Global change: informing the Australian Sugar Industry on potential impacts, possible strategies for adaptation and best-bet directions for future R&D

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SRDC FINAL REPORT

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Research organisations:

- CSIRO
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The authors would like to thank stakeholders of the Australian sugar industry who attended the Regional Climate Change Workshop held in Maryborough on 24 January 2007 and the Strategic Climate Change Workshop held in Brisbane on 5 February 2007, and the Industry workshop on 29 March 2007. Thanks also to Colin Creighton for facilitation of the Industry workshop (MWNRM), 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.

Executive Summary

The issue

Australia is facing some degree of continuing global change (IPCC 2007) (referred to as climate change in this report, and including climate variables and atmospheric gases). The Agriculture and Food Policy Reference Group (2006) considers that without adequate preparation, climate change could have serious implications for sustainable agriculture in Australia. Changes to current practices are therefore required to accommodate climatic changes and ensure future sustainability of the industry in its present location.

This challenge will require capacity building to help stakeholders interpret projections, consider impacts and risks and develop and adopt adaptation strategies to address climate change. It is also necessary to identify knowledge gaps to guide future R&D investment.

R&D Methodology

A cross-disciplinary team of researchers undertook this preliminary analysis of the impacts of climate change on 5 sugar producing regions in Australia and the identification of knowledge needs for future R&D investment. The research was conducted in consultation with industry stakeholders at 3 workshops.

The focus of this scoping study was limited to assessing the impacts of climate change on the existing Australian sugar industry and no consideration was given to the identification of alternative agricultural land uses for present cane assignment designated areas. The study also excluded explicit consideration of the impacts of other large-scale external drivers (*e.g.* global markets and economies, energy costs and technological developments) and their interactions with climate change.

Maryborough was selected as a case study region to explore impacts at a regional level and qualitatively asses the capacity for adaptation. The crop growth model, APSIM (Keating *et al.,* 2003) was used to quantify the impacts of a change in temperature and rainfall on cane fresh weight. Analysis of subsequent impacts on the harvesting and transport sectors was conducted using a value chain model (SRDC project CSE010).

The results from the Maryborough case study were extrapolated to other sugar-producing regions and future R&D needs identified.

Project outputs

The project delivered the following:

• Industry-wide and regional climate change projections for Maryborough.

• Review of global change impact and adaptation assessments conducted by other industries.

• Procedures and outputs from participative workshops documented to aid future development of response strategies in other regions.

• Increased understanding by workshop participants of: (i) interpretation of climate change projections, (ii) possible impacts on the sugar value chain, (iii) ways to develop and implement regional adaptation strategies.

• Development of a regional-scale conceptual value chain framework to aid future:

(a) evaluation of flow-on impacts of climate change,

(b) identification of likely risks and impacts assuming no change to current practices,

(c) evaluation of adaptation strategies for mitigating negative impacts and capitalising on benefits,

(d) identification of future R&D investment opportunities to address global change.

Three reports have also been produced.

Project outcomes

The expected outcomes from this projected include an increased awareness by industry stakeholders of:

- global change projections, leading to more informed selection of adaptation strategies and increased understanding of the timeliness of their implementation.
- how to accommodate levels of uncertainty in climate change projections.
- personal risk profiles to aid the selection of adaptation strategies suited to individual attitudes.
- skills to manage the transition to new practices required under a changed climate.
- adopting a value-chain perspective when addressing global change, leading to enhanced collaboration between sectors at a regional level and greater industry resilience.
- knowledge gaps, their relative importance, and the effective deployment of R&D funds.

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 & Processing Systems** that take an integrated 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** for either value adding or as a core product and preferably integrated within innovative farming and processing systems to maximise cross-industry benefits;

- **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;

- 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 research arenas and themes.

Background:

Australia is facing some degree of 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. Whilst the Australian sugar industry already experiences extreme seasonal and annual variability in temperatures and rainfall patterns and has progressively developed practices to manage these, future extremes are considered to exceed those presently experienced. Changes to current practices may therefore be required to accommodate climatic changes and ensure future sustainability of the industry in its present location.

It is recognised that in order to foster informed decision-making regarding climate change within the industry, it is necessary for the capacity of individual stakeholders from all sectors to be enhanced to enable:

(a) accurate interpretation of climate change projections by stakeholders,
(b) critical consideration 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, and
(d) development and adoption of adaptation strategies aimed at addressing a change in climate.

Objectives

This research sought to foster informed decision-making by stakeholders in the Australian sugar industry regarding climate change through the:

- identification and selection of adaptation strategies beneficial to whole of industry,
- most effective investment of future R&D funds.

The project team approached the above by guiding strategic thinking industry stakeholders from all sectors through an initial assessment of global change impacts. Questions addressed included:

- What are the current projections and likely impacts and risks?
- How can we accommodate the uncertainties associated with projections within response strategies?
- 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 estimate when capacity thresholds are reached and adaptation strategies require implementation?
- How can we manage the transition from present practices to alternative operations?

Extent to which the objectives were achieved

This study has identified that the vast majority of climate change impacts are likely to occur in the Growers' sector and will manifest in a change in crop productivity. As a consequence of the structure of the sugar industry value chain, the greatest capacity for adaptation ultimately lies with the Growers' sector. Adaptation strategies applicable to the Maryborough region were identified during the Regional workshop (Table 1). The Strategic Vision workshop participants considered these strategies to be generally applicable to most other sugar growing regions in Australia. The responses given by participants during these two workshops suggest that adaptation options will primarily require an extension or enhancement of the present practices used to manage climate variability.

The adaptation strategies identified for the Growers' sector in Table 1 focus on managing warmer temperatures (*i.e.* changing the date of planting and harvesting) and maintaining a sufficient supply of water to the crop (*e.g.* increased use of irrigation and on-farm water storages). As yield cascades through the sugar value chain, all subsequent sectors will be impacted by a change in the quantity of throughput. The Harvester, Transport and Milling sectors must therefore focus their adaptation strategies on developing greater flexibility to respond to changes in throughput by varying capital stock and operations to maintain optimal efficiency.

Table 1. Summary of the potential adaptation strategies that may be implemented by each sector of the sugar industry in Maryborough in response to a change in climate.

Sector	Adaptation option
Grower	• 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 water supply to the crop through: (a) investment in irrigation infrastructure, (b) increased use of supplementary water through irrigation, (c) installation of on-farm water storage facilities, (d) increased demand for sugarcane varieties with greater water use efficiency/drought tolerance (including genetically modified varieties) (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	• Look for efficiencies in harvesting operations (*e.g.* progress the development of harvesting technologies that enable multiple rows to be harvested simultaneously). • Track reductions in crop yield with concomitant decreases in capital stock.
Transport	• Look for efficiencies in transport operations. • Track reductions in crop yield with concomitant decreases in capital stock.
Milling	• Look for efficiencies in milling operations (*e.g.* reduce over-capacity to a minimum, optimise crushing rate. • Offer financial incentives to growers to increase productivity (*e.g.* transport assistance, water availability, leasing of land).

A further refinement of the identified adaptation needs was undertaken at the Industry workshop held in Brisbane on 29 March. Table 2 provides a summary of the recommended key elements that need to be included into an R&D adaptation response strategy (further details can be found in Appendix 3).

Table 2. Summary of the key elements to be included in an R&D adaptation response strategy for the Australian sugar industry.

Essential element in an R&D adaptation strategy
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 greater exploitation of seasonal forecasting tools.
Innovative Farming & Processing Systems that take an integrated 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 so that the industry is more flexible and financially resilient.
Capitalisation of **Bio-energy opportunities** as either value adding or a core product and preferably integrated within innovative farming and processing systems to maximise the cross-industry benefits.
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 the potential threats in biosecurity that may manifest through a changing climate are understood.
Positioning Australia in a **Global Context** - an understanding of climate change impacts on worldwide production, profitability and markets relative to the Australian sugar industry to help continually optimise market position.

The project team documented areas considered by the workshop participants likely to constrain their ability to fully evaluate the potential impacts, risks and adaptation options related to climate change. These have been synthesized into potential R&D funding avenues and expressed in the context of SRDC research arenas. These are documented in this report under the section heading 'Future research needs'.

Methodology

The methodology used in this research has been detailed in Appendix 1. The four stages of the project are summarised in Figure 1. In brief, the first stage of the project required the collation of background information on a range of climate variables for the Queensland region including sea level rise, cyclone and El Niño Southern Oscillation (ENSO). More detailed projections for temperature and rainfall were produced by CSIRO Marine and Atmospheric Research (CMAR). The projections were analysed both qualitatively and quantitatively to assess the likely impact on sugarcane production in the Maryborough region.

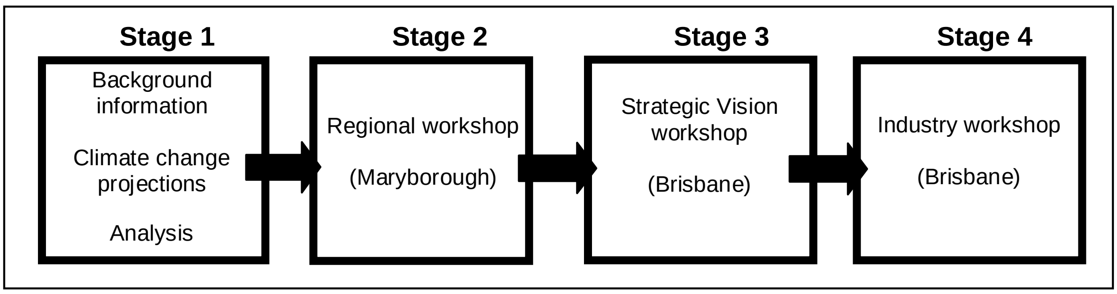

Figure 1. Methodology used to elicit the views of a range of stakeholders in the Australian sugar industry on the impacts and risks of climate change, knowledge gaps and future areas for R&D investment.

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 sugar industry, representing the growers, harvesting, transport and milling sectors. The workshop focussed the current projections of climate change and likely impacts and risks for Maryborough.

The Strategic Vision Climate Change Workshop was subsequently undertaken in Brisbane on 5 February 2007. The participants at this workshop included those members of the industry responsible for making policy level decisions in addition to climate scientists and representatives from State government. The overriding aim of this second workshop was to consider the Maryborough regional case study findings from a broader strategic industry perspective and identify areas for future R&D investment.

The final stage of this scoping study involved a participatory industry-wide workshop held in Brisbane on 29 March 2007. This workshop was attended by a broad range of sugar industry stakeholders and representatives from related industries. The aim of the workshop was to present the findings to date and elicit further detailed feedback on adaptation strategies and key areas for R&D investment.

Outputs

The outputs from this research included:

- Industry-wide and (more detailed) Maryborough regional global change projections.
- Review of global change impact and adaptation assessments conducted by other industries where applicable to the sugar industry.
- Procedures and outputs from participative workshops documented to aid future development of response strategies in other regions.
- Increased understanding by workshop participants of:
  (i) interpretation of climate change projections,
  (ii) possible impacts on the sugar value chain,
  (iii) ways to develop and implement regional adaptation strategies.
- Development of a regional-scale conceptual value chain framework to aid future:
  (i) evaluation of flow-on impacts of climate change (negative and positive),
  (ii) identification of likely risks and impacts assuming no change to current practices,
  (iii) identification of timing of thresholds that require a change of practice,
  (iv) evaluation of adaptation strategies for mitigating negative impacts and capitalising on benefits,
  (v) identification of future R&D investment opportunities to address global change.

The following reports were produced during the course of the project:

- Climate change: informing the Australian Sugar Industry of potential impacts, possible strategies for adaptation and best-bet options for future R&D. Park, et al., 72 pp. (Appendix 1).
- Climate change: informing the Australian Sugar Industry of potential impacts, possible strategies for adaptation and best-bet options for future R&D. SUMMARY REPORT. Park, et al., 9 pp. (Appendix 2).

- Climate change: SRDC technical report (Appendix 3).

Intellectual Property

In the development of a conceptual value-chain framework a number of models were utilised. In the case of the Agricultural Production Systems Simulator (APSIM), as a joint venture partner of the Agricultural Production Systems Research Unit (APSRU), CSE has prior permission to use this software within a research capacity. In the case of models developed during projects CSE005 and CSE010, there are no restrictions on the use of models developed by CSIRO.

Environmental and Social Impacts

There were no direct negative environmental or social impacts associated with conducting this project. As a result of industry-wide adoption of BMP adaptation strategies, it is possible that there will be a reduction in the environmental foot-print of the industry and increased gross margins (as demonstrated in the Herbert case study analysis (Antony et al., 2002)).

The timeliness of the project has helped position the sugar industry favourably to compete for research funds from the recently announced CSIRO Climate Adaptation Flagship.

Expected Outcomes

The expected outcomes from this projected include an increased awareness by sugar industry stakeholders of:

- global change projections, leading to more informed selection of adaptation strategies and increased understanding of the timeliness of their implementation.
- how to accommodate levels of uncertainty in climate change projections within the identification of appropriate adaptation strategies.
- personal risk profiles to aid the selection of adaptation strategies suited to individual attitudes.
- skills to manage the transition to new practices required under a changed climate.
- adopting a value-chain perspective when addressing global change, leading to enhanced collaboration between sectors at a regional level and greater industry resilience.
- knowledge gaps, their relative importance, and the effective deployment of R&D funds.

The extent to which the project has achieved the fostering of informed decision-making by stakeholders regarding global change has been assessed through an evaluation exercise. In the evaluation, a questionnaire aimed at measuring knowledge, attitudes, skills and aspirations (KASA) to global change was completed at both the outset and end of the workshop by participants. The documented changes in KASA were assessed to see if there had been a change as a result of attending the workshop.

Assessment of the evaluations conducted at the three industry workshops is attached in Appendices 4, 5 and 6. In summary,

- Maryborough regional workshop (24 January 2007): “This evaluation clearly demonstrates the shift in the KASA of the stakeholders present at the Regional Climate Change Workshop in Maryborough.”
- Strategic vision workshop, Brisbane (5 February 2007): “Participation in the workshop generally appeared to increase the KASA of the majority of participants, however it is noted that a number of the participants were already working in the area of climate change and had little capacity for increased knowledge and skills.”
- Industry workshop, Brisbane (29 March 2007): “The workshop participants were asked to rate the usefulness of the sessions. All sessions proved to be at least moderately useful, and in many cases considerably useful. On 18 occasions, the participants considered a session to be extremely useful.”

Future Research Needs

Future research needs are documented in Appendix 3. In summary, in order to help inform the allocation of future research and development funds, participants at the 3 climate change workshops were asked to consider present gaps in knowledge that were likely to constrain their ability to fully evaluate the potential impacts, risks and adaptation options related to climate change. The participants were also asked to consider areas where a future change in policy would be required to enhance the resilience within the sugar industry to face the challenges of a future change in climate. The focus of all discussions with stakeholders was on maintaining, and/or increasing, the sustainability of the sugar industry in its present locations.

The knowledge gaps and policy areas identified by the stakeholders and the project team as being required to maintain or increase production, are described within the context of the SRDC research arenas and themes (Tables 3, 4, 5 6 & 7). Further discussion on these R&D recommendations can be found in Appendix 3.

Table 3. Opportunities for R&D to assist in underpinning the sustainability of the Australian sugar industry given present projections of climate change in the arena of Emerging Technologies (Breeding theme).

EMERGING TECHNOLOGIES ARENA		
	Key Deliverables	**Strategies**
Breeding and Physiology	▪ New varieties that provide increased productivity under elevated temperatures and levels of atmospheric CO_2 and changed levels of rainfall ▪ New varieties that are resilient and productive in conditions of marked variability in soil moisture over 4 - 5 years of cropping	▪ **Traits & Opportunities** - Identify what traits (physiological, morphological, phenological and molecular) contribute to the development of improved varieties for the production of the 2 key end products of sugar and biofuel ▪ **Varieties for Climate Change** - Identify and quantify genetic variation for adaptation to desirable traits including increased drought tolerance, water use efficiency and transpiration efficiency ▪ **On Farm Adoption** - Undertake breeding trials to produce desirable cultivars and determine how best to gain adoption, including where necessary changes to farming systems
	▪ Improved breeding systems and evaluation approaches for traits that accelerate genetic gain, and deliver new varieties faster	▪ **Breeding Systems** - Develop capability for models of plant growth to simulate genetic x environment x management (G x E x M) interactions

	▪ Improved understanding of the mechanisms of sugarcane growth as it relates to climate	▪ **Productivity in a Changed Climate** - Undertake physiological research into the process of sucrose accumulation, and the relationship between atmospheric CO_2 concentration, temperature and crop growth

Table 4. Opportunities for R&D to assist in underpinning the sustainability of the Australian sugar industry given present projections of climate change in the arena of Regional Futures (Farming and harvesting systems theme).

REGIONAL FUTURES ARENA		
	Key Deliverables	**Strategies**
Farming and harvesting systems	▪ Improved management of soil and water resources, especially resilience to a more variable climate from productivity, profitability and sustainability perspectives ▪ Improved productivity through mitigating against marked fluctuations in soil moisture and water availability ▪ Improved management of all inputs on-farm – labour, water, nutrients and herbicides to deliver profitability improvements and to commensurately reduce impact off farm, to improve sustainability, especially in extreme events	▪ **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. 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** - Application of a soil health system to farming practices and systems that 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 accompanying practices as part of Farming Management Systems which implies the benefits in profitability and sustainability will need to be well quantified. ▪ **Precision Agriculture** - Further development of precision agriculture based farming systems within the context of an increasingly variable climate and their adoption – probably in parallel to soil health improvements and building into precision agriculture links to seasonal forecasting to provide flexibility in on farm practices. ▪ **Water Availability** – Key knowledge gaps that will need to be addressed principally at regional scale 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 sugar 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 linking water use to seasonal forecasts and predictions on soil moisture. ▪ **Opportunities for Increased Water Availability** – Strategies to increase water capture, storage, supply and re-use at both on-farm and regional scales to mitigate against competing demands for

		water and increased variability in soil moisture. ▪ **Sea Level Rise Implications** - Conduct a risk assessment of areas potentially vulnerable to sea level rise and salt water intrusion into aquifers, together with the identification of regional and on-farm adaptation strategies.
	▪ Maximising productivity through more flexible and climate attuned farming systems	▪ **Harvest frequency** - Using systems modelling and empirical research to investigate the potential for 3 sugarcane crops to be produced in 2 calendar years when seasonal conditions allow. ▪ **Cropping Cycles** - Investigate 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.
	▪ Improved risk management of the farming system enterprise	▪ **Seasonal Forecasting & Risk** - Develop tools that link seasonal forecasts to practice throughout the value chain, especially for key areas of risk, thereby introducing improved flexibility in all on and off-farm practices.
	▪ Renewable energy ▪ Greenhouse Gas mitigation	▪ **Biofuel Opportunities across the Value Chain** - Conduct life cycle analysis on cane production and alternate cover 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.

Table 5. Opportunities for R&D to assist in underpinning the sustainability of the Australian sugar industry given present projections of climate change in the arena of Regional Futures (Transport, Milling and Marketing Systems theme).

	Key Deliverables	Strategies
Transport, Milling and Marketing Systems	▪ Increased efficiencies and profitability responding with flexibility to a more variable climate	▪ **Transport and Milling Systems** – building on previous systems-based operations analysis, provide for key cost saving opportunities, 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 may prove to be as attractive as the opportunities for Australian wheat.

Table 6. Opportunities for R&D to assist in underpinning the sustainability of the Australian sugar industry given present projections of climate change in the arena of Regional Futures (Value chain integration theme).

Value Chain integration	Key Deliverables	Strategies
	▪ Enhanced industry preparedness for climate change, positioning and adaptation	▪ **Australian Industry Futures** - Assess 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** - Investigate 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 understand the Australian industry's vulnerability in relation to global markets.
	▪ Pest, weed and disease risk management	▪ **Risk Assessment** - Assess and prioritise 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) as a basis to update the Sugarcane Industry Biosecurity Plan.

Table 7. Opportunities for R&D to assist in underpinning the sustainability of the Australian sugar industry given present projections of climate change in the arena of People Development (Individual capacity theme).

PEOPLE DEVELOPMENT ARENA		
Individual capacity	**Key Deliverables**	**Strategies**
	▪ Improved capacity for the sugar industry and its participants to adapt, learn, and innovate	▪ **Climate Knowledge** – building an understanding across the industry of climate change, the opportunities and risks that accompany a more variable climate and how to adapt and apply decision tools that link seasonal forecasting to practice change, adaptation, opportunities of biofuels etc and risk amelioration.

As there will always be uncertainty in future climate scenarios due to highly uncertain levels of future greenhouse emissions, there will be concomitant uncertainties in the science of the global climate system and socio-economic, political and technological developments. It is therefore necessary for climate change impact, risk and adaptation studies be conducted using an active adaptive management approach. This will require that directed change in management or policy be monitored, analysed and learnt from, so as to iteratively and effectively adjust to ongoing climate changes and future projections.

As a consequence of limiting the scope of this study to include only the direct sugar industry impacts, the response strategies suggested by industry stakeholders consider only incremental adaptive change, rather than radical redeployment of natural resources to alternative agricultural or land use practices. As the study has, in the main part, provided a qualitative assessment, little consideration has been given to the quantitative capacity of the adaptation options to redress the impacts of climate change or maintain the resilience of the industry in its present locations. We therefore cannot discount the prospect that climate change and its multiple interactions with other large-scale external drivers, will require adaptation that goes far beyond the incremental changes in current activities identified in this study. Profound adaptation may require that economic resources are shifted to their highest value uses (*i.e.* possibly away from sugarcane production), thus requiring flexible rural communities and governance and industrial systems to facilitate any changes in land use.

Recommendations

Recommendations arising from this research project are summarised in the "Future Research Needs" section above and discussed more fully in appendix 3 published by SRDC). The following is a summary of the draft analysis:

List of Publications

The following reports were produced during the course of the project:

- Climate change: informing the Australian Sugar Industry of potential impacts, possible strategies for adaptation and best-bet options for future R&D. Park et al., 72 pp. (Appendix 1).
- Climate change: informing the Australian Sugar Industry of potential impacts, possible strategies for adaptation and best-bet options for future R&D. SUMMARY REPORT. Park et al., 9 pp. (Appendix 2).
- Climate change: SRDC technical report. Park et al., (Appendix 3).

List of Appendices*

Appendix 1:	Climate change: informing the Australian Sugar Industry of potential impacts, possible strategies for adaptation and best-bet options for future R&D. Park, et al., 72 pp.
Appendix 2:	Climate change: informing the Australian Sugar Industry of potential impacts, possible strategies for adaptation and best-bet options for future R&D. SUMMARY REPORT. Park, et al., 9 pp.
Appendix 3:	Climate change: SRDC technical report.
Appendix 4:	Regional and Strategic Vision Climate Change Workshops: KASA evaluation
Appendix 5:	Evaluation questionnaire Industry workshop, Brisbane

Please note that all of the above appendices are reports that contain their own appendices.

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Appendix 1

Climate change: informing the Australian Sugar Industry of potential impacts, possible strategies for adaptation and best-bet options for future R&D. Park, et al., 72 pp.

Climate change: informing the Australian Sugar Industry of potential impacts, possible strategies for adaptation and best-bet options for future R&D

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Executive summary

The task

Australia is facing some degree of 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 the possible knowledge needs and the adaptation options available to the industry. The study was undertaken by a cross-disciplinary team of researchers and conducted in a consultative manner with sugar industry stakeholders attending workshops held in Maryborough and Brisbane during the period January to February 2007.

The aim of the project was to foster informed decision-making regarding climate change and enhance the capacity of all sectors to enable:

- accurate interpretation of climate change projections,
- critical consideration of the likely impacts and risks on each sector of the industry and the value chain as a whole,
- identification of knowledge needs which may in turn translate into research projects and
- development and adoption of adaptation strategies aimed reducing the adverse impacts of climate change and capitalising on any beneficial impacts.

Focus on the Sugar industry

The focus of the scoping study was limited to assessing the impacts of climate change on the existing Australian sugar industry. As a consequence, no consideration was given to the identification of alternative agricultural land uses for cane assignment areas. Rather, the intention of the study was to explore the necessary actions required to be taken by the Australian sugar industry to maintain production, profitability and sustainability in its present locations.

The study also excluded explicit consideration of the impacts of many other large-scale external drivers and their interactions with climate change, that are likely to impact the sugar industry over the coming decades. These drivers include global change in markets and economies, demographic changes in agricultural industries and regions, continued degradation of the resource base for agricultural production and its associated natural environment, rising energy costs and technological development. These external drivers are dealt with in Howden *et al*., (2006).

Maryborough projected climate changes

Maryborough was used as a case study region to explore climate change impacts at a regional level and qualitatively asses the capacity for adaptation. CSIRO Marine and Atmospheric Research (CMAR) produced projections for the Maryborough region which suggest:

a. Annual mean rainfall is projected to decrease by 1 to 14% by the year 2030, and between 2 to 42% by 2070.

b. Annual mean temperatures are projected to increase by 0.5 to 1.2 ^{o}C by 2030 and 1.0 to 3.7 ^{o}C by 2070.

Changes in other climate variables include:

- an increase in atmospheric CO_2 concentrations up to 450 ppm by 2030 and 700 ppm by 2070,
- a rise in sea level of between 9 to 88 cm by 2100,
- an increase in annual average potential evaporation of between 0 to 8% per degree of global warming, enhanced drying associated with El Niño events and
- an increase in the intensity of tropical cyclones.

Translating projected climate change into sugar industry impacts

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. The best potential outcome for 2030 (assuming no implementation of adaptation response strategies), 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 would be around 8%, whilst potential reductions may be up to 47%. Uncertainty regarding the crop response to climate change is due in part to the uncertainty regarding the magnitude and potential changes in temperature and rainfall and the extent to which the sugarcane crop will benefit from increases in carbon dioxide (referred to as CO_2 fertilisation). The simulated data suggests a progressive increase in the variability of cane yields over time in both rainfed and irrigated production.

In the majority of cases the primary impacts of climate change are likely to occur within the growers sector and manifest in a change in the quantity of cane yield produced. Secondary impacts will be a change in throughput across the harvesting, transport and milling sectors. Any reduction in yield is obviously a negative impact, whilst any increase would be positive. It is uncertain what will happen to CCS levels.

Climate change impacts likely to occur across the value chain have been categorised as either:

- those associated with other large-scale external drivers (*e.g.* urban encroachment).
- Impacts likely to be negative for all regions (*e.g.* reduced winter temperatures are likely to favour the spread of diseases such as smut).
- Impacts likely to be positive for all regions (*e.g.* a projected general increase in solar radiation and the associated potential to increase productivity provided other resources are non-limiting).
- Regionally-specific impacts (*e.g.* the potential reduction in rainfall is likely to have a generally negative impact on the industry, with the exception of the Northern region which presently may experience periods of extreme rainfall that constrain productivity).

Using the Maryborough case study, a preliminary analysis was conducted on the impact of changed sugarcane production on the harvesting and transport sectors of the value chain. The analysis was conducted using the value chain model developed in the SRDC project CSE010 (Archer *et al.*, 2004; Thorburn *et al.*, 2006). Table 1 shows that whilst overall harvesting costs decreased with an increasing change in climate (as one would expect), the cost per tonne of cane increased. This is due to reduced harvesting efficiency and lower returns on harvesting capital. The impacts on transport costs per tonne of cane are not as big as those for harvesting since the Maryborough region is based on road transport and can readily increase or reduce capacity with minimal cost. This would not be the case where rail transport is used.

Table 1. Preliminary analysis for climate change impacts in Maryborough in terms of total and per tonne of cane (tc) costs.

	% Change from 2003				
	Tonnes	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

Extrapolating the impacts of climate change to other sugar-producing regions

In order to conduct a preliminary appraisal of the potential impacts of climate change on all 5 sugar-producing regions on the east coast of Australia, stakeholders at the Strategic Vision Workshop were presented with projections of temperature, rainfall and evaporation for each region. Table 2 provides a summary of the main present and future concerns/pressures on sugarcane production in each region, particularly those likely to be impacted by a change in climate.

Table 2. Summary of the main present and future pressures on sugarcane production in the 5 regions located on the eastern coast of Australia. The issues noted are those likely to be particularly impacted by a change in climate.

Region	Present constraints	Likely impact of future climate change
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.
	Offsite movement of chemicals to Great Barrier Reef Marine Park.	Likely to increase with the projection of more extreme events (*e.g.* flooding, cyclones).
	Incidence of smut.	Likely to increase as a result of projected increases in temperature.
		Projected reduction in spring rainfall likely to inhibit establishment of ratoon crops.
Herbert / Burdekin	Not presently water limited.	Likely to experience increasing competition for water from Burdekin Dam due to variable climate coupled with human population growth and industrial expansion of Townsville area.
	Rising water table and salinity issues in the channel irrigation areas.	Likely to increase with increased use of irrigation as a result of projected increases in temperature.
	Incidence of smut.	Likely to increase as a result of projected increases in temperature.
	Rising water table.	Likely to be exacerbated/degraded by projections of sea level rise.
		Projected reduction in rainfall likely to limit recharge of aquifer.
		Projected reduction in winter and spring rainfall likely to increase the efficiency of harvesting.
Central	Experiences limited water supply.	Likely to be exacerbated by projected decrease in rainfall.

Region	Present constraints	Likely impact of future climate change
	Frost-prone areas in the western districts	Projections of an increase in minimum temperatures likely to decrease frost damage.
	Incidence of smut	Likely to increase as a result of projected increases in temperature.
	Offsite movement of chemicals to the Great Barrier Reef Marine Park.	Likely to increase with the projection of more extreme events (*e.g.* flooding, cyclones).
		Projected increase in temperatures likely to extend the growing season.
		Projected increases in temperatures likely to lessen the chance for ripening, thereby necessitating an increased use of ripeners.
Southern	Experiences limited water.	Likely to be exacerbated by projected decrease in rainfall.
	Crop growth presently limited by low winter temperatures and short duration of growing season.	Projections of an increase in minimum temperatures likely to reduce constraint.
	Incidence of smut.	Likely to increase as a result of projected increases in temperature.
	Present competition for land-use from other crops *e.g.* horticulture and tree.	Likely to increase due to the reduced risk associated with growing annual crops compared to the 4-5 year duration of sugarcane.
NSW	Presently low radiation.	Projections of an increase in radiation likely to reduce constraint.
	Presently frost-prone production.	Projections of an increase in minimum temperatures likely to decrease frost damage.
	Crop growth presently limited by low winter temperatures and short duration of growing season (necessitating 2-year crops).	Projections of an increase in minimum temperatures likely to reduce constraint.
	Presence of potential and actual 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.
	Incidence of smut.	Likely to increase as a result of projected increases in temperature.
		Projections for a decrease in the reliability of summer rainfall will reduce crop growth.

Adaptation options

This preliminary study has shown that a range of adaptation strategies will be required to address the challenges of a change in climate. Adaptation to large-scale external drivers, such as urban encroachment and increased competition for water resources, is likely to require whole-of-industry strategic planning and policy development. The interaction of climate change with other external driving factors needs to be more fully understood before this may be possible.

The vast geographic extent of the sugar industry on the east coast of Australia and the broad range of biophysical conditions that the crop is presently grown in, will necessitate that whole-of-industry strategic planning and policy development also consider regional differences and their specific adaptation needs.

The Maryborough case study highlighted the need to consider impacts and the development of adaptation responses in a value-chain context. Table 3 provides a summary of the adaptation options suggested by sugar industry stakeholders at a regional and industry-wide workshop considered applicable to the industry sectors in Maryborough. Many of these responses are likely to be applicable to other sugar producing regions in Australia, but adaptation strategies will need to be developed on a regional basis.

Table 3. Summary of the potential adaptation strategies that may be implemented by each sector of the Australian sugar industry.

Sector	Adaptation options
Growing	• 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 water supply to the crop through: (g) investment in irrigation infrastructure, (h) increased use of supplementary water through irrigation, (i) installation of on-farm water storage facilities, (j) increased demand for sugarcane varieties with greater water use efficiency/drought tolerance (including genetically modified varieties) (k) increased efficiency in irrigation technologies (*e.g.* trickle tape) (l) 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.
Harvesting	• Look for efficiencies in harvesting operations (*e.g.* progress the development of harvesting technologies that enable multiple rows to be harvested simultaneously). • Track reductions in crop yield with concomitant decreases in capital stock.
Transport	• Look for efficiencies in transport operations. • Track reductions in crop yield with concomitant decreases in capital stock.
Milling	• Look for efficiencies in milling operations (*e.g.* reduce over-capacity to a minimum, optimise crushing rate. • Offer financial incentives to growers to increase productivity (*e.g.* transport assistance, water availability, leasing of land).

This study has shown that the vast majority of climate change impacts are likely to occur in the Growing sector, and will manifest in a change in crop productivity. As a consequence of the structure of the sugar industry value chain, the greatest capacity for adaptation ultimately lies with the Growing sector. The responses given by the industry stakeholders at the two workshops suggest that adaptation options will require an extension or enhancement of the on-going practices used in the past and at present to manage the substantially variable climate on the east coast of Australia. The adaptation strategies identified for the Growing 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 (*i.e.* increased use of irrigation and on-farm water storages).

As cane yield cascades through the sugar value chain, all subsequent sectors will be impacted by a change in the quantity of throughput. The Harvesting, Transport and Milling sectors must therefore focus their adaptation strategies on developing greater flexibility to respond to changes in throughput by varying capital stock and operations to maintain optimal efficiency.

Successful adaptation to climate change will need both strategic preparation and tactical response strategies. Adaptation measures will need to reflect and enhance current 'best-practices' designed to cope with adverse conditions such as drought. Adoption of these new practices will require, amongst other things: a) confidence that the climate really is changing, b) the motivation to change to avoid risks or use opportunities, c) demonstrated technologies to enable change to occur, d) support during transitions to new management, and e) altered transport and market infrastructure. The effectiveness of adaptation strategies is likely to vary across regions and sectors and must therefore be analysed in relation to the likely costs of climate impacts.

Issues beyond consideration

As a consequence of limiting the scope of this study to include only the direct sugar industry impacts, the response strategies suggested by industry stakeholders consider only incremental adaptive change, rather than radical redeployment of natural resources to alternative agricultural or land use practices. As the study has, in the main part, provided a qualitative assessment, little consideration has been given to the quantitative capacity of the adaptation options to redress the impacts of climate change or maintain the resilience of the industry in its present locations. We therefore cannot discount the prospect that climate change and its multiple interactions with other large-scale external drivers, will require adaptation that goes far beyond the incremental changes in current activities discussed in this study. Profound adaptation may require that economic resources are shifted to their highest value uses (*i.e.* possibly away from sugarcane production), thus requiring flexible rural communities and governance and industrial systems to facilitate any changes in land use.

Knowledge gaps and future R&D investment

To help inform the allocation of future research and development funds, participants at both the Regional Climate Change Workshop (Maryborough) and Strategic Vision Workshop (Brisbane) were asked to consider present gaps in knowledge that were likely to constrain their ability to fully evaluate the potential impacts, risks and adaptation options related to climate change. The participants were also asked to consider areas where a future change in policy would be required to enhance the resilience within the sugar industry to face the challenges of a future change in climate. The focus of all discussions with stakeholders was on maintaining, and/or increasing, the sustainability of the sugar industry in its present locations.

The knowledge gaps and policy areas identified by the stakeholders and the project team as being required to maintain, or increase, production, have been categorised into those aimed at:

- Improving tactical response strategies,
- Enabling sustainable management of sugarcane in the wider landscape,
- Building stakeholder capacity and resilience,
- Managing water availability and sea level rise,
- Policy adjustments.

The participants at the Strategic Vision workshop were asked to identify what they considered to be the most critical topic for future research and development. Table 4 shows the topics in descending order of perceived importance.

Table 4. Most critical topics for future research and development as voted for by 16 industry stakeholders.

Topics for future research and development	Number of participants voting topic as top priority
Breeding for greater water use efficiency and/or drought tolerance	High (more than 4)
Economics of best management practice	
Basic plant physiology on response of the crop to increased CO_2 and temperature	Medium (between 2 and 3)
Greater understanding of C-balance associated with sugar production (relate this to ecosystem services provided)	
Relative impact of climate change on regions and international competitors	
Audit of greenhouse emissions / mitigation options (relate to carbon trading markets)	Individually noted issues
Effects of climate change on industry infrastructure	
Impacts and risks of sea level rise	
Greater understanding of seasonal variability in climate (and application of this to marketing)	
Investigation into additional/alternative crops to sugarcane	
Identification of other locations suitable for sugarcane production	
Further assessment of the opportunities / threats/ risk associated with climate change	
Communication of climate change projections, potential impacts and risks	

As there will always be uncertainty in future climate scenarios due to highly uncertain levels of future greenhouse emissions, and concomitant uncertainties in the science of the global climate system and socio-economic, political and technological developments, research into climate change will require an active adaptive management approach. This will require that directed change in management or policy be monitored, analysed and learnt from, so as to iteratively and effectively adjust to ongoing climate changes. Such an approach has profound implications for stakeholder capacity-building, R&D, monitoring and policy.

Concluding remarks

The vulnerability of the sugar industry to a change in climate will be determined by the capacity of adaptation actions to reduce the negative impacts of climate change and the potential of stakeholders to capitalise on any beneficial outcomes. This study has provided a first attempt at defining the issues likely to be faced by the sugar producing regions on the east coast of Australia. Climate impact studies conducted for other agricultural industries show that practicable and financially-viable adaptation actions will have very significant benefits in ameliorating risks of negative climate changes and enhancing opportunities where they occur (Howden *et al.*, 2003). The benefit to cost ratio of undertaking R&D into these adaptations appears to be very large (indicative ratios greatly exceed 100:1). This study highlights some of the areas where further resources may best be placed to help improve the sustainability of the industry in the face of an uncertain future.

Contents

Introduction

Along with all other primary industries in Australia, the sugar industry is being called upon to rise to the challenges of maintaining economic, environmental and social sustainability in the face of an uncertain future climate.

Sugar-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 climates.

Projected changes to both average temperature and rainfall, and their variability, mean that it is now timely for the industry to consider whether current management practices will enable the future sustainability of the industry in its present locations.

SRDC have recognised that in order 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) critical consideration 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, and
(d) development and adoption of adaptation strategies aimed at addressing a change in climate.

In addition, in order to support capacity building in the industry, this SRDC-funded project aims to identify knowledge gaps and areas requiring investment of future R&D funds.

This report provides a summary of a scoping study assessing the needs of the sugar industry to address the future challenges of climate change. The project team consisted of a number of personnel from CSIRO and the Department of Primary Industries and Fisheries, with expertise covering the fields of agriculture, climate science, and value-chain analysis. The report documents participatory workshops held with industry stakeholders in Maryborough and Brisbane during the period January to February 2007.

