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The Australian cotton water story...

A decade of Research & Development 2002–12

Compiled and produced by the Cotton Catchment Communities CRC (2005–12) for the Australian Cotton Industry by the *The Australian Cottongrower* magazine.

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Welcome to the cotton water story

■ Guy Roth, Jane Trindall, Sandra Williams, Dave Wigginton, Graham Harris, Melanie Jenson and Lynda George

THE Australian cotton industry has seen a dramatic improvement in all facets of the cotton industry's management of water over the past decade. With the droughts behind us and the floods upon us the importance of water and its management for this nation is now, more than ever apparent. Water is the limiting factor of production for the Australian cotton industry, so growing 'more crop per drop' has been an important goal for cotton water research. The CRC model enabled new research providers, including natural resource management bodies, to partner with industry broadening the scope of water research and development to encompass catchment and community research where cotton is grown to achieve world's best practise in environmental stewardship.

This publication brings together a 'snapshot' of the breadth of cotton water related discipline research and development done on cotton plants, fields, farms, catchments and communities.

An important part of improving water use productivity is knowing how to measure it. A significant effort was devoted to tools and knowledge to enable this.

Research projects are not serving their purpose unless their outputs are delivered to end users and put into practice. This water story brings together some these outcomes, for example:

- A 40 per cent increase in cotton water productivity over the last decade.
- Cotton yields 2.5 times the world average of high quality product.
- New tools and knowledge for farmers and their advisers.
- Changed attitudes on issues such as deep drainage and furrow irrigation practices.
- Local catchment groundwater knowledge and products.
- Science to underpin decisions and management in seven catchments that is already contributing to improved natural resource condition.
- Eight rural communities quantifying their social and economic relationship with water.

Last season's industry grower survey found that:

- 70 per cent of irrigators used soil moisture probes for irrigation scheduling, which is up from 40 per cent in 2006.
- 62 per cent of groundwater irrigators regularly monitor water quality, which is up from 20 per cent in 2006.
- 96 per cent of irrigators had made improvements to their furrow irrigation systems.

The cotton water R&D portfolio has looked at cotton and the landscapes where cotton is grown in an integrated way based on science agreed and trusted by all stakeholders. A partnership approach to environmental water science in cotton growing regions will start a conversation on what success looks like in relation to delivering environmental water and will provide confidence for people engaged in a localised approach to find a balance for a healthy working Basin.

It is important to establish clear priorities for research and development to continue to build the Australian Cotton Water Story for the next 10 years. It is imperative to engage growers, other R&D end users as well as research participants in this process. *The Australian Cotton Water Story – a decade of research and development* has enabled us to harness the

collective wisdom of the cotton water R&D community and gather our thoughts about future directions for cotton water RD&E.

Research and development priorities at the start of the next decade of cotton water research include:

- A continued focus on plant breeding, agronomy, soil and irrigation management, both in fully irrigated, partly irrigated and rainfed environments.
- Reducing the major losses related to evaporation, distribution losses and improving application efficiency and uniformity.
- Monitoring water use and calculating efficiencies.
- Alternative irrigation systems where applicable.
- Optimisation of water, carbon, energy, labour interactions.
- An even greater emphasis on people, knowledge and adoption.
- Local science partnerships on environmental water research, surface and groundwater connectivity and regional water quality.
- Long term local monitoring of communities in relation to water availability.

Compiling this document has given us the opportunity to reflect on the great achievements over the past decade in cotton related water R&D. This was over a period made difficult the worst drought on record and then major flooding across the industry. As the climate change debate continues and predictions of scarcity, and unpredictability face the industry as future challenges, there are some exciting innovations and conversations to be had which could further transform the management of our precious water resource.

We would like to thank all the growers, consultants, industry staff and research and extension staff who have contributed to this publication. Cotton water research has been a collaborative partnership of many individuals and organisations. May that continue.

Thanks for reading the Cotton Industry Water Story.

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FRONT COVER: Top – Latest water saving technology on Little Mollee near Narrabri NSW. (Joshua Smith)

Bottom – Cotton field near Wee Waa. (Guy Roth)

Cotton Catchment Communities CRC (2005–2012)

■ Philip Armytage, CEO



WATER is a pivotal resource, fundamental to cotton production, the environment and communities where cotton is grown. Historically, cotton water R&D has involved many levels: on-farm, on plant breeding, agronomy and irrigation efficiency – to produce more crop per drop.

The Cotton Catchment Communities CRC is the first agricultural CRC to integrate social, environmental and production related science in one CRC. This has given the cotton industry the opportunity to broaden our view and investigate water in a holistic manner – on-farm, in catchments where cotton is grown and its importance to regional cotton communities. Great achievements have been made.

Since 2005, cotton water RD&E has led to improvements in the cotton industry's water use efficiency, understanding of groundwater resources, wetland ecology and the social relationship of cotton communities with the use of water for irrigation. The strength of this story is in the sum of its parts and growers, consultants, Cotton Australia, Cotton CRC (past and present), CRDC, research providers and government agencies have all contributed to the fabric and strength of this story. The CRC collaboration framework has allowed us to harness the efforts of multiple organisations to develop, deliver and tell the Australian Cotton Water Story.

Key to a CRC is the collaborative effort of its core participants and affiliated partners, who focus on common goals and take into consideration industry priorities. This is the true nature of a CRC. Our water portfolio has been the embodiment of collaborative research, with many organisations striving towards a common goal.

Over the past seven years the CRC has collaborated with over 30 organisations and has invested nearly \$30 million (cash and in-kind) in water related research and development. This is a major effort and highlights the pivotal role of the CRC, co-ordinating research and development for this critical resource.

The Cotton Catchment Communities CRC has:

- Better prepared industry – \$114.1 million of economic benefits to the Australian cotton industry.
- Better prepared environment – Science to underpin decisions and management in seven catchments.
- Better prepared communities – Strategies to cope with change.

Over the past 10 years we have seen the cotton industry improve its water use efficiency by 40 per cent. Around 28 per cent of these improvements can be attributed directly to the Cotton Catchment Communities CRC. Importantly, many of the CRC investments are set to return significant benefits in future years. A remedy for the largest source of water loss on cotton

"The CRC has given the cotton industry the opportunity to broaden our view and investigate water in a holistic manner – on-farm, in catchments where cotton is grown and its importance to regional cotton communities."

farms, evaporation from on-farm storages, is tantalisingly close with the collaborative development of new evaporation reducing monolayers. The future looks rosy for improved irrigation systems which combine labour and water savings, addressing two of the biggest challenges facing the industry now and in years to come. Our groundwater research has made the modelling and water quality testing of aquifers feasible in areas where coal seam gas (CSG) extraction is proposed giving us the tools to accurately quantify the real impact of the CSG industry if problems occur. Our insights into the wellbeing of communities in cotton growing regions and their reliance on water have started to build the self reliance of our communities.

Our water RD&E portfolio has been the embodiment of collaborative research, with many organisations striving towards a common goal. While I experience a sense of loss as the CRC comes to an end, it simultaneously gives me great pleasure to see this publication – *The Australian Cotton Water Story – A decade of research and development* celebrate how working together we have achieved great things to better manage this vital resource. This publication brings together over 80 articles, involving nearly 100 cotton water researchers and extension staff to bring together the pieces of the Australian Cotton Water Story articulating the collective efforts over the past 10 years to better manage this critical resource.



Water management in our wide brown land

■ Adam Kay, CEO, Cotton Australia



WATER is both a cotton grower's most precious natural resource and one of Australia's greatest environmental challenges. Without water crops will not grow, food and natural fibres would not be produced and regional communities could not thrive.

As we have seen with the long and winding Murray Darling Basin plan debate, water management in the wide brown land remains a very complex and often contentious issue, which presents few easy solutions. Often the best hope for the future of water management comes from those very farmers whose future viability relies on making good daily decisions about water use.

Technology has produced some amazing changes within the cotton industry; the advent of biotechnology cotton has seen the burden of insecticide use drop by around 90 per cent. Biotechnology along with advances in irrigation timing and precision has seen Australian cotton secure a reputation as the most water-efficient cotton industry in the world.

Combining the use of appropriate varieties with a massive research effort and early adoption of the latest irrigation technologies, means Australian cotton fibre can be produced using less water per hectare than ever before. Water use productivity for Australian cotton has doubled in the last 25 years with plans to double it again in the next decade. Achieving this aspirational goal is going to mean a continued strong focus on research and development. While there might be a lot of unknowns in the current ongoing water debate, the certainty that research will always remain the key to unlocking the secrets of increased water efficiency remains beyond doubt.

Cotton Australia has been playing a leadership role towards advocating the industry's goals for improving water use as well as being a fully-fledged participant in the ongoing wider political discussion about the future of water allocation in the Murray Darling. Driving and supporting the research effort towards greater water efficiency, Cotton Australia has been steering and guiding the industry's major investments in water R&D.

The fruits of the industry's research have already produced results by nominating the five key areas that cotton growers should focus on:

- Maximising storage and distribution efficiency (on-farm dams and channels).
- Maximising application efficiency (putting water on the crop).
- Achieving uniform application (putting water on the crop).
- Monitoring water use and calculating efficiencies (while the crop is growing).
- Adopting alternative irrigation systems (where applicable) such as overhead sprinklers, bankless channels and drip irrigation.

Another program championed and driven by Cotton Australia is the Australian Cotton Industry's Best Management Practices (myBMP) possibly the most comprehensive environmental farm management program of all Australian agricultural industries

*"When the well is dry,
we know the worth
of water"*

— Benjamin Franklin

with a specific water management module devoted to improving water use practices.

The myBMP Water Management module is designed to help cotton growers make efficiency gains by bringing together the latest research and knowledge on water use and management. Topics range from managing and measuring water

sources and collection (storages, bores, overland flow and stored soil moisture) through to field distribution.

All aspects of water application are covered including surface irrigation, centre pivot and lateral moves, drip irrigation as well as dryland water usage.

Farms that achieve all Level 2 myBMP water practices have been certified as having achieved the following benchmarks:

- Used available tools to schedule irrigations and monitor soil water levels.
- Estimated soils capacity to hold and store water for each field and soil type.
- Estimated losses from storages and channels.
- Maintained storages to minimise leaks and seepage, particularly in dry times.
- Maximised crop yields by understanding and managing bore water quality.
- Calculated and recorded the irrigation water use index.
- Identified problem areas in irrigation fields and addressed them.
- Matched flow rates to soil, slope and run length so furrows come out evenly.
- Planned for and installed centre pivot or lateral move systems with a professional so it works effectively.
- Ensured drip irrigation systems are operating effectively.

With a growing number of research organisations showing interest in the area of increased water efficiency, Cotton Australia has been able to demonstrate the organisations in-depth understanding of the issues confronting researchers by delivering feedback directly from cotton growers. The imperative and general research directions guided by Cotton Australia are the result of intensive discussion and consideration from panels made up of cotton growers. Cotton Australia's farming systems advisory panel is also responsible for reviewing CRDC annual research proposals and they reflect industry priorities for water use research and development.

With the closure of the Cotton CRC and the migration of that continued research effort the capacity of Cotton Australia to provide advice and direction directly from our grower base will continue to be an invaluable guidance tool for future water efficiency research.



A challenge to double our water use efficiency

■ Bruce Finney, Executive Director, Cotton Research and Development Corporation



A **GA**INST the background of the worst drought on record and a national agenda for water reform the Australian cotton industry, in the early 2000s, set itself a challenge to double its water use efficiency.

Looking back this was the beginning of a critical research agenda that enabled the industry to understand its water use and drive profound water management improvements. With the best producers now achieving near two bales of cotton per megalitre of water – almost double the industry average of just a decade ago.

The water reform agenda tested all involved to better understand and contribute to the public debate around access to water and the long term sustainability of river systems. The industry has recognised that improvement in water use efficiency is only part of the necessary response to this much larger agenda.

Over the decade the CRDC R&D in collaboration with the Cotton CRC and the National Program for Sustainable Irrigation has strategically invested with other research agencies in a broad portfolio of water R&D. That portfolio of research has extended across crop, farm, catchment, community and industry scales. A commitment to supporting the adoption of the research results was also made. Throughout this there are many achievements to be recognised.

Research has assisted the industry to agree upon a common methodology for measuring water use efficiency and established ongoing benchmarking research programs in collaboration with the grains industry in Northern NSW.

Water R&D knowledge has been compiled and extended through the industry publication WATERPak. This publication was revised and expanded to include grain crops and integrate with the *myBMP* (best management practices) program then extended in a modular training program.

Research to understand deep drainage reached maturity through this period with the implications for water quality and sustainability tested. Cotton CRC research contributed significantly to new technical capacity for measuring and expanding groundwater system knowledge.

Connecting good science, policy development and implementation proved to be as challenging as it had in the past. The Cotton CRC were successful in building new research partnerships and science that contributed to water reform that considered productivity, environmental and community aspects in a holistic manner.

Climatic variability proved to be a driver for new extension demands for water R&D knowledge. During the drought growers showed much interest in dryland techniques for maximising soil water storage and availability that were showcased at “Big Day Out” events. When major flooding damaged crops throughout QLD and NSW during 2011 and 2012, researchers and the industry Development & Delivery Team experimented and brought together the available knowledge on recovery strategies for flooded crops.

Improvement to irrigation systems and crop water

management was a major area of endeavour. At the crop level research investigated the differences in water requirements between genetically modified and conventional cotton varieties as well as opportunities for better matching crop water needs and climatic variability with dynamic irrigation deficits. Research investigated the possibilities for reducing pump energy use, optimising & real-time control of CPLM systems, optimal irrigation via real-time adaptive control for CPLM and furrow as well the validation of new irrigation scheduling tools for cotton.

In 2009 the industry established a vision for its future, Vision 2029, which seeks to inspire the industry to become the producer and supplier of the most environmentally and socially responsible cotton on the globe. At the national scale there is still much to finalise in terms of water reform and implementation of future irrigation R&D arrangements. There is no doubt that the interlinked issues of carbon, energy and water will be of critical importance. Given the commitment and capacity of the Australian cotton industry and its research community to drive improvement it will equally be very interesting to reflect on how the industry's vision has influenced water research and the performance of the cotton industry in another decade's time.



Australian Government
Cotton Research and Development Corporation

A decade of change in water productivity

■ Graham Harris, QLD Department of Agriculture Fisheries and Forestry, Cotton Catchment Communities CRC

IN BRIEF...

- The past decade has seen floods and extended drought, but cotton growers have consistently improved yields and reduced water use.
- Irrigation Water Use Index (IWUI) has improved from 1.1 bales per megalitre in 2000–01 to 1.9 bales per megalitre in 2009–10.

THE past decade has seen almost every possible water scenario in the cotton industry with record droughts, record crops and record water productivity. Despite the numerous challenges during this time, Irrigation Water Use Index (IWUI) has improved from 1.1 bales per megalitre in 2000–01 to 1.9 bales per megalitre in 2009–10. Given the Australian industry was already a world leader in cotton water use efficiency, this improvement represents a massive increase in crop water productivity, and demonstrates the commitment of growers to making the most of their available water.

Although the decade started strongly, with increasing production leading to a new record crop (at the time) in the 2000–01 season, the ‘millennium drought’ from 2002 to 2010 severely reduced the availability of water for irrigation and resulted in a slashing of irrigated cotton areas and production

(Figure 1). During this time some regions experienced successive years of zero water allocation and the industry contracted as water supplies reduced.

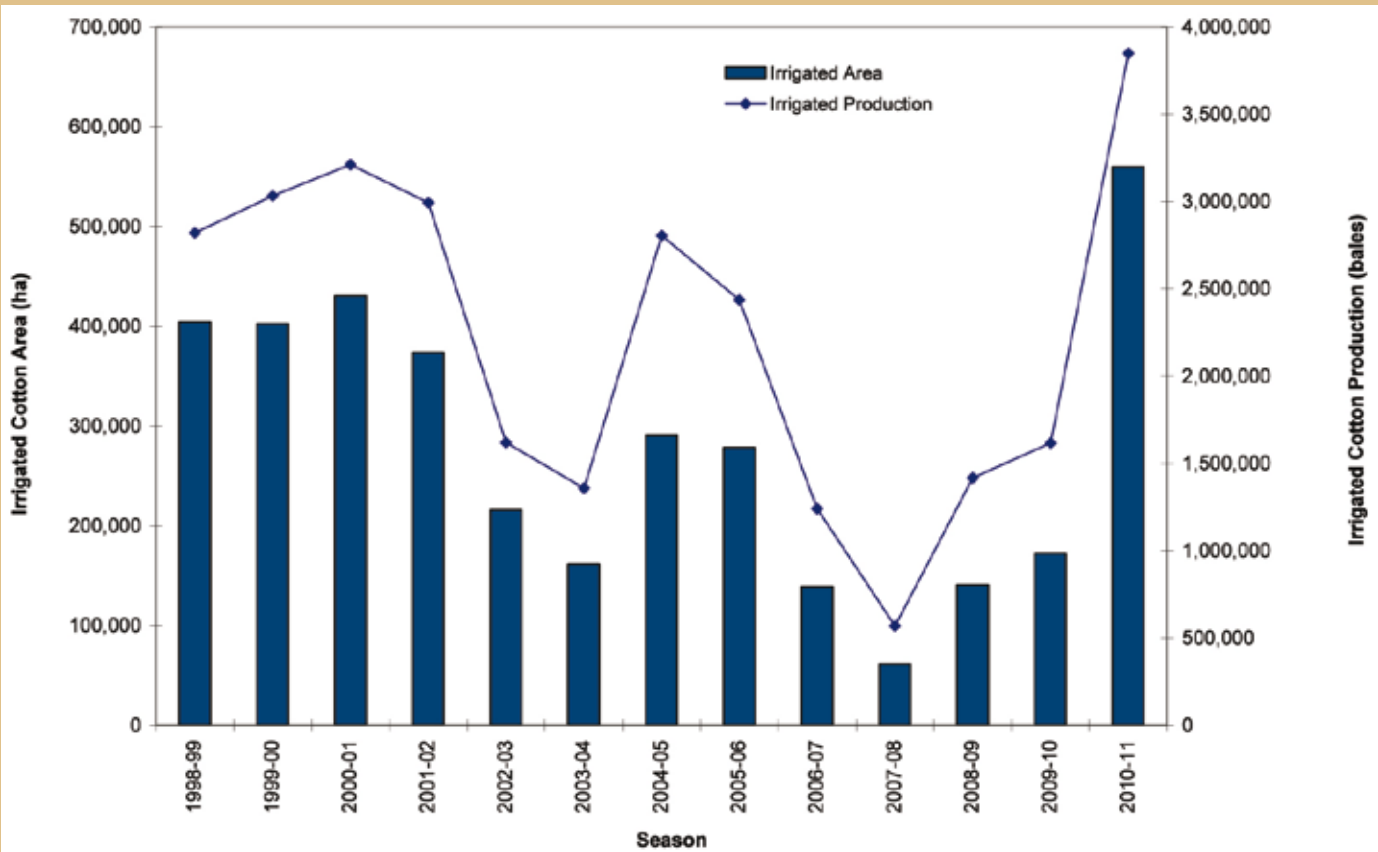
This culminated in the 2007–08 season with the smallest crop in 30 years; an 85 per cent reduction in area since 2001. But production was to quickly bounce back, as more favourable rainfall conditions in 2010–11 significantly increased the area and production reached a record high.

Whilst seasonal conditions drove variable annual plantings and production, growers managed to increase yield over the decade (Figure 2), although a slight decrease in the 2010–11 season is due to increased area planted to cotton and the damage resulting from flooding during that season. At the same time, the average total applied irrigation has decreased slightly (Figure 2).

Together these trends have led to a very significant improvement in water productivity in irrigated cotton (Figure 3). Irrigation Water Use Index (IWUI) has improved from 1.1 bales per megalitre in 2000–01 to 1.9 bales per megalitre in 2009–10. Data from numerous individual farms obtained through recent industry studies is also included in Figure 3 and confirms the trend evident from overarching industry water use and yield data.

The Irrigation Water Use Index (IWUI) is a coarse measure of the water productivity achieved by the cotton industry during the past decade which can vary from year to year in response to the amount of rainfall received. It should always be considered in

FIGURE 1: The impact of drought on irrigated Australian cotton production (Source: *Australian Cottongrower*)



context with other WUE indices which have been collected at the individual farm and field scale. Industry wide (ABS) data on the volume of water applied to cotton in 2010–11 is as yet unavailable so a figure for IWUI for this season cannot yet be determined.

This upward trend in IWUI is a result of improved genetics and crop management as well as improved irrigation practices. Many of the changes that cotton growers have made have been underpinned by the research, development and extension effort of the partners within the Cotton CRC. Projects researching Bollgard irrigation management and deep drainage, coupled with the water use efficiency extension effort and the emphasis on “measure to manage” have been particularly important in this achievement.

