moisture deficit (DSMD), and GDD can have a direct effect on New Zealand’s economy, by causing deviations from normal in New Zealand’s annual milk production. The estimated loss to GDP from the 1998/99 drought was NZ$539 million (MAF, 2000). Thus the drier climate projected for parts of NZ in coming decades, and the changes in growing degree days expected from projected future increases in temperature (MfE, 2004) could well affect agricultural productivity in parts of New Zealand, and hence national GDP. Part 1 of this report is the first step in a project to quantify some of the impacts of projected climate changes on New Zealand agricultural production and the resultant economic impacts.

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[1] In this report “the 2030s” is shorthand for the period 2020-2049, and “the 2080s” for 2070-2099

[2] In the drought risk report, the term “severe drought” refers to one-in-twenty year dry year under the present climate (1972–2003). “Dryness” is measured using the accumulated Potential Evapotranspiration Deficit (PED) for a growing year (July – June 30th). The annual PED accumulation can be interpreted as 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.

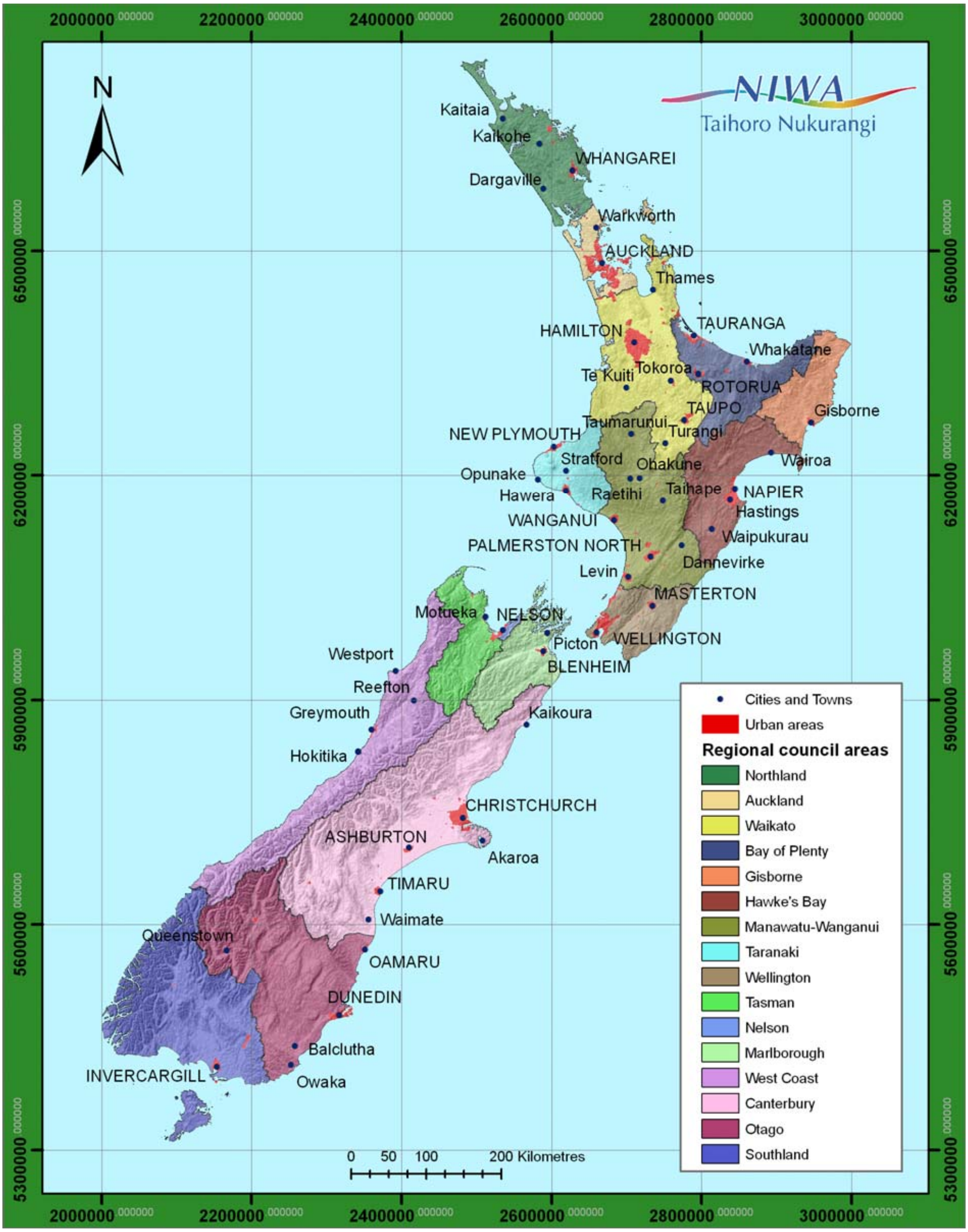


Figure 1.1: *New Zealand regional council areas. Source: Statistics New Zealand.*

2. Climate Scenarios Projected for the 2030s and 2080s

Key Points:

- Future changes in global climate (and hence New Zealand climate) will be influenced by global greenhouse gas emission pathways, which in turn are dependent on (unknown) economic, social and political changes. A range of plausible future climate scenarios is often considered, in order to span possible future emission pathways.
- These global scenarios have to be “downscaled” for New Zealand, to take account of local topographic and geographical influences. Such downscaled scenarios were used by NIWA in a previous study of expected changes in drought risk.
- For the scenarios considered in that report, droughts of the severity currently experienced with an average return interval of 20 years are projected to become appreciably more common in eastern regions later in the coming century. Eastern regions are also projected to become drier in average years. Such changes are expected to lead to regional changes in agricultural production, especially from dryland pastoral farming.
- A set of downscaled regional scenarios for the 2030s and 2080s is described, from one of the climate models used in the IPCC TAR (HadCM2) which projects significant changes in west-east rainfall patterns across New Zealand. These scenarios will be used to project future changes in pastoral production in Section 7 of this report. These scenarios correspond to global temperature changes bracketing the central 50% of the projections in the IPCC TAR.
- For the downscaled scenario corresponding to a global temperature rise 75% across the IPCC TAR range (the “h75” scenario), an increase of 500–800 Growing Degree Days (base 5°C) is projected in the 2080s compared to 1990 for most of the North Island, and some northern and eastern parts of the South Island (from South Canterbury north).
- For the “h75” downscaled scenario drier conditions, corresponding to an increase of 100–200 mm in the annual soil moisture deficit index, are projected for the 2080s (compared to 1990) for some eastern parts of Marlborough and the Wairarapa, much of Hawke’s Bay and Gisborne, and parts of the Bay of Plenty and Northland. More drying, corresponding to increases of over 200 mm in the deficit index, are projected for substantial parts of Hawke’s Bay and Gisborne.
- Preliminary work based on an average of 12 models from the IPCC’s Fourth Assessment Report (see Section 8) indicates the annual soil moisture content in Hawke’s Bay and Gisborne is projected to increase due to projected increases in summer rainfall in the east of the country. This represents a marked difference to the summer rainfall changes projected by the HadCM2 model.

The standard approach to assessing future impacts of climate change is to develop “scenarios” that take account of the range of estimated future emissions of greenhouse gases, and also the variations between models in the projected patterns for the New Zealand region. The global climate models project trends in broad climate patterns across the Pacific, but do not take account of the detailed effects of New Zealand’s topography on the local climate. Projected local changes are inferred from the coarser-scale information in the global climate models by a process known as “downscaling” (Mullan et al, 2001).

For NIWA’s report on projected future changes in drought risk (Mullan et al, 2005) results from two sets of global model runs from the IPCC TAR (Houghton et al, 2001) were chosen for developing these future scenarios: a set from a Commonwealth Scientific and Industrial Research Organisation (CSIRO) model known as ‘CSIRO Mark 2’ and a set from a model from the Hadley Centre in the United Kingdom MetOffice (‘HadCM2’). These models have been used in previous New Zealand climate change work (e.g. MfE, 2004), and exhibit similar global-average temperature changes. However, their downscaled changes for New Zealand are rather different. The downscaled HadCM2 results project that New Zealand’s east will warm faster than the west in future, and also become drier. The CSIRO Mark 2 results, on the other hand, exhibit a larger (but geographically more uniform) temperature increase over the country but little change to the current west to east rainfall pattern.

For the IPCC TAR global temperature projections were developed for 35 different future emissions scenarios. None of these scenarios incorporated emissions reductions developed specifically in response to international climate change policy agreements (such as the Kyoto protocol), but some of them assumed more use of renewables for energy generation and more improvements in energy use efficiency than others. These scenarios and the associated modelling led to projections of increases of between 1.4 °C and 5.8 °C in global mean surface temperatures by 2100. The authors of the NIWA drought risk report produced two projections for each of the global model runs used (CSIRO Mark 2 and HadCM2). The first projection corresponded to a global temperature change 25% of the way between the lower and upper bounds of the IPCC TAR range, and the second to a global change 75% of the way across this range. This choice reflected the fact that some climate scientists considered the extremes of the IPCC TAR range to be less likely than the intermediate values (e.g. Wigley and Raper, 2001). The drought report authors chose to use scenarios bracketing the central 50% of the IPCC scenarios, rather than focusing on the possibly lower probability extremes.

Regional results from the scaled “25%” and “75%” global climate model runs were then adjusted to take account of the influences of New Zealand’s detailed landform and topography through a technique called “statistical downscaling”. This starts with historical climate observations in New Zealand, and calculates “downscaling relationships” between broad regional climate patterns and these local climate observations. These downscaling relationships were then applied to the broad future regional climate patterns projected by the global climate models, in order to provide more locally detailed projections for New Zealand (e.g. Mullan et al, 2001). A special gridded January 1972–December 2003 New Zealand climate data set (Tait et al, 2005a) which uses daily measurements from New Zealand climate observing stations to estimate climate parameters on a 0.05° latitude by 0.05° longitude grid (approximately 5 km by 4 km) was used to develop the downscaling relationships.

More details on the scenarios and downscaling methods are provided in the NIWA drought report (Mullan et al, 2005). Figures 2.1(a) and 2.1(b) are reproduced below from that report, and show projected changes in the recurrence interval of very dry periods by the 2080s for a “low-medium” scenario (25% IPCC plus CSIRO Mark 2 model) and “a “medium-high” scenario (75% IPCC plus HadCM2 model – i.e. corresponding to the h75 scenario in the present report). The “2080s” refers to the period 2070–2099, and the 2030s to the period 2020–2049. Even under the “low-medium” scenario, by the 2080s, severe droughts (defined as a *current* one-in-twenty year drought) are projected to occur at least twice as often as currently in the following areas: inland and northern parts of Otago; eastern parts of Canterbury and Marlborough; parts of the Wairarapa, Hawke’s Bay, Bay of Plenty, and Northland (figure 2.1(a)). Note; the NIWA drought report was based on an analysis of scenarios from the IPCC TAR. Plans are underway to perform a similar study using scenarios from the IPCC AR4.

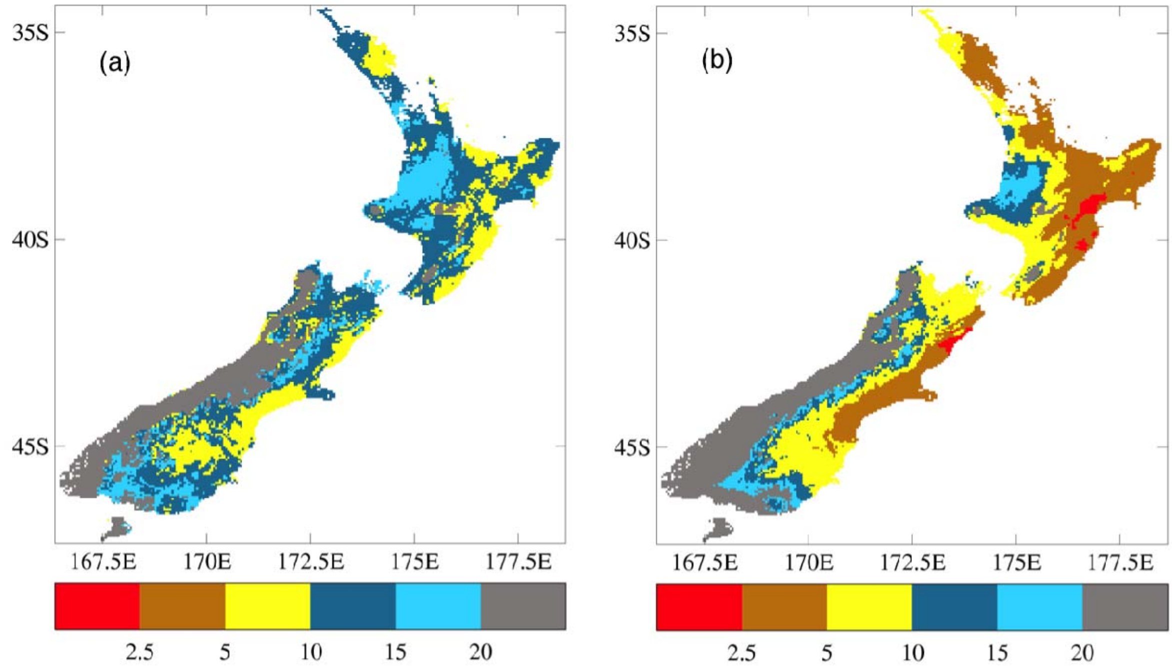


Figure 2.1: *Projected average recurrence interval (years) in the 2080s under the (a) "low-medium" and (b) medium-high" climate scenarios, for the driest annual conditions that currently occur on average once every 20 years. The measure used is the PED (Potential Evapotranspiration Deficit) accumulated over a growing year (July to June). Example: In the left hand map Timaru is in a yellow region. This means the current one-in-twenty year drought could occur (on average) between once every 5 years and once every 10 years, in the 2080s under the "low-medium" scenario, i.e. 2 to 4 times more frequently than at present. (Mullan et al, 2005).*

2.1 Climate scenarios for the quantitative agricultural production modelling undertaken in this report

The resources available for the quantitative production modelling undertaken in the present report (Section 7) were limited. We restricted our considerations to future spatial patterns downscaled from just one of the IPCC TAR models (HadCM2), under the 25% and 75% IPCC scenarios. Thus the quantitative simulations of production changes in this report should not be viewed as firm predictions for the 2030s and 2080s. They should be considered as sensitivity studies, indicating how production could change under a plausible climate scenario which leads to stronger west-east contrasts in rainfall and drought than those we experience presently. In addition, Section 8 presents the results of some preliminary work based on an average of 12 climate models prepared for the IPCC AR4. These results provide a useful comparison to the HadCM2 model results presented in Section 7, but again should be viewed in terms of a sensitivity study.

The climate variables utilised in the production modelling are the growing degree days base 5°C for an agricultural year (July 1st to June 30th), and the annual soil moisture deficit from July 1st to June 30th. The equations used for estimating agricultural productivity in Section 4, based on work by Baisden (2006), utilise growing degree days (base 5°C) for an agricultural year, and an annual (July–June) water deficit index. The water deficit index is the sum of 12 monthly water deficits calculated following the method used by Baisden in his published paper: Monthly totals of rainfall and potential evapotranspiration (PET) are obtained for points on the 0.05° latitude longitude grid over New Zealand described earlier in this page. If the rainfall for a given month exceeds the monthly PET, the water deficit for that month is set to zero. For other months the water deficit is monthly PET minus monthly rainfall. The water deficits calculated in this way for each of the 12 months making up the agricultural year are then added to produce a water deficit index for the year for use in the calculations. In the rest of this report this calculated annual water deficit is referred to by the symbol SMD (for Soil Moisture Deficit).

For the historical base period (1972–2003) the monthly rainfalls and moisture deficits are calculated from actual measurements of rainfall, solar radiation, temperature, humidity and wind interpolated on to the 0.05° latitude / longitude grid. For future periods they are estimated from downscaled climate model projections based on the methods outlined in the NIWA drought report (Mullan et al, 2005).

The future projections provide a series of annually varying rainfall and moisture index projections for each grid point and for each year in the period 2020–2049 ("the 2030s") and the period 2070–2099 ("the 2080s"). As explained in the drought report, the projection procedure leaves the year to year variability in projected monthly rainfall at a given grid point the same as under the present climate, but with the projected long-term monthly average rainfall scaled to give the same values as the downscaled 30-year averages from the global models.

To illustrate the scenarios to be used in Section 7, figures 2.2 and 2.3 show actual gridded annual GDD and SMD index values for the July 1972–June 1973 year, and projections for the changes out to the July 2020–June 2021 year and the July 2070–June 2071 year. Note that this is just the first year of the 2030s period, calculated by adding the scenario change on to the 1972/73 climate.

Figure 2.2 shows that for the h75 downscaled scenario, an increase of 500–800 GDD (base 5°C) is projected in the 2080s compared to 1990 for most of the North Island, and some northern and eastern parts of the South Island (from South Canterbury north). For the same scenario, figure 2.3 shows that an increase in the annual soil moisture deficit index of 100–200 mm is projected for the 2080s (compared to 1990) for some eastern parts of Marlborough and the Wairarapa, much of Hawke's Bay and Gisborne, and parts of the Bay of Plenty and Northland. Increases of over 200 mm are projected for substantial parts of Hawke's Bay and Gisborne. However, note that early results based on an average of 12 models prepared for the IPCC Fourth Assessment Report (see Section 8) indicate that soil moisture deficit in Hawke's Bay and Gisborne, particularly in summer, may decrease in the future due to projected increases in rainfall in this region.

We again wish to emphasize that the scenarios shown in Figures 2.2 and 2.3 are a small subset of the downscaled New Zealand regional scenarios described in the local government guidance material prepared by NIWA (MfE, 2004). Research is currently underway at NIWA to prepare a set of downscaled regional scenarios for New Zealand from the global climate model runs used in the IPCC AR4 and Section 8 of this report shows some preliminary work based on these scenarios. Research is also underway in using a regional climate model to do downscaling for New Zealand, as an additional tool to the statistical downscaling technique used to date. It may be useful to undertake more of the pastoral production modelling work described in Section 7 for a wider range of scenarios, once these new downscaled results are available.

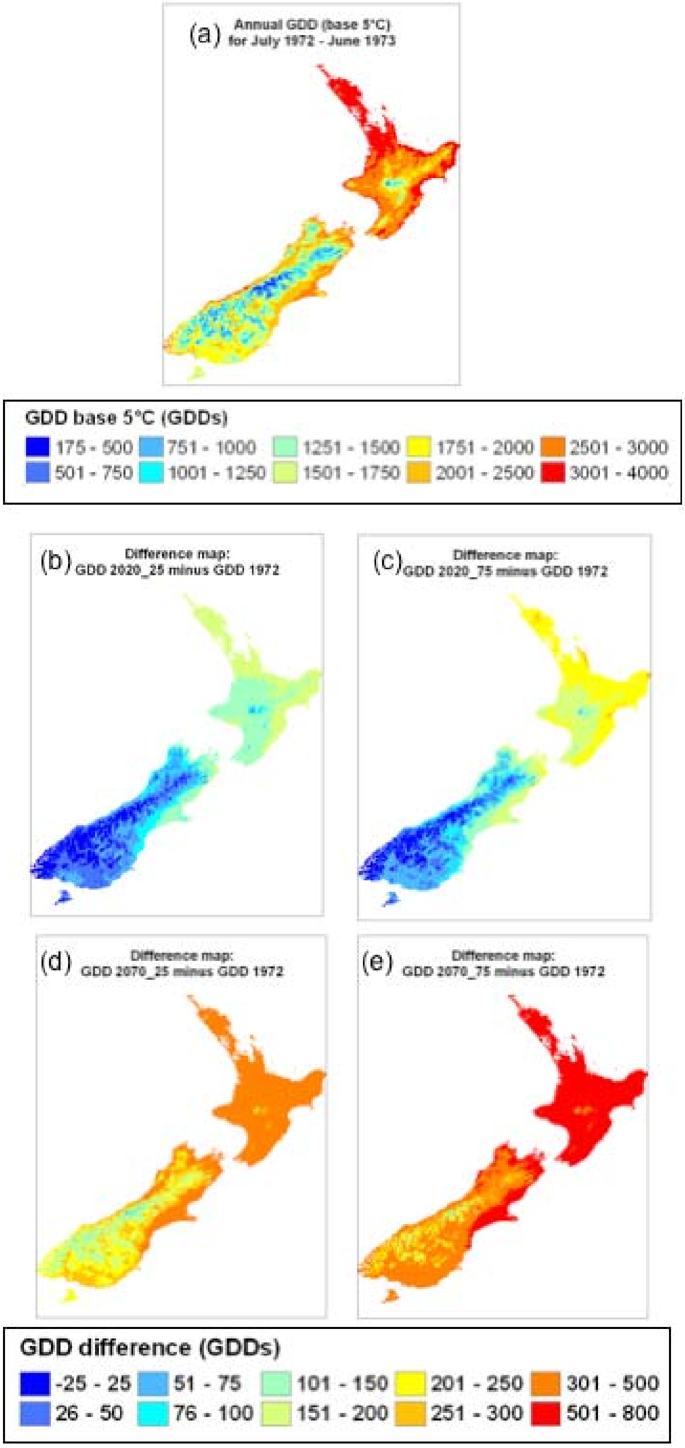


Figure 2.2: *Examples of annual growing degree day (GDD, base 5 °C) data and projections used in producing the agricultural productivity projections in Section 4:*
(a) For the agricultural year July 1972 – June 1973
(b) Increases to 2020/21, for IPCC TAR low-moderate global temperature changes (h25)
(c) Increases to 2020/21, for IPCC TAR moderate-high global temperature changes (h75)
(d) Increases to 2070/71, for IPCC TAR low-moderate global temperature changes (h25)
(e) Increases to 2070/71, for IPCC TAR moderate-high global temperature changes (h75)
(b) – (e) are all downscaled projections from IPCC TAR HadCM2 model runs.

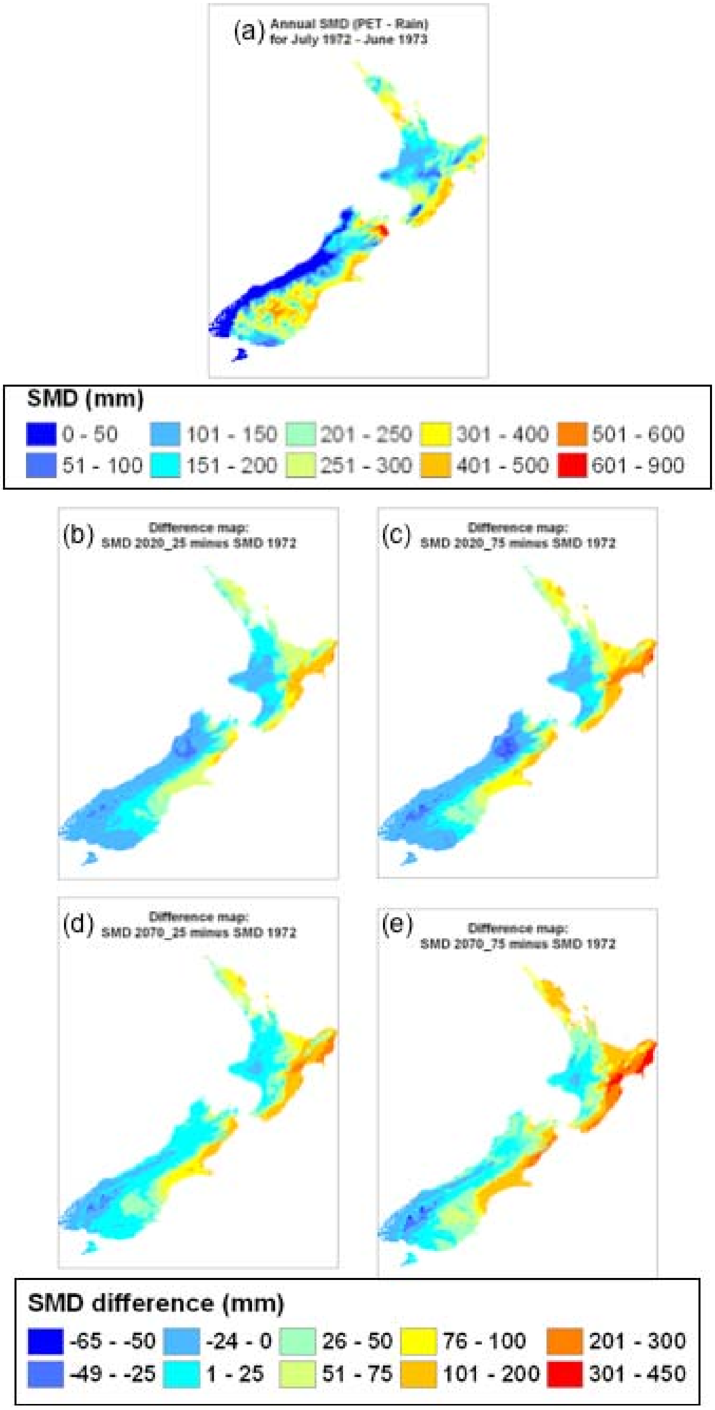


Figure 2.3: *Examples of annual moisture deficit index (SMD, mm) data and projections used in producing the agricultural productivity projections in Section 4:*
(a) For the agricultural year July 1972 – June 1973
(b) Changes to 2020/21, for IPCC TAR low-moderate global temperature changes (h25)
(c) Changes to 2020/21, for IPCC TAR moderate-high global temperature changes (h75)
(d) Changes to 2070/71, for IPCC TAR low-moderate global temperature changes (h25)
(e) Changes to 2070/71, for IPCC TAR moderate-high global temperature changes (h75)
(b) – (e) are all downscaled projections from IPCC TAR HadCM2 model runs.

3. Current and likely future constraints and demands on water usage and storage for agriculture.

Key Points

- Water for irrigation is the dominant consumptive use for water in New Zealand, currently accounting for 77% of consented water use.
- The area of land which is irrigated has been expanding at 40% per decade since 1990. A particularly visible example of this growth is the expansion of dairy farming in the eastern South Island.
- The NIWA drought report projects that soil conditions will become drier in the east of New Zealand later this century. These eastern regions contain most of the currently water-short areas of New Zealand. Drier conditions are expected to increase the demand for water.
- Given that flows in the Alps-fed rivers of Canterbury and Otago are expected to increase (on average) under most climate change scenarios, one might expect increased water supply reliability from irrigation systems fed from this source.
- Information available from studies undertaken to date is not sufficient to determine whether the likely increase in water supply from these Alps-fed rivers will compensate for the likely increase in demand.
- Agricultural regions in eastern New Zealand which do not have Alps-fed rivers are likely to face greater shortages of water in future: this would include Northland, Hawke's Bay, and parts of Tasman, and Marlborough.

The productivity of agriculture is significantly affected by whether sufficient water is available to meet demand. Both the availability of water and the demand for water are expected to change significantly over the time period considered in this report. Factors affecting availability and demand are discussed below, followed by an assessment of the changing balance between the two factors, and regional patterns of that balance.

3.1 Demand for water

Agricultural demand for water is driven by two main factors:

- Climatic conditions
- Land use and associated productivity targets

If the climate becomes drier (i.e., lower precipitation and warmer temperatures), then, other things being equal, the agricultural demand for water is higher. To achieve a given level of production using a particular land use practice, soil moisture deficits that develop during the growing season in many parts of New Zealand need to be reduced. If rainfall is not sufficient, then irrigation can be used to reduce deficits, if water is available.

Land uses with a high demand per unit land area for water are generally those requiring irrigation, such as dairying and irrigated cropping or horticulture. Within a given land use in a given climate, there are variations in demand, depending for example on the productivity targets (it may require more water to raise productivity) and efficiency of farming methods (it may be possible to achieve the same productivity using less water). So if land use or farming methods change, this can influence demand for water.

3.1.1 Current demand

Water for irrigation is the dominant consumptive use of water in New Zealand (Aqualinc Research, 2006), accounting for 77% of consented water use. Irrigation water is taken predominantly from groundwater (33% of consented volume) and surface water (60% of consented volume) sources. Of all the water consented for consumptive use in New Zealand, 55% of the consented volume is in Canterbury, and 18% is in Otago. Nationally, water allocation increased by approximately 50 percent between 1999 and 2006. The growth rate of irrigated area is approximately 5% per annum (Lincoln Environmental, 2000; Aqualinc Research Ltd, 2006), and the estimated irrigated area in 2006 was approximately 9700 km^2 (Aqualinc Research Ltd, 2006).

The map in Figure 3.1(a) identifies those regions with a current PED greater than 200 mm – the shaded area is very broadly consistent with the areas of New Zealand where consents are held to irrigate (see Figure 3.9 of Aqualinc Research Ltd (2006)). However, the area shaded is approximately 65,000 km^2, much greater than the current irrigated area. Approximately 9000 km^2 of New Zealand has PED in excess of 400 mm (Figure 3.1(b)). The presence of high PED values does not necessarily imply a demand for irrigation – for example, the land use or topography may be inconsistent with irrigated agriculture, even though the climate information may suggest a water deficit. The reason for preferring a 200 mm threshold in this report is that it does represent the threshold where irrigation currently is required: locations with PED less than 200mm do not generally irrigate at present. Locations with PED greater than 200 mm <u>may</u> irrigate.

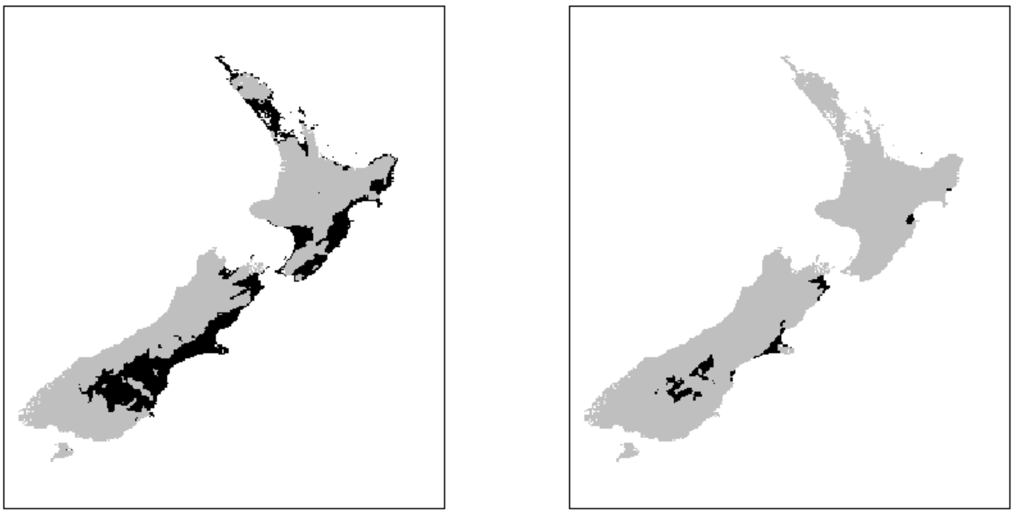


Figure 3.1: *Locations (in black) with long-term average PED greater than 200 mm (left) and 400 mm (right) under current climate.*

3.1.2 Future Prospects for Demand

As indicated earlier in this report, based on an assessment of IPCC TAR scenarios climate conditions are projected to become drier in the east of New Zealand, which comprises most of the currently water-short areas of New Zealand. Drier conditions are expected to increase the demand for water.

