If you are participating in the presentations this year, please provide a written report and a copy of your final report presentation by 31 October. If not, please provide a written report by 30 September.

Part 1 - Summary Details

Please use your TAB key to complete Parts 1 & 2.

Cotton CRC Project Number: CCC CRC 5.3.03 (CRDC ref: CRC63)

Project Title: Delivering Science to Agribusiness: Smart Approaches to Cotton Irrigation Management

Project Commencement Date: 1/7/04 **Project Completion Date:** 30/6/07

CRDC Program: Capacity & Community **CRC Program:** The Farm

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Signature of Research Provider Representative: _____

Part 3 – Final Report Guide (due within 3 months on completion of project)

Background

1. Outline the background to the project.

With increasing focus on water used in agriculture and continued pressure to maximise efficiency within cotton irrigated systems, this project aimed to improve understanding of irrigation management within emerging systems and to develop future tools to assist with water management in these systems. This project continued research from CSP139C – 'Application of crop simulation within the Australian Cotton industry' (Richards), which demonstrated the value of focussed risk analysis tools to cotton growers and developed the HydroLOGIC irrigation management system.

Previous research and industry feedback has shown significant opportunities exist to:

- Improve HydroLOGIC's useability, to increase its capabilities by incorporating seasonal climate forecasts into assessing management decisions, and to increase its usefulness by adding the capacity to integrate water management across the farm.
- Explore the water use efficiency of alternative cropping systems, e.g. vetch-cotton rotations and skip planted irrigated crops.
- Identify appropriate irrigation strategies for Bollgard II crops.
- Improve integration of current irrigation management tools.

Research conducted within this project formed a key application and feedback link within the Cotton Management Support System Team, which developed targeted, cotton specific management tools for the Australian industry. The provision of training to growers, consultants and specialised water extension staff (such as Qld's RWUEI2) was a key component, both to maintain relevance and links with water users, but also to identify emerging opportunities for future tools and materials development, e.g. WaterPAK. This project also supported the CSIRO Plant Industry water research team of Mr Stephen Yeates (scientific development), Mr Dirk Richards (DSS development and application) and Mr James Neilsen (plant water relations).

The broad aims of this project were:

- Conduct irrigation research for emerging crop management issues and alternative cotton cropping systems.
- Provide industry with an enhanced version of HydroLOGIC
- Document a decision framework for integrating irrigation management tools.

Objectives

2. List the project objectives and the extent to which these have been achieved.

Conduct irrigation research for emerging crop management issues and alternative cotton cropping systems.

This objective has been achieved through the following activities:

Emerging crop management issues

This project supported 3 seasons of irrigation research into Bollgard II physiology and management, following concerns relating to management of high fruit retention crops. At the time of Bollgard introduction, it was thought that it may be necessary to modify the way the Bollgard crop is irrigated to ensure that optimum yield is attained. Note that research in this area overlapped with several objectives specified and reported in CSP161C - Physiology of high retention cotton crops (Steve Yeates). These comparisons of water use between conventional and Bollgard varieties were the first experiments dedicated to this scientific objective worldwide, with support from Monsanto received and acknowledged.

Some of the issues investigated were:

- Investigating whether earlier and heavier fruit retention reduces plant root development thus impacting on water extraction, later crop growth and yield.
- Documented the crop water requirements of both conventional and Bollgard II crops.
- Modifying irrigation scheduling to ensure optimum growth early in crop development to handle high fruit loads and avoid early cut-out (links with CRC 1.2.03 Optimal Production and Water Use of High Retention Cotton and other New Technologies- Yeates).

Alternative cotton cropping systems

- Research in this area addressed components of water use efficiency within the vetch-cotton rotation system and cotton grown under lateral move irrigation. Specific activities were:
  - Data collection was undertaken in an experiment conducted by Auscott Narrabri over the 2004-05 and 2005-06 seasons, comparing cotton grown under lateral move irrigation to conventional furrow irrigation.
  - Measurement of soil water status under cotton-vetch and continuous cotton systems in collaboration with Dr Ian Rochester.
  - Collaboration with Emma Brotherton (nee Carrigan) (QDPI&F) and Sarah Hood (SIS)in using HydroLOGIC to estimate the soil moisture balance in the Cotton CRC-QDPI&F siphon-less irrigation project.

Provide industry with an enhanced version of HydroLOGIC

This objective has been achieved.

The HydroLOGIC software was released in September 2003, with significant grower and consultant demand, and was designed to provide detailed risk analysis information for different irrigation strategies, particularly under limited water situations. Ongoing development and evaluation was required to maintain the focus, relevance and success of this management system through:

- Maintaining and enhancing HydroLOGIC training initiatives within the industry.
- Investigation of climate forecast analysis techniques within HydroLOGIC, based on concepts such as SOI phase and other seasonal climate forecasting techniques.
- Evaluation of HydroLOGIC to provide management advice for alternative irrigation systems such as drip and overhead systems.

The following HydroLOGIC versions and associated resources were developed and delivered to industry:

- V1.2.0 (minor upgrade) in September 2004
- Leaf Area Photoguide support documents in September 2004
- V2.1.0 (major upgrade) in September 2005
- V2.2.0 (minor upgrade) in November 2005
- Ozcot engine upgrade in January 2006
- V2.2.0 web deliver version in June 2007

Document a decision framework for integrating irrigation management tools.

This objective has been achieved.

This research objective sought to understand the position of different irrigation management tools within the irrigator's decision framework, and provide information on links and overlaps between each defined tool and their application, and their strengths and weaknesses. Two seasons (2005-06 and 2006-07) of collaborative irrigation optimisation trials were conducted with Aquatech Consulting Pty Ltd on two farms in the Namoi Valley, with the main purpose of these trials to demonstrate and investigate:

- The value of crop and irrigation system monitoring using the Irrimate™ service.
- The benefits of using HydroLOGIC for scheduling decisions and maintaining whole farm water balance records with WaterTRACK™.
- The opportunities to integrate these tools.
- How irrigations could be optimised using HydroLOGIC and Irrimate™ equipment.

Methods

3. Detail the methodology and justify the methodology used. Include any discoveries in methods that may benefit other related research.

Conduct irrigation research for emerging crop management issues and alternative cotton cropping systems.

In collaboration with Steve Yeates, several experiments were initiated during the project to address irrigation research questions. These included:

- During the 2004-05 and 2005-06 seasons, a large scale replicated trial comparing the cotton plants response to moisture stress at different development stages in Bollgard and conventional varieties was conducted at Narrabri. This involved measurement of plant growth, soil moisture, water applied during irrigation events (channel, head-ditch and tail-drain), maturity and yield.
- A small scale trial at Keytah, Moree during the 2004-05 season compared the plant response to a single skipped irrigation event. This involved monitoring plant biomass, soil moisture using neutron and capacitance probes, probe calibration and yield.
- During the 2006-07 season, a large scale replicated trial was established at Narrabri to repeat the previous 2 season's water balance calculations, with the inclusion of Roundup Ready Flex, fully irrigated Bollgard II and conventional varieties. The response to water stress of Bollgard II at cut-out and post cut-out was also repeated. This involved measurement of plant growth, soil moisture, water applied during irrigation events (channel, head-ditch and tail-drain), maturity and yield.

Specific methods of measurement included:

Irrigation water application
At each irrigation event, water levels were monitored using Odyssey capacitance water depth recorders at head ditch and tail drain. Siphon input was then calculated using the Bos head height siphon flow equation (Bos, 1989), and tail water was measured with recording flumes. The total water applied to each plot was then calculated, taking the soil moisture deficit into consideration. The application efficiency was calculated by dividing the irrigation water infiltrated into the soil by the water applied by siphon.

Soil moisture
Neutron probe access tubes were installed in each treatment to measure the soil moisture deficit prior to each irrigation and when through drainage had ceased. This deficit information was used in conjunction with the irrigation water applied results to calculate the total water infiltrated to the profile at each irrigation event. Extensive soil cores were also taken during the 2006-07 growing season to improve the local neutron probe calibration constructed during previous seasons.

In the area of irrigation research with alternative cotton cropping systems, the following activities were conducted:

- Data collection was undertaken in an experiment conducted by Auscott Narrabri over the 2004-05 and 2005-06 seasons, comparing cotton grown under lateral move irrigation to conventional furrow irrigation. This involved monitoring biomass, soil moisture data recorded by capacitance and neutron probe methods and yield. It was anticipated that these records would be used to validate the OZCOT model for this irrigation system. The ultimate aim of these comparisons would be to develop the HydroLOGIC software for overhead irrigation systems.
- Measurement of soil water status under cotton-vetch and continuous cotton systems was continued during the 2004-05 season in collaboration with Dr Ian Rochester. Capacitance probes and gravimetric samples were used to monitor soil moisture, with soil characterisation sites (using the ponding technique) established in both farming system treatments to measurement differences in plant water holding capacity.
- Collaboration with Emma Brotherton (nee Carrigan) (QDPI&F) and Sarah Hood (SIS) in using HydroLOGIC to estimate the soil moisture balance in the Cotton CRC-QDPI&F siphon-less irrigation project. This project compared four different irrigation systems with conventional furrow irrigated fields across four properties in the St George and Border Rivers regions. HydroLOGIC was also used to estimate the effective rainfall and infiltration, with growers' observations used to validate these predictions. Specific field information used in this modelling included general crop agronomy, irrigation dates, SILO and local rainfall records.

Land restrictions at ACRI have prevented the establishment of a dedicated trial investigating skip planted cotton, however discussions were held with Dr Phil Goyne (Qld DPI) regarding this management systems and a subsequent experiment located on the Darling Downs. These discussions focussed on trial design, varieties and appropriate measurements. It was anticipated that this collaboration would continue in future, with data collected by Dr Goyne potentially of use in development of the OZCOT model. Collaboration was also initiated with Dr Goyne in the area of new extraction front velocity functions based on extrapolation of soil

moisture information, with software developed by APSRU for the development of extraction front velocity functions obtained. These functions would assist in the development of the OZCOT model, and ultimately HydroLOGIC, to simulate the skip irrigated system.

Provide industry with an enhanced version of HydroLOGIC

The process used for development of HydroLOGIC was a mix of evolutionary prototyping and participatory action research, as used successfully elsewhere in the development and application of decision support and simulation technologies in agricultural production. Key elements of this approach include working alongside farmers with software tools, gathering feedback and updating software applications, in parallel with on-farm experiments evaluating the applicability and value of the system. This process was initiated in 2002 prior to official release and continued until 2006, involving growers, consultants and other industry personnel. Model and system rigour were validated using quantitative data including the soil moisture balance, fruiting dynamics, and leaf area development.

