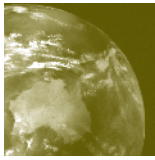


2008

Climate change and the Australian Sugarcane Industry : Impacts, adaptation and R&D opportunities

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Australian Government
Sugar Research and Development Corporation

Investing in Sugarcane Industry Innovation

Climate Change and the Australian Sugarcane Industry: *Impacts, adaptation and R&D opportunities*



Climate Change and the Australian Sugarcane Industry:

Impacts, adaptation and R&D opportunities

ISSN 1327-9475

The authors would like to thank the representatives of the Australian sugarcane industry who attended the Industry Climate Change Workshop held in Maryborough on 24 January 2007, the Strategic Climate Change Workshop held in Brisbane on 5 February 2007 and the Industry Workshop held in Brisbane on 29 March 2007. The information sharing and innovative ideas that characterised all these workshops made this report possible. Thanks also to Rohan Nelson (CSIRO), Geoff Inman-Bamber (CSIRO), Andrew Higgins (CSIRO), Ainsley Archer (CSIRO), Diana Maldonado (SRDC) and Robert Troedson (SRDC) for helpful feedback on early drafts of this report.

Based on the final report of projects CSE019 and SRD011 by Park, S., Creighton, C., Howden, M.

Edited by L Matthieson

Design by Graystone Studio

Printed by ??? ???

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Climate Change and the Australian Sugarcane Industry:
Impacts, adaptation and R&D opportunities

Foreword

The sugarcane industry is strongly influenced by the impacts of weather and seasonal variation, and an understanding of the long-term impacts of climate change and climate variability is essential.

If the industry is to capitalise on the opportunities and minimise the risks associated with climate change, every sector needs to be aware of what impacts such change could have right along the value chain.

The need to invest in R&D to better understand the risk that climate change and climate variability poses for the agricultural sector was reinforced with the May 2007 announcement of a new set of rural research and development priorities by the Australian Government.

In the same year the Sugar Research and Development Corporation contracted two projects to analyse how the sugarcane industry can respond and adapt adequately to future climate change and to identify a range of R&D strategies the industry can implement across the value chain.

This publication summarises the results of the projects and is an important tool to guide investment into R&D to improve the industry's ability to prepare for, and respond to, the potential impacts of climate change.

SRDC recognises the importance of placing climate on the agenda now and has incorporated climate change into its Research and Development Plan 2007-2012. The Corporation will invest in R&D activities to enhance industry preparedness for climate change through its *Regional Futures*, *Emerging Technologies* and *People Development* Investment Arenas.

I commend this publication to anyone interested in understanding the implications of climate change in the sugarcane industry and determining actions for the future.



Ian Knop AM
Chair

Sugar Research & Development Corporation

Executive summary

The scope & method

Australia is facing continuing climate change (IPCC 2007). The Agriculture and Food Policy Reference Group (2006) considers that without adequate preparation, climate change could have serious implications for sustainable agriculture and rural communities in Australia.

This SRDC funded scoping study has been undertaken to provide a preliminary analysis of the impacts of climate change on the east coast sugar producing regions of Australia, and to identify the knowledge needs and the adaptation options available to the sugarcane industry to address climate change. The study was conducted in a consultative manner with sugarcane industry stakeholders representing all sectors of the industry attending workshops held in Maryborough and Brisbane during the period January to March 2007.

Adaptation & flexibility

The vulnerability of the sugarcane industry to a change in climate will be reduced by increasing its adaptation capacity. This involves actions and research to reduce the negative impacts of climate change, to skill up decision makers in all sectors of the industry to respond rapidly to an increasingly variable climate and to capitalise on the various opportunities that come with change.

Report details


For the sugarcane industry along the east coast of Australia the report details:

- Projections of climate change for the sugarcane industry regions (Chapter 3);
- The adaptation opportunities for the Maryborough case study region and for the entire industry (Chapters 5 and 7); and
- A summary of R&D opportunities framed within the SRDC Investment Arenas (Chapter 8).

Project findings

This study concludes that the minimisation of climate change impacts and realisation of opportunities will necessitate future R&D investment. The portfolio of R&D projects required will likely include the following elements:

- Improvements in **farming practice**, especially precision irrigation, on-paddock water use and off-paddock water quality impacts and the management of increased climate variability through seasonal forecasting;
- **Innovative farming and processing systems** that take an integrated and sustainable approach to risk and opportunity across all inputs such as plant varieties, nutrient management practices and energy use in mills through to the outputs of sugar, fertiliser and bio-energy ensuring a flexible and financially resilient industry;
- Capitalisation of **bio-energy opportunities and carbon trading potential** for value adding and preferably integrated within innovative farming and processing systems to maximise cross-industry benefits;
- Greater focus in **plant improvement** in varietal characteristics that enhance resilience to climate change, industry adaptation to higher temperature, reduced water availability, and extreme events;

- 
- **Enhancing human capital** through building skills and enhancing science capability in climate understanding and risk management across the sugar industry so that the knowledge and tools required by the industry may be delivered;
 - Linking of **biosecurity management** to a changing climate so that potential threats in biosecurity are understood; and
 - An understanding of the **global context** of climate change impacts on worldwide production, profitability and markets relative to the Australian sugar industry to help continually optimise market position.

The proposed topics of priority for R&D have been developed in the context of SRDC Investment Arenas and themes. This study has shown that climate change must be considered as an integral part of all sugarcane value chain activities today, and increasingly so into the future as impacts unfold. R&D will be necessary to rise to the challenges and uncertainties facing the sugarcane industry. The R&D needs identified in this report will better inform the sugarcane industry on best-bet options for adaptation to climate change.

Key R&D directions

Many of the knowledge gaps detailed in this report can be best filled through the enhancement of existing R&D activity. For example, research into plant agronomy and plant genetics already incorporates many of the key attributes of climate, albeit with increased emphasis on climate related attributes called for as part of the response to a changing climate. Likewise, research on sustainability of on-farm practices is already addressing issues regarding off-farm impacts. A more variable and event-driven climate will make this research even more imperative if the sugarcane industry is to respond to community demands and demonstrate resilience.

Other knowledge gaps are specific to climate change and increasing climate variability, such as providing decision tools to foster more flexible and climate responsive practices across the value chain. As with any major R&D investments, prior to embarking on substantial revision or changes to SRDC investment directions, such opportunities will require detailed scoping as a precursor to any major R&D investment.

Additional knowledge gaps will undoubtedly come to light as the sugarcane industry responds to Australia's changing climate. Australian agriculture and its science support are world renown for innovation. Part of the challenge for sugarcane R&D investment will be to be open to such innovation, wherever it might come from, and to combine with others to maximise the return on investment from research. Working in partnership with other investors will often be cost-effective – for example, to better understand the northern Australian climate, the implications of threats such as the impact of sea level rise and to improve the skill in seasonal forecasting.

Last but not least, there is much to be done to improve overall industry knowledge of climate change and facilitate how individuals, enterprises and companies across the value chain incorporate climate into their mainstream activities. Building social capital through targeted extension, improving skills and providing a more industry-wide knowledge base are all essential.

By cultivating an industry knowledge base, the Australian sugarcane industry can rapidly respond to a changing climate. Within this, the key need is to review existing industry information systems and institutional silos. There is a strongly emerging need to bring together the various productivity services and Geographic Information Systems (GIS) data sets in ways that will allow the entire industry to collectively position its future in both a productivity and sustainability context.

Adaptive research

Global investment in climate science will bring marked improvements in our understanding of the global climate, seasonal forecasting and climate change within the next three to five years. R&D strategies cannot by nature be complete and must have a limited time frame of relevance – in the case of the majority of material in this report, probably less than five years. At the same time, maintaining a close understanding of developments in climate science and ensuring strong international links will be essential for the sugarcane industry in implementing strategic responses to a changing climate.

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1. Introduction

Australia is undoubtedly facing some degree of continuing climate change (IPCC, 2007, see Box 1 (page 8) for summary information from the IPCC for Australia and New Zealand). The Agriculture and Food Policy Reference Group (2006) considers that without adequate preparation, climate change could have serious implications for sustainable agriculture and rural and regional communities in Australia. Along with all other agricultural and fisheries industries in Australia, the sugarcane industry is being called upon to rise to the challenges of maintaining economic, environmental and social sustainability in the face of a changing climate.

Sugarcane-growing regions span over 2,000 km of the east coast of Australia and experience extreme seasonal and annual variability in temperatures and rainfall. Agronomic practices have progressively developed over the decades to manage production across this broad range of climate variability. Projected changes to both average temperature and rainfall, and their variability, mean that it is now timely for the sugarcane industry to evaluate whether current management practices will need to change to respond to the changing climate so that the industry continues to develop in both profitability and sustainability perspectives.

The Sugar Research and Development Corporation (SRDC) recognises that to foster informed decision-making regarding climate change, the capacity of individual stakeholders from all sectors must be enhanced to enable:

- (a) accurate interpretation of climate change projections
- (b) evaluation of the likely impacts and risks on each sector of the industry and the value chain as a whole
- (c) identification of knowledge needs which may in turn translate into research projects
- (d) development and implementation of adaptation strategies aimed at addressing Australia's changing climate.

This report identifies knowledge gaps and investment priorities for Research and Development (R&D) relating to the challenges of responding to a changing climate.

2. Method

Project Team - This report is based on a scoping study contracted by the SRDC to assess the needs of the sugarcane industry in facing the challenges of climate change. The research team consisted of personnel from CSIRO, Managing Climate Variability Joint Venture and the Queensland Department of Primary Industries and Fisheries with expertise covering the fields of agriculture, climate science, climate variability, natural resource management and value-chain analysis. The project involved participatory workshops with a cross-section of industry stakeholders in Maryborough and Brisbane in early 2007.

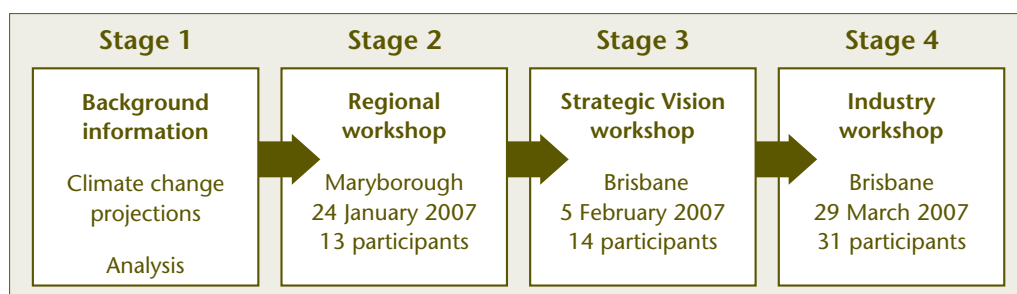
Study Direction - The intention of the study was to examine the impacts of climate change on the Australian sugarcane industry and explore what actions might be required to maintain production, profitability and sustainability of the industry in its present locations.

Study Focus - The study concentrated on the implications of Australia's changing climate on the sugarcane industry. It did not attempt to identify alternate land uses that may possibly be more suitable for cane growing areas, or consider the possibly of more suitable locations for cane growing under changing climatic conditions. Nor did the scoping study consider how other large-scale external drivers likely to influence the sugarcane industry in coming decades, may interact with climate change. These drivers are dealt with in Howden *et al.*, (2006) and include: global change in markets and economies; demographic changes in agricultural industries and regions; continued degradation of the resource base for agricultural production; rising energy costs; and technological development.

