Relocation of Intensive Agriculture to Northern Queensland
The Cotton Industry

[1,2]Neil White, [2]Shahbaz Mushtaq,

[2]Geoff Cockfield, [1]Brendan Power

[1]Department of Agriculture, Fisheries & Forestry, Toowoomba

[2]University of Southern Queensland, Toowoomba

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Executive summary

Development of new agricultural industries in northern Australia is often perceived as a solution to changes in water availability that have occurred within southern Australia as a result of changes to government policy in response to and exacerbated by climate change. This report examines the likely private, social and community costs and benefits associated with the establishment of a cotton industry in the Burdekin.

The research undertaken covers three spatial scales by modelling the response of cotton and to climate change at the crop and farm scale and linking this to regional scale modelling of the economy. Modelling crop growth as either a standalone crop or as part of a farm enterprise provides the clearest picture of how yields and water use will be affected under climate change. The alternative to this is to undertake very costly trials in environmental chambers. For this reason it is critical that funding for model development especially for crops being crop in novel environments be seen as a high priority for climate change and adaptation studies.

Crop level simulations not only provide information on how the crop responds to climate change, they also illustrate that that these responses are the result of complex interactions and cannot necessarily be derived from the climate information alone. These simulations showed that climate change would lead to decreased cotton yields in 2030 and 2050 without the affect of CO_2 fertilisation. Without CO_2 fertilisation, yields would be decreased by 3.2% and 17.8%. Including CO_2 fertilisation increased yields initially by 5.9%, but these were reduced by 3.6% in 2050. This still represents a major offset and at least ameliorates the impact of climate change on yield. To cope with the decreased in-crop rainfall (4.5% by 2030 and 15.8% in 2050) and an initial increase in evapotranspiration of 2% in 2030 and a 10% decrease in 2050, irrigation was increased by 47.4% and 48.7% in order to maintain a 65%.

At this stage it was not possible to undertake such an analysis for the Burdekin, nor the next level of integration using a farm enterprise model. However, from the detailed work undertaken by CSIRO and Qld DAFF agronomists and trials undertaken by growers in the Burdekin we concluded that there was an opportunity to have cotton as a complimentary crop with a landscape dominated by sugarcane. The impact of climate change on the crop's performance can only hinted at. Radiation and high rainfall at critical stages of the crop's growth are a major risk for cotton producers. Climate modelling suggests that while temperatures are consistently predicted to increase, possibly conferring greater flexibility in planting dates, the outlook for rainfall is less consistent.

Modelling of cotton at the farm enterprise scale provided information on the change in yield, water use and profitability when cotton competes for resources, principally water for irrigation. A model farm, based on an irrigated farm in the Darling Downs, comprised irrigated cotton, wheat and maize and dryland sorghum. Water availability was reduced in 2030 and 2050 to combine the impact of climate change with changes in water policy. Changes to water allocation in the Condamine catchment are complicated because of the diversity of sources and a modest 14% decrease in bore allocation was simulated. Two adaptation strategies were considered that took into account industry advice that growers that identified themselves as cotton producers are likely to remain so the approach taken was to allow for partial irrigation of cotton with a less dense planting. Without adaptation the enterprise has to reduce the area of cotton planted causing reductions in farm level gross margins. The degree to which the crop mix changed was reflected in the scenarios developed for the regional scale modelling.

The costs and benefits of relocating a proportion of the cotton industry from the Darling Down to the Burdekin are derived using regional scale modelling of the economy using a large scale, dynamic, computable general equilibrium (CGE) model of the world economy (Tasman Global). This is a powerful tool for undertaking economic analysis at the regional, state, national and global levels. CGE models mimic the workings of the economy through a system of interdependent behavioural and accounting equations which are linked to an input-output database. These models provide a representation of the whole economy, set in a national and international trading context, starting with individual markets, producers and consumers and building up the system via demands and production from each component. When an economic shock or change is applied to a model, each of the markets adjusts according to the set of behavioural parameters which are underpinned by economic theory.

In this study the model is driven by reducing cotton production in the Darling Downs in accordance with relationships found between water availability and replacement by other crops and by increasing cotton production in the Burdekin.

Two scenarios were considered:

- Scenario 1: Cotton is grown using the fallow period between the last rattoon crop of sugarcane and the new planting. In this scenario there is no competition between cotton and sugarcane
- Scenario 2: Cotton displaces sugarcane production

Two time periods were used, 2030 and 2050. Under scenario 1, real economic output declines in the Darling Downs by $9.4 million in 2030 and by $25.5 million in 2050. On the other hands, relocation of cotton in fallow sugarcane land has resulted in increased real output in the Burdekin of $54 million and $84 million, respectively. Overall, with this relocation, Australian real economic output will increase by $37.5 million and 48.3 million, respectively.

When cotton is relocated to the Burdekin in competition with sugar cane, the Burdekin region also experiences a fall in real economic output due to due to the higher value per hectare of the sugar cane. The real economic output of the Burdekin will decrease by 12.7 $millions in 2030 and $15.2 million in 2050, respectively. Under this scenario, Australian real economic output will decrease by $16.0 million and 21.5 million, respectively.

Regional scale modelling such as this allowed us to overcome some of the limitations of the crop modelling. It was originally planned that farm-scale modelling would be undertaken in the Burdekin. When it became apparent that this would not be valid the regional approach was able to fill this gap and provide a higher level of information that places the relocation in context with the regional and national economies.

Darling Down cotton farmers are comparatively diversified already and so they will be relatively able to change the production systems. The loss of water, as a result of changing climate and water policy, would not significantly impact production system and profitability, if suitable adaption options are available.

Relocation of cotton production system to additional sugar cane fallow land or new area development in Burdekin would be viable option. The relocation of irrigated cotton to Burdekin, and as a result of production will have positive impact on export and GDP. This is primarily due to flexibility in the Darling Down cropping systems with suitable climatic conditions which allows growers to shift to various configuration of cotton production.

There could be large effects on regional economies, especially if cotton relocation will replace sugarcane land. The increase in cotton production will not compensate for the reduction in the higher value sugarcane production. This will be a cost to the economy over and above the direct cost of the environmental water. Some level of government support would be required to manage negative impacts.

Given the amount of water buyback for environmental purposes under MDB plan, farm and regional modelling result suggest there will be minimal impact on regional output. These negative regional impacts could be better managed by developing suitable adaptation strategies and by relocating some of the cotton production system to areas such as Burdekin.

Acknowledgements

This project was conducted with funding from the Department of Agriculture, Fisheries and Forestry (DAFF, Canberra). We are extremely grateful to the many people who have contributed in a variety of ways to this project, including key cotton industry representatives. Guy Jakeman from ACIL Tasman for carrying out the regional economic modelling and for providing us with ideas for the research and Stephen Yeates (CSIRO), Paul Grundy and Graham Harris (Qld DAFF) for their time and expertise in this area.

1 Introduction

1.1 Background

Climate change poses significant challenges to Australia, especially the challenges faced by the agricultural sector are further exacerbated by likely enhanced climate variability and increased frequency of extreme weather and climate events. It is expected that the southern part of Australia will generally become drier, while there is a likelihood of increased rainfall and the frequency and intensity of extreme events in parts of the north (IPCC 2007).

The possibility that climate change will lead to less rainfall in the south-east of mainland Australia triggered renewed interest in northern irrigation projects with proposals to reconfigure the geography of intensive agriculture (Camkin *et al.* 2007; Shanahan 2007; ABC News 2008; Northern Australia Land and Water Taskforce 2009b). One driver of this renewed interest in northern agriculture was to secure a 'potential new food basket' in the face of climate change (Shanahan 2007). This expansion could then offset possible decreases in the irrigated area and output of the Murray Darling Basin (MDB) as a result of decreased inflows, buybacks of environmental water under the Murray Darling Basin Plan (Murray-Darling Basin Authority 2010) and water trading, possibly to non-agricultural uses (National Water Commission 2009).

While there would be an offset at the national level, with production moving from one location to another, the regional impacts could be significant, especially given that agricultural production was for many years a mainstay of regional development (Davison 2005) and there are many communities highly dependent on irrigation schemes. Water-dependent communities have been dealing with adjustment pressures for many years as a consequence of climate variability, volatile commodity prices, shifting exchange rates, government policies and social trends (National Water Commission 2009). The combination of future expectations of reduced total water availability and the national imperative to provide a greater share of the available water for the environment, particularly in the MDB, means that the irrigation sector faces significant additional pressures. There is evidence of a great deal of uncertainty in the community in regard to the potential implications of major structural reforms in irrigation sector and there is a risk of over investment in infrastructure renewal if the likely extent of future structural adjustment is not adequately recognised (National Water Commission 2009).

Some industries are already looking to establish production centres in the north, for example the Peanut Company of Australia had planned to produce 13,500 tonnes of peanuts and 25,000 tonnes of corn and other crops from two newly established Katherine properties requiring an investment of over $20M. However, at the time of writing the properties have been sold to a company that produces sandalwood and it is unclear whether peanuts would be grown in future. For such investments to succeed, it is imperative that sustainable and profitable rotational systems are identified and adopted. There have however, been many attempts to develop intensive crop production in northern areas with a number of notable failures (see for critical reviews Davidson 1966; Graham-Taylor 1982; Wooding 2008) leading to a great deal of caution in regard to recent proposals for more development, considering that concerns about two previous developments did not include environmental considerations to the extent that they are a contemporary concern. There are then, four questions in relation to northern irrigation developments:

- Are there the natural resources (soil and water) to support irrigated agriculture?
- Are there suitable crops and crop varieties?
- Will it be profitable?
- What are the social impacts?

Some work has been undertaken to identify suitable soils and available water in the northern areas (Camkin *et al.* 2007; Northern Australia Land and Water Taskforce 2009a) and this work is recommended to continue (Northern Australia Land and Water Taskforce 2009b). We focus mainly on the last two questions with the assumptions that there are suitable soils and crops and available water. These are heroic assumptions and all recommendations should be seen as confined only to consideration of the private and public benefit if those resources are available. This project will provide information to support decisions on the incremental and transformational changes that are already happening in northern Queensland by looking at cotton production systems in the Burdekin as part of a sustainable and profitable rotation system. This will be investigated at three spatial (paddock, farm, region) and temporal (baseline, 2030 and 2070) scales. We also consider the net effects of shifting agricultural production by examining possible structural adjustment in the cotton areas, given a reduction in available water. This work can also contribute to discussions about the future of the Murray-Darling Basin in that the on-farm and regional impacts of reducing water allocations are examined.

1.2 Aims and objective of the report

This report is part of a suite of programs funded under the Climate Change Research Program that aim to identify likely private, social and community costs and benefits, in terms of production, farm business profitability, economic risk, and environmental impacts, of relocating agricultural industries to northern Queensland.

Project objectives: The project activities include to:

- Use crop and farm scale models of cotton production in the Darling Downs to understand the affect of climate change and water policy on yields and gross margins;
- Develop plausible adaptation strategies for irrigated cotton production on the Darling Downs;
- Develop a coordinated approach to analysing options for cotton cropping systems in northern Australia and provide relevant local and regional information with regards to the increased risks and opportunities from climate change;
- Assess the likely impact of relocating cotton production systems and associated industry to northern Queensland using both productivity and economic metrics; and
- Provide advice on effective Government policy that supports the sustainable growth of Australian primary industries by increasing the preparedness of farmers from vulnerable regions to mitigate impacts and identify opportunities from expected changes in climate.

This is case study focuses on the cotton industry as an industry immediately affected by the current policy and climate changes.

2 The relocation of agriculture as industry policy

In this section we develop a conceptual model of policy developments, based on some basic economic principles, as a means of organising the discussion of the research. The contention is that governments in developed countries, including Australia, have moved through three broad stages of industry development policy for agriculture. By industry policy we mean '…collective action aimed at building up new industries and firms, and restructuring old ones' with the goals including economic growth (Stewart 1994), general welfare and social stability (Freedman and Stonecash 1997). The goals of agricultural 'industry' policy in Australia have included: the reform of emancipated convicts (Connors 1970; Ward 1975); the civilisation of the frontier (Pike 1962; Waterson 1968; Johnston 1988); offsetting the effects of an economic depression (Connors 1970); supplying resources to the industrial hub of the British Empire (Schedvin 1988); and managing social unrest after the gold rushes and the first world war (Callaghan and Millington 1956; Connors 1970; Ward 1975; Lake 1987), but into the twentieth century, the aims were generally economic growth and regional development.

The three policy stages are: establishment and support (of an industry); self-sufficiency, competitiveness and structural adjustment; and post-productivist adjustment. The stages are not discrete with policy legacies and path dependency and various reversals but the model serves to illustrate dominant trends. In regard to establishment and support, this has been well-documented in Australia with colonial and then state governments distributing land and providing subsidised finance in return for requiring particular development outcomes, such as clearing and grain production (Roberts 1924; Connors 1970; Lake 1987) The 'support' mechanisms developed during the 20th century included at various times: input subsidies, such as machinery and fertilizer bounties; tariffs on competing imports; and the creation of centralised marketing systems, such as the Queensland Cotton Board (see Table 1 for a summary). The commodity boards shifted market power to the sellers through collective marketing and also enabled governments to provide underwriting arrangements. In addition, for public irrigation schemes, water costs were often effectively subsidised with, at best, recovery of the distribution costs.

Hence, the initial subsidies encouraged producers to enter the market, shifting the 'supply curve' further to the right (S to Ss in Figure 1) than would have been the case with no government intervention. In addition and assuming there are limits to the number of producers who can or wish to enter the market, those and/or other subsidies encourage growers to stay in the industry because of a high price (Ps) relative to the cost of production (Cs), because subsidies effectively reduce marginal costs (MC) relative to prices. This approach was however, criticised, notably by some agricultural economists, from the 1960s (for overviews see Gruen 1986; Cockfield 2009) as being against the liberal principles of efficiency and competitiveness, foreshadowing the second stage of industry policy: self-sufficiency, competitiveness and structural adjustment. From the early 1970s, there was a general move to reduce agricultural (and secondary industry) support with the winding back of tariffs, a reduction in subsidies and the privatisation of marketing boards (for an overview see Cockfield and Botterill 2006).

The argument was that Australia did not have the resources to match the US and EEC (later EU) subsidisation or market power so the only option was to encourage competitive and efficient industries (Hawke and Kerin 1986; Kerin and Cook 1988; Hawke 1989; Kerin 1989). For irrigated agriculture, the consequences were: the phasing out of input subsidies on machinery and fertiliser (1970s on); increasing water prices to cover infrastructure (1990s); the deregulation of water pricing and trading, which would reflect the opportunity cost (1990s-2000s) and the removal of the marketing boards (1980s-1990s).

With these policy changes, the market would become more competitive and the tendency would be for production to move towards Q in Figure 1. This is because costs would tend to move from Cs towards P,

Table 1 Early Industry Assistance for Australian Agriculture

Policy	Elements
Production subsidies	Land (through ballots and allocations below market value); Water 'rights' (at little or no cost); Finance; production inputs (e.g. machinery; fertiliser)
Funding for research and development	State agricultural agencies; agricultural colleges; commodity-based research centres; research corporations; regional natural resources management bodies
Infrastructure provision	Silos; railways; roads; social services; dams and water distribution systems
Industry protection	Tariffs on imported substitutes Non-tariff barriers such as quarantines rules
Market adjustments	Marketing board monopolies; commodity price averaging and guarantees
Export facilitation	Export corporations and trade networks
Safety nets	Drought assistance; exceptional circumstances
Industry adjustment	Farm build-up loans; exit grants; innovation grants; farm business advice; regional adjustment packages (e.g. Dairy industry)

prompting producers to consider other crop options or to exit the industry, thereby shifting the supply curve towards S. This would include an increase in the opportunity cost of water as markets developed for alternative uses for that water. There are in reality offsetting developments that help maintain production levels, such as increased farm size for economies of scale and the constant innovation that is a feature of agriculture whereby producers are always battling cost increases with little control over prices. In addition, production decisions are highly correlated with water availability, as opposed to just the price of water, and water availability can vary considerably, as will be discussed later in the report. To aid the processes of structural adjustment, such as farm amalgamations, technological innovations and industry exit, governments created a range of rural adjustment schemes that have gone through a number of incarnations: from the Rural Reconstruction Scheme (1970s) to Advancing Agriculture Australia. There could be more changes for the cotton industry that result from this policy stage, including the removal of limits on trading water out of regions and agriculture. On top of that, there is a case for arguing that a third stage of industry policy has commenced which is likely to bring more major change.

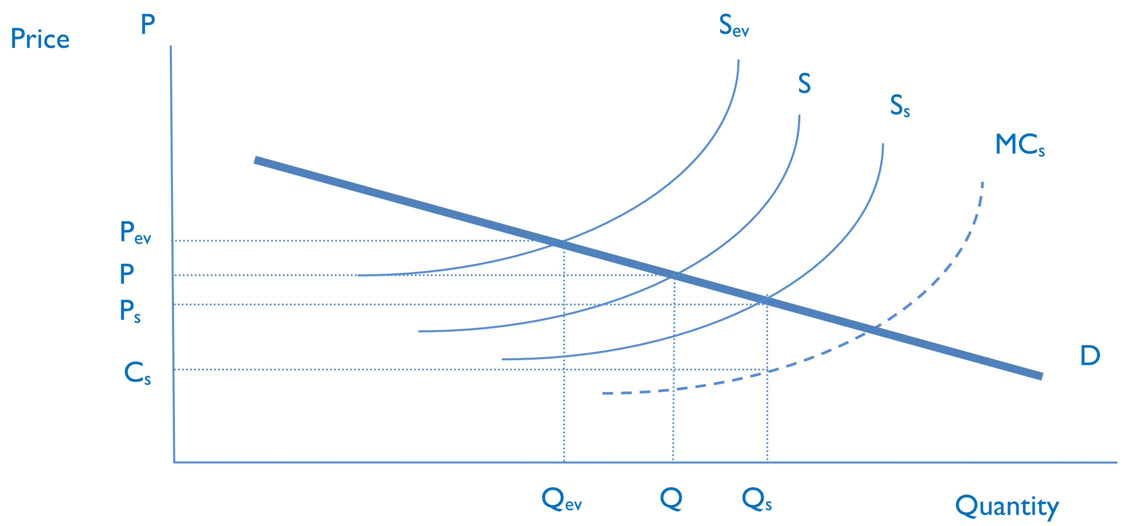

Figure 1 A model of the Australian cotton market with 2 stages of policy adjustment

The demand schedule is probably relatively flat because Australian production hardly affects the world market and exports comprise 80% of Australian sales, though there is some differentiation by the style of rice (see later discussion). The supply curves eventually become almost vertical because of natural resources limits and the increasing cost of shifting capital from other industries.

We suggest that all irrigation industries, especially those in the Murray-Darling Basin, are likely to undergo what might be termed post-productivist adjustment as implicit environmental and social 'subsidies' are removed. With an increased focus on externalities, the costs of agricultural production are now considered to include environmental and social (post-productivist) values such as clean water and air, environmental flows, habitat for non-human species and the recreational and existence value of non-agricultural vegetation. Examples of post-productivist revocations in other industries include: limits on industrial and effluent discharges into waterways; the restriction of logging in native forests; and the carbon tax, or emissions trading. All of these initiatives require producer adjustments with the adoption of waste management or emissions control technology, the purchase of sequestration offsets, the switch to commercial plantation timber, or exit from the industry. In the case of irrigators in the Murray-Darling Basin, governments have decided that water was 'over-allocated' at the expense of the environment and therefore some needs to be bought back for that purpose. This will further decrease supply to where environmental values are considered (Sev in Figure 1), and net production will also decrease, as will be discussed in a later section.

