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Committee Secretary
Standing Committee on Primary Industries and Resources
PO Box 6021
House of Representatives
Parliament House
Canberra ACT 2600

20 March 2009

Dear Secretary

Re: Inquiry into the role of government in assisting Australian farmers to adapt to the impacts of climate change

We thank you for the opportunity to provide comments on the above inquiry. Our detailed responses to the Terms of Reference for which we have the expertise to address are attached.

We provide our comments on the basis that CSIRO has core strengths in agricultural science and in the cross-scale, interdisciplinary approaches needed to address climate change adaptation and to develop transformation options and pathways. CSIRO is a well best equipped R&D organisation to provide whole-of-system analyses and decision-relevant technologies and information to support Australia's primary industries, government policymakers and regional bodies in their adaptation to climate change.

If you require anything further please contact Kilian Perrem of CSIRO's Government Relations team (kilian.perrem@csiro.au ph 02 6276 6480) or my Executive Officer Jenny Baxter (jenny.baxter@csiro.au ph 07 3214 2910) in the first instance.

Yours sincerely

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CSIRO

CSIRO Submission 09/336

House Standing Committee on Primary Industries and Resources

Inquiry into the role of government in assisting Australian farmers to adapt to the impacts of climate change

March 2009

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Executive Summary

Australia's climate is changing and further change seems inevitable despite efforts to reduce greenhouse gas emissions. For primary industries to continue to thrive in the future the sector needs to anticipate these changes, be prepared for uncertainty, and develop and implement adaptation strategies now.

The recent Intergovernmental Panel on Climate Change Fourth Assessment Report (Hennessy et al. 2007; IPCC 2007) concluded that the agriculture sector in Australia is particularly vulnerable to climate changes, with potential negative impacts on the amount of produce, quality of produce, reliability of production and on the natural resource base on which agriculture depends. This vulnerability requires high levels of adaptive responses.

There is a strong rationale for an increasing focus on adaptation of agriculture to climate change. This need arises from several considerations (Howden et al 2007):

1. Past emissions of greenhouse gases have already committed the globe to further warming of approximately 0.1°C per decade for several decades, making some level of impact, and necessary adaptation responses, already unavoidable.
2. The emissions of the major greenhouse gases are continuing to increase, with the resultant changes in atmospheric CO_2 concentration, global temperature, and sea level observed today already at the high end of those implied by the scenarios considered by the Intergovernmental Panel on Climate Change (IPCC). Furthermore, some climate change impacts are happening faster than previously considered likely. If these trends continue, then more proactive and rapid adaptation will be needed.
3. There is currently slow progress in developing global emission-reduction agreements beyond the Kyoto Protocol, leading to concerns about the level of future global emissions and hence climate changes and associated impacts.
4. The high end of the scenario range for climate change has increased over time, and these potentially higher global temperatures may have nonlinear and increasingly negative impacts on existing agricultural activities.
5. Climate changes may also provide opportunities for agricultural investment, rewarding early action taken to capitalize on these options.

Climate change will have a direct impact on crop growth and yield through direct changes in plant productivity resulting from temperature increases, increased variability in temperature and altered rainfall patterns across space and time. Climate change can also indirectly affect plant productivity through alterations to pest and diseases dynamics. For farmers to successfully adapt to the impacts of climate change consideration must be made of both direct and indirect impacts.

Some adaptive responses to climate change used by farmers will involve incremental alterations to production practices, e.g. changing crop varieties, timing of sowing and harvesting, and pest management practices. In some cases large-scale transformational responses will be necessary which may involve the translocation of entire industries. Some production practices currently being used by farmers to address current variability in weather conditions will also be useful for ameliorating some of the impacts of climate change.

Adaptation will need to take a flexible, risk-based approach that incorporates future uncertainty and provides strategies that will be able to cope with a range of possible local climate changes. Initial efforts in preparing adaptation strategies should focus on equipping primary producers with alternative adaptation options suitable for the range of uncertain future climate changes and the capacity to evaluate and implement these as needed, rather than focussing too strongly yet on exactly where and when these impacts and adaptations will occur.

Adaptation measures will have to reflect and enhance current 'best-practices' designed to cope with adverse conditions such as drought. Marginal production areas are amongst the most vulnerable and will likely be amongst the first areas in which the impacts of climate change will exceed adaptive capacity. It will be important to identify areas where climate change risks and opportunities require strong policy intervention (beyond simply supporting adaptation within existing land uses) such as transformation to new land use activities. There is also a need to look at system wide implications of climate adaptation to assess both unintended negative consequences or win-win opportunities from adaptation. For example, an adaptation strategy might be to shift areas of a farm that become marginal for agricultural production as climate changes into vegetation plantings for biosequestration and carbon markets. This could have biodiversity benefits and overall more sustainable agricultural production.

This submission draws heavily on a major report prepared recently by CSIRO for Land and Water Australia entitled "An overview of climate change adaptation in Australian primary industries – impacts, options and priorities" (Stokes & Howden eds. 2008). The submission begins by providing current and future adaptation strategies for each agricultural sector. Part 2 gives an overview of current scientific and policy efforts to support agricultural adaptation. Finally, the submission examines the role of rural R&D and the need for a coordinated approach to enable rural R&D to be most efficient and effective in its delivery. Rural R&D strategies should avoid duplication where a uniform approach is possible (e.g. climate projections) bearing in mind that individual solutions will continue to be needed for individual sectors and regions.

CSIRO's expertise in relation to the Inquiry's Terms of Reference

CSIRO's applied strategic position in the National Innovation System, coupled with its integrative capacity, make it an essential player in national climate adaptation responses, as recognised by the establishment of the CSIRO Climate Adaptation National Research Flagship as a complement to the university-led National Climate Change Adaptation Research Facility.

CSIRO has core strengths in agricultural science and in the cross-scale, interdisciplinary approaches needed to address climate change adaptation and to develop transformation options and pathways. CSIRO is the best equipped R&D organisation to provide whole-of-system analyses and decision-relevant technologies and information to support Australia's primary industries, government policymakers and regional bodies in their adaptation to climate change. Key advantages include:

- national coverage, capacity to undertake interdisciplinary science and to transfer and apply underpinning knowledge developed in different contexts, strength in agriculture and NRM research;
- strong linkages to industry practitioners, policymakers, community leaders and the general research community and our commitment to undertaking relevant, credible and legitimate science enhancing prospects for achieving real impact;
- whole-of-system analysis capability from the climate science to biophysical impacts to economic impacts to social impacts to policy and decision relevant solutions without the vested interests of a particular jurisdiction or industry and without artificial bounds due to disciplinary narrowness; the ability to connect to other aligned areas such as climate science, agricultural science, social science, economics, transformational biology, ICT, mining, energy and water R&D.

This submission has specifically addressed the Inquiry terms of Reference which focus on the impacts of climate change on agriculture and the potential adaptation responses. These adaptation responses will inevitably interact with initiatives and activities to mitigate climate change i.e. emissions reduction and biosequestration. So while this submission has not addressed the opportunities and challenges associated with mitigation in the agricultural sector, CSIRO would be happy to provide input into the Inquiry on this topic.

Part 1. Adaptation options for Australian agriculture

This section addresses the first of the Inquiry's terms of reference, i.e.
i) Current and prospective adaptations to the impacts of climate change on agriculture and the potential impacts on downstream processing

Overview for approaches to adaptation

As the reality of climate change is being increasingly accepted, attention is rapidly shifting from describing the likely impacts of climate change to addressing the challenges of adaptation. Australian agriculture, which already has to manage extreme climatic variability, is in a position to be leading Australian industry in innovative and proactive responses to climate change - and it needs to be as it is amongst the most vulnerable sectors in Australia (PMSEIC 2007, IPCC 2007). It is highly likely that climate change will add further complexity to the current challenges of managing environmental and market risk.

Assessing the likely economic and social costs of climate change has so far been tackled at a broad scale but early estimates (Gunasekera et al 2007, Heyhoe et al. 2007, Howden and Crimp 2005, Howden et al. 2007) suggest significant impacts at regional and national scales e.g. 5% loss of GDP by 2050. Adapting to climate change can reduce these costs and Heyhoe et al. (2007) suggested at the regional scale that adaptation may halve the likely economic impact of climate change. Howden and Crimp (2005) assessed the value of some simple agronomic adaptation options for the Australian wheat industry and found that these will likely increase farm-gate income by an average of between $150M and $500M per annum by 2070.

There are many potential incremental adaptation options available to offset projected impacts (Howden *et al.*, 2007). These incremental adaptation options often involve build on existing approaches to better manage climate variability, technological fixes e.g. new plant varieties, improved water use efficiency, etc., to much more significant change in enterprise mix and land use change. Implementation of these options is likely to have substantial benefits under moderate climate change for some cropping systems (Howden and Crimp, 2005; Howden and Jones 2004). This has been clearly demonstrated in the past with incremental innovation to environmental, policy and economic drivers a hallmark of agriculture's success in Australia.

However, it is highly unlikely that even well planned incremental innovation will suffice in response to some of the future projected climate changes as recent syntheses of the value of adaptation options to agriculture suggest that there are significant limits to the benefits of adaptations within existing agricultural systems (Easterling et al. 2007, Howden et al. 2007). These studies concluded that more transformational change will be required to adapt to more significant climate changes. So a major challenge for agriculture is to plan ahead and determine where and when incremental adaptation will not be sufficient to cope with climate change and to develop approaches that will be required to address transformational change in land management and land use. This level of forward planning is unprecedented in Australian agriculture and needs to be supported by both science and policy.

This is just not a simple case of acquiring more certain climate change projections and determining which areas may no longer be climatically suitable for current agricultural activities. Other factors that need to be considered include social and economic vulnerability, adaptive capacity, new technologies, governance systems, and policies such as structural adjustment (Howden et al. 2007).

To illustrate this point there have been over the last year or so calls for some farming regions in marginal environments to be eased out of farming ahead of the projected climate changes. However, many factors other than climate determine vulnerability (Nelson et al. 2005) and within marginal environments there are some farmers who are struggling and are not viable while others are at the forefront of innovation and risk management and are both economically viable and environmentally sustainable. This highlights the complexity of vulnerability and adaptive capacity and the potential dangers in a 'one-size-fits-all' policy. Clearly climate change will put some regions of Australia under immense economic, social and environmental stress with implications for both individual farmer and rural community viability.

Transformational change to address these climate changes need to be developed with a full systems understanding of the climatic, economic and social forces at work. This is partly because the combined economic and environmental drivers of global change may interact in surprising ways. For example, the significant ongoing changes in climate predicted by the IPCC will impact an Australian agricultural sector that is under constant change from international market forces. This is dramatically illustrated by a continuous consolidation of farms since the mid 1960s associated with long term declines in farmers' terms of trade. Farm numbers in Australia have fallen from around 200,000 in 1966-67 to around 130,000 in 2004-05, resulting in significant economic and social change in rural communities. In this transformational change process, larger and more efficient farms have been able to increase their profitability through technical and management innovations that increase their productivity. However, these changes have also led to social impacts in some regions, such as the depopulation and economic decline of some rural communities.

Climate change will therefore impact Australian agriculture against a backdrop of constant economic and social change, and these impacts will occur at multiple scales. Most fundamentally, climate change will affect the relative productivity of alternative land uses, as changes in rainfall and temperature differentially impact different types of crop and livestock. The viability and vulnerability of alternative agricultural land uses will also depend on the effect of climate change on world prices, as climate changes affects the relative productivity of Australia's trading partners and competitors. All of these changes will take place against a changing institutional context, including changes in greenhouse mitigation policy such as carbon trading schemes.

Successful adaptation to the combined influences of climate, world markets and policy will need to be transformational in several ways. Perhaps most importantly, the multiples scales at which climate change is likely to affect Australian agriculture could require an unusual degree of coordinated adaptation between farmers, communities, industries and governments across those scales (Figure 1). Effects to adapt and adopt sustainable farming practices in response to climate change will need to be considered within broader opportunities to change enterprise mix on farm, as well as the mix of on- and off-farm livelihood activities.

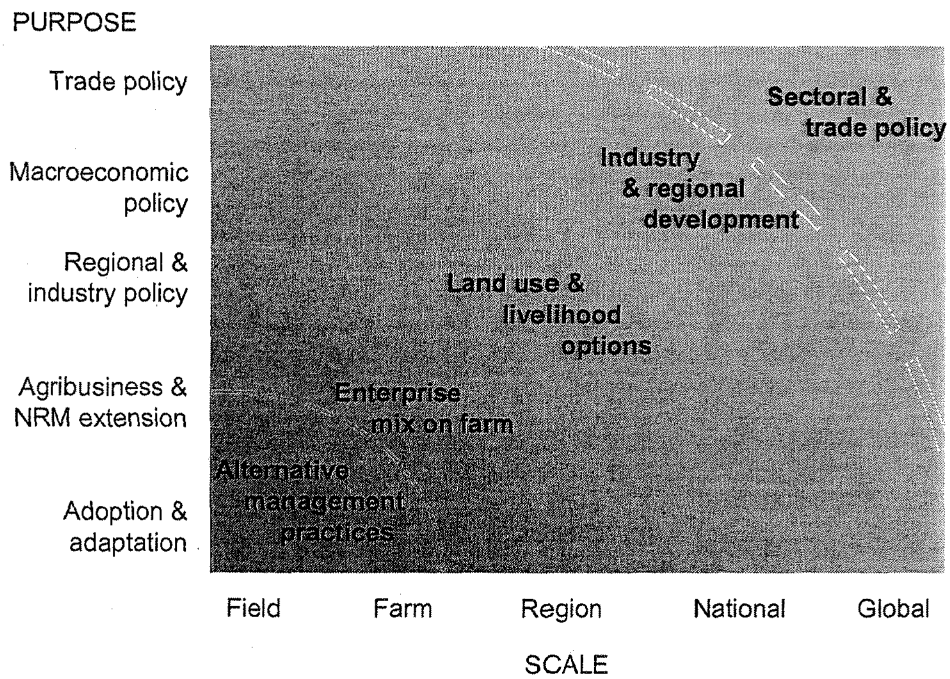

Figure 1: A conceptual map of coordinated adaptation for Australian agriculture across nested scales.

Additionally, the system wide implications of adaptation options need to be explored to avoid both unintended consequences e.g. maladaptation through adopting new farming practices that are more energy intensive and to take advantage of win-win opportunities. A good example of possible win-win opportunities is in the area of landscape and biodiversity management. A possible adaptation strategy to climate change might be to diversify increasingly marginal areas for agricultural production into vegetation plantings to access carbon market opportunities. These vegetation plantings, if done with appropriate planning, could contribute significantly to conservation of biodiversity and provide additional benefits such as shade or reduce dryland salinity.

Adaptation within farm enterprises will in turn need to be coordinated with industry and regional development policy aimed at creating new opportunities for rural communities. At the broadest scale, the role of agriculture in the national economy needs to be constantly reviewed against the changing productivity of other sectors, in part influenced by trade policy and international relations.

Overview of specific on-farm adaptation options

CSIRO has recently prepared for Land and Water Australia a 346 page report providing "An overview of climate change adaptation in Australian primary industries – impacts, options and priorities" (Stokes & Howden eds. 2008). The study (also referred to here as the 'CSIRO-LWA report) was one of two consultancies commissioned by Land and Water Australia (LWA) as input to the development of the national Climate Change Research Strategy for Primary Industries (CCRSPI) (http://lwa.gov.au/ccrspi/). The CCRSPI is a joint initiative of the Rural Research and Development Corporations; the Federal, State and Territory governments; CSIRO and universities and is managed by LWA.