Stakeholder Engagement - The study relied extensively on consultation with the sugarcane industry – its growers, organisations and support research agencies - to collate the impacts of climate change on the industry and identify adaptation strategies. It took a regional approach, building up a picture of wider industry impacts by discussing local impacts in the context of each of the eastern Australian sugarcane growing regions.

Figure 1 illustrates the method used to elicit the views of the sugarcane industry on: the likely impacts and risks of climate change; specific challenges faced by each sugarcane-growing region on the east coast of Australia; adaptation strategies; and a range of opportunities that require R&D.

Figure 1. Method used to elicit the views of the Australian sugarcane industry on the impacts and risks of climate change and the knowledge gaps and opportunities for R&D.



Case Study Selection and Characterisation - The Maryborough sugarcane-growing region was selected as a case study to conduct a detailed assessment of regionally-specific climate change impacts and adaptation responses. Maryborough was chosen since its location (close to the coast and tidal

waterways), its low-lying production areas and its substantial reliance on rainfed production are typical of many of the sugarcane-producing regions on the east coast of Australia. It also provided the opportunity to build on previous work conducted on the value-chain in the region.

The first stage of the project involved the collation of background information on a range of climate variables for Queensland, including sea level rise, cyclone and El Niño Southern Oscillation (ENSO). CSIRO Marine and Atmospheric Research (CMAR) produced more detailed projections for temperature and rainfall for the Maryborough region, and these were analysed both qualitatively and quantitatively to assess the likely impact on sugarcane production in the region (see Appendix 1). Appendix 3, Figure 5 shows the projected changes as applied to monthly mean historic rainfall and temperature data for the Maryborough region.

Maryborough Workshop - Information gathered and analysed in stage 1 of the project was presented at a Regional Climate Change Workshop held in Maryborough on 24 January 2007. The workshop was attended by 13 members of the local sugarcane industry, representing the growing, harvesting, transport and milling sectors. The questions addressing climate change during the workshop included:

- What are the current projections and likely impacts and risks for Maryborough?
- How can we identify the most effective adaptation strategies to minimise negative impacts and capitalise on potential benefits at a whole-of-industry level?
- How can we accommodate the uncertainties associated with projections within response strategies?
- How can we estimate when capacity thresholds are reached and adaptation strategies require implementation?
- How can we manage the transition from present practices to alternative operations?

Visioning Workshop - A Strategic Vision Climate Change Workshop was subsequently undertaken in Brisbane on 5 February 2007. The 14 participants at this workshop included climate scientists, representatives from state government and members of the sugarcane industry responsible for making policy level decisions. The overriding aim of this second workshop was to consider the findings from the Maryborough regional case study from a broader strategic industry perspective and identify areas for R&D investment. More specifically the participants were asked to:

- Consider the applicability of the Maryborough Regional Climate Change Workshop to other sugarcane-growing regions and the industry as a whole.
- Consider the impact of climate change regionally and on the whole of the industry.
- Consider the need to develop both regionally-specific and industry-wide response strategies aimed at minimising negative impacts and capitalising on potential benefits.
- Consider if, how and when to manage the transition from present practices to alternative operations.
- Consider what policy support is required to facilitate the above.
- Identify knowledge gaps and areas requiring R&D to further enhance the capacity of the industry to address the challenges of climate change.

Industry Workshop - The final stage of the study involved an industry-wide workshop attended by 31 participants from a broad range of disciplines within the sugarcane industry and from related industries and government bodies. The workshop explored the following questions in greater detail than had been covered in previous workshops:

- What are the industry-wide implications for productivity, profitability and sustainability?
- How will a changing climate manifest itself in terms of priority challenges in each of the five sugarcane growing regions?
- What are the strategies (short and long term) required to adapt to climate change and what are the key areas for R&D investment?

3. Climate change projections for Australia and the cane-growing regions of the east coast

The climate is changing. Whilst global mean temperatures have risen approximately 0.7°C since the mid 1800s, the extent of change has not been evenly distributed across the Earth. Measured changes in rainfall patterns, sea levels, rates of glacial retreat and biological responses are consistent with expectations of 'greenhouse' climate change (IPCC, 2007). The year 2005 was the warmest in Australia in over 200 years of historical record. The last 10 years was the warmest decade ever recorded instrumentally, and the last 100 years were the warmest of the millennium, perhaps even of the last 800,000 years.

The most recent report of the Intergovernmental Panel on Climate Change (IPCC, 2007) concludes that there is now strong evidence for a human influence in these changes and that these trends will continue for the foreseeable future due to continued emissions of carbon dioxide (CO₂) and other greenhouse gases from fossil fuels and other sources. The most up-to-date predictions are for a further increase in global average temperatures of between 1.5 to 6.4°C by the end of the present century. Roughly speaking, a 1°C rise in average temperature will make Melbourne's climate similar to that currently experienced by Wagga; a 3°C rise like that of Dubbo; and a 6°C rise like that just north of Roma. Making a similar comparison for the sugarcane districts is difficult due to the absence of a strong temperature gradient with latitude on the coastal strip of eastern Australia. As a rough guide, a 2°C increase in annual mean temperature would make Maryborough's temperatures similar to those experienced in St Lawrence, nearly 600 km further north.

Box 1. Key elements for Australia and New Zealand from the Inter-Governmental Panel on Climate Change (4) report.

As a result of reduced precipitation and increased evaporation, water security problems are projected to intensify by 2030 in southern and eastern Australia and, in New Zealand, in Northland and some eastern regions. ** D [11.4]

Significant loss of biodiversity is projected to occur by 2020 in some ecologically-rich sites including the Great Barrier Reef and Queensland Wet Tropics. Other sites at risk include Kakadu wetlands, south-west Australia, sub-Antarctic islands and the alpine areas of both countries. *** D [11.4]

Ongoing coastal development and population growth in areas such as Cairns and Southeast Queensland (Australia) and Northland to Bay of Plenty (New Zealand), are projected to exacerbate risks from sea-level rise and increases in the severity and frequency of storms and coastal flooding by 2050. *** D [11.4, 11.6]

Production from agriculture and forestry by 2030 is projected to decline over much of southern and eastern Australia, and over parts of eastern New Zealand, due to increased drought and fire. However, in New Zealand, initial benefits to agriculture and forestry are projected in western and southern areas and close to major rivers due to a longer growing season, less frost and increased rainfall. ** N [11.4]

The region has substantial adaptive capacity due to well-developed economies and scientific and technical capabilities, but there are considerable constraints to implementation and major challenges from changes in extreme events. Natural systems have limited adaptive capacity. ** N [11.2, 11.5]

Changing Conditions for Australian Agricultural Production

The predicted temperature rises and other climatic changes will have implications for:

- key agricultural attributes such as plant available moisture and catchment/hydrology and thus stored water available for irrigation
- plant growth rates (accelerated phenology in response to increases in atmospheric CO₂) and shorter crop duration requirements
- hazards to agricultural production, such as the predicted increased severity (but not necessarily frequency) of cyclones and floods
- markets, as a changing global climate impacts on production worldwide.

There is likely to be a general decline in annual mean rainfall across most of Queensland, but at the same time there may be more local rainfall in northerly regions during summer months and increases in rainfall intensity. There is also the possibility of entering a more El-Niño-like mean climate condition.

Sea level is expected to rise by 18 to 59 cm by the end of this century due solely to the thermal expansion of the world's oceans.

Given that the sugarcane industry is mainly located on coastal floodplains, the combination of sea level rise with increased storm and cyclone intensity will significantly increase the likelihood of inundation, damage to industry infrastructure, and soil erosion and nutrient loss from cane paddocks.

It is important to note that this estimate of sea level rise does not include possible additional rises resulting from the rapid disintegration of polar ice sheets. This factor has been excluded from the above projections due to the current lack of consensus among the IPCC on the likely scale and timing of ice melt.

Climate Predictions for Sugarcane Growing regions

Figure 2 and Figure 3 provide a range within which rainfall (%), temperature (°C) and evaporation (%) are projected to change across the sugarcane-growing regions of east coast Australia by the years 2030 and 2070 (the two periods of IPCC 2007 predictions) relative to 1990.

Fifteen global and regional climate models were used to produce this range of projections. By using a large number of models it is possible to assess a range of projections that capture the various representations of climate science currently found in the scientific community. All 15 models were considered to have superior pattern correlations and low root-mean-square error when compared to past climate data for the Australian region. From these 15 models, two models were chosen to roughly represent the 20th percentile (dry) and 80th percentile (wet) of rainfall changes, respectively, in Queensland. By using this method, the models span most of the range of uncertainty in rainfall change in the state. Since rainfall changes have strong correlations with temperature and radiation changes, these two models also span most of the uncertainty in temperature and radiation change. The two models selected were the HADGEM and NCAR models. (See Appendix 1 for further details on the methodology use to produce the Maryborough climate projections).

An alternative approach to producing climate change projections would have been to select only one or two models that show the best skill in predicting past climate. However, by selecting a wider range of models, it is possible to examine the “driest” and “wettest” case scenarios and accommodate these within impact assessments and the development of adaptation strategies.

However, as a result of using a range of 15 models, some climate variable projections indicate a simultaneous increase and decrease, e.g. summer rainfall. This reflects the uncertainty presently associated with some projections, particularly rainfall. However, the majority of the 15 models indicate a likely decrease in annual and seasonal rainfall for all seasons by 2030, and a widespread decrease by 2070, with the exception of summer rainfall in the northern region.

Updated climate projections are being produced by CSIRO that will provide the 10th, 50th and 90th percentile projections from a range of climate models. When these are released at the end of 2007, they will enable the median (50th percentile), or most common projection, to be identified across the key selected GCM’s with the most skill and offer perhaps a greater ease of interpretation.

Figure 2. Projections of temperature, rainfall and evaporation for each of the five sugarcane growing regions on the east coast of Australia for the year 2030.
Data interpreted from Cai *et al.*, (2005).

