AN INVESTIGATION OF IN-FIELD IRRIGATION MANAGEMENT PRACTICES TO IMPROVE THE EFFICIENCY OF FURROW IRRIGATED COTTON PRODUCTION SYSTEMS

FINAL REPORT

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Rural Water Use Efficiency Initiative

Research and Development Program - Project 11

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Executive Summary

The Australian cotton industry relies heavily on surface irrigation systems to maintain its production levels. However, expanding development and the requirements for environmental flows have placed a significant demand on industry to secure and manage its water resource in an economically and environmentally sustainable manner. The improvement of water use efficiency is a strategic step to achieving economic and environmental sustainability goals in irrigation developments.

A plethora of past research work has been undertaken in furrow irrigation systems to show the pathways of water loss and the potential for cost effective improvement in efficiency. Much of this work has suggested that deep drainage contributes to a significant part of the loss of water in surface irrigated cotton production systems. Further, this deep drainage can potentially contribute to salinity problems, nutrient and pollutant leaching into groundwater and groundwater table rise. However, deep drainage has continued to be poorly understood or grasped by industry. Many and varied methods of measurement and estimation of deep drainage have been used by researchers to quantify the amount of deep drainage occurring due to irrigation and understand the processes and key irrigation management variables affecting deep drainage. However, the range of deep drainage measurement methodologies and results reported has added to the uncertainty associated with the adequacy of deep drainage measurement and the effectiveness of the various management options.

The evaluation of alternative management practices for surface irrigated cotton systems has demonstrated that even simple changes in the irrigation application (eg. changing the application rate and time) can significantly improve (up to 30%) the efficiency of irrigation applications by reducing tailwater and deep drainage. However, opportunities also existed to further extend improved irrigation management practices within the major cotton growing valleys in Queensland. Simple methods of assessing irrigation efficiency and performance can be applied to benchmark efficiency and demonstrate the level of improvement in irrigation efficiency obtained through the adoption of best management practices.

The Queensland Department of Natural Resources and Mines commissioned this project with the aims of (a) measuring the volume balance components and quantifying deep drainage associated with surface irrigated cotton production systems, (b) assessing alternative surface irrigation management practices to improve volumetric and agronomic efficiencies, and (c) delivering and extending cost effective methods of improving surface irrigation efficiencies amongst cotton grower groups. To achieve these aims, field trials and grower field days and workshops were conducted throughout the project.

The key outcomes from this work include:

- Further refinement and development of the measurement tools for conducting volume balance assessments at the furrow and field scales;
- Confirmed that substantial deep drainage does occur under commercial surface irrigation of cotton;
- Highlighted the limitations of point scale measurement tools (i.e. lysimeters and neutron moisture meters) to predict volume balance parameters at the furrow and field scales;
- Demonstrated that irrigation performance measurements can be used to provide a measure of deep drainage risk under surface irrigation;
- Confirmed the potential to improve irrigation performance by optimising management variables (eg. inflow rates and cut-off times);
- Obtained and collated baseline data on surface irrigation management and efficiencies as a resource for further research and evaluation;

- Demonstrated that improving surface irrigation performance reduces waterlogging and crop stress events but that this needs to be understood and monitored as part of the crop agronomic management;
- Refined crop monitoring protocols to better target agronomic responses to changes in irrigation management;
- Contributed to the development of industry standard Best Management Practice;
- Raised awareness and initiated adoption of best management practices for surface irrigation across all cotton growing areas in Queensland; and
- Improved industry and farmer level capacity building through targeted extension workshops involving more than 220 growers and more than 90% of relevant industry extension staff.

1. Background and Project Opportunities

Surface irrigation is widely practiced by much of the Australian cotton industry. However, demand for water resources has been increasing due to expanding development and the requirements for environmental flows. Efficient use of water resources is needed to ensure that the water resource is being utilised in an economically and environmentally sustainable manner.

Research conducted by the National Centre for Engineering in Agriculture on behalf of the cotton industry (eg. Dalton *et al*. 2001) and has provided a clear understanding of the performance and efficiencies of surface irrigation systems in the cotton industry. While some opportunities exist to improve the efficiency of on-farm storage and distribution systems, the improved management of furrow irrigation applications provides the greatest opportunity for cost effective improvement in efficiency (Dalton *et al*., 2001, Raine and Foley 2002). Measured irrigation efficiencies of 50 to 95% on an event basis and 30 to 85% on a seasonal basis indicate that substantial losses to deep drainage are occurring on many furrow irrigated cotton fields.

