OPTIONS FOR VICTORIAN AGRICULTURE IN A ‘NEW’ CLIMATE

A pilot study linking climate change scenario modelling and land suitability modelling

PHASE 2: CLIMATE CHANGE AND AGRICULTURE - IMPACTS AND ADAPTATION FRAMEWORK

VOLUME ONE

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DEPARTMENT OF PRIMARY INDUSTRIES VICTORIA

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The Project Team acknowledges the International Global Change Institute (IGCI), University of Waikato, New Zealand, for supplying the original source code for OzClim in 1996, from the CLIMPACTS system. (http://www.waikato.ac.nz/igci/climpacts/system.htm).

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EXECUTIVE SUMMARY

Volume One

The Victorian Greenhouse Strategy – VGS (State of Victoria, 2002) was developed as a timely response to the serious threat posed by climate change resulting from the enhanced greenhouse effect. The VGS has a range of goals and response actions relating to the Victorian Government and community and the changes required to manage the enhanced greenhouse effect.

This project relates to the goals of the VGS by considering the capacity of Victorians to understand and respond to the likely impact of climate change on the agricultural sector. In particular, it aims to build a partnership with CSIRO climate specialists and work with Local Government and community to develop a better scientific approach to the consideration of climate change impact.

A greater understanding of the long-run sustainability of any agricultural enterprise in relation to climate change is essential to provide direction for long-term strategic planning. A key component of strategic planning at a regional and/or industry level is the need for information that has an explicit connection between enterprise and the environmental conditions in the region of concern. In this context, climate impact scenarios and adaptation scenarios are major elements of the long-term biophysical viability of agriculture.

CSIRO Atmospheric Research has further developed the OzClim scenario generator that describes how our climate may change during the next 100 years. This has been achieved by combining a range of global warming projections, with projected regional climate changes obtained from a range of atmosphere-ocean general circulation models. Most importantly, in the project, reported in this document, OzClim combines generalised patterns of change with a Bureau of Meteorology (BoM) observed database and thus provides scenarios of possible future climate change.

For this study, a technique, developed by Primary Industries Research Victoria (PIRVic), that uses an expert based multi-criteria modelling system and Geographic Information Systems (GIS) for mapping was employed - this is known as Regional Land Suitability Analysis (LSA). Based on an agreed set of regionally specific factors, the suitability of a region for growing a specific agriculture commodity is determined. The final outputs are a set of maps that show the suitability of the region for the commodity of concern.

Climate impact models were developed for Apples and Pears in the Goulburn-Broken Region and regional impact scenarios for 2000, 2020 and 2050 were analysed. The climate impact models were developed using the expert-based multi-criteria methodology, referred above. This involved a panel of experts providing advice for each of the commodities; the panel included local growers, soil scientists, industry people and other various experts.

The project also developed a climate impact model for wheat in the Mallee-Wimmera Region and investigated the calibration of this model with historical yield data for various climatic conditions. Difficulties were experienced in finding relationships
between the purely biophysical determinants of crop suitability and the actual yield data. A key finding from this application is that the wheat industry is highly adaptive and that it is, increasingly, geared toward adapting to conditions of extreme biophysical variability.

Results from this modelling process showed that the impact of climate change on the growth of Pome Fruit could be significantly changed in the spatial location of suitable areas. Areas that were once prime fruit growing areas may, in the future, not sustain viable production levels.

The main aspects of this study and its conclusions are reported in this Volume.

**Volume Two**

The second volume of this report is a compendium of mapped modelling outputs of the project. The concepts and methods used to generate these maps are fully described in Volume One. There is also a brief spatial description and an area analysis for each overall land suitability map presented in Volume One. Full analysis of the implications for these outputs is not considered in this pilot project; however, issues of adaptation in the wheat and Apple and Pear industries are discussed.

The first section in Volume Two provides a series of maps resulting from the linkage of land suitability analysis for Apples and Pears and climate change scenarios generated by OzClim, a CSIRO climate change modelling tool. The maps include overall land suitability for Apples and Pears in future climate scenarios for the Goulburn Broken Region. Mapped outputs also include overall climate suitability, rainfall suitability and temperature suitability for Apples and Pears. A change detection analysis shows potential change in land suitability for Apples and Pears in the Goulburn Broken Region between the years 2000 and 2050.

The second section in Volume Two provides maps of Spring Wheat suitability using historic climate data provided by the Bureau of Meteorology. Climate data from 1992, 1996 and 2002 were used to model Spring Wheat suitability and respectively represent moderate, good and poor wheat production years in the Mallee – Wimmera Region. Analysing wheat yields in each of these years and comparing them to climate suitability, from the Spring Wheat land suitability model, a positive relationship (significant at the 1% level) between climate suitability and yield was obtained. The maps in Volume Two clearly show the changes in Spring Wheat suitability based on actual climate data and reflect the wheat production in each of those years.

**MAIN CONCLUSIONS REACHED IN THE PILOT PROJECT**

**Key Learning**

1. LSA models and Climate Change Impact models can be integrated successfully. This increases the capability of both modelling approaches for determining the biophysical impacts of greenhouse induced climate change on agricultural industries.
2. The models are robust expert systems suitable for providing a long-term perspective at a regional scale, as they: (a) are well suited to average climate conditions, (b) express spatial variation in climate change scenarios, and (c) provide excellent starting points (broad scale) for climate change risks assessment.

However, the modelling tools are limited for building better knowledge about climate change risk management for the following reasons.

1. Climate science and scenarios have extremely high levels of uncertainty. They are based on IPCC estimates associated with various social, economic, and technological storylines. As such, they are not simply extrapolations of historical climate monitoring.

2. Climate change scenarios produce a range of possible future climate. They are not designed to capture changes in present-day variability. Recent improved general circulation models are showing significant skill in modelling extremes and the impacts of climate change on these extremes. This is a significant issue for understanding our “coping ranges” and identifying the particular climate variable that may be important in determining the nature of climate risk.

3. For many climate attributes that are needed to understand plant growth suitability, it is difficult to estimate their response to climate change utilising monthly averaged data, due to temporal uncertainties driving model fitting. This includes: (a) extremes (b) Chill Units (for Pome Fruits) require daily time steps, and there is a need to for better understanding of how vernalisation impacts on some regions (e.g. Goulburn-Broken), and (c) timing and volume of autumn break (for Wheat) requires daily or at least weekly or half week time sequences.

4. There are some spatial problems in calibrating LSA models (e.g.; for Wheat) against years for productivity and climate.

In addition, the Pilot Project substantially concentrated on the biophysical impacts of climate change. There is a need, therefore, to extend this to take into account the holistic consideration of social, economic and environmental impacts.

**Overall Learning**

1. Impacts are varied across regions and industries, and for different aspects of climate change. For instance, current Pome Fruit varieties will suffer from excess heat accumulation in Goulburn-Broken, while there is no significant impact on Blue Gums in Gippsland. Parallel studies demonstrate that the same applies to other primary industries, such as fisheries, as well as biodiversity.

2. The modelling and mapping involved in the Pilot Project was useful to promote understanding and knowledge about climate change and DPI capability.
3. The Science of Climate Change (and Risk) is very complex and requires time, appropriate resources and strong collaboration across DPI to build our capacity and that of primary industries.

4. Even if changes in climate could be accurately predicted, uncertainty would still surround the effects that these changes will have in our society and industries.

5. There is a need for the formulation of a *Climate Change Risk-Uncertainty Assessment and Decision-Making Framework* to better understand the vulnerability and capacity to adapt to climate change impact on the regions and industries of Victoria.
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The stakes associated with projected climate change are high. Numerous Earth systems that sustain human societies are sensitive to climate and will be impacted by changes in climate. Impacts can be expected in ocean circulation; sea level; the water cycle; carbon and nutrient cycles; air quality; the productivity and structure of natural ecosystems; the productivity of agriculture, grazing and timber lands; and the geographic distribution, behaviour, abundance and survival of plant and animal species, including vectors and hosts of human diseases. Changes in these systems in response to climate change, as well as direct effects of climate change on humans, would affect human welfare positively and negatively.

(IPCC, 2001, p.21)

VICTORIA – RESPONDING TO CAUSE AND EFFECT OF CLIMATE CHANGE

What is the Enhanced Greenhouse Effect?

The atmosphere has always acted as a greenhouse providing an energy holding tank of the sun’s radiation in the form of warmth. The enhanced greenhouse effect is best understood as the increased global warming that occurs as a direct result of an increasing amount of a range of gases - including Carbon Dioxide (CO₂) and Nitrous Oxide (N₂O) from human activity. The increased warming is caused by the effect this extra percentage of greenhouse gases has on solar radiation moving through the atmosphere (see Figure 1).