CSIRO's report for LWA was prepared by a small, cross-disciplinary team of researchers with valuable input from relatively few industry participants. Due to the limited participation and the paucity of existing analyses of benefits and costs of implementation of adaptation strategies, this study should be seen as a starting point from which to engage with primary industries – not a final analysis.

The following key messages for adaptation of water resources and for each of Australia's major agricultural sectors are taken directly from the most recent review of climate change adaptation in the Australian agricultural sector, prepared by CSIRO for Land and Water Australia (Stokes & Howden eds 2008). Further details on more specific current and future adaptation options can be found in Appendix 1

Water Resources

Three quarters of Australia's irrigated land area has been nominated as occurring in catchments with "high" or "very high" risk scores, highlighting the close spatial and causal links between irrigation and water supply constraints. In the irrigation regions of the Murray-Darling Basin, north-eastern New South Wales and south-eastern Queensland, multiple factors interact to threaten water resources: significant development of surface and groundwater resources, declining rainfall in recent decades, and projected reductions in future rainfall and runoff.

For adaptation to succeed, a "whole of climate" approach to operational and strategic decision making is needed. The most prudent course is to treat the decreased levels of rainfall occurring over the past decade as the "new normal". The greenhouse signal for rainfall over much of Australia is likely to be negative and may accelerate in line with warming.

On-farm and systems efficiencies can be improved through better use of technology, co-ordination of delivery mechanisms, evaporation control, retrofitting leaky systems, the provision of probabilistic seasonal forecasts and improved scheduling.

Integrated catchment management is the principal resource management framework in Australia. The relationships between water quality, surface and groundwater extraction, waterway management and land-use need to be considered in an integrated manner, incorporating both climate and non-climatic influences. Institutional arrangements will need to be improved to manage this.

It will be essential to assess options for adaptation in highly allocated systems. Existing measures to augment supply or the creation of a free water market may not provide sufficient or socially acceptable solutions if changes to supply become substantial. Additional measures will need to be found, and their social acceptability needs to be considered.

There is a need to develop conceptual frameworks and tools using risk management principles to include climate change in water planning and management. Stakeholders acknowledge the importance of climate change but at present lack methods to include it in their mainstream business. Contingency plans acknowledging progressive levels of stress are needed (e.g., green, yellow, amber and red system status).

Grains

Adaptations to climate change are likely to be important in Australian cropping systems dealing with climate change, with moderate climate changes possibly turning a problem into an opportunity, and more negative climate changes significantly increasing vulnerability to climate change. In the wheat industry alone, relatively simple adaptations may be worth between $100M to $500M p.a. at the farm gate. Further benefits are likely if a wider range of adaptations is practiced but these remain to be evaluated.

There are a range of technical adaptations such as changed crop management practices, new varieties, altered rotations and improved water management that may, in various situations, have significant benefit. In many cases, these are consistent with existing best management practice for climate risk. However, these practices may need to be modified, enhanced or integrated in different ways to cope with the likely challenges of climate change

There are also a range of potential adaptations in the decision environment in which farm and associated enterprises operate such as industry and regional development policies, stewardship programs, infrastructure development, industry capacity development programs and other policies such as those relating to drought support, rural adjustment and trade amongst many others. Maintaining a flexible R&D base with the capacity for focussed, relevant and rapid response to the changing needs of the cropping industries was seen as a high priority by the farmer participants in the grains chapter of the CSIRO-LWA review.

There are many adaptations for the cropping industry that are consistent with those in other industries. However, a common need raised by the farmers is increasing the accessibility of climate scenario data, providing web-based access from a centralised database that can deliver the climate variables needed at the time and spatial scales of interest, for a range of global climate models and for a range of emissions scenarios with several different climate downscaling methods

The translation of these climate scenarios into adaptation action will need participatory research with participants across the agricultural value chain. In particular these studies will carry the analysis from climate to biophysical impacts on crops and cropping systems to enterprise level adaptation options to farm financial impacts to regional economic and social impacts (such as via livelihoods analysis) and then through to policy options. Integration and adaptive learning are critical and could occur through social and analytical links back to the enterprise scale.

Cotton

Less availability of water resources resulting from climate change will increase competition for these resources between irrigated cotton production and other crops and environmental uses which emphasises the need for continual improvement in whole farm and crop water use efficiencies.

There will be a need to maintain and increase cotton profitability through practices that increase in both yield and fibre quality, whilst improving resource use (especially water and nitrogen use).

Regional specific effects will need to be assessed thoroughly as the predominant cotton production regions span from southern NSW to north Queensland. This is necessary so that cotton growers can assess likely impacts at their business level. Research into the development of responsible and sustainable cotton systems for northern Australia where water supply is more assured is also needed.

Research into integrated affects of climate change (temperature, CO_2, and water stress) on cotton growth, yield and quality need further analysis, including the development of varieties tolerant to abiotic stress (especially heat and water deficits). Consideration or allowances in these studies of adaptation of both cotton cultivars and insect pests that will have been selected in rising CO_2 environments is also needed.

Cotton is adapted to hot climates. With the current geographical spread of Australia's cotton breeding program along with new biotechnology tools and other plant and crop physiological research identifying and assessing adaptation traits, new varieties with improved water use efficiency and heat tolerance will be selected that are better suited to climate variability and change.

Rice

Limitations in projected irrigation water supply under climate change are likely to have a significant negative impact on Australian rice production, which is totally dependent on supply of irrigation water.

Evapotranspiration rates over the rice-growing period are projected to increase over the next century, however the effect on total water demand of rice crops may be balanced in part by faster development of the crop and a shorter growth cycle.

The net impact of increased temperatures and CO_2 on rice is largely unknown in the Australian environment, however climate change may increase the risk of heat-damaged crops (not currently a major issue). The risk of low-temperature damage during reproductive phase, one of the major historical limitations to rice production, is likely to be reduced under climate change projections.

There is some scope to further adapt existing rice production methods to reduce irrigation demand – through reduction in the duration of ponding via operational (direct drilling) and breeding (yield/duration) means, as well as reduction in deep percolation losses through enhanced definition and regulation of rice-suitable soils. However the overall potential for water savings is limited, and the consequence of less water will be less rice. Aerobic and alternate-wet-and-dry (AWD) rice may present the Australian rice industry with new options for increasing water productivity (kg grain/ML) in a changing climate. The viability of these novel rice production systems for the Australian environment warrants immediate research.

Potential new methods of rice production (aerobic culture) may allow expansion of rice growing to new areas or regions.

The rice industry has been highly successful in increasing water-use efficiency over its history, and must continue to do so in adapting to climatic change. Rice farmers will need to consider a wide range of potential farming system changes (new varieties/crops, rotations, water priorities, irrigation methods, farm layouts, use of seasonal climate forecasts in management) to adapt to predicted changes in on-farm climate and water supply over the coming century. Research into the viability of new farming system ideas, in comparison with traditional systems, is urgently needed to allow for future farm planning.

Sugarcane

Probably the greatest impact (and adaptation challenge) for the Australian sugarcane industry will be the projected change in the amount, frequency and intensity of future rainfall. In many regions the amount of effective rainfall available to the crop will be reduced, whilst water demand is likely to increase due to greater rates of evapotranspiration linked to atmospheric warming.

A range of adaptation strategies are needed across the entire sugar cane industry value chain in the coming years if it is remain sustainable under a changing climate. Strategies must be tailored to individual regions to take account of differences in biophysical and logistical characteristics.

Adaptation options available to the sugarcane industry can be categorised into those seeking to:

- improve the management of limited water supplies;
- technological fixes based on reductionist analysis;
- engineering design principles, or computer-aided models;
- altered cropping system design agronomic management (typically requiring changes in attitudes and behaviour);
- decision making tools (including the use of climate forecasting and information sources); and
- institutional change.

The CSIRO-LWA report (Howden et al. 2008) details numerous knowledge gaps and priority areas for research, development and extension (R,D&E). These include: improvements to farming practice; development of innovative farming and processing systems that take an integrated and sustainable approach to risk and opportunity across all inputs; capitalisation of bio-energy opportunities and carbon trading potential for value adding; greater focus on sugarcane physiology and plant improvement in varietal characteristics; enhancing human capital through building skills and enhancing science capability in climate understanding and risk management; the linking of biosecurity management to a changing climate; and a greater understanding of the global context of climate change impacts on worldwide production, profitability and markets relative to the Australian sugar industry.

Many of the knowledge gaps listed above can be best filled through the enhancement of existing R,D&E activities. Other knowledge gaps are either related to projection uncertainty and impacts of future climate variability, or sugarcane physiology.

Building social capital through targeted extension, improving skills and providing an improved industry-wide knowledge base are all essential for future adaptation. Additional knowledge gaps will undoubtedly come to light as the sugarcane industry responds to the changing climate.

Viticulture

A warmer climate will hasten the progression of phenological stages of winegrape vines so that ripening will occur earlier in the season. Budburst may be affected in some of the more maritime climates due to less chilling over the winter dormancy period. Grape quality will be negatively impacted if no adaptation measures are implemented.

The water demand of winegrape vines will increase in a warmer climate while rainfall and, more importantly, runoff to water storages is projected to decrease. Shifting to cooler sites can alleviate some of the warming impact. As vineyards have a life of 30+ years, planning for this should begin now.

Within regions, existing varieties can be replaced with 'longer season' varieties to compensate for the warmer temperatures and compressed phenology. Winery infrastructure and staffing levels need to accommodate more compressed vintages, i.e. possible increased intake over a shorter period. Consumer education to accept new wine styles and varieties will be important.

Horticulture

Site suitability may change for some horticultural crops. There may be a reduction in areas for growing stone- and pome-fruits requiring chilling, and an expansion in areas for growing subtropical crops.

Sunburn, timing of crop stages, vegetable crop bolting (premature flowering), colouration effects, flowering and pollination timing and failure, and other quality and yield issues will need to be monitored.

Varietal selection can be used to better match the crop to the new climate regime. Utilising existing variation or breeding new varieties can facilitate adaptation. Drought tolerant plants for amenity horticulture will be favoured in drier climates.

Water demand will increase for most crops growing under warmer conditions. Changes in rainfall and evaporation are likely to reduce soil moisture and runoff in much of southern and eastern Australia. Increased water demand combined with reduced water supply poses significant challenges. Increasing water use efficiency practices will be paramount.

CO_2 concentration will increase in the atmosphere but the net effect is crop specific. Elevated CO_2 can enhance photosynthesis and water use efficiency in some plants. More research will need to be undertaken to fully understand the impact on each crop.

Pests and disease pressure may change. Decreasing rainfall and humidity may reduce fungal pressure, depending on the timing. Summer rain may increase in some regions (e.g. Northern NSW) favouring fungal growth. Flooding due to extreme rainfall events could benefit some soil borne pathogens. Cold season suppression of some pest species may be reduced. Higher temperatures can increase the activity of pests and diseases, and perhaps have a negative impact on the effectiveness of parasites and beneficial organisms.

A greater range of tropical produce may become available. The cost of crops tends to rise during droughts, which are likely to occur more often. Consumers may require assistance to accept some changed quality of produce (colour changes).

Integrating knowledge from agronomists, agro-meteorologists, and farmers to assess and access the utility of short- and medium-term forecasts, and long-term climate projections to capture and evaluate relevant knowledge will enable risk assessments to be undertaken that include the social, economic and environmental costs and benefits of adaptation. We need research on adaptive governance, resilience and barriers to adaptation. Industry-wide strategic planning will assist the industry to manage these future changes effectively.

Forestry

Australia's native forests include more than two thousand tree species many of which are highly vulnerable to climate change because of their narrow climatic ranges. For example, a 2°C increase in mean annual temperature would result in more than 40% of all the eucalypt species (of which there are more than 800) being in a climate outside of their current range.

Australia's plantation forests are dominated by *Pinus radiata* (radiata pine) and *Eucalyptus globulus subsp. globulus* (blue gum), which together account for about 69 per cent of the total plantation area. As both are grown over relatively wide climatic ranges, they should not be highly vulnerable to climate change in the short to medium term. However, impacts are likely in specific regions and at the current economic limits of the planted area.

Bioclimatic analysis can identify plantations that currently experience particularly hot and/or dry conditions. These sites could be monitored to provide an early warning if conditions become unsuitable for particular species in particular regions.

Plantation productivity may be increased by rising levels of atmospheric carbon dioxide, but may be reduced by temperature changes, especially in conjunction with greater water loss at higher temperatures or if rainfall is reduced.

There is an urgent need to improve the understanding of the effects of increased levels of atmospheric carbon dioxide and changes in temperature and rainfall on tree growth. It is particularly important to assess whether growth rates of particular species are likely to be increased or decreased at particular sites and how trees respond to stress through particular combinations of climate change. This is one of the largest uncertainties in predicting the impact of climate change on both native and exotic forests

There are also potential problems due to increased risks from pests and diseases, as well as potentially more frequent and severe bushfires. Increased frequency and intensity of fire has major implications for the benefits that Australian society obtains from forests. In particular:

- Most of Australia's consumed water originates from forests. The 1939 'Black Friday' forest wildfires reduced water inflows to Melbourne's catchments by 400GL per year (90% of Melbourne's water use) due to the increased water demands of post-fire regrowth vegetation.
- Globally forests account for 95% of carbon stored in live vegetation, equivalent to the amount of carbon in the atmosphere; 2.7 times if soils are included. The 2006/07 bushfires released an amount of CO_2 equivalent to that sequestered by six million hectares of plantations (~ three times the current plantation estate).

Broadacre Grazing

The main challenges facing the grazing industry are likely to be declines in pasture productivity, reduced forage quality, livestock heat stress, greater problems with some pests and weeds, more frequent droughts, more intense rainfall events, and greater risks of soil erosion.

Increased adoption of climate forecasting to inform existing strategies for coping with climate variability will assist the grazing industry in dealing with the early stages of climate change (but these strategies need to incorporate considerations of long-term climate change trends).

The adaptation challenge needs to be clearly defined by quantifying the range of impacts uncertain climate change will have on the grazing industry and framing these challenges in terms of existing management pressures. Likely responses of pastoralists and policy makers to these impacts need to be determined and comprehensively evaluated.

The most arid and least productive rangelands may be the most severely impacted by climate change, while the more productive eastern and northern rangelands may provide some opportunities for slight increases in production. However, a rigorous analysis of the regional variation in impacts of climate change on rangelands still needs to be conducted.

Participatory research approaches that utilise producer knowledge will assist in assessing the vulnerability of the pastoral industry to climate change, identifying practical adaptation options, and determining the limits of adaptations for coping with climate change.

Intensive Livestock

Warmer and drier conditions are projected for most intensive livestock producing regions, raising the likelihood of heat stress conditions. Competition for feed stock may increase as options for biofuels and international food markets increases. Increased climatic variability, including changes in rainfall, will challenge traditional dairy production systems.

Enterprise level adaptation needs to be complemented by policy level analysis and possible reform. Enterprise and policy level adaptation options should be developed and tested through comprehensive systems analysis

Traditional high energy and water use options for improving the environment of livestock under higher heat stress conditions are likely to be maladaptive. Low energy options should be identified and evaluated.

Fisheries & Aquaculture

General ocean warming around Australia (in particular on the east coast) and strengthening of the East Australia Current is predicted to change the distribution of species targeted in wild fisheries, and modify the location of suitable environments for aquaculture species.