Deep drainage can potentially contribute to poor water use efficiency, salinity problems, nutrient and pollutant leaching into groundwater and groundwater table rise. However, deep drainage has remained a contentious issue and one that has not been well understood or grasped by industry. Several studies have presented results of significant seasonal and individual (single event) irrigation deep drainage volumes. However, these findings are contrary to the widely held industry view that typical "cotton soils" of high clay content have a low saturated hydraulic conductivity and therefore, should have minimal deep drainage. Many and varied methods of measurement and estimation of deep drainage (eg. volume balance methods, lysimeters and soil solute studies) have been used by researchers to quantify the amount of deep drainage occurring in irrigation systems and understand the processes and key irrigation management variables associated with deep drainage. However, there is still uncertainty regarding the extent of deep drainage under surface irrigation and a focussed research directive has been difficult achieve.

The development of best management practices for surface irrigated cotton systems (Dalton *et al*. 2001) demonstrated that even simple changes in irrigation management (eg. application rate and time) could significantly improve efficiency (up to 30%) by reducing tailwater and deep drainage and better matching the water applied to the soil moisture deficit. However, these practices have not been widely adopted within the major cotton growing valleys of Queensland. Similarly, there are opportunities to expand the uptake of the simple methods of assessing irrigation efficiency and performance to benchmark efficiency and demonstrate the level of improvement in irrigation efficiency obtained through the adoption of best management practices.

The Queensland Department of Natural Resources and Mines commissioned this project with the aims of: (a) measuring the volume balance components and quantifying deep drainage associated with surface irrigated cotton production systems, (b) assessing alternative surface irrigation management practices to improve volumetric and agronomic efficiencies, and (c) delivering and extending cost effective methods of improving surface irrigation efficiencies amongst cotton grower groups. The key objectives of the project were to:

1. maintain a strategic pool of original research knowledge and directive into the effect of irrigation management practices on the water balance and irrigation efficiency of furrow irrigated cotton production systems,
2. provide a better understanding of the surface irrigation system water balance through physical measurement of all irrigation water balance parameters,
3. undertake a detailed study of the effect of irrigation management practices on the water balance of irrigated cotton,
4. investigate alternate irrigation management practices and develop best management practices to improve irrigation efficiency, and

5. deliver and demonstrate research findings and extend cost effective methods of improving irrigation efficiency amongst farmer groups in collaboration with the RWUEI adoption staff.

Field trials were conducted on commercial farms during each of the three project years. The field trials were used to: (a) quantify the components of the volume balance under surface irrigation, (b) evaluate the measurement technologies, (c) assess the alternative irrigation management practices and (d) provide a focus for the extension activities. The full details of the field trial activities are provided in Milestone Reports 1 to 3. A summary including the location and purpose of each field trial is provided in table 1. Field days and workshops were conducted throughout the project and the baseline data of the infield management practices and efficiencies necessary to predict deep drainage risk in furrow irrigated cotton regions was also generated (addresses objectives 4 and 5).

Table 1. Summary of field trial sites and activities

Year	Co-operator & Location	Outline/Purpose	Objectives addressed
1	Scott Seis, Macalister	Evaluation of alternative deep drainage measurement methods. NR&M lysimeter installed and other methods of deep drainage measurement were undertaken	1, 2 & 3
1	Cam Turner Goondiwindi	Volumetric and agronomic efficiency measurements and optimisation strategies evaluated	1, 2 & 4
2	Scott Seis, Macalister	Evaluation of alternative deep drainage measurement methods. NR&M lysimeter installed and other methods of deep drainage measurement were undertaken	1, 2 & 3
2	Neville Walton near Macalister	Volumetric, agronomic and economic irrigation efficiency measurements and optimisation were undertaken	1, 2, & 4
3	Patrick Hilliar near Macalister	Full volume balance measurements undertaken to determine deep drainage on furrow irrigated cotton on cracking clay vertisols	1, 2, & 3

This final report provides a summary of the project activities and outcomes. For consistency with the project aims, this final report is separated into the following areas of activities:

Section 2 – Quantifying deep drainage and evaluating the methods of measurement.

The experimental work in this section of the project was undertaken over the 3 years of the project. Detailed results and conclusions from this section of the project are presented in Milestone Reports 1 -3

Section 3 – Assessing alternative surface irrigation management practices to improve volumetric and agronomic efficiency.

The experimental work in this section of the project was undertaken in the first two years of the project. Detailed results and conclusions from this section of the project are presented in Milestone Reports 1 – 3.

Section 4 – Extension of research findings including industry extension and the development of a deep drainage predictive tool from infiltration characteristic data.