Figure 1  The main concepts of the enhanced greenhouse effect

(Source: State of Victoria, 2002)
What are we doing about it?

The Victorian Greenhouse Strategy (VGS) was developed as a timely response to the serious threat posed by climate change resulting from the enhanced greenhouse effect (see www.greenhouse.vic.gov.au). The VGS has a range of goals and response actions relating to the Victorian Government and community and the changes required to manage the enhanced greenhouse effect.

The VGS is being implemented in collaboration with a range of key stakeholders that will share in the responsibility for implementation and the benefits brought about by a less carbon intensive society.

The specific goals of the VGS are as follows:

1. Build awareness and understanding of greenhouse issues;
2. Limit Victoria’s greenhouse gas emissions and enhance greenhouse sinks;
3. Position Victoria to prosper in a future carbon constrained economy – including by creating an environment in which Victorian industry can take advantage of business opportunities in greenhouse gas mitigation; and,
4. Develop a greater understanding of climate change impacts and, where appropriate, initiate adaptation actions relevant to Victoria.

This project relates directly to these goals in the following ways:

Climate Change: Impacts and Adaptation

The purpose of this project is to consider the capacity of Victorians to understand and respond to the likely impact of climate change on the agricultural sector. This approach adopts the generally accepted Inter-governmental Panel on Climate Change viewpoint (IPCC, 2001), that climate change is occurring and we (Government and the community) must decide how to deal with it now.

Government Leadership

Through the development of this project and the long-term partnership built with the most capable climate change research and development (R&D) organisation in Australia - CSIRO- Climate Impacts Group, the State of Victoria has clearly taken a leadership role in climate change impact and adaptation R&D.

Working with Local Government and the Community

This initial work will lead to the development of better scientific approach to the consideration of climate change impact as well as better tools for understanding and communicating the issues of impact and adaptation.
CLIMATE CHANGE - ISSUES, IMPACTS AND ADAPTATION

What is happening?

Over many thousands of years, climate change has been a common phenomenon with significant impact on the Earth-Atmosphere system. These temperature changes were triggered by variations in the orbit of the Earth, which changed the distribution of solar radiation received on the planet. Over recent decades, scientists have begun to consider the possibility of rapid climate change brought about by the activities of a global population in excess of 6 billion people.

How do we know for sure?

Observational evidence of climate change is increasing (Figure 2), and this provides mounting confidence that the global climate is changing, and has changed significantly since the industrial revolution. The main messages are the following1:

- **Temperature increase.** Global mean surface temperature has increased about 0.6°C since the beginning of the 20th century, with night-time minimums increasing more than daytime maximums. While the warming record shows significant spatial and temporal variability, the global upward trend is unambiguous. Most of the warming in the 20th century occurred from about 1910 to 1945 and since 1976 (see Figure 2).

Figure 2  Global average near-surface annual temperatures; anomalies compared to (1961-1990) for the period 1860 - July 2001

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1 This information has been obtained from:
Available online at [http://www.ipcc.ch/](http://www.ipcc.ch/)
**Warming trends compared.** Twentieth century warming is likely to be the largest during any century over the past 1,000 years for the Northern Hemisphere, with the 1990s the warmest decade and 1998 the warmest year. The 10 warmest years since 1860 have all been recorded since 1980. Persistent positive monthly mean temperature anomalies (positive temperature differences compared to 1961-90 average) have been recorded since 1985 (see Figure 3).

**Precipitation changes.** Precipitation over land surfaces has increased in the mid- and high latitudes but decreased in the subtropics and tropics. There has also been a likely increase in extreme precipitation events over the northern mid- and high latitudes.

**Extreme precipitation events.** While trends in temperature and precipitation extremes vary globally, there is growing evidence for more extreme precipitation events, and the overall areas of the world affected either by droughts or excessive wetness have increased (Collins and Della Marta, 1999).

**Glaciers.** There has been a widespread retreat of mountain glaciers in non-polar regions during the 20th century. Northern hemisphere sea-ice extent has decreased 10-15% since the 1950s, and Arctic summer sea-ice thickness is likely to have declined by 40%.

**Sea-level rise.** Global sea level has risen between 0.1 – 0.25 metres largely due to thermal expansion of the oceans, and to a lesser extent due to the melting of land-based glaciers. The rate of sea-level rise during the 20th century was about 10 times higher than the average rate during the last 3,000 years. Global ocean heat content has also increased since the late 1950’s.
El Niño. More frequent, persistent and intense El Niño events have been observed in recent decades. The persistent 1990 to mid-1995 warm phase of the El Niño-Southern Oscillation (ENSO) event was exceptional in the 120-year record of the phenomenon. The 1997 El Niño event appears to have been the strongest on record. Some climate model global warming scenarios suggest a warming pattern in the Pacific ocean similar to what occurs during an El Niño event now. Thus, against this projected warming, future El Niño events might occur more frequently and be more intense.

What does that mean for Agriculture in the long run?

The importance in understanding long-run sustainability of any agricultural enterprise in relation to climate change is essential to provide key direction for long-term strategic planning. A key component of strategic planning at a regional and/or industry level is the need for information that has an explicit connection between enterprise and the environmental conditions in the region. There are two interrelated phases for this kind of work.

Impact Scenarios – Information for the Future

Various industry bodies, natural resource and land use planning and management agencies in Victoria need to be aware of long-term biophysical viability of agriculture when considering long term strategies and future scenarios for ecologically sustainable resource use, trade outlooks, land capability and infrastructure.

Adaptation Scenarios – Options for the Future

On the basis of any likely impact of climate change, the organisations in Victoria need to be able to build capacity in the land management community and agricultural processing industries, where appropriate, for adaptation to different species, cultivars and/or practices.

The consideration of detailed adaptation measures is beyond the scope of this study. Future work will develop options for the future as the VGS begins to engage more fully with industry. The emphasis of current work is to consider the information inputs that can assist in the development of adaptation measures.
EMISSIONS SCENARIOS AND CLIMATE CHANGE SCENARIO GENERATION

What do we mean by an emissions scenario?

There is a close link between increased greenhouse gas emissions and climate change. Figure 4 shows the relationship between the concentration of carbon dioxide in air bubbles in ice and estimates of temperature change.

Figure 4  Carbon Dioxide and Global Warming

Most of the increase in carbon dioxide (CO₂) comes from the burning of fossil fuels such as oil, coal and natural gas, and from land clearing. Currently, about 7 billion tonnes of carbon (as carbon dioxide) are emitted each year during the combustion of fossil fuels and 1-2 billion tonnes per year from land clearing. In Australia, annual CO₂ production per person is about 16 tonnes.
Current population projections show that the world’s population is likely to reach 9 billion by 2050 and 10-11 billion by the end of the century. The demands this will make for increased production and consumption of goods and services and for land, energy and materials will greatly intensify pressure on the environment and living resources, not just of developing countries but throughout the entire world. These pressures will be felt acutely in Australia because of its uniquely fragile environment.

On the basis of a range of social and economic scenarios for the future of the world, scientists and policy makers have developed a related set of estimates for greenhouse gas emissions into the atmosphere. These are known as emissions scenarios.

The latest set of emissions scenarios issued by the Intergovernmental Panel on Climate Change (IPCC, 2000) were employed for this pilot project. The Special Report on Emission Scenarios (SRES) produced 40 future emission scenarios for greenhouse gases and sulphate aerosols. The SRES information can be found on a website (sres.ciesin.org).

Figure 5 gives an indication of the emissions scenarios that have been calculated on the basis of the storylines of our future world development.

Figure 5  Some examples of emissions scenarios produced by the IPCC

For this study the A1F1 (extreme) and the B1 (improving) scenarios were used to produce regional impact assessments. The storyline of global development for these is briefly mentioned below:
Scenario A1F1 is described as follows:

“The A1 storyline and scenario family describes a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into four groups that describe alternative directions of technological change in the energy system. The A1F1 group is a fossil fuel intensive scenario”.

Scenario B1 is described as follows:

“The B1 storyline and scenario family describes a convergent world with the same global population that peaks in the mid-21st century and declines thereafter. There is rapid change in economic structures towards a services and information economy, with reduction in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability including improved equity, but without additional climate initiatives.”

**How do different emissions scenarios affect the changing climate?**

The higher the levels of greenhouse gases in the atmosphere produced when we burn fossil fuels and continue with certain agricultural practices, the more intense will be the change in climate on a global scale.

**Figure 6** shows how the range of emissions scenarios will cause a change in global average temperature.
**How do we know what the future climate might be like in our region?**

CSIRO Atmospheric Research has applied the *OzClim* scenario generator to describe how Victorian climate may change during the next 100 years. This has been achieved by combining a range of projected global warming with projected regional climate changes obtained from a range of atmosphere-ocean general circulation models (AOGCMs).