The scoping study was conducted within a clearly defined remit that limited its focus to the impacts of climate change on the existing Australian sugar industry. As a consequence of adopting an industry as opposed to a regional focus, we gave no consideration to the identification of alternative agricultural land uses that may be deemed more suitable for cane assignment areas in future years. Rather, the intention of the study was to explore the necessary actions required to be taken by the Australian sugar industry to maintain production, profitability and sustainability in its present locations. The Maryborough region was used in a case study to explore the necessity of assessing regionally-specific climate change impacts and adaptation responses. This scoping study also excluded explicit consideration of the impacts of many other large-scale external drivers, and their interaction with climate change, that are likely to impact the sugar industry over the coming decades. These drivers include global change in markets and economies, demographic changes in agricultural industries and regions, continued degradation of the resource base for agricultural production and its associated natural environment, rising energy costs and technological development and are dealt with in Howden *et al*. (2006).

Methodology

Fig. 1 provides a schematic of the methodology used to elicit the views of a range of stakeholders in the sugar industry on the impacts and risks of climate change and knowledge gaps and future areas for R&D investment.

The first stage of the project required the collation of background information on a range of climate variables for the Queensland region including sea level rise, cyclone and El Niño Southern Oscillation (ENSO). More detailed projections for temperature and rainfall were produced by CSIRO Marine and Atmospheric Research (CMAR) (see Appendix 1.1 for methodology used to produce climate change projections for Maryborough). The projections were analysed both qualitatively and quantitatively to assess the likely impact on sugarcane production in the Maryborough region.

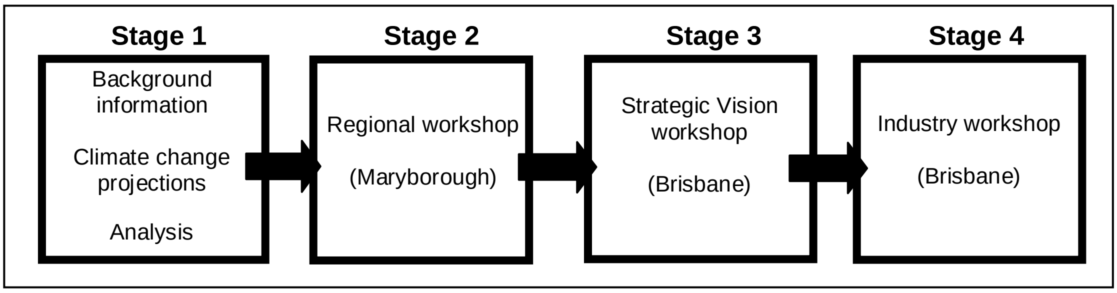

Figure 1. Methodology used to elicit the views of a range of stakeholders in the Australian sugar industry on the impacts and risks of climate change and knowledge gaps and future areas for R&D investment.

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 sugar industry, representing the growers, harvesting, transport and milling sectors (see Appendix 1.2 for a list of workshop participants). The questions addressed 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?

The Strategic Vision Climate Change Workshop was subsequently undertaken in Brisbane on 5 February 2007. The participants at this workshop included those members of the industry responsible for making policy level decisions in addition to climate scientists and representatives from State government (see Appendix 1.3 for a list of workshop participants). The overriding aim of this second workshop was to consider the Maryborough regional case study findings from a broader strategic industry perspective and identify areas for future R&D investment. More specifically the participants were asked to:

- Consider the applicability of the Regional Climate Change Workshop held at Maryborough on 24 Jan 2007 to other sugar-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 capitalise 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 future R&D to further enhance the capacity of the industry to address the challenges of climate change.

The final stage of the scoping study involves a participatory industry-wide workshop aimed at communicating the possible impacts of climate change and opportunities for further R&D investment to underpin adaptation responses.

Global and regional climate change projections (science and observations of climate change)

The following section provides a brief summary of the evidence supporting claims of a change in climate, recent trends and future projections. Particular emphasis is given to the case-study region of Maryborough.

The climate is changing. Global mean temperatures have risen approximately 0.7^{o}C since the mid 1800s and changes in rainfall patterns, sea levels, rates of glacial retreat and biological responses have also been detected which are consistent with expectations of ‘greenhouse’ climate change (IPCC 2007). The warmest year in Australia’s historical record was 2005. It was 1.1^{o}C higher than the 1960 to 1990 average. The last decade 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 (CO_2) 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 1.5 to 6.4^{o}C by the end of the present century. To place these changes in perspective, a 1^{o}C rise in average temperature will make Melbourne’s climate similar to that currently experienced by Wagga, a 3^{o}C rise like that of Dubbo, a 4^{o}C rise like that of Moree and a 6^{o}C rise like that just north of Roma. Intuitively, it is hard to conceive that such temperature changes will not have implications for Australian agriculture.

In addition to these projected temperature increases there will be increases in atmospheric carbon dioxide (Fig. 2), changes in mean rainfall with the prospect of a general decline across most of Queensland but with a possible increase in the more northerly locations during summer months (Fig. 3), increases in rainfall intensity and the possibility of entering a more El-Niño-like mean climate condition. Sea level has already risen at a rate of 1.7mm/year over the past century with this rate increasing over time (Church and White 2006) being about 3mm/year since 1993 (Church *et al*., 2004). Sea level is expected to rise 18 to 59 cm by the end of this century due to through thermal expansion of the world’s oceans. These sea level rises in combination with the potential for increased storm and cyclone intensity are anticipated to increase significantly the risk of coastal inundation.

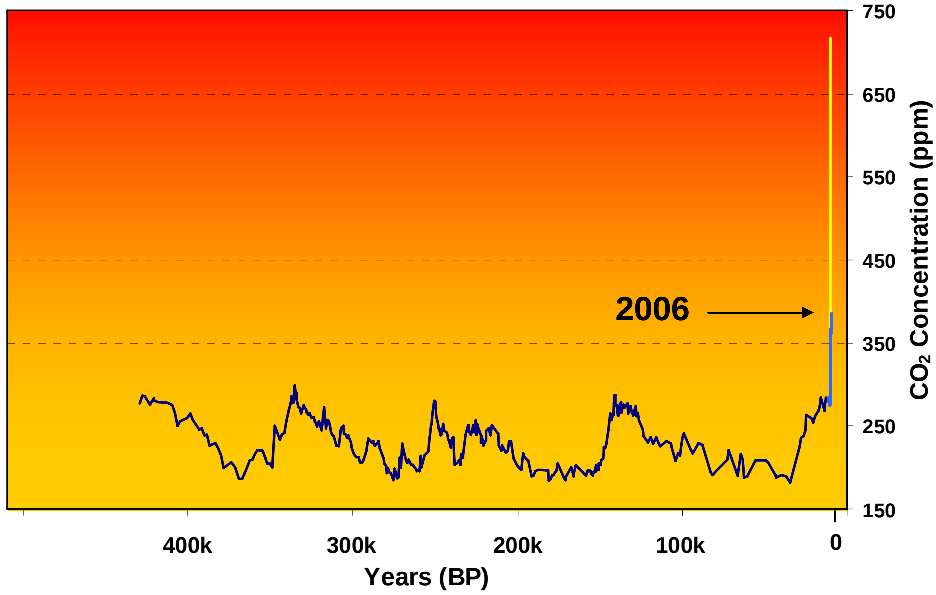

Figure 2. Variations in atmospheric CO2 from the Vostok ice core (Petit *et al*. 1999) and direct measurements from Mauna Loa as well as for future mid-range projections to 2100 (IPCC 2001).

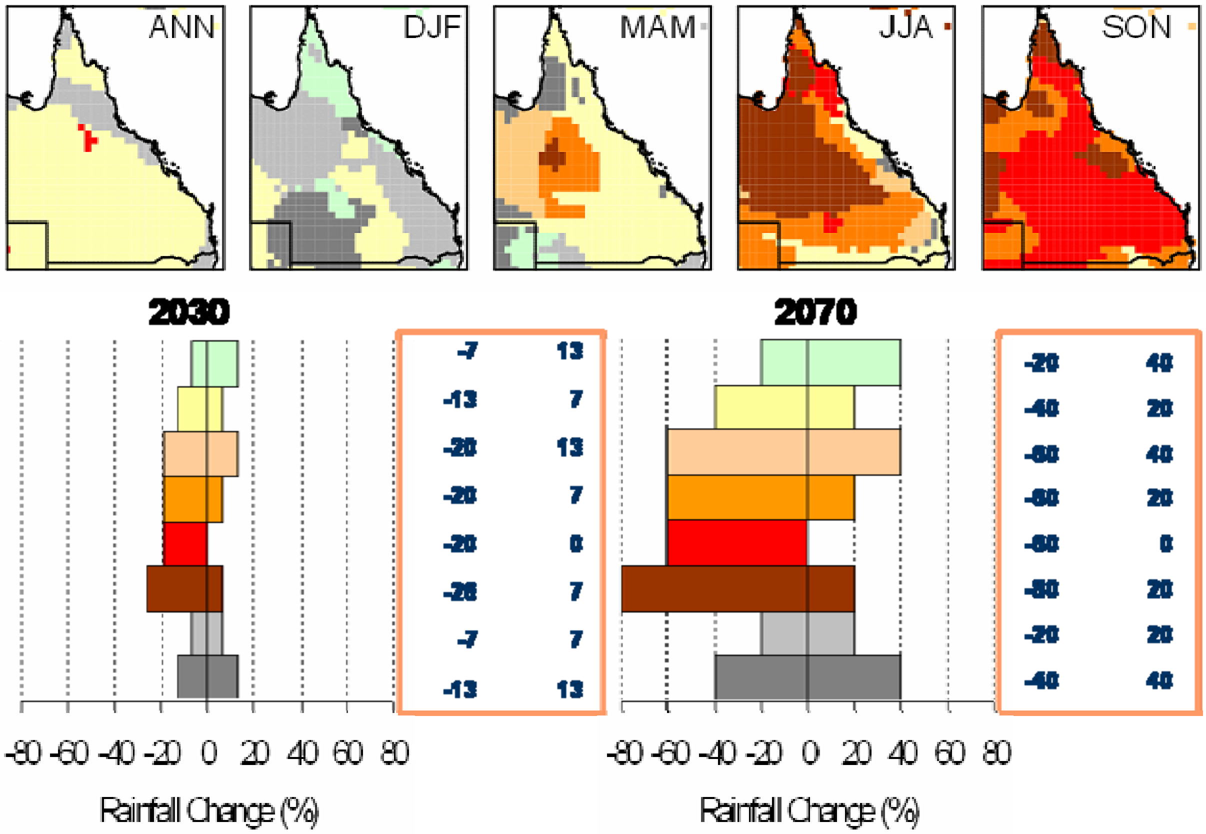

Figure 3. Mean seasonal and annual rainfall projections for Queensland for 2030 and 2070 (Cai, *et al*., 2005).

Climate change in Maryborough

In the Maryborough region there are significant historical trends of increasing temperatures with an increase of almost 1°C over the past 70 years (Fig. 4). These changes are in line with future projections of climate change for both 2030 and 2070: 0.2 to 1.6°C warmer by 2030 and 0.7 to 4.8°C warmer by 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 for Maryborough are presented later in the report (Figs 5 & 6) but in brief, they vary considerably between the Global Climate Models used ranging from an annual change of -1% to about -14% by 2030 and from about -2% to -42% by 2070. It must be noted however that these results do not span the full range of change expressed by all the current GCM models.

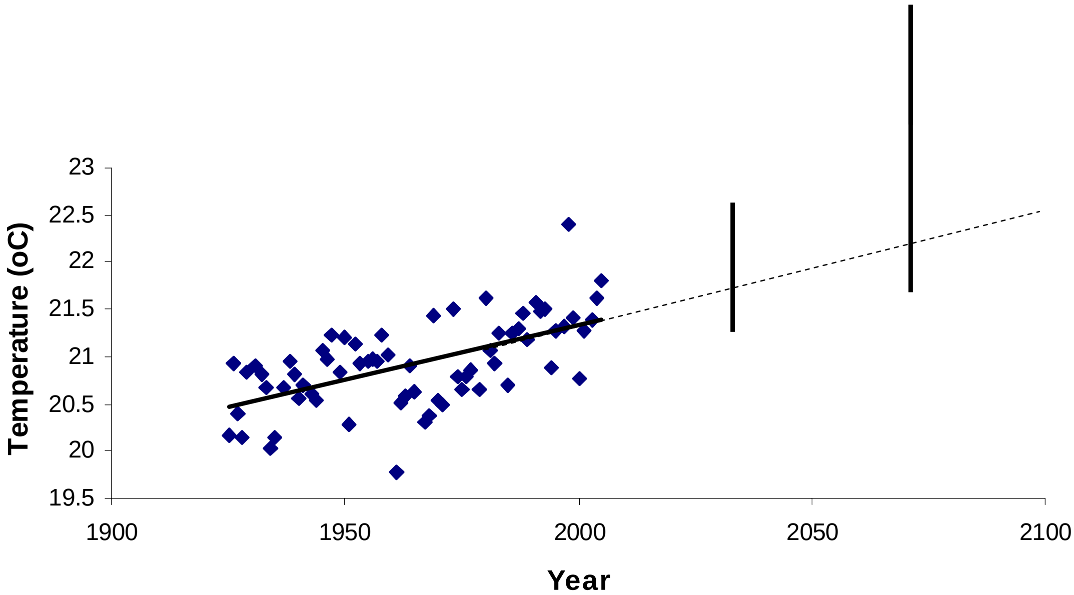

Figure 4. Mean annual temperature for Maryborough from 1930 onwards, with a linear trend included (solid black line). The dotted line is an extrapolation of this trend, intersecting with the range of temperature changes projected for Maryborough in 2030 and 2070 (CSIRO 2001).

Climate change actions in other industries

This section details the likely steps to be included in a climate change assessment conducted by an agricultural industry. It also provides a brief review of climate change impacts and adaptation actions being undertaken in a range of Australian agricultural industries.

Climate change will have significant impacts on agricultural industries. Some of these changes will be positive and some negative. To manage the impact of climate change on agriculture, it will be essential that a clear understanding of what the impacts will be and what, if any, management strategies can be identified and implemented to either take advantage of any potentially positive responses or offset any negative impacts.

In Australia, management responses to climate change have to date generally tended to be based on an extension or enhancement of existing activities aimed at managing the impacts of existing climate variability. There has been a general lack of research and evaluation in terms of the broader costs and benefits of differing adaptation strategies.

Australian agricultural industries are still in the early stages of assessing the impacts and consequences of climate change while already managing production systems within a highly variable climate. Few industries have gone beyond qualitatively assessing impacts and potential response strategies.

The first step in addressing the challenges of climate change for Australian agriculture is to assess the impact of climate change, followed by the development of management and adaptation strategies.

Likely steps involved in impacts and adaptation studies

Steps involved in assessing the impacts of climate change might include identifying current "at risk" production sites and vulnerable industries. This may involve:

- documenting climate change scenarios (based on best available science), including the level of understanding of likely impacts on different industries,
- documenting climate change scenarios for major overseas production regions,
- providing feedback to climate change model outputs and asking if current climate change model scenarios are appropriate for production systems to respond to.

Developing management and adaptation strategies might include:

- Identifying existing management options that can be used to manage both climate variability as well as climate change,
- identifying alternative regions that may be more suitable for production,
- monitoring impacts of ongoing climate variability on existing production systems,
- identifying industry, business or production system strengths with the aim of increasing overall resilience,
- ensuring information on change climate has an appropriate level of input to decision making. This will vary between decisions, *i.e.* shorter term tactical decision making may have little to no climate change input, whilst longer term strategic decisions have a higher level,
- undertaking costs/benefit analysis to identify the potential gains and losses between different management and adaptation strategies,
- identifying barriers to adoption including knowledge gaps and capability barriers.

Brief review of impact and adaptation actions in a range of Australian agricultural industries

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 for a number of major industries in the agriculture sector in Australia. The plant crop industries are classified as cropping, horticulture and vegetables, viticulture, sugarcane and farm forestry. Gazing and intensive livestock have also been included in the review as climate change is likely to impact pasture productivity.

Each of the industries reviewed by Howden *et al*., (2003) reports 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. A brief summary of likely impacts and priorities for climate change adaptation strategies for a range of industries included in the Howden *et al*., (2003) study and a number of other industries is shown in Appendix 1.4.

The following provides a summary of the many potential adaptation options common across the agricultural industries reviewed by Howden *et al*., (2003) . Industry-specific knowledge gaps and priority action areas are not included in these general themes.

Policy: Develop linkages to existing government policies and initiatives (*e.g.* Greenhouse Gas Abatement Program, Greenhouse Challenge, salinity, water quality, rural restructuring) and into integrated catchment management so as to enhance resilience to climate change.

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

Communication: Ensure communication of broader climate change information as well as industry-specific and region-specific information as it becomes available.

Climate data and monitoring: Maintenance of effective climate data collection, distribution and analysis systems to link into ongoing evaluation and adaptation. Monitor climate conditions and relate these to yield and quality aspects to support/facilitate adaptive management. Develop climate projections that can be downscaled so as to be relevant to farm and catchment scale. Consideration could be given to the introduction of climate change adaptation into Environmental Management Systems.

R&D and training: Undertake further adaptation studies that include broad-based costs and benefits to inform policy decisions. Maintain the research and development base (people, skills, institutions) to enable ongoing evaluation of climate/CO_2/(cultivar, species or landuse)/management relationships, and to streamline rapid R&D responses (for example, to evaluate new adaptations or new climate change scenarios). This R&D needs to be developed in a participatory way so that it can contribute to training to improve self-reliance in the agricultural sector and to provide the knowledge base for farm-scale adaptation.

Breeding and selection: Maintain public sector support for agricultural biotechnology and conventional breeding with access to global gene pools so as to have suitable varieties and species for higher CO_2 and temperature regimes and changed moisture availability.

Model development and application: Develop further systems modelling capabilities such as APSIM for crops and AussieGrass and GrazFeed for grazing that link with meteorological data distribution services, and can use projections of climate and CO_2 levels, natural resource status and management options to provide quantitative approaches to risk management for use in several of these cross-industry adaptation issues. These models have been the basis for successful development of participatory research approaches that enable access to climate data and interpretation of the data in relation to farmers own records and to analyse alternative management options. Such models can assist pro-active decision making on-farm and inform policy and can extend findings from individual sites to large areas.

Seasonal forecasting: Facilitate the adoption of seasonal climate forecasts (*e.g.* those based on El Niño and La Niña, sea-surface temperatures, etc) to help farmers, industry and policy incrementally adapt to climate change whilst managing for climate variability. Maximise the usefulness of forecasts by combining them with on-ground measurements (*i.e.* soil moisture, nitrogen), market information and systems modelling.

Pests, diseases and weeds: Maintain or improve quarantine capabilities, sentinel monitoring programs and commitment to identification and management of pests, diseases and weed threats. Improve the effectiveness of pest, disease and weed management practices through predictive tools such as quantitative models, integrated pest management, area-wide pest management, routine record keeping of climate and pest/disease/weed threat, and through development of resistant species and improved management practices.

Nutrition: Adjust nutrient supply to maintain grain, pasture and fruit quality through application of fertiliser, enhanced legume-sourced nitrogen inputs or through varietal selection or management action. Note however, that this may have implications for greenhouse emissions (via field-based emissions of nitrous oxide or emissions of CO_2 during manufacture), soil acidification and waterway eutrophication.

Water: Increase water use efficiency by 1) a combination of policy settings that encourage development of effective water-trading systems that allow for climate variability and climate change and that support development of related information networks, 2) improve water distribution systems to reduce leakage and evaporation, 3) developing farmer expertise in water management tools (crop models, decision support tools) and 4) enhancing adoption of appropriate water-saving technologies.

Landuse change and diversification: Undertake risk assessments to evaluate needs and opportunities for changing varieties, species, management or landuse/location in response to climate trends or climate projections. Support assessments of the benefits (and costs) of diversifying farm enterprises.

Salinity: Determine the impact of climate change (interacting with land management) on salinity risk (both dryland and irrigated) and inform policies, such as the National Action Plan for Salinity and Water Quality, accordingly.

Conclusion

The above brief review highlights the fact that there is unlikely to be no one solution to all the challenges raised by climate change and that the best adaptation strategies are industry-specific and aimed at developing more resilient systems. For Australian agricultural industries to successfully adapt to climate change there will be a need to develop both pre-emptive and reactive adaptation strategies and options. Industries will therefore need to continue to change management strategies to cope with a changing climate in addition to developing and implementing best practice aimed at increases in efficiencies and productivity. Early adaptation strategies, particularly in regard to enhancing resilience, have the potential to significantly reduce the negative impacts of climate change (Howden *et al*. 2004).

It may be argued that currently the best defence in managing the impacts of climate change in any production system, is to improve the ability to manage current climate variability. It can also be argued that it is irrelevant if changes in management are undertaken in response to climate change or the need to remain economically viable – as long as suitable management decisions for that industry in that location are made. See Appendix 1.5 for a list of tools developed for managing climate variability.

Climate change impacts and risks: Maryborough case study

This chapter details projected changes in a range of climate variables for the Maryborough region. Then considers the likely impact of these changes, both quantitatively and qualitatively, on sugarcane production in Maryborough.

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. Model simulations were run using historic climate data amended according to climate change projections 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 sugar industry. This assessment was conducted in participation with local stakeholders at the Regional Climate Change Workshop in Maryborough. Potential adaptation strategies were also discussed with industry stakeholders.

Climate change projections for the Maryborough region

Climate change projections were produced for the Maryborough region by CSIRO Marine and Atmospheric Research (CMAR) (Fig. 5). The methodology used to produce the projections is detailed in Appendix 1.1. Historic climate data for the Maryborough region was amended according to the climate change projections in order to consider mean changes in rainfall (Fig. 6) and temperature (Fig. 7) for the years 2030 and 2070. (Monthly low and high value projections for rainfall and temperature are presented in Appendix 1.6). By modifying climate data by a monthly proportional increase or decrease, we have failed to take into account any change in the intensity of rainfall or changes to the number of rainfall days per year. It is also assumed that there will be no change in either the frequency or intensity of El Niño/La Nina events, whereas predictions suggest that the ENSO cycle is likely to alter in future years. Temperature changes have been equally applied to both maximum and minimum temperatures, despite projections indicating a greater increase to minimum temperatures.

Notwithstanding these limitations and assumptions, the method used to alter climate data in this study offers a pragmatic approach to climate change assessment in the absence of easily applied, more sophisticated methods of producing daily climate data under a future climate.

Projections for other atmospheric and climatic variable are presented in Table 5.

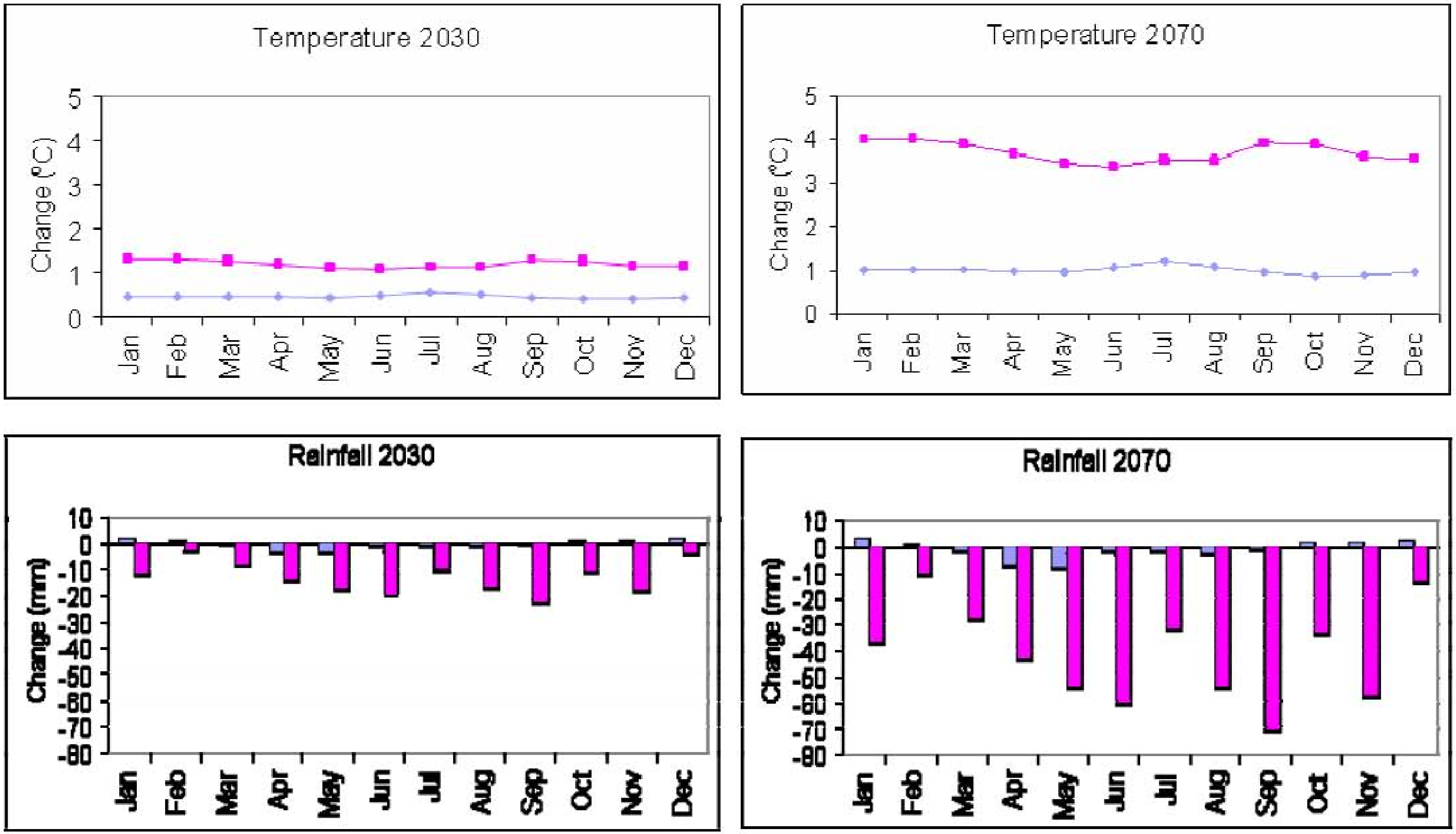

Figure 5. Monthly temperature and rainfall projections (relative to 1990) for the Maryborough region for the years 2030 and 2070 produced by CSIRO Marine and Atmospheric Research (CMAR) using NCAR (blue) and UKMO (pink) climate change models.

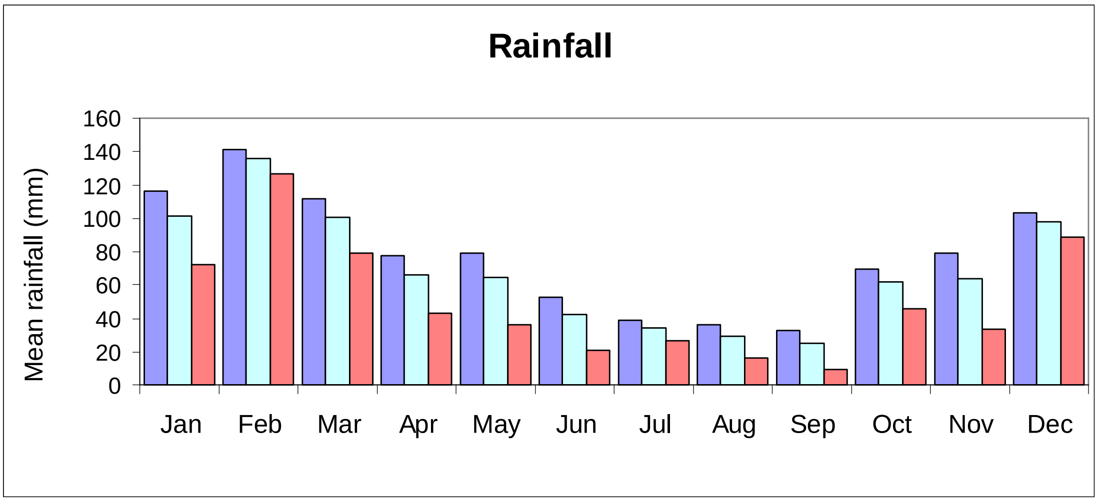

Figure 6. Mean monthly rainfall for the Maryborough region for the years 1979 to 2006 (source: Maryborough Mill) (dark blue). Historic mean rainfall data amended according to CMAR climate change projections for 2030 (light blue) and 2070 (red).

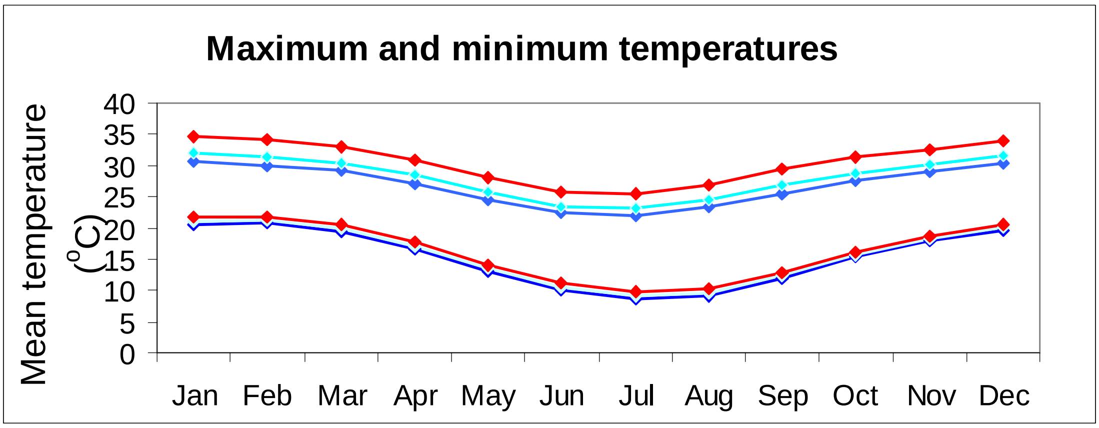

Figure 7. Mean monthly maximum and minimum temperatures for the Maryborough region for the years 1979 to 2006 (dark blue) (source: http://www.bom.gov.au/silo/). Historic mean temperature data amended according to CMAR climate change projections for 2030 (light blue) and 2070 (red).

Table 5. Projections for a range of atmospheric and climatic variables.

Climate variable	Projected change	Source
Atmospheric CO_2 concentration	2030: increase to 425-449 ppm. 2070: increase to 518-702 ppm.	IPCC (2001)
Sea level	Rise by 9 to 88 cm by 2100 (0.8 to 8 cm / decade)	CSIRO (2001)
Potential evaporation	Annual average increase of 0 to 8% per degree of global warming	CSIRO (2001)
El Niño Southern oscillation (ENSO)	Enhanced drying associated with El Niño events	CSIRO (2001)
Tropical cyclones	Locations – likely to be unchanged Intensity - Maximum wind-speeds may increase by 5 – 20% by 2100. Frequency – uncertain (modulated by changes in ENSO and other climate patterns).	CSIRO (2001)

Quantitative assessment of the impacts of a change in temperature and rainfall on sugarcane production

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. Properties for each soil type are detailed in Appendix 1.7.

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/m^2. 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 3 days) occurred. No irrigation was applied for at least 8 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 CO_2 were included in the APSIM simulations. This was done by multiplying the default transpiration efficiency (TE) and radiation use efficiency (RUE) coefficients by the CO_2 factors produced using equations (1) and (2), respectively:

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

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

where CO_2 is the predicted level of atmospheric CO_2 for that year. An atmospheric CO_2 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 1.6). The two models were selected from 15 climate models deemed the most reliable climate models for the Maryborough region (determined by comparing observed and simulated patterns of average temperature, precipitation and mean sea-level pressure. The UKMO and NCAR models roughly represent the 20th percentile (greatest decrease in rainfall) and 80th percentile (least decrease in rainfall), respectively, 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. The climate change projections provided a high and low value to indicate the range within which the climate variable is likely to change by the years 2030 and 2070 (relative to averages calculated for the period 1961 to 1990).

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). Thirty-six 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 5 different values. These were produced by splitting projected low and high value ranges for each model for the years 2030 and 2070 into 4 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 total of 25 scenarios of combined temperature and rainfall change were produced for projections obtained from each of the climate change models. A further simulation was run for no change in temperature and rainfall to provide a present-day baseline for comparison. Examples for temperature and rainfall at 2030 using the NCAR model projections are shown in Appendix 1.8.

No change was made to the frequency in the number of rainfall days. The simulation data for the first 4 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.

Results of APSIM simulations

Mean percentage change in yield for the 80 years simulated was calculated for each of the 25 temperature and rainfall scenarios run for 2030 and 2070. From these the 'best' and 'worst' percentage changes in simulated yield for the NCAR and UKMO model projections are shown in Table 6. The best potential outcome for 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 would be around 8%, whilst potential reductions may be up to 47%.

Table 6. 'Best' and 'Worst' percent 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	Worst	Best	Worst	Best	Worst	Best	Worst
7.4	-0.5	5.3	-3.9	7.9	-7.3	3.7	-46.9

Fig. 8 shows annual cane yields obtained over the 80 years of crop simulations for the 25 climate change scenarios. The simulated data suggests a progressive increase in the variability of cane yields over time, given the projected changes in CO_2, 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 somewhat less than rainfed (as would be expected). The relatively higher temperatures and greater reduction in rainfall projected by the UKMO model have resulted in increased variability under these scenarios compared to the lower-end projections provided by the NCAR model.

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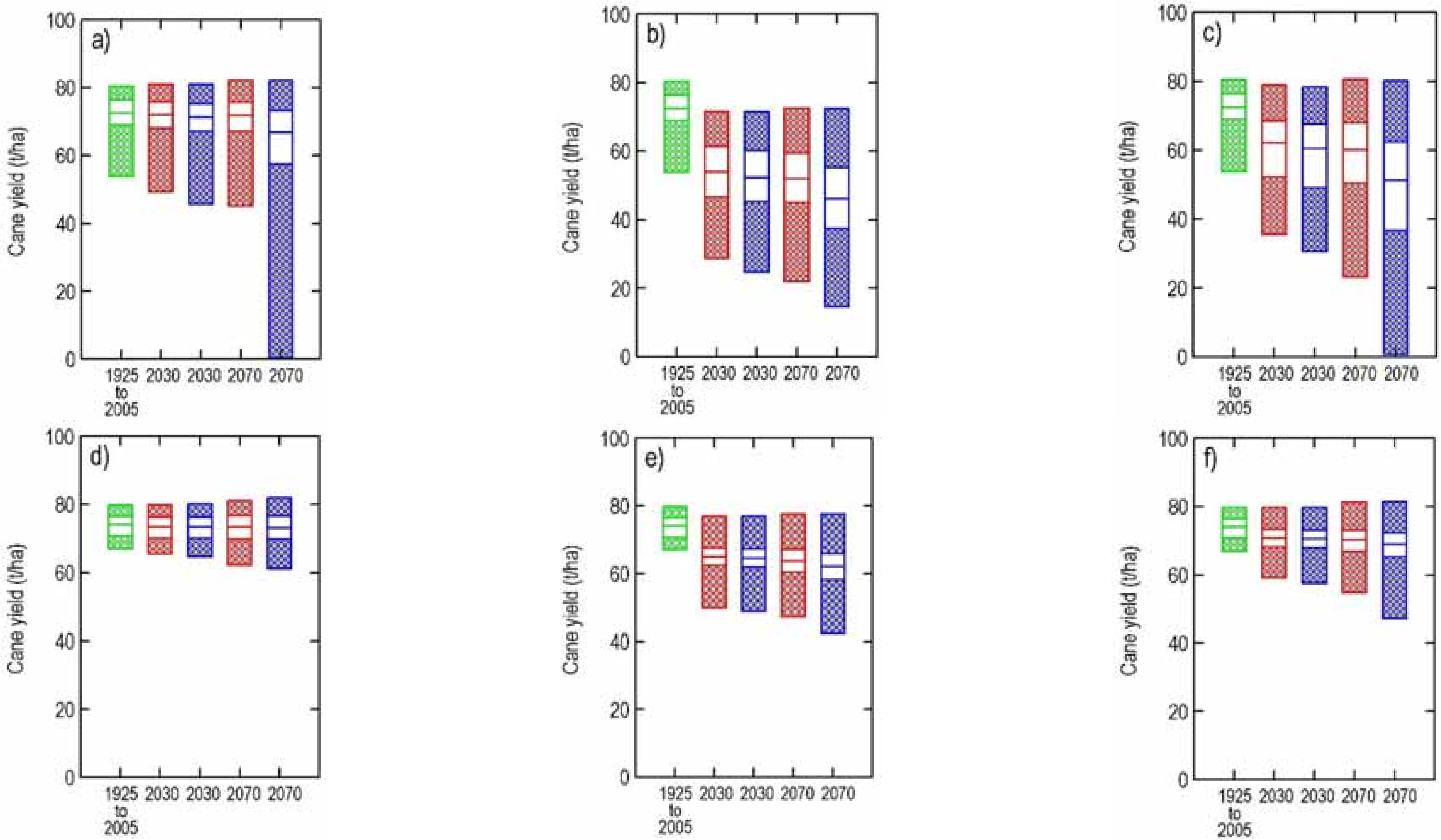


Figure 8. Simulated range of mean cane yields for Maryborough on Bidwill (a,d), Robur (b,e) and Watalgan (c,f) soils, under rainfed and irrigated production, respectively. Period of simulations from 1925 to 2005 (green bar), the single year of 2030, and the single year of 2070. Projections used are from the NCAR (red) and UKMO (blue) climate change models. Centre line in bars indicate median yield and extent of white box indicates the 25th and 75th percentiles.

Probability distributions of yield change (%) for climate changes were identified by the participants at the Maryborough workshops for a) dryland cane on the Bidwill soil and b) irrigated cane on the Bidwill soil (Fig. 9). These graphs cover the full range of changes in temperature and rainfall identified and were translated to yield changes based on historical sensitivity to variations in rainfall and temperature as assessed by APSIM simulations. There is clearly a significant difference between the possible yield changes arising from the GCM-based scenarios and the stakeholder-based scenarios (Fig. 9). The latter are implemented using the stakeholders own assessment of possible climate changes. In this particular instance, it needs to be emphasised that those assessments should be regarded as preliminary and with a too-small sample-size.