This work was undertaken during the first two years of the project. Detailed results and conclusions from this section of the project are presented in Milestone Report 2 (Parts 3 & 4).

The implications of this research for the cotton industry and the recommendations for future work are provided in sections 5 and 6, respectively.

2. Quantifying Deep Drainage and Evaluating the Methods of Measurement

Deep drainage in surface irrigated cotton production systems has remained a contentious issue and one that has not been well understood or grasped by industry. It can potentially contribute to poor water use efficiency, salinity problems, nutrient and pollutant leaching into groundwater and groundwater table rise. Dalton (2000) used volume balance measurements to calculate seasonal irrigation deep drainage losses from two fields in the McIntyre Valley of 105 mm (14%) and 197 mm (29%). Deep drainage associated with individual irrigation events ranged from 1 mm (1%) to 57 mm (50%). Zischke and Gordon (2000) modelled deep drainage losses across four cotton-growing areas in NSW and QLD of 9 to 972 mm per year based on soil properties. They also physically measured deep drainage fluxes using a lysimeter and found losses of 95 to 305 mm/yr under drip-irrigated cotton and 162 to 182 mm/yr under furrow irrigated cotton on the Darling Downs.

Silburn and Montgomery (2001) cite the widely held view (Hearn, 1998) that the typical "cotton soils" of high clay content have a low saturated hydraulic conductivity and therefore minimal deep drainage. However, they also cite the Shaw and Yule (1978) measurements of significant deep drainage and chloride leaching on lighter textured soils in Emerald. Obviously these soils are not comparable but the issue of soil type inherently clouds deep drainage questions within the industry. One specific concern is the potential for over-generalisations associated with the use of the term "cotton soils" and the lack of multi-site specific and soil specific drainage data.

Silburn and Montgomery (2001) refer to a range of reported studies using different measurement methodologies (ie. chloride mass balance, SaLF modelling, lysimeter studies, measured and modelled water balance and observed groundwater responses) to suggest that deep drainage could be in the order of 100-200 mm per year (or 1-2 ML/ha) for the soils commonly irrigated within the cotton industry. While the evidence seems to consistently suggest that many irrigated cotton farming systems exhibit deep drainage, there is still some debate within the industry as to the reality of deep drainage as well as the size and nature of any possible salinity threat. While there are many reasons for this current position, probably one of the main reasons is the lack of a standardised, accurate and reliable deep drainage measurement method. Hence, the main aim of this component of the project was to quantify deep drainage and evaluate the various methods to measure/estimate deep drainage under furrow irrigated cotton systems. This section discusses (i) the refinement of the volume balance approach, (ii) the assessment of the alternative measurement approaches investigated and (iii) the development of a deep drainage risk assessment tool using the measured infiltration characteristics and irrigation management practices.

Refining the Volume Balance Approach to Measuring Deep Drainage

Key Outcomes

- ***Further refinement and development of the measurement tools for conducting detailed volume balance assessments at the furrow and field scales***
- ***Confirmed that substantial deep drainage does occur under commercial surface irrigation of cotton***

Experiments were established over three years at two sites near Macalister (Darling Downs) on irrigated cracking clay vertisols. Results from the first two years of the project experiments (Milestone Reports 1 and 2) highlighted limitations in many point scale measurement systems (such as the lysimeter) thus limiting the accuracy and reliability of measurements of the water balance. During the third year of the project, a detailed volume balance study was undertaken including accurate measurement of the major water balance components (Milestone Report 3).

An experimental site was set up (on a cracking clay vertisol) to undertake detailed irrigation water balance measurements at the furrow scale to calculate deep drainage using the volume balance method. Water applied, soil moisture, tailwater and evapotranspiration measurements were measured from eight rows to represent the volume balance of the furrow irrigated production system.

A protocol of cross checks and rigorous sensor calibration was adopted to ensure that the water balance components were accurately measured. A Bowen Ratio Energy Balance method of evapotranspiration measurement was used to obtain measures of evapotranspiration during irrigation events. Accurate measurements of tailwater volumes were achieved through calibrated H-flumes. Soil moisture measurements were corrected for soil shrink-swell behaviour to improve the accuracy of soil moisture measurement. Further cross checks of the deep drainage measurements were provided using a soil solute mass balance study. Finally the irrigation advance and hydraulic properties were measured to enable the simulation model SIRMOD to be used to calculate infiltration and estimate deep drainage for comparison.