Northern	Spring	Summer	Autumn	Winter
Rainfall (%)	-20 to 0	-7 to 13	-13 to 7	-20 to 0
Temperature (°C)	0.2 to 1.6	0.2 to 1.6	0.2 to 1.6	0.2 to 1.3
Evaporation (%)	1 to 8	0 to 16	0 to 16	1 to 8

Herb/Burkekin	Spring	Summer	Autumn	Winter
Rainfall (%)	-20 to 7	-13 to 13	-13 to 7	-13 to 7
Temperature (°C)	0.2 to 1.6	0.2 to 1.6	0.2 to 1.6	0.2 to 1.6
Evaporation (%)	1 to 8	0 to 16	0 to 16	1 to 8

Central	Spring	Summer	Autumn	Winter
Rainfall (%)	-20 to 7	-7 to 13	-13 to 7	-13 to 7
Temperature (°C)	0.2 to 1.6	0.2 to 1.6	0.2 to 1.6	0.2 to 1.6
Evaporation (%)	1 to 8	0 to 16	0 to 16	1 to 8

Southern	Spring	Summer	Autumn	Winter
Rainfall (%)	-20 to 0	-7 to 7	-13 to 7	-13 to 7
Temperature (°C)	0.2 to 1.6	0.2 to 1.6	0.2 to 1.3	0.2 to 1.6
Evaporation (%)	0 to 16	0 to 16	1 to 8	0 to 16

NSW	Spring	Summer	Autumn	Winter
Rainfall (%)	-20 to 7	-7 to 7	-7 to 7	-13 to 7
Temperature (°C)	0.2 to 1.6	0.2 to 1.6	0.2 to 1.8	0.2 to 1.6
Evaporation (%)	0 to 16	1 to 8	1 to 8	1 to 13

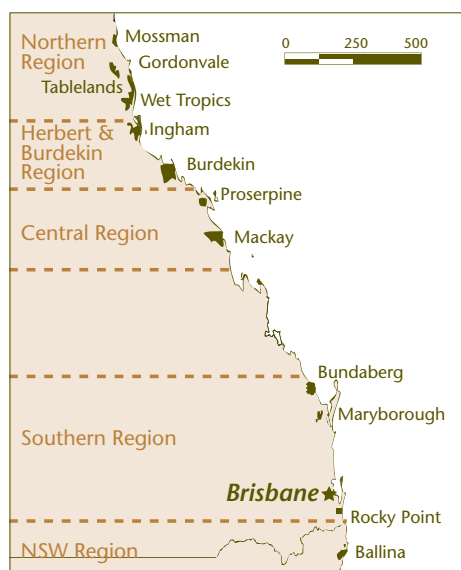
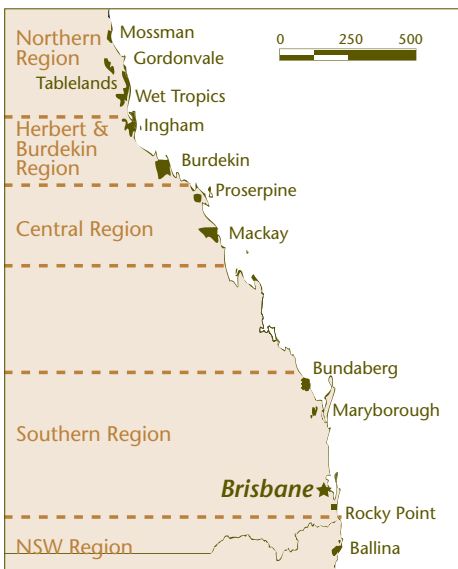


Figure 3. Projections of temperature, rainfall and evaporation for each of the five sugarcane growing regions on the east coast of Australia for the year 2070. Data interpreted from Cai *et al.*, (2005).



Northern	Spring	Summer	Autumn	Winter
Rainfall (%)	-60 to 0	-20 to 40	-40 to 20	-60 to 0
Temperature (°C)	0.7 to 4.8	0.7 to 4.8	0.7 to 4.0	0.7 to 4.0
Evaporation (%)	2 to 24	0 to 48	0 to 48	2 to 24

Herb/Burdekin	Spring	Summer	Autumn	Winter
Rainfall (%)	-60 to 0	-40 to 40	-40 to 20	-40 to 20
Temperature (°C)	0.7 to 4.8	0.7 to 4.8	0.7 to 4.8	0.7 to 4.8
Evaporation (%)	2 to 24	0 to 48	0 to 48	2 to 24

Central	Spring	Summer	Autumn	Winter
Rainfall (%)	-60 to 20	-20 to 40	-40 to 20	-40 to 20
Temperature (°C)	0.7 to 4.8	0.7 to 4.8	0.7 to 4.8	0.7 to 4.8
Evaporation (%)	2 to 24	0 to 48	0 to 48	2 to 24

Southern	Spring	Summer	Autumn	Winter
Rainfall (%)	-60 to 0	-20 to 20	-40 to 20	-40 to 20
Temperature (°C)	0.7 to 4.8	0.7 to 4.8	0.7 to 4.0	0.7 to 4.8
Evaporation (%)	0 to 48	0 to 48	2 to 24	0 to 48

NSW	Spring	Summer	Autumn	Winter
Rainfall (%)	-60 to 20	-20 to 20	-20 to 20	-40 to 20
Temperature (°C)	0.7 to 4.8	0.7 to 4.8	0.7 to 4.8	0.7 to 4.8
Evaporation (%)	0 to 48	2 to 24	2 to 24	2 to 40



4. Climate change actions in other industries

Australian agricultural industries are generally working through the early stages of assessing the impacts and consequences of climate change. To date, few industries have gone beyond qualitatively assessing impacts and potential response strategies.

An Australia Greenhouse Office (AGO) study conducted by Howden *et al.*, (2003) offers a broad overview of likely impacts and potential options for Australian agriculture to adapt to climate change. All of the industries reviewed by Howden *et al.*, (2003) report a sensitivity to climate variations ranging from minor to substantial and it is therefore anticipated that climate changes are likely to have some impact and that adaptations will often be needed to both offset negative impacts and take advantage of positive impacts. The following is a brief summary of adaptation actions currently being considered and/or implemented by other agricultural industries.

Policy: Develop or improve linkages to existing government policies and initiatives (e.g. Greenhouse Gas Abatement Program, Greenhouse Challenge, salinity, water quality, rural restructuring, and integrated catchment management).

Managing transitions: Develop mechanisms to provide technical and financial support during transitions to new systems that are more adapted to the emerging climate.

Communication: Actively distribute 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. Monitor climate conditions and relate these to yield and quality aspects. Develop climate projections that are relevant at farm and catchment scales, e.g. via environmental management systems.

Research, development and training: Undertake participatory adaptation studies to inform policy decisions and develop capacity. Maintain the R&D skills and resources needed for ongoing evaluation and response to climate change issues.

Breeding and selection: Maintain access to global gene pools so as to have suitable varieties and species for higher CO₂, higher temperatures and changed moisture availability.

Modelling: Develop further systems modelling capabilities to provide quantitative approaches to risk management, assist proactive on-farm decision making, and support policy development.

Seasonal forecasting: Facilitate the adoption of seasonal climate forecasts to help farmers and industry adapt to climate change whilst managing for climate variability. Combining this with on-ground measurements, market information and systems modelling will maximise the usefulness of seasonal forecasting.

Pests, diseases and weeds: Maintain or improve biosecurity quarantine, monitoring and prevention mechanisms. Strengthen invasive species management tools and practices.

Nutrition: Adjust nutrient supply to maintain product quality. Note however, that this may have implications for greenhouse emissions and other environmental issues.

Water: Increase water use efficiency through water trading systems that recognise climate issues; improved water distribution systems; enhanced farmer expertise; and increased uptake of appropriate water saving technologies.

Land-use change and diversification: Evaluate the need and opportunity to change land-use or location in response to climate trends or climate projections. Assess 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).

Prompt Action: Early adaptation strategies, particularly in regard to enhancing resilience, that have the potential to significantly reduce the negative impacts of climate change.

The above review shows that many adaptation strategies are aimed at developing more resilient systems. One approach to this is through the improved management of climate variability. See Appendix 2 for a list of tools and resources developed by other agricultural industries for managing climate variability.



5. Climate vulnerability at a regional level: Maryborough case study

The details of the Maryborough case study, set out below, demonstrate how climate change impact and adaptation assessments can be done effectively at a regional level by recognising the integrated nature of the sugarcane industry value chain.

Developing temperature and rainfall projections for Maryborough

To produce temperature and rainfall projections for the Maryborough region, the wettest and driest scenarios were used from a range of the best climate models for the Australian region. These wettest and driest projections were produced by the National Centre for Atmospheric Research (NCAR) and the UK MetOffice (UKMO) models respectively. Together these model projections span most of the range of uncertainty in rainfall change for Australia. The NCAR model was also included in the selection of 12 models used to produce the Queensland climate change projections (Cai *et al.*, 2005).

Since rainfall changes have strong correlations with temperature and radiation changes, these two models also span most of the uncertainty in temperature and radiation change. For full details of the methodology used to produce regional climate change projections for Maryborough see Appendix 1.

In summary, for the Maryborough region, these models show:

- Annual mean rainfall is projected to decrease by 1 to 14% by the year 2030, and between 2 to 42% by 2070.
- Annual mean temperatures are projected to increase by 0.5 to 1.2 °C by 2030 and 1.0 to 3.7 °C by 2070.

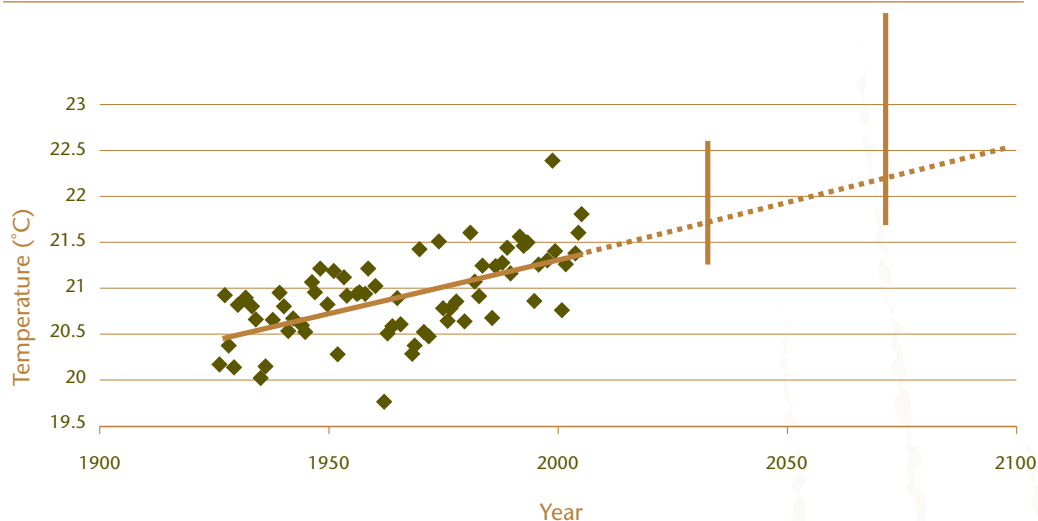
Changes in other global and national-scale climate variables likely to affect the region include:

- increase in atmospheric CO₂ concentrations up to 450 ppm by 2030 and 700 ppm by 2070
- rise in sea level of between 18 to 59 cm by 2100
- increase in annual average potential evaporation of between 0 to 8% per degree of global warming
- enhanced drying associated with El Niño events
- an increase in the intensity of tropical cyclones.

Comparing past and future climate changes in Maryborough

In the Maryborough region there is a significant historical trend of increasing temperatures, including an increase of almost 1°C over the past 70 years (Figure 4). These changes are in line with projections of climate change i.e. 0.2 to 1.6°C warmer by 2030 and 0.7 to 4.8°C warmer by 2070 (represented by the vertical bars in Figure 4).

Figure 4. Mean annual temperature for Maryborough from 1930 onwards, with a linear trend included (solid black line). The dotted line is an extrapolation of this trend, intersecting with the range of temperature changes projected for Maryborough in 2030 and 2070.



In contrast, there is very little consistent trend in historical rainfall due in part to the high year-to-year variability and also to decadal variations in rainfall. Projections of rainfall range from an annual change of -1% to about -14% by 2030 and from between -2% to -42% by 2070. Whilst this is not the full range of changes expressed by current climate change models, it provides some indication of the direction and potential scale of change.

Impacts of increased temperatures and decreased rainfall on crop production

The crop growth model, Agricultural Production Systems Simulator (APSIM) (Keating *et al.*, 2003) was used to quantify the impacts of a change in temperature and rainfall on cane fresh weight grown in the Maryborough region (see Appendix 3 for details). APSIM yield simulations were run using historic climate data amended according to wettest and driest climate change projections produced for the years 2030 and 2070. The qualitative effect of a change in a range of climate variables and the projected change in crop yield was assessed for all sectors of the sugarcane industry.

