Australian horticulture's response to climate change and climate variability

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QLD Department of Primary Industries & Fisheries

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This report :-

- provides a format and a process whereby individual horticulture industries might determine the Impacts, Adaptation Capabilities, followed by a Vulnerability assessment of those specific industries, and then be in a position to develop Adaptation Strategies to Climate Change.
- reviews the outcomes of CVAP funded research in light of the needs of Horticulture industries specifically, and builds on this research to determine the potential to develop a tool to manage climate variability (with an emphasis on temperature).
- commences answering the questions – “What are the impacts of climate change on three (3) selected horticultural regions, and production systems in those regions?”; “How vulnerable are these selected horticulture regions of Australia and the associated production systems, to climate change?”; and for individual growers in these selected regions, outcomes of this work provides some answers to the question - "What does climate change mean for my farm?"

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Media Summary

This project on horticulture's response to climate change and climate variability was conducted between 2006 and 2008, and engaged with growers, consultants and scientists in three major horticultural regions in Australia.

Together with an assessment of tools capable of assisting growers and their advisers to better manage climate variability, the objective of this project was to commence answering the question – "What are the Impacts of climate change on selected horticultural regions and production systems in those regions, and what Adaptation Strategies will be useful in addressing these impacts?"

For individual growers in these selected regions, outcomes of this work can start to answer the question - "What does climate change mean for my farm and my business?"

Tools used in managing climate variability, have in the main been designed and constructed for a specific purpose and for a specific agricultural or pastoral industry. An assessment of 27 projects funded by the Managing for Climate Variability Program (MCVP) of Land and Water Australia (LWA) has demonstrated that none of these tools have been designed specifically with any horticultural industry or application in mind. This report shows that a different predictive system delivering forecasts with a longer lead time and short season length which are required for horticulture, are more likely to be achieved using dynamical modelling techniques, than previous statistical methods used in tools designed for other agricultural industries.

Dynamical modelling techniques are employed in the Predictive Ocean Atmosphere Model for Australia (POAMA). This is a state-of-the-art seasonal to inter-annual seasonal forecast system based on a coupled ocean/ atmosphere model and ocean/atmosphere/land observation assimilation systems - http://poama.bom.gov.au/experimental/poama15/map_rt.html. Although the outputs are currently only experimental, they provide an opportunity for developing improved temperature forecasts for Australian Horticulture. For this to occur, horticulture needs to engage with climate scientists developing these newer systems, and provide them with details of the specific climate dependant needs of horticulture in Australia.

With increasing temperatures and changes to rainfall patterns which are currently uncertain, the simplest climate change adaptation strategies will be employed and are currently being employed by growers. These will be the use of more adaptable cultivars and a range of cultural practices which enable growers to maintain current production in current locations – i.e. adapt to the 'new' climate in the current location. This will be driven in the first instance to maintain profitability through market timing, market access and market share.

If climate change impacts exceed growers adaptation capacity at a specific location, more adaptation responses will be required. A southward shift of production following the southward shift of agri-climatic zones is then more likely to occur if growers are to maintain profitability through appropriate market timing, market access and market share.

Previous assessments of climate change adaptations have been made for other industries. One of the general conclusions from these analyses is that the best defence against future climate change is to continue to develop the capacity and knowledge to manage our response to current climate variability more effectively.

It is recommended that industry note the priorities, and desired outcomes listed in the Horticulture Climate Change Action Plan, and increase R,D&E investment to address these climate change (and climate variability) priorities.

Technical Summary

Nature of the problem

To date there has been limited research into climate change and climate variability in the Australian horticulture sector, in comparison with the extensive R&D conducted in broad-acre agriculture and the grazing industries. In 2005/06 HAL funded the project – "Scoping Study - Climate Change and Climate Variability - Risks and Opportunities for Horticulture". One of the recommendations was that the steps in addressing climate change in horticulture in Australia should include identifying those industries and/or specific locations which are most at risk from climate change, followed by the development of adaptation strategies for those industries and regions at risk. At the same time, climate variability (particularly temperature) will continue to challenge managers of horticultural supply and demand chains (production and marketing). Forecasting tools need to be developed with the requirements of horticultural industries and managers specifically in mind.

Research undertaken

The first component of this project has focused on understanding how to improve the management of *climate variability* from a horticulture perspective, with an emphasis on temperature variability. A review was conducted of 27 projects previously funded by MCVP across a range of agricultural industries, of which 15 projects provided information or were capable of delivering an outcome which could have application in horticulture.

This project has also sought to commence answering the question – "What are the impacts of *climate change* on selected horticultural regions and production systems in those regions, and what adaptation strategies will be useful in addressing these impacts?" For individual growers in these selected regions, outcomes of this work can start to answer the question - "What does climate change mean for my farm and business?"

Major research findings and industry outcomes

Tools used in managing *climate variability*, have in the main been designed and constructed for a specific purpose and for a specific agricultural or pastoral industry. None of these tools have been designed specifically with any horticultural industry or application in mind.

This report shows that <u>a different predictive system delivering forecasts</u> with a longer lead time and short season length, which are required for horticulture, are more likely to be achieved using dynamical modelling techniques than previous statistical methods used in other agricultural industries. For this to occur, horticulture needs to engage with climate scientists developing these newer systems, and provide them with details of the specific climate dependant needs of horticulture in Australia.

Future *climate change* will deliver <u>impacts</u> to horticulture as a consequence of increasing temperatures and changes to rainfall patterns. The most easily accessed and managed <u>adaptation</u> strategies will be employed and are currently being employed by growers, and these will be the use of more adaptable cultivars and a range of cultural practices which enable growers to maintain current production in current locations – i.e. adapt to the 'new' climate in the current location. This will be driven in the first instance to maintain profitability through market timing, market access and market share.

If climate change impacts exceed growers adaptation capacity at a specific location, then a southward shift of production, following the southward shift of agri-climatic zones, is more likely to occur if growers are to maintain current crop production and profitability through appropriate market timing, market access and market share.

Most of the anticipated climate changes point towards the need for a very high standard of crop management in order to respond to the challenges that expected changes pose. Industry and farm managers will need to distinguish between 'old climate expectations' and 'new climate realities' in determining and implementing new adaptation strategies or options.

Previous assessments of climate change adaptations have been made for agricultural industries other than horticulture. One of the general conclusions from these analyses is that the best defence against future climate change is to continue to develop the capacity and knowledge to manage our response to climate variability more effectively.

Climate change is occurring and there are two options; ignore it in the hope that it will go away and accept the consequences; or develop strategies to adapt to and manage the impacts of climate change.

Horticulture Climate Change Action Plan

The National Agriculture Climate Change Action Plan (NACCAP) was developed with four (4) Focus Areas – Adaptation, Mitigation, R&D and Awareness and Communication.

For simplicity, this Horticulture Climate Change Action Plan has incorporated the R&D Focus Area into both the Adaptation and Mitigation areas – leaving specific Actions which Australian Horticulture needs to address under three (3) Focus Areas – (1) Adaptation, (2) Mitigation, (3) Information, Awareness and Communication.

Recommendations to industry, research peers and HAL

a) Horticulture Climate Change Action Plan

It is recommended that industry note the priorities, and desired outcomes listed in this Action Plan, and increase R,D&E investment to address these climate change (and climate variability) priorities and achieve these outcomes.

b) Managing Climate Variability

It is recommended that industry engages with climate scientists who are developing the Predictive Ocean Atmosphere Model for Australia, and providing them with the information which is specific to the needs of horticulture in Australia.

c) Adapting to Climate Change

It is recommended that industry initiate an R,D&E investment to address these specific climate change issues relating to Adapting to Climate Change; Mitigating Greenhouse Gasses; and informing growers, scientists, politicians and the community

d) Temperature Thresholds

It is recommended that the horticultural industry develop a clear and defined understanding of how climate change will impact cropping systems and businesses in specific regions at temperatures up to 4^{o}C.

Introduction

Background to this project

To date there has been limited research into climate change and climate variability in the Australian horticulture sector, in comparison with the extensive R&D conducted in broad-acre agriculture and the grazing industries. In 2005/06 HAL funded the project – "VG05051: Scoping Study - Climate Change and Climate Variability - Risks and Opportunities for Horticulture". This one-year scoping study focused on the gathering of knowledge on work already undertaken in the area of climate variability and climate change, and the potential for the Australian vegetable industry to capitalise on tools and programs currently available.

The Final Report "Climate Change and Climate Variability – Risks and Opportunities for Horticulture" identified key issues and provided recommendations specifically for the vegetable industry, including conclusions for the horticulture industry as a whole. In summary, the steps in addressing climate change in horticulture in Australia should include identifying those industries and/or specific locations which are most at risk from climate change, followed by the development of adaptation strategies for those industries and regions at risk. At the same time, climate variability (particularly temperature) will continue to challenge managers of horticultural supply and demand chains (production and marketing). Forecasting tools need to be developed, with the requirements of horticultural industries and managers specifically in mind.

There is a large amount of climate information available to grazing and cropping industries, but much of this is not in a form which is useful to horticulture. There is an opportunity to develop and disseminate climate information with specific application to the horticulture sector.

The Scoping Study identified the following climate change priority issues worthy of investigating :-

- What are the climate change impacts for the most vulnerable crops and regions?
- How vulnerable are horticultural crops and regions to climate change?
- Where are the knowledge gaps preventing adaptation to climate change?
- What are the potential adaptation strategies for crops and regions?
- What are the costs and benefits of these adaptation strategies?
- How practical and acceptable are these strategies and what is the capability of industries and individual growers to implement these strategies?
- What are the barriers to adoption?

For horticultural industries to successfully adapt to increasing temperatures and changing rainfall patterns, there will be a need to understand the impact of climate change on specific regions and cropping systems, how vulnerable these regions and cropping systems are, and then develop both pre-emptive and reactive adaptation strategies or options.

1.0 Horticulture Climate Change Action Plan

The National Agriculture Climate Change Action Plan (NACCAP) - www.daff.gov.au/__data/assets/pdf_file/0006/33981/nat_ag_clim_chang_**action_plan**2006.pdf was developed for the Natural Resource Management Ministerial Council in 2006. The NACCAP focuses on research and development to build knowledge, solutions and tools that will assist managers to deal with the impacts of climate change. The outcomes sought are practical methods of climate change adaptation and mitigation for all of Australian agriculture. The NACCP was developed with four (4) Focus Areas – Adaptation; Mitigation; R&D; Awareness and Communication.

2.0 Climate Variability in Australia

The Managing for Climate Variability Program within Land and Water Australia has funded twenty-seven (27) projects which have outcomes for a range of agricultural industries, and potential outcomes and/or information applicable to horticulture.

These projects have developed, modified or utilized tools to manage climate variability and climate change in agricultural industries and regions in Australia. These tools are being used to assist growers to make better management decisions associated with rainfall and in some cases temperature variability.
For horticultural growers to better manage temperature variability, and make improved management decisions, they will need to have available to them tools which have been designed for their specific needs.

The focus of this project will be on temperature variability and impacts, to the exclusion of rainfall effects, because the majority of horticulture in Australia is fully irrigated. While this approach does not discount the importance of rainfall and associated runoff into irrigation storages, it is temperature which determines to a great extent the location and performance of the majority of horticultural commodities in Australia.

3.0 Climate Change in Australia

Most of the anticipated climate changes point towards the need for a very high standard of crop management in order to respond to the challenges that expected changes pose. Industry and farm managers will need to **distinguish between 'old climate expectations' and 'new climate realities**' in determining and implementing new adaptation strategies or options.

Climate affects Australian horticultural industries in a range of ways through impacts on industry location, plant growth, pest and disease risk and product quality (Howden, et al., 2003). Amongst many other considerations, management and infrastructure decisions attempt to account for these climatic effects and risks. Such decisions will usually use the historical climate as a guide to future conditions, as there are no scientifically validated or published tools available which have been designed specifically with the requirements of horticultural industries in mind.

There is increasing evidence that human activities are already changing the global climate, and that more change seems likely. Consequently, historical conditions may become increasingly less pertinent as a guide to industry activities or industry adjustment.

Vulnerability to climate change is a function of the impacts of climate change on regions or farming systems, and the adaptive capacity of the farming systems in these regions. i.e. a particular region or farming system would be considered to be highly vulnerable to climate change, if there is little or no capacity to adapt to (or negate the effects of) the impacts of future climate change.

Vulnerability = Impacts – Adaptive Capacity

The IPCC defines vulnerability as "The extent to which climate change may damage or harm a system" (IPCC, 2001). A vulnerable system is one which is sensitive to changes in climate variables (impacts) and a system which is not able to readily adapt (low adaptive capacity) (Olmos, 2001).

3.1 Rainfall

Since 1900, Australian annual average rainfall shows a moderate increase (7.9mm/decade), but it is dominated by high year-to-year variability (Smith, 2004). While north-eastern Australia has become wetter since 1950, much of eastern and southern Australia has become drier. This is due to a weakening or southward shift of the frontal systems that bring most rain to these regions (Marshall, 2003). Rainfall intensity in eastern Australia has increased from 1910 to 1998, but has decreased in the far southwest of Australia (Haylock and Nicholls, 2000) over this same time period. Over New South Wales, extreme daily rainfall intensity and frequency has decreased from 1950 to 2003 (Hennessy *et al*., 2004b).

The frequency of tropical cyclones in the Australian region has decreased since 1967 (Hennessy *et al*., 2004c), along with an increase in cyclone intensity, possibly as a result of a shift in areas of formation. Explosively developing cyclones, including east coast lows off the New South Wales coast, have increased between 1979 and 1999 (Lim and Simmonds, 2002).

There appear to be many potentially significant impacts of climate change on horticultural industries, some of which may be positive, some negative. It will be essential in reducing the impact of climate change, that a clearer understanding of what these impacts are, and that management strategies be identified and implemented to either offset the negative impacts, or to take advantage of positive responses. Previous assessments of climate change adaptations have been made for other industries (e.g. Howden et al., 2003). One of the general conclusions from these analyses is that the best defence against future climate change is to continue to develop the capacity and knowledge to manage our response to current climate variability more effectively.

3.2 Temperature

Australian annual mean temperatures have increased by 0.9^{o}C since 1910, with significant variations from region to region (CSIRO, 2007; Smith, 2004), with night-time temperatures increasing faster than daytime temperatures. Night-time (minimum) temperatures have particularly risen sharply in the northeast of Australia. There are also trends from 1957 to 2003 of increasing frequency in hot days (35^{o}C or more) of 0.08 days per year and a decreasing trend in cold nights (5^{o}C or less) of 0.16 nights per year (Hennessy *et al*., 2004a).

"The best estimate of annual warming over Australia by 2030 relative to 1990 is about 1.0ºC for the mid-range emissions. Warming will be a little less in coastal areas and a little more inland. The pattern varies little seasonally, although warming is less in winter in the south. The range of uncertainty due to differences between models is about 0.6ºC to 1.5ºC for most of Australia, with the probability of the warming exceeding 1ºC by 2030 being 10-20% for coastal areas, and more than 50% for inland regions." Department of Climate Change (2007). Mean temperature change is likely to be greatest inland and least on the coast. Most warming is expected to occur in spring and summer, and least in winter.

Climate change is occurring and there are two options; ignore it in the hope that it will go away and accept the consequences; or develop strategies to manage climate change.

All horticultural crops are sensitive to temperature, and most have specific temperature requirements for the development of optimum yield and quality (Deuter, 2008).

Climate change will impact horticultural commodities and regions through all of the following :-

- Changes in the suitability and adaptability of current cultivars as temperatures change, together with changes in the optimum growing periods and locations for horticultural crops
- Changes in the distribution of existing pests, diseases and weeds, and an increased threat of new incursions

- Increased incidence of physiological disorders such as tip burn and blossom end rot
- Greater potential for downgrading product quality e.g. because of increased incidence of sunburn
- Increases in pollination failures if heat stress days occur during flowering
- Increased risk of spread and proliferation of soil borne diseases as a result of more intense rainfall events (coupled with warmer temperatures)
- Increased irrigation demand especially during dry periods
- Changing reliability of irrigation schemes, through impacts on recharge of surface and groundwater storages
- Increased atmospheric CO_2 concentrations will benefit productivity of most horticultural crops, although the extent of this benefit is unknown
- Increased risk of soil erosion and off-farm effects of nutrients and pesticides, from extreme rainfall events
- Increased input costs – especially fuel, fertilisers & pesticides
- Additional input cost impacts when agriculture is included in an Emissions Trading Scheme (ETS)

With increasing temperatures, and changes to rainfall patterns which are currently uncertain, the simplest adaptation strategies will be employed and are currently being employed by growers. These adaptation options are likely to be closely associated with management options already well understood by growers (Howden et.al., 2007). These are the use of more adaptable cultivars and a range of cultural practices which enable growers to maintain current production in current locations – i.e. adapt to the 'new' climate in the current location. This will be driven in the first instance to maintain profitability through market timing, market access and market share.

If climate change impacts exceed growers adaptation capacity at a specific location, then a southward shift of production following the southward shift of agroclimatic zones is more likely to occur if growers are to maintain profitability through appropriate market timing, market access and market share (Kingwell, 2006).

Method

Together with an assessment of tools capable of assisting growers and their advisers to better manage *climate variability*, this project has commenced addressing the *climate change* recommendations from project VG05051. One of the recommendations was to identify those regions in Australia which are at most risk from future climate change; and then address this vulnerability by developing adaptation strategies.

This project has sought to commence answering the questions :-

- What are the impacts of climate change on selected horticultural regions and production systems in those regions?
- How vulnerable are these selected horticulture regions of Australia and the associated production systems, to climate change?

This project on horticulture's response to climate change and climate variability was conducted by DPI&F (Qld) and CSIRO Scientists between 2006 and 2008 in partnership with Horticulture Australia Ltd (HAL) and the Managing for Climate Variability Program (MCVP).

The project team engaged with growers, consultants and scientists in three major horticultural regions in Australia (Riverina, New South Wales; Lockyer Valley, South-East Queensland; and the Burdekin, North Queensland). For individual growers in these selected regions, outcomes of this work can start to answer the question - "What does climate change mean for my farm and business?"

The MCVP within Land and Water Australia (LWA) has funded twenty-seven (27) projects which have outcomes for a range of agricultural industries, and potential outcomes and/or information applicable to horticulture. These projects have developed, modified or utilized tools to manage climate variability and climate change in agricultural industries and regions in Australia. These tools are being used to assist growers to make better management decisions associated with rainfall and in some cases temperature variability.

1.0 Horticulture Climate Change Action Plan – A Horticulture Climate Change Action Plan has been developed to highlight the specific needs of Australian horticulture in relation to climate change. This has been built on the National Agriculture Climate Change Action Plan (NACCAP) www.daff.gov.au/__data/assets/pdf_file/0006/33981/nat_ag_clim_chang_**action_plan**2006.pdf , which was developed for the Natural Resource Management Ministerial Council in 2006. The NACCAP focuses on research and development to build knowledge, solutions and tools that will assist managers to deal with the impacts of climate change. The outcomes sought are practical methods of climate change adaptation and mitigation for all of Australian agriculture. The NACCP was developed with four (4) Focus Areas – Adaptation; Mitigation; R&D; Awareness and Communication.
For simplicity, this Horticulture Climate Change Action Plan has incorporated the R&D Focus Area into both the Adaptation and Mitigation areas – leaving specific Actions which Australian Horticulture needs to address under three (3) Focus Areas – (1) Adaptation, (2) Mitigation, (3) Information, Awareness & Communication.

2.0 Climate Variability – activities have focused on understanding how to improve the management of climate variability from a horticulture perspective, with an emphasis on temperature variability, through a review outcomes of previous studies funded by MCVP in a range of agricultural industries. Twenty-seven (27) projects funded by MCVP were assessed, of which fifteen (15) projects provided some information (or were considered to be capable of delivering an outcome) which could have application in horticulture.

This review has assessed :-

- tools to manage climate variability and climate change. These tools have been assessed on their ability to assist growers of horticultural crops to make better management decisions associated with temperature variability especially;
- the need and level of modifications to existing tools which will increase the usefulness of these tools to growers of horticultural crops; and
- the requirements for developing tools suited to horticulture, addressing the specific needs of growers of horticultural crops, including the longer lead times and shorter season lengths (in contrast to those required by broad-acre production systems).

3.0 Climate Change – activities have focused on Impacts, Vulnerability and Adaptation to climate change.

As the next steps in providing a better understanding of the impacts of climate on horticulture industries, this project has provided a format or process whereby individual horticulture industries might determine the Impacts, Adaptation Strategies and the Vulnerability of those specific industries to Climate Change.

To achieve this three (3) horticultural regions were selected, and workshops were conducted in the Riverina, New South Wales; Lockyer Valley, South-East Queensland; and the Burdekin, North Queensland.

Using a combination of desktop studies and engagement with leading growers, consultants and scientists in these three locations, answers to the following questions were sought :-

- Impacts - What are the impacts of climate change on each of the selected horticulture regions and production systems?
- Adaptation Capability – How adaptable are the horticulture production systems in these selected regions of Australia?
- Vulnerability - How vulnerable are these selected horticulture regions and the associated production systems, to climate change?
- Adaptation Strategies - What are some of the potential and acceptable strategies which growers and industries could consider, which will reduce the impacts of climate change on their business?

4.0 Information – activities have focused on development of horticulture specific information.

- Participants at each of the three regional workshops have been provided with climate change scenarios, and other relevant material to assist them in understanding climate change and the impact this will have on their industries.