Point scale limitations associated with soil moisture measurement resulted where found to create uncertainties in the volume balance method. However, improved levels of confidence in deep drainage estimates were obtained where the soil moisture measures were adjusted to incorporate the soil shrinking and swelling volume correction. Deep drainage was estimated using the volume balance method to range from 13.9 - 41.0 mm for individual irrigations and to be approximately 124 mm on average for the furrow throughout the whole season (Table 2). Simulation model (SIRMOD) estimates of deep drainage ranged from 15.1 to 42.5 mm for individual irrigations and 144.1 mm for the season. A seasonal field average deep drainage of 71.5 mm was measured using the chloride mass balance method. The similarity in the volumes deep drainage estimated/measured by each method confirms that significant deep drainage did occur at the trial site. Similarly, the closeness of the volume balance and SIRMOD deep drainage estimates over both the individual and season timeframes indicates that the irrigation performance evaluations conducted using SIRMOD can be used with confidence.

While the average estimate of deep drainage using the chloride mass balance approach was in the same order of magnitude as the other methods (Table 2), the estimates for deep drainage within the field varied greatly from –41 to 198 mm (Milestone Report 3, Table 7). This wide range of estimated values and the lack of consistency in these values with the volumes infiltrated raises significant concerns over the accuracy of this method over short time frames. Hence, further research should be conducted to confirm the potential to use chloride profiles over either event or seasonal timeframes for deep drainage estimation.

Table 2. Estimates of deep drainage under furrow irrigated cotton at Macalister (2002/03)[1]

ASSESSMENT METHOD	IRRIGATION EVENT DEEP DRAINAGE (mm)	SEASONAL DEEP DRAINAGE (mm)
Volume balance	13.9 – 41.0	123.9
Infilt/SIRMOD evaluation	15.1 – 42.5	144.1
Chloride mass balance	Not Applicable	71.5

[1] Irrigation applied = 643 mm; In-season rainfall = 317 mm

Comparison between the Volume Balance, Lysimeter and SIRMOD estimated infiltration for point scale assessment of deep drainage

Key Outcomes

- ***Highlighted the limitations of point scale measurement tools (i.e. lysimeters and neutron moisture meters) to predict volume balance parameters at the furrow and field scales***

Research work conducted during the first two years of the project at Macalister on the Darling Downs utilised the NR&M lysimeter to take continuous deep drainage measurements. Two irrigations were conducted by the grower during the first season (Year 1 Technical Report, Part 1) and one irrigation during the second season (Milestone Report 2, Part 1).

The lysimeter experienced malfunction during the first season. The only lysimeter data that was collected during the first season was the recording that the lysimeter overtopped its volume capacity during the first irrigation. Based on the volume and plan dimensions of the lysimeter it can be calculated that greater than 44 mm deep drainage occurred during this irrigation. The modelled SIRMOD data is presented as an average deep drainage over the length of the furrow and also the deep drainage at the specific location of the lysimeter. SIRMOD estimated that 53 mm of drainage occurred at the lysimeter location and an average of 29 mm drainage occurred along the length of the furrow. There was reasonable correlation with the deep drainage levels measured by the lysimeter and SIRMOD in the first irrigation of the first season. In the second season of trial work, the lysimeter was repaired for more reliable operation and the volume balance method was more thorough due to funding availability.

The use of the irrigation advance data and InfiltV5 enabled the measurement of the infiltration function at an integrated furrow scale for individual irrigation events. Assuming the infiltration is consistent along the furrow length, an estimate of the infiltrated volumes at point scales within the field could be obtained. Where an accurate measure of soil moisture deficit at the same scale is obtained, this provides the ability to estimate deep drainage. There was a reasonable correlation with the deep drainage levels measured by the lysimeter and that calculated using the furrow averaged infiltration function and SIRMOD. This suggests that infiltration averaging along the furrow was appropriate for the furrow and management conditions investigated and that simulation modelling can be used to provide point scale measures of infiltration. However, as deep drainage is calculated by as the difference between the calculated volume infiltrated and the measured deficit, the accuracy of deep drainage estimates using this method are greatly affected by the scale and accuracy of the deficit measure.

The deep drainage measure calculated using the volume balance calculation for the whole furrow was not well correlated with the point scale measure/calculation obtained with the other two methods. The volume balance methodology adopted in the first two years of the project was inadequate. The soil moisture deficits were based on poor neutron probe calibrations and there were difficulties with tailwater measurement and in translating point scale measurements (ie deficits) to furrow or field scale. Hence, it did not provide a reliable method of measuring deep drainage at the point scales.

In most irrigations, the lysimeter at the trial site failed in its measurement of deep drainage due to equipment malfunction. Until this particular installation is renovated or replaced, this instrument cannot be considered a viable means of measuring deep drainage. The accuracy of the lysimeter as a method of deep drainage measurement is also difficult to define. Further, it only provides a point scale measure of deep drainage. It is difficult to be confident that such a device is representative of broader scales based on variable factors including field lengths, flow rates, soil cracking and soil moisture.