The methods and activities used to deliver improved versions of HydroLOGIC included:

Regional training workshops
These workshops were held in September 2004 and 2005 at locations around the industry and involved growers, consultants, extension staff and other industry personnel. In 2004, training workshops were at Moree, Goondiwindi, Dalby, Theodore, St George, Wee Waa, Gunnedah, Hillston and Bourke, and involved 74 cotton growers and consultants. In 2005, training workshops were held in Moree, Goondiwindi, Toowoomba, Dalby, Theodore, Emerald, St George, Hillston, Bourke, Narrabri and Gunnedah, and involved 65 cotton growers, consultants and industry personnel. Interactive workshops involving discussions of HydroLOGIC application were also conducted during the 'hands-on-research' sessions at the 2004 Australia Cotton Conference, involving 34 growers and consultants, and the 2006 conference involving 54 growers and consultants.

User surveys
A major survey of all registered HydroLOGIC users was completed by project staff and members of the Cotton CRC water focus team in March 2007. The current registered user list was compiled and provided to individual valley extension staff, who contacted each user individually to; a) assess usage of HydroLOGIC for benchmarking purposes and b) collect field and farm level water use efficiency information where appropriate. A total of 84 replies were collected and responses analysed for common themes and potential case study documentation.

Specification and white paper documentation
Investigation and documentation of refinements to the HydroLOGIC management system was achieved during the project through consultation with users and software developers, and driven by support requests. A discussion paper was written in 2005 outlining development of HydroLOGIC with SOI functionality, which was subsequently reviewed and circulated to other members of the CSIRO Plant Industry Decision Support Development Team. Potential specification upgrades to facilitate simulation of overhead irrigation and drip systems have also been identified following discussions between documented through discussions held between Dirk Richards, David Johnston, Steve Yeates (CSIRO) and Peter DeVoil (APSRU)

as part of the Cotton CRC / GRDC 'High yielding irrigated grains in cotton production systems' project.

Documentation of views and barriers from grower involved in collaborative on-farm experiments
The irrigation optimization experiments conducted in the Lower Namoi in 2005-06 and 2006-07 have provided useful feedback on improvements to HydroLOGIC. This feedback was collected through informal interviews and discussions, and through grower comments contained within the individual research summaries. A range of specific improvements to the software were identified during the course of this research, and where possible changes were made during the season. Further details on these experiments can be found in the 2005-06 Cotton CRC 'On-farm irrigation optimisation trial' research reports for Waverley and Kilmarnock.

HydroLOGIC demonstration experiments in collaboration with local extension staff.
Dedicated HydroLOGIC demonstration experiments were conducted at the following locations; in 2004-05 at Bourke (Tony Thompson) and Boomi (Emma Carrigan); and in 2005-06 at Goondiwindi (Emma Carrigan), Merah North (Mitch Carter), Hillston (Scott Vaessen), and Wee Waa (Mick Rollins, Steve Madden Agriculture). At these locations, paired research sites comprising either one field split in half or paired fields side by side, were selected to allow a direct comparison between the existing growers irrigation management and field management using HydroLOGIC. Measurements of soil moisture, plant development, weather and yield were taken, with water input and output measured using suitable metering equipment if available. Assistance was provided on soil sampling strategy, analysis type and lab preferences. During the season, operational support in running HydroLOGIC was given at all sites and assistance in compilation of results for subsequent publication in valley trial books. Results from these HydroLOGIC demonstration trials were collated and used in presentations to industry during the project.

Promotional material for extension
HydroLOGIC application documentation was developed as part of the project for use within training sessions, Cotton CRC publications and by Cotton CRC extension staff. Specific task information such as timing of first irrigation and benchmarking was distributed via; individual valley CottonTales; the Irrigation Knowledge Management in Cotton and Grain Irrigation: Cotton and Grains Irrigation Workshop Series; and through CSD 'Web on Wednesday' and 'Facts on Friday' mediums.

Document a decision framework for integrating irrigation management tools.

Four collaborative experiments involving growers, CSIRO, NSW DPI, Aquatech Consulting, and the Cotton CRC were conducted in the Namoi Valley during the project to investigate and document opportunities for integrated irrigation decision aid application and usage. Specific objectives of these optimisation trials were to evaluate and promote the HydroLOGIC, Irrimate™, and WaterTrack™ tools to the industry and use of these tools to highlight water savings and improvements in water use efficiency in comparison to existing water management strategies. These research sites were located on farms at Burren Junction and Boggabri, where a single field was selected, and then split into standard and optimised irrigation treatments. Scheduling on the optimised treatment was determined through HydroLOGIC, with irrigation application and the amount of infiltration measured using the

Irrimate™ siphon meters, advance sensors, and tail water flume flow meters. The WaterTrack software was run for the whole farm which included the field being monitored. An essential component of this research was that the growers changed their irrigation schedule and water application technique when HydroLOGIC and Irrimate™ indicated a potential advantage. Final yields and water use indices in the optimised treatment were subsequently compared with the remainder of the field and the whole farm average.

Measurements on these sites involved storage surveys, the installation of sensors for continuous volume information, in-field application monitoring equipment, with plant growth and water use monitored by fruit count, leaf area estimation, and using capacitance and neutron probes.

Water movement and application
Where necessary, AgriFlow MACE meters were installed to monitor water entering the system. All water applications on the field were evaluated by CSIRO using the Irrimate™ equipment, with Irrimate analysis by Aquatech and Rod Jackson (NSW DPI) and subsequent irrigations altered to the optimum practice where possible. A survey of level and distance from the head-ditch to each advance sensor location (total of six) was done prior to first in-crop irrigation. At each irrigation event the number of siphons, the head-ditch head and siphon size or measured siphon flow and run-time was recorded.

Weather
Weather information was collected for these sites from a range of sources by CSIRO. On-farm rainfall records were used where possible, supplemented with records downloaded from local Agrilink™ farm weather stations. The subsequent combined weather records were used in HydroLOGIC and WaterTrack™ for the whole of the season. A Tiny Tag temperature sensor was placed at the head ditch at each experiment to allow correlation with AgWISE™ and SILO temperature records.

Crop growth
Fruit development was monitored by CSIRO within each management area adjacent to the probe sites, whilst leaf area development was estimated using the HydroLOGIC LAI photo-guide from the head ditch. This information was used in HydroLOGIC to schedule the next irrigation and determine the optimum irrigation strategy.

Soil moisture
Soil moisture was monitored by CSIRO by neutron probe and capacitance technology (C-probe) within each management area. Neutron probe readings were taken at 10, 20, 30, 40, 50, 60, 80, 100 and 120cm depths, while the C-Probe readings were taken at 20, 40, 60, 80, 100 and 120cm depths. A soil moisture deficit was calculated from the neutron probe readings using an appropriate calibration curve and correlated with gravimetric soil moisture samples where possible. This information was used in HydroLOGIC to schedule the next irrigation and determine the optimum irrigation strategy, and in WaterTrack™ to compare with calculated daily soil moisture deficits.

Further details on methods and types of measurements for these experiments are contained within the Cotton CRC ‘On-farm irrigation optimisation trial’ research reports.

Results

4. Detail and discuss the results for each objective including the statistical analysis of results.

Conduct irrigation research for emerging crop management issues and alternative cotton cropping systems.

Research results from the 2004-05 and 2005-06 experiments were reported in two papers at the 13th Australian Cotton Conference, via Cotton CRC and CSIRO media releases, CSD publications and at several industry meetings by Mr Yeates and Mr Richards. This projects area of involvement was primarily in terms of monitoring water application and use related to the Bollgard II Research Hypotheses - Is the water requirement of Bollgard the same as conventional cotton?

A brief summary of the overall results is presented here, with further detail provided in the annual reports for CSP161C. Key results were:

- Compared to Bollgard treatments, the conventional cotton had a very high proportion of tipping to the main stem which delayed maturity and boll growth.
- Provided differences in fruit load are considered there was no difference between Bollgard and conventional cotton in response to normal irrigation deficits.
- Extraction patterns and the depth of rooting were similar in the Bollgard and conventional treatments by the end of the season.
- Bollgard®II had the potential to use less water whilst maintaining a yield advantage (Table 1).
- Crop response in Bollgard II can be explained by the differences in crop growth.
- Bollgard®II showed similar sensitivity to water stress in early flowering and soil water extraction was the same as conventional cotton.
- Bollgard II may be more sensitive to larger deficits (>55-60% PAWC), late in flowering and should be watered before conventional fields.
- A reduction in gross (irrigation + rainfall) and irrigation water use efficiency was only found in Bollgard®II where moisture stress was experienced at or close to cut-out.

Table 1. Yields from Bollgard and conventional irrigation experiments (2004, 2005, 2006).

Treatment	2004-05	Treatment	2005-06	Treatment	2006-07
Sicot 71BR Full irrigation	9.5	Sicot 71BR Full irrigation	9.6	Sicot 71BR Full irrigation	9.90
Sicot 71 Full irrigation	9.1	Sicot 71 Full irrigation	8.5	Sicot 71 Full irrigation	11.08
Sicot 71BR skip 1st	7.4	Sicot 71BR skip 1st	7.3	Sicot 80BR Full Irrigation	9.76
Sicot 71 skip 1st	7.5	Sicot 71 skip 1st	6.4	Sicot 80 Full Irrigation	9.74
Sicot 71BR skip 2nd	9.3	Sicot 71BR skip 2nd	7.3	Sicot 71BR Skip cut-out irrigation	8.99
Sicot 71 skip 2nd	9.1	Sicot 71 skip 2nd	8.3	Sicot 71BR Skip post cut-out Irrigation	10.07
Sicot 71BR skip 3rd	6.5	Sicot 71BR skip 3rd	5.7		
Sicot 71 skip 3rd	7.8	Sicot 71 skip 3rd	6.9		
		Sicot 71BR skip 4th and 5th	9.2		
		Sicot 71 skip 4th and 5th	8.5		
Average of all treatments					
Bollgard	8.2	Bollgard	7.8	Bollgard	9.68
Conventional	8.4	Conventional	7.7	Conventional	10.41

Moisture extraction

The depth and rate of moisture extraction was investigated during the 2004 and 2005 experiments, indicating very little difference in moisture extraction between the Bollgard®II and conventional full irrigation treatments (Figure 1). The conventional generally reached a marginally higher deficit, which was associated with the conventional variety producing greater leaf area in both seasons. Differences in late season extraction were apparent in 2004 where a longer season allowed the plants to continue growing later in the season and generate a higher leaf area in the conventional treatments (most likely caused by tipping-out).