Mean percentage change in yield for the 80 years simulated was calculated for a combination of 25 different temperature and rainfall changes within the projected scenarios for 2030 and 2070. This resulted in a total of 2,000 simulations being run for both 2030 and 2070.

The 'best' and 'worst' percentage changes in simulated yield for the NCAR and UKMO model projections are shown in Table 1. The best potential outcome for Maryborough in 2030 is projected to be an increase in yield of around 7%, whilst the worst may be a reduction of around 4%. By 2070, any potential increases in yield could be around 8%, whilst potential reductions may be up to 47%.

Table 1. 'Best', median (med.) and 'worst' per cent change in simulated mean yield for the NCAR and UKMO model projections for the years 2030 and 2070.

2030						2070					
NCAR			UKMO			NCAR			UKMO		
Best	Med.	Worst	Best	Med.	Worst	Best	Med.	Worst	Best	Med.	Worst
7.4	2.8	-0.5	5.3	0.9	-3.9	7.9	0.4	-7.3	3.7	-5.5	-46.9

The simulated data suggested a progressive increase in the variability of cane yields over time, given the projected changes in CO₂, temperature and rainfall, compared to historic climate data. This increase in variability occurs in both rainfed and irrigated production, although the increase in irrigated production is less than rainfed, as would be expected.

Value chain impacts

A preliminary analysis was conducted on the incremental impact of changes in sugarcane production on the harvesting and transport sectors of the value chain in the Maryborough region. The analysis was conducted using the value chain model developed in the SRDC project CSE010 *Integrated value chain scenarios for enhanced mill region profitability* (Archer *et al.*, 2004; Thorburn *et al.*, 2006). The value chain model was run to produce estimates of the percentage change in costs (relative to the year 2003). The model was parameterised with the worst-case scenario estimates of yield declines of 3.9% and 46.9% for 2030 and 2070, respectively, and run under the assumption that the mill throughput rate would not change (Table 2).

Table 2. Preliminary analysis for climate change impacts in Maryborough in terms of total and per tonne of cane (tc) costs.

	% Change from 2003				
	Tonnes/ha	Harvesting costs		Transport costs	
		Total	Per tc	Total	Per tc
2030	-3.9	-2.5	1.5	-5.6	-1.7
2070	-46.9	-27.0	34.1	-40.6	12.5

Whilst overall harvesting costs are likely to decrease with the projected change in climate, the cost per tonne of cane is likely to increase due to reduced harvesting efficiency and lower returns on harvesting capital.

The Maryborough region relies on road transport, the capacity of which can be readily altered with minimal cost. So, the impact on costs per tonne of cane in the transport sector is likely to be less than that for harvesting. This would not be the case in regions where rail transport is used since it involves a large amount of capital in rail track, locomotives and wagons, which are owned by the mill. Nearly all of this capital will still be present and maintained under a reduced tonnes/ha, which would substantially increase the costs of transport per tonne of cane.

Primary and secondary impacts in the Maryborough region

Participants at the Maryborough workshop were asked to consider the potential impacts of climate change given the projections and analysis presented above. At the workshop, impacts were categorised as either:

- *primary* - at the point where they initially impacted a sector; or
- *secondary* - a subsequent impact arising in either an up or down-stream sector of the value chain.

The following is a summary of the impacts as identified by the workshop participants. The projected increase in temperature and reduction in rainfall in the Maryborough region are likely to result in a number of primary and secondary impacts. Further details are provided in Appendix 4, Table 12.

Impacts that offer a positive benefit for the industry may include:

- a likely reduction in the incidence and severity of frosts
- a decrease in the duration of winter conditions and a simultaneous increase in the duration of the growing season
- accelerated crop phenology (rate of growth)
- reduced wet-weather down-time
- reduced damage to the stool of ratoon crops
- an extended window for planting.


However, increased temperature and reduced rainfall may also result in negative impacts including:

- increasingly marginal production in dryland areas potentially resulting in the cessation of production
- increased water stress occurring during the critical period of early plant growth
- greater competition for limited water resources resulting in a possible decrease in the amount of available water and/or its cost
- an increase in the abundance of pests and diseases
- the introduction of new pests and diseases to the region.

In some cases a positive impact in one sector may result in a negative impact elsewhere in the value chain. For example, an extended harvest season may be positive for the harvesting, transport and milling sectors since it would reduce the requirement for capital stock (harvesters, trucks, etc), but it may be negative for the growing sector since a greater proportion of the crop may be harvested at a time when CCS levels are less than optimal. One potential response to this impact is a revision of the cane payment formula.

The likely increase in soil moisture deficit will mean greater benefits from investing in irrigation infrastructure. Of course, the level of returns will also depend on other factors such as the relative cost and availability of water. Greater use of irrigation may however reduce the variability of annual yields and throughput along the value chain enabling better planning for all sectors in the region.

It is uncertain what will happen to CCS levels in the Maryborough region. This reflects a gap in industry knowledge and the need for further R&D investment to help address the projected changes in climate.



In the majority of cases the primary impacts of climate change were considered to occur within the growing sector, with many secondary impacts cascading across the three downstream sectors of the industry. In one instance, an impact was identified as initially occurring in the harvesting sector (*i.e.* a decrease in rainfall during harvest season being likely to result in easier harvesting of the crop and less wet weather downtime). A secondary impact of this was considered likely to be experienced upstream in the value chain in the growing sector, manifesting as a reduction in the amount of damage sustained by the stools of ratoon crops.

6. Climate change impacts across all sugarcane growing regions

To explore the potential impacts of climate change across all sugarcane-growing regions on the east coast of Australia, stakeholders at the Strategic Vision workshop were asked to identify the present climate-related constraints to sugarcane production in each region and the likely impacts of a change in climate. The key climate change pressures on sugarcane production in each region are detailed in Table 3. They can be grouped into the following:

Impacts likely to be negative for all regions

A number of factors directly related to a change in climate are likely to negatively impact all regions. These include an increase in more extreme events and the likely increase in the environmental impact of agricultural practices within the landscape. For example, there is likely to be an increase in the offsite movement of nutrients and chemicals during cyclone and flooding events. For irrigated cane areas the increased use of irrigation water as a result of reduced rainfall is likely to exacerbate issues of soil salinity and rising water tables. For the floodplain and coastal areas, sea level rise is likely to impact on drainage and tidal intrusion. Reduced winter temperatures are likely to favour the spread of diseases.

The primary impacts of a change in climate are likely to be seen in a change in the quantity of cane yield produced and hence throughput across the harvesting, transport and milling sectors. Any reduction in yield has negative impacts.

Impacts likely to be positive for all regions

These include a projected general increase in temperature and levels of solar radiation and the associated potential to increase productivity and reduce crop duration provided other resources such as water and nutrients are non-limiting. Reduced rainfall during the 'dry-off' and harvesting period is likely to improve the efficiency of harvesting operations.

Impacts associated with other large-scale external drivers

Climate change is one of many large-scale external drivers impacting the sustainability of the Australian sugarcane industry. Many of these drivers are likely to interact with climate change. For example, the projected increase in the population of coastal environments will increase the demands on coastal water resources, whilst the projected decrease in rainfall is likely to reduce the quality and quantity of available water. Likewise, increasing urban encroachment is an external driver that is presently impacting numerous regions of the sugarcane industry and is likely to increase over the coming decades. Adaptation to large-scale external drivers is likely to require whole-of-industry strategic planning and policy. The interaction of climate change with these other external driving factors needs to be more fully understood before this is possible, which is beyond the scope of this project.

Regionally-specific impacts

Regional variation in the sugarcane industry implies that the magnitude of impacts and opportunities will vary. For example, the potential reduction in rainfall is likely to have a generally negative impact on the industry, with the exception of the northern region, which may benefit from a reduction in present levels of rainfall that regularly constrain productivity and hinder the timeliness of farming and harvesting operations.

An increase in winter minimum temperatures is likely to reduce the incidence of frost events in Central, Southern and NSW regions, thereby extending growth during winter months and reducing the necessity to stand crops over to a second year as is sometimes presently required in the Southern and NSW regions. This may also mean an expansion of the industry further up the river valleys, such as for the Clarence, above Tyndale. This expansion may compensate for loss of land to competing land uses, such as coastal and peri-urban development.

Across all the sugarcane-growing regions the lower lying floodplain areas will be impacted by sea level rise – a key issue given the importance of drainage for productivity and acid sulphate soil management.

Likewise, while regional impact will vary, for all regions there is an overall increased likelihood of diseases.

Countering these potentially negative impacts, virtually all areas, with an increase in temperature, should increase productivity, assuming sufficient water is available from irrigation or rainfall for plant growth.

Table 3. Key climate change related pressures on sugarcane production on the eastern coast of Australia.

Region	Present constraints	Likely impact of climate change
1. Northern	Low radiation experienced when cloudy	Constraint likely to decrease with projected increase in radiation and decrease in rainfall
	Extent/frequency of cyclone damage	Likely to increase with projected increase in cyclone intensity
	Excess of water during wet season	Likely to decrease with projected decrease in rainfall, although with increased climate variability, some seasons may be wetter
	Offsite movement of nutrients, chemicals and sediments to Great Barrier Reef Lagoon	Likely to increase with the projected increase in the number of extreme events e.g. flooding, cyclones
	Incidence of diseases, e.g. smut	Likely to increase as a result of projected increases in temperature
	Crop establishment	Projected reduction in spring rainfall may in some seasons inhibit establishment of ratoon crops
	Drainage	Likely to be exacerbated by projections of sea level rise

Region	Present constraints	Likely impact of climate change
2. Herbert Burdekin	Not presently water limited in Burdekin	Likely to experience increasing competition for water from Burdekin Dam due to variable climate coupled with human population growth and industrial expansion of Townsville - Bowen
	Rising water table and salinity issues in the Burdekin River Irrigation Area	Without improvements in water use efficiency and scheduling, likely to increase with increased use of irrigation as a result of projected increases in temperature and a reduction in rainfall
	Incidence of diseases, e.g. smut	Likely to increase as a result of projected increases in temperature
	Rising saline groundwater table (Burdekin) and drainage (Herbert and lower Burdekin)	Likely to be exacerbated by projected sea level rise
	Catchment hydrology and water availability (Burdekin floodplain)	Projected variability/reduction in rainfall will alter recharge to Burdekin aquifer
	Flexibility of harvest	Projected reduction in winter and spring rainfall likely to increase the efficiency of harvesting
	Offsite movement of chemicals, nutrients and sediments to Great Barrier Reef Lagoon	Likely to increase with the projected increase in the number of extreme events, e.g. flooding, cyclones
	Tidal intrusion in the Herbert and lower Burdekin deltas	Likely to be exacerbated by projected sea level rise
3. Central	Experiences limited water supply	Likely to be exacerbated by projected increased variability in rainfall
	Frost-prone areas in the western districts	Projections of an increase in minimum temperatures likely to decrease frost damage
	Incidence of diseases, e.g. smut	Likely to increase as a result of projected increases in temperature
	Offsite movement of chemicals, nutrients and sediments to the Great Barrier Reef Lagoon	Likely to increase with the projection of more extreme events, e.g. flooding, cyclones
	Yield in a variable climate	Projected increase in temperatures likely to extend the growing season with the potential of increased productivity
	Drainage and tidal intrusion in the lower floodplains	Likely to be exacerbated by projected sea level rise

Region	Present constraints	Likely impact of climate change
4. Southern	Experiences limited water	Likely to be exacerbated by projected decrease in rainfall
	Crop growth limited by low winter temperatures and short duration of growing season	Projections of an increase in minimum temperatures likely to reduce constraint and potentially increase productivity
	Incidence of diseases, e.g. smut	Increased likelihood of incidence as a result of projected increases in temperature
	Present competition for land-use from other crops e.g. horticulture and tree crops	May increase due to the reduced risk in a variable climate associated with growing annual crops compared to the 4-5 year duration of sugarcane
5. NSW	Presently low radiation	Projections of an increase in radiation likely to reduce constraint and potentially increase productivity
	Presently frost-prone production	Projections of an increase in minimum temperatures likely to decrease frost damage and allow expansion of suitable areas
	Crop growth presently limited by low winter temperatures and short duration of growing season (necessitating two-year crops)	Projections of an increase in minimum temperatures likely to reduce constraint and potentially increase productivity
	Acid sulphate soils and need for drainage requires careful management of the water table	Projections of sea level rise likely to increase difficulty of management and potentially reduce areas suitable for growth
	Incidence of diseases, e.g. smut	Likely to increase as a result of projected increases in temperature
	Seasonal variability	Projections for a decrease in the reliability of summer rainfall will reduce crop growth, however increased temperatures may negate this through increased productivity

7. What adaptation strategies will be required?

This preliminary study has shown that a wide range of adaptation strategies will be required to address the challenges of a continued change in climate.