Further reading: WATERpak Chapter 2.2 – Water use efficiency in the Australian cotton industry. ▲

FIGURE 2: Irrigated Cotton yield and water use trends
(Source: Australian Cottongrower and Australian Bureau of Statistics)

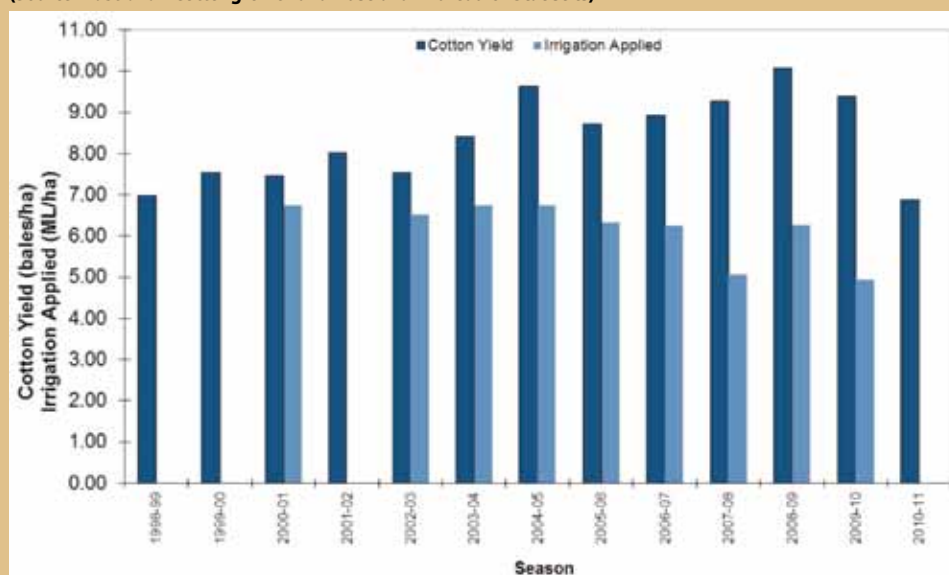
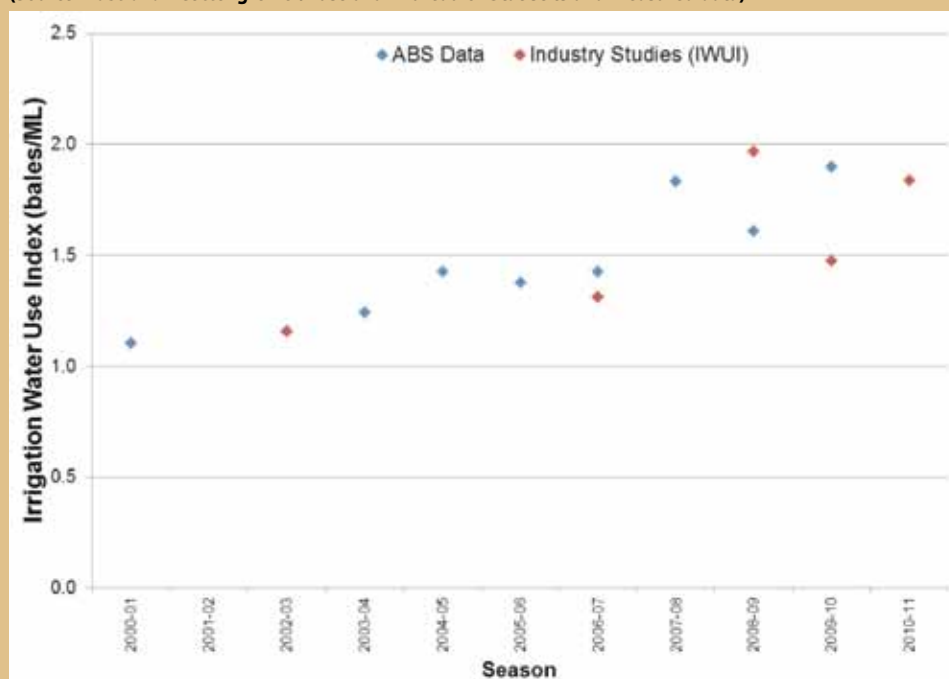


FIGURE 3: Irrigated cotton productivity (bales/ML irrigation water applied)
(Source: Australian Cottongrower/Australian Bureau of Statistics and measured data)



Benchmarking WUE in the Australian cotton industry

■ Janelle Montgomery, NSW DPI and David Wigginton, DW Consulting Services

IN BRIEF...

- New user friendly water performance tools have been used in recent projects to determine industry water use efficiency benchmarks.
- The average performance of irrigated cotton farms has seen a 40 per cent improvement over the previous decade.
- Measurement is extremely valuable for individual enterprises to benchmark current performance and determine where improvements can be made.

WATER use efficiency (WUE) benchmarking is critical for individual farmers and the Australian cotton industry as a whole. For individuals, it is important to compare current performance with previous seasons and the performance of others in order to improve management practices. For the industry, it is important to know how productively water is used, and to demonstrate improvements in water use efficiency over time. A number of recent benchmarking activities have been undertaken to provide the industry with this information.

A wide variety of water use performance benchmarks can be calculated depending upon the specific inputs used (bales, tonnes, profit, water applied, ETc, rainfall, effective rainfall, etc.) and the scale at which they are determined (field, channel, farm). Some of these calculations can also be quite difficult to perform manually.

Software tools can be very useful to speed up manual calculations but, until recently, there were few tools that could undertake the complex calculations required for large surface irrigated farms. The Watertrack™ suite of tools were developed to fulfil this role.

From an industry point of view, Watertrack™ can ensure consistency when performance benchmarks are being determined. This is critical when comparing benchmark results between farms or across seasons.

Whilst Watertrack™ calculates a range of different benchmarks, two are most important for analysing the performance of the whole industry:

- Irrigation Water Use Index (IWUI) relates yield to irrigation water applied. This index varies a lot from year to year depending on how much rainfall the farm receives.
- Gross Production Water Use Index (GPWUI) relates yield to total water used to grow the crop, including irrigation water applied, rainfall and stored soil moisture.

These projects have demonstrated the value in determining standard irrigation benchmarks and the ease with which this can be achieved using modern tools. Whilst seasonal variation in data does occur, average water use performance collected during the most recent studies has shown around a 40 per cent improvement from that collected in a study 10 years earlier.

The ability to determine losses from individual irrigation system components is a very useful addition to standard benchmark calculations, as this information can highlight those areas of the farm which have the greatest potential for performance improvement. This is particularly important when irrigation infrastructure investments might be considered.

Since 1997, various studies have provided snapshots of industry irrigation performance (see further reading). But these studies often contained subtle differences in definitions and methodologies and in 2007, Payero and Harris suggested that “the lack of good annual and robust benchmarking data is an issue that the cotton industry and irrigation sector as a whole needs to address”.

The development of the Watertrack™ suite of tools provided an opportunity for the industry to collect standardised benchmarking data as well as promote the value of these types of tools to growers. Subsequently, a number of projects have utilised these tools to collect data from numerous properties across a number of seasons (as indicated in Table 1).

Water use performance

The number and location of farms from which data were collected varied between seasons, as indicated in Table 1. The average GPWUI from 2006 to 2011 (1.10 bales per megalitre) shows an increase of about 40 per cent since the study conducted by Tennakoon and Milroy (2003) (0.79 bales per megalitre) 10 years earlier.

Some variability between the seasonal average results in Table 1 is evident. This demonstrates the kind of variations that occur due to seasonal and regional differences. For example, the 2009–10 and 2010–11 seasons were very wet, with significant flooding on many farms, which may have impacted both irrigation requirements and yield potential. Similarly, 2009–11 results pertain only to farms in the Queensland Murray Darling Basin, where different irrigation requirements and soil types may be evident.

A true picture of variability can be obtained by looking at an overview of the IWUI and GPWUI for all individual farms, as

TABLE 1: Number and location of benchmark farms and average results

Season	Number of farms	Location of farms	Average IWUI (bales/ML)	Average GPWUI (bales/ML)	Average yield (bales/ha)
2006–07	37	Hillston to Emerald	1.31	1.13	10.7
2008–09	46	Hillston to Emerald	1.97	1.14	10.6
2009–10	15	Condamine & Lower Balonne	1.47	0.93	9.2
2010–11	12	Condamine & Lower Balonne	1.84	0.94	10.3
Total	108	Average	1.70	1.10	10.4

shown in Figures 1 (IWUI) and 2 (GPWUI). The IWUI for individual farms varied from 0.80 to greater than four bales per megalitre, while the GPWUI varied from 0.64 to 1.71 bales per megalitre. These results demonstrate the level of performance that is possible and can be used by individual growers to compare their own irrigation performance.

Water losses

In the 2009–10 and 2010–11 seasons, Watertrack Divider was used, which allows the losses from each component of the irrigation system to be determined. This data is vital for guiding management decisions and is especially important for anyone considering investment to improve irrigation performance. Whilst the benchmarking undertaken in the previous section allows performance to be measured and compared, the information provided here can diagnose where performance improvements may best be made.

Analysis of water losses were undertaken for a total of 30 farms. Each farm had previously received a measurement of storage evaporation and seepage and this data was used in the analysis. Seepage rates for these storages ranged from 0.5 mm per day to six mm per day, with 75 per cent having seepage of less than two mm per day.

The average final use (or loss) of all available water for all farms is illustrated in Figure 3. The data indicates that approximately 63 per cent of all water is used by the crop. The largest loss of water occurred in on-farm storages, which account for 25 per cent of the total water, followed by in-field application loss, which accounts for 11 per cent of the total available water. Channel and drain losses are very low at less than one per cent each.

But as with the water performance benchmarks discussed previously, losses on individual farms varied significantly. Storage losses ranged from less than five per cent to more than 45 per

FIGURE 1: Irrigation Water Use Index (IWUI) for each individual farm

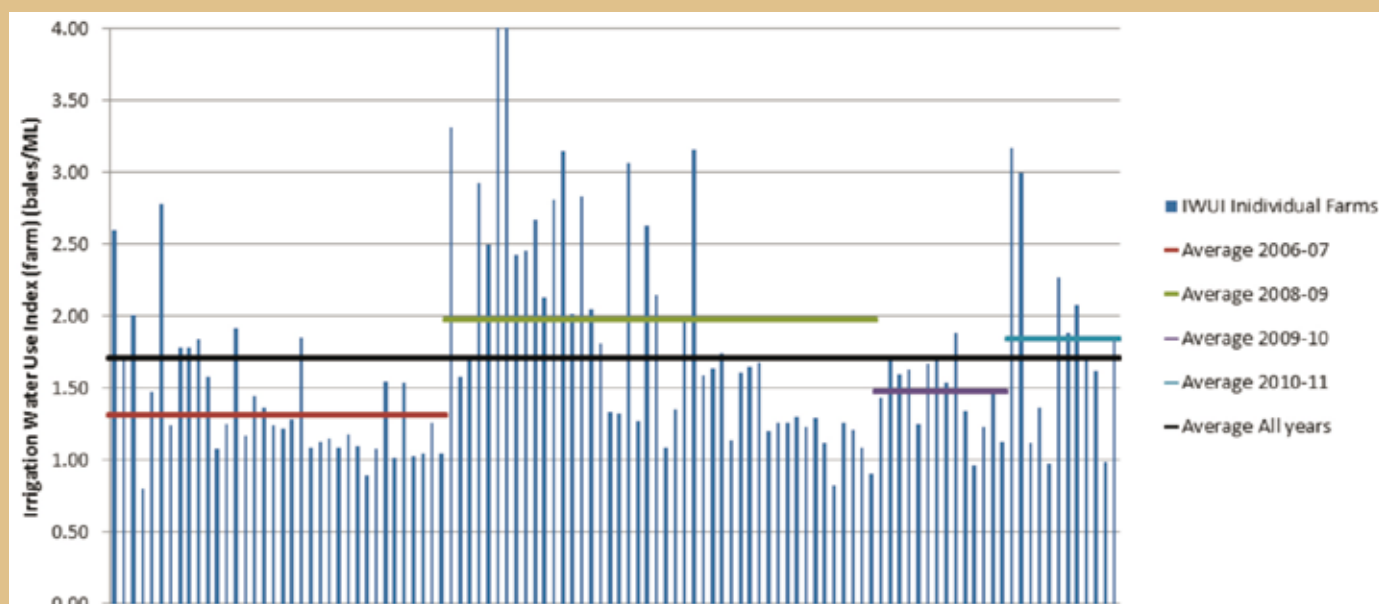
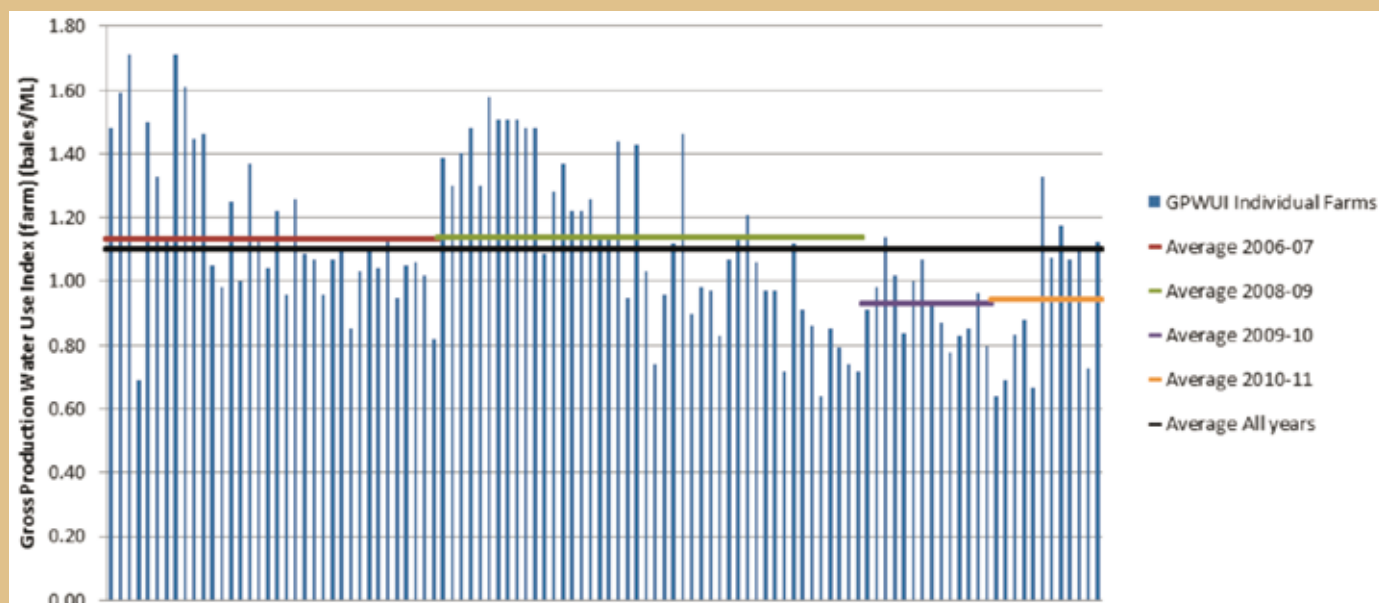


FIGURE 2: Gross Production Water Use Index (GPWUI) for each individual farm





Jenelle Hare, Janelle Montgomery and Graham Harris at a Deep Drainage Forum in Narrabri 2009.

cent of overall farm water. Such a range shows the importance of understanding the water use characteristics of individual farms when considering how water use efficiency might be improved.

Losses in channels and drains were consistently less than five per cent of total farm water while field application losses were typically around 15 per cent or less, although a couple of farms had losses of greater than 20 per cent. A high proportion of field losses often correlated with a low proportion of storage losses, so that the overall loss was not abnormally high.

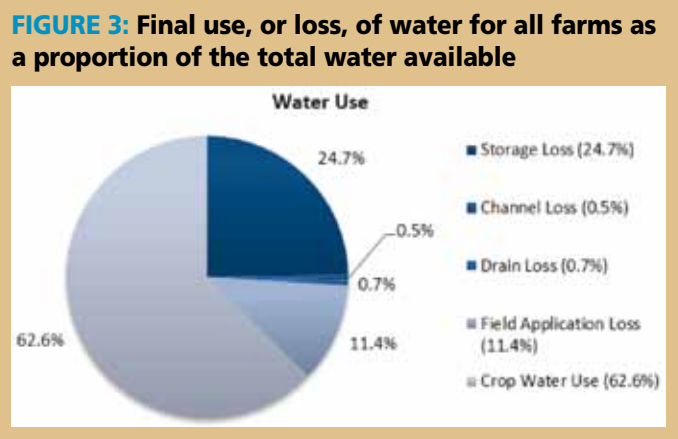
Some farms were evaluated in both seasons, to determine how substantial any seasonal differences in the loss components may be. Most parameters varied to some extent between seasons, with the largest change being a 12 percentage point reduction in storage loss, from 20 per cent in 2009–10 to eight per cent in 2010–11. This demonstrates the effect that seasonal conditions and management changes can have and the importance of monitoring over time to determine true performance levels and trends.

Continued collection of this data over time will enable the cotton industry to better track water use performance which is a critical undertaking for the industry as a whole. It is hoped that more individual irrigators will adopt similar measurement techniques so that they can use the information to determine their water use efficiency improvements and to identify potential performance targets.

Further reading: Tennakoon, SB and Milroy SP. 2003. Crop water use efficiency on irrigated cotton farms in Australia. *Agricultural Water Management*. 61:179–194

For further information www.cottoncrc.org.au or www.crdc.com.au.

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Saving water on the Namoi

■ George Truman and Stacey Vogel, Namoi Catchment Management Authority, Cotton Catchment Communities CRC

IN BRIEF...

- All irrigators found undertaking an evaluation made them more aware of opportunities to improve Water Use Efficiency.
- Identifying where losses may occur greatly improves efficiency and reduces costs.
- In excess of \$1.2 million has been invested by cotton growers, Namoi CMA and Cotton CRC to implement WUE best practise on cotton farms in the Namoi catchment.
- On average, farms involved have improved their WUE by 15 per cent equating to at least 5000 megalitres of saved water over 8000 hectares of irrigated cropping land, all of which is now managed under best practice.

OVER the past two years, 80 growers have participated in the Cotton CRC's 'Cotton and grains irrigation' workshops, while 20 attended the groundwater systems workshop. A total of 15 growers have obtained incentive funds to implement on-ground changes.

With increasing awareness of water use efficiency (WUE) and a range of tools developed to assist irrigators improve efficiency, a partnership was established between the Cotton CRC and Namoi

Catchment Management Authority (NCMA) to undertake a series of whole farm WUE evaluations during 2006 and 2008 in the Namoi Valley in Northern NSW. An evaluation of these tools was then initiated in 2009 with interesting results.

Assessments included soil moisture monitoring, survey of storages, seepage and evaporation analysis of storages and channels, installation of storage meters, and in-field evaluations. Many irrigators, including Paul Hawkins, identified that "by obtaining figures of WUE it makes you aware of what you are doing and then you can determine where to make improvements".

Storage, delivery and application of water on farm are the main areas where water can be better used. These are where the greatest losses can occur, through evaporation from storages and dams, losses through leaky channels, head ditches and storages and deep drainage from fields through over-irrigation or poor water management. Irrigators have recognised that storage of water has led to significant losses through seepage associated with lighter textured soils (sands and gravels), and through evaporation from open storages.

Some changes being made by irrigators are to minimise the volume of water being kept in the storage by understanding the farm's water requirements and only storing what is needed. It is

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Soil moisture probes are used to monitor moisture throughout the season. The cotton industry has the highest adoption of soil moisture monitoring tools compared to other crops.

important not to be left with any extra water in the storage at the end of the season. This can be achieved through a Whole Farm Water Balance which provides information on what the water requirements are throughout a season. Other ways to reduce water loss is to construct multiple cells and store all water in one cell, thus reducing the surface area over which evaporation can occur. Increasing cost associated with water and energy when pumping water provides plenty of incentive to adopt WUE initiatives.

The delivery of water to the field is important. It is good to get water on and off the field as quickly as possible to minimise the potential for deep drainage. This is particularly important in lighter textured soils where there is more likelihood of drainage below the root zone. Some of the monitoring has included a comparison between single and double siphons as well as using 65mm siphons to improve water flow and shorten irrigation times. Other factors to consider are row length, field shape and field slope.

Capacitance probes are a useful tool when used in conjunction with knowledge of the field and plant requirements and many of the Namoi irrigators reiterated this.

"They are useful after a rainfall event to see how much the profile has filled and can also give irrigators an idea of what is happening below the crop – at what depth is water being drawn from?" according to Mark Shimhausser.

"Having this as an online web-based resource gives irrigators the data when it is required and in an easy to use format," says Mike Carberry.

Knowing the amount of water the storage holds is important,

as not to pump more than required and increase energy costs.

"Nor do you want water left in the storage at the end of the season," according to irrigator Paul Hawkins.

Most irrigators had some idea of the amount of water their storages held with the use of gauge boards. But with an accurate survey and installation of sensors this led to much more accurate measurements resulting in significant water savings. Irrigator Matt Norrie found that this tool was easy to use and allows him to track and evaluate irrigations and plan water management.

WaterTrack is a spatial tool that benchmarks water management at the whole farm level. It can relate water use efficiency as returns in dollars per megalitre or megalitre per bale. It does require a considerable amount of documenting and therefore relies on significant input by farm staff. Overall it can give useful results on individual fields – what the differences were, how individual fields performed and assess what was done right – or wrong according to Mike Carberry.

All the irrigators evaluated found undertaking an evaluation made them more aware of opportunities to improve their WUE. They identified that increasing yield and bales per megalitre were important challenges in addressing WUE. By putting a figure on losses makes you more aware and provides the impetus to continue to make changes, according to Quentin Vogel.

The adoption of WUE initiatives is all about measuring and managing the resource. You need to know what you've got, what you are using and what your losses are. Benchmarking this information is required to make good decisions on future on-farm water management.

