Dr Andrew Johnson
Group Executive – Environment
Queensland Bioscience Precinct
306 Carmody road
Telephone (07) 3214 2383 • Facsimile :(07) 3214 2288 • ABN 41 687 119 230

CSIRO

Our Ref: 07/269

The Secretary
Senate Standing Committee on Rural and Regional Affairs and Transport
PO Box 6100
Parliament House
Canberra ACT 2600

27 March 2008

Dear Ms Radcliffe

Re: Comments on the re-adopted inquiry on Climate Change and the Australian Agricultural Sector

We thank you for the opportunity to provide comments on the inquiry into Climate Change and the Australian Agricultural Sector. Our detailed responses to the Terms of Reference are attached. We also thank you for extending the deadline to allow us to prepare our submission.

The attached response is based on CSIRO's 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. Our strong linkages to industry practitioners, policymakers, community leaders and the general research community have also informed our submission.

Please do not hesitate to contact Dr Andrew Ash, Director of the Climate Adaptation National Research Flagship (Ph: (07) 3214 2346 andrew.ash@csiro.au) if you require anything further.

Yours sincerely

Dr Andrew Johnson
Group Executive - Environment

CSIRO Submission 07/269

Senate Standing Committee on Rural and Regional Affairs and Transport

Inquiry into Climate Change and the Australian Agricultural Sector

March 2008

Enquiries should be addressed to:

Dr Andrew Ash

Director

Climate Adaptation National Research Flagship

306 Carmody Rd

St Lucia Qld 4067

Ph: (07) 3214 2346

Email: andrew.ash@csiro.au

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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 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 CO2 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.

The benefits and positive opportunities presented by climate change may peak during the initial stages (about mid century), but the negative impacts may lag behind, becoming progressively stronger over time and with greater build up of greenhouse gases in the atmosphere. Caution is therefore needed not to underestimate the long-term challenge of climate change based on initial, more moderate experiences.

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.

This submission draws heavily on a major new report prepared recently by CSIRO for Land and Water Australia entitled "An overview of climate change adaptation in the Australian agricultural sector – impacts, option and priorities" (Stokes & Howden eds. 2008). The submission begins with an overview of the varying ways climate change is expected to affect weather patterns in each of Australia's ten major agro-climate zones and summarises the key adaptation issues facing each agricultural sector. Part 2 gives an overview of current scientific and policy efforts to support agricultural adaptation, and puts forward a set of options and recommended actions for agriculture overall, and for specific farm industries. Finally, the submission offers a brief summary of the scientific literature on drought policy, in light of projected climate change, and suggests a new approach based on the principles of adaptive management.

With projections indicating that droughts are likely to dramatically increase in frequency with climate change in the next few decades there is now an added urgency to the need to reshape drought assistance policies. 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 community based tiers of governance similar to Landcare groups or Catchment Management Authorities.

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

It is essential that management of climate change risks is based on reliable and relevant information, with clear articulation of uncertainties. Australian primary industries have evolved to deal with substantial variations in climate: the Australia of droughts and flooding rains. However, future climate is likely to be increasingly outside the experience of the past, making existing technologies and practices mismatched with the prevailing climate. Research and development is a key way to proactively and reliably redesign and realign technologies, management and expectations with the evolving climate.

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;
- A long history of innovative research into predicting and managing drought, from the enterprise scale to the national policy scale.

Part 1. Australia’s Future Climate and its Implications for Agriculture

This section addresses the first of the Inquiry’s terms of reference, ie.
i) The scientific evidence available on the likely future climate of Australia’s key agricultural production zones, and its implications for current farm enterprises and possible future industries.

Background to the CSIRO-LWA Report

CSIRO has recently prepared a 338 page report providing “An overview of climate change adaptation in the Australian agricultural sector – impacts, option 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 Climate Change Research Strategy for Primary Industries (CCRSPI) (http://sites.lwa.gov.au/ccrspi/).

The CCRSPI is a joint initiative of the Rural Research and Development Corporations; the CSIRO; and the Federal, State and Territory governments; managed by LWA.

At the time of writing, a draft Research Strategy has been developed and is awaiting consideration by the Primary Industries Standing Committee. LWA expects to finalise and publish the Strategy and its accompanying Appendices (including the CSIRO report) by mid-April 2008.

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.

As part of a parallel process, LWA commissioned a set of consultations with key representatives of Australia’s primary industries. Both sources of feedback will be used in prioritising and planning future research and management needs for preparing Australian agriculture for climate change.

Region-specific considerations for agriculture

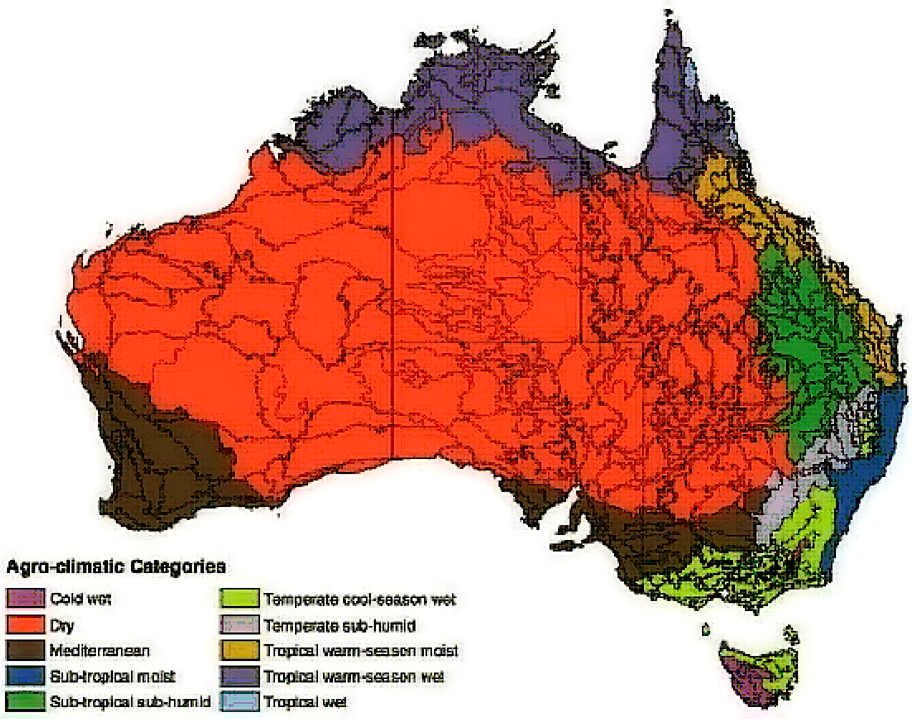
Scientific evidence available on the likely future climate of Australia’s key agricultural production zones has been summarized along with information for the whole country in the “Climate Change in Australia” report prepared by CSIRO and the Australian Bureau of Meteorology, released in October 2007 (http://www.climatechangeinaustralia.gov.au/). The implications of these changes are discussed in detail in Stokes & Howden (eds) 2008.

Some broad generalizations can be made about how plant growth, which underpins all the primary industries addressed in this submission, will be affected by climate change. Warmer temperatures may benefit perennial plants in cool climates, but annuals and plants growing in hot climates may be negatively affected. Plant productivity would be expected to increase or decrease in accord with any changes in rainfall, while the direct effects of CO_2 in stimulating plant growth and increasing water use efficiency could help by partly offsetting increases in evaporation or decreases in rainfall.

While there are some general principles about how impacts of climate change will vary geographically, regional indications of climate change impacts are highly uncertain. The underpinning regional projections of climate change are themselves highly uncertain and span a wide range of variation (CSIRO 2007). Subsequent interpretations of impacts introduce added uncertainty about how biological systems will respond and are based on informed synthesis of current knowledge (rather than rigorous analysis). Hence, regional climate change projections are currently more useful for describing the wide range of uncertainty and for probabilistic risk assessment than serving as reliable predictors for planning and decision making.

The comments in the following table should therefore be used as an indication of the likely range of impacts for which primary industries will have to prepare, and NOT as reliable predictions of exactly where specific impacts will occur.

Table 1.3: Summary of regional variation in climate change issues for terrestrial primary industries. Australia has been divided into ten agro-climate zones (groupings of IBRA bioregions) following the regionalization of Hobbs & McIntyre (2005).