The question being examined within this project is then, should producers be encouraged to consider cotton production in non-traditional areas, so as to offset some of the expected decrease in the southern area? Further to that, should governments be supporting relocation of production and if so, by what means? The purpose of this section was to set out a conceptual framework for organising the overall discussion but in particular, to use the concept of the three stages to highlight some potential dilemmas for governments. If cotton production in the Burdekin region was relatively profitable government roles could reasonably be confined to research and extension on crop production techniques, the expansion of the water distribution system and perhaps some additional roads, social services and milling infrastructure. All of these are standard government roles and the costs of the additional the infrastructure could be recouped through full cost charges. If there is not a clear case that cotton is competitive with other land uses, then governments have to decide if there is to be additional support to facilitate this expansion. This would mean that just as the southern irrigation area is going through third-stage adjustment, there would be some first stage support in order to encourage the establishment of a northern cotton (geographically infant) industry. This would not necessarily be a return to colonial agricultural policies but forms of assistance could include special efforts to develop northern varieties that could cope with the tropical climate, reduced water costs, subsidised social infrastructure, grants to establish processing infrastructure and so on. This would be somewhat contrary to the general trend of second stage industry policy that prevails in most agricultural industries.

3 Cotton industry, climate change and water availability

3.1 Cotton industry significance

Cotton is largely grown in inland regions of Australia from central inland Queensland to southern New South Wales, about two-thirds of Australia's cotton is grown in New South Wales, and the remainder in Queensland. About 80 per cent of cotton farms are irrigated and as part of the enterprise mix generally produce other crops such as wheat and sorghum and/or graze sheep and cattle. Cotton is grown predominantly in areas of variable rainfall, high temperatures and high evaporation. Dryland cotton is normally an opportunity crop when conditions suit. The area of cotton grown each year varies and is largely driven by water availability and price and about 400,000 hectares of irrigated cotton is grown in Australia (McRae *et al.* 2007).

3.1.1 Cotton harvested area

Cotton harvested areas in NSW and Queensland, along with total harvested area, is shown in Figure 2. In general cotton area has increased since 1975–76 to 2000. However, since 2001 the area has declined significantly due to continuing drought conditions and water shortages in both Queensland and NSW. Major drought, and as a result almost zero water allocations with poor cotton prices, has significantly impacted 2006-07 and 2007-08 crops resulting in the smallest harvest in the last 25 years (Roth 2010).

3.1.2 Cotton yields and production

Australian average lint yields are now the highest of any major cotton producing country in the world and yields have continued to edge upwards (Figure 3). Despite year to year variation and seasonal conditions, Australian cotton yields have improved steadily over period. During the last 20 years, cotton yields have increased on average at 32.9 kg of lint per hectare per year (Roth 2010).

Figures 2 to 5 show the amount of cotton seed and lint production in New South Wales, Queensland and total Australia. In general, cottonseed and lint production followed harvested area but with a difference in increase yield. Similar to cotton area harvest, production fell significantly during 2007-08 due to drought conditions. Recent La Nińa conditions have provided good supplies of irrigation water and together with high cotton prices Australian cotton production is forecast to increase by around 20 per cent in 2011–12 to a record 1.1 million tonnes or 4 million bales (ABARE 2012).

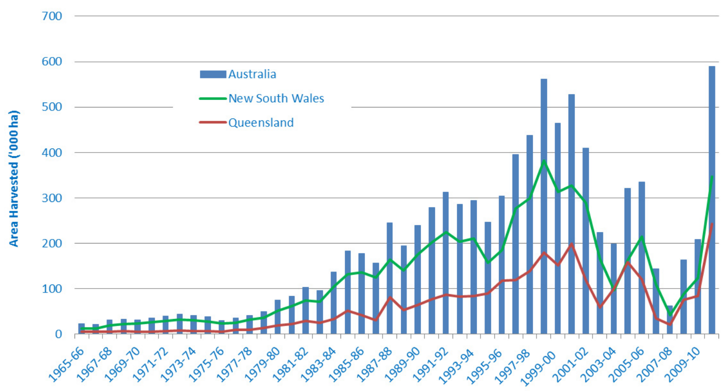

Figure 2 Cotton harvested area: Australia, New South Wales and Queensland.

Source: ABARE: 2012

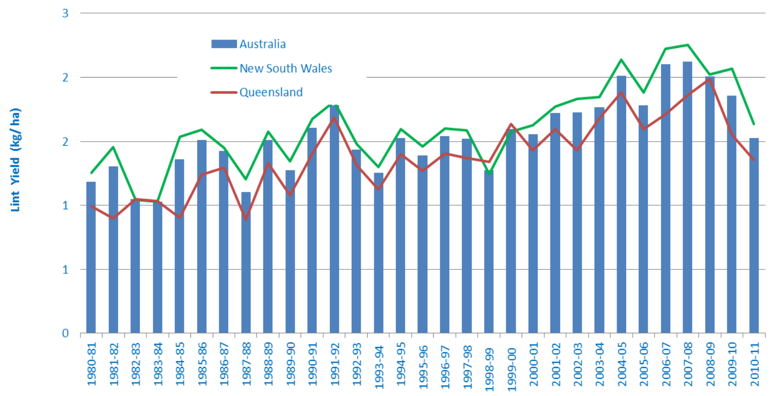

Figure 3 Cotton lint yield: Australia, New South Wales and Queensland

Source: ABARE: 2012

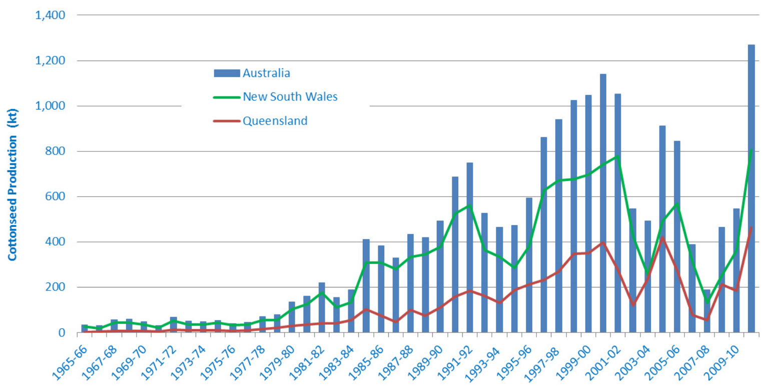

Figure 4 Cottonseed production: Australia, New South Wales and Queensland

Source: ABARE: 2012

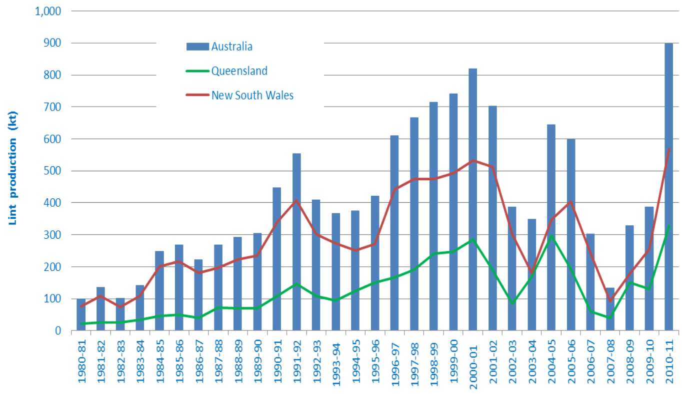

Figure 5 **Cottonseed production: Australia, New South Wales and Queensland**

Source: ABARE: 2012

3.1.3 Gross value of cotton production

Australian cotton is traded in a competitive market by several major cotton merchants. Cotton growers use a sophisticated range of risk management and price hedging strategies to manage price and currency fluctuations. There is no government price support in Australia. On a global scale Australia is a relatively small producer growing about three per cent of the world's cotton although has a reputation for producing high quality cotton. Virtually all is for export. The current major buyers of Australian cotton (in order) are China, Indonesia, Thailand, South Korea, and Japan. In particular years, China and India have been significant consumers of Australian cotton.

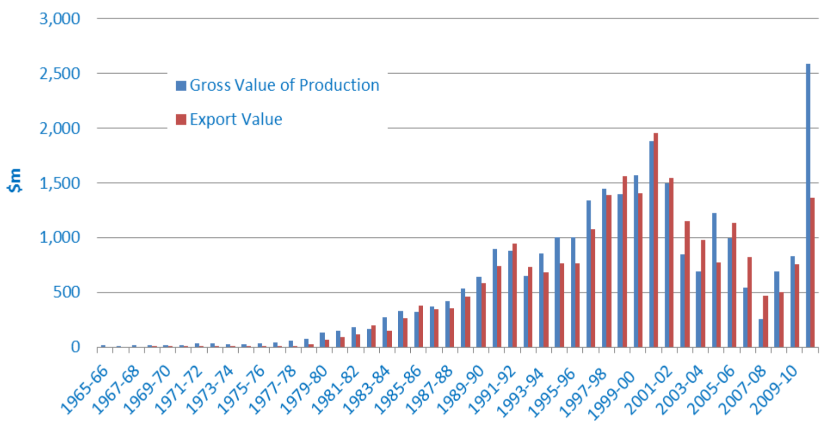

Figure 6 **Gross value of production and export values in Australia**

Source: ABARE: 2012

The gross value of cotton production and export values are presented in Figure 6. The gross value of production peaked at $1.9 and 2.5 billion in 2000–01 and 2010-11, respectively. However, during the last decade gross value has declined due to extremely low water availability and poor seasonal conditions. In 2007–08 the gross value of production was at a 34 year low of $259 million. It is forecasted to rise during 2011-12 (ABARE 2012). Australian cotton exports are therefore forecast to increase by 89 per cent in 2011–12 to a record 955,000 tonnes, Figure 6. This forecast is driven by strong export demand and expected record cotton production in 2011–12. Cotton exports are forecast to increase by a further 12.5

per cent in 2012–13, to 1.1 million tonnes. If realised, Australia would become the third largest cotton exporter in the world, behind the United States and India, surpassing Uzbekistan (ABARE 2012).

3.1.4 Key characteristic of cotton farms

Roth (2010) has documented some general characteristics of farms that grow cotton as the main irrigated activity (Table 2). The average total farm area where cotton is the main crop is more than 4,400 ha, with

Table 2 Characteristics of farms with cotton as the main irrigated activity.
Source: Roth, (2010)

Characteristic	Unit	Average Figure
Area of holding	ha	4,404
Area irrigated	ha	404
Area irrigated (cotton)	ha	343
Water use (farm)	ML	2,541
Water use (cotton)	ML	2,334
Water use intensity (cotton)	ML	6.0
Gross value of production (farm)	$	1,795,000
Gross value of production (irrigated cotton)	$	1,184,000
Gross value of production (all irrigated crops)	$	1,265,000

cotton comprising about 10% of that. About 80 per cent of farms are irrigated and other commodities include cereal grains, such as wheat and sorghum and beef. During 2003-04, a typical cotton farm grew about 404 ha of irrigated crops, of which 343 ha was cotton. In a typical farm, cotton makes up the largest proportion 66% ($1,184,000) of farm income in terms of gross value of production in 2003–04.

3.2 Climate change and water availability

Changes to Australia's already variable climate will present great challenges and opportunities for the cotton industry. While the Australian cotton industry is a major success story, in terms of increased productivity and water use efficiency while reducing negative environmental impacts, cotton farming is still highly dependent on climate, because temperature, light, and water are the main drivers of crop growth. Importantly, supply and demand for irrigation water are also influenced by climate change. Less water will result in increased competition between irrigated cotton production and other crops and environmental uses which emphasises the need for continual improvement in whole farm and crop water use efficiencies.

Cotton has a level of resilience to high temperatures and drought due to its vertical tap root. The crop is, however, sensitive to water availability, particularly at the height of flowering and boll formation. Increased CO_2 has the potential to increase photosynthesis and water use efficiency leading to higher crop yields. However, the benefits may be offset by declines in rainfall, increases in temperature and/or increases in atmospheric evaporative demand (McRae *et al.* 2007).

Plants need adequate water to grow and to maintain their temperature within an optimal range. Without water for cooling, plants may suffer heat stress. Irrigation water is used to maintain adequate growing and temperature conditions for cotton. The amount and timing of water availability during the growing season, through precipitation or irrigation, are critical for cotton. If water supply variability increases, it will affect plant growth and cause reduced yields (Karl *et al.* 2009).

3.3 Projected Changes in Climate for the Darling Downs and Burdekin

Projected climate changes for the Darling Downs and Burdekin as documented in the data provided by the Consistent Climate Change Scenarios project are documented below for 2030 and 2050. The AIFI and A1B scenarios are compared using four models for temperature and radiation as these have a significant impact on the growth of cotton. Changes in rainfall have been included because they influence the amount of irrigation water required.

3.3.1 Radiation

Radiation has a key role in crop development and is a key difference between the traditional growing areas and the Burdekin. The Burdekin is a tropical region with a distinct wet and dry season and the timing and duration of the wet season has a significant impact on the growing season for cotton, given that the duration of cloud cover reduces radiation levels. Problems in receiving sufficient radiation for cotton were reported for the Ord River Irrigation Area (Yeates *et al.* 2007). Paul Grundy (pers. comm.) has identified March as a period which strongly influences the outcome for cotton crops planted in late December in the Burdekin. Plants compensate for low light in a number of ways, chief among these are increasing their leaf area during periods of low light. Leaf area index (LAI) is the area of the plant's leaves divided by a unit area of ground. Typically a mature cotton plant will have a LAI of 3 to 4, i.e. for every m^2 of ground there are 3 to 4 m^2 of leaf. If February has been relatively dry with useful levels of radiation, then the cotton will have a lower leaf area index (LAI) and if March is wet and accompanied by low levels of radiation then the plant will have insufficient leaf area to produce a high yield at harvest. Disappointingly, the OZCOT model was developed for higher light regimes, e.g. Namoi Valley, Darling Downs, central Highlands, and does not adequately cope with the light regime in the tropics, so that yield estimations for the northern regions from this model are inaccurate at this stage.

The

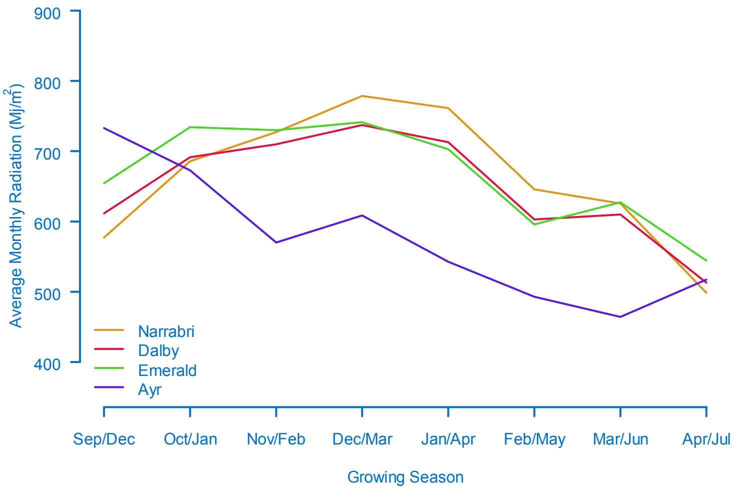

Figure 7. Total monthly radiation received during the growing season for four stations representative of traditional growing areas and the Burdekin.
Narrabri – Namoi Valley, Dalby – Darling Downs, Emerald – Central Highlands and Ayr – Burdekin. Growing seasons are September to April except Ayr December to July

spread of radiation received during the growing season shows two distinct patterns. In the tropical north, cotton is planted prior to the onset of the wet season and has to continue growth when radiation and temperature are declining. In contrast, cotton growth in the traditional areas is timed to take advantage of increasing light and temperature (Figure 7).

An alternative planting window of early May has been considered as this would have the benefit of avoiding the wet season in the early stages of crop establishment. The disadvantage of this is the lower levels of radiation during flowering and boll formation, from October to December, compared to the traditional growing regions (Figure 8). There is also a problem whereby the lower temperatures require the crop to be harvested during the onset of the wet season in early December. Although the harvest would be earlier under climate change it will remain a risky proposition due to the onset of the wet season.

Radiation changes only minimally under climate change with only small and inconstant trends between the models. These small changes in radiation levels must be judged against the variability within the historical data set. Hence any change in radiation due to climate change will be swamped by the year to year variation, Figure 9 ,

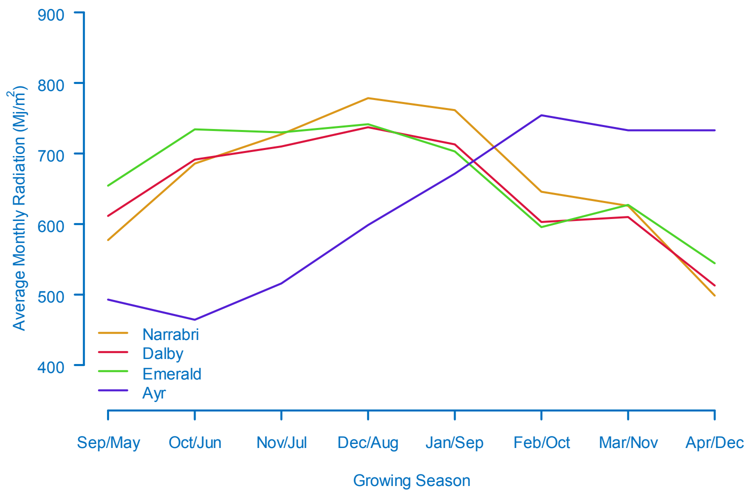

Figure 8 **Total Monthly radiation received during the growing season for four stations representative of traditional growing areas and the Burdekin with a planting date in May in the Burdekin**

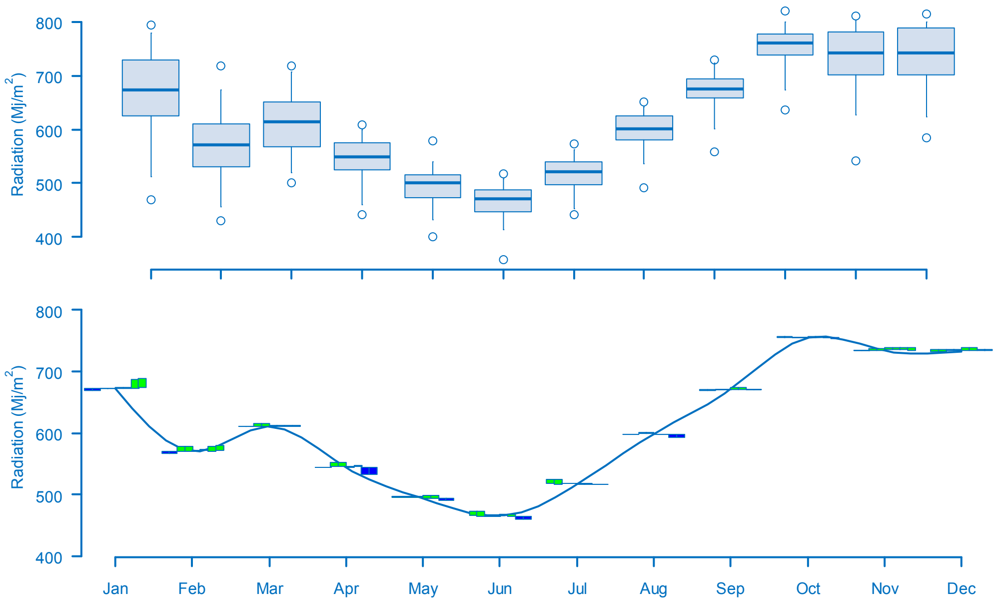

Figure 9 **Historical (top) and projected changes (lower) in radiation at Ayr in 2050 under the A1FI and A1B scenarios.**
Upper: monthly radiation 1957 to 2010. Lower: monthly median radiation as line; change in radiation arranged as 4 pairs of models (CCCMA-47, GFDL-21, CSIRO-MK3.5, MIROC-H) for A1FI and A1B scenarios

3.3.2 Temperature

Temperature is key variable for any crop and in conjunction with radiation determines the rate at which the crop reaches maturity. A day degree approach is generally used to model development as this allows the accumulation of heat units and takes into account thresholds and optimal ranges.

The temperature regime for the Burdekin has a distinctly different profile to traditional growing areas, showing a marked decline in average temperature over the growing season for plantings occurring in December,

Figure 10. If planting in the Burdekin is shifted to May (Figure 11), there is a gradual increase in temperature over the growing season, but minimum temperatures are close to the cold shock threshold, Figure 12. This tends to result in a late finish and the risk is that the crop will be reaching maturity when the rainy season starts.