The Final Report can be found at www.cottoncrc.org.au



Measuring to improve water storage efficiency

■ David Wigginton, National Centre for Engineering in Agriculture, University of Southern Queensland

IN BRIEF...

- Storages are the largest source of on-farm water loss, accounting for up to 45 per cent of all farm water. For most storages, evaporation is the largest source of water loss.
- In about 20 per cent of cases, grower estimates of seepage were higher or lower than the measured seepage. But even small errors in estimated seepage rate can accumulate to significant volumetric differences.
- The cost of saving water using either cell division or wall height strategies was reasonable, with an average cost in the order of \$150 per megalitre per year. The cost was as low as \$15 per megalitre per year for cell division and \$59 per megalitre per year for wall height increase.

ON-FARM storages are generally the largest source of water loss on cotton farms. Recent analysis of whole farm water losses (see article *Benchmarking in the Australian Cotton Industry*) suggested an average of 25 per cent of all farm water is lost in storage, but this was as high as 45 per cent for individual farms. “Measurement to improve the water efficiency of on-farm storages in the cotton industry” aims to enable growers and industry to better understand storage losses.

This project measured seepage and evaporation losses from 136 storages and found evaporation was the largest component of loss in most storages, with most seepage results being less than four mm per day. But some storages still had very high seepage losses of greater than 10 mm per day and growers found the measurements invaluable for improving the accuracy of water budgets and water efficiency calculations.

To support these measurements, the project also prepared whole farm water balances for 30 farms and calculated the cost effectiveness of storage structural solutions for 15 farms. A number of comprehensive publications which provide more detail are available on the Cotton CRC website www.cottoncrc.org.au.

Storage seepage and evaporation

This project was principally designed to encourage the measurement of storage seepage and evaporation losses using newly developed measurement technology. A network of consultants was utilised to undertake measurements for 136 storages across all cotton regions using the Irrimate™ Seepage

and Evaporation Meter. Table 1 presents a summary of the seepage and evaporation figures for all storages.

Seepage ranged widely, however the average seepage was only 2.3 mm per day as most results were very low (Figure 1). Significantly, 88 per cent of storages (120) had seepage of less than four mm per day, a rate which could be considered as low, with most of these (89) indicating extremely low seepage of less than two mm per day. A single outlier exists for a storage that was known to leak very badly and was confirmed to have seepage of 38 mm per day. This storage contained water during the measurement period for the first time in more than six years (since being purchased by the current owner) and was drained within a matter of weeks.

While most seepage results were quite low, it was important to see how close existing grower seepage estimates might be to the actual measured results. Hence growers were asked to estimate their level of seepage before the evaluation was conducted. While most grower estimates were reasonably close to the measured results, there were about 20 per cent of cases

where the measured seepage could be classified differently to the estimate provided. For example, in one case where the grower estimated a very high seepage rate, the measured seepage rate was quite low at less than 3.5 mm per day.

But even small errors made by growers who estimate their losses can compound into a large volumetric discrepancy. One grower involved in the project operated quite an advanced water budget

“88 per cent of storages had low seepage of less than four mm per day.”

FIGURE 1: Histogram of measured seepage results for each category of grower predicted seepage. The outlier (38 mm per day) has been removed for improved clarity but was correctly estimated by the grower as very high.

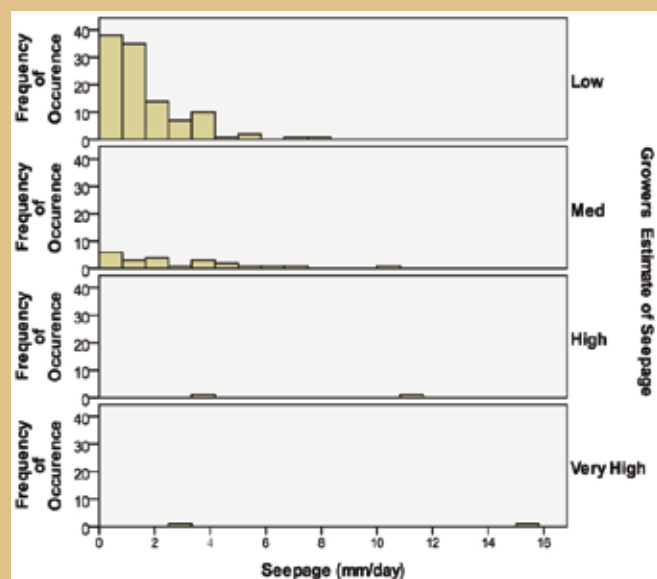


TABLE 1: Summary of key data

	Mean	Minimum	Maximum
Seepage (mm/day)	2.3	0	38.1
Evaporation m/year	1.52	1.03	2.18
Dam factor (k_{dam})	0.97	0.67	1.31
Storage size (ML)	1950	75	14,000

to manage farm water use, which used an estimate of storage seepage to determine volumetric seepage losses. After having his seepage measured through this project it was determined to be low at only three mm per day. But his existing estimate of seepage was only one mm per day. This meant that although both his measured and estimated seepage could be categorized as low, his actual seepage was three times higher than he had estimated and his water budget was out by 50 megalitre per month.

Evaporation results cannot be presented in the same way as seepage data because storage evaporation depends very heavily on the atmospheric evaporative demand experienced at the storage site at any particular point in time. But evaporation from individual storages will also be influenced by a range of site specific variables including surrounding features (trees, hills), surface water temperature, proximity to other water large water bodies, etc. Therefore, a 'dam factor' (kdam) can be applied to local climatic data to estimate evaporation for individual storages.

A dam factor was determined for each measured storage and the average annual evaporation for each storage (Figure 2) was calculated by applying the individual kdam to long term evaporation data for each site obtained from the SILO service. The majority (82 per cent) of dam factors were between 0.8 and 1.2 and average annual evaporation ranged from around one mm per year to just over two mm per year.

Cost effectiveness of storage structural modifications

Once the actual seepage and evaporation losses for an individual storage have been measured, it is possible to determine how any potential issues can be remedied. In order to assess the cost effectiveness of seepage and evaporation solutions across a number of different storages, the project evaluated 15 case studies of potential storage structural modifications.

Structural modifications have been identified in previous

studies as the most likely economical solutions for cotton farms, where water supply is typically very irregular. But their cost effectiveness across a number of storages has not been specifically assessed. Such modifications can include dividing a storage into cells, or raising the height of the wall. In either case, the modification serves to reduce the surface area available for evaporation and seepage for a given volume of water.

The 15 structural modification strategies were analysed using the Evaporation and Seepage Ready Reckoner (readyreckoner.nceaprd.usq.edu.au), an existing tool for economic evaluation of evaporation and seepage solutions. Generally, cell division strategies involved dividing a single storage into two cells. The size of the cells and placement of the wall was determined to maximise the savings for the individual storage. Wall height strategies involved increasing the height of a particular storage so that it was able to store the volume of another nearby storage, which could then be decommissioned.

A number of parameters were consistent across all case studies (Table 2).

A typical water holding pattern is required by the Ready Reckoner to determine the storage water losses, and it consists of two characteristics:

- For each month, the typical proportion of years that the storage holds water; and,
 - For those months when water is held in storage, how full is the storage (as a percentage of the full volume).
- The typical water holding patterns of the storages being

TABLE 2: Storage structural modification basic parameters	
Annual maintenance cost of the new wall	\$500 pa
Cost of earthworks	\$3 per m ³
Discount rate	5% pa
Lifespan of earthworks	60 years

FIGURE 2: Histogram of potential annual evaporation for all sites after application of individually-determined dam factors.

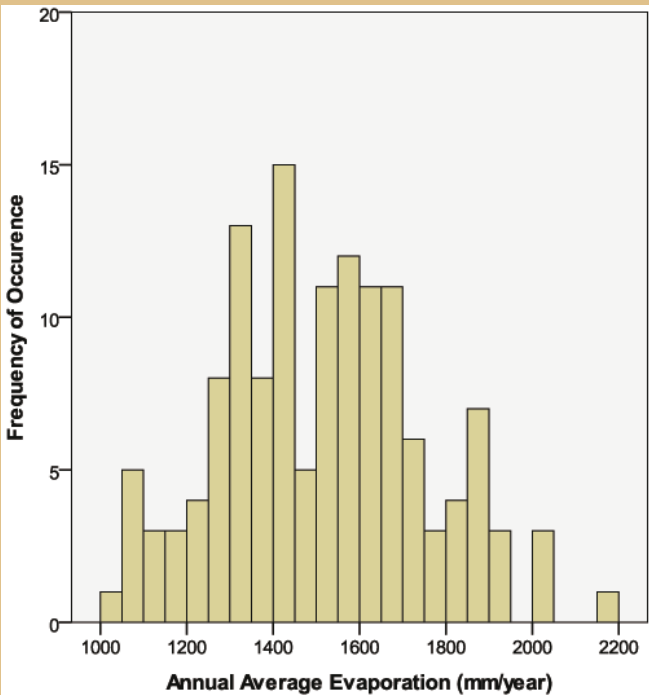
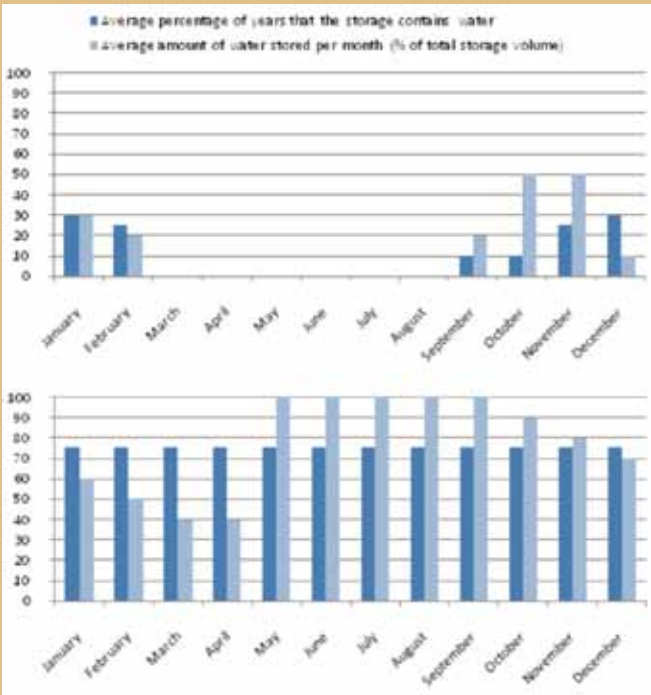


FIGURE 3: An example of the difference in water holding patterns for two storages.



investigated varied considerably, with some storages holding water quite regularly, while others had very low reliability. Two example water holding patterns are illustrated in Figure 3.

Results

The results (Table 3) indicate that the cost of water saved was often reasonably attractive, when compared with the typical value of water available from temporary transfer markets. Having said this, only individual growers will be able to determine an acceptable cost for water saved under their particular conditions. The limiting factors for the implementation of wall height strategies are the high total cost (due to the availability of capital) and the practicality in some situations, particularly where the necessary wall would be unacceptably high.

It should be noted that the method for determining the relative proportion of cells was quite simplistic, in that a particular cell was nominated to always be the first to receive water. A more complex analysis which allows the transfer of water between cells might yield different optimum cell size ratios, and would most likely further decrease the cost of water saved. Storages are the largest source of on-farm water loss. In this project, average storage losses across 30 farms accounted for 25 per cent of all farm water. The largest individual storage loss was 45 per cent, but previous studies have measured even greater proportions. For most storages, evaporation is the largest source of water loss, and this is typically between one and two metres per year if the storage contains water year round.

Seepage losses were typically quite low, with 88 per cent of storages having seepage of less than four mm per day. While most growers believed they had an accurate estimate of seepage, 20 per cent of growers actually estimated their seepage to be

in a higher or lower category than their measured seepage. But for those growers who accurately categorised their seepage loss, even small differences in their measured seepage can accumulate to significant volumetric differences.

The cost effectiveness of cell division and wall height strategies was determined for 15 storages, with an average cost in the order of \$150 per megalitre per year. The cost was as low as \$15 per megalitre per year for cell division and \$59 per megalitre per year for wall height increase, but was as high as \$350, suggesting that individual analysis should be undertaken before investments are made.

Further reading: <http://bit.ly/storagemods>

Funding: National Water Commission through its Raising National Water Standards Program and the Cotton Catchment Communities CRC. Funding for whole farm water balance and storage modification analysis was provided by the Healthy HeadWaters Water Use Efficiency project. ▲

TABLE 3: Water savings and costs for all case studies

CELL DIVISION STRATEGIES						
Farm number	Cell split ratio	Storage volume (ML)	Storage area (ha)	Water saved (ML)	Capital cost	Cost of saved water (\$/ML/year)
1	50:50	1200	22	31.8	\$162,150	\$285
2	50:50	3963	130	1011	\$278,050	\$15
3	25:75	350	7.5	37.7	\$111,780	\$170
4	50:50	1000	34.5	52.3	\$161,595	\$173
5	50:50	1100	29.4	40.1	\$161,595	\$225
6	50:50	1500	27	234.8	\$269,541	\$63
7	50:50	350	11.5	15.5	\$93,150	\$350
8	25:75	450	10.7	94.3	\$123,750	\$75
13	50:50	3000	97.3	201	\$547,000	\$143
14	50:50	963	25.7	98.8	\$105,450	\$56
15	50:50	12000	337	1404	\$390,000	\$15
Average		2352	67	293	\$218,551	\$143
WALL HEIGHT STRATEGIES						
Farm number		Storage volume (ML)	Storage area (ha)	Water saved (ML)	Capital cost	Cost of saved water (\$/ML/year)
9		1400	30.2	525.8	\$2,700,000	\$272
10		3850	74	2065	\$6,252,756	\$159
11		900	23.1	585	\$1,800,000	\$163
12		265	6.5	611.8	\$3,499,500	\$302
14		3000	97.3	211.7	\$234,838	\$59
15		963	25.7	2929	\$3,412,500	\$62
Average		1730	43	1155	\$2,983,266	\$169

Native aquaculture in farm water storages

■ David Foley, NSW Department of Primary Industries

IN BRIEF...

- Of all Eastern Australian freshwater fish, silver perch is the easiest to culture.
- When pond construction, water and infrastructure costs are offset by other farm activities, growing silver perch in farm storages is highly feasible.
- Main impediments are lack of experience, the necessary large operational scale, and finding and developing suitable markets.
- Research has identified the ideal cage culture conditions and methods suitable for a profitable large scale venture.

NATIVE fish culture in farm dams is standard practice in most countries where land, food, water and fertilisers are scarce or at a premium. Omnivorous fish are grown in farm ponds for food, while fish waste fertilises irrigation water used to grow more food or crops.

In Australia, land, food, water and fertiliser must not be scarce or at a premium, as most finfish aquaculture involves marine carnivores such as tuna, kingfish, and salmon. Marine carnivores require other fish to feed them, and the waste only causes problems. Most of the world's aquaculture production is of freshwater omnivorous carp. Non-native carp degrade Australian waterways and are regarded as a noxious pest.

Australian inland native freshwater fish are highly regarded as food and sport fish. Inland native freshwater fish were once an important source of food for native cultures, and later became the target of an important commercial inland fishery. While the diversion of runoff waters may have played a part in the demise of the fishery, water stored for irrigation can be beneficially utilised to grow Australian native fish, as well as irrigate crops.

Of all the Eastern Australian freshwater fish, the silver perch is the easiest to culture because it is tough, grows quickly, prefers to school in large groups, but most of all is easy to feed, adapting to artificial feeding from a very young age. Silver perch is an ideal candidate for freshwater aquaculture, but the pond based industry in eastern Australia has failed to reach its full potential due to high losses from bird predation and difficulties feeding and managing stocks in green ponds. Floating cages are a low cost and flexible way to utilise existing water bodies, and can prevent bird predation as well as overcome many of the management difficulties associated with pond culture. Our research at the Grafton Aquaculture Centre (GAC) looked for the best ways to grow out silver perch fingerlings in cages, in a water storage reservoir.

A number of experiments were run over three years to look for the best stocking densities, commercially available diets, and cage designs. Also examined was a method for maintaining fish growth and survival during winter (when irrigation storages may be low) by overwintering fingerlings in a warm water recirculating tank system. The overall results from these experiments were compared to those for previous pond culture experiments at GAC, using a computer based financial model developed by the Qld Department of Agriculture Fisheries and Forestry for silver perch farming titled Perchprofit.



Silver perch ready for market.

The most important finding was the high rates of survival for silver perch fingerlings grown in cages compared to those grown in ponds (97 per cent in cages compared to 30–70 per cent in ponds), and the influence high survival had on potential profitability. The research found that for one to 20 gram fingerlings, stocking densities of 500 to 1000 fish per cubic metre were ideal for the best growth. For larger fingerlings, stocking densities of 100 fish per cubic metre produced the best growth, and least tail damage.

Overwintering fingerlings in heated recirculation system tanks improved survival, but also reduced the time needed to grow fish to market size. By the end of the following summer season, fish overwintered in tanks went to market, while those overwintered in ponds had to stay until at least halfway through the next summer season. The findings also support a link between fish growth and survival, fish welfare, and farm profitability.

Silver perch can and should be grown in cages. Animal welfare objectives include freedom from fear and pain, hunger and disease. While fish may not have the brain parts to experience fear, they react directly to their environment, releasing hormones that inhibit growth under stressful conditions. The excellent growth and survival during the experiments, due to protection from predators, as well as the ease of feeding, handling and disease monitoring suggests that silver perch in cages may have better animal welfare outcomes than those grown in ponds.

While water conditions are not always suitable in some storages, particularly during pumping, cages will allow the flexibility to maintain internal cage water quality during farm activities and extreme weather events. The main impediments to growing silver perch in Australian water storages are lack of experience, the necessary large operational scale, and finding

and developing suitable markets. ABARE have reported that the profitability of growing silver perch in ponds is marginal at best. But when pond construction, water and infrastructure costs are offset by other farm activities, growing silver perch in farm storages is highly feasible.

There are still several challenges to farmers wishing to better utilise their irrigation water. A major challenge is that a large production scale of around 100 tonnes per annum would be required to ensure long term profitability and market development. Without an on-farm trial program or scientific extension available, it will be risky to attempt a profitably sized venture. Silver perch are currently gaining high prices at the Sydney Fish Market, but the influence of a potentially large supply of cage grown silver perch on current market prices is unknown.

But with land, food, water and fertiliser all becoming increasingly scarce, (even in Australia) our research has identified the ideal cage culture conditions and methods suitable for a profitable large scale venture. The cage culture of native silver perch, with or without overwintering, could become a profitable addition to Australian irrigation farming systems.

Project Final Report at www.cottoncrc.org.au

Funding: Cotton Catchment Communities CRC, NSW Department of Primary Industries. ▲



A number of experiments were run over three years to look for the best stocking densities, commercially available diets, and cage designs.



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- 1 **SCALE:** worked in a catchment of 24 434 km², 2.75 million ha, 225 000 people and 3 100 farmers
- 2 **INVESTMENT:** Secured investment of over \$20 Million
- 3 **RETURN ON INVESTMENT:** For every \$1, attracted an extra \$4.67
- 4 **PARTNERSHIPS:** 84 different partnerships: shared the knowledge, learnings left the legacy
- 5 **BIODIVERSITY:** 52 821 ha of native vegetation enhanced via threat mitigation, weed control and plantings
- 6 **RIVER:** 11 wetlands and 398 km stream banks enhanced
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- 8 **ABORIGINAL:** Protected 11 high value aboriginal sites
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- 10 **SCIENCE KNOWLEDGE:** 330 cultural site assessments; 65 socio economic assessments; 386 biophysical, economic or socially related plans; 35 research studies



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An advancing front of monolayer film in the foreground on cotton water storage at St George, Queensland in March 2012 shown by the smooth water surface in the image. (Photo: Guy Roth)

Evolution of polymers mitigates evaporation

■ Dr Ian Dagley, CEO CRC for Polymers

IN BRIEF...

- Development of an improved ultra-thin film (monolayer) evaporation mitigation system is well underway.
- Improvements include longevity on water surface and ability to maintain evaporation savings under wind conditions, which were limitations of previous technologies.
- Development also underway of automated application system giving users the “set and forget” option for their evaporation mitigation strategy.
- An evaporation savings of 35 per cent was demonstrated at one stage of a trial in Queensland.

EVAPORATION from water storages is a major issue affecting agricultural regions of Australia with annual losses potentially exceeding 40 per cent of water stored. Loss of this water can lead to reduced agricultural productivity. While a range of structural evaporation mitigation options (for example floating covers, suspended shade cloth) are available for small storages (less than 10 hectares), many storage dams have surface areas greater than 10 hectares and existing structural products are less applicable and require large capital outlays.

For such large storages, chemical ultra-thin films (for example chemical or polymer-based monolayers), either on their own or in combination with other systems, provide a compelling option. They offer the advantage of being applied to stored water only

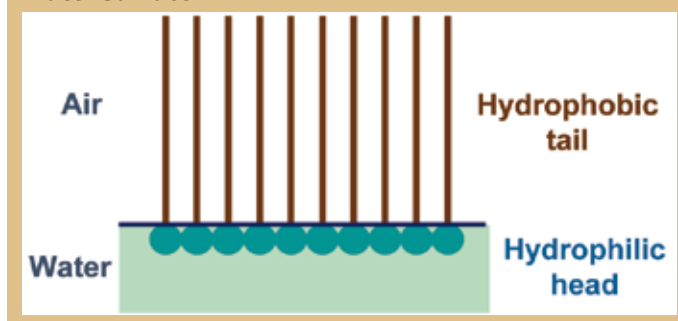
during periods when the evaporation rates are high and have low capital costs. However previously developed products have limitations and have not found widespread use. This research has focussed on developing improved chemical ultra-thin film products and demonstrating their effectiveness in a range of field trials.