Industries	Regional climate change impacts and issues
- Cold wet	
Cropping	Very little cereal cropping practiced. Increasing temperatures may increase crop growths and expand the growing season.
Forestry	Much of this region is included in National Parks, so native tree species may be at risk from climate change, but few if any commercial forest areas would be affected.
Intensive livestock	Dairy likely to benefit from warming and drying. Possibly reduced energy demand for heating of productions sheds.
Water resources	Median greenhouse runoff projection slight decrease. Declining snowpack, making streamflow less reliable. Tasmania mainly self extracting; Kosciusko Plateau important source area for irrigation source water in MDB. Catchment risk score very low to low in Tasmania, moderate to high on the mainland.
- Dry	
Cropping	Cropping limited, restricted area of irrigation which may be challenged due to increasing demand but decreasing supply of water.
Forestry	Most of this region is too arid for commercial forestry though there may be some potential for oil mallee and carbon sequestration plantings in the higher-rainfall edges of the region. Care should be taken in establishing and managing these plantations, as being in already relatively low rainfall areas they would be potentially vulnerable to any further rainfall reductions.
Grazing	This vast arid area is likely to experience the greatest warming and drying trends within the rangelands. This will further stress many enterprises that are already only marginally viable and where few opportunities for adaptation exist.
Water resources	Median greenhouse runoff projection positive in central south, slight decrease on fringes of region, especially in the east. Most of the irrigation in these areas is self extracting and opportunistic likely to more constrained. Catchment risk score very low (western half) and low to moderate (eastern half).

Industries	Regional climate change impacts and issues
- Mediterranean	
Cropping	Potentially large reductions in rainfall will reduce yields markedly leading to flow on effects to regional communities and businesses. In such an eventuality, cropping will become more challenging at the current dry margins but may expand into areas currently generally too wet for regular cropping. There may be reductions in the risk of dryland salinisation. A range of adaptations, particularly aimed at improving crop water management.
Rice	Water supplies are projected to become more limited while individual crop demand is likely to increase. The likelihood of cold damage during flowering may decline, whereas risks of crop heat-damage may increase. There is some scope to adapt rice production in current ponded culture, however aerobic and alternate-wet-and-dry rice represent future adaptation options. A wide range of potential farming system changes need to be considered, including greater utilisation/understanding of seasonal climate forecasts.
Viticulture	Phenological shifts to winegrape vines may result in ripening in a warmer part of the season. Quality will be affected. Grapevine variety suitability will change and planting of 'longer season' varieties to fit the warmer climate will reduce any negative impact. Water may become a limiting factor for grape production in these regions.
Horticulture	Timing of crop cycles for annual horticulture crops may be hastened requiring crop scheduling and marketing responses. Reduction in chilling over winter may affect suitability for growing of some perennial fruit crops. Increasing frequency of extreme temperature events resulting in undesirable physiological responses must be managed. Water availability and security of supply is essential, especially for perennial horticulture.
Forestry	There are major areas of commercial plantings, particularly in Western Australia and South Australia. Bioclimatic analysis should be used to identify particularly vulnerable *E. globulus* (blue gum), *P. radiata* (radiata pine), *P. pinaster* (maritime pine) and oil mallee plantings, so these can be monitored to provide early warning of any problems. Many eucalypts in native forests in the southwest have narrow climatic ranges and may be particularly vulnerable to climate change.
Intensive livestock	Irrigated dairy likely to be impacted by reduced water allocation, and increased temperatures. Landscape rehydration through wetland creation is a priority. Heat stress issues for stock. Increased energy demand for cooling production sheds; increased demand for new energy efficient designs or retrofitting of exiting sheds.
Water resources	Median greenhouse runoff projection moderate to large decrease for the south-west component and substantially negative for south-east component. In the south-east, most water sourced from upstream in the MDB. Increased demand and reduced supply a substantial issue in both regions. Catchment risk score moderate to very high (west) and low to very high (east).
- Subtropical moist	
Cropping	Cropping limited in area, restricted area of irrigation which may be increasingly challenged due to increasing demand from climate and other users but decreasing supply of water.
Sugarcane (Southern region)	Present limited supply of irrigation water is likely to be exacerbated by the projected decrease in rainfall. Adaptation must focus on improved efficiency of water use. Projected warming will increase the duration of the growing season. Planting earlier in the season needs to be considered in a value-chain contest. Present competition for land-use from other crops may increase, particularly from short-duration annual crops. Diversification options also need to be considered in terms of short, medium and long-term climate change projections.
Horticulture	Frost reduction in these regions may see expansion of horticultural production suited to this climate. Crop phenology will be affected requiring intake scheduling and marketing responses for vegetable cropping.
Forestry	There are significant areas of hardwoods particularly *E. pilularis* and *E. grandis*. Preliminary analyses suggest neither species is likely to be at high risk in this region, but care should be taken to look for any developing problems, such as reduced productivity or new pests and diseases.
Intensive livestock	Irrigated dairy likely to be impacted by reduced water allocation, and increased temperatures. Heat stress issues for stock. Increased energy demand for cooling production sheds; increased demand for new energy efficient designs or retrofitting of exiting sheds.
Water resources	Median greenhouse runoff projection slight decrease. Local concentrations of irrigation (mainly self extraction) will be affected. Drier conditions with increased flood risk from east coast lows likely. Most storages not as substantial as those inland. Catchment risk score moderate to very high.
- Subtropical sub-humid	
Cropping	Potentially significant reductions in yield and quality of winter crops such as wheat due to likely reductions in rainfall and existing exposure to high temperatures in the northern part of this region. Potential reductions in frost may increase crop options. Summer rainfall seems equally likely to increase as to decrease and this also may provide some options to alter the balance of cropping. Adaptations include increased opportunistic cropping, increased attention to managing stored soil moisture and the use of seasonal climate forecasts.
Cotton	Less irrigation water, higher temperatures and greater evaporative demand by crops will impact yield and fibre quality. Improved water use efficiency (irrigation practice and variety choice) and tolerance to heat stress (variety choice) and modification of crop management (planting date, row configurations, irrigation scheduling) will need to be re-considered to help offset these issues.

Industries	Regional climate change impacts and issues
Forestry	Plantation forestry is not a major activity in the Brigalow belt. The dominant species *Acacia harpophylla* (Brigalow) is widely distributed and is unlikely to be at high risk from climate change.
Grazing	The negative affects of declines in rainfall and increasing incidence of drought on the productivity of these savannas may initially be offset from by the benefits of higher CO_2 and a prolonged growing season from warming. More intense rainfall may increase the risks of soil erosion, rising CO_2 may favour trees at the expense of pasture production, and pasture quality may decline.
Intensive livestock	Feedlots are likely to be impacted by increased temperatures and reduced water availability. Increased energy demand for cooling production sheds; increased demand for new energy efficient designs or retrofitting of exiting sheds.
Water resources	Median greenhouse runoff projection large decrease. Warmer conditions will increase water stress. Self-extracted water sources less well buffered than distributive systems. Catchment risk score high to very high.
- Temperate cool-season wet	
Cropping	Potentially significant reductions in yield of winter crops such as wheat due to likely reductions in rainfall. Reductions in irrigations water may push existing irrigated systems into a more opportunistic mode where there is partial irrigation or irrigation only once every several years on average. Adaptations include a range of changes in crops and crop management, increased opportunistic cropping, increased attention to managing stored soil moisture and the use of seasonal climate forecasts, increased water use efficiency.
Viticulture	Some areas, previously too cool for viticulture may become suitable. Some varieties that would not ripen in the present climate may be successfully planted in the future warmer climate. Phenological shifts to existing winegrape vines may result in ripening in a warmer part of the season. Quality will be affected. Grapevine variety suitability will change and planting of 'longer season' varieties (than presently planted) to fit the warmer climate will reduce any negative impact. Water may become a limiting factor for grape production in these regions. Disease incidence may reduce with lower rainfall in spring.
Horticulture	Extreme temperature impacts resulting in damage and/or undesirable crop physiological responses will need to be managed. Disease/pest impacts may be reduced with lower projected rainfall. Phenological and cropping cycles may be reduced. Some presently marginally cool regions may become more suitable for horticultural production. Security of supply of water is required especially for perennial horticulture.
Forestry	This is one of the most important plantation areas, including all or part of the Green Triangle (southern SA and southwest Vic), Tasmania, Central Victoria, Murray Valley, Central Gippsland, East Gippsland, Southern Tablelands, Central Tablelands and Northern Tablelands National Plantation Inventory regions. *P. radiata* and *E. globulus* are the major species. Likely impacts of climate change on these plantations are being analysed by CSIRO Forestry as part of a project for Forest and Wood Products Australia.
Intensive livestock	Dairy likely to benefit from warming, particularly in Tasmania. Some heat stress issues for stock. Possible increased energy demand for cooling or warming production sheds; increased demand for new energy efficient designs or retrofitting of exiting sheds.
Water resources	Median greenhouse runoff projections slight decrease (coastal) to moderate decrease (inland). Internal catchment water sources in the south and east and important source area supplying downstream MDB in the north. Disappearing snow pack in higher areas. Local irrigation will not be as affected as warmer areas. Flood risk in the east probably increased. Catchment risk score moderate to very high.
- Temperate subhumid	
Cropping	Potentially significant reductions in yield of winter crops such as wheat due to likely reductions in rainfall. Reductions in irrigations water may push existing irrigated systems into a more opportunistic mode where there is partial irrigation or irrigation only once every several years on average. Adaptations include a range of changes in crops and crop management, increased opportunistic cropping, increased attention to managing stored soil moisture and the use of seasonal climate forecasts, increased water use efficiency.
Cotton	Warmer conditions may allow for improved growing conditions (longer seasons) leading to possible industry expansion, if irrigation water is available.
Rice	Water supplies are projected to become more limited while individual crop demand is likely to increase. The likelihood of cold damage during flowering may decline, whereas the risk of crop heat-damage may increase. There is some scope to adapt rice production in current ponded culture, however aerobic and alternate-wet-and-dry rice represent future adaptation options. A wide range of potential farming system changes need to be considered, including greater utilisation/understanding of seasonal climate forecasts.
Forestry	This region includes part of the Western Slopes of New South Wales. Forestry is not a major activity in the region at present, but there may be future oil mallee plantings for carbon sequestration. Care should be taken in establishing and managing these plantations, as being in already relatively low rainfall areas they would be potentially vulnerable to any further rainfall reductions.
Intensive	Irrigated dairy likely to be impacted by reduced water allocation, and increased temperatures. Heat