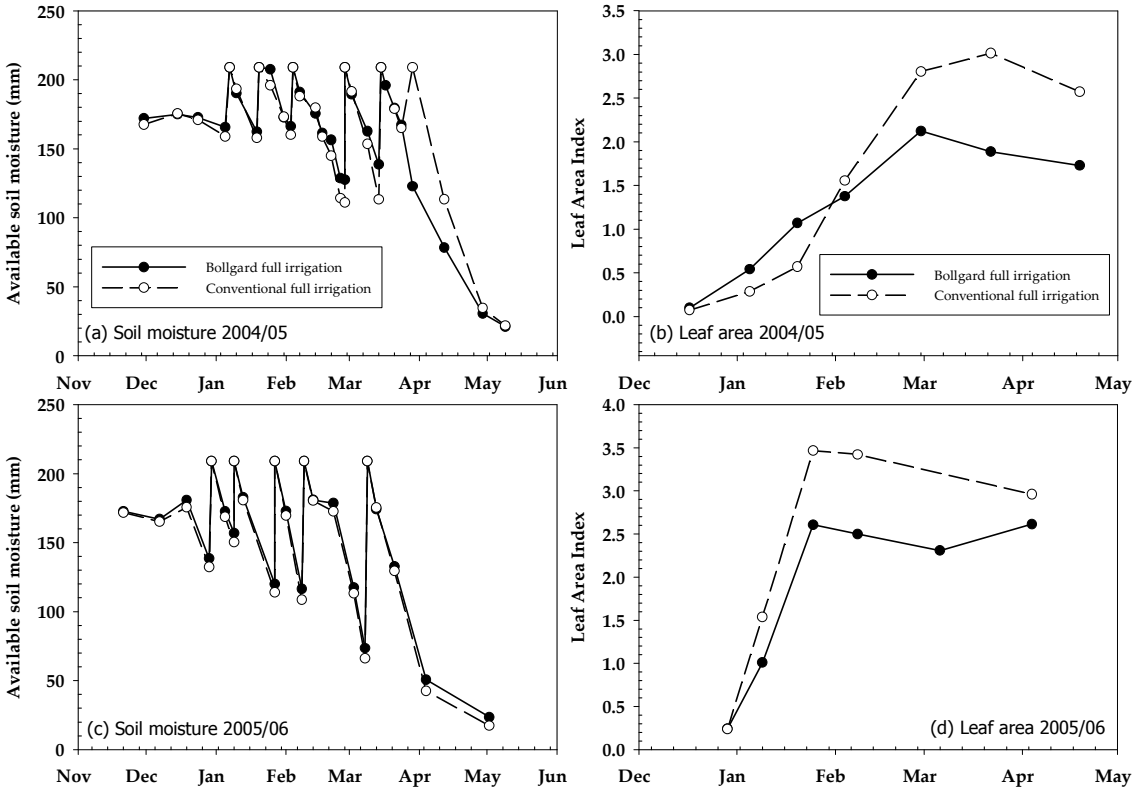

Figure 1. Soil moisture extraction and leaf area development (2004 and 2005).

Applied irrigation water

The total water applied to each treatment and the in-field application efficiency was calculated for each irrigation and totalled at the end of the season (Table 2). The two year average (2004-05 and 2005-06) for the Bollgard®II full irrigation treatment totalled 6.3ML/ha, as opposed to 7.0ML/ha for the conventional full irrigation treatment. This difference was 0.9ML/ha in 2004 and 0.4ML/ha in 2005. In general, less water was required in the Bollgard®II variety than the conventional equivalent in the majority of treatments, with the exception of the Skip fourth and fifth treatment in 2005. This difference was primarily due to these Bollgard®II plots receiving a larger water application during the first in-crop irrigation on the 30th of December 2005.

Table 2. Total irrigation water applied, 2004/05, 2005/06, and 2006/07

Treatment	2004-05 ML/ha	2005-06 ML/ha	Treatment	2006-07 ML/ha
Sicot 71BR Full irrigation	6.9	5.7	Sicot 71BR Full irrigation	6.3
Sicot 71 Full irrigation	7.8	6.1	Sicot 71 Full irrigation	6.5
Sicot 71BR skip 1st	5.8	4.5	Sicot 80BR Full Irrigation	6.3
Sicot 71 skip 1st	6.6	4.5	Sicot 80 Full Irrigation	6.8
Sicot 71BR skip 2nd	6.0	5.0	Sicot 71BR Skip cut-out irrigation	5.7
Sicot 71 skip 2nd	6.3	5.0	Sicot 71BR Skip post cut-out Irrigation	5.6
Sicot 71BR skip 3rd	5.2	4.7		
Sicot 71 skip 3rd	6.4	4.9		
Sicot 71BR skip 4th and 5th		3.2		
Sicot 71 skip 4th and 5th		3.0		
Average of all treatments				
Bollgard	6.0	4.6	Bollgard	5.9
Conventional	6.8	4.7	Conventional	6.6

The results from the 2006 experiment confirm the general expectation of reduced irrigation water use, when compared with the corresponding conventional variety. The advantage to skipping the irrigation post cut-out was again confirmed, with Sicot 71BR consistently using less irrigation water whilst maintaining a yield advantage.

Further details can be found in two ACGRA Cotton Conference papers written by Dirk Richards and Steve Yeates detailing the Bollgard water use research. Titled 'Does Bollgard®II cotton use more water?' and 'Progress in evaluating the moisture stress response of Bollgard II® compared with conventional cotton', they appear in the proceedings of the 13th Australian Cotton Conference, Gold Coast, August 2006.

Irrigation research for alternative cotton cropping systems.

Overhead application systems

Initial evaluation of HydroLOGIC for drip and overhead systems indicated several areas where HydroLOGIC would require further development. These include incorporating application efficiency and reduced deficit irrigation into the existing framework, with the OZCOT model requiring further refinement of the soil water balance to allow placement of water at depth and incorporation of any plant growth research under these systems. To facilitate testing of HydroLOGIC and OZCOT specifically under overhead systems, plant growth and soil moisture extraction information were collected from sites at Wee Waa (Auscott Narrabri and NSW DPI) and Goondiwindi (Carrigan/McGary, Qld DPI&F and Qld DNR&W).

Auscott Narrabri
This collaborative field experiment was established in 2004-05, with two fields irrigated by lateral move and two fields directly adjacent irrigated by furrow irrigation. The 60ha fields were planted with Sicala 60BRR and Sicot 71BRR, and treated the same in regard to crop management. Both fields had the same starting moisture, with irrigation scheduling

determined using c-probes. Mace meters where installed by Auscott at the head ditch end and tail drain end of the furrow irrigation site to measure water onto the field and water off.

Comparisons between plant growth observations indicated greater variation between cultivars than between the different irrigation systems (Figure 2). Concerns were raised at this time about the incidence of Verticillium wilt under the lateral move and the potential impact on growth and yield. However, a disease survey conducted by Dr Stephen Allen found a higher incidence of Verticillium wilt was a consequence of a) the presence of substantial levels of pathogen inoculum as a result of the previous cropping history, and b) the favourable weather conditions which featured significant cool periods during November, December, January, February and early March. He concluded that without any historical record of the distribution of Verticillium wilt across the whole field there is no evidence that Verticillium wilt was more severe under lateral move irrigation than under furrow irrigation.

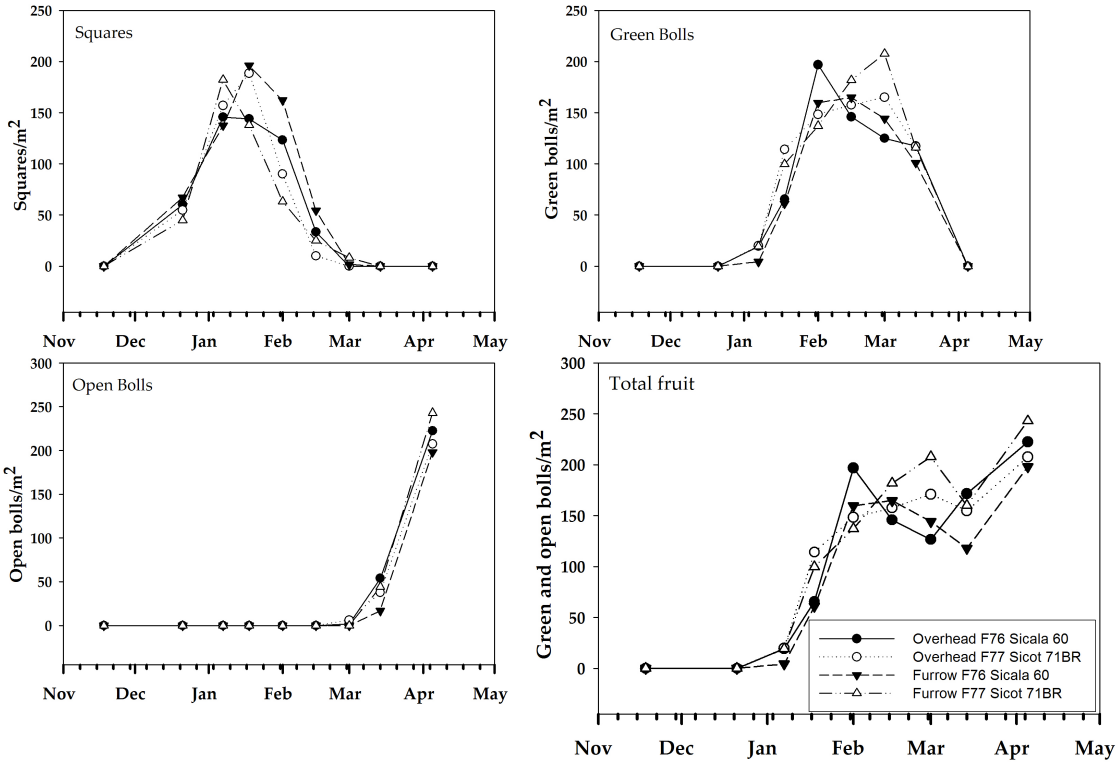

Figure 2. Fruit development curves, Auscott Narrabri, 2004/05 season.

Final yield results indicated the lateral move irrigation system achieved a higher yield than the furrow irrigation system by approximately 1 b/ha for both varieties (Figure 3).