- A web site ahs been developed which is linked to the HAL Environment and Climate Website (http://www.horticulture.com.au/delivering_know-how/Environment/themes.asp#a_200)

5.0 Adaptation Strategies – activities have focused on determining practical and appropriate adaptation strategies for horticultural industries and growers in the three selected regions.

Results

1.0 Climate Change Action Plan

Summary of findings from Appendix I.
National Agriculture Climate Change Action Plan (NACCAP) focuses on research and development to build knowledge, solutions and tools that will assist managers of Australian agricultural businesses to deal with the impacts of climate change. It was developed with four (4) Focus Areas – Adaptation; Mitigation; R&D; Awareness and Communication.
For simplicity, the Horticulture Climate Change Action Plan has incorporated the R&D Focus Area into both the Adaptation and Mitigation areas – leaving specific Actions which Australian Horticulture needs to address under three (3) Focus Areas – (1) Adaptation, (2) Mitigation, (3) Information, Awareness & Communication.
The Horticulture Plan addresses the horticulture specific 'desired outcomes' and 'priorities' for Australian horticulture's response to climate change, as well as a list of potential questions which will be answered when this plan is fully implemented. An example from each of the Focus Areas is provided below :-

1.1 Adaptation

One of the desired adaptation outcomes for Australian horticulture is the existence of resilient and adaptive horticultural production systems which are less vulnerable to climate change and climate variability.
One of the priorities for Australian Horticulture in achieving this desired outcome will be to iidentify and build on successful strategies of adaptation by the horticultural sector to climate changes already experienced.
A question which actions, addressed by this priority will answer is, "Do horticulture producers (and their advisors) have appropriate tools and an understanding of climate change and variability issues, to avoid the risks and/or take advantage of the opportunities of a variable and changing climate?"

1.2 Mitigation

Two of the desired mitigation outcomes for Australian horticulture are reduced greenhouse gas emissions from horticultural production systems, and profitable horticultural production systems which contribute to greenhouse gas abatement.

Two of the priorities for Australian Horticulture in mitigating greenhouse gasses are to determine the contribution ("Carbon Footprint") which all horticulture (and specific regions and commodities) make to N_2O and CO_2 emissions, and to identify and promote horticulture specific Best Management Practices (BMP) which minimise N_2O and CO_2 emissions, and at the same time promote the simultaneous goals of productivity, sustainability, adaptability and abatement.

Two of the questions which actions addressed by this priority will answer are, "Do we understand how to reduce greenhouse gas emissions from horticulture cropping systems?" and "Are current fertilizer management practices in horticulture appropriate for managing N_2O emissions?"

1.3 Information, Awareness and Communication

Two ddesired awareness outcomes for Australian horticulture is a clear understanding of climate change and climate variability issues by stakeholders in horticulture, and horticulture producers and their advisors having sufficient understanding of climate change and climate variability issues to be able to make appropriate risk management decisions.
Two of the priorities for Australian horticulture for informing growers, scientists, politicians and the community are to develop information products which promote horticulture specific messages to the

community as well as to stakeholders in horticulture, and ddevelop and disseminate specific information to raise awareness in the most vulnerable industries and regions.

A question which these actions addressed by this priority will answer is, "Do horticulture producers (and their advisors) have appropriate tools and an understanding of climate change and variability issues, to avoid the risks and/or take advantage of the opportunities of a variable and changing climate?"

2.0 Climate Variability

2.1 MCVP funded projects

Summary of findings from Appendix II.
Appendix II provides the details of an assessment of MCVP funded projects with outcomes of significance to Horticulture, and how these outcomes can be useful in horticultural industries. Twenty-seven (27) projects funded by MCVP were assessed, of which fifteen (15) projects provided some information (or were considered to be capable of delivering an outcome) which could have application in horticulture.

Currently the limitation on the use of tools for managing climate variability in horticultural industries is the lack of climate science understanding that addresses the lead-time and season length requirements of horticultural industries. The combination of long season (3 months) and short lead-time (zero), which are appropriate for other agricultural industries, is a significant constraint to the use of forecasting tools in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful. Given a sound forecast system that meets the requirements of the industry the appropriate tools can be produced. There are no forecast systems based on the Southern Oscillation Index (SOI) and Sea Surface temperatures (SST) which have been extensively tested for longer lead-times and shorter seasons. There are many tools which have been developed for the management of rainfall variability, but none which address the need for a greater understanding of temperature variability. Temperature variability is the main parameter which affects the performance of most horticultural crops.

- Several projects investigated longer lead time forecasts (2 months or more), and shorter season lengths (1 week to 2 months). These will be of significant interest and usefulness to horticulture if tools encompassing these refinements are available to horticulture.

- One project may have application in the establishment of forestry plantings associated with horticulture businesses, and may well have application in the establishment of some fruit tree species and in some regions of Australia.

- A project supporting nationwide and local monitoring and modelling of evaporative demand has application to R&D in irrigation management in Horticulture.

- Two projects use the computer simulation model APSIM together with paddock specific soil, crop and climate data to generate information about the likely outcomes of farming decisions. A "Yield Prophet" or "Whopper Cropper" for horticulture would require the same crop modelling input as has been developed for the range of broad-acre crops included in APSIM. Additional APSIM modelling capability for horticulture crops will be required for this to become a reality. There exists in APSIM the generic 'PLANT' module. This has recently been parameterised to develop a broccoli and sweet corn module. With similar parameterisation from experimental trials other horticultural crops could be modelled within APSIM.

- A project aiming at developing a new approach to seasonal forecasting based on an understanding of the fundamental physical processes and synoptic systems responsible for rainfall was assessed. A new forecasting system, which has the capacity to deliver forecasts with longer lead times and shorter season lengths (especially for temperature) is what is required in horticulture for improved decision making in a variable climate.

- If the value of weather derivatives can be demonstrated in agriculture, then there are most likely to be similar opportunities to use this tool in horticulture in relation to severe weather events such as frost, cyclones and hail, which have devastating effects on individual growers and industries.

- In complex systems, which exist in agriculture, and especially in horticulture, the processes of engagement and participation by decision makers and scientists are time consuming for the participants, but have the potential to deliver a useful outcome. This participatory process has been used successfully in horticulture (and other areas of agriculture) for developing improved Integrated Pest Management (IPM) outcomes. This could also hold true for complex climate based decision making outcomes in horticulture. Tools to assist this process will need to be available to horticulture for improved decision making to be achieved. The specifications for the development of these tools for managing climate variability could be an outcome of a participatory engagement process with horticulture growers and their advisors.

- Several projects have used a similar approach to that which is being taken in this current HAL funded project (AH06019) which aims to :-
    - Analyse how climate has been changing
    - Assess how these changes have influenced cropping enterprises
    - Identify key management adaptations that will enable farmers to more effectively manage climate variability as well as future trends in climate arising through climate change
    - Identify priority issues that could be better managed with enhanced use of information on historical climate variation, seasonal climate forecasts and trends in climate factors
    - Identify key climate change adaptation strategies

- A similar approach as "Masters of the Climate revisited: Innovative farmers coming through drought**",** using practical horticulturaly oriented case studies, would be of benefit to horticulture. An assessment of the successes and failures experienced by farmers in applying seasonal climate forecasting to various horticultural practices in their efforts to manage for climate variability, would highlight the need for, and the specific requirements of tools to assist horticulture growers and their advisors, to better manage climate variability.

- Several projects confirmed that there is a need to develop and deliver an integrated package of information, tools and training that targets climate risk management in terms of content, timing and delivery. Horticulture is no different from other segments of agriculture in its need to understand farmer knowledge, attitudes, skills, aptitudes and current practice in relation to climate risk management. Similarly, there is a need to develop and deliver an integrated package of information, tools and training that targets the specific needs of horticulture.

2.2 Tools

Appendix III provides details of the potential for the development of a Tool to manage temperature variability for horticulture. It outlines what currently exists, and what is required to provide a tool to better manage climate (temperature) variability in horticulture.

Summary of findings from Appendix III.
Tools used in managing climate variability, have in the main been designed and constructed for a specific purpose and for a specific agricultural or pastoral industry. None of these tools have been designed specifically with any horticultural industry or application in mind.

2.3 What Currently Exists?

Tools and sources of information used in managing climate variability have mainly been designed and constructed for a specific purpose and for a specific agricultural or pastoral industry. Given that none of these tools and information sources have been designed specifically for any horticultural industry or application, they are of some assistance to Australian horticultural growers and their advisors.

- Bureau of Meteorology (BOM) – Seasonal Temperature Outlook – http://www.bom.gov.au/climate/
- LongPaddock – http://www.longpaddock.qld.gov.au/
- Madden Julian Oscillation (MJO) – http://www.apsru.gov.au/mjo/ or http://www.bom.gov.au/climate/tropnote/tropnote.shtml
- AgClimate - http://www.agclimate.org/
- Rainman StreamFlow version 4. - http://www.dpi.qld.gov.au/rainman/
- Southern Oscillation Index (SOI) – http://www.bom.gov.au/climate/glossary/soi.shtml or http://www.longpaddock.qld.gov.au/SeasonalClimateOutlook/SouthernOscillationIndex/index.html or http://www.longpaddock.qld.gov.au/SeasonalClimateOutlook/RainfallProbability/index.html
- Sea Surface Temperatures (SST) http://www.longpaddock.qld.gov.au/SeasonalClimateOutlook/SeaSurfaceTemperature/index.html
- The Predictive Ocean Atmosphere Model for Australia (POAMA) is a state-of-the-art seasonal to inter-annual seasonal forecast system based on a coupled ocean/ atmosphere model and ocean/atmosphere/land observation assimilation systems – Experimental Products are available on the web - http://poama.bom.gov.au/experimental/poama15/map_rt.html - the "Monthly Spatial Map Forecasts" provide temperature forecasts, as a spatial output for all of Australia.

2.4 What is Required to address the needs of Horticulture?

2.41 What should this potential Tool do?

Capacity to provide temperature (and rainfall) forecasts that make an improvement on current temperature (and rainfall) forecast information by providing information that has:

- a lead time of between zero and 6 months;
- a forecast period of 1 – 4 weeks (i.e. a season length of 1-4 weeks); and
- information targeted to assist growers and their advisors in making improved management decisions.

2.42 What capability should this tool have?

1. Be region specific – i.e. capable of providing a forecast for a defined location, e.g. this might be East Gippsland or the Burdekin; or Hay or Manjimup.
2. Forecast Maximum and Minimum Temperatures (from which other factors might be calculated – e.g. heat stress days, diurnal variation, degree days, chilling hours etc.
3. Be specifically designed for the needs of fruit and vegetable growers and their advisors in Australia.

2.43 Limitations of Current Forecast Systems.

Currently the limitation on the use of tools in horticulture is the combination of long season (3 months) and short lead-time (zero), which are incorporated in current tools for managing climate variability. These are appropriate for other agricultural industries, but are a significant constraint to the use of these forecasting tools in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful. Temperature is the major factor in determining where horticulture crops can be grown successfully, and then how well these crops perform under varying seasonal conditions. Horticultural industries' requirements for seasonal temperature (and rainfall) forecasting information is wide and varied (large number of commodities and cropping systems spread over a very wide range of climatic regions).

2.5 What needs to be done to develop this tool?

A different predictive system will be required if a longer lead time and short season length forecast, which is required for horticulture, can be achieved. The SOI and SST based forecast systems which are currently available for rainfall and temperature have been validated only for short lead times and three-month seasons. These are termed statistical prediction systems, however, the future of prediction systems might lie with dynamical prediction systems based on numerical modelling

Significant advances in the development and deployment of dynamical models are expected in the future. A joint development between CSIRO and BMRC is the Australian Community and Earth System Simulator (ACCESS), a coupled model, which will be used as a major component in the POAMA dynamical seasonal prediction system at the Bureau of Meteorology.

The Predictive Ocean Atmosphere Model for Australia (POAMA) is a state-of-the-art seasonal to inter-annual seasonal forecast system based on a coupled ocean/ atmosphere model and ocean/atmosphere/land observation assimilation systems - http://poama.bom.gov.au/experimental/poama15/map_rt.html - the "Monthly Spatial Map Forecasts" provide temperature forecasts, as a spatial output for all of Australia. This is currently an experimental forecast, and the output covers the whole of Australia in one map. An improvement on this will be the production of more regional outputs, e.g. – East Gippsland, The Burdekin etc, which will provide more useful temperature forecast information on which Horticultural managers can make improved decisions.

3.0 Climate Change (Impacts, Vulnerability and Adaptation Strategies)

As the next steps in providing a better understanding of the impacts of climate change on horticultural industries, this project has provided a format or process whereby individual horticulture industries might determine the impacts, adaptation capacity, and hence the vulnerability of those specific industries or regions to climate change.

To achieve this three horticultural regions were selected and in workshops with leading growers, consultants and scientists, the following questions were posed :-

- What are the likely impacts of climate change on the selected region and production systems, with a particular emphasis on temperature?
- What are the potential and acceptable adaptation strategies which growers have used and could continue to use to reduce the impacts of climate change on their business?

Appendix IV provides details of the three workshops, and their outcomes, conducted in the Riverina, New South Wales; Lockyer Valley, South-East Queensland; and the Burdekin, North Queensland.

Summary of findings from Appendix IV.

Horticulture in Australia consists of a large number of diverse industries (fruit, vegetables, floriculture, turf and ornamentals) which are located in a wide range of production regions because of the diverse micro-climates and soils which are available in those regions. Horticulture contributes ≈ $7 billion (gross value at the farm gate) to the economy every year. On this basis, horticulture is the second largest agricultural industry in Australia after the beef industry. These industries vary in their **vulnerability** to past and future impacts of climate change :-

- **Production Timing** and **Location Suitability** (crops mature earlier and take less time from planting or fruit set to harvest). Currently not vulnerable but depending on the crop and location, those crops which are close to temperature thresholds ('tipping points'), are very vulnerable.

- **Product Quality** (quality affected by increasing heat stress days, and a lack of 'adaptability'). Currently vulnerable, as the availability of new vegetable cultivars specifically adapted to the Australian environment may be restricted as the Australian market for seed is quite small in comparison to the overseas market. Likely to increase in vulnerability.

- **Inputs** (availability and costs of water and fuel). All industries and growers are very vulnerable, as they have limited ability to reduce costs and/or pass on increased costs.

- **Pest and Disease Effects** (increasing activity of pests & diseases – reduced effectiveness of parasites and beneficial organisms – emergence of new pests and diseases). All industries are vulnerable to new and increased pest and disease activity.

All horticultural crops are sensitive to temperature, and most have specific temperature requirements for the development of optimum yield and quality.

Climate change will impact horticultural commodities and regions through all of the following :-

- Changes in the suitability and adaptability of current cultivars as temperatures change, together with changes in the optimum growing periods and locations for horticultural crops
- Changes in the distribution of existing pests, diseases and weeds, and an increased threat of new incursions
- Increased incidence of disorders such as tip burn and blossom end rot
- Greater potential for loss of product quality e.g. because of increased incidence of sunburn
- Increases in pollination failures if heat stress days occur during flowering
- Increased risk of spread and proliferation of soil borne diseases as a result of more intense rainfall events (coupled with warmer temperatures)
- Increased irrigation demand especially during dry periods
- Increased atmospheric CO_2 concentrations will benefit productivity of most horticultural crops, although the extent of this benefit is unknown
- Increased risk of soil erosion and off-farm transport of nutrients and pesticides, due to an increase in the frequency and intensity of extreme rainfall events

With increasing temperatures, and changes to rainfall patterns which are currently uncertain, the most easily accessed and managed adaptation strategies will be employed and are currently being employed by growers. These will include the use of more adaptable cultivars and a range of cultural practices which enable growers to maintain current production in current locations – i.e. adapt to the 'new' climate in the current location. This will be driven in the first instance to maintain profitability through market timing, market access and market share.
If climate change impacts exceed growers adaptation capacity at a specific location, then a southward shift of production following the southward shift of agri-climatic zones is more likely to occur if growers are to maintain current crop production and profitability through appropriate market timing, market access and market share.
This strategy contrasts with other agricultural industries , e.g. sugarcane, where the emphasis is on remaining in the same location and adapting by changing crop species and cropping system.

In documenting the Adaptation Strategies currently being employed by growers who attended the workshops in the Riverina, Lockyer Valley, and the Burdekin, some understanding of the impacts, adaptive capacity and vulnerability of these farming systems can be deduced (Fig 1).

Vulnerability to climate change is a function of the impacts of climate change on regions or farming systems, and the adaptive capacity of the farming systems in these regions. i.e. a particular region or farming system would be considered to be highly vulnerable to climate change, if there is little or no capacity to adapt to (or negate the effects of) the impacts of future climate change.

Vulnerability = Impacts – Adaptive Capacity

Fig 1. - An assessment of Adaptive Capacity and Vulnerability in relation to selected Impacts in three horticultural Regions of Australia.

Impacts	Adaptive Capacity	Vulnerability
Production Timing and **Location Suitability** (crops mature earlier and take less time from planting or fruit set to harvest)	Growers are already making the following adaptations :- Changing marketing plans to account for these changes; Moving some of their production to more favourable locations; and Using more 'adaptable' crops/cultivars. Growers in some regions (summer season), may be able to take advantage of extending production into winter. Growers in other regions (winter season) will have their production season shortened.	Currently not vulnerable. This will change to being vulnerable if crops/cultivars are unable to cope with increasing temperatures (i.e. thresholds are reached). All vegetable growers and regions are vulnerable, if more adaptable cultivars are not available, or more suitable locations are not available. Depending on the crop and location, those crops which are close to temperature thresholds ('tipping points'), will be very vulnerable.
Product Quality (quality affected by increasing heat stress days, and a lack of 'adaptability')	There is a need for more adaptable cultivars for the vegetable industry. The decision makers are the seed companies who currently source the majority of cultivars from overseas breeding programs.	Currently vulnerable, as the market for new vegetable cultivars which might be specifically adapted to the Australian environment is quite small in comparison to the overseas market. Likely to increase in vulnerability.
	Increasing number of heat stress days will result in a narrowing of production windows, and the potential for production to shift to more suitable (cooler) regions.	Growers are currently adapting well. All industries are increasing in vulnerability, especially as available crops/cultivars approach and exceed critical temperature thresholds.
Inputs (availability and costs of water and fuel)	Drought has been a driver of decisions involving access and use of irrigation water. Some vegetable growers have moved production to areas where water is available. Fuel costs will increase (as will all other inputs derived from fossil fuels – fertilizers and pesticides).	Some growers and some industries (especially permanent fruit crops) are very vulnerable (currently and into the future). All industries and growers are very vulnerable, as they have limited ability to reduce costs and/or pass on increased costs.
Pest and Disease Effects (increasing activity of pests & diseases – reduced effectiveness of parasites and beneficial organisms – emergence of new pests and diseases)	Current (and future) Integrated Pest and Disease Management Systems (IPDM) will make a significant contribution to overcoming these impacts.	All industries are vulnerable to increased pest and disease activity (continually improving IPDM systems will be one mechanism to delay and reduce the impacts). All industries are vulnerable to the effects of new pests and diseases (new to Australia and/or new to the region).

Discussion

1.0 Climate Change Action Plan

Activities in this component of the project have focused on developing an Action Plan for horticulture which can be used by policy makers, scientists and growers to understand the priorities and actions needed to address these priorities. This Action Plan has been developed from the National Agriculture Climate Change Action Plan (NACCAP) which focuses on Australian agriculture, whereas the Horticulture Climate Change Action Plan addresses the horticulture specific priorities and desired outcomes for Australian horticulture.
It does this by providing a list of desired outcomes applicable to growers, scientists and policy makers associated with horticulture in Australia.
These desired outcomes can be achieved through actions addressing a list of climate change priorities which are specific to horticulture.

2.0 Climate Variability

Activities in this component of the project have focused on understanding how to improve the management of climate variability from a horticultural perspective, with an emphasis on temperature variability.

Currently the limitation on the availability of tools for use by managers of horticultural businesses is the lack of climate science understanding that addresses the lead-time and season length requirements of the horticultural industry. The combination of long season (3 months) and short lead-time (zero), which are appropriate for other agricultural industries, is a significant constraint to the development of forecasting tools in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful. Given a sound forecast system that meets the requirements of the industry, the appropriate tools can be produced.

There are no forecast systems based on the Southern Oscillation Index (SOI) and Sea Surface Temperatures (SST) which have been extensively tested for longer lead-times and shorter seasons.

This review has confirmed the previous Scoping Study outcome, and identified a number of projects which have activities and outcomes which could provide appropriate input for R&D specifically aimed at applications for managing climate variability in horticulture.

Current tools and sources of information used in managing climate variability have mainly been designed and constructed for a specific purpose and for a specific agricultural or pastoral industry. Although none of these tools and information sources have been designed specifically for any horticultural industry or application, they are of some assistance to Australian horticultural growers and their advisors.

2.1 What is Required to address the Management of Climate Variability needs of Horticulture?

To ensure that any future tools are useful to growers, managers and advisers in the Australian horticultural industry, a number of factors need to be considered. A tool needs to have the capacity to provide temperature (and perhaps rainfall) forecasts that make a significant improvement on current temperature (and rainfall) forecast information by providing :-

- a lead time of between zero and 6 months;
- a forecast period of 1 – 4 weeks (i.e. a season length of 1-4 weeks);
- Be region specific – i.e. capable of providing a forecast for a defined location or horticultural region; and
- Forecast Maximum and Minimum Temperatures (from which other factors might be calculated – e.g. heat stress days, diurnal variation, degree days, chilling hours etc.