Chemical ultra-thin films (monolayers) typically act like a detergent, very efficiently spreading out across the surface to provide a thin (often only a single molecule thick) layer that is not visible and reduces evaporation by restricting the transfer of water into the air. Due to this unique ability to form an ultra-thin layer, only a very small amount of material is needed to establish a protective film on a water body. For example, for a one hectare dam only 80–100 g of material is needed. To put this into context, the amount equivalent to three scoops of standard laundry powder would cover a 10,000 m² water body! A schematic diagram showing a typical monolayer on the water surface is shown in Figure 1.

Other unique properties of this ultra-thin film technology include the ability to re-form following a disturbance such as those caused by wind, birds, livestock and other animals. This means application of this technology will not detrimentally impact animal or human use of the treated water body, and use of the water body will not cause any significant disruption to the evaporation performance of the film.

A fundamental breakthrough in 2008–09 was the

FIGURE 1: Schematic diagram of a monolayer on the water surface.



development of novel ultra-thin materials which demonstrate significant improvements in performance compared to previous technologies. These included improvements in longevity on the water surface and ability to maintain evaporation savings under wind conditions, two limitations identified with the previous technologies. This breakthrough has subsequently been protected by a patent application and extensive laboratory-scale testing has identified the best performing system to progress to field trials.

A range of small and medium-scale field trial sites have been set-up across Australia including 3.7 m² troughs, 135 m² ponds and 330 m² dams at Dookie, Victoria and 220 m² sections of a lined disused (non-flowing) irrigation channel at Yanco in NSW.

A range of trials have been conducted investigating factors such as different chemical and physical formulations, different application rates and regimes, and the effect of water quality. Unfortunately recent summer seasons have been unusually wet and cool and the field trials were often interrupted by rain events making the study more challenging. Despite this, evaporation savings of 40 to 60 per cent were consistently observed throughout these small and medium-scale field trials demonstrating the effectiveness of the new technology.

The next step is to undertake larger scale field trials to further demonstrate the technology. To date a trial has been carried out on a 16 hectare dam at Forest Hill (Queensland) from which a large number of observations and understandings were obtained that were used to further improve the product. An evaporation savings of 35 per cent was demonstrated at one stage of this trial.

Over the summer of 2011–12 a field trial site was established on a cotton farm at St George in Queensland using two similar sized (approximately eight hectare) dams. Where the film was present the surface was smoother and reflected the sky. Beyond the advancing front of the film, the water was more affected by surface waves.

But heavy rain and flooding has unfortunately limited site availability and therefore limited data has been obtained to date. Despite the weather plans are still in place to conduct further large scale field trials over the coming evaporation seasons to obtain the results needed to progress development through to the next stage of commercialisation.

Concurrently, development of an automated application system that will give users the option to 'set and forget' their evaporation mitigation strategy is underway. Automated applicators can be programmed to dispense product according to specific application protocols that are currently under development, allowing users the option of deploying these applicators on their water storage with occasional refilling being the only labour required. Alternatively, users may opt to

dispense the product by hand, without the use of an automated application system. Due to the uniqueness of this product, either option should produce good evaporation savings for the user.

In addition to the field trials, appropriate environmental testing is being carried out. This is necessary to ensure there is no negative environmental impact of these films on the aquatic environment, livestock, other animals, or humans. A regime has been developed in consultation with potential end users and commercial partners. This regime includes toxicity testing and a ready biodegradability study, and testing is currently underway. The contents of the current system under development are commonly used in products that have been employed in diverse uses, and in uses where there is human exposure, such as detergents and cosmetics. As such, they already have approval for use indicating they are non-toxic. Initial toxicity testing has shown that the materials are considered non-toxic, particularly at the extremely low levels that will be used.

The development of an improved ultra-thin film (monolayer) evaporation mitigation system is well underway. A breakthrough discovery in the laboratories has led to the development of a novel product which has progressed through extensive laboratory testing, small and medium-scale field trials, and is now in the process of undergoing trials in larger water bodies. An environmental testing regime has been put in place and progress so far is indicating no negative environmental impacts through use of this product. Continued large-scale trials, further development of an automated application system and finalising the environmental testing are the project aims heading into the future.

Further reading at www.crdc.com.au

Funding: The research was initiated through a collaboration between three CRCs: Cotton Catchment Communities, Irrigation Futures, and Polymers. It was then continued by the CRC for Polymers which provided longer-term funding support for research at The University of Melbourne. Irrigation CRC, National Program for Sustainable Irrigation, National Water Commission, State Government of Victoria. Further funding for the research has been provided by National Program for Sustainable Irrigation, National Water Commission and State Government of Victoria. ▲

Calculating evaporation loss

■ Erik Schmidt, National Centre for Engineering in Agriculture, University of Southern Queensland

IN BRIEF...

- Annual evaporation losses from irrigation storage dams and channels are significant.
- Tools have been developed to assess evaporation and seepage losses from storage dams.
- The cost benefit of evaporation control is a key driver when investing in evaporation management technologies.
- Chemical monolayers are being developed by the CRC Polymers as a low cost method to reduce evaporation losses.

VARIOUS products are already being used commercially for evaporation management, but come at high capital cost and are not considered appropriate for large areas.

Research conducted by the CRC for Irrigation Futures, Cotton Catchment Communities CRC and the CRC Polymers as well as the National Program for Sustainable Irrigation has focussed on the development of tools and resources for measuring evaporation loss from dams, assessing the economics of minimising evaporation losses and more recently monolayer evaporation control systems and associated application technologies.

Measuring evaporation losses for farm dams

Monitoring systems have been developed to assess evaporation and seepage losses from storage dams. The system is based on accurate measurements of water depth using pressure sensitive transducers installed in the dam. The monitoring systems and associated data analysis software have been commercialised by Aquatech Consulting as the Irrimate™ Seepage and Evaporation Meter.

The system uses an accurate pressure sensitive transducer to measure changes in water level every 15 minutes. Rainfall, wind velocity and water temperature is also logged for use in the analysis which requires at least 20 days worth of quality data with periods of rainfall and storage inflow/outflow excluded.

Data analysis is achieved using customised software (EvapCalc) to compare measured water level changes and estimates of evaporation loss. This process allows the evaporation and seepage components of the total loss to be separated, thus determining an average seepage rate and evaporation rate. The systems have recently been used in a study for the National Water Commission to assess seepage and evaporation losses from 136 storages located across the cotton industry. The study found that 88 per cent of storages had low seepage of less than four mm per day and annual evaporation for individual storages (if storages held water year round) ranged from around one metre per year to just over two metres per year.

Economic viability

The cost benefit of evaporation control is a key driver when investing in the technologies described above. The potential cost of installing and operating evaporation control systems, including increasing wall height or introducing cells for better water management will be a function of:



Irrimate™ Seepage and Evaporation Meter.

- Earthworks, installation and maintenance costs which are very dependent on site situation and installation issues.
- Annual and seasonal evaporation losses from storages at the location.
- Efficiency of the system in mitigating evaporation.
- Storage operating conditions.

The annualised cost of the system needs to be compared to the value of water to the landholder in terms of increased crop production, cost of water to be purchased or the potential to trade a water surplus.



Irrigators are urged to try the Ready Reckoner calculator.

A Ready Reckoner has been developed to help undertake such economic analyses. The calculator allows site-specific assessment of evaporation mitigation systems. The user enters appropriate data to customise the Ready Reckoner to their site. The Ready Reckoner returns the volume of water saved (in ML) and the cost of the evaporation mitigation system used to save this water (\$ per ML saved per year). The calculator is located at <http://readyreckoner.nceaprd.usq.edu.au/readyreckoner.aspx>.

Monolayers for evaporation mitigation

While floating covers and suspended shade cloth structures have been used effectively to reduce evaporation they require large capital outlay. Chemical monolayers are being developed by the CRC Polymers as a low cost method to reduce evaporation losses. These products are biodegradable and there is a need to reapply frequently (ie between one and five days). Water savings have been shown to be highly variable and dependant especially on prevailing wind, temperature and water quality.

Advantages of these products are the low capital cost and choice to apply only when needed. Monolayers can best be managed using an application system that doses according to prevailing conditions.

Monolayer application, monitoring and control systems

The National Centre for Engineering in Agriculture has developed a 'smart' autonomous monolayer application system capable of adjusting the rate and location of monolayer placement, according to prevailing weather conditions. This system, when combined with new monolayer products currently under development, will allow optimum management of monolayer application.

The system is capable of adjusting the rate and location of monolayer application according to prevailing weather conditions on-site, to maintain monolayer coverage and comprises an automatic weather station (AWS), co-ordinator and a number of applicators. The AWS measures the necessary on-site weather conditions, such as wind speed, wind direction and rainfall, and reports this information to the co-ordinator. The co-ordinator then uses this information to determine which applicators to apply from and the appropriate application rate for each. The co-ordinator relays this information to the appropriate applicators through a wireless communication network. The system has been successfully demonstrated on a 16 hectare farm dam trial site.

A framework for design, deployment and management of monolayer application systems has been developed. This informs the selection of appropriate equipment, including the design and number of applicators, their arrangement on-site and application strategies for a given dam site; and also ensures sustained autonomous operation is efficient in evaporation reduction and applying the monolayer.

Farm dam management information including resources on evaporation and seepage losses can be found at the following link. <http://ncea-linux.usq.edu.au/farmdammanagement/>

Funding: CRC for Irrigation Futures, Cotton Catchment Communities CRC, CRC for Polymers, National Program for Sustainable Irrigation. ▲



A monolayer application unit with automated dosage control works in accordance with prevailing weather conditions.

Space-age technology used industry-wide

■ John Hornbuckle and Richard Soppe, CSIRO

IN BRIEF...

- IrriSAT is an industry wide, high resolution, low cost crop water use and benchmarking service.
- Provides daily crop water use information and also predicts crop water use for the coming seven days.
- Uses a web interface which was developed using Google Maps and allows consultants to easily monitor multiple farms and fields.
- System has its greatest strengths in benchmarking crop water use productivity across farms and regions.

AN industry wide, high resolution, low cost crop water use and benchmarking service – that's been the goal of the IrriSAT system being developed and trialed over the 2010–11 and 2011–12 irrigation seasons on more than 80 000 ha of cotton fields. The technology makes use of satellite imaging for monitoring crop growth and a series of weather stations spread throughout the cotton growing areas to produce high resolution site specific crop water use information on a daily basis which can be used for water management and also benchmarking. The technology also includes a seven-day weather forecast for short-term irrigation water management decisions.

IrriSAT uses a web interface developed using Google Maps and allows users to easily monitor multiple farms and fields. Users upload three pieces of irrigation information: irrigation date; amount of irrigation water applied and daily rainfall. IrriSAT regularly obtains satellite imagery to determine current crop growth through a measure of the Normalised Difference Vegetation Index (NDVI). These NDVI values are then correlated to an individual crop coefficient. The satellite derived data is then combined with local weather station data to provide an accurate measure of daily crop water use and a prediction of crop water use for the coming seven days.

This is useful information to help with water management decisions. Spatial crop water use information determined by IrriSAT is also available through the interface and allows users to investigate water use differences within and between fields using the system (Figure 1). This information can be used to change management decisions or to gain a better understanding of how or why fields might be affected by different management options.

One of the great strengths of IrriSAT is it is able to cover entire irrigation regions using remote sensed satellite imaging which allows benchmarking of crop water use index (CWUI) across a farm or across an entire irrigated region or catchment. It provides a regional snapshot of the performance of row configurations, irrigation systems and irrigation deficit management strategies which can be seen to affect yield and water use efficiency performance.

It this early stage the IrriSAT system has been trialed with both consultants and directly with irrigators across the Gwydir region for the 2010–11 and 2011–12 seasons and the Namoi and Border Rivers for the last irrigation season. This adaptive research

FIGURE 1: Spatial crop water use differences across irrigated cotton fields determined by IrriSAT.



and extension has allowed the system to be improved each year to focus on the key questions and delivery of information which really assists in developing this tool for universal use.

So far the feedback we have received has been very positive and most see the IrriSAT system as a tool which has its greatest strengths in benchmarking crop water use productivity across farms and regions to see where improvements can potentially be made.

Rob Holmes, HMAg, Moree says the greatest use he has for using IrriSAT crop water use information was for benchmarking his clients' cotton crops.

"When I'm calculating the crop water use index I need a reliable estimate of ETC. The IrriSAT technology has provided me with this," Rob said.

"It's quick and easily obtained for my end-of-season benchmarks. It reflects the whole paddock, rather than just a single square metre of the paddock.

"Benchmarking crop water use allows me to look back over the season with my clients and compare crop productivity in terms of water use between fields and farms. We can discuss what might be occurring in field and try to improve over time."

As we move forward with water management, we believe tools such as IrriSAT will be able to play a key part in understanding how to best make use of water across not just a paddock but also a farm or catchment.

Funding: Cotton Research and Development Corporation

Further reading at www.crdc.com.au

Cotton heads north

■ Stephen Yeates CSIRO Plant Industry, Paul Grundy DEEDI, Geoff Strickland, John Moulden, Penny Goldsmith WA Dept of Ag & Food, Andrew Davies CSIRO Ecosystems Science

IN BRIEF...

- NORpak-Ord River helped pull together 10 years of research into a cotton production manual for The Ord.
- Research found yields equivalent to other summer cropping areas in Australia.
- Adoption of a range of best management practices arising from research has already helped farmers achieve good cotton yields in the lower Burdekin.
- Like The Ord, the Burdekin climate changes the way cotton grows and therefore successful production requires management tailored to these changes.

SEVERAL Cotton CRC projects have focused on water-secure regions in tropical Australia: The Ord River WA where research and development was completed and the lower Burdekin in North Queensland where a new feasibility study has started. Both regions have unique climates for cotton growth. Research has focused on understanding the different plant growth in each region and developing appropriate best management practices.

Dry season cotton in The Ord

By growing Bt transgenic cotton in the dry season (winter) and using Integrated Pest Management techniques, insect pests in The Ord River WA are well controlled. But the dry season poses significant challenges for crop growth. Temperatures and solar radiation are the reverse of summer cropping in temperate Australia. That is rather than a growing season that follows the pattern of cool-hot-cool the pattern in the dry season is hot-cool-hot.

Mid-season (early boll filling) radiation coincides with the shortest days of the year and is 20 per cent less than for the same growth stage in temperate Australia. Despite these climate limitations our research found yields equivalent to summer cropping in temperate Australia. The major change in management is to ensure that sowing occurs from March to April and the crop has an extended flowering period so that a greater contribution to yield from later flowering bolls can occur.

Due to very cold nights coinciding with early flowering, these flowers make only small contributions to yield; the opposite to what occurs in temperate Australia. Management of growth regulators, water, nutrients, varieties and pest damage thresholds is tailored to maximising the length of the flowering period to ensure compensatory yield from flowers pollinating when day length and temperatures increase.

A major output from this research in 2007 was *NORpak-Ord River* which helped pull together 10 years of research into a cotton production manual for the region. *NORpak-Ord River* also challenged the GM (genetically modified) debate by demonstrating the merits of GM varieties as part of a production system that has a reduced environmental footprint compared with the conventional system. Recent commercial scale validations proved that farmers, with little cotton experience,



Ord River entomologists John Moulden and Geoff Strickland.



Paul Grundy experiencing in wet and cloudy conditions in the Burdekin.

can produce high yielding cotton using *NORpak-Ord River*. This experience combined with a more favourable political environment and cotton prices was the basis for significant commercial plantings in The Ord in the 2011 dry season.

Wet season cotton in the lower Burdekin

Because dry season temperatures were too cold for cotton, sowing early in the wet season (late December/January) then picking in the dry months of June/July proved the best option in the Burdekin. Fortunately wet season insect pest numbers were much lower than in the Ord River. But the wet season provided new challenges for cotton production.

Like the Ord River the Burdekin climate changes the way cotton grows and successful production requires management practices tailored to these changes. We predicted that high humidity, rainfall and cloud during flowering could limit growth and cause fruit to shed. So too much rainfall in the Burdekin could be a constraint to production.

Research data has demonstrated that wet season fruit shedding has limited impact on crop yield provided that the crop is managed to ensure later compensatory fruit set when sunny conditions later return. Research since 2007 has made significant progress to identify practices that ensure maximum late compensatory fruit set. Practices like the best sowing date and variety combined with management tactics for nitrogen, water, insects, crop trimming and growth regulators.

We found selecting the correct variety and managing for a

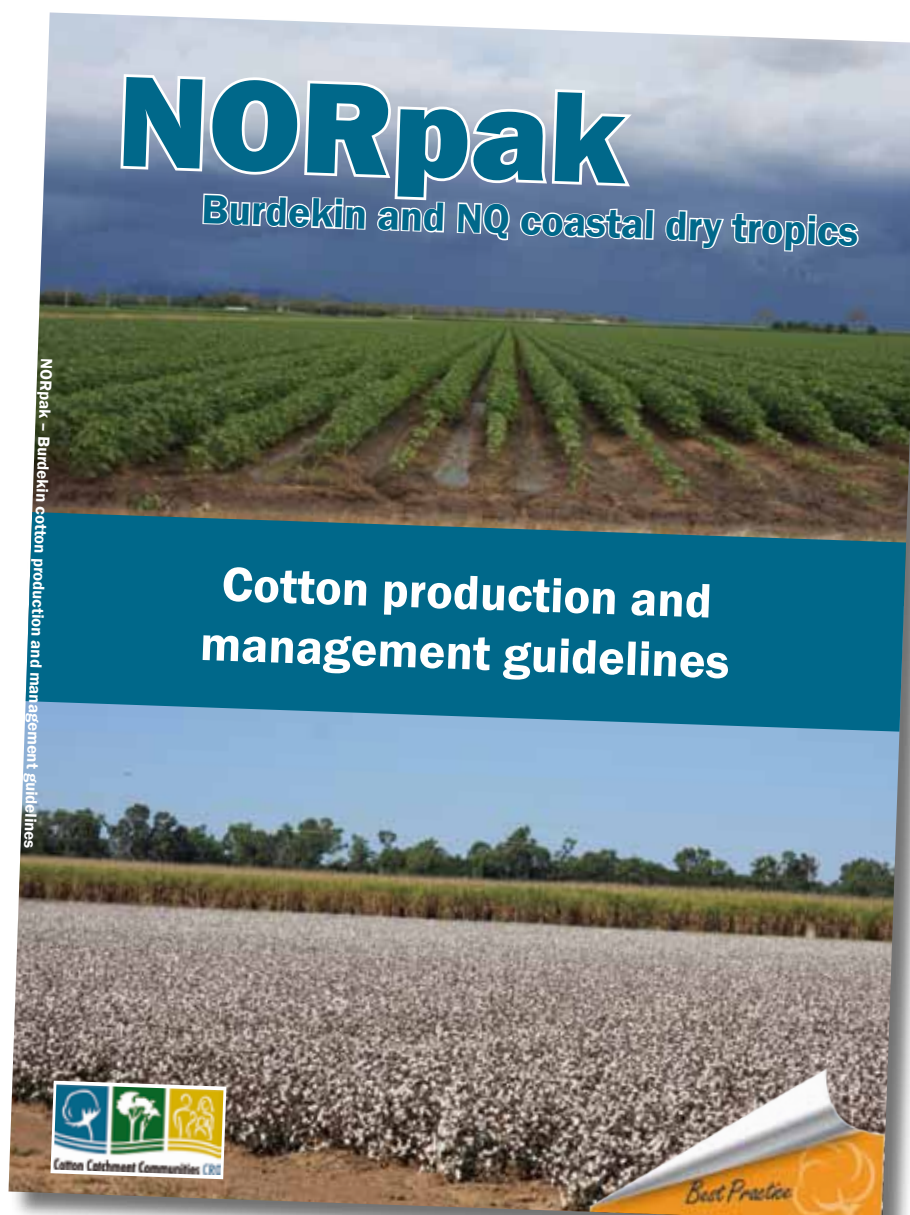
compensatory top crop was essential to successfully manage the wet season. Sicot 70 BRF has a more determinate growth habit and will retain fruit during wet overcast conditions, in this case resulting in small and tight-locked bolls, reducing later compensation. Siokra 24 BRF shed fruit during earlier cloudy weather and instead grew a compensatory top crop setting all bolls during Autumn. In our experiment the Siokra 24 yielded significantly more (9.4 bales per hectare) than the Sicot 70 (8.2 bales per hectare).

Crop trimming is one innovation where early season crops have the terminal shoot mechanically cut off which delays the onset of crop flowering and encourages the plant to grow an open 'vase' shaped canopy which allows for better sunlight interception.

Adoption of a range of practices arising from this research has already helped growers test farming cotton in the region.

Funded by: Cotton CRC and Cotton Research & Development Corporation.