A current very significant trend in land use is the expansion of irrigated area, which has been growing at 50% per decade since 1990. A particularly visible example of this growth is the expansion of dairy farming in the eastern South Island, with an associated increase in the demand for irrigation. Although this expansion cannot continue forever, there is still considerable potential for growth in irrigated area over the coming decades.

To assess the potential impact of climate change on demand, here we make the untested assumption that changes in PED determine changes in demand. On that basis, we have analyzed the maps of PED for the 2030s and 2080s to determine percentage increases in area that may require irrigation. These are listed in Table 3.1. This indicates an increase by the 2030s of 26–35% over the current area of New Zealand that potentially requires irrigation, and a 33–53% increase by the 2080s. It is important to reiterate that this is based on climate data alone, and does not consider impacts of topography, soils and land use in determining irrigation demand.

Table 3.1: *Areas with more than 200 mm PED that may require irrigation under future scenarios*

Scenario	**2030s low-med**	**2030s med-high**	**2080s low-med**	**2080s med-high**
% increase in area with PED > 200 mm	26	35	33	53

If one instead considers a higher threshold to define the potential need for irrigation, such as PED greater than 400 mm, then there are much larger percentage increases in the area with potential need for irrigation – ranging from 120% for “2030s – low-med” to 300% for “2080s – med-high”.

Indications of the projected new areas that may require new irrigation as a result of climate change are shown in Figure 3.2 and Figure 3.3. The projections indicate that the majority of the new areas with PED more than 200 mm are predominantly in eastern New Zealand, and in the North Island, though there are also expansions in Tasman, Marlborough, Canterbury foothills and Otago. Note this method makes the very restrictive assumption that climate alone controls the demand for irrigation – a more precise method needs to take account of factors such as land use, topography, and availability of water.

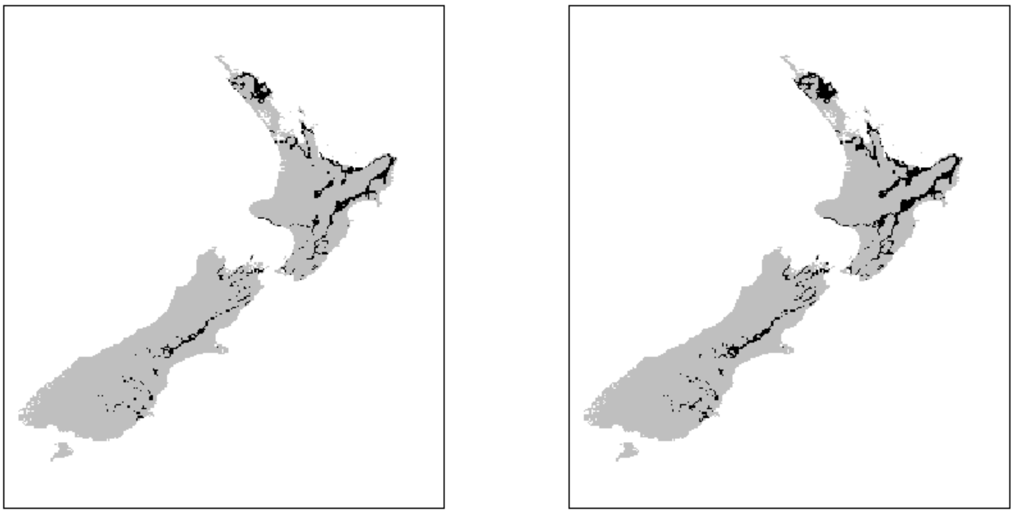


Figure 3.2: *New areas with climate-driven need for irrigation assuming projected 2030s climate under the 25% (left) and 75% (right) IPCC TAR climate scenarios: locations (in black) where long-term average PED changes from below to above 200 mm*

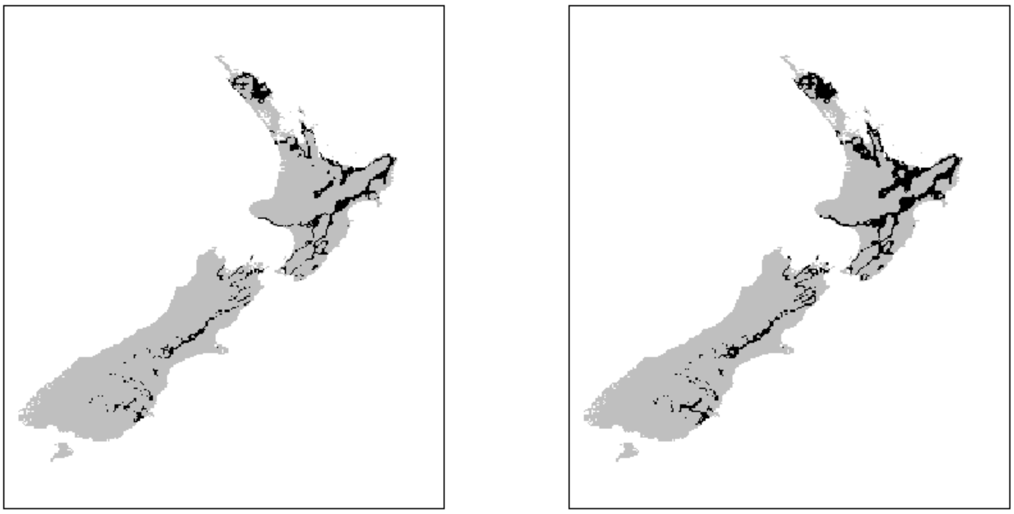


Figure 3.3: *New areas with climate-driven need for irrigation assuming projected 2080s climate under the 25% (left) and 75% (right) IPCC TAR climate scenarios: locations (in black) where long-term average PED changes from below to above 200 mm.*

3.2 Availability of water

To determine the amount of water available, it is necessary to assess the total resource, and then set aside the amount of water to be allocated to other priorities, such as maintenance of in-stream habitat values. This process is managed by Regional Councils and Unitary Authorities, under the Resource Management Act. Typically, plans are put in place to determine allocation limits for sources of water, and consents are assessed to determine whether they can be granted within the current allocation limits.

The total water resource depends on hydrological and climatic features, and varies strongly from place to place (e.g. Woods et al, 2006). The amount of water set aside to protect the in-stream or other values varies from region to region, and also within regions. Indicative assessments of the extent of surface water allocation show that up to half the average annual low flow is allocated in some parts of New Zealand, such as Hawke's Bay, Wellington, Nelson, Canterbury and Otago (Aqualinc Research Ltd, 2006). Heavily allocated or over-allocated groundwater sources in New Zealand include those parts of the mid-Canterbury plains denoted as "red zones" by Environment Canterbury (Aitcheson-Earl et al, 2004).

3.2.1 Future prospects for availability of water

At present, no scenarios are available for the effect of climate change on the water resources available in rivers and groundwater aquifers. From projected climate changes based on IPCC TAR models (more rain in the west, less in the east, higher temperatures), one can reasonably speculate that

- Flows in Alps-fed rivers are likely to increase in winter since there is expected to be not only increased winter precipitation, but also a relative increase in rain versus snow under the projected higher temperatures.
- The remaining seasonal patterns for Alps-fed rivers are unclear (because the changes in snowmelt are complex), so it is not clear how spring and summer river flows will change.
- Flows in lowland streams in the east are likely to decrease with the drier local climate.

The changes in flows in hill-country rivers are unknown, since they are fed by catchments that include both drying and wetting areas. Similar statements apply for the major aquifers, since many of them are fed by a mixture of sources (both rainfall- and river-recharge), which are subject to a range of climate changes. A detailed assessment would be required to quantify the above changes, which is outside the scope of this study.

3.2.2 Current water shortages

Several regions of New Zealand, including Northland, Hawke's Bay, Tasman, Marlborough, Canterbury and Otago, typically experience a natural shortfall of water in the growing season, and thus their agricultural productivity is currently constrained, though irrigation is used to mitigate this to some extent. All of these regions have major irrigation schemes with a net contribution (over dryland farming) of at least $5 million per annum (MAF Policy, 2004).

As an example, in Canterbury, the region with the greatest volume allocated for irrigation, and the largest irrigated area, approximately 32% of the 5872 consent holders[3] are subject to a restriction on water use when river or groundwater levels are low. Data are not readily available at regional or national scales on the numbers of irrigators restricted in each year, how often the restrictions are applied, or what impact they have.

It is important to note that the occurrence of water shortages is also affected by the type of irrigation infrastructure, as well as the climate and land use. For example, an irrigation

[3] Personal communication, Brett Aldridge, Environment Canterbury

system fed by a run-of-river water source is more likely to face shortages than one with a substantial water storage, which allows irrigation water to be provided during dry periods, by storing the water from earlier in the season when flows were larger.

Water shortages occur when demand for water exceeds water availability for long enough to affect production – this critical length of shortage depends on the land use. The most common situation is for a hot dry summer in which rainfall is low, evaporative losses from plants are high, and so demand is high. In many places, at the same time, local groundwater levels and river flows are low. Exceptions to this scenario are those regions where a large river or groundwater system is supplied mainly by water from outside the local region, for example, the Alps-fed rivers of Canterbury and Otago, which can be in flood during a northwest storm, while the adjacent plains in the lower reaches of the river are parched. In the eastern South Island, the lowland and foothills streams are typically fully allocated at present, so that no additional water is available from run-of-river takes. One proposed strategy in the Canterbury Strategic Water Study (Lincoln Environmental, 2002) is to take more water from Alps-fed rivers (which tend to have higher flows in spring and summer), and to store water in off-river storages whenever the Alps-fed rivers are above their minimum flows.

Given that flows in the Alps-fed rivers of Canterbury and Otago are expected to increase under most climate change scenarios, one might expect increased water supply reliability from irrigation systems fed from this source. However, demands for irrigation water in the east of New Zealand are also likely to increase under most climate change scenarios. The available information is not sufficient to know whether the likely increase in water supply will compensate for the likely increase in demand. Agricultural regions in eastern New Zealand which do not have Alps-fed rivers are likely to face greater shortages of water in future: this would include Northland, Hawke’s Bay, and parts of Tasman, and Marlborough.

4. Changing risks of significant drought occurring over two adjacent agricultural years.

Key Points

- For the present climate, annual PED greater than 200 mm in two agricultural years (July–June) running occur 59% of the time for lowland Canterbury, 46% of the time for lowland Hawke's Bay, and 25% of the time for lowland Gisborne.
- Under the medium-high climate scenario considered in the NIWA drought report, these frequencies of occurrence are projected to increase in the 2080s to 86% of the time for lowland Canterbury, 85% for lowland Hawke's Bay, and 73% for lowland Gisborne.
- Projected changes in the frequency of occurrence of two successive agricultural years with PED values of more than 400mm, for the medium-high scenario from the drought report are: Hawke's Bay (3% from 'now' increasing to 49% in the 2080s), Canterbury (12% now to 39% in the 2080s), Marlborough (16% now to 31% in the 2080s), and Gisborne (1% now to 30% in the 2080s).
- This IPCC TAR HadCM2 model-based analysis suggests that Hawke's Bay and Gisborne could be particularly subject to increases in successive dry years in the future. However, details of such changes are likely to depend on the particular climate model used in the downscaling assessment. The subsequent modelling we undertook based on the IPCC AR4 models (section 8) indicated less vulnerability for Gisborne. Such changes will also depend on whether the frequency of El Niño conditions changes in future – a topic on which there is not yet a clear scientific consensus.

Suffering drought conditions through more than one consecutive growing season can be particularly devastating to agricultural production. Obviously, increasing the PED or level of dryness everywhere must increase the likelihood of consecutive droughts. However, quantifying any change in consecutive droughts is not simple, and a number of issues need to be appreciated. Firstly, there is basic question of what one defines as a 'drought'. The 2005 drought report considered a 'severe drought' as having a 1-in-20 year occurrence (or a probability of 5% in any one year). Given that the analysis database was only 31 years long (1972/73 growing year to 2002/03 growing year), consecutive severe droughts did not occur under the current climate, but this level of deficit did occasionally occur in successive years under the more extreme future scenarios.

One caveat, in particular, should be noted. The scenario analysis used a specific historical period (1972–2003) and perturbed the PED observations for the future scenarios. Thus, the sequence of wet/dry years remains exactly the same in the future scenarios, albeit with successively higher PED accumulations for more extreme cases. However, droughts often occur in association with extremes of the El Niño-Southern Oscillation (ENSO), either El Niños or La Niñas (see Fig. 6.7.1 in Mullan *et al*, 2005). The specific sequence of ENSO events, or any changes in their frequency of occurrence or severity in the future, would obviously affect the likelihood of successive dry years. This is not taken into account with the present methodology, although we note that there is still no agreement from climate models over whether ENSO events will change in frequency or severity in the future. Thus a default assumption of 'no change' is reasonable. Obviously the exact sequencing of wet/dry years cannot be forecast.

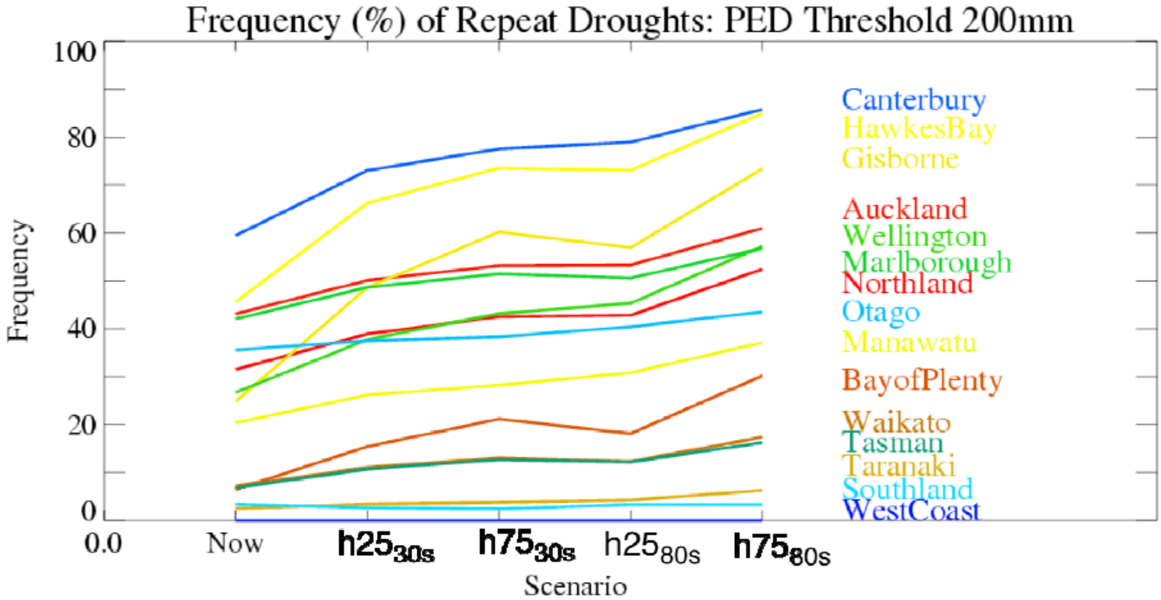
Notwithstanding these issues, the likely future occurrence of successive droughts is assessed here from a re-analysis of the underlying data of the Mullan *et al* (2005) drought report using the simple approach of a specific PED threshold. Two thresholds are taken as examples: 200 mm, which represents the threshold above which some irrigation is currently required, and a larger 400 mm threshold. (See Figure 3.1)

Figure 4.1 shows how the frequency of successive drought changes between the current climate (labelled 'now") and the four future scenarios (labelled $h25_{30s}$, $h75_{30s}$, $h25_{80s}$, and $h75_{80s}$). The scenario labelling refers to the Hadley model ('h') in the 2030s (subscript 30s) or 2080s (subscript 80s) with low (25%) and high (75%) scaling. For each case, the end-of-year PED accumulations on a 0.05 degree grid were taken, and broken down according to Regional Council boundaries. Only those grid-points below 500m altitude were considered, on the basis that higher altitude land was less likely to be suitable for agriculture. No consideration was given to soil type or current land use.

At each grid-point there is a time series of 31 years of annual PED values. A 'repeat drought' was deemed to occur if the threshold PED was exceeded in two successive years at that grid-point. For example, *two* repeat droughts could occur with three very dry years in a row (i.e., above the threshold of either 200 mm or 400 mm), or alternatively with two sets of two very dry years somewhere within the 31-year data period. Note that it is possible, with this approach, for a summer drought to occur in two successive years, but for there to be a wetting-up and recovery over the winter. The number of repeat droughts was then normalised (divide count by 30, and multiply by 100%), so a value of 100 means the PED threshold was exceeded in *every* year. Figure 4.1 plots this normalised frequency averaged over all the grid-points of the domain within each Regional Council area.

An annual PED of 200mm or more is quite common in the drier eastern regions of New Zealand – the average PED exceeds 300mm in many places (Fig 2.1 of Mullan *et al,* 2005), so it is not surprising to find repeat 'droughts' of this level occur 59% of the time (averaged over all low-land points) in Canterbury under the present climate, closely followed by Hawke's Bay with 46%. This frequency rises to 86% for Canterbury, and 85% for Hawke's Bay, under the most extreme scenario considered here of 75% scaling in the 2080s ($h75_{80s}$). For the scenario patterns considered, the Gisborne region also shows a disproportionate increase from 25% in the current climate to 73% in the $h75_{80s}$ scenario.

The lower panel of Figure 4.1 shows the results for the higher PED threshold of 400 mm. In this case, the worst affected regions under the warming scenarios are: Hawke's Bay (3% from 'now' increasing to 49% under $h75_{80s}$), Canterbury (12% to 39%), Marlborough (16% to 31%), and Gisborne (1% to 30%). Under the 400 mm PED threshold, there are no successive droughts for Taranaki, West Coast or Southland in any of the scenarios, and very small frequencies (under 5%) for Bay of Plenty, Waikato and Tasman. This analysis suggests that Hawke's Bay and Gisborne could be particularly subject to increases in successive droughts in the future (these two regions show the largest *changes* in repeat drought occurrence). However, details of such changes are likely to depend on the particular climate model used in the downscaling assessment.



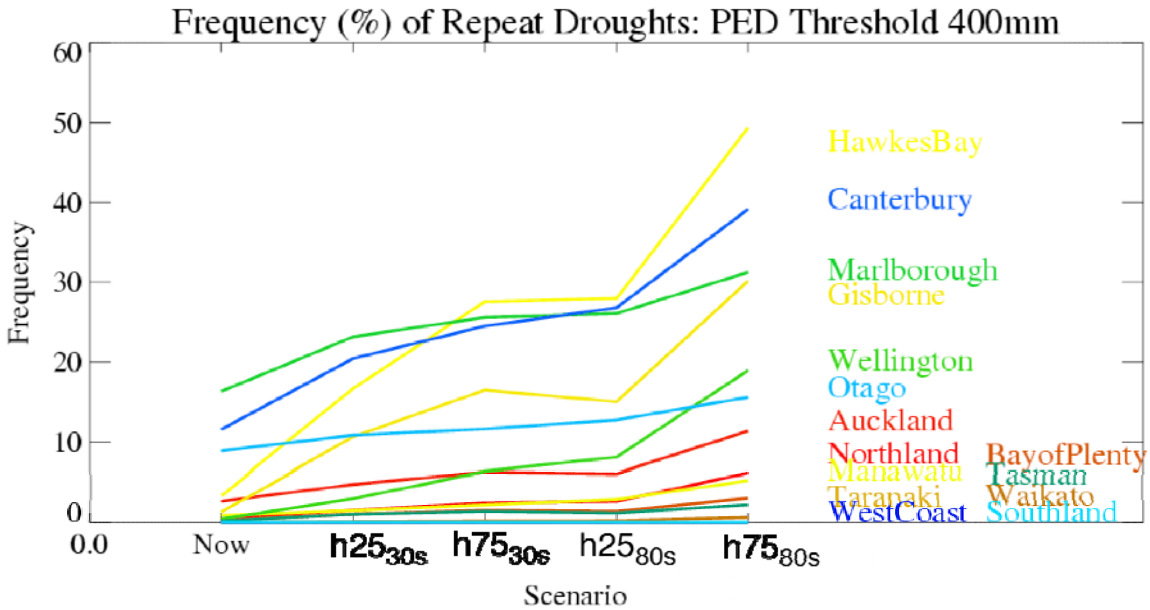


Figure 4.1: *Frequency of consecutive droughts at specified PED thresholds of 200 mm (upper panel) and 400mm (lower panel). Results are shown for all 15 Regional Council regions, and for the current climate ('now') and the four future scenarios. Results are averages over all grid-points below 500m within a given Regional Council area. A value of 100 means every grid-point within the domain exceeds the annual PED accumulation threshold every year of the 31-year simulation period. (See text for further explanation of the calculation methodology and its interpretation).*

5. Present Spatial Land-Use Patterns and Productivity for Various Agricultural Land Uses

Key Points

- This Section documents the information – mostly for the July 2001–June 2002 agricultural year – used as a baseline for the future projections described in Section 7.
- No specific conclusions are drawn – this material is provided for background information.

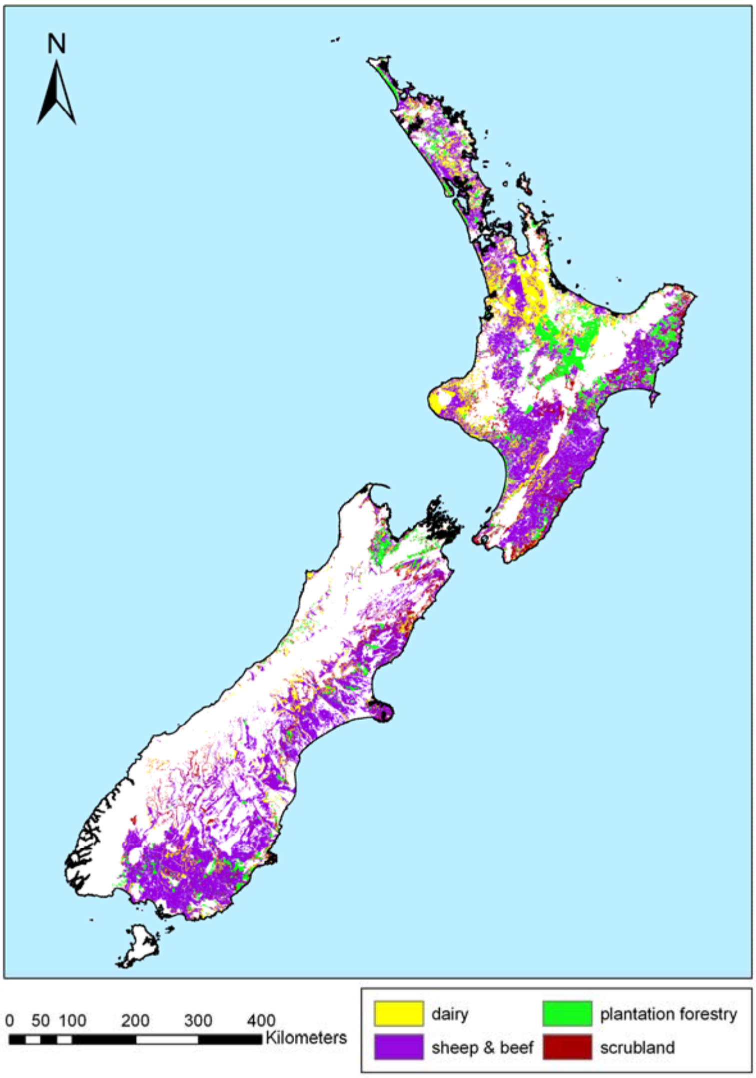


Figure 5.1: *Present (July 2001–June 2002) land-use, for dairy, sheep and beef, and forestry. Data source:* Land Use in Rural New Zealand (*LURNZ*) *(see Hendy et al, 2006). Note that individual pixels are allocated to only one of these land uses, based on the predominant land use in the pixel.*

Table 5.1. *Dairy production per Regional Council, 1 July 2000–30 June 2002. Data sources: Milk solid production statistics at Territorial Authority level from Livestock Improvement Corporation[4]; Area of dairying in each regional council area accumulated from LURNZ pixels (Fig 5.1); Total national annual export revenue for dairy products from Statistics NZ[5]; This revenue was allocated to Regional Councils according to the distribution of dairy payout per hectare in each Regional Council area calculated from the Livestock Improvement Corporation numbers.*

Regional Council	Average kg milksolids per effective ha	Dairy payout per ha	Export revenue by Regional Council, $M
Northland	576	3083	$388.4
Auckland	647	3462	$129.9
Waikato	838	4484	$2,368.7
Bay of Plenty	828	4427	$490.0
Gisborne	887	4745	$18.5
Hawke's Bay	834	4463	$109.8
Taranaki	891	4767	$940.3
Manawatu-Wanganui	874	4675	$626.7
Wellington	869	4649	$160.1
Tasman	771	4125	$87.5
Nelson	777	4157	$2.4
Marlborough	721	3857	$38.3
West Coast	644	3446	$133.2
Canterbury	1005	5378	$865.5
Otago	929	4972	$232.2
Southland	920	4924	$468.6

[4] 2001/2002 New Zealand Dairy Statistics. Available online at http://www.lic.co.nz/113_5.cfm
[5] http://www.stats.govt.nz/analytical-reports/agriculture-statistics-2002/the-agricultural-industry.htm

Table 5.2: *Sheep and beef production per Regional Council. Data Sources: Sheep/beef farm revenue by farm class and region provided by Meat and Wool NZ. Revenue per hectare, by class and region was then mapped on to sheep/beef pixels on the LURNZ grid, and built up to provide Regional Council totals. The total 2001/02 national export revenue for sheep and beef of $4.08 billion dollars (from Statistics New Zealand) was then allocated to Regional Councils according to the distribution of revenue per ha in each Regional Council.*

Regional Council	Export revenue ($M)
Northland	247.6
Auckland	112.7
Waikato	429.7
Bay of Plenty	53.6
Gisborne	173.7
Hawke's Bay	363.3
Taranaki	92.9
Manawatu-Wanganui	641.8
Wellington	156.7
Tasman	25.0
Nelson	0.9
Marlborough	27.7
West Coast	15.2
Canterbury	541.6
Otago	518.2
Southland	679.5

Table 5.3: *Estimated breakdown by Regional Council area of export revenue from horticulture, July 2001–June 2002. National Export revenue was allocated regionally in proportion to the distribution of the crop's area across Regional Councils. Data sources: Land use area: Statistics New Zealand Agricultural Production Census 2002; National export revenue: http://www.stats.govt.nz/analytical-reports/agriculture-statistics-2002/the-agricultural-industry.htm*

Region	Apples 2002 Million $ FOB	Kiwifruit 2002 Million $ FOB	Wine grapes 2002 Million $ FOB	Onions 2002 Million $ FOB
Northland	$4	$31	$1	.
Auckland	$7	$31	$12	$29
Waikato	$11	$41	$3	$39
Bay of Plenty	$4	$443	.	.
Gisborne	$11	$15	$25	.
Hawke's Bay	$212	$10	$55	$7
Taranaki	.	.	.	.
Manawatu-Wanganui	.	$5	.	$6
Wellington	$11	.	$12	.
Tasman/West Coast	$108	$31	$7	.
Nelson/Marlborough	$11	.	$109	.
Canterbury	$11	.	$10	$17
Otago/Southland	$29	.	$16	.
Total New Zealand	$421	$618	$252	$101

6. Past work on impacts of climate change on growing locations and productivity for New Zealand agriculture

Key Points

- Work done as part of the CLIMPACTS collaboration projected an 8–10% increase in pasture dry matter production in 2020 (compared to 1990), averaged across five sites in different parts of New Zealand for a mid-range IPCC scenario, for all seasons.
- Averaged across five New Zealand sites, increases in pasture dry matter production of 19% (spring), 24% (summer), 21% (autumn) and 27% (winter) were projected by the CLIMPACTS collaborators for 2050 (again compared to 1990).
- The CLIMPACTS work projected larger increases in pasture production for relatively cool and moist places (e.g. Gore), and smaller increases in places which are already warm and dry (e.g. Gisborne).
- These projections do not consider the effect of possible changes towards lower quality pasture species in the northern parts of New Zealand, or of possible increases in pests and diseases with a warming climate. They are for dry-land sites, so do not consider either present irrigation or possible changes in water availability for irrigation.
- CLIMPACTS collaborators concluded that for New Zealand wheat production out to 2100, “most of the implications of climate change are positive”. They noted that irrigation will remain a substantial need in Canterbury, and that to realise the increased yield potential from carbon dioxide fertilisation the need for nitrogen fertiliser will likely increase.
- CLIMPACTS concluded major changes in apple production due to global warming were unlikely, at least out to 2050. For a mid-range climate scenario, increases of 5–8% in fruit diameter at maturity are projected at several New Zealand locations by 2100, and dates of full bloom and of maturity might be 12–15 days earlier. Availability of water for irrigation in the Hawke’s Bay and Nelson regions may increasingly become an issue.
- CLIMPACTS noted that conditions in Northland might become uneconomic for Hayward kiwifruit by 2050 under a high climate change scenario, even with the use of chemical “dormancy-breaking agents”, and Hayward kiwifruit production in the Bay of Plenty may become uneconomic without the use of such agents. However conditions for this variety may improve in coming decades in Hawke’s Bay and Nelson.
- Other potential constraints on kiwifruit production include availability of water for irrigation, and competition for land from other valuable crops such as grapes. Production from the new “Zespri Gold” cultivar might be less sensitive to warmer winter temperatures than is the case for the Hayward variety.
- The IPCC TAR implies that the New Zealand wine industry may benefit from warm, dry eastern conditions over coming decades, except that limitations on water availability for irrigation may become a growing problem. Rising temperatures may make growing maize less risky in the south, but water availability may become an issue in Canterbury.