Whole-of-industry strategic planning and policy development needs to carefully consider the significant differences in the adaptation needs of each region.


The interaction of climate change with other external driving factors also needs to be more fully understood.

Table 4 provides a summary of adaptation options for each sector of the industry. These strategies were suggested by sugarcane industry stakeholders at the regional and industry-wide workshops in relation to the industry sectors in Maryborough. Many of these responses are also likely to be applicable to some or all of the other sugarcane producing regions in Australia.

Table 4. Summary of the potential adaptation strategies that may be implemented by each sector of the Australian sugarcane industry.

Sector	Adaptation options
Grower	<ul style="list-style-type: none"> • Bring the growing season forward to track increases in minimum temperatures. • Implement a longer harvest season to capitalise on increases in minimum temperatures. • Consider planting cane throughout the winter period. • Increase guaranteed water supply to the crop through: <ol style="list-style-type: none"> (a) investment in irrigation infrastructure, (b) increased use of supplementary water through irrigation, (c) installation of on-farm water storage facilities, (d) sugarcane varieties with greater water use efficiency/drought tolerance (e) increased efficiency in irrigation technologies (e.g. trickle tape) (f) increased use of irrigation technologies requiring a low input of labour (e.g. centre pivot). • Consider pest strategies presently used by more northerly regions to assess efficacy of pest control responses.
Harvester	<ul style="list-style-type: none"> • Look for efficiencies in harvesting operations (e.g. progress the development of harvesting technologies that enable multiple rows to be harvested simultaneously). • Decrease capital stock in proportion to reductions in crop yield.
Transport	<ul style="list-style-type: none"> • Look for efficiencies in transport operations. • Decrease capital stock in proportion to reductions in crop yield.
Milling	<ul style="list-style-type: none"> • Continue to improve efficiencies in milling operations (e.g. reduce over-capacity to a minimum, optimise crushing rate). • Continue to develop closer links to farmers and farm practice improvements to foster increased productivity, such as offering financial incentives to growers to improve practices/increase productivity.

The adaptation strategies identified for the Grower sector focus on managing warmer temperatures (i.e. changing the date of planting and harvesting) and maintaining a sufficient supply of water to the crop (increased use of irrigation and on-farm water storages). As yield changes cascades through the sugarcane value chain, all subsequent sectors will be impacted by a change in the quantity and quality of throughput. The Harvester, Transport and Milling sectors will therefore be required to focus



their adaptation strategies on developing greater flexibility to respond to changes in throughput by varying capital stock and operations to maintain optimal efficiency.

Since the vast majority of climate change impacts would appear likely to occur in the growing sector (manifesting in a change, often a decline in crop yield) the greatest potential for adaptation appears to lie with growers and on-farm practice. In the majority of cases, the adaptation strategies suggested by the stakeholders at Maryborough were an extension or enhancement of present practices used to manage seasonal and annual variability in climate.

The gaps in industry knowledge centre around the lack of knowledge of on-farm/paddock practice in a spatial form that would allow modelling of various scenarios. With better knowledge of practice and productivity and profitability variations, the return on investment in various practice improvements and research activities could be estimated. This knowledge is required even without factoring in a changing climate if the issues of yield decline and the need for increased productivity from a declining area of canelands is to be addressed. This would then allow for targeted incentives, extension programs and research to incorporate climate as one of the many variables within farming systems management.

8. Research, development and extension needs for profitability and sustainability to meet the challenges of climate change

A great deal of value has already been delivered to the sugarcane industry through well-targeted R&D. The need for research and technologies is becoming stronger in the face of further climatic variability, hotter mean temperatures, sea level rise, more extreme events and reduced rainfall in many regions. This situation will necessitate R&D investments that focus on mitigating the most negative impacts and grasping the more promising opportunities for industry profitability and sustainability.

To help inform the allocation of R&D funds, participants at all three workshops (particularly the Industry Workshop in Brisbane) were asked to consider opportunities for improving the profitability and sustainability of the Australian sugarcane industry in the face of a changing climate. Linked to this question was the identification of gaps in knowledge that need to be addressed in order to cultivate and exploit opportunities. The range of ideas collated regarding opportunities for climate related R&D investment fall under the following investment arenas and themes as defined in the SRDC R&D plan 2007-2012:

Regional Futures Investment Arena:

- Value Chain Integration Theme
- Farming and Harvesting Systems Theme
- Transport, Milling and Marketing Systems Theme

Emerging Technologies Investment Arena:

- Genetics Breeding Systems Theme

People Development Investment Arena:

- Individual Capacity Theme
- Social Capacity Theme

Tables 5 to 10 detail the R&D opportunities identified by industry stakeholders grouped under each of these arenas and themes.

Investment Strategies for the Regional Futures Arena

To enhance industry preparedness it will be necessary to have a greater understanding of the implications of climate change on the value chain and on other sugarcane producing nations. A greater awareness of biosecurity risks under a changed climate will also offer improved preparedness for an uncertain future.

Table 5 identifies Australian industry futures, global industry futures and biosecurity risk as three key knowledge gaps that require climate change focused inquiry. All strategies detailed could be undertaken using a phased approach, with an initial short and limited investment project aimed at scoping the opportunities for R&D investment, building the business case and recommending in detail key areas for R,D&E. It's recommended that all strategies at least proceed through this initial scoping phase.

Table 5. Opportunities for R&D to assist in underpinning the sustainability of the Australian sugarcane industry given present projections of climate change in the arena of Regional Futures (Value chain integration theme).

REGIONAL FUTURES INVESTMENT ARENA	
Value Chain integration	Strategies
	<ul style="list-style-type: none"> • Australian Industry Futures – Enhanced industry preparedness for climate change, positioning and adaptation will necessitate an assessment of the value chain implications of a suite of variables likely to play a role in industry profitability. Examples include: increases in the intensification of sugarcane production; key areas of infrastructure risk to extreme events and their thresholds of vulnerability; competition with other land uses; water scarcity; the profitability of various adaptation strategies; identification of alternative/additional geographic locations in Australia for sugarcane production; and any Australian policy on emissions trading. • Global Industry Futures – Enhanced industry preparedness for climate change, positioning and adaptation will also require an investigation of the impacts of climate change on other sugar producing nations and the interactions with trade policy to better position the Australian industry, develop key adaptation strategies and provide an understanding of the Australian industry’s vulnerability in the global marketplace.
	<ul style="list-style-type: none"> • Biosecurity Risk Assessment - Assessment and prioritisation of the implications of climate change on the distribution, life-cycle and ecology, abundance and management of pests, weeds and disease (as detailed in the National Agriculture and Climate Change Action Plan 2006 – 2009) will provide climate related threats and opportunities as an update to the Sugarcane Industry Biosecurity Plan.

Farming and Harvesting Systems

The R&D challenges within the Farming and Harvesting Systems Theme are substantial, reflecting the extent of the impact of climate change on this component of the industry’s operations. The on-farm challenges of dealing with a more variable climate are multiple and effective responses will need to be based on an improved understanding of climate change implications. There are also multiple opportunities that may be able to deliver benefits through the use of improved seasonal forecasting, a greater range of decision support tools and a markedly improved suite of practices that increase resilience, reduce risk and mitigate against off-farm impacts. Strategies to address these opportunities are detailed in Table 6.

More resilient and profitable practices, and fostering widespread adoption of these amongst all growers, are key to the adaptation to a changing climate. The sugarcane industry’s practices, especially in terms of nutrient management and herbicide use, are already under the microscope as shown by the Queensland and Australian Governments’ Reef Water Quality Protection Plan. The prediction by the Australian Institute of Marine Science, James Cook University and Great Barrier Reef Marine Park Authority of a “climate change double whammy” in terms of coral bleaching caused by increased sea surface temperature and reduced water quality caused by more extreme events within sugarcane catchments is already of media interest.

Best positioning the industry to meet these climate related challenges and increased scrutiny will require substantial improvements in farming and harvesting practices. Included in this is the need to increase the flexibility within practice to deal with an increasingly variable and event driven climate, incorporate seasonal forecasting into farm practices such as herbicide and nutrient applications and respond through irrigation and precision agriculture improvements to more variable available soil moisture levels and growing conditions.



Investing in Sugarcane Industry Innovation

It is recommended that the development of increasingly resilient, profitable and sustainable practices in the context of a changing and more variable climate, is an area worthy of increased R&D investment. Some of this work, such as improved seasonal forecasting skill and on-farm practice tools, can be done in partnership with other rural R&D corporations. Other areas, such as improving the productivity opportunities of a changing climate, will need to be conducted explicitly for the sugarcane industry and across the industry value chain.

Industry response to climate change challenges will also imply involvement in a range of activities commissioned by other agencies and conducted in partnership with other resource users – such as the impact of sea level rise, the changing catchment hydrology and water availability, and the opportunities for carbon sequestration and biofuels. It is recommended that these issues be explored through collaborative approaches, including contribution to initiatives led by other R&D institutions.

Table 6. Opportunities for R&D to assist in underpinning the sustainability of the Australian sugarcane industry given present projections of climate change in the arena of Regional Futures (Farming and harvesting systems theme).