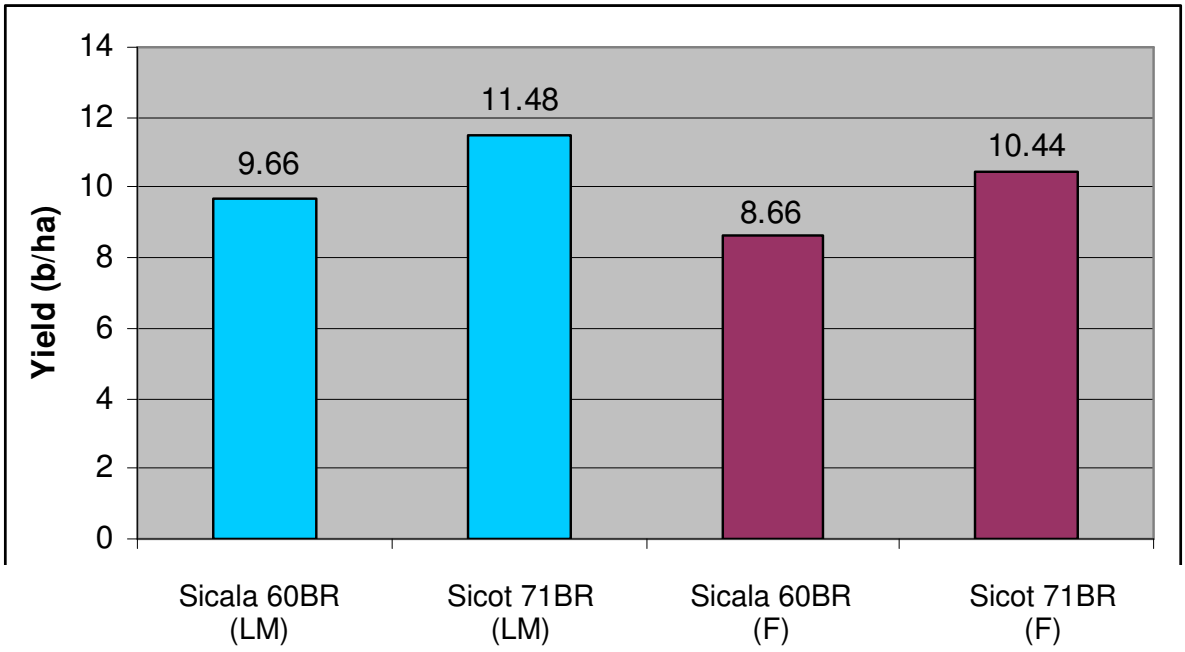

Figure 3. Yield comparison of Auscott lateral move and furrow irrigation experiment

Detailed analysis of water use still needs to be undertaken.

Cotton CRC-QDPI&F siphon-less irrigation project.
This collaboration research effort with Emma Brotherton (nee Carrigan) (QDPI&F) and Sarah Hood (SIS) involved using HydroLOGIC to estimate the soil moisture balance in the Cotton CRC-QDPI&F siphon-less irrigation project. This project compared four different irrigation systems with conventional furrow irrigated fields across four properties in the St George and Border Rivers regions. HydroLOGIC was also used to estimate the effective rainfall and infiltration, with growers' observations used to validate these predictions.

Further details on this research can be found in Hood, S., Carrigan, E., 2006. Evaluating Alternative and Bankless irrigation systems, paper presented and published at the 13th Cotton Conference, Gold Coast, 10th August 2006.

Water use efficiency of the cotton-vetch rotation systems
Measurements of soil moisture trends under the cotton-vetch and continuous cotton systems were initiated under CSP139C, and continued during the 2004-05 season in collaboration with Dr Ian Rochester. Capacitance probes and gravimetric samples were used to monitor soil moisture, with soil characterisation sites (using the APSRU ponding technique) established in both farming system treatments to measurement differences in plant water holding capacity. The characterisation results indicated changes had occurred in layer and total capacity to depth, with a 32mm difference measured in plant available water holding capacity (Figure 4). Changes in the surface water holding capacity are a result of additional organic matter returned by green manuring, however subsequent investigations by Dr Rochester indicate the possibility of root chemical interactions over time at depth.

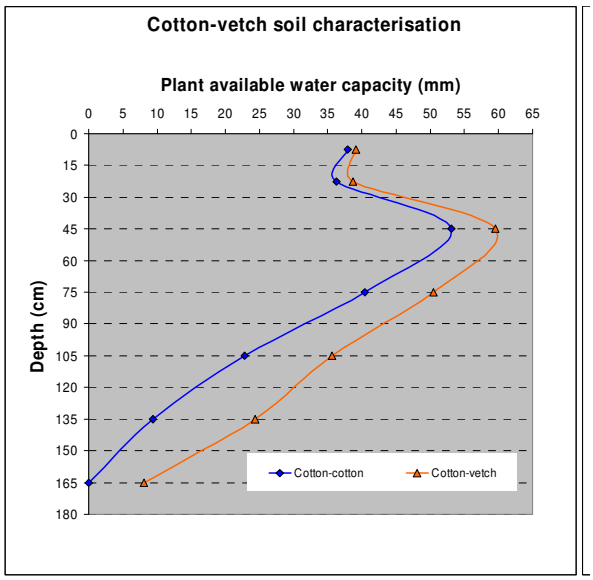

Figure 4. Plant available water capacity determined through ponding, Field 6, Australian Cotton Research Institute for cotton_cotton and cotton _vetch rotations.

Provide industry with an enhanced version of HydroLOGIC

Enhanced versions of HydroLOGIC were developed and delivered to industry through:

- Major upgrade in September 2005 (V2.1.0),
- Minor upgrades in September 2004 (V1.2.0) and November 2005 (V2.2.0),
- Several software patches,
- Leaf Area Photoguide support documents produced in November 2004.
- Over 22 workshops involving growers, consultants, extension staff and other industry personnel,
- Over 7,000km travelled conducting training workshops in all growing regions from Hillston to Emerald.

The new version of HydroLOGIC released in September 2005 incorporated many new features in response to feedback from growers, consultants and researchers. These included: screen defaulting, enhancements to irrigation deficit triggers, updating run dates for all scenarios, a streamlined one step process for running scenarios and report generation, and developing two new reports.

Regional training workshops

These workshops were held in September 2004 and 2005 at locations around the industry and involved growers, consultants, extension staff and other industry personnel. In 2004, training workshops were at Moree, Goondiwindi, Dalby, Theodore, St George, Wee Waa, Gunnedah, Hillston and Bourke, and involved 74 cotton growers and consultants. In 2005, training workshops were held in Moree, Goondiwindi, Toowoomba, Dalby, Theodore, Emerald, St George, Hillston, Bourke, Narrabri and Gunnedah, and involved 65 cotton growers, consultants and industry personnel. Interactive workshops involving discussions of HydroLOGIC application were also conducted during the 'hands-on-research' sessions at the 2004 Australia Cotton Conference, involving 34 growers and consultants, and the 2006 conference involving 54 growers and consultants.

User surveys.
A major survey of all registered HydroLOGIC users was completed by project staff and members of the Cotton CRC water focus team in March 2007. The current registered user list was compiled and provided to individual valley extension staff, who then contacted each user individually to; a) assess usage of HydroLOGIC for benchmarking purposes and b) collect field and farm level water use efficiency information where appropriate. A total of 84 replies were collected, with a large number of users indicating insufficient water as a primary reason for lack of use of the software (Figure 5). This activity also highlighted a range of potential case studies for water management, in addition to HydroLOGIC use case studies, which have subsequently been investigated by members of the Cotton CRC water focus team.

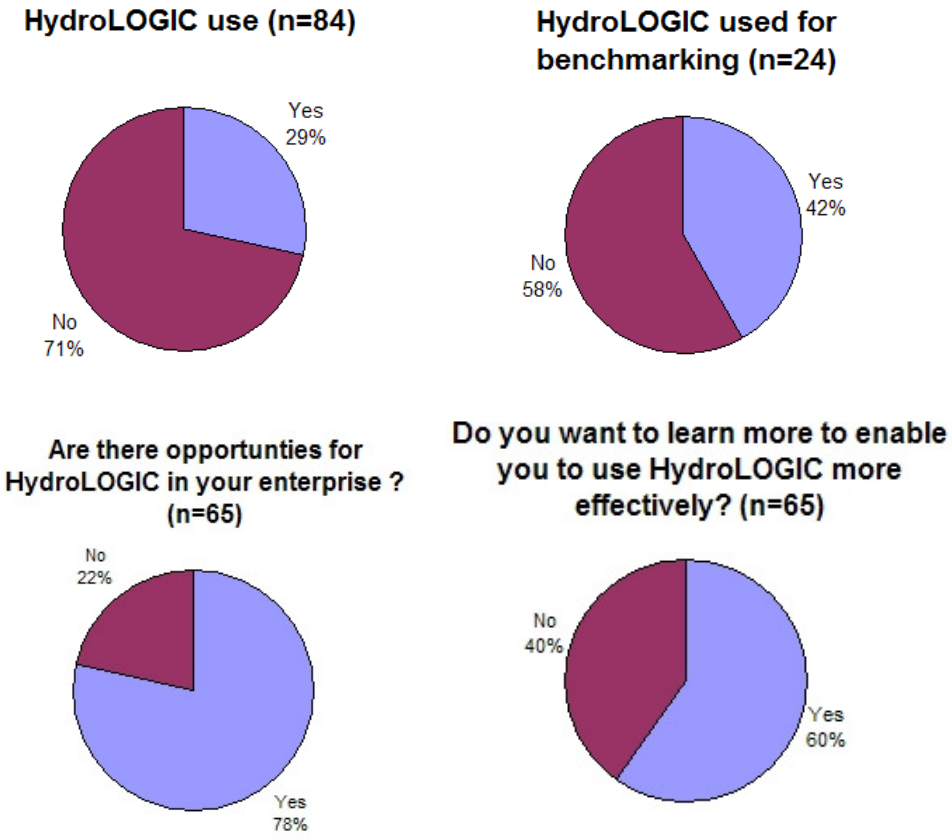

Figure 5. HydroLOGIC user survey results, March 2007.

Specification and white paper documentation
Investigation and documentation of refinements to the HydroLOGIC management system was achieved during the project through consultation with users and software developers, driven by support requests and documented in discussion white papers. These discussion papers were subsequently reviewed and circulated to other members of the CSIRO Plant Industry Decision Support Development Team and the Cotton CRC. Documents were produced on:

- The development of HydroLOGIC with SOI functionality was written in June 2005, to enable the characterisation of model outputs by climatic conditions. Subsequent development of the CottBASE product has lessened the need for this development. This

achievement has been reported in the final report for CRC93 'Delivering Science to Agribusiness - Cotton Management Support Systems'.

- Enhanced soil water management in HydroLOGIC was written in February 2005 outlining strategies for incorporation of capacitance information into the HydroLOGIC system, and the option to define layers in soil profile

Documentation of views and barriers from grower involved in collaborative on-farm experiments

The irrigation optimization experiments conducted in the Lower Namoi in 2005-06 and 2006-07 have provided useful feedback on improvements to HydroLOGIC. This feedback was collected through informal interviews and discussions, and through grower comments contained within the individual research summaries. A range of specific improvements to the software were identified during the course of this research, and where possible changes were made during the season. Further details on these experiments can be found in the 2005-06 Cotton CRC 'On-farm irrigation optimisation trial' research reports for Waverley and Kilmarnock.

A range of specific improvements to the software were identified during the course of this research, which may act as barriers to adoption. Potential enhancements to HydroLOGIC include; the ability to simulate regulated deficit irrigations and partial refilling of the soil profile at irrigation events; scenario analysis and reporting using seasonal climate forecasts and individual seasons; and streamlining the optimisation routine for the immediate next irrigation. Changes were identified in how the training and promotion of these irrigation tools could be delivered as a result of time limitations of individual growers and reduced interest by the local industry. A perception noted was that software packages may be too complicated and involved for the average small family farm, as opposed to the larger corporate and family farms with full time managers. Continued support in using these types of tools was highlighted by both growers involved in this research to encourage further and ongoing use of each tool. The current one day training format for HydroLOGIC was highlighted as being longer than desired, especially during the growing season. Possibilities exist to deliver short and concise training sessions using full-motion video tutorial of software procedures with accompanying interpretation presentations. These tutorials can be developed in a range of media types and delivered through the desktop online help or World Wide Web.