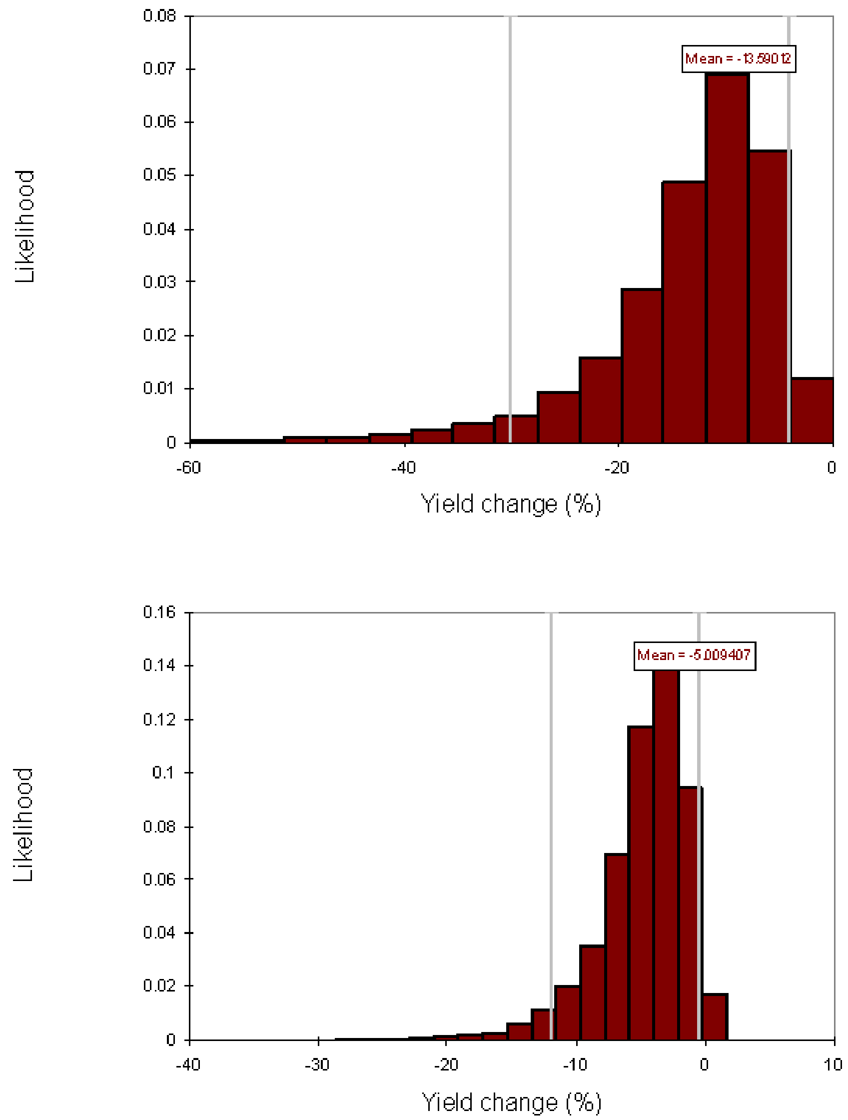


Figure 9. Probability distributions of yield change (%) for climate changes identified by the participants at the Maryborough workshops for a) dryland cane on the Bidwill soil and b) irrigated cane on the Bidwill soil.

Climate change adaptation options

This chapter explores the potential adaptation options available to sugar production in the Maryborough region. The Maryborough region was used as a case study to highlight the impacts of climate change on the multiple sectors of the sugar industry and the need to consider impacts and adaptation strategies throughout the value chain.

Maryborough case study impacts and adaptation responses

Having been presented with the projected changes in climate for the Maryborough region, stakeholders at both the workshop held in Maryborough on 24 January 2007 and in Brisbane on 5 February 2005, were asked to hypothesise as to the likely impacts of a change in various climate variables on sugarcane production in the four sectors of the value chain and consider the potential adaptation actions required to maintain sustainable production. Table 7 summarises the views expressed at these workshops, together with additional feed-back received during subsequent one-to-one discussions with stakeholders.

In order to consider the likely order of the knock-on effects of a change in climate on the value chain, impacts were initially categorised as either ‘primary’ or ‘secondary’. For example, the primary impact of a reduction in rainfall may result in an increase in crop stress, prompting response strategies to be implemented that focus on increased use of irrigation water. Increased use of irrigation was consequently considered by the participants of the Maryborough workshop to have several secondary impacts in the form of reduced variability in yield (assuming sufficient water was available for irrigation), a more predictable throughput across the value chain and increased use of irrigation technologies that favoured low labour input. Impacts were also categorised as either positive (+), negative (-), neutral (x), or, both positive and negative (±).

Table 7 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
Projection: Increase in temperature. **Primary impact:** Increase in daily minimum temperatures resulting in: (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. (-). **Response:** (a) bring growing season forward. (b) implement a longer harvesting season.	**Secondary impact:** Increased duration of the harvest season would require fewer machines to be in operation (reduced capital stock). (+) **Response:** Decrease capital stock accordingly.	**Secondary impact:** Increased duration of the harvest season would require fewer machines to be in operation (reduced capital stock). (+) **Response:** Decrease capital stock accordingly.	**Secondary impact:** Extended duration of crushing season would favour increased continuity of labour. (+) **Response:** None.
Projection: Decrease in rainfall and increase in temperature. **Primary impact:** Reduction in cane yield resulting in (a) the need to diversify into alternative crops (*e.g.* sugarbeet). (±) (b) increasing amounts of household labour focused on generating off-farm income. (±) **Response:** uncertain.	**Secondary impact:** Reduced throughput. (-) **Response:** Look for efficiencies in harvesting (*e.g.* progress the development of harvesting technologies that enable multiple rows to be harvested simultaneously.	**Secondary impact:** Reduced throughput. (-) **Response:** Look for efficiencies in transportation.	**Secondary impact:** (a) Reduced throughput. (-) (b) increased pressure to value-add by producing alternative products from cane. (±) **Response:** (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).
Secondary impact: Less damage to stool of ratoon crop. (+)	**Projection:** Decrease in rainfall during harvest season. **Primary impact:** Crop easier to harvest, less wet-weather downtime, ,improved efficiency, less cane loss. (+) **Response:** None required.	**Secondary impact:** Less wet-weather downtime. More efficient operations. (+) **Response:** None required.	**Secondary impact:** More efficient supply of cane to mill, less down time. (+) **Response:** None required.

Grower	Harvester	Transport	Milling
Projection: Decrease in rainfall. **Primary impact:** Increased moisture stress (particularly during January and February), leading to: (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). (+) **Response:** increase supply of water to the crop through: (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). **Secondary impacts:** Increased use of supplementary water resulting in: (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).	**Secondary impact:** Change in volume of throughput (generally considered to be a reduction). (-) **Response:** As required.	**Secondary impact:** Change in volume of throughput (generally considered to be a reduction). (-) **Response:** As required.	**Secondary impact:** Change in volume of throughput (generally considered to be a reduction). (-) **Response:** As required.
Projection: Decrease in rainfall and increase in temperature. **Primary impact:** Some stakeholders thought CCS would increase, whilst others thought it would decrease. (±) **Response:** undecided.			

Grower	Harvester	Transport	Milling
Projection: Increase in temperature. **Primary impact:** (a) accelerated crop phenology (increased growth during available growing season). (+) (b) extended window for planting. (+) **Response:** Consider planting cane throughout the winter period.	**Secondary impact:** (a) extended harvest season enabling fewer machines to be required (reduced capital stock). (+) (b) increased continuity of labour. (+) **Response:** Decrease capital stock accordingly.	**Secondary impact:** (a) extended harvest season enabling fewer machines to be required (reduced capital stock). (+) (b) increased continuity of labour. (+) **Response:** Decrease capital stock accordingly.	**Secondary impact:** Extended duration of crushing season would favour increased continuity of labour. (+) **Response:** None.
Projections: Decrease in rainfall in January and February. **Primary impact:** increased water stress occurring during the most critical time (early growth). (-) **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). Response: Install irrigation and build on-farm water storage.			
Projection: Decrease in rainfall. **Primary impact:** Greater competition for water from other users in the region (*e.g.* industry, urban, tourism) resulting in: (a) decrease in the quantity of available water. (-) (b) increase in the cost of water. (-) (c) available water diverted to higher value crops. (-) **Response:** uncertain.			

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

In the majority of cases the primary impacts of climate change occurred at the Growers sector, with 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 may then be experienced upstream in the value chain manifesting as a reduction in the amount of damage sustained by the stools of ratoon crops.

In the majority of cases, 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 is obviously a negative impact, whilst any increase would be positive. It is uncertain what will happen to CCS levels in the Maryborough region. This reflected gaps in industry knowledge and the need for further research in order to help plan for future changes in climate.

In some cases a positive impact in one sector may result in a negative impact in elsewhere in the value chain. For example, whilst an extended harvest season may provide benefits to harvesting, transport and milling in the form of a reduced requirement for quantities of capital stock (harvesters, trucks etc), such an impact on the growers sector was considered to be negative, as a greater proportion of crops were therefore likely to be harvested at a time when CCS levels were less than optimal. A potential response to this impact is a revision to the cane payment formula.

In some cases it was not possible to identify appropriate response strategies. This reflected gaps in industry knowledge and the need for further research in order to help plan for future changes in climate. As this scoping study was a first attempt at assessing the effects of climate change and potential adaptation strategies, quantification of the net effect of individual impacts, or the capacity for individual response strategies to ameliorate these, was not considered. However, it was noted that in the case of irrigation, present infrastructure has insufficient capacity to supply enough water to meet crop demand regardless of the availability of water supply.

Extrapolating the impacts of climate change to other sugar-producing regions

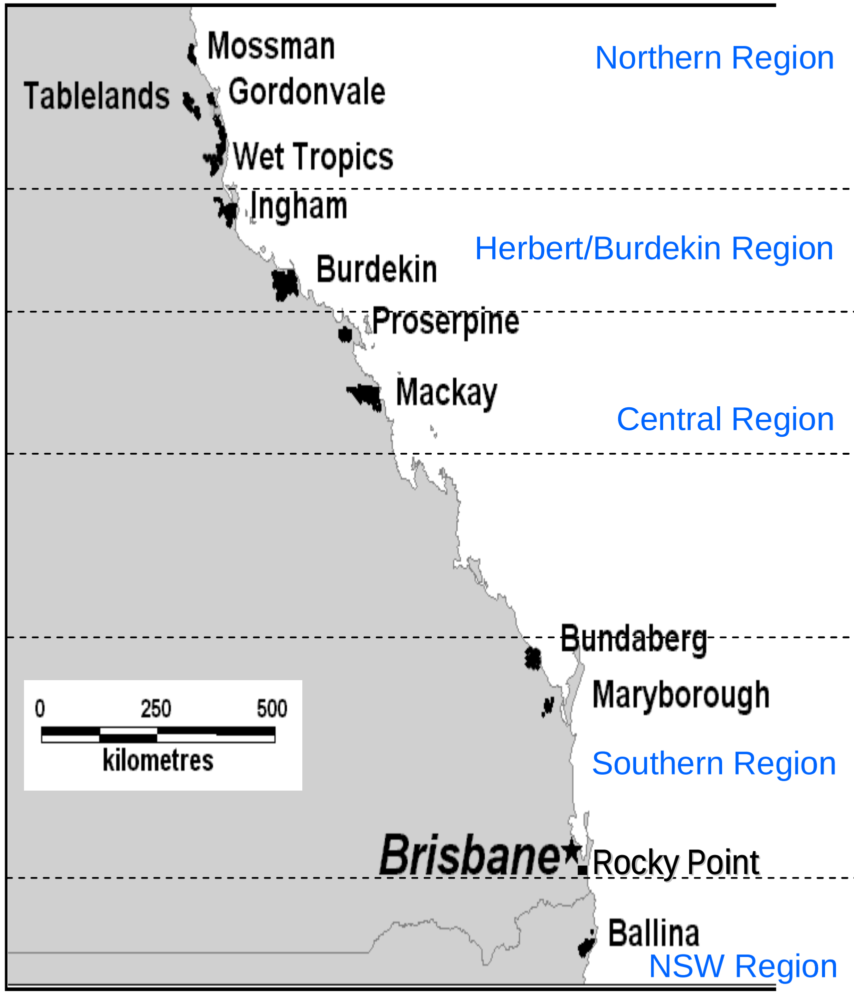
This chapter considers the potential impacts of climate change on all sugar growing regions on the east coast of Australia. The analysis highlights the regional-specific nature of impacts and the range of resulting adaptation responses.

The vulnerability of the sugar industry will be determined by the capacity for adaptation actions to reduce the negative impacts of climate change and capitalise on any potentially beneficial impacts. The following is a qualitative assessment of the broad impacts of climate change on all sectors of the sugar industry on the east coast of Australia and potential adaptation strategies.

Impacts of climate change on all regions

In order to conduct a primary appraisal of the potential impacts of climate change on all 5 sugar-producing regions on the east coast of Australia, stakeholders at the Strategic Vision Workshop were presented with projections of temperature, rainfall and evaporation for each region (Figs. 10 & 11) (Cai *et al.*, 2005). The figures provide a range within which rainfall (%), temperature (^{o}C) and evaporation (%) are projected to change by the years 2030 and 2070 relative to 1990. These projections have been produced using 12 global and regional climate models. As a suite of models have been used to provide a range of future projections, some projections for summer rainfall indicate a simultaneous increase and decrease. However, the majority of the 12 models indicate a likely decrease in annual and seasonal rainfall for all seasons throughout the sugar-growing regions by 2030, and a widespread decrease by 2070, with the exception of summer rainfall in the Northern region.

Table 8 provides a summary of the main present and future concerns/pressures on sugarcane production in each region, particularly those likely to be impacted by a change in climate.



Northern	Spr	Sum	Aut	Win
Rainfall (%)	-20 to 0	-7 to 13	-13 to 7	-20 to 0
Temperature (ºC)	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

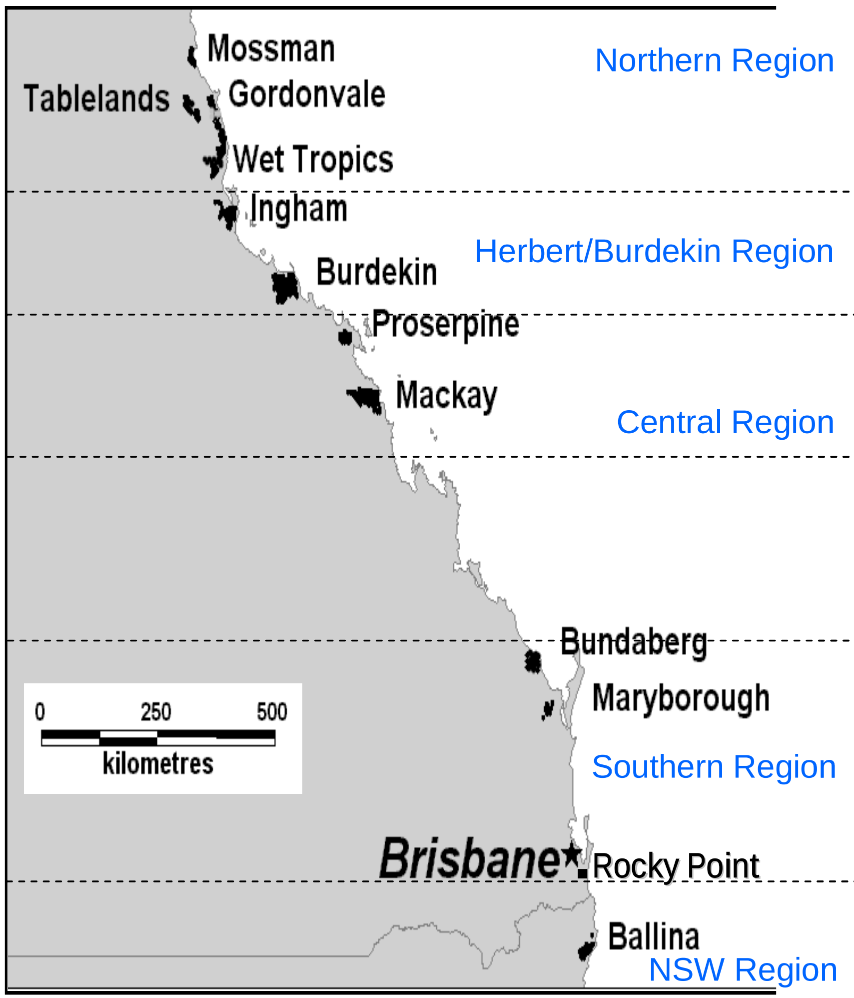
Herbert/Burdekin	Spr	Sum	Aut	Win
Rainfall (%)	-20 to 0	-13 to 13	-13 to 7	-13 to 7
Temperature (ºC)	0.2 to 1.6	0.2 to 1.6	0.2 to 1.6	0.2 to 1.6
Evaporation (%)	1 to 8	0 to 16	0 to 16	1 to 8

Central	Spr	Sum	Aut	Win
Rainfall (%)	-20 to 7	-7 to 13	-13 to 7	-13 to 7
Temperature (ºC)	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	Spr	Sum	Aut	Win
Rainfall (%)	-20 to 0	-7 to 7	-13 to 7	-13 to 7
Temperature (ºC)	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	Spr	Sum	Aut	Win
Rainfall (%)	-20 to 7	-7 to 7	-7 to 7	-13 to 7
Temperature (ºC)	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 10. Projections of temperature, rainfall and evaporation for each of the 5 sugar-growing regions on the east coast of Australia for the single year of 2030. Source: Cai *et al.* (2005).



Northern	Spr	Sum	Aut	Win
Rainfall (%)	-60 to 0	-20 to 40	-40 to 20	-60 to 0
Temperature (ºC)	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

Herbert/Burdekin	Spr	Sum	Aut	Win
Rainfall (%)	-60 to 0	-40 to 40	-40 to 20	-40 to 20
Temperature (ºC)	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	Spr	Sum	Aut	Win
Rainfall (%)	-60 to 20	-20 to 40	-40 to 20	-40 to 20
Temperature (ºC)	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	Spr	Sum	Aut	Win
Rainfall (%)	-60 to 0	-20 to 20	-40 to 20	-40 to 20
Temperature (ºC)	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	Spr	Sum	Aut	Win
Rainfall (%)	-60 to 20	-20 to 20	-20 to 20	-40 to 20
Temperature (ºC)	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

Figure 11. Projections of temperature, rainfall and evaporation for each of the 5 sugar-growing regions on the east coast of Australia for the single year of 2070. Source: Cai *et al.* (2005).

Table 8. Summary of the main present and future pressures on sugarcane production in the 5 regions located on the eastern coast of Australia. The issues noted are those likely to be particularly impacted by a change in climate.

Region	Present constraints	Likely impact of future climate change
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.
	Offsite movement of chemicals to Great Barrier Reef Marine Park.	Likely to increase with the projection of more extreme events (*e.g.* flooding, cyclones).
	Incidence of smut.	Likely to increase as a result of projected increases in temperature.
		Projected reduction in spring rainfall likely to inhibit establishment of ratoon crops.
Herbert / Burdekin	Not presently water limited.	Likely to experience increasing competition for water from Burdekin Dam due to variable climate coupled with human population growth and industrial expansion of Townsville area.
	Rising water table and salinity issues in the channel irrigation areas.	Likely to increase with increased use of irrigation as a result of projected increases in temperature.
	Incidence of smut.	Likely to increase as a result of projected increases in temperature.
	Rising water table.	Likely to be exacerbated/ degraded by projections of sea level rise.
		Projected reduction in rainfall likely to limit recharge of aquifer.
		Projected reduction in winter and spring rainfall likely to increase the efficiency of harvesting.
Central	Experiences limited water supply.	Likely to be exacerbated by projected decrease in rainfall.
	Frost-prone areas in the western districts	Projections of an increase in minimum temperatures likely to decrease frost damage.
	Incidence of smut	Likely to increase as a result of projected increases in temperature.
	Offsite movement of chemicals to the Great Barrier Reef Marine Park.	Likely to increase with the projection of more extreme events (*e.g.* flooding, cyclones).
		Projected increase in temperatures likely to extend the growing season.
		Projected increases in temperatures likely to lessen the chance for ripening, thereby necessitating an increased use of ripeners.
Southern	Experiences limited water.	Likely to be exacerbated by projected decrease in rainfall.
	Crop growth presently limited by low winter temperatures and short duration of growing season.	Projections of an increase in minimum temperatures likely to reduce constraint.

Region	Present constraints	Likely impact of future climate change
	Incidence of smut.	Likely to increase as a result of projected increases in temperature.
	Present competition for land-use from other crops *e.g.* horticulture and tree.	Likely to increase due to the reduced risk associated with growing annual crops compared to the 4-5 year duration of sugarcane.
NSW	Presently low radiation.	Projections of an increase in radiation likely to reduce constraint.
	Presently frost-prone production.	Projections of an increase in minimum temperatures likely to decrease frost damage.
	Crop growth presently limited by low winter temperatures and short duration of growing season (necessitating 2-year crops).	Projections of an increase in minimum temperatures likely to reduce constraint.
	Presence of potential and actual 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.
	Incidence of smut.	Likely to increase as a result of projected increases in temperature.
		Projections for a decrease in the reliability of summer rainfall will reduce crop growth.

The main present and future concerns/pressures on sugarcane production in each region detailed in Table 8 can be categorised into the following:

Impacts associated with other large-scale external drivers

Climate change is one of many large-scale external drivers impacting the present and future sustainability of the Australian sugar industry in its present locations. Many of these drivers are likely to interact with the issue of 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 supplies. Increasing urban encroachment is another external driver that is presently impacting large sections of the sugar industry and is likely to increase in future years. Future projections for the present shortage of agricultural labour, particularly in the Central region, are unknown. Competition from alternative agricultural crops is likely to continue as the projected increase in the variability of climate variables increases the attractiveness of lower risk annual crops.

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 a projected increase in the intensity of cyclone events which is likely to have a greater impact on more northerly regions than Southern and NSW. An increase in more extreme events is likely to increase the environmental impact of agricultural practices within the landscape, for example an increase in the offsite movement of chemicals during flooding and cyclone events. An increased use of irrigation water as a result of reduced rainfall is likely to exacerbate issues with soil salinity and rising water tables. Reduced winter temperatures are likely to favour the spread of diseases such as smut.

Impacts likely to be positive for all regions

A number of factors directly related to a change in climate are likely to positively impact all regions. These include a projected general increase in solar radiation and the associated potential to increase productivity provided other resources are non-limiting. Reduced rainfall during the ‘dry-off’ and harvesting period is likely to improve the efficiency of harvesting operations.

Regionally-specific impacts

A number of factors directly related to a change in climate are likely to impact only a proportion of the regions, or result in varying degrees of impacts from positive to negative across the industry. 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 presently may experience periods of extreme rainfall that constrain productivity. A reduction 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.

Adaptation options

This preliminary study has shown that a range of adaptation strategies will be required to address the challenges of a change in climate. Adaptation to large-scale external drivers, such as urban encroachment and increased competition for water resources, is likely to require whole-of-industry strategic planning and policy development. The interaction of climate change with other external driving factors needs to be more fully understood before this may be possible.

The vast geographic extent of the sugar industry on the east coast of Australia and the broad range of biophysical conditions that the crop is presently grown in, will necessitate that whole-of-industry strategic planning and policy development also consider regional differences and their specific adaptation needs.

The Maryborough case study highlighted the need to consider impacts and the development of adaptation responses in a value-chain context. Table 9 provides a summary of the range of adaptation options considered applicable to the industry sectors in Maryborough, however many of these responses are likely to be applicable to other sugar producing regions in Australia. For a greater exploration of potential impacts and associated adaptation options for the Maryborough region see Table 7.

Table 9. Summary of the potential adaptation strategies that may be implemented by each sector of the Australian sugar industry.

Sector	Adaptation option
Grower	• 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 water supply to the crop through: (e) investment in irrigation infrastructure, (f) increased use of supplementary water through irrigation, (g) installation of on-farm water storage facilities, (h) increased demand for sugarcane varieties with greater water use efficiency/drought tolerance (including genetically modified varieties) (i) increased efficiency in irrigation technologies (*e.g.* trickle tape) (j) increased use of irrigation technologies requiring a low input of labour (*e.g.* centre pivot). a. Consider pest strategies presently used by more northerly regions to assess efficacy of pest control responses.
Harvester	• Look for efficiencies in harvesting operations (*e.g.* progress the development of harvesting technologies that enable multiple rows to be harvested simultaneously). • Track reductions in crop yield with concomitant decreases in capital stock.
Transport	• Look for efficiencies in transport operations. • Track reductions in crop yield with concomitant decreases in capital stock.
Milling	• Look for efficiencies in milling operations (*e.g.* reduce over-capacity to a minimum, optimise crushing rate. • Offer financial incentives to growers to increase productivity (*e.g.* transport assistance, water availability, leasing of land).

This study has shown that the vast majority of climate change impacts are likely to occur in the Growers' sector, and will manifest in a change in crop productivity. As a consequence of the structure of the sugar industry value chain, the greatest capacity for adaptation ultimately lies with the Growers' sector. The responses given by the industry stakeholders at the two workshops suggests that adaptation options will require an extension or enhancement of the present practices used to manage the variable climate. The adaptation strategies identified for the Growers' 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 cascades through the sugar value chain, all subsequent sectors will be impacted by a change in the quantity of throughput. The Harvester, Transport and Milling sectors must therefore focus their adaptation strategies on developing greater flexibility to respond to changes in throughput by varying capital stock and operations to maintain optimal efficiency.

Assessment of value chain impacts

Here we considered the potential impacts from a change in climate occurring beyond the farm gate, with consideration to the industry activities of harvesting, cane transport, milling, sugar transport and storage/marketing.

Due to the complexity of the sugar value chain, a detailed analysis was not undertaken as per the farming sector in the previous sections. This was necessary as at a whole value chain level it is difficult to highlight the full range of climate change impacts that are likely to occur, as well as separate out the effects of climate change from other large-scale external drivers.

This section details feedback on value chain impacts gained from the Strategic Vision and Maryborough Climate Change Workshops. The feedback at these workshops tended to focus mainly on incremental changes in production operations and productivity. We have therefore also included some more radical impacts in the analysis in this section.

Qualitative assessment of the impacts of climate change on the value chain
Some of the key categories of impacts for the value chain have been identified as:

1) Flow on effects from changes in sugarcane yield and the inter-annual variability of these yields;
2) Changes in disruptions and economic risks from increased climate variability and increased extreme events;
3) Changes in economics of scale in growing harvesting and milling;
4) Changes in the resilience of the industry players and their ability to produce products from sugarcane in a sustainable manner;
5) Changes to external drivers that affect the Australian sugar industry. This includes price of energy, sugar, and carbon trading;
6) Changes in subsidised and protected markets operating in other sugar producing countries.

The extent of the above impacts can range from incremental, to a complete industry restructure, diversification, or closure of some major sugar producing regions. On an activity basis, the following have been identified as some of the potential key impacts:

Harvesting:
1) There is the potential for increased variability of wet weather disruptions throughout the harvest season. To adapt to this, harvesting contractors will likely seek greater migration flexibility.
2) A lower cane yield from climate change will increase costs of harvesting on a per hectare basis, and a probable reduction in the number of harvesters to achieve a viable cost per tonne of cane.
3) Since the sugar industry is a "push chain", the above impacts on harvesting will demand greater flexibility in transport and logistics at the harvesting-transport interface. Without this, there would be a substantial increase in knock-on delays to harvesters due to increased logistical difficulties.

4) There may also be major changes to harvesting technologies in infrastructure to adapt to crop size or changes in products produced from sugarcane (*e.g.* electricity, animal feed).

Cane Transport:

1) The impact of climate change on cane transport itself may be incremental (*e.g.* increased costs per tonne of cane), and will instead be affected by changes upstream in the chain (*e.g.* increased shifting of harvesters across the district).
2) If the suitability of sugarcane growing land changes substantially around a mill area, the average distance of travel to the mill may increase substantially, thus leading to a major increase in transport costs.
3) An increased attractiveness towards transport options with reduced greenhouse emissions per tonne of cane, may also mean changes in the vehicles used.

Milling:

1) Increased temperature would lead to increased use of air conditioning and therefore increased the use of energy. More energy would be required to cool water required in processing (increased expense and efficiency).
2) A reduced cane yield would lead to a shorter harvesting season and less efficient use of milling capital and possibly more difficulty in maintaining the seasonal workforce. This would put pressure on the mill to either close or become a multi-purpose mill producing other products from cane and alternative crops (*e.g.* building materials).
3) Projected increases in extreme weather events would increase major down time events for the mill (including damage) which would extend season length and increase the risks of not being able to harvest all of the cane during the season.
4) A projected increase in the frequency of extreme events may reduce the mill's ability to recover from these events, since financial reserves to recover from such events would deplete more rapidly. This may also have stock market impacts on milling companies, with investors shifting to lower risk options.
5) One potential benefit of climate change would be the increased requirement for green energy production alternatives, such as cogeneration from sugar milling and efficient biomass incineration. Renewable energy credits value may increase to make whole crop harvesting for the co-generation of energy a viable secondary or even primary function for sugar mills.

Storage and Marketing:

1) If climate change leads to a more variable inter-annual sugar yield, it would reduce the efficiency of use of sugar storage facilities in the ports, making it more difficult to guarantee supply levels to international customers.

Whilst storage and marketing is not the end of the value chain, about 80% of Australian raw sugar is currently exported. This may change substantially depending on the future size of the Australian sugar industry and the domestic demand for alternative energy from sugarcane. Since most Australian sugar is exported, this report has not considered the impacts of climate change on the food manufacturing and retail/consumer sub-chains.

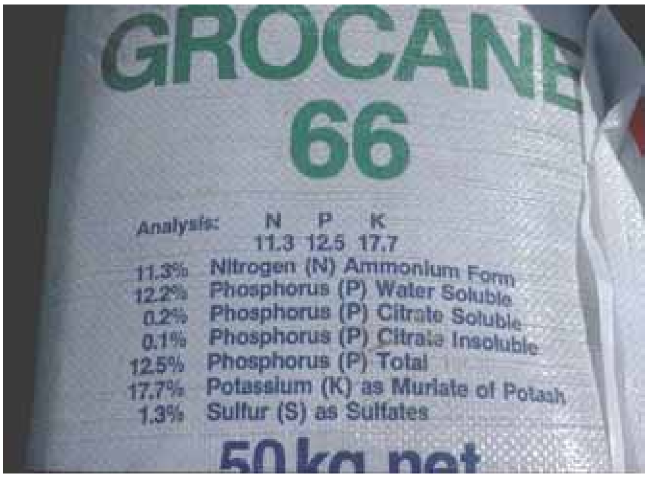
Quantitative assessment of the impacts of climate change on the value chain
Using the Maryborough case study, we conducted a preliminary analysis on the incremental impact of changed sugarcane production on the remainder of the chain. We looked at the impact of three scenarios: base case (2003), 2030 and 2070. For the 2030 and 2070 scenarios, the changes in cane yield were estimated at -3.9% and -46.9% respectively, (these changes in yield were produced using APSIM simulations and the UKMO climate change model). With the reduced cane yield for 2030 and 2070, the mill throughput rate, tonnes of cane per hour (tc/hr), was assumed to not change.

The analysis was conducted using the value chain model developed in the SRDC project CSE010 (Archer *et al.*, 2004; Thorburn *et al.*, 2006) which captures adequate biophysical detail, is comprehensive in modelling social aspects and is developed rapidly for the region being modelled. For this preliminary analysis we considered the harvesting and cane transport only, with the milling activity requiring further modelling and simulations beyond the scope of this scoping study. Table 10 shows the percentage change in costs associated with harvesting and transport relative to the year 2003. Whilst overall harvesting costs decreased with the climate change scenarios (as one would expect), the cost per tonne of cane increased. This is due to reduced harvesting efficiency and lower returns on harvesting capital. The impacts per tonne of cane are not as big as those for transport, since the Maryborough region is based on road transport and can readily increase or reduce capacity with minimal cost. This would not be the case where rail transport is used. Results can be enhanced through greater input from sectors to capture management responses to radical changes in production.

Table 10. Preliminary analysis for climate change impacts in Maryborough in terms of total and per tonne of cane (tc) costs.

	% Change from 2003				
	Tonnes	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

Knowledge gaps, policy changes and future R&D funding



To help inform the allocation of future research and development funds, participants at both the Regional Climate Change Workshop (Maryborough) and Strategic Vision Workshop (Brisbane) were asked to consider present gaps in knowledge that were likely to constrain their ability to fully evaluate the potential impacts, risks and adaptation options relating to climate change.

The participants were also asked to consider areas where a future change in policy would be required to enhance the resilience within the sugar industry to face the challenges of a future change in climate. The focus of all discussions with stakeholders was on maintaining, and/or increasing, the sustainability of the sugar industry in its present locations.

The knowledge gaps and policy areas identified by the stakeholders and the project team as being required to maintain, or increase, production, have been categorised into those aimed at:

- Improving tactical response strategies,
- Enabling sustainable management of sugarcane in the wider landscape,
- Building stakeholder capacity and resilience,
- Managing water and sea level rise,
- Policy adjustments.

Improving tactical response strategies

- Need for a better understanding of the influence of different environments and management practices on the performance of individual varieties. Assessment of whether models (such as APSIM) could be used to help quantify the G x E interaction.
- As the complex genome in sugarcane is likely to inhibit progress with the breeding of more water use efficient/drought tolerant varieties, direct efforts into the use of traditional breeding methods to identify useful markers for these traits.
- Need to consider present SRDC project proposals (*e.g.* one related to drought resistance) to include a climate change component.
- Increased exploitation in breeding program of presently known genetic diversity for transpiration efficiency (unpublished data) and ratooning ability in sugarcane.
- Increased understanding of incidence of pests and diseases to accompany present efforts in breeding program.
- Identification of alternative geographic locations that would enable the production of sugarcane.
- Better understanding of the timing of implementation required for response strategies to be implemented (need further quantification of impact on yield and the identification of physiological thresholds in the cane plant).
- Evaluate a range of potential adaptation options for their utility in reducing the risks, or taking advantage of climate change impacts. Include consideration of broader costs and benefits and compare these to a “business as usual” scenario.

- Extend impact and adaptation analysis to all regions of the sugar industry to identify key areas of vulnerability.
- Improved understanding of determinants of CCS in order to better predict levels under a changed climate.
- In order to maximise potential gains from CO_2 fertilisation and increased temperatures, undertake fundamental sugarcane physiological studies to quantify the relationship between atmospheric CO_2 concentration, temperature and crop growth.

Enabling sustainable management of sugarcane in the wider landscape

- Assessment of present best management practices in light of climate change projections to consider if modifications or the development of novel practices are required to maintain an environmentally and economically sustainable industry.
- Improved assessments of response strategies to quantify production and environmental effects of changes in practices.
- Consider how changes in climate are likely to affect the efficiency of nitrogen fertilisers and consider ways to enhance best management practices to reduce offsite effects.
- Assessment of the ecosystem services provided by sugarcane production and the better promotion and provision of these to wider society under a changed climate. Particular focus to be given to carbon sequestration.
- Assessment of the potential for further encroachment of urban development on sugarcane production areas in the face of climate change (anticipated movement of increased populations to the coastal regions).
- Identification of alternative/additional suitable areas of land for sugarcane production.

Building stakeholder capacity and resilience

- Assessment of the resilience of the industry, its thresholds of resilience, and how this will be impacted by increased extreme events from climate change.
- Increase capacity within the sugar community (through policies and mechanisms to provide technical and financial support) to interpret climate change projections, assess impacts at a farm and regional value-chain level, and develop and implement response strategies in a timely manner.
- Maintenance of effective climate data collection, distribution and analysis systems to link into ongoing evaluation and adaptation. Monitor climate conditions and relate these to yield and CCS aspects to support/facilitate adaptive management.
- Develop climate projections that can be downscaled so as to be relevant to farm and regional scales.
- Further develop systems modeling capabilities, such as APSIM, to assist pro-active decision making on-farm and inform policy. For example, link systems modeling with meteorological data distribution services and use projections of climate and CO_2 levels, natural resource status and management options to provide quantitative approaches to risk management.
- Assess the potential impacts of climate change on industry infrastructure.
- Gain a greater understanding of seasonal climate variability and apply this to improve marketing strategies.
- Investigate alternative and/or additional crop species suitable for production on sugarcane assignment land.
- Undertake quantitative and qualitative market research to identify and understand the current knowledge, attitudes, and beliefs of industry stakeholders towards climate change. This information would provide a baseline from which to design and implement effective communication strategies to raise awareness, relate industry-specific and regional-specific information as and when it becomes

available and encourage the necessary behavioural adaptations among industry participants.

Managing water and sea level rise

- Undertake an assessment to identify the risks of a rise in sea level to the sugar producing regions. Quantify the risk of flooding, and intrusion of sea water into coastal aquifers.
- Estimate future demand for water by the industry in relation to potential supply.
- Promote increased use of seasonal forecasting to estimate levels of stream flow and hence amounts of allocation water provided to growers together with increased use of irrigation scheduling.
- Improved communication and the development of increased incentives offered to growers to encourage the use of more water efficient technologies.
- Promote increased water use efficiency by a) a combination of policy settings that encourages the development of effective water-trading systems that allow for climate variability and climate change and that support development of related information networks, b) improve water distribution systems to reduce leakage and evaporation, c) develop farmer expertise in water management tools (crop models, decision support tools), and d) enhancing adoption of appropriate water-saving technologies.
- Determine the impact of climate change (interacting with land management) on salinity risk (both dryland and irrigated) and inform policies, such as the National Action Plan for Salinity and Water Quality, accordingly.

Policy adjustments

- Reconsideration of the current mandate for 10% ethanol in petrol and other renewable energy targets (as detailed in the Mandatory Renewable Energy Target (MRET) scheme).
- Need for comprehensive life cycle assessment to enable the consideration of potential mitigation strategies for all sectors and the opportunities available for the sugar industry to participate in a carbon trading market in future years.
- Identification and development of a diverse range of products that can be derived from sugarcane (*e.g.* sugar, biomass, fermentables). Consideration of the necessary re-organisation of the industry (at a regional scale) to facilitate this.
- Assess the climate change impacts on Australia’s competitors (*e.g.* Brazil, India, Thailand) and the interactions with trade policy, to consider future changes in international competitiveness relative to the Australian industry.
- Undertake a macro-economics assessment of how global climate change will impact the international demand for sugar and ethanol, interact with trade policy and impact international prices.
- Explore linkages to existing government policies and initiatives (*e.g.* Greenhouse Gas Abatement Program, Greenhouse Challenge, salinity, water quality, rural restructuring) to enhance resilience to climate change.

The participants at the Strategic Vision workshop were asked to identify what they considered to be the most critical topic for future research and development. Table 11 shows the topics in descending order of perceived importance.

Table 11. Most critical topics for future research and development as voted for by 16 industry stakeholders.

Topics for future research and development	Number of participants voting topic as top priority
Breeding for greater water use efficiency and/or drought tolerance	High (more than 4)
Economics of best management practice	
Basic plant physiology on response of the crop to increased CO_2 and temperature	Medium (between 2 and 3)
Greater understanding of C-balance associated with sugar production (relate this to ecosystem services provided)	
Relative impact of climate change on regions and international competitors	
Audit of greenhouse emissions / mitigation options (relate to carbon trading markets)	Individually noted issues
Effects of climate change on industry infrastructure	
Impacts and risks of sea level rise	
Greater understanding of seasonal variability in climate (and application of this to marketing)	
Investigation into additional/alternative crops to sugarcane	
Identification of other locations suitable for sugarcane production	
Further assessment of the opportunities / threats/ risk associated with climate change	
Communication of climate change projections, potential impacts and risks	

The ranking exercise conducted by the participants at the Strategic Vision workshop highlights the different perceptions held both within and across the multiple sectors of the sugar industry regarding the most critical areas for future research and development funding.