In this section, we review results from previous work in New Zealand on climatic constraints on growing locations and productivity for various agricultural land uses (sheep, beef, dairy, horticulture and crops), and how these constraints may change under scenarios for future New Zealand climate. Most of the published work on impacts of climate change on agricultural productivity in New Zealand was undertaken by researchers collaborating under the CLIMPACTS project. Results pertaining to pastoral agriculture, kiwifruit, apples and wheat were published in the CLIMPACTS report (Warrick et al, 2001), and summarised by Kenny (2001). This material provided the basis for most of the comments regarding pastoral farming, cropping and horticulture in the Australia and New Zealand chapter (Pittock and Wratt, 2001) of the IPCC TAR. Projections for particular agricultural activities were as follows:

6.1 Pastoral Agriculture

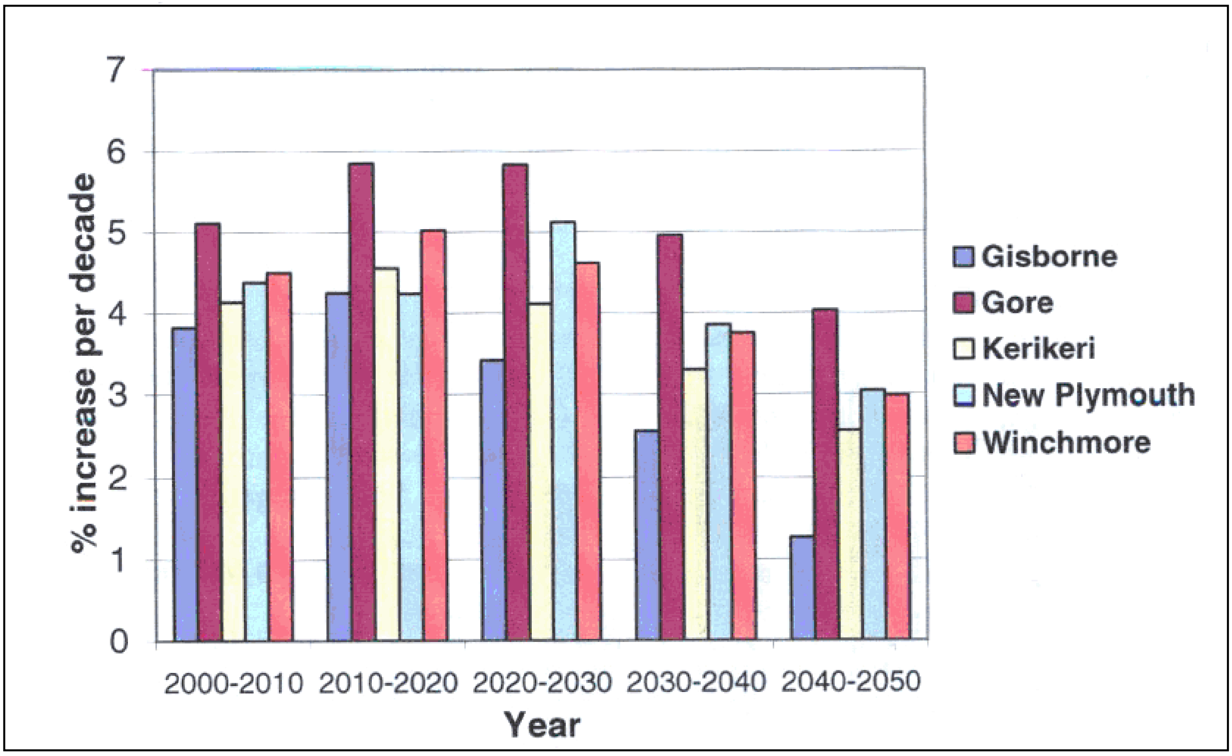


Figure 6.1: *Projected percent increase in pasture dry matter yield per decade at five sites in New Zealand using the HadCM2 global climate model for a mid-range IPCC emission scenario. (Clark et al, 2001).*

The CLIMPACTS work on managed pastures (Clark et al, 2001) included estimates of changes in pasture dry matter yield out to 2050 using climate patterns downscaled to New Zealand regional scales from HadCM2 global climate model results, for three IPCC TAR global scenarios. Projections were made for five locations in different parts of New Zealand (Figure 6.1). These projections used a physiological model of pasture growth which takes account of temperature, solar radiation, soil moisture, and the effects of increasing carbon dioxide concentrations on photosynthesis ("carbon dioxide fertilisation").

Averaged across the five sites, an 8–10% increase in yield (compared to 1990) was projected by 2020 for a mid-range IPCC scenario, for all seasons. Increases of 19% (spring), 24% (summer), 21% (autumn) and 27% (winter) were projected for 2050 (again compared to 1990). As can be seen from Figure 4.1, there are differences across the country, with larger increases projected for relatively cool and moist places (e.g. Gore) and smaller increases in places which are already warm and dry (e.g. Gisborne). The projected rates of increase are larger in the early parts of the 21st century than in mid-century (Figure 6.1).

These projections do not consider possible changes in pasture composition. Clark et al (2001) suggest that lower quality pasture species such as paspalum and kikuyu will continue to spread south in the northern parts of New Zealand). The projections also ignore possible increases in pests and diseases with a warming climate. They are for dry-land sites, so do not consider either present irrigation or possible changes in water availability, which may be particularly important for dairy farms.

6.2 Wheat Production

Jamieson and Cloughley (2001) predict that for New Zealand wheat production out to 2100, “most of the implications of climate change are positive”. Projected carbon dioxide fertilisation is large enough to overcome reductions in crop duration caused by warming. The increasing earliness of crops caused by climate warming to some extent reduces the exposure of the crop to drought risk by avoiding the driest time of the year. These researchers note that irrigation will remain a substantial need in Canterbury, and that to realise the increased yield potential from carbon dioxide fertilisation the need for nitrogen fertiliser will likely increase.

6.3 Apples

Austin and Hall (2001) conclude the New Zealand apple industry is unlikely to observe major changes in apple production due to global warming, at least out to 2050. They say that over this period changes are more likely to be driven by market requirements than by the impacts of projected climate changes.

Their simulations predict increases of fruit diameter at maturity for Havelock North, Riwaka and Lincoln of 5% to 8% by 2100 compared to present average sizes, under the IPCC SRES A1 scenario (a mid-range scenario). However these projected mean changes lie within the range of present year-to-year variability, amounting to only about 0.6 of the standard deviation in present yearly values. By 2100 dates of full bloom and of maturity might be 12–15 days earlier for a mid-range scenario. Kenny (2001) notes that the availability of water for irrigation in the Hawke’s Bay and Nelson regions may be the largest climate-related issue for the apple industry over coming decades.

6.4 Kiwifruit

The CLIMPACTS researchers did not provide projections of how New Zealand’s total production of kiwifruit might change under global warming. However, they noted that a drop of flower numbers due to winter warming might make conditions in Northland uneconomic for Hayward kiwifruit by 2050 under a high climate change scenario, even with the use of chemical “dormancy-breaking agents”. They say Hayward kiwifruit production in the Bay of Plenty may also become uneconomic “without dormancy-breaking agents”. However, they say conditions for this variety may improve in coming decades in Hawke’s Bay and Nelson, due to fewer or less severe late frosts, and warmer summer conditions. They note that other potential constraints include availability of water for irrigation, and competition for land from other valuable crops such as grapes.

Austin and Hall (2001) state that the new “Zespri Gold” cultivar has a more prolific natural flowering habit than the Hayward variety, and hence there is a greater margin available before flower numbers drop too low because of higher winter temperatures.

6.5 Grapes

The Australia and New Zealand chapter (Pittock and Wratt, 2001) of the IPCC TAR notes that the New Zealand wine industry to date has shown a largely beneficial response to the kind of warm and dry conditions which are expected to become more dominant in the east. A southern expansion of grapes over the past few decades has also been noted. Limitations on water availability for irrigation are again identified as a potential future problem.

6.6 Maize and Sweetcorn

The Australia and New Zealand chapter (Pittock and Wratt, 2001) of the IPCC TAR suggests that rising temperatures may make growing maize less risky in the south, but water availability may become an issue in Canterbury. It also states that climate warming is reducing risks for late sown crops of sweetcorn, extending the production season and moving the southern production margin further south. However in the South Island, production is irrigated, and is vulnerable to changes in river flow and underground water supply.

7. New Projections of Changes in Pastoral Production for the 2030s and 2080s due to Changes in Growing Degree Days and Soil Moisture

Key Points

- This section contains new projections of future changes in production from pastoral farming (dairy, and sheep/beef) for the climate scenarios described in Section 2.1, for the 2030s and 2080s. These climate scenarios are derived from one of the climate models used in the IPCC TAR (the HadCM2 model). This model leads to scenarios with significant changes to the west–east rainfall patterns across New Zealand (wetter in the west; drier in the east).
- The projections use current relationships between spatial variations in pasture growth around New Zealand, and spatial variations in GDD and SMD, in order to project production under a changed future climate.
- The results can be viewed as a sensitivity study of how New Zealand total and regional pastoral productivity could change under a scenario which includes a significant decrease in rainfall in many eastern areas.
- The projected driest years in the 2030s and 2080s are worse for national average production than the worst year experienced from 1971–2002. The estimated production in this worst climatic year during 1971–2002 was 64% of the long term average for dairy, and 67% of the long-term average for sheep/beef. Under the climate change scenarios, the projected worst years reach 52% and 50% of the 1971–2002 average for dairy and sheep/beef respectively.
- Average year and worst year production both decline for east coast locations (Wellington, Hawke's Bay, Canterbury, Bay of Plenty, Gisborne), and also for Northland. This applies to both dairy and sheep/beef.
- Improvements in production are projected for both dairying and sheep/beef in Southland and the West Coast. These are regions which are projected to remain moist while warming.
- For average years, the new projections show no strong trend during the coming century in production when accumulated over the whole country. Projected national dairy production ranges from 96–101% of the 1972–2002 average, and projected sheep/beef production from 91–96% of the 1972–2002 average.
- The methodology used for the projections in this section does not predict possible changes in production due to increased carbon dioxide concentrations in the atmosphere (carbon dioxide 'fertilisation'). These could conceivably modify the projections made in this section, by adding 10–15% to pastoral production by mid-century in areas not constrained by soil fertility.
- However, preliminary work based on an average of 12 models from the IPCC AR4 (see Section 8) indicates average and worst year production in the East Coast of the North Island is not as adversely affected as is projected by the HadCM2 model.

In this section we report new projections of changes in pastoral productivity prepared specially for this report, utilising relationships between NPP, SMD and GDD developed by Baisden (2006). These projections draw on the downscaled climate change scenarios for New Zealand outlined in Section 1. From these projections we develop maps showing potential changes in sheep/beef production and in dairy production, for the scenarios from Section 1.

7.1 Methods Used for Calculating Climate Impacts on Pasture Production

Baisden (2006) identified a simple predictive relationship linking annual net primary productivity (plant growth) in NZ pastures to GDD, SMD and average soil particle size. This relationship is easily calculated and, taking soil particle size to be constant over time, allows the two countervailing effects of climate change on pasture growth – enhanced growing season length and strong moisture limitation – to be evaluated to obtain a projection of overall impacts on pasture production.

To confirm the Baisden (2006) methodology, we tested the map-level predictions of average NPP against multi-year averages from pasture clipping experiments published in the New Zealand Journal of Experimental Agriculture. The nearest NPP estimate from Baisden (2006) is compared to 14-day clippings from 26 sites in Figure 7.1. The comparison demonstrates a strong relationship between the observed data and model relationship (R^2 = 0.43), given the difficulty of matching data collected at sites to mapped data with grid references accurate to only ~1 km. The productivity index also estimates total NPP, rather than aboveground NPP (ANPP) – leading to additional variability and accounting for the factor of around two difference between NPP and ANPP in Figure 7.1. Variability in Figure 7.1 will also include variation in soil properties and farm management.

The root mean square error (RMSE; a measure of the goodness of fit) for the relationship in Figure 7.1 is equivalent to a coefficient of variation of 23% for absolute predictions of pasture productivity. The methodology used henceforth reduces any effects of this large variability by making predictions relative to a reference period (1971–2002) and normalizing data for each region and farm type to economic statistics by region. When placed in relative terms, we consider changes greater than 10% to be meaningful in the context of this study.

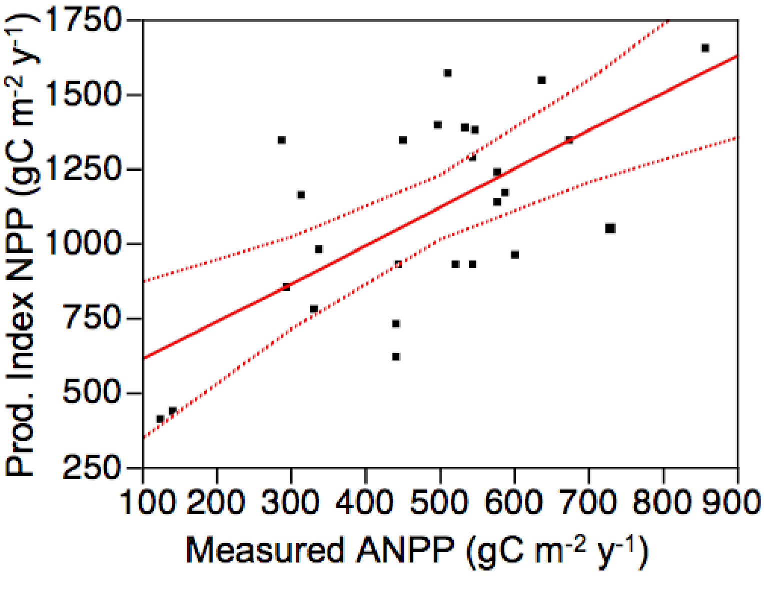


***Figure 7.1**. Comparison of measured ANPP (above ground net primary productivity) from published pasture clipping experiments, and net primary productivity (NPP) estimated at the approximate location of the experiments (within 1 km) using the modelling method of Baisden (2006). The solid red line indicates the best linear fit between the measured ANPP and predicted ANPP (R^2=0.43). The dotted red line indicates the 95% confidence level (CL) for the relationship between the measurements and model predictions. This CL (RMSE = 23%) applies to estimates generated for large numbers of sites or areas, such as the regional figures in this report. Variation of individual sites outside this CL is expected, resulting from variation in soil properties from mapped coordinates, management, and variation in the ratio of aboveground to total NPP (including roots growth).*

It is important to note that the equation for calculating the NPP index was developed based on long-term average data, and produces “zero” values in years where SMD substantially exceeds average values for the driest areas of New Zealand. These “zero” values are depicted as dark red in map figures. These “zero” values are unlikely to represent truly zero plant growth, but probably describe situations where animal farming fails completely without dependence on irrigation or feed imports. The “zero” values may contribute somewhat to instability in estimates of production. We also note that these relationships between productivity, GDD and SMD were developed through a regression analysis of spatial variations in these parameters across New Zealand (e.g. less pasture growth occurring in regions with lower GDD). The relationships will be used in this section to project possible future temporal changes in production, due to temporal changes in climate. Finally, these projections do not take into account the possible effect of carbon dioxide ‘fertilisation’ in a future climate with higher carbon dioxide levels, a matter which will be discussed along with the results.

We produced predictions based on the relationship defined by Baisden (2006) for the recent historic period (1972–2002) based on actual climate, and projections for the two future periods based on the medium-low and medium-high climate change scenario. We were careful in scaling pasture production to recognize that large areas of poor quality pasture produce relatively little animal growth, so we corrected pasture NPP using a temporally averaged estimate of the digestibility (D) based on the metabolisable energy (ME) in pasture. Our estimate of D was derived from a long-term average value of remote sensed data developed for calculating the energy budgets of grazing animals for a national methane inventory (Dymond et al, 2005). Areas of sheep/beef and dairying were delineated for each Regional Council area as described by the LURNZ model (Hendy et al, 2006). We therefore calculate animal production to be proportional to the product of NPP and D. Our estimates of metabolisable pasture growth (MPG, Figure 7.2) account for the difference between carbon and plant dry matter using a factor of 0.5 and assume that aboveground NPP is half of total NPP, i.e.:

$$MPG = 0.5 * D * NPP$$

Our final step in scaling was to ensure that all our calculations of climate change impacts are scaled relative to recent (July 2001–June 2002) agricultural production for sheep/beef and dairy farming in each region (the data summarised in Section 5). To accomplish this, we scaled each region’s animal production to be proportional to economic data on the export value of animal products, for each of the two farming sectors (Table 7.1). Our normalization approach was designed to correct for the lack of agronomic and economic detail that could have been simulated in region or site-specific modelling approaches which were beyond the scope of this project. For the dairy sector, milk solids data were also available to confirm the accuracy of our scaling methods, and therefore used to assess the success of our approach.

Table 7.1 *Regional scaling factors for normalizing calculated metabolisable pasture growth to economic animal production, based on economic statistics for export revenue.*

Regional council	Sheep/Beef	Dairy
Northland	0.59	0.84
Auckland	0.92	1.15
Waikato	0.90	0.92
Bay of Plenty	0.89	1.02
Gisborne	1.62	0.85
Hawke's Bay	1.24	1.03
Taranaki	0.88	0.75
Manawatu-Wanganui	1.03	0.85
Wellington	1.35	0.86
Tasman	1.11	0.54
Nelson	4.10	0.75
Marlborough	1.65	0.59
West Coast	0.75	0.49
Canterbury	1.88	0.99
Otago	1.73	1.34
Southland	1.57	1.39

7.2 Results: Projected impacts on dairy production and sheep/beef production

Results from applying the methodology outlined in the previous section are displayed in the following figures and tables. There was not time in the present project to carry out a rigorous assessment of the uncertainties in the projections, but as mentioned in the methodology section we suggest that only projected changes of 10% or more should be considered as "significant".

Figure 7.2 displays present metabolisable pasture growth estimates over New Zealand, calculated using the climate data described in Section 2.1. To indicate the variations due to year to year natural variability in the climate (e.g. between El Niño and La Niña years) we have also displayed (in Figure 7.3) results for two years which were particularly dry in the east: the 1977/78 year and the 1997/98 year. The 1997/98 plot suggests virtually no metabolisable growth in unirrigated pasture in some eastern regions.

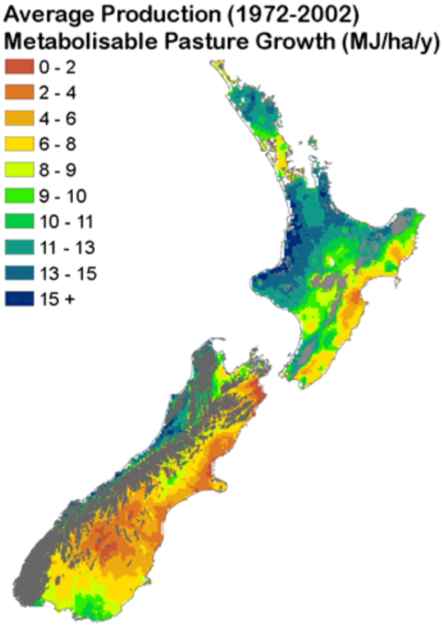


Figure 7.2: *Estimates of average pasture production for the period July 1972–June 2002. This combines estimated above ground dry matter production with digestibility of herbage for ruminant animals, following the procedure outlined in Section 7.1. Areas shown in grey are Land Use Capability Class 8 (Mountain Land) unsuitable for any pastoral use.*

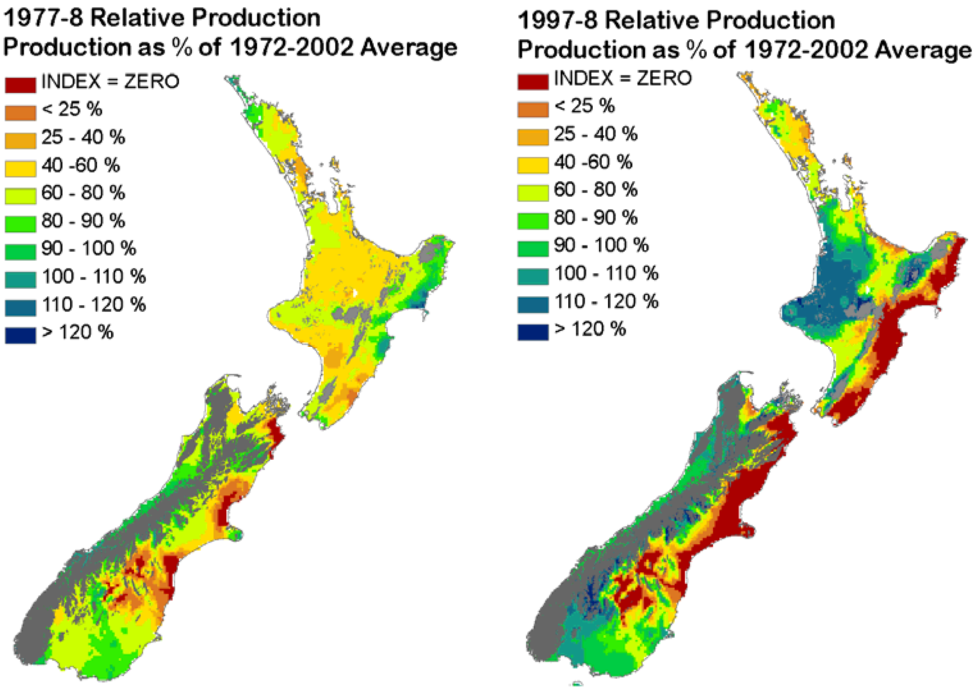


Figure 7.3: *Relative production estimates (compared to the 1972–2002 average) based on metabolisable pasture growth estimates, for two agricultural years with unusually dry conditions over parts of New Zealand. These simulate an effect from the observed variability in climate, but do not account for any non-climatic economic conditions affecting agriculture. Areas shown in grey are Land Use Capability Class 8 (Mountain Land) unsuitable for any pastoral use.*

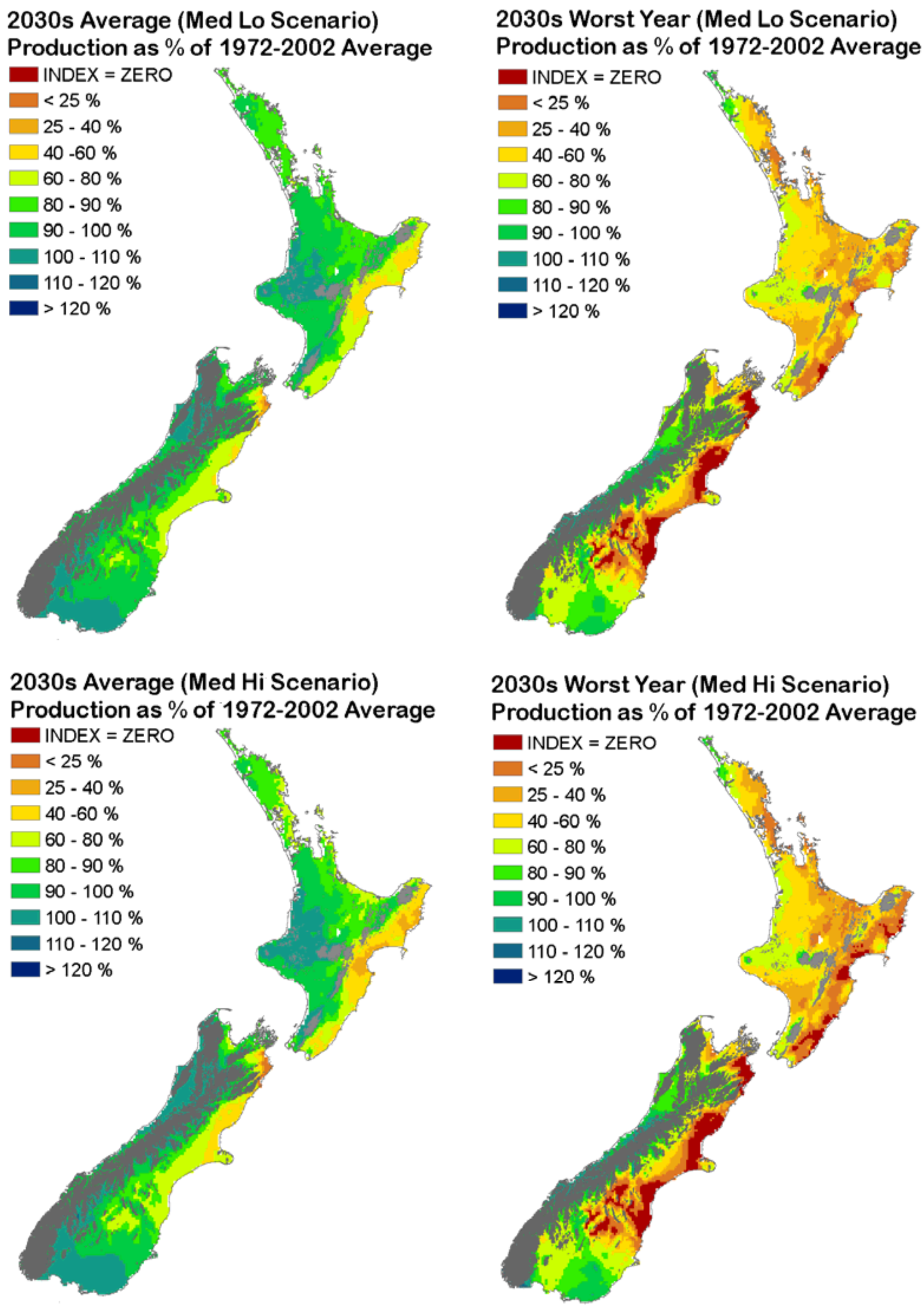


Figure 7.4: *Relative production projections for the 2030s, based on IPCC TAR models and metabolisable pasture growth estimates. These take into account projected climate scenarios but do not account for any changes in CO_2 fertilisation or in non-climatic economic conditions affecting agriculture. Areas shown in grey are Land Use Capability Class 8 (Mountain Land) unsuitable for any pastoral use.*

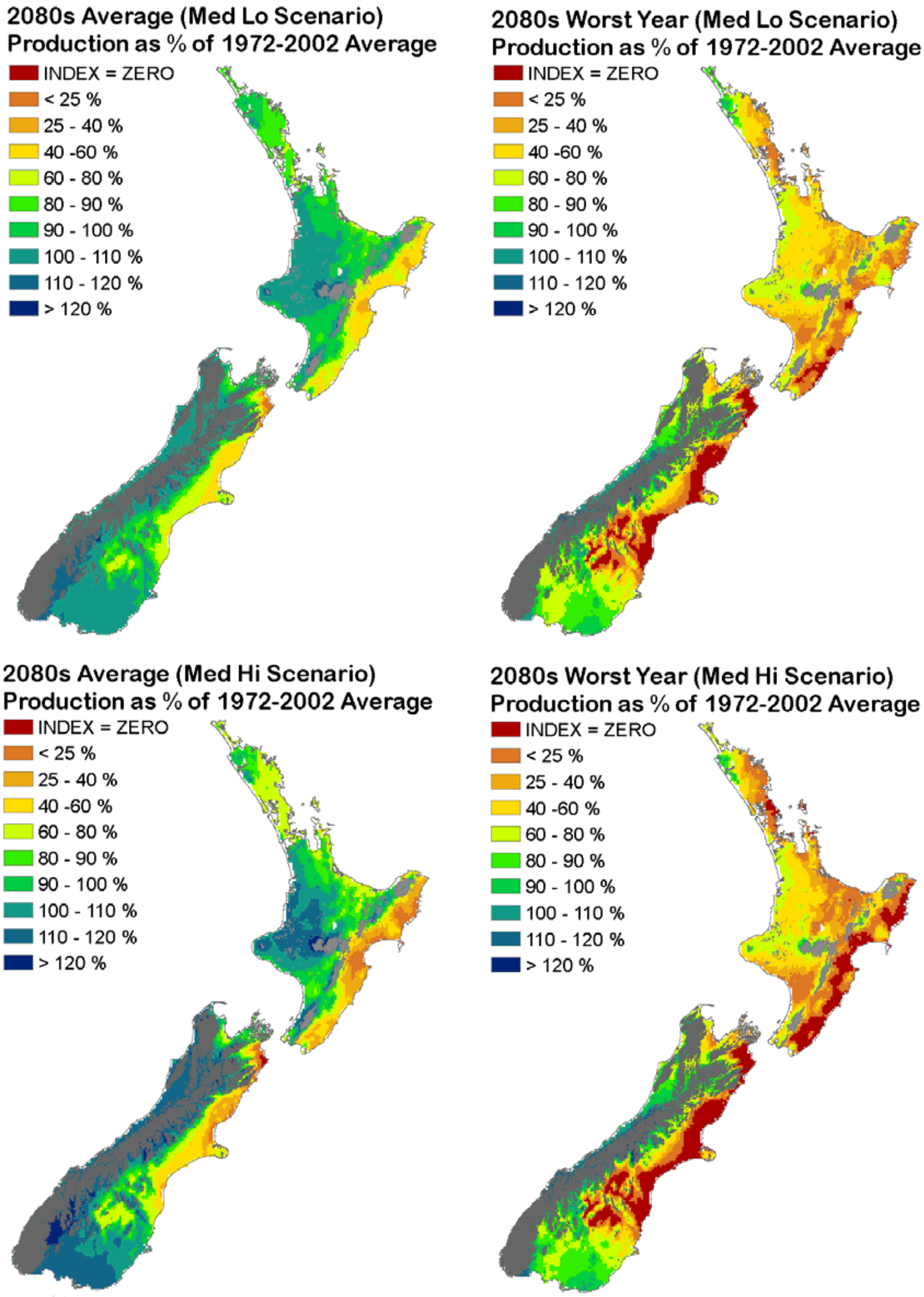


Figure 7.5: *Relative production projections for the 2080s, based on IPCC TAR models and metabolisable pasture growth estimates. These take into account projected climate scenarios but do not account for any changes in CO_2 fertilisation or in non-climatic economic conditions affecting agriculture. Areas shown in grey are Land Use Capability Class 8 (Mountain Land) unsuitable for any pastoral use.*

Figure 7.4 shows relative productivity changes for the 2030s (2020–2049) compared to the baseline period (July 1972–June 2002), for the two climate scenarios outlined in Section 2.1. Recall that these scenarios both use statistical downscaling from the HadCM2 global model runs from the IPCC TAR, which predict a significant increase in the west–east gradient of annual rainfall across New Zealand. The “medium-low” scenario corresponds to a global temperature change 25% of the way between the lowest and highest of the IPCC TAR estimates (i.e. the h25 climate scenario), and the “medium-high” scenario to a global temperature change 75% of the way across this range (i.e. the h75 climate scenario). For both scenarios, the projected change in average conditions amounts to a modest increase in metabolisable plant growth in some western areas, a decrease in some eastern areas, and little change across much of the country. However the projected “worst year” exhibits a significant reduction in growth over substantial parts of the country. (Remember these projections are for unirrigated land).

Figure 7.5 displays relative productivity changes through to the 2080s (2070–2099) projected for the two climate scenarios outlined in Section 2.1. The spatial patterns are similar to those discussed above for the 2030s, but the magnitudes and/or extent of some of the projected regional changes are larger. Note, preliminary work based on an average of 12 models from the IPCC AR4 (see Section 8) indicates future average and worst year production in the East Coast of the North Island is not as adversely affected as is projected by the HadCM2 model.

The following tables display regional changes in dairy (Table 7.2) and sheep/beef (Table 7.3) production out to the 2030s and 2080s, projected using the methods described in Section 7.1. Again, we remind readers that these projections are for just the two climate scenarios outlined in Section 2.1, both of which use statistical downscaling from the HadCM2 global model runs that project a significant increase in the west–east gradient of annual rainfall across New Zealand.

7.2.1 Dairy Production

The net projected change in dairy production for the country as a whole, averaged over both of these future periods, is small (2–4% reduction in the 2030s, and 0–1% increase in the 2080s, from Table 7.2) for the climate change scenarios considered. These changes are less than the “10% or more” guideline given in the previous section for considering whether projected changes are significant in light of methodological uncertainties. However, as expected from the metabolisable pasture growth projections (Figures 7.3 and 7.4), significant regional variations occur in the projected average change – increases in presently moist regions such as Southland, Taranaki and Westland (presumably due to increasing growing degree days without soil moisture constraints), and decreases in most eastern areas. Projected changes in “average” dairy production for the Waikato are very small (-3% to +2% from Table 7.2). The production in average years for Canterbury (the “dry” area with the largest dairy production) is projected to decline by no more than 10% (-2% to -10%, Table 7.2).

However what is noticeable is that the national “worst year” dairy production for both the 2030s and the 2080s is projected to be less than the “worst year” production from the baseline period of 1972–2002. Regionally, there are production decreases in the projected “worst-year” for the major dairying areas of Waikato (although at less than the 10% margin of uncertainty for some scenarios) and Canterbury. However the projected “worst years” for Southland show a modest improvement (although still less than 10%) and for Taranaki show little change (Table 7.2).