*OzClim* is a PC-based regional climate scenario generator for Australia that simplifies the process of calculating future climate change for application to impact models. It is chiefly used as a research tool for climate sensitivity studies by allowing the construction of future climate change scenarios for risk assessment.

The OzClim WebPages at [http://www.dar.csiro.au/publications/OzClim.htm](http://www.dar.csiro.au/publications/OzClim.htm) provide the following information:
- Background describing the development of OzClim
- Creation of future climate and regional patterns of climate change
- Tutorial assisting with the use of OzClim.

OzClim is a stand-alone climate scenario generator that has been developed by CSIRO Atmospheric Research and the International Global Change Institute at the University of Waikato in New Zealand.
OzClim has two key functions:

1) A regional scenario generator for Australia using GCM patterns to provide regional climate change scenarios for 5-yearly intervals from 1995–2100. Variables currently supported are temperature and rainfall and evaporation.

2) The capacity to ‘plug in’ a range of impact models to explore the sensitivity of impacts to different emissions scenarios and climate sensitivities. Three demonstration models are currently in OzClim, with several also under development, but more are being sought. The potential also exists to explore various adaptation and management strategies.

Most importantly, OzClim combines generalised patterns of change with a Bureau of Meteorology (BoM) observed database and thus provides scenarios of possible future climate change.
REGIONAL LAND SUITABILITY ANALYSIS

How does climate change impact our agricultural potential?

Broad scale impact of climate change on agricultural production/productivity and land use has been considered by a number of researchers. Each of these refers to a large range of different methods for estimating the impact of climate change on the likely yield of a specific commodity (e.g. wheat, maize, soybeans). Some consider the impact of higher CO₂ levels and different water availability scenarios in controlled experiments, while others consider an integrated shift by incorporating plant growth characteristics into farm-based economic models.

For this study, we used a technique developed by PIRVic, that uses an expert modelling system and geographic information systems for mapping. This is known as Regional Land Suitability Analysis (LSA). Based on an agreed set of regionally specific factors, the suitability of a region for growing a specific commodity is determined. The final outputs are a set of maps that show the individual factors (e.g. Rainfall during the flowering season for cool climate grapes) and the combined factors for the overall suitability of the specific commodity of the region of concern.

LSA is used because it allows for the plugging in and out of different climate information. By combining the climate scenarios produced by Ozclim with the LSA, maps of suitability of a region can be produced for different projected future periods. For this project, the LSA maps have been produced for Apples and Pears in the Goulburn – Broken Region at 2000, 2020 and 2050 for the improving and extreme emissions scenarios. LSA maps have also been produced for wheat in the Mallee – Wimmera Region using historical climate records from 1992, 1996 and 2002.
This is a continuation of the Pilot Project ‘Options for Victorian Agriculture in a “new” Climate’ which linked climate change scenario modelling and land suitability modelling.

Objectives of this phase 2 have been set as follows:

1. Develop a Climate Impact model for Wheat in the Mallee-Wimmera Region.

2. Calibrate the Climate Impact model for wheat with historical yield data for various climate-types (good, moderate and bad years) and study relationship and variability.

3. Analyse the spatial impact of climate change in terms of yields and dollars.

4. Produce climate scenarios from OzClim to study variability.


6. Identify the spatial variability of change for Apples and Pears.

7. Study the historic value of Apple and Pear Industry in Victoria and Goulburn-Broken.
METHODOLOGY

Land Suitability Modelling for Agriculture

The procedure to develop the expert-based Multi-criteria Land Suitability model involves a panel of experts to provide advice for each commodity, and may include local growers, soil scientists, industry people and other various experts. The Analytical Hierarchy Process (AHP) is utilised to establish weights for selected factors. Following is a description of steps related to land suitability model development:

- **Define the issue(s) or problem, and specify the solution desired.** The issue(s) are determined by the particular needs and concerns at the regional level.

- **Identify the focus.** The focus forms the pinnacle of the hierarchy and is the outcome being sought from the application of AHP.

- **Identify the criteria.** Criteria in the form of critical factors for growth for selected commodities, or groups of them, are based on acknowledged bibliography and agreed upon by experts.

- **Construct the hierarchy.** The hierarchy is structured in the form of a decision tree with the overall objective, or focus, at the top. It enables to assess the impact of elements of a higher level on those of a lower level, or alternatively the contribution of elements in the lower level to the importance or fulfilment of the elements in the level above. “Elements (criteria) that are of less immediate interest can be represented in general terms at the higher levels of the hierarchy and elements critical to the problem at hand can be developed to greater depth and specificity” (Saaty, 1994). Where necessary, primary criteria ought to be broken down into secondary and tertiary criteria. The criteria may be reviewed and modified.

- **Assign intensity ratings** to the range of data values for the critical factors that have been identified. The rating is made in terms of the impact on each of the lowest level criteria (factors) for each primary criterion. By assigning intensity ratings, experts can provide an assessment of the critical factors in relation to the level at which they may become limiting to the suitability (plant growth for example) or protection of the environment.

- **Weight the criteria** by posing a set of questions between pairs of criterion at each level of the hierarchy to establish the relative importance or priority. The pair wise comparisons is a robust technique for capturing preferences as the user compares all factors against each other but only two factors at a time, and thus can make a more reliable judgement. The pair wise ratings are determined on a 9-point continuous scale and are entered into a pair wise comparison matrix. In the land suitability application, environmental factors that may contribute to, or impact upon, commodity (vegetable, tree or pasture) growth and production are weighted.
The AHP weights are calculated using the WEIGHT module in IDRISI GIS software. A consistency ratio is also calculated to measure the consistency of the pair-wise comparison.

- **Model Development** is then done using the Model Builder in ArcView GIS. The suitability model is defined with the AHP hierarchy, criteria weights and data value ratings formulated previously. Model is then fed with necessary data and executed to produce the resultant suitability map.

*Validate the Suitability Maps.* The resultant commodity map is obtained from processing all the map overlays by reclassifying field values to AHP ratings, multiplying each by the associated weight, and afterwards summing the maps together for each level of the hierarchy. The final map ranks areas in terms of suitability for the production of a commodity that has an index range of 0 (zero) to 10 (ten), where 0 represents a site with little or no value and a site of 10 represents a near perfect site. For a regional or a local application this index can be categorised into a four class rating system, such as very low, low, moderate and high suitability. The same panel of experts is used to validate the final suitability outcome and ensure the accuracy of the maps. If necessary, weightings and intensity ratings of the 'criteria for growth' can be adjusted.

### Change Detection

- Commodity suitability scenarios for the years 2000 and 2050 were compared using image analysis techniques to do a change-detection and identify the spatial variability of climate change impact.

### Relating Climate Change Impact to yields/dollars

- Historical climate data were collected from BOM for selected good, moderate and bad climate years.
- Historical wheat production data were collected from ABS Agricultural census for selected good, moderate and bad years.
- Commodity suitability maps were produced using the suitability models developed for wheat.
- Correlation coefficients between climate suitability and yields and land suitability and yields were calculated using EXCEL.

### DEVELOPMENT OF MODELS

Several one-day workshops were conducted in Horsham and Tatura and involved relevant experts for Wheat, Apple and Pear to develop the models. Analytical Hierarchy Process (AHP) techniques were used in the workshops to establish weights for various factors identified important for the selected commodities.

Some of the factors, that have been included in the Apple and Pear models by the experts, could not be addressed due to data issues. The current version of OzClim
scenario generator operates only on monthly climate timescales. To assess the change in chilling units for the Apple and Pear models requires daily time scale data for both current and future climates. Climatological data for the Wind and Radiation factors was not available at the high spatial resolution required for the GIS data grids (5 kilometres). Therefore, the Chilling, Wind and Radiation factors were not considered in the Apple and Pear model and their weights were distributed to other factors proportionately.

Also, temperature factors “value classes” for the Apple and Pear Models developed for the Goulburn Broken Region have been modified, since the value ranges (assigned by the experts) cancelled the whole study area. Therefore, previous “value ranges” for the growth of these commodities has been used to run the models. These previous “value ranges” were obtained from an earlier developed, generic Pome Fruit Model. This Pome Fruit Model was developed with expert input, for Victoria wide application.
The Goulburn Broken Region covers an area of approximately 24,800 square kilometres; about 10.5% of Victoria’s total area (see Map 1). The landscape of the region includes low lying floodplains occurring along the Murray River in the north and mountainous regions in the south, including Mount Buller with an elevation of 1806 metres above sea level. The climate varies with topography with the mean maximum temperature of approximately 21°C whilst the mean minimum temperature is around 8°C. Summer temperatures are generally around 30°C in the north, but are considerably cooler in the southern mountainous region. During winter, average daily maximum temperatures are approximately 13°C in the north and about 4°C in the south. Average annual rainfall in the north is approximately 400-500mm with rainfall increasing southward (860mm at Lake Eildon) and up to 2000mm in the ranges.