Consideration of changes in distribution may allow fisheries management to facilitate adaptation to climate change. Selective breeding of aquaculture species may allow adaptation to warmer conditions, although changes in location may be inevitable for some operations. Focused regional studies on the relationship between the climate variables and the species of interest are one way to improve understanding of the potential impacts of climate change.

Potential impacts on downstream processing

Impact on supply of biofuels

Climate change will present a new and developing opportunity for biofuels in Australia. The use of biofuels is one mitigation strategy that can reduce greenhouse gases. However, the production of biofuels may be affected by the impacts of climate change and careful thought needs to go into the location of feedstocks for biofuel production and its relationship with land used for food production. As biofuels is an emerging industry and is not yet locked in to particular locations, it is in a position to take advantage of early planning and to address climate change adaptation issues associated with its supply chain. For example, there is likely to be less reliance on moving production facilities if crop locations could be anticipated in advance.

There are many different technological pathways to producing biofuels, bioelectricity and other bioproducts.

The various production pathways can be broadly grouped into

- First generation technology – which means that it is already used by commercial enterprises.
- Second generation technology – this represents a step change in technology – it has been physically demonstrated but is not yet commercial due to scale-up issues, or it is not commercially viable due to very high conversion costs.
- Third generation technology – this means that the process is at the conceptual planning stage, 'on drawing board' or at benchtop demonstration stage, but has a long way to go before it can be deployed.

Each of these different technologies has close links to the types of biomass that can be used to feed the process (known as biomass feedstocks). In addition to the types of technologies and feedstocks, assessments must be made in relation to the current production base for biomass (i.e. what is already being produced in Australia) as well as future production base (which may include new and novel plant species, or changes in land use to produce energy crops or forests etc). These are shown in Table 1.

Table 1. Feedstocks and conversion technologies for biofuels, bioelectricity and bioproducts. Those addressed in this report are in red. Adapted from O'Connell *et al.* (2007) Issues and prospects.

	1st gen fuels	**2nd gen fuels / 1st gen bioelectricity**	**3rd gen biorefineries**
Current production base	• Sugar and starch crops • Oilseed crops	• Crop residues (sugar, cereal) • Existing agricultural or rangeland grasses • Farm forestry • Plantation forestry — pulplogs, thinnings, harvest residues • Native forest wood and residues • Waste streams	**Integrated processing -** • Food • Feed • Fibre • Electricity • 1st gen fuels • New gen fuels • High value bioproducts as petrochemical replacements • No 'waste' **New/rearranged value chains => bioeconomy**
Future production base	• Expanded (more area, improved yield) or reduced area (due to climate change) current agricultural production base • GM crops • Novel energy crops e.g. Pongamia, Jatropha, Agave	• Expansion of conventional plantation forestry • New systems of dedicated energy forestry e.g. short rotation or coppicing • Expansion of grasses or new types of energy grass production • Genetically modified and novel crops • Algae	

Production of biofuels is dependent on the quantity and geographic location of the biomass. As such, the production of biofuels will be affected by the adaptation undertaken by the suppliers of these crops to maintain crop quality and quantity.

Different parts of the plant can be used with different technologies. For example with a cereal crop, ethanol is currently produced only from grain using first generation technology. By moving production to use second generation technologies however, the fate of the stalks or stubble from the grain could be diverted away from the current system of being retained in a minimum tillage system (or in some areas being burnt), to being

- Co-fired in the a coal fired power station to produce bioelectricity
- Converted into ethanol via enzymatic technologies
- Converted directly into syndiesel using thermochemical processes
- Converted by pyrolysis into biochar and syngas (which could be used to produce syndiesel or run a turbine for bioelectricity)
- In future, being fed into a biorefinery to make a range of bioproducts (e.g. bioplastics, adhesives) as well as energy or fuel as a co-product

O'Connell et al (2007) provides additional information in relation to biofuels.

Food processing and manufacture

Little attention has yet been given to the impacts of climate change on the whole value chain of food from production, to processing, to transport, to retail supply and to changing consumer demands and preferences, and the adaptation responses that are needed to climate impacts. More effort needs to go into this area of supply chains from the food industry.

However, there are some lessons that can be drawn on from existing approaches to supply chain challenges that are relevant to future climate change impacts. For example, food manufacturers have been required to invest (short-term & long-term) into production operations in order to secure produce for value-addition. Food manufacturing has declined and/or restructured in some operations reliant on the supply of local produce (e.g. milk, tomato, rice, potato & fruit). Alternatively some food manufacturers are sourcing commodities & ingredients from different localities and overseas in order to maintain supply of manufactured food products. Significant commodity & ingredient supply constraints are currently being experienced due to climate related impacts (e.g. drought, water restrictions).

Food processing facilities may need to be relocated in response to climate change. The facilities are generally located in growing supply regions and are a long-term asset, critical to the life-blood of regional communities. Food manufacturers need to make long-term investment decisions on these critical assets. A greater understanding of potential climate change impacts on the reliability and variability of supply of key commodities is required. This may include identifying potential productivity changes, shifts in growing regions, influence of adaptation practices (new varieties) and broader impacts/competitiveness across global markets.

In addition, food manufacturers will need to modify their operations due to the adaptive measures undertaken by their suppliers in response to climate change influences on markets, legislation and production. Food manufacturers will be affected in two ways:

1. The potential effect on supply from growing regions:
    - declining productivity volumes (e.g. irrigation restrictions, increased risk of crop failure)
    - shift in growing region – will other existing or new growing areas be favoured & require transition phase
    - change in seasonality
    - change in varieties to be cultivated, including GMO
    - introduction of new disease, pests, potential risk of crop failure
    - limited or restricted supply, is it a sustainably managed resource
2. The potential effect on product quality, function and safety of supplies:
    - Nutritional compositional change due to environmental stress, variety, growing region (e.g. protein level)
    - Alteration of ingredient functionality and effect on end-product quality (e.g. gellation strength)
    - Microbiological and infestation occurrences due to increased environmental stress & variability.

Part 2. The role of government in assisting farmers adapt to climate change

This section addresses the second of the Inquiry's terms of reference, i.e.
The role of government in:

- *augmenting the shift towards farming practices which promote resilience in the farm sector in the face of climate change;*
- *promoting research, extension and training which assists the farm sector to better adapt to climate change.*

Barriers to effective adaptation

There is clearly a strong case for investing in adaptation responses. However, there is often an assumption that governments, industries and individual landholders have the capacity to implement adaptation options where in reality there are attitudinal, social, behavioural, institutional or environmental barriers to adopting adaptation measures. Howden et al. (2007) has suggested a number of approaches to overcome these barriers to build adaptive capacity and to change the decision environment. These include:

1. Acceptance that climate change is real and will amplify over the coming decades. Effective communication and unambiguous detection and attribution of climate change will facilitate acceptance of climate change.
2. Confidence that the projected changes will significantly impact on farming enterprises. This requires systems research with industry participation and effective communication strategies that can demonstrate clearly the impacts of climate change even though climate projections may have uncertainties.
3. Technical and other management options available and targeted to specific regions and industries (e.g., improved crop, forage, livestock, forest germplasm; nutritional management).
4. Early warning of likely major land use changes resulting from climate change that allows early policy intervention in supporting transitions and structural adjustment. Options include direct financial support, alternative livelihoods not so dependent on agriculture, building social capital and community resilience, infrastructure development, new land use and land tenure arrangements..
5. Adaptive management and governance in policy, institutions and industries that support agriculture. Regular monitoring of adaptation approaches to assess their costs, benefits and effects with efficient feedbacks to policy and management to facilitate continuing adjustments and improvements in adaptation.

A generic conceptual model of adaptation engagement has been developed by CSIRO (Figure 2) to help overcome barriers to adaptation that would assist in implementing the five steps outlined above. The model is presented as a pathway of stages, with different drivers and barriers relevant at different stages along the pathway. It is envisaged that the model will help to guide engagement efforts with stakeholder groups at different stages on the pathway.

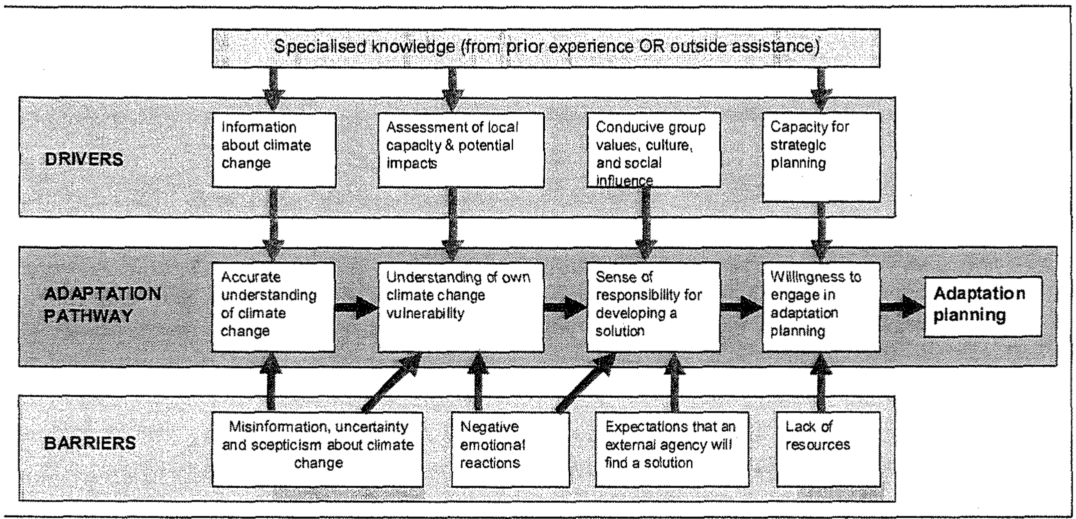

Figure 2. A pathway for adaptation engagement with associated drivers and barriers.

Government can play a key role in building adaptive capacity in rural industries and communities through supporting appropriate education and training and through facilitating more streamlined approaches to adaptive management and governance. Climate change will pose a whole new range of challenges that may require changes to policies and legislation that government will need to consider.

Current government initiatives to facilitate adaptation

The Federal Government has commenced several initiatives to assist the farming sector to adapt to climate change. The initiatives have included the development of a National Agriculture and Climate Change Action Plan and Australia's Farming Future program; the launch of CSIRO's Climate Adaptation National Research Flagship; and the creation of the National Climate Adaptation Research Facility

Federal Government Policy Framework

The Federal Government policy framework includes the National Agriculture and Climate Change Action Plan, Australian Farming Futures program and a national drought policy

The National Agriculture and Climate Change Action Plan

The plan provides the overarching framework for climate change policy for Australian governments and the agricultural sector. Adaptation is the first of four strategies and aims to build resilience into Australian agricultural systems to cope with climate change.

Australian Farming Futures

Australia's Farming Future is the Australian Government's climate change initiative for primary industries. It provides $130 million over four years to help primary producers adapt and respond to climate change. The Climate Change Research Program will provide funding for research projects and on-farm demonstration activities.

National drought policy

The two key forms of assistance provided under the national drought policy are interest rate subsidies and income support for farmers in areas declared to be suffering a severe and prolonged downturn in income caused by drought, termed *exceptional circumstances*. This is complemented by a national system of farm management deposits (FMDs) designed to assist farmers to smooth income variability from year to year. State governments also provide various transaction subsidies on fodder and livestock transport for agisting livestock.

Adaptive governance provides an alternative perspective for analysing Australian drought policy, with potential to create practical and constructive options for policy makers seeking to balance its multiple objectives (Nelson et al 2008). From an adaptive governance perspective, the deep concern held by Australian society for rural communities affected by drought can be viewed as a depletable but renewable common property resource that can be sustainably managed by rural communities in cooperation with governments.

Sustainable management of this resource could be facilitated through nested and polycentric governance systems similar to those that have already evolved in other arenas of natural resource management in Australia. Stafford Smith (2005) flagged the potential advantages of governance structures for Australian drought policy in which policy development is coordinated nationally with regional implementation. The creation of community based tiers of governance similar to Landcare groups and Catchment Management Authorities is an innovative and constructive option for managing the moral hazard issues associated with drought assistance that inevitably extend beyond the reach of traditional centralised expert management.

It is important to stress that adaptive governance is very different to devolution or decentralisation in that it seeks to integrate the best possible characteristics of government and community resource governance systems.

Promoting research, extension and training which assists the farm sector to better adapt to climate change.

The CSIRO Climate Adaptation National Research Flagship and the National Climate Adaptation Research Facility are two initiatives sponsored by the Federal Government that promote research, extension and training aimed at assisting the farm sector.

The CSIRO Climate Adaptation National Research Flagship

In May 2007 the Federal Government announced $44 million funding for the new CSIRO Climate Adaptation National Research Flagship. The National Research Flagships Program was established by CSIRO to deliver scientific solutions to advance Australia's most vital national objectives. Flagships are partnerships of leading Australian scientists, research institutions, commercial companies, CSIRO and selected international partners.

The Climate Adaptation Flagship has four research themes:

- Pathways to adaptation
- Sustainable Cities and Coasts
- Managing Species and Natural Ecosystems
- Adaptive Primary Industries, Enterprises and Communities

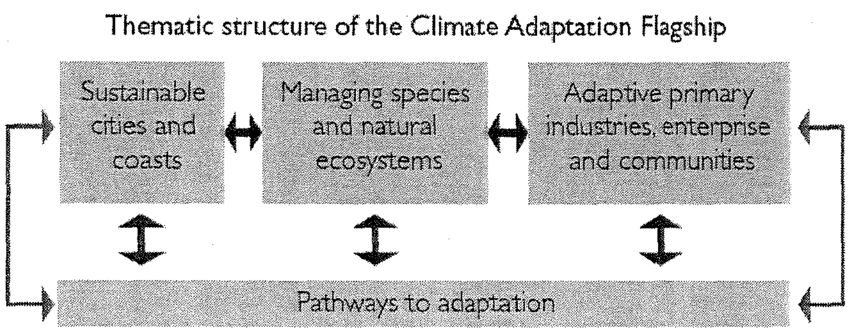

Figure 3. Thematic structure of the Climate Adaptation Flagship

Theme four is developing adaptation options for Australia's primary industry and resource sectors so as to reduce the vulnerabilities and enhance strategic opportunities created by climate change. The Theme:

- Provides practical adaptation strategies that will sustain livelihoods by ensuring the long term viability of rural enterprises and communities threatened by climate change.
- Uses participatory engagement to build improved management of uncertainty into management and governance systems, and support transformative change where necessary.
- Explores adaptation options and tools for agriculture, forestry and marine industries that can assist policy makers and industry to minimise negative consequences of climate change and take advantage of new opportunities.
- Develops new management techniques or technologies that enable industries and enterprises to adapt to climate change (e.g. degradable polymer films to manipulate intensive crop micro-climate).

Research activities in the Adaptive Primary Industries theme are closely aligned with the Climate Change Research Strategy for Primary Industries and the National Agriculture and Climate Change Action Plan 2006-2009

- A 'roadmap' outlining the theme's research and engagement strategy is presented in Figure 4, below.