Further reading: NORpak-Ord River Irrigation Area. Cotton production and management guidelines for the Ord River Irrigation Area (ORIA) 2007. Yeates S, Strickland G, Moulden J, Davies A. Cotton Catchment Communities Cooperative Research Centre.
http://www.cottoncrc.org.au/content/Industry/Publications/Northern_Production.aspx



Maximising profits of irrigated cotton

■ José Payero and Graham Harris,
QLD Department of Agriculture Fisheries and Forestry

IN BRIEF...

- The maximisation of irrigated cotton profits is a complex question as it depends on both economic and agronomic factors.
- The economic factors include the relative relationship between crop price and cost of production. The agronomic factors include the yield response of cotton to irrigation.
- Both the economic and agronomic factors can be highly variable with season and location.

In this analysis we simulated farm gross margins for three scenarios:

1. **Scenario 1 – Water is limited and land is not.**
2. **Scenario 2 – Land is limited, but water is not**
3. **Scenario 3 – Both land and water can vary within a certain limit.**

We conducted the simulations assuming current cotton price and cost of production and typical yield response to irrigation for arid, semi-arid, and humid environments. We found that to maximise farm gross margin (FGM), different irrigation strategies need to be implemented for the different scenarios and environments.

The cotton yield response to irrigation that can be expected at each of the three test environments, see in Table 1.

TABLE 1: Parameters used to represent the yield response to irrigation for cotton in three environments. Note that dryland yield in the arid environment is negative as a certain amount of irrigation is required to produce any yield.

Environment	Arid	Semi-arid	Humid
Maximum yield (bales/ha)	12	12	12
Dryland yield (bales/ha)	-3	3	6
Irrigation required for maximum (mm)	600	400	300

TABLE 2: Cost and prices used to calculate farm gross margin of cotton production (Adapted from NSW Department of Primary Industries).

Item	Cost/price	Units
Lint price	\$540	\$/bale
Seed price	\$215	\$/tonne
Cost of production	\$2709	\$/ha
Cost of irrigation	\$44.39	\$per ML/ha
Cost of module lifting	\$3	\$/bale
Cartage cost	\$10	\$/bale
Ginning cost	\$55	\$/bale
Cost of levies	\$4.50	\$/bale



José Payero.

Graham Harris.

We calculated farm gross margin (FGM) as
 $FGM = \text{Revenue} - \text{Variable costs}$

Revenue included both lint and seed yield and independent prices for each. The implications of irrigation on lint quality and corresponding prices were not included. Variable costs included generic production costs (per hectare), irrigation costs (per megalitre per hectare) as well as ginning, cartage, levies and module handling costs (per bale). Table 2 lists the costs and prices used for FGM analysis.

We then calculated FGM for the three environments (arid, semi-arid, and humid) for different combinations of irrigated area and irrigation applied for the following scenarios:

FIGURE 1: Economic analysis of irrigation options in three environments (Arid, Semi-arid, and Humid) in the case when water is limited to 100 ML and land is not limited. FGM = farm gross margin.

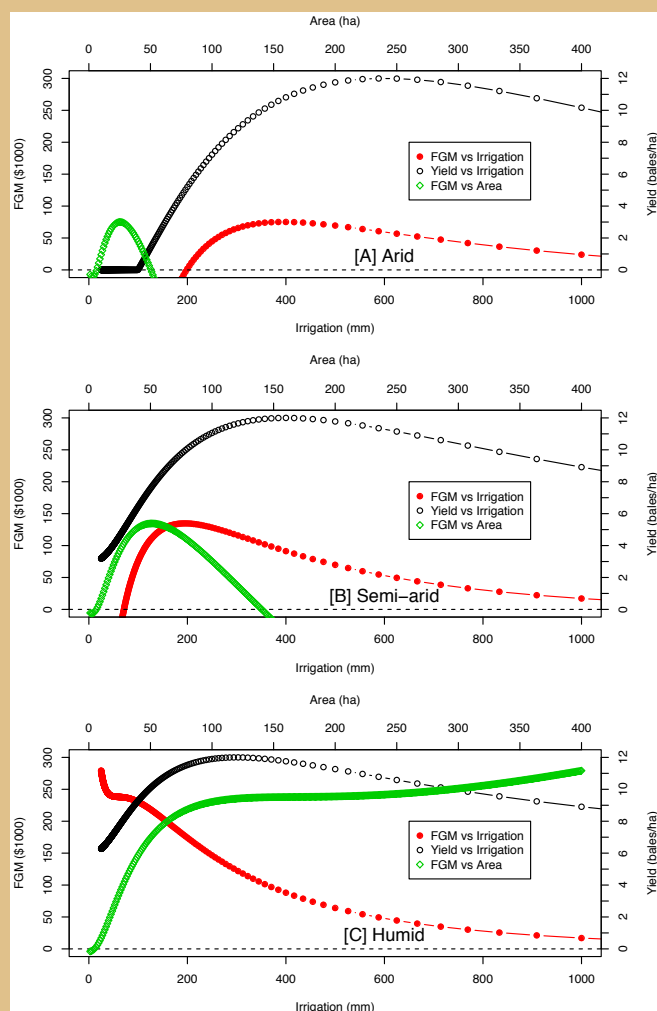
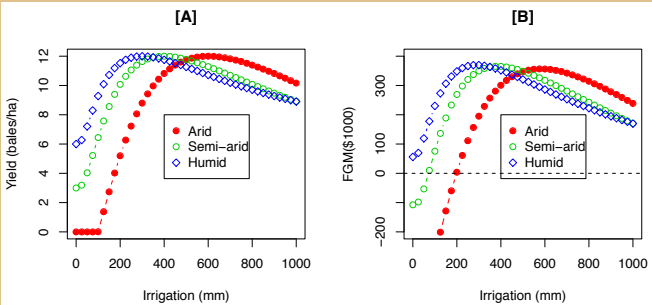


FIGURE 2: Simulated relationship between irrigation and [A] cotton lint yield and [B] farm gross margin (FGM) under three environments (Arid, Semi-arid, and Humid) in the case when land is limited to 100 ha and water is not limited.



Scenario 1 – Water is limited and land is not

For **Scenario 1**, we assumed that water was limited to 100 megalitres and land was not limited. Since water was limited, increasing area implied reducing irrigation and vice versa.

Yield, area, and FGM as a function of irrigation applied for this scenario are shown in Figure 1 for the three environments. For the arid environment in this example, FGM was maximised by using a supplementary irrigation strategy in which area was limited to 25 hectares and 400 mm of irrigation was applied. In this case, it would have taken 600 mm of irrigation to obtain maximum yield (12 bales per hectare). By reducing irrigation, yield was reduced to 10.8 bales per hectare. But, accepting a 10 per cent reduction in yield resulted in maximum FGM and in a 33 per cent reduction in irrigation.

For the semi-arid environment, FGM was also maximised by using a supplementary irrigation strategy in which only 51 hectares were irrigated using 196 mm, rather than the 400 mm that would have taken to obtain the maximum yield. In this case, yield was reduced to 9.98 bales per hectare, a 17 per cent yield reduction with a 51 per cent reduction in irrigation.

For the humid environment, on the other hand, FGM decreased with irrigation and increased as the area increased. Therefore, the best strategy was not to irrigate and to plant as much area as possible.

Scenario 2 – Land is limited, but water is not

For this scenario, we assumed that land was limited to 100 hectares and water was not limited. Results in Figure 2 show that for all three environments, the relationship between irrigation and FGM followed the same trend as that between irrigation and yield. Therefore, FGM was maximised when yield was maximised.

Scenario 3 – Both land and water can be varied within a certain limit.

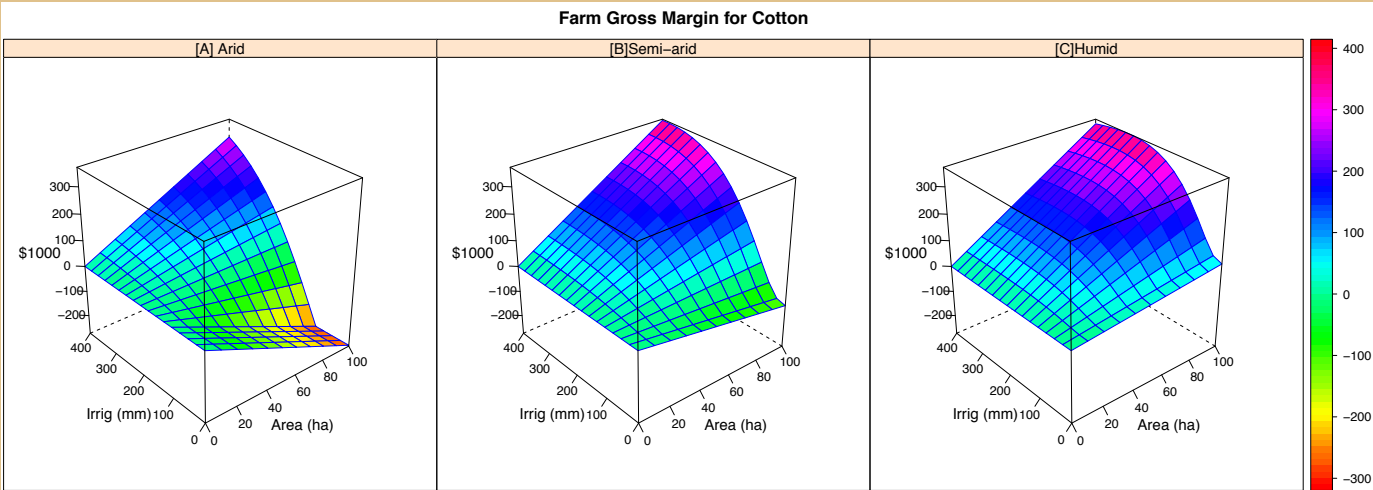
For this scenario we assumed that land was limited to 100 hectares and water to 400 megalitres (400 ML/100 ha = 4 ML/ha = 400 mm). Therefore, the grower can vary both the land irrigated and the amount of irrigation applied.

Results in Figure 3 show that for the arid and semi-arid environments, increasing area at very low levels of irrigation tended to decrease FGM. But for higher levels of irrigation, increasing area and irrigation both tended to increase FGM. For the humid environment, on the other hand, FGM increased as area increased, even at very low irrigation level (and even without irrigation). Since land was limited, for all three environments, FGM was maximised when yield was maximised.

From the above analysis we concluded that to maximise FGM, different irrigation strategies need to be implemented for the different scenarios and environments. But we should note that this economic analysis would be sensitive to changes in prices and to changes to the yield response to irrigation.

Funding: Cotton Catchment Communities CRC and Cotton Research & Development Corporation.

FIGURE 3: Simulated farm gross margin (FGM) under three environments (Arid, Semi-arid, and Humid) in the case when land is limited to 100 ha and water is limited to 400 ML (4 ML/ha = 400 mm).



Using water efficiently in the Condamine

IN BRIEF...

- Researchers and extension staff worked closely with consultants and growers in a mentoring capacity to achieve:
- 25 per cent increase in cotton consultants with improved skills and knowledge in Water Use Efficiency (WUE).
- 2344 hectares of irrigated cotton land in the Condamine Catchment utilising WUE best practice.
- Increased understanding of the economic benefit of implementing WUE best practise.
- Estimated water savings of 0.15ML to 0.72ML per hectare for the 13 participating farmers.

IN 2007, with water becoming an increasingly scarce and consequently valuable input in production systems, the Condamine Alliance, Cotton CRC and Department of Agriculture Fisheries and Forestry worked together to improve water use efficiency best management practices on cotton farms within the Condamine Catchment. This involved training for cotton consultants and their grower clients, an economic evaluation of the benefits of adopting WUE practices and incentive funding for WUE evaluations.

The economic evaluation found that the recommended WUE changes, resulting from each grower's WUE evaluation, would result in a positive return on investment for the grower.

"The economics was invaluable. Growers need the financial implications of managing natural resources in order to understand the benefit in full," says Olive Hood, Cotton Australia Project Leader.

A team effort by cotton grower Brett Bidstrupp, cotton consultant Murray Boshammer and Cotton Australia's water project manager Olive Hood have combined to improve WUE on 'Alderton', 50 kilometres west of Condamine in Queensland.

This 3000 hectare family owned and run enterprise has a mix of grazing, dryland and irrigated cropping and has been severely impacted by the drought, with just 130 hectares of cotton grown over the past two seasons.

"We've got a licorice all-sorts of soil types on this property, ranging from red loams suitable for growing peanuts and watermelons through to darker brown clays that are ideal for corn and cotton," Brett said.

"These soils types can all occur in one field which makes management very difficult because they require varying amounts of water to grow varying amounts of crops."

Another issue is the naturally undulating nature of the landscape, which results in uneven fields.

Murray said "for furrow irrigation, this means that water travels down the paddock at different speeds, the soil takes on water at different rates and that translates to uneven crop growth and yields".

The Irrimate evaluations conducted by Murray as part of a Cotton Australia project provided solid data relating to these issues.

"By looking at the results of electromagnetic surveys and in-field water use efficiency assessments, we were able to identify the different soil types and look at how each responded under irrigation," he said.

"Each soil type had different infiltration characteristics and



Cotton grower Brett Bidstrupp and Murray Boshammer from Total Agricultural Services Pty Ltd, Dalby, Qld. Murray said by looking at the results of electromagnetic surveys and in-field water use efficiency assessments, he was able to identify the different soil types and look at how each responded under irrigation. He was then able to work out the best irrigation rates and inflows for the characteristics of the soil.

held different levels of water in the head ditch, so we were then able to work out the best irrigation rates and inflows for the characteristics of the soil."

All of this data was used to place C-probes in optimum positions throughout the field for better irrigation scheduling, and siphon sizes were adjusted at different points along the paddock to change the rates of water application to suit the various soil types. Brett and his team have also taken the guesswork out of water budgeting by accurately mapping storage capacity, allowing a reading for how much water is stored every 10 centimetres.

"If we know how much water the crop's using and how much we've got in storage, we can accurately forecast how much we can grow with the water we've got and that makes for better planning. It's a whole lot better than me standing at the top of the storage and taking a guess," Brett said.

A number of storage surveys conducted by Murray across the Darling Downs have all shown that growers are starting with a lot less water than they thought they had. He said original estimates on a lot of storages were done when the dam was "full to the brim which is impossible and so many growers are making decisions based on inaccurate information".

According to Brett Bidstrupp, the biggest benefit has been the ability to track water a lot more efficiently.

"Our philosophy has become you can't manage what you can't measure," he said.

"We now know how much water is going on a crop, what yield we're likely to get out of it, how much water is on the farm and how much we're using at any one time and that's got to be better for our farm business."

Funding:
Cotton Catchment Communities CRC, Condamine Alliance, Department of Agriculture Fisheries and Forestry.



Improve water management with *myBMP*

PLANNING simply means thinking ahead, vital to the success of any farming operation. Planning helps identify issues and potential challenges facing your business allowing timely intervention or preparation. Good farm planning requires an understanding of the farm's resources, especially its water, soils and infrastructure that are the foundations of any agricultural operation. The initial planning step involves assessing and recording a farm's resources and then identifying what risks or management issues need to be considered. You can then develop appropriate plans for how you manage your valuable farm assets as efficiently and responsibly as possible.

The cotton industry's Best Practice initiative, *myBMP* can assist with the process of farm planning by helping identify potential risks that may be associated with a particular activity and then providing suggested solutions to managing those risks. Practices in *myBMP* represent a step-by-step check list which can be used as a guide to risk management and better farm planning.

The *myBMP* program is fully supported by accessing the extensive information, tools and resources available from cotton industry research and extension community meaning that growers have direct access as they are developed to a centralised location with the latest information tools and resources making *myBMP* a key delivery tool for industry research and extension.

The Water, Soils and Natural Assets modules of *myBMP* have been designed to help manage a farm's water, soils and natural assets resources with a focus on making efficiency gains by bringing together the latest research and knowledge on management of these important resources. *WATERpak* is a key information source supporting these modules and covers topics ranging from managing and measuring water sources (storages, bores, overland flow and stored soil moisture) through to field irrigation. All aspects of water management are covered including surface irrigation, centre pivot, lateral moves, drip irrigation and dryland water management.

Why water management planning is important

Knowledge and understanding of many factors and processes are required to address on-farm water losses in the areas of seepage, evaporation, deep drainage and run-off. Good planning is essential to ensure that the wide range of potential issues and factors affecting an irrigated cotton farm are taken into account.

Many improvements in water use efficiency may be easily gained through simple changes to management practices which don't necessarily require extensive farm redevelopment or changes to newer systems of higher water use efficiency. Indeed, experience to date has shown that the installation of new and efficient irrigation systems technology is not the only answer to improving water use efficiency.

The easiest improvements in whole farm water-use efficiency often come from minimising deep drainage and tailwater losses, and this can additionally help improve yield by reducing water logging. These gains may only require a simple change in the management of irrigation water onto the crop, for example, by reducing the time water is run. Significant gains may also be able to be made in the control of evaporative and seepage losses from storages and channels.

A good plan should not only allow you to maximise water use efficiency and return per megalitre: it should mean that you

achieve the standard of environmental management expected by both the industry and the community.

This module of the Cotton Industry *myBMP* system is designed to help make efficiency gains by bringing together the latest research and knowledge on water use and management. Topics range from managing and measuring water sources and collection (storages, bores, overland flow and stored soil moisture) through to field distribution. All aspects of water application are covered including surface irrigation, centre pivot and lateral moves, drip irrigation as well as dryland water usage.

Once you have completed the *myBMP* Water module to at least Level 2, you will have achieved the following:

- Used available tools to schedule your irrigations and monitor soil water levels;
- Estimated your soils capacity to hold and store water for your fields and soil types;
- Estimated your losses from storages and channels;
- Maintained your storages to minimise leaks and seepage, particularly in dry times;
- Maximised crop yields by understanding and managing bore water quality;
- Calculated and recorded your irrigation water use index;
- Identified problem areas in irrigation fields and addressed them;
- Matched your flow rates to soil, slope and run length so furrows come out evenly;
- Planned for and installed your centre pivot or lateral move with a professional so it works effectively; and,
- Ensured your drip irrigation system is operating effectively.

WATERpak and *myBMP* are both excellent tools that can be used to develop a full farm plan, identify improvement options and benchmark your farms water use against the industry standards.

www.myBMP.com.au
1800COTTON



*my*BMP

CASE STUDY

Pipes through the bank

■ Nikki Pilcher and Mary Philp, QLD Department of Agriculture Fisheries and Forestry

SAUNDERS FARMING PTY LTD

Owners:	Craig and Sharon Saunders
Location:	St George
Total area:	3000 hectares
Cotton area:	647 hectares
2010–11 yield:	11.25 bales/ha
2010–11 water:	7.2 ML/ha
Field length:	500 to 1700 metres

CRAIG and Sharon Saunders own and run three irrigated cotton, dryland wheat and grazing properties in the St George area (part of the Balonne River Catchment) in Queensland. The original property “Ford Park” has been in the Saunders family for more than 40 years, with Craig and Sharon taking over management in the 1990s.

Four years ago Craig joined forces with Justin Schultz of WaterBiz to investigate alternatives to traditional siphon irrigation. As a result Craig and Justin designed and constructed a siphon-less watering utilising pipes through the bank (PTB) with variable rates of flow. Each pipe waters 11 furrows or 12 metres and is designed to suit the 12-metre machinery in use.

Saunders Farming also operates a centre pivot machine irrigating 89 hectares with a system capacity of 10.1 mm per day. This machine is located on Craig’s marginal country, irrigating red hard setting soils.

Motivator for change

It was initially thought that the main motivator for change four years ago was water savings, and a 25 per cent water saving has been achieved. But looking back, the team have realised that the real motivator was actually labour. The team have not only achieved this water saving, but have also had a labour saving of 50 per cent and yield increase of 20 per cent.

Justin has found that the main water savings are not a result of the pipes but actually by optimising the flow rate and the run times. In the 2010–11 season the traditionally lowest yielding farm actually out yielded the original farm for the first time. This improvement was associated with reduced water logging as they are now able to get water on and off fields quickly.

The evolution of design

Saunders Farming initially started working with Olive Hood more than seven years ago, using the Irrimate tool which confirmed that the only real option for efficient watering was to run the system with higher flow rates (due to run length and soil type). But higher flow rates needed an increased number of siphons and hence the labour to start them. Therefore the team investigated options for retro-fitting the existing irrigation infrastructure so it was easier to maintain, reduced labour, allowed uniformity of application across the farm and increase

water use efficiency.

Then four years ago, Craig told Justin he was “sick of changing siphons – so we’ve got to come up with a better way to irrigate”. Since then the farm has progressed from using 1.5-inch siphons on 1000-metre row lengths for 24-hour waterings, to three-inch siphons on 1000-metre rows taking 12 hours, to the first pipe through the bank (PTB) system.

Initially flexible fluming was installed inside the head ditch. While working really well for two hours it then blocked up with short lengths of grass stopping the water flow completely. Undeterred, the team then tried through the bank pipes made from recycled milk bottles (Green Pipe), set at 12-metre spacings and watering 11 furrows each. This system uses adjustable flaps to control water flow. The team attribute the ability to either adjust the flap, or adjust the head on the head ditch to achieve an optimum water output, as a key to the system’s success. The variable system has meant cotton fields could be watered according to the crop’s specific requirements at the time, with rates adjusted during the watering based on extensive data from C-Probes, Irrimate and the new SISCO (Surface Irrigation Simulation Calibration and Optimisation) tool).