Map 1  Goulburn Broken Region, South-Eastern Australia

The population of the region in 1996 was approximately 156,500, with 41% of the population living in rural areas. The major towns include Shepparton (25,363), Benalla (8,582), Mooroopna (6,582), Seymour (6,294) and Kyabram (5,738). Major land uses in the region include dryland agriculture (58%), irrigated agriculture (8%), native forests (26%), plantations forests (1%), urban uses (4%) and water bodies

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2 Information on the Goulburn Broken region has been summarised from the Victorian Resources Online (Goulburn Broken Homepage)
(2%). The highest value agricultural industries in the region include grazing for dairy and meat and fruit production. The Shepparton Irrigation Region covers an area of approximately 520,000 hectares, of which 54% is irrigated. Agricultural activities in the irrigation region include grazing pastures, cropping, orchards, vegetable growing, vineyards and woodlots.

**Apples and Pears**

Apples and Pears are categorised as Pome Fruit. Major Pome Fruit growing regions in Victoria include the Goulburn Valley, the eastern metropolitan area of Melbourne, Harcourt, Bacchus Marsh, Gippsland and the Mornington Peninsula. Victoria is the major grower of Apples and Pears in Australia accounting for 36% of Australia’s apples and 87% of Australia’s pears. In 2003 Victoria produced 117,681 tonnes of apples and 119,156 tonnes of pears. The Victorian Pome Fruit industry is worth approximately $112 million dollars per annum. Exports of apples from Victoria in 2000 were valued at $3.5 million, with pear exports worth $18.7 million (DPI 2004). Export markets include the UK, Europe and South-East Asia.

The Goulburn Valley produces approximately 85% of Australia’s pears and 16% of Australia’s apples. The region exports 16% of its fresh fruit production and approximately 55% of processed fruit. The major Apple and Pear growing areas are around Shepparton, Kyabram, Tatura and Cobram.

**Map 2** and **Map 3** show the production of Apples and Pears in Victoria in 2001 based on Statistical Local Area boundaries and demonstrate the high production of Apples and Pears in the Goulburn Valley. The region is responsible for 90 per cent of Australia’s deciduous canned fruit production including; apples, pears, peaches, apricots, plums and nectarines. The main varieties of apples grown in Victoria include Cripps Pink (Pink LadyTM) which comprises 26% of total tree numbers, Granny Smith (16%), Galas (14%) and Delicious varieties (10%). The main types of pears grown in Victoria are Packham, Williams Bon Cretian and Buerre Bosc varieties, comprising 92% of all pears produced.

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3 Unless otherwise stated, the information in this section has been obtained from Apple & Pear Australia Limited (APAL) - [http://www.apal.org.au/research/vic.htm](http://www.apal.org.au/research/vic.htm)
Map 2  Victorian Apple Production in 2001

Map 3  Victorian Pear Production in 2001
Factors Influencing Apple and Pear Growth

Soil - Pome Fruits are more tolerant of a range of soils than many other fruit trees. Poor soils do not allow for the production of heavy crops without the expensive application of nutrients; therefore fertile soils are most suitable. Deep, well-structured soils with good drainage are preferred, allowing for greater root penetration; giving trees more chance of withstanding dry periods and ensuring against root rots during excessively wet periods. Pome Fruits are intolerant of high soil salinity levels and prefer soils with a pH in the range of 5.5–7.5.

Climate - Pome Fruits prefer temperate climates, with cool to cold winters, and mild to warm summers. Mean January temperatures of between 16ºC and 23ºC are optimal. Pome Fruit require moderate to warm temperatures during the growing season and cooler temperatures during maturation. The chilling requirements of Pome Fruit growth make them most suited to climates with cool winters. Apple trees need a winter cool enough to give them a ‘rest’ or dormant period. Apple trees need consistently available moisture during the growing season to promote regular and heavy production. Frosts are harmful once buds begin to open, so late flowering varieties are sometimes favoured. Strong winds and hail can severely damage Pome Fruit crops.

Landscape - Gentle slopes facing north are desirable for the growth of Pome Fruits to allow for warmer conditions and more heat absorption from the sun. Steeper and south-facing slopes are unsuitable because of the lack of sunlight and cold southerly air streams. Crops on steep slopes are only limited by the safe and efficient use of machinery and equipment, although gentle slopes are optimum.

Weighting the Criteria

Land suitability for Apples and Pears was conducted specifically for the Goulburn Broken Region assuming productivity of 30 to 60 tonnes per hectare.

Figure 7 and Figure 8 represent the Apple Land Suitability Model. Figure 7 depicts the climate criteria of apple land suitability and Figure 8 depicts the soil and landscape criteria. This model represents the hierarchy and weightings of the critical growth criteria for the production of apples at 30 to 60 tonnes per hectare per year.

Figure 9 and Figure 10 represent the Pear Land Suitability Model. Figure 9 depicts the climate criteria of pear land suitability and Figure 10 depicts soil and landscape criteria. This model represents the hierarchy and weightings of the critical growth criteria for the production of pears at 30 to 60 tonnes per hectare per year.

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**POME FRUIT LAND SUITABILITY**

Biophysical AHP Model

(Climate Factors)

APPLES - Managed

(Goulburn Broken)

Early - Late Yield 30 - 60 t/ha

Criteria for Growth HIERARCHY

---

**Figure 7**  Pome Fruit - Apple Land Suitability - Climate Factors
Figure 8  Pome Fruit - Apple Land Suitability - Soil and Landscape Factors
Figure 9  Pome Fruit - Pear Land Suitability - Climate Factors
POME FRUIT LAND SUITABILITY
Biophysical AHP Model
(Soil and Landscape Factors)

PEARS - Managed
(Goulburn Broken)
Early - Late Yield 30-60 t/ha
Criteria for Growth AHP HIERARCHY

Figure 10  Pome Fruit - Pear Land Suitability - Soil and Landscape Factors
**Land suitability for growing apples in the Goulburn - Broken Region**

The commodity maps (as reproduced in the following pages) developed by the modelling process, clearly outline the predicted impact of climate change on suitability for growing apples in the Goulburn - Broken Region.

**Map 4** shows land suitability for the production of apples across the Goulburn - Broken Region in the year 2000. Areas that are highly suitable for apple production are located in the north of the region on the riverine plains, while areas of low suitability are located in the south-west of the region, on steep slopes of the Great Dividing Range.

**Map 5** shows land suitability for the production of apples in the year 2020 under a moderate emissions scenario (B1). Between 2000 and 2020 the area of high suitability for growing apples will extend south, crossing the Goulburn River in the west and stretching down as far as Lake Makoan in the east. The area of low suitability will migrate upslope, but will not change substantially in the size of the area.

**Map 6** shows land suitability for the production of apples in the year 2050 under a moderate emissions scenario (B1). Between 2020 and 2050 the contiguous area of high suitability for apple production will move further south, extending along the Goulburn valley as far as Nagambie and almost reaching Seymour. While these areas will extend as far as Euroa and pass Benalla, areas in the north that were once highly suitable will become moderately suitable. The overall area of apple suitability will remain almost the same. Areas of low suitability will diminish only slightly.

**Map 7** illustrates the predicted land suitability for growing apples across the Goulburn - Broken Region in the year 2050 under an extreme emissions scenario (A1F1). Under this scenario the area highly suitable land for the production of apples is reduced in overall size and moves significantly to the central west of the region. The area of high suitability identified in the 2000 scenario is almost completely reduced to moderately suitable. However the area does not move significantly south when compared to the moderate emissions scenario for 2050.