7.2.2 Sheep and Beef Production

For the two climate change scenarios outlined in Section 2.1, the net projected changes in sheep/beef production for the country as a whole averaged over both of the future periods are negative, but again less than the "10% or more" significance guideline. Again, significant regional changes are projected, with decreases in some eastern areas (especially Canterbury, Gisborne, and Hawke's Bay) and increases in Southland. Production in the "worst years" in the major eastern sheep/beef production area of Canterbury is projected to decrease significantly (Table 7.3).

7.3 Assumptions Underlying the New Pastoral Production Estimates

This study was designed as an initial investigation based on existing data and methodologies, drawing on limited resources. Thus projections in this Section for changes in pastoral production are based on only two scenarios for future globally-averaged temperature changes, and the New Zealand climate projections come from statistical downscaling of just one IPCC TAR global climate model (HadCM2) for these two global futures. Thus this section is best viewed as a "risk assessment" of the changes in agricultural production which may occur under climate scenarios which exhibit significant changes in west–east rainfall distribution across New Zealand.

Other constraints on this initial study, which it would be useful to address through further research work include:

- The methodology used in this section projects future variations of pasture growth under a changed climate based on present relations between spatial variations in pasture growth across New Zealand and spatial variations in climate. While this provides estimates of how pasture growth may change in response to changes in climate, it cannot provide estimates of how pasture growth might also be directly affected by increasing atmospheric carbon dioxide concentrations ("carbon dioxide fertilisation").

- There are varying estimates in the literature for this effect. In a recent summary of the international FACE (Free-Air Carbon Dioxide Enrichment) experiment results, Ainsworth and Long (2005) state that C3 grasses show about a 10% increase in dry matter production at elevated carbon dioxide concentrations of 475–600 ppm, legumes an increase of about 24%, and that C4 grasses show little change in dry matter production as a result of elevated carbon dioxide concentrations. However, Edwards et al (2003) have reported some results in which plants grown in an environment with high atmospheric CO_2, where the soils have had a long-term exposure to high carbon dioxide concentrations, show no difference in leaf and root biomass. Newton et al (in press) report on seven years of a New Zealand FACE elevated CO_2 experiment in which the grass is grazed by animals. They found no change in production of C3 grasses, and an initial increase in the productivity of legumes (clover) which decreased over time.

- We have assumed a static value for digestibility of pasture, which does not vary with climate or carbon dioxide concentration. Future changes of climate and carbon dioxide concentrations may lead to changes in pasture composition and feed quality for animals (Newton et al, in press). Also, the assumption that regional annual dairy and sheep/beef production are proportional to metabolisable pasture growth does not account for response measures to dry conditions such as transport of feed from other regions, or sale of stock for fattening elsewhere.

- Another potential effect of CO_2 enhancement is a change in water use efficiency in plants. This is discussed in the NIWA drought report (Mullan et al, 2005). Under higher CO_2 concentrations the stomatal resistance of plants is expected to increase (thereby reducing PET), but plant leaf area is also expected to increase (with an opposite effect on PET). Changes in PET could influence the SMD index used in our equation for estimating pastoral production. The NIWA drought report makes the default assumption of no overall direct effect of CO_2 enhancement on PET, which is also implicitly assumed in the present report[6].

- The future projections in this section do not fully account for irrigated agriculture. The projected decreases in agricultural production in drier regions may be at least partially offset by increased irrigation, in places where water availability for irrigation does not become a constraint (see Section 3).

- Finally, the projections in this section investigate the likely influence of local changes in climate, but do not consider the possible effects of changes in economics on production – including possible changes in agricultural production in other parts of the world resulting from climate changes.

Table 7.2a: *Average projected effect on national export revenue – Dairy. All values are presented as a percentage of the average value for the 1972–2002 period. Totals reflect normalisation of each region's productivity to 2001–2002 export revenue.*

Region	1972-2002	2030s		2080s		Expected variation, all future scenarios
	Fraction of National Export Revenue	Low-Medium (h25)	Medium High (h75)	Low-Medium (h25)	Medium High (h75)	
Northland	0.045	92%	88%	91%	81%	-(8-19%)
Auckland	0.015	94%	90%	94%	86%	-(6-14%)
Waikato	0.346	98%	97%	102%	101%	-3 to +2%
Bay of Plenty	0.070	90%	85%	93%	83%	-(7-15%)
Gisborne	0.004	72%	61%	68%	48%	(-28-52%)
Hawke's Bay	0.014	68%	57%	63%	44%	-(32-56%)
Taranaki	0.130	104%	105%	108%	113%	+(4-13%)
Manawatu-Wanganui	0.084	100%	100%	102%	101%	0 to +2%
Wellington	0.002	86%	80%	81%	69%	-(14-31%)
Tasman	0.012	98%	97%	103%	104%	-3 to +4%
Nelson	0.000	121%	120%	103%	126%	+(3-26%)
Marlborough	0.006	93%	90%	98%	94%	-(2-10%)
West Coast	0.003	104%	105%	111%	116%	+(4-16%)
Canterbury	0.121	93%	90%	98%	96%	-(2-10%)
Otago	0.033	101%	102%	105%	108%	+(1-8%)
Southland	0.071	104%	105%	111%	118%	+(4-18%)
Total	**1.000**	**98%**	**96%**	**101%**	**100%**	**-4 to +1%**

[6] A sensitivity study undertaken for the drought report suggest the general findings of that report regarding reduced average recurrence intervals for drought in eastern areas are robust to potential influences of enhanced CO_2 concentrations on evapotranspiration. However the quantitative values for the changes in average recurrence intervals could show some changes.

Table 7.2b: *As for Table 7.2a but for worst years – Dairy.*

Region	1972-2002	2030s		2080s		Expected variation, all future scenarios
		Low-Medium (h25)	Medium High (h75)	Low-Medium (h25)	Medium High (h75)	
Northland	68%	54%	48%	53%	39%	-(46-61%)
Auckland	49%	39%	34%	39%	29%	-(61-71%)
Waikato	58%	52%	49%	54%	49%	-(42-51%)
Bay of Plenty	55%	37%	29%	39%	21%	-(61-79%)
Gisborne	87%	41%	27%	41%	16%	-(59-84%)
Hawke's Bay	87%	47%	32%	44%	19%	-(53-81%)
Taranaki	63%	63%	63%	61%	57%	-(39-43%)
Manawatu-Wanganui	51%	47%	45%	41%	34%	-(53-66%)
Wellington	61%	40%	33%	32%	22%	-(60-78%)
Tasman	64%	60%	58%	61%	58%	-(40-42%)
Nelson	82%	76%	74%	76%	66%	-(24-34%)
Marlborough	74%	64%	60%	67%	61%	-(33-40%)
West Coast	89%	93%	95%	95%	98%	-(2-7%)
Canterbury	71%	62%	58%	64%	61%	-(36-42%)
Otago	73%	75%	75%	72%	72%	-(25-28%)
Southland	82%	86%	88%	88%	90%	-(10-14%)
Total	**64%**	**57%**	**54%**	**57%**	**52%**	**-(43-48%)**

Table 7.3a: *Average projected effect on national export revenue – Sheep and beef. All values are presented as a percentage of the average value for the 1972–2002 period. Totals reflect normalisation of each region's productivity to 2001–2002 export revenue.*

Region	1972-2002	2030s		2080s		Expected variation, all future scenarios
	Fraction of National Export Revenue	Low-Medium (h25)	Medium High (h75)	Low-Medium (h25)	Medium High (h75)	
Northland	0.051	93%	88%	92%	82%	-(7-18%)
Auckland	0.022	95%	91%	94%	87%	-(5-13%)
Waikato	0.118	100%	99%	105%	105%	-1 to +5%
Bay of Plenty	0.014	89%	83%	91%	81%	-(9-19%)
Gisborne	0.041	70%	58%	66%	46%	-(30-54%)
Hawke's Bay	0.076	67%	55%	61%	41%	-(33-59%)
Taranaki	0.023	104%	104%	108%	111%	+(4-11%)
Manawatu-Wanganui	0.156	98%	97%	101%	99%	-3 to +1%
Wellington	0.032	81%	72%	74%	57%	-(19-43%)
Tasman	0.006	98%	97%	103%	104%	-3 to +4%
Nelson	0.000	97%	94%	97%	97%	-(3-6%)
Marlborough	0.007	91%	87%	97%	93%	-(3-13%)
West Coast	0.004	104%	105%	111%	116%	+(4-16%)
Canterbury	0.130	87%	82%	88%	79%	-(12-21%)
Otago	0.136	101%	101%	106%	109%	+(1-6%)
Southland	0.183	104%	106%	112%	119%	+(4-19%)
Total	**1.000**	**94%**	**91%**	**96%**	**93%**	**-(4-9%)**

Table 7.3b: *As for Table 7.2a but for worst years – Sheep and beef.*

Region	1972-2002	2030s		2080s		Expected variation, all future scenarios
		Low-Medium (h25)	Medium High (h75)	Low-Medium (h25)	Medium High (h75)	
Northland	70%	55%	50%	55%	41%	-(45-59%)
Auckland	55%	46%	41%	46%	38%	-(54-62%)
Waikato	57%	54%	52%	55%	52%	-(45-48%)
Bay of Plenty	56%	38%	31%	38%	19%	-(62-81%)
Gisborne	87%	42%	27%	41%	20%	-(68-80%)
Hawke's Bay	82%	40%	25%	36%	15%	-(60-85%)
Taranaki	63%	63%	63%	61%	57%	-(39-43%)
Manawatu-Wanganui	53%	47%	45%	43%	38%	-(53-62%)
Wellington	48%	26%	18%	18%	10%	-(74-90%)
Tasman	65%	61%	60%	62%	59%	-(38-41%)
Nelson	72%	61%	57%	64%	58%	-(39-43%)
Marlborough	74%	65%	61%	68%	63%	-(32-39%)
West Coast	89%	93%	95%	95%	98%	-(2-7%)
Canterbury	56%	43%	38%	41%	35%	-(57-65%)
Otago	74%	75%	75%	73%	72%	-(25-28%)
Southland	79%	83%	85%	84%	88%	-(12-21%)
Total	**67%**	**57%**	**54%**	**56%**	**50%**	**-(53-50%)**

8. Preliminary Results from an Analysis of IPCC Fourth Assessment Report Climate Models

Key Points

- This section describes some preliminary work on the impact of climate change on Net Primary Production in New Zealand based on newly developed downscaled climate projections. The new projections are based on data from updated global climate models released for the IPCC AR4 in 2007.
- The AR4 scenarios used for this work are different to the scenarios used in Section 7. The previous analyses were for the 2030s and 2080s, and were based on one climate model (HadCM2) and two emissions pathways. Here, one emission scenario is analysed (the A1B scenario) and the downscaled output from 12 models are averaged for the future years 2040 and 2090.
- Due to these differences, the results from this preliminary analysis are not meant to supersede those reported in Section 7; rather they provide additional information on the sensitivity of projected changes in agricultural production in New Zealand to differences in climate change scenarios.
- Projections of future summer rainfall for some areas of New Zealand, such as the East Coast of the North Island, show a considerable spread across the 12 AR4 models. The average of the 12 AR4 model rainfall projections indicates increased summer rainfall in the east of the North Island (by as much as +10% by 2090), which is a marked departure from the HadCM2 projections described in Section 2 which indicated a decline in summer rainfall in this region (by as much as -10% by the 2080s).
- The median years in the future periods still show similar overall net primary productivity with some increases (e.g., West Coasts) and some decreases (e.g., South Island East Coast regions), compared with the period 1972–2001. The largest difference from the productivity projections described in Section 7 is seen in the East Coast region north of Napier, where the AR4 12-model average NPP for the future period median years now show similar or increased productivity compared to the reference period.
- For the worst (lowest overall production) years in the future periods, the AR4 results suggest production drops to 52% of the recent median year. This is similar to the results presented in Section 7 which suggested a drop to between 50 and 57% of the 30-year average for the recent period.

At the time of writing this report, output from 12 updated global climate models described in the IPCC AR4 was being analysed and downscaled for New Zealand by scientists at NIWA. This section presents the results of a short analysis on the affect of climate change on future pastoral production in New Zealand, comparable to the results presented in Section 7, but using projections based on an average of the 12 new climate scenarios. These results do not supersede those presented in the previous chapters; rather they provide additional information on the sensitivity of projected changes in agricultural production in New Zealand to variations in climate change scenarios. Further work is required to make better use of these newly developed scenarios to provide.

8.1 Climate Scenarios Projected for 2040 and 2090

The IPCC released the AR4 in 2007 (IPCC, 2007). Lying behind the conclusions of this report was an enormous amount of scientific research, much of it dependent on simulations of future climate by complex global climate models. These climate models are driven by future greenhouse gas concentrations in the atmosphere, which have been specified by the IPCC in what are known as the SRES emissions scenarios. Six of the SRES scenarios were selected for detailed study by the IPCC in the AR4, and climate model results were archived for use internationally by scientists.

NIWA has taken climate model output from 12 of the global models, driven by the middle-of-the-road emissions scenario known as SRES A1B, and produced downscaled changes of temperature and precipitation over New Zealand for the two future periods 2030–2049 (also referred to by the mid-point reference year "2040") and 2080–2099 (also referred to as "2090"). These latest downscaled projections are of course different from those described in Section 2. However, they are still 50 and 100 year changes ending at the same dates (2049 and 2099), although the mid-point of the period is shifted forward in time by 5 years compared to the projections from the older climate model. The new projections for New Zealand will form the basis of an updated climate change Guidance Manual prepared by NIWA for the Ministry for the Environment (MfE, 2008, in press). This new Manual will supersede the first edition published in 2004 (MfE, 2004), where fewer climate models were available (6 have projections out to 2050, but only 4 continue through to 2100).

One of the key differences noted in the new projections with a larger sample of climate models is in the seasonality of the projected changes. There is a strong consensus between the 12 models that future temperature increases in spring will be smaller than those for the other three seasons. For scenarios of future rainfall, the 12-model average shows a marked distinction between the winter/spring and the summer/autumn seasons. The winter and spring pattern, which also dominates the annual-average pattern, is for more persistent westerly winds across New Zealand, leading to increased rainfall in western districts and reduced rainfall in the east and north of the country. In the other two seasons, and especially in summer, the model consensus is for reduced westerlies over the North Island and increases in summer rainfall in the east of the North Island. It should be noted that there is a considerable spread across the 12 models in projected summer rainfall changes, and some (such as the HadCM3 model, which is an upgrade of the single model described in Section 2) still indicate decreases in the east of the North Island (see Figure 8.1).

Figure 8.2 shows scenarios of projected changes in annual-average and summer rainfall, comparing the new 12-model average at 2090 with the 2080s medium-high rainfall changes described in Section 2. The 12-model average of increased summer rainfall in the east is a marked departure from the HadCM2 scenario.

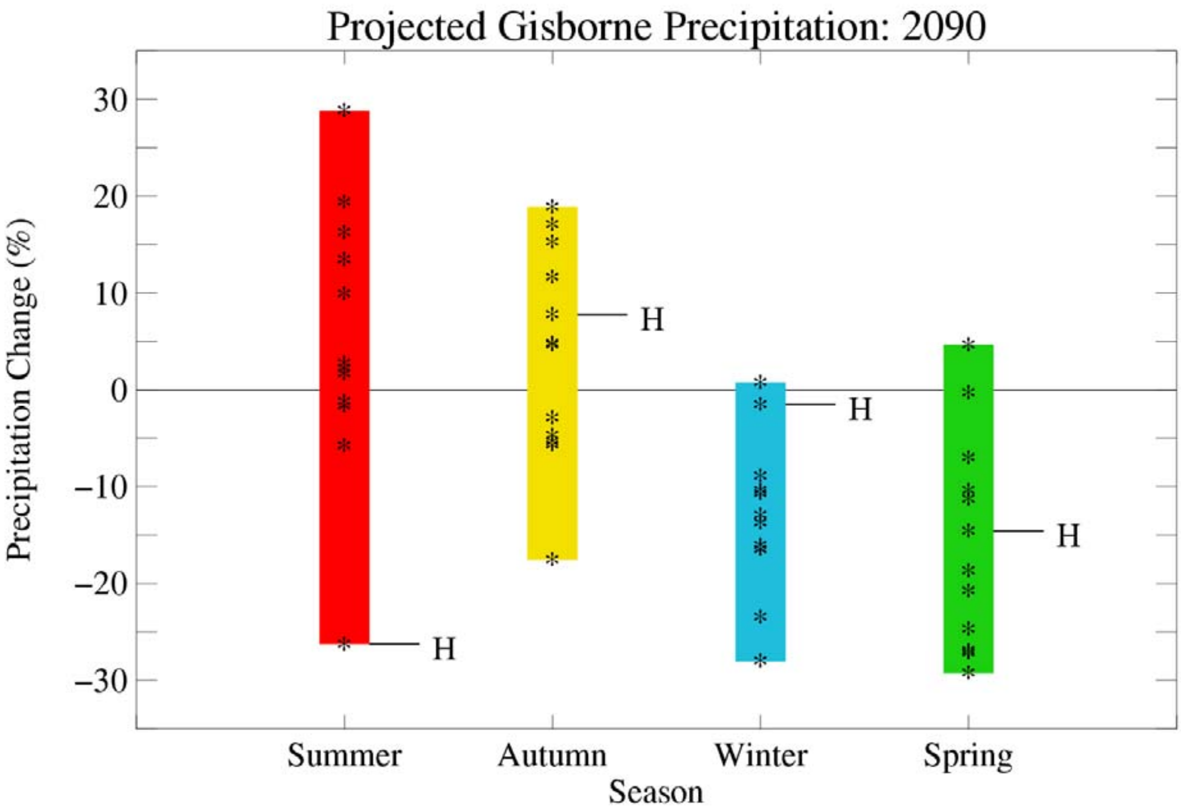


Figure 8.1: *Range in projected seasonal precipitation change (in %) by 2090 for the A1B emissions scenario for the grid-point co-located with Gisborne City. Vertical coloured bars show the range over all 12 models, and stars the 12 individual model values. The downscaled projections from the HadCM3 model are identified with an 'H'.*

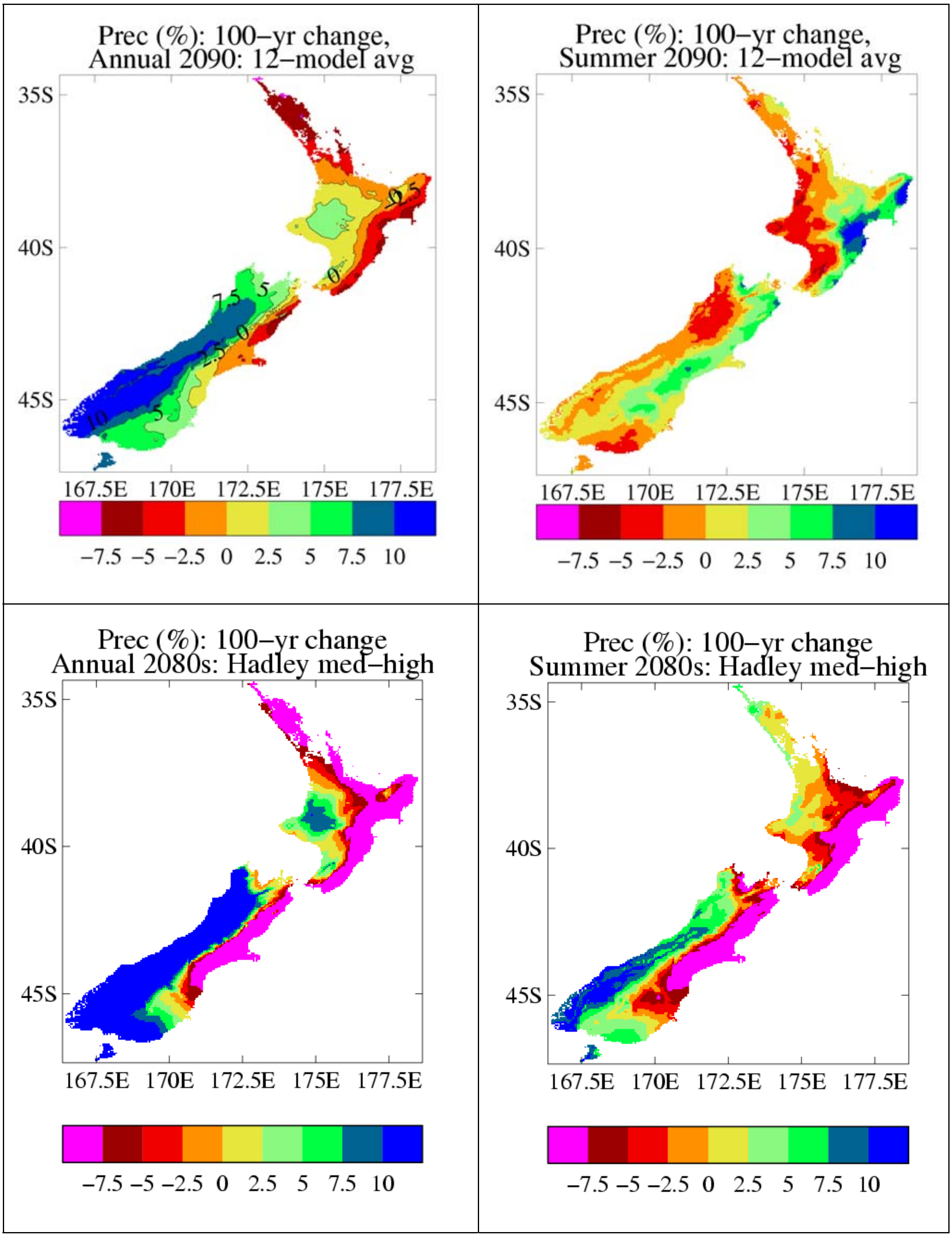


Figure 8.2: *Projected changes (in %) in annual-average and summer rainfall for New Zealand based on AR4 and HadCM2 scenarios: (upper 2 panels) the 12-model average changes at 2090 (AR4), and; (lower 2 panels) HadCM2 changes with medium-high scaling at 2080s.*

8.2 Projections of Changes in Growing Degree Days and Soil Moisture for 2030–2049 and 2080–2099

For this preliminary study, the SMD index (PET – Rainfall) and GDD base 5°C data for the median (1989/90) and worst (1977/78) drought years over the period 1972–2001 were produced. The selection of the median and worst years was based on a ranking of annual PED (see Section 4 for a description of PED) data, spatially-averaged over all of New Zealand. The SMD index and GDD data for the median and worst years of the future periods 2030–2049 and 2080–2099 were also produced based on a scaling approach of the 1989/90 and 1977/78 data using the AR4 12-model average climate projections described in Section 8.1.

Figures 8.3 and 8.4 show the AR4 12-model average changes to the 1972–2001 median annual GDD and SMD index. These maps show patterns that are generally similar to those originally produced using the HadCM2 scenarios for the 2030s and 2080s (Figure 8.3 is comparable with Figure 2.2; and Figure 8.4 is comparable with Figure 2.3). The largest difference from the earlier figures is seen in the East Coast region north of Napier, where the AR4 12-model annual SMD index for the median years in the 2030–2049 and 2080–2099 periods now show reduced deficits compared with those based on the single HadCM2 model. This is a result of the projected increase in summer precipitation shown in the AR4 12-model average for this region.

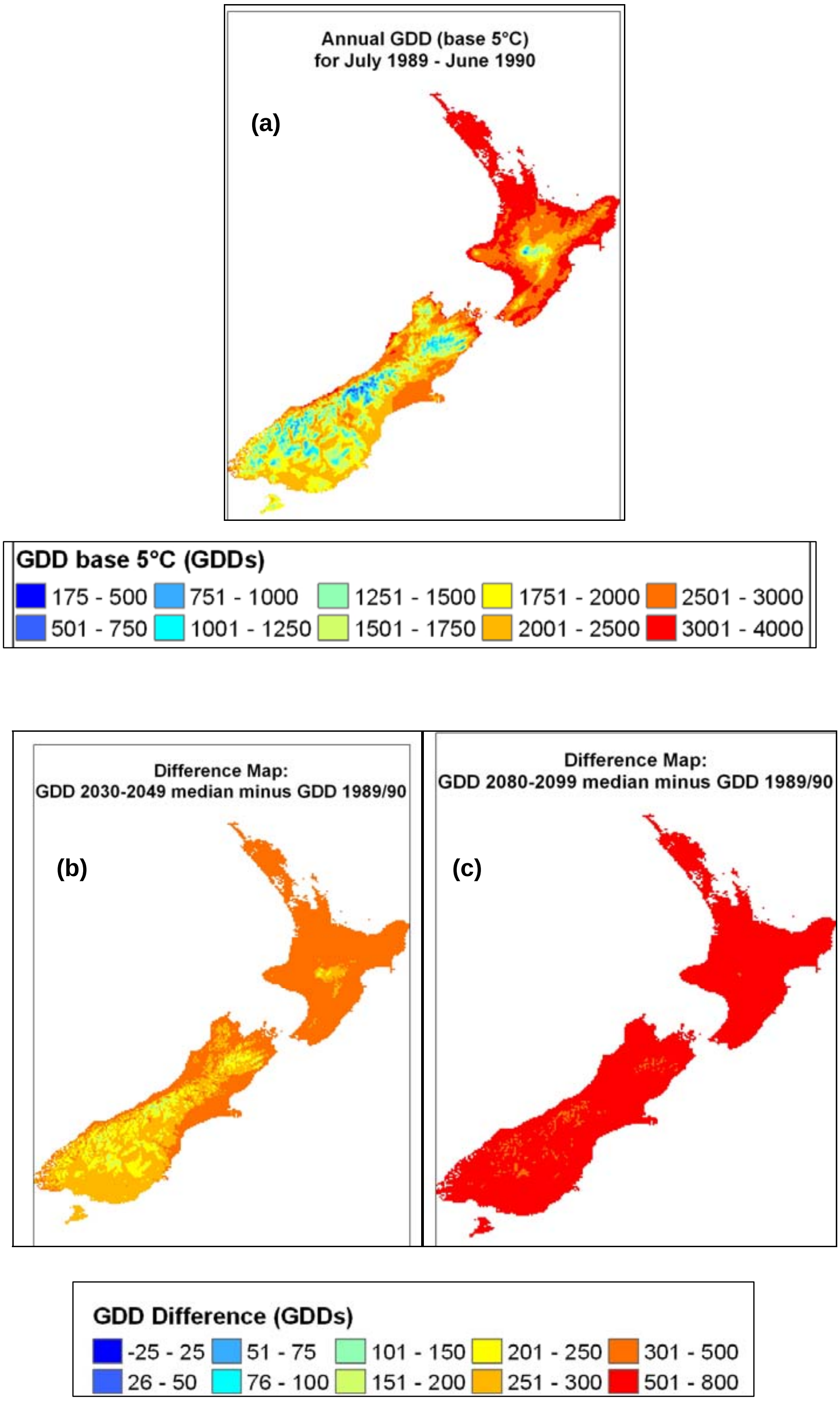


Figure 8.3: *Examples of annual growing degree day (GDD, base 5 °C) data and AR4-based projections used in producing the agricultural productivity projections in Section 4: (a)GDD for the agricultural year July 1989 – June 1990; (b) Increases to the 2030–2049 median GDD; and (c) Increases to the 2080–2099 median GDD.*

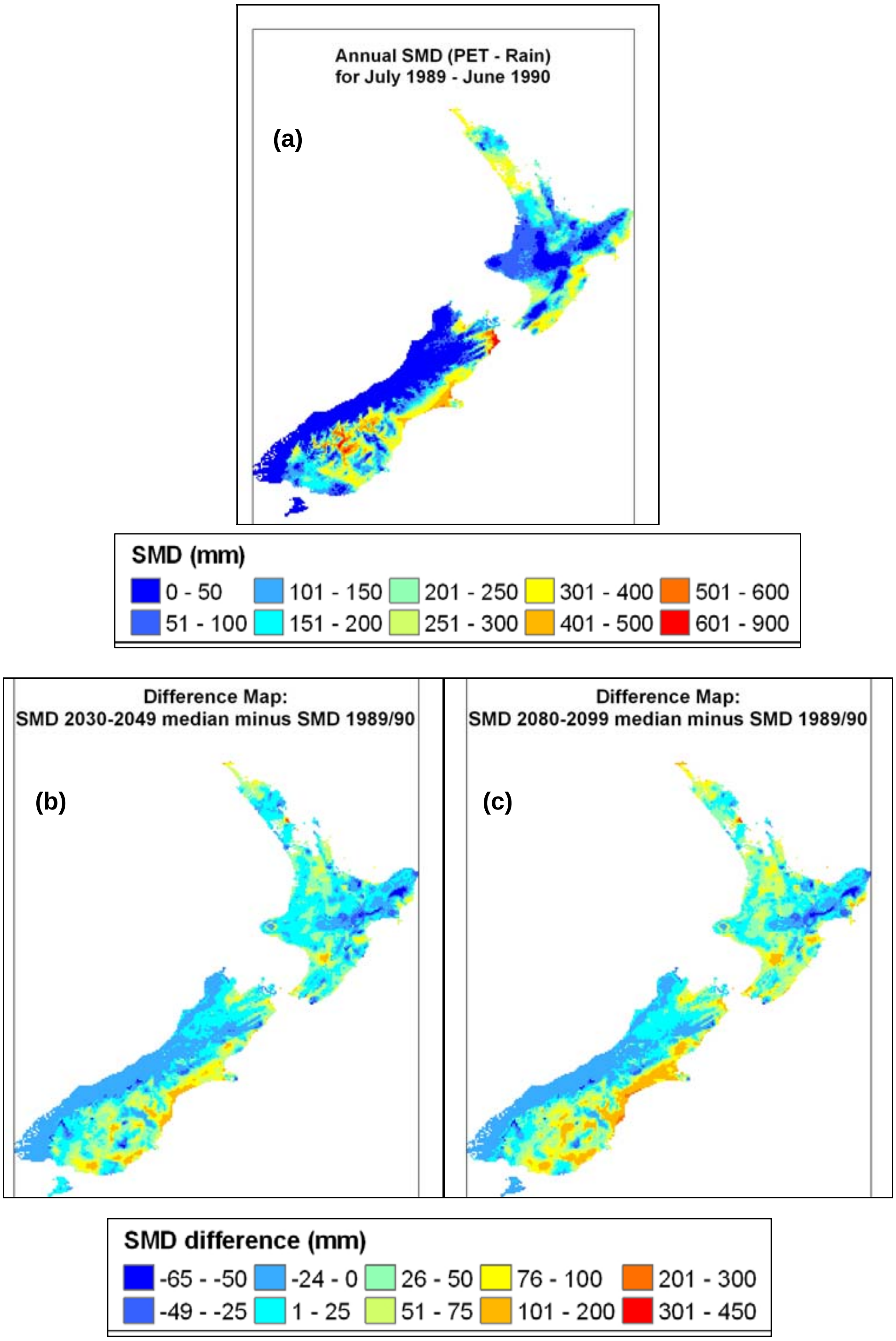


Figure 8.4: *Examples of annual moisture deficit index (SMD, mm) data and AR4-based projections used in producing the agricultural productivity projections in Section 4: (a)SMD for the agricultural year July 1989 – June 1990; (b) Changes to the 2030–2049 median SMD; and (c) Changes to the 2080–2099 median SMD.*

8.3 Projections of Changes in Pastoral Production for 2030–2049 and 2080–2099 due to Changes in Growing Degree Days and Soil Moisture

The SMD index and GDD data (median and worst years for 1972–2001, 2030–2049 and 2080–2099) were used to estimate NPP as described in Section 7 using the model of Baisden (2006). The additional steps of segregating dairying from sheep/beef pastures and accounting for lower digestibility in poorer pasture were not performed. These calculations were required previously to calibrate animal production data to recent economic statistics, allowing economic analysis. Instead, all calculations in Figures 8.5–8.7 and Table 8.1 represent biophysical production (NPP) in the year of interest, relative to the 1989/90 reference year which was the median of the 30 years of spatially-averaged PED data. The average production relative to the reference year was calculated for all areas mapped as high producing pasture in 2001/02 (as represented in the Land Cover Database; LCDB2). Areas with null or zero production values were excluded from the average.