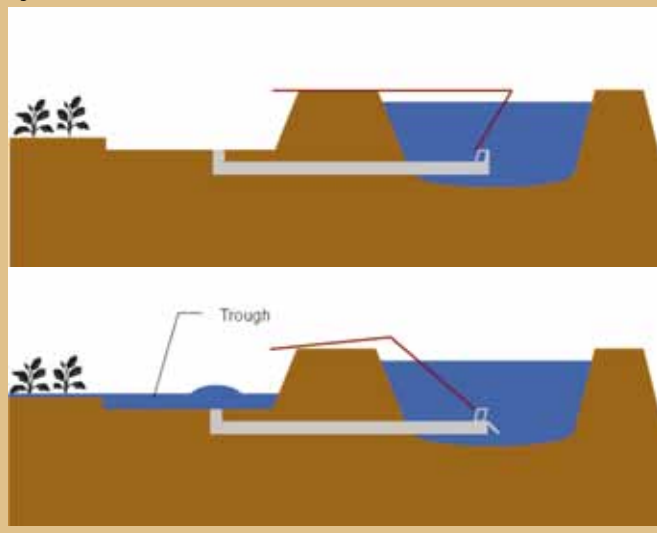
The 2011–12 season will see the entire cotton irrigation area being watered with the PTB pipes and one centre pivot machine.

Uniformity between rows

The use of PTBs within the cotton industry is not new, although they fell out of favour with many growers as it was difficult to obtain uniform flow into each furrow. Saunders Farming and WaterBiz have overcome these issues by narrowing the spacing between the pipes to 12 metres. The diameter of the pipes is also smaller than trialled in other areas, allowing finer control of discharge.

Uniform flow down each row is obtained through a trough

FIGURE 1: Cross-section view of PTB irrigation system



across the top of the rows in the launch bay area (Figure 2). Water comes out of the PTBs and fills this depression before rising up and evenly flowing down the furrows.

The other important factor affecting uniformity between the rows are the high flow rates being used. These flows are much higher than those used by most other irrigation properties. Justin believes that “because of the amount of water we’re pushing down the rows, we have to get uniformity, there’s just no other way for it to happen”.

While wheel tracks are still an issue, the pipe outlets are located in the guess rows (Figure 2). Therefore water has to move to the edge of each launch bay area before it flows down the wheel tracks.

- A system evaluation, conducted by Justin Schultz, has found:
- Distribution Uniformity of 90 per cent or better (how evenly water infiltrates along the furrow length);
 - Application efficiency of 85 per cent or better (the total water infiltrated as percentage of total water applied); and,
 - Requirement efficiencies of 100 per cent (the percentage of deficit filled at an irrigation).

Benefits

Saunders Farming has found a number of benefits of using the PTB irrigation system, including:

- Water savings
- Labour savings
- Increased yields due to less water logging and better water management
- Easily adaptable to existing siphon systems
- Optimising irrigation to eight-hour shifts
- Simpler irrigation

Water savings:	25 per cent
Yield increase:	20 per cent
Labour savings:	50 per cent

Cost

Craig Saunders has found the cost of retro-fitting pipes through the bank on a traditional siphon furrow field is about \$500 per hectare. This cost includes both the cost of the pipe and the earthworks required. They have found a cost effective source of pipe in The Green Pipe company. Each length of pipe costs approximately \$450 with the adjustable valve attached. Saunders

“We’ve gone and identified whatever the design constraints are and then we built a system around that... I think if you were to follow that procedure, you would end up with a great result as well.”

Farming fabricates their own handles which they then attach to each of the adjustable valves.

Craig believes that maintenance is somewhat similar to that of a conventional siphon system. While there are no rotobucks and less repairs with shovels, the PTB system does require the trough area to be graded to drop it about 100 mm. They have found there is less maintenance required on the head ditch each year as they can be built bigger than normal because their size is not restricted by siphons. At this stage, the Saunders Farming team have not had any

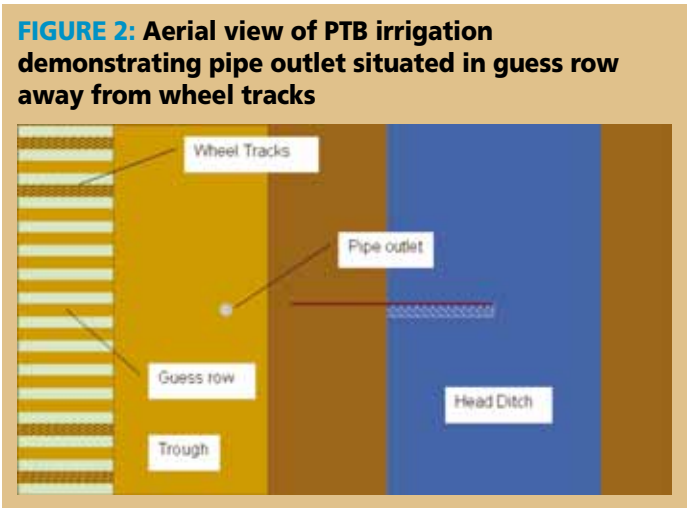
maintenance issues in relation to the adjustable valves and pipes as they have only been installed a short time. They envisage though that maintenance will be required for the valves and mechanism that seal the pipe down the track, which could be done between seasons.



Cotton being irrigated with pipe through the bank system.



Launch bay area, notice the depression (trough) along the top of the rows to ensure even water distribution between rows.



"It is imperative to consider using a water specialist who can assist you identify your system constraints and design a system that suits your needs."

Where to now?

Saunders Farming is heading towards total automation of their system with the help of in-row sensors. When water hits these sensors it sends a signal to the head ditch which opens and shuts the appropriate gates. Although still a few years away, it is progression towards watering without leaving the office.

Acknowledgement: The More Profit Per Drop team would like to acknowledge all of the information provided by Craig Saunders, Saunders Farming Pty Ltd and Justin Schultz, WaterBiz in the development of this case study.

This is one of a series of Case Studies prepared by Queensland Department of Agriculture, Fisheries and Forestry as part of the Healthy HeadWaters Water Use Efficiency (HHWUE) project. This project is managed by the Queensland Department of Natural Resources and Mines and funded by the Australian Government as part of the Sustainable Rural Water Use and Infrastructure Program under the Water for the Future initiative. ▲



Irrigating with PTB system, St George.



Pipe through the bank with valve mechanism.

Water Team: A driver for adoption

INVESTMENT in water research comes to fruition when growers identify areas of their water management that might be improved and determine how research solutions can be applied. For many years, the cotton industry has been serviced by dedicated and knowledgeable water extension professionals whose efforts have been critical in encouraging and supporting the adoption of new management practices and technologies.

In the early 2000s, the Cotton CRC Water Team was formed when water extension officers from the newly formed Rural Water Use Efficiency program in Qld joined with existing NSW Irrigation Officers and a number of industry water researchers as part of the Australian Cotton CRC. The team was to play a critical role in supporting considerable advances in water management within the industry.

Although only a little over a decade ago, the industry perception of water use efficiency and the potential for improved irrigation practices was very different to today. Many believed that furrow irrigation practices at the time were as efficient as they could be and that deep drainage did not occur in the self-sealing black clay soils that dominated most irrigated cotton fields. Although some growers had used existing scheduling tools such as neutron probes, the use of objective irrigation scheduling was not widespread, and few growers had ever measured irrigation volumes with any accuracy, let alone calculated water use efficiency benchmarks.

As new research and technology became available at this time to address many of these issues, the Cotton CRC Water Team was busy adapting it to local conditions and promoting it to growers and consultants. Water team members undertook furrow optimisation trials across many cotton growing regions to measure the performance of irrigation events and provide improved management options. Many growers subsequently invested in these techniques through commercial providers and changes in the way that surface irrigation events are managed have been widespread.

Similarly, new objective soil moisture monitoring techniques, especially capacitance probes, had been recently released and were widely trialled by the water team. The cotton industry now boasts one of the highest rates of adoption of these techniques of any irrigated crop in Australia.

Water team members were also involved in early efforts to quantify evaporation from on-farm storages and to determine the effectiveness of different solutions. Trials undertaken by water team members directly led to the establishment of a major research project into storage evaporation, with many subsequent projects continuing over the ensuing years to develop new techniques for storage management and new products to minimise evaporation.

But one of the most important legacies of cotton water extension is the focus on measurement as the first step towards improved water management. Whilst this sounds simple enough, measuring water on cotton farms can be challenging. For example, there are numerous physical conditions which can make flow metering difficult. But understanding existing water use and performance is critical to be able to determine which irrigation system components might require improvement and the scope to which new research solutions can be applied.

Members of the Cotton CRC Water Team have undertaken a number of projects to provide water use efficiency information and support to cotton growers in order to facilitate water use performance improvements. For example, a number of recent projects have collected water use and production information using a new commercial tool called Watertrack Rapid, with the aim of demonstrating the value of water use efficiency benchmarking to growers.

As new water management techniques have been progressively adopted, some decision making processes have become more complex and the delivery of water extension has consequently taken new forms. Whilst awareness raising activities and demonstration trials will likely always form some part of water extension practice, more emphasis is now placed on training and the development of a skilled support sector.

Many of the articles in this publication have been contributed by members of the Cotton CRC Water Team and provide an excellent overview of the important work that they have undertaken over many years. Into the future, new challenges and opportunities will undoubtedly mean that water management remains one of the highest priorities for the cotton industry. A strong network of water professionals will therefore be important to support the industry for years to come. ▲



Pumps course run by Peter Smith and Janelle Montgomery at Mungindi in 2008. (Photo: Peter Smith)

Towards healthier headwaters

THE Healthy HeadWaters Water Use Efficiency (HHWUE) project is being delivered in Queensland by the Department of Environment and Resource Management (DERM) with funding from the Australian Government's *Water for the Future* initiative through the Sustainable Rural Water Use and Infrastructure Program.

The project is helping Queensland Murray–Darling Basin (QMDB) irrigators invest in more efficient irrigation systems and technologies that reduce water loss and deliver long-term economic benefits. It is also returning a share of water savings to the Basin's rivers, wetlands and floodplains.

The project comprises three key components:

- A Basin Appraisal Study;
- Complementary Measures; and,
- Infrastructure.

Under the Basin Appraisal Study, funding was provided for two key external consultancies. The first identified, at a catchment scale, the potential water savings to be realised through the implementation of a range of on-farm water use practices, technologies and measures. The second investigated the on-farm economics of changing irrigation practices.

Complementary Measures supported the infrastructure project by enabling irrigators to access other services under the HHWUE project including information about water efficient technologies, analysis of existing practices on farms and options for improving water efficiency. A centre pivot and lateral move (CPLM) benchmarking project and training in Irrigation Australia Limited certification were also run in conjunction with the main infrastructure project.

In addition to the above, an extension service was provided by the Department of Employment, Economic Development and Innovation (DEEDI) to improve water use efficiency in irrigated agriculture in the QMDB and support the implementation of the HHWUE Project. Some of the outputs of this project included training/workshops, case studies, CPLM DVD and a blog (*More Profit per Drop*).

Under the infrastructure project, irrigators receive up to 80 per cent of the cost of on-farm infrastructure projects where sound estimates of associated water use efficiency gains can be shown. In return, participants in the HHWUE project provide at least 50 per cent of the water savings to the Australian Government for environmental use via a permanent trade of water allocation.

The HHWUE project Phase 1 consisted of two funding rounds and will be delivered by October 2013. Applications to the HHWUE project in each round were assessed against a range of criteria, in line with the Australian Government's principles for funding under the *Water for the Future* initiative:

Delivery of substantial and lasting returns of water to the environment;

- Securing a long-term future for irrigation communities; and,
- Delivery of value for money in the context of the above.



Table 1 summarises the projects being completed under round one and approved from round two of Phase 1.

Examples of infrastructure funded to date include:

- Upgrade of surface irrigation by redesigning delivery and reconfiguring fields;
- Installation or upgrade of overhead irrigation (centre pivot or lateral move machines);
- Conversion from surface irrigation to trickle or subsurface irrigation; and,
- Replacement, upgrade or reconfiguration of storages and channels to minimise seepage and evaporation loss.

To date, 4938 megalitres has been returned to the Australian government; four projects have been completed; and Australian government funds of almost \$13 million have been provided to irrigators

Phase 2 of the HHWUE Project has been approved and a call for applications under round three will open later in 2012.

For more information, contact the HHWUE project team on:

HHWUE project
 203 Tor Street
 Toowoomba Qld 4350
 Phone: (07) 4529 1321
 Email: hwwue@derm.qld.gov.au
 Website: www.derm.qld.gov.au

TABLE 1:

Round	No. applications	Total project cost (excl. GST)	Funding sought (excl. GST)	Total water savings (ML)	Transferable savings (ML)
1	7*	\$22 205 565	\$17 200 621	9595	4938
2	7	\$13 768 966	\$9 401 799	4811	2614

*An additional three approved round one on-farm projects with total project costs of \$5,155,576 and total water savings of 1,829 ML, were withdrawn by the irrigators.

Gains through alternative irrigation systems

■ Lance Pendergast QLD Department of Agriculture Fisheries and Forestry



Lance Pendergast.

IN BRIEF...

- Alternative irrigation systems to furrow can provide significant gains in water use efficiency (WUE) and yield.
- Performance is dependent on appropriate design, system evaluation, appropriate maintenance and management.
- Aeration of irrigation water or ‘oxygation’, has improved yields and WUE by 14 per cent (as averaged over seven seasons).
- Gains in WUE and a more recent focus on improving energy use efficiencies recognises two are inherently linked.

In recent years, there has been increased investment in alternative irrigation systems. These include centre pivot and lateral move irrigation (CPLM), subsurface drip irrigation (SDI), and bankless channel systems.

Measurements have confirmed that all of these systems, including furrow irrigation, have the potential for high water use efficiency. But optimising any system depends on an appropriate design to meet site-specific conditions, on-going system maintenance and use of appropriate management strategies. Furthermore, each system may have specific advantages and disadvantages in other aspects of the farming system.

Reasons for using alternative systems vary. Soil types and reduced labour requirements are also a major driver although the quest for improved water use efficiency (WUE) is cited as a principal reason for investing in alternatives.

CPLM system evaluations conducted by industry extension officers in recent years have shown that the performance of these systems is often below their potential. Typically this has been attributed to inappropriate design characteristics such as unsuitable emitter packages or inadequate system pressure.

Over time, pressure reduction due to pump problems or partial blockages may develop and any departure from optimum design specifications can impinge on system performance. The resulting impact on distribution uniformity, WUE and yields can be significant even before it is visually evident. SDI systems also need appropriate attention to ensure they are performing to specification.

It is recommended that commissioning of any new installation



Bankless channel system at ‘Bullamon Plains’, Thallon, Queensland.

should include a system evaluation to confirm that it is performing as per design specifications. This benefits both the supplier and the irrigator as it can assist in a quick resolution of any problem.

FIGURE 1: Two different bankless channel field designs

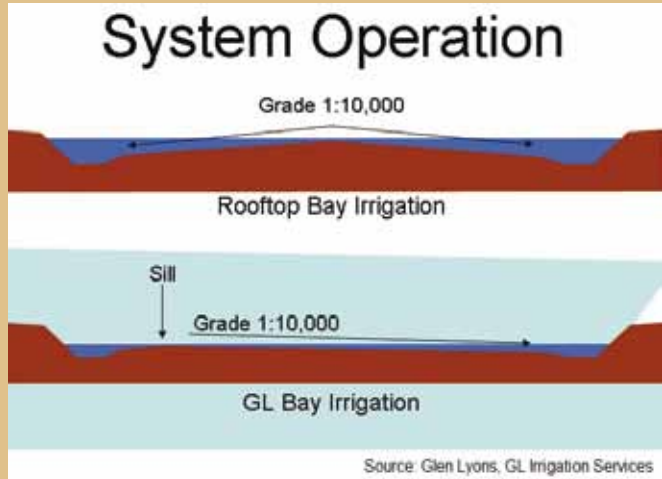


TABLE: 1: Summary of Irrigation Benchmarks for CPLM systems for Australian Cotton – 2010/11. Montgomery, J. (2011) Water Smart Cotton Grains, Final Report, NPSI, CRDC.			
IWU _{field} (bales/ML)	Average	Range	Sample size
Lateral move	5.09	1.80–17.5	21
Centre pivot	3.41	2.00–5.50	19
GPWU _{field, effective} (bales/ML)			
Lateral move	1.40	0.70–1.90	21
Centre pivot	1.33	0.98–1.88	19



New cotton up and away under centre pivot irrigation.

With any new system, optimum performance may require a different operational logic to that used successfully in furrow irrigation. With furrow irrigation, often factors such as scheme supply characteristics, or the ability water various fields in a given time-frame can limit the potential for modifying furrow irrigation scheduling to meet changing circumstances.

It can also be difficult to adjust for anticipated rainfall or unexpected variation in weather conditions. The ability of some alternative irrigation systems to deliver precise amounts of irrigation in a timely manner is a major contributor to achieving improved WUE and yields.

Refill points can be more readily adjusted in anticipation of rainfall as the system is able to add water to the profile on short notice when required. A recent study of CPLM performance showed large variability in performance (Table 1) which was only partially due to the irrigation system. This demonstrates that optimum CPLM performance depends largely on management.

In addition to monitoring, industry continues to look at ways of improving efficiencies. In SDI the aeration of irrigation water (a process termed 'oxygenation'), through minor modification of existing infrastructure, has improved yields and WUE by 14 per cent (as averaged over seven seasons).

In recent years bankless channel and pipe through the bank (PTB) systems have been implemented by a small number of irrigators. These systems have demonstrated a fact common to all irrigation systems – that site specific conditions must be carefully considered as they have a large impact on system performance.

A challenge facing all systems is to develop the means to benchmark performance – you must be able to 'measure to manage'. Operators cannot fine tune systems unless the critical parameters are known.

While cotton irrigators have made significant gains in WUE over the past decade, there has been recent focus on improving energy use efficiencies and recognition that the two are inherently linked. Pressurised alternative systems such as CPLM and SDI typically incur additional pump energy expenditure in comparison to the pumping costs associated with typical gravity fed furrow systems. On the other hand, these systems may allow energy savings to be made in other areas, such as reducing machinery operations through minimum tillage practices and eliminating operations associated with rotabucks, head-ditches and tail-drains. Therefore it is important that irrigation energy use is considered in relation to the whole-farm energy use balance. Regardless, it is still vitally important to ensure pumping systems are as efficient as possible.

An extensive body of information is now available to assist irrigators in the selection of appropriate systems, their maintenance, and the appropriate management strategies to maximise production efficiencies.

Further reading:
Growers Guide to Centre Pivots and Lateral Moves www.moreprofitperdrop.com.au
Final report www.cottoncrc.org.au

Funding: Cotton Catchment Communities CRC and QLD DERM.



Benchmarking furrow irrigation

■ Malcolm Gillies National Centre for Engineering in Agriculture (NCEA), University of Southern Queensland

IN BRIEF...

- Hundreds of surface irrigation performance evaluations conducted over the past decade.
- A new database brings this data together to provide benchmarks of irrigation performance.
- Analysis of 542 measured events shows median application efficiency of 79.5 per cent.
- For evaluations also optimised, average application efficiency could be increased by almost 10 per cent with average water saving of 0.17 megalitres per hectare.
- Ongoing data entry and analysis will refine results and provide an understanding of how performance may have improved over time.

THE Australian cotton industry can stake the claim of being one of the leaders in irrigation practice and innovation, particularly for surface irrigation. A key driver of this is the ability to monitor and model furrow irrigation provided through the use of the Irrimate in-field evaluation system.

Over the past decade, hundreds of evaluations have been performed in order to guide individual growers and inform researchers. However gathering industry wide figures on irrigation management remains very difficult. A database in order to capture this information has been developed. The Irrimate Surface Irrigation Database (ISID) provides benchmarks of surface irrigation management and performance and enables ongoing future data collection.

Background

Furrow irrigation is a dominant application technique in the cotton industry and is ideally suited to the heavy cracking clays typical of districts in which cotton is grown and is readily

adaptable to changes in water availability and commodity prices. Pressurised systems do offer benefits but also pose new issues such as increased energy costs.

The Irrimate suite of monitoring tools and computer software for furrow irrigation, developed by the NCEA, has been widely adopted by the industry. Over the past decade there have been a large number of evaluations carried out by commercial consultants across NSW and QLD funded by individual growers. In addition, many research trials have been conducted relying on the same techniques to quantify water use.

These different evaluations have often been undertaken using unique ways of analysing and archiving field data, resulting in much data which is difficult to combine when conducting industry-wide studies. This project aimed to assist the Australian cotton industry to gain a better understanding of irrigation management, water use efficiency and deep drainage at the district and industry level. It also aimed to demonstrate to the wider community how growers are responsible users of water resources and are striving to improve efficiency and reduce off farm impacts.

The ISID system

At its core, ISID is comprised of a secure database which is accessed through an internet portal. Access to the system is via two levels, a consultant/technician level and an overview level. The consultant is able to create and upload evaluations, but only view and edit those evaluations which they originally entered.

The overview level user is able to interrogate the database at a more generic level to gain industry wide irrigation statistics but cannot access the details of individual evaluations or growers. In this way the privacy of growers is maintained at all times. The database is capable of storing all field measurements that are required as part of the field. Results that are reported include performance measures such as application efficiency with and without runoff reuse, distribution uniformity, deep drainage depths, and management variables such as inflow rates and cut-off times.