**Map 8** illustrates the predicted change in suitability of climatic conditions for growing apples in the Goulburn - Broken Region between 2000 and 2050. This indicates clearly that areas in the central west of the region will have increased suitability for growing apples, while areas in the north of the region, which currently encompass highly suitable areas, will decrease in suitability. An intermediate region north of Benalla, Shepparton and Kyabram will remain largely unchanged, as will areas in southern part of the region where steep terrain becomes an overriding factor.
Map 4  Apple Suitability 2000 – Base Climate

Apple Suitability 2000 Goulburn - Broken Region
Early - Late Yield 30 - 60 tonnes/ha
Climate Data from OZClim Climate Scenario Generator
Base Climate (2000)

This map is suitable for strategic planning purposes, rather than specific site investigation. Further site investigation should be undertaken prior to site-specific development proceeding.
Map 5  Apple Suitability 2020 - B1 Scenario

This map is suitable for strategic planning purposes, rather than specific site investigation. Further detailed site analysis should be carried out prior to site-specific development proceeding.
Map 6  Apple Suitability 2050 - B1 Scenario

Apple Suitability 2050 Goulburn - Broken Region
Early - Late Yield 30 - 60 tonnes/ha

Climate Data from OZClim Climate Scenario Generator
CSIRO Mk3 Climate Model - Scenario B1 (2050)

Data source: Climate data - CSIRO-OzClim (Data Scale: 1:250,000)
Sols and ERI data - DPI, 2015/2016 (Data Scale: 1:250,000)
Data source: Corporate Geospatial Data Library, DPI, 2008 (Data Scale: 1:25,000), using Geodetic projection.

This map is suitable for strategic planning purposes, rather than specific site investigation. Further detailed site analysis should be carried out prior to site-specific development proceeding.
Map 7  Apple Suitability 2050 - A1F Scenario

Apple Suitability 2050 Goulburn - Broken Region
Early - Late Yield 30 - 60 tonnes/ha

Climate Data from OZClim Climate Scenario Generator
CSIRO Mk3 Climate Model - Scenario A1F1 (2050)

Prepared for: Options for Victorian Agriculture in a ‘New’ Climate
Jenny, 2004 CSIRO
Model No: A1-F-Mk3-implicit
Workflow: Transverse Mercator/Projection

Data source: Climatic data - CSIRO-OZClim (Data Scale: 1:250,000)
Sides and ENH data - CGL, 2007/2010 (Data Scale: 1:250,000) State
data source: Corporate Geospatial Data Library, CGL, 2008 (Data
Scale: 1:25,000), using Geodetic Projection.
Map 8   Apples, Climate Suitability Change 2000 - 2050

Data source: Climate data - CSIRO-OzClim (Data Scale: 1:250,000).
Topo and DEM data - DPI, 2009 (Data Scale: 1:250,000).
State data source: Corporate Geospatial Data Library, DPI, 2008 (Data Scale: 1:25,000), using OsmAnd Population.

This map is suitable for strategic planning purposes, rather than specific site investigation. Further detailed site analysis should be carried out prior to site-specific development proceeding.
Table 1 shows that between 2000 (base climate) and 2050 (B1 scenario), there has been a large increase in highly suitable land for apples, with a major decrease in moderately suitable land and a minor decrease in low suitable land. In 2000, 15% of the Goulburn Broken is rated as having high suitability for apples and in 2050 the model predicts that 32% of the region will have high suitability, over double of the 2000 area. Moderately suitable land will decrease from 80% to 64% of the Goulburn Broken region. Restricted areas remain unchanged, while low suitable areas decrease from 2.7% in 2000 to 2.1% in 2050. Comparison of the B1 2050 (moderate emissions scenario) and A1F1 2050 (high emissions scenario), shows that there are differences in the area of low, moderate and high land suitability for apples. The B1 2050 scenario predicts more highly suitable land for growing apples, when compared to the A1F1 2050 scenario.

Table 2 shows the results of the change detection analysis on apples between 2000 (base climate) and 2050 (A1F1 - high emissions scenario). The results show that almost 48% of the Goulburn Broken Region is predicted to have increased suitability for apples, about 13% of the region will decrease in suitability for apples and about 38% of the region will remain unchanged.

<table>
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<th>Scenario</th>
<th>Suitability</th>
<th>Area (Ha)</th>
<th>Area %</th>
<th>Area (Ha)</th>
<th>Area %</th>
<th>Area (Ha)</th>
<th>Area %</th>
<th>B1 Change 2000 – 2050 (Ha)</th>
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</thead>
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Table 1 Area Statement – Apples

Table 2 Change Detection Analysis of Apples

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<th>Change in Suitability</th>
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<th>% of total area</th>
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Land suitability for growing pears in the Goulburn - Broken Region

The commodity maps developed by the modelling process clearly outline the predicted impact of climate change on suitability for growing pears in the Goulburn - Broken Region.

Map 9 shows land suitability for the production of pears across the Goulburn - Broken Region in the year 2000. Areas that are highly suitable for pear production are located in the north of the region on the riverine plains, and in an area around Rushworth and Murchison, while most areas of low suitability are located in the south-west of the region, on steep slopes of the Great Dividing Range. The bulk of the region is rated as moderately suitable for pear production.

Map 10 shows land suitability for the production of pears in the year 2020 under a moderate emissions scenario (B1). Between 2000 and 2020 the area of high suitability for growing pears will extend to the south-west, as far as the Goulburn River in its western extreme and further south than Lake Makoan in its southern extreme. The overall area of high suitability will grow by about 30 per cent. The area of low suitability will not change substantially in area.

Map 11 shows land suitability for the production of pears in the year 2050 under a moderate emissions scenario (B1). Between 2020 and 2050 the contiguous area of high suitability for pear production will extend to the west of the region spanning an area between Barmah in the north and Rushworth in the south. Significant areas will also remain in the eastern section of the region, north of Lake Makoan. Under this scenario, the overall area of high pear suitability will increase by about 10 percent and areas of low suitability will decrease by about 10 percent.

Map 12 illustrates the predicted land suitability for growing pears across the Goulburn - Broken Region in the year 2050 under an extreme emissions scenario (A1F1). Under this scenario, the area highly suitable for the production of pears remains approximately the same, but the contiguous area highly suitable moves significantly to the central west of the region. The area of high suitability identified in the 2000 scenario is almost completely reduced to moderately suitable. A relatively isolated area classified as highly suitable remains in the west of the region around Lake Makoan, and areas of low suitability retreat up the southern flanks of the Great Dividing Range and reduce in area by about 20 percent.

Map 13 illustrates the predicted change in suitability of climatic conditions for growing pears in the Goulburn - Broken Region between 2000 and 2050. This indicates clearly that areas in the central west of the region will have increased suitability for growing pears, while areas in the north of the region, which currently encompass highly suitable areas, will decrease in suitability. An intermediate region north of Benalla, Shepparton and Kyabram will remain largely unchanged, as will areas in southern part of the region where steep terrain becomes an overriding factor.
Map 9  Pear Suitability 2000 – Base Climate

Pear Suitability 2000 Goulburn - Broken Region
Early - Late Yield 30 - 60 tonnes/ha
Climate Data from OZClim Climate Scenario Generator
Base Climate (2000)

This map is suitable for strategic planning purposes, rather than specific site investigation. Further detailed site analysis should be carried out prior to site-specific development proceeding.

Data source: Climate data - CSIRO-OzClim (Data Scale: 1:755,000); Soil and ESR data - DPI, 2001/2002 (Data Scale: 1:50,000); Base data source - Corporate Geospatial Data Library, DPI, 2008 (Data Scale: 1:25,000); Australian Topographic Projection.

Prepared for Options for Victorian Agriculture in a 'New' Climate.
July, 2004 EPP
Model by: Baselab (000 ecos)
Map 10  Pear Suitability 2020 - B1 Scenario

Pear Suitability 2020 Goulburn - Broken Region
Early - Late Yield 30 - 60 tonnes/ha
Climate Data from OZClim Climate Scenario Generator
CSIRO Mk3 Climate Model - Scenario B1 (2020)

This map is suitable for strategic planning purposes, rather than specific site investigation.
Further detailed site analysis should be carried out prior to site-specific development proceeding.
Map 11  Pear Suitability 2050 - B1 Scenario

Pear Suitability 2050 Goulburn - Broken Region
Early - Late Yield 30 - 60 tonnes/ha

Climate Data from OZClim Climate Scenario Generator
CSIRO Mk3 Climate Model - Scenario B1 (2050)

This map is suitable for strategic planning purposes, rather than specific site investigation. Further detailed site analysis should be carried out prior to site-specific development proceeding.
Map 12  Pear Suitability 2050 - A1F Scenario

Pear Suitability 2050 Goulburn - Broken Region
Early - Late Yield 30 - 60 tonnes/ha

Climate Data from OZClim Climate Scenario Generator
CSIRO Mk3 Climate Model - Scenario A1F1 (2050)

Data source: Climate data - CSIRO-OZClim (Data Scale: 1:250,000),
Socio and ENS data - DPI 2001/2002 Data Scale: 1:250,000, Basis Data source: Corporate Geospatial Data Library, DPI, 2004 (Data Scale: 1:25,000), Using Geodre Projections.