Clearly, when deciding on which areas will receive funding, a distinction must be made between those topics necessitating a relatively large investment of R&D funding over a long time, such as breeding of improved water use efficiency and/or drought tolerance cultivars, and those topics that are likely to be relatively inexpensive to accomplish and offer outcomes in the nearer future, such as those related to communication.

It is noted that many of the research areas mentioned above are already the recipients of research funding from R&D organisations and, whilst much knowledge is yet to be gained, a substantial amount is presently in the public domain. As a change in climate is anticipated to be progressive, an iterative approach will be required to continually identifying knowledge gaps, policy change requirements and future topics for R&D funding.

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Appendix 1.1: 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 (110-155ºE, 11-45ºS) 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 future 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 1.2: List of participants at the Regional Climate Change Workshop, Maryborough, 24 January 2007.

Project Team
Sarah Park, Cropping Systems Scientist, CSIRO, Toowoomba
Mark Howden, Research Scientist, CSIRO, Canberra
Andrew Higgins, Operations Research Analyst, CSIRO, Brisbane
Dave McRae, Climatologist, QDPI, Toowoomba

CANEGROWERS
Jeff Schmidt
Alan Otto
Ashley Petersen
Jeff Atkinson
Trevor Turner
Tony Coutts-Smith

Maryborough Sugar
Peter Downs
Trevor Crook
Dennis Kaye
John Burman
Yolande Lambert

Maryborough Cane Productivity Services
Frank Sestak
Penni Hetherington

SRDC
Claire Power, Communications Manager
Diana Maldonado, Investment Manager

Appendix 1.3: List of participants at the Strategic Vision Climate Change Workshop, Brisbane, 5 February 2007.

Project Team
Sarah Park, Cropping Systems Scientist, CSIRO, Toowoomba
Mark Howden, Research Scientist, CSIRO, Canberra
Andrew Higgins, Operations Research Analyst, CSIRO, Brisbane
Dave McRae, Climatologist, QDPI, Toowoomba

CANEGROWERS
Bernard Milford (Senior Manager – Policy)

Queensland Sugar Limited
Lee Gordon (Marketing Manager)

BSES
Ross Gilmore (Manager, Research and Development)
Graham Kingston (Principal Scientist)
Xianming Wei (Researcher)
Robert Aitken (Senior Extension Officer, Harwood)

Sunshine Sugar
Rick Beattie (Manager, Agricultural Services)

Land and Water Australia
Colin Creighton (Program Coordinator, Managing Climate Variability Program)

CSIRO
Geoff Inman-Bamber (Sugarcane Systems Agronomist)
Geoff McDonald (Regional Planner)
Heidi Horan (Research Officer)
Di Prestwidge (Systems Analyst)

SRDC
Diana Maldonado (Research and Development Investment Manager)

Sugar Milling Council
Jim Crane

Queensland Department of Primary Industries/ University of Southern Queensland
Roger Stone (Chief Climatologist, QDPI & Associate Professor (Climatology), USQ)

Queensland Department of Natural Resources, Mines and Water
Pushpa Onta (Principal Project Officer (Strategic Water Initiative))

Appendix 1.4: Brief summary of likely impacts and adaptation strategies for a range of agricultural industries

Cropping (Howden *et al*., 2003)
Impact:
No quantitative data is presented, however it is noted that the industry is highly sensitive to climate with both wet and dry years causing substantial fluctuations in regional yield and grain quality. Drought conditions can halve yields and whilst irrigation is practiced in some regions to reduce the fluctuations caused by dry years, even irrigation cannot remove climate risks due to reduced allocations. High rainfall years can cause problems with water-logging, flooding, rain and hail damage, higher pest and disease loads and intermittent recharge of water to groundwater tables.

Response strategies:
- Develop further risk amelioration approaches (*e.g.* zero tillage and other minimum disturbance techniques, retaining residue, extending fallows, row spacing, planting density, staggering planting times, erosion control infrastructure) and controlled traffic approaches – even all-weather traffic.
- Research and revise soil fertility management (fertilizer application, type and timing, increase legume phase in rotations) on an ongoing basis.
- Alter planting rules to be more opportunistic depending on environmental condition (*e.g.* soil moisture), climate (*e.g.* frost risk) and markets.
- Develop warnings prior to planting of likelihood of very hot days and high erosion potential.
- Selection of varieties with appropriate thermal time and vernalisation requirements, heat shock resistance, drought tolerance (*i.e.* Staygreen), high protein levels, resistance to new pest and diseases and perhaps that set flowers in hot/windy conditions.

Horticulture and vegetables (Webb *et al*., 2003)
Response strategies:
- Change varieties so they are suited for future conditions and re-assess industry location.
- Research on altering management to change bud burst, canopy density etc in fruit trees.
- Undertake risk assessment to assess sustainability in more marginal areas (e.g chilling requirements).

Viticulture (Webb and Barlow, 2003)
Impact:
Global warming will hasten the progression of the phenological stages of the vine so that ripening will occur earlier. For example, in the warmer viticulture regions (*e.g.* Swan Valley (WA), Sunraysia, Riverina, Hunter Valley), higher ripening temperatures will allow for an even shorter window from which to determine the optimum harvest time. In intermediate climates the season will begin earlier and phenological stages will be accelerated leading to ripening in the earlier hotter months with the chance of reduced quality. In cooler climates (Tasmania, Mornington Peninsula) global warming may allow varieties that are marginal now, to be grown and ripened more fully.

Response strategies:
- Change varieties of grapes grown in a region and look for new sites.
- Undertake risk assessment to assess sustainability in more marginal areas.
- Analyse chilling requirement.

- Assess vine management needed for CO_2-induced increased growth and changed water requirements.
- Assess vine and water management to reduce variability in yield and quality.
- Modify management of the inter-row environment. This will vary between regions.

Farm forestry (Booth *et al*., 2003)
Impact:
Any reduction in rainfall, as seen in various climate change scenarios, coupled with increased water requirements in a warmer climate, is likely to lead to increased tree mortality and represents the major concern for tree plantations in Australia. Based on summarising all available evidence, it is expected that the growth of poplar trees may be stimulated by about 30% by doubling CO_2 concentration. As water use efficiency can be greatly enhanced by increased CO_2 concentration, relative plant responses to increases in CO_2 should be most pronounced under water-limited conditions. In modelling studies, the simulated responses to climate change differed greatly across the continent. For example, positive growth responses to increasing temperature were found in wet and nutrient-limited regions. However, these same regions showed only slight responses to increased CO_2 concentration.

Response strategies:
- Develop detailed assessment of drought tolerance of important species.
- Improve knowledge of the climatic requirements of particular genotypes.
- Identify the optimal strategy between high growth (*e.g.* dense stands with high leaf area) and risk aversion (*e.g.* sparse stands with low leaf area) for particular sites and particular trees/products.
- Evaluate changes to establishment strategies as a result of climate changes.
- Assess vulnerability of species planted near their high-temperature limit.

Livestock industries – grazing and intensive (Crimp *et al*., 2003; Jones and Howden, 2003)
Impact: No quantitative data is presented, but it is predicted that anthropogenic climate change will have very different impacts on the grazing industry across Australia given the range of pasture productivity, herbage quality, pests, diseases and weeds, botanical changes in native pasture species, soil erosion and animal husbandry and health found across the nation. However the key determinant of impact will be changes in the timing and the extent of rainfall. For example, as regional rainfall in southern Australia is projected by some models to reduce by more than 10% in winter and spring, forage, and hence animal, production would be expected to decline even taking into consideration carbon dioxide (CO_2) fertilisation effects. In northern Australia, where consensus model projections show little change in simulated summer rainfall (the main growing season for pastures in that area), positive impacts on plant production could be anticipated.

Response strategies:
- Research and promote greater use of strategic spelling.
- Development of regional safe carrying capacities *i.e.* constant conservative stocking rate.
- Modify timing of mating based on seasonal conditions.
- Research into intensive livestock management in tropical environments particularly dealing with heat stress management.

Cotton
The Australian Greenhouse Office and Cotton Catchment Communities CRC funded project *Climate Change in Cotton Catchment Communities – A Scoping Study* has been developed with two main objectives in mind; to increase understanding of climate change in the cotton industry, and to develop an agreed industry position relating to options for adaptation.

Key outputs from this project include:
- A summary of current knowledge on climate change impacts for cotton industries and cotton-based communities in Australia
- Improved understanding and awareness of climate change issues among the cotton community, including potential impacts and possible future needs of the industry
- Improved understanding within Government of the risks and opportunities associated with climate change for the cotton industry
- Possible adaptation strategies for the cotton industry to respond to climate change
- Improved likelihood that the cotton industry and communities will be able to position themselves to respond favourably to climate change.

An issue raised as part of this project is the need to further develop detailed economic analysis of the impact of climate change on the Australian and global cotton industry. Developing a better understanding and ability to take advantage of CO_2 fertilization and its effects on yield has also been raised.

The general lack of readily available detailed information to support decision making has lead to a request by cotton industry participants for the development of more specific industry reports with emphasis on the whole production system – growing/water supply/ginning/shipping/international trade/economic impact etc.

Rice
The Australian Greenhouse Office has produced reports such as *Australian Rice Growers: Meeting the Greenhouse Challenge* and *Opportunities for Australian agricultural industries to adapt to climate change: Intensive livestock.* These publications present information in an easy to read format and are generally aimed at the production end of the system chain.

The reports present background information on the specific industry (location, size, economic worth), regional projections of climate change, exposure of that industry to climate change and some potential adaptation options. Case studies are used to highlight how existing enterprises are already managing for a changing climate.

Examples of potential adaptation strategies from the rice industry case studies include:
- Change of farm layout to reduce energy input from machinery use.
- Changes in stubble management to increase water use efficiency and improve soil structure, reduce fertiliser input and increase nitrogen and phosphorous fixation. Instead of being burnt excess stubble can be baled and sold off farm. This also maximises the value per megalitre of irrigation water.
- Changes in crop establishment and management such as minimum till and controlled traffic systems. This minimises soil carbon losses, improves soil aeration and reduces greenhouse gas emissions associated with machinery use.

Intensive livestock

Examples of potential adaptation strategies from the intensive livestock case studies include:

- Heat stress has a detrimental impact on milk production and livestock weight gain, egg production and quality and increase animal susceptibility to disease. Adaptation strategies include undertaking milking and other animal husbandry practices in the early morning and afternoon, genetic improvements aimed at increasing heat tolerance in herds, improved diet quality to reduce heat increment loading, modifying design of animal housing and pans to increase space and reduce animal density, improve airflow and access to water, and the general improvement of infrastructure such as shade structures and vegetation management.
- Ensuring water storages can handle changes in rainfall variability and supplies meet peak requirements
- Ensuring an adequate and reliable supply of high quality feed. Climate variability and change has the potential to create large challenges with fodder and grain supply. Potential adaptation strategies include the improvement of on-farm storages (buy feed when prices are cheaper/readily available), changes in enterprise structure (grazing and cropping dairy enterprise to a feedlot dairy), relocation and/or expansion.

Many of these adaptation strategies can be expanded into other agricultural industries. For example the need to ensure the supply of high quality feed may lead to changes in grazing systems from a set stocking rates to a more responsive spell or cell grazing system. The expansion of minimum till and controlled traffic systems has much to offer broad acre cropping through risk amelioration.

Appendix 1.5: Tools for Managing Climate Variability

(Source: Deuter (2006))

Each of the tools listed and summarised below has in the main, been designed and constructed for a specific purpose and for a specific agricultural or pastoral industry.

This section briefly describes each tool, its purpose and where it is being used. In the context of this study, a "Tool for Managing Climate Variability" is defined as any information package (hard copy, CD or web based), or software package (CD or web based), that can be used to improve risk management decision making. This list cannot be considered as being exhaustive.

a) Web Based Tools

1. Rainfall to Pasture Growth Outlook Tool - http://www.mla.com.au/TopicHierarchy/InformationCentre/FeedAndPastures/Pasturemanagement/Rainfall+to+Pasture+Growth+Outlook+tool.htm

Developed with leading beef and sheep producers, the Rainfall to Pasture Growth Outlook Tool shows actual rainfall and indices of soil moisture and pasture growth for the past 9 months and an outlook for the next 3 months for over 3300 locations across southern Australia.

Designed specifically to fit the Meat and Livestock Australia, 'More Beef from Pastures' package, the Rainfall to Pasture Growth Outlook tool takes the guess work out of making a number of very important decisions :-

- What classes of stock should I have on the property at different times of year?
- When should I be calving?
- When should I wean?
- What age should I aim to sell at?
- What pastures could I have?
- How risky is spending money on pasture improvement?

Because the tool covers such a diverse range of soil and pasture types across southern Australia, it provides an index of potential pasture growth, not a prediction of actual growth. The pasture growth index should be interpreted in light of local knowledge as to species, soil type, fertiliser history and aspect.

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

AgClimate provides new tools to help peanut, tomato, potato, pastures and livestock producers in south-eastern USA, understand and plan for climatic conditions. It is an interactive web site with climate, agriculture, and forestry information that allows users to assess management options under forecast climate conditions.

The following is an example output for one element of AgClimate for the Baker County in Florida :-

3. **Cotton Logic** - http://www.mv.pi.csiro.au/CottonLOGIC/index.shtml

The latest management tool that will help with cotton farming decisions, in particular for insect pests and nutrition, has been developed by a team of researchers at CSIRO Plant Industry.

CottonLOGIC is a decision support tool for the Australian Cotton Industry, developed by CSIRO Plant Industry and is distributed for free to Cotton growers and Consultants by the Australian Cotton Cooperative Research Centre.
It will run on Windows 3.x, Windows 95, 98, 2000 and NT operating systems.
Information on insect pressures, crop inputs, pesticide applications, field operations and much more can be stored and easily accessed. This information can then be used to make decisions to improve cotton crop production and sustainability.

It incorporates ;

- EntomoLOGIC- Pest management decision support system
- NutriLOGIC - Analyses soil and petiole nitrate tests and gives Nitrogen recommendations to maximise yield.
- Support for Rotation and Refuge crops
- User-Definable INGARD Thresholds
- Weather Data Entry for Operations
- Forecast Temperature Data Entry for more accurate Heliothis pressure prediction
- A comprehensive range of cotton pest and beneficial insect pictures

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

Yield Prophet is an on-line crop production model designed to provide grain growers with real-time information about the crop during growth. To assist in management decisions, 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. Yield Prophet® is a subscriber only service, however, visitors may browse with restricted access.

Yield Prophet® does not generate recommendations or advice. Yield Prophet® uses the computer simulation model APSIM (see APSRU – p 36.) together with paddock specific soil, crop and climate data to generate information about the likely outcomes of farming decisions. APSIM does not take into account weed competition, pest/disease pressure, pesticide damage, farmer error, or extreme events (such as extreme weather, flood and fire). For more information about APSIM please look at www.apsim.info

If appropriate tools for managing climate change were available, the delivery mechanism used by Yield Prophet could have many advantages.

b) Web Based Sources of Information for Managing Climate Variability

There are numerous web sites that provide information that can be useful to producers, industries, consultants and advisors in making more informed decisions. These information sources aim to provide a better understanding of climate variability, and how this variability affects specific industries.

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

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

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

The Queensland Department of Primary Industries & Fisheries (DPI&F) climate web site 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.

DPI&F is actively pursuing ways to best manage climate variability, and be prepared and be able to take advantage of climate change. The crops and primary industries which are being targeted by this information are in the main, broad-acre grain and grazing industries.

- **Managing Climate Variability R&D Program**
http://www.managingclimate.gov.au/information_resources.asp?section=21#reports

Four of the latest issues of the Climag magazine can be downloaded from the above web site. Also available are case studies of farmers who have used climate applications to better manage their enterprises. It is called the Masters of the Climate , where farmers from across Australia have documented how they have applied new climate forecasting tools and information. This booklet is filled with their insights. All of these case studies are from managers of broad-acre or grazing enterprises. A particularly interesting aspect of this is the "Science Behind the Case Studies" document which is available at - http://www.lwa.gov.au/downloads/publications_pdf/PK050943_Science.pdf

- **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, ElNino, 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

This is a specific listing of 20 climate and weather related web sites in Australia and overseas. They provide detailed information on the seasonal outlook, much of which is useful for horticulture, although not specifically designed for this purpose.

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

The term climate is used in the broadest sense. It spans the past (yesterday's temperature, statistics over a long period) through to the future (outlooks based on slowly changing patterns like El Niño) and information about climate change.

- **National Oceanic and Atmospheric Administration (NOAA) -** http://www.noaa.gov/

A US-based site containing the National Oceanic and Atmospheric Administration (NOAA) services and data. It includes information on current weather watches and warnings, hurricanes, tornadoes, tides and currents, buoys, nautical and aeronautical charts, real-time satellite imagery, environmental, geostationary and polar satellites, El Niño & La Niña, global warming, drought, climate prediction, archived weather data, paleoclimatology and current research on air quality, atmospheric processes and climate and human interactions.

- **The Climate Prediction Centre (CPC) -** http://www.cpc.ncep.noaa.gov/

The Climate Prediction Centre (CPC) in the United States has a very useful internet site for monitoring conditions (eg westerly wind bursts, Kelvin wave activity, sea surface and sub-surface temperatures etc) in the Pacific. The ENSO Diagnostics Discussion in the Climate Highlights section is highly recommended for those interested in progress of El Niño/La Niña state.

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

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

- **Land Water & Wool - Improved seasonal forecasting for wool producers in western Queensland Pastoral Zone**
  - http://www2.dpi.qld.gov.au/climate/14793.html

The purpose of this site is to provide climate information including seasonal forecasts for western Queensland primary producers. The products and climatic descriptions are customised specifically for pastoral management systems located in western Queensland. Maps show the main towns and shire boundaries. The seasonal forecasts are issued for rainfall and pasture growth including a measure of their skill. Skill indicates the confidence that the forecast probabilities will represent the actual outcome. The climate information includes educational material and simple explanations of other websites that help interpret climatic conditions in western Queensland (*e.g.* sea surface temperatures, Madden Julian Oscillation, westerly winds). The educational material helps with understanding of a range of climatic terms including probabilities, medians and skill.

- **Agricultural Production Systems Research Unit (APSRU) -** http://www.apsru.gov.au/apsru/

The Agricultural Production Systems Research Unit (APSRU) is an unincorporated joint venture between the state of Queensland through its Department of Primary Industries and Fisheries and Department of Natural Resources and Mines, CSIRO through its Divisions of Sustainable Ecosystems and Land & Water, and The University of Queensland.

APSRU has developed a number of products including APSIM (Agricultural Production Systems sIMulator). APSIM was developed to simulate biophysical processes in farming systems, particularly as it relates to the economic and ecological outcomes of management practices in the face of climate risk. APSIM is structured around plant, soil and management modules. These modules include a diverse range of crops, pastures and trees, and soil processes including water balance, N and P transformations, soil pH, erosion and a full range of management controls. APSIM resulted from a need for tools that provided accurate predictions of crop production in relation to climate, genotype, soil and management factor while addressing the long-term resource management issues.

c) CD Based Tools

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

Rainman StreamFlow is a forecasting tool, which contains records for Australia, including historical monthly and daily rainfall for 3800 locations; monthly and daily streamflow for nearly 400 locations; and world-wide, monthly rainfall records for some 9500 locations.

Rainman StreamFlow can analyse these records for individual locations for seasonal, monthly and daily rainfall patterns; forecast seasonal rainfall based on the Southern Oscillation Index (SOI) or Sea Surface Temperatures (SST); group locations for spatial analysis; import monthly and daily rainfall and streamflow data; and print results as tables and graphs or maps -
http://www2.dpi.qld.gov.au/rainman/13234.html

The standard seasonal forecast is for 3 months with a zero lead-time.

The Rainman StreamFlow software is available from the Department of Primary Industries and Fisheries, Queensland.

- **Whopper Cropper -**

The information in Whopper Cropper enables grain and cotton crop management advisers and producers to make better crop management decisions, using cropping systems modelling and seasonal climate forecasting. Whopper Cropper combines seasonal climate forecasting with cropping systems modelling to predict the production risk that growers face in the coming cropping season. This helps producers to choose the best management options for the coming season. Whopper Cropper is the result of interaction between researchers and crop management advisers developing this modelling technology and making it widely available.

A “Whopper Cropper” for horticulture would require the same crop modelling input as has been developed for the range of broad-acre crops included in Agricultural Production Systems Simulator (APSIM).

d) Hard Copy Tools

- **"Will it Rain? The effect of the Southern Oscillation and El Nino on Australia.”**

Will It Rain? is a book for farmers, graziers, students and anyone else interested in the weather and seasonal forecasting. Will it Rain? was written as a companion to the Rainman StreamFlow CD and software to explain the weather systems associated with the Southern Oscillation and El Nino - terms which appear frequently in the media. It is available from DPI&F Book Sales for $24.05.
http://dpishop.dpi.qld.gov.au/bookweb/details.cgi?ITEMNO=9780734501394

The book describes : -
- what causes the weather over Australia
- the Southern Oscillation and how it influences seasonal weather
- how the Southern Oscillation affects crop and pasture growth
- how farm managers can use the Southern Oscillation Index to reduce risk from the weather
- present seasonal forecasting information and future developments.
- the third edition contains a new Chapter 6 about new indicators that have potential for more accurate and longer-term seasonal forecasting.

e) Potential Tools

- **Land Suitability Analysis - Spatial Analysis Modelling**

In 2001, the Victorian Government embarked on a 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 project has demonstrated that climate change will impact different agricultural activities in different ways over time and in different regions.

This expert modelling technique allows for an assessment of impact on a wide range of commodities beyond the historic focus of standard cropping and pasture models. It contains the methodology for linking the hierarchical analysis method for land suitability with scenario modelling. It could also be applied to horticulture, overlaying the production requirements of various crops (and varieties of crops), with climate changes.

In the development and practice of **Land Suitability Analysis, DNRE Victoria**, approximately 20 commodity models across fruits, vegetables, cropping, flowers and plantations have been created that are directly transferable for potential climate change impact.

Climate change will impact different agricultural/horticultural activities in diverse ways over time and space. Some areas will become more suitable for certain activities while others will become less suitable.

- **PlantGro**
  http://www.topoclimate.com/plantgro.htm

PlantGro (TM) is 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. The program input is the data contained in plant, soils and climate files. By changing climate files to represent future climate change scenarios, plant growth and development can be predicted.

Appendix 1.6: Monthly low and high value projections for rainfall and temperature change for the years 2030 and 2070 for the (a) NCAR and (b) UKMO models.

(a) NCAR model

Month	Temperature (^{o}C)				Rainfall (% change)			
	2030		2070		2030		2070	
	Low	High	Low	High	Low	High	Low	High
Jan	0.467	1.072	1.011	3.259	0.999	2.295	2.165	6.977
Feb	0.470	1.079	1.018	3.279	0.142	0.327	0.309	0.995
Mar	0.468	1.076	1.015	3.270	-2.569	-1.119	-7.811	-2.424
Apr	0.455	1.046	0.987	3.179	-8.672	-3.777	-26.366	-8.182
May	0.444	1.020	0.962	3.101	-9.458	-4.119	-28.755	-8.924
Jun	0.492	1.129	1.065	3.433	-2.852	-1.242	-8.670	-2.691
Jul	0.560	1.286	1.214	3.910	-2.873	-1.251	-8.736	-2.711
Aug	0.504	1.158	1.093	3.521	-3.908	-1.702	-11.881	-3.687
Sep	0.443	1.017	0.960	3.093	-1.826	-0.795	-5.550	-1.723
Oct	0.406	0.931	0.879	2.831	0.464	1.066	1.006	3.241
Nov	0.414	0.950	0.896	2.888	0.397	0.912	0.861	2.773
Dec	0.445	1.022	0.965	3.109	0.735	1.688	1.593	5.132

(b) UKMO model

Month	Temperature (^{o}C)				Rainfall (% change)			
	2030		2070		2030		2070	
	Low	High	Low	High	Low	High	Low	High
Jan	0.569	1.307	1.233	3.974	-12.493	-5.440	-37.982	-11.788
Feb	0.573	1.317	1.243	4.004	-3.430	-1.494	-10.427	-3.236
Mar	0.557	1.280	1.208	3.892	-9.502	-4.138	-28.890	-8.966
Apr	0.523	1.202	1.134	3.654	-14.476	-6.304	-44.013	-13.659
May	0.493	1.132	1.068	3.441	-17.870	-7.782	-54.330	-16.861
Jun	0.482	1.106	1.044	3.363	-19.840	-8.640	-60.320	-18.720
Jul	0.504	1.157	1.092	3.518	-10.625	-4.627	-32.302	-10.025
Aug	0.504	1.157	1.091	3.516	-17.759	-7.734	-53.993	-16.756
Sep	0.560	1.285	1.213	3.908	-23.199	-10.103	-70.533	-21.890
Oct	0.557	1.279	1.207	3.890	-11.352	-4.944	-34.514	-10.711
Nov	0.513	1.178	1.112	3.582	-18.982	-8.266	-57.711	-17.910
Dec	0.507	1.165	1.099	3.542	-4.530	-1.973	-13.772	-4.274

Appendix 1.7: Summary of properties for three soil types found in the Maryborough region.

	Bidwill ('good')	Watalgan ('average')	Robur ('poor')
Australian Classification *	Red Ferrosol	Red Dermosol	Redoxic Hydrosol, Grey Sodosol
Great Soil Group *	Krasnozem	Red Podozolic	Soloth, minor solodic soil
C:N	12.0	13.3	26.0
C in top 20cm (%)	2.0	2.1	0.5
Rooting Depth (cm)	150	90	60
PAWC (mm)	175	151	52
Condition of surface when dry	Soft	Firm	Hard Setting
Fertility	High	Medium	Low
Water Holding Capacity	High	Medium	Low

* From Wilson (1997) and Wilson *et al.* (1999).

Appendix 1.8: Example of temperature and rainfall change codes and values for the year 2030 using projections from the NCAR climate change model.

Temperature change code and value used for simulations of climate change for the year 2030 using projections from the NCAR climate model.

Month	Temperature change code and value (^oC)					
	0	1	2	3	4	5
Jan	0	0.467	0.618	0.770	0.921	1.072
Feb	0	0.470	0.622	0.775	0.927	1.079
Mar	0	0.468	0.620	0.772	0.924	1.076
Apr	0	0.455	0.603	0.751	0.898	1.046
May	0	0.444	0.588	0.732	0.876	1.020
Jun	0	0.492	0.651	0.811	0.970	1.129
Jul	0	0.560	0.742	0.923	1.105	1.286
Aug	0	0.504	0.668	0.831	0.995	1.158
Sep	0	0.443	0.587	0.730	0.874	1.017
Oct	0	0.406	0.537	0.669	0.800	0.931
Nov	0	0.414	0.548	0.682	0.816	0.950
Dec	0	0.445	0.589	0.734	0.878	1.022

Rainfall change code and value used for simulations of climate change for the year 2030 using projections from the NCAR climate model.

Month	Rainfall change code and value (% change)					
	0	1	2	3	4	5
Jan	0	0.999	1.323	1.647	1.971	2.295
Feb	0	0.142	0.188	0.235	0.281	0.327
Mar	0	-2.569	-2.207	-1.844	-1.482	-1.119
Apr	0	-8.672	-7.448	-6.225	-5.001	-3.777
May	0	-9.458	-8.123	-6.789	-5.454	-4.119
Jun	0	-2.852	-2.450	-2.047	-1.645	-1.242
Jul	0	-2.873	-2.468	-2.062	-1.657	-1.251
Aug	0	-3.908	-3.357	-2.805	-2.254	-1.702
Sep	0	-1.826	-1.568	-1.311	-1.053	-0.795
Oct	0	0.464	0.615	0.765	0.916	1.066
Nov	0	0.397	0.526	0.655	0.783	0.912
Dec	0	0.735	0.973	1.212	1.450	1.688

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Appendix 2

Climate change: informing the Australian Sugar Industry of potential impacts, possible strategies for adaptation and best-bet options for future R&D. SUMMARY REPORT. Park, et al., 9 pp.

Climate change: informing the Australian Sugar Industry of potential impacts, possible strategies for adaptation and best-bet options for future R&D

Sarah Park, Mark Howden, Andrew Higgins, David McRae, Heidi Horan, Kevin Hennessy

March 2007

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CSIRO

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Executive summary

Australia will almost certainly face some degree of continuing climate change in future years (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 the possible adaptation options available to the industry. The 6-month study was undertaken by a small, cross-disciplinary team of researchers and conducted in a consultative manner with sugar industry stakeholders attending workshops held in Maryborough and Brisbane during the period January to February 2007.

The aim of the project was to foster informed decision-making regarding climate change and enhance the capacity of individual stakeholders from all sectors to enable:

- accurate interpretation of climate change projections,
- critical consideration of the likely impacts and risks on each sector of the industry and the value chain as a whole, and
- development and adoption of adaptation strategies aimed reducing the adverse impacts of climate change and capitalising on any beneficial impacts.

In addition, in order to support capacity building in the industry, the study aimed to identify knowledge gaps and areas requiring investment of future R&D funds.

The focus of the scoping study was limited to assessing the impacts of climate change on the Australian sugar industry. As a consequence, no consideration was given to the identification of alternative agricultural land uses for cane assignment areas. Rather, the intention of the study was to explore the necessary actions required to be taken by the Australian sugar industry to maintain production in its present location. The study also excluded explicit consideration of the impacts of many other large-scale external drivers and their interactions with climate change, that are likely to impact the sugar industry over the coming decades. These drivers include global change in markets and economies, demographic change in agricultural industries and regions, continued degradation of the resource base for agricultural production and its associated natural environment, rising energy costs and technological development. These external drivers are dealt with in Howden *et al*., (2006). The report also excludes any consideration of mitigation option available to the sugar industry.

Impact assessment

Maryborough was used as a case study region to explore climate change impacts at a regional level and qualitatively asses the capacity for adaptation. CSIRO Marine and Atmospheric Research (CMAS) produced projections for the Maryborough region which suggest a decrease in mean annual rainfall of between 0.94 to 13.67% by the year 2030, and between 2.03 and 41.57% by 2070. Annual mean temperatures are projected to increase by 0.46 to 1.21 ^{o}C by 2030 and 1.01 to 3.69 ^{o}C by 2070. Changes in other climate variables include an increase in atmospheric CO_2 concentrations up to 449 ppm by 2030 and 702 ppm by 2070, a rise in sea level of between 9 to 88 cm by 2100, an increase in annual average potential evaporation of between 0 to 8% per degree of global warming, enhanced drying associated with El Niño events and an increase in the intensity of tropical cyclones.

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. The best potential outcome for 2030 (assuming no implementation of adaptation response strategies), 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 would be around 8%, whilst potential reductions may be up to 47%. Uncertainty regarding the crop response to climate change is due in part to the uncertainty regarding the magnitude and potential changes in temperature and rainfall and the extent to which the sugarcane crop will benefit from increases in carbon dioxide (referred to as CO_2 fertilisation). The simulated data suggests a progressive increase in the variability of cane yields over time in both rainfed and irrigated production.

In the majority of cases the primary impacts of climate change are likely to occur within the growers sector and manifest in a change in the quantity of cane yield produced. Secondary impacts will be a change in throughput across the harvesting, transport and milling sectors. Any reduction in yield is obviously a negative impact, whilst any increase would be positive. It is uncertain what will happen to CCS levels.

Climate change impacts likely to occur across the value chain have been categorised as either:

- those associated with other large-scale external drivers (*e.g.* urban encroachment).
- Impacts likely to be negative for all regions (*e.g.* reduced winter temperatures are likely to favour the spread of diseases such as smut).
- Impacts likely to be positive for all regions (*e.g.* a projected general increase in solar radiation and the associated potential to increase productivity provided other resources are non-limiting).
- Regionally-specific impacts (*e.g.* the potential reduction in rainfall is likely to have a generally negative impact on the industry, with the exception of the Northern region which presently may experience periods of extreme rainfall that constrain productivity).

Using the Maryborough case study, a preliminary analysis was conducted on the impact of changed sugarcane production on the harvesting and transport sectors of the value chain. The analysis was conducted using the value chain model developed in the SRDC project CSE010 (Archer *et al.*, 2004; Thorburn *et al.*, 2006). Table 1 shows that whilst overall harvesting costs decreased with an increasing change in climate (as one would expect), the cost per tonne of cane increased. This is due to reduced harvesting efficiency and lower returns on harvesting capital. The impacts per tonne of cane are not as big as those for transport since the Maryborough region is based on road transport and can readily increase or reduce capacity with minimal cost. This would not be the case where rail transport is used.

Table 1. Preliminary analysis for climate change impacts in Maryborough in terms of total and per tonne of cane (tc) costs.

	% Change from 2003				
	Tonnes	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

Extrapolating the impacts of climate change to other sugar-producing regions
In order to conduct a primary appraisal of the potential impacts of climate change on all 5 sugar-producing regions on the east coast of Australia, stakeholders at the Strategic Vision Workshop were presented with projections of temperature, rainfall and evaporation for each region. Table 2 provides a summary of the main present and future concerns/pressures on sugarcane production in each region, particularly those likely to be impacted by a change in climate.

Table 2. Summary of the main present and future pressures on sugarcane production in the 5 regions located on the eastern coast of Australia. The issues noted are those likely to be particularly impacted by a change in climate.

Region	Present constraints	Likely impact of future climate change
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.
	Urban encroachment.	Like to increase with increasing human populations.
	Offsite movement of chemicals to Great Barrier Reef Marine Park.	Likely to increase with the projection of more extreme events (*e.g.* flooding, cyclones).
	Incidence of smut.	Likely to increase as a result of projected increases in temperature.
		Projected reduction in spring rainfall likely to inhibit establishment of ratoon crops.
Herbert / Burdekin	Not presently water limited.	Likely to experience increasing competition for water from Burdekin Dam due to human population growth and industrial expansion of Townsville area.
	Rising water table and salinity issues in the channel irrigation areas.	Likely to increase with increased use of irrigation as a result of projected increases in temperature.
	Incidence of smut.	Likely to increase as a result of projected increases in temperature.
	Rising water table.	Likely to be exacerbated/ degraded by projections of sea level rise.
		Projected reduction in rainfall likely to limit recharge of aquifer.
		Projected reduction in winter and spring rainfall likely to increase the efficiency of harvesting.
Central	Experiences limited water supply.	Likely to be exacerbated by projected decrease in rainfall.
	Frost-prone areas in the western districts	Projections of an increase in minimum temperatures likely to decrease frost damage.
	Urban encroachment	Likely to increase with increasing human populations.

	Incidence of smut	Likely to increase as a result of projected increases in temperature.
	Offsite movement of chemicals to the Great Barrier Reef Marine Park.	Likely to increase with the projection of more extreme events (*e.g.* flooding, cyclones).
	Labour shortages.	Future change unknown.
		Projected increase in temperatures likely to extend the growing season.
		Projected increases in temperatures likely to lessen the chance for ripening, thereby necessitating an increased use of ripeners.
Southern	Experiences limited water.	Likely to be exacerbated by projected decrease in rainfall.
	Crop growth presently limited by low winter temperatures and short duration of growing season.	Projections of an increase in minimum temperatures likely to reduce constraint.
	Urban encroachment.	Likely to increase with increasing human populations.
	Incidence of smut.	Likely to increase as a result of projected increases in temperature.
	Present competition for land-use from other crops *e.g.* horticulture and tree.	Likely to increase due to the reduced risk associated with growing annual crops compared to the 4-5 year duration of sugarcane.
NSW	Presently low radiation.	Projections of an increase in radiation likely to reduce constraint.
	Presently frost-prone production.	Projections of an increase in minimum temperatures likely to decrease frost damage.
	Crop growth presently limited by low winter temperatures and short duration of growing season (necessitating 2-year crops).	Projections of an increase in minimum temperatures likely to reduce constraint.
	Presence of potential and actual 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.
	Urban encroachment.	Likely to increase with increasing human populations.
	Incidence of smut.	Likely to increase as a result of projected increases in temperature.
		Projections for a decrease in the reliability of summer rainfall will reduce crop growth.

Adaptation options

This preliminary study has shown that a range of adaptation strategies will be required to address the challenges of a change in climate. Adaptation to large-scale external drivers, such as urban encroachment and increased competition for water resources, is likely to require whole-of-industry strategic planning and policy development. The interaction of climate change with other external driving factors needs to be more fully understood before this may be possible.

The vast geographic extent of the sugar industry on the east coast of Australia and the broad range of biophysical conditions that the crop is presently grown in, will necessitate that whole-of-industry strategic planning and policy development also consider regional differences and their specific adaptation needs.

The Maryborough case study highlighted the need to consider impacts and the development of adaptation responses in a value-chain context. Table 3 provides a summary of the adaptation options suggested by sugar industry stakeholders at a regional and industry-wide workshop considered applicable to the industry sectors in Maryborough. Many of these responses are likely to be applicable to other sugar producing regions in Australia, but adaptation strategies will need to be developed on a regional basis.

Table 3. Summary of the potential adaptation strategies that may be implemented by each sector of the Australian sugar industry.

Sector	Adaptation options
Grower	• 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 water supply to the crop through: (k) investment in irrigation infrastructure, (l) increased use of supplementary water through irrigation, (m) installation of on-farm water storage facilities, (n) increased demand for sugarcane varieties with greater water use efficiency/drought tolerance (including genetically modified varieties) (o) increased efficiency in irrigation technologies (*e.g.* trickle tape) (p) increased use of irrigation technologies requiring a low input of labour (*e.g.* centre pivot). a. Consider pest strategies presently used by more northerly regions to assess efficacy of pest control responses.
Harvester	• Look for efficiencies in harvesting operations (*e.g.* progress the development of harvesting technologies that enable multiple rows to be harvested simultaneously). • Track reductions in crop yield with concomitant decreases in capital stock.
Transport	• Look for efficiencies in transport operations. • Track reductions in crop yield with concomitant decreases in capital stock.
Milling	• Look for efficiencies in milling operations (*e.g.* reduce over-capacity to a minimum, optimise crushing rate. • Offer financial incentives to growers to increase productivity (*e.g.* transport assistance, water availability, leasing of land).

This study has shown that the vast majority of climate change impacts are likely to occur in the Growers' sector, and will manifest in a change in crop productivity. As a consequence of the structure of the sugar industry value chain, the greatest capacity for adaptation ultimately lies with the Growers' sector. The responses given by the industry stakeholders at the two workshops suggests that adaptation options will require an extension or enhancement of the on-going practices used in the past and at present to manage the substantially variable climate on the east coast of Australia. The adaptation strategies identified for the Growers' 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 (*i.e.* increased use of irrigation and on-farm water storages).

As yield cascades through the sugar value chain, all subsequent sectors will be impacted by a change in the quantity of throughput. The Harvester, Transport and Milling sectors must therefore focus their adaptation strategies on developing greater flexibility to respond to changes in throughput by varying capital stock and operations to maintain optimal efficiency.