Development of a Deep Drainage Predictive Tool

Key Outcome

- ***Demonstrated that irrigation performance measurements can be used to provide a measure of deep drainage risk under surface irrigation***

As a consequence of the inherent difficulties of point scale measurements as well as the ability to integrate furrow scale measurements to calculate the event specific infiltration characteristics, a deep drainage predictive tool was developed. It was envisaged that it could be utilised by furrow irrigated cotton growers to assess deep drainage risk in terms of the key management and design variables (i.e. for different field lengths, opportunity times, soil moisture deficits, soil types and regions (St George, Goondiwindi, Darling Downs)) etc. This was seen as a potential industry extension tool and a major potential contributor to best management practice adoption. (Milestone Report 2, Part 4)

The deep drainage predictive tool was developed from a large database (over 150 individual irrigation events, across more than eight regions) of irrigation event water balance and infiltration characteristic monitoring from the last four years (i.e. including previous projects). Infiltration rate, cumulative infiltration volume and subsequent deep drainage volumes for an irrigation event are driven by many variables. Analysis of a large historic data set has shown that trends can be established relating to the variables of irrigation event timing during the season and irrigation duration. Other potential drivers of deep drainage such as soil ESP and irrigation water EC were not measured in the data sets and hence trends with deep drainage were not established. No relationship with soil moisture deficit and deep drainage was found in this data set. The database that has been developed can be added to with future irrigation data to further develop the deep drainage risk assessment tool.

A large volume of data was required to establish these trends for a single soil type in order to encapsulate the range of different variables. The Irrimate, INFILT and SIRMOD package of infiltration characteristic measurement allowed the generation of these data sets for the Goondiwindi region and to a lesser degree the Darling Downs region.

Perhaps more importantly the trends indicate the best management practices to improve irrigation efficiency and reduce deep drainage. Specifically these include management of irrigations specific to timing in the season to reduce deep drainage by reducing the irrigation duration to a minimum.

The data sets to date do not encompass a broad range of soil types for the Darling Downs and St George regions. Further, the quality of this data cannot be guaranteed for the initial phase (first 2 years) of data collection due to the development phase of the data collection process. Therefore the database and deep drainage risk tables may be limited in their application until further and better quality data sets are collected. However the simple process of data collection and deep drainage risk assessment shows promise as a method of deep drainage and irrigation efficiency risk assessment that could be utilised by irrigators, water use efficiency technicians and water use efficiency policy makers.

While this part of the project shows the “proof of concept” of using this data collection and analysis process to generate deep drainage and irrigation efficiency risk assessment tables, it is recommended that further work be undertaken to expand the data set into more soil type categories and better quality data sets (including measurement of other potential variables such as EC and ESP) to further refine these tables. It is recommended that this database be further developed to build an accurate and site-specific regime of deep drainage risk assessment tables.

3. Assessing alternative surface irrigation management practices to improve volumetric and agronomic efficiency

The efficiency of surface (furrow) irrigation is a function of the field design, infiltration characteristics of the soil, and irrigation management practices such as application rate and time (Hanson *et al.*, 1993; Raine *et al.*, 1998). While it is often claimed that the application efficiency of well designed and managed surface irrigated cotton is over 80% (Anthony 1995), there is little published evidence to confirm the widespread existence of these efficiency levels on commercial farms. Relatively high efficiencies (>80%) are possible for surface irrigation under experimental conditions where the levels of management and control are high (Douglas et al 1996 and Yule 1984). However, efficiencies achieved on-farm under commercial conditions are sometimes low and certainly highly variable. For example, Elliott and Walker (1982) reported efficiencies in the order of 50-70% for surface irrigation in Colorado while Smith (1988) observed efficiencies of 30-50% on one cotton farm. Yule (1984) conducted water balance measurements at Emerald in 1982/83 and 1983/84 and found that irrigation application was generally 70 to 90% efficient.

Benchmarking of whole farm irrigation efficiency in the Australian cotton industry (Dalton, 2000; Dalton *et al*., 2001) has shown that irrigation application efficiencies can be 45-95% in individual irrigations and 60-85% on a seasonal basis. This work has shown that there is significant potential for irrigation losses due to deep drainage and tailwater in furrow application systems. Related to this loss is the potential for water logging, valuable water loss to deep drainage, nutrient leaching, salinity risks and high tailwater pumping and de-silting costs. If irrigations are not evaluated then an understanding of the efficiency of irrigation application can only be assumed. Initial monitoring and modelling work using the IRRIMATE/SIRMOD surface irrigation evaluation and simulation package has indicated that there is significant scope for improvement of irrigation application efficiency. This can be achieved through simple modifications of irrigation management practices such as siphon application rate and the length of irrigation time, which can reduce deep drainage and tailwater volumes.