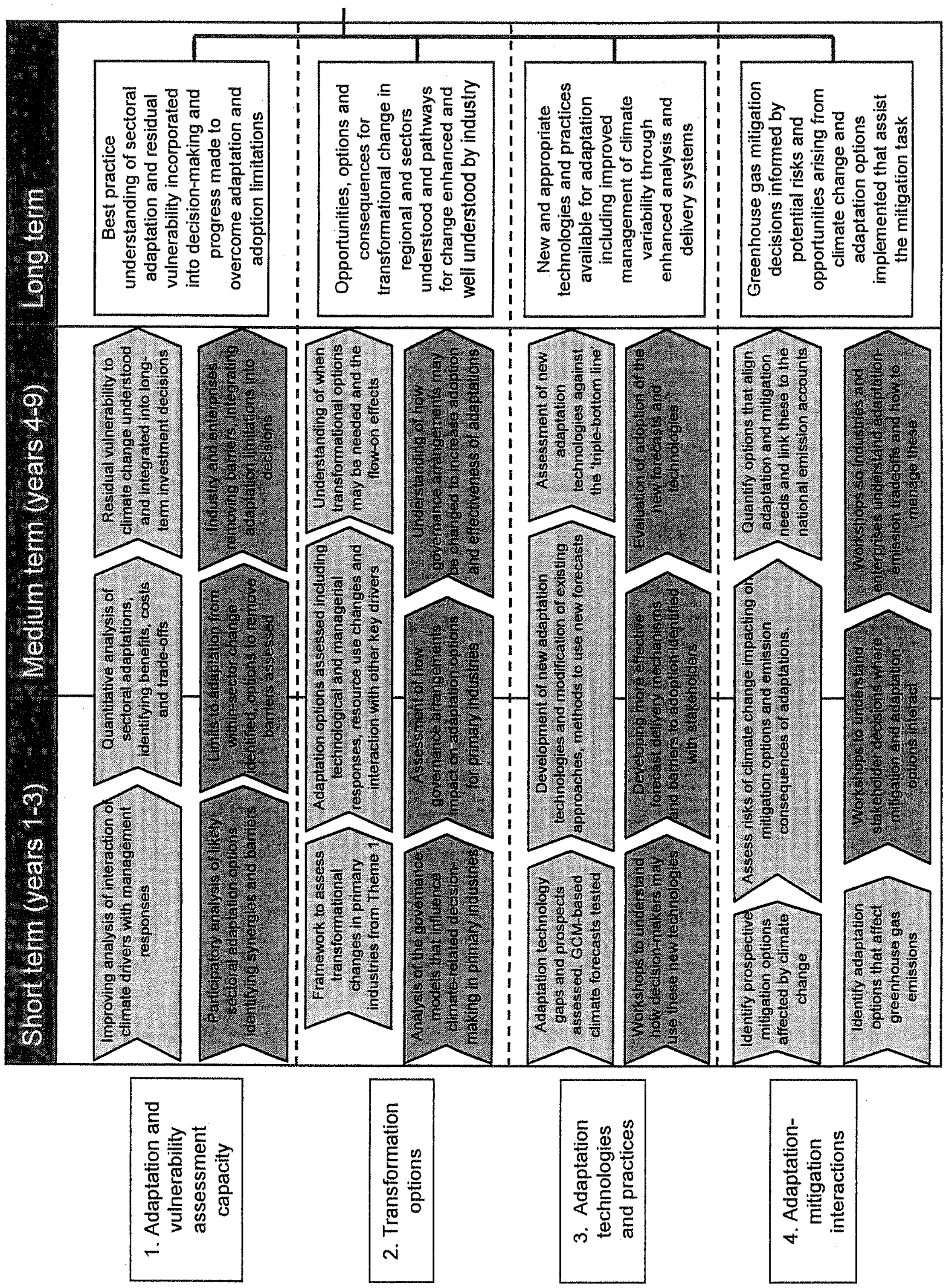

Figure 4. An outline of the research and engagement strategy for the Climate Adaptation Flagship Theme 4: Adaptive Primary Industries, Enterprises and Communities.

The National Climate Adaptation Research Facility

At the same time as announcing the Climate Adaptation Flagship, a new $50 million National Climate Change Adaptation Research Facility (NCCARF) was established. The Facility is hosted by Griffith University, and will play a major role in coordinating and synthesising climate impacts and adaptation research being undertaken across Australia. The CSIRO Climate Adaptation Flagship is working closely with NCCARF and contributing to the development of its National Research Plans.

Part 3. The role of rural research and development

This section addresses the third of the Inquiry's terms of reference, i.e.
The role of rural research and development in assisting farmers to adapt to the impacts of climate change

Australian agriculture is well placed to develop adaptation options to both reduce the negative impacts of climate change and take advantage of some opportunities associated with climate change. Australia is already exposed to extreme climatic variability and this natural variability has shaped the nation's agriculture and led to innovation in adaptation responses. Additionally, Australian agriculture has always strongly supported research and development.

In 2006-2007, approximately 22% of all government expenditure on research and development was directed towards agriculture and primary products with a further 18% expended on environmental management (ABS 2008). Much of the Commonwealth government expenditure was as matching contributions to levies collected from growers through various Rural Research and Development Corporations. As a consequence of this coordinated approach to funding in rural R&D and agriculture's rich history of innovation and productivity increases it is well placed to introduce adaptation options in advance of many other sectors. Given the high vulnerability of agriculture to climate change it is important that rural R&D programs place a high priority on climate adaptation.

There is a history of supporting climate initiatives within the rural R&D sector particularly in relation to coping with drought and in developing seasonal climate forecasts. The Managing Climate Variability Program is the principal example of this coordinated approach to addressing climate initiatives with a number of Rural R&D Corporations contributing to the coordinated MCVP managed by land and Water Australia.

Similarly, the national Climate Change Research Strategy for Primary Industries (CCRSPI), which is managed by land and Water Australia, aims to address climate change and emissions management. The CCRSPI is a joint initiative of the Rural Research and Development Corporations; the Federal, State and Territory governments; CSIRO and universities. The strategy outlines six priorities:

1. Understanding Future Climates
2. Managing Emissions
3. Preparing Industries
4. Accessing Information
5. Facilitating Change
6. Linking Decision Makers

The National Climate Change Research Strategy for Primary Industries (CCRSPI) is an important way for primary industries to come together, share knowledge and invest in new research to prepare and adapt to future climate scenarios. While each of the agricultural sectors will have its own specific issues to deal with in terms of climate adaptation, the CCRSPI initiative helps coordinate effort and avoid duplication, particularly for areas of information that are common across different sectors e.g. climate change projections.

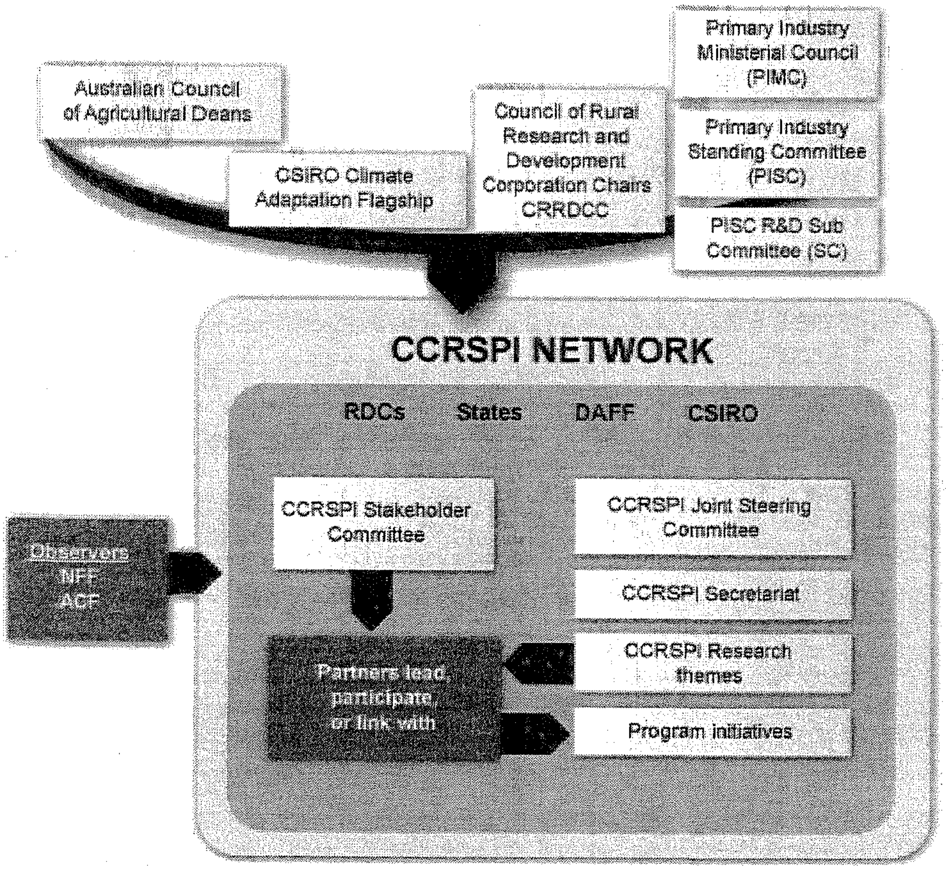

Figure 5: The National Climate Change Research Strategy for Primary Industries (CCRSPI) network

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Appendix 1. Current and future adaptation options

Given that there will be the no one solution for all of the challenges raised by climate change and variability the best adaptation strategy for any industry will be to develop more resilient systems. Early implementation of adaptation strategies particularly in regard to enhancing resilience, have the potential to significantly reduce the negative impacts of climate change (Howden *et al.* 2003).

The following sections provide current and future adaptation options for grains, cotton, rice, sugarcane, viticulture, horticulture, forestry, broad acre grazing, intensive livestock industries, water resources and fisheries and aquaculture.

Grains

Current Options for Dealing with Climate Variability

Recent studies with selected farm managers in Queensland indicate that by using climate information (e.g. seasonal forecasts) in conjunction with systems analyses producers can significantly reduce various risks (e.g. Crimp et al. 2006). By identifying decisions that positively influence the overall farm operation in either economic or environmental terms, these producers have gained a better understanding of the system's vulnerability and started to 'climate proof' their operations.

Examples for actions taken when a forecast is for 'likely to be drier than normal' are: maximising no-till area (water conservation), applying some nitrogen fertiliser early to allow planting on stored soil moisture but splitting the application so as to apply some later if a good season eventuates; planting most wheat later than normal to reduce frost risk. In seasons that are likely to be wetter than normal, management options include: sowing wheat earlier; applying nitrogen to a wheat cover crop grown on a dry profile after cotton (normally not expected to produce a harvestable yield) and applying fungicides to wheat crops to minimise leaf diseases (Meinke and Hochman, 2000).

At the crop level, wheat plantings are now 3-4 weeks earlier than in the 1950s (Stephens and Lyons 1998). This is largely the result of a drastically reduced frost incidence in this environment. However, this change was aided by the availability of new wheat cultivars that are well-suited to this environment. Although these changes started to happen in the 1970s and 80s it is only recently that climate trends were identified as one of the drivers (Howden et al. 2003).

At the cropping systems level, Central Queensland has been a summer cropping dominated region. This was a consequence of climatic conditions favouring summer cropping at a time when the region was first opened up to cropping. Recent climatic patterns (since about the early 1980s) do not favour either summer or winter cropping (Howden et al. 2001). Consequently, cropping systems in Central Queensland have developed into a very opportunistic system, whereby producers can make use of climatic events and rapidly change rotations and summer or winter crops are planted whenever opportunities arise (Pollock et al., 2001). This highlights that cropping systems are to a large extent 'self-adapting', i.e. a string of subtle changes leading to new systems that can only be attributed to climate changes after the event.

At the national level there have been strong trends to earlier sowing times over the past two decades with sowing progressing a day earlier per year on average but greater rates in Queensland and Western Australia (Stephens and Lyons 1998). This appears to be related to the adoption of new herbicide and planting technologies which increase speed of soil preparation and reduce rainfall requirements to sow (Kerr et al. 1992). Earlier sowing dates may also be in response to the strong observed increases in minimum temperatures over this period (Torok and Nicholls 1996) and decreases in frost frequency and duration (Stone et al. 1996). These changes reduce the likelihood of frost damage to early sown crops, thus allowing earlier planting strategies. Nicholls (1997) estimates that this effect plus other more minor climate changes have contributed 30-50% of the observed increase in national yields over the past five decades although this analysis is disputed (Godden et al. 1998, Gifford et al. 1998). Increases in atmospheric carbon dioxide levels may have also contributed to increased yields by an estimated 8% over the past 100 years (Howden et al. 1999).

Adaptation options for the Australian cropping industries to deal with climate change

Many of the management level adaptation options are largely extensions or intensifications of existing climate risk management or production enhancement activities in response to a potential change in the climate risk profile (Howden et al. 2007). For cropping systems there are many potential ways to alter management to deal with projected climatic and atmospheric changes. If widely adopted, these adaptations singly or in combination have substantial potential to offset negative climate change impacts and take advantage of positive ones. For example, in a modelling study for Modena in Italy (Tubiello et al. 2000), simple and feasible adaptations altered significant negative impacts on sorghum (-48 to -58%) to neutral to marginally positive ones (0 to +12%). In that case the adaptations were to alter varieties and planting times to avoid drought and heat stress during the hotter and drier summer months predicted under climate change. When summarized across many adaptation studies globally, there is a tendency for most of the benefits of adapting the existing systems to be gained under moderate warming (<2oC) then to level off with increasing temperature changes (Howden et al. 2007). Additionally, the yield benefits tend to be greater under scenarios of increased rainfall than those with decreased rainfall: reflecting the fact that there are many ways of more effectively using more abundant resources, whereas there are fewer and less effective options for significantly ameliorating risks when conditions become more limiting. Overall, the potential benefits of management adaptations are substantial and are similar in temperate and tropical systems (17.9% versus 18.6%). There are a number of management strategies that could be employed to adapt to climate change. They are:

- Varietal change
- Species change
- Planting time variation
- Crop management (spacing, tillage, fallows, rotations, irrigation)
- Nutrient management change (fertilisation and rotations)
- Erosion management
- Salinity management
- Moisture conservation
- Use of seasonal forecasting
- Irrigation
- Monitoring and evaluation of local climate and production systems
- Management of pest and diseases
- Land use change (infrastructure, knowledge base)

Table 0. Summary of climate change adaptation options for the grain industry indicating whether the option 1) has already been assessed or is a remaining knowledge gap, 2) is highly feasible, 3) would be feasible / effective immediately, or 4) should be a high priority for research, assessment and implementation in developing adaptation strategies.