Successful adaptation to climate change will need both strategic preparation and tactical response strategies. Adaptation measures will need to reflect and enhance current 'best-practices' designed to cope with adverse conditions such as drought. Adoption of these new practices will require, amongst other things: a) confidence that the climate really is changing, b) the motivation to change to avoid risks or use opportunities, c) demonstrated technologies to enable change to occur, d) support during transitions to new management, and e) altered transport and market infrastructure. The effectiveness of adaptation strategies is likely to vary across regions and sectors and must therefore be analysed in relation to the likely costs of climate impacts.

It should be noted that as a consequence of limiting the scope of this study to include only the sugar industry, the response strategies suggested by industry stakeholders consider only incremental adaptive change, rather than radical redeployment of natural resources to alternative agricultural or land use practices. As the study has, in the main part, provided a qualitative assessment, little consideration has been given to the quantitative capacity of the adaptation options to redress the impacts of climate change or maintain the resilience of the industry in its present location. We therefore cannot discount the prospect that climate change and its multiple interactions with other large-scale external drivers, will require adaptation that goes far beyond the incremental changes in current activities discussed in this study. Profound adaptation may require that economic resources are shifted to their highest value uses (*i.e.* away from sugarcane production), thus requiring flexible rural communities and governance and industrial systems to facilitate any changes in land use.

Knowledge gaps and future R&D investment

In order to help inform the allocation of future research and development funds, participants at both the Regional Climate Change Workshop (Maryborough) and Strategic Vision Workshop (Brisbane) were asked to consider present gaps in knowledge that were likely to constrain their ability to fully evaluate the potential impacts, risks and adaptation options related to climate change. The participants were also asked to consider areas where a future change in policy would be required to enhance the resilience within the sugar industry to face the challenges of a future change in climate. The focus of all discussions with stakeholders was on maintaining, and/or increasing, the sustainability of the sugar industry in its present location.

The knowledge gaps and policy areas identified by the stakeholders and the project team as being required to maintain, or increase, production, have been categorised into those aimed at:

- Improving tactical response strategies,
- Enabling sustainable management of sugarcane in the wider landscape,
- Building stakeholder capacity and resilience,
- Managing water and sea level rise,
- Policy adjustments.

The participants at the Strategic Vision workshop were asked to identify what they considered to be the most critical topic for future research and development. Table 4 shows the topics in descending order of perceived importance.

Table 4. Most critical topics for future research and development as voted for by industry stakeholders.

Topics for future research and development	Number of participants voting topic as top priority
Breeding for greater water use efficiency and/or drought tolerance	5
Economics of best management practice	4
Basic plant physiology on response of the crop to increased CO_2 and temperature	2
Greater understanding of C-balance associated with sugar production (relate this to ecosystem services provided)	2
Relative impact of climate change on regions and international competitors	2
Audit of greenhouse emissions / mitigation options (relate to carbon trading markets)	1
Effects of climate change on industry infrastructure	1
Impacts and risks of sea level rise	1
Greater understanding of seasonal variability in climate (and application of this to marketing)	1
Investigation into additional/alternative crops to sugarcane	1
Identification of other locations suitable for sugarcane production	1
Further assessment of the opportunities / threats/ risk associated with climate change	1
Communication of climate change projections, potential impacts and risks	1

As there will always be uncertainty in future climate scenarios due to highly uncertain levels of future greenhouse emissions, uncertainties in the science of the global climate system and socio-economic, political and technological developments, research into climate change will require an active adaptive management approach. This will require that directed change in management or policy be monitored, analysed and learnt from, so as to iteratively and effectively adjust to ongoing climate changes. Such an approach has profound implications for stakeholder capacity-building, R&D, monitoring and policy.

Concluding remarks

The vulnerability of the sugar industry to a change in climate will be determined by the capacity with which adaptation actions can reduce the negative impacts of climate change and the potential of stakeholders to capitalise on any beneficial outcomes. This study has provided a first attempt at defining the issues likely to be faced by the sugar producing regions on the east coast of Australia. Climate impact studies conducted for other agricultural industries show that practicable and financially-viable adaptation actions will have very significant benefits in ameliorating risks of negative climate changes and enhancing opportunities where they occur (Howden *et al.*, 2003). The benefit to cost ratio of undertaking R&D into these adaptations appears to be very large (indicative ratios greatly exceed 100:1). This study highlights some of the areas where further resources may best be placed to help improve the sustainability of the industry in the face of an uncertain future.

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Appendix 3

Climate change: SRDC technical report

(This document is to be published by SRDC as a technical report.
The report is attached in draft format.)

Park, S., Howden, M., Creighton, C., Higgins, A., McRae, D., Horan, H., Hennessy, K.

The authors would like to thank the representatives of the Australian sugar 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.

Contents

Key Elements for Australia and New Zealand from the Intergovernmental 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]

Summary

Purpose: This report by the Sugar Research and Development Corporation (SRDC) provides a draft strategy for R&D investment around the challenges of climate change and increasing climate variability.

Basis: This work is based on projections of climate change and implications built upon IPCC4 findings and sugar industry stakeholder thinking on the likely impacts, risks and adaptive capacity within the Australian sugar production industry. The concepts expressed in this report have resulted from a series of workshops held with participants in the sugar industry representing all sectors of the industry. These concepts have been synthesized and documented by a project team of agriculture and climate scientists and value-chain analysts including Colin Creighton, Sarah Park, Mark Howden, Andrew Higgins, David McRae, Heidi Horan, and Kevin Hennessy.

Adaptation to a Changing Climate: Along with all other primary industries, the sugar industry is being called upon to rise to the challenges of maintaining sustainable production in the face of an uncertain and changing climate. The vulnerability of the sugar industry to increased variability and change in climate will be moderated by the capacity with which adaptation actions can reduce the negative impacts of climate change and the industry can realise opportunities and beneficial outcomes that an altered climate might bring. Minimisation of climate change impact and realisation of opportunities necessitates a well thought through R&D investment strategy. This is likely to include as essential elements:

- Improvements in **Farming Practice**, especially precision irrigation, on paddock water use and off paddock water quality impacts so that the industry can accommodate increased climate variability, is exploiting seasonal forecasts and is working within seasonal conditions;

- **Innovative Farming & Processing Systems** that take an integrated approach to risk and opportunity across all inputs such as plant varieties, nutrient management practices and energy use in mill through to outputs of sugar, fertiliser and bio-energy so that the industry is more flexible and financially resilient;

- Capitalising on **Bio-energy opportunities** as either a value adding or core product and preferably integrated within innovative farming and processing systems to maximise the across-industry benefits;

- **Enhancing Human Capital** – building skills and enhancing science capability in climate understanding and risk management across the sugar industry so that the knowledge and tools that the industry requires are delivered;

- Linking **Biosecurity Management** to a changing climate so that the threats in biosecurity that might manifest themselves through this changing climate are understood; and

- Positioning Australia in a **Global Context** - requiring an understanding of climate change impacts on worldwide production, profitability and markets so that the Australian industry can continually position itself.

Opportunities and Benefit of R&D: This study has provided a first step at defining the issues likely to be faced by the sugar producing regions on the east coast of Australia. Climate impact studies conducted for other agricultural industries show that practicable and financially-viable adaptation actions will have very significant benefits in ameliorating risks of climate change and enhancing opportunities (Howden *et al.*, 2003). The benefit to cost ratio of undertaking R&D into these adaptations appears to be very large (indicative ratios may greatly exceed 100:1).

Report Contents: This report details:

- Projections of climate change relevant to the sugar industry regions on the east coast of Australia;
- The process and outputs used in determining R&D opportunities for a case study region (Maryborough) and for the whole industry; and
- A summary of R&D opportunities related to climate change and framed within the SRDC investment arenas as detailed in the SRDC R&D plan 2007-2012.

Gathering Industry Input: The Maryborough region was used as a case study to highlight the impacts of climate change across the sugar industry and the need to consider impacts and adaptation strategies as they cascade through the value chain. Primary and secondary impacts of climate change were postulated by the regional stakeholders and adaptation strategies discussed.

The Brisbane workshop attended by policy level stakeholders from across the industry, built on outputs from the Maryborough workshop and extrapolated to other sugar-growing regions to provide a primary assessment of whole of industry vulnerability and R&D opportunities.

An Industry Workshop, involving farmers from across the sugar growing regions plus members of the SRDC Board consolidated on all findings, developing themes and topics for future science investment.

Next Steps: Table 6 of this report [page XX] builds on the SRDC Research Arenas to suggest key areas of R&D investment. Key criteria to be considered as SRDC plans the next steps include:

- **Regional Application within an Industry-wide Context -** Assessments of the impacts of climate change on the sugar industry, its vulnerability and opportunities for adaptation, need to be undertaken at both regional scales and within an industry wide context. This is preferably done as nested suites of activities. This will ensure that climate change projections are translated to regions in terms of potential impact and then applied to define the full range of biophysical and social conditions under which opportunities can be explored. Adaptation responses can then be more effectively tailored to the needs of each region and integrated up to provide industry wide implications. A regional approach linked to an industry wide context will also ensure that regionally-specific pressures from other major external drivers, such as urban encroachment and more industry-wide issues such as changing policies for water allocation are all incorporated into sugar industry opportunities.

- **Partnerships for Increased R&D Return on investment –** Climate change is global and many of our best models for predicting change and how it will be manifested by seasonal weather conditions are resulting from international science collaboration. Yet the impact and the opportunities are best identified by region or by commodity. SRDC will need to partner to ensure access to

Australia's and indeed global climate science skills while still ensuring that the findings of such research are downscaled to the needs of the sugar industry.

- **Ensuring a Systems Context to R&D investments** - Climate change implies multiple primary and secondary impacts that are likely to cascade through the sectors of the sugar value chain. Climate is only one of the stressors and opportunities for the sugar industry and should not be considered in total isolation from other R&D activities. For example R&D into improved varieties will need to also select for likely climate conditions – but the principle goal of R&D for improved varieties remains the same – to provide for a more productive and profitable industry. Building increased synergies between R&D fields and incorporating climate into the R&D agenda will be challenging but will ensure a higher return on research investment.

- **Industry Engagement and Skills** – There are multiple facts, myths and half truths around the current debate on climate change. It is essential therefore that a common understanding of climate change, its causes, impacts and the opportunities for the sugar industry, are built across all sectors of the sugar value chain. Climate change will manifest itself in the sugar growing areas through increased climate variability. Equipping the industry to exploit, innovate and adapt to this variability is essential and can only be done by building on a base of common understanding.

- **Science Planning** - R&D investment must be well-targeted. Research resources are scarce, both in terms of available dollars and science capability. As the change in climate is anticipated to be progressive, an iterative approach will be required to continually identify knowledge gaps, policy opportunities and topics that offer maximum returns on R&D investment. Good planning is required to incorporate all the above criteria and develop links to investments and outputs from other R&D programs. To ensure industry benefit, it is essential therefore to provide science leadership to translate plans into action and science management working across disciplines and initiatives.

The proposed topics of priority for R&D linked to the SRDC Arenas as detailed in Table 6 provide much of the substance for SRDC to work through in its next steps in developing its response to climate change. Much can be done through building on existing investments and processes. Through SRDC and its stakeholders the industry will be collectively well placed to deal with an increasingly variable and changing climate.

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

A Changing Climate

The climate is changing. Global mean temperatures have risen approximately 0.7^{o}C since the mid 1800s. Changes in rainfall patterns, sea levels, rates of glacial retreat and biological responses have been measured which are consistent with expectations of 'greenhouse' climate change (IPCC 2007). 2005 was the warmest year 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 (CO_2) 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^{o}C by the end of the present century. To place these changes in perspective, a 1^{o}C rise in average temperature will make Melbourne's climate similar to that currently experienced by Wagga, a 3^{o}C rise like that of Dubbo, a 4^{o}C rise like that of Moree and a 6^{o}C rise like that just north of Roma.

Changing Conditions for Australian Agricultural Production

The predicted temperature changes along with all other changing features of our climate will have implications for:

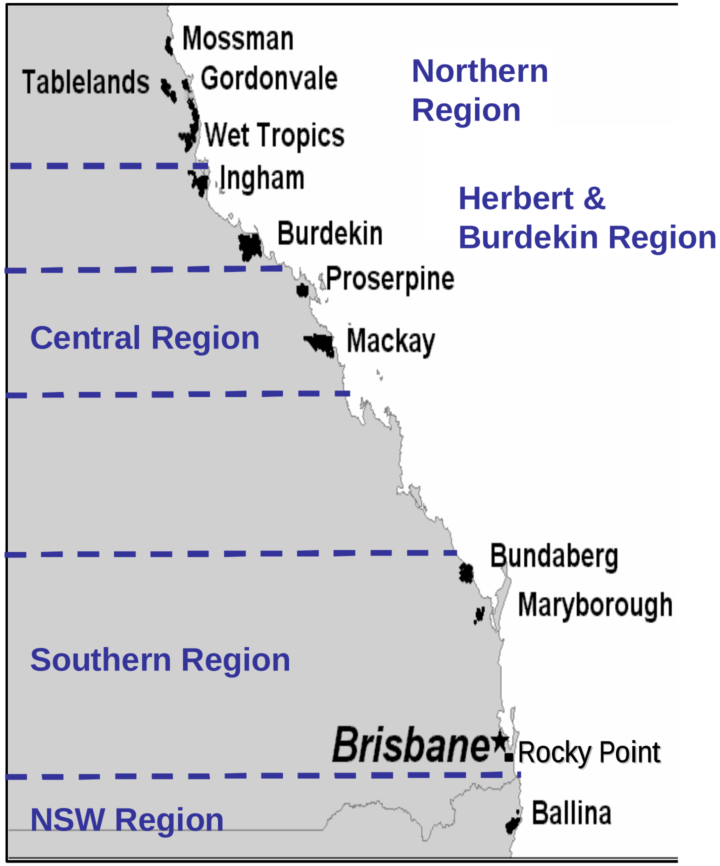
- key agricultural attributes such as plant available moisture and stored water available for irrigation,
- hazards to agricultural production such as the predicted increased severity [but not necessarily frequency] of cyclones and floods, and
- markets, particularly as a changing global climate impacts on production worldwide.

There is likely to be increases in atmospheric carbon dioxide, a general decline in annual mean rainfall across most of Queensland but with a possible increase in the more northerly locations during summer months, increases in rainfall intensity and the possibility of entering a more El-Niño-like mean climate condition.

Sea level is expected through thermal expansion of the world's oceans to rise 18 to 59 cm by the end of this century. This estimate excludes possible rises from rapid disintegration of ice sheets. Given the sugar industry's predominant location on coastal floodplains, these sea level rises in combination with increased storm and cyclone intensity significantly increases the likelihood of inundation, soil erosion, nutrient loss off paddock and damage to industry infrastructure.

Rainfall, Temperature and Evaporation Predictions for Sugar Growing regions

Figures 1 and 2 provide a range within which rainfall (%), temperature (^{o}C) and evaporation (%) are projected to change across the sugar-growing regions of east coast Australia by the years 2030 and 2070 [the two periods of IPCC 2007 predictions] relative to 1990. Twelve global and regional climate models were used to produce this range of projections. Using this method means that some projections for summer rainfall indicate a simultaneous increase and decrease. This reflects the uncertainty associated with rainfall projections at present, however the majority of the 12 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.



Northern	Spr	Sum	Aut	Win
Rainfall (%)	-20 to 0	-7 to 13	-13 to 7	-20 to 0
Temperature (oC)	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

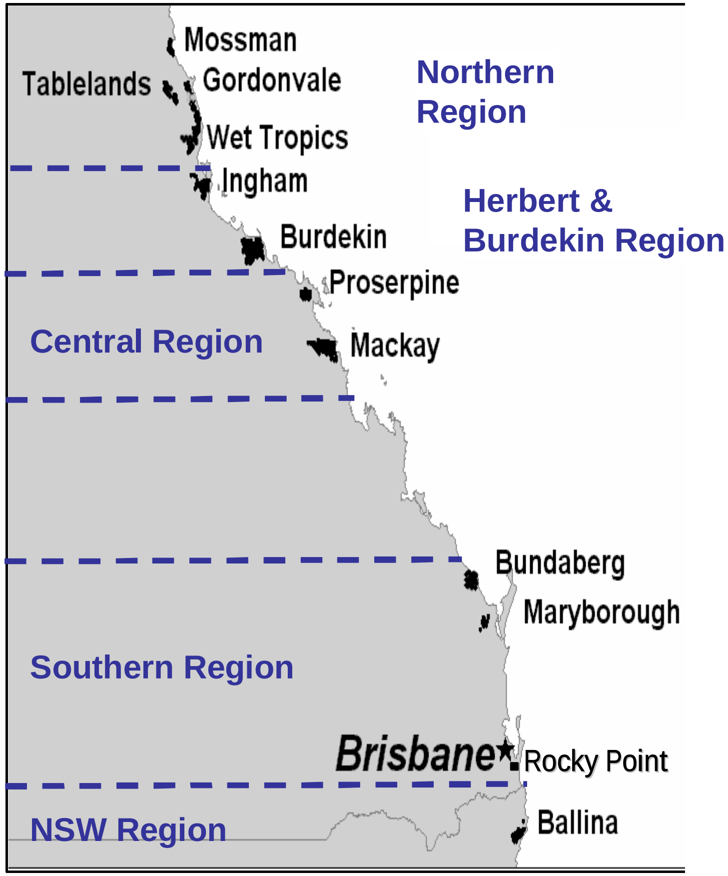
Herb/Burdekin	Spr	Sum	Aut	Win
Rainfall (%)	-20 to 0	-13 to 13	-13 to 7	-13 to 7
Temperature (oC)	0.2 to 1.6	0.2 to 1.6	0.2 to 1.6	0.2 to 1.6
Evaporation (%)	1 to 8	0 to 16	0 to 16	1 to 8

Central	Spr	Sum	Aut	Win
Rainfall (%)	-20 to 7	-7 to 13	-13 to 7	-13 to 7
Temperature (oC)	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	Spr	Sum	Aut	Win
Rainfall (%)	-20 to 0	-7 to 7	-13 to 7	-13 to 7
Temperature (oC)	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	Spr	Sum	Aut	Win
Rainfall (%)	-20 to 7	-7 to 7	-7 to 7	-13 to 7
Temperature (oC)	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 1. Projections of temperature, rainfall and evaporation for each of the 5 sugar-growing regions on the east coast of Australia for the year 2030. Data extracted from Cai *et al.* (2005).



Northern	Spr	Sum	Aut	Win
Rainfall (%)	-60 to 0	-20 to 40	-40 to 20	-60 to 0
Temperature (oC)	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	Spr	Sum	Aut	Win
Rainfall (%)	-60 to 0	-40 to 40	-40 to 20	-40 to 20
Temperature (oC)	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	Spr	Sum	Aut	Win
Rainfall (%)	-60 to 20	-20 to 40	-40 to 20	-40 to 20
Temperature (oC)	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	Spr	Sum	Aut	Win
Rainfall (%)	-60 to 0	-20 to 20	-40 to 20	-40 to 20
Temperature (oC)	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	Spr	Sum	Aut	Win
Rainfall (%)	-60 to 20	-20 to 20	-20 to 20	-40 to 20
Temperature (oC)	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

Figure 2. Projections of temperature, rainfall and evaporation for each of the 5 sugar-growing regions on the east coast of Australia for the year 2070. Data extracted from Cai *et al.* (2005).

Identifying potential impacts, adaptation strategies and opportunities

This section summarises the method used to collate the potential impacts of climate change on the Australian sugar industry and identify adaptation strategies. The focus of this approach was at the regional level and relied extensively on consultation with the sugar industry – its growers, organisations and support research agencies.

Figure 3 provides a schematic of the method used to elicit the views of the sugar industry on the likely impacts and risks of climate change, specific challenges faced by each of the sugar-growing region on east coast Australia, adaptation strategies and a range of opportunities that require R&D.

The first stage of the project was the collation of background information on a range of climate variables for the Queensland region including sea level rise, cyclone and El Niño Southern Oscillation (ENSO) to provide a basis for sugar industry discussion. Maryborough was selected as a case-study region and more detailed projections for temperature and rainfall were produced for the area by CSIRO Marine and Atmospheric Research (see Appendix 1 for the method used to produce these projections). The Maryborough region was selected for this study as it's located close to the coast and tidal waterways, low-lying production areas and substantial reliance on rainfed production is typical of many of the sugar-producing regions on the east coast of Australian.

The climate change projections were analysed both qualitatively and quantitatively to assess the likely impact on sugarcane production in the Maryborough region.

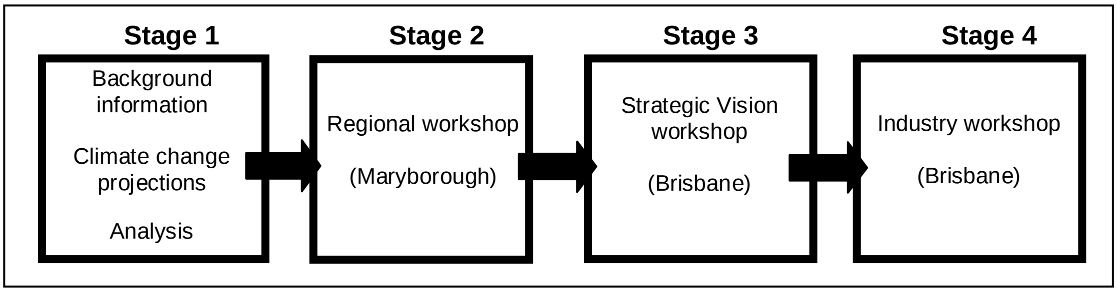


Figure 3. Method used to elicit the views of the Australian sugar industry on the impacts and risks of climate change and the knowledge gaps and opportunities for R&D.

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 sugar industry, representing the growers, harvesting, transport and milling sectors. The questions addressed 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?

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

- Consider the applicability of the Regional Climate Change Workshop held at Maryborough to other sugar-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 opportunities.
- 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 opportunities requiring R&D to enhance the capacity of the industry to address the challenges of climate change.

The final stage of this study involved a participatory industry-wide workshop held in Brisbane on 29 March 2007. Participants included members of the sugar and related industries and government bodies. The participants were asked to detail the opportunities available to the sugar industry to maintain or increase sustainable production within a changing climate. This workshop included a series of presentations to scope the magnitude of the climate change issue, the identification of key areas for R,D&E and the detailing of selected R&D opportunities, especially from the perspective of the potential return on investment to the sugar industry from R&D investment.

Climate vulnerability at a regional level: Maryborough case study

Details of the Maryborough case study are presented here to demonstrate how climate change impact and adaptation assessments are effectively undertaken at a regional level by recognising the integrated nature of the sugar 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 and together they span most of the range of uncertainty in rainfall change for Australia. 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. Full details of the methodology used to produce the temperature and rainfall projections for the Maryborough region are detailed in Appendix 1.

Past and future climate changes in Maryborough

Mean annual temperatures in the Maryborough region have increased by almost 1°C over the past 70 years (Fig. 4). These changes are in line with future projections of climate change for both 2030 and 2070:

- 0.2 to 1.6°C warmer by 2030;
- 0.7 to 4.8°C warmer by 2070.

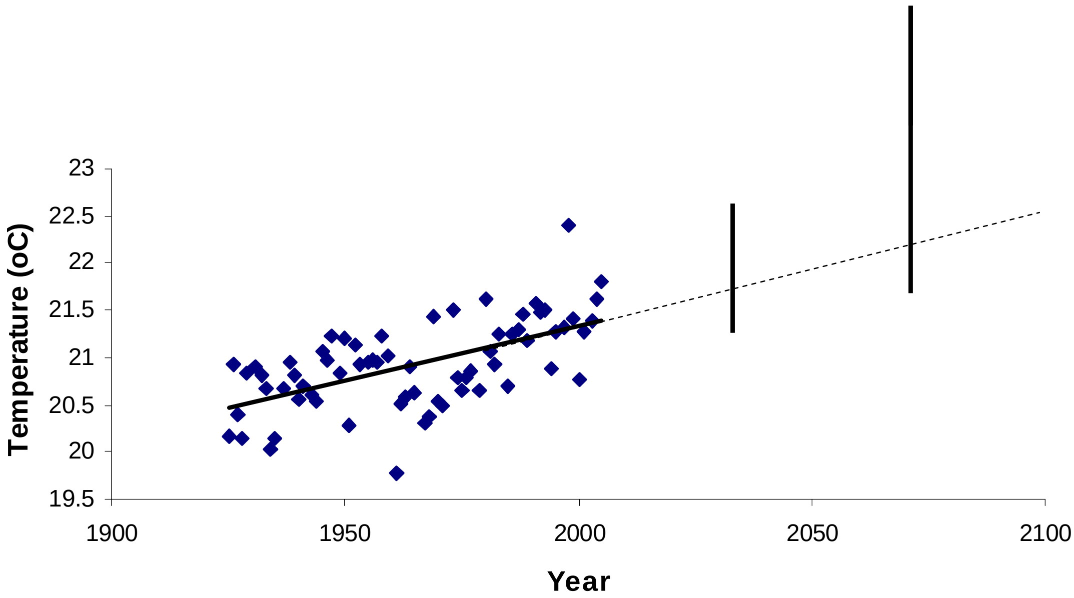


Figure 4. Mean annual temperature for Maryborough from 1930 onwards, with a linear trend included (solid black line). The dotted line is an extrapolation of this trend, intersecting with the range of temperature changes projected for Maryborough in 2030 and 2070 (CSIRO 2001).

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 2 for details of the methodology used). 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 sugar 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. 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 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' and 'Worst' percent 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	Worst	Best	Worst	Best	Worst	Best	Worst
7.4	-0.5	5.3	-3.9	7.9	-7.3	3.7	-46.9

The simulated data suggested a progressive increase in the variability of cane yields over time, given the projected changes in CO_2, 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. The analysis was conducted using the value chain model developed in the SRDC project CSE010 (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 to use the estimated yield changes 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	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. This is due to reduced harvesting efficiency and lower returns on harvesting capital. The impacts per tonne of cane in the harvesting sector are not likely to be as big as those for transport, since the Maryborough region is based on road transport, the capacity of which can be readily altered with minimal cost. This would not be the case in regions where rail transport is used.

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. Impacts were categorised as

- *primary*: at the point where they initially impacted a sector;

- *secondary:* as subsequent impacts arising in other up or down-stream sectors of the value chain.

The following is a summary of the primary and secondary impacts likely to occur in Maryborough as a result of climate change. Further details are documented in Appendix 3.

- In the majority of cases the primary impacts of climate change were considered to occur within the Growers 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 Growers' sector, manifesting as a reduction in the amount of damage sustained by the stools of ratoon crops.
- In the majority of cases, 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 impact. It is uncertain what will happen to CCS levels in the Maryborough region. This reflects gaps in industry knowledge and the need for R&D to plan for changes in climate.
- In some cases a positive impact in one sector is thought likely to result in a negative impact elsewhere in the value chain. For example, whilst an extended harvest season may provide benefits to harvesting, transport and milling in the form of a reduced requirement for quantities of capital stock (harvesters, trucks, etc), such an impact on the Growers' sector was considered to be negative, as a greater proportion of crops were likely to be harvested at a time when CCS levels are less than optimal. A potential response to this impact is a revision to the cane payment formula.

Climate change impacts across all sugar growing regions

To detail the potential impacts of climate change across all sugar-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 impact of a change in climate (Table 3).

Table 3. Key climate change related pressures on sugarcane production, 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
	Offsite movement of chemicals to Great Barrier Reef Marine Park	Likely to increase with the projected increase in the number of extreme events (*e.g.* flooding, cyclones)

Region	Present constraints	Likely impact of climate change
	Incidence of smut	Likely to increase as a result of projected increases in temperature
	Crop establishment	Projected reduction in spring rainfall likely to inhibit establishment of ratoon crops
	Drainage	Likely to be exacerbated by projections of sea level rise
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
	Rising water table and salinity issues in the Burdekin channel irrigation areas	Likely to increase with increased use of irrigation as a result of projected increases in temperature
	Incidence of smut	Likely to increase as a result of projected increases in temperature
	Rising water table & drainage	Likely to be exacerbated/ degraded by projected sea level rise
	Catchment hydrology & water availability	Projected reduction in rainfall likely to limit recharge of aquifer
	Flexibility of Harvest	Projected reduction in winter and spring rainfall likely to increase the efficiency of harvesting
	Offsite movement of chemicals to Great Barrier Reef Marine Park	Likely to increase with the projected increase in the number of extreme events (*e.g.* flooding, cyclones)
	Drainage and 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 decrease in rainfall
	Frost-prone areas in the western districts	Projections of an increase in minimum temperatures likely to decrease frost damage
	Incidence of smut	Likely to increase as a result of projected increases in temperature
	Offsite movement of chemicals to the Great Barrier Reef Marine Park	Likely to increase with the projected more extreme events (*e.g.* flooding, cyclones)
	Yield in a variable climate	Projected increase in temperatures likely to extend the growing season
	Drainage and tidal intrusion in the lower floodplains	Likely to be exacerbated by projected sea level rise
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
	Incidence of 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	Likely to increase due to the reduced risk in a variable climate associated

Region	Present constraints	Likely impact of climate change
		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
	Presently frost-prone production	Projections of an increase in minimum temperatures likely to decrease frost damage
	Crop growth presently limited by low winter temperatures and short duration of growing season (necessitating 2-year crops)	Projections of an increase in minimum temperatures likely to reduce constraint
	Presence of potential and actual 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
	Incidence of 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

The key climate change pressures on sugarcane production in each region can be grouped into the following:

Impacts associated with other large-scale external drivers

Climate change is one of many large-scale external drivers impacting the sustainability of the Australian sugar 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 large sections of the sugar 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.

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 such as smut.

Impacts likely to be positive for all regions

These include a projected general increase in levels of solar radiation and the associated potential to increase productivity 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.

Regionally-specific impacts

It is important to recognise regional variation in the sugar industry. 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 presently may experience periods of extreme rainfall that constrain productivity. A reduction 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.

What adaptation strategies will be required?

The Maryborough region

Adaptation strategies appropriate for the climate change projections presented for the Maryborough region were considered by local stakeholders (Table 4). The adaptation strategies identified for the Growers' 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 sugar 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.

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

Sector	Adaptation options
Grower	• 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 water supply to the crop through: (a) investment in irrigation infrastructure, (b) increased use of supplementary water through irrigation, (c) installation of on-farm water storage facilities, (d) increased demand for sugarcane varieties with greater water use efficiency/drought tolerance (including genetically modified varieties) (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	• Look for efficiencies in harvesting operations (*e.g.* progress the development of harvesting technologies that enable multiple rows to be harvested simultaneously). • Track reductions in crop yield with concomitant decreases in capital stock.
Transport	• Look for efficiencies in transport operations. • Track reductions in crop yield with concomitant decreases in capital stock.
Milling	• Look for efficiencies in milling operations (*e.g.* reduce over-capacity to a minimum, optimise crushing rate.

	• Offer financial incentives to growers to increase productivity (*e.g.* transport assistance, water availability, leasing of land).

As the vast majority of climate change impacts would appear likely to occur in the Growers' sector (manifesting in a change in crop yield), the greatest capacity for adaptation appears to consequently lie with growers themselves. 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. In some cases it was not possible to identify appropriate response strategies. This reflected gaps in industry knowledge and the need for further R&D in order to help plan for changes in climate.

Other regions

Many of the adaptation options considered applicable to the industry sectors in Maryborough, are likely to be applicable to other sugar producing regions in Australia. However the vast geographic extent of the sugar industry and the broad range of biophysical conditions that the crop is presently grown in, will necessitate that whole-of-industry strategic planning of adaptation strategies, including policy development, consider regional differences and their specific impacts, risks and adaptation needs.

Opportunities for sustainability in the face of climate change

Whilst a great deal of value has already been delivered to the sugar industry through well-targeted R&D, further variability of an already highly variable climate, hotter mean temperatures, sea level rise and a concomitant decrease in rainfall in many regions, will necessitate additional R&D investments that focus on negating the greatest negative impacts and targeting the most promising opportunities for industry profitability and environmental sustainability.

To help inform the allocation of R&D funds, participants at all three climate change workshops were asked to consider opportunities for improving the sustainability of the Australian sugar industry in the face of a changing climate and the present gaps in knowledge that need to be addressed in order to cultivate and exploit these. The range of ideas collated regarding opportunities for climate change R&D needs fall under the following headings as defined in the SRDC R&D plan 2007-2012:

- Breeding and physiology
- Farming and harvesting systems
- Transport, milling and marketing systems
- Value chain integration
- Individual capacity

Tables 5, 6 and 7 detail the R&D opportunities identified by industry stakeholders with the investment arenas defined by SRDC.

Table 5. Opportunities for R&D to assist in underpinning the sustainability of the Australian sugar industry given present projections of climate change in the arena of Emerging Technologies (Breeding theme).

EMERGING TECHNOLOGIES ARENA		
Br	**Key Deliverables**	**Strategies**

	▪ New varieties that provide increased productivity under elevated temperatures and levels of atmospheric CO_2 and changed levels of rainfall ▪ New varieties that are resilient and productive in conditions of marked variability in soil moisture over 4 - 5 years of cropping	▪ **Traits & Opportunities** - Identify what traits (physiological, morphological, phonological and molecular) contribute to the development of improved varieties for the production of the 2 key end products of sugar and biofuel ▪ **Varieties for Climate Change** - Identify and quantify genetic variation for adaptation to desirable traits including increased drought tolerance, water use efficiency and transpiration efficiency ▪ **On Farm Adoption** - Undertake breeding trials to produce desirable cultivars and determine how best to gain adoption, including where necessary changes to farming systems
	▪ Improved breeding systems and evaluation approaches for traits that accelerate genetic gain, and deliver new varieties faster	▪ **Breeding Systems** - Develop capability for models of plant growth to simulate genetic x environment x management (G x E x M) interactions
	▪ Improved understanding of the mechanisms of sugarcane growth as it relates to climate	▪ **Productivity in a Changed Climate** - Undertake physiological research into the process of sucrose accumulation, and the relationship between atmospheric CO_2 concentration, temperature and crop growth

Implications for SRDC Investment Strategies in Breeding and Physiology:
Overall, most, if not all of the key deliverables can be accommodated through shifts in emphasis or additions to existing and proposed R&D projects within Breeding and Physiology. Integrating the knowledge needs of a changing climate within the existing breadth of R&D investment is likely to be the most cost-effective and efficient manner to accommodate climate change concerns – using the key deliverables defined here as additional criteria for R&D investment in Breeding and Physiology.

The 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. It is well recognised that many new varieties presently take an average of 12 years to be released as commercial cultivars and then, probably up to another 10 years for widespread industry adoption. Continued and possibly increased investment in Breeding and Physiology including the key deliverables relating to climate change is therefore recommended.

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

REGIONAL FUTURES ARENA		
	Key Deliverables	**Strategies**
Farming and harvesting systems	▪ Improved management of soil and water resources, especially resilience to a more variable climate from productivity, profitability and sustainability perspectives ▪ Improved productivity	▪ **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. 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** - Application of a soil health system to farming practices and systems that accommodate

	through mitigating against marked fluctuations in soil moisture and water availability ▪ Improved management of all inputs on-farm – labour, water, nutrients and herbicides to deliver profitability improvements and to commensurately reduce impact off farm, to improve sustainability, especially in extreme events	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 accompanying practices as part of Farming Management Systems which implies the benefits in profitability and sustainability will need to be well quantified. ▪ **Precision Agriculture** - Further development of precision agriculture based farming systems within the context of an increasingly variable climate and their adoption – probably in parallel to soil health improvements and building into precision agriculture links to seasonal forecasting to provide flexibility in on farm practices. ▪ **Water Availability** – Key knowledge gaps that will need to be addressed principally at regional scale 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 sugar 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 linking water use to seasonal forecasts and predictions on soil moisture. ▪ **Opportunities for Increased Water Availability** – Strategies to increase water capture, storage, supply and re-use at both on-farm and regional scales to mitigate against competing demands for water and increased variability in soil moisture. ▪ **Sea Level Rise Implications** - Conduct a risk assessment of areas potentially vulnerable to sea level rise and salt water intrusion into aquifers, together with the identification of regional and on-farm adaptation strategies.
	▪ Maximising productivity through more flexible and climate attuned farming systems	▪ **Harvest frequency** - Using systems modelling and empirical research to investigate the potential for 3 sugarcane crops to be produced in 2 calendar years when seasonal conditions allow. ▪ **Cropping Cycles** - Investigate 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.
	▪ Improved risk management of the farming system enterprise	▪ **Seasonal Forecasting & Risk** - Develop tools that link seasonal forecasts to practice throughout the value chain, especially for key areas of risk, thereby introducing improved flexibility in all on and off-farm practices.
	▪ Renewable energy ▪ Greenhouse Gas	▪ **Biofuel Opportunities across the Value Chain** - Conduct life cycle analysis on cane production and alternate cover crops on farm and within the milling

	mitigation	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.

Implications for SRDC Investment Strategies in Farming and Harvesting Systems:
The R,D&E challenges within the Farming and Harvesting Systems are substantial, reflecting the extent of impact of climate change on this component of the cane industry's operations. Challenges on-farm in dealing with a more variable climate are multiple and will need to be based on an improved understanding of climate change implications. Opportunities are also multiple and will need to exploit improved seasonal forecasting, a greater range of decision support tools and a marked improved suite of practices that increase resilience, reduce risk and mitigate against off-farm impacts.

The cane industry practices, especially in terms of nutrient management and herbicide use, are already under the microscope within the Australian – e.g. the Queensland Government Joint Reef Water Quality Plan. Various predictions from AIMS, JCU and GBRMPA based researchers for a "double whammy" in terms of coral bleaching caused by increased sea surface temperature and reduced water quality from cane catchments are already of media interest. Industry positioning will require substantial improvements in practice and increased practice flexibility, dealing with an increasingly variable and event driven climate, incorporating seasonal forecasting into farm practices such as herbicide and nutrient applications and responding through irrigation and precision agriculture improvements to more variable available soil moisture levels and growing conditions.

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

Industry positioning will also imply involvement in a range of activities commissioned by other agencies and done in partnership with other resource uses – 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, often through contribution to initiatives led by other R&D institutions.

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

	Key Deliverables	Strategies
Transpo rt,	▪ Increased efficiencies and profitability responding with flexibility to a more variable climate	▪ **Transport and Milling Systems** – building on previous systems-based operations analysis, provide for key cost saving opportunities, 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 may prove to be as attractive as the opportunities for Australian wheat.

Implications for SRDC Investment Strategies in Transport, Milling and Marketing Systems:
The areas of R&D proposed require a preliminary analysis / business case to be conducted. The above three opportunities arising from adaption to climate change need to be compared to other R&D opportunities in the Transport, Milling and Marketing Systems to demonstrate potentially higher returns on investment thereby maximising the impact of R&D funds.