HydroLOGIC demonstration experiments in collaboration with local extension staff.

These dedicated HydroLOGIC demonstration experiments were conducted at the following locations; in 2004-05 at Bourke (Tony Thompson) and Boomi (Emma Carrigan); and in 2005-06 at Goondiwindi (Emma Carrigan), Merah North (Mitch Carter), Hillston (Scott Vaessen), and Wee Waa (Mick Rollins, Steve Madden Agriculture). Feedback from these trial co-operators and users indicated a mixture of strategic and tactical use including; area to plant depending on water available; confirming scheduling decisions (consultants); benchmarking crop water use after harvest. A summary of the 2004 Border Rivers HydroLOGIC Demonstration Trial is presented here.

2004 Border Rivers HydroLOGIC Demonstration Trial (Emma Carrigan)

This Trial was located at 'Courallie' on the Boomi R, and used split fields, with the majority of the field 35ha under the standard irrigation management, and approx 10ha scheduled using

Hydrologic. This allowed a direct comparison between the grower's irrigation management strategy and the HydroLOGIC strategy, and successfully demonstrated that the HydroLOGIC support Decision tool could be used to aid irrigation decision-making. The key application of the software was late in the season and when determining the last irrigation, with HydroLOGIC indicating that the final irrigation was not requ

Table 3. 2004/05 Border Rivers HydroLOGIC trial details

Normal scheduling	HydroLOGIC Scheduling
6/10/2004	6/10/2004
14/12/2004	14/12/2004
5/01/2005	5/01/2005
15/01/2005	17/01/2005
25/01/2005	27/01/2005
6/02/2005	6/02/2005
19/02/2005	20/02/2005
25/02/2005	

Final yields determined by handpicking were 13.95 bales/ha and 14.02 bales/ha for the standard and HydroLOGIC managed areas respectively. Opportunities identified with the co-operation of the grower and consultant included; increased grower involvement in running the program, utilising a decision diary getting accustomed to the program i.e. input of data; further soil characterisation and neutron probe calibration to allow for more confidence in using the irrigation date on a range of deficits and scheduling irrigations on maximum yield potential; and use Hydrologic to the full potential especially to determine deficit, in terms of achieving highest yield potential.

Results from this and other HydroLOGIC demonstration trials were collated and used in presentations to industry and Cotton CRC extension material during the project. For further details please refer to the publications list provided.

Promotional material for extension
Specific task information such as timing of first irrigation and benchmarking was distributed via; individual valley CottonTales; the Irrigation Knowledge Management in Cotton and Grain Irrigation: Cotton and Grains Irrigation Workshop Series; and through CSD 'Web on Wednesday' and 'Facts on Friday' mediums. For further details please refer to the publications list provided.

'Notable Quotes'

'If I knew everything about cotton and in HydroLOGIC then I wouldn't need to use it, but as I don't then I am interested'. Jeremy Kitchen, Moree, 2004.

'All my clients are using it so I had better find out about it'. Mick Rollins, Steve Madden Agriculture, 2005, who initiated a HydroLOGIC trial at Wee Waa to gain confidence in the tool.

Document a decision framework for integrating irrigation management tools.

Four water management trials were conducted in the Namoi Valley over the 2005/06 and 2006/07 cotton seasons, on Waverley, Burren Junction, and Kilmarnock, Boggabri. The purpose of these trials was to; assist the growers with their on-farm water management; validate and identify improvements to the HydroLOGIC, Irrimate™, and WaterTrack™ products; identify the potential to integrate the three products; assist in benchmarking irrigation performance; and promote Irrimate™, WaterTrack™, and HydroLOGIC to the industry. Figure 6 shows the decision framework investigated through this research, with a circular pattern of information value adding at each decision point.

All products had been rigorously tested previously and were further validated through these trials. Field measurements were taken throughout the season for soil moisture, plant growth, pumped water volume, irrigation application, and stored water volume. These measurements were compared against the calculations of each product which resulted in the successful validation of each product. Some improvements were also made to the products based on advice from the growers involved.

Field water use benchmarking was performed on each trial site using HydroLOGIC and WaterTrack™. These results did vary between products. Results showed that WaterTrack, which is specifically designed to calculate water use and losses at each operation for the whole farm, and balanced against estimated water use, calculated accurate whole farm benchmark figures. HydroLOGIC, which uses a powerful yield response model (OZCOT), aggregates water losses from storages, in distribution and in application into an estimated irrigation efficiency. As a result HydroLOGIC calculates different gross water use benchmarking figures to those from WaterTrack™. This will depend largely on the accuracy of the assumed irrigation efficiency. This result was not unexpected due to the different foci of the tools, but also indicates potential synergy within the tools. It is important to note that the individual crop water use calculated by HydroLOGIC is unaffected by this efficiency estimate.

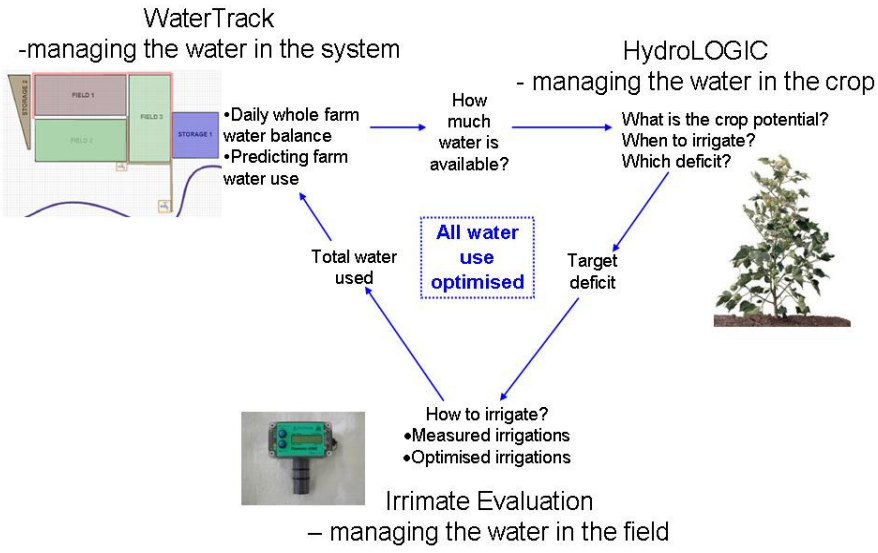

Figure 6. The irrigation management decision framework.

Through the addition of soil infiltration data from Irrimate evaluations, WaterTrack was able to calculate accurate field benchmarking figures for a single field, although calculated crop water use differed between the tools. HydroLOGIC calculates crop water use (evapotranspiration) through a rigorous daily evaluation of both soil and plant components, while WaterTrack calculates daily crop water use from interpolated potential evapotranspiration and crop factors (Allen et al., 1998). Daily deficits from both HydroLOGIC and WaterTrack were compared with C-Probe and Neutron Probe readings. While there were differences in calculated crop water use between the tools, additional work calibrating the measured soil moisture deficits is required to determine the cause of these differences. However, all tools provided good commercial estimates of crop water use and use of either would result in better irrigation practice.

Burren Junction site

HydroLOGIC was able to confirm that irrigation scheduling was very close to optimum at Burren Junction, while Irrimate™ demonstrated that to completely refill the soil profile in this season, an extended irrigation time would have been required with the risk of waterlogging. WaterTrack™ identified acceptable losses through seepage in the storage, channels and drains, and only minimal deep percolation losses in the field. This site was characterised by a pattern of decreasing infiltration late in the growing season, confirmed in both seasons by C-probes and Irrimate evaluation.

Left: Return channel, Waverley.
Photo: Dirk Richards

Right: Field 52 North from Storage 4,
Photo: Dirk Richards

Irrigation scheduling

The results from both seasons on this site reflect a manager who pays particular attention to irrigation scheduling using a range of tools, including monitoring C-probes, visual crop response, and predicted high evaporative demand conditions. As a result, both treatments were irrigated on the same day or one day apart, which confirmed HydroLOGIC ability to accurately predict crop water use (Table 4). The actual irrigation deficits differed between the treatments as a result of variation in soil type, texture and infiltration capacity as shown by subsequent EM38 survey.

Table 4. Waverley irrigation dates and deficits; (a) Field 52, 2005/06; (b) Field 10, 2006/07.

(a)

Irrig No.	Date	Standard	Date	Optimised	Difference
Pre-Irrig.	-	-	-	-	-
1	9-Dec	77mm	9-Dec	78mm	Same Day
2	26-Dec	68mm	27-Dec	90mm	1 day
3	4-Jan	81mm	5-Jan	101mm	1 day
4	13-Jan	92mm	14-Jan	109mm	1 day
5	24-Jan	89mm	25-Jan	99mm	1 day
6	2-Feb	95mm*	3-Feb	89mm*	1 day
7	13-Feb	135mm	14-Feb	128mm	1 day

* estimated with HydroLOGIC

(b)

Irrig No.	Date	Standard	Optimised		Difference
Pre-Irrig.	10-Sep	76mm	76mm	(est.)	
1	26-Nov	78mm	86mm		Same Day
2	17-Dec	89mm	101mm		Same Day
3	8-Jan	83mm	100mm	(5-Jan probe)	Same Day
4	20-Jan	92mm	114mm		Same Day
5	31-Jan	115mm	144mm		Same Day
6	12-Feb	106mm	140mm		Same Day
7	28-Feb	149mm	169mm	(26-Feb probe)	Same Day

Final yield

It was unfortunate that field variation had a larger effect on crop growth than any other factor, as shown by the final yields with both HydroLOGIC areas suffering from reduced infiltration and moisture stress in both growing seasons (Table 5).

Table 5. Waverley final yields; (a) Field 52, 2005/06; (b) Field 10, 2006/07.