All adaptations	Options already assessed	Options with high feasibility	Immediacy	Priority activities
Adaptation to climate change – policy level				
Develop linkages to existing government policies and initiatives e.g. GGAP, Greenhouse challenge, salinity, water quality, rural restructuring	X	✓	✓	✓
Ensure communication of broader climate change information	✓	✓	✓	✓
Maintenance of effective climate data distribution and analysis systems	✓	✓	✓	✓
Modification of existing Federal and State Drought policies to encourage adaptation	X	X	✓	X
Continue training to improve self-reliance and to provide knowledge base for adapting	✓	✓	✓	✓
Policy settings that encourage development of effective water-trading systems that allow for climate variability and support development of related information networks	✓	✓	✓	✓
Public sector support for a vigorous agricultural research and breeding effort with access to global gene pools	✓	✓	✓	✓
Maintain R&D capacity, undertake further adaptation studies which include costs/benefits and streamline rapid R&D responses	✓	✓	✓	✓
Develop further crop systems modelling capabilities such as APSIM and quantitative approaches to risk	✓	✓	✓	✓

management				
Encourage appropriate industry structures to enable flexibility	X	X	✓	X
Encourage diversification of farm enterprises	✓	X	✓	X
Ensure support during transition periods caused by climate change and assist new industry establishment	X	✓	X	X
Altering transport and market infrastructure to support altered production regimes caused by climate change	X	✓	X	X
Encourage financial institutions to be responsive to changing industry needs	X	✓	X	X
Continuing commitment from all levels of government for pest, disease and weed control including border protection	✓	✓	✓	✓
Introduction of climate change adaptation into Environmental Management Systems	X	✓	✓	✓
Adaptation to climate change – crop and farm management				
Development of participatory research approaches to assist pro-active decision making on-farm and across the value chain	✓	✓	✓	✓
Develop further risk amelioration approaches (e.g. zero tillage and other minimum disturbance techniques, retaining residue, extending fallows, row spacing, planting density, staggering planting times, erosion control infrastructure)	✓	✓	✓	✓
Develop further controlled traffic approaches – even all-weather traffic	✓	✓	✓	✓
Research and revise soil fertility management (fertilizer application, type and timing, increase legume phase in rotations) on an ongoing basis	✓	✓	✓	✓
Alter planting rules to be more opportunistic depending on environmental condition (e.g. soil moisture), climate (e.g. frost risk) and markets	✓	✓	✓	✓
Expand routine record keeping of weather, production, degradation, pest and diseases, weed invasion	X	✓	✓	✓
Tools and extension to enable farmers to access climate data and interpret the data in relation to their crop records and analyse alternative management options (e.g. Yield Prophet).	✓	✓	✓	✓
Adaptation to climate change – climate information and use				
Improve dynamic climate modelling tailored towards decision making in agriculture	X	X	✓	X
Incorporate seasonal forecasts and climate change into farm enterprise plans so as to be able to readily adapt	X	✓	✓	✓
Maximise utility of forecasts by RD&E on combining them with on-ground measurements (i.e. soil moisture, nitrogen), market information and systems modelling.	✓	✓	✓	✓
Warnings prior to planting of likelihood of very hot days and high erosion potential	X	✓	✓	✓
Adaptation to climate change – water resource issues				
Further improvements in water distribution systems (to reduce leakage and evaporation), irrigation practices such as water application methods, irrigation scheduling and moisture monitoring to increase efficiency of use	✓	✓	✓	✓
Maintain access rights to water	✓	?	✓	?
Develop water trading system (and associated information base) that can help buffer increased variability	X	✓	✓	✓
Maximise water capture and storage on-farm – needs R&D and policy support	✓	✓	✓	✓
Adaptation to climate change – managing pests, disease and weeds				
Improve pest predictive tools and indicators	✓	✓	✓	✓
Improve quantitative modelling of individual pests to identify most appropriate time to introduce controls	✓	X	X	X
Further development of Area-wide Management operations	✓	X	✓	?

Further development of Integrated Pest Management	✓	✓	✓	✓
Improved monitoring and responses to emerging pest, disease and weed issues	✓	X	✓	X
Adaptation to climate change – crop breeding				
Selection of varieties with appropriate thermal time and vernalisation requirements, heat shock resistance, drought tolerance (i.e. Staygreen), high protein levels, resistance to new pest and diseases and perhaps that set flowers in hot/windy conditions	✓	✓	✓	✓
Ongoing evaluation of cultivar/management/climate relationships	✓	✓	✓	✓
Adaptation to climate change – land use				
Potential for cotton, summer-growing grains and pulses further south	X	✓	X	X
Movement to more livestock in the enterprise mix	X	✓	X	X

Cotton

Current Options for Dealing with Climate Variability

The wide geographic spread of the industry means that management practices are different in cotton producing regions in response to their various climates. Specific cotton crop management options for dealing with issues relating to climate variability are:

- Variety selection
- Planting time variation
- Irrigation management
- One of the management techniques that rain-fed cotton growers have is to modify row configuration.
- Manipulating Crop Maturity
- Maintain crop nutrition
- Pest management
- Regional Expansion - There is significant opportunity for cropping regions such as the Ord and Burdekin Irrigation Areas in northern Australia to produce cotton.
- Extension Material and Decision Tools

Guidelines for crop management practices specific to Australian cotton systems are delivered in through publications and decision support tools.

Adaptation Options for Dealing with Climate Change

Many of the potential adaptation responses available to the Australian cotton industry have production efficiency benefits regardless of the rate and nature of future climate change. Key industry production issues that will encompass climate change include:

- Improving nitrogen use efficiency of crops.
- Improving water use efficiency of the whole cotton farming system. Cotton growers are increasing seeing themselves as irrigated growers rather than just cotton growers to be more opportunistic for gains in water use.
- Improving management of climate variability (improving use of short, medium and long-term weather and climate forecasts, improving climate risk management including understanding and managing the trends and extremes regionally and globally for production and implications for our markets such as impact of potential global drying trends on our competitors).
- Plant breeding and farming systems to take advantage of increased temperatures, handle increased water stress, improve agronomic water use efficiency, and respond to elevated atmospheric CO_2.
- Avoiding resistance of pests (both insects and weeds) through appropriate integrated pest and weed management systems to maintain transgenic technologies.
- Capacity to forecast likely pest pressures.
- Auditing energy use in cotton farming systems including developing benchmarks and tools to assess and improve efficiency and being ready to exploit opportunities such as bio-diesel.
- Developing Best Management Practices for minimising the industry's greenhouse carbon footprint.

Table 0. Summary of climate change adaptation options for the cotton industry indicating whether the option 1) has already been assessed or is a remaining knowledge gap, 2) is highly feasible, 3) would be feasible / effective immediately, or 4) should be a high priority for research, assessment and implementation in developing adaptation strategies.

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
Policy/Industry				
Develop linkages to existing government policies and initiatives e.g. GGAP, Greenhouse challenge, salinity,	X	✓	✓	✓

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
water quality, rural restructuring				
Expansion of industry to other regions (including northern Australia)	✓	✓	X	X
Ensure communication of broader climate change information	✓	✓	✓	✓
Address community resilience to the effects of climate change on the cotton industry	X	✓	X	X
Maintenance of effective climate data distribution and analysis systems	✓	✓	✓	✓
Continue training to improve self-reliance and to provide knowledge base for adapting	✓	✓	✓	✓
Policy settings that encourage development of effective water-trading systems that allow for climate variability and support development of related information networks	✓	✓	✓	✓
Public sector support for a vigorous agricultural research and breeding effort with access to global gene pools	✓	✓	✓	✓
Maintain R&D capacity, undertake further adaptation studies which include costs/benefits and streamline rapid R&D responses	X	✓	✓	✓
Develop further crop systems modelling capabilities such as OZCOT and APSIM and quantitative approaches to risk management	✓	✓	✓	✓
Encourage appropriate industry structures to enable flexibility	X	X	✓	X
Encourage diversification of farm enterprises (other crops and livestock)	✓	✓	✓	✓
Ensure support during transition periods caused by climate change and assist new industry establishment	X	✓	X	X
Investigate trends and extremes resulting from climate change both regionally and globally for production and explore implications for our markets and impact on our competitors	X	X	X	X
Altering transport and market infrastructure to support altered production regimes caused by climate change	X	✓	X	X
Encourage financial institutions to be responsive to changing industry needs	X	✓	X	X
Continuing commitment from all levels of government for pest, disease and weed control including border protection	✓	✓	✓	✓
Introduction of climate change adaptation (including minimising industry's greenhouse carbon footprint) into Environmental Management Systems (BMP Cotton)	✓	✓	✓	✓
Auditing energy use in cotton farming systems including developing benchmarks and tools to assess and improve efficiency and being ready to exploit opportunities such as bio-diesel	X	✓	X	X
Provide information that acknowledges that exiting industry is a legitimate adaptation strategy	X	✓	X	X
Crop and farm management				
Maintain farm profitability	✓	✓	✓	✓
Development of participatory research approaches to assist pro-active decision making on-farm	✓	✓	✓	✓
Improve nitrogen use efficiency of cotton crops	✓	✓	✓	✓
Develop practices to take advantage of increased temperatures especially at the start and end of the growing season to raise yields	✓	✓	✓	✓
Improved management options in limited water situations (alterative irrigation systems; row configurations, irrigation scheduling strategies)	✓	✓	✓	✓
Research and revise soil fertility management (fertilizer application, type and timing, increase legume phase in rotations) on an ongoing basis	✓	✓	✓	✓
Alter planting rules to be improve yield and quality	X	✓	✓	✓

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
Expand routine record keeping of weather, production, degradation, pest and diseases, weed invasion	✓	✓	✓	✓
Avoiding resistance of pests (both insects and weeds) through appropriate integrated pest and weed management systems to maintain transgenic technologies	✓	✓	✓	✓
Maximise whole farm water and crop water use efficiencies	✓	✓	✓	✓
Tools and extension to enable farmers to access climate data and interpret the data in relation to their crop records and analyse alternative management options.	X	✓	✓	✓
Develop tools to measure crop water use accurately	✓	✓	✓	✓
Develop cotton systems that are earlier maturing, use less water and allow more crops to be grown in rotation	X	✓	X	X
Link on-farm adaptation with catchments impacts	✓	✓	✓	✓
Climate information and use				
Improve dynamic climate modelling tailored towards decision making in agriculture	✓	✓	✓	✓
Provision of information to cotton growers of the likely impacts at their business level (downscaling climate change predictions to regional scales)	X	✓	✓	✓
Incorporate seasonal forecasts and climate change into farm enterprise plans so as to be able to readily adapt	X	✓	✓	✓
Maximise utility of forecasts by RD&E on combining them with on-ground measurements (i.e. soil moisture, nitrogen), market information and systems modelling.	✓	✓	✓	✓
Warnings prior to planting of likelihood of very hot days and high erosion potential	✓	✓	X	✓
Enhance capacity to forecast pest pressures (weeds, invertebrate and diseases)	X	✓	✓	✓
Water resource issues				
Further improvements in water distribution systems (to reduce leakage and evaporation), irrigation practices such as water application methods, irrigation scheduling and moisture monitoring to increase efficiency of use	✓	✓	✓	✓
Maintain access rights to water	✓	?	✓	✓
Develop water trading system (and associated information base) that can help buffer increased variability	X	✓	✓	?
Maximise water capture and storage on-farm – needs R&D and policy support	✓	✓	✓	✓
Develop greater understanding of water availability in relation to river flows	✓	✓	✓	✓
Managing pests, disease and weeds				
Improve pest predictive tools and indicators	✓	✓	✓	✓
Improve quantitative modelling of individual pests to identify most appropriate time to introduce controls	X	✓	X	X
Further development of Area-wide Management operations	✓	✓	✓	X
Further development of Integrated Pest Management	✓	✓	✓	✓
Improved monitoring and responses to emerging pest, disease and weed issues	✓	✓	✓	✓
Crop breeding				
Selection of varieties with appropriate, heat shock resistance, drought tolerance, higher agronomic water use efficiency, improved fibre quality, resistance to new pest and diseases (including introgression of new transgenic traits).	✓	✓	✓	✓
Ongoing evaluation of cultivar/management/climate relationships (including investigations in higher CO_2 environments) on both yield and quality	✓	✓	✓	✓

Rice

Current Options for Dealing with Climate Variability

Surface water is the major source of irrigation water supply for rice-growers in the Riverina (river water, pumped directly or diverted into canal systems), although some groundwater is also used (Humphreys *et al.* 2006). Farmers' own licences entitle them to a certain water allocations, however allocation amounts are regulated according to annual dam supply. In brief explanation, water licence entitlements are divided into high and low security. A 'high security' licence guarantees the licensee of receiving their full entitlement in 99% of seasons. High security licences are generally issued for town water supplies, stock and domestic needs, industrial uses, as well as permanent plantings like vineyards and orchards. The remaining water available for use after environmental demands and high security allocations have been met is termed 'general security'. This is made available to farmers growing annual crops such as rice, wheat, soybeans and pastures. General security allocations are by definition subject to much greater variation from vagaries in climate, represented by in inflows into the storage dams.

Most of the options currently available for dealing with climate variability relate to the supply of water. The options include:

- Cropping Area Modification
- Purchase/sale of Water on Open Market
- Investment in more efficient irrigation technology
- Flexible rotations
- Sowing winter crops directly after rice
- Nutrient management adjustment
- Water Management
- Stubble retention

Adaptation Options for Dealing with Climate Change

Altering varieties, planting times, nitrogen management and irrigation management to better match the new environments experienced under climate change is likely to increase yields compared to a non-action scenario. This can be viewed as the benefits of adaptation. When summarised over a large number of studies globally, the benefits of adaptation increase significantly with increasing levels of change. However, a similar analysis in wheat-based cropping systems suggests that there are limits to the benefits from management adaptations without making more fundamental system changes (Howden *et al.* 2007). In that case, the benefits were largely found with only a 2 to 3°C increase in temperature and the associated changes in rainfall and CO_2. Rice systems appear to have a greater range of adaptive response with this being found up to 5°C. However, many of the studies on which this analysis is based assume continuing availability of irrigation water and this may not eventuate. When options for fine-tuning the underlying rice-based system have been exhausted with high levels of climate change, there will be a need to adopt more systemic change such as moving to intermittently-irrigated systems or dryland systems. As stated by Humphreys *et al.* 2006, there is limited scope for further significant increase in irrigation or input water productivity by reducing water application under the current Australian rice farming system, and future savings must come from implementation of alternative, lower water-use systems with greater water productivity.

Reductions and increased variability in irrigation water supply are likely to represent the greatest challenge to the Australian rice industry from projected climate change. Hence water use efficiency (WUE) measures in existing systems figure strongly in consideration of current options for dealing with the threat, in addition to future prospects for alternative systems. Options are considered below, firstly looking at potential water productivity improvements in existing systems, and secondly looking at a range of new ideas and potential modifications to systems which may hold the promise of enhancements to whole farm water productivity.

- The strategies to Increase on-farm water use efficiency within current farming systems are:
    - Better definition of rice-suitable soils
    - Piping water on-farm
    - Piping water in the district, or lining supply channels
    - Whole farm planning
    - Raised beds in bays

- Irrigation Scheduling
- Combine and sod sowing of rice
- New cultivars

- The strategies to increase on-farm WUE by modifying farming systems are:
  - Increase use of alternate wet and dry (AWD) rice
  - New farm layouts
  - Investment in more efficient irrigation technology
  - New crops, rotations and priorities for water

Table 0. Summary of climate change adaptation options for the rice industry indicating whether the option 1) has already been assessed or is a remaining knowledge gap, 2) is highly feasible, 3) would be feasible / effective immediately, or 4) should be a high priority for research, assessment and implementation in developing adaptation strategies.