The aims of this component of the project were to:

- Evaluate the potential to improve volumetric efficiencies by reducing deep drainage and tailwater through better matching of irrigation application rate and time with irrigation deficit;
- Evaluate the potential to improve agronomic efficiencies by reducing crop waterlogging through shorter periods of inundation;
- assess the effect of the above two aims on economic irrigation efficiency; and
- integrate volumetric and agronomic monitoring systems to optimise irrigation management.

Key Outcomes

- ***Confirmed the potential to improve irrigation performance by optimising management variables (e.g.. inflow rates and cut-off times)***
- ***Demonstrated that improving surface irrigation performance reduces waterlogging and crop stress events but that this needs to be understood and monitored as part of the crop agronomic management***
- ***Refined crop monitoring protocols to better target agronomic responses to changes in irrigation management***

A trial was undertaken in Goondiwindi on a cracking grey clay soil in 2000/01 (Year 1 Technical Report, Part 2) to attempt to optimise irrigation flowrates and siphon cut-off times to minimise deep drainage and tailwater losses and water logging and thus improve volumetric and agronomic efficiency. The trial returned positive volumetric efficiency improvements and a significant reduction in water logging periods (up to 10 days reduced waterlogging). However insufficient agronomic monitoring and management returned a sub-optimal result in terms of agronomic irrigation efficiency. Hence, a further trial was conducted (2001/02) which married together both "volumetric" and "agronomic" irrigation efficiency monitoring and optimisation (Milestone Report 2, Part 2). This trial was undertaken near Dalby on a box soil. This experiment succeeded in demonstrating improvements in volumetric (water savings), agronomic (yield increases) and economic (increased return through greater production and reduced costs) water use efficiency.

The experimental program for the second trial involved one field that was split into a treatment and control block. Both blocks were similar in field length, size and slope and were monitored according to volumetric, agronomic and economic performance indicators. The treatment block was optimised according to the volumetric and agronomic performance indicators such as irrigation application rate and duration (volumetric optimisation), crop soil moisture, nodes above white flower, internode length etc (agronomic optimisation).

The experimental design included any variation between treatment and control management such as irrigation scheduling, growth regulation (pix application), pest management, nutrient and harvest time due to less waterlogging and/or other determining factors. Hence these were monitored and managed independently on both the treatment and control.

An indeterminate variety was used in both the treatment and control blocks such that any significant changes in plant response to the crop were less critical. The option for a second pix treatment within the treatment was available if needed (say over 32 rows) in case the crop grew significantly rank due to decreased waterlogging.

The main outcome of this experimental program was the improvement in water use efficiency through the simple management of irrigation application parameters such as application rate and duration. In summary irrigation improvements achieved by optimising irrigation application rate and time included:

- Volumetric efficiencies
  - 5 % increase in the irrigation application efficiency.
  - 16 mm per season reduction in tailwater
  - 33 mm per season reduction in deep drainage.
- Agronomic efficiency
  - Significant reductions in waterlogging periods due to irrigation throughout the season (up to 10 days waterlogging reduction)
  - Consequent extra 0.45 bales per hectare of crop production
- Economic Efficiency
  - $32 per megalitre greater return on water investment due to reduced water logging, water savings directed to extra production, improved yield and reduced pumping costs

Further, the improvement in volumetric, agronomic and economic water use efficiency could have been even more significant had the experimental program been undertaken on a farm that was not already achieving industry best practice (80% application efficiency as current practice). The ability to use the volumetric and agronomic irrigation monitoring and optimisation demonstrates that even the best practitioners can also achieve efficiency gains.

4. Extension of Research Findings

Irrigated cotton production has been typically managed by monitoring soil moisture changes. This has been achieved through the use of the neutron probe and more recently other soil moisture monitoring devices. However, if we step back and look at the whole farm water management picture, soil moisture only represents one part of the irrigation management equation.

Soil moisture monitoring has historically been used only for the timing of irrigation scheduling (ie. to determine "when" to irrigate). Essentially the soil moisture data gives the current soil moisture level in relation to a full point or field capacity (i.e. the full profile) and a refill point or some value above wilting point to reduce stress. In terms of the management of the plant this is valuable information. Depending on the available water in the soil profile "soil moisture deficits" in the cotton industry are typically managed in the order of 50–100 mm. However, it should be noted that if the soil moisture monitoring device is not calibrated against true values of volumetric soil moisture (ie. using bulk density and gravimetric sampling) then these are only relative values or soil moisture units and not accurate volumetric measures.