Figures 8.5–8.7 show the productivity in median and worst years from the recent, 2030–2049 and 2080–2099 periods, relative to the median year from the most recent period. These maps show patterns that are generally similar to those produced for using the HadCM2 scenarios for the 2030s and 2080s (Figure 8.5 is comparable with Figure 7.3 (left map); Figure 8.6 is comparable with Figure 7.4, and Figure 8.7 is comparable with Figure 7.5. Note, the index=zero areas on the AR4 maps are now coloured white, where previously they were coloured red).

The median years in the future periods still show similar overall productivity with some increases (e.g., West Coasts) and some decreases (e.g., South Island East Coast regions). The largest difference from the earlier figures is seen in the East Coast region north of Napier, where the AR4 12-model average NPP for the median years in the 2030–2049 and 2080–2099 periods now show increased productivity. This is a result of the projected increase in summer precipitation shown in the AR4 12-model average for this region. The worst years show widespread decreased productivity as before, though the decrease is less in the North Island East Coast region than that shown in Figures 7.4 and 7.5.

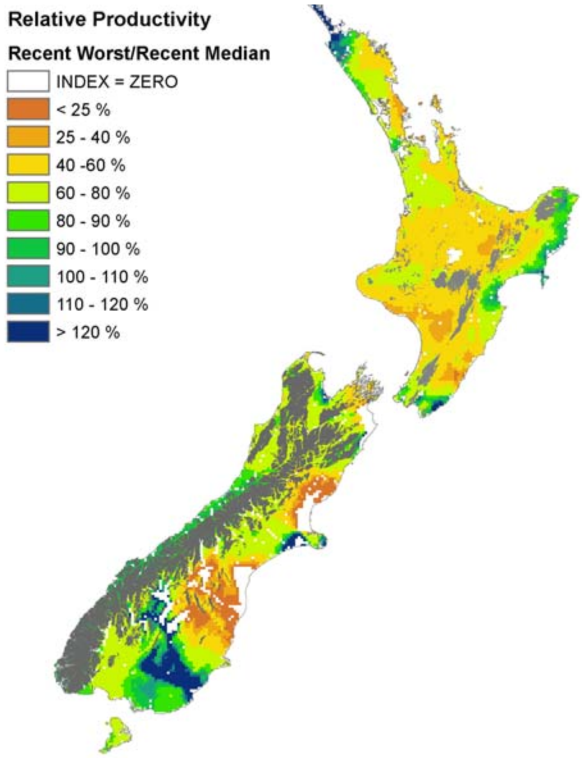


Figure 8.5: *Relative production estimate (compared to 1989/90; the 1972–2001 median PED year) based on metabolisable pasture growth estimates, for 1977/78; an agricultural year with unusually dry conditions over parts of New Zealand. This simulates an effect from the observed variability in climate, but does not account for any non-climatic economic conditions affecting agriculture. Areas shown in grey are Land Use Capability Class 8 (Mountain Land) unsuitable for any pastoral use. Note, the index=zero areas on the AR4 maps are now coloured white, where previously they were coloured red).*

Table 8.1 reports national pasture production under the AR4 12-model average projections, suggesting that median production will remain similar to present levels. The result supports those based on the HadCM2 scenarios presented in Section 7 where the average pasture production was close to the reference level, ranging from 91% to 116% across the farm types, future time periods and emissions scenarios examined. These small changes in productivity are believed to be roughly within the uncertainty of our projections. The AR4 result in Table 8.1 also echoes the previous results for the worst year in each 30 year period – the worst years appear to get worse using both HadCM2 and AR4 scenarios. For comparison, the worst year in the recent past had 71% of the median production, and 64% and 67% of the average for dairy and sheep/beef respectively. For the future periods, the AR4 results suggested production drops to 52% of the recent median year. The HadCM2 results suggested a drop to between 50 and 57% of the 30-year average for the recent period.

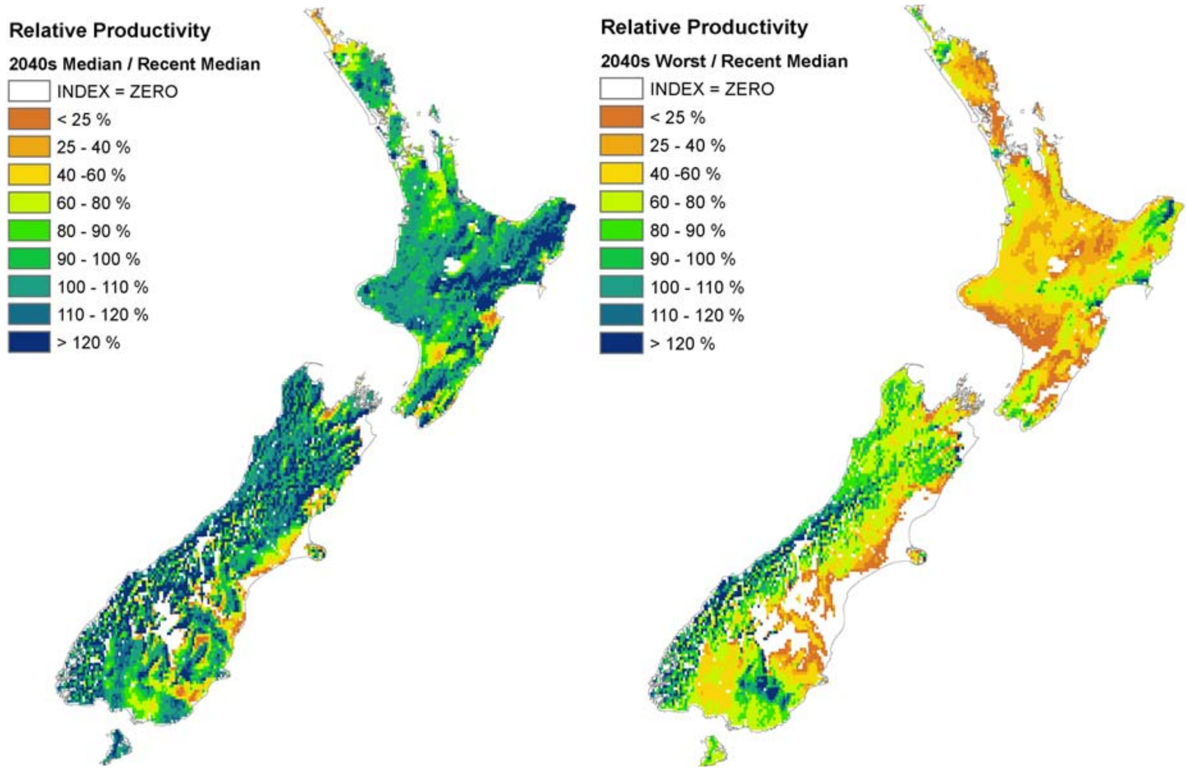


Figure 8.6: *Relative production projections for the period 2030–2049, based on IPCC AR4 models and metabolisable pasture growth estimates. These take into account projected climate scenarios but do not account for any changes in CO_2 fertilisation or in non-climatic economic conditions affecting agriculture. Note, the index=zero areas on the AR4 maps are now coloured white, where previously they were coloured red).*

Table 8.1: *National pasture production from areas under high producing pasture in 2002, relative to the median year during the recent period (1989/90).*

Period	Median	Worst
Recent	Reference	70.9%
2030–2049	100.2%	51.9%
2080–2099	103.1%	51.7%

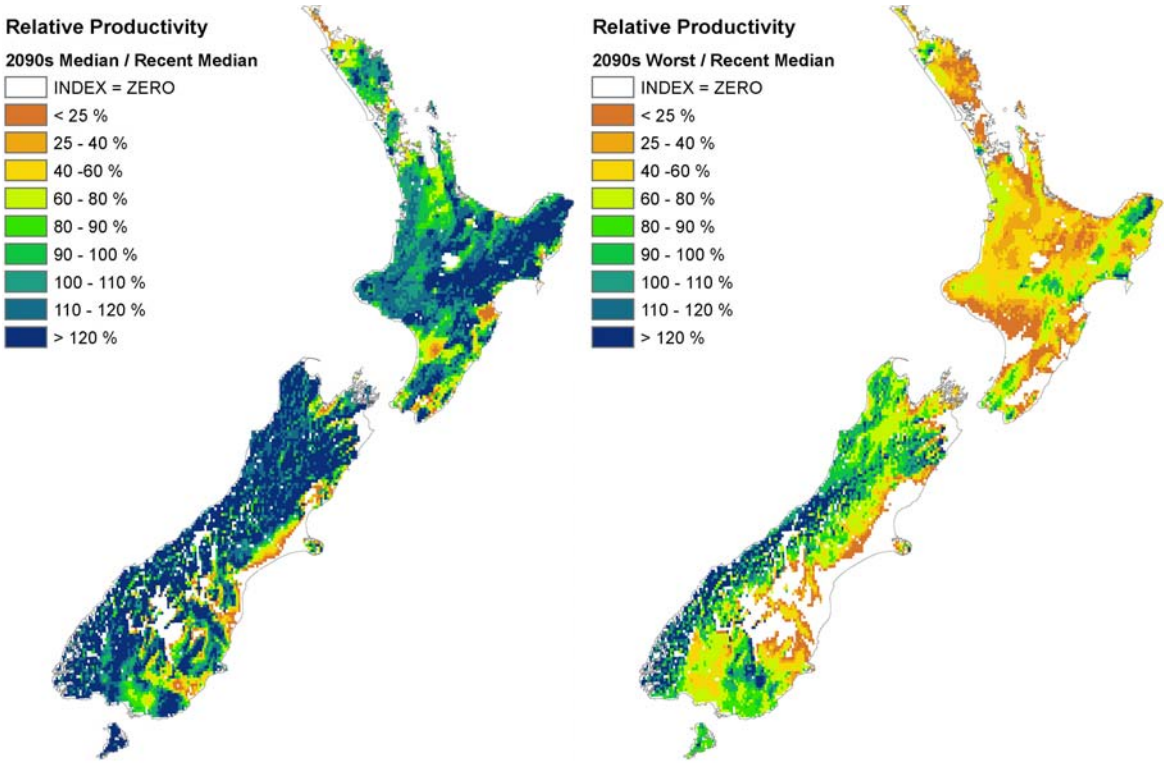


Figure 8.7: *Relative production projections for the period 2080–2099, based on IPCC AR4 models and metabolisable pasture growth estimates. These take into account projected climate scenarios but do not account for any changes in CO_2 fertilisation or in non-climatic economic conditions affecting agriculture. Note, the index=zero areas on the AR4 maps are now coloured white, where previously they were coloured red).*

9. Discussion and Conclusions

The following are the key conclusions from the new pastoral production projections made for this report. For climate change scenarios corresponding to global temperature changes 25% and 75% of the way between the lowest and highest of the IPCC TAR estimates, and obtained by downscaling from the HadCM2 global climate model which projects an increased west-east gradient in annual rainfall across New Zealand:

- At the regional level, substantial changes are projected for some areas. Average and worst year production is projected to decrease for east coast locations (Wellington, Hawke's Bay, Canterbury, Bay of Plenty, and Gisborne) and also for Northland. Improved production is projected in Southland and Westland. These changes apply to both dairy and sheep/beef production.
- Projected changes in 30-year averages of total national pastoral-based production (for 2020–2049 and for 2070–2099) show no major long-term trends compared to the period 1971–2002.

In comparison, the CLIMPACTS work (Section 6) for a mid-range climate scenario projected increases in pastoral production averaged over five sites from around New Zealand of 8–10% by 2020 and around 20% by 2050. Pastoral yield was projected to increase at all five of the sites considered.

Some of the differences between the "new" projections and the CLIMPACTS projections may be because the CLIMPACTS pastoral work factored in a direct CO_2 'fertilisation' effect from increasing greenhouse gas concentrations. From the literature discussed in Section 7.2 it appears that the likely direct effect of CO_2 enhancement on growth of New Zealand grazed pasture is still rather uncertain. For concentrations of 475–600 ppm it may lie somewhere between no change and an increase of up to about 15%. This enhancement is probably smaller than that commonly assumed from CO_2 fertilisation at the time the CLIMPACTS work was undertaken.

The preliminary work based on the IPCC AR4 models (Section 8) supports the conclusions bulleted above, with the exception of the impact projected for the east coast region north of Napier. While some AR4 models still indicate decreased summer rainfall in this area, the average of the 12 AR4 model rainfall projections indicates increased summer rainfall (by as much as +10% by 2090), which is a marked departure from the HadCM2 projections which indicate a decline in summer rainfall in this region (by as much as -10% by the 2080s). The result of this projected increase in summer rainfall in this area is the AR4 12-model average NPP for the future period median years now show similar or increased productivity compared with the reference period.

In Section 7.2 we list some other constraints on the new pastoral production projections, and suggest they are best viewed as a "risk assessment" of changes in agricultural production which may occur under plausible climate scenarios which exhibit significant changes in west–east rainfall distribution across New Zealand. Nevertheless, we consider our findings that substantial region-to-region differences are likely in future productivity changes from pastoral agriculture are reasonably robust – at least for climate scenarios incorporating significant changes in west-east rainfall gradients across New Zealand.

Some of the matters discussed in this report may also have implications for pasture and animal management, and for the timing of production peaks. In their report on future drought projections, Mullan et al (2005) pointed out that because all the scenarios they considered project increased PED accumulation over the course of a year, drought periods are likely to 'expand' into spring and autumn more often than currently. For their most severe scenario (corresponding to the h75 scenario in the present report), the drying of pasture in spring is projected to advance by about a month in the 2080s in dry eastern regions, compared to the current climate. The present report also points to a likely increase in growing-degree-days over the country (Section 2.1). This is likely to, in part, reflect an earlier start to pasture growth in the late winter or early spring of "average" years later in the century, and a later cut-off in autumn or early winter. Farmers might choose to bring forward some of their operations to fit such changes, perhaps resulting (for example) in lambs being ready for the works earlier than at present.

Our recommendations for future work include the following points:

- It is desirable to produce national and regional projections of future pastoral-based productivity for a wider range of scenarios. We suggest this could be usefully done with climate projections downscaled from the latest set of global model runs undertaken for the IPCC AR4 (i.e. expanding on the preliminary work shown in Section 8), considering both statistical downscaling (as used in this study) and physical downscaling using regional climate models.
- It would be desirable to use a bio-physical model such as that under development by AgResearch, to project future changes in pasture growth due both to changes in climate (including irrigation water availability) and changes in carbon dioxide concentrations coupled to nutrient availability, aboveground/belowground allocation, herbage digestibility and ruminant physiology. From a detailed process model analysis, it is likely that simple analyses such as the present study can be extended to be better targeted and calibrated to yield more robust results across a range of agronomic, soil and climate conditions.
- Further work, following economic analysis, could focus on identifying climate impacts on production in New Zealand in three categories – (1) impacts where New Zealand is "in sync" with the rest of the world (such as CO_2 'fertilization') and therefore little impact on export economics is likely; (2) impacts where New Zealand is potentially out of sync with other areas globally and likely to be affected strongly economically; and (3) strongly localised impacts within New Zealand likely to require adaptation responses (e.g. increased drought in some areas, changes in growing season).

Some of these concepts are included in research proposed under the new "Ecoclimate" collaboration, for which part of the funding is presently under review with the Foundation for Research, Science and Technology.

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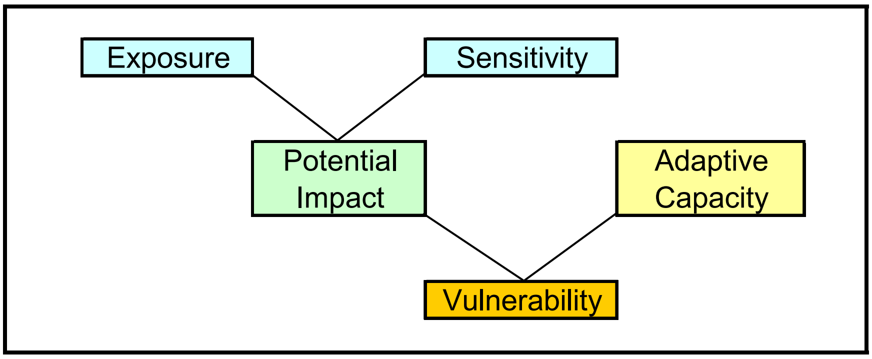
PART 2
Literature Review
of the Economic Effects of Climate Change
on New Zealand Agriculture

1. Metrics for Measuring the Effects of Climate Change

A recent study by the Organisation for Economic Co-operation and Development (OECD, 2006) presents some metrics for assessing the economic effects of climate change and climate change policies on agriculture. The framework noted by Stern (2006)[7] shown below, forms the basis of the suggested metrics.

Figure 1.1: *Vulnerability to Climate Change*



Under each heading the following metrics are suggested:

Exposure (biophysical)

- climate: temperature and precipitation (means and variability)
- soil; water availability, quality and storage;
- crop yield, output

Sensitivity (agricultural system)

- land resources,
- production technology

Adaptation (socio-economic)

- crop insurance, irrigation
- land value, value-added
- nutrition, people at risk of hunger
- land use and sequestration, bio-energy production
- synergy with mitigation strategies

In our assessment of the effects of climate change on New Zealand agriculture we shall not be considering all of the above metrics, as some are not particularly relevant to the project. Our focus will be on climate indicators (especially days of soil moisture deficit), agricultural

[7] See Stern (2006), p94.

output, agricultural value-added (GDP), and economy-wide GDP. For extreme events the insured values of destroyed assets tend to be the most common measure of loss.

1.1 Measuring the Loss in GDP

Probably the main expected manifestation of climate change on New Zealand agriculture is an increase in the frequency and severity of droughts. What economic effects would this have on agriculture and on the wider economy?

Consider a typical scenario such as the loss in exports of processed agricultural products as result of a drought. There is direct loss of gross output in both the farming and food processing industries. As exports are a component of GDP-Expenditure, the initial reduction in GDP is equal to the reduction in exports.

Lower gross output in agriculture will lead to lower value-added in agriculture, but the change in value-added could be less than the change in gross output – if expenditure on intermediate inputs can be reduced, or greater than the change in gross output – if the drought leads to more spending on intermediate inputs such as supplementary feed and energy for irrigation. The more that expenditure on intermediate inputs is reduced, the more of the reduction in agricultural gross output is transmitted to lower value-added in other industries.

This process, and its flow-on effects on the value-added of still more industries, is just the mechanism by which the reduction in GDP measured by expenditure equates to the reduction in GDP measured by income. To the extent that some of the inputs used by the agriculture and processing industries, and their supplying industries are imported, the eventual reduction in GDP (however measured) will be alleviated.

The reductions in industry value added can be expected to reduce household consumption largely because of lower wages, to reduce government consumption because of lower tax receipts (assuming no change in the fiscal surplus) and to reduce capital formation because of lower profits. Hence there is another round of reductions in GDP on the expenditure side of the accounts, which is matched by another round of reductions in industry value-added. Eventually this process converges to a new equilibrium.[8]

Up to this point we have dealt only with the loss of production. There might also be a loss of capital stock such as pasture. This is likely to extend the loss of production into future time periods, as well as raise the cost of restoring production. From a measurement perspective the destruction or loss of capital stock is treated as (accelerated) depreciation. Thus less of the nation's GDP is available for consumption.

1.2 Extreme climate change events

For temporary events the indirect effects may not fully materialise. For example the reduction in household spending power may be softened by borrowing or a reduction in accumulated savings, or farmers may have insurance for loss of income.

An insurance payout effectively spreads the cost of a drought over a longer period of time, and may also spread it over a wider range of industries and regions. Borrowing must eventually be paid for out of income, spreading the cost forwards over time, while a decline in savings may be seen as spreading the cost backwards over time.

Thus (baring preventative measures, which are usually not costless), while there is no escaping the loss in value-added caused by an unexpected extreme climate event, the

[8] This can be demonstrated mathematically.

concentration of the negative economic effects in both time and space depend on adaptive capacity in the form of preparation, insurance markets, and access to credit.

1.3 Gradual climate change

The costs of climate change may be thought of as having two components:

1. Costs arising directly from changes in temperature, rainfall etc (such as how these affect biomass production, the demand for energy or human health).

2. Costs of adjustment or transition, particularly the cost of stranded assets (and destroyed assets in the case of temporary severe events).

We use the term 'gradual' to refer to a period long enough to avoid the costs associated with stranded assets. In agriculture, with the possible exception of soils, this is probably a few decades. Infrastructural assets in areas such as water and energy have longer lifetimes. With regard to agriculture then, the cost of climate change has two components:

1. Gradual: the cost arising from lower biomass production because of a different climate. (This could be positive.)

2. Adjustment: the cost of the climate changing too quickly to fully utilise existing capital stock and too quickly for animal and plant physiology to adapt.

Some degree of adaptation is likely, implying less output sensitivity to gradual climate change than to sudden climate change.

In a welfare economics framework adverse climate change can be treated as negative technological change. Hence there is a reduction in consumer (and producer) surplus. The consequence at the macroeconomic level is that agriculture and those industries that supply agriculture, contribute a smaller share to GDP. However, the overall decline in GDP is determined not by the reduction in net agricultural output, but by the difference in the productivity of labour and capital (and land) used in other industries (and agriculture) with climate change, relative to their productivity in agriculture without climate change.

Treating changes in the climate analogously to changes in technological progress is useful from an agricultural production function perspective, and thus for estimating the costs of climate change, but it still requires a baseline. That is, just what is 'normal' or 'business as usual' with respect to climate uncertainty?

Pesticides might be applied every year even though in some years it will turn out not to have been necessary because the weather/climate was not as expected, where 'expected' presumably means some average over the last 5–10 years. If expectations change, and if the application of pesticides changes in response, is this part of the cost of climate change, or is it just part of the cost of dealing with climate uncertainty – which is always present? Where such changes in farming practice and farm management occur slowly over time, it is difficult to disentangle what is driving them – changes in climate, changes in commodity prices, changes in interest rates, or even changes in family circumstances. Furthermore, costs that are related to adaptation are more difficult to identify than the costs of lost production and destroyed assets.

Climate change is anticipated to be characterised by both gradual changes in trends and changes in the frequency and severity of extreme events. For practical purposes the key difference between an extreme climate event such as a flood or drought versus adaptation to gradual climate change is the degree of predictability, although how many unexpected droughts need to occur before they become an expected part of longer term climate change is clearly the fundamental issue when it comes to taking adaptive actions. This is not to imply that perfect prediction will obviate the effects of climate change as farmers have limited capacity to respond.

1.4 Caveats

Returning to the OECD (2006) paper on measurement metrics, the report describes the results of examining the SRES Scenario A2[9] with an agro-ecological dynamic crop model and two global circulation models (from the Hadley Centre and CSIRO), with and without mitigation of emissions; namely atmospheric CO_2 concentrations of 550ppm by 2100 and 800 ppm by 2100 respectively. The metrics used are agricultural output, agricultural GDP and the number of people at risk of hunger.

Without mitigation the effect on global agricultural production is projected to be less than 2% during the next 30 years, rising to less than 5% by the end of the century. Unfortunately poorer developing countries in sub-tropical regions will experience much larger negative impacts, even without considering a greater frequency of severe weather events. With mitigation of emissions most of the negative effects on production and on the number of people at risk of hunger do not eventuate. Some negative effects remain because not all global warming can be avoided.

Understandably, specific information about the effects on New Zealand agricultural production is not presented in this study. The closest fit is for a region called Developed Pacific Asia, for which the impact of mitigation on agricultural GDP is small and negative between 2010 and 2080. This unexpected result arises because the benefits from elevated CO_2 levels on biomass yield are absent under mitigation.

However, the caveats to these findings are worth bearing in mind when considering the New Zealand research described in the next section. In particular:

- While crop yields may respond favourably to elevated levels of CO_2, the higher temperatures and likely higher frequency of extreme events will probably offset this if warming is more than about 2.5ºC.
- The CO_2 fertilization effect is uncertain, especially its interaction with water availability, pests and disease.
- The impacts of climate change may be relatively small when compared to the effects of socio-economic changes.
- There are no adaptation responses.

With regard to adaptation, the authors deliberately avoid what they describe as 'Ricardian' models which express the value of agricultural land as a function of climate variables, soil, irrigation, proximity to markets etc; because they see such models as implicitly including too wide an array of adaptation responses to apply to climate changes over time, as opposed to climate differences over space. However, their argument seems to conflate costs arising directly from changes in the climate regime itself with costs related to transition to a new climate regime, a point which was discussed above.

Perhaps the most crucial factor that the analysis ignores is the cost of mitigation. While mitigation is clearly effective, it may not always be cost-effective. Global circulation models and crop models are simply not set-up to look at that issue, which requires a general equilibrium economic model. In fact a more integrated modelling approach is better still. Such an approach is currently being developed by the EcoClimate consortium which has four

[9] IPCC (2000)

main modelling components; a climate model, a land use model, a biomass production (dynamic crop) model and a general equilibrium economic model.[10]

[10] See Appendix A for more information.

2. Literature Review – Dry Periods

The aim of this literature review is to obtain estimates of the historical effects of climate change on agriculture, and (where possible) through agriculture on the wider economy. Research on the effects of climate change on New Zealand agriculture is not abundant, but dates back nearly 40 years to Maunder (1968, 1971a, 1971b).

Past research is essentially of two types:

- Econometric analysis of time series that relate economic activity indicators to climate indicators.
- Case by case analysis of the effects of extreme climate or weather events.

The econometric studies usually span a number of decades and the unit of time is typically a quarter or a year. This makes them unsuitable for studying very short-lived severe events such as floods, but they do capture the effects of dry or wet periods (quarters or years), and thus the effects of droughts. Conversely, the extreme event studies focus almost exclusively on floods and associated storms.

Robust measurement is lacking in most of the extreme event studies, although most were not conducted with such an aim in mind. They also contain little information on production loss, concentrating instead on asset loss. Perhaps this is simply because production losses are relatively temporary whereas assets can take many years to rebuild. Also, assets are generally insured or their replacement costs are reasonably easy to calculate, so values on asset loss are more commonly quoted that values on production loss.

We have located and reviewed six comprehensive studies, five of which look at the historical effects of climate on agriculture at a national level, the other focussing on the 1998/99 drought in Canterbury. This is followed by an overview of the severe event (flood) studies.

The six comprehensive studies use different approaches, cover different historical time periods, regions and agricultural sub-sectors, and differ in the extent to which they allow for second round effects. Table 2.1 on the following page presents an overall summary of the six, reconciled as far as possible to a common basis. The results show a high degree of consistency.

Broadly speaking, for a change of one standard deviation in DSMD, reductions in agricultural gross output are usually less than 5%. The consequential effect on the nation's GDP is around 0.1%. However, the effects are non-linear. A change of three standard deviations in DSMD reduces national GDP by around 1%. Of course the effects are larger in regions that are more reliant on agriculture.

Long term climate trends may include a trend in the average value of an indicator (such as DSMD), and may also include a trend of the variance of an indicator. The two are not unrelated. An increase in the frequency and severity of droughts – as expected for New Zealand under climate change – could raise both the variance of DSMD and its average value.

Table 2.1: *Change in Output Variable for 1 Standard Deviation (σ) Change in Annual DSMD.*

	Agricultural output	Ag output in long run (stock nos)	Ag value-added	NZ/region GDP	Comment
Tweedie & Spencer	-5.8% sheepmeat -3.9% beef -2.6% milk -2.2% wool	-13.7% cows -5.1% sheep -7.9% beef stock			Long run effects allow for persistent climate change, but are not jointly estimated.
Wallace & Evans	-5.3% to 0% sheep (wet) -2.1% to -0.8% sheep (dry) -13.4% to -2.0% beef (wet) -0.8% to 2.8% beef (dry)		-2.4% to 1.0% (wet) -1.5% to 0.4% (dry)	≈ 0.1% (rough estimate for all NZ)	Ranges cover results over four South Island regions
Forbes	-2.1% milk -1.3% lamb -0.8% wool 1.3% adult cattle 5.9% adult sheep				Accelerated slaughter rate for adult animals would impact negatively on future output.
Buckle et al				≈ 0.1% ≈ 1.0% for 4.2σ (for all NZ)	1-2% of GDP in Australia for a 'major' drought.
Agriculture NZ & Butcher Partners	-5.8% dairy -5.7% arable -4.1% livestock			≈ 2% Canterbury region GDP over 3 years	Changes relate to 1.5σ change in SMD in first year and 0.9σ in second year, Canterbury only.
Tait et al	-3% to -4% (milksolids)			-0.5% to -0.2% (for -10% change milksolids)	NZ GDP effect related to degree of anticipation of climate change

In so far as the historical variability in the climate (or at least in DSMD) has been around a reasonably flat trend (in terms of both mean and variance), historical econometric studies will usually overstate the negative effects of climate change on agricultural output and on the economy in general. This is because past reactions by farmers (in particular) are based on certain 'stationary' expectations about the climate. For example the cost of an irrigation scheme relative to the loss in output from a dry year may be high if dry years are infrequent, but the relative economics could reverse if dry years become the new norm. Models of gross agricultural output would show a much larger negative effect in the former case than in the latter but, interestingly, the effect on value-added (GDP) measured over a decade or two would probably be closer. Other responses can be expected at a sectoral level – for example the loss of dairy output in an unexpected dry year might not occur under a persistently drier climate that is characterised by a more suitable pattern of land use.

Referring back to the discussion above, time series econometric studies tend to encompass more of the <u>transitional</u> costs of climate change as opposed to the <u>permanent</u> costs of a different climate.

For this reason it is our strong belief that estimates of the effect of climate change on agriculture over the next 30 years and beyond cannot be reliably estimated from existing historical studies. Improved estimates require more use of:

- Cross-spatial studies which show how farms of a given type differ in terms of their input mix, management, incomes etc, because of different regional climates,[11] (assuming that some regions will have future climates that are similar to existing climates in other regions).

- Models of land use and land use change (such as Motu's LURNZ model).

- General Equilibrium (GE) models to allow for the macroeconomic effects of changes in national productive efficiency and allocative efficiency arising from a permanently different climate. As demonstrated in the study by Tait et al (2005), GE models can also be used to help compensate for the limited ability of time series models of non-trending series to pick up the effects of persistent climate change.

[11] That is, Ricardian studies of the type not favoured by the authors of OECD (2006)!

Tweedie, A.J. & G.H. Spencer (1981): 'Supply Behaviour in New Zealand's Export Industries', Reserve Bank of New Zealand Research Paper No. 31, Wellington.

Type of climate change:	gradual/historical
Industries:	dairy, beef, sheepmeat, wool
Region:	all New Zealand
Climate indicators:	days of soil moisture deficit (DSMD)

While the focus of Tweedie and Spencer (1981) is the econometric estimation of export supply functions over the period 1961–1978, their analysis produces estimates of the effects of climate (measured in terms of DSMD) on agricultural production.