Prepared for: Options for Victorian Agriculture in a ‘New’ Climate
June 2004 GRIP Model No: A1F1(2050)
Worps (Transverse Mercator) Projection

This map is suitable for strategic planning purposes, rather than specific site investigation. Further detailed site analysis should be carried out prior to site-specific development proceeding.
Table 3 shows that between 2000 (base climate) and 2050 (B1 scenario), there has been a large increase in highly suitable land for pears, a decrease in moderately suitable land and a small decrease in low suitable land. In 2000, 8% of the Goulburn Broken is rated as having high suitability for pears and in 2050 the model predicts that 17.3% of the region will have high suitability, over double of the 2000 area. Moderately suitable land will decrease from 86% to 78% of the Goulburn Broken Region. Restricted areas remain unchanged, while low suitable areas decrease from 4.3% in 2000 to 3.5% in 2050. Comparison of the B1 2050 (moderate emissions scenario) and A1F1 2050 (high emissions scenario), shows that there are differences in the area of low, moderate and high land suitability for pears. The B1 2050 scenario predicts more highly suitable land for growing pears, when compared to the A1F1 2050 scenario.

Table 4 shows the results of the change detection analysis on pears between 2000 (base climate) and 2050 (A1F1 - high emissions scenario). The results show that almost 50% of the Goulburn Broken Region is predicted to have increased suitability for pears, about 13% of the region will decrease in suitability for pears and about 37% of the region will remain unchanged.

### Table 3  Area Statement – Pears

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<th>Pears</th>
<th>Number of hectares and percentage of Goulburn Broken area for each suitability class.</th>
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<td>2000 (Base)</td>
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<tr>
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<td>Area (Ha)</td>
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<table>
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<th>Scenario A1F1</th>
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<th>Area %</th>
<th>A1F1 - B1 2050 Difference (Ha)</th>
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### Table 4  Change Detection Analysis of Pears

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<td>Increased</td>
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REGIONAL SCENARIOS: MALLEE WIMMERA – WHEAT

Mallee – Wimmera Region

The Mallee – Wimmera Region covers an area of approximately 69,300 square kilometers, about 30% of Victoria’s total area, (see Map 14). The region is agriculturally diverse, extending into key irrigation areas, extensive dryland cropping and grazing regions. Dryland farming includes sheep and cattle grazing, grains, legumes and hay crops. Irrigated agriculture includes citrus, vegetable production and horticulture.

Map 14 Mallee Wimmera Region, South-Eastern Australia

This region produces up to 50% of Victoria's wheat, 90% of Victoria's dried fruits, 30% of Australia's wine grapes, with significant quantities of citrus, avocados, olives, and a wide variety of vegetable crops.

Approximately 38% of the region is public land that consists mainly of parks including the Murray-Sunset National Park, Wyperfeld National Park, Hattah-Kulkyne National Park and Murray-Kulkyne Park. There are 913 wetlands in the Mallee including 14 "high value" wetlands and there are 500 small reserves used for conservation, scattered through the agricultural area and large tracts of riverine and dryland State Forest.

The entire region is underlain by highly saline groundwater not far beneath the surface. The majority of soil types in the region are shallow and fragile, have poor fertility and are prone to degradation.
Wheat in the Mallee-Wimmera

Wheat is the most important cereal grain in world commerce. Wheat production in Australia has an annual gross value averaging A$3.1 billion over the last five years. Australia is a relatively small producer of grain, with the major cereals, wheat and barley each accounting for around 3% of annual world production. This is a buoyant industry, with wheat yields, on average, rising by around 2.3% per year over the past 20 years. North-west Victoria is the centre of wheat production in this state (see Map 15). The Mallee - Wimmera Region accounts for almost 85% of the total Victorian wheat production.

Map 15  Area of wheat grown in Victoria - hectares by shire (Hillman and Smith, 1996)

Within this total production, there is some variation in quality, due to the suitability of different varieties grown in certain environments for the manufacture of particular foods. Particular wheat harvests are segregated to maintain quality, based on consumer demand. The majority of wheat in Victoria, for instance, can be regarded as segregated into Australian Hard 1 (minimum protein 11.5%), Australian Premium White (minimum protein 10.0%) and Australian Standard White. Special categories of segregations are Australian Noodle (protein range 9.5%-11.5%), Australian Soft 1 (maximum protein 9.5%) and Australian Feed. Varieties not meeting the specifications of these segregations will be received as Australian General Purpose. The high protein wheats sought by domestic millers for traditional bread products come from the Mallee (Hillman and Smith, 1996).

However, as domestic demand is limited due to Australia's small population, about 80% of our wheat and barley is exported. This results in Australia accounting for between 8% and 15% of world trade in each of these grains, and making it the fourth largest exporter after the United States, Canada and the European Union (Australian Foods, http://www.australianfoods.com/community/community_all.htm?id=1).

Information in this section has been obtained from Hillman M. and Smith I. Growing Wheat (1996) Department of Primary Industry, Notes Series.
Weighting the Criteria

Land suitability for Spring Wheat was conducted considering the short growing season of Meering and Frame varieties with Mallee sowing occurring in May and Wimmera sowing occurring in June each year, to produce a yield of between 1 to 6 tonnes per hectare.

Figure 11 represents the hierarchy and weightings of the critical growth criteria (climate and soil) for the production of Spring Wheat at 1 to 6 tonnes per hectare per year.
SPRING WHEAT
SHORT SEASON - MEERING / FRAME VARIETIES
Yield 1 - 6 tons/ha
Wimmera Sowing - June / Mallee Sowing - May
Criteria for Growth
AHP HIERARCHY

Figure 11  Spring Wheat Land Suitability - Criteria for Growth
Experts were consulted to identify recent good, moderate and poor wheat production years in the Mallee-Wimmera. It was decided that 1996 was a good year for wheat production, 1992 was moderate year and 2002 was a poor year. Climate data was received from the Bureau of Meteorology for the years 1992, 1996 and 2002 and incorporated into the Spring Wheat land suitability model.

The wheat land suitability model was run for these three different years, representing what was a good, moderate and poor year in terms of production and climate. The output from the model for the three years reflect changes in the climatic factors of that year and therefore should indicate the land suitability of Spring Wheat based on variations in climate.

Map 16 shows land suitability for the production of Spring Wheat across the Mallee-Wimmera Region in 1992. The model was developed for Meering and Frame short season varieties to yield 1-6 tonnes per hectare, with sowing in June in the Wimmera, and May in the Mallee. As mentioned, 1992 was identified by expert opinion as a moderate production year.

Climate data for the model was obtained from the Bureau of Meteorology, soils data was developed by DPI, base data from the DSE Corporate Geospatial Data Library at 1:25000 and topographic information was included from the Auslig Geodata Topo-250k at 1:250,000.

While a few small areas in the south east are identified as having high suitability for growing wheat, the bulk of the region is moderately suitable for growing Spring Wheat. Areas in the north of the Mallee are clearly classified as having low suitability and an area around Robinvale is classified as restricted. Areas that are restricted fall outside the requirements of the predicted yield and would be likely to produce yields of less than 1 tonne per hectare. In particular, around Robinvale a combination of increased heat stress and low rainfall indicate that this area would not be suitable for the production of wheat.

The small areas of high suitability in the south east around the Grampians represent areas of high orographic rainfall and highly suitable soils. It should be noted however, that this may be an anomaly caused by the coarse texture of the climate data.

Map 17 shows land suitability for the production of Spring Wheat across the Mallee-Wimmera Region in 1996. The model was developed for Meering and Frame short season varieties to yield 1-6 tonnes per hectare, with sowing in June in the Wimmera, and May in the Mallee. As mentioned, 1996 was identified using expert opinion as a good production year.

While a few small areas in the south east are identified as high suitability for growing wheat, the bulk of the area is moderately suitable. Areas in the north of the Mallee are clearly classified as having low suitability. However, unlike the moderate year, the...
area around Robinvale is classified as having low suitability and is not classified as restricted.

The areas of high suitability around the Grampians have changed slightly, but their areas are still too insignificant, at this scale, to indicate a viable area of high suitability.

Overall the areas of suitability have changed little from the moderate year. The most significant change is that some areas around Murrayville in the west of the Mallee and Patchewollock and Speed in the centre of the Mallee that were classified as having low suitability in the moderate year, are now classified as having moderate suitability.

Map 18 shows land suitability for the production of Spring Wheat across the Mallee-Wimmera Region in 2002. The model was developed for Meering and Frame short season varieties to yield 1-6 tonnes per hectare, with sowing in June in the Wimmera, and May in the Mallee. As mentioned, 2002 was identified by expert opinion as a bad production year.

