# An Impact Assessment of CRDC Water Use Efficiency Investments 2011-2015

## Final Report to Cotton Research and Development Corporation

**Agtrans Research**

**January 2017**

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# Abbreviations

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| ABS | Australian Bureau of Statistics |
| ACRI | Australian Cotton Research Institute |
| BCR | Benefit-Cost Ratio |
| BIOTIC | Biologically Identified Optimal Temperature Interactive Console |
| CBA | Cost-Benefit Analysis |
| CHCG&IA | Central Highlands Cotton Growers & Irrigators Association |
| CTF | Controlled Traffic Farming |
| CP/LM | Centre-Pivot/Lateral-Move |
| CQ | Central Queensland |
| CRC | Cooperative Research Centre |
| CRDC | Cotton Research and Development Corporation |
| CRRDC | Council of Rural Research and Development Corporations |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| D&D | Development and Delivery |
| DAWR | Department of Agriculture and Water Resources |
| DIIS | Department of Industry, Innovation and Science |
| GDP | Gross Domestic Product |
| GHG | Greenhouse gas |
| GJ | Gigajoule |
| GPWUI | Gross Production Water Use Index |
| Ha | Hectare |
| IRR | Internal Rate of Return |
| IRRICOM | Communication of Irrigation Research in Cotton |
| IWUI | Irrigation Water Use Index |
| MDB | Murray-Darling Basin |
| MIRR | Modified Internal Rate of Return |
| ML | Megalitre |
| N | Nitrogen |
| NCEA | National Centre for Engineering in Agriculture |
| NPV | Net Present Value |
| NUE | Nitrogen Use Efficiency |
| NSW DPI | New South Wales Department of Primary Industries |
| P | Phosphorus |
| PEM | Pump Efficiency Monitor |
| PVB | Present Value of Benefits |

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| PVC | Present Value of Costs |
| PWSII | Promoting Water-Smart Infrastructure Investment |
| R&D | Research and Development |
| RD&E | Research, Development and Extension |
| RDC | Research and Development Corporation[1] |
| SIP | Smarter Irrigation Project |
| WUE | Water Use Efficiency |

[1] Note that this report uses the term RDC to include not only the six Research and Development Corporations but also the nine rural industry owned companies that receive matching dollar support from the Commonwealth Government.

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# Executive Summary

### The Report

This report presents the results of an impact assessment of a cluster of six WUE projects funded by the CRDC over the years 2010-2015. In addition to CRDC funding (a combination of statutory levies paid by industry participants and matching Commonwealth funding), other resources were provided by research organisation contributions.

### Methods

The six individual projects were first analysed qualitatively within a logical framework that considered project rationale, objectives, activities/outputs, outcomes, and impacts. Several of the impacts were then valued. Benefits were calculated for a range of time frames up to 30 years from the year of last investment. Past and future cash flows in 2015/16 $ terms were discounted to the year 2015/16 using a discount rate of 5% to estimate investment criteria.

### Impacts

Most the impacts identified were economic in nature, however some social and environmental impacts also were identified. Some of the cluster impacts were valued; the decision not to value certain impacts was due either to a high degree of uncertainty surrounding potential impacts, a shortage of necessary data, or the likely low relative significance of the benefit compared to those that were valued. It is expected the Australian cotton growing industry will be the primary beneficiary of the investment with only minor spill-over benefits to other cropping industries.

### Investment Criteria

Total funding from all sources for all six projects totalled $4.90 million (present value terms). The benefits from all six projects were valued at $40.62 million (present value terms). This gave a net present value of $35.72 million, and a benefit-cost ratio of 8.29 to 1.

# 1. Introduction

### Background to Impact Assessment

The primary purpose of impact assessments of CRDC investment is to assist with portfolio management and provide accountability to the CRDC Board, its levy paying industries and the Australian Government. The results of the impact assessments can also can be used as inputs into the development and/or assessments of further research investments.

A further purpose of the CRDC impact assessments is to contribute to a process being undertaken for the Council of Rural Research & Development Corporations (CRRDC). This process aims to demonstrate the impacts and benefits that have emerged or are likely to emerge from the 15 Rural Research and Development Corporations (RDCs) including producer-owned companies. Valuation of these impacts, along with identification of investment expenditure, is required to demonstrate the RDCs' contribution to Australian rural industry as well as environmental and social impacts to Australia.

### The Importance of Cotton Water Use Efficiency Research

Water use efficiency (WUE) in an agricultural context can be defined as the measure of a cropping system's capacity to convert water into plant biomass, grain or other harvested output. It includes both the use of water stored in the soil and rainfall during the growing season. In simple terms WUE can be said to have increased if farm output per unit of water input increases, or if water use can be decreased while maintaining current production levels. In addition to this objective, WUE research also seeks to enable improvement in other areas of water management, such as reducing the costs of supplying water to the crop and minimising adverse environmental impacts should they exist.

While WUE is a relevant consideration in all agricultural production, it is particularly important to Australian cotton production. With water security under threat from climate change and increased competition from other users, water, rather than land, is becoming a limiting factor for Australian cotton production. Irrigated cotton currently represents 82% of the total Australian cotton area and almost 95% of total lint production (ABS, 2016) although these figures do not distinguish between partially and fully irrigated cotton. Cotton is also the largest user of water amongst Australian cropping industries. This places an economic, social and political imperative on the industry to increase WUE.

# 2. Methods

The evaluation approach follows general evaluation guidelines that are now well entrenched within the Australian primary industry research sector including RDCs, Cooperative Research Centres (CRCs) and some Universities. The impact assessment uses Cost-Benefit Analysis (CBA). This entails both qualitative and quantitative approaches that are in accord with the evaluation guidelines of the Council of Research and Development Corporations (CRRDC, 2014).

The evaluation process was first to identify and briefly describe objectives, activities & outputs, outcomes, and impacts for each project investment. The individual project outcomes and impacts were then integrated and described at the aggregate cluster level. The principal economic, environmental and social impacts at the cluster level were then summarised in a triple bottom line table.

Some, but not all, of the impacts identified were then valued in monetary terms. The decision not to value certain impacts was made based on a range of factors including difficulty linking project outcomes to impacts, shortage of evidence to justify the impact, or a high degree of uncertainty prohibiting accurate evaluation. Therefore, those impacts valued are deemed to represent the principal benefits derived from the cluster investment.

These benefits were then compared against the cluster investment costs. This allowed aggregate investment criteria to be produced for the whole WUE cluster of six projects.

# 3. Description of Projects

Table 1 provides a list of the project codes and titles of all six projects defined in the population of the WUE cluster.

Table 1: Projects Included in the Population of the WUE Cluster

| Project Code | Project Title |
|---|---|
| **CLW1102** | Quantifying Deep Drainage in an Irrigated Cotton Landscape |
| **CSP1305** | Irrigation Strategies in a Limited Water Environment |
| **DAN1205** | Promoting Water Smart Infrastructure Investment in NSW (PWSII) |
| **DAN1502** | Optimising Water and Nitrogen Fertiliser Management in Cotton |
| **DAQ1303** | Optimising Water and Energy Use in the Central Queensland Irrigation Sector |
| **US1503** | Water Use Efficiency, Gross Margin, Yield and Quality of 1m and 1.5m Row Irrigated Cotton |

A full description of each of the six projects is presented in Table 2. The projects are summarised in a logical framework format (rationale, objectives, activities and outputs, outcomes and impacts).