Separate coefficients are estimated for the longer run equilibrium effects of climate on the desired number of animals and the shorter run effects on production of meat, milk and wool. Over a period of a year or so climate affects the slaughter rate, the production of milk per cow, and the growth rate of wool. The results are summarised in Table 2.2.

Table 2.2: *Change in Output Variable for 1 Standard Deviation Change in Annual DSMD.*

	Elasticity with respect to DSMD	% change for 1 sd change DSMD	Lag	DSMD year end
Sheep numbers	-0.16	-5.1	0,1	Sept
Sheepmeat production	-0.18	-5.8	1	Sept
Wool production [12]	-0.07	-2.2	0	Jan
Beef stock numbers (at equilibrium)	-0.18	-7.9	0	Sept
Beef production	-0.09	-3.9	1	Sept
Cow numbers (at equilibrium)	-0.26	-13.7	1	May
Milk production	-0.05	-2.6	0	May

Tweedie and Spencer (1981) comment that the effect on dairy production seems low in relation to the effects of climate on other agricultural production. They suggest that this may be attributable to total cattle numbers being used in the equation rather than just cows in milk.

A rise of one standard deviation in DSMD leads to declines in agricultural output (that is declines in the production of meat, milk and wool) ranging from a low of -2.2% for wool to a high of -5.8% for sheep meat.

As noted, the results for stock numbers have a different interpretation in that they relate to the long run equilibrium response of stock numbers to persistent – if not permanent – changes in the climate. For example, if DSMD were to change from their historical levels to be consistently one standard deviation higher, cow numbers would be 13.7% lower. Beef cattle numbers have a lower sensitivity at only 1.9%, while sheep numbers would be 5.1% lower.[13] These responses would capture changes in farming practice and presumably some degree of adaptation in plant and animal physiology. Note though that they are not jointly

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[12] These numbers may not fully reflect the effects of complementarity (meat and slipe wool) and substitutability between wool and meat production, especially during a drought.
[13] This is an estimate evaluated at the mean as the sheep model did not produce a sensible long run equation.

estimated, so a fall in say the number of dairy cows might be offset by a rise in beef cattle as the relative economics of different types of farming changes.

Wallace, R. & L. T. Evans (1985): 'Effects of climate on agricultural production and profit', Victoria University of Wellington Research Project on Economic Planning, Occasional Paper No 84.

Type of climate change: gradual/historical
Industries: sheep and beef farming (on Class VI land)
Region: South Island regions
Climate indicators: days of soil moisture deficit (DSMD)

Wallace and Evans (1985) use a panel database covering the period 1950–1979 to estimate the effect of annual climate variability (measured by standard deviations in DSMD) on expected farm outputs, inputs and profit. To allow for asymmetric responses to dry and wet conditions they use separate series for positive and negative deviations in DSMD. Inputs of non-hired labour and capital stock, including herd size are held fixed, as are input and output prices. Hence the estimated effects should be interpreted as short run or first round effects.

Their main results are summarised in the Table 2.3. No error margins are given in the report so we cannot infer much about the robustness of the results.

Table 2.3: *Percent change in output/input for 1 standard deviation change DSMD one year earlier*

	Marlborough		Canterbury		Otago		Southland	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Profit	-0.9	0.9	-1.0	0.7	-1.5	1.0	0.4	-2.4
Sheep output	-1.5	-0.7	-2.1	-1.7	-2.0	0.0	-0.8	-5.3
Beef output	-0.4	-3.7	-0.3	-7.3	-0.8	-2.0	2.8	-13.4
Cash crop	2.4	0.9	2.8	0.7	3.5	1.0	13.0	-2.4
Hired labour	-3.0	-10.0	-3.5	-9.7	-2.8	-2.0	-3.7	-13.0
Fertiliser	1.5	-1.5	0.7	-1.4	0.0	0.0	-3.3	-4.9
Other inputs	0.0	-5.4	-0.3	-3.8	-0.8	-1.3	2.8	-11.4

A departure from normal DSMD in either direction has negative effects on sheep output. Furthermore the effects are roughly equal in magnitude, except for Southland where the wet weather effect is much stronger. This is attributed to the generally wetter soil in Southland such that even further wetness is particularly deleterious. Beef output is more sensitive to wetter conditions than to drier conditions, again especially in Southland

Profitably shows opposing effects between dry and wet years. All adverse climatic conditions are met by reductions in labour input which helps to offset the effect of lower production on profit, but in Marlborough and Canterbury greater expenditure on fertiliser confounds this effect. Presumably though, not increasing fertiliser would lead to even larger falls in output and thus even lower profit. Cash crop production rises under all conditions except in Southland under wetter weather, also helping to offset lower sheep and beef production.

A number of other findings by Wallace and Evans (1985) are worth noting:

1. Including sunshine hours yields little additional explanatory power. This is probably because of correlation between sunshine hours and temperature.

2. Including contemporaneous deviations in DSMD as well as lagged DSMD produces low coefficients on current conditions if they are wet. For dry years, however, current

deviations in DSMD have similar effects to lagged deviations in DSMD, at least for farms in Ashburton – the only district for which this was tested.

3. First order correlation in DSMD is low, implying that the probability of two similar years in a row is also low.

4. Evidence is mixed on whether responses to changes in DSMD the current period vary with the DSMD in the previous period. Ashburton shows less variability than Southland, but only these two regions were examined.

Overall, the effects of a one standard deviation change in DSMD on the sheep and beef output is about 2% and 3% respectively. These are reasonably comparable with, although slightly lower than the effects estimated by Tweedie and Spencer (1981) at 5.8% and 3.9% respectively. As Wallace and Evans (1985) deal exclusively with regions that have Class VI sheep farms, it is possible that these farms are better prepared to deal with climate variability on sheep and beef production than similar farms elsewhere in New Zealand.

From the 1995/96 inter-industry table, sheep, beef and dairy farming account for about 3.5% of GDP (which is less than it was in the 1970s). Hence the current economy-wide effects of a one standard deviation change in DSMD implied by the results of Wallace and Evans (1985) would be in the range 0.07%–0.11%, assuming a pro rata effect from gross output to value-added.

Forbes, R. (1998): 'The El Nino weather pattern and pastoral supply response forecasting', paper presented to Annual Conference of the New Zealand Agricultural and Resource Society, Blenheim 4–5 July.

Type of climate change:	gradual/historical
Industries:	dairy, beef, sheepmeat, wool
Region:	relevant regions in all New Zealand
Climate indicators:	days of soil moisture deficit (DSMD)

Forbes (1998) uses the MAF Pastoral Supply Response Model (PSRM) to predict changes in agricultural output caused by the climatic conditions during 1997–99. The model contains econometrically based estimates of the effect of climate (measured in terms of DSMD) on agricultural production. Data covers the period 1961 to 1998 (May). Forbes (1998) main results are shown below in the first two columns of Table 2.4. The last column has been derived from figures in the report.

Table 2.4: *Percent change in output for 1 standard deviation change DSMD for two years after the 1998 drought*

	Yr end June 1998 % change	Yr end June 1999 % change	% change for 1 sd change in DSMD in 1 year
Stock Numbers			
Total sheep	-2.3	-2.8	-1.9
Breeding flock	-1.4	-2.7	-1.2
Total beef	-0.6	-1.0	-0.7
Breeding herd	-1.8	-1.9	-2.0
Meat Production			
Lamb kill	-1.6	-2.3	-1.3
Adult sheep kill	7.1	-0.9	5.9
Adult cattle kill	1.2	0.0	1.3
Milksolids/cow	-1.9	na	-2.1
Greasy wool/sheep	-1.0	-0.8	-0.8

The standardised effects of DSMD are similar to those in the studies by Tweedie & Spencer (1981) and Wallace & Evans (1985), except that Forbes (1998) shows a strong positive effect on the slaughter rates for adult animals. This may have been an effect that was peculiar to the 1998 drought and/or to the PSR model.

Buckle, R.A., K. Kim, H. Kirkham, N. McLellan & J. Sharma (2002): 'A structural VAR model of the New Zealand business cycle', New Zealand Treasury Working paper 02/26.

Type of climate change:	extreme event
Industries:	whole economy via agriculture
Region:	all New Zealand
Climate indicators:	soil moisture deficit

Buckle et al (2002) look at climate variability as a source of economic shocks using a structural Vector Autoregressive (VAR) model of the New Zealand economy. Their objective was to identify the impact of climatic conditions on New Zealand business cycle fluctuations. Quarterly DSMD is the climate indicator that is used in the model, measured in terms of quarterly differences from normal, defined over 1983–2002 (Figure 2.1).

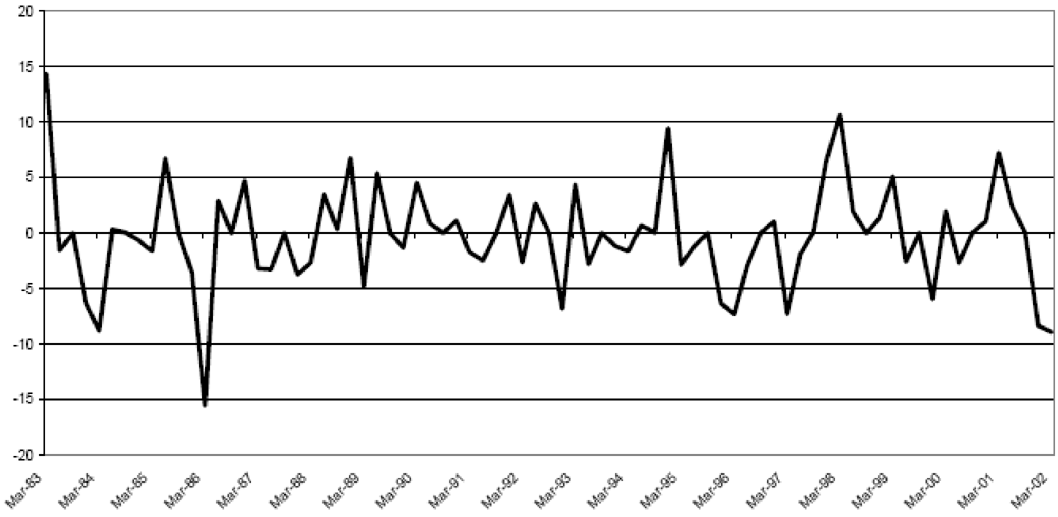

Figure 2.1: *Days of soil moisture deficit per quarter (differences from mean)*

The effects of climate variations from normal are measured using the common VAR technique of Impulse Response Functions. They reveal that a change of about 0.9 standard deviations in quarterly DSMD[14] leads to an immediate (same quarter) reduction in GDP of about 0.07%, but the trough in GDP at about -0.1% is delayed by two quarters (Figure 2.2, top panel). The overall decline in GDP in the first year is about 0.08% and in the second year is about 0.04%, with negligible change beyond that. The 0.08% compares favourably with the implied national effect from the research by Wallace and Evans (1985). The fact that the estimate by Buckle et al (2002) is at the lower end of the range is probably because it incorporates offsetting macroeconomic effects such as product substitution by consumers.

Export volumes (of agricultural products) increase contemporaneously with the climate shock, probably reflecting an increase in the slaughter rate by farmers in response to unanticipated drier conditions (Figure 2.2, lower panel). Eventually though, exports also decline, with the trough at around 0.25% occurring with a three quarter delay. The overall decline in the first year is no more than about 0.02% and insignificant thereafter.

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[14] Note that the standard deviation of the differences from normal is the same as the standard deviation of the raw DSMD data.

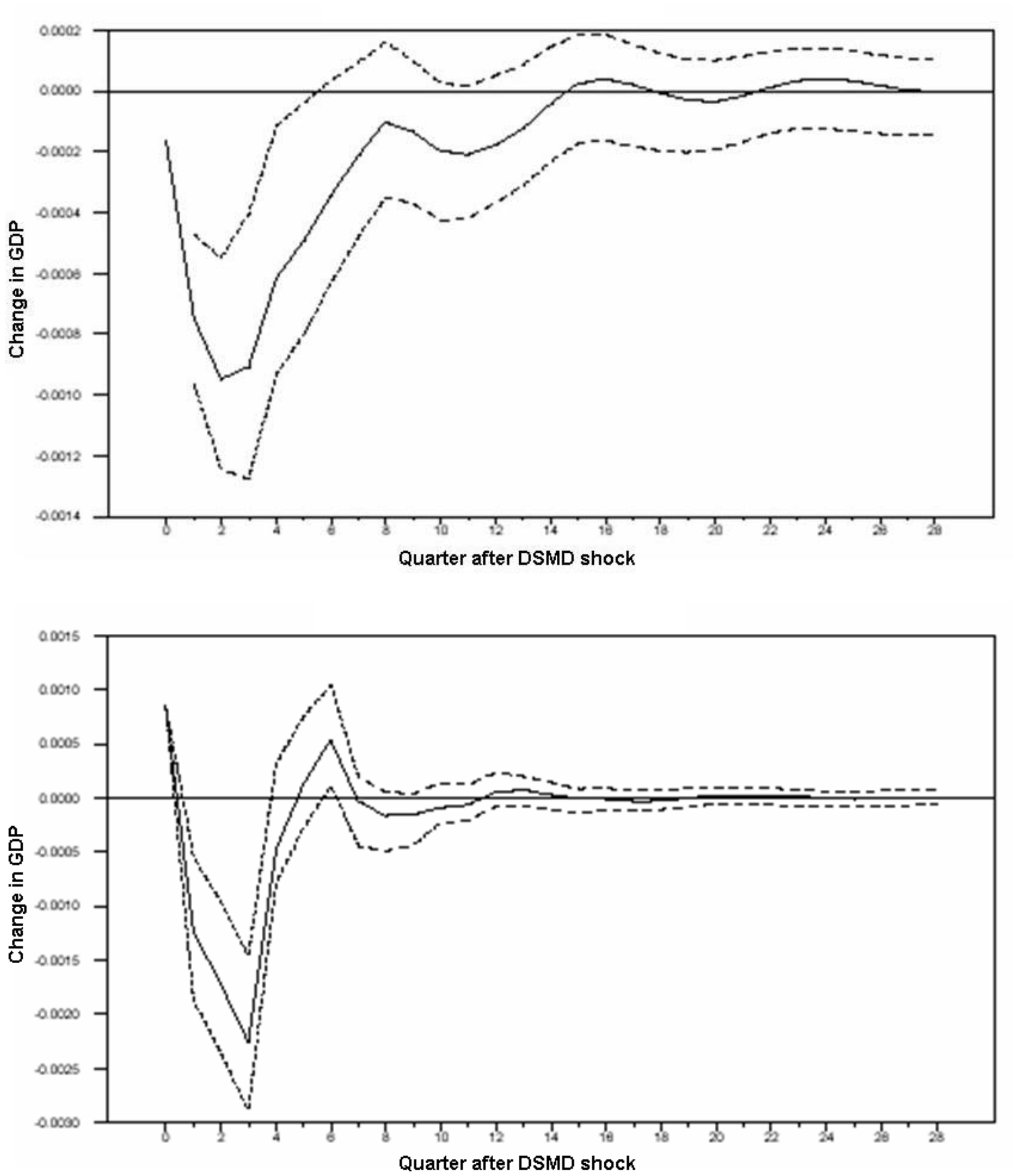

Figure 2.2: *Effect on GDP (top panel) and exports (lower panel) resulting from a 'shock' of about 0.9 standard deviations in quarterly DSMD. The solid line is the mean response and the outer dashed lines represent 68% confidence bands.*

The 1998/99 drought represented an increase in DSMD of about 4.2 standard deviations of quarterly DSMD from normal which, based on the impulse response functions would suggest a reduction in GDP in the first year of around 0.5%. In fact Buckle et al estimate the impact at about 1%. We attribute this both to substantial non-linearity in the direct effects of climate variability on agriculture and to the flow-on effects on the wider economy.

Basher (1996) estimates that the impact of climate variability (although this is not statistically defined) on GDP is about 1.5%, of which meat and wool account for 0.4%, dairy for 0.2% and other agriculture (mostly horticulture) another 0.2%. Most of the non-agricultural component is accounted for by electricity and transport.

While comparing the effects of droughts in different countries is difficult; White (2000) estimates that in Australia a major drought leads to reduction of 1–2% in GDP. Using the ORANI general equilibrium model White (2000) estimates that the 1994/95 drought reduced GDP by 1.1%, with agricultural gross output falling by 9.6%. In the following year GDP is estimated to have fallen another 0.4%.

Agriculture New Zealand and Butcher Partners Limited (2002): 'Regional economic impacts of the 1997–1999 Canterbury drought', MAF Policy Technical Report 2000/18.

Type of climate change: extreme event
Industries: dairying, arable, livestock farming
Region: Canterbury
Climate indicators: see table below

Table 2.5: *Number of standard deviations from the mean (1971–2003) of selected climate indicators for four years for the Canterbury region.*

	Win rain	Spr rain	Sum DSMD	Win GDD	Spr GDD
1996		-1.4		-1.3	0.1
1997	-0.1	-1.6	1.5	-0.7	-0.3
1998	-0.6	-0.5	0.9	0.8	0.2
1999			0.2		

The climate indicators are not described in the report, but have been calculated for relevant seasons using NIWA data. In the study, farmers were asked to rate the severity of the drought on a scale of 1 (no negative effects) to 7. Average scores ranged from 4.5 to 6.6 across the six farm categories – three types, irrigated and not irrigated. The sample weighted mean score is 5.3, suggesting a reasonably severe drought.

Economic Impacts

The direct loss in agricultural gross output is estimated at about $137m, spread over a period of two years for dairying and three years for arable and livestock farms. The average annual proportionate reductions in output were 5.8% in dairying, 5.7% in arable farming and 4.1% in livestock farming, giving an overall weighted average annual decline of 4.9%. In relation to the expressed severity of the drought, this reduction seems quite small. The authors attribute this to the use of better drought management techniques learned from experience with previous droughts. That is, enhanced adaptive capacity has reduced vulnerability – refer to Figure 1.1.

As discussed earlier, economic loss should be measured in terms of the change in value-added. This is recognised by the authors who split the change in value-added into two components:

1. A reduction in quantity or quality of production (gross output).

2. Increased expenditure to mitigate effects (e.g. irrigation, animal feed), but also some reduction as a consequence of lower output (e.g. farm maintenance, pest control).

In addition to production loss the authors also note the loss of pasture and the consequent expenditure on re-grassing. This is financed out of future value-added.

Rather than start from a reduction in final demand – exports or private consumption – the starting point for the analysis is taken as the loss of agricultural production. This means that the analysis has to include 'forward linkages' to capture the effect on processing industries, in addition to the usual 'backward linkages' for the effect on industries that supply agriculture. Forward linkages for arable farming are assumed to be zero as processors could obtain substitute raw material inputs from offshore. Table 2.6 shows the estimated economic impacts.

Table 2.6: *Economic Impacts of 1997–99 Canterbury Drought*

	Direct VA	Backward Linkages	Forward linkages [15]	Total
Dairy	32.6	4.6	17.6	54.8
Arable	55.8	4.3	0.0	60.1
Livestock	142.0[16]	16.0	7.0	165.0
	230.4	24.9	24.6	279.9

The total loss of regional value-added is $280m, or about 2% of regional GDP, but spread over the three years 1997/98 to 1999/2000.

As discussed above, Buckle et al (2002) estimate that the 1998/99 drought reduced national GDP by about 1% in that year. It is difficult to compare these estimates. Buckle's is based on a higher nation-wide increase in DSMD than occurred in Canterbury with marked effects on dairy production in other regions, but then two of the major regional economies (Wellington and Auckland) would have been much less affected by the drought. About the most one can infer is that the two estimates are not inconsistent.

Other Impacts

The report also looks at another aspect of the relationship between climate and production – irrigation. It is estimated that the contribution of irrigation to gross output in a normal climatic year is $144m compared to actual gross output of about $1004m, implying an increase relative to no irrigation of about 17%, although the calculation does not take into account the effect that irrigation has on land use.

It is also estimated that the decline in agricultural gross output caused by the drought would have been worse by $79m (spread over two years), were it not for irrigation. As can be seen in Table 2.7, the benefits of irrigation are proportionately less in a typical dry year, which the authors attribute primarily to water restrictions and their relatively greater impact on livestock farming compared to arable and dairy farming.

Table 2.7: *Agriculture Gross Output ($m)*

	Normal Year	Drought Year	Difference
Without irrigation	860	850	10
Irrigation	144	105	39
Total	1004	955	49

No information is given on the effect of irrigation on agricultural value-added, although most farmers reported a positive effect. Arable farmers were most ambivalent.

[15] These forward linkages include backward linkages for food processing, other than agriculture.
[16] This comprises $93m in directly lost value-added and $49m for the reduction in feed stored.

Tait A.B.; Renwick, J.A. and Stroombergen, A.H. (2005): 'The economic implications of climate-induced variations in milk production', NZ Journal of Agricultural Research, 48, 213–225.

Type of climate change: gradual, historical
Industries: dairy farming
Region: dairying regions for output, all NZ for economic effects
Climate indicators: see table below

The main objective of the study was to ascertain the effects that a warmer climate might have on dairy production and via that on the economy as a whole. Clearly, as discussed earlier, the effects are strongly driven by the pace of climate change and the various adaptive responses that this generates. This study took a medium term (10–20 years ahead) focus. Over this time period labour can and would move between industries as the medium to longer term effects of climate change become more apparent. Capital stock, however, is not so flexible.

Based on econometrically estimated relationships, Tait et al (2005) note that deviations from normal climatic conditions in either direction tend to be associated with lower dairy production, although this could be as much a function of farm set-up, management etc, as of animal physiology. Changes of one standard deviation in the main climate variables that are correlated with production of milksolids (summer DSMD, winter GDD, spring GDD and winter rain) lead to a change of 3–4% in milksolids production per cow. This compares well with the estimate of 2.6% obtained by Tweedie and Spencer (1981).

However, the effect is not linear. The driest year in dairying regions was 1998/99, in which year the production of milksolids per cow fell by around 10%.[17] As can be seen Table 2.8, the main indicators generally changed by less than ±1.6 standard deviations. It is possible that the drought during the summer of the previous year had already led to drier than normal pastures before the 1998/99 drought began.

Table 2.8: *Climate deviations from mean in 1998/99 (number of standard deviations)*

	Win Rain	Sum DSMD	Win GDD	Spr GDD
South Auckland, Waikato	-1.6	1.6	-1.6	-0.5
Taranaki	-1.3	0.3	-1.8	-0.9
Northland	0.4	-0.4	-0.9	0.6
Bay of Plenty	1.1	0.6	-0.8	-0.5
Manawatu & Wanganui	-2.1	1.7	-1.5	-0.8
weighted mean absolute sd	1.4	1.1	1.5	0.6

For modelling purposes the effects of climate change on milksolids/cow were assumed to be similar to those that occurred in 1998/99. A general equilibrium model was 'shocked' thus:

1. A reduction in exports of processed dairy products corresponding to a 10% fall in milksolids per cow.

2. A reduction in the productivity of capital stock (in agriculture and dairy processing) as capital stock is fixed the medium term.

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[17] This more than the fall in dairy production in Canterbury in that year, analysed in the study by Agriculture New Zealand and Butcher Partners (2002), but Canterbury is not one of the main dairying regions.

3. A fourfold increase in supplementary animal feed costs, which is also equivalent to a reduction in factor productivity.

In fact a number of scenarios are reported in Tait et al (2005), but the three main ones are:

- Scenario A: 10% fall in milksolids production, all manifested in lower exports.
- Scenario B: As in A with a fourfold increase in spending on feed.
- Scenario C: As in A with inflexible real wage rates.

The main economy-wide effects obtained through general equilibrium modelling are summarised in Table 2.9.

Table 2.9: *Macroeconomic Effects of a 10% Reduction in Milksolids Production (% change relative to no climate change)*

	A	B	C
Private Consumption	-0.3	-0.3	-0.5
Exports	-0.4	-1.0	-0.6
Gross Domestic Product	-0.2	-0.5	-0.3
Employment	0.0	0.0	-0.3
Real wage rates	-0.3	-0.4	0.0

Scenario A is a representation of the 10–20 year effects of persistent climate change on milk production and its flow-on effects to the wider economy, with a reasonable amount of adaptation. Private consumption is 0.3% lower than without climate change and GDP is 0.2% lower. The decline in welfare is driven primarily by the capital stock stranded in agriculture and the reduction in exports.

Scenario B provides a different longer term response to a warmer climate, one where the requirement for supplementary feed becomes a normal part of dairy farming. As this is analogous to lower productivity, with labour and capital now having to produce something – animal feed – that previously was not necessary, the loss in GDP is considerably higher. There is a general reduction in the international competitiveness of other industries, leading to a 1% decline in exports, although there is no further decline in private consumption.

While Scenario B looked at adaptation by farmers, Scenario C looks at adaptation in the wider economy. In Scenario A, wage rates are flexible and adjust to clear the labour market, but in Scenario C it is as assumed that the higher food prices caused by the rise in DSMD (more frequent droughts) pass through into higher nominal wages so that real wage rates are unchanged. This is perhaps more realistic in the short term than in the long term.

There is a fall in employment of 0.3% as all industries become less competitive. The government, being under a fiscal constraint, raises tax rates to compensate for higher spending on unemployment benefits and potentially less tax revenue. This reduces the economy's allocative efficiency.

The main inference to be drawn from the report is that if climate change reduces the production of milksolids per cow by 10%, there is a significant national welfare loss (0.2–0.5%) over the medium term. The loss is mitigated if:

- At the industry level; better information and planning reduces the inefficient use of capital in dairy farming and deters farming in areas that cannot sustain sufficient production of biomass in a drier climate.

- At the national level; wages respond to changes in labour demand and supply, allowing other industries to expand at a faster rate if agriculture (or at least dairy farming) is forced to grow at a slower rate – relative to a scenario with no climate change.

3. Literature Review – Floods and Storms

Assessing the costs of floods and storms is rather different than assessing the costs of gradual climate change. New Zealand Institute for Economic Research (NZIER, 2004), in their discussion on floods, define two categories with potentially different effects:

1. Flash floods and groundwater rise;
2. Dam/levee/reservoir failure and river flooding.

With regard to metrics measuring economic loss, the NZIER note that GDP is unlikely to capture the full effects of flood impacts:

- Differences in value between goods destroyed and changes in GDP;
- GDP may ignore many of the sectoral transfers that arise during a flood;
- Floods provide opportunities to increase activity in some sectors, increasing GDP;
- GDP may not capture the full effect of flood-induced price changes which could change an individual's welfare but not GDP.

Insurance values are also inadequate:

- Underinsurance – people do not receive adequate compensation to cover the assets protected;
- Non-insurance – people do not insurance for their assets, so therefore their losses are not included in the insurance pay out statistics;
- Overstatement – People could be paid out more than what their assets are worth. This is likely to have less impact than non-insured cases.

The NZIER note that full economic costs should include damage to buildings and goods, economic production lost, damage to infrastructure and government services, and alternative accommodation for families and alternative facilities for businesses. The time spent cleaning up after floods may restrict an individual's consumption spending but in many cases this will just delay spending rather than reduce it. Any impact of the restriction of spending is also likely to be minimal.

This leads NZIER to suggest four types of costs:

1. Tangible, direct: e.g. damage to food and electrical appliances;
2. Tangible, indirect: e.g. business disruption, lost wages;
3. Intangible, direct: e.g. lost photographs, drownings;
4. Intangible, indirect: e.g. delays in education.

The documents on flood events that we have reviewed focus exclusively on tangible costs, but even then the estimates are shaky. Most reports quote only estimated loss and damage costs for assets, or the value of insurance claims. Cost impacts on agriculture are not at all well covered and depend not only on the climate but also on the socio-economic scenarios describing population density, housing types, land-use and so on.

In addition to the descriptions provided below there is an accompanying spreadsheet (Summary.xls) which summarises the available hydrological and related indicators for each event. In Objective 3 of this project we investigate whether these indicators can be sensibly linked to economic loss.

3.1 List of Flood Assessment Reports summarised here

1. Taupo, Waikato and Waipa Management Zones Leap Day Flood Event: February 29 to March 5, 2004, Environment Waikato Technical Report 2004/06 87

2. Waikato and Waipa Rivers Flood Event 6–16 July 2002, Environment Waikato Technical Report 2002/12 88

3. The Weather Bomb, 21 June 2002, Environment Waikato Technical Report 2002/10 89

4. Waikato Regional Flood Event of 9–20 July 1998, Environment Waikato Technical Report 1998/15 90

5. The Waikato Weather Bomb: Understanding the Impact, NZIER report to the New Zealand Climate Change Office 91

6. Review of the February 2004 Flood Event: Review Team Report, Ministry of Civil Defence....... 93

7. The July 1998 Floods and Damage to Environment Bay of Plenty's Infrastructural Assets: Request for Assistance under Governments Natural Disaster Recovery Plan, Environment Bay of Plenty Operations Report 98/10. 94

8. Bay of Plenty Region July 2004 and December 2004 Flood Events: Claim by Environment Bay of Plenty for Government Assistance towards Response Costs and Costs of Reinstatement of Damaged River and Drainage Scheme Infrastructural Assets, Environment Bay of Plenty Operations Publication 2005/06 95

9. Matata Business Case, Whakatane District Council 96

10. Application to Government for Financial Assistance July 2004 Storm, Flood and Earthquake Events, Environment Bay of Plenty Operations Publication 2004/04 96

11. Miscellaneous Flood Reports, Northland Regional Council 97

12. Inquiry into Government Assistance to the East Coast Region in the Wake of Cyclone Bola, Gisborne District Council 98

13. Recovery Report from Labour Weekend Floods, Gisborne D.C. 99

14. PGG Wrightson Report on the effects of the 2005 flood event, Gisborne District Council....... 100

15. Civil Defence Emergency and Flood Damage: Cyclone Bola, Gisborne District Council......... 101

16. Gisborne Flood 25–26 July 1985, Gisborne District Council 101

17. Storm: Civil Defence – Storm and Flood Report, Horizons Regional Council 102

18. Waitotara Valley February 2004 Storm Event, Taranaki District Council 104

19. Taranaki Flood 10–15 March 1990, Taranaki Regional Council et al 105

20. Impact, various newsletters, Ministry of Civil Defence and Emergency Management. 109

21. Floods and Droughts: the New Zealand Experience, edited for New Zealand Hydrological Society 111

22. Social, Economic, Environmental Sustainability Report 2005, IAG New Zealand.................... 112

23. Claims History, Insurance Council of New Zealand 113

1. Taupo, Waikato and Waipa Management Zones Leap Day Flood Event: February 29 to March 5, 2004, Environment Waikato Technical Report 2004/06

Extreme Event	Flood
Event date	February 29 to March 5, 2004

Hydrological data

The report outlines the meteorological events leading up to and during the flood and the management strategies that were employed by the agencies involved. This information includes:

Antecedent Precipitation Index – measures the amount of rainfall the soils can absorb prior to run off occurring

Regional rainfall statistics

- 36 hr event totals
- Peak intensity per hour
- Feb 2004 total
- Feb normal total
- % above normal

Flood wave travel times between key sites

River level summary – 18 waterways

- Peak flow
- Peak level
- Estimated return period

Number of flood warnings

Damage

Farmland

During this flood an estimated ~6,000 ha of productive farmland was affected however the report failures to estimate the economic cost of this flooding.