The other side of the irrigation management picture is the management of the volume of irrigation application to meet the soil moisture deficit (typically termed the irrigation application efficiency). Essentially if the soil moisture probe is well calibrated, then the data should provide an indication to the irrigator of both "when" AND "how much" to irrigate. With a poor measure of the actual soil moisture deficit and little understanding of the options to vary the water applied by surface irrigation, irrigation management in the cotton industry has historically been stuck in the paradigm of soil moisture monitoring to determine "when" to irrigate with little consideration of "how much" to irrigate. This has led to inherent inefficiency in irrigation application.

Furrow irrigation management in the cotton industry has rarely considered the management of irrigation applications and in particular, "how much" water is actually being applied and/or lost from the system. With questions such as "How much water does my siphon put out?" and "How much water should be applied?" still not being asked, irrigators have an uncertain perspective of irrigation efficiency and losses such as deep drainage. Hence, the aims of this component of the project were to:

1. develop and promote irrigation best management practice;
2. equip irrigators with the tools and skills to be able to measure their own irrigation efficiency and losses;
3. create awareness of the potential differences between irrigation water applied and that required for an irrigation event;
4. encourage irrigators to make more informed decisions about irrigation efficiency management improvements to reduce losses; and
5. encourage irrigators to value (cost / benefit) the potential water savings, cost savings and production improvements that could be made through improved irrigation management.

Key Outcomes

- ***Contributed to the development of industry standard best management practices***
- ***Raised awareness and initiated adoption of irrigation Best Management Practices across all cotton growing areas of Queensland***
- ***Improved industry and farmer level capacity building through targeted extension workshops involving more than 220 growers and more than 90% of relevant industry extension staff***

Information, data and outcomes of the project have been presented to over 1000 industry stakeholders including irrigators, researchers, government officers, industry development officers and consultants. Of these approximately 220 growers and cotton consultants in eight cotton growing regions have attended a detailed training workshop program on evaluating irrigation performance. These outcomes have formed part of Cotton Industry Best Practice Guidelines for irrigation and water management. Grower awareness of the opportunities to improve water security through water use efficiency improvements has also been raised through grower focussed field days and broader industry presentations.

Research findings were extended to industry through field days and workshops within the Cotton and Grains Adoption Program. Field days and workshops had two main components. Firstly to present the data from the research project and secondly an emphasis on the importance of measuring the irrigation system water balance to gain a better understanding of the efficiencies and potential magnitude of losses. The project "Best Management Practices for improving whole farm irrigation efficiency in the Australian cotton industry" undertaken by the NCEA (Dalton *et al*., 2001) demonstrated farmer friendly methods of monitoring irrigation efficiency and improving irrigation management. These monitoring and management practices were further refined and developed in this current project and presented as part of a workshop program designed to empower and motivate irrigators towards self monitoring and better irrigation management. The workshops were presented using the concept of "measure it to manage it" to promote the findings of the research project. The concept of "measure it to manage it" is not a new one. The Environmental Management System (EMS) approach has typically emphasised that without a measured knowledge of the system it is speculative to manage the system. Similarly, without a knowledge of the volume of water being applied to a field and the amount of water used by the crop, any measure or quotation of efficiency would be speculative.

Workshop participants were shown how to convert water volumes (typically megalitres) over areas (hectares) into millimetres since soil moisture monitoring (if properly calibrated) and rainfall is commonly presented in millimetres. The workshop focus was to quantify how to measure water applied (siphon flow) using three methods and compare this with the water required (soil moisture deficit). While the measurement of tailwater and deep drainage were not physically undertaken in the workshops some crude methods of estimating the tailwater/drainage split in the loss volume were considered.

After measuring and calculating the millimetres of water applied to a field participants were encouraged to compare this with irrigation soil moisture deficits from soil moisture and irrigation scheduling devices. While these were not necessarily calibrated and/or accurate the exercise itself helped to address these questions and concerns regarding soil moisture devices.

Workshop participants were then encouraged to participate in an irrigation efficiency measurement and benchmarking exercise to be coordinated and collated by the Cotton and Grains WUE Officers in each
region.

Workshops were conducted in Dingo, Emerald, Theodore, Dirranbandi, St George, Goondiwindi, Dalby and Pampas. Irrigation targets (soil moisture deficits) ranging from 60mm to 150 mm were identified while actual applications of 90mm to 210 mm were measured thus showing considerable opportunity to improve efficiency and save water.