2.2 What should to be done to develop this tool to meet the Climate Variability needs of Horticulture?

The Predictive Ocean Atmosphere Model for Australia (POAMA) is a state-of-the-art seasonal to inter-annual seasonal forecast system based on a coupled ocean/ atmosphere model and ocean/atmosphere/land observation assimilation systems - http://poama.bom.gov.au/experimental/poama15/map_rt.html - the "Monthly Spatial Map Forecasts" provide temperature forecasts, as a spatial output for all of Australia

This report shows that a different predictive system delivering forecasts with a longer lead time and short season length required for horticulture, are more likely to be achieved using dynamical modelling techniques, than previous statistical methods.

For this to occur, horticulture needs to engage with climate scientists who are developing these newer systems, and providing them with the information which is specific to the needs of horticulture in Australia.
This engagement has commenced through an involvement in the Eastern Australian Climate Knowledge (EACK) Project, which has thoroughly scoped user needs in terms of improved risk management systems in eastern Australia in relation to climate variability, including the needs of horticulture.

3.0 Climate Change

Activities in this component of the project have focused on impacts, vulnerability and adaptation to climate change, from a horticultural perspective.

As the next steps in providing a better understanding of the impacts of climate on horticulture industries, this project has provided a process whereby individual horticulture industries might determine the impacts, adaptation strategies and the vulnerability of those specific industries to climate change.

Flexibility has been the key to adaptation in horticulture to date, and is likely to continue to be an important component of adaptation strategies as climates continue to change. Growers have been able to manage climate variability reasonably well to date, although major improvements could be made if tools to assist with the management of climate variability, both temperature and rainfall, were designed specifically with the needs of horticultural growers and industries in mind.

The current drought has provided opportunities for some growers who have been able to relocate production to where water for irrigation is available. Those who have done this successfully will be in a much better position to also manage ongoing climate change successfully.

3.1 Climate Change Impacts

Climate change will ***impact*** horticultural businesses, commodities and regions. Impact assessments for broad-acre agriculture, especially for the wheat industry have been published widely. This is not the case for horticulture, except for viticulture. Thresholds for the large range of horticultural crops are also not well known, especially for the vegetable sector.

In Australian horticulture, the following impacts, including some examples, have already occurred and are likely to continue to occur with further increases in temperature :-

Production Timing - crops will develop more rapidly and mature earlier (accelerated phenology). For example - the winter lettuce and brassica season (mid-April to October) in south-east Queensland will be shortened by several weeks to a month by the year 2030, if more adaptable cultivars are not readily available to the industry.

Product Quality and Yield - increased heat stress will affect fruit size, quality and pollination of some crops. For example - for avocados, increased heat stress will adversely affect fruit size and the capacity to 'store' a mature crop on the tree. Floral abortion will occur in capsicum when temperatures exceed 30ºC.

Inputs (Availability and Costs) - more irrigation (water) will be required because of higher evaporative demand, with increasing temperatures. This will increase the costs of purchasing water, if it is available, and pumping water under hotter conditions. This, together with increasing fuel costs, will increase the cost of producing all irrigated crops.

Effects on Cultural Practices - an increasing incidence of out of season and extreme temperature and rainfall events, will affect the timing of cultural practices as well as have negatively affecting yields and product quality. Most crops will develop more rapidly, changing current crop schedules and marketing arrangements.

Pest and Disease effects - in general, higher temperatures will increase pest and disease activity, alter their development rate including that of host crops, and increase survivability of some organisms, especially in warmer winters. Changing rainfall amounts and patterns will modify this temperature effect for each organism. For example - an extra generation of insect pests such as heliothis will be possible in most locations; and higher temperatures will have negative effects on survivability and reproduction of scale parasites in citrus and trichogramma in vegetables.

3.106 - Marketing Arrangements - higher temperatures will change production and marketing arrangements between regions as a result of accelerated phenology. For example - in tropical and sub-tropical regions, vegetable growers producing winter crops will be negatively impacted as the winter production season shortens. However, this will provide opportunities for other more southerly regions currently too cold to produce crops in late autumn and early spring, to grow crops and market products in this time slot.

Post-harvest costs - post-harvest treatment and cooling costs for some fruit and vegetable crops will increase as additional field heat will need to be removed prior to transport to market. For example - under higher night temperatures, poor rind colour development occurs in citrus in the Riverina and the Burnett.

Production Location - production of some crops in some regions will benefit from an extended production season, whilst others will be negatively affected. It is expected that this will gradually induce relocation of production in the absence of adaptation actions which include introduction of more adaptable cultivars in those areas where higher temperatures become a limitation to production. For example - the establishment of the citrus industry in Central Queensland in the 1980's and 1990's following a significant increase in winter temperatures as compared with the 1960's.

Increased Productivity - increases in temperature and CO_2 may increase yields of some crops, providing positive productivity outcomes. For example - large variations in response to increased CO_2 levels have been found across a range of horticultural commodities. Where positive responses have been found (e.g. potato, lettuce, avocado and citrus), increasing temperatures may offset any increased productivity. However, positive response needs to be found in the marketable plant part and this will only be realised if all resources are non-limiting.

Environmental Impacts - an increasing awareness of climate change and its effects will increase the need for growers to understand and use carbon-neutral practices and/or reduce practices that are deemed detrimental to the environment (maladaptive adaptation practices).

Financial Viability – for perennial horticulture which has a long-term investment horizon, there will be a need for more information and decision making tools to determine the long-term investments required for commodities (especially those where cultivars are not rapidly changing – avocados vs. low-chill stonefruit vs. vegetables). An increase in the intensity of cyclones will impact production systems, the community and consumers. For example – in the case of Cyclone Larry (March 2006) $A350 million crop, property and infrastructure losses were experienced by the banana industry and communities of North Queensland. Such extreme events could easily be experienced in the future in other industries and communities in northern Australia.

Source of Current (and Future) Cultivars - the majority of cultivars used in horticulture are sourced from overseas (this is especially the case for most of the seed propagated vegetable cultivars, with potatoes a notable exception). This will be exacerbated by the fact that Australian production is very small in relation to the major fruit and vegetable producing countries of USA and Europe, from where most cultivars are sourced. Climate changes in these countries may not necessarily result in the development of cultivars suitable for Australia's environments.

These impacts are consistent with those identified by other researchers (AGO, 2003).

3.2 Climate Change and Adaptation Strategies

With increasing temperatures and changes to rainfall patterns which are currently uncertain, the simplest adaptation strategies (*autonomous and assisted adaptation*) will be employed and are currently being employed by growers. These will be the use of more adaptable cultivars and a range of cultural practices which enable growers to maintain current production in current locations – i.e. adapt to the 'new' climate in the current location. This will be driven in the first instance to maintain profitability through market timing, market access and market share.

If climate change impacts exceed growers adaptation capacity at a specific location, more *transformational adaptation* responses will be required. A southward shift of production following the southward shift of agri-climatic zones is then more likely to occur if growers are to maintain profitability through appropriate market timing, market access and market share.

Flexibility has been the key to adaptation in horticulture to date, and is likely to continue to be an important component of adaptation strategies as climates continue to change. Growers have been able to manage climate variability reasonably well, although major improvements could be made if tools to assist with the management of climate variability, both temperature and rainfall, were designed specifically with the needs of horticultural growers and industries in mind.

The current drought has provided opportunities for some growers who have been able to shift production to where water for irrigation is available. Those who have done this successfully will be in a much better position to also manage climate change successfully.

The following are desirable climate change adaptation outcomes for horticulture, which are consistent with the adaptation strategies suggested by other researchers (ABARE, 2007) :-

- Resilient and adaptive horticultural production systems which are less vulnerable to climate change and climate variability
- Improved resilience to changes in pest and disease incidence
- Increased ability to capitalise on new market opportunities
- Regionally specific climate change scenarios, which are very relevant to managers of horticultural enterprises
- Practical tools available to horticultural growers and their advisors to better manage climate change and climate variability.

These desired outcomes are achieved through the following adaptation strategies which are well understood and adopted by horticultural managers in Australia :-

3.21 - Site Selection

Site selection to avoid unsuitable climate factors is practiced as a matter of course in horticulture. For all horticultural crops, temperature is the main climatic factor which determines where and when crops are grown, and also has a significant influence on crop performance (i.e. time to harvest, product quality, and to a less extent, yield).

A pilot study linking climate change scenario modelling and land suitability modelling was conducted in the East Gippsland region in 2004 to model the potential implications of climate change on the future production of selected agricultural commodities (cool climate grapes, plantation blue gum, spring wheat). Similar studies in major horticultural regions would determine vulnerability of current commodities, and develop adaptation strategies to better cope with the impacts.

3.22 - Crop Management

Chemical treatments such as hydrogen cyanamide to induce budbreak in fruit crops, cultural treatments including evaporative cooling through overhead irrigation, strategic applications of nitrogen and irrigation, and sunburn protection using kaolin based products are currently being used in subtropical and tropical cropping systems. Their use will increase, especially if alternative more adaptable cultivars are not available.

Planting dates of some crops such as sweet corn are based on soil temperature conditions, which automatically allows the adaptation to climate variability to occur. The changes in production times which result from increasing temperatures, will need to be taken into account with changes to production and marketing plans.

3.23 - Cultivar Selection

Selection of available cultivars which are more adaptable to a changing and variable climate will be the main tool for adaptation in the vegetable industry, and less so in the perennial fruit industry where long term investment in orchards reduces the application of this adaptation strategy.

3.24 - Water management

Many horticultural growers have adopted more efficient irrigation technologies which are providing significant water-use efficiencies. This will continue, together with an increased understanding of crop water requirements and the use of new technologies to monitor and manage irrigation systems.

3.25 - Pests and diseases

Integrated Pest and Disease Management (IPDM) practices are common in all horticultural regions and commodities, and continuous improvement in these systems, and their adoption, will be an important part of adapting to a changing climate.

3.3 Climate Change and Vulnerability

Vulnerability to climate change is a function of the impacts of climate change on regions or farming systems, and the adaptive capacity of the farming systems in these regions. i.e. a particular region or farming system would be considered to be highly vulnerable to climate change, if there is little or no capacity to adapt to (or negate the effects of) the impacts of future climate change.

In documenting the Adaptation Strategies currently being employed by growers who attended the workshops in the Riverina, Lockyer Valley, and the Burdekin, some understanding of the impacts, adaptive capacity and vulnerability of these farming systems can be deduced :-

3.31- Production Timing and **Location Suitability -** Currently not vulnerable. This will change to being vulnerable if crops/cultivars are unable to cope with increasing temperatures (i.e. thresholds are reached). All vegetable growers and regions are vulnerable, if more adaptable cultivars are not available, or more suitable locations are not available. Depending on the crop and location, those crops which are close to temperature thresholds ('tipping points'), will be very vulnerable.

3.32- Product Quality - Currently vulnerable, as the market for new vegetable cultivars which might be specifically adapted to the Australian environment is quite small in comparison to the overseas market. Likely to increase in vulnerability. Growers are currently adapting well. All industries are increasing in vulnerability, especially as available crops/cultivars approach and exceed critical temperature thresholds.

3.33- Inputs - Some growers and some industries (especially permanent fruit crops) are very vulnerable (currently and into the future). All industries and growers are very vulnerable, as they have limited ability to reduce costs and/or pass on increased costs.

3.34- Pest and Disease Effects - All industries are vulnerable to increased pest and disease activity (continually improving IPDM systems will be one mechanism to delay and reduce the impacts). All industries are vulnerable to the effects of new pests and diseases (new to Australia and/or new to the region).

Technology Transfer

- Participants at each of the three regional workshops conducted in the Riverina, New South Wales; Lockyer Valley, South-East Queensland; and the Burdekin, North Queensland, were provided with regional downscaled climate change scenarios, analysis of historical temperature trends, and other relevant material to assist them in understanding climate change and the impact this will have on their region and their industries. – Appendix III provides a summary of the climate change information made available to growers at each of theses workshops; and Appendix V provides the agenda for the Griffith Workshop.
- A web site has been established - http://www2.dpi.qld.gov.au/horticulture/18741.html - containing climate change and variability information specific to horticulture. This is linked to the HAL Environment and Climate Website (http://www.horticulture.com.au/delivering_know-how/Environment/themes.asp#a_200)
- The *National Agriculture and Climate Change Action Plan 2006-2009* (the Action Plan) - *Taking the Next Steps* Workshop, was attended on Thursday 22 March 2007 in Canberra. A report on the outcomes of this workshop has been made available to HAL. This workshop provided opportunities to present climate change issues of significance to Horticulture to a wide audience of policy makers and scientists. In response to the release of this Agriculture Action Plan, a "Climate Change Action Plan for Horticulture" has been developed – see Appendix IV.
- The NSWDPI Climate Change Adaptability Workshop was attended in 2007. This workshop was a joint initiative of the Climatology in Agriculture extension program (ClimInAg) and the Climate Change Adaptation research project (CARAT); both of these projects are funded by the NSW Greenhouse office. This workshop provided opportunities to present climate change issues of significance to Horticulture to an audience of scientists. It also provided a very useful opportunity to collaborate with NSW colleagues in the Griffith Adaptation Workshop for this project.
- A survey (face to face interview) was completed on "User needs analysis for better seasonal forecasting – Bureau of Meteorology and Managing Climate Variability", conducted by eConnect Communication (publishers of the Climag Newsletter). This survey provided an opportunity to present Climate Change issues of significance to Horticulture. This information will be used to develop improved information products by the Bureau of Meteorology and Managing Climate Variability Program. Full report is available at :- http://npsi.gov.au/products/pf081456 (accessed 13th Dec 2008).
- A Panel discussion for the project "Eastern Australia Climate Knowledge" was attended in 2008 to contribute specific Horticultural information associated with the question – "What do you think are the opportunities for improved intra-seasonal forecasts (i.e. weeks to a few months) and decision/discussion support tools?". A project proposal (to be submitted to LWA) addressing the specific needs of Horticultural industries, is being developed as a direct outcome of this Panel Discussion.
- The project team made significant contributions to the project - "Improving the Capacity of Queensland's Intensive Agriculture to Manage Climate Change", led by Queensland Farmers Federation (QFF) and funded by DAFF. These contributions were made by way of membership of an Expert Panel, and presentations to growers of regional downscaled climate change scenarios, analysis of historical temperature trends, and other relevant material to assist them in understanding climate change and the impact this will have on their region and their industries.

Panel discussion for the project "Eastern Australia Climate Knowledge" 4th Sept 2008 to contribute specific Horticultural information associated with the question – "What do you think are the opportunities for improved intra-seasonal forecasts (i.e. weeks to a few months) and decision/discussion support tools?". A project proposal (to be submitted to LWA) addressing the specific needs of Horticultural industries, is being developed as a direct outcome of this Panel Discussion.

Recommendations

1.0 Horticulture Climate Change Action Plan

The Horticulture Climate Change Action Plan addresses the horticulture specific priorities and desired outcomes for Australian horticulture. It does this by providing a list of desired outcomes applicable to growers, scientists and policy makers associated with horticulture in Australia. These desired outcomes can be achieved through actions addressing a list of climate change priorities which are specific to horticulture.

1.1 It is recommended that industry note the priorities, and desired outcomes listed in this Action Plan, and increase R,D&E investment to address these climate change (and climate variability) priorities and achieve these outcomes.

2.0 Climate Variability

Tools used in managing climate variability, have in the main been designed and constructed for a specific purpose and for a specific agricultural or pastoral industry. None of these tools have been designed specifically with any horticultural industry or application in mind.
This report shows that a different predictive system delivering forecasts with a longer lead time and a short season length which are required for horticulture, are more likely to be achieved using dynamical modelling techniques, than previous statistical methods used in other agricultural industries.
The Predictive Ocean Atmosphere Model for Australia (POAMA) is a state-of-the-art seasonal to inter-annual seasonal forecast system based on a coupled ocean/ atmosphere model and ocean/atmosphere/land observation assimilation systems - http://poama.bom.gov.au/experimental/poama15/map_rt.html - the outputs are currently only experimental, but provides an opportunity for improved temperature forecasts for Australian Horticulture.

2.1 It is recommended that industry engages with climate scientists who are developing the Predictive Ocean Atmosphere Model for Australia, and providing them with the information which is specific to the needs of horticulture in Australia.

This engagement has commenced through the Project Leaders' involvement in the Eastern Australian Climate Knowledge (EACK) Project (funded by LWA), which has thoroughly scoped user needs in terms of improved risk management systems in eastern Australia in relation to climate variability, including the needs of horticulture.

3.0 Climate Change

The Horticulture Climate Change Action Plan addresses the large range of horticulture specific priorities and desired outcomes for Australian horticulture, and a specific recommendation refers to this action plan (see above).

To address the impacts of future climate change, the following specific recommendations are presented.

3.1 It is recommended that industry note the following, and initiate an R,D&E investment to address these <u>specific climate change issues</u>.

- Priorities for Australian Horticulture in **<u>Adapting to Climate Change</u>**

3.1.1 Work closely with CSIRO scientists to obtain regional climate change scenarios (downscaling) for all Horticulture regions (to 2030) – update as improved scenarios become available.

3.1.2 Assess the vulnerability of all or major regions and/or horticultural commodities; identify current "at risk" production sites (regions) and/or industries; and identify the long-term (2030 and 2070) opportunities and threats to horticultural regions and cropping systems, as a consequence of climate change (long term adaptation).

3.1.3 Review and/or develop where necessary, Best Management Practices (BMP) for horticulture, which include adaptation and mitigation components (short term adaptation).

3.1.4 Document the effects of climate change for major overseas production regions, especially in those countries that are major competitors to Australian production, and identify additional export opportunities for Australian growers.

- Priorities for Australian Horticulture in **<u>Mitigating Greenhouse Gasses</u>**

3.1.5 Determine the contribution ("Carbon Footprint") which all horticulture (and specific regions and commodities) make to N_2O and CO_2 emissions, and develop on-farm measures of N_2O and CO_2 emissions (indicator tools for GHG emissions), which are scientifically consistent and verifiable for measuring greenhouse gas emissions from each of the cropping systems and regions of horticultural significance.

3.1.6 Identify and promote horticulture specific Best Management Practices (BMP) which minimise N_2O and CO_2 emissions, and at the same time promote the simultaneous goals of productivity, sustainability, adaptability and abatement, and identify the gaps in our understanding and the ability of current BMP's to sufficiently mitigate greenhouse gasses.

- Priorities for Australian Horticulture for **<u>informing</u>** growers, scientists, politicians and the community

3.1.7 Develop information products which promote horticulture specific messages to the community as well as to stakeholders in horticulture.
3.1.8 Communicate scientifically based information on observed climate trends, climate change projections and possible impacts to key industry sectors raise awareness in the most vulnerable industries and regions..

Many horticultural regions have already experienced a rise in both maximum and minimum temperatures compared with the 1961 to 1990 base line period. As a result of these changes, growers have already experienced an impact of climate change of up to 1^{o}C rise in temperatures, and in the main, have successfully adapted to these changes. Future climate change will deliver impacts to horticulture as a consequence of increasing temperatures and changes to rainfall patterns.

3.2 It is recommended that the horticultural industry develop a clear and defined understanding of how climate change will impact cropping systems and businesses in specific regions at temperatures up to 4^{o}C.

Projected rises in temperatures up to 4^{o}C by 2070 will be a real challenge to horticulture, as thresholds (especially temperature thresholds) for the large range of horticultural crops are not well known, especially for the vegetable sector.

A two year project, "Critical thresholds ('tipping points') and climate change impacts/adaptation in horticulture", funded by LWA and HAL (together with Landcare Australia and Woolworths), has commenced to address the understanding of critical temperature thresholds in a limited range of horticultural crops.

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Appendix I – Horticulture Climate Change Action Plan

The National Agriculture Climate Change Action Plan (NACCAP) was developed with four (4) Focus Areas – Adaptation, Mitigation, R&D and Awareness and Communication. www.daff.gov.au/__data/assets/pdf_file/0006/33981/nat_ag_clim_chang_**action_plan**2006.pdf
For simplicity, this Horticulture Climate Change Action Plan has incorporated the R&D Focus Area into both the Adaptation and Mitigation areas – leaving specific Actions which Australian Horticulture needs to address under three (3) Focus Areas – **(1) Adaptation, (2) Mitigation, (3) Information, Awareness & Communication.**

1. – Adaptation

Desired Adaptation Outcomes for Australian Horticulture

- **Resilient and Adaptive Horticultural Production Systems which are less vulnerable to climate change and climate variability.**
- **Improved industry resilience to changes in pest and disease incidence.**
- **Increased ability to capitalise on new market opportunities.**
- **Regionally specific climate change scenarios, which are relevant to managers of horticultural enterprises.**
- **Practical tools available to horticultural growers and their advisors to better manage climate change and climate variability.**

Priorities for Australian Horticulture in Adapting to Climate Change

- Identify and build on **successful strategies of adaptation by the horticultural sector** to climate changes already experienced.
- Obtain **regional climate change scenarios (downscaling)** for all Horticulture regions (to 2030) – update as improved scenarios become available.
- Develop **Impact Assessments** for all or major commodities in these regions.
- **Assess the Vulnerability** of all or major regions and/or horticultural commodities and Identify current “at risk” production sites (regions) and/or industries.
- Identify the **long-term (2030 and 2070) opportunities and threats** to horticultural regions and cropping systems, as a consequence of climate change - long term adaptation.
- Develop (in consultation with growers and their advisors), **Adaptation Strategies** which are appropriate, practical, and economically sound.
- Review and/or develop where necessary, **Best Management Practices (BMP)** for horticulture, which include adaptation and mitigation components.
- Assess the **economic benefits of agri-forestry in horticulture** as well as the benefits it might bring for adaptation and mitigation.
- Document the effects of **climate change for major overseas production regions**, especially in those countries that are major competitors to Australian production.
- **Identify additional export opportunities** for Australian growers

- Identify **alternative regions that may be suitable for production**, to take advantage of these market opportunities.
- Investigate the **“food miles” concept** and the effects decisions on markets and production opportunities for horticulture.
- **Develop horticulture specific forecasting tools** that can be used for climate change and climate variability (especially temperature variability) related decision making at a farm and regional scale.