Industries	Regional climate change impacts and issues
livestock	stress issues for stock. Increased energy demand for cooling production sheds; increased demand for new energy efficient designs or retrofitting of exiting sheds.
Water resources	Median greenhouse runoff projection moderate decrease. Region mostly sources water from further east subject, to moderate decrease also. Increase in water stress and storages not as large as on Murray system, so less carry-over resource. Catchment risk score high to very high.
- Tropical warm-season moist	
Cropping	Sugarcane the dominant crop. As discussed in the chapter on sugarcane, in the north of this region, prospects of lower rainfall may increase yields through increased sunshine but in the south, reductions in rainfall will reduce yields or increase demands for increasingly scarce irrigation water. Some increase in risks of soil erosion and pests and diseases. Adaptations in planting regimes and changing harvest chain.
Cotton	Development of a sustainable cotton cropping system for the Burdekin Irrigation Area
Sugarcane (Northern, Herbert & Burdekin and Central regions)	Crop damage from wind and cyclones may increase. Nutrient and sediment runoff into the Great Barrier Reef lagoon may increase. Northern region: Increased waterlogging may limit paddock access, particularly during the growing season. Reduced spring rain would negatively impact crop establishment. Herbert & Burdekin region: The security of water supply from the Burdekin Dam may be threatened. Rising water table and salinity issues, exacerbated by rising sea levels, will require improvements in irrigation. Declines in winter and spring rain may increasing trafficability, improving harvesting efficiency. Central region: Limited water supplies may be further strained by projected drying. Warming will extend growing seasons and improve crop growth in the frost-prone western districts. Poor drainage and tidal intrusion in the lower floodplains are likely to be exacerbated by projected sea level rise.
Horticulture	Expansion of industry may occur with decreased frost risk. Heat stress/flooding/erosion/ and cyclones can all have devastating impacts and risk assessments will need to be undertaken with regard to these. Cropping cycles will change with increasing temperatures and intake scheduling and marketing responses will need to be adjusted.
Forestry	South East Queensland is the major forestry centre in this region, with pine species accounting for about 83% of the plantation area. The same species, *P. elliottii* (slash pine) *P. caribaea* (caribbean pine) and their hybrid, as well as the native *Araucaria cunninghamii* (hoop pine) are grown further north, so selected sites should be monitored to provide some early warning of any problems associated with climate change.
Grazing	Productivity of these savannas may be negatively affected by some decline in rainfall and increasing incidence of drought. More intense rainfall may increase the risks of soil erosion, rising CO_2 may favour trees at the expense of pasture production, and pasture quality may decline.
Intensive livestock	Irrigated dairy likely to be impacted by reduced water allocation, and increased temperatures. Heat stress issues for stock. Cloud cover during wet season will continue to be an issue for pasture growth in the north. Increased energy demand for cooling production sheds; increased demand for new energy efficient designs or retrofitting of exiting sheds.
Water resources	Median greenhouse runoff projection slight to moderate decrease. Local concentrations of irrigated tropical agriculture at risk of drought. Cyclone and storm damage risk may increase. Catchment risk scores moderate to very high.
- Tropical warm-season wet	
Cropping	Limited dryland cropping with summer crops such as sorghum and also some irrigated crops. All crops are likely to be increasingly negatively affected by high temperatures but if increases in rainfall occur (approx 30% probability) this may alleviate restricted growing seasons for the dryland crops in particular.
Cotton	Establishment of sizeable cotton industry within the Ord Irrigation Area
Horticulture	Expansion of industry may occur with decreased frost risk. Heat stress/flooding/erosion/ and cyclones can all have devastating impacts and risk assessments will need to be undertaken with regard to these. Cropping cycles will change with increasing temperatures and intake scheduling and marketing responses will need to be adjusted.
Forestry	The area of plantations in the Northern Territory is relatively small, but expanding rapidly. The total area in 2005 was about 16,000 ha, of which 85% were *Acacia mangium.* Similar areas of *Khaya senegalensis* (African mahogany) are likely to be planted in coming years.
Grazing	Northern savannas are likely to be the rangelands where productivity is least affected by climate change. But more intense rainfall may increase the risks of soil erosion, rising CO_2 may favour trees at the expense of pasture production, and pasture quality may decline.
Intensive livestock	Not applicable for dairy. Increased energy demand for cooling production sheds; increased demand for new energy efficient designs or retrofitting of exiting sheds.
Water resources	Median greenhouse runoff projection slight increase on Cape York to slight decrease further west. Substantial wet season but only one substantial water storage: Lake Argyle. Catchment risk scores very low to low in the west and low to moderate on Cape York.

Industries	Regional climate change impacts and issues
- Tropical wet	
Cropping	Sugarcane the dominant crop. As discussed in the chapter on sugarcane, prospects of lower rainfall may increase yields through increased sunshine. Some increase in risks of soil erosion and pests and diseases. Adaptations in planting regimes and changing harvest chain.
Forestry	The plantation area of the Ingham-Cairns region of North Queensland is not large, but it may provide some useful early warning of possible climate change problems with growing pine species important in South East Queensland under warming conditions. Conserving highly species diverse tropical rainforests in their current condition may be difficult under climate change. However, the diversity of species may provide some capacity to adapt to climate change.
Intensive livestock	Not applicable for dairy. Increased energy demand for cooling production sheds; increased demand for new energy efficient designs or retrofitting of exiting sheds.
Water resources	Median greenhouse runoff projection slight increase. No notable irrigation. Catchment risk scores low to moderate.

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).

Key messages for each major agricultural industry

The following key messages 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 and background information are available in that report.

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.

Maladaptation can occur through both over and under-adaptation to potential climate changes. Effective monitoring of adaptation at a range of scales could help reduce the risks of maladaptation by learning what adaptations work, which do not and why. Assessment to ensure that adaptations do not increase net greenhouse gas emissions is critical.

There are many adaptations for the cropping industry that are consistent with those in other industries. These are dealt with elsewhere in this report. 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 cops 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.

The industry needs to maintain R&D capacity, undertake further adaptation studies which include costs/benefits and develop focused and streamlined rapid R&D responses.

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^{o}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).

Biosequestration

Current projections are for approximately 21 Mt CO_2-e per annum to be sequestered in Australia by afforestation and reforestation under Kyoto Protocol rules over the commitment period 2008–12. This is more than 80% of the expected increase in emissions due to transport over the same period when compared with the 1990 baseline (see Department of Climate Change report 'Tracking to the Kyoto Target 2007').

The imperative to reduce GHG emissions is likely to drive new industries associated with probable large private sector investment in GHG offsets. This has the potential to drive very significant land use change. There is already a fledgling 'biosequestration industry' which will now expand rapidly, and in many cases ahead of formal policy. It will develop into an industry consisting of established agricultural, plantation and land-owning organisations, combining with a number of fast-moving start-up companies to provide the necessary financial instruments. It will need the support of appropriate policy and regulatory frameworks, and a solid research underpinning.

From the policy drivers outlined above and the number of start-up companies operating in this area already, there is the potential for enormous growth and national/international impact. For example, Woodside Petroleum has recently entered a $100 million carbon offset contract with CO_2 Australia, and Greening Australia is developing a similar-sized fund.

Carbon trading in Australia for GHG offsets has the potential to be very large. As an indicative conservative example 5 million hectares of tree plantings would annually provide 50 million tonnes of CO_2 net emissions reduction, which at $20 per tonne CO_2 equates to $1 billion of annual trading.

Such massive potential increases in tree plantings could, with appropriate research and technology, support a large biofuel industry that would not impact negatively on land currently used for food production. CSIRO's Energy Futures Flagship is evaluating the potential of biofuels from forest residues.

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.

Part 2. The Need for a National Agriculture Adaptation Strategy

This section addresses the second of the Inquiry's terms of reference, ie.
ii) The need for a national strategy to assist Australian agricultural industries to adapt to climate change.