Table 8. Opportunities for R&D to assist in underpinning the sustainability of the Australian sugar industry given present projections of climate change in the arena of Regional Futures (Value chain integration theme).

	Key Deliverables	Strategies
Value Chain integration	▪ Enhanced industry preparedness for climate change, positioning and adaptation	▪ **Australian Industry Futures** - Assess 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** - Investigate 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 understand the Australian industry's vulnerability in relation to global markets.
	▪ Pest, weed and disease risk management	▪ **Risk Assessment** - Assess and prioritise 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) as a basis to update the Sugarcane Industry Biosecurity Plan.

Implications for SRDC Investment Strategies in Value Chain R&D:
The above three knowledge gaps are clearly climate change focused areas of inquiry. All strategies could be undertaken within a phased approach with an initial short and limited investment project aimed at scoping the opportunities for R&D

investment and recommending in detail key areas for further R,D&E investment. All strategies are recommended to at least proceed through this initial scoping phase.

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

PEOPLE DEVELOPMENT ARENA		
	Key Deliverables	**Strategies**
Individual capacity	▪ Improved capacity for the sugar industry and its participants to adapt, learn, and innovate	▪ **Climate Knowledge** – building an understanding across the industry of climate change, the opportunities and risks that accompany a more variable climate and how to adapt and apply decision tools that link seasonal forecasting to practice change, adaptation, opportunities of biofuels etc and risk amelioration.

Implications for SRDC Investment Strategies in Individual Capacity R&D:
As with the previous knowledge gaps, this area of investment is focused on climate change and climate variability. It is imperative that the sugar industry position itself and equip its participants with the best available knowledge and tools to respond to a changing climate. 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 sugar 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 skill in seasonal forecasting improve. Therefore a second phase of climate knowledge is recommended for about 5 years after the completion of phase I.

Resource appraisal, Monitoring & Information Collation

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

- **Coastal Mapping**– ensuring any Government-based topographical surveys, digital elevation models, floodplain inundation scenarios and so on provide information at fine enough scale to be relevant to the sugar industry;
- **Water quality and quantity information** – ensuring any monitoring and modelling also provides information that the sugar industry can use to assess its progress in water use efficiency and reduction in off-farm water quality issues;
- **Information Systems Integration** – building from the GIS / data stores of all Productivity Boards / Mills an improved and seamless set of information across the industry upon which various climate scenarios 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, pests etc as a platform for rapid response, and
- **Global Intelligence** - maintaining market, productivity and profitability information as part of Australian industry positioning.

Concluding remarks

This assessment of climate change and the sugar industry has identified the nature of the impact on Australia's sugar industry and suggested key areas for R&D to fill knowledge gaps essential to aid the industry's response to climate change.

Implementation will also take multiple forms. Some activities are best commissioned directly by SRDC. Others are best implemented as add-ons to existing activities. Some are best undertaken quite separate to the sugar industry, but with relevance to sugar industry applications incorporated in project design. Others might require participation in Science Consortia such as to improve seasonal forecasting capability for Northern Australia, 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 will require scoping in detail as a precursor to major R&D investment. Other gaps will undoubtedly come to light as the sugar industry responds to Australia's changing climate. Australian agriculture and its science support are world renown for innovation. Part of the challenge for Sugar R&D investment is to be open to such innovation, wherever it might come from to fill such gaps.

Therefore any R&D Strategy by nature cannot be complete and must have a limited time frame of relevance – in this case, probably less than 5 years. This is largely because huge global investment in climate science is likely to bring marked improvements in understanding global climate, climate forecasting and climate change within the next 3 to 5 years. Maintaining a close understanding of developments in climate science and ensuring strong international links are part of the challenge in implementing this strategy.

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Appendix 3.1: 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 (110-155ºE, 11-45ºS) 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 3.2 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.

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/m^2. 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 3 days) occurred. No irrigation was applied for at least 8 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 CO_2 were included in the APSIM simulations. This was done by multiplying the default transpiration efficiency (TE) and radiation use efficiency (RUE) coefficients by the CO_2 factors produced using equations (1) and (2), respectively:

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

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

where CO_2 is the predicted level of atmospheric CO_2 for that year. An atmospheric CO_2 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 5 different values. These were produced by splitting projected low and high value ranges for each model for the years 2030 and 2070 into 4 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 4 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.

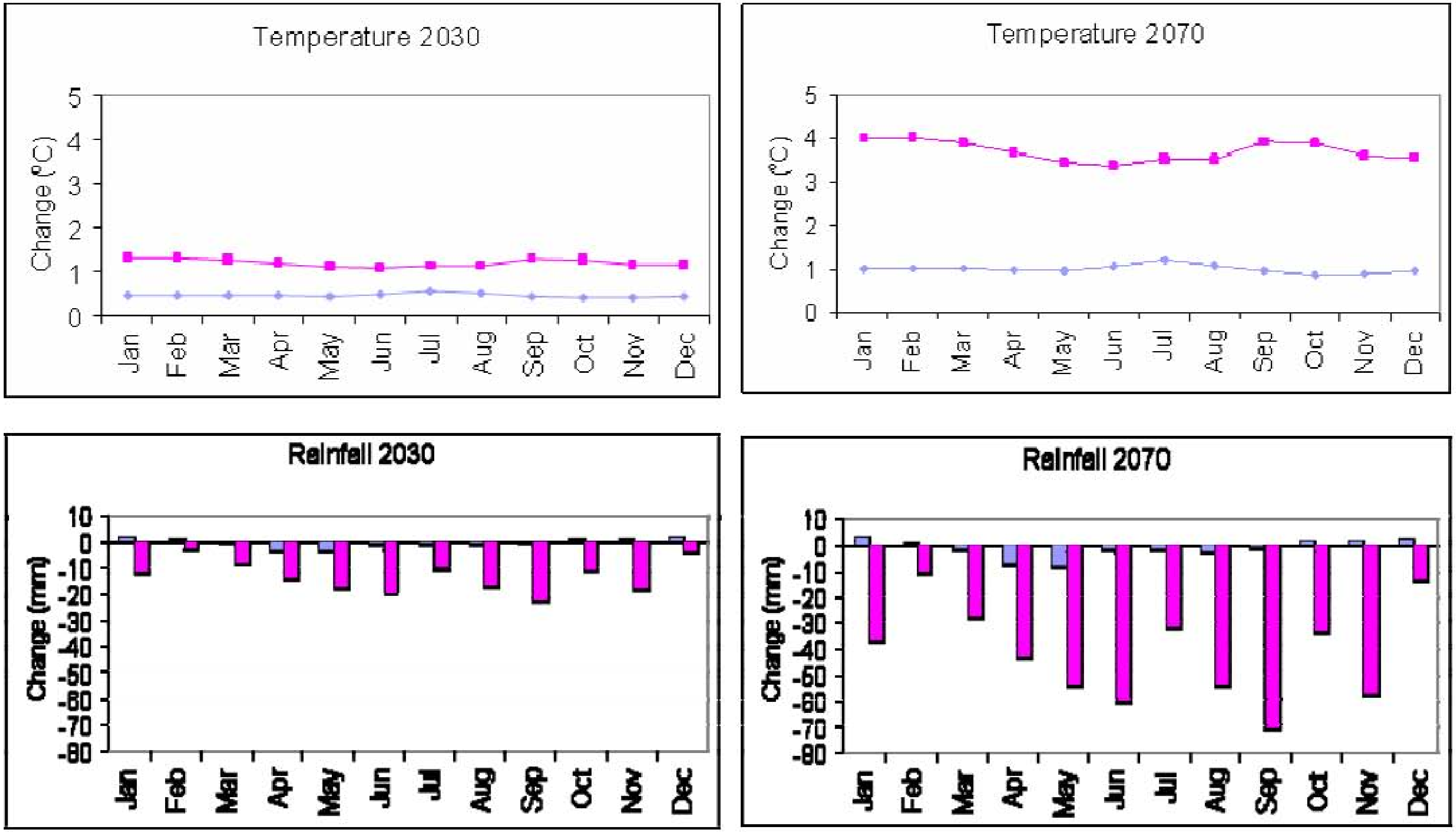

Figure 5. Monthly temperature and rainfall projections (relative to 1990) for the Maryborough region for the years 2030 and 2070 produced by CSIRO Marine and Atmospheric Research (CMAR) using the NCAR (blue) and UKMO (pink) climate models.

Appendix 3.3 Likely primary and secondary impacts resulting from a change in climate in Maryborough.

Table 10 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
Projection: Increase in temperature. **Primary impact:** Increase in daily minimum temperatures resulting in: (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. (-). **Response:** (c) bring growing season forward. (d) implement a longer harvesting season.	**Secondary impact:** Increased duration of the harvest season would require fewer machines to be in operation (reduced capital stock). (+) **Response:** Decrease capital stock accordingly.	**Secondary impact:** Increased duration of the harvest season would require fewer machines to be in operation (reduced capital stock). (+) **Response:** Decrease capital stock accordingly.	**Secondary impact:** Extended duration of crushing season would favour increased continuity of labour. (+) **Response:** None.
Projection: Decrease in rainfall and increase in temperature. **Primary impact:** Reduction in cane yield resulting in (c) the need to diversify into alternative crops (*e.g.* sugarbeet). (±) (d) increasing amounts of household labour focused on generating off-farm income. (±) **Response:** uncertain.	**Secondary impact:** Reduced throughput. (-) **Response:** Look for efficiencies in harvesting (*e.g.* progress the development of harvesting technologies that enable multiple rows to be harvested simultaneously.	**Secondary impact:** Reduced throughput. (-) **Response:** Look for efficiencies in transportation.	**Secondary impact:** (a) Reduced throughput. (-) (b) increased pressure to value-add by producing alternative products from cane. (±) **Response:** (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).
Secondary impact: Less damage to stool of ratoon crop. (+)	**Projection:** Decrease in rainfall during harvest season. **Primary impact:** Crop easier to harvest, less wet-weather downtime, ,improved efficiency, less cane loss. (+) **Response:** None required.	**Secondary impact:** Less wet-weather downtime. More efficient operations. (+) **Response:** None required.	**Secondary impact:** More efficient supply of cane to mill, less down time. (+) **Response:** None required.

Grower	Harvester	Transport	Milling
Projection: Decrease in rainfall. **Primary impact:** Increased moisture stress (particularly during January and February), leading to: (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). (+) **Response:** increase supply of water to the crop through: (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). **Secondary impacts:** Increased use of supplementary water resulting in: (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).	**Secondary impact:** Change in volume of throughput (generally considered to be a reduction). (-) **Response:** As required.	**Secondary impact:** Change in volume of throughput (generally considered to be a reduction). (-) **Response:** As required.	**Secondary impact:** Change in volume of throughput (generally considered to be a reduction). (-) **Response:** As required.
Projection: Decrease in rainfall and increase in temperature. **Primary impact:** Some stakeholders thought CCS would increase, whilst others thought it would decrease. (±) **Response:** undecided.			

Grower	Harvester	Transport	Milling
Projection: Increase in temperature. **Primary impact:** (a) accelerated crop phenology (increased growth during available growing season). (+) (b) extended window for planting. (+) **Response:** Consider planting cane throughout the winter period.	**Secondary impact:** (a) extended harvest season enabling fewer machines to be required (reduced capital stock). (+) (b) increased continuity of labour. (+) **Response:** Decrease capital stock accordingly.	**Secondary impact:** (a) extended harvest season enabling fewer machines to be required (reduced capital stock). (+) (b) increased continuity of labour. (+) **Response:** Decrease capital stock accordingly.	**Secondary impact:** Extended duration of crushing season would favour increased continuity of labour. (+) **Response:** None.
Projections: Decrease in rainfall in January and February. **Primary impact:** increased water stress occurring during the most critical time (early growth). (-) **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). Response: Install irrigation and build on-farm water storage.			
Projection: Decrease in rainfall. **Primary impact:** Greater competition for water from other users in the region (*e.g.* industry, urban, tourism) resulting in: (d) decrease in the quantity of available water. (-) (e) increase in the cost of water. (-) (f) available water diverted to higher value crops. (-) **Response:** uncertain.			

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

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Appendix 4
Regional and Strategic Vision Climate Change Workshops: KASA evaluation

Regional Climate Change Workshop: KASA evaluation

Aim of the questionnaire

An evaluation was conducted at the Regional Climate Change Workshop held in Maryborough on Wednesday 24 January 2007 in the form of a questionnaire. The aim of the questionnaire was to evaluate the **K**nowledge, **A**ttitudes, **S**kills and **A**spirations (**KASA**) of stakeholders working within the Australian sugarcane value chain to the impacts of, and potential for adaptation to, climate change. The evaluation questionnaire consisted of 2 parts (see Appendices 4.1 & 4.2). Part 1 of the questionnaire was completed at the beginning of the 3-hour workshop and contained 17 questions aimed at assessing prior knowledge of climate change, experiences of climate change and stakeholders' attitudes towards the importance, or otherwise, of climate change to the future of the Australian sugar industry. Part 2 of the evaluation was completed at the end of the workshop and contained a subset of 10 of the questions contained in Part 1. The aim of Part 2 was to assess if the KASA of stakeholders had changed as a result of participating in the workshop.

In the majority of cases the questions used a simple rating system to capture answers. For some questions, more open-ended answers were required in order to provide further information. The following is an analysis of the information gathered from parts 1 and 2 of the evaluation questionnaire completed by the 15 regional stakeholders attending the workshop.

General information and prior knowledge

The majority of the participants of the Regional Climate Change Workshop were primarily involved in the Growing sector of the Australian sugar industry, whilst three participants each represented associated with the Harvest and Transport, Milling, and Research and Development sectors. Nobody had attended a similar event on climate change in the past 3 years and at the outset of the workshop the majority of participants (93%) considered their knowledge of global climate change issues to be minimal or moderate (Fig. 1). This knowledge increased as a result of participating in the workshop, with over 90% of stakeholders considering their knowledge to be moderate, substantial or significant by the end of the event.

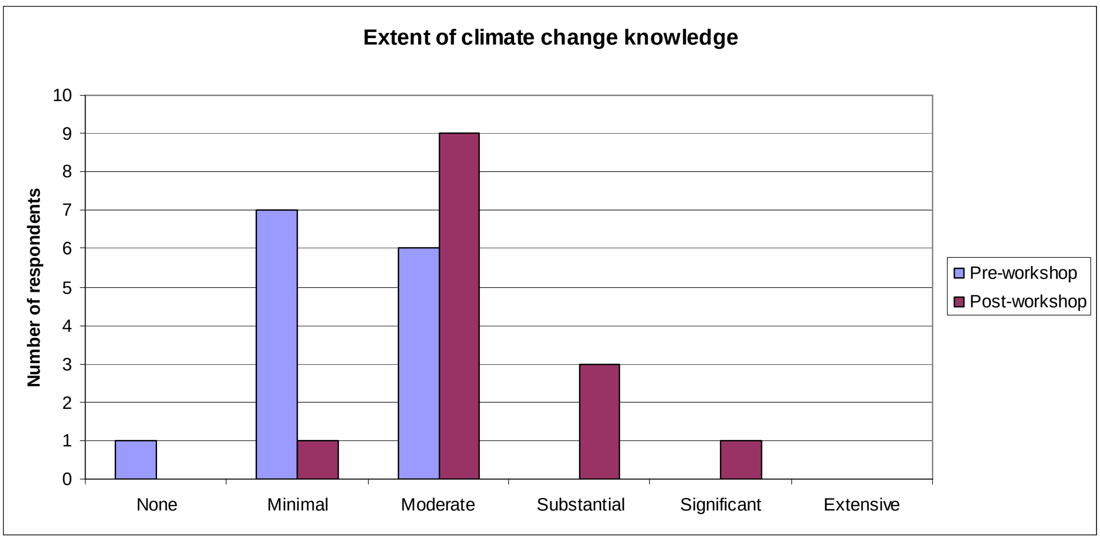

Fig. 1. Extent of knowledge of global climate change issues.

Further evidence of an increase in knowledge after participating in the workshop was also demonstrated when 29% of participants at the outset of the workshop stated that they were aware of the difference between the terms 'prediction' and 'projection' when related to climate change, and this increased to 85% at the end of the event. Similarly, all participants did not know of the climate change projections for Maryborough at the outset of the workshop, whilst all but one participant claimed to know the future climate change projections at the end of the workshop. It was not clear why one participant did not consider that they knew the projections for Maryborough at the end of the workshop.

Personal experience

Nearly one third of the participants (31%) considered themselves to have experienced a change in the 'average' climate (temperature, rainfall patterns, frequency and intensity of cyclones, etc) in the Maryborough region during the past 10 years. However, only 2 of these considered today's climate to be outside the ranges expected from 'normal' climate variation. Where the variation was considered outside the realms of 'normal' variability, the extent of the variation was considered to be between minimal (1 respondent) and substantial (3 respondents). Whilst the responses to the last two questions do not fully reconcile (with only 2 respondents considering today's climate to be outside the realms of 'normal' variability, yet 4 respondents considering this variability to be minimal to substantial), it is important to note that the data suggests the majority of stakeholders believed the present climate to be within the range of historic variability at the outset of the workshop.

Figure 2 shows the extent to which the participants presently factored climate change projections into their future plans. In the majority of cases (46%), concern for future climate change was minimal, with an extra 23% taking no consideration of projections. In total, nearly 70% of stakeholders presently took minimal or no account of climate change projections when planning for the future.

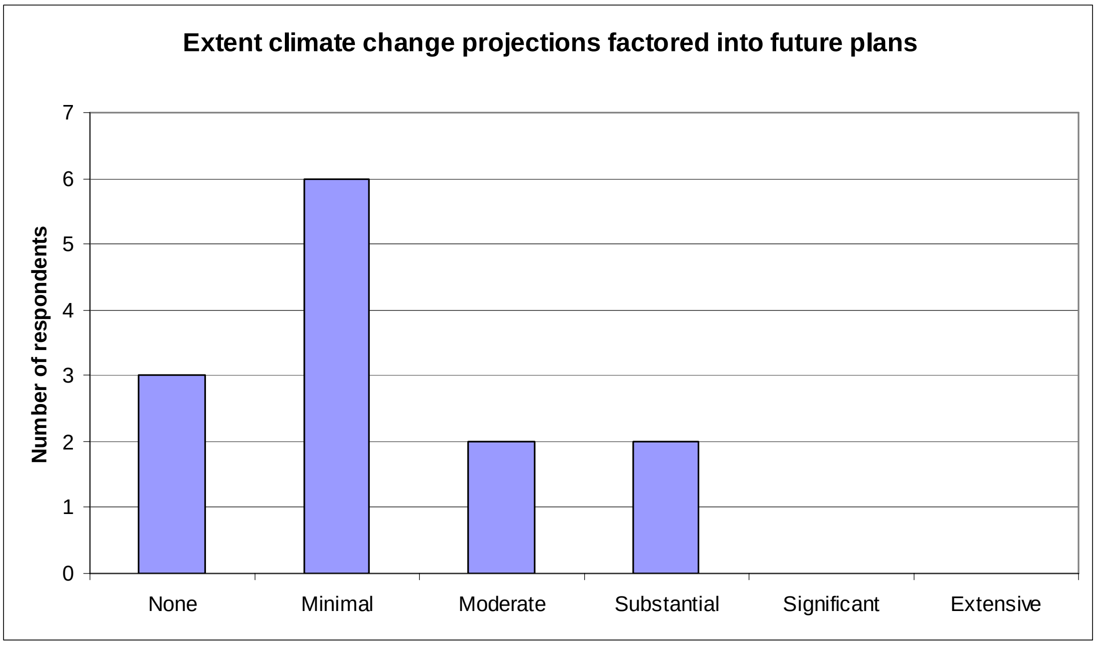

Fig. 2. The extent to which climate change projections are currently factored into the future plans of stakeholders in the Australian sugar industry.

Impact and adaptation

Nearly 70% of the participants of the workshop had made no change to management practices over the past 10 years as a result of climate. For those growers that had made changes to their practices, these came in the form of introducing trash blanketing to their cropping system for increased moisture retention and improved irrigation practices. The impact of these changes were considered to be either 'moderate' or 'substantial'.

In terms of future climate change, at the outset of the workshop the majority of stakeholders considered the extent of the likely impact to be minimal on both a single sector of the industry (Fig. 3) and the entire value chain (Fig. 4). Of note is the consideration by two participants that there is unlikely to be any impact at the value chain level. After participating in the workshop, the majority of stakeholders considered the impact on a single sector to have increased to moderate, with two stakeholders considering it to be significant. At the value chain level there was a similar increase in the likely impact with participants almost evenly distributed between 'minimal', 'moderate' and 'substantial'. As a result of participating in the workshop all stakeholders considered a change in climate would impact the Australian sugar industry at both the individual sector and value chain level.

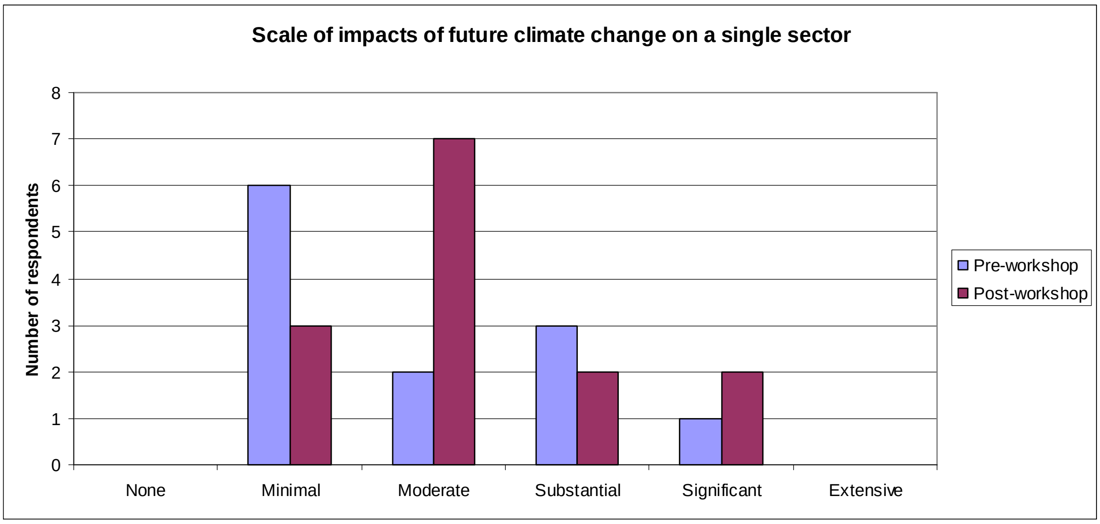

Fig. 3. The extent of impact of future climate change on a single sector of the Australian sugar industry.

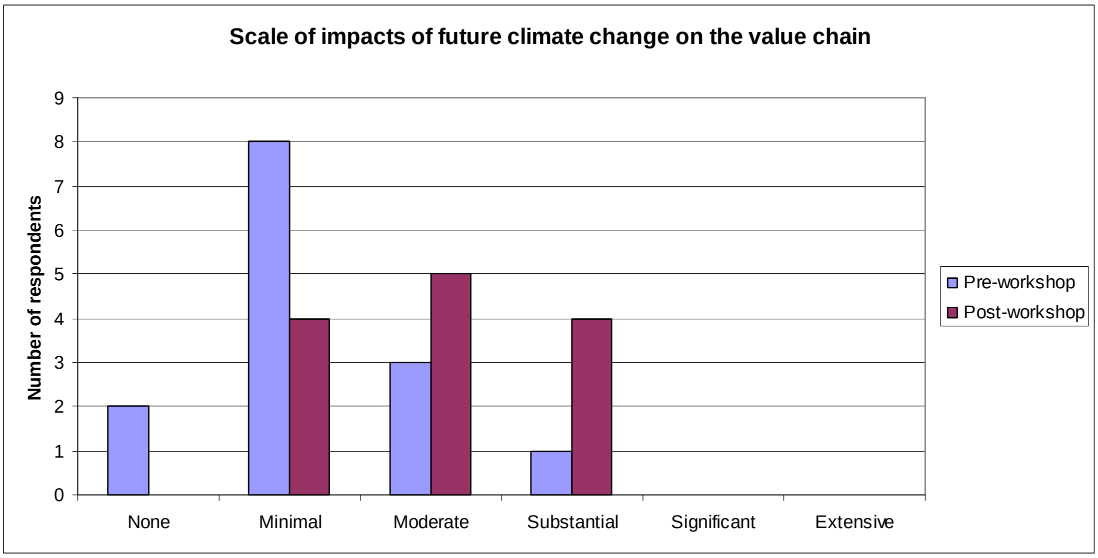

Fig. 4. The extent of impact of future climate change on the Australian sugar industry value chain.

Future

Over 70% of the industry stakeholders in attendance at the workshop considered the capacity of their skills and knowledge to interpret climate change projections and develop an adaptation plan for a single sector of industry, to be either minimal or non-existent at the outset of the workshop (Fig. 5). Overall personal capacity to respond to climate change increased as a result of participating, with nearly 70% of stakeholders rating their skills and knowledge as either moderate or substantial by the end of the workshop.

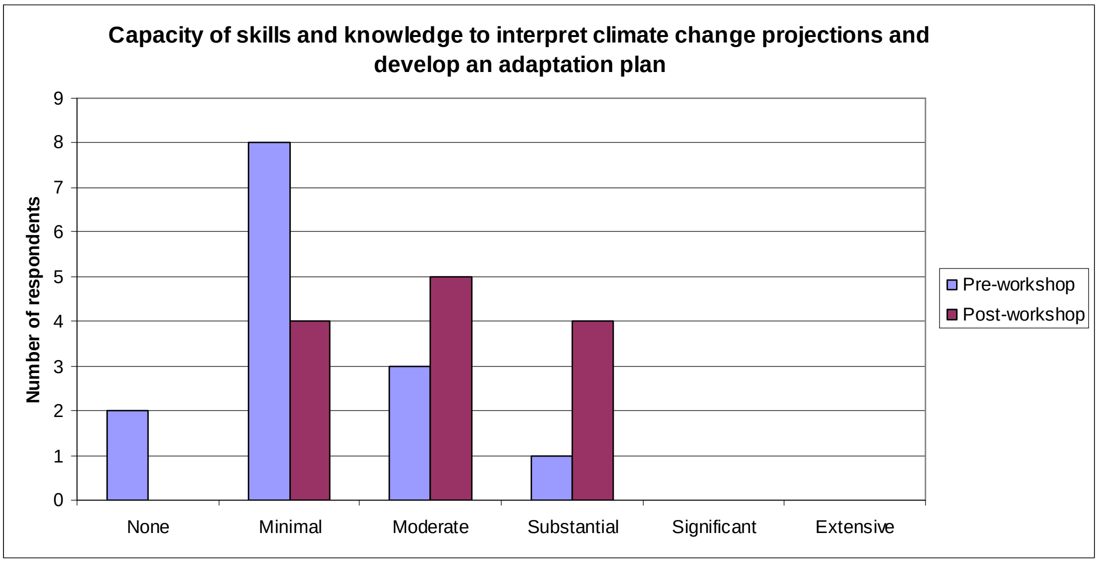

Fig. 5. The capacity of skills and knowledge acquired to interpret climate change projections and develop an adaptation plan for a single sector of the Australian sugar industry.

Table 1 provides a list of the responses given by the stakeholders both before and after the workshop to the question of how they will decide *when* to make changes to management practices as a result of changes in 'normal' climate. Responses made before the workshop was conducted can be categorised into those which require a greater indication of a change in climate (marked with '1'), an indication of a lack of skill and knowledge in understanding issues related to climate change (marked with '2'), and those that appear pragmatic in terms of awaiting opportunities for implementing response strategies and being driven by financial necessity (marked with '3'). These responses differ somewhat to those given after the workshop where responses can be categorised by those indicating a perceived immediate need to implement response strategies (marked with '4'), indication of a greater awareness and future intended use of climate change projections (marked with '5'), and those that appear pragmatic in terms of awaiting opportunities to implement response strategies and being driven by financial necessity (marked with '6').

A greater acceptance of a long-term change in climate and the need to adapt is seen by contrasting those responses marked '1' with those marked '4'. Moreover, the shift from feeling inadequately skilled or knowledgeable to respond to climate change expressed prior to the workshop, to a great confidence in utilising climate change projection can be seen by comparing responses marked '2' to those marked '5'. Responses marked '3' and '6' indicate a continued pragmatic response in terms of awaiting opportunities to implement response strategies and being driven by financial necessity.

Table 1. Responses given by the stakeholders both before and after the workshop to the question of how they will decide *when* to make changes to management practices as a result of changes in 'normal' climate.

Pre-workshop	Post-workshop
When there is a change in climate[1]	Now[4]
When there is a distinct pattern confirming climate change[1]	Start considering climate in management practices now[4]
When I identify a change in climate is occurring[1]	As projections become a reality[5]
When projections dictate[1]	Be informed[5]
Unsure[2]	By use of climate projections and financial capacity[5,6]
Unsure[2]	Changes to the size of the total harvest for the season which can be a attributed to a change of climate[6]
When my knowledge base is improved to allow me to understand the issues[2]	When there is an income loss[6]
As they happen, or affect operations[3]	Decline in financial viability[6]
When it impacts on returns of the business[3]	When money changes allows[6]
When opportunity arises[3]	When opportunities arise. [6]
Research investment direction	

When asked to what extent stakeholder's thought climate change projections would contribute to their decision-making regarding management practices in the next 10 years, the majority of participants (50%) considered this to be minimal prior to the workshop. This shifted to 86% of participants considering using climate change projections after the workshop had been conducted.

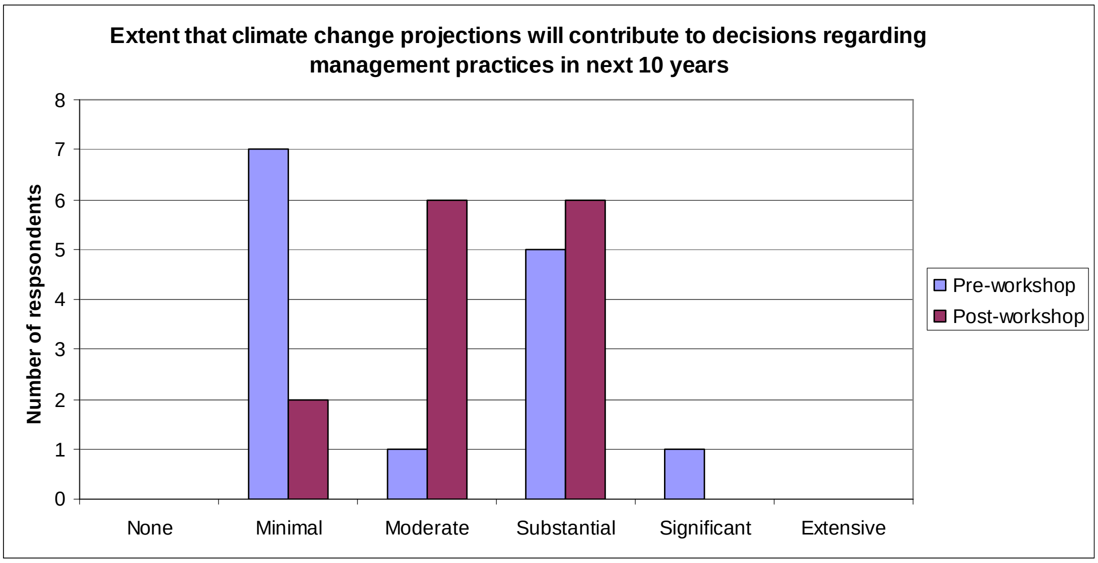

Fig. 6. Extent to which climate change projections will contribute to decisions regarding management practices in the next 10 years in the Australian sugar industry.

In terms of the potential of climate change projections to increase the economic, social and environmental sustainability of sugarcane productivity in the Maryborough region, the majority of stakeholders (46%) considered this to be minimal at the outset of the workshop (Fig. 7). However, after participating in the workshop their views shifted towards a more optimistic view, with nearly 80% of participants considering their potential usefulness to be either moderate, substantial or significant.

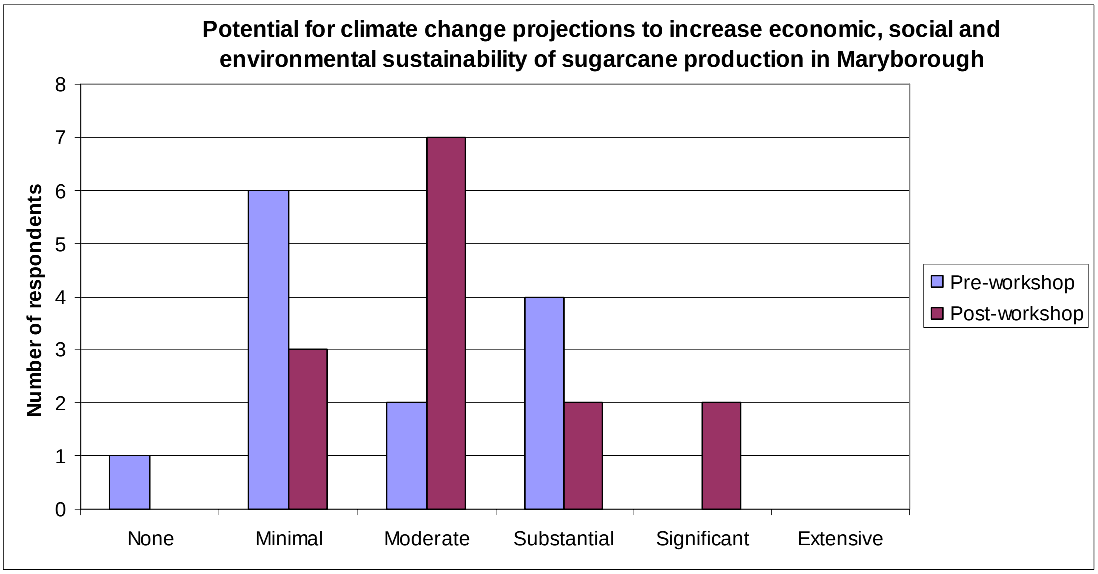

Fig. 7. Potential for climate change projections to increase economic, social and environmental sustainability of sugarcane production in Maryborough.

When asked if there were any other comments, the majority of the stakeholders chose not to respond. However, two comments were received both before and after the workshop (Table 2). The former comments revealed a scepticism for climate change and offered the suggestion that this was likely to be based on a lack of information, whilst the second comment reiterates the need for practical response strategies that do not impact (or have minimal impact) on business profitability. Having completed the workshop, it was gratifying to receive a comment regarding the informative nature of the workshop and a clear indication that a member of the Maryborough stakeholders had accepted the evidence for a change in climate, albeit believing that responses would evolve and the impact was difficult to plan for.

Table 2. Responses given by the stakeholders both before and after the workshop to the question of how they will decide *when* to make changes to management practices as a result of changes in 'normal' climate.

Pre-workshop	Post-workshop
Not convinced about climate change for this area probably due to lack of information.	Thank you, very informative.
Management decisions generally based on profitability. Want to be sustainable and practice best management practices as long as they are practical and do not impact or have minimal impact on business profitability.	Climate change is obviously occurring and should be considered. However, it is part of development and evolution. Responses will evolve. It is difficult to plan for.

Discussion and conclusion

The aim of this project was to foster informed decision-making by stakeholders in the Australian sugar industry regarding climate change through (a) the identification and selection of adaptation strategies beneficial to whole of industry, and (b) identification of the most effective investment of future R&D funds. The former point was the focus of the evaluation conducted at the Regional Climate Change Workshop in Maryborough.

The contents of the workshop were designed to guide the strategic thinking of stakeholders from all sectors of the industry through an initial assessment of global change impacts. The questions addressed during the workshop included:

- What are the current projections and likely impacts and risks?
- How can we accommodate the uncertainties associated with projections within response strategies?
- 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 estimate when capacity thresholds are reached and adaptation strategies require implementation?
- How can we manage the transition from present practices to alternative operations?

The questions contained on part 1 and 2 of the evaluation sort to assess a change in the KASA of participants and build the capacity of individuals to start addressing the above questions. From the results presented here it can be seen that stakeholders from all four sectors of the industry (growers, harvesters, transport and milling) participated in the workshop, in addition to representatives of the Research and Development sector. The overall initial knowledge of climate change issues was relatively low and although nearly one third of participants considered themselves to have experienced a change in 'average' climate in the Maryborough region during the past 10 years, few individuals at the outset of the workshop attributed this to long-term climate change with the majority of stakeholders believing the present climate to be within the range of historic variability. This translated into few individuals having changed their management practices over the past 10 years as a result of climate. The four individuals that did make changes to their management practices had focussed on increasing the availability of water to the crop through improvements in irrigation and greater moisture retention through trash blanketing.

Initially, the majority of stakeholders considered the future impacts of climate change on a single sector of the industry and the industry as a whole to be minimal and the use of climate change projections had little value in increasing economic, social and environmental sustainability of sugarcane productivity in the Maryborough region. Consequently few individuals had factored climate change projections into their future plans. The lack of a pro-active response to ameliorate the changes in long-term climate was clearly exacerbated by the low capacity of the stakeholders' skills and knowledge to interpret projections and develop an adaptation plan. The comment by one stakeholder that they were "not convinced about climate change for this area probably due to lack of information" appears to have captured the general KASA of the participants at the outset of the workshop.

Participation in the workshop clearly increased the KASA of the participants. An increase in their general knowledge of climate change issues was documented in more than one question on the questionnaire and more detailed knowledge of projections for the Maryborough region was evident. As a result of this, the majority of stakeholders increased their perceived impact of climate change on a single sector and the whole of the industry, with two stakeholders considering the impact on a single sector to be significant.

Most illuminating were the responses given to the question of how stakeholders would decide *when* to make changes to management practices as a result of changes in 'normal' climate. The shift from feeling inadequately skilled or knowledgeable that was expressed prior to the workshop shifted substantially towards a greater confidence in utilising climate change projections within present-day practices and longer-term decision-making activities covering the next 10 years. The shift in KASA clearly translated into a more optimistic assessment of the potential of climate change projections to increase the economic, social and environmental sustainability of sugarcane productivity in the Maryborough region.

It appears that the workshop was also undertaken at a time when sectors of the industry were already starting to explore the potential impacts of climate change. For example, following the workshop Trevor Crook (Maryborough Sugar Factory) commented that the workshop was "timely" as he had recently been assigned the task of assessing the potential impact of climate change on the Maryborough Sugar Factor and developing and executing response strategies.

This evaluation clearly demonstrates the shift in the KASA of the stakeholders present at the Regional Climate Change Workshop in Maryborough. It is hoped that this will translate into more informed development and implementation of climate change adaptation strategies for the sugar industry. Clearly and decisions made and actions taken of the industry stakeholders will be balanced with the need to reconcile short-term financial necessity with longer term economic, environmental and social sustainability.