Both minimum and maximum temperature increases for all scenarios and GCMs examined, Figure 13. As these were calculated using monthly change factors the best way of understanding the impact of these changes is via day degree modelling. This can be undertaken explicitly or as part of a crop model. Both approaches were undertaken as part of this project and are discussed in section 4.

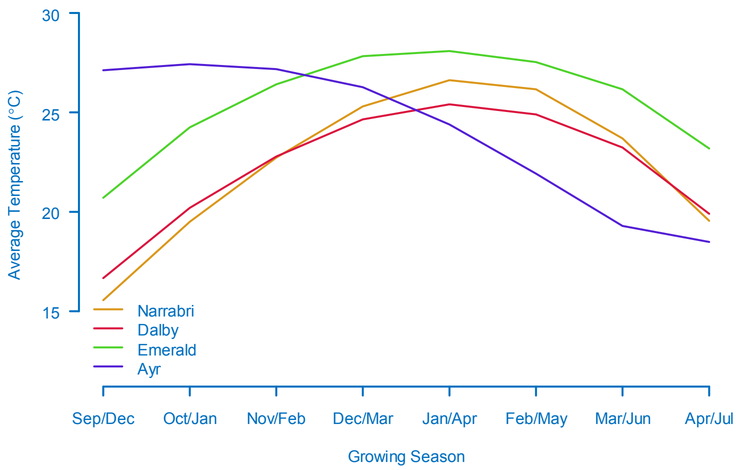

Figure 10 Average monthly temperature during the growing season for four stations representative of traditional growing areas and the Burdekin. Planting in the Burdekin occurs in late December.

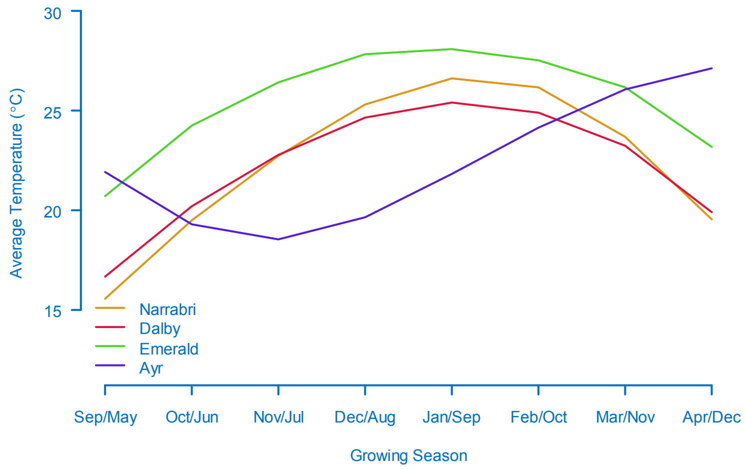

Figure 11 **Average monthly temperature during the growing season for four stations representative of traditional growing areas and the Burdekin. Planting in the Burdekin occurs in May.**

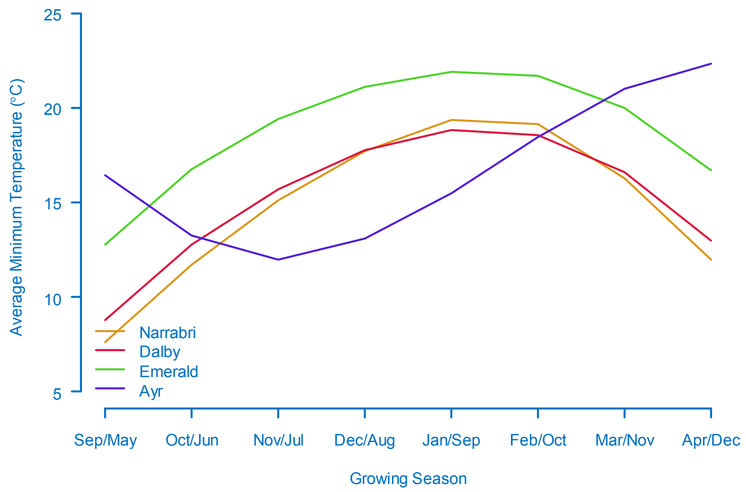

Figure 12. **Average monthly minimum temperature during the growing season for four stations representative of traditional growing areas and the Burdekin. Planting in the Burdekin occurs in May.**

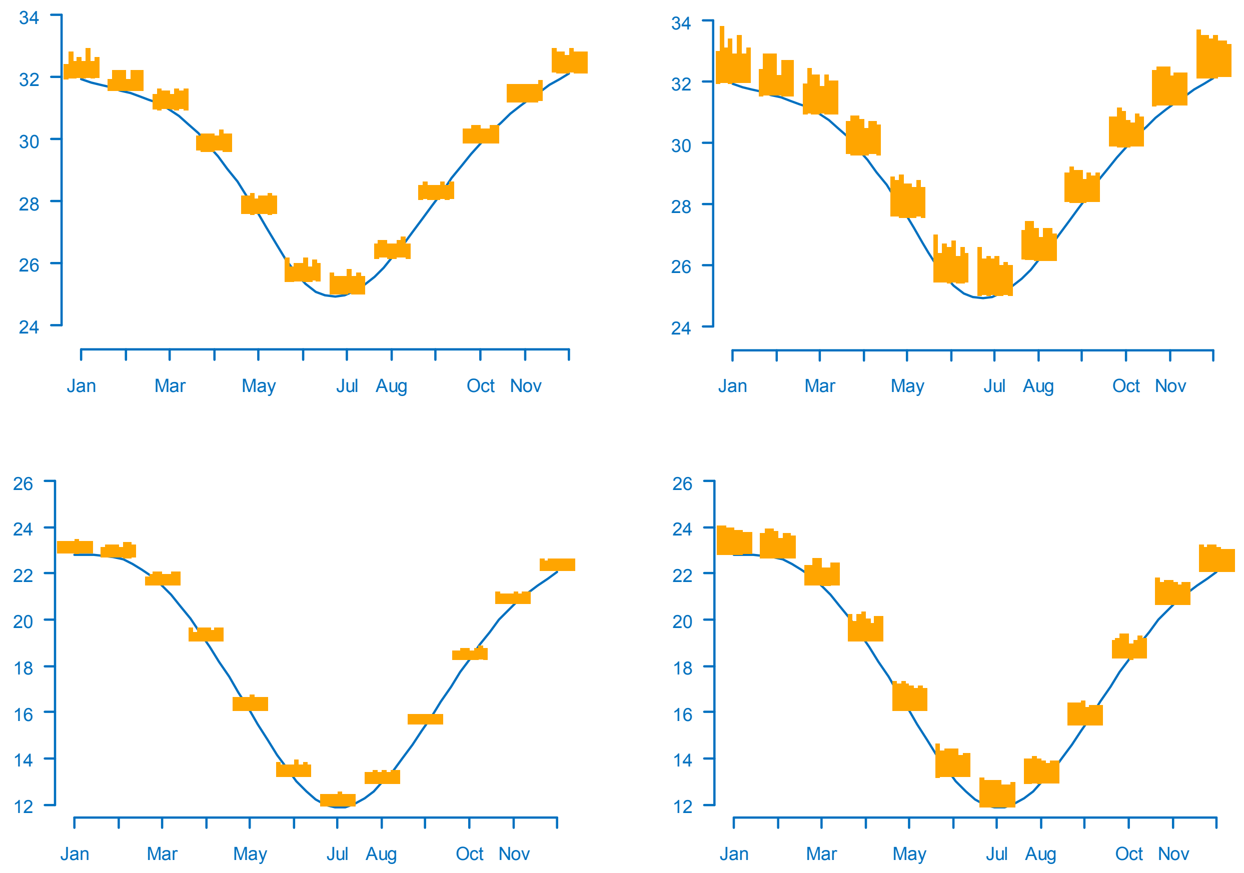

Figure 13 **Maximum (upper) and minimum (lower) temperatures for Ayr for 2030 (left) and 2050 (right). Lines represent the historical mean. GCM and scenario data arranged as Figure 9.**

3.3.3 Rainfall

Rainfall during the early part of the growing season in Ayr is significantly higher than the traditional growing areas (Figure 14). Under climate change the future projections for rainfall are consistent between scenarios, but the models are distinct. CCCMA-47 and CSIRO-MK3.4 show a decrease in rainfall while GFDL-21 and MIROC-H show an increase in rainfall, Figure 15. Since the data created for these models is a simple multiplication factor there is no indication of how the distribution of rain days and intensity change under global warming. However, a consistent reduction in rainfall in December might reduce the number of planting dates that are unsuccessful due to high rainfall and the shift in probability of a rainfall exceeding 300mm drops from 7% to 4-5% in most cases and no longer occurs under the CSIRO-MK3.5 model by 2050.

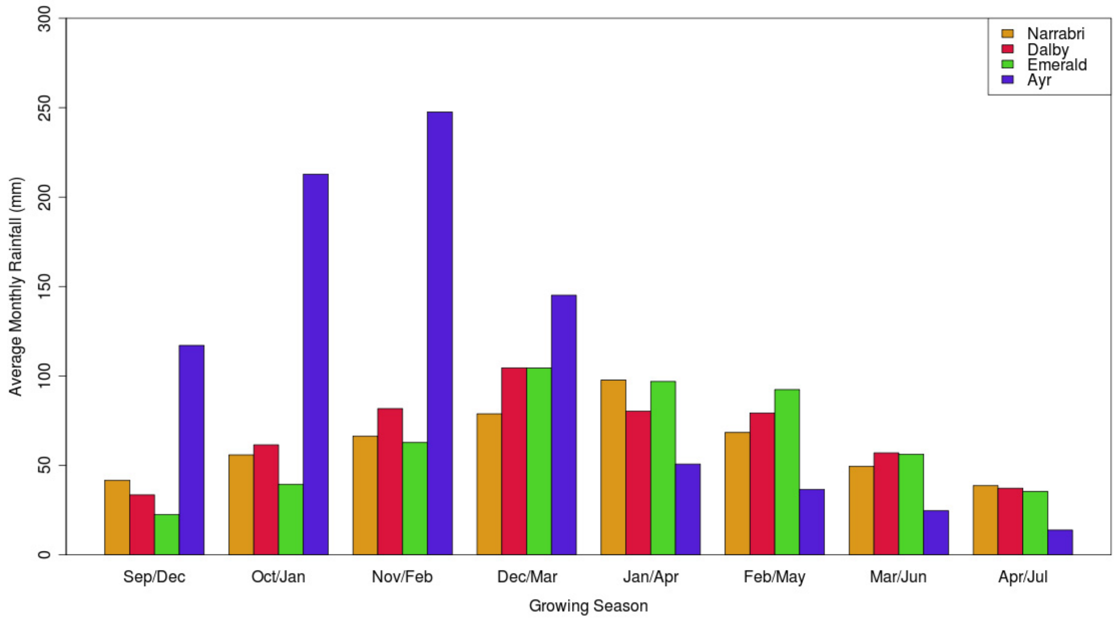

Figure 14 **Monthly rainfall received during the growing season for four stations representative of traditional growing areas and the Burdekin**

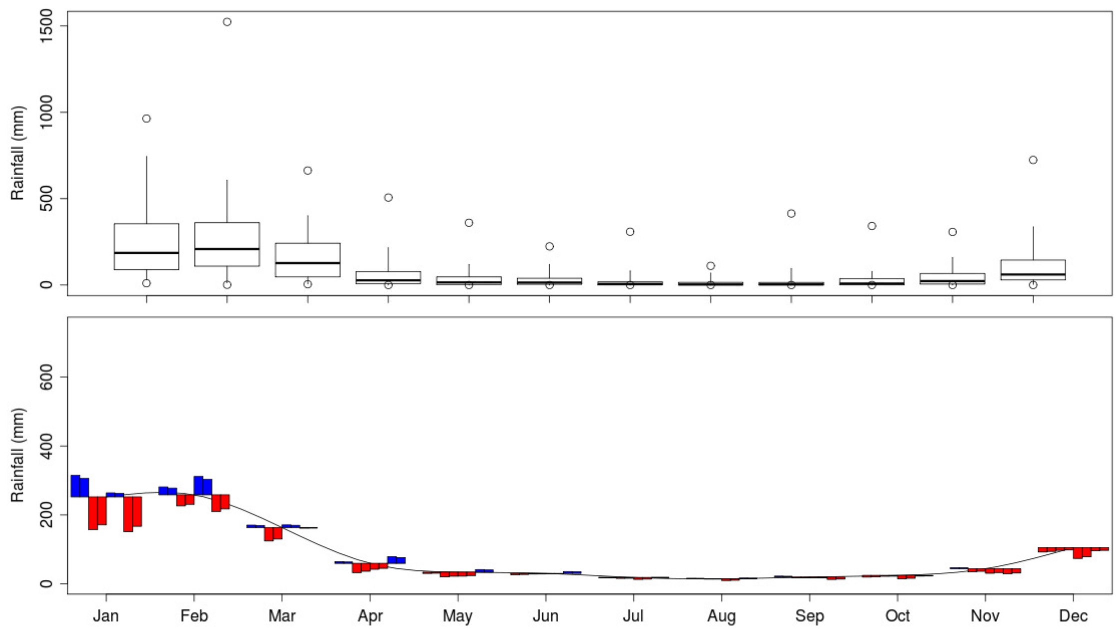

Figure 15 **Historical (top) and projected changes (lower) in rainfall at Ayr in 2050 under the A1FI and A1B scenarios. Data arranged as for Figure 9.**

Changes in rainfall for the traditional growing areas are more pronounced which is consistent with the overall trend in drying in eastern Australia, Figure 16. This will put increasing pressure on water resources and the outcome of national policy decisions regarding water in the MDB will become significant and determine the mix of irrigated versus dry land cropping.

The agronomic practices that have been developed for the traditional growing areas do not successfully transfer to the tropics. An important consideration is the loss of nitrogen under high rainfall and the need for a greater number of small applications of fertiliser during the growth period. Other agronomic practices such the application of growth retardants needed to prevent the cotton from flowering too early, have to use a different set of rules for application. This makes cotton a more difficult crop to grow even for experienced cotton growers and is difficult for growers within the region to be able to take on as a novel crop. A manual of agronomic practices is under development for the region and should be available in mid-2012.

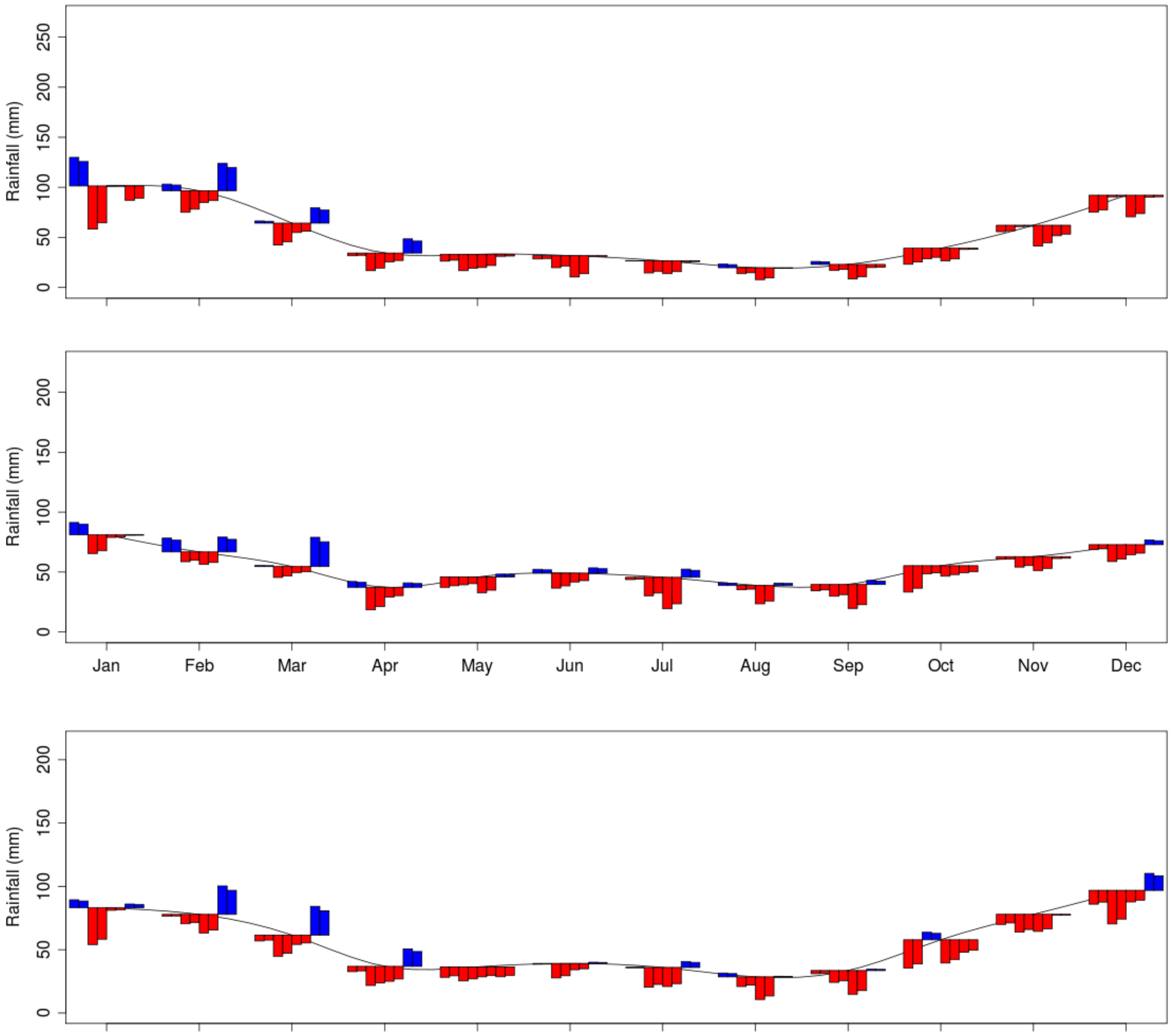

Figure 16 Changes in rainfall for each of the three traditional growing areas in 2050. Emerald - top, Dalby – middle, Narrabri – lower. Data arranged as for lower part of Figure 9.

4 Empirical Assessment Methodology

4.1 Project Conceptual Framework

The conceptual framework to examine the impacts of relocation of production at the farm, regional and national levels is set out in Figure 17. The methodology involves crop and farm level estimates of productivity and responses to water scarcity linked to structural adjustment models. The framework recognises that the decisions made by farmers can impact on industries (and vice versa) and local and regional communities. Relocation decisions are driven by expectations about the future profitability of cotton farming based on a range of market, social, technological, government policy and environmental considerations. At the regional level the project uses the ACIL Tasman General Equilibrium model, *Tasman Global*. This is an analytical tool that can capture these linkages on a regional, state, national and global scale. The model enables the analysis of issues at these scales and the determination of the impacts of various economic changes on production, consumption and trade at the macroeconomic and industry levels. In the case of the regional cotton model, a reference case simulation will be developed (business-as-usual) with which various scenarios will be compared

4.1.1 Crop and farm level assessment

Crop and farm scale modelling was undertaken using APSIM (McCown *et al.* 1995) and the APSFarm framework (Power *et al.* 2011). These simulations provide an assessment of the response of cotton as a standalone crop and as part of a farm enterprise. A modelling approach such as this provides a coherent methodology to place industry and regional scale information in perspective and guides the development of the regional scale scenarios. An alternative modelling platform, DSSAT (Jones *et al.* 2003), provides much of the same functionality as APSIM, but is less focussed on Australian conditions, e.g. soil types are difficult to compare and the cotton model does not have the varieties of cotton that are used on the Darling Downs. APSIM provides direct access to Australian soils and to over 4000 weather stations via SILO (Jeffrey *et al.* 2001). The cotton model used in APSIM is based on OZCOT which has been used extensively throughout the cotton growing regions in Australia. After extensive testing of the DSSAT cotton model, it was felt that APSIM provided a better pathway to understand the impact of climate change on cotton production as it had relevant cultivars available and has been tested extensively in the traditional growing areas throughout Australia.