Table 2: Project Descriptions

| **CLW1102: Quantifying Deep Drainage in an Irrigated Cotton Landscape** | |
|---|---|
| Project Details | Research Organisation: CSIRO Land and Water<br>Period: 2010 – 2011<br>Principal Investigator: Anthony Ringrose-Voase |
| Rationale | Deep drainage is a relatively small but nonetheless important factor in soil water balance calculations. The term refers to downward movement of water beyond a depth at which it can be extracted by plant roots. In irrigated agriculture, a degree of deep drainage is essential to prevent accumulation of salts in the root zone, however, drainage in excess of these requirements can have several negative effects. It is wasteful, as lost water cannot be utilised by plants, and nutrients (e.g. nitrogen) are leached from the root zone. This leaching of nutrients and other chemicals can also lead to contamination of aquifers and waterways. In arid and semi-arid climates where native vegetation has been cleared for agriculture, deep drainage can contribute to soil waterlogging and salinity issues.<br><br>Despite its importance deep drainage remains one of the least-understood components of the soil water balance for cotton. Results from previous investigations indicated that deep drainage is complex and invalidates many assumptions in contemporary water balance models. Drainage is typically the most difficult component of the water balance to measure and previous methods all had weaknesses in how they measured and/or estimated drainage.<br><br>Determining the fate of drainage, how much of it reaches groundwater and the timeframe of the process were identified as priorities for the Cotton CRC. In 2003, CRDC project CRC47C established an equilibrium tension lysimeter under a cotton-wheat plot at the Australian Cotton Research Institute (ACRI). This facility enabled accurate measurement of deep drainage and other components of the water balance. The information provided by this facility acts as a benchmark against which to test |

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| | less expensive methods of estimating drainage. In addition, the lysimeter facility provides an opportunity to examine whether drainage from cotton is contaminated by salts, fertilisers or other agrochemicals.<br><br>Work at this facility has spanned several projects and produced valuable insight into the soil water balance. Project CLW1102 was intended to continue this work and add to the body of understanding surrounding soil drainage. |
| Objectives | 1. To quantify the water balance, in particular deep drainage, in an irrigated cotton landscape, including different management practices and soils.<br>2. To improve process understanding and models of the water balance in heavy clay soils, in particular with regard to 'by-pass flow'.<br>3. To investigate links between drainage from the root zone and groundwater.<br>4. To assess and compare different technologies to measure soil water that could be tactically used by irrigators to improve water management and lessen drainage. |
| Activities and Outputs | • The previously-established ACRI lysimeter facility was used to study drainage, drainage contaminants and drainage interaction with groundwater in a heavy clay soil under a furrow-irrigated cotton/wheat rotation. The facility provided accurate, high frequency measurements of drainage.<br>• The tension lysimeter provided data used to measure soil moisture content at various depths, along with analysis of groundwater head pressure and chemical content of drainage water. This information was used to determine the rates, timings and content of deep drainage flows. The information also identified risk factors likely to trigger or exacerbate drainage.<br>• It was found that the majority of nitrogen leached is after the first four irrigations, highlighting the importance of avoiding drainage early in the season when nitrogen (N) is most available. It was therefore suggested losses of N due to drainage could be reduced through greater use of split fertiliser applications with a greater proportion of N being applied once drainage rates have reduced.<br>• The project examined the role of drainage in aquifer recharge. Findings established a tentative link between peaks in deep drainage and peaks in recharge rates 1-4 weeks later.<br>• Two alternative and lower cost methods of estimating drainage were tested in the vicinity of the tension lysimeter – chloride mass balance determinations and barrel lysimeters. These systems were shown to be generally less accurate and responsive in comparison to the tension lysimeter, however some of this variance was likely due to differences in measuring location and soil profile.<br>• Results furthered the understanding of the two types of soil drainage, namely matrix drainage and by-pass flow drainage.<br>• It was found that most drainage (and thus water and nutrient loss) during the irrigation season occurs as by-pass flow as opposed to matrix drainage. Matrix drainage was found to be a more effective means of leaching unwanted salts than by-pass drainage.<br>• It was realised that existing water balance equations can be used to adequately simulate matrix drainage but not by-pass drainage. Development of a predictive model for soil water by-pass flow was attempted, however this proved difficult. At project completion, it had only been possible to develop a conceptual, empirical model of drainage over the 48 hours after irrigation events. |
| Outcomes | • The higher costs of the tension lysimeter mean it is likely to supplement, rather than replace cheaper measurement options. Furthermore, the increased accuracy of the tension lysimeter can highlight weaknesses in other methods, which can then be accounted for when interpreting results (Anthony Ringrose-Voase, pers. comm., 2016). |

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| | • The preliminary model developed in this project showed potential to be used as a tool for predicting by-pass flow drainage. If the research was continued and provided more data, this could become a valuable tool for practical applications.<br>• The aim of any future monitoring and shorter-term experiments must be to develop system understanding that can be applied (most likely through the use of simulation modelling) to a wider range of soils, management practices and climates than those represented at the ACRI facility. This would require design of a measurement program that could be carried out on a much wider variety of situations in order to verify such models.<br>• If project findings can provide improved capability to predict drainage this will assist with development of strategies to improve water use efficiency through a decrease in the overall amount of undesirable drainage.<br>• The findings of this research could be packaged in a way which could aid growers to better understand the major drivers for drainage, its dangers and steps that could be taken to reduce the risk of excessive drainage.<br>• Improved knowledge of the role of drainage in soil nitrogen losses may lead to refinements to fertiliser management applications.<br>• Better understanding of deep drainage will allow growers to better estimate how to allow for deep drainage in their water balance calculations and determine if they have sufficient leaching fraction to prevent build-up of salts.<br>• Investigations into deep drainage were continued in project CLW 1301 - *Measuring deep drainage from a cotton/wheat trial*, which investigated the handling of soil water in farming systems models. |
| Impacts | • Potential increase in on-farm WUE due to improved soil water balance calculations.<br>• Potential increase in on-farm nitrogen use efficiency through improved understanding of water and soil nitrogen leaching processes and implications for fertiliser application strategies.<br>• Potential reduction in off-farm impacts from nutrient (particularly nitrogen) losses.<br>• Increased research capacity and scientific knowledge. |

| **CSP1305: Irrigation Strategies in a Limited Water Environment** | |
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| Project Details | Research Organisation: CSIRO<br>Period: July 2012 to June 2015<br>Principal Investigator: Rose Brodrick |
| Rationale | Irrigation scheduling is a key aspect of irrigation management. When faced with limited water, timing of water application is critical in order to maximise water use efficiency (WUE), cotton yield and quality.<br><br>Improving scheduling decisions when water is limiting requires reliable identification of crop stress, clear understanding of the consequences of water stress at different critical stages of crop growth, understanding the effectiveness of irrigating to assist crop recovery in terms of yield and quality, and quantifying the risks associated with irrigation decisions in terms of the crop response and the short-term climate outlook.<br><br>Previous research into irrigation scheduling had focused primarily on improving WUE in fully irrigated systems. New research was required to extend knowledge on the interaction between soil type, soil moisture content, evaporative demand and plant stress to optimise yield and profitability in situations where the crop is water-limited, such as with alternative row configurations and partially irrigated systems. |

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| | Traditional irrigation scheduling generally relies on a fixed deficit (refill point) approach based on soil moisture content. Prior to this project CSIRO had recently developed the 'dynamic deficit' approach, where the deficit for irrigation is varied in response to observed and predicted climatic conditions within the season. While this system had shown promise as a means of increasing WUE and yields over previous methods, it had yet to be validated in grower fields across different regions.<br><br>To facilitate enhanced irrigation scheduling there was a need also to develop new means for understanding crop stress responses. This project aimed to achieve this by developing 'stress trigger points', which could be used to identify when crop stress was significantly impacting yield potential. Researchers were well-placed to investigate these factors by utilising new plant monitoring technologies and new knowledge generated from recently completed projects. |
| Objectives | 1. To test the validity and practicality of dynamic deficits in growers' fields across cotton regions.<br>2. To establish the relationship between crop stress and yield under limited water irrigation/partially irrigated conditions (including skip row configurations, 60 inch, 1 in 1 out).<br>3. To investigate the use of crop and plant 'stress triggers' utilising infrared sensors as a way to manage irrigations in a limited water environment.<br>4. To deliver this information to industry in a format suitable for different scheduling approaches (e.g. myBMP, web tools, WATERpak). |
| Activities and Outputs | • Field experiments were conducted to test the dynamic deficit approach against the traditional method of fixed deficits and the HydroLOGIC method. While results from these experiments were varied, dynamic deficits were shown to have the potential to result in superior WUE at comparable yields.<br>• The dynamic deficit experiments showed that when the forecast was for cooler than average conditions irrigations could be safely delayed and if a rainfall event occurred during this period, this could reduce the irrigation requirements.<br>• Further experiments investigated the relationship between plant stress and yield under a number of different limited-water irrigation strategies. These experiments were spread across four cotton growing regions.<br>• Three large-scale field experiments were conducted measuring the impact of various irrigation timings under limited water. These experiments compared crop and plant stress responses, yield and quality for crops irrigated at different growth stages with staggered irrigations.<br>• The OZCOT cotton crop simulation model was modified to use climate forecasts of reference evapotranspiration as an input, and the model was used to assess the current strategies, and if potential existed to modify strategies to optimise yield, quality and WUE using dynamic deficits and different limited water strategies.<br>• Nine publications (5 industry publications, 2 refereed conference papers, a conference abstract and an e-summary) were published on the research results from the dynamic deficit experiments and limited water experiments. Results were presented at a range of different field days, grower meetings and conferences.<br>• The IRRICOM (communication of irrigation research in cotton) workshop was initiated. This workshop was attended by numerous Australian and some international persons, with the goal of communicating the development of an integrated system for irrigation scheduling.<br>• The series of myBMP irrigation scheduling guidelines was reviewed and updated to incorporate the findings of this project and other recent research. |
| Outcomes | • Understanding of alternative irrigation scheduling techniques has been advanced. |