<u>Some Questions which these Actions will answer</u>

- **Are we aware of, and do we understand the adaptation strategies which growers have successfully employed to manage their enterprises in an already changing climate?**
- **Do horticulture producers (and their advisors) have appropriate tools and an understanding of climate change and variability issues, to avoid the risks and/or take advantage of the opportunities of a variable and changing climate?**
- **Are current climate change scenarios sufficiently regionally specific to enable appropriate vulnerability assessments for horticultural commodities and/or production regions?**
- **What are the changes in distribution and abundance of pests, diseases and weeds under a changing climate?**
- **What are the impacts for managers of pests, diseases and weeds, of a changing climate?**
- **Are there new market opportunities (domestic and export) as a result of climate change effects in Australia and overseas?**
- **Are the current scenarios sufficiently regionally specific, for horticulture to respond appropriately with adaptation and mitigation strategies which are practical, effective and profitable?**
- **What are the tools, which are being used by managers of agricultural systems to manage climate risk, which can be improved/modified to have an application in horticulture?**
- **What is the level of understanding in the R&D community of the special research needs for farm management (decision support) tools in horticulture?**

2. – *Mitigation*

Desired Mitigation Outcomes for Australian Horticulture

- **Reduced Greenhouse Gas emissions from Horticultural Production systems.**
- **Profitable horticultural production systems which contribute to greenhouse gas abatement.**
- **More energy efficient horticultural production and marketing systems.**
- **Increased ability to capitalise on consumer perceptions and new market opportunities.**
- **Cost effective biofuel usage and production in horticulture.**
- **Biosequestration applicable to horticultural cropping systems.**

Priorities for Australian Horticulture in Mitigating Greenhouse Gasses

- Determine the contribution **("Carbon Footprint")** which all horticulture (and specific regions and commodities) make to N_2O and CO_2 emissions.
- Develop on-farm measures of N_2O and CO_2 emissions **(indicator tools for GHG emissions**), which are scientifically consistent and verifiable for measuring greenhouse gas emissions from each of the cropping systems and regions of horticultural significance.
- **Identify and promote horticulture specific Best Management Practices (BMP)** which minimise N_2O and CO_2 emissions, and at the same time promote the simultaneous goals of productivity, sustainability, adaptability and abatement.
- **Identify the gaps in our understanding** and the ability of current BMP's to sufficiently mitigate greenhouse gasses.
- Assess Controlled Traffic/Minimal Till systems in vegetable production systems for **energy efficiency** as well as issues associated with reduced greenhouse gas emissions.
- Assess the **economic benefits of agri-forestry in horticulture** as well as the benefits it might bring for adaptation and mitigation.
- Review and/or develop where necessary, **Best Management Practices (BMP)** for horticulture, which include adaptation and mitigation components.
- Investigate the **"food miles" concept** and the effects decisions on markets and production opportunities for horticulture.
- Develop on-farm measures of energy use **(energy audit tools)** that identify areas where cost reductions and environmental benefit can be obtained.
- **Assess the potential cost efficiencies of bioenergy and renewable energy sources** for the horticultural sector.
- **Investigate the profitability of bioenergy crops** as alternative and rotation/fallow crops in horticulture cropping systems.

Some Questions which these Actions will answer

- **What contribution does horticulture in Australia make to greenhouse gas emissions?**
- **Are they different for each commodity/cropping system?**
- **Are they different for each production region?**
- **Do we understand how to reduce greenhouse gas emissions from horticulture cropping systems?**
- **Are current fertilizer management practices in horticulture appropriate for managing N_2O emissions?**
- **Can soils under horticultural crop management be net sequesters of Carbon?**
- **What opportunities exist for horticulture to become more energy efficient on farm?**
- **What opportunities exist for horticulture to become more energy efficient along the supply and demand chain?**
- **Are there new market opportunities (domestic and export) as a result of climate change effects in Australia and overseas?**
- **Are consumers willing to preferentially purchase "low carbon" fruit and vegetables?**
- **Can horticultural cropping systems play an important role in emissions trading, and ?**
- **Are there any crops which can be grown as part of horticultural production systems which can have economic benefits to farmers, whilst providing a feedstock for biofuel production?**
- **Can horticultural cropping systems play an important role in emissions trading?**
- **Can horticultural cropping systems play an important role in biosequestration and emissions trading?**

3. – *Information, Awareness and Communication*

Desired Awareness Outcomes for Australian Horticulture

- **A clear understanding of climate change and climate variability issues by stakeholders in horticulture.**
- **Horticulture producers and their advisors having sufficient understanding of climate change and climate variability issues to be able to make appropriate risk management decisions.**
- **Horticulture producers and their advisors having sufficient understanding of climate change and climate variability issues to be able to make appropriate risk management decisions.**

Priorities for Australian Horticulture for informing growers, scientists, politicians and the community

- Develop information products which **promote horticulture specific messages to the community** as well as to stakeholders in horticulture.
- Develop and disseminate specific information to **raise awareness in the most vulnerable industries and regions**.
- **Communicate climate change issues to growers and their advisors**, by taking (making) opportunities to present climate change information (including results of R&D) and engaging in discussions and motivating to consider the implications of climate change for their businesses, society and the environment.
- **Communicate scientifically based information** on observed climate trends, climate change projections and possible impacts to key industry sectors.

Some Questions which these Actions will answer

- **Do we know which commodities and/or regions are most at risk from climate change?**
- **Are horticulture growers and their advisors aware of the implications of climate change to their industries and businesses?**
- **What are the important messages which will increase climate change awareness amongst stakeholders in all horticulture industries?**
- **Do horticulture producers (and their advisors) have appropriate tools and an understanding of climate change and variability issues, to avoid the risks and/or take advantage of the opportunities of a variable and changing climate?**

Appendix II - "Review of outcomes of MCVP funded research applicable to horticulture"

Twenty seven Project Fact Sheets available from the MCVP web site in 2007 were reviewed. Each project was assessed for outcomes which have potential for application in horticulture, and especially for improved management of temperature variability.

Summary of findings.

The Scoping Study [VG05051] reported the following outcome - "*Currently the limitation on the use of tools (climate applications for managing climate variability) in horticultural industries, is the lack of climate science understanding that addresses the lead-time and season requirements of the horticultural industry.*
The combination of long season (3 months) and short lead-time (zero), which are appropriate for other agricultural industries, is a significant constraint to the use of forecasting tools in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful. Given a sound forecast system that meets the requirements of the industry the appropriate tools can be produced.
There are no forecast systems based on the SOI and SST's which have been extensively tested for longer lead-times and shorter seasons."

This review has confirmed the Scoping Study outcome, and identified a number of projects which have activities and outcomes which could provide appropriate input for R&D specifically aimed at applications for managing climate variability in horticulture.

The following 27 project fact sheets describe the project's aims, methods, achievements and current priorities.

http://www.managingclimate.gov.au/Publications_and_Tools/Project_Fact_Sheets/index.aspx

AGRICULTURE

1. Improving Dairy Farmers Feedbase Management with Seasonal Climate Forecasts (pdf 380kb)
2. Increasing the Adoption and Accuracy of Aussie Grass in the Northern Territory (pdf 379kb)
3. Assessing and Developing Targeted Climate Forecasts for the Sugar Industry (pdf 380kb)
4. Improving Prediction of the Northern Australian Wet Season (pdf 379kb)

NATURAL RESOURCES

5. Climate Science for Better Natural Resource Management in Western NSW (381kb)
6. Increasing Success of Tree Establishment by Using Seasonal Climate Forecasts (pdf 379kb)
7. Producing, Verifying and Distributing Synthetic Evaporation and Evapotranspiration Data (pdf 380kb)
8. Integrating NRM Implications into a Production-based Seasonal Climate Risk Management System (pdf 378kb)
9. Enabling Natural Resource Management Decision Makers to Make Better Use of Climate Science (pdf 378kb)
10. Managing Natural Resource Issues in a Variable and Changing Climate (pdf 379kb)

THE GRAINS INDUSTRY

11. 'Prophetable' Cropping Using Seasonal Forecasting Tools (pdf 380kb)
12. Oceans to Grains: a New Approach to Targeted Seasonal Forecasts (pdf 380kb)

ECONOMIC APPLICATIONS

ADAPTING TO CLIMATE CHANGE

COMMUNICATING CLIMATE RISK MANAGEMENT

GRAINS RESEARCH AND DEVELOPMENT CORPORATION LINKED PROJECTS

The following is an assessment of each of the project outcomes which have potential for application in horticulture, and especially for improved management of temperature variability.

AGRICULTURE

1. Improving Dairy Farmers Feedbase Management with Seasonal Climate Forecasts

This project has used the well established SOI and SST predictive system to "Investigate historical weather data for variability and the predictive skill of the SOI and SST for representative coastal zones within the sub-tropical dairy region". The SOI and SST predictive system currently has limited application in horticulture, as reported in the Scoping Study [VG05051] - "*Currently the limitation on the use of tools (climate applications for managing climate variability) in horticultural industries, is the lack of climate science understanding that addresses the lead-time and season requirements of the horticultural industry.*
The combination of long season (3 months) and short lead-time (zero), which are appropriate for other agricultural industries, is a significant constraint to the use of forecasting tools in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful. Given a sound forecast system that meets the requirements of the industry the appropriate tools can be produced.
There are no forecast systems based on the SOI and SST's which have been extensively tested for longer lead-times and shorter seasons."

For the outcomes of this project to have potential application in horticulture, and especially for improved management of temperature variability, forecasting tools would need to be developed, with the requirements of horticultural industries and managers specifically in mind.

2. Stimulating the adoption of AussieGRASS in the Northern Territory

This project aimed at an improved understanding by land managers, advisers and policy officers of applications of AussieGRASS products to sustainable management of rangelands in the NT.

AussieGRASS is a decision support package which simulates pasture growth, feed shortages and total standing dry matter on a 5 km^2 grid at the state and national level. It produces maps to demonstrate spatial variation.

AussieGRASS, and other decision support tools such as WinGrasp, GrazeOn and GrassCheck calculate sustainable stocking rates depending on feed availability at the paddock level, and usually involve adjusting stock numbers depending on feed availability, market prices, output targets, plant cover and palatable plant production.

AussieGRASS uses the well established SOI system as a predictor in developing the outputs of this decision support system. The SOI system has been the benchmark climate forecasting predictor for many agricultural industries in Australia, but the tools which have been developed so far have not been developed with the needs of horticultural industries in mind. The combination of long season (3 months) and short lead-time (zero), which are appropriate for other agricultural industries, is a significant constraint to the use of forecasting tools in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful.

3. Assessing and developing targeted climate forecasts for the sugar industry

This project has used the well established five-phase SOI system, which has been the benchmark climate forecasting system for many agricultural industries in Australia.
A modified version of the traditional field significance method was used to compare a range of forecasting systems.
The key learning revealed was that, collectively, the forecasting systems considered all performed well for the sugar industry. They have limited application in horticulture, as reported in the Scoping Study [VG05051] – "*The combination of long season (3 months) and short lead-time (zero), which are appropriate for other agricultural industries, is a significant constraint to the use of forecasting tools in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful.*"

4. Improving prediction of the northern Australian wet season

This project aims to better predict the onset, duration and termination of the northern Australian wet season to support better decision making in Australia's northern agricultural industries, through reducing climate-related risk to agricultural industries (using the grazing industry as a case study) by providing improved quantification and predictions of the northern Australian wet season and creating new technologies for better decision making in climate-sensitive systems of northern Australia

Variability of the northern wet season poses a significant risk for many climate-sensitive industries. Industries such as grazing, grain, sugar and horticulture are severely affected by the vagaries of climate.

Desired Outcomes

- At leads of 2 or more months, probabilistic predictions of the entire wet season rainfall (defined as Dec-Mar or Oct-Apr). For example, at the beginning of August, probabilistic prediction of the October to April rainfall could be produced based on knowledge of the state of the El Niño-Southern Oscillation (ENSO). These forecasts could then be updated monthly until the beginning of the wet season.
- At leads of 2 months or less, probabilistic predictions of shorter-averaged periods within the wet season. These shorter-averaged periods will have lengths from 1 week to 2 months. Some of these forecasts could be updated daily. The forecasts at longer leads will primarily use information coming from ENSO. Shorter lead forecasts will use information that is updated daily (eg forecasts based on the passage of the Madden-Julian Oscillation - MJO). These systems will need to provide forecasts such as the probability of exceeding predetermined thresholds (eg 50 or 200 mm of rain in the coming week and subsequent week, the coming month or the following month).
- Predictions of 'onset date' of the wet season.

The desired outcomes (listed above) will have relevance to horticulture, even though grazing is being used as the case study for this project. In particular, the longer lead time forecasts (2 months or more), and the shorter season lengths (1 week to 2 months), will be of significant interest and usefulness to horticulture. Application of these outcomes to temperature, as well as rainfall would increase the application of this R&D to horticulture.

NATURAL RESOURCES

5. <u>Climate science for better natural resource management in western New South Wales</u>

The project aims to develop a capacity to predict regional trends in total ground cover, and provide early warning of potential degradation events, by linking AussieGRASS products and seasonal climate forecasts. It will develop relationships between total standing dry matter (TSDM) produced by the AussieGRASS spatial growth model and the dynamic component of ground cover derived from the NSW Rangeland Assessment Program (RAP). Relationships will be developed for 11 regional vegetation communities covering 85% of the three target CMAs. Estimates of total ground cover can then be produced by adding this dynamic component to estimates of the static component contributed by surface features such as rock, cryptogamic crust and low shrub.

Combining a capacity to model total ground cover with seasonal climate forecasts, to estimate the probability of future ground cover trends, will allow land degradation alerts to be issued under specified conditions.

AussieGRASS uses the well established SOI system as a predictor in developing the outputs of this decision support system. The SOI system has been the benchmark climate forecasting for many agricultural industries in Australia, but the tools which have been developed so far have not been developed with the needs of horticultural industries in mind. The combination of long season (3 months) and short lead-time (zero), which are appropriate for other agricultural industries, is a significant constraint to the use of forecasting tools in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful.

6. Increasing success of tree establishment by using seasonal climate forecasts

This project is addressing the question: can revegetation success be improved through the use of climate information, through developing relationships between climate-related factors and tree establishment success based on both empirical and modelling data, and using these relationships to predict occurrence of conditions that are conducive to successful establishment? This project has demonstrated that even relatively minor differences in rainfall and soil moisture stress, can influence health and mortality of eucalypt seedlings.

This outcome will have application in the establishment of forestry plantings associated with horticulture businesses, and may well have application in the establishment of some fruit tree species and in some regions of Australia.

7. Producing, verifying and distributing synthetic evaporation and evapotranspiration data for Australia.

This project aimed at delivering reliable, up-to-date, historical potential evapotranspiration (PET) data, in a readily usable form, to improve the efficiency of biophysical and hydrological modelling by researchers, and improve the information available to decision makers.
This project has delivered PET spatial time-series data, and gridded data covering the whole of Australia at 5km resolution for every day, back to 1910. The PET data are available through NRW's SILO web service.

This project has provided data which will support nationwide and local monitoring and modelling of evaporative demand, all of which has application to R&D in irrigation management in Horticulture.

8. Integrating NRM implications into a production-based SCRM system

This project is aimed at developing information relevant to the management of deep drainage, runoff and soil erosion risks and production-based crop management decisions, and integrating this capability into the Yield Prophet system www.yieldprophet.com.au.

Yield Prophet relies on access to the modelling capability of APSIM. Currently there are no tested horticultural models within the APSIM framework, which will allow the integration of natural resource issues with production-based crop management decisions in horticulture using the Yield Prophet concept.

A "Yield Prophet for Horticulture" would be a useful tool to assist growers and their advisors in making improved management decisions. APSIM modelling capability for horticulture crops will be required for this to become a reality.

9. Enabling NRM decision makers to make better use of climate science

This project is aimed at developing and evaluating frameworks that enable NRM decision makers to integrate the advances in climate science into their planning and decision making, and to detail a range of specific climatically risky decisions.
This project, has shown from previous experience in participatory research with farmers in farming systems projects, that proceeding from a general area of concern or problematic issue to a clearly defined decision that can be analysed and solved is not a trivial task. However, with patience, it is often the most valuable part of the engagement between managers and professional agricultural scientists. In complex systems, which exist in agriculture, and especially in Horticulture, the processes of engagement and participation by decision makers and scientists are time consuming for the participants, but have the potential to deliver a useful outcome. This participatory process has been used successfully in Horticulture (and other areas of agriculture) for developing improved Integrated pest Management (IPM) outcomes. This could also hold true for complex climate based decision making outcomes in horticulture. Tools to assist this process will need to be available to horticulture, for improved decision making to be achieved.

The specifications for the development of these tools could be an outcome of a participatory engagement process with horticulture growers and their advisors.

10. Managing natural resources in a variable and changing climate

With an emphasis in natural resource management, this project aims to :-

- Analyse how climate has been changing
- Assess how these changes have influenced cropping enterprises
- Identify key management adaptations that will enable farmers to more effectively manage climate variability as well as future trends in climate arising through climate change
- Identify priority issues that could be better managed with enhanced use of information on historical climate variation, seasonal climate forecasts and trends in climate factors
- Identify key climate change adaptation strategies

A similar approach is being taken in the current HAL funded project - AH06019 – "Australian horticulture's response to climate change and climate variability", which will identify key climate change adaptation strategies with growers and their advisors in three important horticultural regions of Australia.

THE GRAINS INDUSTRY

11. 'Prophetable' cropping using seasonal forecasting tools

Yield Prophet® uses the computer simulation model APSIM together with paddock specific soil, crop and climate data to generate information about the likely outcomes of farming decisions. Yield Prophet® [http://www.yieldprophet.com.au] does not generate recommendations or advice. It relies on access to the modelling capability of APSIM.

Currently there are no tested horticultural models within the APSIM framework, which will allow the integration of climate variability with production-based crop management decisions in horticulture using the Yield Prophet concept. There exists in APSIM the generic 'PLANT' module. This has recently been parameterised to develop a Broccoli module. A 'Sweet corn' module is available. With similar parameterisation from experimental trials, other horticultural crops could be modelled within APSIM.
A "Yield Prophet for Horticulture" would be a useful tool to assist growers and their advisors in making improved management decisions. APSIM modelling capability for horticulture crops will be required for this to become a reality.

12. <u>Oceans to Grains: A new approach to targeted seasonal forecasts</u>

This projects aims at developing a new approach to seasonal forecasting based on looking at the fundamental physical processes and synoptic systems responsible for rainfall, and relating the frequency and intensity of these systems to long time-scale features of the atmosphere and ocean, and exploiting synergies between forecast timing and skill and management responses, thus developing a targeted forecast system that should out-perform and be more relevant than more broadly-based forecast systems.

This will be achieved through focusing on three regions that provide a cross-section of grain growers in south-east Australia, and that represent low, medium and high rainfall cropping systems, to benchmark the value of existing operational forecasts (BOM, SOI); catalogue climate-sensitive management decisions, and the climate forecasts and skill required to make these decisions; develop new seasonal climate forecast systems (SCFs) using the ocean-based statistical prediction system; develop appropriate management responses to the new and old climate forecasts; and interact with farmer groups to exchange information about project results, to assess how best to communicate our results, and to get feedback and new ideas.
So far this project has identified the dominant synoptic system that causes rainfall in south-east Australia, which is a system called a 'cut-off low', which produces more rain primarily because it moves more slowly than a cold front. This work which has been published in the Journal of Applied Meteorology, will attempt to relate moisture sources and trigger mechanisms back to ocean temperatures, to develop a forecast system with a suitable lead time.

This project is assessing the potential to use a new approach to seasonal forecasting, independent of, but perhaps complementary to, the SOI based systems which are currently the most widely used SCF available. A new forecasting system, which has the capacity to deliver forecasts with longer lead times and shorter season lengths (especially for temperature) is what is required in horticulture for improved decision making in a variable climate.

13. <u>Horses for courses: Using the best tools to manage climate risk</u>

This project has used a range of the most promising decision support tools and forecasting indices to assist growers to learn about and evaluate the costs and benefits of using climate forecasts, with and without reference to historical climate records, and to inform crop management decisions.

The tools selected were APSIM, PYCAL and '3 year paddock WUE' yield prediction tools, and NULogic (CSBP) and SYN (DAWA) N tools. Each of these have specific application to broad acre agriculture, with very limited application to horticulture.

The process used to work with growers and their advisors would be extremely appropriate and useful to horticulture, if there were a range of tools available which had direct application to managing climate variability in horticulture production systems. To date no such tools are available.