Neither model performed reliably in the Burdekin since this environment is very different to those in which the models ware developed. For this reason a simple day degrees model has been used for the Burdekin to investigate planting dates and to illustrate the limitations of the cropping system in an environment as discussed in section 3.3.

The performance of the APSIM cotton model for the Darling Downs is well understood and it is very capable at predicting yield for this system. A recent study (Power *et al.* 2011) was used as the basis for modelling grain-cotton enterprises on the Darling Downs. The approach described in that paper using APSFarm was followed except for some improvements in the way in which overland flow is captured and irrigation decisions are made. The approach differs from the traditional APSIM methodology in that APSFarm is a dynamic framework that integrates multiple bio-physical models that operate at the paddock, farm and sub-catchment level. In essence, APSFarm incorporates multiple APSIM simulations and combines this with a set of rules for crop rotation, machinery and labour availability and cost of management operations and sets these against the background of climate variability. In this way the impact of climate change can be modelled such that changes in rainfall, temperature and CO_2 are reflected in crop growth and yield and changes in water policy influence the decision to plant which crop within a rotation.

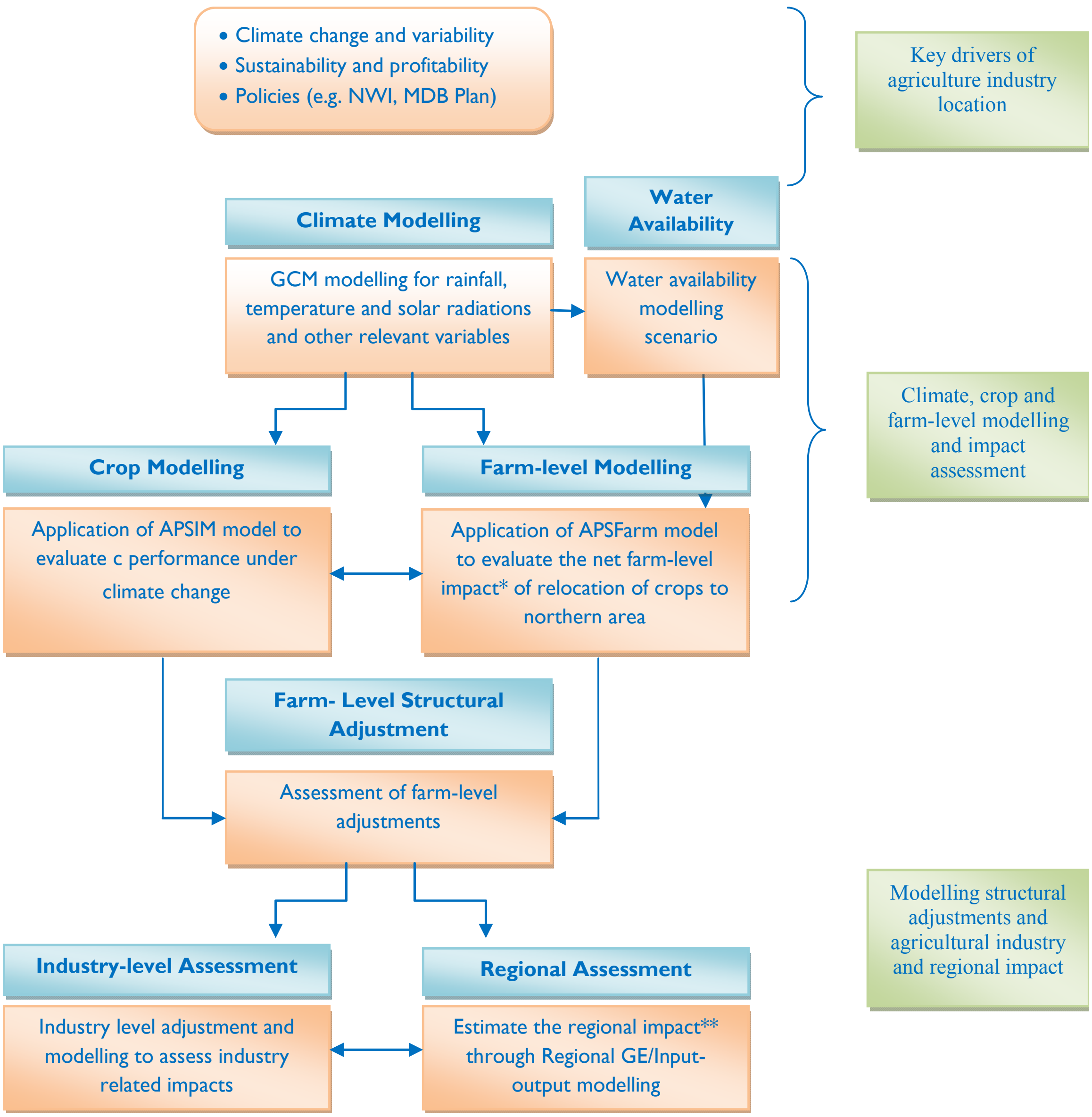

Figure 17 Project conceptual framework

* Net farm level impact = current farm level income ($)-income from next best alternate enterprises

** Net industry impact (e.g. cotton) = Direct Economic Impact (Direct value added by cotton industry- value added from next best alternative 'dryland' enterprises) + Indirect Economic Impact (Value added by cotton industry processing net change in output + All other net indirect effects- Value added by alternate industry processing net change in output + All other net indirect effects)

4.1.2 Day degrees and crop modelling

Day degrees model: The model used was the same as that found within OZCOT within APSIM and used on the CottASSIST[1] web site. The number of heat units or day degrees (DD) required for various stages of plant development (Table 3) is a simple tool for predicting and monitoring the progress of a crop. Day degrees are accumulated by calculating the number of days in which the temperature is above a given threshold. For cotton the threshold temperature is 12°C. So a day in which the average temperature was 18°C would accumulate 6 day degrees. In practice the calculation is done using hourly temperature accumulated over a 24 hour period. A cold shock delay is incorporated when the minimum temperature is below 11°C. This increases the day degree requirement for a growth stage by 5.2 degrees. Sowing dates of

[1] http://cottassist.cottoncrc.org.au/

15 October and 20 December were used for the Darling Downs and Burdekin respectively. Growth targets for cotton are shown in Table 3.

Table 3 Growth targets for cotton measured in cumulative day degrees from sowing.

Growth target	Day degrees required for growth target	Description
Emergence	80	Appearance of cotyledons
5th True leaf	330	
1st Square	505	The flower bud of a cotton plant. These are often the preferred site of insect damage.
1st Flower	777	
Peak Flower	1302	
Open Boll	1527	Cotton boll is the name of the rounded seed pod of the cotton plant. The fibres harvested for cotton develop within the boll. As the boll matures the cotton boll opens. This would release the seed in normal growth
60% Open	2050	When 60% of the cotton bolls have opened the crop is defoliated prior to harvesting.

The day degree model was calculated for the present climate and future climates at 2030 and 2050 using the CSIRO-MK 3.5, MIROC-H, GFDL-21 and CCCMA-47 models. The A1FI and AIB scenarios were considered.

APSIM Modelling: The APSIM OZCOT model (Hearn 1994) has been used extensively throughout Australia to model cotton production and performs well within the traditional growing regions. It does not, however, produce realistic results for the Burdekin region because of its inability to properly model the leaf area under the very different light regime that is encountered (Stephen Yeates pers comm.). Without a crop model to integrate changes in temperature, rainfall and radiation under climate change it is difficult to predict if the crop will perform adequately in the future. The analysis of the climate in the Burdekin and how this will change suggests that the most important drivers will be temperature and CO_2 fertilisation, Figure 18.

Attempts to use the APSIM OZCOT model in the Burdekin have been problematic as the model does not respond to important events, such as low light in February/March, in the same way that the crop does in the field. This led us to investigate the use of the DSSAT cotton model. However, after considerable effort to use the model in a meaningful way it was felt that the lack of suitable cultivars for Australia was problematic, even though initial trials produced yields in the correct range this was not necessarily for the correct reasons. Using the model to predict changes in yield under climate change under these conditions was not advisable.

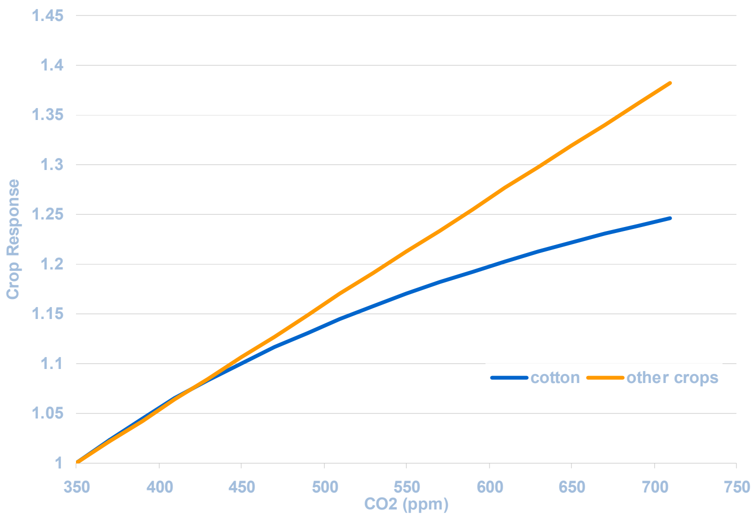

Figure 18 Crop response to CO_2 fertilisation

The effect of climate change with and without CO_2 fertilisation was examined for cotton grown on the Darling Downs under the A1FI scenario in 2030 and 2050. The present value of CO_2 was set at 350 ppm and 449 ppm for 2030 and 555 ppm for 2050 as prescribed by the Consistent Climate Change Scenario data. These simulations were undertaken using the CSIRO MK 3.5 projections such that nitrogen stress does not occur and irrigation provides at least 65% available soil water (ASW). These simulations were designed to provide information on the impact of climate change on yield and irrigation water requirements.

APSFarm modelling**:** A detailed analysis of a typical farm enterprise was undertaken for the Darling Downs using the approach of Power *et al.* (2011). The enterprise consisted of solid (1 m rows) planting of cotton with full irrigation, with irrigated wheat and maize and dryland sorghum. The farm consisted of 12 management units, effectively proxies for paddocks, with a total area of 446.5 ha. Irrigation water was supplied via two on-farm storages that are filled via captured on-farm runoff, off-farm overland flow and access to a bore (200 ML/year). This allocation was reduced by 14% to 172 ML/year in 2030 and 2050 to simulate possible reductions that might occur. The draft MDB plan provides a wide range of estimates for reductions in water allocation for the Condamine catchment and the figure we have used was selected to cause an impact on water allocation that was neither negligible nor too extreme.

Table 4 Details of cropping system used in the APSFarm modelling on the Darling Downs.

Description	Wheat	Maize	Sorghum	Cotton (1m)	Strategy 1	Strategy 2
Cultivar	Hartog	Dekalb x182	Early	SR71BR		
Sowing Depth (mm)	30			50		
Plant Density (m^{-2})	120	8	4.5	10		
Row Spacing (mm)				1000	200	200
Fertiliser Amount (kg/ha)	200	220	50	240	170	170
Fertiliser Depth (mm)	50					
Fertiliser Type	NH_4					
Irrigation Threshold (% ASW)	0.4	0.4	0	0.65		
Water requirement (ML/ha)	4	3	0	4	2	0
Max. in-crop irrigations	2		0	4	2	2
Planting Window	1-30 Jun	15-30 Sep	1-15 Nov	1 Oct-15 Nov as single crop 1-30 Oct when planted with Cotton (2m)	1-15 Nov	
Other	Up to 80 ha	Up to 40 ha	> 80 ha fallow available	Up to 200 ha		

In response to climate change two adaptation strategies were considered. The baseline scenario was to continue with the current production system and document how the farm profit changes in response to changes in climate and water allocation policy. Adaptations were considered that were aimed at keeping cotton as part of the cropping mix based on discussions with industry representatives. The first option was to allow for partially irrigated cotton planted with 2 m spacing and the third option was to allow for "dryland" cotton to be used with 2 m row spacing. This was achieved in the model by allowing planting without checking if there was sufficient irrigation water available. Details of the cropping system are shown in Table 4.

Simulations were undertaken using a long term patched historical climate record (Jeffrey *et al.* 2001) for Dalby, Queensland for the period 1900 to 2010. Data for overland flow was modelled and calibrated against farmer's expectations using the procedure outlined in Power *et al.* (2011) for present and future scenarios. The future climate was simulated using the CSIRO Mk 3.5 model for the A1FI scenario using the QCCCE Consistent Climate Change Scenario data set. A gross margin analysis was undertaken using the costs detailed in Appendix I which accounted for the various crops and costs of irrigation.

4.1.3 Regional modelling approach

Tasman Global is a large scale, dynamic, computable general equilibrium (CGE) model of the world economy that is a powerful tool for undertaking economic analysis at the regional, state, national and global levels. CGE models mimic the workings of the economy through a system of interdependent behavioural and accounting equations which are linked to an input-output database. These models provide a representation of the whole economy, set in a national and international trading context, starting with individual markets, producers and consumers and building up the system via demands and production from each component. When an economic shock or change is applied to a model, each of the markets adjusts according to the set of behavioural parameters[2] which are underpinned by economic theory.

The generalised nature of CGE models enables a much broader range of analyses to be undertaken (generally in a more robust manner) compared to input-output multiplier techniques, which are also used for economic impact assessments. In addition to recognising the linkages between industries in an economy, general equilibrium models also recognise economic constraints. For example, an increased demand for labour may increase real wages if there is full employment. A key advantage of CGE models is that they capture both the direct and indirect impacts of economic changes while taking account of economic constraints. For example, *Tasman Global* captures the expansion in economic activity driven by investment and at the same time accounts for the constraints faced by an economy in terms of the availability of labour, capital and other inputs. Another key advantage of CGE models is that they capture a range of economic impacts across a wide range of industries in a single consistent framework that enables rigorous assessment of a range of policy scenarios. More detail of the *Tasman Global* model is provided in Appendix II.

4.2 Cotton relocation scenarios

4.2.1 Baseline scenario:

For the baseline scenario, long-term average rainfall and water availability was selected against which a climate change and water buy-back (through Murray Darling Basin Plan) scenarios are compared. The baseline scenario assumes, with average rainfall and water availability, cotton farmers will operate close to their historically average levels of cotton area and production.

4.2.2 Scenario 1: Cotton grown in fallow sugarcane land

This scenario assumes that there is no displacement of sugarcane by cotton in the Burdekin region. Sugarcane is currently a high value crop and farmers are reluctant to replace sugarcane with cotton. However, there is a window of opportunity available to grow cotton on fallow sugarcane land every four years.

[2] An example of a behavioural parameter is the *price elasticity of demand* – the responsiveness of demand for a commodity to a change in the price of that commodity.

Part A: 2030 climate with new MDB CAP in place

- ***For the Darling Downs:*** Based on climate modelling using CSIRO MK3.5 under A1F1 emission scenario, annual rainfall is expected to decrease by 20.5% by 2030. At the same time, another 100 GL or 14% of the water reduction is planned under new MDB cap. Using simple statistical model involving rainfall and area relationship, it is estimated that there will be a 18.4% (8,449 ha) reduction in cotton area, compared with the baseline scenario. Support from APSIM crop and APSFarm level modelling and discussions with key informants from the cotton industry, the reduction in the irrigated cotton area could be replaced with:
    - *Partial irrigated cotton (2m spacing with pre-irrigation): 2,112 ha or 25% of the 8,449 ha*
    - *Partial irrigated cotton (2m spacing without pre-irrigation): 2,957 ha (35%)*
    - *Dryland cotton: 1,690 ha (20%)*
    - *Sorghum: 1,690 ha (20%)*
- ***For the Burdekin*:** Based on the data from ABS on sugarcane area and considering four sugarcane rattoons followed by fallow land, about 20,000 ha of fallow sugarcane land is available each year (ABS, 2010).

Part B: 2050 climate with new MDB CAP in place.

- ***For the Darling Downs*:** Based on climate modelling using CSIRO MK3.5 under A1F1 emission scenario, rainfall is expected to decrease by 42.2% by 2050 and there is the 14% of reduction in available water planned under the new MDB cap. Using the same model as above, it is estimated that a reduction of 28.1% (12,892 ha) may occur in the cotton area, compared with baseline scenario. It is estimated that the reduction in the irrigated cotton area will be converted in to:
    - *Partial irrigated cotton (2m spacing with pre-irrigation): 1,267 ha (15%)*
    - *Partial irrigated cotton (2m spacing without pre-irrigation): 2,957 ha (30%)*
    - *Dryland cotton: 2,535 ha (30%)*
    - *Sorghum: 2,112 ha (25%)*
- ***For Burdekin***. Same as 2030 scenario, it is estimated that 20,000 ha of fallow land will be available each year for cotton because of the four year sugarcane rattoon cycle.

4.2.3 Scenario 2: Cotton grown in displaced sugarcane land with competition with sugarcane

In this scenario we assume that there is competition between cotton and sugarcane with no additional land available. Any additional cotton grown will displace sugarcane. On a 'dollars per hectare' basis, a hectare of land dedicated to sugarcane production is generally of higher value than a hectare dedicated to cotton.

Part A: 2030 climate with new MDB CAP in place

- ***For the Darling Downs:*** same as scenario 1.

- ***For the Burdekin*****:** Assume that there is competition between cotton and sugarcane. Any additional cotton displaces sugarcane crop. As a result, assuming additional water availability, 8,449 ha of cotton will displace 8,449 ha of sugarcane.

Part B: 2050 climate with new MDB CAP in place.

- ***For the Darling Downs*****:** same as scenario 1
- ***For the Burdekin*****:** Assume that there is competition between cotton and sugarcane. Any additional cotton displaces sugarcane crop. As a result, assuming additional water availability, 12,892 ha of cotton will displace 12,892 of sugarcane.

5 Crop Modelling

Day degree models were calculated for the Burdekin in lieu of a suitable crop model. The crop growth target of 60% open bolls was used as an indicator of the timing of farm operations that would require access to the paddock and when the crop is likely to be damaged by rain.

5.1 Day Degree Model of Cotton in the Burdekin

The calculation of day degrees (section 3.3.2) for Ayr with a planting date of 20 December shows that the crop reaches the 60% Open growth stage 146 days after sowing (das), i.e. 15 May (Table 5). This is the average of the sowing dates from 1957 to 2009. Using the climate change projections from the version 1.1 data provided by QCCCE (Consistent Climate Change Scenarios), we can readily see the reduction in the number of days after sowing (Table 5) and the year to year variation,

Figure 19. The average reduction in days from sowing to harvesting is 8 to 14 days for by 2030 under the A1FI scenario and up to 25 days by 2050 (Table 5).