In parallel with this project the NCEA has produced the computer model SISCO, an upgrade of the software component of the Irrimate evaluation system.

SISCO has the optional functionality to upload measurements and results directly to the ISID server hence simplifying the process of data capture and hopefully ensuring that the database remains current.

Results

Currently there are in excess of 540 individual irrigation events within ISID. All major cotton growing catchments are represented with data stretching from the 2000–01 to 2011–12 seasons. Table 1 represents a statistical summary of all irrigation events currently in the database.

It is important to note that the majority of the measurements were not collected under controlled experimental conditions but represent irrigation performance under normal grower management. Secondly it must be noted that these results include both in season and pre-season watering events.

The application efficiency is defined as the percentage of total

TABLE 1: Summary of ISID results (542 events)

	Average	1st Quartile	Median	3rd Quartile
Flow rate (L/s per 2 m width)	4.4	2.9	3.8	5.6
Run time (hours)	12.6	8.6	11.6	14.8
Total water applied (ML/Ha)	1.36	0.96	1.2	1.56
Application efficiency (%)	64.6	53.3	64.6	77.5
Application efficiency with tail water recycling* (%)	76.3	64.7	79.5	90.4
Infiltration (mm)	108.9	76.9	98.9	126.8
Deep drainage (mm)	28.4	3.4	16.6	41.4
Runoff (mm)	26.5	7.6	17.9	32.6

*Assuming that 85 per cent of the tail water is recovered.

*Many prefer the median (middle) value rather than the simple average value as the latter is susceptible to being skewed by outliers.

TABLE 2: As measured and predicted performance under suggested management strategy (476 events)

	Measured (average)	Optimised (average)
Flow rate (L/s per 2 m width)	4.4	5.8
Run time (hours)	12.7	8.4
Total Water applied (ML/ha)	1.42	1.16
Application efficiency (%)	63.7	72.6
Application efficiency with tailwater recycling* (%)	75.6	84.8
Infiltration (mm)	113.1	97.7
Deep drainage (mm)	30.4	15.0
Runoff (mm)	28.2	18.4

* Assuming that 85 per cent of the tail water is recovered

water applied to the field that is added to the root zone storage and can be used by the crop. A more meaningful value for the majority of growers is the application efficiency with tailwater recycling which takes into account runoff can be recaptured for future use. A number of industry studies have determined losses in tailwater systems to be less than 15 per cent.

As shown (Table 1) the average application efficiency is 64.6 per cent with an immediate 12 per cent water saving through adoption of effective tail water recycling. The average application rate for the typical two-metre alternate row irrigation is 4.4 litres per second for a 12.5 hour duration resulting in a total application of 1.36 megalitres per hectare of which on average 20 per cent exits the field as runoff.

For growers, the major purpose of field evaluation is identification of strategies to improve performance (e.g. inflow rate and run time). For the majority of events, ISID also contains this optimised flow rate and run time and the predicted efficiency of the same field under that strategy.

Table 2 is a summary of the average improvement to irrigation performance achievable through adoption of recommended changes to inflow rates and cut off times.

Application efficiency improvements of 10 per cent were possible for these events, with a halving of both the volume of water lost to deep drainage and runoff. Assuming that 85 per cent of tail water is recycled this approximately equates to a water saving of 0.17 megalitres per hectare per event.

Future possibilities

ISID contains a representative sample of the surface irrigation evaluations conducted by the industry. This database can assist with prioritising future research and trials to improve our understanding of irrigation. The system is also designed to streamline data entry, so ISID will be automatically updated in future seasons. The database will assist consultants and extension staff to provide irrigation information to growers based on district, soil type and field characteristics.

Further information:

www.ncea.org.au
www.cottoncrc.org.au

Funding: Cotton Catchment Communities CRC.



A grower-led approach to research

■ Zara Lowien, Gwydir Valley Irrigators Association and Nick Gillingham, Sundown Pastoral Company

IN BRIEF...

- Demonstration of a successful grower-led, industry driven trial program.
- Relevant and practical information for growers on on-farm water-use efficiency.
- Successful adaptive management and engagement strategy.

In the Gwydir Valley, furrow irrigation makes up more than 90 per cent of irrigation methods practiced. In response to prolonged low water availability during the last drought, growers in the Gwydir Valley began to question how they could maximise their water use and maintain or improve their productivity.

In the past alternative methods of irrigation have been attempted including pipe through the bank (PTB), overhead (lateral and pivot) and drip. There have been varied levels of success with these methods; the reasons for their success or demise are wide-ranging and not conclusive. Many were attempting to decipher the practicality and real efficiencies from these options.

The questions and difficulties encountered were not uncommon across all irrigated cotton growing regions within Australia. But the growers in the Gwydir felt that they need local, regionally specific information that could assist them in future decision making.

Following that discussion, in 2008 the Gwydir Valley Irrigators Association (GVIA) applied for funding from the National Water Commission to undertake a national water standards project aimed at improving irrigation efficiency in the Australian cotton industry, primarily in North West NSW. The project began in 2008 and is completed in April 2012.

The project was different to other trials as it focussed on a grower-led approach, directed through the GVIA. The GVIA



A Keytah drip irrigation trial.

represents more than 250 irrigation entitlement holders in the Gwydir Valley, centred on the town of Moree. The Association aims to build a secure future for its members, the environment and the GwydirValley community through irrigated agriculture. The project by its conception was already fully supported from the growers who are also members of the Association.

Executive Officer Zara Lowien believes that the success of the trial stems from this grower-driven basis.

"Growers are constantly pressured for time and resources but the response to events and information from this trial has always been outstanding and hasn't appeared to waver as the trial progressed," Zara said.

"Growers respond to the work being produced because they wanted it and they are governing what they are trialling and getting out of it."



Gwydir Valley cotton grower Tony Bailey, Australian Food and Fibre, and Peter Birch of B&W Rural Moree were at one of the Keytah field days to see alternative irrigation methods first hand.



Irrigating the bankless trial at Keytah.

The concept

From the grass-roots desire within the GVIA, the decision was made to initiate local, grower-led trials to prepare those within the industry for a future with less water.

The project objectives and tasks were to be met through establishing a grower-led approach for over-seeing and implementing research that was valley specific but could also be used to inform the wider industry. On-ground support for the implementation of the trial program was sourced via contract work or partnership arrangements with other research and extension organisations.

The establishment of a steering committee including technical representatives and local growers was enhanced through the linkages the project had with GVIA and importantly, its committee and members. The steering committee decided that all of project objectives could be best met through establishing a range of practical and accurate irrigation systems which can be easily used by irrigators in determining future irrigation methods so as to maximise their water use efficiency.

A significant part of this project has been a four-system comparative trial at 'Keytah' west of Moree to provide accurate information on the efficiency of relatively common irrigation systems used across Australia and around the world – lateral move, bankless channel and drip irrigation. Furrow siphon irrigation was also recorded as a control. Each system was measured using a holistic approach recording all and only the water used in the system, therefore not including the water lost getting to each system or in storage before irrigation.

Although the main focus of the project was the Keytah Trial, there were two off season trials also developed recognising new and emerging activities growers were implementing and aimed to generate more scientific data on the practices. Additional information on how to improve or alter the application and timing of furrow irrigation in an attempt to balance water savings, labour savings and yield was sought through the pipe through bank trial at 'Telleraga' Moree and the row configuration and limited water trial at 'Redbank' Moree.

The evaluation

The evaluation of the project in April 2012 limited the capacity to fully assess the outcomes of the project. This is heightened by the fact the 2011–12 project results are not complete and irrigators do not have that crucial second year of data on which to make their conclusions. But in the interim the results from the evaluation of the project were overwhelmingly in support of the trial program and how it has operated. The adaptive management strategy by the steering committee has helped to ensure the project was relevant to the irrigation industry.

The real achievement of the project is has been the testing of the grower-led research approach, which has resulted in the project maintaining its 'relevance' and the interest of irrigators in the Gwydir and beyond. As the approach was different to other trials, it was seen as one of the few trials where information and discussion was on the practicalities of adopting irrigation efficiencies and that was useful to others operations.

The inherent link with the GVIA committee has also helped to encourage a grower-led foundation.

The grower responses collected from the independent evaluation confirmed that the grower-led approach was a practical way to increase the knowledge of and uptake of irrigation efficiency practices. The trial provided growers data that was meaningful. This data was valuable and was relevant



The trial provided growers with data that was meaningful.

to them; it was easily understood and could be used to make informed decisions for their operations.

The approach also enhanced the effectiveness of the education and extension program through field days and direct grower interaction. Growers felt comfortable interacting with the management staff at field days and other times. It is important to note that Sundown Pastoral Co in particular welcome visitors and provide updates and talks outside of the scope of the project.

The GVIA will continue to adopt and manage the grower-led approach when implementing trials in the future. The GVIA committee and staff believe that this framework ensures the programs greatest success in engaging and informing growers about water-use efficiency.

Funding: National Water Commission – raising national water standards program

Acknowledgement of trial hosts: Sundown Pastoral Co, Australian Food and Fibre Limited

Collaborators: CSIRO, CSD and NSW DPI.



Using aerated water for drip irrigation

■ Lance Pendergast, QLD Department of Agriculture Fisheries and Forestry

IN BRIEF...

- Oxygenation is a term used to describe the use of aerated water (at the rate of 12 per cent air by volume of water), for subsurface drip irrigation.
- Positive effects of oxygenation were noted consistently on lint yield over a number of seasons.
- An increase in WUE was associated with higher yield in the oxygenation plots for the same amount of irrigation water applied.

A **LONG-TERM** oxygenation field study from 2004 to 2012 on a vertisol soil at 'Nyang' Emerald measured the effects of oxygenation on cotton lint yield, quality and water use efficiency (WUE), as well as long-term changes in soil chemical, physical and biological properties.

The trial aimed to determine the longer-term effect of oxygenation and evaluate aeration uniformity and crop performance along the lateral row length.

In the first two seasons the effect of oxygenation was quantified at two irrigation rates 85 per cent and 105 per cent of crop evapotranspiration (ET_c). In 2006–07 there was insufficient water for the trial due to drought. In the 2007–08 and 2008–09 seasons only one irrigation rate (85 per cent ET_c) was tested. In subsequent seasons, the irrigation rate was increased to 100 per cent.

Positive effects of oxygenation were noted consistently on lint yield over a number of seasons. Yield increased with oxygenation in all trial years when irrigation rate was maintained at 85 per cent of ET_c or above. An increase in WUE was associated with higher yield in the oxygenation plots for the same amount of irrigation water applied. Yields in all years benefitted from oxygenation, although the difference was not statistically significant in every year. The average yield increase across all years was 14.7 per cent (Table 1).

A number of controlled environment studies suggested that the aeration can be non-uniform along the drip lateral. Intensive plant sampling and data collection along the length of drip line was conducted in a number of seasons.

Field data from the trial in 2005–06 suggest that there is no major difference in terms of benefit of oxygenation along a drip line until beyond 165 metres from the start of the drip line.

Likewise in 2008–09 and 2011–12 there was no differential

effect of oxygenation according to distance from the air injection point, although in both the latter years there was an indication of a positive effect further from the injection point.

We did find effects of oxygenation on soil penetrometer resistance, which increased with oxygenation due most likely to the more effective water uptake and drying of soil with oxygenation. Soil biological activities (as indicated by increased fluorescein) were enhanced (Table 2) in the oxygenation treatment compared to the control.

A simple economic analysis (Tables 3 and 4), indicates a return on investment of \$562.50 per hectare per year, giving a payback period of a little over two years.

Further readings:

Pendergast, L. (2012). *Benefits of aeration of subsurface drip irrigation water – field evidence on CQ highlands vertosols*. PhD thesis, CQUniversity, Rockhampton, Australia, pp245.

Midmore, D. J. Bhattarai, S. P. (2012). *Oxygenation- Optimising delivery and benefits of aerated irrigation water*. NPSI Final report. Product code: NPSI 06–12. pp 40. National Program for Sustainable Irrigation, Australia. <http://npsi.gov.au>

Funding: Cotton Catchment Communities CRC and National Program for Sustainable Irrigation (NPSI) ▲

TABLE 3: Details of cost to retro-fit air injection to 0.4 ha plots at current site

Item	Unit	Price (\$)	Cost (\$)*
Venturi injector	1	265	265
PVC elbows	4	10	40
PVC t-pieces	2	10	20
Valves	2	45	90
Pressure gauges	2	30	60
TOTAL			475
Cost of oxygenation 1 ha (475 x 2.5)			1187
*Costs would be less if installed with new system			

TABLE 4: Details of returns per ha at current site

Yield (control)	Yield (oxygenation)	Yield difference (bale/ha)	Cotton price (\$/bale)	Return on investment (\$/ha/year)
8.05	9.10	1.05	500	525
Return to investment , yrs (1187/525)				2.26yrs

TABLE 1: Lint yield (bales/ha) was generally higher in oxygenation plots.

Treatment	2004–05	2005–06	2007–08	2008–09	2009–10	2010–11	2011–12	Combined
Oxygenation	9.32	9.33	8.84	6.90	9.11	9.04	11.21	9.10
Control	7.35	8.02	7.89	6.47	8.33	7.71	10.62	8.05

TABLE 2: Effect of long term oxygenation on soil biological properties, Nyang, Emerald.

Treatments	Fluorescein ($\mu\text{g/g dwsoil/h}$)	CFU bacteria (Log)	CFU fungus (Log)	Soil respiration ($\text{g com m}^{-2}\text{h}^{-1}$)
Oxygenation	46.49 $\pm$ 0.87	5.81 $\pm$ 0.061	3.50 $\pm$ 0.106	0.890 $\pm$ 0.079
Control	42.68 $\pm$ 0.79	5.93 $\pm$ 0.055	3.51 $\pm$ 0.051	0.698 $\pm$ 0.041
Furrow	36.32 $\pm$ 1.38	5.96 $\pm$ 0.062	3.22 $\pm$ 0.100	

NB: Amount of fluorescein produced by the hydrolysis of fluorescein diacetate (FDA) is directly proportional to the microbial activity in the soil (Swisher and Carroll, 1980).

Precision irrigation through adaptive control

■ Rod Smith, Alison McCarthy National Centre for Engineering in Agriculture, University of Southern Queensland

ADAPTIVE control systems automatically and continuously re-adjust ('retune') the irrigation application decision to retain the desired performance of the system, to account for temporal and spatial variability of crop water requirements in the field.

The traditional irrigation application systems (surface and pressurised) are at the limit of their irrigation performance under current management practices. But future gains in performance can be achieved through the use of advanced technologies and management, in particular the use of adaptive control, thus converting them to precision irrigation systems.

Precision irrigation requires real-time knowledge of the factors which are limiting production at any time in all areas of the field. The experience from precision agriculture suggests that the variables controlling crop yield are those that require within season management (e.g. water, nitrogen, pests and diseases), all of which can be addressed with an automated response. The precision agriculture experience also suggests that the temporal variations (within and between seasons) are greater than the spatial variability that the variable rate technologies attempt to address.

Precision irrigation implies a system that can adapt to the prevailing conditions. Also implied is the idea that the system will be managed to achieve a specific target which, for example, may be maximum water use efficiency, maximum yield or maximum profitability. This requires access to detailed data regarding the crop, soil, weather, environment and other production inputs, the interaction of these variables and the agronomic responses to these inputs at the relevant spatial scale.

Crop simulation models provide the first step towards the identification of optimal strategies. Models able to simulate the behaviour and performance of the application system are another necessary feature of the precision irrigation 'toolkit'.

Surface irrigation as a precision method

The idea of precision irrigation can be extended to any irrigation application method, the conceptualisation of surface irrigation as a precision system. In this case, 'smart' automation involving real-time optimisation of individual irrigation events is used to manage, optimise and control each set of furrows.

To optimise seasonal WUE a further layer of decision support is required. The crop response to the irrigations needs to be monitored and modelled continuously through the season to determine the irrigation timing and amounts that give the desired response. This information also helps to determine the preferred strategy for management of the individual irrigation events and to account for the effects of spatial variability along the length of the furrows.

Real-time optimisation of furrow irrigation

There is considerable scope for improvement in both the efficiency and uniformity of surface irrigation applications and management strategies and technologies are available to start to achieve these improvements.

Improvement of furrow irrigation performance through the process of evaluation and simulation with the Irrimate suite of

tools has been adopted in the cotton industry. Adaptive real-time optimisation builds on these existing tools and processes and can provide an even higher level of irrigation performance. When coupled with automation, substantial labour savings can also be provided.

Trials of the real time optimisation system were undertaken on a furrow irrigated cotton property at St George in south-western Queensland. Four irrigations in the summer season of 2010–11 were monitored in a section of the field that used pipes-through-the-bank (PTB) to supply groups of 11 furrows that were 970 metres long and spaced one metre apart. The results showed that the irrigation times predicted by the system were shorter than those used by the farmer in irrigating the remainder of the field. This translated to reduced runoff and deep percolation and higher application efficiencies as a direct result of the real-time optimisation.

Development and adoption of a successful commercial system will deliver irrigation performance and labour savings similar to the pressurised systems used within the industry but at greatly reduced capital and energy costs.

Adaptive control of centre pivot and lateral move irrigation

Precision irrigation is also possible using CPLM systems where the amount of irrigation can be varied spatially. But precision management of such systems requires new adaptive control techniques. A simulation framework, VARIwise, was created to develop, simulate and evaluate uniform and site-specific irrigation control strategies that may be applied to precision CPLM systems. This is the first step in the development of a system for the management and adaptive control of spatially varied CPLM irrigation. The continuing work on VARIwise is directed toward this purpose.

VARIwise can be used to evaluate the performance of existing irrigation control strategies with different field and irrigation system properties. For example, the uniformity of irrigation application from an irrigation system can affect the spatial variability of crop yield across a field.

Final Report at www.crdc.com.au

Funding: Cotton Catchment Communities CRC and Cotton Research and Development Corporation

Further reading:

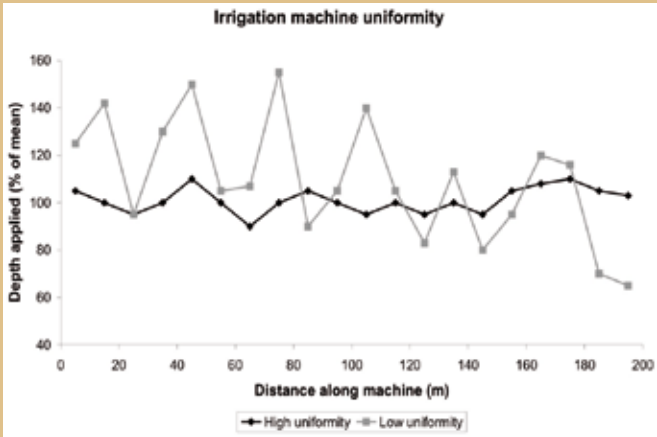
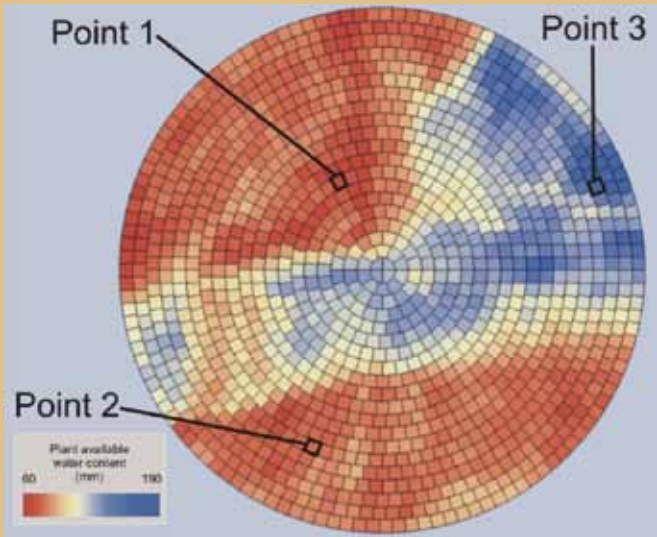
Smith, RJ, Baillie, JN, McCarthy, AC, Raine, SR and Baillie, CP (2010) Review of precision irrigation technologies and their application. Report for the National Program for Sustainable Irrigation, NCEA Publication 1003017/1. www.npsi.gov.au

Smith, RJ, Raine, SR, McCarthy, AC and Hancock, NH (2009) Managing spatial and temporal variation in irrigated agriculture through adaptive control. *Australian Journal of Multi-disciplinary Engineering*, 7(1): 79-90. ▲

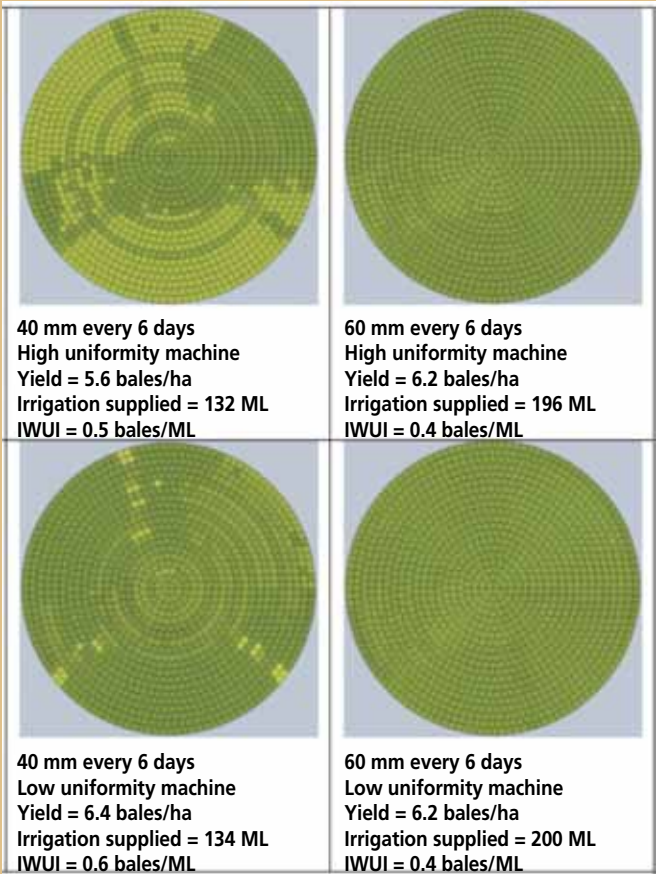
CASE STUDIES

A centre pivot-irrigated cotton field with spatially varying soil properties shown in figure below was simulated with two irrigation machine uniformity distributions.