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
Policy level				
Develop linkages to existing government policies and initiatives e.g. GGAP, Greenhouse challenge, salinity, water quality, rural restructuring	✓	✓	✓	✓
Ensure communication of broader climate change information	✓	✓	✓	✓
Maintenance of effective climate data distribution and analysis systems	✓	✓	✓	✓
Modification of existing Federal and State Drought policies to encourage adaptation	X	X	✓	✓
Continue training to improve self-reliance and to provide knowledge base for adapting	X	✓	✓	✓
Policy settings that encourage development of effective water-trading systems that allow for climate variability and support development of related information networks	✓	✓	✓	✓
Public sector support for a vigorous agricultural research and breeding effort with access to global gene pools	✓	✓	✓	✓
Maintain R&D capacity, undertake further adaptation studies which include costs/benefits and streamline rapid R&D responses	✓	✓	✓	✓
Develop further crop systems modelling capabilities such as APSIM and quantitative approaches to risk management	✓	✓	X	✓
Encourage appropriate industry structures to enable flexibility	?	?	?	?
Encourage diversification of farm enterprises	✓	X	X	✓
Ensure support during transition periods caused by climate change and assist new industry establishment	X	✓	X	✓
Altering transport and market infrastructure to support altered production regimes caused by climate change	X	✓	X	X
Encourage financial institutions to be responsive to changing industry needs	?	?	?	✓
Continuing commitment from all levels of government for pest, disease and weed control including border protection	✓	✓	✓	✓
Introduction of climate change adaptation into Environmental Management Systems	✓	✓	✓	✓
Crop and farm management				
Establish new higher water productivity farming systems (potentially including aerobic & AWD rice)	?	?	?	✓
Investment in more efficient irrigation technology	?	?	?	✓
Improved farm plans and layouts	?	?	?	✓
Development of participatory research approaches to assist pro-active decision making on-farm	?	✓	✓	✓

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
Develop further risk amelioration approaches (e.g. zero tillage and other minimum disturbance techniques, retaining residue, extending fallows, row spacing, planting density, staggering planting times, erosion control infrastructure)	✓	✓	✓	✓
Develop further controlled traffic approaches – even all-weather traffic	✓	✓	✓	✓
Research and revise soil fertility management (fertilizer application, type and timing, increase legume phase in rotations) on an ongoing basis	✓	✓	✓	✓
Alter planting rules to be more opportunistic depending on environmental condition (e.g. soil moisture), climate (e.g. frost risk) and markets	✓	✓	✓	✓
Expand routine record keeping of weather, production, degradation, pest and diseases, weed invasion	X	✓	✓	✓
Tools and extension to enable farmers to access climate data and interpret the data in relation to their crop records and analyse alternative management options.	X	✓	✓	✓
Climate information and use				
Improve dynamic climate modelling tailored towards decision making in agriculture	?	?	?	✓
Incorporate seasonal forecasts and climate change into farm enterprise plans so as to be able to readily adapt	?	?	?	✓
Maximise utility of forecasts by RD&E on combining them with on-ground measurements (i.e. soil moisture, nitrogen), market information and systems modelling.	?	?	?	✓
Warnings prior to planting of likelihood of very hot days and high erosion potential	?	?	?	✓
Water resource issues				
Further improvements in water distribution systems (to reduce leakage and evaporation), irrigation practices such as water application methods, irrigation scheduling and moisture monitoring to increase efficiency of use	✓	X	X	✓
Maintain access rights to water	✓	?	✓	?
Develop water trading system (and associated information base) that can help buffer increased variability	✓	✓	✓	X
Maximise water capture and storage on-farm – needs R&D and policy support	?	?	X	✓
Managing pests, disease and weeds				
Improve pest predictive tools and indicators	✓	✓	✓	✓
Improve quantitative modelling of individual pests to identify most appropriate time to introduce controls	X	✓	X	X
Further development of Area-wide Management operations	✓	X	✓	?
Further development of Integrated Pest Management	✓	✓	✓	?
Improved monitoring and responses to emerging pest, disease and weed issues	✓	✓	✓	X
Crop breeding				
Selection of varieties with appropriate thermal time and vernalisation requirements, heat shock resistance, drought tolerance (i.e. Staygreen), high protein levels, resistance to new pest and diseases and perhaps that set flowers in hot/windy conditions	?	✓	?	✓
Ongoing evaluation of cultivar/management/climate relationships	?	✓	✓	✓
Land use				
Potential for cotton, summer-growing grains and pulses further south	?	?	?	✓
Movement to more livestock in the enterprise mix	?	?	?	✓

Sugarcane

Current Options for Dealing with Climate Variability

A number of web-based sources of information and tools are presently available (or in design) to assist sugarcane industry stakeholders manage climate variability through informed decision making. These include the tools and information sources which are generally applicable to a wide range of agricultural industries.

The tools and forecasting systems are used to support a range of management decisions that are impacted by climate, and for which reliable seasonal climate forecasts are available. Technologies presently exist to help optimise planting and harvesting dates, the scheduling of limited irrigation water, nitrogen fertiliser management (for both optimal production and minimal environmental impact), drying-off strategies, and the design of on-farm water storage facilities. One example is the ENSO El Nino/Southern Oscillation signal. This can be used early in the year in certain sugarcane-growing regions to predict likely climate, and hence sugarcane productivity, around the time of harvest. Having this information 7 months prior to harvest enables the scheduling of harvest start date to be optimised for productivity. Such information is also useful to marketers planning customer allocations, shipping schedules and storage requirements for the next season, and has been found to provide financial benefits for the industry (Anthony *et al.* 2002).

Adaptation Options for Dealing with Climate Change

The sugarcane industry in Australia has a long record of managing the impacts of weather and climate-related events. Nevertheless, additional adaptation measures will be required to reduce the adverse impacts of projected climate change and variability, regardless of the scale of mitigation undertaken over the next two to three decades. Similar to other cropping systems, many of the management-level adaptation options suitable to the sugarcane production system are largely extensions or intensifications of existing climate risk management or production enhancement activities in response to a potential change in the climate risk (Howden et al., 2007). Adaptation strategies can be categorised into the following approaches:

- Improved management of limited water supplies
- Technological fixes
- Cropping system design and agronomic management strategies
- Improved decision-making
- Institutional change

Table 0. Summary of climate change adaptation options for the sugarcane industry indicating whether the option 1) has already been assessed or is a remaining knowledge gap, 2) is highly feasible, 3) would be feasible / effective immediately, or 4) should be a high priority for research, assessment and implementation in developing adaptation strategies.

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
Policy level				
Develop linkages to existing government policies and initiatives e.g. GGAP, Greenhouse challenge, salinity, water quality, rural restructuring	X	✓	✓	✓
Ensure communication of broader climate change information	✓	✓	✓	✓
Maintenance of effective climate data distribution and analysis systems	✓	✓	✓	✓
Modification of existing Federal and State Drought policies to encourage adaptation	X	X	✓	X
Continue training to improve self-reliance and to provide knowledge base for adapting	✓	✓	✓	✓
Policy settings that encourage development of effective water-trading systems that allow for climate variability and support development of related information networks	✓	✓	✓	✓
Public sector support for a vigorous agricultural research and breeding effort with access to global gene pools	✓	✓	✓	✓
Maintain R&D capacity, undertake further adaptation studies which include costs/benefits and streamline rapid R&D responses	✓	✓	✓	✓

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
Develop further crop systems modelling capabilities such as APSIM and quantitative approaches to risk management	✓	✓	✓	✓
Encourage appropriate industry structures to enable flexibility	X	X	✓	X
Encourage diversification of farm enterprises	✓	X	✓	X
Ensure support during transition periods caused by climate change and assist new industry establishment	X	✓	X	X
Altering transport and market infrastructure to support altered production regimes caused by climate change	X	✓	X	X
Encourage financial institutions to be responsive to changing industry needs	X	✓	X	X
Continuing commitment from all levels of government for pest, disease and weed control including border protection	✓	✓	✓	✓
Introduction of climate change adaptation into Environmental Management Systems	X	✓	✓	✓
Crop and farm management				
Development of participatory research approaches to assist pro-active decision making on-farm	✓	✓	✓	✓
Develop further risk amelioration approaches (e.g. zero tillage and other minimum disturbance techniques, retaining residue, extending fallows, row spacing, planting density, staggering planting times, erosion control infrastructure)	✓	✓	✓	✓
Develop further controlled traffic approaches – even all-weather traffic	✓	✓	✓	X
Research and revise soil fertility management (fertilizer application, type and timing, increase legume phase in rotations) on an ongoing basis	✓	✓	✓	✓
Alter planting rules to be more opportunistic depending on environmental condition (e.g. soil moisture), climate (e.g. frost risk) and markets	✓	✓	✓	✓
Expand routine record keeping of weather, production, degradation, pest and diseases, weed invasion	X	✓	✓	✓
Tools and extension to enable farmers to access climate data and interpret the data in relation to their crop records and analyse alternative management options.	X	✓	✓	✓
Climate information and use				
Improve dynamic climate modelling tailored towards decision making in agriculture	✓	✓	✓	✓
Incorporate seasonal forecasts and climate change into farm enterprise plans so as to be able to readily adapt	✓	✓	✓	✓
Maximise utility of forecasts by R, D&E on combining them with on-ground measurements (i.e. soil moisture, nitrogen), market information and systems modelling.	✓	✓	✓	✓
Warnings prior to planting of likelihood of very hot days and high erosion potential	✓	✓	X	✓
Water resource issues				
Further improvements in water distribution systems (to reduce leakage and evaporation), irrigation practices such as water application methods, irrigation scheduling and moisture monitoring to increase efficiency of use	✓	✓	✓	✓
Maintain access rights to water	✓	?	✓	?
Develop water trading system (and associated information base) that can help buffer increased variability	X	?	✓	?
Maximise water capture and storage on-farm – needs R&D and policy support	✓	✓	✓	✓
Managing pests, disease and weeds				
Improve pest predictive tools and indicators	✓	✓	X	✓
Improve quantitative modelling of individual pests to identify most appropriate time to introduce controls	✓	✓	X	✓

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
Further development of Area-wide Management operations	✓	✓	X	✓
Further development of Integrated Pest Management	✓	✓	✓	✓
Improved monitoring and responses to emerging pest, disease and weed issues	✓	✓	✓	✓
Crop breeding				
Selection of varieties with appropriate thermal time and vernalisation requirements, heat shock resistance, drought tolerance (i.e. Staygreen), high protein levels, resistance to new pest and diseases and perhaps that set flowers in hot/windy conditions	✓	?	✓	✓
Ongoing evaluation of cultivar/management/climate relationships	✓	✓	✓	✓
Land use				
Potential for cotton, summer-growing grains and pulses further south	N/A	N/A	N/A	N/A
Movement to more livestock in the enterprise mix	X	✓	X	X

Viticulture

Current Options for Dealing with Climate Variability

Most grape varieties can have various end uses, which facilitate adaptation to interannual temperature variability. Chardonnay grapes for instance, can be used in sparkling wine or a more full-bodied white table wine depending on the temperature of the growing season. The winemaker commonly blends wine from different regions, or different varieties, to take advantage of the complementary flavour profiles developed in the grapes.

Windbreaks can be useful to protect the outside rows of a vineyard from hot, dry, northerly winds. They can impact negatively by housing birds (a pest problem), robbing vines of nutrients and water, and increasing the risk of frost by trapping of cold air around the vines.

Frost is presently managed by site selection, overhead sprinklers, helicopters (to create air movement and mixing), soil moisture maintenance (through irrigation), vine training systems (higher canopy), keeping soil surface cleaner (free of mulch), and foggers.

In Australia most grape production occurs where the water requirement of vines is far higher than the quantity of water provided by rainfall. Irrigation has therefore been widely adopted in Australia. To manage water availability to the vines the majority of vineyards in Australia are equipped with soil moisture monitoring devices ranging from simple gypsum blocks, to neutron probes. In areas with salinity issues, computer controlled irrigation systems are used to increase efficiency while reducing the impact on the environment.

Adaptation Options for Dealing with Climate Change

Suitability for growing different winegrape varieties will change in a warmer climate. Matching a variety of winegrape to a particular climate so that the winegrapes ripen at the optimal time in the harvest period is fundamental for the production of quality wine. Two main adaptation options exist for the viticulture industry to adapt to a warming climate: Either new sites can be selected for a particular variety to match the warmer climate; or 'longer-season' varieties than those presently planted can be established in existing sites. Other adaptation options include:

- Modification of viticultural practices to affect timing of bud-break
- Viticultural management adaptations to increased vegetative growth
- Adjustment of vine nutrition to address imbalance in carbon:nitrogen ratios
- Management to reduce the impact of increased yield variability
- Short-term and longer-term forecasting of rainfall
- Vineyard irrigation management
- Viticultural practices to address salinity
- Water purification and recycling
- Management of the inter-row environment
- Pest and disease risk management

Table 0. Summary of climate change adaptation options for the viticulture industry indicating whether the option 1) has already been assessed or is a remaining knowledge gap, 2) is highly feasible, 3) would be feasible / effective immediately, or 4) should be a high priority for research, assessment and implementation in developing adaptation strategies.

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
Temperature increase				
Change varieties of winegrapes grown in a region	✓	✓	✓	✓
Assess new sites	✓	✓	✓	✓
Vineyard design strategies to ameliorate climate impacts	✓	✓	X	X
Chilling requirement analysis	X	✓	✓	✓
Consumer and product flexibility	✓	✓	X	X
CO_2 enrichment				

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
Cultural management to increased growth	X	✓	✓	✓
CO_2 on vine water interactions	X	✓	✓	✓
Vine nutrition to address imbalance in C: N ratios	X	✓	X	X
Impact of the interaction of a temperature increase and CO_2 enrichment				
Cultural management to reduce variability	X	✓	✓	✓
Infrastructure adaptation for varying yields	✓	X	X / ✓	X
Economic and legal adaptations to manage the financial risk of yield variation	X	✓	X	X
Rainfall changes				
Water balance predictions (inc. extremes)	X	✓	✓	✓
Irrigation management to increase efficiency	✓	✓	✓	X / ✓
Water purification and recycling	X / ✓	✓	✓	✓
Management of the inter-row environment	X	✓	✓	✓
Pest and disease risk management	X	✓	X	X
Salinity				
Irrigation and cultural practices to address salinity	X	✓	✓	✓

Horticulture

Current Options for Dealing with Climate Variability

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).

Variability in the ripening of fruit and vegetables due to seasonal temperature variability has long been managed as a matter of course. Timing of production techniques, such as sowing, planting, fertilizing, irrigation, and using protective covers can be adapted to manage climate variability (Krug 1997). Earlier production in some years is possible due to decreased frosts (Peet and Wolfe 2000), however depending on the region, higher temperatures can shorten the growth of some individual crops and extend the season of production in others.

Intervarietal variation in chilling requirement is utilized with some stone and pome fruit (e.g. Golden Queen Peach (Atkins and Morgan 1990)) and kiwi fruit varieties (e.g. Zespri Gold kiwi fruit) (Kenny 2001) to reduce the risk of poor dormancy break. Cultivar selection and planting dates are directed toward either suppressing flower initiation, in the case of celery, onion or cabbage, or delaying it in the case of broccoli and cauliflower, until the seedling is big enough to support formation of a large head. Many vegetable growers base planting dates on soil temperature conditions, which automatically allows the adaptation to climate variability to occur.

In Australia, most horticultural production occurs where the water requirement of crops is far higher than that provided by effective rainfall (rainfall minus evaporation). Irrigation has become widely adopted in Australia so that yield and quality can be maximised, and so that the development phases of crops can be better predicted (giving more surety of harvest dates to maximise the marketing plans of growers). A large percentage of horticultural enterprises in Australia are equipped with soil moisture monitoring devices ranging from simple gypsum blocks to neutron probes. These enable improved efficiency in water use.

Climate variability also affects pest and disease incidence. Pesticides are increasingly used along with both cultural practices and biological control methods. However, pesticides are expensive and not always effective whilst integrated management of horticultural pests in relation to current climatic variability depends on effective monitoring and predictive systems.

Fruit and vegetable growth and quality are very sensitive to extremes of weather such as very high temperature, severe frost and persistent drought. Consequently, some producers are now considering crop selection based on seasonal forecasting predictions. Seasonal forecasts are routinely produced now for both rainfall and temperature. For example, peanut processing and marketing bodies profitably use forecasts of likely production to adjust their operations strategically (Meinke and Hammer 1997).