Table 5. Mean days after sowing to reach 60% open bolls under two climate change scenarios for a sowing date of 20 December

	Days after Sowing	Date		Days after Sowing	Date
Present	146	15 May			
A1B 2030			**A1FI 2030**		
CSIRO-MK35 (M)	135	4 May	CSIRO-MK35 (M)	135	4 May
MIROC-H (H)	132	1 May	MIROC-H (H)	132	1 May
GFDL-21 (L)	137	6 May	GFDL-21 (L)	137	6 May
CCCMA-47 (L)	138	7 May	CCCMA-47 (L)	138	7 May
A1B 2050			**A1FI 2050**		
CSIRO-MK35 (M)	129	28 April	CSIRO-MK35 (M)	126	25 April
MIROC-H (H)	124	23 April	MIROC-H (H)	121	20 April
GFDL-21 (L)	132	1 May	GFDL-21 (L)	130	29 April
CCCMA-47 (L)	134	3 May	CCCMA-47 (L)	132	1 May

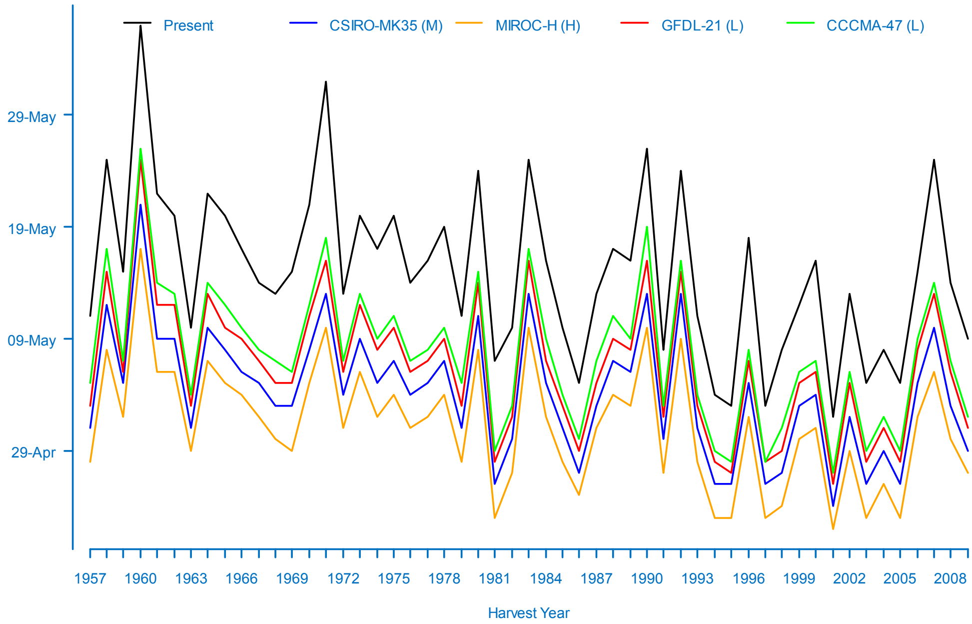

Figure 19. **Variation in timing of the final growth target, 60% open bolls, for present and future climates in 2030 under the A1FI scenario in the Burdekin for a planting date of 20 December**

The wet start to the growing season and the low radiation levels often experienced in February/March has led researchers to consider a later planting opportunity. This has been difficult to achieve from an agronomic standpoint (Paul Grundy, pers. comm.) and the crop is likely to reach a critical stage during the onset of the summer rains. Under current climatic conditions, sowing cotton on 1 May, in order to avoid the wet season during the early stages of development, results in a crop that is not due for harvest until 10 December. This risks the cotton being exposed to rain when the fibres are exposed or it would be too wet to harvest the crop successfully. Under climate change the expected harvest dates are moved to early to late November, which may provide an opportunity to sow in early May, Table 6.

Table 6. **Sowing to 60% open bolls under two climate change scenarios for a sowing date of 1 May**

	Days after Sowing	Date		Days after Sowing	Date
Present	223	10 Dec			
A1B 2030			**A1FI 2030**		
CSIRO-MK35 (M)	208	25 Nov	CSIRO-MK35 (M)	209	26 Nov
MIROC-H (H)	204	21 Nov	MIROC-H (H)	205	22 Nov
GFDL-21 (L)	213	30 Nov	GFDL-21 (L)	213	30 Nov
CCCMA-47 (L)	212	29 Nov	CCCMA-47 (L)	213	30 Nov
A1B 2050			**A1FI 2050**		
CSIRO-MK35 (M)	199	16 Nov	CSIRO-MK35 (M)	194	11 Nov
MIROC-H (H)	193	10 Nov	MIROC-H (H)	189	6 Nov
GFDL-21 (L)	207	24 Nov	GFDL-21 (L)	203	20 Nov
CCCMA-47 (L)	204	21 Nov	CCCMA-47 (L)	202	19 Nov

5.2 APSIM crop model of cotton

Darling Downs

A deeper understanding of the impact of climate change can be gained using the APSIM crop model as discussed in section 4.1.2. Using this model for the Darling Downs we can examine the impact of CO_2 fertilisation and climate change on yield and water use.

The effect of climate change with and without CO_2 fertilisation, Figure 18, was examined for the Darling Downs under the A1FI scenario in 2030 and 2050. The present level of CO_2 was set at 350 ppm with 449

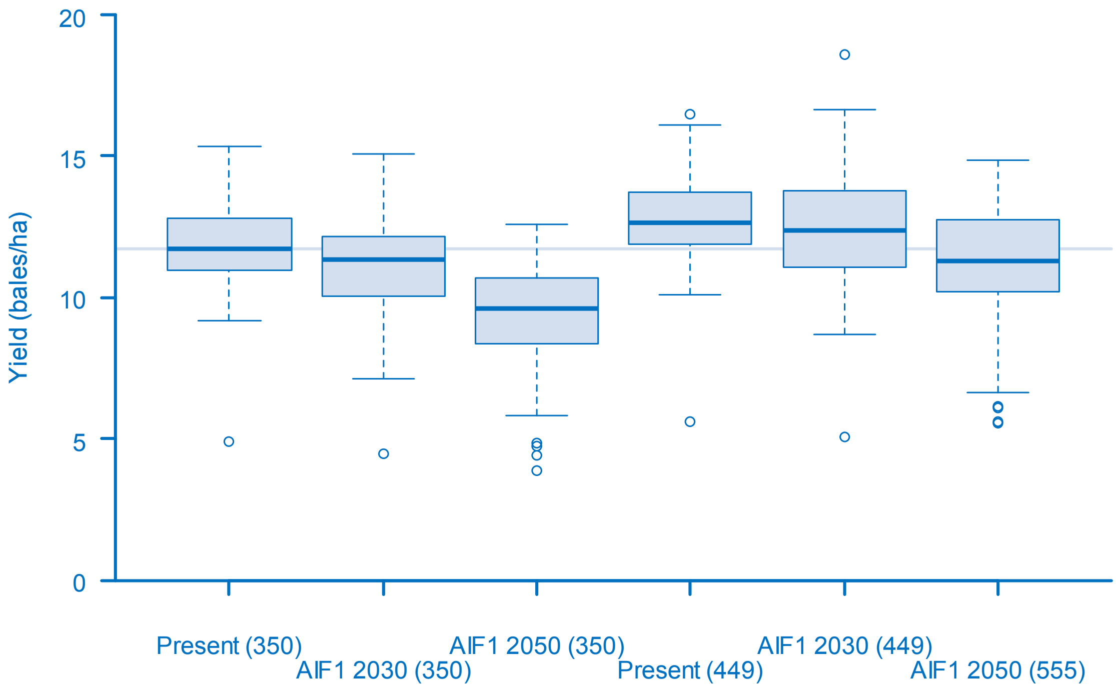

Figure 20. Cotton yield response to CO2 under climate change at Dalby, Darling Downs with irrigation at 65% water deficit. Values in brackets refer to ppm CO2. Cotton planted at 1 m row spacing, planted on 15 October. Other details as for

Table 4 Details of cropping system used in the APSFarm modelling on the Darling Downs.

ppm for 2030 and 555 ppm for 2050 as prescribed by the Consistent Climate Change Scenario data and using the CSIRO MK 3.5 model. The effect of climate change at Dalby is complicated by the interaction of increased temperature and CO_2 fertilisation. If CO_2 is increased to 449 ppm using the present historical weather data then the median yield is increased by 8%. Under the 2030 scenario with CO_2 at the level of 350 ppm, yield is decreased by 3%, however, CO_2 fertilisation provides an increased yield of nearly 6%. By 2050 there is decrease in yield of 17.8% without CO_2 fertilisation and a 3.6% decrease with CO_2 fertilisation, Figure 20. These simulations were undertaken so that nitrogen stress does not occur and irrigation provides at least a 65% available soil water (ASW). To cope with the decreased in-crop rainfall (4.5% by 2030 and 15.8% in 2050) and an initial increase in evapotranspiration recorded during crop growth of 2% in 2030 and a 10% decrease in 2050, irrigation was increased by 47.4% and 48.7% in order to maintain the 65% target.

These simulations demonstrate the complex interactions that exist and highlight the importance of enhancing the cotton model so that the response of the crop in places such as Burdekin, Ord River, and Katherine can be properly assessed. Without access to models that behave correctly in a tropical environment such as the Burdekin it will be difficult to provide good information for long-term policy and investment decisions under changes in water policy, control of excess nutrients loads and the complex changes to the way in which the climate behaves under global warming.

Burdekin

Without access to suitable modelling of cotton production in the Burdekin we will rely heavily on the experimental and limited commercial plantings that have been undertaken. Trials have been undertaken in the Burdekin and commercial crops grown that provide an indication of the yields. In discussions with experienced growers from the Darling Downs, the yields have tended to be about 70% of the yield expected on the Darling Downs under irrigation, i.e. around 7 – 8 bales/ha (Table 7).

Table 7. Cotton yields recorded from field trials in the Burdekin

Harvest Year	Yield (bales/ha)	Planting and harvest dates	Source
2008	6.5 – 7.2	3 January 2008 – 25 June 2008	CSD web site[#]
2009	5.6 – 6.49	27 December 2008 – 12 July 2009	CSD web site
2009	3.0 – 9.5, ave=6.5	Late December planting	Cotton Yearbook 2009
2009	8 – 9 ~12	Early and late December Planting 8 January	The Australian Cottongrower Oct-Nov 2009
2010	6.6 – 7.5	Not recorded	CSD web site

\# http://www.csd.net.au/trials/variety/

Yields for cotton in the Burdekin for 2030 and 2050 are unlikely to be affected by water restrictions and so the impact on yield is likely to be positive because of CO_2 fertilisation and warmer temperatures. This may increase yields, but at this stage it is difficult to predict by how much without a reliable crop model.

From the trials and experimental work undertaken by researchers and commercial growers in the district we are confident that cotton can play a role as a complementary crop to sugarcane in the Burdekin Delta. Whether in the long-term this is in conjunction with rice or one of these wins out over the other will be governed by a range of socio-economic factors. One of the major determinants will be the success of commercial scale plantings and the spread of agronomic knowledge. Modelling the impact of climate change needs to be undertaken using models that can consistently and reliably simulate the very different suite of conditions that will be faced by growers in the tropics. Changes to the model need to be supported and this will require some additional experimental work to understand the interaction of light, temperature and CO_2 fertilisation. Additionally a more robust procedure for the provision of climate change data needs to be found that can shed light on the change in intensity of rainfall and other extreme events. This needs to include a suite of GCMs and hopefully will be addressed when the next round of the IPCC reports become available.

6 Farm level Assessment

Analyses undertaken at the farm level using APSFarm, Power *et al.* (2011), take crop modelling a step further by integrating the production of cotton with decisions that have to be made about the allocation of limited resources. The main limitation that was considered in this study was the use of water given that restrictions would be placed on this in the future. A modest 14% reduction in bore allocation was coupled with modelled changes in overland flow, with maize and wheat also used as irrigated crops within the rotation. We also provided a mechanism by which cotton was preferentially retained in the mix of crops because an enterprise that is built around cotton is likely to remain so unless very strong forces act upon it and because of this our approach differs from that of Power *et al.* (2011) in that water allocation was not optimised across all crops.

Adaptation to climate change and reduced water allocation as a result of national policy was introduced into the simulation by considering opportunities for partial irrigation and dryland planting of cotton at wider row spacing. The other crops (wheat, maize and sorghum) retained the present agronomic conditions and water requirements. This approach was similar to that taken by Power *et al.* (2011) in that the farm comprises a set of paddocks or management units, a suite of crops and water storages (on-farm dams) that are supplemented from bore water. A gross margin analysis is therefore possible that takes into account the cost of producing a crop including planting, harvesting, value of the product and irrigation. Details of the simulation methodology are discussed in section 4.1.2.

6.1. Crop Yield

The simulations using the APSFarm approach, but without any adaptation (solid planting with full irrigation), show that cotton yield increases slightly in the future, Figure 21. For cotton planted at a 2 m row spacing with partial irrigation the increase in yield was 2.6% and 11.6% respectively when compared to cotton planted at 2m under the present climate. However, this actually represents a 12.1% and 4.4% decrease when compared to cotton planted at 1 m row spacing with the present climate. The decrease in water availability results in changes in area of the crops planted and hence overall production. This has an impact on gross margins, not only in terms of reduced income, but also greater year to year variation. The area of cotton planted at 1 m row spacing was reduced by 21.2% and 19.2% in 2030 and 2050. Allowing only partially irrigated cotton as the adaptation strategy (Strategy 1, Figure 22), the overall area of cotton increased by 36% and 38% respectively. With Strategy 2 (Figure 23), the area of solid planted cotton was reduced by 45% in 2030 and 2050, but the total area of cotton increased by 90% in 2030, falling back to 67% in 2050, Table 8.

Table 8. Area planted to cotton with and without adaptation

	Area Planted (ha)		
Type of Planting	**Present**	**2030**	**2050**
Without adaptation			
Cotton (1m)	73.0	58.0	47.0
Strategy 1			
Cotton (1m)	73.0	57.5	59.0
Cotton (2m)		42.0	42.0
Total cotton	73.0	99.5	101.0
Strategy 2			
Cotton (1m)	73.0	40.0	40.0
Cotton (2m)		99.5	84.0
Total cotton	73.0	139.5	124.0

The impact of climate change and reduced water allocation can be partially offset with adaptation applied to cotton production. A more complete investigation could be undertaken whereby the whole farm enterprise is optimised, however, that is outside the scope of the report and we were primarily interested in understanding how relocation of cotton production causes impacts at a regional scale.

Yields using the 2 m row spacing were increased by a similar margin to the solid planting, but there is also an increase in the year to year variation in cotton yields for both row spacing compared to continuous solid planting of cotton.

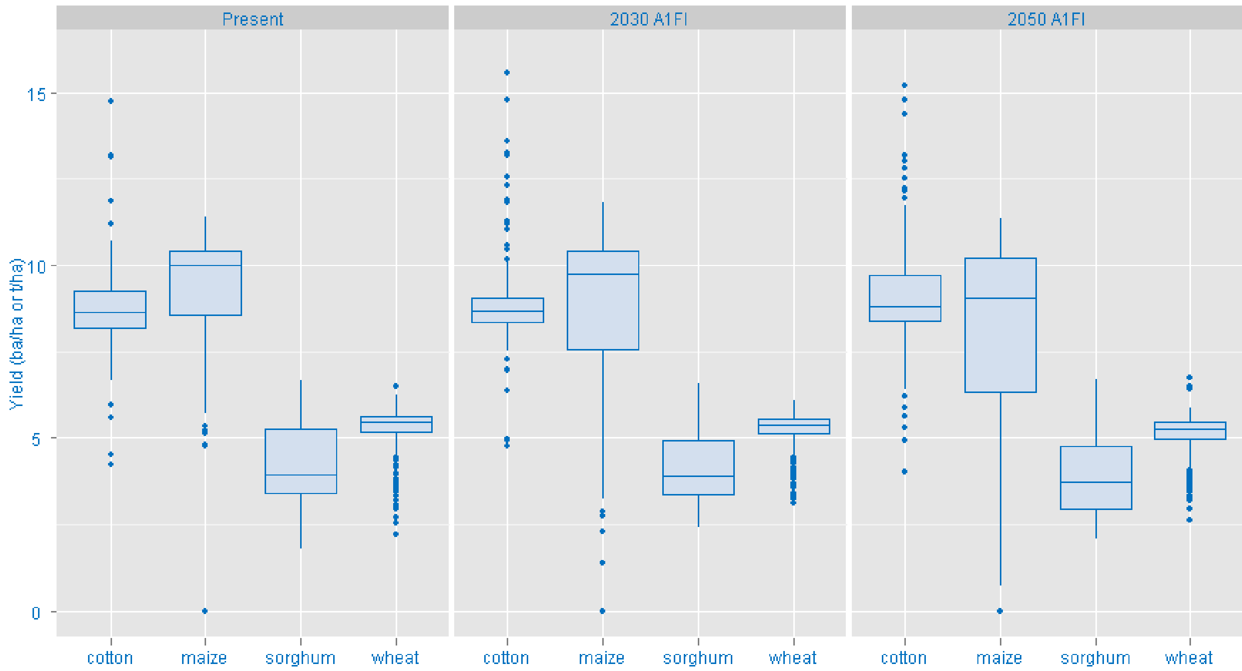

Figure 21. Yield for cotton using 1 m planting and full irrigation under present and future conditions with the A1FI scenario and a 14% reduction in water allocation.

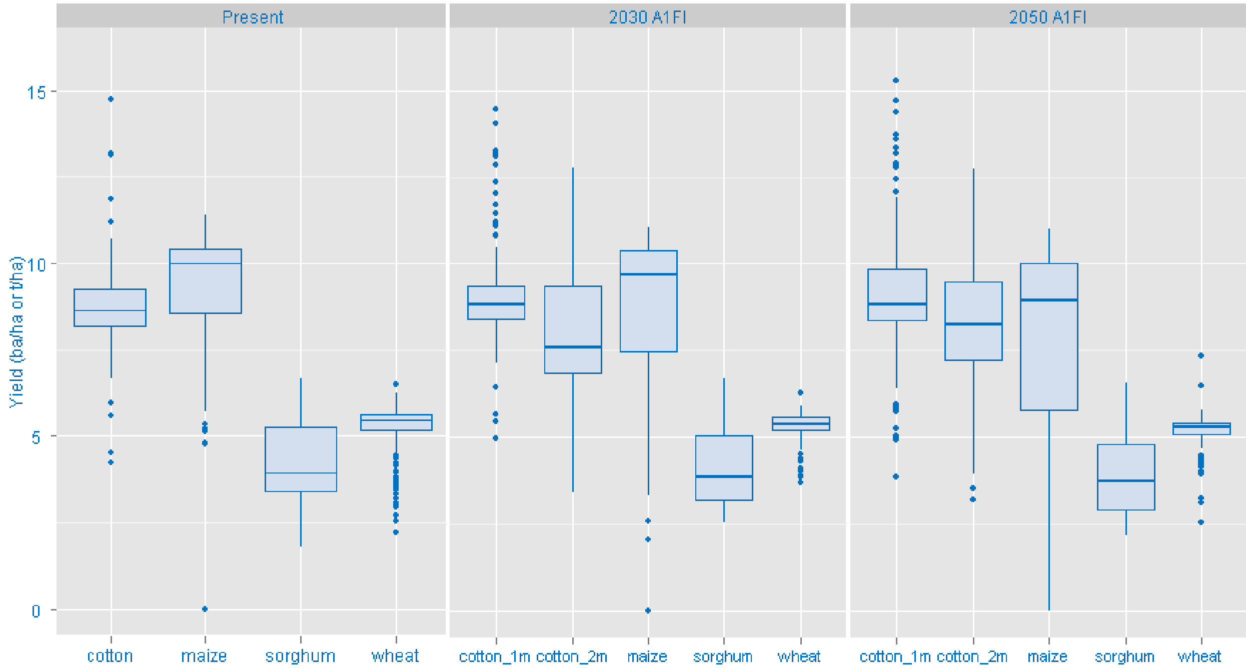

Figure 22. Yields under adaptation strategy 1

Under Strategy 2, the yields are similar in terms of the median, but the extreme values cover a greater range and hence the strategy whereby there is no account taken of available stored water is a riskier proposition, Figure 23.