14. National WhopperCropper delivering risk management to agricultural advisors

Information on "Whopper Cropper: a *discussion support system* for managing climate risk in Australia's northern cropping systems" is available at :-
http://www.bom.gov.au/climate/cli2000/rNelson.html

WhopperCropper is a database of pre-run APSIM simulations with an easy to-use graphical interface facilitating time series, probability and diagnostic analyses, and was developed in response to a demand by extension professionals for access to the broad-acre cropping systems modelling capability of the APSIM model and to seasonal climate forecasting using the SOI phase forecasting system.

A "Whopper Cropper" for horticulture would require the same crop modelling input as has been developed for the range of broad-acre crops included in APSIM. There exists in APSIM the generic 'PLANT' module. This has recently been parameterised to develop a Broccoli module. Similarly a 'Sweet corn' module is available. With parameterisation from experimental Trials, other horticultural crops could be modelled.

ECONOMIC APPLICATIONS

15. Enhanced forecasting of farm financial performance

Farm income is influenced significantly by climate variability. Managing farm income risk caused by climate variability involves predicting the likelihood and extent of adverse events, and taking cost effective steps to limit their impact.

If farmers could use information such as the Southern Oscillation Index (SOI) to plan when and how much money to set aside, the likelihood of farmers realising years of very low income could be reduced.
One of the desired outcomes of this project was to illustrate the possible benefits in risk reduction of using Farm Management Deposits in conjunction with the SOI. The approach is expected to provide a clear indication to clients, such as financial institutions, policy makers, and industry representatives, how the technology can be exploited, which in turn is expected to lead on to more demand-driven developments in the future.

Results show that some regions can benefit in terms of farm's increasing their probability of breaking even by knowing what SOI phase is expected in the next season. Further refinement of the relationship between SOI phases and farm incomes will be required for this to be realised.

Because the majority of horticultural cropping systems are less dependant on pre-planting as well as within-crop rainfall (the majority of horticultural crops are fully irrigated), the link between the SOI and farm incomes is less pronounced than that for grain crops and for grazing industries.

16. Farmers applying seasonal climate forecasting for profitable and sustainable resource use

The objective of the research is to evaluate tools for seasonal climate forecasting (SCF) on farm profitability, the type and intensity of agricultural land use, and land degradation (soil erosion and deep drainage), and to assess how currently available SCFs are influenced by attitudes towards risk, the level of state variables (soil moisture at planting and product prices) and unit prices attached to land degradation effects.

This project has demonstrated that while there have been recent advances in understanding and predicting climatic variations, much uncertainty remains about the usefulness of forecasting technologies in the management of typical broad acre farming systems in Australia. It is no wonder then that there remains significant uncertainty about the usefulness of SCF tools in horticulture, where none have been developed with the needs of horticulture in mind.

17. Innovative weather and climate risk management using derivative trading

This project aims to improve the understanding of the potential value of SOI-based and other similar weather/climate derivatives to the Australian wheat industry. The project seeks to ascertain the value of hedging tools that can capitalise on our improved understanding of climate variability and weather/climate derivatives for the wheat industry.

Many studies have shown that farm and shire crop yield and quality are strongly associated with the SOI, especially for years with low starting soil moisture. The SOI may also indicate international productivity and pricing. Thus, SOI forecasts may also be able to aid derivative pricing and portfolio management.

Weather derivatives are financial instruments that can be used by organizations or individuals as part of a risk management strategy to reduce risk associated with adverse or unexpected weather conditions. The difference from other derivatives is that the underlying asset (rain/temperature/hail/etc) has no direct value to price the weather derivative. Farmers can use weather derivatives to hedge against poor harvests caused by drought or frost; theme parks may want to insure against rainy weekends during peak summer seasons; and gas and power companies may use heating degree days (HDD) or cooling degree days (CDD) contracts to smooth earnings. (from – http://en.wikipedia.org/wiki/Weather_derivatives).

Perhaps there is an opportunity to assess the value of weather derivatives in horticulture in relation to severe weather events such as frost, cyclones and hail, which have devastating effects on individual growers and industries.

ADAPTING TO CLIMATE CHANGE

18. Incorporating climate change in catchment management strategies

This project aims to assess these risks in multidisciplinary terms in relation to the availability of water for human and environmental use on the catchments; the implications of this for current water management and catchment plans; and to develop a simple planning aid to assist catchment bodies with their community processes in making similar assessments for their catchment planning and water resources management.

If there are to be climate-sensitive catchment plans, there is a need for a simple, community-friendly decision aid to incorporate the implications of climate change in sustainable water management, by developing a simple planning aid to assist catchment bodies with their community processes in making similar assessments for their catchment planning and water resources management. This process will be useful to horticulture growers and industries, because water security (for irrigation purposes) is affected by climate variability and climate change.

19. Managing grazing systems in a variable, non-stationary climate

Analyses of national climatic events (e.g. drought, flood and extreme temperatures) suggest increasing frequency of events falling outside the long-term historical experience. As current agricultural practices have been strongly shaped by historical climate conditions, the impacts of projected changes in future climate need to be assessed in order to quantify and plan for likely changes in future productivity and landscape condition.
This project aimed to assess recent climate trends and explore the resultant impacts on the grazing industries; and assess the implications of current and projected climate changes for on-farm adaptation.
The sub-objectives of this project included :- quantify historical trends in key climate factors such as temperature and rainfall (amount, duration and intensity); quantify the consequences of these historical trends on natural resource management issues, such as deep drainage and runoff; for on-farm enterprise issues, such as pasture production and heat stress in cattle, assess the impact of a range of likely climate change projections on natural resource management issues, heat stress and pasture production, using the most recent consensus climate change scenarios for the Burnett study region; and discuss possible management responses to these issues.

The analysis of both historical maximum and minimum temperatures revealed a consistent pattern of warming across the study region although only the warming trends in minimum temperature were statistically significant.

The impact of climate change on heat stress was large, with significant increases experienced across all sub-regions. The impacts were greatest in the Central and North sub-regions, with over 100% increase in heat stress simulated by 2070.
These results are consistent with the limited assessment of climate change in specific horticulture regions around Australia. The impacts of heat stress on crops, and the need for adaptation strategies is as important in horticulture as it is for the grazing industry.

A somewhat similar approach is being taken in the current HAL funded project - AH06019 – "Australian horticulture's response to climate change and climate variability", which will identify key climate change adaptation strategies with growers and their advisors in three important horticultural regions of Australia.

20. Managing agricultural systems in a variable, non-stationary climate

Climate variability is the major risk factor for the agronomic and environmental performance of agricultural systems. There is now firm evidence that, in addition to year-to-year variability, there are also trends in climate factors that result in a non-stationary, i.e. changing, climate.
The consequences are measurable and substantial. Good risk managers can no longer afford to dismiss this evidence. Appropriate risk management strategies need to take both variability and change into account in order to achieve the best possible outcomes. Due to the long timeframe involved over which such climate trends manifest themselves (decades rather than years), current practices are to some extend 'self-adapting', whereby producers and policymakers modify

behaviours based on most recent experiences. The masking effect of variability means that such subconscious self-adaptation is haphazard, non-specific and often involves considerable lag periods. This project :- 1. Quantified historic trends in key climate factors such as changes in temperature extremes, frost and rainfall. 2. Quantified the likely consequences of these trends on production; 3. Developed possible management responses to these issues; and 4. Outlined the approaches needed in order to assist industry in a well-managed transition towards more resilient agricultural systems that can accommodate such trends and variability in climate factors and hence cope with the possible effects of climate change.

The project also resulted in conference and journal publications, including:

- Meinke, H. and Stone, R.C., 2005. Seasonal and inter-annual climate forecasting: the new tool for increasing preparedness to climate variability and change in agricultural planning and operations. Climatic Change, 70: 221-253.
- Meinke, H., Donald, L., deVoil, P., Power, B., Baethgen, W., Howden, M., Allan, R. and Bates, B., 2004. How predictable is the climate and how can we use it in managing cropping risks? Invited Symposium Paper, Proceedings of the 4th International Crop Science Congress, 26 Sep – 1 Oct 2004, Brisbane, Australia, published on CD and <www.cropscience.org.au>.
- Howden, S.M., Meinke, H., Power, B. and McKeon, G.M, 2003. Risk management of wheat in a non-stationary climate: frost in Central Queensland. Post, D.A. (ed.) Integrative modelling of biophysical, social and economic systems for resource management solutions. Proceedings of the International Congress on Modelling and Simulation, July 2003, Townsville, Australia, pp 17-22.

The approach being taken in the current HAL funded project - AH06019 – “Australian horticulture's response to climate change and climate variability”, will identify key climate change adaptation strategies with growers and their advisors in three important horticultural regions of Australia.

21. Agro-ecological implications of change to the terrestrial water balance

The generic assumption among the natural resource management community is that, as the enhanced greenhouse effect warms the earth, the terrestrial surface should become more arid due to increases in atmospheric demand (often called potential evaporation) that are larger than any changes in rainfall. If true, this would have a negative impact on nearly all aspects of agricultural productivity, urban water supply, wetlands management, environmental flows etc. This view is prevalent in the media both in Australia and internationally. However, measurements from around the world show the reverse.

This project has shown that the trends in Australian pan evaporation are consistent with trends in the underlying meteorological variables (solar radiation, VPD, wind speed). Declining wind speed is the most important factor, while declines in solar radiation are also important regionally. Exactly why the wind speed would have decreased so much awaits further investigation.

Rotstayn, L. D., Dix, M. R., Roderick, M. L. and Farquhar, G. D. (2005) Pan evaporation in 20th century global climate simulations: Model implementation and results for Australia. 17th Annual Bureau of Meteorology Research Centre Modelling Workshop - Hydrometeorological Applications of Weather and Climate Modelling, 3-6 October 2005, A. J. Hollis, Editor, BMRC Research Report No. 111, 25-28. Available at www.bom.gov.au/bmrc/pubs/researchreports/RR111.pdf.

A conclusion from this study, that warming does not necessarily mean drying, has positive implications for horticulture as well as agriculture, especially in relation to the management of water supplies for irrigation.

COMMUNICATING CLIMATE RISK MANAGEMENT

22. Masters of the Climate revisited: Innovative farmers coming through drought

The project aimed to improve knowledge within the target audiences of the various methods available to manage for climate variability, and how they worked during a major drought. The project provided practical case studies of the success and failures experienced by farmers in applying various agricultural practices in their efforts to manage for climate variability. Part of the approach was to discuss how their technical methods succeeded or failed, what factors contributed to success/failure, and what lessons could be learned for future application.

The target audiences were from grazing and cropping industries, where tools to manage climate variability have been developed. Although there are no tools with specific application to horticulture, a similar approach to assessing the value of practical case studies of the success and failures experienced by farmers in applying various horticultural practices in their efforts to manage for climate variability, would be of benefit to horticulture to highlight the need for specific tools to assist horticulture growers and their advisors, to better manage climate variability.

23. Building effective climate risk management in the Western Australia grain belt

Previous work in climate risk management has identified a clear need for an understanding of farmer knowledge, attitudes, skills, aptitudes and current practice in relation to climate risk management in agriculture. There is a similar need to evaluate the effectiveness and delivery of current extension packages and the extent to which they meet the needs of farmers and landholders, and there is a need to develop and deliver an integrated package of information, tools and training that targets these needs in terms of content, timing and delivery.

This project aims to develop and deliver an integrated package of information, tools and training that targets these needs in terms of content, timing and delivery, through several geographically and farming system distinct farmers groups and selected supply network intermediaries.

Horticulture is no different from other parts of agriculture in its need to understand farmer knowledge, attitudes, skills, aptitudes and current practice in relation to climate risk management. Similarly, there is a need to develop and deliver an integrated package of information, tools and training that targets these needs.

24. Growing capacity in seasonal climate risk management in south-east Australia

This project aims to create an inventory of climate risk management tools applicable to crop and pasture production in south-east Australia, identify their strengths and weaknesses from the perspective of farmers in different regions; work with farmer groups to encourage support for the adoption of climate risk management tools appropriate for each industry and region; and identify regional strengths and weaknesses for each tool.
There are mixed messages in farming circles regarding the relevance of seasonal climate risk management (SCRM) tools. Technical information has been generated by climate risk researchers

but currently has minimal market value among the vast majority of farmers. This project will build industry capacity in the area of SCRM to create the realisation that SCRM has a market value and is a priority area in which farmers and agribusiness should invest resources.
With greater uptake, producers can make informed decisions that better manage production and environmental risks faced at the beginning and during the production season.

As reported in the Scoping Study [VG05051], seasonal climate risk management (SCRM) tools have not been developed with the specific needs of horticulture in mind. This review of the R&D funded by the MVC program, highlights the need for SCRM tools specifically for horticulture.

GRAINS RESEARCH AND DEVELOPMENT CORPORATION LINKED PROJECTS

25. Climate change, wheat yield and cropping risks in Western Australia

This project has investigated the effects and risks of changing climate variability over time. A major benefit to the grains industry is that a clearer picture of future climate risks can be obtained. Long-term industry planning will have access to better information on future climate-related risks and opportunities.

As for the grains industry, climate change is an important issue for the longer-term development of Horticultural industries.

26. Better long-lead seasonal and crop forecasts for southern Australia

Most forecasting systems only deliver seasonal outlooks for the next three months and do not show much skill until the end of the predictability barrier at the end of autumn i.e. early June/July. However, by then most of the major management decisions related to the winter grain crop in southern Australia have been made, i.e. area of crop, crop type, forward contracts, fertiliser, herbicides etc.

The sequence of atmospheric (pressure, winds) and oceanographic variables (sea surface temperatures) leading into ENSO events was mapped. This included the transitions to strong and weak El Niño, from El Niño to neutral, and from El Niño to La Niña. New indices to track changes in ENSO State have been determined, i.e. an El Niño Prediction Index (EPI), ENSO Transition Index (ETI) and a more broad-scale measure of the Southern Oscillation (MeanSOI).
Through the improved understanding of the dynamics of ENSO, these indices have been combined into an analogue year selection system, which chooses the five most similar analogue years (to the present year) from the historical record. The analogue system enables the prediction of the developing ENSO state by the end of the year, and importantly, by using the median rainfall ranking of the five years, to spatially map Australia's future expected rainfall.
An experimental ENSO sequence system (ESS) has been found to skilfully forecast eastern Pacific sea surface temperatures a year in advance, and skilfully predict May-October rainfall for much of the country with 4-6 months lead-time. The largest decline in the MeanSOI between October (year -1) and May is a clear indicator of whether an El Niño event will develop, and is a strong indicator of major drought years in the Australian grain belt.

The outcomes of this project will have relevance to horticulture, even though grain industries are being used as the case study for this project. In particular, the longer lead time forecasts will be of significant interest and usefulness to horticulture, particularly if these forecasts can be applied to temperature.

27. Can we forecast wheat yields and grain protein in Western Australia?

This project reviewed and tested the forecasting skills of SOI (Southern Oscillation Index), SST (Sea Surface Temperature), mid-latitude forecasting indices, forecasts from GCM's and other emerging forecasting systems for the WA wheat belt; assessed the value of forecasts for predicting wheat yield, grain protein, and gross margins from wheat cropping for WA; and discussed with WA farmers the practical value of seasonal forecasts for sowing and N management decisions.

The reason for doing this review and testing is because it is not known whether the skill of current operational forecasting systems is sufficient so that management decisions based on forecasts generate enhanced gross margins over strategies that do not consider forecast information.

Results show that the skill of most forecasting systems at the beginning of the season in May is low for south-west WA. The best performing was the experimental system GESS (Global ENSO Sequence System) of Dr David Stephens (DAWA), which is still under development. The value of seasonal rainfall forecasts declines toward higher rainfall regions and on low water holding soils. For the application considered (N management, sowing decision), the skill of SOI and SST predictors was too low to be economically valuable.

This project has attempted to combine a number of prediction systems which will provide an opportunity for farmers to make improved management decisions. This approach could have real benefits for horticulture, where there are currently no specific tools to assist the management of climate variability.

The Southern Oscillation is the most important influence on the year to year variability of our weather in Australia. The Southern Oscillation explains about 40% of the variation in eastern Australian rainfall. Where other predictors and/or indices can be utililised to improve the skill of these tools, agriculture and horticulture are likely to benefit.

Appendix III - "The potential for the development of a Tool to manage temperature variability for horticulture".

Tools used in managing climate variability, have in the main been designed and constructed for a specific purpose and for a specific agricultural or pastoral industry. None of these tools have been designed specifically with any horticultural industry or application in mind.

What Currently Exists?

Tools used in managing climate variability have mainly been designed and constructed for a specific purpose and for a specific agricultural or pastoral industry. Given that none of these tools have been designed specifically for any horticultural industry or application, there are tools which are of some assistance to Australian horticultural growers and their advisors. These were reviewed in the Scoping Study Project [VG05051] and are briefly described below :-

- **Bureau of Meteorology (BOM) – Seasonal Temperature Outlook –** http://www.bom.gov.au/climate/

Advice on the status and development of ENSO (ElNino-Southern Oscillation) has been provided from a number of sources in Australia since 1989, initially from the National Climate Centre.
The Bureau of Meteorology (BOM) produces three-monthly outlook information for each state, and nationally, and is updated regularly, e.g. the most recent National Seasonal Temperature Outlook is available at :- [http://www.bom.gov.au/climate/ahead/] **A corresponding outlook is issued for rainfall.**
These rainfall and temperature outlooks are based on Sea Surface Temperature (SST) patterns in the Pacific and Indian Oceans and they relate to a three month season with a zero lead-time. The combination of long season (3 months) and short lead-time (zero) is a significant constraint to the use of this tool in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful.

- **LongPaddock –** http://www.longpaddock.qld.gov.au/

The Long Paddock website is provided by the Queensland Government. It supplies decision-support information services to help clients in all states of Australia to better manage climatic risks. It contains detailed information on the current climate situation including Sea Surface Temperatures (SST), value of the Southern Oscillation Index (SOI), recent rainfall events, seasonal outlooks, drought maps and pasture growth forecasts.
The information is aimed at grazing and grain industries in the main, although much of the information has application and can be useful to managers of horticultural enterprises.

- **Madden Julian Oscillation (MJO) –** http://www.apsru.gov.au/mjo/ or http://www.bom.gov.au/climate/tropnote/tropnote.shtml

The MJO is a band of low air pressure originating off the east coast of central Africa travelling eastward across the Indian Ocean and northern Australia roughly every 30 to 60 days. Research has shown the MJO to be a useful indicator of the timing of potential rainfall events (but not amounts).

Knowledge of the position of the MJO can be useful for improving tactical decision making by managers of agricultural, grazing and horticultural enterprises.

- **AgClimate** - http://www.agclimate.org/

AgClimate provides a web-based tool to help peanut, tomato, potato, pastures and livestock producers in south-eastern USA, understand and plan for climatic conditions. It is an interactive web site with climate, horticulture, agriculture, and forestry information that allows users to assess management options under forecast climate conditions.
AgClimate has very limited use in horticulture in Australia, but it could be used as the basis for a similar tool and a mechanism for the delivery of climate based information, if developed specifically for selected locations and horticultural cropping systems in Australia.

- **Rainman StreamFlow version 4. -** http://www.dpi.qld.gov.au/rainman/

Rainman StreamFlow is a CD based forecasting tool which contains records for Australia including historical monthly and daily rainfall for 3800 locations; monthly and daily stream flow for nearly 400 locations; and world-wide, monthly rainfall records for some 9500 locations.
Rainman StreamFlow can analyse these records of individual locations for seasonal, monthly and daily rainfall patterns; forecast seasonal rainfall based on the Southern Oscillation Index (SOI) or Sea Surface Temperatures (SST); group locations for spatial analysis; import monthly and daily rainfall and stream flow data; and print results as tables and graphs or maps - http://www2.dpi.qld.gov.au/rainman/13234.html
The standard seasonal forecast is for 3 months with a zero lead-time, which is a significant constraint to the use of this tool in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful.

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- **Southern Oscillation Index (SOI) –** http://www.bom.gov.au/climate/glossary/soi.shtml or http://www.longpaddock.qld.gov.au/SeasonalClimateOutlook/SouthernOscillationIndex/index.html or http://www.longpaddock.qld.gov.au/SeasonalClimateOutlook/RainfallProbability/index.html

The Southern Oscillation Index (SOI) is calculated from the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin. The SOI is a prediction system which is used in a number of forecasting tools (e.g. Rainman StreamFlow).

- **Sea Surface Temperatures (SST)**
  http://www.longpaddock.qld.gov.au/SeasonalClimateOutlook/SeaSurfaceTemperature/index.html

Sea-Surface Temperature patterns in the Pacific Ocean and Indian Oceans are important in driving climate variability and are useful guides to potential climate patterns in Australia (and other parts of the world). SST's are used by the Bureau of Meteorology in developing rainfall and temperature outlooks.

What is Required?

a) What should this potential Tool do?

Capacity to provide temperature (and rainfall) forecasts that make an improvement on current temperature (and rainfall) forecast information by providing information that has:

- a lead time of between zero and 6 months; and
- a forecast period of 1 – 4 weeks (i.e. a season length of 1-4 weeks).
- information targeted to assist growers and their advisors in making improved management decisions, see following example.

Lettuce – in the Australian environment temperature varies considerably from season to season and year to year in most districts. As a consequence cultivar selection and planting times cannot always be satisfactorily matched with the temperature conditions that significantly influence quality during the head filling stage, which is up to 4 months after transplanting, depending on season and location. To be able to make much better decisions on cultivar selection, planting dates and marketing plans, growers and their advisors need information on the temperature regime for the 2-4 weeks leading up to harvest. This forecast is required well before planting, due to the need for growers to plan production and order lettuce seedlings of the appropriate cultivar. This is a forecast with a 3-4 months lead-time.

b) What capability should this tool have?