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| | • Better understanding of crop stress indicators will assist further development of irrigation techniques in limited-water environments.<br>• IRRICOM was a key initiative in bringing together irrigation scientists working on cotton that led to the Smarter Irrigation for Profit (SIP) project as part of the Rural R&D for profit program. The SIP aims to improve the profit of cotton, dairy, rice and sugar irrigators and consists of three components: scheduling, automation and networking.<br>• Work in the areas covered in this project is ongoing as part of the SIP project.<br>• It is hoped that with further research dynamic deficits will be able to be incorporated into updated irrigation scheduling systems, however as of 2016 the system is not yet at the commercial adoption stage (Rose Brodrick, pers. comm., 2016). |
| Impacts | • Increase in WUE for cotton growers through two pathways:<br>  o Improved understanding of scientists and growers of irrigation scheduling in limited water environments.<br>  o Potential future adoption by growers of improved scheduling methodologies, such as dynamic deficits.<br>• Increased scientific knowledge and research collaboration. |

| **DAN1205: Promoting Water Smart Infrastructure Investment in NSW (PWSII)** | |
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| Project Details | Research Organisation: NSW DPI<br>Period: December 2011 to June 2014<br>Principal Investigator: Janelle Montgomery |
| Rationale | Cotton producers have access to a wide range of options for on-farm irrigation infrastructure. Modern technologies such as automated control, centre pivot, lateral move and drip irrigation systems offer the potential for achieving higher water use efficiencies (WUE) over traditional methods such as flood and furrow irrigation. However, while these systems can lead to savings in water and labour inputs, they may require higher energy use. Furthermore, a 2009 NSW DPI project found that most on-farm infrastructure projects required large capital investment to achieve significant water savings.<br><br>It was therefore considered essential that producers have sufficient information and decision-making capability to identify irrigation infrastructure best-suited to their individual operations. Key information requirements included establishment/development costs, energy usage, water use efficiency, labour requirements and suitability to different farming systems. It is also important that irrigators have the technical skills required to measure, compare, integrate and analyse these factors.<br><br>To achieve these goals an effective system of benchmarks for irrigation water and energy use efficiencies needed to be developed. Alongside this aim, ongoing extension work needed to be conducted to drive adoption of practices increasing WUE. Hence, this project commenced with a strong focus on extension to improve the overall efficiency of irrigation infrastructure in the NSW cotton industry. |
| Objectives | 1. To benchmark irrigation water use efficiency (bales/ML) and whole farm energy use (GJ/Ha, GJ/ML, GJ/bale) for irrigated cotton.<br>2. To deliver irrigation training to irrigators and consultants to increase their knowledge of best irrigation management practice and on-farm energy use and efficiency.<br>3. To increase irrigator knowledge of alternative irrigation systems including centre pivot, lateral move and drip irrigation systems, etc. |

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| | 4. To coordinate and support forums/field days/conferences to build relationships between researchers and extension staff, irrigators and consultants and to support myBMP.<br>5. The water Technical Specialist of the cotton industry Development and Delivery (D&D) team was to lead and co-ordinate a cotton industry-wide water use efficiency campaign. |
| Activities and Outputs | • Irrigation water use efficiency for the Australian cotton industry was benchmarked during the 2012/13 season using the on-line irrigation benchmarking program, Watertrack Rapid™. This program combines all on-farm losses into a single figure and enables irrigators to quantify the magnitude of total water losses and their sources. This information can then be used to identify possible areas of improvement or further investigation.<br>• Irrigation data were collected by surveying 46 cotton irrigators located from Central Qld to Southern NSW. Water use indices, including Crop Water Use Index, Irrigation Water Use Index (IWUI) and Gross Production Water Use Index (GPWUI) were calculated. Industry average crop yield, total available water, crop evapotranspiration and on-farm water losses were also estimated.<br>• Survey results indicated that there was substantial scope for large improvements in on-farm water management on some cotton farms.<br>• The EnergyCalc Tool developed by the National Centre for Engineering in Agriculture (NCEA) and the iPad App, EnergyCalc Lite, were used to collate on-farm energy use information for Level 2 energy assessments and to calculate energy use efficiency benchmarks. Through demonstrations, information resources and video materials, the project also aimed to help irrigators keep more extensive records and conduct measurements to enable thorough assessments of on-farm energy use. The project included both whole farm (Level 2) and partial (e.g. irrigation only, Level 3) energy assessments.<br>• A Pump Efficiency Monitor (PEM) was developed by NCEA as part of this project and trialled on-farm at a commercial operation in Goondiwindi. The PEM continuously measures water flow rate, pressure head, engine and pump speed, and diesel consumption during a pumping event. These variables are used to examine pump performance to identify peak efficiency, maximum flow rate and any improvements required to reduce energy costs.<br>• The Goondiwindi property was used as a demonstration farm for on-farm energy use measurement and monitoring. In collaboration with commercial entities the project demonstrated different methods of collecting energy use data from pump sites.<br>• Twenty-six irrigation training events were delivered to 342 participants across the industry. Training was delivered through workshops, farm walks and technology demonstrations. Training covered modern irrigation technology such as Centre Pivot and Lateral Move (CP/LM) infrastructure, irrigation scheduling, irrigation system selection, water use efficiency and energy assessment. Evaluation of the workshops identified that attendees gained from increased knowledge. The standard of instruction was generally well received, although some areas were identified as needing improvement.<br>• An extensive communication strategy involving case studies, articles, videos and other means was implemented to disseminate information and resources to cotton irrigators.<br>• Project staff were involved in collaboration with a range of industry organisations including NCEA, CSIRO, government bodies, research organisations and grower groups. |
| Outcomes | • The benchmarks produced in this project have enabled comparison of individual enterprises against regional and industry averages, resulting in improved targets and focus for improvement. This information can also be used by research and |

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| | policy institutions to observe if, how and at what rate WUE improvements are occurring.<br>• Training and extension activities have increased industry understanding of the range of factors encompassing WUE, as well as a means for improving WUE. Specific focus areas for improvement include improved scheduling, application rates and infrastructure.<br>• Cotton growers now have greater capacity to make informed decisions regarding investments in irrigation infrastructure in order to achieve best practice.<br>• Increased industry knowledge combined with sustained extension activities are likely to increase water, energy and cost efficiency of irrigated cotton production.<br>• Following project completion, the Principal Investigator has continued in her role of providing extension and advisory services to the industry. This sustained extension effort is likely to contribute to increased industry awareness of energy efficiency issues.<br>• Development of relationships and increased collaboration between NSW DPI and NCEA will aid further research work.<br>• Grower surveys indicated a positive response to project extension activities, indicating a strong likelihood that practice changes are being adopted in the industry. |
| Impacts | • Increased cotton WUE through improved infrastructure investment choices and operational practices.<br>• Potential reduction in farm operating costs due to energy and labour savings.<br>• Potentially reduced greenhouse gas emissions due to improved energy efficiency.<br>• Increased industry extension and decision-making capacity. |

| **DAN1502: Optimising Water and Nitrogen Fertiliser Management in Cotton** | |
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| Project Details | Research Organisation: NSW DPI<br>Period: July 2014 to September 2015<br>Principal Investigator: Jonathan Baird |
| Rationale | The combination of increasing fertiliser expenditure alongside decreasing nitrogen use efficiency (NUE) has become an issue impacting profitability of the cotton industry. This is due in part to the emerging trend of growers applying increasing rates of nitrogen fertiliser in the belief that action is required in order to achieve high yields with the latest varieties. Further investigation was required to determine whether these inputs were in fact necessary, or if they were instead representing excessive compensation for poor NUE.<br><br>In addition to cost implications, poor NUE also has negative implications for water quality and soil health. Water management influences a number of processes central to NUE, including denitrification, volatilisation, and run-off/leaching processes. While the general existence of these relationships was well-known, there was a shortage of information with enough specificity to be useful in influencing management strategies. This project therefore sought to quantify the relationship between NUE and water use efficiency (WUE), thus enabling producers to better determine optimal application rates for the two inputs. |
| Objectives | 1. To investigate the impact of different irrigation and nitrogen management strategies on nitrogen uptake and nitrogen use efficiency.<br>2. To communicate results/findings to industry. |