The Current Research and Policy Context

The issue of climate change and agriculture in Australia is receiving considerable attention from farmers, industry bodies, the media, scientists and policy makers. In recent years there have been a number of key policy and research developments.

The National Agriculture and Climate Change Action Plan 2006-2009

In 2006 the Natural Resource Management Ministerial Council released 'The National Agriculture and Climate Change Action Plan 2006-2009'. The Action Plan represented "an agreement by Australian governments to develop a coordinated framework for climate change policy in agriculture to contribute to the development of a sustainable, competitive and profitable Australian agricultural sector into the future".

The Action Plan is guided by a set of principles and includes strategies and actions for four focus areas: adaptation; mitigation; research and development; and awareness and communication.

Federal Government Policy Framework

The current Federal Government's policies in relation to climate change and agriculture include the 'Australia's Farming Future Initiative' and a commitment to develop a 'National Agriculture and Climate Change Adaptation Action Plan' (ALP 2007).

The 'Australia's Farming Future Initiative' aims to assist Australian primary industry sectors to adapt and respond to climate and includes:

- $60 million over four years for a Climate Change Adaptation Partnerships Program.
- $15 million over four years for a Climate Change and Productivity Research Program.
- $55 million over four years in a Climate Change Adjustment Program.

According to election policy statements (ALP 2007), the 'National Agriculture and Climate Change Adaptation Action Plan' will include:

- Supporting climate change research to better understand the implications for agriculture.
- Integrating adaptation responses into agricultural policies and natural resource management programs to respond to climate risks and pressures – for example to understand the impacts of temperature changes on plant and animal health.
- Building resilience into existing agricultural management systems to better identify and manage the impacts of climate change.
- Managing the impact of climate change on native and invasive species and disease incursions in agricultural and natural resource systems.
- Taking advantage of market opportunities that may arise from climate change – including developing new tools, products and services for the domestic market and for export into growing international markets.

The Climate Change Research Strategy for Primary Industries

As mentioned in Part 1, a Climate Change Research Strategy for Primary Industries is currently being developed by LWA. The CCRSPI is a joint initiative of the Rural Research and Development Corporations; CSIRO; and the Federal, State and Territory governments; managed by Land & Water Australia.

At the time of writing, a draft Research Strategy has been developed and is awaiting consideration by the Primary Industries Standing Committee. LWA expects to finalise and publish the Strategy and its accompanying Appendices (including the CSIRO report) by mid-April 2008.

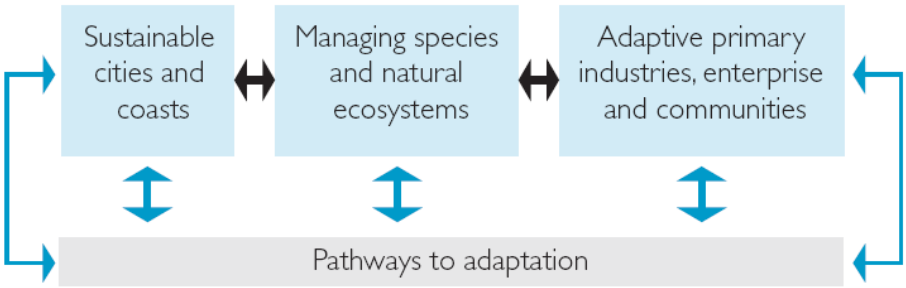
The CSIRO Climate Adaptation National Research Flagship

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

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 (eg. 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 1, below.

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.

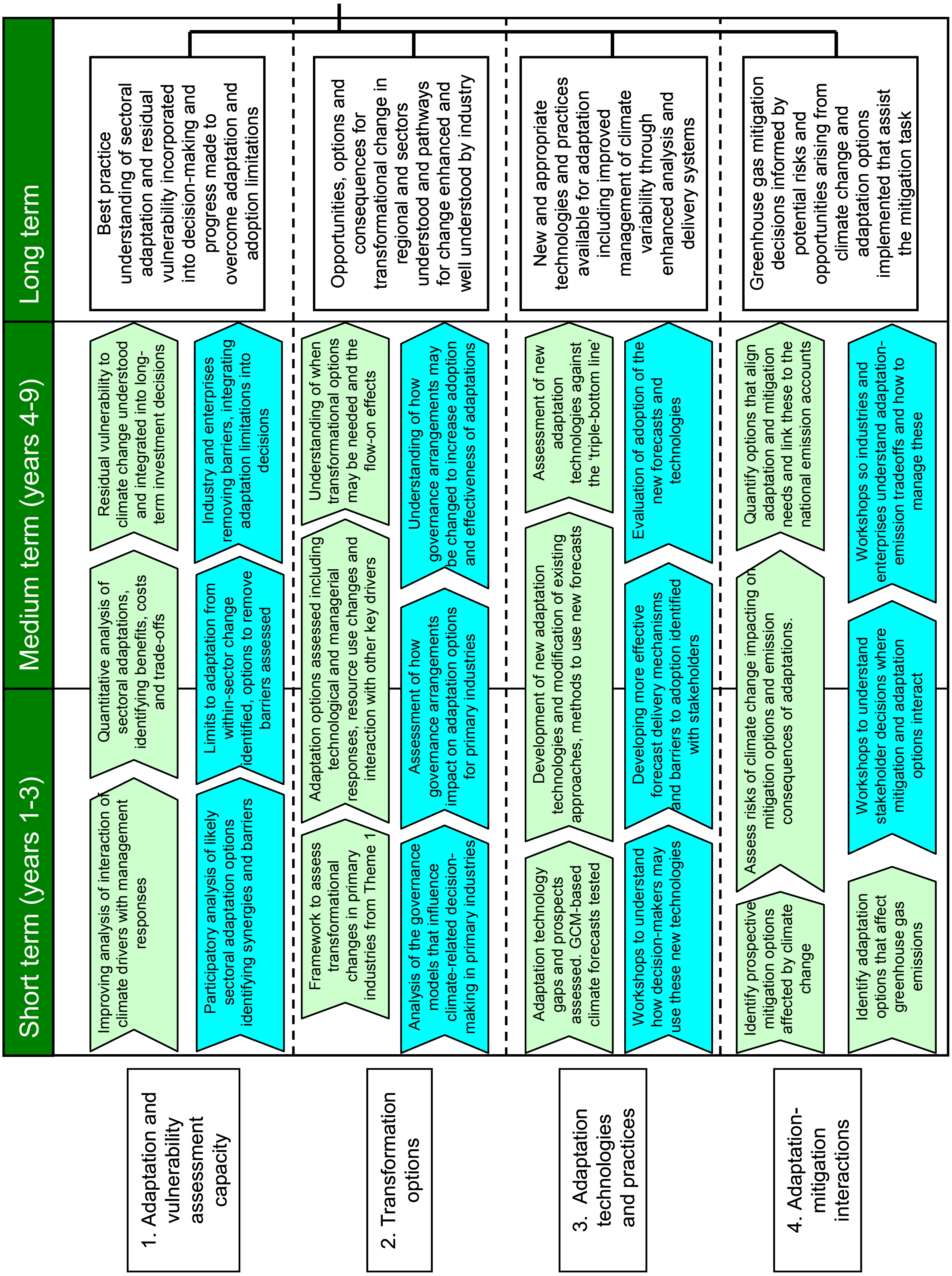


Figure 1. An outline of the research and engagement strategy for the Climate Adaptation Flagship Theme 4: Adaptive Primary Industries, Enterprises and Communities.

Recommendations and Options for Agricultural Adaptation

Successful adaptation to climate change will need both strategic preparation and tactical response strategies. Adoption of these new practices will require, amongst other things:

1) confidence that the climate really is changing;
2) the motivation to change to avoid risks or use opportunities;
3) demonstrated technologies to enable change to occur;
4) support during transitions to new management or new land use;
5) altered transport and market infrastructure; and
6) an effective monitoring and evaluation system to learn which adaptations work well, which do not and why.

Adaptation measures will have to reflect and enhance current 'best-practices' designed to cope with adverse conditions such as drought. In the short-term, a common adaptation option will be to enhance and promote existing management strategies for dealing with climate variability. This will automatically track early stages of climate change until longer-term trends become clearer.

The recent CSIRO-LWA report on climate change and agriculture (Stokes & Howden eds 2008) identified a suite of possible adaptation actions for agriculture in general, and for each of the major agricultural industries. The actions listed in Tables 1.1 and 1.2 (below) demonstrate the scope of possible adaptation actions and strategies that should be considered in the development of any proposed new or updated national strategy to assist Australian agricultural industries to adapt to climate change.

The possible actions listed were identified by the team of scientists contributing to the CSIRO-LWA report, and so far have had only limited input from industry stakeholders. Hence, the suggestions and comments in the tables below should be taken as a starting point for further discussions with industries and communities, not a final answer.

Adaptation Issues Common across Industries

The following table is taken directly from (Stokes & Howden eds 2008).

Table 1.1: Summary of climate change adaptation issues that are shared across primary industries.