Infrastructure

The cost of the flood on the flood scheme, including remedial and reinstatement works is estimated at $1.9 million (Lake Taupo Management Zone $1,375,000; Tauranga Taupo River $310,000; Waipa Zone $203,500).

Provisional flood damage costs to highways, properties, housing and local infrastructure is estimated at $4.0 million which includes the $1.9 million discussed above.

The methodology used for estimating costs or the effect that these costs would have on the economy was not discussed in this report.

2. Waikato and Waipa Rivers Flood Event 6–16 July 2002, Environment Waikato Technical Report 2002/12

Extreme Event	Flood
Event date	6 to 16 July 2002

Hydrological data

This flood was the result of six weeks of heavy rainfall rather than a single storm, leading to saturated soils and raised river levels. The technical report gives details on the media releases, timeline associated with the flood, meteorological and hydrological information and assesses the management procedures used including:

Rainfall information
- Event total in 8 areas
- July mean

River level data – 15 waterways
- Peak level
- Mean level
- Peak flow
- Return period
- Difference from 1998 event

Flood warnings

Damage

Farmland

Approximately 4,200 ha of productive land were inundated in the flood. The cost of this was not quantified.

Infrastructure

Initial estimate of the remedial works required to maintain the flood protection scheme were reported as follows:

Waikato District Council:	
Floodgates	$15,000 Replacement and maintenance
Kimihia pump	$10,000 Outlet pipe and headwall
Kimihia stopbank	$10,000 Topping to design level
Harvey’s Pump	$15,000 Refurbishment
Franklin District Council	
Compartment 3 & 4 Pumps	$20,000 & $15,000 Refurbishment
Millar Farlane Pump	$10,000 Refurbishment
Contour Drain Stopbank	$55,000 Renewal
Environment Waikato	
Deroles Stopbank	$10,000 Ballast for seepage control
Morrison Road Floodgate	$5,000 Erosion protection.
TOTAL	$165,000

However, not all of these costs can be directly attributable to the flood. Consequently, the flood damage is approximately $80,000 not including the costs of actual work during the event or losses in farm productivity. The methodology used for estimating costs or the effect that these costs would have on the economy are not discussed.

3. The Weather Bomb, 21 June 2002, Environment Waikato Technical Report 2002/10

Extreme Event	Storm
Event date	21 June 2002

This report outlines the meteorological and hydrological processes during this event, timeline of events, management practices and summary of the costs involved.

Hydrological data

The meteorological and hydrological data available is as follows:

Rainfall information
  - 24 hour total
    - additional total rainfall and duration data is provided from additional sources where available (large number of sites)
  - Peak intensity
  - Return period

Maximum wind speeds
Barometric pressure
River level information – many waterways but incomplete
  - Peak flow estimates
  - Catchment area
  - Specific discharge
  - Estimated return period
  - Level above mean annual normal

Damage

Insurance

This event was the largest insurance claim in New Zealand caused by a single event with 14,000 claims lodged nationally totalling $25 million. A breakdown of the types of insurance claims for the Royal and SunAlliance insurance group is included, but there is no information on whether this was replacing the damaged goods with new or used goods. A high level of uninsured cases is noted.

Infrastructure

The total estimated cost of repairing the flood scheme was estimated at $525,000. Within the Thames Coromandel District Council zone, the cost to the council is estimated as $1.8 million and house and property damage is thought to exceed $6 million. Within the South Waikato District Council zone, the response cost was $800,000 and damage to house and property damage is estimated at $220,000. Consequently the agency response costs are estimated at $3.87 million and the damage to property and houses is $6.22 million giving a total cost of around $10 million.

The methodology used for estimating costs or the effect that these costs would have on the economy were not discuss in this report. Information on the response costs has been included but these include the remedial work carried out and not purely the cost of the agencies managing the event.

4. Waikato Regional Flood Event of 9–20 July 1998, Environment Waikato Technical Report 1998/15

Extreme Event	Flood
Event date	9–20 July 1998

This report outlines the meteorological, hydrological and management events associated with the flood as well as summarising the costs of the event.

Hydrological data

This event was caused by above normal rainfall, saturated ground conditions, back to back storms, two major river systems in flood joining together and heavy and sustained inflows into Lake Taupo.

Rainfall statistics
- Sample date
- Event start time
- Max intensity 72 hours
- Return period
  - Instantaneous
  - 1 day
  - 1 week
  - 1 month
- July total
- % above normal July rainfall

River level summary – many waterways
- Peak time/date
- Peak level
- Peak flow
- Return period
- Annual Exceedance Probability

Flood peaks – 5 waterways
- Level
- Flow

Damage

Farmland

This report also outlines the damage costs to farmland. These were estimated to be $1.784 million with the average damage per hectare $515 in the Lower Waikato area. This would be lower in other areas though as the land was under water for less time. Approximately 11,000 ha of farmland were flooded during this event and the breakdown by location is available in the report.

Infrastructure

The cost of the flood to Environment Waikato, District Councils, Transit, the Department of Conservation and Huntly College is approximately $25 million. The majority of the costs associated with the flood were generated from damage to state highways and local roads. Transit suffered the largest loss ($14.853 million). This figure includes $5 million to repair the Mahoenui landslip and travel time disruption and vehicle operating costs due to state highway closures. However there is no detail on methodology or assumptions behind these calculations.

5. The Waikato Weather Bomb: Understanding the Impact, NZIER report to the New Zealand Climate Change Office

Extreme Event	Weather Bomb
Event date	March 2004
Region	Upper North Island

This report has the results of a survey of individuals who were in the areas affected by the Weather Bomb in 2004. The results from the survey are then extrapolated and combined with the NZIER Computable General Equilibrium (CGE) model to provide estimates of the damage and economic effect that the weather bomb had. Intangible economic impacts were not assessed.

The survey had a return rate of 33.1% for the domestic respondents and the business respondents had a return rate of 28.5%. The margin of error for the sample is 4.8% and 12.0% for the domestic and business surveys respectively.

Hydrological Data

In the Coromandel and Southern Waikato areas rainfall totals exceeded 200 mm in 24 hours at 7 rain gauges and much of that rain fell in a single hour. Return analysis by Environment Waikato suggested that it was a 1 in 100 year event.

Household losses were disproportionately low when the mean flooding in the house is <5cm deep and disproportionately high when mean flooding in the house is more than 50 cm deep. It rises proportionately between these two figures. Vehicle mean losses jump on properties with mean household flooding above 5 cm then remain relatively constant.

Damage

Direct Impacts

The Insurance Council of New Zealand estimate that the value of claims made as a result of the weather bomb across all of New Zealand is around $21.5 million (~$8 million of this is in the Thames-Coromandel area). According to the survey the sum of insured losses was $2.9 million and $0.5 million for domestic and business respondents respectively suggesting a 0.84/0.16 split. Applying this split to the ICNZ total implies that the total household loss is $6.7 million and business loss is $1.3 million in the Thames-Coromandel area. Value of uninsured losses was $0.7 million and $0.2 million for households and businesses. Scaling this up based on reported and ICNZ total insured damage figures suggests $2.1 million of insured damage.

Emergency response costs in the Thames-Coromandel area are estimated at $3.1 million and thus the total costs for this region is thought to be $13.2 million.

Indirect Impacts

Three main forms

- Business disruption losses
- Potential impact on insurance claims
- Second and subsequent round effects of the above and direct effects

The survey suggests that the net impact of the weather bomb on business sales was nearly $60,000 (positive!). However this is likely to be misleading due to many negative impacts, such as damage to property, not being included.

IAG has suggested that average excess payable on their claims was $150 for the event. Thus the cost borne by households and business in the Thames-Coromandel area was around $450,000.

Using the NZIER CGE model the impact of the weather bomb on the industry output, factor demand and household welfare were found to be affected by less than 1%. This is probably because:

- The duration of the event was relatively short
- The severity of the event in terms of its direct economic costs were relatively mild
- The Thames-Coromandel area is a small borderless economy.

Losses in the South Waikato area were relatively insignificant compared to those in the Thames-Coromandel area. Households reported around $400,000 and $50,000 of insured and uninsured losses respectively.

The appendices at the back of this report also provide information on the data obtained from the survey such as the total expenditure not covered by insurance companies by region and type of damage, assistance received in volunteer labour and donations, and business impacts such as trading time lost and insured stock losses. There is also data from the EQC stating the number and cost of claims by status (e.g. finalised, declined, awaiting action etc.) and region, and data from AMI Insurance stating the number and cost of claims by region and type such as house storm, house contents and farm storm.

6. Review of the February 2004 Flood Event: Review Team Report, Ministry of Civil Defence

Extreme Event	Flood
Event date	February 2004

In February 2004, there was a succession of extreme weather events which impacted on a number of regions and caused extensive damage.

Damage

Farmland

Dairying and hill country sheep and beef farms suffered losses estimated at $107.4 million and crop losses were estimated at $24 million. Around 4,009 hectares of forested land was damaged during the flood event. Also up to 30% of some farmer's grazable land was lost during the flood event.

Total

The overall economic impact is thought to be close to $400 million. However there is no indication of how that is calculated. The report does suggest that the cost of the storms during this month had varying estimates. Again the method or studies in which these estimates are generated is not clear.

7. The July 1998 Floods and Damage to Environment Bay of Plenty's Infrastructural Assets: Request for Assistance under Governments Natural Disaster Recovery Plan, Environment Bay of Plenty Operations Report 98/10.

Extreme Event	Flood
Event date	July 1998

This report outlines the damage to river and drainage infrastructure, other losses, and the climatic event that occurred.

Hydrological Data

These floods were caused by severe and prolonged rainfall in July 1998. The climatic data that is available is as follows:

Rainfall data – 8 catchments

- Total rainfall July 1–16
- Percentage of mean annual total rainfall

Return period by river

Damage

Damage is not related to the peak flow or maximum flood height but instead to the duration of the flood.

Farmland

Through good monitoring and warning systems, total stock losses were thought to be only about 20 dairy cows and cattle.

Infrastructure

A breakdown of costs is available in the report including the location of the work and the type of work that is carried out. An additional 10% was added on to costs as an allowance for engineering costs involved with investigation, design, planning and supervision of the works. The total cost of repairing the damage associated with the flood was estimated at $4,413,321 including the 10% contingency sum. Other cost to pay for manpower ($100,040) and contract works ($64,860) contribute an additional $164,900 to the cost of the flood. The methodology used for calculating this figures is not known.

8. Bay of Plenty Region July 2004 and December 2004 Flood Events: Claim by Environment Bay of Plenty for Government Assistance towards Response Costs and Costs of Reinstatement of Damaged River and Drainage Scheme Infrastructural Assets, Environment Bay of Plenty Operations Publication 2005/06

Extreme Event	Flood and Storm
Event date	July and December 2004

Hydrological Data

The July flood event was the largest recorded in the Whakatane River since formal river level records began in 1956 and larger than estimates dating back to 1906. However, no statistics are given in this report.

Damage

Farmland

Approximately a third of the Rangataiki plains (11,000 ha) were inundated to varying depths up to 2m. 15,000 dairy cows were relocated to pastures outside the affected area as a result.

Infrastructure

Three of the major schemes and 7 minor schemes suffered severe damage. Erosion damage in December is estimated to have caused an additional $1 million in damage repairs. Total estimated cost of response activities and reinstatement of damaged assets for July (and December) floods is expected to be $11.55 million plus GST (approximately $13 million including GST).

9. Matata Business Case, Whakatane District Council

Extreme Event	Flood and landslips
Event date	May 2005

Hydrological Data

On 18th May 2005, a band of extremely heavy rain passed over the catchments behind Matata causing many landslips and flooding. An estimated 700,000 m^3 of debris was deposited in and around Matata and in the Matata lagoon.

Damage

31 households were deemed unsafe and a further 16 were able to be occupied but needed to be evacuated if there was a heavy rain warning. The report outlines the expected cost of a number of different recovery options.

$5,229,300 was proposed to be spent on Matata regeneration including $1,333,100 sought from the central Government. At the time that the report was written though the options suggested had not been finalised.

This report utilises a cost benefit analysis that was written by NZIER.

10. Application to Government for Financial Assistance July 2004 Storm, Flood and Earthquake Events, Environment Bay of Plenty Operations Publication 2004/04

Extreme Event	Flood and Earthquakes
Event date	July 2004
Region	Eastern Bay of Plenty

Hydrological Data

For 21 sites in 6 catchments, rainfall totals for 15–18 July 2004 and normal July rainfall levels are provided. In another table, a number of sites are listed with their peak rainfall intensities listed for 1, 2, 3, 6, 12, 24, 48, 72 and 96 hour periods. River Level Hydrographs are also provided for 6 rivers. In the text, return rates were given for the each of the rivers (e.g. page 11 for the Whakatane River).

Damage

Infrastructure

Total costs were estimated to be $10,486,650, itemised into damage to the drainage schemes, general inspections, flood response activities etc. Appendix 5 of the report gives details of the response and recovery costs associated with the flood including the sites, amount of damage and rates used to calculate damage.

Economic Impact

Damage occurred in a disadvantaged community with low incomes and low employment rates. Dairy is an important industry but during the flood about 17,000 ha was under water and milk production at Fonterra’s milk factory was delayed by 3 days. ~450 farms and lifestyle blocks were affected with ~10,000 cows and 1000 yearling moved. Many farmers would lose an entire year’s income.

11. Miscellaneous Flood Reports, Northland Regional Council

The Northland regional council provided sections of 14 reports mainly on the hydrological and meteorological events of floods that have occurred in their region since 1971. Points of interest from these publications are below:

April 1971
Rain gauges overflowed preventing accurate measures of rainfall.
400 ha of land was affected mainly by slips and silting of pasture land – no cost of this is given
~30 acres of grassland was destroyed by slips.
Silt and gravel up to 2 feet thick in some paddocks.
Loss of 30 cattle and 44 sheep, 15 miles of fencing and one cow shed partially destroyed
155 chains of road were damaged, 5 bridges needed repair and 65 culverts needed renewing.

July 1973
Peak flow estimates and rainfall data are provided
Major reconstruction of the Mangawhero Stream is likely to cost $150,000 to $200,000.

February 1974
Rainfall intensity and daily rainfall level data and river discharge levels given
Severe storm damage – 1 bridge was lost, severe slip and gully erosion.

May 1975
Rainfall data is provided
Farmland was damaged by slips – worst areas 20% of soil was removed
Loss of fencing, river flats covered by deposit of silt and vegetation, silted-up drains and waterways and some stock lost.
50 claims for earthquake and war damage totalling $75,000
Estimates of repair costs total $60,000 – all infrastructure (split in report)
Total damage to public and private property including farm land may be $150,000

January 1986
Maximum rainfall level report
~12 ha buried under timber and gravel to a depth of over 1 metre
~200 ha of farmland is affected by slipping
Fences buried or damaged, road buried and drainage channels filled in.
6 houses damaged by flooding and deposition and 3 others are a risk

January 1999
Rainfall levels recorded – rainfall increased with altitude
30 –40% of land has been bared down to bedrock in some sub-catchments
54 houses and a Marae were damaged.

June 2002
Unconfirmed 180mm of rain fell in two hours
9 houses were damaged, bridges and fences were washed away and access roads were damaged.

12. Inquiry into Government Assistance to the East Coast Region in the Wake of Cyclone Bola, Gisborne District Council

Extreme Event	Cyclone and associated flood
Region	East Coast
Date	6 – 9th March 1988

This is a report of the Primary Production Committee into the Government spending on the Cyclone Bola recovery.

Hydrological Details

Most of the East Coast area received over 400mm rain during the event with the heaviest falls of 900mm falling inland from Tolaga Bay.

Damage

Farmland

The total non-insurable losses, on an indemnity basis, to farming and horticulture in all areas of the North Island affected by Cyclone Bola are estimated at approximately $90 million.
Infrastructure

The estimated cost of pipeline reinstatement of the water supply is $6.6 million. Approximately 300 houses required substantial renovation or relocation.

Industry

The following statistics from 22 companies in Wairoa surveyed on the effects of Cyclone Bola:

- An average of 61% loss in turnover was experienced in the first week following Bola (available disaggregated)
- An average 23% decrease in turnover was experienced in the first month (available disaggregated)
- Over the next 12 months, 15 expected 25% drop, 7 expected 25–50% loss and 1 expected a loss greater than 50%.

13. Recovery Report from Labour Weekend Floods, Gisborne D.C.

Extreme Event	Flood
Region	East Coast
Date	Labour weekend October 2005

Hydrological Data

Over the 36 hour period rainfall of up to 385 mm was recorded at one station with amounts averaging 230mm in other locations and intensities of up to 44mm/hour.
River levels on the Hjikawai and Waipaoa Rivers peaked at 13.9m and 10.8m respectively.

Damage

Farmland

2000 ha of cropping land on the Gisborne flats and 1000 ha at Tolaga Bay suffered varying degrees of silting and debris deposits with most crops already planted being totally destroyed. Of these 2100 ha would not able to be replanted with a farm gate loss of crops of $10 million.

14. PGG Wrightson Report on the effects of the 2005 flood event, Gisborne District Council

Extreme Event	Flood
Region	Tolaga Bay flats
Date	October 2005

Hydrological Data

None

Damage

Financial losses

Crop	Area lost (ha)	Loss of Net Income	Extra cost of replanting
Squash	118	286,635	164,298
Sweetcorn	36	81,108	29,880
Maize	47	85,832	58,186
Grapes	4	40,000	10,000

Assuming that the flood led to a 30% reduction of the productive land area the economic loss of net income on an annual basis would be:

Squash	99 ha	$240,077
Sweetcorn	13 ha	$29,289
Maize	16 ha	$29,219
Total		$298,585

This assumes that this land is never going to be productive again which is unlikely to be the case. This will be gradual though and so the economic costs would need to reflect the lower initial land productivity.

The report also includes a report by area and a more extensive list of crops. The table outlines the area lost in the October 2005 flood, area able to be replanted, estimated costs of replanting per ha and the estimated loss of income. There is also a summary table outlining the areas that are able to be replanted, the cost of re-establishment and the total costs.

15. Civil Defence Emergency and Flood Damage: Cyclone Bola, Gisborne District Council

Extreme Event	Cyclone
Region	Cook County
Date	March 1998

Hydrological Data

Provisional 24 rainfall recording were recorded for various sites each day for 3 days.

Damage

Infrastructure

The damage to roads and bridges within the Cook County district is estimated to be around $9.7 million (cost of fully reinstating). Additional reinstatement cost of just over $2 million was estimated for State Highway 36.

Initial house and building inspections	2,018
Number of houses inundated	124
Houses to be demolished	16
Requisitions on properties	89
Follow-up inspections on houses	250
Septic tank notification	297
Head of stock destroyed	12,000+

16. Gisborne Flood 25–26 July 1985, Gisborne District Council

Extreme Event	Flood
Region	Gisborne
Date	25–26 July 1985

Hydrological Data

Daily rainfall data is provided in the report but it comes from a number of sources and its reliability is likely to be questionable. The private gauges were likely to be read at non-standard times and thus some of the figures may be contradictory.
Maximum river levels are also provided.

Damage

Infrastructure

Damage caused to river and drainage works is expected to total at least $400,000, half of which is required to de-silt drains around the perimeter of the Poverty Bay Flats.

Preliminary estimates of flood damage restoration works for the Board river and drainage areas and districts is $393,400 (available disaggregated).

17. Storm: Civil Defence – Storm and Flood Report, Horizons Regional Council

Extreme Event	Flood and Storm
Event date	February 2004

Hydrological Data

This report gives the following for rainfall at a number of sites:

- Maximum rainfall – 3 hours, 6 hours, 12 hours, 24 hours

The following detail is also provided for river levels at many recording sites:

- Peak height
- Peak flow
- Return period
-

Damage

Farming

Types of damage experienced included stock losses, interruptions to milking, crop loss, loss of pasture from slipped hill country, damage to fences, plant and equipment, damage to homesteads and buildings, silting and flood damage, loss of grazing, loss of feed and production, delays in re-establishing pastures and loss of access.

By farm type:

- Dairying $41.4m
- Sheep, beef and deer $66.0m
- Crop $24.0m
- Forestry $28–49m
- Total $159–180m

Data is also provided on the amount of erosion per council and catchment (Erosion is more likely the more rain that there is and on flatter slopes. Thus in a 100 year return event more erosion is likely to occur and on flatter slopes than a 10 year return event).

Infrastructure

Total estimated cost to the region's river and drainage schemes is $19.6 million ($9.2m was covered by insurance). $9 million of this was damage to rockwork and $6 million to tree protection works. Total estimated cost of repair work to non-scheme rivers is $5.3 million.

Other Estimates

Central Government estimated the cost of damage to the lower North Island at approximately $355 million of which agriculture accounted for approximately $185m.
The insurance payout is calculated at $112 million but doesn't include losses for uninsured property, infrastructure and crops. Breakdown of insurance claims:

- Domestic $45.9m
- Commercial material damage $46.3m
- Business interruption/loss of profits $13.6m
- Marine $0.4m
- Motor vehicle $5.1m
- Other $0.8m

An associated report by the Economic Task Group ('Manawatu – Wanganui Floods Economic Evaluation', Interim report to Vision Manawatu[18]) gives the following additional damage costs, based on "informed estimates":

- Roading and rail $75.2m
- Communications & energy $10.5m
- Water (waste) $1.3m

The report also claims that the value of direct losses amounts to 5% of regional GDP, but it seems that this includes both lost production and lost assets, as well as the addition of losses over more than one year. Furthermore, the losses in output are probably losses in gross output rather than losses in net output or value-added.

[18] It seems that no final report was produced.

18. Waitotara Valley February 2004 Storm Event, Taranaki District Council

Extreme Event	Flood, storm and landslips
Event date	February 2004

Hydrological Data

Prior to the start of this event soil moisture levels were reasonably high due to a significant amount of rainfall during the first two weeks of February.

This report contains rainfall data collected during the event. However, it has been recognised that the upper parts of the catchment, of which there were no records, are likely to have received more rain – based on the observed damage. A hydrograph and rainfall record over the month of February is also given for the recording station at Rimunui Station.

Damage

Farmland

Total area of landslides was 465 ha (landslide includes both slip scar and the debris trail) – identified by Landcare research.

The worst affected areas of landsliding had up to about 8% of the area affected.

Effect of landslides – Landcare Research

The immediate effects were a loss of approximately 2400 stock units. The long term effects are estimated to be 116 ha loss of effective area and the total loss in livestock less than 800 stock units. The timing of the event impacted on finishing lambs and setting up pastures for spring lambing.

Assumptions used
25% of slips were fresh
Land where slips occur is capable of running 7 stock units.
Scars take up to 10 years to get back to 80–100% of pre-slip production

Infrastructure
Initial Estimates are given in the following categories:

Track clearance – est. # properties * aver days/property * aver cost per day
Bridge – est. 3 properties * aver bridge per property * aver cost per bridge
Culverts – est. # properties * aver # culverts/property * aver cost per culvert
Fencing – est. # properties * aver fence length/property * aver cost per m
Slip revegetation – est. affected land * aver cost per ha
Deposition revegetation – est. affected land * aver cost per ha
Forestry windthrow – est affected land * cost per ha
Loss of production – 3 different land classifications
Stock losses
Damage to buildings

Total cost $6,321,495

19. Taranaki Flood 10–15 March 1990, Taranaki Regional Council et al

Extreme Event	Flood
Event date	10 – 15 March 1990

This report is set out a little differently to the other reports in that it is a compilation of reports on how each of a number of organisations fared in the flood. In summary the flood caused $11,835,870 worth of damage.

General Hydrological Data

The storm was the remnants of Cyclone Hilda which originated near the Solomon Islands but broke up before reaching NZ. However, there was still considerable of moisture in the system. The report gives miscellaneous peak rainfall statistics and return information.

Taranaki Regional Council

Hydrological Data

The regions largest river peaked at 25–26,000 cumecs. Rivers tended to have peak flows of approximately 20 – 30 year return rate and rainfalls were up to 50 year return periods.

Damage

Damage to existing works	$888,189
River damage	$1,691,889
Slip damage	$590,692
Total damage	$3,170,707

Slip damage can be thought of as damage to farmland while the other two categories can be thought of as infrastructure damage. Each of these costs is disaggregated and information given on the work carried out, location and costs per unit.

New Plymouth District Council

This report only deals with the costs directly associated with the New Plymouth District Council's property or facilities and does not cover the extensive damage to private facilities. This possibly is a problem with many of the council generated reports.

Hydrological Data

Rainfall data for 8 – 15 March is given for 6 rainfall stations across the district
Flooding throughout the district is estimated to be a 30 –50 year event but some back country areas were assessed at 50 –100 year return events.

Damage

Emergency Costs $189,500

Emergency Administration
Public Health
Parks and Reserves
Roading
Services and Flood Protection Repairs

Recovery Costs $2,163,800

Roading
Flood Protection and Floodway Maintenance
Sewerage
Stormwater
General Works
Each of these is disaggregated to finer detail

Employment Service Work Schemes	$572,000
Total Damage	$2,353,300

Stratford District Council

Damage

The estimated costs of the storm damage were $724,000 with an additional $104,000 worth of costs during the emergency period. The storm caused 250 major slips on district roads and 90 major slips on State Highway 43.

South Taranaki District Council

Hydrological Data

The flood on the 29/30 January had at least a 50 year return cycle in the Makakaho Valley and the 10th March flood in the Waitotara Valley had a 50 year return cycle. A third flood happened in the Waitotara Catchment on the 20th of March with a 10 year return period.

Damage

Net damage to roads and bridges is estimated to be $300,000. Of this approximately $40,000 worth of repairs had been carried out when the flood of 10th March occurred.

Insurance

Insurance companies were very generous and interpreted their cover as widely as possible. Some sheep yards were covered with mud more than 500mm thick. The precise loss of stock was not able to be identified until after the muster which hadn't occurred when this report was written. While farmers were covered for some things there are not policy options which cover fences, gates and unspecified bridges on their land.

When this report was written 382 claims had been lodged with an estimated cost of $569,000 with an average cost per claim of $1,500, which is a fair indication of the most common type of claim made (e.g. water damage to carpet, wallpaper and items in basements etc).

Ministry of Agriculture and Forestry

The Ministry of Agriculture and Forestry carried out a survey to assess the damage experienced by farmers in the area with responses from approximately half of the farmers in the area. The survey does not include the costs resulting from the loss of the Mahakatino River bridge which is likely to have been between $200,000 and $300,000.

Damage

Farmland: Total slip area of 3,473 ha which is a 2.4% of the total area or 3.6% of the productive area in the region. In addition to this 1,546 ha were silted. The damage experienced per farm is likely to be $10,561 but this varies by locality (figures per locality and per farm within each locality are given).

Total damage according to this survey is $3.99 million. Scaling this up to take account of the response rate (assuming no difference between those who did and did not respond) is conservatively predicted to raise damage costs to $5–6 million.

Additional report on the effect on horticulture

Up to 500mm of rain feel on the Egmont Ring Plain north of the mountain during the weekend of the 10th of March. The evenness and the continual nature of the rain meant that many horticultural crops were water logged for at least 5 days.

Reports from vegetable growers suggest that a number of properties could lose up to $30,000 or more from ruined crops. This is unlikely to lead to price rises in the local vegetable market though as most produce comes from outside the region. Little effect is expected in the fruit market as a direct response to the floods, as fruit crop areas were already declining due to poor returns. The flower industry was already over saturated at the time of the flood so this event is likely to take some of the pressure out of the over-supplied market.

Federated Farmers

This report provides rainfall data from a number of properties in the area over different time scales. Damage figures are cited at $3.99 million with average farm damage of $10,500. But the worst affected area had average per farm losses of $18,000.

Damage to accessways is likely to cost $1,614,900 to re-establish in addition to the estimated $250,000 needed for the Landcorp bridge (Mahakatino River bridge) replacement.

Pastoral damage:

Lost to slipping	347 ha	$163,500
Lost by silting	1546 ha	$111,600
Lost production		$141,000 – no calculation information
Total		$416,100

Fencing and yards:	$470,000
Dams and Drains:	$297,100

Other losses:

Loss milk production	$13,400 – inability to have milk collected
Losses of stored hay	$36,000
Losses of silage	$77,500
Farm forestry damage	$100,000
Beekeeping	$16,000 – hives and lost production
Capital losses:	$74,900 – disaggregated
Livestock losses:	$67,500 – disaggregated by species
Total cost	$3,994,300

Farmers estimate that they will lose on average $6,000 worth of income with the highest estimate $30,000. Also farmers will be destocked 10,000 sheep, 1,000 cattle and sundry other stock.

An estimated 5,000 ha of land will be out of production in the short to medium term if no restoration work is undertaken leading to at least 40,000 stock units needing to be destocked to maintain the current level of stock performance. This level of destocking will mean a loss of production of $750,000 in the 1990/91 year and that farmers will make a production loss of $1.2 million rather than the predicted $560,000.

Department of Conservation

The cost of repairing the storm damage to the conservation land in the area is estimated to be $33,200 for materials and use 245–250 person days worth of labour.

Telecom

240 customer faults were reported in addition to the 3575 customers effected by large cables with water damage. The total cost of repairs (in terms of staff salaries, equipment hire, materials and additional circuits) is around $85,120 which is covered by Telecom and not charged to customers or Civil Defence.

Transit New Zealand

Flood damage costs are given by State Highway but also disaggregated down to individual locations with details of the damage at each site. Total costs were given as follows:

SH3	$380,000
SH3A	$17,000
SH40	$334,000
SH45	$80,000

Wanganui Electric Power Board

This report outlines the details of power related damage in the region over the period by location including the shutting down of the City Bridge Substation due to flooding. Costs are given by location but the total cost directly experienced by the power board was $68,500.

Taranaki Electric Power Board

Total estimated costs to the Power Board as a direct results of the storm = $120,000
Overtime costs of staff brought back to work = $1,250
Vehicle running costs = $1,000

Marae

Ngati Poura Marae in Waitotara had $1,500 worth of damage

Taranaki Harbour Board

The only costs experienced by the Harbour Board are related to clearing detritus from the harbour which cost approximately $450.

20. Impact, various newsletters, Ministry of Civil Defence and Emergency Management.

Edition	Volume 19, September 2004
Region	BOP
Event date	July 2004
Extreme Event	Floods, landslides and earthquakes

Hydrological Data

The regions weather conditions became extreme when a large high pressure system stalled over the region.

The river was measured to be 5.38m above the level of its normal flow at its peak. It was measured to be 7.7m deep on the morning of Sunday 18 July.

Damage

Farmland

Breach in the Rangitaiki River resulted in an estimated 17,000 hectares of farmland being flooded. Some farms reported water up to 7m deep. An estimated 450 farms were affected with over 110 classified as severely damaged. 8,000 hectares were badly flooded and an estimated 3,000 – 4,000 ha needed regrassing.

Infrastructure

Part of State Highway 2 and a railway bridge were totally swept away. The breach to the stopbank was 100m wide and ~5m deep. Repair work required more than 16,000 tonnes of gravel.

The Government also approved an estimated $30 million support package.

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Edition	Volume 21, June 2005
Region	BOP
Event date	May 2005
Extreme Event	Floods

Hydrological

309 mm of rain dumped on Tauranga in 24 hours – more than it usually receives in all of May. The Western Bay of Plenty received around 30% of its annual rainfall over the next 36 hours. At its peak intensity there was 58mm of rain an hour.