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| | 3. To provide technical support to regional cotton development officers (Cotton Info Team) in the implementation of on-farm trials in the NSW Border Rivers, Gwydir and Namoi Valleys. |
| Activities and Outputs | • A literature review was conducted investigating the status of past and current research on nitrogen management in cotton production.<br>• A water and nitrogen experiment was established on a commercial farm within the Upper Namoi Valley. This experiment aimed to investigate the impacts of different irrigation deficits and nitrogen applications. The experiment was designed to track factors including soil water balances, plant growth/yield, nitrogen uptake and greenhouse gas emissions.<br>• Experimental data enabled project staff to calculate WUE, NUE and gross margins from the various treatments. A 'moderate' input strategy of 250 kg N/ha with a deficit of 70mm was found to result in highest WUE, NUE, yield and gross margins per hectare.<br>• Under the conditions of the experiment, there was no significant observed productivity benefit from increasing nitrogen applications to high (>250 kg/ha) levels.<br>• Trial results and input management strategies were presented at key industry forums, conferences and field days. Further extension was conducted via publications, articles and meetings with grower groups.<br>• Assistance was provided to regional cotton development officers in areas such as technical support, soil core analysis and calculation of soil mineral nitrogen. Assistance with the installation of soil water and water flow measurement equipment was also provided. |
| Outcomes | • Extension of project results has continued through various media in 2015/16.<br>• Research has continued in CRDC project FTRG1601, which aimed to validate the findings of this project as well as investigate the impact of different nitrogen fertiliser placement and irrigation management strategies on greenhouse gas emissions.<br>• By conducting trials and demonstrations on commercial farms rather than research stations, grower engagement in industry research and confidence in project results has been increased.<br>• Some growers now have greater awareness of the factors influencing water and nitrogen use efficiencies. This information can be used to improve input timings and quantities in order to reduce losses and maximise overall productivity and profitability. |
| Impacts | • Increase in the gross margin for adopting growers due to reduction in excessive nitrogen usage.<br>• Potential increase in WUE due to improved water/nitrogen balance.<br>• Potential reduction in off-farm impacts from nitrogen losses.<br>• Minor reduction in greenhouse gas emissions due to reduced nitrogen fertiliser application. |

| **DAQ1303: Optimising Water and Energy Use in the Central Queensland (CQ) Irrigation Sector** | |
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| Project Details | Research Organisation: QLD Department of Agriculture, Fisheries & Forestry<br>Period: July 2012 to June 2013<br>Principal Investigator: Lance Pendergast |
| Rationale | Pumping costs typically constitute a major component of irrigation system energy use. Due to recent increases in energy costs, pumping now represents a major cost in most irrigated cotton production systems. This rise in energy costs, combined with growing public concerns over greenhouse gas emissions, has greatly increased the demand for research to deliver improvements in on-farm energy efficiency. |

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| | A second area of rising cost is the monitoring and operating of irrigation systems. Traditional methods are typically labour-intensive and inconvenient for the grower. The need for change in this area has become apparent with skilled farm labour becoming increasingly difficult to source and retain.<br><br>Automated irrigation infrastructure presents a possible solution to the issues of energy and labour costs. The greater monitoring capability of automated systems has the potential to enhance irrigators' ability to identify optimum irrigation techniques, and to adopt emerging methods such as dynamic deficit and Biologically Identified Optimal Temperature Interactive Console (BIOTIC) scheduling. However, automated systems typically have significant installation costs, and may have greater energy requirements in some instances.<br><br>The extreme variability of the Central Queensland climate poses an additional challenge to producers striving to optimise yields and water use efficiency (WUE). To address these issues there was a need to gather reliable information on the energy efficiency of traditional and automated systems, to develop and evaluate automated systems, and to increase the capacity of irrigators to identify the most efficient irrigation methods for their operations. |
| Objectives | 1. To establish an advisory committee.<br>2. To develop techniques to automate furrow irrigation.<br>3. To ascertain and promote pumping system energy benchmarks.<br>4. To evaluate performance of overhead irrigation systems and publish results.<br>5. To provide support to the Fitzroy Basin Association.<br>6. To provide advice to irrigators concerning water use and energy efficiencies.<br>7. To ensure interaction with the local irrigator group, the Central Highlands Cotton Growers & Irrigators Association (CHCG&IA).<br>8. To provide technical advice to the Cotton D&D team. |
| Activities and Outputs | • An advisory committee was established with members of the CHCG&IA. This committee was used to keep growers informed with project activities throughout its duration.<br>• On-farm trialling of automation technology was conducted to support another CRDC-funded project, 'Sensor technology to enable full automation of irrigation'. Trials in this latter project focussed on verifying the performance of the AutoSISCO scheduling system in furrow irrigation, and investigating sensor placement. These investigations provided data on the optimum downfield position of advance/depth sensors.<br>• The project completed six pump system evaluations intended to assist growers with improving their production efficiencies and provided data to facilitate benchmarking of energy use. These evaluations have formed the basis for a range of presentations addressing their value for assisting in efforts to reduce energy costs. Results from these evaluations were provided to individual growers and entered to the Irrigation Pump Evaluation and Reporting Tool data base.<br>• Evaluation of overhead irrigation systems was conducted on six centre pivot systems. Of these systems three were identified as operating below their design pressure while one was above. The performance of the two remaining systems was rated as excellent.<br>• Results of the evaluations have been integrated into the database of the National Centre for Engineering in Agriculture (NCEA.)<br>• Assistance and technical advice was provided to the Fitzroy Basin Association. This work focussed on promoting uptake of the myBMP (Best Management Practice) program, as well as providing general advice on new developments in irrigation infrastructure. |

| | |
|---|---|
| | • Extension activities were undertaken to promote efficient irrigation water and energy use. These included regular presentations at local irrigator association meetings, presentations at conferences and via media, representation by project staff on special interest groups, and assistance with revision of both the myBMP system and WATERpak irrigation management guidelines.<br>• The project proposal and progress updates were submitted and discussed at the general CHCG&IA members' meetings. This provided researchers with an avenue for disseminating information, requesting assistance and demonstrating commitment to growers. |
| Outcomes | • Performance evaluations conducted by the project of both overhead system and pumping system performance have expanded the resource base critical to the development and promotion of water and energy use efficiency benchmarking industry wide. Inclusion of these results provided additional data sets to those already recorded in NCEA databases.<br>• Findings from this project have been incorporated into the WATERpak guidelines and were introduced into technical revisions of the myBMP guidelines (Lance Pendergast, pers. comm., 2016).<br>• Increased evidence for benefits of irrigation energy efficiency evaluations and automated furrow irrigation will lead to a stronger case for adoption of these systems.<br>• Project work was continued in the three year, CRDC-funded project DAQ1404. This subsequent project was centred on three areas: continuation of furrow automation trialling, dynamic deficits, and a derivative of BIOTIC scheduling using thermal imagery of canopy temperature. The goal of the project was to conduct field trials validating findings from other research in order to determine their potential for adoption specifically in the CQ region.<br>• The ease of use of automation aids inexperienced growers in achieving high water-use efficiencies substantially faster than trial-and-error with traditional approaches. (Lance Pendergast, pers. comm., 2016).<br>• With most Australian cotton growers using furrow irrigation, automation of existing furrow infrastructure provides a cheaper means of achieving efficiency gains than adoption of alternative systems, such as CP/LM or flood irrigation, which may require extensive earthworks and machinery purchases.<br>• Benchmarking findings can be used to improve energy efficiency - where a pump system is identified as performing outside its optimum range, operators are better equipped to make performance analyses and identify cost effective options for improvement.<br>• Results of the performance evaluations have provided valuable assistance in identifying the source of problems related to energy use and therefore equip the grower with information that can be used to rectify issues of poor performance.<br>• Discussion with growers subsequent to each evaluation provided the individual operators with additional information to assist in efforts directed towards achieving improved water & energy use efficiencies. Gains in both aspects typically translate to enhanced profitability of their enterprise.<br>• The outputs of performance evaluations such as increased efficiency gains have been utilised to promote benefits and have stimulated uptake of these efficiency evaluations, both within the CQ irrigation community, and to the broader cotton industry.<br>• Aside from the provision of specific activities (e.g. trialling, pump and centre-pivot evaluations) the project continued to fulfil the role as a general contact point in relation to water and energy use issues. This included providing advice within and beyond the CQ region including to state and federal government agencies. |