4 Be region specific – i.e. capable of providing a forecast for a defined location, e.g. this might be East Gippsland or the Burdekin; or Hay or Manjimup.

5 Forecast Maximum and Minimum Temperatures (from which other factors might be calculated – e.g. heat stress days, diurnal variation, degree days, chilling hours etc.

6 Be specifically designed for the needs of fruit and vegetable growers and their advisors in Australia.

c) Limitations of Current Forecast Systems.

Currently the limitation on the use of tools (climate applications for managing climate variability) in horticultural industries, is the lack of climate science understanding that addresses the lead-time and season requirements of the horticultural industry.

The combination of long season (3 months) and short lead-time (zero), which are incorporated in current tools for managing climate variability, are appropriate for other agricultural industries, but are a significant constraint to the use of these forecasting tools in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful.

There are no forecast systems based on the Southern Oscillation Index (SOI) and Sea Surface temperatures (SST's) which have been extensively tested and readily available for longer lead-times and shorter seasons. It is expected, although this has not been extensively tested, that other forecast systems would be needed to be able to provide this requirement for horticulture for rainfall forecasts. Given a sound forecast system that meets the requirements of horticultural managers, the appropriate tools can be produced.

Temperature is the major factor in determining where horticulture crops can be grown successfully, and then how well these crops perform under varying seasonal conditions. Horticultural industries' requirements for **seasonal temperature (and rainfall) forecasting information**, is wide and varied (large number of commodities and cropping systems, spread over a very wide range of climatic regions).

d) How will the output be delivered to users, and what should this tool look like?

AgClimate is an example of how the output of this potential tool could be delivered - http://www.agclimate.org/
AgClimate provides a web-based tool to help peanut, tomato, potato, pastures and livestock producers in south-eastern USA, understand and plan for climatic conditions. It is an interactive web site with climate, horticulture, agriculture, and forestry information that allows users to assess management options under forecast climate conditions.
AgClimate has very limited use in horticulture in Australia, but it could be used as the basis for a similar tool and a mechanism for the delivery of climate based information, if developed specifically for selected locations and horticultural cropping systems in Australia.

What needs to be done to develop this tool?

A different predictive system will be required if a longer lead time and short season length forecast, which is required for horticulture, can be achieved. The SOI and SST based forecast systems which are currently available for rainfall and temperature have been validated only for short lead times and three-month seasons. These are termed statistical prediction systems, however, the future of prediction systems might lie with dynamical prediction systems based on numerical modelling

A workshop on the "Science of Seasonal Climate Prediction" was conducted in Canberra on 2-3 August 2006. The report of this workshop is available at http://www.science.org.au/events/seasonal/index.htm

This report compares statistical and dynamical prediction systems, including their current and future strengths and weaknesses. The conclusion which can be drawn from this workshop is that dynamical prediction systems of the future are more likely to be able to provide the longer lead times and short season lengths as well as account for the changing climate, which currently is a significant limitation to further development of currently available statistical prediction systems.

> "*Statistical prediction systems are based on the historical relationship between local climate variables, such as rainfall and temperature, and large-scale drivers of climate, such as the Southern Oscillation (as measured by the SOI) and patterns of sea-surface temperature (SST) in the Pacific and Indian Oceans*". (p. 4 – Science of Seasonal Climate Prediction – Report of Workshop. Australian Academy of Science, Canberra. 2-3 August 2006).

> "*Coupled (dynamical) models offer the long term potential to provide seasonal predictions in an era of possible climate change, whereas, by definition, statistical* approaches *cannot be used if climate relationships are changing*" (Alves, 2006).

Significant advances in the development and deployment of dynamical models are expected in the future. A joint development between CSIRO and BMRC is the Australian Community and Earth System Simulator (ACCESS), a coupled model, which will be used as a major component in the POAMA dynamical seasonal prediction system at the Bureau of Meteorology.

The Predictive Ocean Atmosphere Model for Australia (POAMA) is a state-of-the-art seasonal to inter-annual seasonal forecast system based on a coupled ocean/ atmosphere model and ocean/atmosphere/land observation assimilation systems - http://poama.bom.gov.au/

A version of the POAMA system is being made operational in 2007 and the complete POAMA-2 system will be operational in 2008. A key focus of the new system is the generation of regional products such as rainfall and temperature over Australia.

Operational Products are currently available from the POAMA model - http://poama.bom.gov.au/operational/index.htm

These products do not as yet deliver on the specific requirements for horticulture (see - What is Required? – above). For these specific requirements to be taken into account in the development of temperature (and rainfall) forecasts for horticulture, there needs to be an engagement with climate scientists who are developing these newer systems, highlighting the specific needs of horticulture in Australia.

Conclusions

The Scoping Study [VG05051] reported the following outcome –

"Currently the limitation on the use of tools (climate applications for managing climate variability) in horticultural industries, is the lack of climate science understanding that addresses the lead-time and season requirements of the horticultural industry.
The combination of long season (3 months) and short lead-time (zero), which are appropriate for other agricultural industries, is a significant constraint to the use of forecasting tools in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful. Given a sound forecast system that meets the requirements of the industry the appropriate tools can be produced.
There are no forecast systems based on the SOI and SST's which have been extensively tested for longer lead-times and shorter seasons."

This report shows that a different predictive system delivering forecasts with a longer lead time and short season length which are required for horticulture, are more likely to be achieved using dynamical modelling techniques, than previous statistical methods.

For this to occur, horticulture needs to engage with climate scientists who are developing these newer systems, and providing them with the information which is specific to the needs of horticulture in Australia.

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Appendix IV – "The development of adaptation strategies for the most vulnerable horticultural regions in Australia"

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Summary

Horticulture in Australia consists of a large number of diverse industries (fruit, vegetables, floriculture, turf and ornamentals), which are grown in a wide range of production regions because of the diverse micro-climates and soils which are available in those regions. Horticulture contributes ≈ $7 billion (gross value at the farm gate) to the economy every year. On this basis, horticulture is the second largest agricultural industry in Australia after the beef industry.

All horticultural crops are sensitive to temperature, and most have specific temperature requirements for the development of optimum yield and quality.

Climate change will impact horticultural commodities and regions through all of the following :-

- Changes in the suitability and adaptability of current cultivars as temperatures change, together with changes in the optimum growing periods and locations for horticultural crops
- Changes in the distribution of existing pests, diseases and weeds, and an increased threat of new incursions
- Increased incidence of disorders such as tip burn and blossom end rot
- Greater potential for loss of product quality e.g. because of increased incidence of sunburn
- Increases in pollination failures if heat stress days occur during flowering
- Increased risk of spread and proliferation of soil borne diseases as a result of more intense rainfall events (coupled with warmer temperatures)
- Increased irrigation demand especially during dry periods
- Increased atmospheric CO_2 concentrations will benefit productivity of most horticultural crops, although the extent of this benefit is unknown
- Increased risk of soil erosion and off-farm effects of nutrients and pesticides, from extreme rainfall events

With increasing temperatures, and changes to rainfall patterns which are currently uncertain, the simplest adaptation strategies will be employed and are currently being employed by growers. These will be the use of more adaptable cultivars and a range of cultural practices which enable growers to maintain current production in current locations – i.e. adapt to the 'new' climate in the current location. This will be driven in the first instance to maintain profitability through market timing, market access and market share.
If climate change impacts exceed growers adaptation capacity at a specific location, then a southward shift of production following the southward shift of agroclimatic zones is more likely to occur if growers are to maintain profitability through appropriate market timing, market access and market share.

Table 1. summarises some appropriate Risk Management Options (Adaptation Strategies).

Background

Using a combination of engagement with leading growers, consultants and scientists and literature reviews, the following questions were posed : -

Impacts - What are the impacts of climate change on selected horticulture regions and production systems?

Adaptation Strategies - what are some of the potential and acceptable strategies which growers and industries could consider, which will reduce the impacts of climate change on their business?

For horticultural industries to successfully adapt to increasing temperatures and changing rainfall patterns, there will be a need to understand the impact of climate change on specific regions and cropping systems, how vulnerable these regions and cropping systems are, and then develop both pre-emptive and reactive adaptation strategies or options.

As the next steps in providing a better understanding of the impacts of climate on horticulture industries, this project provides a format or process whereby individual horticulture industries might determine the Impacts and Adaptation Strategies to be able to respond to a changing climate.

To this end, three regions in Australia were selected for their diversity of location and cropping, and the level of past and future climate change, to conduct workshops with leading growers, consultants and scientists.

The locations selected were – The Lockyer Valley, south-east Queensland; the Central Riverina, southern NSW; and the Burdekin, north Queensland.

The major horticulture crops represented at these locations are as follows :-

1. Lockyer Valley (Gatton)
Horticultural production is dominated by vegetable systems (see Appendix 1 for production estimates) with very much smaller production of avocadoes, mangoes and stone fruit.

2. Central Riverina (Griffith)
The Riverina is made up of horticultural production districts around Hay and Hillston, the Southern Riverina around Darlington Point and the Central Riverina around Griffith. In the Central Riverina, vegetables, citrus and wine grapes are grown (see Appendix 2 for production estimates).
The most important vegetable crops are pumpkin, rockmelon, onions, potato and carrots.

3. Burdekin (Ayr)
Vegetable production is dominated by green beans, sweet corn, rockmelon, capsicum and other cucurbits (see Appendix 3 for production estimates), with substantial production of mangoes.

Impacts of climate change

Climate Change will impact, and is already impacting horticultural industries and businesses as a consequence of the effects of a change in a number of climatic factors :-

- **Increasing Temperatures**

All horticultural crops are sensitive to temperature, and most have specific temperature requirements for the development of high yields and quality.

Decisions on the location of production and crop and cultivar selection, are influenced by temperature, access to and timing of markets, suitable soils and availability and reliability of irrigation water.

- **Changes in rainfall amounts, distribution and intensity.**

The majority of horticultural industries have a dependence on irrigation, and very little rain grown production occurs. Rainfall has positive and negative effects on horticultural production.

When "normal in-season" rainfall events occur, irrigation storages (dams and aquifers) are replenished, and the amount of irrigation required to grow crops is reduced. "Out of season" rainfall events, especially if high in intensity, often have devastating consequences for product quality and production.

All horticultural regions will continue normal production for extended periods of time as droughts develop. This situation has occurred in many horticultural regions for a number of years without significant rainfall which produces storage replenishing runoff. This is in direct contrast with much of the broad-acre and grazing industries which depend on pre-planting and in-crop rainfall to produce economic yields.

The current drought has demonstrated the limits to which individual production regions can endure – e.g. Production of fruit and vegetable crops in the Murray Darling Basin of NSW and Victoria, in particular, has been severely impacted, but only after more than 5 years of significantly reduced flows in the river system. Similarly, vegetable production in the Lockyer Valley in SE Queensland has continued at normal production levels until 2003, with no significant recharge into the aquifers since 1996. Many other horticultural regions in Australia have approached the limit of irrigation water availability after 2 to 10 years of significantly reduced runoff from rainfall. Over the past few years, most of these regions have received some runoff, and many have had storages completely replenished.

Where future changing climates deliver less rainfall, and consequently less runoff, changes will need to be made to the capture and storage of irrigation water together with more water-use efficient irrigation systems, for growers to be able to continue production.

Specific Impacts

Many horticultural regions have already seen a rise in both maximum and minimum temperatures compared with the 1961 to 1990 base period. As a result of these changes, growers have already experienced up to 1^{o}C rise in temperatures, and have successfully adapted to these changes.

Impact assessments for broad-acre agriculture, especially for the wheat industry have been published widely. This is not the case for horticulture, except for viticulture.

Thresholds for the large range of horticultural crops are also not well known, especially for the vegetable sector.

Arriving at an understanding of the effects of climate change is made even more complex by the large number of commodities classified as horticultural crops (over 100 in Australia), and the wide range of regional climates which exist.

The following impacts, including some examples, have already occurred and are likely to continue to occur, with a further increase in temperature :-

<u>Production Timing</u> - Crops will develop more rapidly and mature earlier (taking less time from planting or fruit set to harvest). Vegetable growers producing summer crops in temperate regions will have the additional option of planting earlier, and later, therefore extending the production season. In tropical and sub-tropical regions, vegetable growers producing winter crops will be negatively impacted as the winter production season will be shortened.

- The winter lettuce and brassica season (mid-April to October) in south-east Queensland will be shortened by several weeks to a month by 2030 without the availability of more adaptable cultivars.
- For citrus, grapes, sweet corn and rockmelons in the Riverina, crops will mature earlier by about 10-14 days.
- Temperatures will be increasing, but photoperiods will not change. Onions are very photoperiod sensitive, so the effect will be on reducing time to harvest, which will have implications for bulb size and quality (smaller bulbs produced as the crop develops more rapidly); the fruiting season of strawberries will be reduced under increasing temperatures as runner production commences and flower (and fruit) production is reduced as day temperatures reach 28-30ºC.
- Soil temperatures will increase earlier in spring in temperate regions, providing opportunities for sweet corn to be planted earlier than is currently possible. Similarly, cucurbit crops which are currently established in the field using greenhouse grown transplants, will be able to be planted more cost effectively using direct seeding techniques, as long as the risks of late frosts are accounted for.

<u>Product Quality and Yield</u> - Increased heat stress will affect fruit size, quality and pollination of some crops.

- For avocados, increased heat stress will adversely affect fruit size and the capacity to ‘store’ a mature crop on the tree.
- Many vegetable crop cultivars are currently not as adaptable to higher (or more variable) temperatures as they were a decade ago.
- Poor pollination, especially under low humidity and high temperatures will occur in many crops (e.g. sweet corn, cucurbits, tomato and avocado), together with a reduction in the number of pollinator insect species present.
- Floral abortion will occur in capsicum when temperatures exceed 30ºC.
- Tomatoes have a threshold of 35^{o}C – above this they are likely to experience a reduction in quality – the number of times that this occurs is likely to increase in the future.
- Higher temperatures will reduce tuber initiation in potatoes.
- Increasing carbon dioxide could increase the incidence of brown fleck disorder in potato.
- Poor pollination will occur in many crops grown for seed (lettuce, sweet corn, cucurbits and carrots).
- Lettuce tipburn, a disorder occurring under low humidity and temperatures greater than 30ºC, will become more prevalent in the absence of more adaptable cultivars.
- Out of season high temperatures cause bolting (premature seed head production) of lettuce and celery, resulting in poor quality heads, and reduced yields. Increasing temperatures will force growers to narrow the production window for these crops to maintain quality and yields.
- Pollen germination in tomato is affected at temperatures above 27ºC leading to fewer fruit numbers (or smaller fruit) and lower yields.
- Colour development in apples occurs through the production of anthocyanin. Anthocyanin production is reduced by high temperatures. Similarly, in capsicum red colour development during ripening is inhibited above 27ºC.
- Pome and stone fruits require a specific amount of winter chilling to develop fruitful buds and satisfactorily break dormancy in the spring. Increasing minimum temperatures under climate change may induce insufficient chilling accumulation resulting in uneven or delayed bud break. For the pome fruit growing regions of Manjimup (WA) and the Granite Belt (Qld), which are currently marginal for chilling (i.e. there are some years when climate variability is such that 1200 chilling hours are not reached), a 1^{o}C warming will significantly decrease the number of

years when sufficient chilling will be achieved, and a 2^{o}C warming will make apple production at these sites, using high chill cultivars, uneconomical.

- A number of fruit commodities (e.g. pome fruit, stone fruit and avocadoes) require cross-pollinating cultivars for effective fruit set. Increasing temperatures may adversely affect the synchronization of flowering of these cultivars, resulting in inefficient pollination and reduced yield and quality.

Inputs (Availability and Costs)

- More irrigation (water) will be required because of higher evaporative demand. This will increase the costs of purchasing water, if it is available, and pumping water under hotter conditions. This, together with increasing fuel costs because of greenhouse gas emissions issues, will increase the cost of producing all irrigated crops. In some regions irrigation systems will not be able to cope with the increased demand.
- There will be increased irrigation requirements for preventing tip-burn (lettuce) and other induced disorders such as blossom-end rot (tomatoes).
- Overhead irrigation may be more of a necessity for cooling in lettuce and other leafy vegetables – contrasting with potentially reduced availability of water for irrigation.
- Perennial fruit crops are very vulnerable to short-term shortages of irrigation water availability. To some extent where this has occurred in the recent drought, the high value of horticultural crops has enabled some growers to purchase irrigation water and divert it from other lower returning agricultural uses.
- Competition for irrigation water has already occurred, and the cost of water has increased. Water for irrigation in horticultural crops will be diverted from other uses as long as the economic returns are sufficient. Secure supplies of water will need to be considered at a cost which relates to the return for the product grown with a secure water supply.
- If drought conditions do become more frequent, or their severity increases due to climate change, then the lifestyle (or amenity horticulture) sector will be affected. More drought tolerant plants and more efficient irrigation techniques will be required for industry and consumers to be able to adapt.
- Climate change will increase the cost of labour for harvesting, especially in northern regions, as fewer people (predominantly backpackers) will find the regional climate favourable in which to work. Increasing travel costs, will exacerbate this.
- The cost of freight, packaging, pesticides and fertilizer will increase as a result of greenhouse gas mitigation activities, and the increasing costs of fossil fuels (see mitigation opportunities – latter section of this report).

Effects on Cultural Practices

- An increasing incidence of out of season and extreme rainfall events, including consequent flooding, will affect the timing of cultural practices as well as the negative effects on yield and product quality. The damage caused to the vegetable industry (crop damage, erosion, soil and infrastructure losses) in the Lockyer Valley in May 1996 from out of season flooding was estimated to be $20M.
- Increasing temperatures will impact greenhouse production, especially production in sub-tropical regions, where current summer temperatures restrict production to the cooler months of the year, because temperature thresholds are often exceeded. Additional technologies for cooling greenhouses will be required for these production systems to continue. Greenhouse production in temperate (or highland) regions will be impacted less, and for summer production the impacts may not be felt for many years, especially where temperature thresholds are much higher than

current maximum temperatures. Positive impacts on reduced costs of heating for winter production will occur as temperatures rise.

- Most vegetable crops will develop more rapidly, changing current crop schedules and marketing arrangements. More frequent consecutive plantings for crops such as lettuce and brassicas will be required to regain regular production patterns. Therefore there is a need for a better understanding of the indices (e.g. the number of days over a specific temperature threshold, say 35^{o}C) which will be a part of future climates, and the effects these will have on yield and quality, as well as other factors such as time to harvest, pollination, etc.

<u>Pest and Disease effects</u> - In general, higher temperatures will increase pest and disease activity, alter their development rate, including that of host crops, and increase survivability of some organisms, especially in warmer winters. Changing rainfall amounts and patterns will modify this temperature effect for each organism.

- Higher temperatures will generally result in increased insect pest activity – e.g. an extra generation of insect pests such as heliothis will be possible in most locations.
- Higher temperatures will result in a longer period of pest activity, especially where production is extended – e.g. Diamondback Moth (DBM) is a pest of worldwide significance wherever brassica vegetable crops are grown. This pest is most destructive when an extended season occurs or where temperatures during the production season are high. With a warming climate DBM will have an increased impact in all brassica growing regions, particularly sub-tropical regions, and increasingly so in temperate regions.
- Under warmer (and perhaps drier) conditions in the future, thrips will reproduce and survive more easily. This situation has already been experienced during the drought conditions of the past 5 or more years.
- Higher temperatures will have negative effects on survivability and reproduction of some important parasites and predators - e.g. scale parasites in citrus and trichogramma in vegetables.
- Higher temperatures will provide opportunities for new pests which are currently not able to survive cold/cool winters – e.g. #1. Silverleaf Whitefly will extend into southern regions, where it either currently doesn't exist, only occurs sporadically, or occurs only in modified environments such as greenhouses – e.g. #2. The Murrumbidgee Irrigation Area (MIA) is Queensland Fruit Fly (QFF) free, and this freedom status is maintained by monitoring and trapping. Greater incursion pressure can be expected in the MIA from QFF, as the climate becomes more favourable for QFF development and survival.
- Increasing temperatures, especially during the winter, will provide a survival mechanism for pests such as Silverleaf Whitefly, and its weed and crop hosts. This will allow an extension of the current SLW habitat from subtropical to more temperate regions as climate continues to change.
- For scale and mites pests in a range of horticultural crops especially citrus, dryer and dustier conditions will increase the occurrence and appearance of these pests earlier in the season.
- Higher temperatures, combined with lower humidity will compromise the effectiveness of some biological pesticides - e.g. Nuclear Polyhedrosis Virus (NPV) used extensively in sweet corn and tomatoes for managing heliothis, is most effective under cool, moist conditions.
- Pathogens which require free moisture or high humidity to reproduce and establish (e.g. Black Spot in Apple, Brown Rot in Stone Fruit and a range of leaf and soil-borne pathogens of fruit and vegetables), will be less prevalent in those regions where spring and summer rainfall is likely to reduce and dry conditions prevail for longer periods between rainfall events, and vice versa for those regions where rainfall increases.

- As the number of extreme rainfall events increases, soil conditions will favour the establishment and reproduction of soil borne pathogens such as *Phytophthora cinnamomi* in avocado and *Sclerotinia scleroteorum* in lettuce as well as many plant parasitic nematodes.
- As for insects and diseases, weeds will have opportunities to spread to regions where they are currently unable to establish because of temperature constraints. This will provide opportunities for vectors of virus diseases (e.g. Silverleaf Whitefly as a vector of Tomato Yellow Leaf Curl Virus which is hosted on a range of weed species in the Solanum genus) to over-winter in more southerly regions as temperatures, especially winter temperatures, rise.