While the area around the Grampians in the south east is still identified as highly suitability for growing wheat, a large tract of land in the centre of the region, that was classified as moderately suitable in the moderate and good years, is now classified as having low suitability. Of particular significance is the substantial area in the north of the region which is now classified as restricted. That is, this vast zone is deemed not suitable for growing Meering or Frame varieties to achieve yields greater than 1 tonne per hectare.

The areas of high suitability around the Grampians have enlarged to some extent, but their areas are still too insignificant, at this scale, to indicate a viable area of high suitability. Note that topography is not included in the model; in the case of the Grampians, the inclusion of topography could well exclude these areas.
Map 16  Spring Wheat Suitability 1992

Spring Wheat Suitability Mallee-Wimmera 1992
Moderate Production Year
Short Season - Moering / Frame Varieties
Yield 1–6 tonnes/ha
Wimmera Sowing - June / Mallee Sowing - May
Climate Data from Bureau of Meteorology

Legend:
- High
- Moderate
- Low
- Very Low
- Restricted

Data source: Climate 2000 - Bureau of Meteorology, 2002
GIS aand DEM data - DPI, (Regional) (Data Scale: 1:25,000)
Base data source: Corporate Geospatial Library, DPI, 2004
(Data Scale: 1:25,000), AusTopo, Survey South Australia 2004

This map is suitable for strategic planning purposes, rather than specific site investigation. Further detailed site analysis should be carried out prior to site-specific development proceeding.
Map 17  Spring Wheat Suitability 1996

Spring Wheat Suitability Mallee-Wimmera 1996
Good Production Year
Short Season - Merino / Frame Varieties
Yield 1-6 tonnes/ha
Wimmera Sowing - June / Mallee Sowing - May
Climate Data from Bureau of Meteorology

This map is suitable for strategic planning purposes, rather than specific site investigation. Further detailed site analysis should be carried out prior to site-specific development proceeding.
Map 18  Spring Wheat Suitability 2002

Spring Wheat Suitability Mallee-Wimmera 2002
Bad Production Year

Short Season - Meering / Frame Varieties
Yield 1-6 tonnes/ha
Wimmera Sowing - June / Malise Sowing - May
Climate Data from Bureau of Meteorology

Mallee Region
Wimmera Region

This map is suitable for strategic planning purposes, rather than specific site investigation. Further detailed site analysis should be carried out prior to site-specific development proceeding.

Data source: Climate 2002 - Bureau of Meteorology, 2002
GSM and DEM data - DPI, (vc:012002) (Data Scale: 1:25,000)
Bare data source: Corporate Geospatial Library, DPI, 2004
(Bare Scale: 1:25,000); AusTopo-Australian NTVD35

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April, 2004 SIP
Model No: Wheat02
Wormap (Transverse Mercator) Projection

Phase 2 – Volume One

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RELATING CLIMATE CHANGE TO PRODUCTIVITY AND SUITABILITY

An effort was made to find the relationship between change in land suitability due to climate and crop production. Recent historical (to offset any significant change in technological influence) climate data were used to perform land suitability analysis of Spring Wheat in the Mallee-Wimmera Region. Climate data was received from the Bureau of Meteorology for the years 1992, 1996 and 2002, corresponding to moderate, good and poor years. The climate data was incorporated into the Spring Wheat land suitability model.

Agricultural survey/census data from the Australian Bureau of Statistics (ABS) was used at the parish level to determine wheat yields in each parish within the Mallee – Wimmera Region. However, ABS no longer collects data at the parish level because of accuracy issues, and therefore 2002 wheat production data is not available at the parish level. Statistical Local Area (SLA) level data could be used, but wheat production data for 2002 at the SLA level will not be available until after July 2004. Additionally, the scale of SLA data is coarse and would not allow for detailed analysis of variation of wheat yields across the Mallee – Wimmera Region. Therefore, 2002, considered by experts as a ‘bad’ year was dropped from the analysis.

Wheat land suitability due to climate change in the two chosen years 1992 and 1996) were then compared to actual wheat production per hectare in those years. This was done so that the Spring Wheat land suitability model outputs could be compared to real yield data from the relevant years to test if land suitability was a good indicator of productivity. It was also decided that the soil section of the model should be removed in order to show just climate related features. Soil characteristics were assumed to be constant.

A correlation coefficient analysis was carried out using the following method:

- Composite climate suitability layers for wheat (grids created by the land suitability model) were converted to vector layers (shape files).

- Those climate suitability shape layers for each of those two years and parish layers (shape files) having respective years of production data were UNIONed using ArcView GIS. This produced datasets having both a climate suitability index and production data for wheat.

- The datasets were then modified by dropping those areas having no yield data or suitability less than one. Datasets were then exported so that it can be analysed using EXCEL spread sheet.

- EXCEL was then used to calculate Pearson correlation coefficients (r) between climate suitability index for wheat and wheat yield per hectare for 1992 and 1996.
Table 5  Pearson correlation coefficient (r) between Climate Suitability and Production

<table>
<thead>
<tr>
<th>Year</th>
<th>Polygons</th>
<th>r</th>
<th>Significance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>401</td>
<td>+0.254</td>
<td>Significant at 1%</td>
</tr>
<tr>
<td>1996</td>
<td>550</td>
<td>+0.347</td>
<td>Significant at 1%</td>
</tr>
</tbody>
</table>

These results recorded in Table 5 show that there is a significant positive relationship between climate influence on land suitability and yield. It should be noted however, that there are many other factors that were not included in the model. For example, analysis of the yield data showed generally higher wheat yields around major towns and transport corridors. This could suggest that factors other than biophysical, (i.e., economic and social factors), could also be influencing wheat production.

There has been a lot of discussion about how to use real yield data to calibrate the model. This is because a large number of farm management issues impact on yield and these are not directly allowed for in the model, though it is assumed that experts while participating in the model development do reflect their knowledge based on best management practices. For example late autumn rain can be accommodated by using a cultivar that has a shorter growing cycle. Thus late rain in the model would indicate lower suitability for the area, but the farmer has accounted for this by changing his management practice. Use of superphosphates may allow high yield production in low suitability areas and therefore wheat suitability based on biophysical factors alone may not be representative of wheat production.

There is still discussion whether it is preferable to have a comprehensive model – that would need to include a number of additional factors or whether the model should be simplified even further.

This exercise, in effect, largely related the spatial variability of climate to production at two temporal snapshots. An improved methodology would be to study historical data of a suitable wheat producing area over a period of say, 20 years (1980- present), to determine the temporal scenario of climate variability and its effect on land suitability for wheat, and then to relate the present climate variability suitability relationship to future climate scenarios.
ADAPTATION TO CLIMATE CHANGE AND RISK ASSESSMENT

It is clear that the observable spatial pattern of yield in the wheat industry is influenced by a raft of other factors other than the purely biophysical factors. At the very local scale, the viability of a particular wheat crop must hinge on an appropriate temporal and spatial distribution of rainfall and temperature. However, the pattern of adaptation to climate change in agriculture will be partly determined by the broad scale response to probable changing climatic conditions by government and farming organisations. It will also be determined by the normal, farm scale, response to climate variability in the continual pursuit of higher farm income. Additionally, it will be determined by the natural response of other environmental components to these changed climatic conditions.

ADAPTATION IN THE WHEAT INDUSTRY

In the Wheat Industry recent changes have seen the loosening of government control and a gradual deregulation of the market. Substantially, under present circumstances, adaptation to changing climate conditions will be born by individual farmers.

Howden et al (2003) describe the key areas of adaptation for cropping industries as: varietal change, species change, planting time variation, crop management, nutrient management, erosion management, salinisation management, moisture conservation, improved seasonal forecasting, irrigation, monitoring and evaluation, management of pests and diseases, R&D, education, land use change, and financial institutions. While all these areas can be influenced by government policy, all, except for R&D and education, are responses required of individual farmers.

The most important factor regarding adaptation in the Wheat Industry is the development of new varieties to take advantage of marginal growing conditions. The continued improvement of crop value in marginal climate conditions will provide an impetus to direct adaptation to the ongoing change represented by climate change. In particular, the development of two new varieties Drysdale and Rees are thought to offer up to a 5% increase in yield in dry areas.

The Grains Research and Development Corporation (GRDC) consider that the uptake of new genetic technology is dependant upon grower confidence and the accessibility of information about cultivar performance. This uptake has been assisted by the trend toward new breeding entities and a market driven crop breeding program which is a departure from the previous centralised, government driven approach (Enright, 2004).

According to research conducted for the GRDC, 34% of grain growers have changed crop production practices in the last two years as a reaction to new opportunities presented by advances in scientific research and development. That is, they are adopting new varieties and updating their crop production practices. Enright (2004) argues that a particular product emphasis of this change is the improved treatment of
insect infestation on grains storage, and a large increase in lucerne seed sales in many areas, the latter indicating increased investment in a strategy to alleviate dryland salinity and weed growth.