| | |
|---|---|
| | • The provision of case studies has facilitated efforts to improve both water use and energy use efficiencies of cotton production systems throughout the industry. |
| Impacts | • Increased water use efficiency due to increased adoption of automated irrigation infrastructure and enhanced scheduling methods.<br>• Potential reduction in on-farm energy costs due to enhanced pumping efficiency.<br>• Potential cost reduction in farm labour costs due to adoption of automated systems.<br>• Potential reduction in greenhouse gas emissions due to increased energy efficiency.<br>• Potential increase in farmer quality of life due to reduced requirement to conduct inconvenient manual irrigation adjustments. |
| **US1503: Water Use Efficiency, Gross Margin, Yield and Quality of 1m and 1.5m Row Irrigated Cotton** | |
| Project Details | Research Organisation: University of Sydney<br>Period: November 2014 – May 2015<br>Principal Investigator: Daniel Tan (supervisor), Timothy Bartimote (student) |
| Rationale | Row spacing is an important agronomic concern in large-scale cropping enterprises with implications for field layout, machinery, and overall productivity. Selection of row spacing necessitates a trade-off between maximising the number of plants, against minimising inter-plant competition for access to sunlight, water and soil nutrients. Standard row spacing in the Australian cotton industry is 1m, and the majority of machinery, cultivars and practices are based around this row spacing.<br><br>Increasing competition for water resources has led to water, rather than land, often being the limiting factor for production of irrigated cotton Producers therefore may elect to increase row spacing to exchange reduced production per unit of land for increased production per unit of water.<br><br>The above can be achieved either by skipping one or more plant rows at a fixed interval in a 'skip row' configuration, or by increasing the spacing between rows. Single-skip (where every third row is skipped) is commonly used in the industry, however such a setup precludes the use of controlled traffic farming (CTF). A 1.5m row spacing produces the same number of plants per hectare while also enabling growers to utilise CTF and so benefit from reduced soil compaction.<br><br>The CRDC Summer and Honours Scholarship program aims to "provide students with an opportunity to work on a real project in a working environment as part of their professional development". The scholarships enable university students to conduct short research, extension or industry projects under the direct supervision of a researcher or extension officer from either the public or private sector (CRDC, 2016a).<br><br>With row spacing being an area of ongoing interest in the industry, this project was funded as a scholarship grant, with the dual purposes of providing a comparison between conventional and wide row cotton systems, while also supporting the development of new cotton research capacity. |
| Objectives | 1. To compare water use efficiency (bales/ML) between wide row (1.5 m) and conventional (1.0 m) cotton systems. Particularly with the use of "green" water such as rainfall and deep soil moisture.<br>2. To conduct a detailed gross margin and economic analysis.<br>3. To investigate if there is a difference in yield and fibre quality between conventional and wide row cotton systems. |

| | |
|---|---|
| Activities and Outputs | • A replicated plot experiment was established at Auscott at Warren to compare 1.5m row spacing and conventional 1m spacing systems.<br>• The experiment considered the following key variables: water inputs/losses, cotton yield, fibre quality, profitability/gross margin, and differences due to changes in machine traffic footprint.<br>• The result of the experiment was that 1.5m cotton rows produced more bales/ML while 1m cotton rows produced more bales/ha, however the latter required an increase in inputs. Fibre quality was slightly higher in the 1.5m row spacing.<br>• Gross margin analysis was conducted based on the experimental results. 1.5m cotton was found to produce a gross margin almost $200/ha higher than 1m rows. This was attributable to cost of production savings for the 1.5m cotton outweighing higher yield/ha for the 1.0m cotton. Areas of significant cost savings included seed, fertiliser, and water.<br>• The activities conducted in this project form the basis of a student's honours thesis, submitted in 2015. |
| Outcomes | • The results of this study lend support to the proposition that a 1.5m row spacing could be a superior choice to conventional 1m spacing in certain limited-water environments.<br>• Further research is needed to examine the impact of row spacing in a range of cotton growing regions and irrigation scenarios. If this occurs, growers will be better able to assess the potential merits of adopting a wider row spacing in their operations.<br>• Findings were presented by the scholarship recipient at the Australian Cotton Research Conference in September 2015. The project supervisor presented findings at the 2016 World Cotton Research Conference in Brazil (Daniel Tan, pers. comm., 2016).<br>• Discussions with growers have suggested that an increasing number are incorporating 1.5m spacing in their operations (Daniel Tan, pers. comm., 2016). |
| Impacts | • Increased industry capacity due to development of skilled research personnel.<br>• Increase in cotton grower profitability due to adoption of wider row spacing leading to greater returns per unit of water applied and encouragement of wider use of CTF. |

# 4. Project Investment

## The Investment

The following tables show the annual investment by project for both CRDC (Table 3) and for researchers and any other investors (Table 4). Table 5 provides the total investment by year from both sources.

Table 3: Investment by CRDC for Years Ending June 2011 to June 2015 (nominal $)

| Project ID | 2011 | 2012 | 2013 | 2014 | 2015 | Total |
|---|---|---|---|---|---|---|
| CLW1102 | 41,055 | 0 | 0 | 0 | 0 | 41,055 |
| CSP1305 | 0 | 0 | 325,973 | 333,408 | 344,914 | 1,004,295 |
| DAN1205 | 0 | 225,241 | 462,509 | 537,793 | 0 | 1,225,543 |
| DAN1502 | 0 | 0 | 0 | 0 | 113,442 | 113,442 |
| DAQ1303 | 0 | 0 | 153,327 | 0 | 0 | 153,327 |
| US1503 | 0 | 0 | 0 | 0 | 5,000 | 5,000 |
| **Totals** | 41,055 | 225,241 | 941,809 | 871,201 | 463,356 | 2,542,662 |

Table 4: Investment by Researchers and Others for Years Ending June 2011 to June 2015 (nominal $)

| Project ID | 2011 | 2012 | 2013 | 2014 | 2015 | Total |
|---|---|---|---|---|---|---|
| CLW1102 | 63,933 | 0 | 0 | 0 | 0 | 63,933 |
| CSP1305 | 0 | 0 | 241,709 | 247,580 | 256,112 | 745,401 |
| DAN1205 | 0 | 129,209 | 239,187 | 316,080 | 0 | 684,476 |
| DAN1502 | 0 | 0 | 0 | 0 | 105,612 | 105,612 |
| DAQ1303 | 0 | 0 | 216,256 | 0 | 0 | 216,256 |
| US1503 | 0 | 0 | 0 | 0 | 0 | 3,576 (a) |
| **Totals** | 63,933 | 129,209 | 697,152 | 563,660 | 361,724 | 1,819,254 |

(a) Imputed from ratio of other to CRDC for all other five projects

Table 5: Total Annual Investment by Year (nominal $)

| Year ending June | CRDC | Researchers and Others | Total |
|---|---|---|---|
| 2011 | 41,055 | 63,933 | 104,988 |
| 2012 | 225,241 | 129,209 | 354,450 |
| 2013 | 941,809 | 697,152 | 1,638,961 |
| 2014 | 871,201 | 563,660 | 1,434,861 |
| 2015 | 463,356 | 365,300 | 828,656 |
| **Total** | **2,542,662** | **1,819,254** | **4,361,916** |

**Program Management and Extension Costs**
The average cost of managing the WUE projects was added to the total project costs via a management cost multiplier (1.14:1); this was estimated based on the reported share of ‘employee benefits’ & ‘supplier’ expenses in total CRDC expenditure (CRDC, 2015). No additional costs of extension were included as most projects were either extension-focussed or already included an extension component.

# 5. Impacts

The principal potential impacts for the WUE project cluster were assembled from the logical frameworks developed for the individual projects. In addition, several general impacts applicable to all six projects were identified. Table 6 summarises the key potential impacts identified and signifies whether a contribution was made to each potential impact by each of the six projects.

Table 6: Contribution by Project to Principal WUE Cluster Impacts

| **Project Code** | **Increased water use efficiency** | **Improved N use efficiency** | **Potential increase in profits due to energy and/or labour savings** | **Reduced off-farm impacts from nutrient losses to terrestrial and aquatic areas** | **Reduced GHG emissions to environment** | **Increased scientific research & industry capacity** | **Lifestyle benefits from changed labour requirements** | **Regional community spillovers** |
|---|---|---|---|---|---|---|---|---|
| CLW1102 | ✓ | ✓ | | ✓ | | ✓ | | ✓ |
| CSP1305 | ✓ | | | | | ✓ | | ✓ |
| DAN1205 | ✓ | | ✓ | | ✓ | ✓ | | ✓ |
| DAN1502 | ✓ | ✓ | | ✓ | ✓ | | | ✓ |
| DAQ1303 | ✓ | | ✓ | | ✓ | | ✓ | ✓ |
| US1503 | ✓ | | ✓ | | | ✓ | | ✓ |

From Table 6, the potential impacts then were condensed and described in a triple bottom line context. Table 7 provides a summary of the principal types of impacts associated with economic, environmental and social categories.