Policy
Develop linkages to existing government policies and initiatives (e.g. Greenhouse Gas Abatement Program, Greenhouse Challenge Plus, salinity, water quality, rural restructuring) and into integrated catchment management so as to enhance the capacity to adapt to climate change.
Managing transitions
Develop policies and mechanisms to provide technical and financial support during transitions to new systems that are more adapted to the emerging climate.
Accepting Uncertainty
Enhance capacity for land and marine managers and supporting institutions to deal with uncertainty. Current and future actions will have to be taken based on uncertain regional- / farm-scale predictions and observations of climate changes. Adaptation strategies will need to enhance adaptive capacity by ensuring that rural communities are equipped to cope with a range of possible, but uncertain changes in local climatic conditions.
Communication
Ensure communication of broader climate change information as well as industry-specific and region-specific information as it becomes available.
Climate data and monitoring
Maintain effective climate data collection, distribution and analysis systems to link into ongoing evaluation and adaptation. Monitor climate conditions and relate these to yield and quality aspects to support/facilitate adaptive management. Develop climate projections that can be downscaled so as to be relevant to farm, catchment and coastal scales. Consideration could be given to the introduction of climate change adaptation into Environmental Management Systems.
R&D and training
Undertake further adaptation studies that include broad-based costs and benefits to inform policy decisions. Maintain the research and development base (people, skills, institutions) to enable ongoing evaluation of

climate/CO_2/(cultivar, species or land use)/management relationships, and to streamline rapid R&D responses (for example, to evaluate new adaptations or new climate change scenarios). This R&D needs to be developed in a participatory way so that it can contribute to training that improves self-reliance in the agricultural sector and provides the knowledge base for farm-scale adaptation.
Breeding and selection
Maintain public sector support for agricultural biotechnology and conventional breeding with access to global gene pools so as to have suitable varieties and species for higher CO_2 and temperature regimes and changed moisture availability.
Model development and application
Develop further systems modelling capabilities such as APSIM for crops and AussieGrass and GrazFeed for grazing that link with meteorological data distribution services, and can use projections of climate and CO_2 levels, natural resource status and management options to provide quantitative approaches to risk management for use in several of these cross-industry adaptation issues. These models have been the basis for successful development of participatory research approaches that enable access to climate data and interpretation of the data in relation to farmers own records and to analyse alternative management options. Such models can assist pro-active decision making on-farm and inform policy and can extend findings from individual sites to large areas.
Seasonal forecasting
Facilitate the adoption of seasonal climate forecasts (e.g. those based on El Niño and La Niña, sea-surface temperatures, etc) to help farmers, industry and policy incrementally adapt to climate change whilst managing for climate variability. Maximise the usefulness of forecasts by combining them with on-ground/water measurements (e.g., soil moisture, nitrogen, ocean temperature), market information and systems modelling.
Pests, diseases and weeds
Maintain or improve quarantine capabilities, sentinel monitoring programs and commitment to identification and management of pests, diseases and weed threats. Improve the effectiveness of pest, disease and weed management practices through predictive tools such as quantitative models, integrated pest management, area-wide pest management, routine record keeping of climate and pest/disease/weed threat, and through development of resistant species and improved management practices.
Nutrition
Adjust nutrient supply to maintain grain, fruit, fibre and pasture quality through application of fertiliser, enhanced legume-sourced nitrogen inputs or through varietal selection or management action. Note however, that this may have implications for greenhouse emissions (via field-based emissions of nitrous oxide or emissions of CO_2 during manufacture). Any increases in nutrient supply will have to be carefully managed to minimize soil acidification, waterway eutrophication or runoff into estuaries and marine systems.
Water
Increase water use efficiency by 1) a combination of policy settings that encourage development of effective water-trading systems that allow for climate variability and climate change and that support development of related information networks, 2) improve water distribution systems to reduce leakage and evaporation, 3) developing farmer expertise in water management tools (crop models, decision support tools) and 4) enhancing adoption of appropriate water-saving technologies.
Land use/location change and diversification
Undertake risk assessments to evaluate needs and opportunities for changing varieties, species, management or land use/location in response to climate trends or climate projections. Support assessments of the benefits (and costs) of diversifying farm enterprises.
Salinity
Determine the impact of climate change (interacting with land management) on salinity risk (both dryland and irrigated) and inform policies, such as the National Action Plan for Salinity and Water Quality, accordingly.

Industry Specific Priorities

The following table is taken directly from (Stokes & Howden eds 2008).

Table 1.2: Summary of priorities for climate change adaptation strategies for Australian agriculture sectors based on identified knowledge gaps and other criteria documented in the report. Note that these exclude the cross-industry components listed above.

Grains
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) and controlled traffic approaches.

Development of crop 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.
Alter planting rules to be more opportunistic depending on environmental condition (e.g. soil moisture), climate (e.g. frost risk) and markets.
Provide tools and extension to enable farmers to access climate data at the scale needed for their decisions and analyse alternative management and land use options including in real-time using approaches akin to Yield Prophet^{TM}.
Research and revise soil fertility management (fertilizer application, type and timing, increase legume phase in rotations) on an ongoing basis.
Analyse value-chain and regional adaptation options that translate climate scenarios into meaningful quantities for the stakeholders involved and that include technical, managerial, structural and policy adaptations with consideration of interactions with a large range of other stressors, opportunities and barriers.
Cotton
Improve whole farm and crop water use efficiencies by enabling further improvements in water distribution systems (to reduce leakage and evaporation), irrigation practices such as water application methods, irrigation scheduling and utilizing moisture monitoring techniques.
Develop management systems that improve cotton nitrogen use efficiency.
Select 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).
Provide information to cotton growers on the likely impacts at their business level (downscaling climate change predictions to regional scales).
Maintain R&D capacity, undertake further adaptation studies which include costs/benefits and streamline rapid R&D responses.
Conduct responsible research into the development of cotton systems in northern Australia.
Research the integrated affects of climate change (temperature, CO_2, and water stress) on cotton growth and yield need further analysis.
Conduct research into avoiding resistance of pests (both insects and weeds) through appropriate integrated pest and weed management systems to maintain transgenic technologies.
Enhance capacity to predict and forecast pest issues in relation to climate change and variability.
Rice
Increase water productivity of cropping systems, through continuing efforts to reduce rice water use, consideration of new crops and rotations, irrigation technologies and farm layouts.
Assess cost benefits of investing in more efficient irrigation methods and farm layouts, as a function of soil type and location.
Assess potential for aerobic and alternate-wet-and-dry (AWD) rice culture in Australian environments; investigate potential benefits and limitations; define optimal water management strategies, fertilisation and weed control issues.
Consider cost-benefits of reducing water conveyancing losses both on-farm and in irrigation district.
Use electromagnetic technology (EM31) to better define which soils are suitable for ponded rice production (to reduce drainage losses).
Sugarcane
Improve farming practices, especially precision irrigation, on-paddock water use and off-paddock water quality impacts and the management of increased climate variability through seasonal forecasting.
Promote innovative farming and processing systems that take an integrated and sustainable approach to risk and opportunity across all inputs.
Capitalise bio-energy opportunities and carbon trading potential for value adding, preferably integrated within innovative farming and processing systems to maximise cross industry benefits.
Focus research on sugarcane physiology and plant improvement in varietal characteristics that enhance resilience to climate change, linked to industry adaptation to higher temperatures, reduced water availability, and extreme events. This will also require knowledge of the genetic x environment x management (G*E*M) interactions.
Enhance human capital through building skills and enhance science capability in climate understanding and risk management across the sugarcane industry.
Include climate change considerations in biosecurity management.
Develop an understanding of the global context of climate change impacts on worldwide production, profitability and markets relative to the Australian sugarcane industry.
Viticulture
Change varieties of winegrapes grown in a region in a gradual but timely manner to better suit the projected climate. New ‘longer season’ varieties can be sourced/bred.
Assess the potential for new sites. Incorporate an analysis of chilling requirements. Also consider other factors such as increasing risk of exposure to bushfire smoke at some sites.