The adoption of new genetic technologies is dependant on access to the largest possible pool of germplasm. In particular, the success of this genetic research is dependant on collaboration with international organisations such as the International Maize and Wheat Improvement Centre in Mexico. This type of collaborative work has resulted in the continuing development of 'synthetic wheats', where commercial varieties are being crossed with their wild relatives to produce wheat varieties that are more tolerant to drought, heat and frost.

Other factors that will affect the viability of particular areas for growing wheat include the development of high rainfall varieties and the increasing cost of fertiliser. Recent research has been successful at extending the viability of wheat varieties into high rainfall environments. In particular, varieties have been developed that are resistant to Barley Yellow Dwarf Virus (BYDV). Howden et al (2003) speculate that under more extreme climate change scenarios the increased cost of fertiliser was not clearly offset by increased farm income.

The report by (Howden et al, 2004) has predicted that investment in developing adaptation strategies, however, could be highly effective. In particular it found that adaptation strategies such as changing varieties and changing planting windows would change the mean value of national production from a reduction of $35 million a year due to climate change, to a gain of $61 million; that is a benefit of nearly $100 million per year.

Interactions with other environmental variables effected by climate change may also have unknown consequences for wheat production. The encroachment of dryland salinity onto cropping land, or changes to soil fertility could adversely influence overall wheat yield. Overriding all local and regional scale adaptation to climate change will be the response of international wheat markets. Victoria exports about 80% of its wheat crop, and the international price is influenced by supply, demand, exchange rates and climate.

While, at the local scale, the impact of climate change on agricultural management will be significant, at the regional scale, the value and characteristics of overall wheat production will be influenced by the uptake of adaptation strategies. However, the outer limits of adaptive strategies are still largely unknown.

**ADAPTATION IN THE APPLE AND PEAR INDUSTRY**

In the production of Apples and Pears, as with other commodities in the horticulture and vegetable industries, considerable effort is expended in avoiding climate risk through the provision of irrigation. As well as drought, extreme climatic events, such as very high temperatures and severe frost can have catastrophic effects on fruit growth and quality. However, Webb et al (2003) postulates that in areas where mean daily temperatures currently do not exceed 25°C during growing season, climate change could be beneficial, while in areas where mean daily temperatures already
exceed 25°C the effect of climate change may be negative. Modelling for this pilot project bears out this general concept in relation to Apples and Pears.

Adaptation to climate change for these commodities, however, may take a very complex route. Unlike annual crop varieties, the adaptive cycle for genetic technologies in Pome Fruits is much longer. In addition to changing varieties, Webb et al (2003) argue that adaptations for horticulture and vegetable crops might include: changing the broad location, changing site location, changing species, altering management to change bud burst or canopy density, changing crop production schedules, increased monitoring, increased use of forecasting, adapting harvesting to allow for increased crop variability, developing new markets and investment in biotechnology and conventional breeding.

While changing the location of a farming activity in the face of changing climatic conditions would be a possibility, it is likely that farmers in areas that become suitable for growing Pome Fruits will take the opportunity to change to Pome Fruit production. Important to these future changes will be the provision of infrastructure and, in particular, a contentious issue will be the provision of water to irrigate these new areas. Currently, 50% percent of fruit crops are irrigated. It is likely that the issue of water availability may be a significant brake on the increase in production of Apples and Pears in the future.

Other issues that effect Apple and Pears include the reduction of chilling time. Deciduous fruit need vernalisation, or accumulated chilling, to promote growth on dormant trees. Webb et al claim that temperature increases of 1°C or more can cause a significant reduction in the number of years in which crops have adequate vernalisation. This is thought to be particularly the case in marginal zones such as Swan Hill in Victoria.

As with the wheat industry, the Pome Fruit industry may be influenced by interactions with other environmental variables under pressure from climate change. These variables, including the encroachment of dryland salinity onto cropping land, and changes to soil fertility, would result in highly uncertain future outcomes.

As a general conclusion, it could be said at root of adaptation in these industries is the need to change farm scale management practices. However, the provision of infrastructure and services to agricultural areas needs to be monitored and anticipated by government agencies and other responsible groups.
ENVIRONMENTAL RISK ASSESSMENT FOR CLIMATE CHANGE IMPACT

In setting priority areas for climate change impacts one needs to assess the critical environmental risks the community is going to face due to climate change. We need to understand the risk of climate change both in terms of biophysical systems and socio-economic systems. A suitable framework is needed to analyse these environmental risks that are going to affect resources that the community utilises for living. The adaptation issues can only be considered effectively when the risks have been identified and prioritised.

Such a framework (Jones 2001) may consider systematic uncertainties of climate change through a sequence of biophysical and socio-economic climate impacts following the IPCC guidelines for assessing climate change impacts and adaptation. A flexible approach is necessary that combines scientific methods and broader social decision-making. The impact threshold needs to be identified reflecting the region and activity. The critical threshold can help assess the adaptation scope and priorities.

As a direct result of the experience of this project, DPI is developing a decision making framework to take the assessment of climate change impact into whole new areas. In particular, a framework is being developed that is iterative– emphasising the importance of an adaptive approach to managing climate change impacts and implementing response measures. Within this broad decision making framework, individual components will also need to be reassessed iteratively. This will allow for the review of decisions, and the examination of the decisions taken in the light of new information on climate change and its impacts.

The Framework should also identify methods and techniques for risk assessment and forecasting, options appraisal and decision analysis. Using these methods/techniques will be important in formulating and delivering policies and projects that are successful in confronting an uncertain and risky future.

This broad framework will allow us to identify, screen, evaluate and prioritise climate risks and options for decisions which promote adaptation to climate change, before moving on to more detailed risk assessments and options appraisals.
LESIONS FROM THE PILOT PROJECT TO DATE

MAIN CONCLUSIONS REACHED IN THE PILOT PROJECT

Key Learning

1. LSA models and Climate Change Impact models can be integrated successfully. This increases the capability of both modelling approaches for determining the biophysical impacts of greenhouse induced climate change on agricultural industries.

2. The models are robust expert systems suitable for providing a long-term perspective at a regional scale, as they: (a) are well suited to average climate conditions, (b) express spatial variation in climate change scenarios, and (c) provide excellent starting points (broad scale) for climate change risks assessment.

However, the modelling tools are limited for building better knowledge about climate change risk management for the following reasons (we learned a lot in relation to this).

1. Climate science and scenarios have extremely high levels of uncertainty. They are based on IPCC estimates associated with various social, economic, and technological storylines. As such, they are not simply extrapolations of historical climate monitoring.

2. Climate change scenarios produce a range of possible future climate. They are not designed to capture changes in present-day variability. Recent improved general circulation models are showing significant skill in modelling extremes and the impacts of climate change on these extremes. This is a significant issue for understanding our “coping ranges” and identifying the particular climate variable that may be important in determining the nature of climate risk.

3. For many climate attributes that are needed to understand plant growth suitability, it is difficult to estimate their response to climate change utilising monthly averaged data, due to temporal uncertainties driving model fitting. This includes: (a) extremes (b) Chill Units (for Pome Fruits) require daily time steps, and there is a need to for better understanding of how vernalisation impacts on some regions (e.g. Goulburn-Broken), and (c) timing and volume of autumn break (for Wheat) requires daily or at least weekly or half week time sequences.

4. There are some spatial problems in calibrating LSA models (e.g.; for Wheat) against years for productivity and climate.

In addition, the Pilot Project substantially concentrated on the biophysical impacts of climate change. There is a need, therefore, to extend this to take into account the holistic consideration of social, economic and environmental impacts.
Overall Learning

1. Impacts are varied across regions and industries, and for different aspects of climate change. For instance, current Pome Fruit varieties will suffer from excess heat accumulation in Goulburn-Broken, while there is no significant impact on Blue Gums in Gippsland. Parallel studies demonstrate that the same applies to other primary industries, such as fisheries, as well as biodiversity.

2. The modelling and mapping involved in the Pilot Project was useful to promote understanding and knowledge about climate change and increase DPI capability.

3. The Science of Climate Change (and Risk) is very complex and requires time, appropriate resources and strong collaboration across DPI to build our capacity and that of primary industries.

4. Even if changes in climate could be accurately predicted, uncertainty would still surround the effects that these changes will have in our society and industries.

5. There is a need for the formulation of a Climate Change Risk-Uncertainty Assessment and Decision-Making Framework to better understand the vulnerability and capacity to adapt to climate change impact on the regions and industries of Victoria.
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