Table 7: Triple Bottom Line Categories of Principal Impacts from the WUE Cluster Investment

| | |
|---|---|
| Economic | • Increased water use efficiency contributing to higher productivity and profitability.<br>• Increased nitrogen use efficiency contributing to higher productivity and profitability.<br>• Potential increase in profits due to energy and/or labour savings. |
| Environmental | • Reduced nutrient losses to environment contributing to increased water quality off-farm.<br>• Reduced greenhouse gas emissions. |
| Social | • Increased scientific research and industry capacity.<br>• Lifestyle benefits for growers from changed labour requirements.<br>• Increased community well-being through the spill-over effects of increased farm productivity and profitability. |

### Public versus Private Benefits

Most benefits identified in this evaluation are cotton industry related and therefore are considered private benefits. Some public benefits also have been delivered, including minor environmental benefits and social benefits.

Some direct environmental and social impacts were reported in Tables 6 and 7; for example, lifestyle benefits for cotton growers. Some indirect social benefits were delivered also, including increased community incomes, often the result of spillovers from increased/maintained cotton industry incomes.

### Distribution of Impacts along the Supply Chain

Most impacts are concentrated at farm/producer level. Some benefits and costs will likely be passed along the input and output supply chains in proportion to the elasticities of supply and demand at different stages along the chain.

### Impacts on other Industries

Some project outputs are not specific to cotton and could be applied to other industries. Greater understanding of deep drainage processes is relevant to various other crop industries, particularly those reliant on irrigation.

### Impacts Overseas

Overseas benefits are not expected to be significant, as most research outputs apply to Australian cotton production at the producer level.

### Match with National Priorities

The Australian Government's Science and Research Priorities and Rural RD&E priorities are reproduced in Table 8. The cluster contributes primarily to Rural RD&E priorities 3 and 4, and to Science and Research priority 2 with some minor contributions to priorities 5 and 7.

Table 8: Australian Government Research Priorities

| **Australian Government** | |
|---|---|
| **Rural RD&E Priorities (est. 2015)** | **Science and Research Priorities (est. 2015)** |
| 1. Advanced technology<br>2. Biosecurity<br>3. Soil, water and managing natural resources<br>4. Adoption of R&D | 1. Food<br>2. Soil and Water<br>3. Transport<br>4. Cybersecurity<br>5. Energy and Resources<br>6. Manufacturing<br>7. Environmental Change<br>8. Health |

Sources: DAWR (2015) and OCS (2016)

# 6. Valuation of Impacts

## Impacts Valued

Analyses were undertaken for total benefits that included future expected benefits. A degree of conservatism was used when finalising assumptions, particularly when a high degree of uncertainty was involved. Sensitivity analyses were undertaken for those variables where there was greatest uncertainty or for those that were identified as key drivers of the investment criteria.

Two of the impacts identified in Table 7 were valued. All six projects in the population were identified as contributing to one or more of the two impacts valued in the analysis. The two benefits were:

- Benefit 1: Increased Water Use Efficiency
- Benefit 2: Increased Nitrogen Use Efficiency

## Impacts Not Valued

Not all impacts identified in Table 7 could be valued in the assessment. This was for various reasons including time and resources, availability of baseline data, quantifying the causal relationships between the research outputs and their specific impact, and the difficulty of placing credible monetary values on some of the environmental and social benefits.

The economic impacts identified but not valued included:

- Potentially increased profits due to energy and/or labour savings.

The environmental impacts identified but not valued include:

- Reduced nutrient exports off farm potentially contributing to improved water quality.
- Reduced greenhouse gas emissions.

The social impacts identified but not valued include:

- Increased scientific and research capacity.
- Increased community well-being through the spill-over effects of increased farm productivity and profitability.
- Lifestyle benefits for growers adopting labour-saving technologies.

### Valuation of Benefit 1: Increased Water Use Efficiency

*Valuing WUE gains*

Water use efficiency can be measured by several indices, with the Irrigation Water Use Efficiency Index (IWUI), and the Gross Production Water Use Index (GPWUI) two prominent measures (CRDC, 2012). IWUI measures yield against irrigation water applied, producing a figure in bales/megalitre of water applied. While the figure is relatively simple to calculate, it can vary substantially in response to changes in irrigation water application which in turn varies with seasonal rainfall. GPWUI accounts for total water (irrigation, residual soil moisture and rainfall) available to the crop. GPWUI therefore provides a more comprehensive measure, however its theoretically superior accuracy cannot be achieved if accurate data on rainfall and soil moisture are not available.

Obtaining an estimate of the total water available to the crop over time is difficult, whereas substantial data exists regarding irrigation applications. For this reason, the current analysis used increased IWUI as a means for measuring increases in WUE, with a conservative IWUI estimate to account for annual variability in the volume of irrigation water applied relative to other water sources.

The WUE gains attributable to this cluster have been achieved through numerous pathways. For purpose of this analysis, these pathways have been broken down into three broad categories as presented in Table 9.

Table 9: Categorisation of WUE Gains

| Category | Mechanisms | Upfront costs | Ongoing costs | WUE gains |
|---|---|---|---|---|
| **Practice change** | Improved scheduling regimes, improved monitoring | Low | Low | Relatively low |
| **Automation** | Automation of existing furrow irrigation infrastructure | Moderate | Low | Moderate, particularly for inexperienced growers |
| **New irrigation systems** | Adoption of CP/LM infrastructure | High | Moderate-high | Moderate-high |

Based on this initial categorisation, estimates were made for the costs and benefits specific to each category of WUE gains. Estimates were based on industry publications and discussions with research personnel. It should be noted these gains are considered as averages for those adopting – those growers already achieving high WUE are unlikely to be among those adopting.

Costs were considered via two categories: initial (capital and installation) and ongoing (operating and maintenance). Initial costs refer to areas such as purchase/modification of machinery and installation of monitoring/automation systems. Ongoing costs were difficult to quantify; for example, new technologies which lead to labour savings and efficiency gains also may have increased maintenance and energy costs. In the case of automation, it has been assumed that labour savings will be offset by increased maintenance costs. Estimation of these costs was based on a cost per hectare rather than per ML of water saved. Changes assigned to the research projects are provided in Table 10.

Table 10: Changes in Costs and Efficiency Gains for WUE Categories

| Category | Upfront costs ($/ha) | Ongoing costs ($/ha) | WUE gains | Source |
|---|---|---|---|---|
| **Practice Change** | 0 | 25 | 3% | Agtrans Research & Janelle Montgomery |
| **Automation** | 500 | 0 | 7.5% | Agtrans Research & Lance Pendergast |
| **New irrigation systems** | 3,500 | 250 | 20% | Agtrans Research, Janelle Montgomery & private irrigation consultants |

Adoption of practice changes is expected to occur more rapidly than changes involving infrastructure investment. Also, some of the WUE findings from the research investment are applicable to the entire industry, while others were focused on specific industry sectors. Adoption for practice changes was assumed to be relatively high as historically the cotton industry has shown a high degree of capacity and willingness to adopt new technologies (CRDC & Cotton Australia, 2014). Assumptions for adoption are provided in Table 11.

Table 11: Adoption Estimates for WUE Improvements

| Category | Year of first adoption | Year of maximum adoption | Maximum adoption | Source |
|---|---|---|---|---|
| **Practice Change** | 2015 | 2018 | 20% of irrigation by volume | Agtrans Research after discussions with Janelle Montgomery |
| **Automation** | 2017 | 2022 | 5% (of 90% of industry already using furrow irrigation) | Agtrans Research after discussions with Lance Pendergast |
| **New irrigation systems** | 2017 | 2022 | 5% (of 90% of industry) | Agtrans Research after discussions with Janelle Montgomery & private irrigation consultants |

*Attribution*
The research findings, practice improvements and extension activities in these six projects have not occurred in isolation. In many cases, they represent a continuation of previous research activities by building on previous findings, or by continuing established extension programs. Also, the realisation of the impacts assumed will likely require some additional extension effort to ensure continued adoption in the future. Gaining a definitive estimate of these specific costs is difficult, therefore a general attribution factor of 50% has been applied to the impacts valued to allow for other contributing factors.