Evaluation questionnaire Maryborough Regional workshop

Knowledge, Attitude, Skills and Aspirations (KASA) of stakeholders within the Australian sugarcane industry to the impacts of, and potential for adaptation to, climate change

SRDC-funded project (CSE019),
Global change: informing the Australian sugar industry on potential impacts, possible strategies for adaptation and best-bet directions for future R&D

Evaluation Questionnaire - Part 1

Aim of the questionnaire

The aim of this questionnaire is to evaluate the **K**nowledge, **A**ttitudes, **S**kills and **A**spirations (**KASA**) of stakeholders working within the Australian sugarcane value chain to the impacts of, and potential for adaptation to, climate change.

The questionnaire consists of 2 parts. Part 1 contains 17 questions generally aimed at assessing your prior knowledge of climate change, experiences of climate change and attitudes towards how important, or otherwise, you consider climate change to be to the future of the Australian sugar industry. Part 1 of the questionnaire is to be completed at the outset of the workshop.

Part 2 of the questionnaire contains 10 questions. Many of these questions are repeated from Part 1. The aim of Part 2 is to assess if your knowledge, attitudes, skills and aspirations regarding climate change have changed as a result of participating in this workshop.

Your participation

In many cases the questions use a simple rating system to capture answers. For some questions, more open-ended answers are required in order to provide further information.

While the insights gained during the research may be published, **individual responses will remain confidential.**

Thank you for agreeing to participate in this research. Your participation in the workshops and questionnaire is completely voluntary. If you have any questions, please do not hesitate to ask.

Sarah Park

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Tel: (07) 4688 1174, Mob: 0419 887 304

General information and prior knowledge

1. Which sector(s) of the Australian sugar industry do you consider yourself to represent the majority of your time?

Growers	Harvesting and Transport	Milling	Research and Development

2. Which climate change workshop(s) organised through project CSE019 have you attended:

Regional (Maryborough)	Strategic Vision (QBP)	Industry (Brisbane)

3. Have you attended any other workshops/seminars etc on climate change in the past 3 years?

No	Yes. If so, briefly describe content.

4. How would you rate the extent of your knowledge of global climate change issues in general?

None	Minimal	Moderate	Substantial	Significant	Extensive

5. Are you aware of the difference between the terms ‘prediction’ and ‘projection’ when related to climate change?

No	Yes

6. Are you aware of recent temperature and rainfall projections for the Queensland areas under sugarcane production?

No	Yes, if so, what are these?

Personal experience

7. Do you consider that you have experienced a change in the ‘average’ climate (temperature, rainfall patterns, frequency and intensity of cyclones, etc) in your region during the past 10 years?

No	Yes, if so what are these changes?

8. Do you consider that today's temperatures, rainfall patterns, frequency and intensity of cyclones, etc are within the range of 'normal' climate variation?

Yes	No. If not, why do you think this?

If 'No', how would you rate the extent of this variation from the 'normal'?

Minimal	Moderate	Substantial	Significant	Extensive

9. To what extent do you presently factor climate change projections into your future plans?

None	Minimal	Moderate	Substantial	Significant	Extensive

Impact and adaptation

10. Have you made any changes to your management practices over the past 10 years as a result of changes in 'normal' climate?

No	Yes, if so briefly state the management changes you made?

If so, how did you decide on which management changes to make and the extent of the change required?

How would you rate the level of success resulting from these changes?

None	Minimal	Moderate	Substantial

11. What do you consider to be the likely scale of impacts of future climate change on the sector of the Australian sugarcane industry that you work in?

None	Minimal	Moderate	Substantial	Significant	Extensive

12. What do you consider to be the likely scale of impacts of future climate change on the whole of the Australian sugarcane industry value chain?

None	Minimal	Moderate	Substantial	Significant	Extensive

Future

13. How do you rate the capacity of your skills and knowledge to interpret climate change projections and develop a climate change adaptation plan for your sector of the industry?

None	Minimal	Moderate	Substantial	Significant	Extensive

14. How will you decide *when* to make changes to management practices as result of changes in 'normal' climate?

15. To what extent do you think climate change projections will contribute to the decisions you make regarding management practices in the next 10 years?

None	Minimal	Moderate	Substantial	Significant	Extensive

16. How much scope is there for a greater inclusion of climate change projections to increase economic, social and environmental sustainability of sugarcane production in your region?

None	Minimal	Moderate	Substantial	Significant	Extensive

17. Are there any other comments you would like to make?

APPENDIX 4.1 – Evaluation questionnaire Part 2

Evaluation Questionnaire – Part 2

SRDC-funded project CSE019,
Global change: informing the Australian sugar industry on potential impacts, possible strategies for adaptation and best-bet directions for future R&D

The aim of Part 2 of this questionnaire is to assess if your **K**nowledge, **A**ttitudes, **S**kills and **A**spirations (**KASA**) regarding climate change have changed as a result of participating in this workshop. Many of the questions below are repeated from Part 1 of the questionnaire.

1. How would you rate the extent of your knowledge of global climate change issues in general?

None	Minimal	Moderate	Substantial	Significant	Extensive

2. Are you aware of the difference between the terms 'prediction' and 'projection' when related to climate change?

No	Yes

3. Are you aware of recent temperature and rainfall projections for the Queensland areas under sugarcane production?

No	Yes

4. What do you consider to be the likely scale of impacts of future climate change on the sector of the Australian sugarcane industry that you work in?

None	Minimal	Moderate	Substantial	Significant	Extensive

5. What do you consider to be the likely scale of impacts of future climate change on the whole of the Australian sugarcane industry value chain?

None	Minimal	Moderate	Substantial	Significant	Extensive

6. How do you rate the capacity of your skills and knowledge to interpret climate change projections and develop a climate change adaptation plan for your sector of the industry?

None	Minimal	Moderate	Substantial	Significant	Extensive

7. To what extent do you think climate change projections will contribute to the decisions you make regarding management practices in the next 10 years?

None	Minimal	Moderate	Substantial	Significant	Extensive

8. How will you decide *when* to make changes to management practices as result of changes in 'normal' climate?

9. How much scope is there for a greater inclusion of climate change projections to increase economic, social and environmental sustainability of sugarcane projection in your region?

None	Minimal	Moderate	Substantial	Significant	Extensive

10. Are there any other comments you would like to make?

Thank you for your time!

Appendix 4.2

Strategic Vision Climate Change Workshop: KASA evaluation

Aim of the questionnaire

An evaluation was conducted at the Strategic Vision Climate Change Workshop held in Brisbane on Monday 5 February 2007 in the form of a questionnaire. The aim of the questionnaire was to evaluate the **K**nowledge, **A**ttitudes, **S**kills and **A**spirations (**KASA**) of stakeholders working within the Australian sugarcane value chain to the impacts of, and potential for adaptation to, climate change. The evaluation questionnaire consisted of 2 parts (see Appendices 4.1 & 4.2). Part 1 of the questionnaire was completed at the beginning of the 3.5-hour workshop and contained 19 questions aimed at assessing prior knowledge of climate change, experiences of climate change and stakeholders' attitudes towards the importance, or otherwise, of climate change to the future of the Australian Sugar Industry. Part 2 of the evaluation was completed at the end of the workshop and contained a subset of 11 of the questions contained in Part 1. The aim of Part 2 was to assess if the KASA of stakeholders had changed as a result of participating in the workshop. The only difference between the questions asked in this evaluation, and those asked at the Regional Climate Change Workshop held in Maryborough was the inclusion of a question asking participants to provide their personal assessment of what the range of changes in temperature and rainfall are likely to be for the region(s) that they most associate with (or live in) for the years 2030 and 2070. This question was asked in both part 1 and 2 of the questionnaires and the results have been reported upon in a separate report.

In the majority of cases the questions used a simple rating system to capture answers. For some questions, more open-ended answers were required in order to provide further information. The following is an analysis of the information gathered from part 1 of the evaluation questionnaire completed by the 16 Strategic Vision stakeholders attending the workshop, and 11 respondents who subsequently completed part 2 (a number of participants were not able to stay for the full duration of the workshop and therefore were not available for completion of part 2).

General information and prior knowledge

The majority of the participants of the Strategic Vision Climate Change Workshop were primarily involved in the Research and Development sector of the sugar industry, whilst three participants associated with the Growers sector and 2 with Milling. Two additional workshop participants worked for State Government agencies. The vast majority of the participants were interested in the industry as a whole, rather than a single region. Only 4 of the participants had attended a similar event on climate change in the past 3 years. Thus the majority of participants attending the workshop that worked at the policy level of the sugar industry had not attended a similar workshop in recent years. At the outset of the workshop the majority of participants (44%) considered their knowledge of global climate change issues to be moderate (Fig. 1). Knowledge increased as a result of participating in the workshop, with the number of participants considering their knowledge to be minimal, decreasing, whilst those considering their knowledge to be either moderate, substantial or significant, increased. From the brief details given by a number of respondents, it was evident that the issue of climate change was central to their work and that they already had a good knowledge of the issues. The one person (representing 6%) who considered their knowledge as extensive at the outset of the workshop, was likely to have not complete part 2 of the questionnaire.

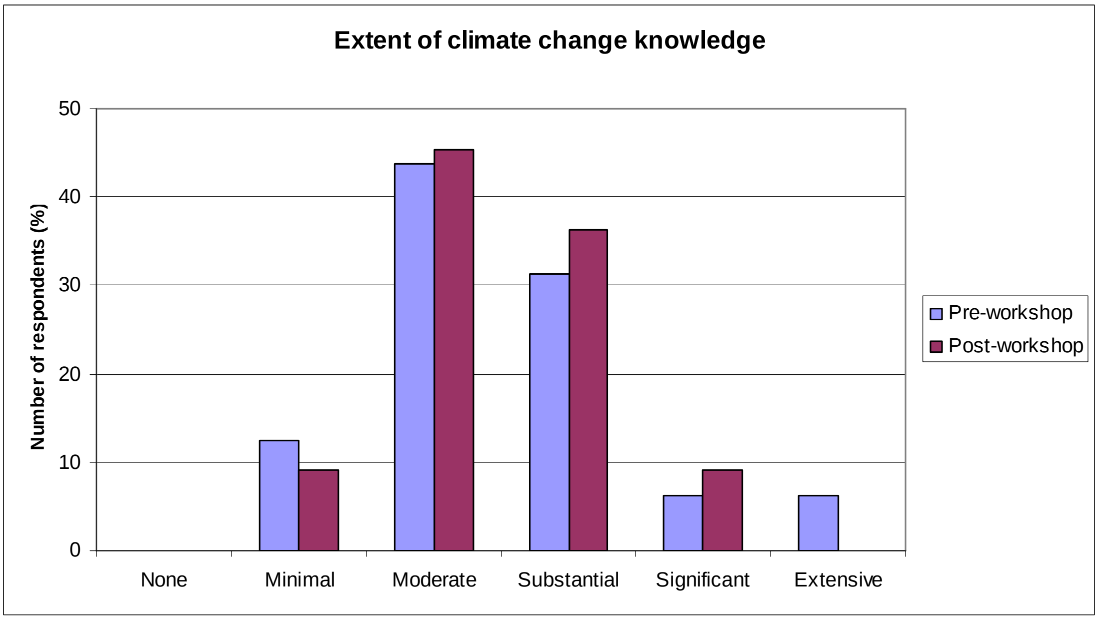

Fig. 1. Extent of knowledge of global climate change issues.

Further evidence of an increase in knowledge after participating in the workshop was also demonstrated when 56% of participants at the outset of the workshop stated that they were aware of the difference between the terms ‘prediction’ and ‘projection’ when related to climate change, and this increased to 73% at the end of the event. Similarly, only 56% of participants came to the workshop knowing the climate change projections for the Queensland areas under sugarcane production, whilst 91% (all but one) of the participants claimed to know the future climate change projections at the end of the workshop. It was not clear why one participant did not consider that they knew the projections at the end of the workshop.

Personal experience

Nearly 80% of the workshop participants considered themselves to have experienced a change in the ‘average’ climate (temperature, rainfall patterns, frequency and intensity of cyclones, etc) during the past 10 years. These changes had manifested in recent droughts, warmer summer months, fewer cool days in winter, increased El Niño-like activities, larger flood events and an onset of the growing season. However, only 36% of these participants considered today’s climate to be outside the ranges expected from ‘normal’ climate variation. Where the variation was consider outside the realms of ‘normal’ variability, the extent of the variation was considered to be moderate.

Figure 2 shows the extent to which the participants presently factored climate change projections into their future plans. Only 29% of stakeholders presently took minimal or no account of climate change projections when planning for the future and 36% gave substantial, significant or extensive consideration to the projections.

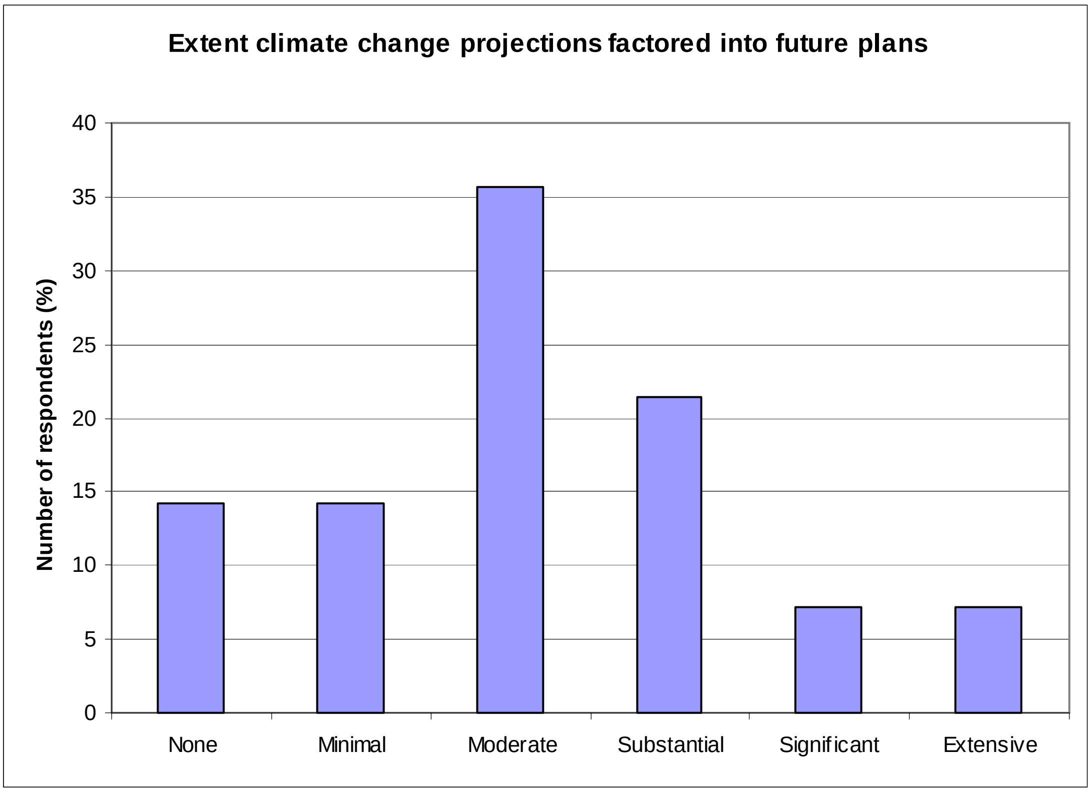

Fig. 2. The extent to which climate change projections are currently factored into the future plans of stakeholders in the Australian Sugar Industry.

Impact and adaptation

Roughly half (53%) of the participants of the workshop had made no change to management practices over the past 10 years as a result of climate. For those participants that had made changes to their practices, these came in the form of modified strategic research and development plans, increases in knowledge and implementation of infrastructure to increase resilience, and an increased focus on water use efficiency and the architecture of the sugarcane plant. The impact of these changes were considered to be either ‘moderate’ or ‘substantial’.

In terms of future climate change, at the outset of the workshop the majority of stakeholders considered the extent of the likely impact to be moderate on both a single sector of the industry (Fig. 3) and the entire value chain (Fig. 4). It is noted that all the participants considered there to be at least some impact of climate change on the industry in future years. After participating in the workshop, the majority of stakeholders considered the impact on a single sector and the whole of the value chain to have increased to substantial.

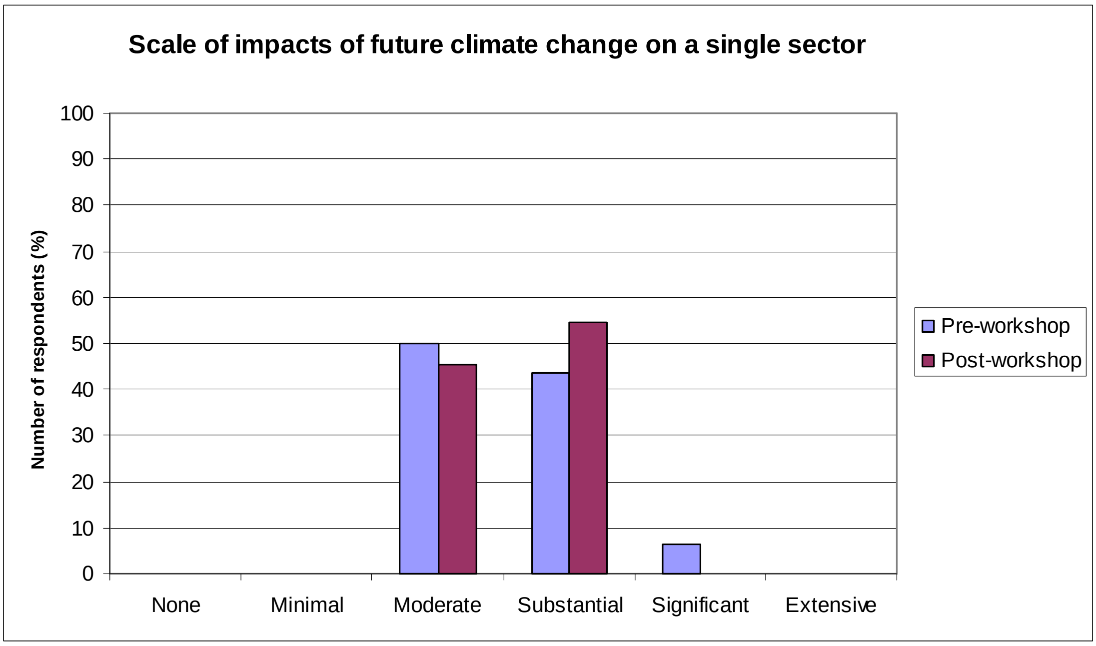

Fig. 3. The extent of impact of future climate change on a single sector of the Australian Sugar Industry.

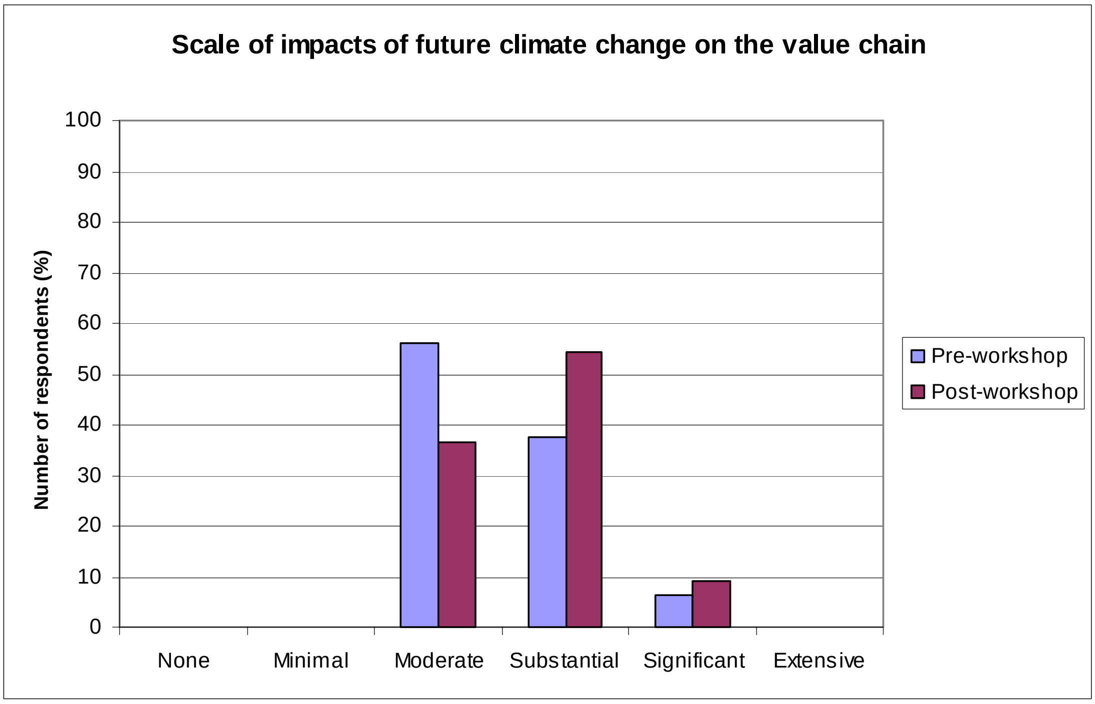

Fig. 4. The extent of impact of future climate change on the Australian Sugar Industry value chain.

Future

Over 60% of the industry stakeholders in attendance at the workshop considered the capacity of their skills and knowledge to interpret climate change projections and develop an adaptation plan for a single sector of the industry, to be either moderate or substantial at the outset of the workshop (Fig. 5). At the end of the workshop the biggest change in the perception of the participants' personal capacity to respond to climate change was a large increase in the number of people considering their capacity as substantial.

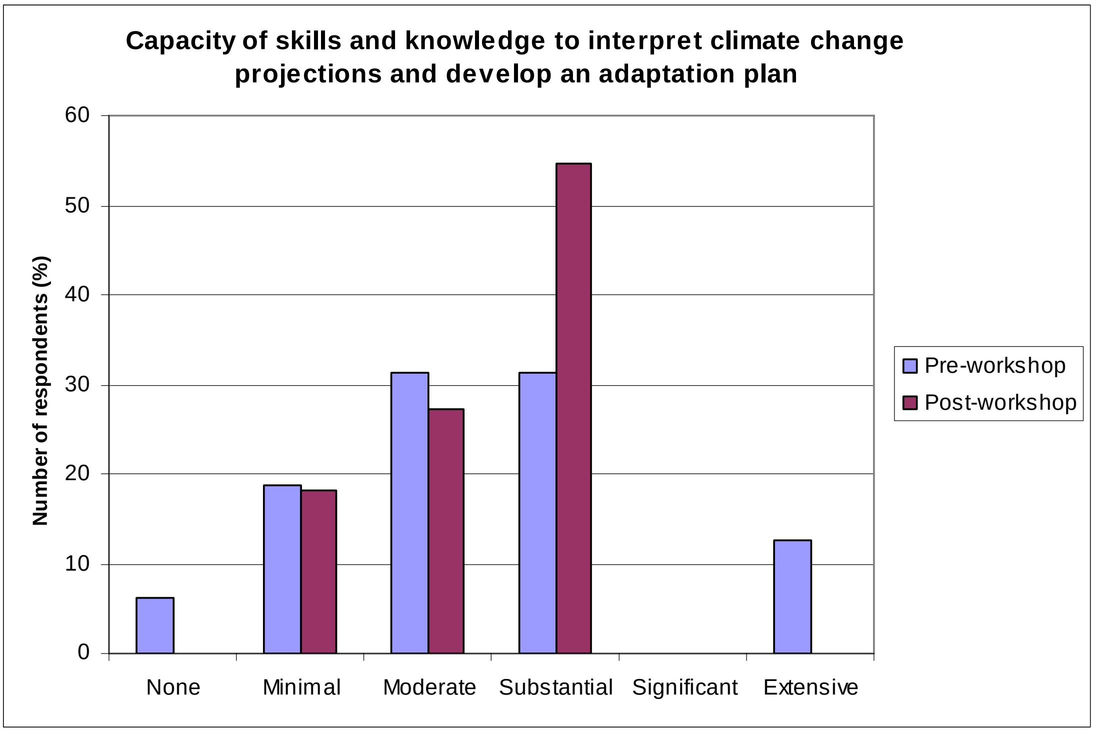

Fig. 5. The capacity of skills and knowledge acquired to interpret climate change projections and develop an adaptation plan for a single sector of the Australian Sugar Industry.

Table 1 provides a list of the responses given by the participants both before and after the workshop to the question of how they will decide *when* to make changes to management practices as a result of changes in 'normal' climate. Responses can be categorised into those that considered action should be required now and that it is ongoing (marked '1'), those that are looking to R&D to inform decision-making (marked '2'), those relying on an increase in personal knowledge (marked '3'), those that require further evidence of climate change or its impacts on productivity (marked '4'), and those participants that will rely on external drivers to prompt a response to climate change, e.g. the job market or the availability of water (marked '5').

These responses show that many of the workshop participants considered response activities needed to be planned immediately and that an ongoing process is required to respond to climate changes. These decision are likely to rely on R&D to provide information to enable an increase in personal knowledge and informed decision-making. At the end of the workshop there was a lesser emphasis on waiting for further evidence of climate change or impacts in productivity before implementing action, or looking to external drivers to determine the appropriate time for response strategies to be planned and implemented. These latter statements indicate a greater acceptance of a long-term change in climate and the need for adaptation.

Table 1. Responses given by the participants both before and after the workshop to the question of how they will decide *when* to make changes to management practices as a result of changes in 'normal' climate. Respondents' statements categorised as (1) requiring changes to be made now and ongoing, (2) requiring guidance from R&D, (3) requiring a personal increase in knowledge, (4) responses delayed awaiting further evidence of climate change and/or its impact on productivity, (5) external drivers.

Pre-workshop	Post-workshop
• Should start now.[1] • Ongoing change.[1]	• Already responding to expected changes.[1] • From now.[1] • Act now.[1]
• Investment and changes to R&D.[2] • Economic and physiological modelling.[2]	• Investment policy and R&D projects initiated and planned.[2] • Information provided to industry from R&D providers (SRDC, BSES, CSIRO etc).[2] • APSIM modelling.[2]
• Extensive knowledge of the literature.[3] • Continue to increase my knowledge of the subject and set some action plans based on identified level of change.[3]	• Awareness of where we are now in terms of climate change.[3]
• When there is hard evidence that climate change will impact 'longer term'.[4] • When there is clear evidence that productivity is being affected by climate change.[4] • When clear trend / change emerges with climate system impacts.[4]	• As hard/real trends/data become more reliable - therefore driving a change in the sentiment in a large enough portion of the industry.[4]
• Where the job market develops.[5] • Water availability will drive the timing of any changes.[5]	

When asked to what extent stakeholder's thought climate change projections would contribute to their decision-making regarding management practices over the next 10 years, by the end of the workshop there had been a decrease (compared to the outset of the workshop) in the number of participants considering this to be minimal or moderate, and an increase in those considering the contribution to their decision-making to be substantial or significant (Fig. 6). This indicates a general increase in the intention of the participants to incorporate climate change projections into future decision-making activities.

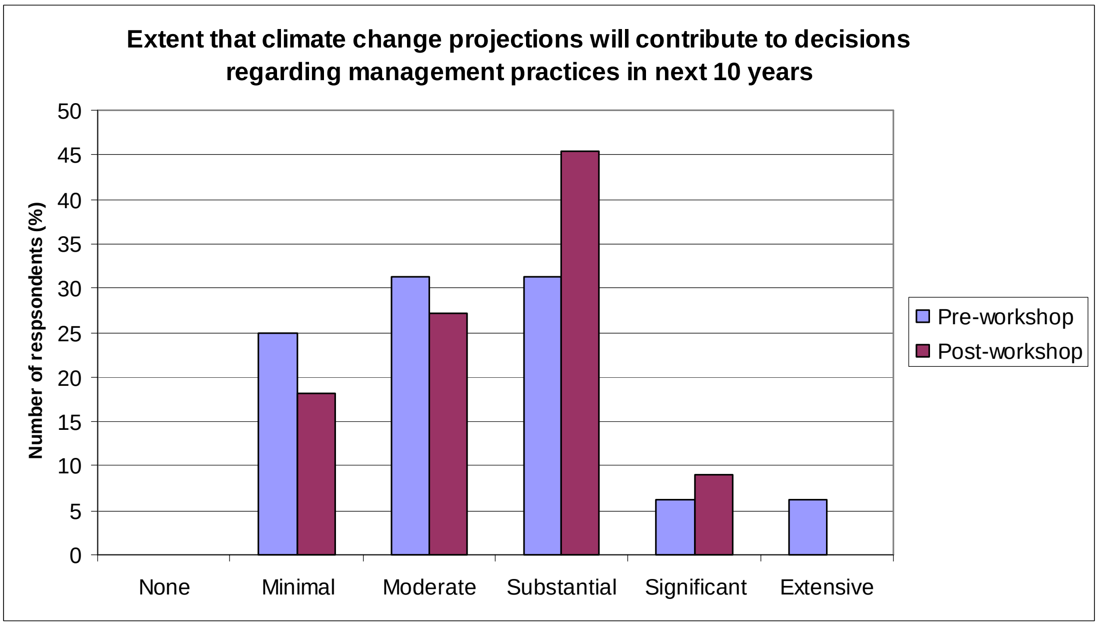

Fig. 6. Extent to which climate change projections will contribute to decisions regarding management practices in the next 10 years in the Australian Sugar Industry.

In terms of the potential of climate change projections to increase the economic, social and environmental sustainability of sugarcane productivity in the industry, at the outset of the workshop the majority of participants considered this to be either moderate or substantial (Fig. 7). At the end of the workshop, there had been a change in the distribution of responses, however the majority of the participants still considered the impact to be moderate, whilst others considered it to be either minimal or significant. The uneven number of respondents before and after the workshop made it difficult to do a direct comparison of these results.

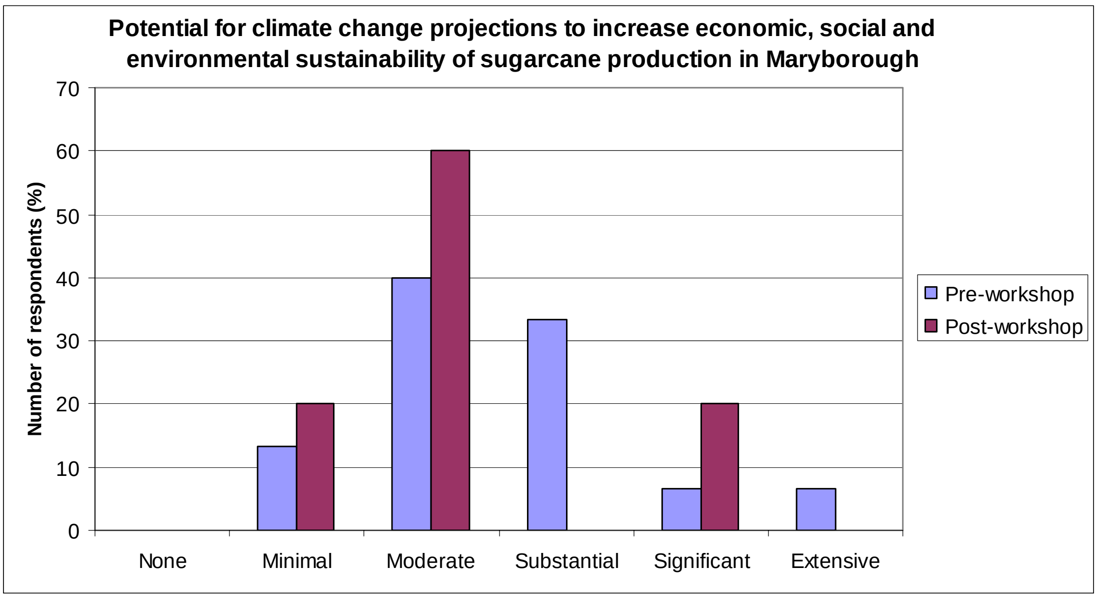

Fig. 7. Potential for climate change projections to increase economic, social and environmental sustainability of sugarcane production in Maryborough.

When asked if there were any other comments, the majority of the participants chose not to respond. However, three comments were received before the workshop and one was received at the end (Table 2).

Table 2. Responses given by the participants both before and after the workshop to the question of how they will decide *when* to make changes to management practices as a result of changes in 'normal' climate.

Pre-workshop	Post-workshop
• Possible competition - market driven view of other crops. Need to develop more efficient crops with less water • Rainfall change is more variable, variability more important. Increased extreme events. Variability / Frost freq etc are the issues. • This project is a good initiative	• Good initiative, need to communicate results

Discussion and conclusion

The aim of this project was to foster informed decision-making by participants in the Australian Sugar Industry regarding climate change through (a) the identification and selection of adaptation strategies beneficial to whole of industry, and (b) identification of the most effective investment of future R&D funds. The overriding aim of the Strategic Vision Workshop was to consider the Maryborough regional case study findings from a broader strategic industry perspective and identify areas for future R&D investment. More specifically the participants were asked to:

- Consider the applicability of the Regional Climate Change Workshop held at Maryborough on 24 Jan 2007 to other sugar-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 capitalise 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 future R&D to further enhance the capacity of the industry to address the challenges of climate change.

The questions contained on part 1 and 2 of the evaluation sort to assess a change in the KASA of participants and build the capacity of individuals to start addressing the above questions. From the results presented here it can be seen that overall initial knowledge of climate change issues was already moderate to substantial but further increased as a result of participation in the workshop. The vast majority of participants considered themselves to have experienced a change in 'average' climate during the past 10 years, but only approximately half of these considered present climate to be outside the range of normal climate variation. Whilst these two statements may be difficult to reconcile, they generally indicate that many of the workshop participants were accepting of the evidence for a long-term change in climate. The general acceptance of the climate change phenomenon translated into nearly all individuals having factored climate change projections into their future plans.

All workshop participants considered that climate change would have at least a moderate impact on the Australian Sugar Industry in future years, at both an individual sector and industry level, but the use of climate change projections had the potential to provide substantially, and even significantly, the impact on the economic, social and environmental sustainability of the industry. This pro-active attitude may in part be attributed to the participants' perceived improvement in the capacity of their skills and knowledge to interpret climate change projections and develop adaptation plans as a result of participating in the workshop.

Participation in the workshop generally appeared to increase the KASA of the majority of participants, however it is noted that a number of the participants were already working in the area of climate change and had little capacity for increased knowledge and skills.

The responses given to the question of how participants would decide *when* to make changes to management practices as a result of changes in 'normal' climate showed a decrease in requiring further evidence of climate change and changes in productivity, and reliance on signals from external drivers (e.g. job market and water availability), to increased reliance on information from R&D and increased personal knowledge. This shift indicates an increased pro-active attitude to the challenges of responding to climate change. Indeed, in subsequent correspondence with Bob Aitken (Senior Extension Officer, BSES Limited, Harwood Sugar Mill) he declared the workshop to have been "informative and useful". Whilst the workshop was seen in a positive light by the majority of the workshop participants, it was generally considered that this activity was only the first stage in a larger programme of R,D&E activities required to better position the industry for the challenges ahead.

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APPENDIX 4.3

Evaluation questionnaire Strategic Vision workshop, Brisbane

Knowledge, Attitude, Skills and Aspirations (KASA) of stakeholders within the Australian sugarcane industry to the impacts of, and potential for adaptation to, climate change

SRDC-funded project (CSE019),
Global change: informing the Australian Sugar Industry on potential impacts, possible strategies for adaptation and best-bet directions for future R&D

Evaluation Questionnaire - Part 1

Aim of the questionnaire

The aim of this questionnaire is to evaluate the **K**nowledge, **A**ttitudes, **S**kills and **A**spirations (**KASA**) of stakeholders working within the Australian sugarcane value chain to the impacts of, and potential for adaptation to, climate change.

The questionnaire consists of 2 parts. Part 1 contains 19 questions generally aimed at assessing your prior knowledge of climate change, experiences of climate change and attitudes towards how important, or otherwise, you consider climate change to be to the future of the Australian sugar industry. Part 1 of the questionnaire is to be completed at the outset of the workshop.

Part 2 of the questionnaire contains 11 questions repeated from Part 1. The aim of Part 2 is to assess if your knowledge, attitudes, skills and aspirations regarding climate change have changed as a result of participating in this workshop.

Your participation

In many cases the questions use a simple rating system to capture answers. For some questions, more open-ended answers are required in order to provide further information. Only very brief responses are required for these questions.

While the insights gained during the research may be published, **individual responses will remain confidential.**

Thank you for agreeing to participate in this research. Your participation in the workshops and questionnaire is completely voluntary. If you have any questions, please do not hesitate to ask.

General information and prior knowledge

1. Which sector(s) of the Australian Sugar Industry do you consider yourself to represent the majority of your time?

Growers	Harvesting and Transport	Milling	Research and Development	I work outside of the Sugar Industry

2. Which region of the industry do you consider yourself to represent the majority of your time?

All regions	None	Far North	Herbert	Burdekin	Central	Southern	NSW

3. Which climate change workshop(s) organised through project CSE019 have you attended:

Regional (Maryborough)	Strategic Vision (QBP, Brisbane)	Industry (Brisbane)

4. Have you attended any other workshops/seminars etc on climate change in the past 3 years?

No	Yes. If so, briefly describe content.

5. How would you rate the extent of your knowledge of global climate change issues in general?

None	Minimal	Moderate	Substantial	Significant	Extensive

6. Are you aware of the difference between the terms ‘prediction’ and ‘projection’ when related to climate change?

No	Yes

7. Are you aware of recent temperature and rainfall projections for the Queensland areas under sugarcane production?

No	Yes

8. State your own personal assessment of what the range of changes in temperature and rainfall are likely to be for the region(s) you most associate with (or live in) for the years 2030 and 2070. *We are not necessarily looking for you to remember published figures, more your thoughts on how future climate is likely to change.*

Year: 2030

	Low extent of change	'Most likely' change	High extent of change
Temperature change (^oC)			
Rainfall change (%)			

Year: 2070

	Low extent of change	'Most likely' change	High extent of change
Temperature change (^oC)			
Rainfall change (%)			

Personal experience

9. Do you consider that you have experienced a change in the 'average' climate (temperature, rainfall patterns, frequency and intensity of cyclones, etc) in your region during the past 10 years?

No	Yes, if so what are these changes?

10. Do you consider that today's temperatures, rainfall patterns, frequency and intensity of cyclones, etc are within the range of 'normal' climate variation?

Yes	No. If not, why do you think this?

If 'No', how would you rate the extent of this variation from the 'normal'?

Minimal	Moderate	Substantial	Significant	Extensive

11. To what extent do you presently factor climate change projections into your future work plans?

None	Minimal	Moderate	Substantial	Significant	Extensive

Impact and adaptation

12. Have you made any changes to your working practices over the past 10 years as a result of changes in ‘normal’ climate?

No	Yes, if so briefly state the changes you made?			
	If so, how did you decide on which practices to change and the extent of the change required?			
	How would you rate the overall level of success resulting from these changes?			
	None	Minimal	Moderate	Substantial

13. What do you consider to be the likely scale of impacts of future climate change on the sector(s) of the Australian sugarcane industry that you work in?

None	Minimal	Moderate	Substantial	Significant	Extensive

14. What do you consider to be the likely scale of impacts of future climate change on the whole of the Australian sugarcane industry value chain?