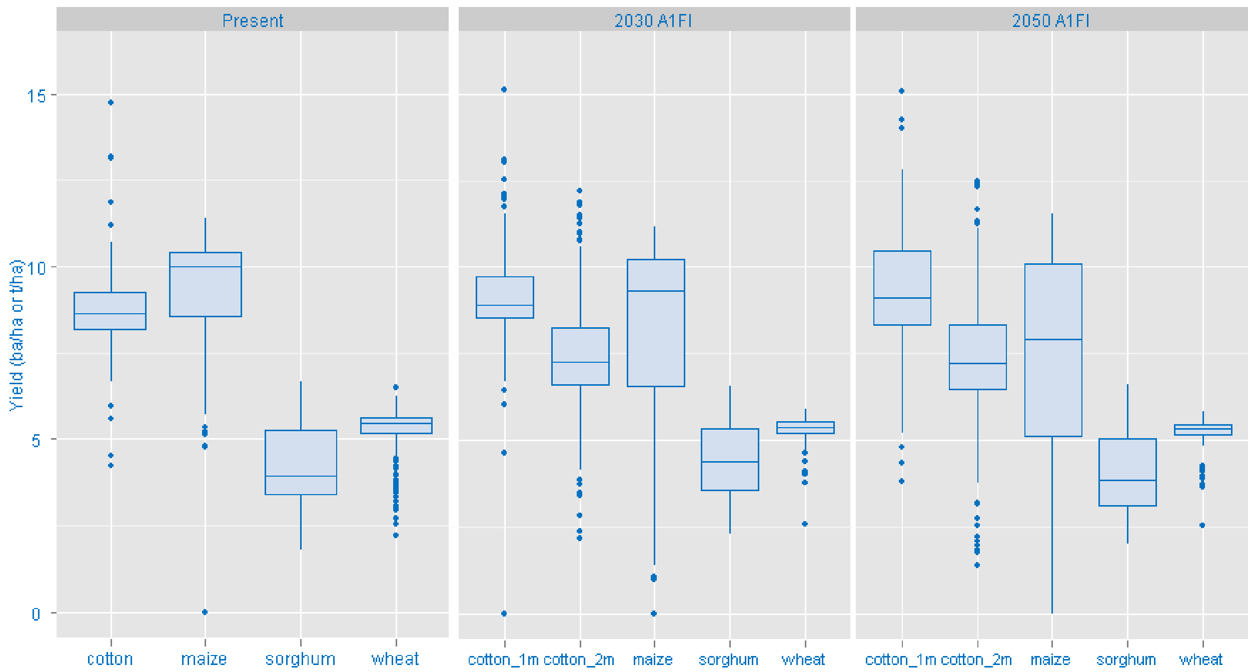

Figure 23 Yields under adaptation strategy 2.

6.2. Irrigation

Total irrigation applied to cotton under present conditions was 257 ML. Under climate change overall cotton irrigation water applied was greater under Strategy 2 (Table 9) which results in a reduced production per ML. However, this strategy has greater risk as seen by comparing the yields for cotton with 2 m rows in Figures 22 and 23. In 2030 and 2050 the proportion of low yields, i.e. less than 5 bales/ha is increased under Strategy 2. If these were to occur in consecutive years, e.g. during a prolonged drought, then the losses incurred by the farm might be too much to bear.

Costs of irrigation were imposed in the model as variable costs and included cost of water capture (from sumps to dams), irrigation (from a dam to paddock), return of tail water (from paddock to dam) and bore allocation (from bore to dams). These costs were $56.50/ML except for the bore allocation which incurred a cost of $110.00/ML. In all cases the bore allocation is exhausted, however, there is 14% less water available in 2030 and 2050, so that would reduce input costs, but makes less water available.

Table 9. Median irrigation applied to crops with and without an adaptation strategy.

	Total ML Applied						
	Without Adaptation			Strategy 1		Strategy 2	
Crop	Present	2030	2050	2030	2050	2030	2050
Cotton 1m	257	210	170	182	181	103	92
Cotton 2 m	-	-	-	73	66	219	197
All Cotton	257	210	170	255	247	322	288
Maize	53	69	57	55	57	52	54
Wheat	143	144	129	105	100	108	71
Total[#]	425	351	335	359	316	364	326
% sourced from bore	47	49	52	48	55	47	53

Total is calculated for each growing season for the whole and is not the sum of the crop medians.

6.3. Gross margins

Gross margins at the farm level were calculated as total gross margin (farm level), crop gross margin and crop gross margin per ha. Overall farm gross margin without adaptation is reduced by 27% in 2030 and 43% by 2050 with losses being nearly due to irrigated crops, whereas sorghum showed a 22-23% increase in gross margin. There was an 8.8% increase in the total gross margin by 2030 although this was reduced by 15.8% by 2050 (i.e. a reduction of 8.8% compared to the present) when partial irrigation was introduced. Allowing dryland cotton to be used in the rotation showed an increase of 49% in farm gross margin by 2030 and 12% by 2050.

Gross margins for cotton grown at 2 m were higher when grown with 1 m rows because the latter has a greater irrigation requirement and higher costs in terms of establishment, Table 10. However, if 2 m is grown to the exclusion of 1 m cotton the overall production is reduced. Farm level gross margins are increased in 2030 and 2050 because the area of cotton planted is increased under both adaptation strategies, Table 8.

Table 10. Median yield and gross margins for cotton grown using 1 m and two adaptation strategies using cotton grown at 2m under the A1FI scenario and CSIRO MK 3.5 model

Yield (Bales/ha)	Present	2030	2050
Cotton 1 m only	8.7	8.8	8.9
Strategy 1		7.6	8.2
Strategy 2		7.2	7.2
Gross Margin ($/ha)			
Cotton 1 m only	813	828	817
Strategy 1		1145	1094
Strategy 2		1174	1146
Farm Gross Margin ($)			
Cotton 1 m only	253,701	186,431	144,688
Strategy 1		276,050	232,478
Strategy 2		329,154	273,321

7 Regional impact of relocating cotton farming to northern Queensland

This section describes the macro-economic impacts potentially associated with a movement of cotton growing from the Darling Downs area to North Queensland in response to changes in water availability potentially associated with climate change.

7.1 Framework of analysis

For this analysis, ACIL Tasman's CGE model, *Tasman Global*, was used to estimate the economic impacts at the regional level. *Tasman Global* is a large scale, dynamic, computable general equilibrium (CGE) model of the world economy that has been developed in-house by ACIL Tasman. *Tasman Global* is a powerful tool for undertaking economic analysis at the regional, state, national and global levels.

CGE models mimic the workings of the economy through a system of interdependent behavioural and accounting equations which are linked to an input-output database. These models provide a representation of the whole economy, set in a national and international trading context, starting with individual markets, producers and consumers and building up the system via demands and production from each component. When an economic shock or change is applied to a model, each of the markets adjusts according to the set of behavioural parameters[3] which are underpinned by economic theory. The generalised nature of CGE models enables a much broader range of analysis to be undertaken (generally in a more robust manner) compared to input-output multiplier techniques, which are also often applied in economic impact assessments.

In addition to recognising the linkages between industries in an economy, general equilibrium models also recognise economic constraints. For example, increased demand for labour may increase real wages if there is full employment.

A key advantage of CGE models is that they capture both the direct and indirect impacts of economic changes while taking account of economic constraints. For example, *Tasman Global* captures the expansion in economic activity driven by an investment, and at the same time accounts for the constraints faced by an economy in terms of availability of labour, capital and other inputs. Another key advantage of CGE models is that they capture a range of economic impacts across a wide range of industries in a single consistent framework that enables rigorous assessment of a range of policy scenarios.

More detail of the Tasman Global model is provided in Appendix II.

7.1.1 Database aggregation

The database which underpins the model contains a wealth of sectoral detail. The foundation of this information is the input-output tables. Industries and regions in the model can be aggregated or disaggregated as required for a specific project. For this project the model has been aggregated to:

- four economies, namely the Darling Downs statistical division (SD) region, the Burdekin local government area (LGA), the Rest of Australia and the Rest of the World. Maps of the Darling Downs SD and the Burdekin LGA are provided in Figure 24

[3] An example of a behavioural parameter is the *price elasticity of demand* – the responsiveness of demand for a commodity to a change in the price of that commodity.

- 34 industries/commodities as presented in Table 11. This aggregation was chosen to provide the maximum detail possible for the key industries related to this analysis.

Darling Down s **Burdekin LGA**

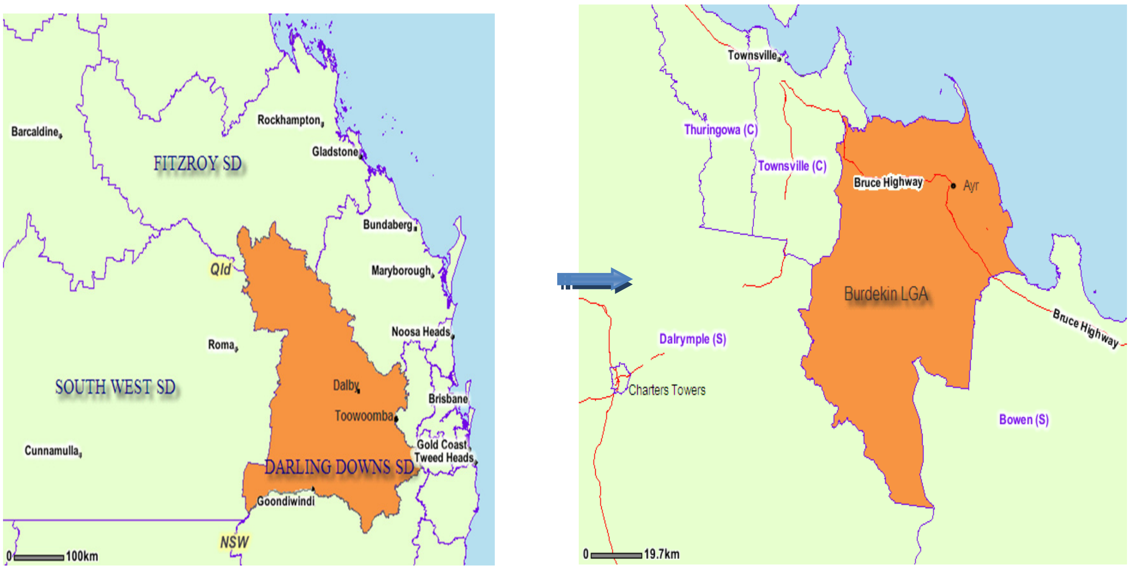

Figure 24 Maps of the key regions for this analysis

Source: Data source: ABS and ACIL Tasman

Table 11 Industry/Commodity aggregation used in Tasman Global modelling

	Industry/Commodity		Industry/Commodity
1	Paddy rice	18	Oil
2	Wheat	19	Gas
3	Cereal grains nec	20	Other mining
4	Vegetables, fruit, nuts	21	Electricity
5	Oil seeds	22	Petroleum and coal products
6	Sugarcane, sugar beet	23	Iron and steel
7	Plant-based fibres	24	Nonferrous metals
8	Crops nec	25	Nonmetallic minerals (including cement, plaster, gravel)
9	Bovine cattle, sheep and goats, horses	26	Chemicals, rubber, plastics
10	Animal products nec	27	Manufacturing
11	Raw milk	28	Water
12	Wool, silk-worm cocoons	29	Construction
13	Fishing and forestry	30	Trade services (includes all retail and wholesale trade, hotels and restaurants)
14	Processed rice	31	Transport services
15	Processed Sugar	32	Other business services
16	Other processed food	33	Government services (including public administration and defence)
17	Coal	34	Dwellings

Note: nec = not elsewhere classified

7.1.2 Reference case assumptions

An important element of CGE analysis is the development of a reference case. The reference case forms the basis against which the impact of alternative policies can be modelled. The outcomes of this modelling are then reported as deviations from the reference case – as shown in Figure 25.

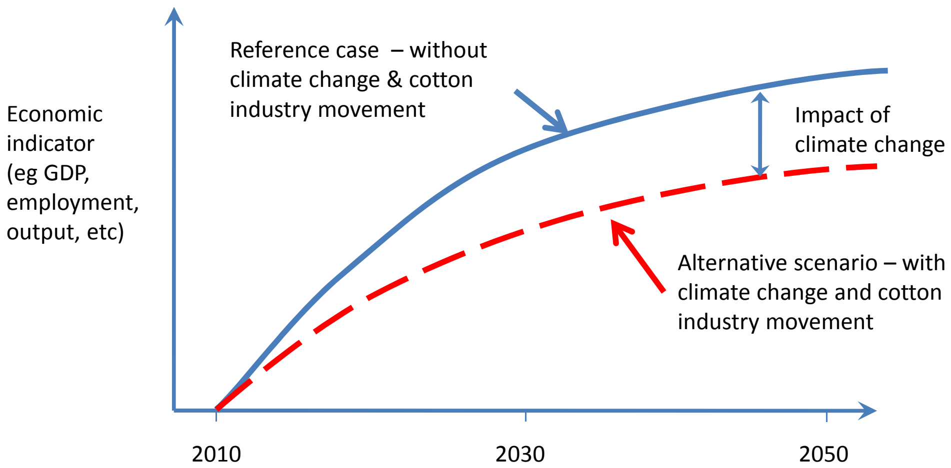

Figure 25 **Estimating the impact of alternative policies (illustrative example)**

To eliminate the impact of price movements in the results, economic variables such as the change in economic output are reported as deviations from their real rather than nominal values. Similarly, all aspects not directly related to the assumed changes in the cotton industry have been kept constant across all the scenarios including, for example, productivity growth, national population and all demand and supply elasticities.

7.1.3 Policy scenarios

The analysis undertaken compares two future times (2030 and 2050) under the A1FI climate project. For both of these future times the analysis of the potential impacts has been limited to the implications of the land underlying the production of cotton and does not consider any potential consequences of changes in water availability on other crops.

Two relocation scenarios have been modelled. The details of the scenarios are provided in section 4.2.

7.1.4 Key scenario assumptions

In the context of this analysis, the principal driver of the economic impacts is the future value that is added to each hectare of land under alternative crops. Underlying the value are the assumptions/projections of the future yields and prices of the key commodities. A second main driver of the economic impacts relates to the downstream value adding of the raw crops. Finally, one of the key strengths of CGE models compared to other economic impact analysis tools (such as input-output multipliers) is that they place explicit constraints on the availability and movement of factors (notably labour) within and across regions. This section discusses the various assumptions that have been made for this analysis.

Commodity assumptions: Figure 26, Figure 27 and Figure 28 present the historical and projected, future yields for the key crops and regions considered in this analysis.

Historically, cotton yields have grown strongly with the average yield in the Darling Downs SD broadly following the Queensland average (Figure 26). The average yield of cotton planted in the Darling Downs region is based on the assumptions from the APSIM modelling (see 6.1). More specifically, the growth in Darling Downs yields over the next 40 years is assumed to be approximately 40 per cent of the historical Queensland trend growth over the past 40 years (Figure 27). As can be seen, the cropping method has a significant impact on the average yield, with closely spaced (1m), irrigated cotton crops yielding over double that of dryland crops.

For this analysis it has been assumed that the yields in the Darling Downs SD increase from:

- 2.18 t/ha for 1m spaced irrigated cotton to 2.39 and 2.58 t/ha by 2030 and 2050, respectively[4]
- 1.67 t/ha for 2m spaced cotton (average of with and without pre-irrigation) to 1.81 and 2.26 t/ha by 2030 and 2050, respectively
- 0.92 t/ha for dryland cotton to 0.99 and 1.09 t/ha by 2030 and 2050, respectively

Based on the assumed average area planted to each of these planting regimes, it is projected that the average cotton yield in the Darling Downs SD moves from 1.87 t/ha to:

- 2.00 and 2.22 t/ha by 2030 and 2050, respectively in the reference case (without climate change)
- 1.87 and 1.95 t/ha by 2030 and 2050, respectively in the policy (with climate change as per the A1FI scenario).

The average yield of 1m spaced irrigated cotton planted in the Burdekin has been assumed to begin at 1.68 t/ha (i.e. 77 per cent of current Darling Downs yields) with future yields increasing at the same rate as those assumed for the Darling Downs (to 1.80 and 1.99 t/ha in 2030 and 2050, respectively).

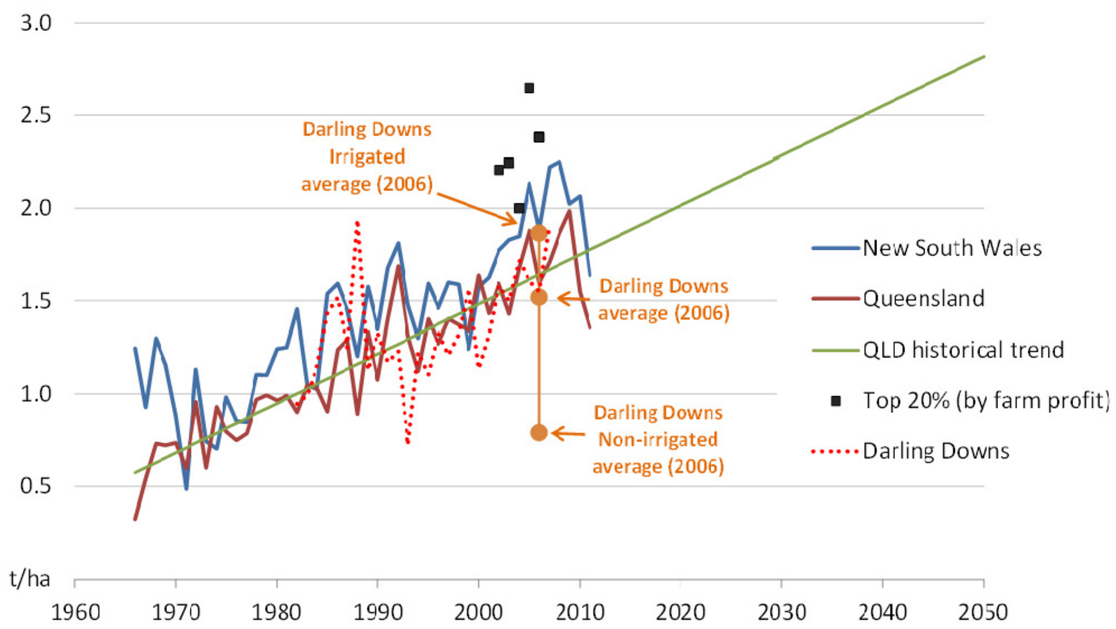

Figure 26 Historical and assumed cotton yield by region

Data source: ABARES commodity statistics, ABS data request, ABS 2005-06 Agricultural Census and ACIL Tasman. "Top 20 %" from CRDC (2007), Australian Cotton Comparative Analysis - 2006 Crop, Cotton Catchment Communities CRC and Cotton Research and Development Corporation.

[4] 1 t/ha is equivalent to 3.7 bales/ha

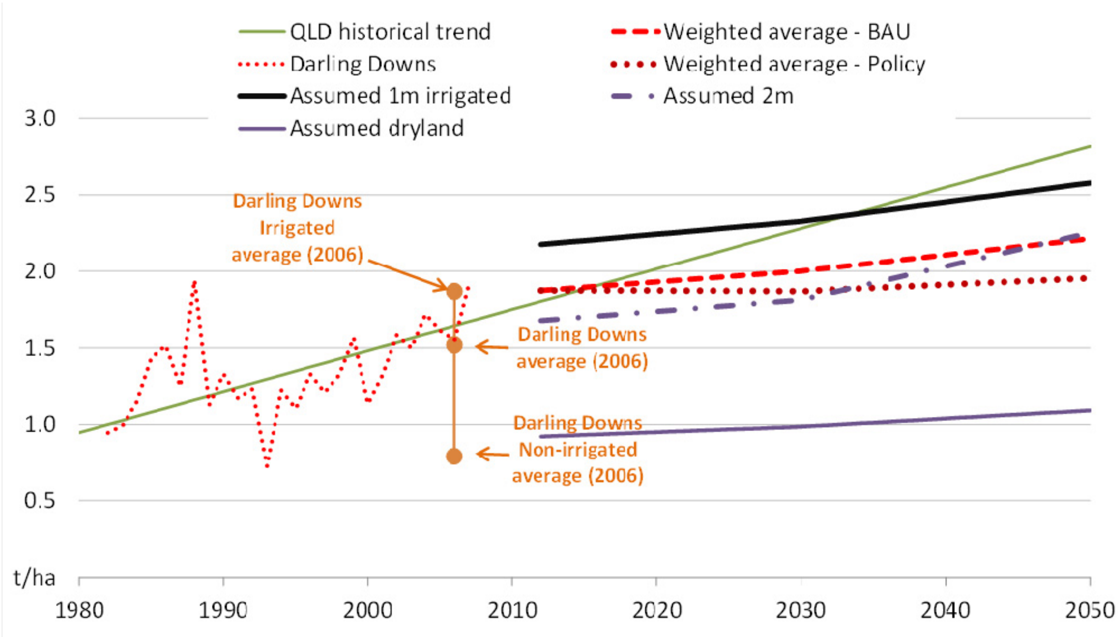

Figure 27 Future average cotton yield and by management type

Data source: ABARES commodity statistics, ABS data request, ABS 2005-06 Agricultural Census and ACIL Tasman. "Top 20 %" from CRDC (2007), Australian Cotton Comparative Analysis - 2006 Crop, Cotton Catchment Communities CRC and Cotton Research and Development Corporation.