Adaptation Options for Dealing with Climate Change

In future, the practice of carefully selecting appropriate sites will be maintained. Consideration of the changing climate should be made when selecting perennial varieties and where these should be planted. Identification of threshold temperatures or other climate conditions for crops, spatially represented for a range of future climates, can expose risky, or less risky, areas. In the cooler regions of Australia some spatial studies have been performed (Hood *et al.* 2002) and are being undertaken (Sposito 2007). There may also be landscape design/locations (i.e. tree belts, valley location) that may enable amelioration of warmer conditions. This type of analysis could be extended to yield or profitability expectations.

Growers can adapt by changing their crop management strategies. Fruit and vegetable growth and quality are very sensitive to extremes of weather such as very high temperature, severe frost and persistent drought. However, the amount of damage suffered often depends on the development stage reached when the extreme conditions occur and this phenological information needs to be incorporated into adaptation strategies. Understanding when the likelihood of extremely hot days (e.g. daily maximum temperature above 35°C) may occur, along side projected phenological timing, can inform risk assessments.

Breeding of heat tolerant, low chill, and more adaptable varieties of various horticultural crops must begin. In the case of perennial fruit crops, consideration of canopy structure could be exploited whereby structures with natural self-shading ability could be selected. Product quality given growth under enhanced CO_2 and elevated temperatures will need to be evaluated and considered in breeding programs.

Under climate change it will be important to have better Decision Support Systems based on a sound understanding of the ecology of each pest to avoid surprise outbreaks. In particular, models should be developed to explain over-wintering of a wide range of insect pests and plant diseases, and changes in the timing and severity of pest populations. Pest/insect models usually base diapause on 7.5-10°C i.e. over wintering occurs when temperatures are below this level. Increased winter temperatures mean these levels may not be reached in some regions resulting in impacts to intervention measures used for control. Adaptations to the changes in the risk of pest and diseases will need to be addressed area by area.

Climate science can provide insights into climatic processes, agricultural systems science can translate these insights into management options and rural sociologists can help determine the options that are most feasible or desirable from a socio-economic perspective. Any scientific breakthroughs in climate forecasting capabilities are much more likely to have an immediate and positive impact if they are conducted and delivered within a framework that includes: farmers, climate scientists, agrometeorologists and rural sociologists (Meinke and Stone 2005; Salinger *et al.* 2005).

Table 0. Summary of climate change adaptation options for the horticulture industries indicating whether the option 1) has already been assessed or is a remaining knowledge gap, 2) is highly feasible, 3) would be feasible / effective immediately, or 4) should be a high priority for research, assessment and implementation in developing adaptation strategies.

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
Temperature increase				
Re-assess location in regional terms.	X	✓	✓	✓
Link climate change and quality issues.	X	✓	✓	✓
Change crop production schedules to align with new climate projections.	X	✓	X	X
Decreased reliance on glasshouses.	X	✓	X	X
Invest in biotechnology and conventional breeding	X	✓	✓	✓
Use seasonal forecasts	✓	✓	✓	✓
Develop markets for new crops.	X	✓	X	X
CO_2				
Ascertain the effect crop by crop.	X	✓	✓	✓
Cost of production changes (e.g. savings in glasshouse management).	X	✓	X	X
Rainfall				
Integrated catchment management.	X	✓	✓	✓
Irrigation management to increase efficiency.	✓	✓	✓	X
Implement water trading in conjunction with water efficiency initiatives.	✓	✓	✓	X
Pests and diseases				
Integrated pest and disease risk management: varies from area to area.	X	✓	✓	✓

Forestry

Current Options for Dealing with Climate Variability

Managing for climatic variability is particularly important for forestry as it can take many years for trees to produce a commercial product. For example, *E. globulus* requires about 12 years to produce a pulpwood crop, *P. radiata* typically takes about 30 years to produce a final sawlog crop and *Acacia melanoxylon* (blackwood) may take 50 or more years to produce high-value timber. The full value of the trees is only realised if the stands complete their full rotation period. Managing for rainfall variability is likely to become more important for forestry as new plantations are increasingly being located in lower rainfall zones to meet natural resource management aims such as salinity control and carbon sequestration (Consortium 2001). For example, Neumann *et al.* (2006) describe how the FloraSearch project is evaluating forestry and agroforestry systems suitable for the 250-650 mm rainfall zone of southern Australia.

Increasingly, growers can anticipate drought problems and adapt their actions accordingly. Tools such as the Queensland Department of Primary Industries RainMan (www.dpi.qld.gov.au/rainman/), Bureau of Meteorology products on the SILO website (www.nrw.qld.gov.au/silo/), Queensland Department of Natural Resources products on the LongPaddock website (www.longpaddock.qld.gov.au/) and the Bureau of Rural Sciences Rainfall Reliability Wizard (www.brs.gov.au/rainfall/) can assist these analyses. Information on likely El Niño conditions, particularly the Southern Oscillation Index (SOI), is also now available to assist decision-making. Another adaptation to reduced rainfall is the selection of species that are drought tolerant. The Australian Low Rainfall Tree Improvement Group (ALRTIG) is a cooperative involving CSIRO, the Australian National University and organisations from New South Wales, South Australia, Tasmania and Victoria, that is developing improved germplasm for low rainfall (400-600mm) environments.

Adaptation Options for Dealing with Climate Change

A number of policy options are listed in Table 8 but these may be somewhat similar across all agricultural sectors and so are not discussed here. Generally there are three situations that forest managers may encounter:

1) *After significant climatic changes have occurred and before establishing a new plantation.* This is the situation that growers may encounter in future decades. In this case the adaptation response for tree growers is relatively simple. They can use the experience gained previously in those places that have a climate similar to that to which the local climate has changed and change species or management options.

2) *The climate changes after plantations have been established.* This is the case when trees have been planted some time ago, but where the rotation length is such that it will take some more years before it is time to harvest the stand, and the climate has changed adversely. In that case, the adaptation options are limited and limited to thinning the stand, adding or withholding fertiliser, or adding water, although irrigation is seldom a practical option.

3) *Significant climatic change has not yet occurred, but it is recognised that conditions may change in the future.* Under those circumstances, different species or provenances may be selected for planting, or trees could be planted at wider spacing from the beginning. These available response strategies could also be described in more general terms, such as by adopting a generally more conservative strategy – to plant fewer trees, select slower-growing, but more resistant ones, or to use less fertiliser. In some already very marginal environments, tree growers may even consider growing no trees at all because of that uncertain future.

Table 0. Summary of climate change adaptation options for the forestry industry indicating whether the option 1) has already been assessed or is a remaining knowledge gap, 2) is highly feasible, 3) would be feasible / effective immediately, or 4) should be a high priority for research, assessment and implementation in developing adaptation strategies.

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
Policy level				
Maintain forestry R&D capacity, undertake further adaptation studies which include costs/benefits and streamline rapid R&D responses	✓	✓	✓	✓
Develop further bioclimatic analysis and forest systems modelling capabilities and quantitative approaches to risk management	✓	✓	✓	✓
Ensure communication of broader climate change information	✓	✓	✓	✓
Provide training to improve self-reliance and to provide	X	✓	✓	✓

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
knowledge base for adapting				
Encourage public sector support for a vigorous forest research and breeding effort e.g. Australian Low Rainfall Tree improvement Group (ALRTIG)	✓	✓	✓	✓
Encourage financial institutions to be responsive to changing industry needs	X	✓	X	X
Support continuing commitment from all levels of government for pest, disease and weed control including border protection	✓	✓	✓	✓
Promote introduction of climate change adaptation into forest management systems	X	?	X	X
Forest management				
Develop systems to assist genotype selection that takes into account likely climate changes over the whole rotation.	X	X	✓	✓
Provide advice on appropriate spacings for different genotypes and environments.	✓	✓	✓	✓
Improve knowledge of water use of plantations under climate change.	X	✓	✓	✓
Provide advice on opportunities to use nutritional adjustments as an adaptation to climate change.	X	X	X	X
Develop systems to minimise fire risk e.g. by assisting in design of firebreaks and planning of controlled burns.	X	✓	✓	✓
Provide advice on appropriate weed management strategies for particular plantation systems.	X	✓	✓	✓
Improve pest and disease predictive tools	✓	✓	✓	✓
Improve monitoring and responses to emerging pest, disease and weed issues	✓	✓	✓	✓
Provide improved advice on establishment techniques to minimise tree deaths	✓	✓	✓	✓
Improve use of climatic data in species-site selection e.g. give greater weight to more recent climatic data	X	✓	✓	✓
Develop participatory research approaches to assist pro-active forest management decision making	✓	✓	✓	✓
Expand routine record keeping of weather, production, degradation, pest and diseases, weed invasion	X	✓	✓	✓
Provide tools and extension to enable foresters to access climate data and interpret the data in relation to their permanent sample plot (PSP) records and analyse alternative management options	X	✓	✓	X
Climate information and use				
Improve regional level climate change modelling to provide more reliable scenarios to assist decision making in forestry	✓	X	✓	✓

Broad acre grazing

Current options for dealing with climate variability

In many parts of Australia, much of the year-to-year variability in rainfall is associated with the El Nino-Southern Oscillation (ENSO) and the Interdecadal Pacific Oscillation (IPO) (McKeon *et al.* 2004). Based on these phenomena, operational seasonal forecasts have been developed using changing patterns in sea surface temperatures (Day *et al.* 2000). These statistical relationships are strongest (and therefore their forecasting utility is greatest) for the eastern third of Australia and are weakest for a north-south band running through eastern Western Australia. Using seasonal climate forecasts to adjust stock numbers is likely to be successful in climates where there is a high probability of extended droughts of more than 1 year (McKeon and Hall 2000). As the majority of grazing enterprises rely on a constant nucleus of breeders (cows or ewes) to maintain herd and flock populations (O'Rourke *et al.* 1992), there is limited flexibility to make rapid adjustments in stock numbers (McKeon and Hall 2000).

There are other strategies for coping with climate variability that do not involve tracking climate variation. These include using a conservative, but constant, stocking rate from year to year; diversifying sources of income; and diversifying climate risk geographically by owning multiple pastoral properties in regions with different patterns of climatic variability. While these strategies would not necessarily provide the automatic benefit of tracking climate change, they may still be of adaptive value in increasing the capacity of pastoral enterprises to with future uncertainty.

Adaptation options for dealing with climate change

In order to adapt to climate change, pastoralists will need to change their management practices to take full advantage of new opportunities and minimize any negative impacts. At a national industry level, there are likely to be winners and losers, with some rangelands becoming more productive while others become less suitable for grazing. For the grazing industry as a whole, it may be possible to offset some of the losses in regions that are negatively affected by taking advantage of opportunities where rangeland productivity increases.). Monitoring trends in pasture production and quality, woody vegetation, pest and weed densities and animal production will raise community awareness and understanding of the impacts of climate change and foster development of adaptation strategies.

Adaptation options of land management that will be impacted by climate change can be summarised into four areas:

- Managing pasture productivity and grazing pressure
- Managing forage quality
- Managing pests, disease and weeds
- Animal husbandry and managing health

Table 0. Summary of climate change adaptation options for the grazing industry indicating whether the option 1) has already been assessed or is a remaining knowledge gap, 2) is highly feasible, 3) would be feasible / effective immediately, or 4) should be a high priority for research, assessment and implementation in developing adaptation strategies.

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
Broad scale adaptation				
Define the adaptation challenge by describing the (uncertain) range of impacts that could affect pastoralists under a range of plausible climate change scenarios.	X	✓	✓	✓
Obtain feedback on the immediate management responses that producers would be likely to employ to deal with impacts (above point).	X	✓	✓	✓
Obtain feedback on the immediate policy responses that policy makers would be likely to employ to deal with impacts (above point).	X	✓	✓	✓
Encourage linkages with existing government policies and initiatives e.g. GGAP, Greenhouse challenge, salinity, water quality	X	✓	✓	✓
Modification of existing Federal and State Drought Schemes to encourage adaptation	X	✓	✓	✓
Introduction of ISO standards to grazing enterprises that acknowledge climate change adaptive management	X	✓	X	X

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
strategies				
Ensure adequate buffering against establishment or adaptation failure	X	✓	✓	✓
Altering transport and market infrastructure to support altered production	X	X	X	X
Improved water management at the on-farm scale	✓	✓	✓	✓
Pasture productivity and grazing pressure				
Redefine safe stocking rates and pasture utilization levels under climate change	X	X	X	X
Diversification of on-farm production	✓	✓	✓	✓
Expand current area of grazing potential	✓	X	X	X
Expand routine record keeping of weather, pest and diseases, weed invasion and outputs	X	✓	✓	✓
Introduce software for use by producers to interpret grazier records	X	✓	✓	✓
Increase sowing of new pastures	✓	✓	X	X
Selection of sown pastures better adapted to higher temperatures and water constraints	✓	✓	✓	X
Provision of additional nitrogen through sown legumes	✓	✓	✓	X
Provision of phosphates to both improved and unimproved pasture *(but well assessed in southern regions)	X*	X	X	X
Provision of urea and phosphates directly to stock via reticulation *(not assessed on a large scale)	X*	✓	✓	X
Greater utilisation of strategic spelling	X	✓	✓	✓
Introduction of responsive stocking rate strategies based on seasonal climate forecasting	X	✓	✓	✓
Development of regional safe carrying capacities i.e. constant conservative stocking rate	✓	✓	X	✓
Development of software to assist pro-active decision making at the on-farm scale	✓	✓	✓	✓
Pests, ferals, diseases and weeds				
Improve pest predictive tools and indicators	✓	✓	✓	✓
Improve quantitative modelling of individual pests to identify most appropriate time to introduce controls	X	✓	✓	✓
Increased use of biological controls	X	✓	X	X
Increased use of insect traps	X	✓	✓	X
Incorporation of alternative chemical and mechanical methods for reducing woody weeds	X	✓	✓	X
Animal husbandry and health				
Selection of animal lines that are resistant to higher temperatures	✓	✓	X	✓
Modify timing of mating based on seasonal conditions	✓	✓	X	✓
Modify timing of supplementation and weaning	✓	✓	X	X
Construction of shading and spraying facilities	✓	X	X	X
Increase use of trees as shading and reducing wind erosion	✓	✓	X	X

Intensive livestock industries

Current Options for Dealing with Climate Variability

The current options for dealing with climate variability in the intensive livestock industry are:

- Intensification of irrigation systems to maximise water use efficiency.
- Agistment of stock outside of the region where necessary.
- Shift from perennial pastures to a mix of annual and perennial pastures.
- Increase forage cropping.
- Use of feedlots.
- Supplementary feeding with grains or other feedstock.
- Ownership of feedstock producing farm.
- Maintenance or reestablishment of shelter trees.
- Changing calving patterns.
- Genetic selection for heat tolerant phenotypes.
- Climate controlled production sheds through mechanical or natural air conditioning.
- Naturally ventilated production sheds.
- Heat abatement through water misting and evaporative cooling of stock.

Adaptation Options for Dealing with Climate Change

Options for dealing with climate change in the intensive livestock industry include:

- Increasing landscape resilience through revegetation and rehydration
- Summer housing for dairy cattle
- Altered farm management
- Redesign of buildings for passive cooling
- Supplementary or complete power generation onsite
- Clustering of compatible industries

Table 0. Summary of climate change adaptation options for the intensive livestock industry indicating whether the option 1) has already been assessed or is a remaining knowledge gap, 2) is highly feasible, 3) would be feasible / effective immediately, or 4) should be a high priority for research, assessment and implementation in developing adaptation strategies.