Damage

Infrastructure

200mm of overnight rain washed out part of the railway line and State Highway 2 near Matata
At least 17 roads in Tauranga and 10 in Matata were damaged as well as power telephones and water supplies disrupted.
471 homes in Tauranga were damaged – 53 needed rebuilding and 14 were condemned
121 homes in Matata were inspected for damage – 36 were declared uninhabitable and 2 were condemned.

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Edition	Volume 23, December 2005
Region	New Zealand
Event date	2005
Extreme Event	General

This publication contains a record of all extreme events that have occurred in NZ and internationally in 2005 with a single paragraph describing each one. (Unfortunately the edge of the page is cut off in the on-line pdf).

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Edition	Volume 23, December 2005
Region	Gisborne
Event date	November 2005
Extreme Event	Flood

Hydrological Data

Significant rainfall with severe intensity over a short period (up to 44 mm/hour).
Highest rainfall recorded north of Tolaga Bay (385mm in 36 hours).
230mm average over region.
Flooding hit at the start of the growing season.

Damage

Farmland

About 2000 ha flooded with an estimated total farm gate loss of $8.4 million.

21. Floods and Droughts: the New Zealand Experience, edited for New Zealand Hydrological Society

Extreme Event	Floods and Droughts
Region	New Zealand

This book provides an insight of previous floods and droughts in NZ.
Historic Flood and Droughts in New Zealand, John Waugh, Horace Freestone and Darryl Lew

Floods

By far the most common civil defence emergency experienced by New Zealanders is from flooding by both rivers and the sea. New Zealand spent over $1 billion dollars (1984 dollars) to prevent flood or in repairing their damage between 1951 and 1984.

Floods in South Canterbury on the 13th March 1986 affected 1000 km^2 after persistent rain over 48 hours peaking at the end of the storm with 50 mm in 2 hours. In less than 24 hours the floods caused $66 million (1986 NZ$) of damage: $60 million to property, roads, railway lines, bridges, crops and livestock and $6.17 million to river control works.

Droughts

The major flood of 1945/46 meant that dairy production average in all Northland factories in March 1946 was 76% below the figure for March 1945.

A Northland drought in 1964 lead to a $440,000 drop in value for butter alone and resulted in some farmers losing 3 to 4 months of lost production.

The 1988/89 drought on the South Island East Coast caused a loss of agricultural production that cost farmers $365 million (McKerchar 1994).

Hydrological extremes and the groundwater system, Paul White

Floods

Hardt (1969) reported that the floods of the January and February 1969 in the Mojave River Basin caused $6 to $12 million damage but also provided substantial groundwater recharge.

Floods and Droughts: Case Studies, Andrew Fenemor

South Canterbury Floods, March 1986

Damage to property, roads, bridges and river control works exceed $60 million (South Canterbury Catchment Board 1987 p. iii). Rainfall intensities for 2, 6, 12 and 24 hour intervals all exceed 1:50 year intensities for Timaru and Kakahu forest. This author alters the South Canterbury Catchment Board figures and suggests damage is ~$74.9 million (breakdown given). The flow from 11 rivers is also given as well as area of farm land flooded, slips, soil loss and silt deposition.

Cyclone Bola, 5–10 March 1988

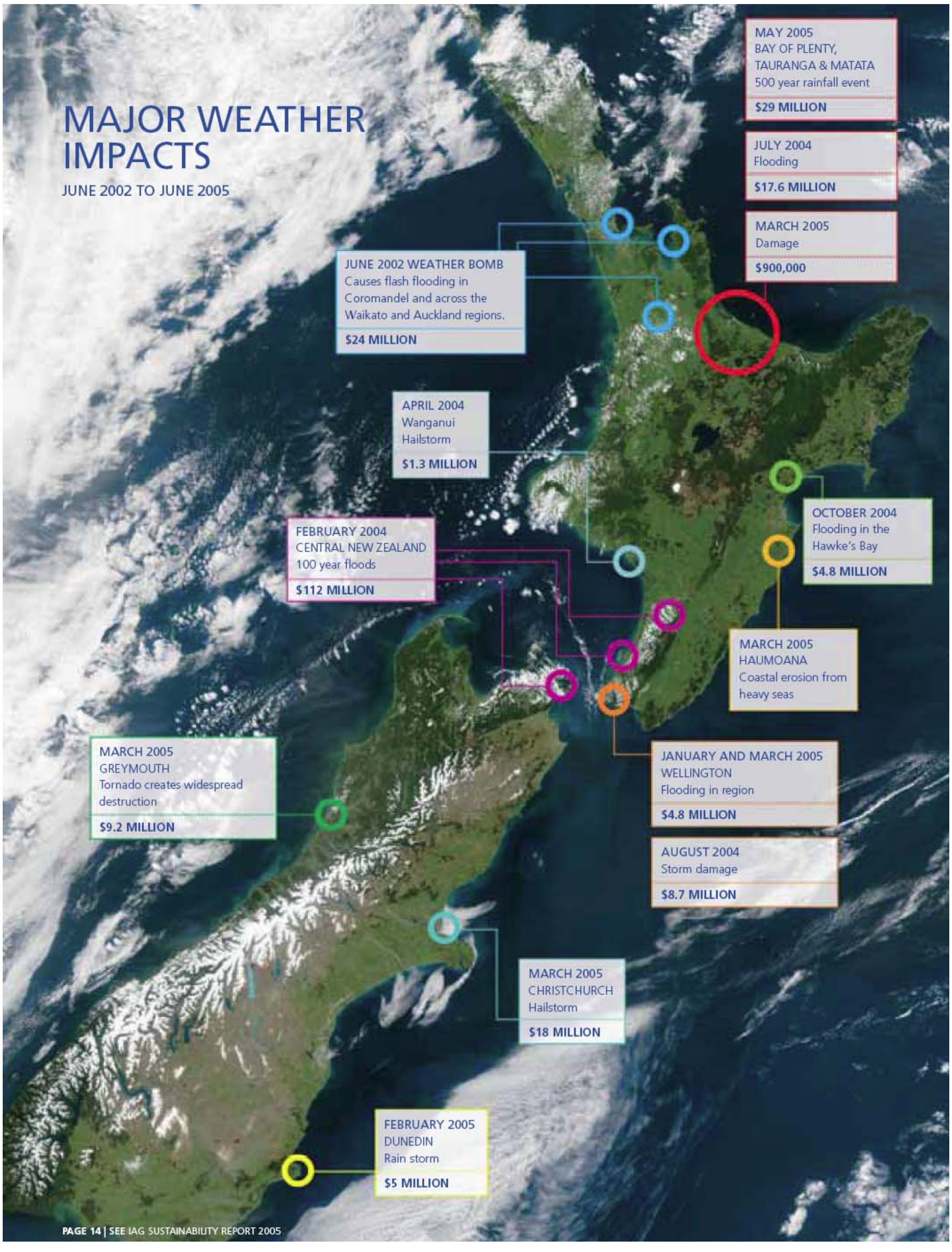
Government disaster relief following this event was $111 million (Parliamentary Commissioner for the Environment 1993). – This is available by type of damage and includes relief costs. Rainfall data for some of the areas are given and the associated floods had a return period of approximately 100 years.

22. Social, Economic, Environmental Sustainability Report 2005, IAG New Zealand

This report discusses climate change and the related increasing frequency of extreme weather events. The figure below contains a good summary of three years worth of events. There are also other statements within the report:

“For the insurance industry, the weather has become a vital concern. Weather-related disasters represent 19 of the top 20 insurance losses in NZ since 1968” (Insurance Council of NZ).”

“In 2004 alone, weather-as-destroyer cost the insurance industry over $145 million. Flooding is by far the most significant cause of damage, being responsible for 70% of all weather-related losses (Insurance Council of NZ).”



23. Claims History, Insurance Council of New Zealand

This report outlines the cost to the insurance industry of claims since 1968 – cited in other publications.

ICNZ
Claims history (Updated 2004) **($ millions)**

Year	Event	Date	Last Quarter	Original $m	Adjusted to Mar 2000 $m	Adjusted to Mar 2004 $m
1968	"Wahine" storm	10/04/1968	31/03/1968	3.50	42.23	46.32
1968	Loss of "Wahine"	10/04/1968	31/03/1968	10.00	120.67	132.34
1975	Canterbury Storms	1/08/1975	30/06/1975	7.00	52.22	57.27
1976	Wellington/Hutt Valley Floods	30/06/1976	31/03/1976	6.20	40.25	44.14
1978	Otago Floods	16/10/1978	30/09/1978	10.30	49.83	54.65
1980	South Island Summer Floods	17/01/1980	31/12/1979	2.30	8.97	9.84
1980	Taieri/Otago/New Plymouth Floods	5/06/1980	31/03/1980	8.00	31.22	34.24
1980	Onehunga Tornado, Auckland	1/08/1980	30/06/1980	0.50	1.95	2.14
1981	Thames/Coromandel/Paeroa Floods	1/04/1981	31/03/1981	7.00	23.17	25.41
1981	Keri Keri Floods	1/03/1981	31/12/1980	2.00	6.62	7.26
1983	Christchurch Storm	30/06/1983	31/03/1983	3.50	8.67	9.51
1983	Marlborough/Golden Bay Floods	30/06/1983	31/03/1983	2.30	5.66	6.21
1984	Invercargill/Southland Floods	1/01/1984	31/12/1983	45.80	103.93	113.98
1984	Greymouth Floods	30/06/1984	31/03/1984	3.50	7.95	8.72
1984	Auckland Floods	30/06/1984	31/03/1984	1.80	4.09	4.49
1985	South Auckland	1/05/1985	31/03/1985	2.90	6.27	6.88
1985	Thames/Coromandel/Te Aroha	30/06/1985	31/03/1985	5.90	12.79	14.03
1985	Wellington/Hutt Valley	30/06/1985	31/03/1985	1.40	3.03	3.32
1985	Auckland Floods	30/06/1985	31/03/1985	3.60	7.80	8.55
1985	Chatham Islands	30/06/1985	31/03/1985	0.80	1.72	1.89
1985	Gisborne Floods	30/06/1985	31/03/1985	1.70	3.68	4.04
1985	Hawkes Bay/Wairarapa	30/06/1985	31/03/1985	0.90	1.95	2.14
1986	Auckland Floods	30/06/1986	31/03/1986	0.40	0.74	0.81
1986	Nelson Floods	30/06/1986	31/03/1986	0.40	0.74	0.81
1986	North Otago/South Canterbury Floods	13/03/1986	31/12/1985	18.50	34.39	37.72
1987	Bay of Plenty Earthquake	30/06/1987	31/03/1987	192.00	356.93	391.46
1988	Cyclone Bola	8/03/1988	31/12/1987	37.00	52.41	57.48
1988	Greymouth Floods	1/05/1988	31/03/1988	3.20	4.55	4.99
1988	Manawatu Floods	25/07/1988	30/06/1988	2.50	3.54	3.88
1988	Greymouth Floods	1/09/1988	30/06/1988	13.40	18.97	20.81
1990	Taranaki/Wanganui Floods	8/08/1990	30/06/1990	1.80	2.30	2.52
1991	Otago Floods	18/02/1991	31/12/1990	1.60	1.90	2.08
1991	Albany Tornado	30/06/1991	31/03/1991	1.50	1.78	1.95
1992	Auckland Tornado	30/06/1992	31/03/1992	1.10	1.26	1.38
1992	Canterbury Snowstorm	28/08/1992	30/06/1992	7.00	8.08	8.86
1993	Kaikoura Flood	24/12/1993	30/09/1993	7.60	8.68	9.52
1994	Hastings Hailstorm *	30/06/1994	31/03/1994	10.80	12.18	13.36
1994	South Canterbury Floods	19/02/1994	31/12/1993	1.50	1.69	1.85
1994	North & South Storm/Floods	1/11/1994	30/09/1994	6.00	6.76	7.41
1995	Whangarei & District Floods	30/06/1995	31/03/1995	1.70	1.89	2.07
1995	New Plymouth Floods	25/04/1995	31/03/1995	3.60	4.01	4.40
1995	Thames/Kaiaua Floods	18/07/1995	30/06/1995	2.80	3.13	3.43
1995	North & South Island Floods	2/07/1995	30/06/1995	4.50	5.02	5.51
1996	Weather related losses June & July	3/07/1996	30/06/1996	8.10	8.41	9.22

Year	Event	Date	Last Quarter	Original $m	Adjusted to Mar 2000 $m	Adjusted to Mar 2004 $m
1996	Weather related losses	1/12/1996	30/09/1996	2.10	2.15	2.36
1996	Cyclone Fergus	30/12/1996	30/09/1996	1.60	1.64	1.80
1997	Cyclone Dreena	11/01/1997	31/12/1996	3.20	3.29	3.61
1997	South Island Storms	21/01/1997	31/12/1996	1.10	1.13	1.24
1997	Wairoa Floods	3/06/1997	31/03/1997	0.50	0.51	0.56
1997	Auckland Floods	24/05/1997	31/03/1997	3.70	3.80	4.17
1997	Northland Floods	30/06/1997	31/03/1997	1.20	1.23	1.35
1997	Coromandel Floods	25/09/1997	30/06/1997	0.50	0.51	0.56

1997	Auckland Floods	28/09/1997	30/06/1997	0.70	0.71	0.78
1997	Southland & Otago Wind & Hail	13/11/1997	30/09/1997	0.40	0.41	0.45
1997	North & South Island Windstorms	1/12/1997	30/09/1997	2.90	2.95	3.24
1997	South Island Windstorms	19/12/1997	30/09/1997	0.20	0.20	0.22
1998	North & South Island Floods/Storms	1/07/1998	30/06/1998	11.80	11.85	13.00
1998	Mercury Energy Crisis	1/05/1998	31/03/1998	10.20	10.29	11.29
1998	North & South Islands Storms	22/10/1998	30/09/1998	6.20	6.27	6.88
1998	North & South Islands Storms	30/10/1998	30/09/1998	2.00	2.02	2.22
1998	Upper North Island Storms	29/11/1998	30/09/1998	5.00	5.06	5.55
1999	Northland & Pukekohe Floods	22/01/1999	31/12/1998	5.00	5.08	5.57
1999	Dargaville Floods	18/04/1999	31/03/1999	1.70	1.72	1.89
1999	Whangarei/Rotorua Floods	1/05/1999	31/03/1999	2.10	2.13	2.34
1999	South Canterbury Storms	2/07/1999	30/06/1999	0.60	0.61	0.67
1999	Queenstown Lakes District Floods	1/12/1999	30/09/1999	46.10	46.42	50.91
2000	Tauranga/Eastern Bay of Plenty Floods	10/04/2000	31/03/2000	1.90	1.90	2.08
2000	Auckland/Coromandel Floods	3/07/2000	30/06/2000	7.60	7.60	8.34
2000	North Island Severe Weather	26/09/2000	30/06/2000	4.20	4.20	4.61
2000	Canterbury Storms	12/10/2000	30/09/2000	9.40	9.40	10.31
2001	Masterton Hailstorm	7/01/2001	31/12/2000	1.50	1.50	1.65
2001	Storm Damage, North Island	4/11/2001	30/09/2001	0.50	0.50	0.55
2001	Wellington/Wairarapa Floods	10/12/2001	30/09/2001	0.60	0.60	0.66
2002	Canterbury Hail Storm	5/01/2002	31/12/2001	3.00	3.00	3.29
2002	Canterbury Flooding	14/01/2002	31/12/2001	0.25	0.25	0.27
2002	Dunedin Flooding	17/01/2002	31/12/2001	0.30	0.30	0.33
2002	Wellington/Wairarapa Flooding	10/01/2002	31/12/2001	0.66	0.66	0.66
2002	North Island Flooding / Storm Damage	21/06/2002	31/03/2002	21.50	21.50	23.58
2003	Lower North Island Flooding/Storm Damage	9&10/06/03		1.0		
2003	North & South Islands /Storms & Floods	3&4/10/03		2.3		
2004	Storm Damage – North Island	20&21/01/04		0.75		
2004	Storm Damage – Lower Nth Island	15&16/02/04		112.00		
2004	Wanganui Hailstorm	06/04/04		1.3		
2004	Eastern Bay of Plenty Floods	17-19 /07/04		17.6		
2004	Storms - North & South Islands	15-20/08/04		8.7		
2004	Flooding - Hawkes Bay	18/10/04		4.8		
2005	Flooding - Wellington Region	06/01/05		2.5		
2005	Rain Storm - Dunedin	07/02/05		5.0		
2005	Greymouth Tornado	10/03/05		9.2		

Year	Event	Date	Last Quarter	Original $m	Adjusted to Mar 2000 $m	Adjusted to Mar 2004 $m
2005	Coastal erosion - Haumoana, H.B.	17-18/03/05		0.030		
2005	Storm damage Bay of Plenty	25/03/05		0.9		
2005	Flooding - Lower Nth Island	31/03/05		0.6		
2005	Christchurch Hailstorm	23-24/04/05		13.0		
2005	BOP Tauranga/Matata	18/05/05		28.5		
2005	Flooding - Gisborne/East Cape	22/10/05		0.7		
2006	Flooding - Oamaru/Dunedin	26/04/06		1.8		
2006	Storms - North & South Islands	12/06/06		42.5		
2006	Storm/Flood events Wgtn., Manawatu, Wairarapa	5-7/07/06		2.7		

* The Hastings Hailstorm - crops $9.4 million.
* These figures do not include Earthquake Commission payouts
* Small isolated events have not been included.

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PART 3
Orders of magnitude of economic costs and benefits of climate change on agriculture in 2030s and 2080s

1. Gradual Climate Change

All climate change scenarios and projections referred to in this Part 3 of the report correspond to those presented in Part 1 which are based on the IPCC TAR model HadCM2. Table 1.1 summarises the results from Tables 7.2 and 7.3 in Part 1, and also adds the DSMD values in terms of the number of standard deviations from a normal year. For the 'worst year' scenarios there are two ways of defining normal – the average for the relevant scenario or the historical average. Which of these is preferred depends on the view one takes about adaptation to slow changes in the climate.

As stated in Part 1, the relationships between pasture growth and soil moisture deficit (and growing degree days) were estimated via spatial cross-section regressions. The results were then used to predict changes in production in the future due to temporal changes in climate.

Table 1.1: *Changes in Agricultural Production for 2030s and 2080s (1972–2002 = 100). SD is standard deviation.*

	1972–2002	**2030s**		**2080s**	
		Med Low	Med High	Med Low	Med High
Dairy					
Average year					
Change in Output*		-2.8%	-4.3%	0.6%	-0.8%
SD change in DSMD compared with historical		0.25	0.36	0.41	0.70
Worst year					
Change in Output*	-36.7%	-43.4%	-46.3%	-43.3%	-49.3%
SD change in DSMD compared with scenario		1.73	1.76	1.79	1.87
SD change in DSMD compared with historical	1.64	1.98	2.12	2.20	2.57
Sheep & Beef					
Average year					
Change in Output*		-6.1%	-8.8%	-3.4%	-6.9%
SD change in DSMD compared with historical		0.25	0.37	0.44	0.72
Worst year					
Change in Output*	-33.5%	-42.7%	-46.0%	-44.1%	-45.5%
SD change in DSMD compared with scenario		1.34	1.36	1.40	1.45
SD change in DSMD compared with historical	1.28	1.60	1.73	1.83	2.17

*weighted

1.1 Average years

Agricultural output in the 'average years' is not much different from its historical 1972–2002 mean, implying that the direct effects of gradual climate change are not a serious threat to national agricultural production over the next 75 years (though Part 1 does show some significant changes at the regional level). As noted earlier, changes less than ±10% are not considered to be statistically significant. The literature review in Part 2 suggests that changes of ±1 standard deviation (σ) in annual DSMD lead to changes in output of less than ±5%. The results above are broadly consistent with this although for sheep and beef production they suggest somewhat more sensitivity to DSMD than we inferred from the time series econometric studies.

Why this should be the case is not clear. One would expect that time series studies would be biased towards showing greater sensitivity by the presence of transitional costs. That is, a sudden and temporary change in DSMD provides little opportunity for either animals or management to adapt to a different climate. In contrast, spatial comparisons reflect mostly permanent differences in DSMD.

On the other hand, time series studies implicitly include a number of short term management reactions such as increased use of irrigation and the importing of feed from other regions, options that may not be permanently available in drier regions.

1.2 Worst years

Over the historical period dairy production was 37% below average in the 'worst year'. For sheep and beef production the worst year historically was 34% below average. These corresponded to changes in DSMD of 1.6σ and 1.3σ respectively.

The review in Part 2 did not yield much information about the effect on agricultural output of larger changes in DSMD. However, the results in Buckle et al (2002) do show considerable nonlinearity. A drought in one quarter of about 0.9σ of quarterly DSMD leads to a fall in annual GDP of about 0.1%, while a drought of 2.2σ of annual DSMD lasting for a whole year reduces GDP by about 1%.[19]

If agricultural output shows a similar nonlinear response to changes in DSMD, a dry period with departures from normal of 1.3σ to 1.6σ of annual DSMD would reduce agricultural output 30–36%, which conforms well with the results in Table 1.1 above.

For the 'worst year' scenarios for the 2030s and 2080s, DSMD departures from normal measured with respect to the associated future 'average years' are around 1.8σ for dairy and 1.4σ for sheep and beef. Measured with respect to historical averages the departures are around 2.2σ and 1.8σ respectively. Again assuming a GDP-like response profile, the implied reduction in agricultural output would be in the range 32–49%, which fits reasonably well with the 43%–49% reductions shown in Table 1.1 – although more for dairy than for sheep and beef.

That is, Baisden's (2006) methodology implies marginally greater sensitivity of agricultural output to climatic variation than implied by the time series research, although more with respect to meat than dairy. As suggested above, this may reflect a greater ability of sheep and beef farmers to react to temporary dry spells than to a permanently drier climate.

[19] Note that the standard deviation for the quarterly data is 4.7, but when expressed on an annual basis it is nearly twice as high at 9.1, implying that dry periods tend to be (at least) yearly phenomena rather than quarterly phenomena, after allowing for normal seasonal variation. Thus a change of 0.9σ in quarterly DSMD for one quarter is approximately equivalent to a change of 0.12σ in annual DSMD.

1.3 Discussion

Overall though the consistency of results is quite remarkable, given the vastly different methodologies employed. The objective of each methodology is identical: to estimate the effect of climate change (changes in DSMD) on agricultural output. One approach uses spatial data in a largely agronomic model, while the other uses (stationary) time series data to determine an *ex post* relationship between DSMD and production.

Theoretically the agronomy model should be a better guide to the effects of permanent differences in the climate on production, as the time series models know about only temporary climatic variation. The latter are negatively biased by the limited ability of farmers to adjust farming practices to mostly unexpected changes in growing conditions, and by the limited adaptability of plant and animal physiology. However, there may be positive bias by the accessibility of temporary assistance such as greater irrigation or the importation of animal feed from neighbouring regions. Higher flows in alpine rivers (discussed in Part 1) might mitigate the effects of a drier climate in Canterbury (analogous to what happens in a drought), but this resource is not available to a permanently drier Hawke's Bay.

A Caution

Many of the water sources in Canterbury are close to, or past, being fully allocated, although there is continuing legal and scientific argument about what is available. In the 1997–99 drought, existing wells were deepened and new wells were drilled, but it might be very difficult to obtain consents to do the same again in future. While in 75 years there may be additional water flowing in the alpine rivers, it is arguable as to how much more could be taken. There is potential for harvesting and storing water at times of high flow – which is currently being investigated by the Central Plains Irrigation study. The conflicts are between in-river uses (including the need to allow large flows to go through to clean out the build up of shingle) and water extraction. And this is just the engineering debate – economics introduces more complications.

More fundamentally, for the purpose of projecting changes in agricultural production under a 'worst year' scenario, what is the appropriate definition of a 'departure from normal' with respect to climate indicators? Over 75 years one might reasonably assume that the configuration of farming capital stock and management practices would have adjusted to match a different climate. Then departures from normal should be measured with respect to what is normal at that future time. For animals and plants, however, full adaptation to a different climate is unlikely. Different regions have permanent differences in NPP (refer Part 1). In that case departures from normal in a 'worst year' might be better measured with respect to historical averages. As shown above, this latter definition leads to greater alignment between the projections of the two methodologies, perhaps implying that the physiological limitations to adapting to a different climate cannot be fully offset by changes in farm management practices. On the other hand, the alignment may just reflect the calibration of the agronomy model to historical spatial climatic differences.

Finally, two caveats are worth reiterating:

1. All of the above discussion is concerned with effects on physical output. No account has been taken of any changes in the prices of inputs or outputs that may be caused by shortages or surpluses of product – whether local or international, or by policy responses to such shortages/surpluses. Price changes have the potential to change agricultural incomes in the opposite direction to changes in physical production.

2. The analysis has considered how climate change affects pastoral productivity and the effect this has on agricultural output based on current land use patterns. There is no allowance for changes in land use. This could be analysed in future with Motu's LURNZ model.

2. Storms and Floods

The literature review in Part 2 provides little in the way of useful and consistent information for measuring the effects of storms on agricultural production, income or assets. We have not been able to obtain sufficiently good relationships between agricultural damage costs and hydrological indicators. However, future research using a different approach should be more productive. We discuss below the essence of an alternative approach.

There are two main impacts of storms on agriculture: slips or landslides, and inundation by flooding.

2.1 Slips

Slips occur on certain rock/soil types which are easily mapped and quantified, and only in response to major storms (typically > 200 mm of rainfall). Soil slip erosion can cover over 10% of particular farms following major storms in pastoral hill country areas of the North Island's east coast, Manawatu/Wanganui and inland Taranaki. The best quantified damage estimates following soil slip erosion are from Cyclone Bola (1988) when severe erosion covering 7% of steep hill country (8300 km^2) in the East Coast region of the North Island caused \$43M in damage and lost production, as well as \$30M in off-farm damages (Blaschke et al, 2000).

It has been possible to estimate the landslide contribution to sediment budgets using a robust linear relationship between storm magnitude (mm of precipitation) and the degree of slipping (the number or area of slips per hectare). See Page et al (2004). Although some uncertainties are inevitable and can cause arguments among researchers, quantifying storm magnitudes over 200 mm, by slope and erosion terrain class (all under pasture), would produce a very useful map. During the 1980s, the Ministry of Works did a good job of estimating the relative change in pasture production (Blaschke et al, 2000) and this has been followed up more recently as mapping methods have improved (Dymond et al, 2005).

Typically, slips can be divided into scar and debris tail based on an average proportion for each event. Both take land out of production (production losses of about 80%) during the year following the event, but the debris tails recover over about 1–3 years, while the scars recover to only 60–80% of their former productivity over 20–40 years along an exponential curve (Trustrum et al, 1984; Blascke et al 2000). Less well quantified is the typical impact of scars on roading, fencing and other infrastructure. Another relevant ongoing cost is sedimentation of waterways where this raises river channels relative to stop banks, which may be protecting both valuable agricultural land and built environments – roads/towns/cities.

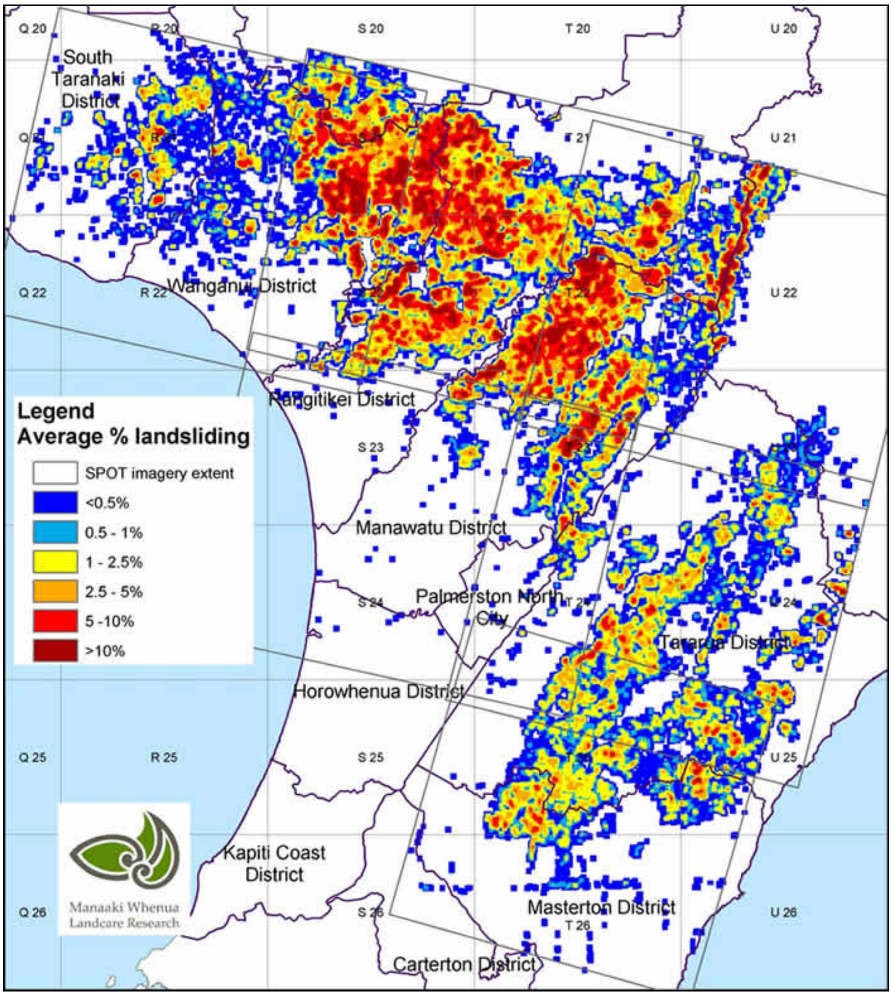
Accordingly it should be possible to estimate the relative changes in risk by summing the storm magnitudes over 200 mm for 1972–2002 historical period and for the four future scenarios specified above. This could be overlain on areas typically prone to soil slip erosion (e.g. Figure 2.1). A significant increase in the summed metric would imply a significant climate change impact worthy of further study, and should be approximately proportional to the change in slipping frequency associated with climate change.

2.2 Flooding

Flooding is more difficult to estimate because of the difficulties of translating rainfall into river stages, as this depends on the geomorphology and vegetation of the landscape and river system. Two concepts can probably be overlain to produce some sensible results.

First, changes in storm frequencies can be estimated from climate scenarios, although much uncertainty still exists in this regard. Second, some useful data exists within Landcare Research's *Land Resource Information System* (LRIS) on the return frequency of floods based on observations made during soil/landscape mapping. Categorical estimates of flood return frequencies range from less than 5 years to about 100 years in this dataset. Some councils, such as Environment Waikato, have produced updated, corrected or more detailed versions of this GIS data. As this information is in GIS, it is possible that it could be overlain on other GIS information, including QVNZ mesh blocks valuations, production estimates (similar to Part 1 of this report) or the *Agribase* database. Any actual analysis would have to take stop banks into account, which as far as we know are not considered in the LRIS layers. Nevertheless, the available GIS data on flood return frequency across this landscape is valuable because it allows floods return frequency to be associated with the value of agriculture, land, and infrastructure for inundation events of varying magnitude. Inundation is highly dependent upon local topography, and as a result, estimates of damage vary widely for events of similar return frequency – as is evident in Part 2.

Figure 2.1: *Summary map of landsliding in the February 2004 storms. Source: Dymond et al (2005).*



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