(a)

Treatment	Sample type	Bales/ha	len	uni	sfi	str	el	mic
Optimised	Maturity Picks	12.1	1.12	81.33	10.90	29.90	4.17	4.93
Standard	Maturity Picks	13.2	1.18	82.20	9.60	30.77	4.17	4.77
Optimised	Segmented Picks	12.5						
Standard	Segmented Picks	12.5						
Optimised	Machine Yield	9.9						
Standard	Machine Yield	11.1						
Optimised	HydroLOGIC Prediction	9.4						
Standard	HydroLOGIC Prediction	10.2						

(b)

Treatment	Sample type	Bales/ha	len	uni	sfi	str	el	mic
Optimised	Maturity Picks	11.6	1.19	83.27	9.23	32.93	4.43	4.60
Standard	Maturity Picks	12.1	1.23	84.17	7.53	33.87	5.13	4.30
Optimised	Machine Yield	11.0						
Standard	Machine Yield	12.6						
Optimised	HydroLOGIC Prediction	10.0						
Standard	HydroLOGIC Prediction	10.1						

"From Waverley's point of view, we would definitely like to look more at HydroLOGIC in the future, particularly coming up to first irrigation, and need a full season running with WaterTrack to understand how this tool can help our business. More information on our soil moisture and water infiltration from probes and Irrimate evaluations will help us with shift times and irrigations."
- Andrew Greste, 2006

Boggabri site

In the 2005/06 season HydroLOGIC was able to save an irrigation through optimising irrigation schedules, while post season Irrimate™ demonstrated that additional savings could be made through adopting more efficient irrigation practices. The Irrimate™ storage meters and WaterTrack™ identified that excessive losses were occurring through seepage in the storage and that 190 Ml could be saved by improvements to the management of this storage. Irrimate™ optimisations of irrigation techniques identified further gains of the same order by changing irrigation practices.

Irrigation scheduling

The results from both seasons on this site reflect a typical small, family operated farm currently restricted by infrastructure and resource availability. The results from the HydroLOGIC treatment indicated some potential to finetune irrigation scheduling with yield and water use advantages. During the 2005/06 season, an irrigation was saved in the HydroLOGIC treatment with a yield advantage (Table 6). Subtle changes in timing during the 2006/07 season did not change final yield, however the ability of the HydroLOGIC software to accurately predict irrigation deficits up to 6 days prior to an event demonstrates the true value of this tool (Table 6c).

Table 6. Kilmarnock irrigation schedules; (a) Field B, 2005/06; (b) Field D, 2006/07; (c) HydroLOGIC predictions during 2006/07.

(a)

Irrig No.	Date	Standard	Date	Optimised	Difference
Pre-Irrig.	-	-	-	-	-
1	30-Dec	103mm *	27-Dec	83mm	3 days
2	18-Jan	81mm *	11-Jan	92mm	7 days
3	29-Jan	95mm	28-Jan	91mm	1 day
4	7-Feb	81mm	8-Feb	75mm	1 day
5	24-Feb	83mm	27-Feb	87mm	3 days
6	11-Mar	98mm			

* Estimated from NMM and calculated evapotranspiration (FAO56)

(b)

Irrig No.	Date	Standard	Date	Optimised	Difference
Pre-Irrig.	10-Oct	102mm	10-Oct	102mm	Same day
1	15-Dec	88mm	13-Dec	91mm	2 days
2	4-Jan	77mm	2-Jan	92mm	2 days
3	16-Jan	96mm	15-Jan	95mm	1 day
4	29-Jan	107mm	26-Jan	49mm	3 days
5	9-Feb	88mm	6-Feb	105mm	3 days
6	21-Feb	108mm	19-Feb	96mm	2 days

(c)

	HydroLOGIC Predictions			Actual Events	
Irrig No.	RunDate	Irrigation Date	Deficit	Date	Measured Deficit
Pre-Irrig.	-	-	-	10-Oct	102mm
1	7-Dec	13-Dec	81mm	13-Dec	91mm
2	1-Jan	2-Jan	92mm	2-Jan	92mm
3	12-Jan	16-Jan	98mm	15-Jan	95mm
4	24-Jan	26-Jan	**95mm**	26-Jan	**49mm** [A]
5	2-Feb	6-Feb	94mm	6-Feb	105mm
6	15-Feb	19-Feb	**74mm**	19-Feb	**96mm** [B]

A. Rain and cloud cover

B. Partial refill of profile at 5th irrigation

Final yield

Excellent final yields were achieved in both seasons at this location, in spite of lower than average rainfall during the 20006/07 growing season (Table 7).

Table 7. Kilmarnock final yields; (a) Field B, 2005/06; (b) Field D, 2006/07.

(a)

Treatment	Sample type	Bales/ha	len	uni	sfi	str	el	mic
Optimised	Maturity Picks	11.8	1.12	80.46	12.15	29.48	4.38	3.36
Standard	Maturity Picks	10.9	1.15	80.33	11.78	30.50	4.10	3.40
Optimised	Segmented Picks	11.7						
Standard	Segmented Picks	10.1						
Optimised	Machine Yield	9.2						
Standard	Machine Yield	9						
Optimised	HydroLOGIC Prediction	9.6						
Standard	HydroLOGIC Prediction	10.44						

(b)

Treatment	Sample type	Bales/ha	len	uni	sfi	str	el	mic
Optimised	Maturity Picks	14.2	1.20	84.50	6.80	34.53	5.97	4.10
Standard	Maturity Picks	14.3	1.21	84.23	6.60	35.83	5.67	3.57
Optimised	Machine Yield	11.2						
Standard	Machine Yield	11.3						
Optimised	HydroLOGIC Prediction	-						
Standard	HydroLOGIC Prediction	-						

Above: Dan Munk, Andrew Murray and John Watson 30th June 2006. Photo: Dirk Richards, CSIRO.
"We would definitely like to look more at HydroLOGIC to help with scheduling in general, and really need a full season running with WaterTrack to understand how this tool can help our business. More information on our soil moisture and water infiltration from soil probes and Irrimate evaluations will help us with shift times and irrigations, and learning more about storage seepage losses has benefits to the farm and the environment. We are dedicated to changing irrigation practices to increase flow rates into the fields to reduce deep drainage and waterlogging, and to ameliorate storage losses where possible. " - John Watson, 2006

Integration opportunities

As each product targets a specific area of water management, there are a range of potential areas for integration of software and knowledge streams that have been highlighted through this research. These include:

- HydroLOGIC calculated deficits could be incorporated into Irrimate to determine the optimum deficit to fine tune the irrigation to. This could also be incorporated into WaterTrack to use in prediction mode.
- WaterTrack accurately calculates losses in every component and thus produces accurate partitioned losses over the whole farm, whilst HydroLOGIC accurately predicts crop water use, based on available soil moisture, leaf area development, fruit development, and assimilate production within the plant. The obvious integration of these tools involves using the amount of water delivered to the plant from WaterTrack within HydroLOGIC to accurately predict field water use.
- Irrimate infiltration curves could be incorporated into HydroLOGIC to allow the simulation of regulated deficit irrigation and partial filling of the root zone at irrigation events.
- Utilising HydroLOGIC within WaterTrack to enhance the localised prediction of crop water use and yield potential.
- Adoption of the seven layer HydroLOGIC soil water balance within WaterTrack, with the potential to utilise the APSIM soil water balance model in the future. This commonality may improve the accuracy of the soil water component and allow simpler integration of HydroLOGIC into WaterTrack, in addition to assisting in data sharing between tools.

There may also have been opportunities in the area of data sharing between WaterTrack, Irrimate and the whole CottonLOGIC suite of tools. Being able to enter farm, field, crop information and observations in a central location would have had obvious benefits to data

integrity and effective use of management time. However the cessation of the cotton management support systems team responsible for the development of decision support in the industry has prevented this being further explored. The cessation of the team and this project means that there will be no further support and training provided for HydroLOGIC. It is anticipated that the current HydroLOGIC software will be only available for download on the CSIRO/CRC software tools website.

Further details on this research can be found in the CSIRO-Cotton CRC Research reports, which outline all details of these experiments.

Outcomes

5. Describe how the project's outputs will contribute to the planned outcomes identified in the project application. Describe the planned outcomes achieved to date.

This project conducted research into methods to maximise the efficiency and profitability of cotton production, irrigation water and other crop inputs. The research and management tools developed through the project allow calculated decisions to be made regarding crop management, the allocation of water and cropping areas on individual farms. By providing management risk information, and improving the efficiency of inputs, growers can maximise the bottom line and ultimately their own sustainability. Widespread extension of project findings and adoption of research outcomes and decision aids has the potential to empower people and improve the perception of the cotton industry to the general public.

Extension and communication of research results has been important to achieving the planned outcomes and adoption within the industry. Findings documented in this final report and elsewhere have been was presented and discussed at the following meetings/forums:

- Research results and information regarding HydroLOGIC was presented at three 'Hand-On-Research' sessions at the 12th Australian Cotton Conference, Broadbeach, 10-12th August 2004.
- An video interview was conducted with David Kelly, 23rd August, regarding the irrigation decision support tool HydroLOGIC and experiences with using it in the 2003-04 season, which subsequently appeared on the 'Web on Wednesday' session at www.csd.net.au. Following release of this footage an interview was given to the Northern Daily Leader on the 14th December.
- Contributions were made to a poster titled '*Decision support tools for Australian farmers'*, which was displayed at the 4th International Crop Science Congress, Brisbane, 27thSeptember-1st October 2004.
- Presentation at the Cotton Consultants Association AGM regarding irrigation scheduling and HydroLOGIC at Goondiwindi, 21st October.
- A Radio interview regarding this seasons Bollgard research was conducted with Moree 2VM, 23rd December 2004.
- Presentations at the Gwydir field day in conjunction with Greg Constable and Steve Yeates, 11th March 2005, regarding research into Bollgard varieties and response to moisture stress at different developmental stages.
- Presentation at the Upper Namoi field day, 21st March 2005, outlining key research results from the Bollgard soil moisture stress research conducted at Moree and Narrabri.
- Represented the CSIRO Cotton research unit at the Narrabri Innovation festival, 2nd May 2005.