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
Policy level				
Comprehensive policy analysis and review across agriculture, energy, taxation and trade portfolios	X	✓	✓	✓
Conduct systems analysis of policy and management adaptation options	X	✓	✓	✓
Building code requirement for passive cooling, appropriate insulation of, and stormwater harvesting from, production sheds	X	✓	X	✓
Zoning for agricultural industrial parks	X	✓	X	X
Understanding the risks to feed supplies from variable supply or competition	X	✓	✓	✓
Assessing the vulnerability of irrigated dairy to reduced water supply	X	✓	✓	✓
Farm management				
Increasing landscape robustness and resilience through revegetation and wetland creation	X	✓	✓	✓
Summer housing for dairy cattle	X	✓	X	X

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
Matching stocking rates with pasture production	✓	✓	✓	✓
Rotational grazing	✓	✓	✓	✓
Modification of grazing times	X	✓	✓	✓
Night feeding in feedlots	X	✓	✓	✓
Timing of reproduction	✓	✓	✓	✓
Alteration of animal or forage types	X	✓	✓	✓
Ensuring adequate storage of water	✓	✓	✓	✓
Use of supplementary feeds	✓	✓	✓	✓
Redesign of buildings for passive cooling	X	✓	✓	✓
On-site power generation	X	✓	X	✓
Climate information and use				
Improve dynamic climate modelling tailored towards decision making in agriculture	✓	✓	✓	✓
Incorporate seasonal forecasts and climate change into farm enterprise plans so as to be able to readily adapt	X	✓	✓	✓
Warnings of heat stress days	✓	✓	✓	✓
Water resource issues				
Rehydrating landscapes through wetland re-creation	X	✓	✓	✓
Further improvements in water distribution systems, irrigation practices such as water application methods, irrigation scheduling and moisture monitoring to increase efficiency of use	✓	✓	✓	✓
Develop water trading system (and associated information base) that can help buffer increased variability	X	?	✓	?
Maximise water capture and storage on-farm – needs R&D and policy support	✓	✓	✓	✓

Water resources

Current Options for Dealing with Climate Variability

A whole of climate approach is required to deal with irrigation, which is currently undergoing a period of significant restructuring as part of the National Water Initiative (*Young et al.* 2006). Much of the irrigation system and its operating rules were set up during the latter half of the 20th century, a period of generally favourable rainfall. The distributed irrigation system was well-adapted to interannual variability, with large carry-over storages and extensive distribution systems with defined water rights. Self extraction from rivers and streams downstream from those storages also benefited. However, the managed system was operated very conservatively, with allocations often set according to the drought of record, or similar criteria (Long and McMahon 1996). Australian water supply systems were very successful in providing a secure water supply, leading many water managers and users to believe that their systems were largely "climate proof" except for the most severe floods and droughts.

While many of the current options for dealing with climate variability will continue to be relevant, especially at the individual farm level, at a system level, large changes are already in train. Because allocations were not capped until the late 1990s, specific management for climate variability was secondary to concerns such as managing waterlogging, salinity, efficiency and productivity. These give rise to actions such as the following:

- identifying irrigation seepage hotspots,
- identifying realisable irrigation water savings, through on farm water management and water saving technology,
- improving irrigation scheduling using moisture sensing and better targeting of growth cycles,
- developing national effluent irrigated plantation guidelines, and
- developing farming systems with reduced deep drainage losses.

Adaptation Options for Dealing with Climate Change

Increasing irrigation efficiency and seasonal prediction systems are stand alone actions that will benefit individual operators and can also be applied at the system scale. They are the subject of a significant research effort. The planning of irrigation futures brings together a large number of strategic and long-term concerns, and provides the platform for their integration. Risk-based decision-making to adaptation into all levels of operation and planning, from tactical to long-term, needs to be developed. Finally, the recommended approach used in assessing and managing change is risk assessment and management, in a process that involves stakeholders and researchers.

Adaptations to increase irrigation efficiency include:

- Identifying high seepage areas in the delivery system, improving channel efficiency and evaporation controls.
- Efficient on-farm delivery systems, laser-layout gravity systems, replacement with hose, microspray and trickle/drip systems.
- Scheduling according to soil moisture, evaporation measurements, timers and sensors, growth phase of crop/pasture, partial root drying (e.g., viticulture).
- More accurate metering, full monitoring of all extractions, staged metering (detecting system losses), improved data collection for physical accounting.

Seasonal predictions of changes in allocations and crop water balance will allow better forward planning for crops and areas planted, scheduling and minimise price risk if there is a need to purchase supplementary water.

Adaptations include:

- ENSO-related indices can be linked to streamflow, which integrates a great deal of potential uncertainty between rainfall and streamflow for an equivalent level of predictability to the relationship between ENSO indices and rainfall (Khan et al. 2004).
- Developing forecast systems based on a combination of medium range weather forecasting and catchment soil moisture which is even closer to streamflow. Both remote sensing and modelling can be used.
- Water distributors providing likelihoods of changes to allocations based on the above systems.

- Seasonal crop modelling of irrigated crops as is now being done in dryland systems, using ongoing information to reduce uncertainty through the season and better target inputs (water, fertiliser etc).

Table 0. Summary of climate change adaptation options for the water industry indicating whether the option 1) has already been assessed or is a remaining knowledge gap, 2) is highly feasible, 3) would be feasible / effective immediately, or 4) should be a high priority for research, assessment and implementation in developing adaptation strategies.

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
Operational				
More efficient on-farm use of water through improved technology and scheduling	✓	✓	✓	✓
Develop and apply probabilistic forecasts of likely water allocation changes	✓	✓	✓	✓
Use of water management tools (crop models, decision support tools)	✓	✓	✓	✓
Increase crop choice to maximise efficiency and profit	✓	✓	✓	?
Improve distribution system operation and delivery	✓	✓	✓	?
Increased monitoring of the water cycle for accounting purposes	✓	✓	✓	✓
Manage stream and channel flow regimes to minimise losses and maintain environmental values	X	✓	✓	✓
Strategic				
Build climate change into integrated catchment management and relevant strategic policies	X	✓	✓	✓
Develop more equitable sharing of climate risks amongst different uses (irrigation/environment)	X	?	?	✓
Build climate change risks into caps/bulk allocation arrangements	X	?	?	X
Prepare for altered flood risks	X	✓	X	X
Continue to improve water trading to remove perverse incentives and reduce the transfer of risk, especially during drought	X	✓	✓	✓
Control over the building of private water storages (e.g. developed within guidelines, need water right)	✓	X	?	X
Introduce income spreading strategies to manage risk	X	✓	✓	X
Build flexibility into allocation choices between agricultural, environmental, urban and industrial uses	X	✓	✓	✓
Develop full cost provisions of water and water trading, and a robust water trading system	X	✓	✓	✓
Improve understanding of groundwater-surface water-climate interactions	X	✓	X	✓
Improve understanding of sustainable yield	X	✓	✓	✓
Long-term planning				
Incorporate climate change into long-term water sharing agreements	✓	✓	✓	✓
Jointly manage climate change and salinity risks	X	✓	✓	✓
Develop groundwater storage options	X	?	X	X
Build adaptation to climate change into new infrastructure	X	✓	✓	✓
Develop understanding of critical thresholds and limits within water collection delivery and use systems	X	✓	✓	✓
Manage catchments and provide strategic design for land-use to maximise water yield and water quality within a framework of long-term sustainability	X	✓	✓	✓
Institutional capacity				
Develop risk-based decision-making into all levels of operation and planning from tactical to long-term	X	✓	✓	✓
Develop better understanding of integrated catchment management amongst different users	X	✓	?	✓
Develop contingency based decision-making instead of	X	✓	✓	✓

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
"one action fits all circumstances"				
Improve multiple understandings of water related "values" through research, discussion and outreach to the community	X	✓	✓	X
Develop a "whole of climate" approach to operational and strategic decision-making	X	✓	✓	✓

Fisheries and Aquaculture

Current Options for Dealing with Climate Variability

Current approaches for dealing with changes in fisheries as a result of climate variability include; changes in fishing ports used, changes in fishery areas, changes in the quota allocated for harvest, and closures in some fisheries or fishing areas. The only Australian example (and perhaps internationally) where environmental information is incorporated into a management response that accounts for seasonal and interannual climate variability is in the east coast pelagic longline fishery. Southern bluefin tuna (*T. maccoyii*, SBT) are restricted to the cooler waters south of the East Australian Current and range further north when the current contracts up the New South Wales coast (Majkowski et al. 1981, Hobday & Hartmann 2006). This response to climate variability has allowed real-time spatial management to be used to restrict catches of SBT by non-quota holders in the east coast fishery by restricting access to ocean regions believed to contain SBT habitat (Hobday & Hartmann 2006). This habitat prediction is based on the relationship between water temperature (from the surface to 200 m) and the abundance of SBT. The current distribution of the tuna habitat is derived with a near-real time ocean model and then relayed to management during the fishing season. As the distribution of the SBT habitat changes during the season, management adjusts the location of restricted access areas throughout the season.

Climate variability is a fact of life for many operators in the aquaculture sector. Attempts are made to reduce the effects of climate variability via feeding (e.g. salmon, barramundi, prawns), cleaning or removal of competitors (e.g. pearl oysters), and thinning conspecifics (e.g. oysters and mussels). Responses to climate variability also occur during or after the "climate" event, such as treatment for disease. Selective breeding is the other major adaptation attempt and there is considerable effort in the aquaculture industry for developing strains with increased biological performance (e.g more robust stocks with fast growth).

Adaptation Options for Dealing with Climate Change

The aquaculture industry has several options for adaptation to climate change including selectively breeding for tolerance to altered temperature regimes or the use of alternate species that are pre-adapted to the temperature regimes; and relocation of production facilities, including the movement of cage systems to deeper offshore waters (Preston and Poloczanska 2007).

For pelagic fisheries, most of the immediate impacts of climate change will be expressed as changes in distribution of the target stocks (Hobday et al 2007). As a result, the potential adaptation options devised to date are mostly around changing distributions. Adaptation strategies include: improvements in locating stocks of fish, changes in home port to increase or minimise economic costs associated with transport, and zoning of fish habitats to minimise unwanted species interactions.

As climate-driven changes in fish distribution occur, however, commercial fishers may not be able to simply follow the stocks as they may contract into different management regions. Information on the potential changes will enhance industry capability to adapt to climate change, and make sensible business and investment decisions. This information does not always exist, and where it does, it may not be accessible to those who need it.

Ecosystem-based fisheries management (EBFM) takes into account interrelationships between exploited fish stocks, non-target species, the environment, and human action (e.g. Link et al 2002). Adaptation options under the EBFM umbrella include developments in bycatch reduction, and improved targeting practises that will have the dual benefit of minimising impacts on non-target species, and provide potential alternatives to spatial closures to protect the particular species. Multi-species fisheries should continue to develop species-specific fishing gears and targeting practices to improve future adaptability. Species-specific gears will allow individual species to be targeted, without impacting other species that may be in decline due to climate change, and protected from fishing.

This move in Australia to EBFM is illustrative for climate adaptation, because it entails explicit recognition for the importance of understanding environmental relationships. Thus, an EBFM approach will also facilitate adaptation to climate change through the holistic approach (Smit and Wandel 2006).

Table 0. Summary of climate change adaptation options for Australian fisheries and aquaculture indicating whether the option 1) has already been assessed or is a remaining knowledge gap, 2) is highly feasible, 3) would be feasible / effective immediately, or 4) should be a high priority for research, assessment and implementation in developing adaptation strategies.

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
Policy level				
Develop linkages to existing government policies and initiatives e.g. GGAP, Greenhouse challenge, salinity, water quality, rural restructuring				
Fisheries	X	X	✓	✓
Aquaculture	X	✓	✓	✓
Ensure communication of broader climate change information				
Fisheries	?	✓	✓	✓
Aquaculture	?	✓	✓	✓
Maintenance of effective climate data distribution and analysis systems				
Fisheries	X	✓	X	✓
Aquaculture	X	✓	X	✓
Continue training to improve self-reliance and to provide knowledge base for adapting				
Fisheries	X	✓	X	X
Aquaculture	X	✓	✓	✓
Increase R&D capacity, undertake further adaptation studies which include costs/benefits and streamline rapid R&D responses				
Fisheries	?	?	✓	✓
Aquaculture	✓	✓	✓	✓
Develop further harvest modelling capabilities and quantitative approaches to risk management				
Fisheries	✓	✓	✓	✓
Aquaculture	?	✓	?	?
Encourage appropriate management, policy, and industry structures to enable flexibility				
Fisheries	X	?	✓	✓
Aquaculture	X	✓	✓	✓
Encourage diversification of enterprises (e.g. ecotourism, scientific charters, recreational fishers)				
Fisheries	?	✓	✓	X
Aquaculture	?	✓	?	X
Ensure support during transition periods caused by climate change and assist new industry establishment or exit from the industry				
Fisheries	✓	?	✓	✓
Aquaculture	?	?	?	?
Altering transport and market infrastructure to support altered production regimes caused by climate change				
Fisheries	X	?	X	X
Aquaculture	?	?	?	?
Introduction of climate change adaptation into Ecosystem-based Fisheries Management, and regional management plans				
Fisheries	?	?	✓	✓
Aquaculture	?	?	✓	✓
Climate information and use				
Improve dynamic climate modelling tailored towards decision making				
Fisheries	?	✓	?	✓
Aquaculture	?	✓	?	✓
Incorporate seasonal forecasts and climate change into business plans to improve adaptive capacity				
Fisheries	?	✓	✓	✓
Aquaculture	?	✓	✓	✓
Development of tools and extension to enable operators to access climate data and interpret the data in relation to				

Adaptation options	Options already assessed	Options with high feasibility	Immediacy	Priority activities
their harvest records and analyse alternative management options. Fisheries Aquaculture	? ✓	? ✓	? ✓	? ✓
Warnings about likelihood of extreme events prior to decision making period Fisheries Aquaculture	? ?	? ?	? ?	? ?
Target species issues				
Improve predictive tools and indicators for species impacted by climate change Fisheries Aquaculture	X X	✓ ✓	✓ ✓	✓ ✓
Selection of varieties with appropriate physical tolerances and phenological characteristics Fisheries Aquaculture	n/a ✓	n/a ✓	n/a ✓	n/a ✓
Ongoing evaluation of climate relationships for key species (e.g. distribution, phenology/life history) Fisheries Aquaculture	✓ ✓	✓ ✓	✓ ✓	✓ ✓
Flexibility to shift efforts between species (fisheries and aquculture) or genetic stocks (aquaculture) to take advantage of novel conditions (e.g. very warm year) Fisheries Aquaculture	? ?	? ?	? ✓	? ✓
Ecosystem management				
Further development of regional management plans that are appropriate for the distribution of the species being harvested or farmed. Fisheries Aquaculture	? ✓	✓ ✓	✓ ✓	✓ X
Develop precautionary approaches that reduce the risk of non-target impacts Fisheries Aquaculture	✓ ✓	✓ ✓	✓ ✓	✓ ✓
Alter harvesting practices to be more opportunistic depending on environmental conditions (e.g. water temperature), climate (e.g. ENSO risk) and markets Fisheries Aquaculture	? ?	? ✓	✓ ✓	X ?
Improve pest and disease predictive tools and indicators Fisheries Aquaculture	X ✓	✓ ✓	✓ ✓	✓ ✓