REGIONAL FUTURES INVESTMENT ARENA	
	Strategies
Farming and harvesting systems	<ul style="list-style-type: none"> • Best Management Practice Audit – In the context of the stressors associated with a changing and more variable climate, evaluate the performance of practices from both profitability and sustainability contexts to identify improved management of soil and water resources. This is likely to lead to the identification of areas where farm practices require improvement, with follow-on R&D then done using a farming systems approach. • Soil Health – Improved productivity through mitigating against marked fluctuations in soil moisture and water availability will require increased attention to soil health as part of farming practices. Improved soil health practices should aim to accommodate the production and sustainability issues of an increasingly variable climate (e.g. attributes like soil moisture holding capacity, reduced erosivity, nutrient retention). This is likely to utilise carbon as an indicator of biological properties, soil erosion and compaction for physical properties and pH for chemical status. Part of the task will be to foster adoption of these measures and any accompanying alternative practices as part of a Farming Management Systems approach. To foster adoption the benefits in profitability and sustainability will need to be well quantified. • Precision Agriculture – The need for improved management of all inputs on-farm will require further development of precision agriculture based farming systems. Adoption will need to be linked to soil health improvements and seasonal forecasting to maximise profitability and foster flexibility in on-farm practices to prevailing climatic conditions and events. • Water Availability – Key knowledge gaps will need to be addressed at a regional scale. These include changes to groundwater levels and quality, (e.g. with sea level rise); changed runoff to dams with increased climate variability and changed catchment hydrology; any changing interactions between water quantity and quality; and changed water demand, both for sugarcane and for other water uses, especially horticulture and urban. • Improved Irrigation Technology and Water Use Efficiency – Improved irrigation technology and water use efficiency are key responses to changing water availability. Part of the management response will be the linking of water use to seasonal forecasts and predictions of soil moisture. • Opportunities for Increased Water Availability – Strategies are required to increase water capture, storage, supply and re-use at both on-farm and regional scales in order to mitigate against competing demands for water and increased variability in soil moisture. • Sea Level Rise Implications - Conducting a risk assessment of areas potentially vulnerable to sea level rise and salt water intrusion into aquifers is the first step and would provide the information base to then identify regional and on-farm adaptation strategies. • Harvest frequency – Maximising productivity will require more flexible and climate attuned farming systems that utilise systems modelling and empirical research to investigate the potential for three sugarcane crops to be produced in two calendar years when seasonal conditions allow. • Cropping Cycles - Investigating the potential of introducing alternative crop species into the cropping cycle for the production outputs of sugar, biomass, other products and/or ecosystem service benefits. • Seasonal Forecasting & Risk – Improved risk management of the farming system enterprise will necessitate the development of tools that link seasonal forecasts to practice throughout the value chain, especially for the key areas of risk to foster improved flexibility in all on and off-farm practices. • Biofuel Opportunities across the Value Chain - Conduct life-cycle analysis on cane production and rotation crops on farm and within the milling cycle for biofuels to validate the potential for renewable energy production within a rapidly changing market context. • Industry Footprint – Audit the contribution of the cane industry to greenhouse gas production to identify areas for practice improvement and the opportunities for the industry to sequester carbon across the value chain.

Transport, Milling and Marketing Systems

Opportunities for R&D investment in this theme include: using systems-based operations analysis and seasonal forecasting decision tools to explore profitability opportunities; the assessment of alternative products such as biofuels; and evaluation of marketing opportunities such as sugar derivatives.

A preliminary analysis or business case for the areas of R&D proposed in Table 7 will allow these to be compared to other R&D opportunities in the Transport, Milling and Marketing Systems Theme to assess likely returns on investment and maximise the impact of R&D funds.

Table 7. Opportunities for R&D to assist in underpinning the sustainability of the Australian sugarcane industry given present projections of climate change in the arena of Regional Futures (Transport, Milling and Marketing Systems theme).

REGIONAL FUTURES INVESTMENT ARENA	
	Strategies
Transport, Milling and Marketing Systems	<ul style="list-style-type: none"> • Transport and Milling Systems – Increased efficiencies and profitability through a flexible response to a more variable climate will require the industry to build upon previous systems-based operations analysis, identify key cost saving opportunities and then develop decision tools for operating procedures that exploit seasonal forecasting to cope with variable climate and the costs that accrue from climate events. • Product & Efficiency Opportunities – Following on from any R&D into alternative products and biofuel options, investigate the potential to extract increasing margins of value from sugarcane, by-products such as bagasse and compost, and other product processing. • Derivatives for Risk Management – Building on recent R&D under the Managing Climate Variability Program, derivatives for marketing sugar need to be developed and may prove to be as attractive as the opportunities for Australian wheat.

Investment Strategies in Emerging Technologies Arena

Genetics and Breeding Systems

The Genetics and Breeding Systems Theme offers opportunities to deliver varieties that are better suited to a changing climate. It may also be possible to deliver improved breeding systems to better identify desirable plant traits and reduce the time from parent selection and crossing to the commercialisation of a cultivar.

Potential R&D strategies include:

- the identification of genetic variation for drought tolerance and water use efficiency traits
- improved cultivar adoption programs
- improved farming systems that incorporate new cultivars
- further development of sugarcane growth models to quantify the genetic x environment x management (GxExM) interaction
- a better understanding of the process of sucrose accumulation and the mechanisms of plant growth as they relate to climate.

Table 8 details investment strategies for the Genetics and Breeding Systems Theme. Overall, most, if not all, of the key deliverables in the arena that are related to the development of new varieties and improved breeding systems can be accommodated through shifts in emphasis or additions to existing and proposed R&D projects. Integrating the knowledge needs of a changing climate within

the existing breadth of R&D investments in the Genetics and Breeding Systems Theme is likely to be the most cost-effective and efficient manner to accommodate climate change concerns.

One key complicating factor that will need to be carefully monitored is the rapidity of climate change and therefore the need for plant breeding and physiological work to keep pace with this change. New varieties take 8-12 years to be developed to commercial cultivar status and several more years for widespread industry adoption. Continued and possibly increased investment in breeding and crop physiology related to climate change is recommended.

Table 8. Opportunities for R&D to assist in underpinning the sustainability of the Australian sugarcane industry given present projections of climate change in the arena of Emerging Technologies (Genetics and breeding systems theme).

Genetics and Breeding Systems	Strategies
	<ul style="list-style-type: none"> • Traits & Opportunities - Identify what traits (physiological, morphological, phenological and molecular) contribute to the development of improved varieties for the production of the two key end products of sugar and biofuel under elevated temperatures and levels of atmospheric CO₂ and changed levels of rainfall. • Varieties for Climate Change - Identify and quantify genetic variation for the adaptation traits of increased drought tolerance and water use efficiency. • On-Farm Adoption - Undertake breeding trials to produce desirable cultivars under a changed climate and determine how best to gain adoption, including where necessary changes to farming systems. • Breeding Systems - Develop capability for models of plant growth to simulate genetic x environment x management (G x E x M) interactions in order to accelerate genetic gain and deliver new varieties faster. • Productivity in a Changed Climate - Undertake physiological research into the process of sucrose accumulation, and the relationship between atmospheric CO₂ concentration, temperature and crop growth in order to improve our understanding of the mechanisms of sugarcane growth as it relates to climate.

Investment Strategies in the People Development Arena

The People Development Arena captures both individual and social capacity themes. Opportunities for both themes focus on better managing climate change and climate variability. In the case of the individual, this would necessitate all stakeholders having sufficient knowledge to understand and assess the impacts, risks, and adaptation options related to their personal circumstances. At the societal level, opportunities for collaboration with other agricultural and related industries will offer the greatest value.

To better manage climate change and climate variability it is imperative that the sugarcane industry equip its stakeholders with the best available knowledge and tools. A first-phase investment might include the roll-out of a module based training program aimed at simply bringing much of the industry up to a common understanding of climate change and its implications – for Australia, Australian agriculture in general, and the sugarcane industry in particular.

Further areas of investment may be best conducted as part of the adoption strategies for particular R&D projects. At the same time, this strategy will need to be re-visited as climate change impacts increase, as decision support tools are developed and as skills in seasonal forecasting improve. Therefore a second phase of outreach to update stakeholders climate knowledge is recommended - probably about five years after the completion of phase one and incorporating research findings and decision support tools from that five year period.

Table 9. Opportunities for R&D to assist in underpinning the sustainability of the Australian sugarcane industry given present projections of climate change in the arena of People Development (individual capacity theme).

Individual capacity	Strategies
	<ul style="list-style-type: none"> • Climate Knowledge – Improved capacity for the sugarcane industry and its participants to adapt, learn, and innovate will necessitate the building of an understanding across the industry of climate change, the opportunities and risks that accompany a more variable climate. Furthermore, this will enable the industry to adapt and apply decision tools that link seasonal forecasting to practice change, adaptation, opportunities such as biofuels and risk amelioration.

Table 10. Opportunities for R&D to assist in underpinning the sustainability of the Australian sugarcane industry given present projections of climate change in the arena of People Development (social capacity theme).

Social capacity	Strategies
	<ul style="list-style-type: none"> • External experience – Improved industry capacity to learn and innovate from agents outside the sugarcane industry will necessitate that the sugarcane industry partners more readily with other agricultural and related industries that are similarly facing the challenges of a changing climate. This may entail the building of collaborative research projects that seek to understand impacts, risks and adaptation actions across a regional/sectoral and/or industry-wide perspective.

Resource Appraisal, Monitoring & Information Collation

With an increasingly variable and changing climate, and with the sugarcane industry already facing challenges in terms of both profitability and sustainability, there are many information collation activities that will assist the sugarcane industry to rapidly respond and adapt to the challenges of climate change. Examples of these include:

- **Coastal Mapping** – ensuring any government-based topographical surveys, digital elevation models, floodplain inundation scenarios etc provide information at a fine enough scale to be relevant to the sugarcane industry.
- **Water quality and quantity information** – ensuring any monitoring and modelling also provides information that the sugarcane industry can use to assess its progress in water use efficiency and off-farm water quality issues.
- **Information Systems Integration** – building from the GIS/data stores of all Productivity Boards and Mills an improved and seamless set of information across the industry upon which various climate scenarios and changes in on-farm practice can be tested.
- **Practice Knowledge** – understanding spatially the practices undertaken on-farm, harvest, transport and mill so that various issues such as water quality impact, industry energy use, nutrient and herbicide export, and carbon mitigation can be rapidly collated, opportunities assessed and management improved.
- **BioSecurity Vigilance** – monitoring for pathogens and pests as a platform for rapid response.
- **Global Intelligence** – maintaining market, productivity and profitability information as part of Australian industry positioning.



9. Conclusion

This assessment has identified the nature of likely impacts on the Australian sugarcane industry as a result of climate change and suggested priority areas for R&D that are essential to aid the industry's response to Australia's changing climate.

This research has shown that climate change must be considered as an integral part of all sugarcane value chain activities today and increasingly so into the future as impacts unfold. R&D will be necessary to rise to the challenges and uncertainties facing the sugarcane industry. The R&D needs identified in this report will better inform the sugarcane industry on best-bet options for adaptation to climate change.


Implementation of R&D is likely to manifest in multiple forms. Some activities are best commissioned directly by SRDC, whilst others are best implemented as add-ons to existing activities. Some R&D will be best undertaken quite separate to the sugarcane industry, but with applications relevant to the sugarcane industry incorporated into the project design. Others, such as improving seasonal forecasting capability for northern Australia, require participation in science consortia to ensure scarce R&D resources are best utilised.

Many of the knowledge gaps detailed in this report can be best filled through the enhancement of existing R&D activity. Other knowledge gaps are specific to climate change and may require detailed scoping as a precursor to any major R&D investment. Additional knowledge gaps will undoubtedly come to light as the sugarcane industry responds to Australia's changing climate. Australian agriculture and its science support are world renown for innovation. Part of the challenge for sugarcane R&D investment is to be open to such innovation wherever it might come from.