- Radio interviews regarding Bollgard research and HydroLOGIC was conducted with Moree 2VM, 9th May 2005, 30th June 2005, and with Gunnedah GGG on the 14th of November 2005.
- Presentation to UNE Cotton production course students regarding crop modelling and irrigation at Narrabri on the 25th May 2005.
- Presentation at the Cotton CRC Extension workshop outlining current and future decision support tools in collaboration with Sandra Deutscher, Bribie Island, 5th -7th July 2005. One outcome from this presentation was the development of the Cotton CRC water quality web tool.
- Compiled research and evaluation results regarding HydroLOGIC application research for presentation at the CSD-CSIRO Research Review by Dr Mike Bange, Narrabri, 20th July 2005.
- Attended and discussed research and DSS development at a Plant Industry DSS workshop held in Canberra, 30th November to 1st December 2005.
- Presentation at the CRC Research Review outlining decision support tools for irrigated cotton water management including HydroLOGIC, 15th-16th August 2005.
- Research results and information regarding HydroLOGIC and Bollgard irrigation trials presented to growers and consultants at technical updates at Goondiwindi (31st January 2006) and St George (1st February).
- Presentation to National Water Initiative staff on HydroLOGIC and current research directions, Narrabri, 9th November 2005.
- Video interviews conducted on the 1st March 2006 with Big Bridge Pty Ltd, regarding water research in cotton at ACRI for possible inclusion in a future water exhibit at the Australian Cotton Centre, Narrabri.
- Cotton CRC water focus team technical update, Narrabri, 4th – 6th April 2006.
- Presentation to the Elders Agronomy Technical team at Goondiwindi on the 6th July 2006, regarding the 2005-06 Bollgard-Conventional irrigation trial results and HydroLOGIC.
- Presentation to Monsanto representatives on the Bollgard-Conventional research results on the 20th July 2006, Toowoomba
- Presentation to Mark Hickman and lecturers from Dalby Ag College as part of the 'Cotton basics' course on the topics of irrigation, water use and decision support aids for irrigation management on the 22nd August 2006
- Presentation at the Cotton CRC Science Day on the Bollgard water research results, at the 13th Cotton Conference, Gold Coast, 7th August 2006.
- Presentation at the 'Whole farm water management' Hands-On-Research session at the 13th Cotton Conference, Gold Coast, 10th August 2006.
- Bollgard research results and HydroLOGIC were discussed on a CSD Web-On-Wednesday video by Steve Yeates and Dirk Richards, available through the CSD web site on 29th November 2006.
- Video footage collected in November 2006 with Big Bridge Pty Ltd, regarding CSIRO water research and decision support in cotton at ACRI for inclusion in a future water exhibit at the Australian Cotton Centre, Narrabri.
- Presentation to UNE Cotton production course students regarding crop modelling and irrigation at Narrabri in August 2006.
- James Neilsen, Steven Yeates and Dirk Richards, as members of the Cotton CRC water team, attended field days throughout the industry presenting trial results from various water related research. These were Moree (8th March), Warren (20th March), Trangie

(13th March), Lower Namoi (8th March), Upper Namoi (21st March), and Hillston (21st March). Cotton growers and consultants were updated on the latest CSIRO water and irrigation research, including water research conducted within CSIRO Plant industry, results from the CRC Irrigation optimisation trials (Richards, Jackson), Bollgard water use, scheduling and physiology trials (Yeates, Richards), and evaporative demand and plant stress research (Neilsen).

- Discussion with Simon Smalley, NRM Water General Manager, Australian Department of Agriculture, Fisheries and Forestry, regarding water use information in cotton, on the 12th January 2007.
- Presentation to visiting Bayer Crop Science representatives from Turkey at Narrabri on the 27th February 2007, regarding the irrigation and physiology research, and decision support tools in the Australian industry.
- Contributions to the Cotton CRC Research and Development for Irrigated Cotton meeting, 22nd March, 2007.
- Discussions with Jan Paul van Moort from Hassall & Associates regarding the marketing proposal for decision support tools and initiatives, Narrabri, 13th April 2007.
- Cotton CRC Water Focus team planning workshop, Goondiwindi, 3rd April 2007.
- Presentation to UNE Cotton production course students regarding crop modelling and irrigation at Narrabri in 23rd May 2007.

6. Please describe any:-

a) technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.);
b) other information developed from research (eg discoveries in methodology, equipment design, etc.); and
c) required changes to the Intellectual Property register.

7. Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. What are the take home messages?

The take home messages from this research project are:

Bollgard water use and scheduling

- Bollgard had a proportionally higher boll load for the size of the plant and a greater yield loss following severe water stress late in flowering compared with the equivalent conventional variety.
- Bollgard showed resilience or adaptation to slight stress via stretching irrigations by reducing leaf area but producing the same yield as fully irrigated with less applied water.
- Bollgard cotton may not have the same yield potential as conventional cotton in longer seasons due to a smaller plant that matures earlier mainly due to less tip damage and higher early retention.
- Extraction patterns and the depth of rooting were similar in the Bollgard and conventional treatments by the end of the season.
- Bollgard®II had the potential to use less water whilst maintaining a yield advantage.
- Bollgard II may be more sensitive to larger deficits (>55-60% PAWC), late in flowering and should be watered before conventional fields.
- A reduction in gross and irrigation water use efficiency was only found in Bollgard®II where moisture stress was experienced at or close to cut-out.

Application and use of HydroLOGIC in the industry

- HydroLOGIC user surveys indicated great value in the current decision support tool, with:
  - 36% of respondents using the software to compare water use across farms,
  - 44% of respondents finding the software easy to use,
  - 50% of respondents finding the data required by the software easy to collect,
  - 78% of respondents saw HydroLOGIC fitting into their enterprise, and
  - 60% of respondents indicating their wanted to learn more about HydroLOGIC.
  - The greatest value in HydroLOGIC was in the areas of limited water (18%), irrigation scheduling (11%) and first irrigation (8%).
- A journal manuscript outlining the development process and attributes of the HydroLOGIC irrigation management software, with particular emphasis on functionality and its application to irrigation decisions within the Australian cotton industry, has been submitted to the Elsevier Agricultural Systems Journal.
- Feedback from HydroLOGIC trial co-operators and users indicated a mixture of strategic and tactical use including; area to plant depending on water available; confirming scheduling decisions (consultants); benchmarking crop water use after harvest. A key application of the software was late in the season and when determining the last irrigation, with HydroLOGIC often indicating that the final irrigation was not required.
- Further development is warranted in the areas of climate forecasting, Bollgard variety attribute developments, soil moisture balance, irrigation application and leaf area observations. Specifications in these areas were developed as part of this project.
- Validating HydroLOGIC for alternative irrigation systems such as lateral move and drip requires further effort.

Documentation and integration of irrigation decision tools

- Research over two seasons demonstrated the value in using the Irrimate™, WaterTrack™, and HydroLOGIC tools to assist in separate aspects of water management. The trials indicated the combined use of these products can result in significant water savings through improved irrigation efficiency, optimised water scheduling, identification of on-farm losses, and changes in farm management and infrastructure.
- All products have been rigorously tested previously and were further validated through these trials. Field measurements were taken throughout the season for soil moisture, plant growth, pumped water volume, irrigation application, and stored water volume. These measurements were compared against the calculations of each product which resulted in the successful validation of each product. Some improvements were also made to the products based on advice from the growers involved.
- All tools provided good commercial estimates of crop water use and use of any would result in better irrigation practice. Through the addition of soil infiltration data from Irrimate evaluations, WaterTrack was able to calculate accurate field benchmarking figures for a single field, although calculated crop water use differed between the tools. HydroLOGIC calculates crop water use (evapotranspiration) through a rigorous daily evaluation of both soil and plant components, while WaterTrack calculates daily crop water use from interpolated potential evapotranspiration and crop factors (Allen et al., 1998). Daily deficits from both HydroLOGIC and WaterTrack were compared with C-Probe and Neutron Probe readings. While there were differences in calculated crop water use between the tools, additional work calibrating the measured soil moisture deficits is required to determine the cause of these differences.

Extension Opportunities

8. Detail a plan for the activities or other steps that may be taken:
   (a) to further develop or to exploit the project technology.
   (b) for the future presentation and dissemination of the project outcomes.
   (c) for future research.

Research results from this project have been successfully communicated to the Australian cotton industry via industry publications, media release, presentations and all other relevant media. An essential component of the projects success has been the close collaboration with the extension network. Continued effort will be required from members of the National Cotton Extension team to maintain the extension and promotion of the research results, tools and resources developed in this project, as IDO's and specialist extension staff are the first point of call for growers and consultants alike. For example, due to the cessation of the cotton management support systems team responsible for the development of decision support, there will be no further support and training provided for HydroLOGIC. This situation is disappointing considering the value of this tool as shown by research in this project. The software will therefore only be available for download on the CSIRO/CRC software tools website.

A journal manuscript titled 'HydroLOGIC: An irrigation management system for Australian cotton' by Q.D. Richards, M. P. Bange and S.B. Johnston, has been submitted to the Elsevier Agricultural Systems Journal. This paper summarises the attributes of the HydroLOGIC irrigation management software, with particular emphasis on functionality and its application to irrigation decisions within the Australian cotton industry. The software development process is documented to provide direction for future software application initiatives, with particular emphasis on a process of user feedback, evaluation and support requirements providing direction to software development.

8. A. List the publications arising from the research project and/or a publication plan. (NB: Where possible, please provide a copy of any publication/s)

Reports

- Richards, QD, Tennakoon, S, Milroy, S, 2004, *Water use efficiency in the Australian cotton industry*, in Dugdale, H., Harris, G., Neilsen, J., Richards, Q.D., Roth, G., Williams, D., (Eds), 2004. WATERpak - a guide for irrigation management in cotton, Cotton Research and Development Corporation and Cotton CRC, Narrabri.
- Milroy, S, Richards, QD, 2004, *Managing irrigated cotton agronomy*, in Dugdale, H., Harris, G., Neilsen, J., Richards, Q.D., Roth, G., Williams, D., (Eds), 2004. WATERpak - a guide for irrigation management in cotton, Cotton Research and Development Corporation and Cotton CRC, Narrabri.
- Milroy, S, Richards, QD, 2004, *Managing irrigation with limited water*, in Dugdale, H., Harris, G., Neilsen, J., Richards, Q.D., Roth, G., Williams, D., (Eds), 2004. WATERpak - a guide for irrigation management in cotton, Cotton Research and Development Corporation and Cotton CRC, Narrabri.
- Richards, QD, Bange, MP, 2004, *HydroLOGIC furrow irrigation water management software*, in Dugdale, H., Harris, G., Neilsen, J., Richards, Q.D., Roth, G., Williams, D.,

(Eds), 2004. WATERpak - a guide for irrigation management in cotton, Cotton Research and Development Corporation and Cotton CRC, Narrabri.

Submitted journal manuscripts

- Richards, Q.D., Bange, M.P., Johnston, S.B., 2007, *HydroLOGIC: An Irrigation Management System for Australian Cotton*, intended for publication in Agricultural Systems.

Peer reviewed conference papers

- Moore, A.D., Angus, J.F., Bange, M.P., Crispin, C.J., Donnelly, J.R., Freer, M., Herrmann, N.I., Ottey, H.E., Richards, Q.D., Salmon, L., Stapper, M., Suladze, A., 2004, *Computer-based decision support tools for Australian farmers*, 4th International Crop Science Congress

Conference papers

- Richards, Q.D., Roberts, G.N., Bange, M.P., Felton-Taylor, C., and Gregory, R., 2004. *Managing cotton under limited water conditions using HydroLOGIC*. Proceedings of the 12th Australian Cotton Conference, Brisbane, August 2004
- Richards, D., Yeates, S., Roberts, J., and Gregory, R., 2006. *Does Bollgard®II cotton use more water?* Proceedings of the 13th Australian Cotton Conference, Gold Coast, August 2006.
- Yeates, S., Richards, D**.**, Roberts, J., and Gregory, R., 2006. *Progress in evaluating the moisture stress response of Bollgard II® compared with conventional cotton.* Proceedings of the 13th Australian Cotton Conference, Gold Coast, August 2006.