<u>Marketing Arrangements</u> - Higher temperatures will change production and marketing arrangements between regions. Crops will develop more rapidly and mature earlier, taking less time from planting or fruit set to harvest.

- In tropical and sub-tropical regions, vegetable growers producing winter crops will be negatively impacted as the winter production season will be shortened e.g. - the season for lettuce, sweet corn and brassica vegetable crops in SE Qld, will be shorter by approximately 2 weeks on either end of the winter season. This will provide opportunities for other more southerly regions which are currently too cold to produce crops in late autumn and early spring, to grow crops and market products in this time slot.
- Citrus and grapes in the Riverina will mature earlier by about 10-14 days. This may have a positive impact, by providing growers with options to market crops earlier with potentially higher returns.

<u>Post-harvest costs</u>

- Under higher temperatures, poor rind colour development occurs in citrus, especially with higher night temperatures in the Riverina and the Burnett. Regreening in Valencia's during summer, will require longer periods of degreening.
- De-greening may become a future management practice, especially for Navel oranges produced in southern regions, to satisfy the needs of consumers.
- Increased costs of grading and marketing for susceptible fruit and vegetables will occur for removing increased amounts of blemished product. Reduced marketable yields associated with damage from sunburn and poor pollination will also occur.
- Post-harvest cooling costs for most vegetable crops will increase as additional field heat will need to be removed prior to transport to market.

<u>Production Location</u> - Production of some crops in some regions will benefit from an extended production season, whilst others will contract. It is expected that this will be a gradual induced relocation of production, in the absence of adaptation actions which include introduction of more adaptable cultivars in those areas where higher temperatures become a limitation to production. The establishment of the citrus industry in Emerald in Central Queensland in the 1980's and 1990's following a significant increase in winter temperatures as compared with the 1960's, is an example of a change to location as a consequence of a changing climate.

- It will be possible for some production districts to extend their production season into the winter - e.g. The Central West of NSW currently produces lettuce only in the spring and autumn. Warmer winters will allow lettuce production to expand into and eventually through the winter as well, whereas current winter lettuce production in the Lockyer Valley will contract as winter temperatures rise. Similarly avocado production will become viable in those districts (e.g. highland areas of southern Qld and northern NSW), which are currently too cold for current cultivars to consistently set fruit.

- If rainfall increases do occur, especially in the tropics, then the disease management advantages offered by dry winter seasons for the production of crops such as rockmelons and mangoes will be significantly reduced.
- Increasing temperatures will impact greenhouse production, especially production in sub-tropical regions, where current summer temperatures restrict production to the cooler months of the year, because temperature thresholds are often exceeded. Additional technologies for cooling greenhouses will be required for these production systems to continue, or this production will be induced to move to more temperate or to highland regions where maximum temperatures are mitigated by altitude. Positive impacts on reduced costs of heating for winter production will occur as temperatures rise.

Increased Productivity - Increases in temperature and CO_2 may increase yields of some crops, providing positive productivity outcomes.

- Large variations in response to increased CO_2 levels have been found across a range of horticultural commodities. Where positive responses have been found (e.g. potato, lettuce, avocado and citrus), increasing temperatures may offset any increased productivity.

Environmental Impacts

- An increase in the intensity of rainfall will increase the potential for erosion events and the export of nutrients and sediments from fields, affecting water quality and impacting other ecosystems such as the Great Barrier Reef. This will require practices aimed at intercepting raindrops and runoff, e.g. residue and stubble retention.
- An increasing awareness of climate change will increase the need for growers to use carbon-neutral practices and reduce practices that are deemed detrimental to the environment.
- Rising sea-levels will impact aquifers used for irrigation in coastal regions.
- With minimum temperatures increasing, the incidence of frosts is projected to decrease. Frost risks may not change, with drier conditions and less cloud cover potentially cancelling out this effect. With increasing temperatures, vegetable crops in some locations will be planted earlier and with the above scenario are likely to be more at risk to late frost damage. Fruit crops which develop more quickly in a warmer spring are also more vulnerable. Australia's variable climate adds to the risks of crop damage from late frosts, as seen from the damage to crops in southern Australia in the spring of 2007.

Financial Viability

- An increase in the intensity of cyclones will have effects on production systems, the community and consumers. The effects of Cyclone Larry (March 2006 - $A350 million crop, property and infrastructure losses) on the banana industry and communities of North Queensland, and the Australian consumer, could easily be repeated in the future in other industries and communities in northern Australia.
- Increasing fuel costs will increase the cost of producing all crops.
- Increasing competition will come from regions that progressively become more suitable for production of similar commodities.
- If quality is valued by the consumer, then growing crops in their "ideal" environment, where the appropriate cultivars perform best, will become an advantage to those growers and locations where this coincides.
- Perennial horticulture in particular has a long-term investment horizon. There will be a need for more information on how to decide on the long-term investments required for these commodities (especially those where cultivars are not rapidly changing – avocados vs. low-chill stonefruit vs. vegetables).

Source of Current (and Future) Cultivars

- The majority of cultivars used in horticulture are sourced from overseas (this is especially the case for most of the seed propagated cultivars – potatoes are a notable exception). Australian production of all commodities is very small in relation to the major fruit and vegetable producing countries of USA and Europe, from where most cultivars are sourced.
- Breeding specifically for Australian conditions for many commodities will not be a viable option for most seed companies. Growers of these horticultural commodities will remain dependant on cultivars being available and adaptable to Australian environments as climates continue to change.
- The commercial reality of the vegetable seed industry, is that cultivars available to Australian growers are those produced for other countries where production is significantly larger. The specific 'needs' of Australian growers will be difficult to satisfy separately from the needs of growers in the much larger growing regions of the world.
- For perennial crops, the capacity of growers to change to better adapted cultivars, if better adapted cultivars are available, is limited by the costs and the time from planting to first harvests in fruit crops. This is a long investment horizon. The other limitation is knowing what cultivars would be adapted to the changed environment – this would need to be extrapolated from other production regions. The costs of getting it wrong are very high.

Climate Change and Adaptation Strategies

Flexibility has been the key to adaptation in horticulture to date, and is likely to continue to be an important component of adaptation strategies as climates continue to change. Growers have been able to manage climate variability reasonably well, although major improvements could be made if tools to assist with the management of climate variability, both temperature and rainfall, were designed specifically with the needs of horticultural growers and industries in mind.

The current drought has provided opportunities for some growers who have been able to shift production to where water for irrigation is available. Those who have done this successfully will be in a much better position to also manage climate change successfully.

The following are desirable climate change adaptation outcomes for horticulture :-

- Resilient and adaptive horticultural production systems which are less vulnerable to climate change and climate variability
- Improved resilience to changes in pest and disease incidence
- Increased ability to capitalise on new market opportunities
- Regionally specific climate change scenarios, which are very relevant to managers of horticultural enterprises
- Practical tools available to horticultural growers and their advisors to better manage climate change and climate variability

Site Selection

Site selection to avoid unsuitable climate factors is practiced as a matter of course in horticulture. For all horticultural crops, temperature is the main climatic factor which determines where and when crops are grown, and also has a significant influence on crop performance (i.e. time to harvest, product quality, and to a less extent, yield).

A pilot study linking climate change scenario modelling and land suitability modelling was conducted in the East Gippsland region in 2004 to model the potential implications of climate change on the future production of selected agricultural commodities (cool climate grapes, plantation blue gum, spring wheat). Similar studies in major horticultural regions would determine vulnerability of current commodities, and develop adaptation strategies to better cope with the impacts.

Crop Management

Chemical treatments such as hydrogen cyanamide to induce budbreak in fruit crops, cultural treatments including evaporative cooling through overhead irrigation, strategic applications of nitrogen and irrigation, and sunburn protection using kaolin based products are currently being used in subtropical and tropical cropping systems. Their use will increase, especially if alternative more adaptable cultivars are not available.

Planting dates of some crops such as sweet corn are based on soil temperature conditions, which automatically allows the adaptation to climate variability to occur. The changes in production times which result from increasing temperatures, will need to be taken into account with changes to production and marketing plans.

Cultivar Selection

Selection of available cultivars which are more adaptable to a changing and variable climate will be the main tool for adaptation in the vegetable industry, and less so in the perennial fruit industry where long term investment in orchards reduces the application of this adaptation strategy.

Water management

Many horticultural growers have adopted more efficient irrigation technologies which are providing significant water-use efficiencies. This will continue, together with an increased understanding of crop water requirements and the use of new technologies to monitor and manage irrigation systems.

Pests and diseases

Integrated Pest and Disease Management (IPDM) practices are common in all horticultural regions and commodities, and continuous improvement in these systems, and their adoption, will be an important part of adapting to a changing climate.

Use of Seasonal forecasts

Fruit and vegetable growth and quality are very sensitive to environmental extremes. Current seasonal rainfall and temperature forecasts have limited application to horticulture because of the lead time and season length requirements of horticulture. Tools used in managing climate variability have mainly been designed and constructed for a specific purpose and for a specific agricultural or pastoral industry. The combination of long season (3 months) and short lead-time (zero), which are incorporated in current tools for managing climate variability, are appropriate for other agricultural industries, but are a significant constraint to the use of these forecasting tools in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful.

Temperature is the major factor in determining where horticulture crops can be grown successfully, and then how well these crops perform under varying seasonal conditions. Horticultural industries' requirements for seasonal temperature (and rainfall) forecasting information, is wide and varied because of the large number of commodities and cropping systems, spread over a very wide range of climatic regions.

Mitigation

It is not known if horticulture is a net emitter or sequester of greenhouse gases (GHG). Many factors will need to be understood to be able to determine this for the large range of commodities, regions and farming systems utilised by growers in these regions.

There is a high probability that most horticultural cropping systems will be net emitters of GHG's, although it is expected that this will be relatively low when compared with other agricultural commodities. The lowest emitters will be those commodities and farming systems which minimise tillage operations and better manage nitrogen fertilizer applications. Both of these practices are increasingly being incorporated into Best Management Practices (BMP's) for horticultural farming systems. These farming systems may also be able to sequester carbon, and provide another income opportunity for horticultural businesses in a changing climate.

There are potential negative impacts on horticulture with the introduction of an emissions trading scheme (ETS) into agriculture. The large number of horticultural commodities utilising the wide range of farming systems in the diversity of production regions, will be a significant challenge to compliance with an ETS, as well as potentially imposing costs in excess of the benefits which might come from an involvement in an ETS.

Conclusions

Because horticulture in Australia consists of a large number of diverse industries, which are grown in a wide range of production regions, climate change impacts and adaptation to these impacts will be as diverse. Many horticultural regions have already experienced a rise in both maximum and minimum temperatures compared with the 1961 to 1990 base period. As a result of these changes, growers have already experienced an impact of climate change of up to 1°C rise in temperatures, and in the main, have successfully adapted to these changes.

Rises in temperatures up to 4°C will be a real challenge to horticulture, as climate indices or thresholds of significance for the large range of horticultural crops are not well known.

To this end, a clear and defined understanding of how climate change will impact cropping systems and businesses in specific regions at temperatures up to 4°C is not readily available.

Arriving at an understanding is made even more complex by the large number of commodities classified as horticultural crops (over 100 in Australia), and the wide range of regional climates which exist.

All of the following issues will affect Australian horticultural industries in some way, and increasingly so as temperatures rise above the level to which growers have been able to readily adapt :-

- Changes in time to harvest for some crops and locations
- Changes in the suitability and availability of cultivars for current and future production locations
- Reduced availability and increased cost of irrigation water in most locations and in some seasons
- Greater seasonal variability
- Increased pest and disease incidence and 'new' pests, diseases and weeds
- Damage from extreme events (rain, hail, wind and heat stress)
- Negative impacts on soils and crops due to extreme temperature and rainfall events and flooding.
- Changes in frost frequency

Understanding how to adapt to climate change can be partially developed through site and cultivar selection. However, to integrate these strategies at the enterprise level will require investment in modelling technologies such as APSFarm (that uses the APSIM system), advanced tree crop management models and potentially utilisation of gene to phenotype modelling as currently used for the selection of maize cultivars.

Gatton (Lockyer Valley) Workshop - Wed 24th October 2007

The following are the responses by vegetable and fruit growers in the Lockyer Valley to the question, "What are the **impacts** of the past and future changes in temperature on my farm/business/crop/industry?"

- Earlier maturing crops, and the season will be shorter – perhaps by 1 month on either end of the winter for Lettuce and Brassica vegetables.
- Avocados – increased heat stress will adversely affect fruit size and capacity to hold the crop for longer periods into the spring.
- Vegetable varieties may not be as appropriate for the current environment. Not as adaptable to the higher temperatures as varieties available 10-15 years ago.
- Poor pollination in some crops (sweet corn and cucurbits).
- More variable temperatures – there will be a need for cultivars which can perform under more variable environments, and hotter environments.
- More irrigation (water) will be required to grow the same crops, because of higher evaporative demand, preventing tip-burn (lettuce) and other induced disorders such as blossom-end rot (tomatoes).
- Higher costs of irrigation under hotter conditions.
- Overhead irrigation may be more of a necessity for cooling in lettuce – contrast with potentially reduced availability of water for irrigation.
- Temperature will be increasing, but photoperiod will not – Onions are very photoperiod sensitive, so the effect will be on reducing time to harvest, which may have implications for bulb size and quality (early smaller bulbs??).
- Higher temperatures will reduce tuber initiation in potatoes.
- Increasing carbon dioxide could increase the incidence of brown fleck in potato.
- Increasing incidence of storms and cyclones – effects on timing of practices and physical effects on plants.
- Increased insect pest activity.
- Higher temperature effects on beneficials (trichogramma in sweet corn).
- As other production districts become warmer in the winter, it is possible for them to be encroaching on winter production from the Lockyer Valley.

The following are the responses by vegetable and fruit growers in the Lockyer Valley to the question - What are you doing (or what can be done) about these impacts of the past and future changes in temperature on my farm/business/crop/industry? – **adaptation strategies**.

- There is a need for shorter duration crops, to reduce the potential risks associated with higher temperatures, and reduced availability of irrigation water.
- Current broccoli and lettuce cultivars are not as adapted to the current (and therefore future) temperature conditions, as were cultivars such as Greenbelt were 15 years ago. There is a need for more adaptable cultivars for the vegetable industry.
- The commercial reality of the vegetable seed industry, is that cultivars available to Australian growers are those produced for other countries where production is significantly

larger. The specific 'needs' of Australian and Lockyer Valley growers will be difficult to satisfy separately from the needs of growers in the much larger growing regions of the world.

- How much do we know about the "threshold temperatures" of current cultivars? How close are we to these thresholds? It is assumed that we are close to these thresholds (see comments above about adaptability of current cultivars). There is a need to know more about what the thresholds are, and therefore how close we are to exceeding them.
- If quality is valued by the consumer, then growing crops in their "ideal" environment where the appropriate cultivars perform best will become an advantage to those growers and locations where this coincides.
- There will be a need for more information on how to decide on the long-term investments required for fruit crops (especially those where cultivars are not rapidly changing – avocados vs. low-chill stonefruit).
- Insect pest management will need to be 'better' than currently, as insects such as thrips will be able to thrive under warmer (and perhaps drier) conditions. This has already been experienced over the past 5 years.
- Can consumers be 'convinced' that superficially blemished produce is just as nutritious and edible as the 'perfect' product?
- There is a need for a better understanding of the indices (e.g. – the number of days over a specific temp threshold say 35^{o}C) which will be a part of future climates, and the effects these will have on yield and quality, as well as other factors such as time to harvest, pollination, etc.
- Will irrigation systems be able to cope with the apparent increased demand?
- "Secure" supplies of water will need to be considered at a cost which relates to the return for the product grown with a secure water supply.
- Grow less more profitably.
- Growers are already changing cultivars in response to a changing climate (see comments on cultivar availability above).
- Adaptation is already happening, so these lessons should not be forgotten as climates continue to change.
- There is a need to better understand the costs and benefits of adaptation options in a changing climate.
- Windbreaks to reduce the effects of wind damage. There is a real need to understand the cost effectiveness of windbreaks - how much wind damage reduction can be achieved; what are the negative effects of planted windbreaks on adjacent crops (water and nutrient requirements especially); and what are the costs of establishment and maintenance.
- There is a need for new options for the control of pests – IPM will become the norm. There will be an increased need to take advantage of new pesticides which are being registered in other crops (e.g. cotton), so that registrations will be encouraged in appropriate situations in horticulture as well.

The Lockyer Valley is a major Queensland production area for winter **Vegetables** (with some important crops e.g. sweet corn – grown in summer). There are about 400 vegetable farms growing $120M of vegetable crops on 12,000ha.
Lettuce ($32M), Potatoes ($20M) and Onions ($17M) Brassicas ($16M) Sweet corn ($15M) are major crops. The Beetroot industry ($8.5M), though small is an important supplier to the processing industry.

Griffith (Central Riverina) Workshop - Thursday 1st Nov 2007

The Riverina is made up of horticultural production districts around Hay and Hillston, the Southern Riverina around Jerilderie and Berrigan and the Central Riverina around Leeton and Griffith.

The following are the responses by citrus and vegetable growers in the Central Riverina district to the question, "What are the **impacts** of the past and future changes in temperature on my farm/business/crop/industry?"

- Earlier maturing crops (citrus/grapes) – by about 10-14 days – positive effect – earlier on the market.
- Earlier maturing crops (vegetables – sweet corn and rockmelons) – by about 14 days.
- Higher cost of grading and marketing due to the effects of sunburn and frost on both fruit and vegetables – cost of removing increased amount of blemished fruit, as well as the reduced marketable yields associated with damage from sunburn and frost.
- Higher costs of irrigation under hotter conditions.
- Poor rind colour development in citrus (navels) under higher temperatures, especially autumn night temperatures – Regreening is something that happens in Valencia's during summer.
- Vegetable varieties may not be as appropriate for the current environment. Not as adaptable to the higher temperatures as varieties available 10-15 years ago.
- Poor pollination in many seed crops (lettuce, sweet corn, cucurbits and carrots) and commercial crops (sweet corn and cucurbits).
- Long-season varieties of citrus are more subject to the effects of a hotter climate (longer period of time for the risks associated with a hotter climate to have a negative effect on yield and quality).
- Scale and mites pests - increase in the occurrence and appearance earlier in the season, because of dryer and dustier conditions.
- Higher temperature effects on parasites (scale parasites in citrus) and other beneficials (trichogramma in vegetables).
- Potential for new pests which currently are not able to survive in the colder winter – e.g. 1. MIA is Queensland Fruit Fly free, and this freedom status is maintained by the monitoring / trapping grid managed by NSW DPI. Greater incursion pressure can be expected from QFF with warmer temperatures as the climate becomes more favourable to QFF development. 2. There is the potential for an extra generation of heliothis, especially if the temperatures do rise further.
- Increased wind damage to crops has been observed. There is insufficient historical data on wind speed and direction to validate this observation.
- As other production districts become warmer in the winter, it is possible for them to be encroaching on winter production from the Riverina. – e.g. 1. The Central West of NSW currently produces lettuce only in the spring and autumn. Warmer winters in the Central West will allow lettuce production to run through the winter as well.

The following are the responses by vegetable and fruit growers in the Lockyer Valley to the question - What are you doing (or what can be done) about these impacts of the past and future changes in temperature on my farm/business/crop/industry? – **adaptation strategies**.

- De-greening may be a future management practice (especially for Navel oranges) to satisfy the needs of consumers.
- Educate consumers to convince them that the green skin is cosmetic – the fruit are as mature as those which they have been used to purchasing.
- Diversify into shorter duration crops, to reduce the potential risks associated with higher temperatures, and reduced availability of irrigation water.
- Windbreaks to reduce the effects of wind damage. There is a real need to understand the cost effectiveness of windbreaks - how much wind damage reduction can be achieved; what are the negative effects of planted windbreaks on adjacent crops (water and nutrient requirements especially); and what are the costs of establishment and maintenance.
- Growers of cucurbits in particular, are already making their first plantings earlier in the spring, because they perceive (or know from experience) that there is less risk of cold and/or frost damage because of higher temperatures in the spring. Similarly for the last plantings in the late summer – these are being made later, because of the reduced risks associated with cold and frost damage.
- There is a need for new options for the control of pests – IPM will become the norm. There will be an increased need to take advantage of new pesticides which are being registered in other crops (e.g. cotton), so that registrations will be encouraged in appropriate situations in horticulture as well.
- Shading of some crops is already being undertaken by some growers in the Riverina, to reduce temperatures.
- There is a need for better adapted varieties in vegetable crops especially – changing to a better adapted variety is relatively simple to do, all other factors being equal.
- For fruit crops, the capacity of growers to change to better adapted varieties (if better adapted ones were available) is limited by the costs and the time from planting to first harvests in fruit crops. The other limitation is knowing what varieties would be adapted to the changed environment – this would need to be extrapolated from other production regions. The costs of getting it wrong are very high.
- Explore niche markets, and/or more creative marketing for crops from the Riverina.