Historically, there hasn't been a noticeable increase in the average sugarcane yield across Australia. Consequently, no productivity improvement has been allowed and the Burdekin region is assumed to maintain its 2005-06 yield of 110 tonnes[5] of sugarcane per hectare throughout the forecast period. Similarly, the ratio of sugarcane per tonne of sugar has also been assumed to remain constant after returning to the average over the past 40 years (7.3 tonnes of cane per tonne of sugar).

[5] This estimate is from the ABS 2005-06 agriculture census. Hooper (2008) estimates that average yields in the Burdekin region in 2005-06 were 118 tonnes per hectare.

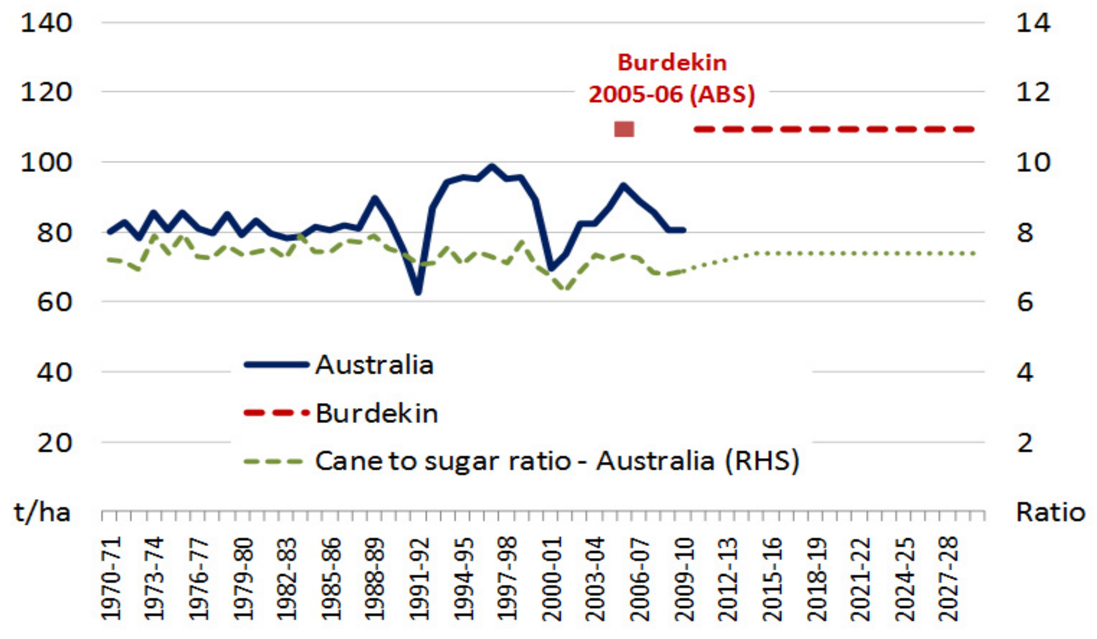

Figure 28 Historical and assumed average sugarcane yield and cane to sugar ratio

Labour market assumptions: *Tasman Global* includes a labour market module that allows for constrained movement between regions of the Australian economy. In the simulations performed with *Tasman Global* the Australian labour market can be treated in a number of ways. Traditionally, CGE modelling utilises one of three labour market assumptions:

- Fixed labour supply (the full employment approach) and zero labour mobility between Australian regions
- Medium term adjustment to labour supply and zero labour mobility between Australian regions
- Full labour mobility between regions so that changes to wages are equalised across Australian regions.

Labour market assumption 2 simply allows local supply to vary in the medium term (five to ten years) before returning to its long run position. It provides a temporary reprieve from labour market constraints.

Labour market assumptions 1 and 3 are more extreme. Under assumption 1, the proposed developments would have to be accomplished with only the current labour available in the Burdekin region, with some allowance for natural growth, i.e. no new labour could be drawn to the Burdekin region as a result of the projects. Under assumption 3 changes to wages in the Burdekin region would be the same as changes to wages in all Australian regions, with labour shifting between Australian regions until changes to wages equalise. Modelling under assumption 3 provides the largest movement in labour across regions.

Because of the very long time horizon of the simulations for this analysis, we have elected to use labour market assumption 3 – namely full labour mobility between Australian regions. In practice, under this assumption, the changes in real wages relative to the reference case are equalised across the three Australian regions thereby allowing migration between the regions in response to changing opportunities. No changes to unemployment rates, participation rates or net international migration have been allowed.

7.2 Results of regional economic impact analysis

7.2.1 Measures of macroeconomic impacts

One of the most common macroeconomic indicators is Gross Domestic Product (GDP) which is a measure of the aggregate output generated by an economy over a period of time (typically a year). From the expenditure side, GDP is calculated by summing total private and government consumption, investment and net trade. At the state level, the GDP equivalent is called GSP (Gross State Product) while changes at the regional level are called GRP (Gross Regional Product).

Although changes in real GDP are useful measures for estimating how much the output of an economy may change, changes in the real income of a region is more important since it provides an indication of the change in economic welfare of the residents of a region. Indeed, it is possible that real GSP can increase with no, or possibly negative, changes in real income. In Tasman Global, changes in real income at the national level is synonymous with real gross national disposable income (RGNDI) reported by the ABS.

The change in real income is equivalent to the change in real economic output, plus the change in net foreign income transfers, plus the change in terms of trade (which measures changes in the purchasing power of a region's exports relative to its imports). As Australians have experienced first-hand in recent years, changes in terms of trade can have a substantial impact on people's welfare independently of changes in real GDP. The change in real income (as projected by Tasman Global) is ACIL Tasman's preferred measure of the change in economic welfare of residents.

To reduce the potential confusion with the various acronyms, the term 'economic output' has been used in the discussion of the results presented in this report.

7.2.2 Macroeconomic impacts: Scenario 1

Table 12 summarises the projected changes in real economic output and real income for each region under each Scenario while Figure 29 and Figure 30 show the year on year changes in real outputs and real income. When analysing the results, it is important to remember that the initial impact of each scenario relates to the assumed changes in agricultural output in the Darling Downs and Burdekin regions. These changes then affect each region's total economic output with effects on the demand for labour and capital.

Capital is naturally mobile (albeit sluggishly) between all regions based on changes in rates of return, while labour is assumed to be fully mobile between Australian regions. Consequently, the supply of factors in the Rest of Australia is also impacted by changes in the demand in the Darling Downs and Burdekin regions. Consequently, at a national level, the Rest of Australia acts to reduce the magnitude of the aggregate impact experienced in the Darling Downs and Burdekin regions.

Table 12 Cumulative change in real economic output and real income under scenario 1, relative to the reference case (in 2010-11 terms)

SCENARIO 1 – Burdekin cotton on fallow land

	A. Real economic output [a]			B. Real income [b]		
	2029-30	2049-50	NPV (2010-11 to 2049-50)	2029-30	2049-50	NPV (2010-11 to 2049-50)
	2010-11$m	2010-11$m	2010-11$m	2010-11$m	2010-11$m	2010-11$m
Darling Downs SD	–9.36	–25.53	–149.90	–8.10	–25.37	–135.81
Burdekin LGA	53.82	84.22	707.86	43.57	74.26	587.71
Rest of Australia	–6.92	–10.31	–92.41	–5.65	–5.92	–70.77
Total Australia	**37.54**	**48.38**	**465.55**	**29.82**	**42.98**	**381.12**

a The term 'real economic output' is used instead of gross regional product (GRP). The sum of the GRP of all three regions equals the change in Australian GDP.
b Real income for Australia is synonymous with real gross national disposable income (RGNDI) as used by the ABS. In this modelling real income is a measure of the change in economic welfare.
Notes: Totals may not add due to rounding. NPV = Net Present Value (calculated using a 4 per cent real discount rate). It should be noted that the NPV calculation only includes the impacts through to 2049-50 even though the impacts will be likely to continue producing beyond this artificial time horizon.

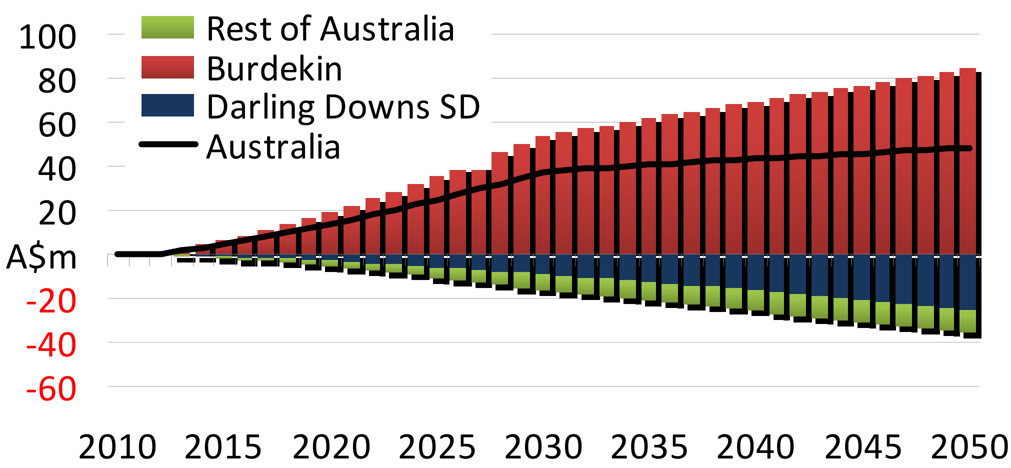

Figure 29 Projected changes in real economic output under scenario 1, relative to the reference case (2010-11 dollars)

Notes: The term 'real economic output' is used instead of gross regional product (GRP). The sum of all three regions GRP equals the change in Australian GDP

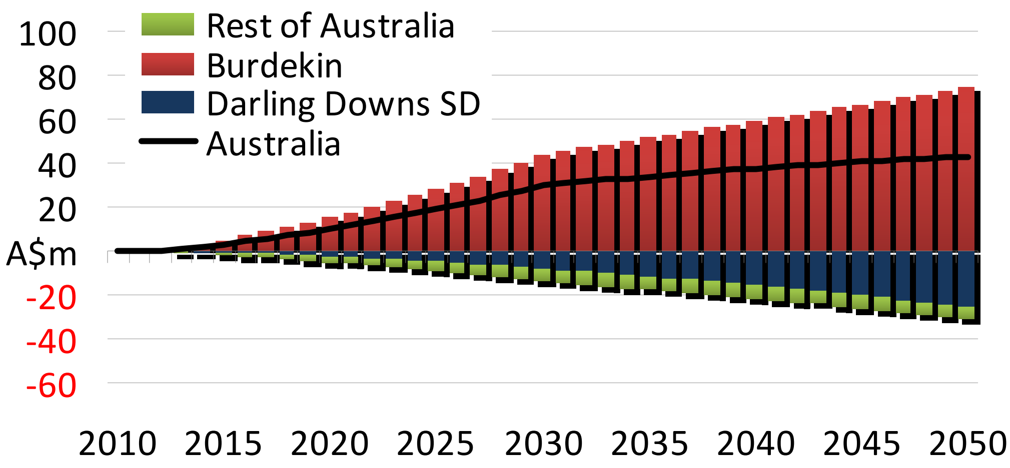

Figure 30 **Projected changes in real income under scenario 1, relative to the reference case (2010-11 dollars)**

Real economic output: Under Scenario 1, the loss of water and consequent switching away from some intensively cropped cotton to less intensive cropping regimes is projected to reduce the real economic output of the Darling Downs region by:

- –$9.4 million in 2029-30 (in 2010-11 terms)
- –$25.5 million in 2049-50 (in 2010-11 terms)
- A cumulative total of –$150 million in net present value terms over the period to 2049-50 (using a four per cent real discount rate).

In the context of a region with around 245,000 people, this is a noticeable change, with the loss in 2049-50 representing an average decrease in real economic output of around $85 per person projected to be living in the Darling Downs at this time.

Due to the assumption under Scenario 1 that there is sufficient fallow land available to introduce a cotton growing industry into the Burdekin region, real economic output in the Burdekin increases6. In particular, under Scenario 2 it is projected that the real economic output of the Burdekin increases by:

- $54 million in 2029-30 (in 2010-11 terms)
- $84 million in 2049-50 (in 2010-11 terms)
- A cumulative total of $708 million in net present value terms over the period to 2049-50 (using a four per cent real discount rate).

In the context of a region with around 18,500 people, this is a substantial change, with the increase in 2049-50 representing an increase in real economic output of around $4,500 per person projected to be living in the Burdekin at this time.

Under Scenario 1, the movement of labour is primarily toward the Burdekin region with some movement of labour away from the Darling Downs and the Rest of Australia. Consequently it is projected that there will be small negative impacts on the Rest of Australia under Scenario 1.

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[6] Essentially real economic output increases because of the increased productivity of existing factors (i.e. land) and because extra factors (labour and capital) are drawn to the region.

- At the national level, real economic output (or real GDP) is projected to increase by:
- $37.5 million in 2029-30 (in 2010-11 terms)
- $48.4 million in 2049-50 (in 2010-11 terms)
- A cumulative total of $465.6 million in net present value terms over the period to 2049-50 (using a four per cent real discount rate).

Real income: Under Scenario 1, the real income (in 2010-11 terms) is projected to change by:

- –$8.1 million in 2029-30 and by –$25.4 million in 2049-50 in the Darling Downs region
- +$43.6 million in 2029-30 and by +$74.3 million in 2049-50 in the Burdekin region
- –$5.7 million in 2029-30 and by –$5.9 million in 2049-50 in the Rest of Australia
- A national total of +$29.8 million in 2029-30 and +$43.0 million in 2049-50

As with the projected changes in real economic output, in the context of the Burdekin and Darling Downs regions these are noticeable changes. In the Burdekin, the projected increase in real income in 2049-50 is equivalent to an average increase in real income of approximately $4,000 per person living in the region at that time, compared with the fall in real income of the Darling Downs region is equivalent to a decrease of around $85 per person.

7.2.3 Macroeconomic impacts: Scenario 2

Table 13 summarises the projected changes in real economic output and real income for each region under Scenario 2 while

Figure 31 and Figure 32 show the year on year changes in real outputs and real income. The key difference between Scenario 1 and Scenario 2 is that the assumed creation of a cotton industry in the Burdekin region comes at the expense of land dedicated to growing sugarcane. This scenario is designed to provide an indication of the potential competition for land that could occur if the Australian cotton industry is preferentially maintained at the expense of other activities. On a 'dollars per hectare' basis, a hectare of Burdekin land dedicated to sugarcane production is generally of higher value than a hectare dedicated to cotton. Therefore, just as the Scenario 1 assumptions explored the one extreme of no competition for the irrigated land in the Burdekin, this scenario explores the other 'extreme' of full competition for irrigated land.

Table 13 Cumulative change in real economic output and real income under scenario 2, relative to the reference case (in 2010-11 terms)

SCENARIO 2 – Burdekin cotton displaces sugar

	A. Real economic output [a]			B. Real income [b]		
	2029-30	2049-50	NPV (2010-11 to 2049-50)	2029-30	2049-50	NPV (2010-11 to 2049-50)
	2010-11$m	2010-11$m	2010-11$m	2010-11$m	2010-11$m	2010-11$m
Darling Downs SD	–9.38	–25.58	–150.22	–8.12	–25.42	–136.10
Burdekin LGA	–12.68	–15.20	–172.77	–50.78	–41.05	–574.94
Rest of Australia	6.04	19.31	100.10	–5.66	–5.94	–71.00
Total Australia	**–16.02**	**–21.47**	**–222.89**	**–64.56**	**–72.41**	**–782.04**

a The term ‘real economic output’ is used instead of gross regional product (GRP). The sum of the GRP of all three regions equals the change in Australian GDP.
b Real income for Australia is synonymous with real gross national disposable income (RGNDI) as used by the ABS. In this modelling real income is a measure of the change in economic welfare.
Notes: Totals may not add due to rounding. NPV = Net Present Value (calculated using a 4 per cent real discount rate). It should be noted that the NPV calculation only includes the impacts through to 2049-50 even though the impacts will be likely to continue producing beyond this artificial time horizon.

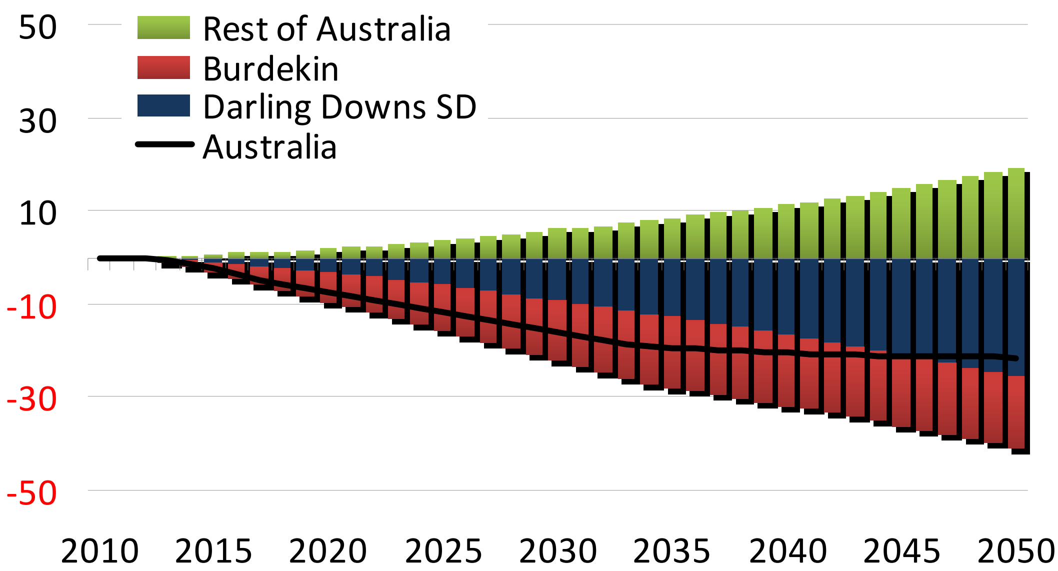

Figure 31 Projected changes in real economic output under scenario 2, relative to the reference case (2010-11 dollars)

Notes: The term ‘real economic output’ is used instead of gross regional product (GRP). The sum of all three regions GRP equals the change in Australian GDP

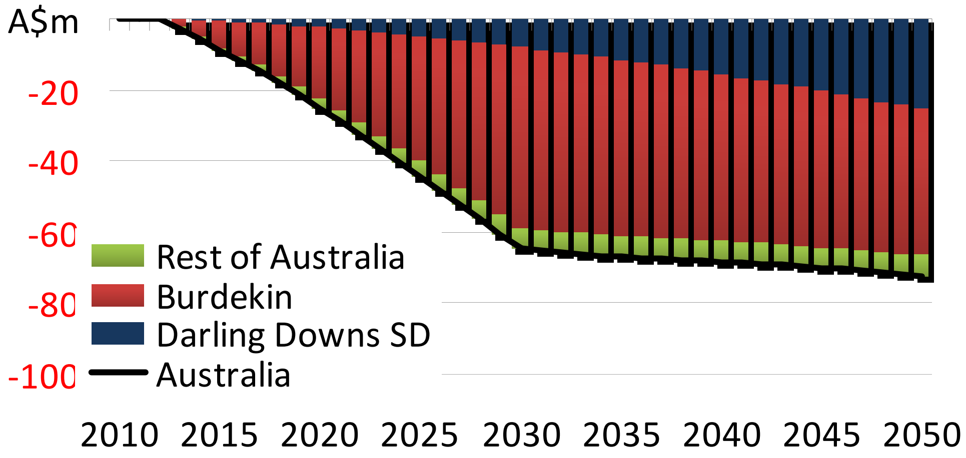

Figure 32 Projected changes in real income under scenario 2, relative to the reference case (2010-11 dollars)

Real economic output: As the assumptions regarding the Darling Downs region are the same under both Scenario1 and 2, the projected impacts on the economy of the Darling Downs region are broadly the same. However, due to the higher value per hectare of the sugarcane, the Burdekin region also experiences a fall in real economic output. In particular, under Scenario 2 it is projected that the real economic output of the Burdekin changes by:

- –$12.7 million in 2029-30 (in 2010-11 terms)
- –$15.2 million in 2049-50 (in 2010-11 terms)
- a cumulative total of –$172.8 million in net present value terms over the period to 2049-50 (using a four per cent real discount rate).