Conference posters

- Moore et al, 2004, '*Decision support tools for Australian farmers'*, 4th International Crop Science Congress, 27th September-1st October 2004, Brisbane.

Collaboration acknowledgements

- Cotton Seed Distributors, 2004. *An Australian guide to Bollgard II management'* publication in October 2004, detailing sowing date simulation response curves for Emerald, Goondiwindi and Hillston, and the HydroLOGIC software.
- Parakrama, A., Jones, R., Letcher, R., 2005, *The farm level impacts of water sharing plans in the Namoi Valley: A stochastic dynamic programming analysis*, paper presented to the 49th Annual Conference of the Australian Agricultural and Resource Economics Society, Coffs Harbour, 9-11 February, 2005.
- Hood, S., Carrigan, E., 2006. *Evaluating Alternative and Bankless irrigation systems*, paper presented and published at the 13th Cotton Conference, Gold Coast, 10th August 2006.
- Cotton Seed Distributors, 2006. *'Options in a low water year'* publication, Cotton Seed Distributors, Australia.

Industry publications

- Deutscher, S., Bange, M., Larsen, D., and Richards, D., 2004. *Delivering science to agribusiness: Australia's cotton research on the net*. The Australian Cottongrower, June-July 2004.

- Richards, D., Bange, M.P., Linsley, D., and Johnston, S., 2004. *Challenging weather conditions during the 2003-04 cotton season,* The Australian Cottongrower, June-July 2004.
- Richards, D., and Bange, M., 2004. *HydroLOGIC irrigation trial*, 2003 Lower Namoi trial book, New South Wales Department of Primary Industries.
- Deutscher, S., Bange, M.P., Larsen, D., Richards, Q.D., 2004. *Delivering science to agribusiness: Australia's cotton research on the we*b, The Australian Cottongrower, June-July 2004.
- Richards, QD, Bange, MP, Linsley, D, Johnston, SB, 2004, *Challenging weather conditions during the 2003-04 cotton season'*, The Australian Cottongrower, June-July 2004.
- Richards, QD, Bange, MP, Linsley, D, Johnston, SB, 2004, *A review of weather conditions during the 2003-04 cotton season in Narrabri'*, 2005 Lower Namoi field day book, New South Wales Department of Primary Industries.
- Richards, QD, 2005. *What's happening in water research this season?* The Australian Cottongrower, February-March 2005
- Richards, QD, 2005, *HydroLOGIC for irrigation decisions*, 2005 Lower Namoi Field day book, New South Wales Department of Primary Industries.
- Richards, D., and Bange, M.P. 2005. *Warm and dry: a perfect recipe for high (irrigated) cotton yields,* The Australian Cottongrower, June-July 2005.
- Richards, Q.D., and Murray, A., 2006, *'On-farm irrigation optimisation trials in 2005/06'*, 2006 Lower Namoi field day book, New South Wales Department of Primary Industries.
- Yeates, S., and Richards, Q.D., 2006, *'Evaluating moisture stress response in Bollgard II® and conventional cotton'*, 2006 Lower Namoi field day book, New South Wales Department of Primary Industries.
- Richards, Q.D., and Murray, A., 2006, *'Optimising on-farm irrigation: 2005-06 trials'*, The Australian Cottongrower, April-May 2006.
- Richards, D., and Bange, M.P., 2006, *2005-06 seasonal climate review*, The Australian Cottongrower, June-July 2006 edition, and in trial result books compiled by cotton industry development officers, in The Australian Cottongrower yearbook, and provided on request to CSD and private consultants.
- Richards, D., and Bange, M.P., 2006. *2006-07 seasonal climate review*. The Australian Cottongrower Magazine, May-June 2006.
- Richards, D., Yeates, S., Neilsen, J.E., 2007. CSIRO Water and Irrigation Research, Cotton CRC Irrigation optimisation trials, Bollgard water use, scheduling and physiology trials, multiple articles which were published in 2007 field day books and as CSIRO research brochures.
- Richards, Q.D., Bange, M.P. 2007. *Using HydroLOGIC in strategic decisions*; *Using HydroLOGIC for benchmarking*. Knowledge Management in Cotton and Grain Irrigation Workshop, compiled by David Wigginton, Cotton and Grains Irrigation Knowledge Broker.

Software manuals, specification and white paper documents

- Richards, Q.D., Bange, M.P., Johnston, S.B., 2005. *HydroLOGIC Irrigation water management and risk analysis software for Cotton User Manual V2.01*, CSIRO Plant Industry and Australian Cotton CRC, Narrabri.

- Richards, Q.D., 2004. Photo-guide for determining Leaf Area Index in Normal Leaf and Okra Leaf varieties, CSIRO Plant Industry, Narrabri.
- Richards, Q.D., 2004. *Implementing SOI and climate forecast in HydroLOGIC*. Development Discussion Paper, CSIRO Plant Industry, Narrabri.
- Richards, Q.D., Linsley, D., Johnston, S.B., 2006. *Cotton CRC Water Quality Calculator Functional Specifications*, CSIRO Plant Industry, Narrabri.
- Richards, Q.D., Linsley, D., Johnston, S.B., 2006. *Cotton CRC Water Quality Calculator help manual*, CSIRO Plant Industry, Narrabri.
- Clancy, L., Richards, Q.D., Bange, M.P., 2006. *CottBASE Functional Specifications,* CSIRO Plant Industry, Narrabri

Media articles

2004

- Richards, QD, Cotton CRC eNews regarding the availability of Leaf Area Index Photoguides for use with HydroLOGIC, 20th December 2004.

2005

- *Decision support workshop well worth attending*, discussing new features of HydroLOGIC and training workshops, Lower Namoi Cottontales #2, September 2005.
- *Cotton growers access latest research*, CSIRO Plant Industry and Cotton CRC media release, September 2005.
- *Important workshop for district cotton growers*, article detailing the decision support workshop and tools, Narrabri Courier, 13th September 2005.
- *New version of cotton irrigation management software HydroLOGIC released,* detailing the decision support workshop and tools, Water Source, Newsletter of the NSW North-West regional committee of the Irrigation Association of Australia, October 2005.

2006

- *Irrigation optimisation trial update*, discussing research results to date. Lower Namoi Cottontales #22 and special edition #1, January 2006.
- *Water use research findings on display*, Balonne Beacon, February 9, 2006.
- *Water Quality Calculator*, outlining a new web tool for irrigators. Lower Namoi Cottontales #27, March 2006.
- *New tool helps manage irrigation water quality*, CSIRO Plant Industry and Cotton CRC media release, March 2006.
- *Insect-resistant cotton also water efficient,* CSIRO Plant Industry Newsletter, Issue 15, Spring 2006. This information also appeared on the SeedQuest web site courtesy of Mr Trevor Johnston.
- *Cotton industry selects its best,* Rural Weekly, 2nd June 2006.
- *Cotton awards finalists announced*, The Australian Cottongrower Magazine, June-July 2006.
- *Cotton Pickers,* Canberra Times, 25th September 2006.
- *Limited water options*, Darling Downs Cottontales #1, October 2006.
- *'Options in a limited water year 2006'* CSD Publication, containing sowing date simulations, published in October 2006.
- *GM Cotton*, Australian R&D review, 15th and 30th October 2006.
- *Drought forces cropping review*, Queensland Country Life, 19th October 2006.

- *Timing of first irrigation and limited water scenarios using HydroLOGIC*', Border Rivers CottonTales #3, 24th November 2006.
- *HydroLOGIC irrigation system for cotton crop*, www.fibre2fashion.com, 1st December 2006.
- CSD '*Fact on Friday'* e-newsletter on using HydroLOGIC to assist with first irrigation decisions, which was distributed by CSD on the 1st December 2006.
- Richards, D., Rochester, I., Deutscher, S., 2007 *Petiole sampling and NutriLOGIC - do you have enough N?* Cotton CRC extension handout and flyer format for general distribution, December 2006.

2007

- *Cotton growers efficient water users*, Goondiwindi Argus, 10th January 2007.
- *Irrigation trials target improved efficiency on the Downs,* The Australian Cottongrower, January-February 2007.

B. Have you developed any online resources and what is the website address?

Information sheets regarding the HydroLOGIC software and trials results have been published online on the CSIRO web site (www.csiro.org.au) and on the Cotton CRC web site (www.cotton.crc.org.au).

Part 4 – Final Report Executive Summary

The broad aims of CCC CRC 5.2.03 'Delivering science to agribusiness: Smart approaches to cotton irrigation management' were to; conduct irrigation research for emerging crop management issues and alternative cotton cropping systems; provide industry with an enhanced version of HydroLOGIC; and document a decision framework for integrating irrigation management tools. This project formed a key application and feedback link within the Cotton Management Support System Team, which developed targeted, cotton specific management tools for the Australian industry. This project also supported the CSIRO Plant Industry water research team of Mr Stephen Yeates (scientific development), Mr Dirk Richards (DSS development and application) and Mr James Neilsen (plant water relations).

Key research findings and outcomes were:

- ***Bollgard water use and scheduling***
  - Extraction patterns and the depth of rooting were similar in the Bollgard and conventional treatments by the end of the season.
  - Bollgard®II had the potential to use less water whilst maintaining a yield advantage.
  - Bollgard®II may be more sensitive to larger deficits (>55-60% PAWC), late in flowering and should be watered before conventional fields.
  - A reduction in gross and irrigation water use efficiency was only found in Bollgard®II where moisture stress was experienced at or close to cut-out.

Application and use of HydroLOGIC in the industry

- Feedback from HydroLOGIC trial co-operators and users indicated a mixture of strategic and tactical use including; area to plant depending on water available; confirming scheduling decisions (consultants); benchmarking crop water use after harvest. A key application of the software was late in the season and when determining the last irrigation, with HydroLOGIC often indicating that the final irrigation was not required.
- HydroLOGIC user surveys indicated great value in this decision support tool, with:
  - 36% of respondents using the software to compare water use across farms,
  - 44% of respondents finding the software easy to use,
  - 50% of respondents finding the data required by the software easy to collect,
  - 78% of respondents saw HydroLOGIC fitting into their enterprise, and
  - 60% of respondents indicating their wanted to learn more about HydroLOGIC.
  - The greatest value in HydroLOGIC was in the areas of limited water (18%), irrigation scheduling (11%) and first irrigation (8%).

Documentation and integration of irrigation decision tools

- Research over two seasons demonstrated the value in using the Irrimate™, WaterTrack™, and HydroLOGIC tools to assist in separate aspects of water management. These experiments indicated the combined use of these products can result in significant water savings through improved irrigation efficiency, optimised water scheduling, identification of on-farm losses, and changes in farm management and infrastructure.
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Research results from this project were successfully communicated to the Australian cotton industry via industry publications, media release, presentations and all other relevant media. An essential component of the projects success was the close collaboration with commercial cotton growers, consultants and the Cotton CRC extension network.