The **availability of water for irrigation** is currently (and perhaps for the foreseeable future) the most limiting factor in horticulture production (and agriculture in general) in the Riverina. As a consequence, growers wanted to discuss the impacts and adaptation strategies associated with limited irrigation water availability :-

- Water security and capacity to deliver water (channel system) is, and will continue to have an effect on which crops can be grown.
- It is estimated that 30% of water is lost in the delivery system (earth channels). Changing this by lining or piping could make a very significant difference to the amount of water available to growers.
- Improved water use efficiency might be achieved by using other methods of irrigation e.g. trickle. This will depend on other changes as well, including the need for on-farm storages, or a changed delivery mechanism.
- Trickle irrigation may also provide other advantages over the current furrow irrigation methods, including more timely agronomic operations which are independent of irrigation timing – i.e. furrows are not wet, so operations such as pesticide application can be carried out at any time; irrigation can be continued up to harvest if necessary – currently irrigation must be discontinued sometime prior to harvest to allow the harvest operation to be carried out on dry paddocks.

Vegetables in the Central Riverina are valued at $50M. The most important crops are pumpkin (1000ha - $17M), Rockmelon (500ha - $9M), Onions (550ha - $9M), potato (750ha - $6M) and carrots (280ha - $3.4M).

The Riverina produces an estimated $94M worth of vegetables from 7500ha each year. This comes from the Central Riverina (3600ha - $50M); Hay (580ha - $16M); Hillston (1100ha - $10M) and the Southern Riverina (2200ha - $18M).

Citrus production comes from 540 producers from 8300 ha of plantings consisting of 3 million trees.
Average annual production of 180 000 tonnes - 85% in production due to continued replanting to meet market demands. (~30% of Australia's citrus production).

- 80 000 tonnes of Valencia oranges (2006-07)
- 60 000 tonnes of Navel oranges (2006)
  (Navel forecast 2007 of 66 000T)
- grapefruit, lemons and mandarins are also grown

● 40 registered packing sheds
● 8 citrus juice processors
● 20% of production is exported (mainly to SE Asian and the USA markets)
● Farm gate value of $45 Million

Ayr Workshop - Thursday 8 November 2007

The following are the responses by vegetable and fruit growers in the Burdekin to the question, "What are the **impacts** of the past and future changes in temperature on my farm/business/crop/industry?"

- Observation that in warmer years, the leaves of sweet corn have been thinner (i.e. reduced LAI). This has implications for the amount of photosynthesis that may take place in a crop and hence its growth.
- Less cloud cover (with reduced rainfall) will increase the level of radiation that a crop is exposed to.
- Tomatoes have a threshold of 35°C – above this they are likely to experience a reduction in quality – the number of times that this occurs is likely to increase in the future.
- Warm temperatures are likely to reduce the possibility of pollination through (a) a reduction in the number of pollinator insect species present (they may not tolerate higher temperatures), and (b) the crop will be in a poorer physiological condition and hence will show a reduced potential to be pollinated.
- Cucurbit production will benefit from an extended period for their production.
- Increasing competition from other regions that progressively become suitable for production of the same crops as presently grown in the Ayr region.
- Increase in cyclone damage will impact on the financial viability of enterprises.
- Increasing fuel costs will increase the cost of producing all crops.
- Increasing temps will means that (a) additional pest species may move into the area, and (b) those pest species already present may increase in abundance, but this will be species specific

and all pest species have a maximum and minimum temperature thresholds regulating their densities.

- The window for vulnerability to pests will be extended as the winter period is reduced.
- Increase in temperature and CO_2 may increase yields, but this may result in supply implications – i.e. oversupply of produce to markets.
- Crops will reduce the amount of nutrients that they uptake due to (a) an increase in temperature accelerating the phonology of crops and hence reducing the time to maturity and the opportunity to take up nutrient, and (b) an increase in temperature will result in the closure of stomata more frequently, truncating transpiration more often with the result that crops have a reduced opportunity for nutrient uptake. Reduced nutrient uptake will have negative implications for harvest quality.
- The quality of produce may also be reduced due to sunburn and increased pests.
- Climate change will increase the cost of (a) labour for harvesting, as less transient labourers (predominantly backpackers) find the regional climate favourable to work in and can afford increasing flight prices due to the increasing price of aviation fuel.
- Climate change will increase the cost of (b) freight due to increasing price of fuel.
- Climate change will increase the cost of (c) packaging as all aspects of its production will be influenced by the increasing cost of petrol and energy.
- Duration of the harvest period – may be shortened with increased temps.
- Increased awareness of climate change will increase the pressure for farmers to farm using carbon-neutral practices and reduce practices that are deemed detrimental for the environment, e.g. burning of sugarcane.
- Increase in the intensity of rainfall will increase the potential for erosion events and exportation of nutrients and sediments from the paddock. This will require practices aimed at intercepting raindrops and runoff, e.g. residue and stubble retention.
- Extreme rainfall events have been associated with rising levels in the saline aquifers underlying agricultural lands in the region. This has brought salts to the surface/within the root zone of crops.

The following are the responses by vegetable and fruit growers in the Lockyer Valley to the question - What are you doing (or what can be done) about these impacts of the past and future changes in temperature on my farm/business/crop/industry? – **adaptation strategies**.

- Provide shade to vulnerable crops through (a) shade netting, (b) companion cropping / intercropping that will provide a natural canopy for smaller crop species, (c) use of shade houses. (NB companion cropping / intercropping would require a reconfiguration of planting arrangements and densities to manage competition and machinery logistics.)
- Use of anti-transpirants to reduce transpiration rates.
- Use varieties that are more suited to warmer temperatures and increased pest populations and species.
- Reduce risk through relocating some production to other areas (this would include moving to other regions in Australia and moving to increased altitudes) to address (a) reducing water availability, and (b) climate change.
- Change in planting dates to optimise the time and potential of pollination.
- Introduction of increased populations of pollinator species.
- Genetic modification.
- Consumer and supermarket education to encourage the consumption and sale of crops outside the present narrow definition of acceptable quality.

The Burdekin is a major production area ($70M gross value) for winter **Vegetables.** Beans ($10M), Capsicums ($17M), Melons ($8M) and other Cucurbits ($16M) are major crops.

Three Regional Examples of Historical Climate Change.

Many horticultural regions have already seen a rise in both maximum and minimum temperatures compared with the 1961 to 1990 base period. Three regions of horticultural significance (Burdekin, Lockyer Valley and Riverina) are examples of an already changing climate, to which growers have successfully adapted.

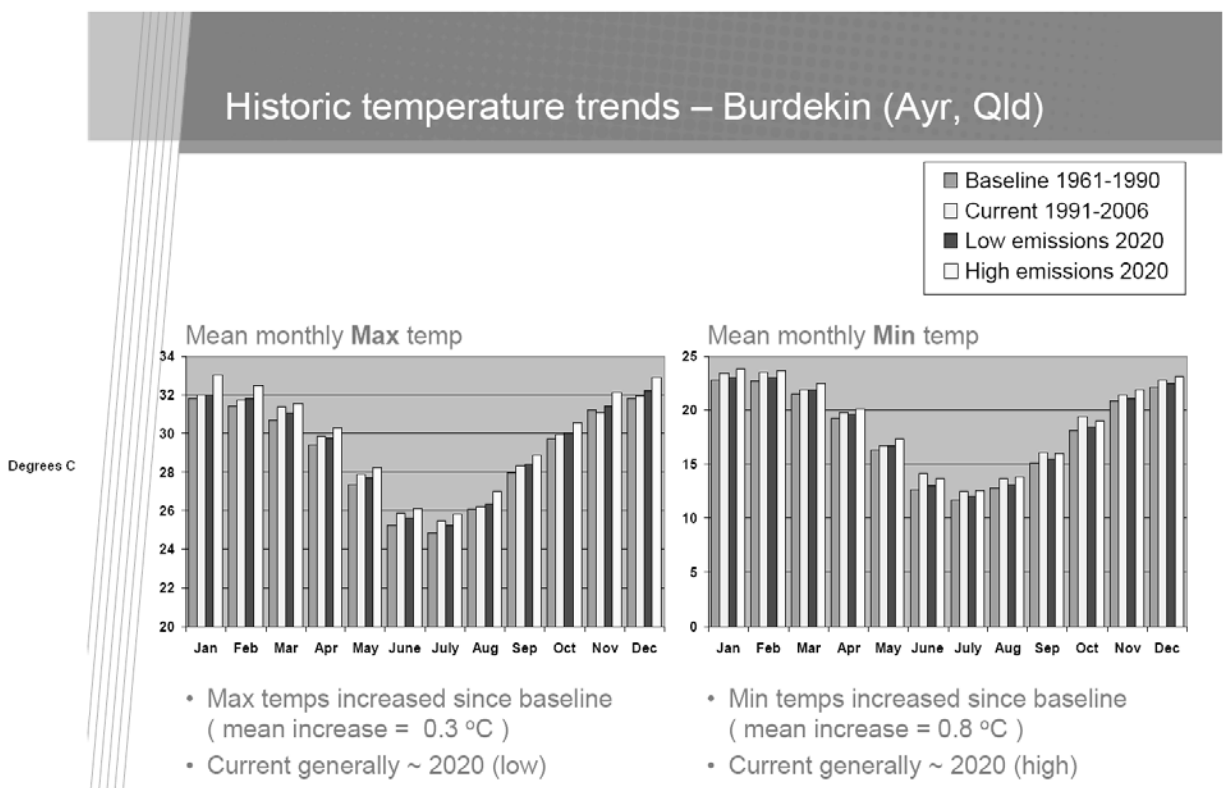
As a result of these changes, growers have already experienced up to 1°C rise in temperatures. Temperatures for the Low Scenario for 2020 are close to current temperatures in each of these three regions. Growers have, in the main, successfully adapted to these changes.

1. Burdekin (North Queensland)

Mean Monthly Maximum and Minimum Temperature – Historical (Baseline), Current and Projected 2020 (Low and High Scenarios)

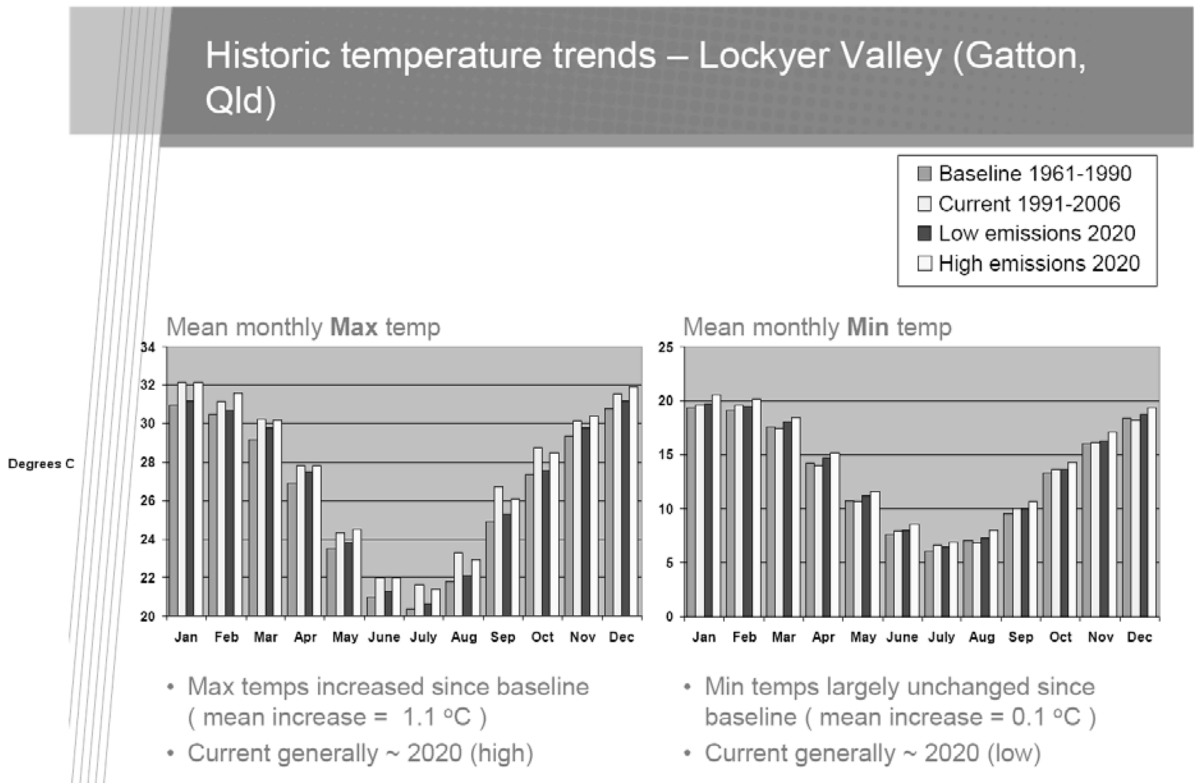
Ayr – North Queensland

Projections by CSIRO Marine and Atmospheric Research



2. - Lockyer Valley (south-east Queensland)

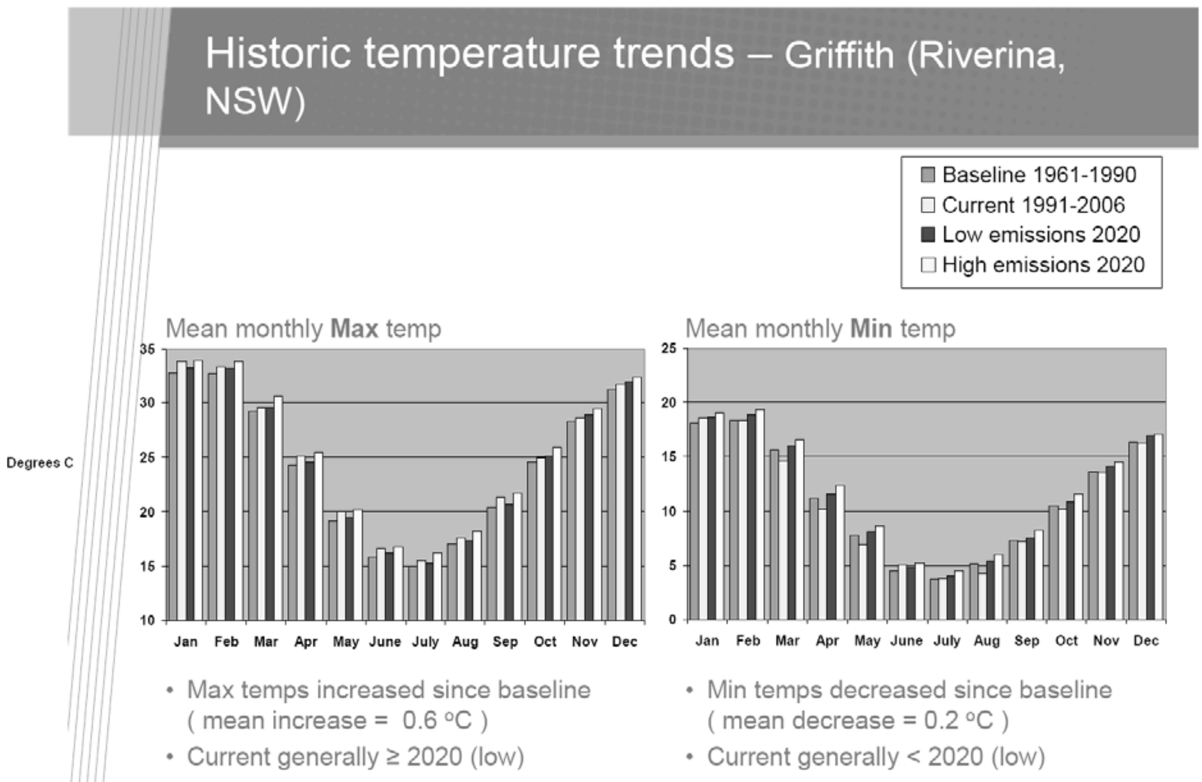
Mean Monthly Maximum and Minimum Temperature – Historical (Baseline), Current and Projected 2020 (Low and High Scenarios)
Gatton – South-east Queensland
Projections by CSIRO Marine and Atmospheric Research



3. - <u>Riverina</u> (southern NSW)

Mean Monthly Maximum and Minimum Temperature – Historical (Baseline), Current and Projected 2020 (Low and High Scenarios)
Griffith – Southern NSW

Projections by CSIRO Marine and Atmospheric Research



**** Table 1. – How might Climate Change affect management decisions in horticulture AND what are some appropriate Risk Management Options (<u>Adaptation Strategies</u>)?**

Decision Issue	Tools or Adaptive Methods	Decision Maker	Possible Impact	Certainty of Impact	Some Risk Management Options (Adaptation Strategies)
Annual Crop Planting Decisions	• Cultivar Choice	Grower and Seed suppliers	Cultivars which are more adaptable to higher temperatures, **<u>are not</u>** available from Australian seed suppliers.	Possible – vegetable cultivars are sourced (in the main) from overseas.	Extend the season by growing in other regions (purchase, lease or 'contract' production to supply the market).
	• Production Period & Production Timing	Grower (and Advisors)	Cultivars which are more adaptable to higher temperatures, **<u>are</u>** available from Australian seed suppliers.	Possible – more likely for some species e.g. lettuce and brassicas.	Lobby seed companies and Peak Bodies to have appropriate cultivars available to the industry.
			Crops maturing earlier resulting in a shorter production season (reduced by several weeks).	Probable – especially if more adaptable cultivars are not available.	Extend the season and maintain position in the market by growing in other regions (purchase, lease or 'contract' production to supply the market).
Property Acquisition	• Location of Production	Grower (and Advisor)	Higher temperatures will force some relocation of production to more suitable production region.	Possible – more likely for some species e.g. lettuce and brassicas.	Maintain position in the market by growing in other regions (purchase, lease or 'contract' production to supply the market).
Crop Management	• Cultural Practices	Grower (and Advisors)	Higher temperatures will have adverse effects on product quality of many crops.	Probable – especially if more adaptable cultivars are not available.	Maintain position in the market by growing in other regions (purchase, lease or 'contract' production to supply the market with high quality product).
			Higher temperatures will increase pest and disease activity for many crops.	Certain.	Continuous improvement in the effectiveness and adoption of IPDM systems.

Decision Issue	Tools or Adaptive Methods	Decision Maker	Possible Impact	Certainty of Impact	Some Risk Management Options (Adaptation Strategies)
Crop Management (cont).	• Pest and Disease Management	Industry Peak Bodies, R&D providers and RDC's	Higher temperatures will increase pest and disease survivability, and extend their range to more southerly regions.	Certain.	Awareness of the potential for movement of 'new' and exotic pests and diseases into production regions; and continuous improvement in the effectiveness and adoption of IPDM systems.
Water management	• Inputs (amount and costs)	Grower (and Advisors)	Higher temperatures will increase the need for more efficient irrigation systems, and/or more irrigation.	Possible – more likely for some crops and especially in southern production regions.	Water Use Efficiency measures including trickle irrigation where appropriate. Irrigation scheduling using latest techniques and appropriate technology.
Marketing Arrangements	• Production Period & Production Timing	Grower and Marketers	Crops maturing earlier (i.e. shorter duration from planting or flowering to harvest).	Probable – especially if more adaptable cultivars are not available.	Maintain position in the market by growing more adaptable cultivars OR growing in other regions (purchase, lease or 'contract' production to supply the market).
			Increased post-harvest costs. Reduced product quality and/or yield.	Probable – especially if more adaptable cultivars are not available.	Maintain position in the market by growing more adaptable cultivars OR growing in other regions (purchase, lease or 'contract' production to supply the market).

** Adapted from Clark, A., Barratt, D., Munro, B., Sims, J., Laughlin, G. and Poulter, D. (2006) – Climate Change – Adaptation in Agriculture. Science for Decision Makers – Bureau of Rural Sciences, Department of Agriculture and Fisheries - www.acera.unimelb.edu.au/materials/brochures/SDM-**Climate**%20**change**.pdf (downloaded 17/3/2008).

Appendix V – Griffith Workshop Agenda.

NSW DEPARTMENT OF
PRIMARY INDUSTRIES

Murrumbidgee
CATCHMENT MANAGEMENT AUTHORITY

Climate Change and Agriculture – Impacts and Adaptation in the Murrumbidgee Catchment

Griffith Ex-Serviceman's Club – Thursday 1st October 2007

9.00am – 4.30pm

AGENDA

Time	Topic	Speaker
8.30 am	Registration, tea/coffee	
9.00 am	Welcome and introduction from the Chair	Murrumbidgee CMA Board member
9.10 am	DPI Climate Risk Management Project	Mr. Gary Allan (NSW DPI)
9.20 am	Observed climate trends and current outlooks for NSW and the region	Mr. Clinton Rakich (Bureau of Meteorology)
9.55 am	Climate Change – the science, current projections and impacts	Dr. Bryson Bates (CSIRO Marine & Atmospheric Research)
10.30 am	Questions from floor	Chair
10.40 am	MORNING TEA	
11.00 am	Impacts on water resources – Regional R&D perspective	Mr.Tariq Rana (CSIRO/CSU)
11.30 am	Impacts on water resources – NSW Government perspective	Mr. Paul Simpson (NSW DWE)
12.00 pm	Industry perspective	Mr. Mike Hedditch (Sunrice)
12.20pm	Questions from the floor	Chair
12.30 pm	LUNCH	
1.30pm – 3.30pm	Workshop sessions – Keys to Adaptation in regional industries	Includes: Broadacre Cropping **Horticulture (Peter Deuter and Sarah Park)** Viticulture

Final session

3.30 pm	Afternoon tea	
3.45 pm	Concluding remarks	Chair Gary Allan (DPI)
4.00 pm	CLOSE	