Global investment in climate science will bring marked improvements in our understanding of the global climate, climate forecasting and climate change within the next three to five years. R&D strategies cannot by nature be complete and must have a limited time frame of relevance – in the case of the majority of material in this report, probably less than five years. At the same time, maintaining a close understanding of developments in climate science and ensuring strong international links will be essential to implementing strategic responses to a changing climate.

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Appendix 1: Methodology used by CSIRO Marine and Atmospheric Sciences to produce climate change projections for the Maryborough region

- Monthly data from 23 global climate models were obtained from the IPCC Model Output website at http://www-pcmdi.llnl.gov/ipcc/info_for_analysts.php.
- The reliability of these climate models in the Australian region (110-155°E, 11-45°S) has been tested by comparing observed and simulated patterns of average (1961-1990) temperature, precipitation and mean sea-level pressure. Of the 23 models, 15 were considered to have superior pattern correlations and low root-mean-square errors.
- For each of the best 15 climate models, the IPCC simulations for the 21st century were based on only 3 of the 40 SRES greenhouse gas emission scenarios (A1, A2 and A1B).
- To overcome this limitation, we created regional climate change projections by linearly regressing the local seasonal mean temperature (or rainfall) against global average temperature, taking the gradient of the relationship at each grid point as the estimated response. The grid point values constitute a pattern of model response, per degree of global warming. Linear regression as a means of pattern extraction is advantageous in that it decouples the model's response from the particular emissions scenario used in the simulation. The resultant patterns can be rescaled by a given amount of global warming to produce a pattern of change that would apply for a given date and global warming scenario. Since the IPCC (2001) global warming projections are based on the full range of SRES emissions scenarios, our scaling method also includes the full range of SRES emissions.
- To derive regional projections for the years 2030 and 2070, the ranges of change per degree of global warming are combined with the IPCC (2001) global warming projections for 2030 and 2070. For example, the upper limit of the regional warming range in 2030 would be the upper limit of the relevant range of regional warming per degree of global warming multiplied by the upper limit of the global warming range for 2030. Correspondingly, the lower limit of the regional warming range is based on the combination of the lower end of the regional warming per degree of global warming multiplied by the lower end of the global warming range. The approach is the same for precipitation change, however, where the lower limit of the range of percent rainfall change is negative this is combined with the upper limit of the projected global warming.
- Rather than using the full set of 15 climate models, we've chosen the HADGEM and NCAR models because they roughly represent the 20th percentile (dry) and 80th percentile (wet) of rainfall changes, respectively, in Qld. Hence they span most of the range of uncertainty in rainfall change. Since rainfall changes have strong correlations with temperature and radiation changes, these two models also span most of the uncertainty in temperature and radiation change.
- For the Maryborough area, we have extracted monthly-average changes in temperature, rainfall and radiation using the linear regression method. These values have been scaled for the years 2030 and 2070.



Appendix 2: Tools and resources for managing climate variability

A list of tools and resources produced to assist other agricultural and pastoral industries to manage climate change and variability.

Rainfall to Pasture Growth Outlook Tool - A decision support tool developed by Meat and Livestock Australia, which shows actual rainfall and indices of soil moisture and pasture growth for the past nine months and an outlook for the next three months for over 3300 locations across southern Australia. <http://www.mla.com.au/TopicHierarchy/InformationCentre/FeedAndPastures/Pasturemanagement/Rainfall+to+Pasture+Growth+Outlook+tool.htm>

AgClimate - <http://www.agclimate.org/>

An interactive web site to help peanut, tomato, potato, pastures and livestock producers in south-eastern USA assess management options under forecast climate conditions.

Cotton Logic - <http://www.mv.pi.csiro.au/CottonLOGIC/index.shtml>

Information on insect pressures, crop inputs, pesticide applications, field operations and much more can be stored, easily accessed and used to make decisions that improve cotton crop production and sustainability. Developed by the CSIRO Plant Industry Division.

Yield Prophet® - <http://www.yieldprophet.com.au/yp/wflogin.aspx>

Online crop production model designed to provide grain growers with real-time information about the crop during growth. Growers enter inputs at any time during the season to generate reports of projected yield outcomes showing the impact of crop type and variety, sowing time, nitrogen fertiliser and irrigation.

LongPaddock - <http://www.longpaddock.qld.gov.au/>

This Queensland Government website contains detailed information on the current climate situation including Sea Surface Temperatures (SST), value of the Southern Oscillation Index (SOI), recent rainfall events, seasonal outlooks, drought maps and pasture growth forecasts. Mainly aimed at grazing and grain industries, but can be useful for horticulture.

Queensland DPI&F Climate Information - <http://www2.dpi.qld.gov.au/climate/>

The Queensland Department of Primary Industries & Fisheries (DPI&F) climate website containing the 'Current Climate Note' and other updates including the latest on the SOI, rainfall probabilities for Queensland and Australia, includes information on sea surface temperatures, regional crop outlooks and information on services, workshops and products.

Managing Climate Variability R&D Program

http://www.managingclimate.gov.au/information_resources.asp?section=21#reports

Download the latest issues of Climag magazine plus the 'Masters of Climate' booklet where managers of broadacre or grazing enterprises across Australia outline how they have applied new climate forecasting tools and information.

NSW Department of Primary Industries - <http://www.agric.nsw.gov.au/reader/nr-climate>

The NSW Department of Primary Industries web site contains information on climate variability, SOI, drought, El Niño, and how to use seasonal rainfall outlook information. None of this information is specifically targeted towards horticulture, although much of this information is useful for managing climate variability by managers of horticultural enterprises.

Climate and weather information sources

<http://www2.dpi.qld.gov.au/climate/9193.html>

Links to 20 climate and weather related websites in Australia and overseas.

APSIM - Agricultural Production Systems sIMulator - <http://www.apsru.gov.au/apsru/>

APSIM simulates biophysical processes in farming systems, particularly as they relate to the economic and ecological outcomes of management practices in the face of climate risk.

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

A forecasting tool which analyses rainfall and stream flow records for individual locations in Australia and provides seasonal rainfall forecasts based on the Southern Oscillation Index (SOI) or Sea Surface Temperatures (SST). Available from the Queensland Department of Primary Industries and Fisheries.

Whopper Cropper

Combines seasonal climate forecasting with cropping systems modelling to predict the production risk that growers face in the coming cropping season and choose the best management options.

“Will it Rain? The Effect of the Southern Oscillation and El Niño on Australia.”

A book for farmers, graziers, students and anyone else interested in the weather and seasonal forecasting. Written as a companion to the Rainman StreamFlow CD and software to explain the weather systems associated with the Southern Oscillation and El Niño. Available from Qld DPI&F Book Sales for \$24.05. <http://www.publications.qld.gov.au>

PlantGro - <http://www.topoclimate.com/plantgro.htm>

A software package that can be used to predict the growth and development of plants under different environmental conditions. It can also predict the activity of insects and plant diseases.

Land Suitability Analysis - Spatial Analysis Modelling

A Victorian Government pilot project which aimed to determine the potential for growing certain commodities (including cool climate grapes) across Gippsland, and the likely shift in that potential as climate change occurs in the region. This expert modelling technique allows for an assessment of climate impact on the distribution of a wide range of commodities including fruits, vegetables, cropping, flowers and plantations.

Appendix 3: Methodology used to produce the quantitative impact of an increased temperature and decreased rainfall in Maryborough

A quantitative assessment of the impact of a change in temperature and rainfall on cane fresh weight grown in the Maryborough region was conducted using the crop growth model, Agricultural Production Systems Simulator (APSIM) (Keating *et al.*, 2003) and by amending historic climate data according to climate change projections for the years 2030 and 2070. Model configuration included the soil water module SOILWAT2 (Probert *et al.*, 1998), the soil nitrogen module SOILN2 (Probert *et al.*, 1998), the surface residue module RESIDUE2 (Thorburn *et al.*, 2001) and the crop module, SUGARCANE (Keating *et al.*, 1999). Soil and management parameters used for simulating cane growth in the Maryborough region were obtained from a previous study conducted by Thorburn *et al.* (2005). Simulations were conducted for three different soil types found in the region (Bidwill, Watalgan and Robur). These were chosen to represent a 'good', 'average' and 'poor' soil, respectively. Details of each soil can be found in Table 11.

Table 11. Details of soils found in the Maryborough sugarcane region (further details can be found in Zund and Brown (2001)).

Soil	Major attributes of dominant soil	Australian classification
Bidwill	Red or occasionally black light clay to light medium clay surface (0.1 to 0.4 m) over a red light clay to light medium clay (>1.5 m) with none to few manganiferous nodules over weathered rock.	Red Ferrosol
Watalgan	Black or brown clay loam surface over an acid, red light clay to medium clay with ferruginous nodules.	Red Dermosol
Robur	Grey loamy sand to sandy loam surface over a conspicuously bleached A2 horizon (0.5 to 1.0 m) over an acid, mottled, sodic, grey sandy light clay to heavy clay.	Redoxic Hydrosol Grey Sodosol

APSIM was parameterized to represent a cropping cycle consisting of a 12-month plant crop (planted 4 September) followed by four 12-month ratoons and a 12-month fallow. All crops were simulated at a density of 10 plants/m². Both plant and ratoon crops were fertilised with 150 kg N/ha 70 days after planting/ratooning at a depth of 80mm. Simulations were run for rainfed and irrigated production. Where irrigation was applied, applications began on 1 November with 37.5mm applied every 14 days unless a significant amount of rainfall (>25 mm over three days) occurred. No irrigation was applied for at least eight days after a significant rainfall event. A total of 375mm was applied to a single crop with a dry-off period of at least 98 days prior to harvesting (subject to rainfall). At harvest, 95% of surface residue was removed.

Elevated concentrations of atmospheric CO₂ were included in the APSIM simulations. This was done by multiplying the default transpiration efficiency (TE) and radiation use efficiency (RUE) coefficients by the CO₂ factors produced using equations (1) and (2), respectively:

$$TE = 0.0008 * CO_2 + (1 - 0.0008 * 350) \quad (1)$$

$$RUE = 0.000143 * CO_2 + 0.94995 \quad (2)$$

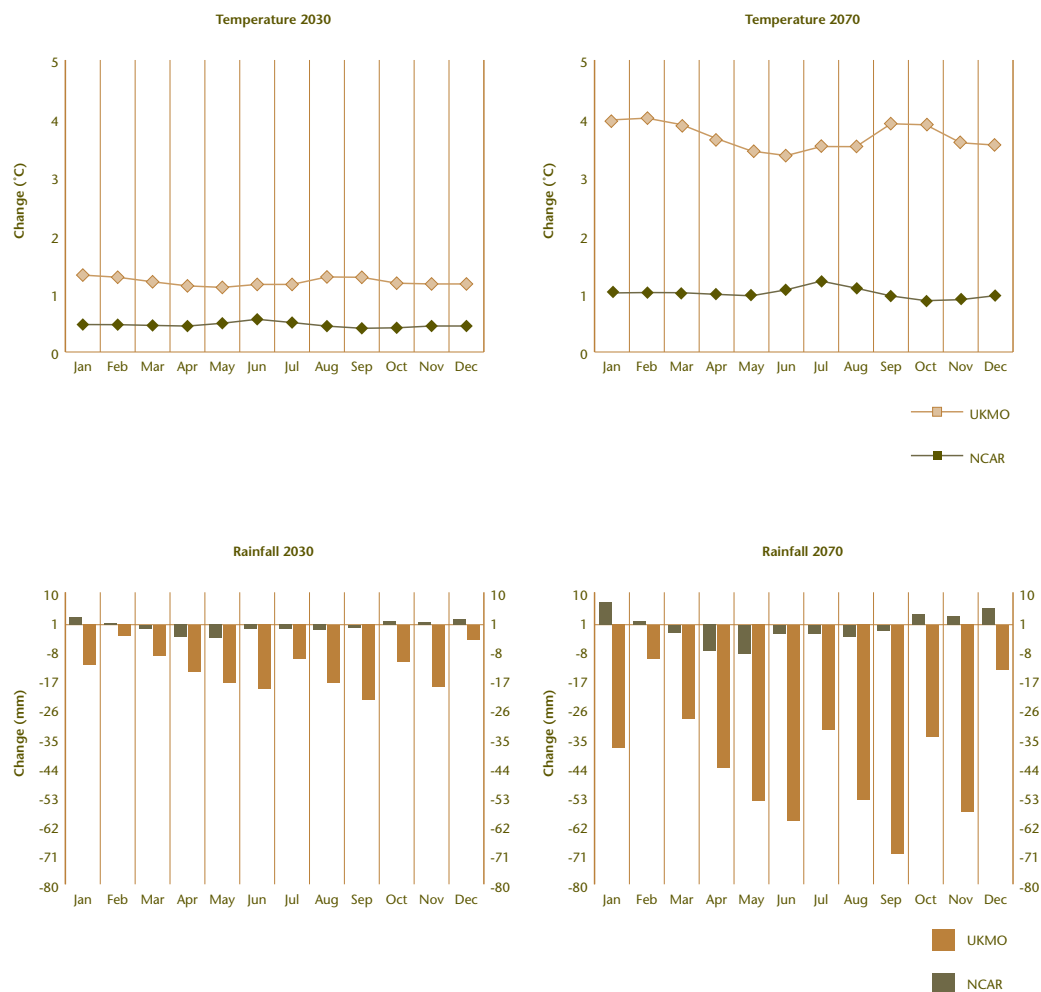
Where CO₂ is the predicted level of atmospheric CO₂ for that year. An atmospheric CO₂ level of 437 ppm was used for simulating crop growth in 2030, and 610 ppm for 2070.

Temperature and rainfall projections for the years 2030 and 2070 were obtained from two climate change models referred to as UKMO and NCAR, respectively (Appendix 1). Daily climate records for the period 1900 to 2005 for the Maryborough region were used to produce the climate change scenarios. Scenarios were constructed by altering historical rainfall and temperature records to take into account the full range of temperature and rainfall changes projected. The climate data were obtained from the Queensland Department of Natural Resources, Mines and Energy Silo patched point datasets (Jeffrey *et al.*, 2001).

Twenty-five climate records were produced for each of the two climate models (NCAR and UKMO) and each projection year (2030 and 2070). The historical maximum and minimum daily temperature and daily rainfall data were amended using five different values. These were produced by splitting projected low and high value ranges for each model for the years 2030 and 2070 into four equidistant intervals. Each value between the high and low projections was given a code. In the case of temperature, these included (1) for minimum increase in temperature, and (5) for maximum increase in temperature. For rainfall this included (1) for maximum reduction in rainfall, and (5) for minimum reduction in rainfall or increase in rainfall. A further simulation was run for no change in temperature and rainfall to provide a present-day baseline for comparison.

No change was made to the frequency in the number of rainfall days. The simulation data for the first four cropping cycles (1900-1924) were discarded from each simulation run so that the model could reach equilibrium and the initial values chosen for the model parameters would not greatly impact results (Lisson *et al.*, 2000). The remaining 80 years of data (1925-2005) were used to consider the potential effects of climate change on cane fresh weight for the years 2030 and 2070.

Figure 5. Monthly temperature and rainfall projections (relative to 1990) for the Maryborough region for the years 2030 and 2070 produced by CSIRO Marine and Atmospheric Research (CMAR) using the NCAR (blue) and UKMO (pink) climate models.



Appendix 4: Likely primary and secondary impacts resulting from a change in climate at Maryborough.

Table 12. Summary of responses from stakeholders at the Regional and Strategic Vision Climate Change Workshops to the potential impacts of climate change and likely responses. Impacts categorised as positive (+), negative (-), neutral (x), or, both positive and negative (±).

Grower	Harvester	Transport	Milling
<p>Projection: Increase in temperature.</p> <p>Primary impact: Increase in daily minimum temperatures resulting in:</p> <ul style="list-style-type: none"> (a) reduced incidence and severity of frosts (presently a limiting factor for some of the production areas in the Maryborough region) (+) (b) decrease in the duration of winter conditions and consequently an increase in the duration of the growing season (+) (c) increase in the potential duration of the harvest season. (-) <p>Response:</p> <ul style="list-style-type: none"> (a) bring growing season forward (b) implement a longer harvesting season. 	<p>Secondary impact: Increased duration of the harvest season would require fewer machines to be in operation (reduced capital stock). (+)</p> <p>Response: Decrease capital stock accordingly.</p>	<p>Secondary impact: Increased duration of the harvest season would require fewer machines to be in operation (reduced capital stock). (+)</p> <p>Response: Decrease capital stock accordingly.</p>	<p>Secondary impact: Extended duration of crushing season would favour increased continuity of labour. (+)</p> <p>Response: None.</p>
<p>Projection: Decrease in rainfall and increase in temperature.</p> <p>Primary impact: Reduction in cane yield resulting in:</p> <ul style="list-style-type: none"> (a) the need to diversify into alternative crops (e.g. sugarbeet) (±) (b) increasing amounts of household labour focused on generating off-farm income. (±) <p>Response: uncertain.</p>	<p>Secondary impact: Reduced throughput. (-)</p> <p>Response: Look for efficiencies in harvesting (e.g. progress the development of harvesting technologies that enable multiple rows to be harvested simultaneously).</p>	<p>Secondary impact: Reduced throughput. (-)</p> <p>Response: Look for efficiencies in transportation.</p>	<p>Secondary impact:</p> <ul style="list-style-type: none"> (a) reduced throughput (-) (b) increased pressure to value-add by producing alternative products from cane. (±) <p>Response:</p> <ul style="list-style-type: none"> (a) over-capacity reduced to a minimum (b) crushing rate reduced sufficiently to maximise extract of juice (c) closure of the mill (d) financial incentives offered to growers to increase productivity (e.g. transport assistance, water availability, leasing of land).
<p>Secondary impact: Less damage to stool of ratoon crop. (+)</p>	<p>Projection: Decrease in rainfall during harvest season.</p> <p>Primary impact: Crop easier to harvest, less wet-weather downtime, improved efficiency, less cane loss. (+)</p> <p>Response: None required.</p>	<p>Secondary impact: Less wet-weather downtime. More efficient operations. (+)</p> <p>Response: None required.</p>	<p>Secondary impact: More efficient supply of cane to mill, less down time. (+)</p> <p>Response: None required.</p>



Grower	Harvester	Transport	Milling
<p>Projection: Decrease in rainfall.</p> <p>Primary impact: Increased moisture stress (particularly during January and February), leading to:</p> <ul style="list-style-type: none"> (a) increased demand for irrigation (resulting in an increased cost of production) (-) (b) increasingly marginal production in dryland areas (potentially resulting in cessation of production (-) (c) increased yield response to irrigation (resulting in an increased return for investment in irrigation infrastructure). (+) <p>Response: increase supply of water to the crop through:</p> <ul style="list-style-type: none"> (a) investment in irrigation infrastructure (b) increase in the use of supplementary water through irrigation (c) installation of on-farm water storage facilities (d) increase demand for sugarcane varieties with greater water use efficiency/drought tolerance (including genetically modified varieties). <p>Secondary impacts: Increased use of supplementary water resulting in:</p> <ul style="list-style-type: none"> (a) a more reliable annual yield and decrease in the variability of throughput through the value chain (+) (b) increased investment in irrigation, particularly those technologies that favour a low input of labour (e.g. centre pivot). 	<p>Secondary impact: Change in volume of throughput (generally considered to be a reduction). (-)</p> <p>Response: As required.</p>	<p>Secondary impact: Change in volume of throughput (generally considered to be a reduction). (-)</p> <p>Response: As required.</p>	<p>Secondary impact: Change in volume of throughput (generally considered to be a reduction). (-)</p> <p>Response: As required.</p>
<p>Projection: Decrease in rainfall and increase in temperature.</p> <p>Primary impact: Some stakeholders thought CCS would increase, whilst others thought it would decrease. (±)</p> <p>Response: Undecided.</p>			

Grower	Harvester	Transport	Milling
<p>Projection: Increase in temperature.</p> <p>Primary impact:</p> <p>(a) accelerated crop phenology (increased growth during available growing season) (+)</p> <p>(b) extended window for planting. (+)</p> <p>Response: Consider planting cane throughout the winter period.</p>	<p>Secondary impact:</p> <p>(a) extended harvest season enabling fewer machines to be required (reduced capital stock) (+)</p> <p>(b) increased continuity of labour. (+)</p> <p>Response: Decrease capital stock accordingly.</p>	<p>Secondary impact:</p> <p>(a) extended harvest season enabling fewer machines to be required (reduced capital stock) (+)</p> <p>(b) increased continuity of labour. (+)</p> <p>Response: Decrease capital stock accordingly.</p>	<p>Secondary impact: Extended duration of crushing season would favour increased continuity of labour. (+)</p> <p>Response: None.</p>
<p>Projections: Decrease in rainfall in January and February.</p> <p>Primary impact: Increased water stress occurring during the most critical time (early growth). (-)</p> <p>Response: Use/install irrigation infrastructure. However, irrigation unable to supply sufficient water to meet crop demand as unable to apply sufficient quantities of water due to infrastructure constraints (not necessarily a lack of water).</p> <p>Response: Install irrigation and build on-farm water storage.</p>			
<p>Projection: Decrease in rainfall.</p> <p>Primary impact: Greater competition for water from other users in the region (e.g. industry, urban, tourism) resulting in:</p> <p>(a) decrease in the quantity of available water (-)</p> <p>(b) increase in the cost of water (-)</p> <p>(c) available water diverted to higher value crops. (-)</p> <p>Response: Uncertain.</p>			

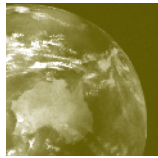
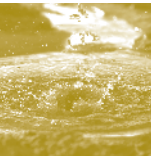


Grower	Harvester	Transport	Milling
<p>Projection: Increase in temperature.</p> <p>Primary impact:</p> <p>(a) increased abundance of pests and diseases (-)</p> <p>(b) introduction of new pest species to the region. (-)</p> <p>Response: Look at response strategies presently used in more northerly production regions.</p>			
			<p>Projection: Increase in temperature.</p> <p>Primary impact: Increased use of air conditioning to keep sugar drying area of the mill cool, necessitating an increased use of energy. (-)</p> <p>Condensation of steam using warmer river water inhibited. (-)</p> <p>Response: Reduce crushing rate (resulting in a decrease in efficiency and increase in expense).</p>
<p>Projection: Decrease in rainfall and increase in temperature.</p> <p>Primary impact: Desirability of Maryborough region increases resulting in urban expansion and increased pressure on agricultural land. (-)</p> <p>Response: Uncertain.</p>			



Investing in Sugarcane Industry Innovation





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