## Valuation of Benefit 2: Increased Nitrogen Use Efficiency

Management of nitrogen (N) inputs is a key component of profitability in broad-acre cropping. A common issue is that of excessive application, where nitrogen is applied at levels where the costs of additional N may be well greater than the marginal yield benefits. This inefficient practice typically results from inadequate understanding of the specific nitrogen requirements for a particular crop, or the application of additional N as 'insurance' against low yields.

*Valuing Nitrogen Savings*
The primary economic benefit delivered by these projects is a reduction in nitrogen use above optimal levels. Prior to project DAN1502 it was suggested that a substantial number of cotton growers were using in excess of 250 kg/ha. It has been estimated that due to the findings of projects including DAN1502, adopting growers will reduce their nitrogen applications by an average of 20 kg/ha. This saving has been valued at $1.35/kg of N, based on a urea price of $620/tonne and 46% N content (Impact Fertilisers, 2016).

*Adoption*
It was reported that in 2012 45% of cotton growers were applying nitrogen in excess of 250 kg/ha (CRDC, 2014). In valuing the reduced N benefit it has been assumed that 25% of these growers will achieve significant N use reductions due to the projects contributing to this benefit. For this evaluation, maximum adoption has been estimated to be achieved by 2020, with first adoption occurring in 2017.

*Attribution*
Two projects from this cluster have been assessed as contributing to this benefit – CLW1102 and DAN1502. DAN1502 was continued directly in project FTRG1601, and several other CRDC-funded projects were also investigating N usage around this time. These additional projects have been considered as a necessary step on the pathway to impact assumed, therefore an attribution factor has been applied based on the share of DAN1502 & CLW1102 in the total costs of all N projects identified. There were five additional projects considered in valuing this benefit.

The five additional projects considered when determining attribution were:

- CGA1405 - Understanding Soils and Plant Nutrition for Cotton Growers
- CRC139 - Nutrient Redistribution Within Cotton Plants
- CRC1115 - Developing N-efficient Cotton Systems that Produce Low GHG Emissions and Promote Healthy Soil
- CRC1117 - Understanding Greenhouse Gas Emission from Broadacre Irrigated Cropping Systems
- FTRG1601 - Identifying Practical Solutions to Optimising Nitrogen Use Efficiency (NUE) and Water Use Efficiency (WUE) in Cotton Production

Projects DAN1502 & CLW1102 invested $0.324 m or 15% of the combined investment in the seven projects ($2.2m), therefore an attribution factor of 15% has been applied to the benefit valued in the current evaluation. The five additional N projects are evaluated in an Agtrans Research impact assessment of CRDC nutrition RD&E investment.

### Counterfactual

It is likely some improvements in water and nitrogen use efficiency would have occurred in the absence of investment in this project cluster. These improvements have been captured through the use of attribution factors for each benefit as previously described.

### Summary of Assumptions

A summary of the key assumptions made for valuation of the impacts is shown in Table 12.

Table 12: Summary of Assumptions

| Variable | Assumption | Source |
|---|---|---|
| ***Benefit 1: Water Use Efficiency*** | | |
| *General Assumptions* | | |
| Base IWUI | 1.1 bales/ML | Conservative estimate based on CRDC (2012) |
| Value of additional output | $350/bale | Conservative estimate based on Cotton Australia (2016) and allowing for quality discounts |
| Cost of harvesting and transporting additional output | $30/bale | Conservative estimate based on Boyce (2015) |
| Industry applicable area – irrigated cotton | 306,684 ha | ABS (2011-2016a), average of years 2011, 2013, 2014 & 2015 |
| Total water usage by irrigated cotton | 2,157,200 ML/annum | ABS (2011-2015b) average |
| Attribution to cluster | 50% | Agtrans Research |
| *Specific Assumptions* | | |
| WUE gains attributable to different impact categories | See Table 10 | Agtrans Research after discussions with research and industry personnel |
| Timing and proportion of industry adopting WUE-increasing measures | See Table 11 | |
| ***Benefit 2: Nitrogen Use Efficiency*** | | |
| Value of elemental N | $1.35/kg | Based on urea price of $620/tonne @ 46% N (Impact Fertilisers, 2016) |
| Nitrogen saving | 20 kg/ha | Agtrans Research based on final report of project DAN1502 |
| Growers using excessive N | 45% of 307,000 ha | CRDC, 2014 |
| Growers adopting N reductions | 25% | Agtrans Research after discussions with research personnel |

| | | |
|---|---|---|
| Year of first adoption | 2017 | Agtrans Research, based on completion of project FTRG1601 in 2016 |
| Year of maximum adoption | 2020 | Agtrans Research |
| Attribution to WUE cluster | 15% | DAN1502 & CLW1102 share of total investment in N research considered |

# 7. Results

All past costs and benefits were expressed in 2015/16 dollar terms using the Implicit Price Deflator for GDP. The CRDC components of project investment costs were all multiplied by a factor of 1.13 to accommodate program management costs (CRDC, 2015). All benefits after 2015/16 were expressed in 2015/16 dollar terms. All costs and benefits were discounted to 2015/16 using a discount rate of 5%. A reinvestment rate of 5% was used for estimating the MIRR. The base analysis used the best available estimates for each variable, notwithstanding a level of uncertainty for many of the estimates. All analyses ran for the length of the investment period plus 30 years from the last year of investment (2014/15) to the final year of benefits assumed.

### Investment Criteria

Tables 13 and 14 show the investment criteria estimated for different periods of benefits for both the total investment and for the CRDC investment respectively. The present value of benefits (PVB) attributable to CRDC investment only, shown in Table 14, has been estimated by multiplying the total PVB ($32.12 million) by the CRDC proportion of nominal investment (58.3%).

Table 13: Investment Criteria for Total Investment in the Six Projects
(Discount rate 5%, Re-investment rate 5%)

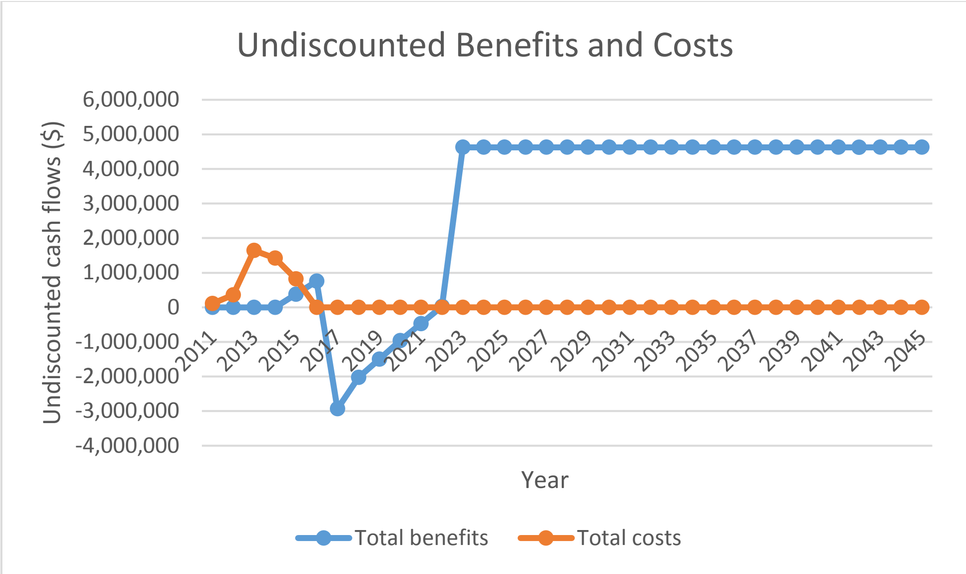
| **Investment criteria** | **Number of years from year of last investment** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **0** | **5** | **10** | **15** | **20** | **25** | **30** |
| Present value of benefits ($m) | 0.40 | -5.57 | 3.47 | 16.38 | 26.49 | 34.41 | 40.62 |
| Present value of costs ($m) | 4.90 | 4.90 | 4.90 | 4.90 | 4.90 | 4.90 | 4.90 |
| Net present value ($m) | -4.50 | -10.47 | -1.43 | 11.48 | 21.59 | 29.51 | 35.72 |
| Benefit-cost ratio | 0.08 | -1.14 | 0.71 | 3.34 | 5.40 | 7.02 | 8.29 |
| Internal rate of return (IRR) (%) | negative | negative | 3.1 | 12.9 | 15.3 | 16.2 | 16.5 |
| Modified IRR (%) | negative | negative | 3.6 | 9.9 | 10.7 | 10.5 | 10.0 |

Table 14: Investment Criteria for CRDC Investment in the Six Projects
(Discount rate 5%, Reinvestment rate 5%)

| **Investment criteria** | **Number of years from year of last investment** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **0** | **5** | **10** | **15** | **20** | **25** | **30** |
| Present value of benefits ($m) | 0.23 | -3.25 | 2.02 | 9.54 | 15.44 | 20.05 | 23.67 |
| Present value of costs ($m) | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 |
| Net present value ($m) | -2.62 | -6.10 | -0.83 | 6.69 | 12.58 | 17.20 | 20.82 |
| Benefit-cost ratio | 0.08 | -1.14 | 0.71 | 3.34 | 5.41 | 7.02 | 8.29 |
| Internal rate of return (IRR) (%) | negative | negative | 2.3 | 12.1 | 14.6 | 15.5 | 15.8 |
| Modified IRR (%) | negative | negative | 2.4 | 9.1 | 10.0 | 9.9 | 9.6 |

The annual undiscounted benefit and cost cash flows for the total investment for the duration of investment period plus 30 years from the last year of investment are shown in Figure 1.