Assess vine response to CO_2-induced increased growth. How will this affect vine growth, yield and yield variability, grape quality and water requirements.
Secure water supplies.
Consider management of the inter-row environment with regard to high rainfall events and also potential frost risk.
Consider possible new winemaking demands (smoke taint/ high alcohol), and also winery infrastructure and harvest logistics.
Horticulture
Change varieties of fruit and vegetables so they are phenologically suited for future conditions and re-assess industry location.
Assess spatial distribution of sites suitable for various horticultural crops, especially with frost likely to reduce in the sub-tropical/tropical regions.
Research on altering crop management and implement breeding programs to avoid adverse crop responses to increasing temperatures.
Determine water access and availability, especially for perennial horticulture.
Assess crop response to enhanced CO_2/ increased temperature.
Forestry
Use bioclimatic analysis to improve knowledge of climatic requirements of particular genotypes and identify vulnerable plantation sites for monitoring.
Evaluate the impacts of high CO_2 and drought risk on tree mortality and establishment strategies. Identify the optimal strategy between high growth (e.g. dense stands with high leaf area) and risk aversion (e.g. sparse stands with low leaf area) for particular sites and particular trees/products.
Develop detailed assessment of drought tolerance of important species and develop drought tolerant genotypes.
Enhance process-based growth models to extend findings on climate change impacts and adaptations from individual sites to large areas. Carry out cost/benefit studies of alternative adaptation strategies.
Develop improved assessments of pest, disease and weed risks as well as appropriate adaptations.
Develop improved assessments of bushfire risks as well as appropriate adaptations.
Grazing
Promote and enhance use of seasonal forecasts in grazing management, and incorporate considerations of projected trends in climate change.
Quantify the range of plausible impacts that uncertain climate change could bring for the grazing industry to clearly define the adaptation challenge.
Determine how pastoralists and policy makers are most likely to respond to climate change impacts and comprehensively evaluate the costs, benefits and likely effectiveness of these reactions, and where impacts are likely to exceed the capacity of pastoralists to cope with the changes.
Research and promote greater use of strategic spelling and other improvements in grazing land management that reduce exposure to risks of climate variability and uncertain climate change.
Develop tools to determine regional safe stocking rates and pasture utilization levels linked to seasonal and projected climate conditions.
Assess animal management options such as modifying the timing of mating based on seasonal conditions.
Improve breeding and management of animal heat stress, particularly where livestock are handled more intensively.
Intensive Livestock
Analyse and develop policies that promote effective adaptation while reducing maladaptation and conflicting policy objectives. This would require comprehensive systems analysis of policy and management adaptation options.
Develop guidelines or building codes for energy and water efficient production sheds, particularly focussing on passive cooling or heating. Link these to revised capability to assess heat stress on livestock.
Understand the risks to feed supplies due to climate variability or reduction through competition from other users of feedstock.
Assess the vulnerability of irrigated dairy to reduced water supply.
Water Resources
Develop approaches to managing water resources that take into account climate change projections as well as seasonal to decadal drivers of climate variation.
Evaluate the costs and benefits of increasing on-farm and systems efficiencies via better use of technology, co-ordination of delivery mechanisms, evaporation control, retrofitting leaky systems, the provision of probabilistic seasonal forecasts, improved scheduling and better understanding of what is needed to implement such measures in a range of different circumstances.
Incorporate climate change considerations more effectively into integrated catchment management, addressing the relationships between water quality, surface and groundwater extraction, waterway management and land-use,. Institutional arrangements may need reviewing to encourage such integration.
Evaluate the implications of moving to full cost pricing and water trading so as to maximise the potential for adaptation and minimise perverse incentives.

Evaluate whether there are clear thresholds in irrigated agriculture (e.g. loss of flows from the MDB leading to the death of tree crops; in-stream salinity becoming too high for irrigation) and the implications of these for water resource management under climate change
Develop a framework for water resource management that takes account of on-going conditions, where business as usual, watching brief, near critical and emergency management are all codified stages that contain strategic considerations relevant to planning horizons under climate change.
Fisheries & Aquaculture
Undertake research on how fisheries and aquaculture management and policy can facilitate flexibility by operators seeking to adapt to climate change – are current management approaches suited to a changing climate?
Collect and analyse data on the impacts of climate variability and trends on marine biology to give insight into the impacts of climate change on fisheries and aquaculture and develop methods for assessing the vulnerability of fished and aquaculture species to environmental variables under climate change, including means, extremes, and cumulative impacts.
Develop robust genetic strains for aquaculture species that perform well in future environments, and examine industry locations and opportunities under future climate scenarios.
Develop predictive models for the occurrence of extreme events, and the thresholds for the biology (particularly for aquaculture). Deliver these warnings at a time in the production cycle that is useful to operators and build the capacity of these operators to integrate this information into their management plans.
Investigate regional case studies for the impacts of climate change on the biological, social and economic relationships in fisheries and aquaculture.

Part 3. Climate Change and Drought Assistance

This section addresses the third of the Inquiry's terms of reference, ie.
iii) the adequacy of existing drought assistance and exceptional circumstances programs to cope with long term climatic changes.

Australian society is concerned for the welfare of rural communities experiencing drought. The challenge faced by governments is to provide a standard of welfare for drought-affected farm-families that is acceptable to the wider Australian community while also meeting sustainability and economic efficiency goals. With projections indicating that droughts are likely to dramatically increase in frequency with climate change in the next few decades (Burke et al. 2006) there is now an added urgency to the long-standing need for a review and overhaul of drought assistance policies.

Current policy objectives

In policy development since the early 1990s, drought has been considered a natural characteristic of Australia's variable and changing climate, with successful management of climate risk recognised as a definitive characteristic of farming excellence (see for example Blackadder 2005). With this focus on self-reliance, the rationale for providing financial support to farmers is "to ensure that farmers with long-term prospects for viability will not be forced to leave the land due to short-term adverse events that are beyond their ability to manage" (DAFF 2005). The policy has multiple objectives which include:

1. encouraging self-reliant approaches to managing climate variability;
2. protecting the natural resource base during times of extreme climate stress;
3. ensuring adequate welfare support for farm families commensurate with that available to other Australians;
4. ensuring that the policy does not impede structural adjustment in the farm sector; and
5. a high level of awareness and understanding of drought and drought policy.

(Adapted from Drought Policy Task Force (1997), cited in Botterill (2005).)

Current policy instruments

The two key forms of assistance provided under 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.

There is now evidence that many of these instruments create perverse incentives, since they can encourage landholders to make decisions or undertake activities that risk damaging the natural resource base. In many cases, the public purse subsequently funds relief for the impact that this damage has on these enterprises (Drought Policy Review Task Force 1990; Heathcote and Stone 2002; Stafford Smith 2003; Nelson *et al.* in press). Tax-related instruments, such as livestock elections, certain livestock valuation measures and perhaps income averaging, have also been shown to have perverse incentive effects in some circumstances (Stafford Smith 2003). Farm management deposits, on the other hand, have been demonstrated as contributing to reserve building in a non-distortionary way (Stafford Smith 2003)

What constitutes 'exceptional circumstances'?

In deciding whether to declare a region as affected by exceptional circumstances, the National Rural Advisory Council (NRAC) and the Minister for Agriculture must decide whether (DAFF 2005):

1. the event is rare and severe, occurring on average once in 20 to 25 years, and on a significant scale in terms of the area and proportion of farm businesses affected;
2. the event has resulted in a rare and severe downturn in farm income over a prolonged period; and
3. the event was not predictable or part of a process of structural adjustment.

Most of Australia's intensive southern agricultural regions have historically been drought declared (DAFF 2007) in a far greater proportion of years than specified by the above exceptional circumstances criteria. Although a national time series of drought declared regions is not routinely published or analysed, monthly updates are regularly published at http://www.daff.gov.au/agriculture-food/drought/ec. Over time, this website reveals that most agricultural regions of southern Australia were continuously drought declared from 2002-03 until at least October 2007 (see Figure 3). A statistical implication of the exceptional circumstances criteria is that regions that have been drought declared for 4 continuous years should not be due for additional assistance for another 80 to 100 years. Indeed, modelling more than a decade ago showed that defining entry and revocation criteria for exceptional circumstances is fraught with difficulties, and that most realistic criteria result in drought being declared for more time that is intended (Stafford Smith and McKeon 1997). A long term analysis by Day et al. (2003) showed that some shires in Queensland have been drought declared in more than twenty percent of years since 1964. Climate change can be expected to exacerbate this trend.

Ongoing provision of exceptional circumstances assistance has proved costly (figure 2). The Australian Government has committed over $3.5 billion to drought assistance since 2001 (Howard 2007) or around $50 000 on average for each of the nearly 70 000 commercial farms in Australia (ABARE 2003).