The workshops were "hands-on" with participants involved in measuring and assessing water balance parameters in the field. While the workshop series and measurement methods did not give a highly accurate picture of the full water balance of an irrigated cotton farm or field, it did however begin to give irrigators an understanding of the possible magnitude of losses and the ability to gain a greater understanding of how to improve their irrigation system design and management. This understanding alone has allowed industry to move towards potential efficiency gains and reduced risks associated with deep drainage and tailwater losses. Simply creating an awareness and paradigm shift in the perception of efficiency and deep drainage is seen as a major outcome of these workshops.

Even from the limited data gathered from the workshops a wide range of irrigation applied vs irrigation required values were recorded. Variability of data and efficiencies between different fields within and between regions shows the potential for massive irrigation application efficiency gains across the state of Queensland. The value of this type of process as a training and awareness raising exercise should not be underestimated.

While limited irrigation benchmarking data sets have subsequently come forward from the different cotton regions this type of approach should continue as a benchmarking, comparative analysis and continual improvement approach to farm irrigation application efficiency improvements, deep drainage risk minimisation and possibly even an Irrigation QA approach.

5. Industry and Environmental Impacts

This project has also demonstrated that positive production, economic and environmental impacts can be achieved via measuring to understand the efficiency of surface irrigated production systems, adoption of best management practices and optimising the performance of these systems.

Detailed assessments of the key management variables to reduce deep drainage and tailwater have shown that these off-site impacts can be significantly reduced through adoption of easily adopted best management practices. Reductions of up to 0.5 ML/ha in deep drainage are achievable through best management practice adoption thus reducing the risk of groundwater table rise and contamination and salinity risk. Further off site impacts including soil erosion will be significantly reduced through adoption of best management practices to reduce tailwater.

The detailed trial work showed that on well managed farms, 5% of the applied water could be saved through optimised management practices. The less detailed workshops highlighted that the potential water savings of up to 30% could be achieved through adoption of simple monitoring and management practices. If a conservative 10% of applied water was saved on only half of the surface irrigated land in the industry, then this would translate into enough water to irrigate an extra 18000-20000 ha. This would result in an increase in industry production of up to 150000 bales/annum with a gross value of approximately $60M per year.

The project has identified that waterlogging associated with inappropriate surface irrigation practices can result in up to ten or more days reduced crop growth each season. In the detailed trial work, yields were increased by 8% savings due to reduced waterlogging associated with improved irrigation management practices. Adoption of these practices could conservatively increase industry production by an estimated 80,000 bales/year with a gross value of $40M per annum.

6. Recommendations for the Future

Key recommendations for future research and to assist in the implementation of the results from this report include:

1. Further development of deep drainage measurement systems

The deep drainage measurement systems developed and/or used in this project are time consuming and expensive. The volume balance approach relies heavily on soil moisture monitoring systems which provide only point scale measures and which under commercial conditions are rarely calibrated. If volume balance methods are to be used routinely for deep drainage assessment, then the accuracy and scale of soil moisture measurement must be improved. The potential to use chloride profiles to estimate deep drainage has been investigated in this project. While the average seasonal estimate was consistent with that obtained using other methods, the variability within the field and lack of consistency with the variation in infiltrated volumes, suggests that further work needs to be conducted to confirm the accuracy and potential to use this method routinely over the event and/or seasonal timeframes.

2. Additional evaluation of the agronomic impacts associated alternative surface irrigation management strategies

The potential to impose waterlogging, and the impact of this water, under surface irrigated cotton production systems is not well understood. This research suggests that surface irrigation management will impact on the agronomic responses

There is a potential to realise large yield improvements through reduction in waterlogging in these systems.

3. Improved deep drainage risk assessment across a wider range of regions and soil types

The measurement of deep drainage in this project focuses heavily on cracking clay soils. Industry and Government should endeavour to expand the range of soils and irrigation management practices over which deep drainage risk assessment is conducted to ensure a balanced industry and catchment perspective in addressing this issue. This project has highlighted the potential to use furrow averaged infiltration characteristics and irrigation management practices within the SIRMOD simulation package to provides a measure of deep drainage risk assessment. However, further work is required to obtain infiltration characteristics and management practices representative across the entire industry.

4. Additional grower and consultant focused training and extension programs

Farmer and consultant based training workshops initiated by this project have demonstrated a simple approach to water use efficiency optimisation. These programs should be continued and further attention given to focusing on the environmental and sustainability impacts of issues such as deep drainage.

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