In the context of the region, this is a noticeable change, with the decrease in 2049-50 representing a loss of real economic output of around $800 per person projected to be living in the Burdekin at this time.

Under Scenario 2, the Rest of Australia is projected to benefit from a movement of labour from both the Darling Downs and Burdekin regions. Consequently it is projected that, under Scenario 2, the real economic output of the Rest of Australia will increase by:

- $6.0 million in 2029-30 and $19.3 million in 2049-50 (in 2010-11 terms)
- a cumulative total of $100 million in net present value terms over the period to 2049-50 (using a four per cent real discount rate).

At the national level, the gains in the Rest of Australia negate a significant amount, but not all, of the losses in the Darling Downs and Burdekin regions. Under Scenario 2, national real economic output (or real GDP) is projected to change by:

- –$16.0 million in 2029-30 (in 2010-11 terms)
- –$21.5 million in 2049-50 (in 2010-11 terms)
- a cumulative total of –$222.9 million in net present value terms over the period to 2049-50 (using a four per cent real discount rate).

At a national level this loss (relative to the reference case) is essentially driven by the lower value of output from the fixed area of land.

***Real income*:** Under Scenario 2, the real income (in 2010-11 terms) is projected to change by:

- –$8.1 million in 2029-30 and by –$25.4 million in 2049-50 in the Darling Downs region
- –$50.8 million in 2029-30 and by –$41.1 million in 2049-50 in the Burdekin region
- –$5.7 million in 2029-30 and by –$5.9 million in 2049-50 in the Rest of Australia
- A national total of –$65 million in 2029-30 and –$72.4 million in 2049-50.

As with the projected changes in real economic output, in the context of the Burdekin economy these are significant changes. In the Burdekin, the projected decrease in real income in 2049-50 is equivalent to an average loss in real income of approximately $4,000 per person living in the region at that time (relative to the reference case).

8 Conclusions and Policy Implication

In this report we demonstrate that that integrating modelling and expert knowledge from the crop to the regional scale can provide a more complete understanding of the biophysical, social and economic impact of relocation of agricultural production.

Farm level simulations showed that without adaptation overall gross margins would be decreased under a combination of climate change and reductions in water availability from underground storage. Some of the reduction in cotton yield was expected as a result of climate change was offset by CO_2 fertilisation as demonstrated by the crop model. The two adaptations explored demonstrate that it is possible to have a productive farm enterprise in the future in this area and that the cropping regime used in these simulations is flexible. The long term gross margin is indicative of the capacity of the system to cope with the changes and individual farm level studies would need to be done on a case-by-case basis to investigate the farm profitability for particular farms.

The study demonstrates that the cotton model is unsuited to non-traditional cropping regions and we recommend that resources should be directed to enhance the model so that it can cope with these situations. Valuable work has been done by Queensland DAFF and CSIRO in the Burdekin and Katherine and could be utilised to redevelop the model. It is likely that other cropping models would also fail to cope with novel agricultural situations and given that our understanding of the impact of climate change can only be assessed using models it is important that these short comings are addressed promptly.

Darling Down cotton farmers are comparatively diversified already and so they will be relatively able to change the production systems. The loss of water, as a result of changing climate and water policy, would not significantly impact production system and profitability, if suitable adaption options are available.

Relocation of cotton production system to additional sugar cane fallow land or new area development in Burdekin would be viable option. The relocation of irrigated cotton to Burdekin, and as a result of production will have positive impact on export and GDP. This is primarily due to flexibility in the Darling Down cropping systems with suitable climatic conditions which allows growers to shift to various configuration of cotton production.

There could be large effects on regional economies, especially if cotton relocation will replace sugarcane land. The increase in cotton production will not compensate for the reduction in the higher value sugarcane production. This will be a cost to the economy over and above the direct cost of the environmental water. Some level of government support would be required to manage negative impacts.

Given the amount of water buyback for environmental purposes under MDB plan, farm and regional modelling result suggest there will be minimal impact on regional output. These negative regional impacts could be better managed by developing suitable adaptation strategies and by relocating some of the cotton production system to areas such as Burdekin.

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Appendix I Prices used for APSFarm gross margin analysis

Sorghum

Event	Description	dollars	units
harvest	Pre Harvest spray (ariel spray + glyphosate)	-$41.00	/ha
harvest	Harvesting	-$39.54	/ha
sow	Primary tillage	-$8.76	/ha
sow	Secondary tillage	-$6.98	/ha
sow	Fertiliser application	-$6.98	/ha
sow	Anhydrous ammonia	-1.58	/kg/ha
sow	Strater Z (40 kg @ $957 / tonne)	-38.28	/ha
sow	Inter-row tillage	-$3.34	/ha
sow	Planting	-$6.98	/ha
sow	Seed (7kg x $9.50/kg)	-$66.50	/ha
sow	glyphosate and boom spraying	-$22.99	/weed event/ha
sow	Herbicide (Atrazine @ 3.5L x $5.50/L + bs)	-$20.64	/ha
sow	Insecticide (NPV @ 0.4L x $55/L + bs)	-$23.39	/ha

Maize

Event	Description	dollars	units
harvest	Crop price	$250.00	/tonne
harvest	Levies	-$2.50	/tonne
harvest	Harvesting	-$49.42	/ha
sow	Primary tillage	-$8.76	/ha
sow	Secondary tillage	-$6.98	/ha
sow	Fertiliser application	-$6.98	/ha
sow	Anhydrous ammonia	-1.58	/kg/ha
sow	Strater Z (40 kg @ $957 / tonne)	-38.28	/ha
sow	Inter-row tillage	-$3.34	/ha
sow	Planting	-$6.98	/ha
sow	Seed (20kg x $12.50/kg)	-$250.00	/ha
sow	glyphosate and boom spraying	-$22.99	/weed event/ha
sow	Herbicide (Atrazine @ 4.0L x $5.50/L + bs)	-$23.39	/ha

Cotton

Event	Description	Cotton 1 m	Cotton 2 m	units
harvest	Crop price	$500.00	$500.00	/bale
harvest	Cottonseed (31% @ 125/tonne)	$5.00	$5.00	/bale
harvest	Cartage/pick-up fee	-$10.00	-$10.00	/bale
harvest	Pick-up fee ($65/module)	-$3.25	-$3.25	/bale
harvest	Cotton Research Levy	-$2.25	-$2.25	/bale
harvest	Cotton Australia Levy	-$2.25	-$2.25	/bale
harvest	Tarps	-$2.90	-$2.90	/bale
harvest	Bollguard II Licence Fee	-$50.00	-$50.00	/bale

harvest	Defoliation (Aerial spray)	-$16.00	-$16.00	/ha
harvest	Defoliation (Dropp Ultra)	-$13.50	-$13.50	/ha
harvest	Defoliation (ethephon (eg Prep))	-$11.70	-$11.70	/ha
harvest	Defoliation (DC-Tron Oil)	-$4.44	-$4.44	/ha
harvest	Defoliation (Dropp Ultra)	-$6.75	-$6.75	/ha
harvest	Cultivation (Stalk pull and mulch)	-$49.64	-$49.64	/ha
harvest	Picking	-$346.00	-$300.00	/ha
sow	Preparation and Cultivation	-$48.46	-$48.46	/ha
sow	Planter	-$9.39	-$9.39	/ha
sow	Seed	-$91.00	-$45.00	/ha
sow	Anhydrous ammonia	-$1.58	-$1.58	/kg/ha
sow	Liquifert Emerald	-$16.00	-$16.00	/ha
sow	Herbicide & application	-$154.67	-$154.67	/ha
sow	Insecticide & application	-$308.00	-$154.00	/ha
sow	Consulting	-$142.00	$142.00	/ha
sow	glyphosate and boom spraying	-$22.99	-$22.99	/weed event/ha

Wheat

Event	Description	dollars	units
harvest	Crop price	$260.00	/tonne
harvest	Levies	-$2.60	/tonne
harvest	Harvesting	-$39.54	/ha
sow	Primary tillage	-$8.76	/ha
sow	Secondary tillage	-$6.98	/ha
sow	Fertiliser application	-$6.98	/ha
sow	Anhydrous ammonia	-1.58	/kg/ha
sow	Strater Z (30 kg @ $957 / tonne)	-28.71	/ha
sow	Inter-row tillage	-$3.34	/ha
sow	Planting	-$8.83	/ha
sow	Seed (60kg x $1.00/kg)	-$60.00	/ha
sow	glyphosate and boom spraying	-$22.99	/weed event/ha
sow	Herbicide (MCPA LVE @ 0.50L x $9.00/L)	-$4.50	/ha

Irrigation

Event	Description	dollars	units
harvest	On-farm Storage	-56.5	$/ML
harvest	Bore	-110	$/ML

Appendix II Overview of Tasman Global Model

ACIL Tasman's computable general equilibrium model *Tasman Global* is a powerful tool for undertaking economic impact analysis at the regional, state, national and global level.
There are various types of economic models and modelling techniques. Many of these are based on partial equilibrium analysis that usually considers a single market. However, in economic analysis, linkages between markets and how these linkages develop and change over time can be critical. *Tasman Global* has been developed to meet this need.

Tasman Global is a large-scale computable general equilibrium model which is designed to account for all sectors within an economy and all economies across the world. ACIL Tasman uses this modelling platform to undertake industry, project, scenario and policy analyses. The model is able to analyse issues at the industry, global, national, state and regional levels and to determine the impacts of various economic changes on production, consumption and trade at the macroeconomic and industry levels.

A dynamic model

Tasman Global is a model that estimates relationships between variables at different points in time. This is in contrast to comparative static models, which compare two equilibriums (one before a policy change and one following). A dynamic model such as *Tasman Global* is beneficial when analysing issues where both the timing of and the adjustment path that economies follow are relevant in the analysis.

In applications of the *Tasman Global* model, a reference case simulation forms a 'business-as-usual' basis with which to compare the results of various simulations. The reference case provides projections of growth in the absence of the changes to be examined. The impact of the change to be examined is then simulated and the results interpreted as deviations from the reference case.

The database

A key advantage of *Tasman Global* is the level of detail in the database underpinning the model. The database is derived from the latest Global Trade Analysis Project (GTAP) database. This database is a fully documented, publicly available global data base which contains complete bilateral trade information, transport and protection linkages among regions for all GTAP commodities.
The GTAP model was constructed at the Centre for Global Trade Analysis at Purdue University in the United States. It is the most up-to-date, detailed database of its type in the world.

Tasman Global builds on the GTAP model's equation structure and database by adding the following important features:

1. dynamics (including detailed population and labour market dynamics)
2. detailed technology representation within key industries (such as electricity generation and iron and steel production)
3. disaggregation of a range of major commodities including iron ore, bauxite, alumina, primary aluminium, brown coal, black coal and LNG
4. the ability to repatriate labour and capital income
5. a detailed emissions accounting abatement framework
6. explicit representation of the states and territories of Australia
7. the capacity to explicitly represent multiple regions within states and territories of Australia.

Nominally the *Tasman Global* database divides the world economy into 120 regions (112 international regions plus the 8 states and territories of Australia) although in reality the regions are frequently disaggregated further. ACIL Tasman regularly models Australian projects or policies at the regional level.

The *Tasman Global* database also contains a wealth of sectoral detail currently identifying up to 70 industries (Appendix III Table 1). The foundation of this information is the input-output tables that underpin the database. The input-output tables account for the distribution of industry production to satisfy industry and final demands. Industry demands, so-called intermediate usage, are the demands from each industry for inputs.

For example, electricity is an input into the production of communications. In other words, the communications industry uses electricity as an intermediate input. Final demands are those made by households, governments, investors and foreigners (export demand). These final demands, as the name suggests, represent the demand for finished goods and services. To continue the example, electricity is used by households – their consumption of electricity is a final demand.
Each sector in the economy is typically assumed to produce one commodity, although in *Tasman Global*, the electricity, diesel and iron and steel sectors are modelled using a 'technology bundle' approach. With this approach, different known production methods are used to generate a homogeneous output for the 'technology bundle' industry. For example, electricity can be generated using brown coal, black coal, petroleum, base load gas, peak load gas, nuclear, hydro, geothermal, biomass, wind, solar or other renewable based technologies – each of which have their own cost structure.

Factors of production:

Capital, land, labour and natural resources are the four primary factors of production. The capital stock in each region (country or group of countries) accumulates through investment (less depreciation) in each period. Land is used only in agriculture industries and is fixed in each region. *Tasman Global* explicitly models natural resource inputs as a sector specific factor of production in resource based sectors (coal mining, oil and gas extraction, other mining, forestry and fishing).

Population growth and labour supply

Population growth is an important determinant of economic growth through the supply of labour and the demand for final goods and services. Population growth for the 112 international regions and for the 8 states and territories of Australia represented in the *Tasman Global* database is projected using ACIL Tasman's in-house demographic model. The demographic model projects how the population in each region grows and how age and gender composition changes over time and is an important tool for determining the changes in regional labour supply and total population over the projection period.

Appendix Table 1 Sectors in the *Tasman Global* database

	Sector		Sector
1	Paddy rice	36	Leather products
2	Wheat	37	Wood products
3	Cereal grains nec	38	Paper products, publishing
4	Vegetables, fruit, nuts	39	Diesel (incl. nonconventional diesel)
5	Oil seeds	40	Other petroleum, coal products
6	Sugarcane, sugar beet	41	Chemical, rubber, plastic products
7	Plant- based fibres	42	Mineral products nec
8	Crops nec	43	Ferrous metals
9	Bovine cattle, sheep, goats, horses	44	Alumina
10	Animal products nec	45	Primary aluminium
11	Raw milk	46	Metals nec
12	Wool, silk worm cocoons	47	Metal products
13	Forestry	48	Motor vehicle and parts
14	Fishing	49	Transport equipment nec
15	Brown coal	50	Electronic equipment
16	Black coal	51	Machinery and equipment nec
17	Oil	52	Manufactures nec
18	Liquefied natural gas (LNG)	53	Electricity generation
19	Other natural gas	54	Electricity transmission and distribution
20	Iron ore	55	Gas manufacture, distribution
21	Bauxite	56	Water
22	Minerals nec	57	Construction
23	Bovine meat products	58	Trade
24	Meat products nec	59	Road transport
25	Vegetables oils and fats	60	Rail and pipeline transport
26	Dairy products	61	Water transport
27	Processed rice	62	Air transport
28	Sugar	63	Transport nec
29	Food products nec	64	Communication
30	Wine	65	Financial services nec
31	Beer	66	Insurance
32	Spirits and RTDs	67	Business services nec
33	Tobacco products and beverages nec	68	Recreational and other services
34	Textiles	69	Public Administration, Defence, Education, Health
35	Wearing apparel	70	Dwellings

Note: nec = not elsewhere classified

For each of the 120 regions in *Tasman Global*, the model projects the changes in age-specific birth, mortality and net migration rates by gender for 101 age cohorts (0-99 and 100+). The demographic model also projects changes in participation rates by gender by age for each region, and, when combined with the age and gender composition of the population, endogenously projects the future supply of labour in each region. Changes in life expectancy are a function of income per person as well as assumed technical progress on lowering mortality rates for a given income (for example, reducing malaria-related mortality through better medicines, education, governance etc).

Participation rates are a function of life expectancy as well as expected changes in higher education rates, fertility rates and changes in the work force as a share of the total population.

Labour supply is derived from the combination of the projected regional population by age by gender and the projected regional participation rates by age by gender. Over the projection period labour supply in most developed economies is projected to grow slower than total population as a result of ageing population effects.

For the Australian states and territories, the projected aggregate labour supply from ACIL Tasman's demographics module is used as the base level potential workforce for the detailed Australian labour market module, which is described in the next section.

The Australian labour market

Tasman Global has a detailed representation of the Australian labour market which has been designed to capture:

- different occupations
- changes to participation rates (or average hours worked) due to changes in real wages
- changes to unemployment rates due to changes in labour demand
- limited substitution between occupations by the firms demanding labour and by the individuals supplying labour; and
- limited labour mobility between states.

Tasman Global recognises 97 different occupations within Australia – although the exact number of occupations depends on the aggregation. The firms who hire labour are provided with some limited scope to change between these 97 labour types as the relative real wage between them changes. Similarly, the individuals supplying labour have a limited ability to change occupations in response to the changing relative real wage between occupations. Finally, as the real wage for a given occupation rises in one state rise relative to other states, workers are given some ability to respond by shifting their location. The model produces results at the 97 3-digit ANZSCO (Australian New Zealand Standard Classification of Occupations) level.

The labour market structure of *Tasman Global* is thus designed to capture the reality of labour markets in Australia, where supply and demand at the occupational level do adjust, but within limits.
Labour supply in *Tasman Global* is presented as a three stage process:

1. labour makes itself available to the workforce based on movements in the real wage and the unemployment rate
2. labour chooses between occupations in a state based on relative real wages within the state; and
3. labour of a given occupation chooses in which state to locate based on movements in the relative real wage for that occupation between states.

By default, *Tasman Global*, like all general equilibrium models, assumes that markets clear. Therefore, overall, supply and demand for different occupations will equate (as is the case in other markets in the model).

Appendix III Cotton Industry level questionnaire

Perception of industry on relocation to north

- What could be sustainable future of cotton industry (in terms of production/scale/export)? And what type of climate changes might hinder you getting there? What can you do to mitigate the risk or exploit opportunities? What are the relative costs and benefits?
- Perceptions of taking out the cotton industry out of towns, and its perceived impact on: Town, mills, transport, storage, supply, housing etc?
- Community perceptions and additional social and environmental issues as a result of relocation
- Perception of the irrigators in Burdekin? How to bring local 'grazier on board'. Are they willing to adapt new farming system? Are they rigid in their farming practices? Farm flexibility issue?
- Key issues in terms of cotton production in northern areas (eg. Pests were one of the biggest problems and Magpie geese are a big issue).
- Land use substitute: What are the land use substitutes for cotton in Darling Down/Burdekin? What sort of crops cotton would be competing in Burdekin (sugarcane? Sandalwood? Chia?)
- How big are the investment needed (in term of $ cost) for set up a cotton processing?
- The impact of structural adjustment/relocation on-farm size and productivity. The impact of scale and intensity of production, the diversity of farm output or the need to find ways to supplement their income
- The impact of structural changes/relocation on the industry performance
- Impact of various climate and economic factors (relocation) and water availability on land values.
- Equity considerations of structural change (relocation) and affects Govt support, if any Structural adjustment in agriculture and regional capacity to implement sustainable adjustment
- Key infrastructure and production, economic and market issues that cotton industry is expected to face if they will relocated to Burdekin
- Is cost of inputs (fertiliser etc) are major concern?

Industry Threshold point (key infrastructure requirements)

- Threshold points for the industry are to maintain core infrastructure, to maintain markets.
- Issue of scale of production. What would be optimal scale of productions in Burdekin?
- Key infrastructure availability and additional requirement (eg. road, mills and irrigation water delivery system)

Climate change and water availability

- Do you think, you will continue to grow cotton in Darling Down given the significance decrease in water availability?
- Impact of water buyback and environmental water requirements on cotton industry?
- Climate change and cotton yield?

Production, quality and economic issues

- Cotton varieties and related economic returns
- Cotton quality issues:
- Sowing time and sowing times and methods: Could be useful for international market
- Cotton production: Potentially of two cotton crops in a year?
- Crop profitability. It costs more to grow a crop here than it does in the Darling Down

Value chain: Demand/Supply/Export/Import

- Domestic and international demand cotton and cotton products?
- Climate and production possibilities in different regions.
- Key driver: international and national market (prices and demand, and supply), national policies (income and structural support) and climate change (higher temperature) and variability (drought etc), others (Food security, bio fuels etc)
- Impact of relocation/climate change on supply, demand and pricing
- Govt support and structural change for relocation of agricultural industry:
- Supplementary (complementary) industry

Industry level cotton relocation scenario:

- Production levels and potential for relocation
- Industry requirements
- Viability of current production system