Figure 1: Annual Cash Flow of Total Benefits and Total Costs in the Project Cluster




## Sources of Benefits

Given the assumptions made, the benefits from the WUE gains contributed higher levels (95%) of total discounted benefits than the projects addressing nitrogen (5% of total benefits). For the WUE projects, all three categories of efficiency gains contributed. Estimates of the relative contributions, given the assumptions made and after application of attribution factors, are shown in Table 15.

Table 15: Contribution to WUE Benefits from Each Source

| Source of WUE Benefits | Contribution to PVB ($m) | Share of WUE benefits (%) |
|---|---|---|
| Practice Change | 23.7 | 61.2 |
| Automation | 13.6 | 35.2 |
| New irrigation systems | 1.4 | 3.6 |
| Total | 38.7 | 100% |

## Sensitivity Analyses

A sensitivity analysis was carried out on the discount rate. The analysis was performed for the total investment and with benefits taken over the life of the investment plus 30 years from the last year of investment. All other parameters were held at their base values. Table 16 presents the results. The results showed a high sensitivity to the discount rate.

Table 16: Sensitivity to Discount Rate
(Total investment, 30 years)

| **Investment Criteria** | **Discount rate** | | |
|---|---|---|---|
| | **0%** | **5% (base)** | **10%** |
| Present value of benefits ($m) | 99.62 | 40.62 | 17.95 |
| Present value of costs ($m) | 4.35 | 4.90 | 5.50 |
| Net present value ($m) | 95.27 | 35.72 | 12.44 |
| Benefit-cost ratio | 22.90 | 8.29 | 3.26 |

Further sensitivity analyses were conducted on the key variables of adoption levels and WUE impact levels (Tables 17 and 18).

Table 17: Sensitivity to Change in Adoption Rates for Both Benefits
(Total investment, 30 years, 5% discount rate)

| **Investment Criteria** | **Adoption rate % (practice change, automation, CP/LM, nitrogen reduction)** | | |
|---|---|---|---|
| | **10, 2.5, 2.5, 12.5 (worst case)** | **20, 5, 5, 25 (base)** | **30, 10, 10, 50 (best case)** |
| Present value of benefits ($m) | 20.31 | 40.62 | 69.40 |
| Present value of costs ($m) | 4.90 | 4.90 | 4.90 |
| Net present value ($m) | 15.41 | 35.72 | 64.50 |
| Benefit-cost ratio | 4.14 | 8.29 | 14.16 |

Table 18: Sensitivity to WUE Improvements
(Total investment, 30 years, 5% discount rate)

| **Investment Criteria** | **WUE % improvement increase (practice change, automation, CP/LM), %** | | |
|---|---|---|---|
| | **2, 5, 15 (worst case)** | **3, 7.5, 20 (base)** | **6, 15, 30 (best case)** |
| Present value of benefits ($m) | 12.19 | 40.62 | 114.89 |
| Present value of costs ($m) | 4.90 | 4.90 | 4.90 |
| Net present value ($m) | 7.29 | 35.72 | 109.99 |
| Benefit-cost ratio | 2.49 | 8.29 | 23.44 |

## Confidence Ratings and other Findings

The results produced are highly dependent on the assumptions made, many of which are uncertain. There are two factors that warrant recognition. The first factor is the coverage of benefits. Where there are multiple types of benefits it is often not possible to quantify all the benefits that may be linked to the investment. The second factor involves uncertainty regarding the assumptions made, including the linkage between the research and the assumed outcomes.

A confidence rating based on these two factors has been given to the results of the investment analysis (Table 19). The rating categories used are High, Medium and Low, where:

High: denotes a good coverage of benefits or reasonable confidence in the assumptions made

Medium: denotes only a reasonable coverage of benefits or some uncertainties in assumptions made

Low: denotes a poor coverage of benefits or many uncertainties in assumptions made

Table 19: Confidence in Analysis of Cluster

| Coverage of Benefits | Confidence in Assumptions |
|---|---|
| Medium-high | Medium |

Coverage of benefits was assessed as medium-high as most benefits were economic in nature relating to increased efficiency of input use and were readily identified by researchers and others. While some impacts were not valued, these were subjectively assessed as being minor relative to those valued.

Confidence in assumptions was rated as medium. While validation of most assumptions was provided subjectively by industry and research personnel, some uncertainty remains regarding the specific levels of impacts captured and associated adoption levels.

The assumptions that have been made for valuing the benefits from these investments are potentially conservative. The principal reason for this was a lack of written evidence available regarding current adoption by the cotton industry of practice changes that may have been driven by the investments and the average and range of the value to growers for making such changes. In this regard, it is suggested that CRDC further develops its capacity to monitor, report and/or assess impacts and adoption from individual or grouped project investments. This can be aided via such mechanisms as assembling feedback from growers at industry events, consultant and agronomist surveys, and specific case studies that could be included in final project reports.

# Conclusions

Funding for the six projects in the cluster totalled \$4.90 million (present value terms) and produced aggregate total expected benefits of \$40.62 million (present value terms). This gave a net present value of \$35.72 million, a benefit-cost ratio of 8.29 to 1, an internal rate of return of 16.5% and a modified internal rate of return of 10.0%.

# References

ABS 2011-2016a, *Agricultural Commodities, Australia–2014-15,* Australian Bureau of Statistics, Canberra

ABS 2011b-2015b, *Water Use of Australian Farms 2014-15,* Australian Bureau of Statistics, Canberra

Cotton Australia 2016, *Economics of Cotton in Australia,* Cotton Australia, Accessed 17 Aug 16, http://cottonaustralia.com.au/cotton-library/fact-sheets/cotton-fact-file-the-economics-of-cotton-in-australia

CRDC 2012, WATERpak – *a guide for irrigation management in cotton and grain farms,* Cotton Research and Development Corporation, Narrabri, NSW

CRDC 2014, *DAN1502 Full Research Proposal*, Cotton Research and Development Corporation, Narrabri, NSW

CRDC 2015, *CRDC Annual Report 2014-15,* Cotton Research and Development Corporation, Narrabri, NSW

CRDC 2016a, *Scholarships,* Cotton Research and Development Corporation, Accessed 23 Aug 16, http://www.crdc.com.au/scholarships

Boyce 2015, *Australian Cotton Comparative Analysis,* Cotton Research and Development Corporation & Boyce Chartered Accountants, NSW

CRDC & Cotton Australia 2014, *Australian Grown Cotton Sustainability Report,* Guy Roth – Roth Rural and Regional Pty Ltd, Narrabri

CRRDC 2014, *Impact Assessment Guidelines – Version 1, May 2014*, CRRDC, Canberra

DAWR 2015, *Rural Research and Development Priorities*, Department of Agriculture and Water Resources, Canberra, ACT, accessed January 2016, http://www.agriculture.gov.au/ag-farm-food/innovation/priorities

Impact Fertilisers 2016, *Urea*, Impact Fertilisers, accessed 21 April 16, http://www.impactfertilisers.com.au/products/nitrogen/urea/ & personal communication

OCS 2016, *Science and Research Priorities,* Office of the Chief Scientist, Department of Industry, Innovation and Science, Canberra, accessed 02 Nov 16, http://science.gov.au/scienceGov/ScienceAndResearchPriorities/Pages/default.aspx