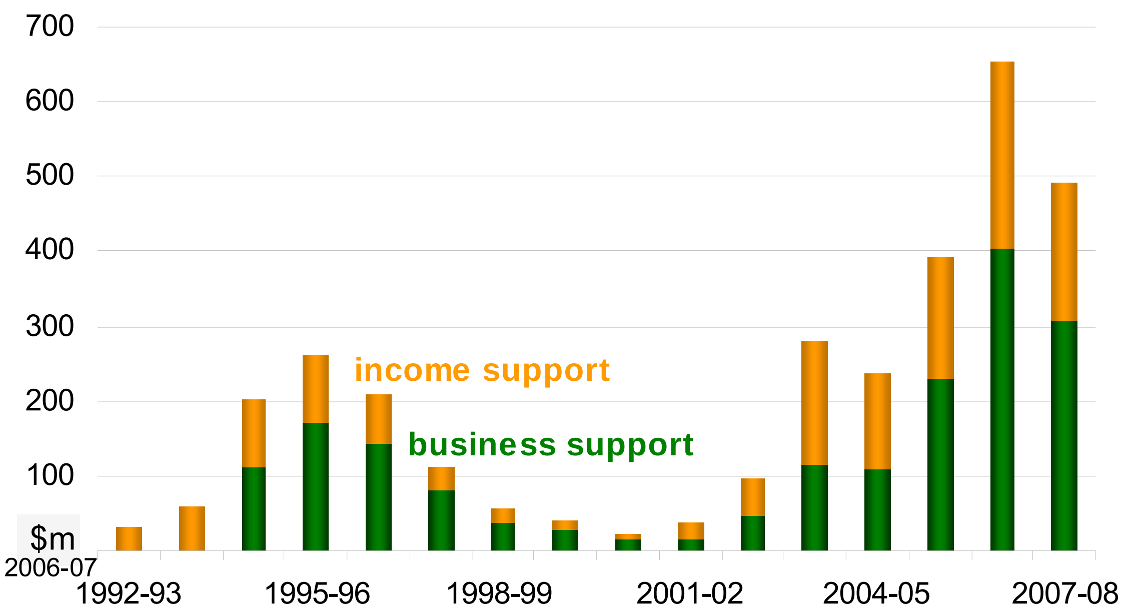


Figure 2. Drought assistance expenditure, source: Philip Glyde, presentation to ABARE Outlook conference March 2008

Improving the science used to support drought policy

There is currently a misalignment between the objectives of drought policy and the science used to support it. The objectives of drought policy focus on reducing the economic and social impacts of drought, while the science supporting drought policy has focused almost exclusively on rainfall and agricultural production. This misalignment has potential implications for the ability of policy to influence drought and agricultural production, at least in the short term. For example, a focus on rainfall and production has distracted from the development and implementation of more holistic methods for measuring the key policy outcome, such as the adaptive capacity of rural communities (figure 3).(Nelson et al 2007b).

The narrow focus of drought science has also constrained the implementation of new technologies with potential to support the implementation of drought policy. Bioeconomic modelling systems have been developed to forecast the direction of movement in farm incomes at the beginning of the financial year (Kokic et al. 2007). This overcomes the moral hazard and timing issues that have been used to justify reliance on rainfall rather than income data in implementing the exceptional circumstances criteria central to Australian drought policy (Nelson et al. 2007a) (figure 4 and 5).

An emphasis on engineering approaches to risk management to support drought policy could be increasingly problematic as climate change accelerates. As traditional forms of climate science continue to pursue predictive skill over longer time frames using new generations of global climate models, it is at risk of being stranded by the high degree of uncertainty surrounding climate change. Consequently, there is an urgent need to complement traditional climate science with research that assists farmers and rural communities to identify and build on their intrinsic capacity to adapt to the significant but unpredictable challenges of a changing climate.

Figure 3. The adaptive capacity of Australian rural communities involved in broadacre agricultural industries estimated using ABARE farm survey data (updated from Nelson et al. 2005, Nelson et al. 2007b).

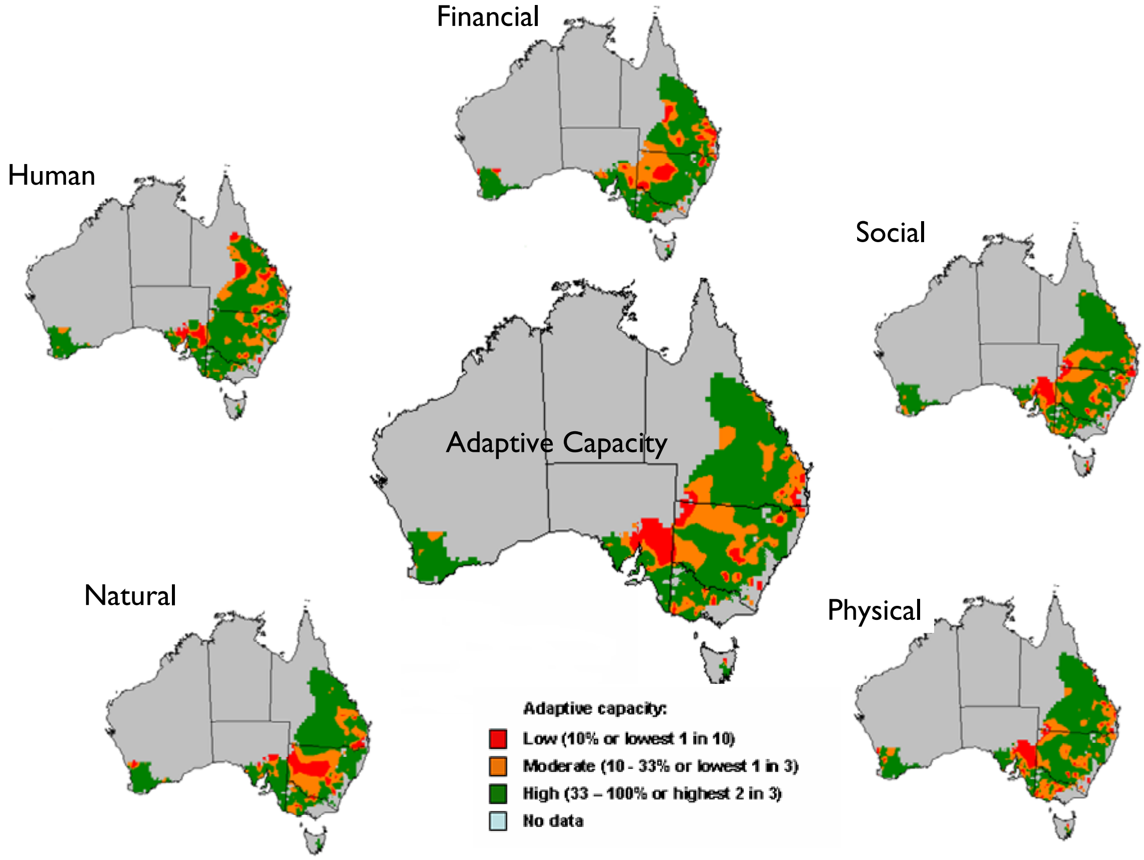


Figure 4: Actual versus forecast ranking of farm incomes in 2001-02.

Figure 4a: The percentile rank of observed income in 2001-02 relative to all observed values from 1977-78 to 2002-03.

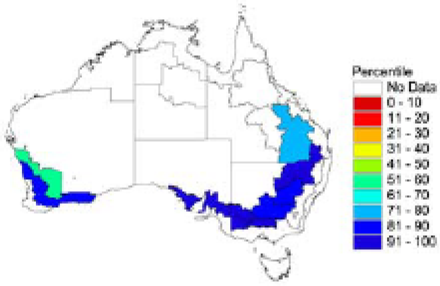


Figure 4b: The probability of exceeding median income for 2001-02 for cropping and mixed crop-livestock farms simulated over 103 years using AgFIRM.

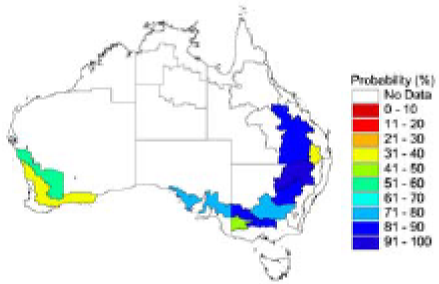


Figure 5: Actual versus forecast ranking of farm incomes in 2002-03

Figure 5a: The percentile rank of observed income in 2002-03 relative to all observed values from 1977-78 to 2002-03.

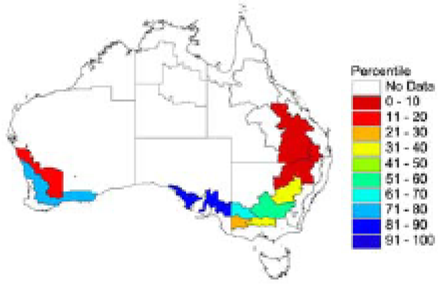
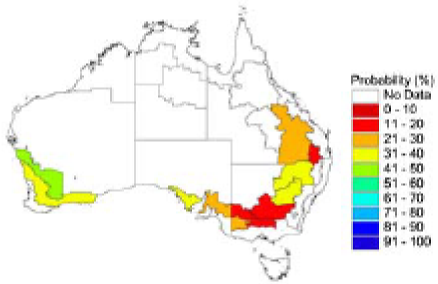


Figure 5b: The probability of exceeding median income for 2002-03 for cropping and mixed crop-livestock farms simulated over 103 years using AgFIRM.



An adaptive approach to drought policy

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 in press).

From this alternative perspective, the current system of administering exceptional circumstances policy has many of the characteristics of a centralised expert management regime. The balanced social, economic and environmental objectives of the policy are not well reflected in the criteria used to grant drought assistance, while the science used to make these decisions is heavily dominated by biophysical measures of climate risk rather than the socioeconomic outcomes important to decision makers.

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.