None	Minimal	Moderate	Substantial	Significant	Extensive

Future

15. How do you rate the capacity of your skills and knowledge to interpret climate change projections and develop a climate change adaptation plan for your sector(s) of the industry (or your industry)?

None	Minimal	Moderate	Substantial	Significant	Extensive

16. How will you decide *when* to make changes to working practices as a result of changes in ‘normal’ climate?

17. To what extent do you think climate change projections will contribute to the decisions you make regarding working practices in the next 10 years?

None	Minimal	Moderate	Substantial	Significant	Extensive

18. How much scope is there for a greater inclusion of climate change projections to increase economic, social and environmental sustainability of sugarcane production in your region?

None	Minimal	Moderate	Substantial	Significant	Extensive

19. Are there any other comments you would like to make?

APPENDIX 4.4

Evaluation Questionnaire – Part 2

SRDC-funded project CSE019,
Global change: informing the Australian Sugar Industry on potential impacts, possible strategies for adaptation and best-bet directions for future R&D

The aim of Part 2 of this questionnaire is to assess if your **K**nowledge, **A**ttitudes, **S**kills and **A**spirations (**KASA**) regarding climate change have changed as a result of participating in this workshop. The questions below are repeated from Part 1 of the questionnaire.

1. How would you rate the extent of your knowledge of global climate change issues in general?

None	Minimal	Moderate	Substantial	Significant	Extensive

2. Are you aware of the difference between the terms 'prediction' and 'projection' when related to climate change?

No	Yes

4. Are you aware of recent temperature and rainfall projections for the Queensland areas under sugarcane production?

No	Yes

4. State your own personal assessment of what the range of changes in temperature and rainfall are likely to be for the region(s) you most associate with (or live in) for the years 2030 and 2070. *We are not necessarily looking for you to remember published figures, more your thoughts on how future climate is likely to change.*

Year: 2030

	Low extent of change	'Most likely' change	High extent of change
Temperature change (^oC)			
Rainfall change (%)			

Year: 2070

	Low extent of change	'Most likely' change	High extent of change
Temperature change (^oC)			
Rainfall change (%)			

5. What do you consider to be the likely scale of impacts of future climate change on the sector(s) of the Australian sugarcane industry (or industry) that you work in?

None	Minimal	Moderate	Substantial	Significant	Extensive

6. What do you consider to be the likely scale of impacts of future climate change on the whole of the Australian sugarcane industry value chain?

None	Minimal	Moderate	Substantial	Significant	Extensive

7. How do you rate the capacity of your skills and knowledge to interpret climate change projections and develop a climate change adaptation plan for your sector of the industry?

None	Minimal	Moderate	Substantial	Significant	Extensive

8. To what extent do you think climate change projections will contribute to the decisions you make regarding working practices in the next 10 years?

None	Minimal	Moderate	Substantial	Significant	Extensive

9. How will you decide *when* to make changes to working practices as result of changes in ‘normal’ climate?

10. How much scope is there for a greater inclusion of climate change projections to increase economic, social and environmental sustainability of sugarcane projection in your region?

None	Minimal	Moderate	Substantial	Significant	Extensive

11. Are there any other comments you would like to make?

Thank you for your time!

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APPENDIX 5
Evaluation questionnaire Industry workshop, Brisbane

Industry Climate Change Workshop: KASA evaluation

Aim of the questionnaire
An evaluation (see appendix 5.1) was conducted at the Industry Climate Change Workshop held in Brisbane on Thursday 29 March 2007. The aim of the evaluation was to assess the efficacy of the workshop and the facilitators in running the sessions. The evaluation consisted of 14 questions. One of the questions related to the participant's own thoughts on how temperature and rainfall would change by the years 2030 and 2070. This question was added to the evaluation to collect data for a forthcoming publication and therefore has not been included in this write up. In the majority of cases the questions used a simple rating system to capture answers. For some questions, more open-ended answers were required in order to provide further information. The following is an analysis of the responses given by participants attending the workshop.

General information
The majority of the participants of the Industry Climate Change Workshop were primarily involved in the Research and Development sector of the sugar industry, whilst 5 participants were associated with the Growers sector and 1 or 2 participants represented the harvesting and transport, milling and marketing sectors (Fig. 1). Two participants at the workshop did not work in the sugar industry. The vast majority of the participants represented the whole of the industry, rather than a single region (Fig. 2).

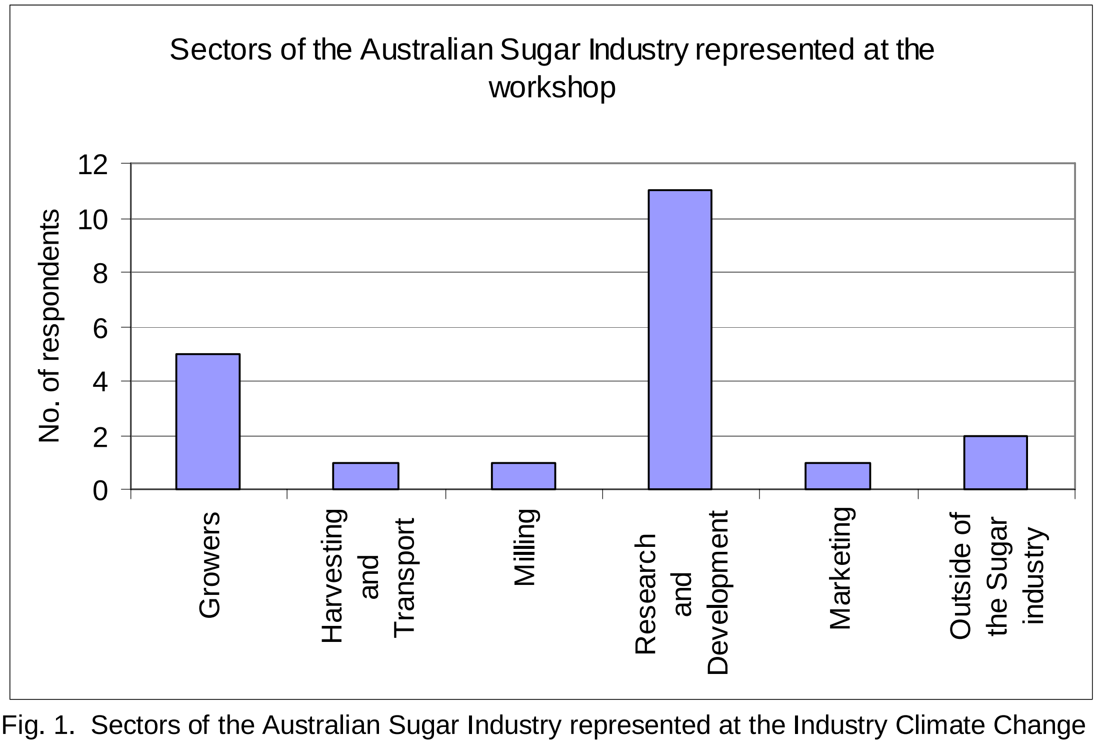

Fig. 1. Sectors of the Australian Sugar Industry represented at the Industry Climate Change Workshop.

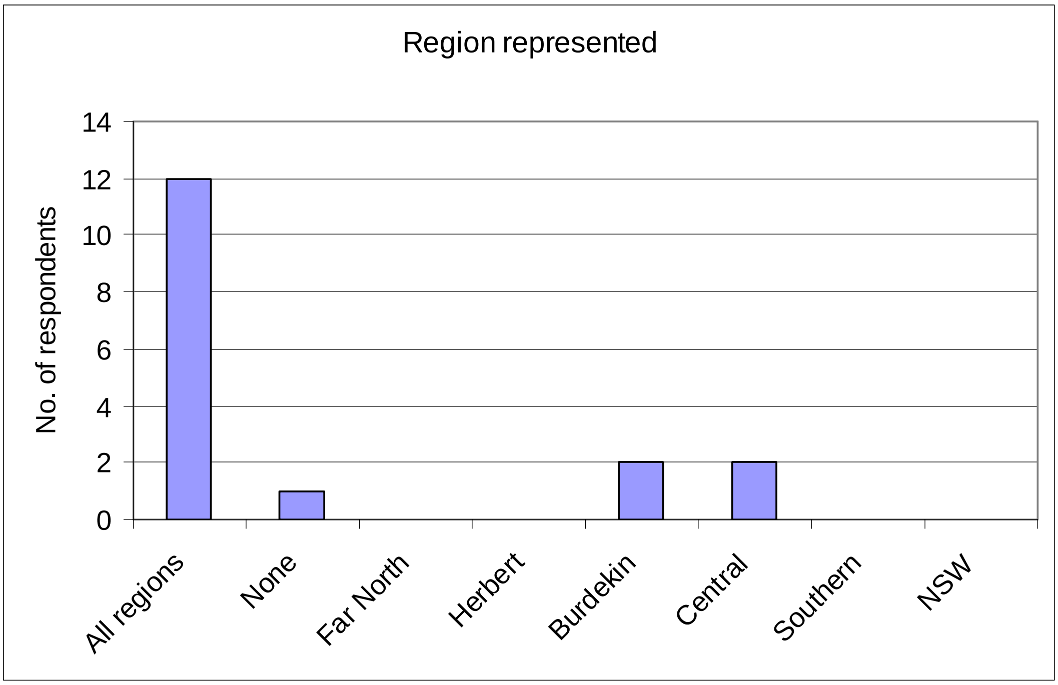

Fig. 2. Regions of the Australian Sugar Industry represented at the Industry Climate Change Workshop.

Perceived likely impact of climate change on the Australian sugar industry
The majority of workshop participants considered the likely future impacts of climate change on the sector(s) that they represented to be between moderate and substantial (Fig. 3). A similar response was expressed when participant's were asked to consider the impacts on the whole of the sugar industry, with even more participants considering the likely impacts to be significant. Clearly, the attendees at the workshop showed concern about the future prospects of the sugar industry in the face of a changing climate.

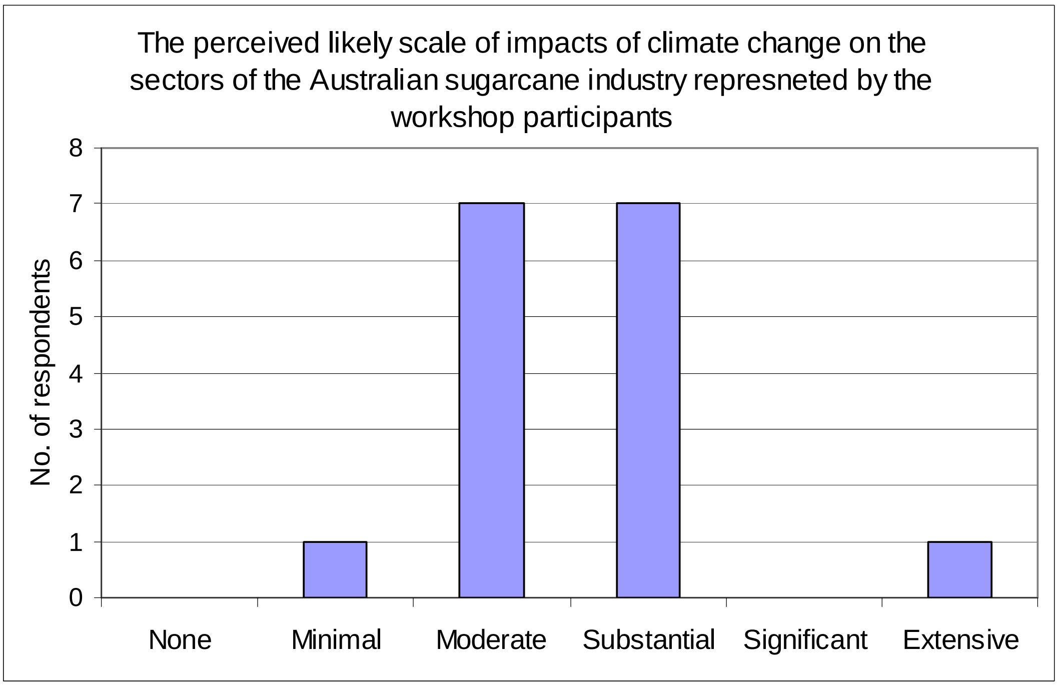

Fig. 3. Perceived likely scale of future impacts of climate change on the sectors of the Australian Sugar Industry represented by the participants at the Industry Climate Change Workshop.

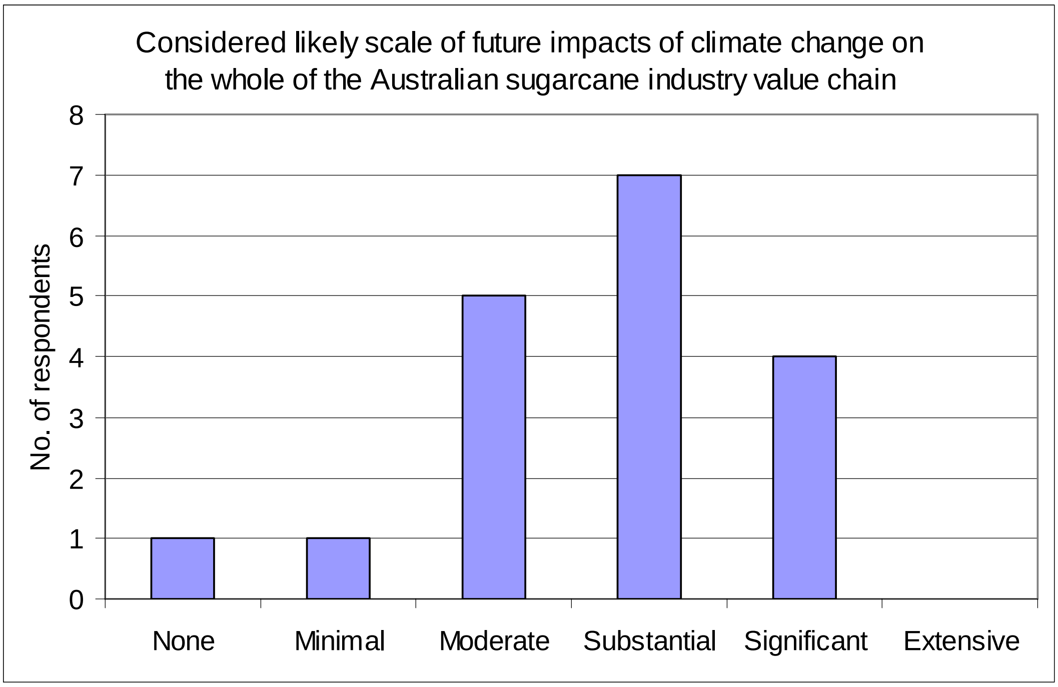

Fig. 4. Considered likely scale of future impacts of climate change on the whole of the Australian Sugarcane Industry represented by the participants at the Industry Climate Change Workshop.

The likely impacts of climate change were considered by the workshop participants to have at least a minimal influence on the economic, social and environmental sustainability of the industry (Fig. 5). The majority of participants thought the scale of influence would be substantial on all aspects of the industry, with a number of people considering the influence to be significant.

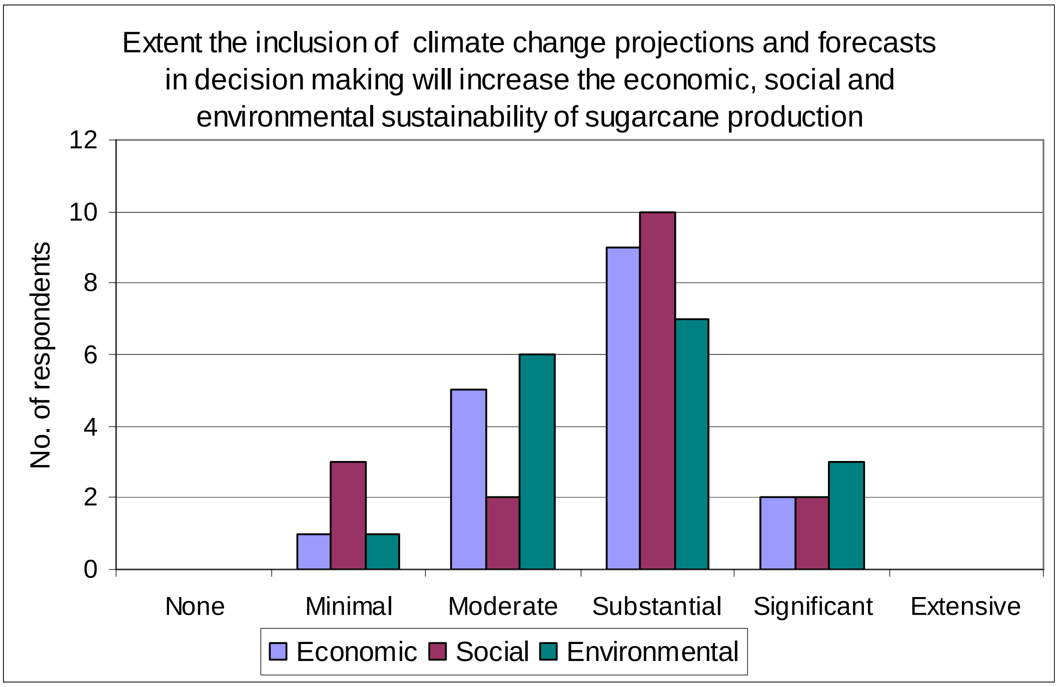

Fig. 5. Considered likely extent the inclusion of climate change projections and forecasts in decision making will increase the economic, social and environmental sustainability of sugarcane production.

Usefulness of the workshop

The workshop participants were provided with information on climate change prior to the workshop. This consisted of:

(a) Executive summary of a climate change report documenting participatory research undertaken to date in the Australian sugar industry as part of SRDC project CSE019,

(b) ABARE article analysing climate change impacts on Australian agriculture and potential capacity for adaptation,

(c) Agenda for the Industry Climate Change Workshop.

The majority of workshop participants considered the material to be considerably useful. No participants considered the material to be of no use. When the participants were asked to comment on the workshop, one participant noted that "the Executive Summary shows some comprehensive work", whilst another suggested that the background information may have been circulated at an earlier date (Table 2).

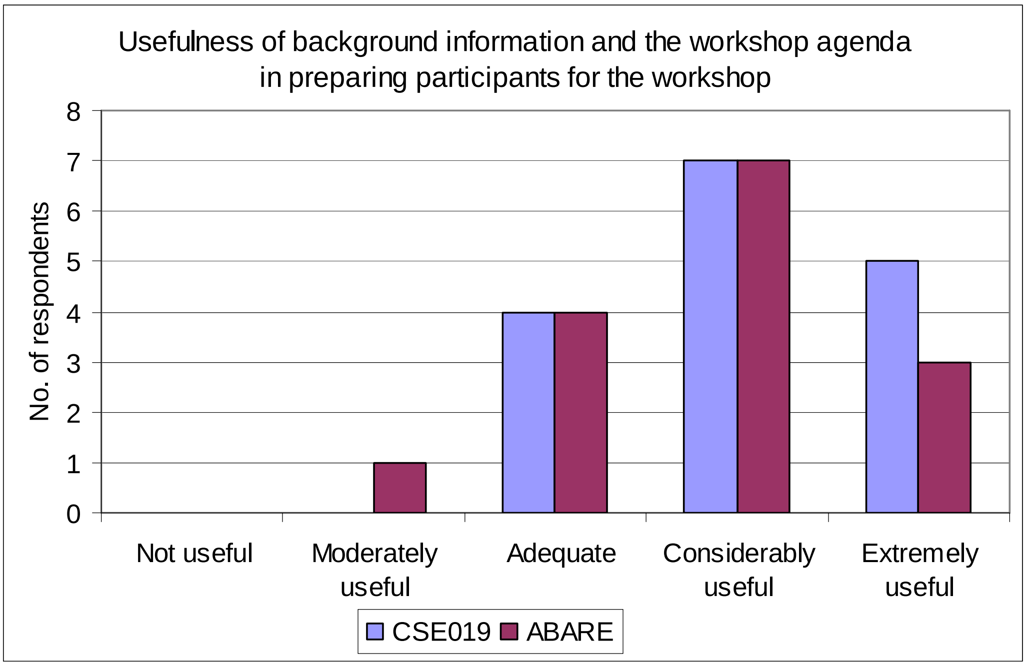

Fig. 6. Usefulness of background information (Executive summary from climate change report produced for project CSE019 and ABARE article) and the workshop agenda in preparing participants for the workshop.

The one-day workshop was split into two clearly defined sections; those aimed at providing information and those requiring the workshop attendees to participate in group discussions. The information sessions content consisting of:

(a) Welcoming the participants, facilitating the introduction of each participant and providing information on the expectations for the day (referred to as 'welcome and introduction' in Fig. 7 below),

(b) An overview of evidence for climate change and increased climate variability both globally and for Australia, including implications for Australia, cane growing regions and opportunities for agriculture to adapt (referred to as 'evidence for climate change')

(c) An overview of the causes of climate variability in Australia and research being undertaken to manage this at an enterprise level (referred to as 'climate variability'),

(d) An overview of participatory climate change research undertaken to date with the Australian sugar industry as part of SRDC project CSE019 (referred to as 'research to date'), and

(e) An overview of the SRDC of the research and development strategy (referred to as 'SRDC R&D strategy').

Two group discussions were held during the day; a morning session where participants were asked to discuss what they considered to be the key implications of climate change on the sugar industry and the associated adaptation strategies and research and development needs; and an afternoon session where participants were asked to elaborate on the research and development needs surround the key implications identified in the prior discussion session and the nature of research projects required to address these.

The workshop participants were asked to rate the usefulness of the sessions (Fig. 7). All sessions proved to be at least moderately useful, and in many cases considerably useful. On 18 occasions, the participants considered a session to be extremely useful. The range of considered rates of usefulness amongst the participants reflects the broad range of interests represented at the workshop.

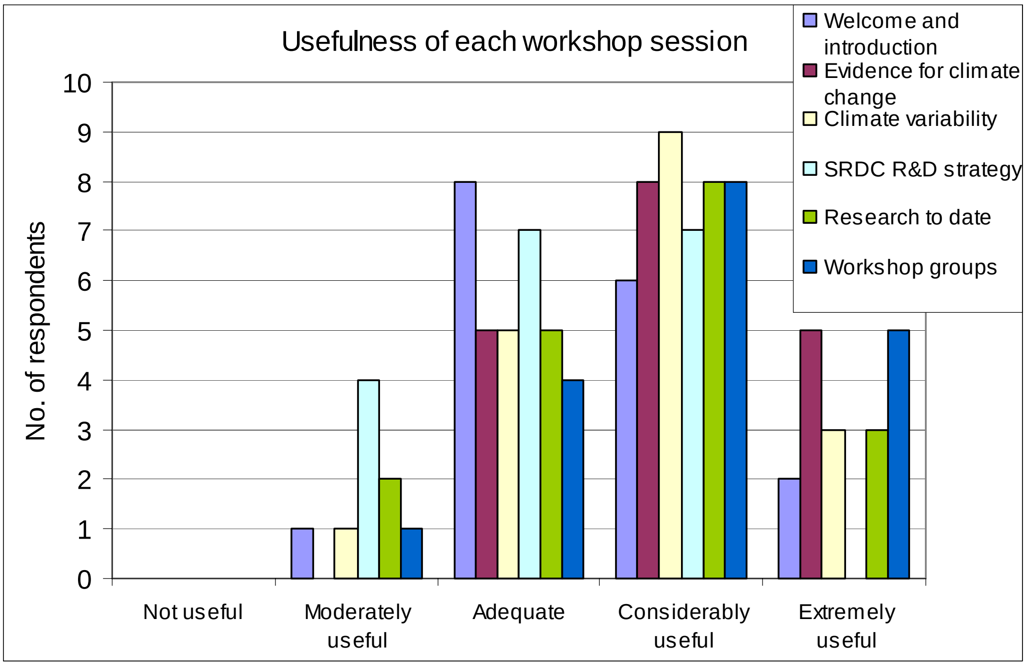

Fig. 7. Usefulness of each session in the workshop as rated by participants.

When the participants were asked how usefulness they found the workshop in identifying the key issues surrounding climate change for the Australian sugar industry and helping inform the development of R&D responses and management strategies to address these, all participants indicated that the workshop was at least adequate in achieving this (Fig. 8). Twelve participants thought the workshop was considerably to extremely useful in achieving this.

In the majority of cases, Colin and Sarah were considered considerably useful in their facilitation of the two group discussion sessions (Fig. 9). Whilst one participants considered them to be moderately useful, 5 participants thought their facilitation and input into the group discussion was extremely useful. A key aim of the group discussions was to promote debate amongst the participants and allow everybody to express their opinion. Encouragingly, 88% of the participants considered the workshops to be at least adequate in achieving this aim, with 65% considering them to be considerably or extremely useful (Fig. 10).

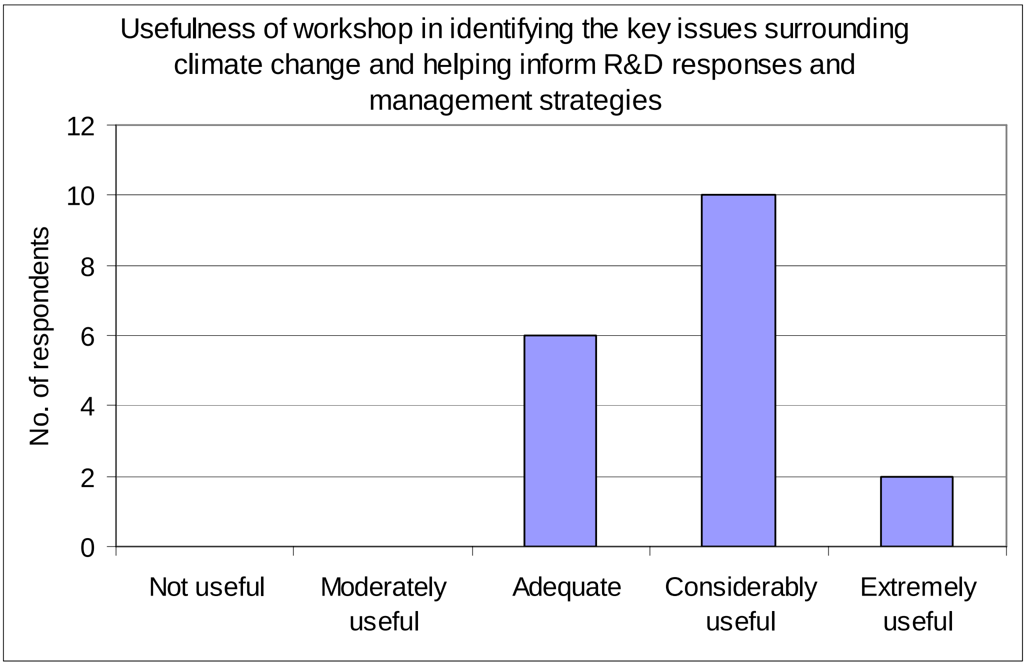

Fig. 8. Usefulness of workshop in identifying the key issues surrounding climate change for the Australian sugar industry and helping inform the development of R&D responses and management strategies to address these.

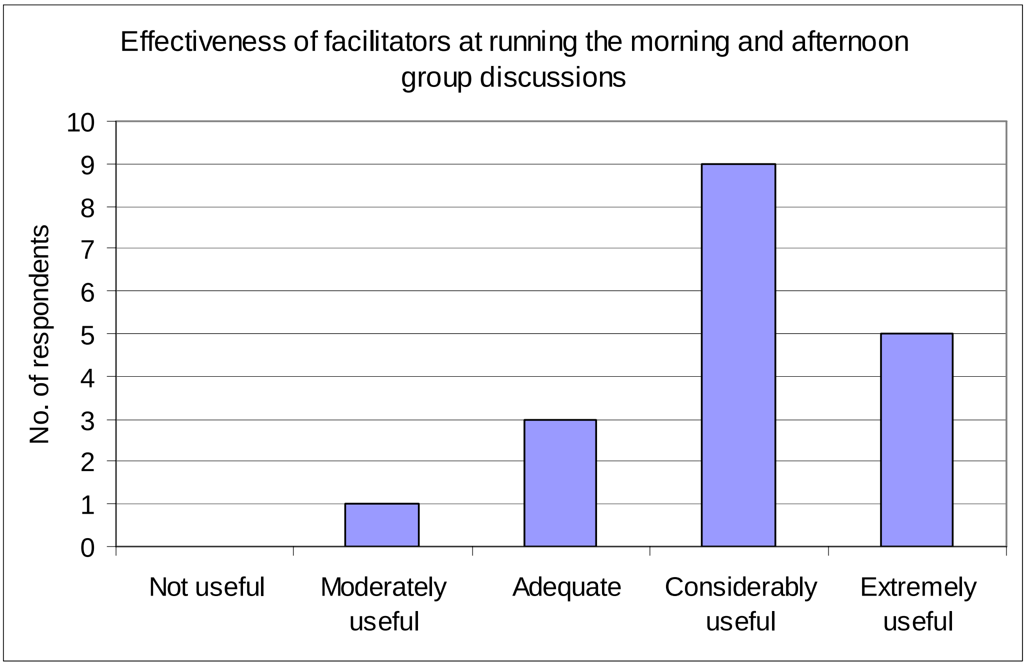

Fig. 9. Effectiveness of facilitators at running the morning and afternoon group discussions.

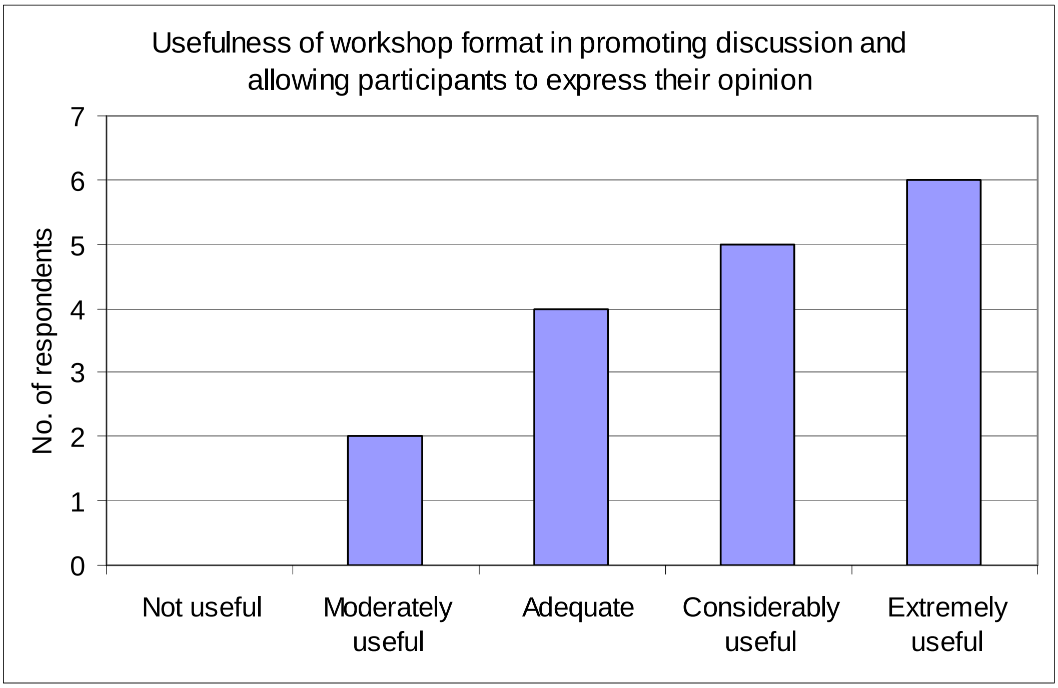

Fig. 10. Usefulness of workshop format in promoting discussion and allowing participants to express their opinion.

The participants were asked to comment on what did and did not work well during the workshop. In the main part, participants provided positive feedback regarding their level of participation, the diversity of attendees, facilitation and achieving an outcome in terms of R&D direction (Table 1). One participant considered the arrangement of the room did not work well, whilst another considered the air conditioner to be too cold. Other comments on aspects of the workshop that did not work well included the time allocated for group discussions; whilst one participant considered this to be too short, another considered it to be too long.

Table 1. Participant's opinions of what worked well and not so well during the Industry Climate Change Workshop.

Worked Well	**Worked Not so well**
Involvement and feedback.	Very technical long-term focus.
Focus groups in the afternoon.	Limited time for discussion, it was mostly just reporting back.
Good diversity of industry sectors.	Possibly too much discussion.
Small group discussions.	
All aspects worked well.	
Colin did a great job facilitating.	
I thought it all went pretty well.	
Getting wide range of industry people together.	
Provided a good idea of what we need to do in terms of R&D.	
Presentations, facilitators, group work.	
Group discussions, presentations.	
All except room arrangement.	
Air conditioner too cold.	

The participants were asked to suggest ways in which the workshop might have been improved. The feedback obtained from this centred around a perceived need for a "very high calibre speaker of international standing to be a keynote speaker", independent facilitation and the duration of the group discussions, the earlier circulation of background information, encouraging greater participation by industry stakeholders, room arrangements and ideas for moving forward with further research in the area of climate change as related to the Australian sugar industry. Many of the comments displayed very positive feedback, stating that “this was a great start to opening the discussion on climate change in sugar. Well done”, “doing this work at an industry level shows leadership and forward thinking. Congratulations and good luck”, and “very informative – thanks”. Additional comments (Table 3) reiterate the appreciation of the participants in participating in this activity and the need to build capacity within the sugar industry to tackle the challenge of continuing to grow sugarcane in under a changing climate.

Table 2. Participant’s ideas for improving the Industry Climate Change Workshop.

Maybe a very high calibre speaker of international standing to be a keynote speaker with better explanation of the greenhouse effect. This will give people more appreciation of the certainty of global warming.
Independent facilitator.
Earlier delivery of background papers. Encourage more industry stakeholder participation.
This was a great start to opening the discussion on climate change in sugar. Well done. The Executive Summary shows some comprehensive work.
More participation.
I thought the balance was alright. My group took a long time to get to terms with creating a research project. So a little more time would have been good. I think it would have been more useful if all the people who indicated they would attend, had attended.
More discussion, less small group activities.
Table arrangements. Morning and afternoon teas in the room
More guidance/facilitation for the 2pm to 3.30pm session to keep it on track and progress the development of R&D needs more full. E.g. working up the key components. Doing this work at an industry level shows leadership and forward thinking. Congratulations and good luck. Hope to continue to be able to be involved and interested to follow the progress. Very informative - thanks.
If SRDC wants to commission research prior to this sort of workshop, it would be good to get the best available team to do the research. It would be helpful if someone produced a list of existing research into climate change that is being conducted by sugar industry research organisations and other agencies.

Table 3. Additional comments made by workshop participants.

Compliments to the organisers.
Projects need to be established to deliver benefits more but with a component that takes into account the potential issues associated with climate change. There is a real need to educate (capacity build) the industry to cope with climate change. The head in the sand approach must be overcome.
Climate change is going to cause major problem, on a global scale. These issues need to be considered. Will the sugar industry still exist in Australia in 100 years time?
Thanks.

Appendix 5.1: Adaptation to Climate Change Workshop - Evaluation

Aims - To help us assess:
(a) the format of the workshop as a useful process for developing a R&D strategy on climate change for the Australian sugar industry,
(b) the quality of information provided both before and during the workshop, and
(c) the facilitation of the workshop to foster thoughts and discussions.

NOTE - The insights gained during the research may be published as part of work to assess how we best share knowledge and transfer science information.

- Completion of this survey indicates your willingness to voluntarily participate.
- You are not required to put your name on this evaluation - **all responses are strictly confidential.**
- Individuals will not be identified on any subsequent reports produced using this information.

Your personal opinions are important and will assist us to identify areas for improvement in the way we conduct such events.

Thank you for your cooperation!!

General information

1. Which sector(s) of the Australian Sugar Industry do you represent?

Growers	Harvesting and Transport	Milling	Research and Development	I work outside of the Sugar Industry

2. Which region do you represent?

All regions	None	Far North	Herbert	Burdekin	Central	Southern	NSW

3. State your own personal assessment of what the range of changes in temperature and rainfall are likely to be for the region(s) you most associate with (or live in) for the years 2030 and 2070. *We are not necessarily looking for you to remember published figures, more your thoughts on how the future climate is likely to change in your opinion.*

Year: 2030

	Low extent of change	'Most likely' change	High extent of change
Temperature change (^oC)			
Rainfall change (%)			

Year: 2070

	Low extent of change	'Most likely' change	High extent of change
Temperature change (^oC)			
Rainfall change			

(%)			

4. What do you consider to be the likely scale of impacts of climate change by the year 2030 on the sector(s) of the Australian sugarcane industry that you work in?

None	Minimal	Moderate	Substantial	Significant	Extensive

5. What do you consider to be the likely scale of impacts of climate change by the year 2030 on the whole of the Australian sugarcane industry value chain?

None	Minimal	Moderate	Substantial	Significant	Extensive

6. To what extent would the inclusion of climate change projections and forecasts in decision making increase economic, social and environmental sustainability of sugarcane production in your region?

	None	Minimal	Moderate	Substantial	Significant	Extensive
Economic						
Social						
Environmental						

Information provided before and during the workshop

7. Please indicate how useful you found each of the workshops sessions:

	Not useful	Moderately useful	Adequate	Considerably useful	Extremely useful
The “Welcome” and “Introductions & Expectations” sections at the start of the day in setting out the schedule and aims for the workshop					
The summary of the evidence for climate change and recent research conducted into climate change science (presented by Colin Creighton)					
The information presented on climate variability in relation to climate change and the Australian sugar industry (presented by Yvette Everingham)					
The presentation of the SRDC R&D plan in providing you with a strategic view of where SRDC is heading (presented by Russell Muchow)					
Summary of recent regional and industry-wide research conducted into climate change impacts and adaptation strategies in the sugar industry (presented by Sarah Park)					

Group discussion periods during the morning and afternoon sessions in providing a forum for discussing key issues					

8. How useful was the background information (Executive summary from project CSE019 and ABARE climate change article) and the workshop agenda in preparing you for this workshop?

Not useful	Moderately useful	Adequate	Considerably useful	Extremely useful

9. How successful was the workshop in identifying the key issues surrounding climate change for the Australian sugar industry and helping inform the development of R&D responses and management strategies to address these issues?

Not successful	Moderately successful	Adequate	Considerably successful	Extremely successful

10. How effective were the facilitators at running the morning and afternoon group discussions?

Not effective	Moderately effective	Adequate	Considerably effective	Extremely effective

11. How useful was the format of the workshop in promoting discussion and allowing you to express your opinion?

Not useful	Moderately useful	Adequate	Considerably useful	Extremely useful

12. In your opinion, what worked well and what not so well in this workshop?

Worked Well	Worked not so well

13. How would you improve the workshop?

14. Are there any other comments you would like to make? On the lines below express your opinions on the various matters that you feel need to be mentioned or expanded. Write on the back of this page or attach additional pages if needed.

Thank you for your time!