Shared ownership and mutual responsibility

There are a number of possible advantages of increased community engagement in enhancing shared ownership and mutual responsibility in the administration of drought assistance (Stafford Smith 2005).

Governance systems that provide communities with authority to allocate finite amounts of assistance determined prior to droughts would reduce the open-ended nature of current incentives to seek assistance, and encourage the conservation of scarce fiscal resources. Limits on drought assistance and rules for its governance pre-agreed with local communities could help to free governments of criticism surrounding intervention during drought. Communities and governments could work together to develop locally relevant conditions for mutual responsibility that do not impede the exit of non-viable farms from the industry.

To be effective, interaction between government and the community would likely benefit from support by regionally distributed scientific support capable of integrating local knowledge and informing the livelihood outcomes of critical importance to decision makers.

Communities and governments could co-design governance in which participants self-select their access to drought assistance according to jointly determined standards of farm and environmental management, including drought preparedness. Self-selection mechanisms supported by local monitoring according to independently set standards would remove the need for multiple central assessments, with potential to greatly improve the responsiveness of drought policy administration to changing seasonal conditions. For example, local Drought Committees and Rural Lands Protection Boards already play an important role in community engagement and exceptional circumstances declaration in States of Queensland and New South Wales, which could be integrated into a nationally coordinated system with pre-agreed and independent standards.

Such a system would also encourage the development of locally-tailored climate adaptation strategies. For example, in the rangelands this might include the establishment of agistment support systems which facilitate modern-day nomadic herding (McAllister et al. 2006), as well as other management in tune with our variable landscapes (Stafford Smith and McAllister 2008).

Governments could also work with local communities to reduce issues of equity between farmers and society more generally by making drought assistance increasingly revenue neutral. Revenue neutral schemes with a high degree of local community ownership have potential to ensure future access to drought assistance as wider community attitudes change under increasing urbanisation and globalisation. For example, the drought assistance contracts proposed by Stoneham et al. (2004) combine revenue neutrality with self-selection, therefore addressing both equity and administrative efficiency concerns.

References

ABARE, 2003. *Australian farm survey report*. Australian Bureau of Agriculture and Resource Economics, Canberra.

Australian Labor Party (2007) 'Labor's Plan for Primary Industries' Official Election Policy Document http://www.alp.org.au/download/now/071119___labors_plan_for_primary_industries22.pdf

Blackadder, J. 2005. Masters of the climate: innovative farmers coming through drought. Managing Climate Variability Research and Development Program, Land & Water Australia, Canberra.

Botterill, L. 2005. Late twentieth century approaches to living with uncertainty: the national drought policy. In L.C. Botterill and D. Wilhite (eds) From disaster response to risk management: Australia's national drought policy. Springer, Dordrecht.

Burke, E. J., Brown, S. J., and Christidis, N. (2006). Modeling the recent evolution of global drought and projections for the twenty-first century with the Hadley Centre climate model. *Journal of Hydrometeorology* **7**, 1113-1125.

DAFF 2007. *Exceptional Circumstances*. Australian Government Department of Agriculture, Fisheries and Forestry: http://www.daff.gov.au/agriculture-food/drought/ec, October.

DAFF 2005. Information handbook: exceptional circumstances assistance. Australian Government Department of Agriculture, Fisheries and Forestry, http://www.affa.gov.au/content/publications.cfm?ObjectID=D43AC96E-FEB9-42A0-9A6BBCD98FA5A401, October.

Day, K., Ahrens, D. and McKeon, G. 2003. Simulating historical droughts: some lessons for drought policy. In R. Stone and I. Partridge (eds), *Science for Drought: Proceedings of the National Drought Forum*, Queensland Department of Primary Industries & Fisheries, Brisbane, pp. 141-151.

Drought Policy Review Task Force (1990). 'Managing for Drought.' (Australian Government Publishing Service: Canberra, Australia.)

Hayman P, Cox P (2005) Drought risk as a negotiated construct. In 'From disaster response to risk management: Australia's national drought policy'. Eds LC Botterill, D Wilhite Springer: Dordrecht, The Netherlands.

Heathcote, R. L. and Stone, R. C. (2002). 'Braving the Bull of Heaven: Drought Management Strategies, Past Present and Future.' (Royal Geographical Society of Queensland: Brisbane, Australia.)

Hennessy K, Fitzharris B, Bates BC, Harvey N, Howden SM, Hughes LSJ, Warrick R (2007) Australia and New Zealand. In 'Climate change 2007 - impacts, adaptation and vulnerability - contribution of Working Group II to the Fourth Assessment Report of the International Panel on Climate Change'. (Eds ML Parry, OF Canziani, JP Palutikof, PJ van der Linden, and CE Hanson) (Cambridge University Press: Cambridge)

Horridge M, Madden J, Wittwer G (2005) The impact of the 2002–2003 drought on Australia. Journal of Policy Modeling 27, 285–308. doi:10.1016/j.jpolmod.2005.01.008

Howard, J., 2007. *Australian Government strengthens drought support*. Media Release 25 September 2007, Prime Minister of Australia, The Hon. John Howard. http://www.mirrigation.com.au/News/PM%20Drought%20Suppt%2025Sep07.pdf

Howden, S. Mark, Jean-Francois Soussana, Francesco N. Tubiello, Netra Chhetri, Michael Dunlop, and Holger Meinke (2007) 'Adapting agriculture to climate change' Proceedings of the National Academy of Sciences, vol. 104, no. 50 pp 19691–19696

IPCC (2007b) 'Climate change 2007 - synthesis report - Fourth Assessment Report of the International Panel on Climate Change.' (Cambridge University Press: Cambridge)

Kokic, P., Nelson, R., Meinke, H., Potgieter, A. and Carter, J., 2007. From rainfall to farm incomes - From rainfall to farm incomes - transforming advice for Australian drought policy: Part II – Development and testing of a bioeconomic modelling system. Australian Journal of Agricultural Research 58:10, 993-1003.

Martin P, Mues C, Phillips P, Shafron W, Van Mellor T, Kokic P, Nelson R, Treadwell R (2007) Farm financial performance—Australian farm income, debt and investment, 2004–05 to 2006–07. Australian Commodities 14, 179–200.

McAllister, R. R. J., Gordon, I. J., Janssen, M. A., and Abel, N. (2006). Pastoralists' responses to variation of rangeland resources in time and space. *Ecological Applications* 16, 572-583.

Nelson, R., Kokic, P. and Meinke, 2007a. From rainfall to farm incomes - transforming advice for Australian drought policy: Part II - Forecasting farm incomes. Australian Journal of Agricultural Research 58:10, 1004-1012.

Nelson, R., Brown, P.R., Darbas, T., Kokic, P. and Cody, K. 2007b. The potential to map the adaptive capacity of Australian land managers for NRM policy using ABS data. CSIRO, Australian Bureau of Agricultural and Resource Economics, prepared for the National Land & Water Resources Audit. http://www.nlwra.gov.au/Natural_Resource_Topics/Socio-economic/index.aspx

Nelson, R., Hatfield-Dodds, S., Howden, M., and Stafford Smith, M. (in press). Meeting the multiple goals of Australian drought policy: insights from adaptive governance. *Environmental Science and Policy*.

Nelson, R., Kokic, P., Elliston, L. and King, J., 2005. Structural adjustment: a vulnerability index for Australian broadacre agriculture. Australian Commodities 12(1), pp. 171-179.

Penm J, Fisher B (2003) Economic overview—prospects for world economic recovery in 2003. Australian Commodities 10, 5–19.

Perry M (2006) Drought-hit Australia battles climate change. Reuters, 2 November (www.planetark.org/dailynewsstory.cfm/newsid/38776/story.htm).

Stafford Smith, M. (2003). Linking environments, decision-making and policy in handling climatic variability. *In*: 'Beyond Drought in Australia: People, Policy and Perspectives'. (Eds L. Botterill and M. Fisher.) pp. 131-151. (CSIRO Publishing: Melbourne.)

Stafford Smith, M. 2005. Living in the Australian environment. In L.C. Botterill and D. Wilhite (eds) *From disaster response to risk management: Australia's national drought policy*. Springer, Dordrecht.

Stafford Smith, D. M. and McAllister, R. R. J. (2008). Managing arid zone natural resources in Australia for spatial and temporal variability – an approach from first principles. *The Rangeland Journal* **30**, in press.

Stafford Smith, D. M., and G. M. McKeon. 1998. Assessing the Historical Frequency of Drought Events on Grazing Properties in Australian Rangelands. *Agricultural Systems* 57:271-299.

Stokes, C.J. & Howden S.M. (eds) 2008. An overview of climate change adaptation in Australian primary industries – impacts, options and priorities. Report prepared for the National Climate Change Research Strategy for Primary Industries. CSIRO, Canberra.

Stoneham, G., Ha, A., Harris, J., Fisher, B. and Strappazzon, L. 2004. *Incentives, information and drought policy*. State of Victoria Department of Primary Industries, Melbourne.