The field used for the case study simulations



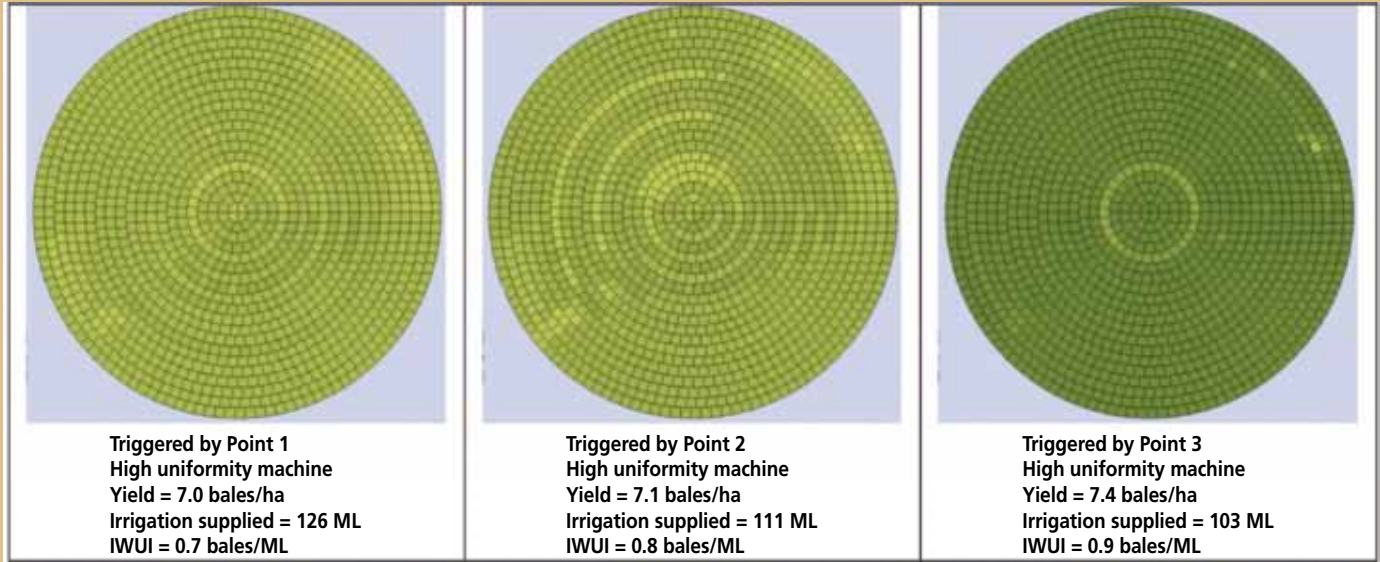
CASE STUDY A: Effect of irrigation application uniformity



LEGEND



CASE STUDY B: Effect of soil moisture sensor location on irrigation performance



Co-ordinating deep drainage research

IN BRIEF...

- The Cotton Catchment Communities CRC involved many organisations in NSW and Queensland to co-ordinate deep drainage research.
- Major outcomes have been achieved including quantification of the amount of deep drainage and a major shift in industry attitudes to this part of the water balance.

WHILE it is now well accepted that deep drainage is a water use efficiency (WUE) component which needs to be managed, back around 2004 it was not regarded so. About 10 years ago, it was still news that the deep clay soils beneath irrigated cotton can 'leak'. Dr Brian Hearn had been highlighting that we simply could not balance all the components of the water balance. In 2004, bringing together the main people in the industry and presenting the evidence about deep drainage achieved a breakthrough. Those assembled agreed this was an issue the cotton industry needed to address. Not only could the cotton industry improve its on-field water use efficiency, it could also work on environmental outcomes such as salinity and surface and groundwater connectivity.

In 2004, the Cotton CRC hosted a two-day workshop funded by the National Program for Sustainable Irrigation brought together universities, CSIRO, state government agencies, CMAs and cotton growers to discuss the issue of deep drainage related to cotton production. The outcomes were:

- An understanding of the current knowledge on deep drainage by all participating researchers in Northern Darling Basin deep drainage.
- An agreed position by researchers and primary stakeholders, (Community groups, Catchment Authorities, commodity groups, investors, regulatory and policy organisations) of future research activities necessary.
- Primary stakeholders informed of the research progress and the implications for their particular interest.
- Stakeholders agreed to a continued coordinated approach.

The deep drainage research became a flagship of the Cotton CRC, which was able to bolster research and include linkages with the groundwater systems. Following on from the workshop, the results were used by the Cotton CRC to kick start a series of deep drainage research projects including the large in-field lysimeter at Narrabri managed by Dr Anthony Ring Rose-Voase, CSIRO and the 'barrel lysimeter' studies by Dr Des McGarry at Queensland Department of Environment and Resource Management.

Overall the work in this area has resulted in a marked increase in the understanding and recognition of deep drainage in cotton production systems over the past 10 years.

Further consensus led to a series of published papers highlighting that deep drainage, even on heavy clay soils in the cotton industry, can range between 10 and 300 mm per year, which are discussed in other sections of this publication.

For more information: www.npsi.gov.au/projects/2223



In 2004, bringing together the main people in the industry and presenting the evidence about deep drainage achieved a breakthrough.

Deep drainage investigated

■ Des McGarry and Thusitha Gunawardena, QLD Department of Environment Resource Management

IN BRIEF...

- Deep drainage occurs in irrigated fields though large quantities (> 2 ML/ha/season) are rare.
- Any reduction in water applied in the pre or first irrigation can dramatically reduce deep drainage.
- The results highlighted the potential for deep drainage to have adverse effects on water quality in the zone beneath the crop rootzone.
- Irrigation management needs to balance leaching requirements and deep drainage to minimise the potential for rootzone salinity as well as off-site drainage impacts.

OVER the past eight years 27 drainage lysimeters were installed across nine sites across irrigated cropping lands in the Upper Murray Darling Basin of QLD and NSW to monitor deep drainage.

The project found deep drainage to be most prevalent at the start of the irrigation season, so any reduction in water applied in the pre or first irrigations can dramatically reduce deep drainage. This might be achieved through especially high flow rates and very short irrigation durations for pre-irrigation and perhaps even initial in-crop irrigations.

The lateral move certainly improved water use efficiency (on average, up to 59 per cent reduction in water applied with equivalent yield) but the almost total lack of deep drainage could be leading to salt accumulation in the rootzone, though longer monitoring is required.

Deep drainage leachates have been found to be very salty relative to the quality of the irrigation waters applied, showing the great potential of salts being moving to rivers and groundwaters. This showed that irrigation management needs to balance leaching requirements and deep drainage to minimise the potential for rootzone salinity as well as off-site drainage impacts.

The deep drainage data collected over the life of the project provided four key results.

Firstly, there was variability in deep drainage from the top of the field to the bottom, with drainage typically reducing from head to tail ditch. The trend may be linked to a current furrow irrigation practise where irrigation siphons are stopped immediately when water reaches the tail ditch, so water inundation is far longer at the head than the tail.

Secondly, the largest deep drainage values generally occurred in the 2002–03 and 2003–04 seasons. In 2003–04 deep drainage was 27 per cent of the water applied at the Goondiwindi site head and 15 per cent at the Dirranbandi site tail. These results seem related to either the use of large diameter siphons (75 mm at Goondiwindi) or lengthy periods of inundation on specific occasions. Overall, the proportion of seasons with deep drainage greater than 100mm (equal to one megalitre per hectare) was small, accounting for only about 20 per cent of recorded values.

Thirdly, there were many examples at all sites where little or no deep drainage was recorded. An extreme example of variability was at the Macalister site which recorded 175 mm of deep drainage at the head of the field in the 2002–03 season, then only five mm at the same location in the 2003–04 season. The likely explanation is that the sorghum crop (of 2003–04) utilised almost all of the 720 mm (7.2 megalitres per hectare) of water applied.

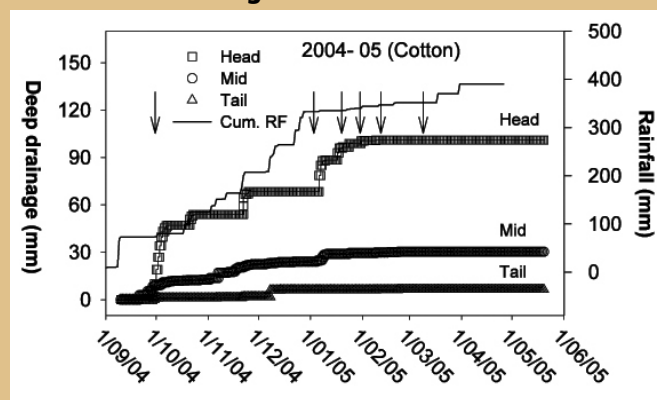
Most evident are the very low values of deep drainage recorded across many sites in the 2005–06 season, due to a combination of limited water supply and above average day and night air temperatures (ie increased evapotranspiration), recorded in that season. Zero values of deep drainage at the Dalby, Goondiwindi and Pampas sites from the 2005 season were associated with restricted availability of irrigation water at these sites in these drought years. Irrigations were infrequent, with small volumes, and were timed for maximum crop and economic benefit.

The fourth key result was a significant proportion of seasonal deep drainage often occurred in the early irrigations. For



Des McGarry discusses deep drainage research.

FIGURE 1: Cumulative deep drainage logged from the Goondiwindi site during the 2004–05 season. Cumulative rainfalls are also shown and the vertical arrows indicate irrigation events.



example, the actual logged deep drainage for data the 2004–05 season at Goondiwindi is presented in Figure 1 to show the within season trends of deep drainage. Evident are the deep drainage ‘step’ increases for the first and second irrigations, after which there was almost no deep drainage at the head, mid or tail locations.

At this site, deep drainage for the first three irrigations in 2004–05 accounted for 80 per cent of the total season deep drainage, due apparently to the farmer practice of shorter duration and more frequent irrigations of more mature crops with greater transpiration and greater soil water deficits later in the season; leaving little water to bypass the rootzone as deep drainage.

Lateral moves and salinity implications

Two adjacent fields at Boggabilla, one under traditional furrow irrigation the other with sprinkler irrigation from a lateral move were selected to monitor deep drainage and root zone solute quality by installing six lysimeters at 1.5 m depth with three in each field. Soil in both fields was grey clay. No deep drainage was recorded in five years (except in one case of pre-season testing). In contrast, in the three seasons when the furrow field was irrigated (2005–06, 2007–08 and 2009–10) there was deep

FIGURE 2: Changes in soil chloride to 1.5 m depth at head, mid and tail locations under the lateral move irrigator over four years at the Boggabilla site. The SD ($\pm$) for the 2009 sampling is shown.

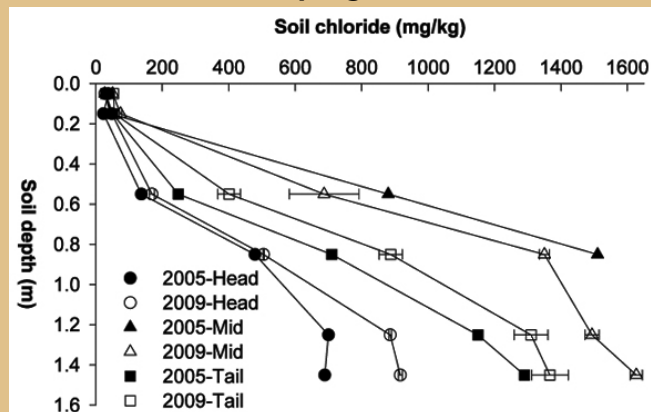
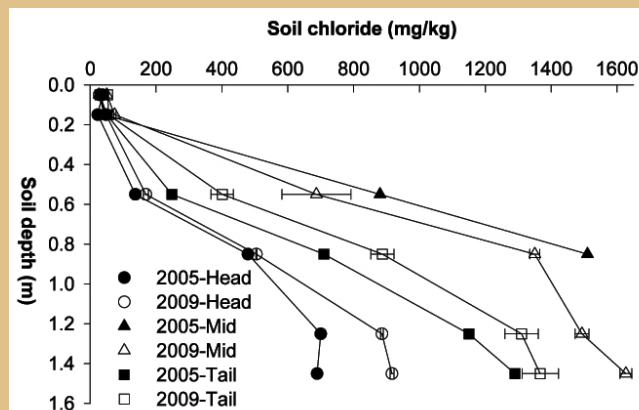


FIGURE 3: Changes in soil chloride to 1.5 m depth at head, mid and tail locations under the furrow irrigation over four years at the Boggabilla site. The SD ($\pm$) for the 2009 values is shown.



Thusitha Gunawardena (right) installing lysimeters.

drainage at the head, mid and tail locations, respectively of 105, 87 and 92 mm, 19, 40 and one mm, and 14, 2 and zero mm.

The total amounts of water applied in any one season also differed strongly between the furrow and lateral move fields. For various summer crops under the lateral move, water applications were: 2.7, 1.9, 1.3, 0.3, 0.6 and two megalitres per hectare in six seasons, compared to 6.3, 4.5 and four megalitres per hectare per season in the furrow field in the three years it was irrigated (2005–06, 2007–08 and 2009–10). This is a 57 per cent, 71 per cent and 50 per cent reduction in water use with the lateral move in the three corresponding seasons.

Crop yield was similar in the two fields when cotton was grown (2005–06 and 2009–10); approximately eight bales per hectare in each field (2007–08 hail damage impaired yield comparison). The similar yields and differences in water supply in 2005–06 and 2009–10 indicated greater irrigation water use efficiency (bales per megalitre) with the lateral move.

Soil salinity dynamics

To monitor changes in soil salts under the two different irrigation practices, soil cores were collected at lysimeter installation then 48 and 56 months later for the lateral move and furrow sides (respectively). Both fields ranged in clay content from 40 to 50 per cent and there was no appreciable difference in soil EC profiles of the two adjacent sites when the initial samples were taken. Irrigation water quality at the Boggabilla site was very good from nearby Whalan Creek, a tributary of the Macintyre River.

Under the lateral move, soil chloride has increased at 50 per cent of the sampled depths in the 48 month period (Figure 2). Lack of replication in the 2005 sampling precluded statistical comparisons, but the tail location showed chloride increases below 0.5m, and at the head location below one metre. Conversely, chloride decreased at the mid location for the two sampled depths below 0.5 m (Figure 2). The largest increase was at 1.5 m depth at the head location – a 25 per cent increase.

Considerable increase in chloride at deeper layers at the head and tail locations may indicate the need for an additional leaching fraction (ie deep drainage) for long term salinity management. In the furrow irrigated field the only large increase in soil chloride was at the head location (Figure 3).

If nothing else, the data supports the need for continual monitoring of root zone salinity particularly as the farmer at this site also grows less salt-tolerant crops than cotton (for example chickpeas).

Deep drainage leachate water quality

The electrical conductivity of the leachates collected in the lysimeter collection bottles at all sites was much greater than the electrical conductivity of waters applied to each field (Figure 4). For example, there were 40 and 60-fold increases in EC between water applied and the leachate at the two St George sites respectively.

The smallest increase in leachate electrical conductivity compared to waters applied (three-fold) was at Macalister, where the water (principally bore) was the poorest quality of all the lysimeter sites – with an electrical conductivity of 4.15 dS/m, and soil electrical conductivity of 1.5 dS/m at 80–90 cm depth (Figure 4). In contrast, soil properties showed electrical conductivity was very low (<0.02 dS/m) throughout at both Dirranbandi and Pampas but 26 and 13 fold increases in leachate electrical conductivity were measured at these sites.

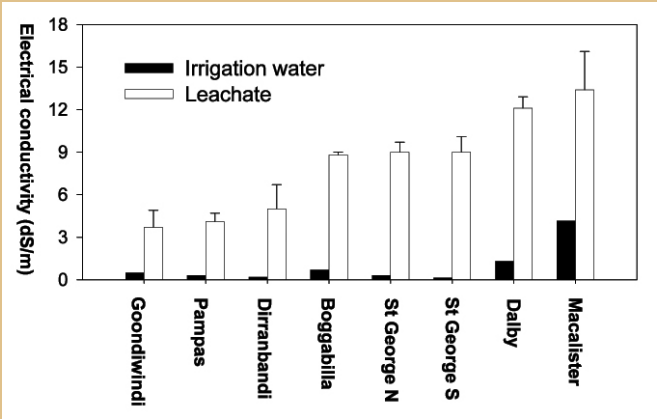
The variable salt transport processes associated with internal drainage are currently not fully rationalised from these data but may be related to bypass flow (through macropores), saturated hydraulic conductivity (mm per day) and exchangeable sodium percentage, specific to each site. These results highlight the potential for adverse effects on water quality in the zone beneath the crop rootzone (termed the vadose or unsaturated zone, being

the portion of Earth between the land surface and the zone of saturation, ie the water table) and perhaps deeper into the water table, if the deep drainage waters reach those depths.

The Final Report can be found at www.cottoncrc.org.au

Funding: Cotton Catchment Communities CRC, Cotton Research and Development Corporation (CRDC), Cotton Australia, Queensland Murray Darling Committee with support from QLD Department of Environment and Resource Management. ▲

FIGURE 4: Water quality, in terms of electrical conductivity (dS/m), of both the irrigation waters applied at eight of the lysimeter sites and the deep drainage water collected (leachate). Data are the means of several irrigations seasons and collection times for each water source.



Lysimetry quantifies deep drainage

■ Anthony Ringrose-Voase, Tony Nadelko CSIRO Land and Water

IN BRIEF...

- Deep drainage in cracking clay soils occurs in two ways; bypass drainage and matrix drainage.
- Irrigations early in the season before the crop is extracting water from the sub-soil can generate large quantities of drainage.
- Some drainage is necessary in irrigated systems in order to leach salts that would otherwise build up near the bottom of the root zone.
- Drainage can remove nitrogen fertiliser from the soil root zone.

USING the Australian Cotton Research Institute's (ACRI) lysimeter facility at Narrabri, it was found deep drainage in cracking clay soils occurs in two ways; bypass drainage and matrix drainage. Matrix drainage occurs when a wetting front moves downwards through the soil, generally over several weeks or months, filling the water holding capacity of the soil until water leaves the root zone as drainage. Bypass drainage occurs when there is 'free' water on the surface such as during furrow irrigation, and occurs very rapidly, within hours or days, with water flowing down cracks and macropores, 'bypassing' the bulk of the soil.

Since 2006 the lysimeter has allowed us to measure drainage accurately and at high frequency at two metres under a cotton-wheat rotation. Six lysimeter trays collect drainage over an area of 1.6 square metres. We installed them by tunnelling horizontally from an access shaft so that the overlying soil is undisturbed (Figure 1). Vacuum is applied to the collection trays and is continuously adjusted to match the suction of the soil at tray depth. This ensures water moves into the trays at the same rate as if they were not there.

Matrix drainage is well illustrated by a drainage event in September 2010 after about nine months of fallow following a wheat crop. The crop had created a soil water deficit of 200mm. After harvest, 640 mm of rain fell over nine months, wetting up successively deeper layers until the wetting front reached two-metres. During the next 35 days the event generated 14 millimetres of drainage. The drainage rate increased slowly over the first 10 days to 0.5 millimetres per day, remaining at this rate for 20 days before slowly decreasing to zero (Figure 2).

Matrix drainage is the 'normal' drainage mechanism in most soils under dryland or irrigated land uses. Its basic cause is that the infiltration of water over an extended period exceeds evapotranspiration, until the soil water holding capacity is exceeded. In contrast to matrix drainage, bypass drainage occurs very rapidly and often in greater volumes. It is of importance in only a few situations – furrow irrigation of cracking clay soils being one of them.

During the 2008–09 cotton season, we found the drainage rate at two-metres depth typically started increasing just six hours after the irrigation front passed overhead and peaked 25 hours after irrigation (Figure 3).

It also declined rapidly. The peak rate was greatest after the first irrigation at 3.2 mm per day and was less after later irrigations (see Figure 3). Whilst irrigation fully wet the top 0.5 metres of soil, it often did not fully wet the soil below 0.5 metres depth despite causing drainage. The speed with which drainage occurred after irrigation and the fact that the sub-soil was not fully wet both suggest that water moves rapidly down macropores 'bypassing' much of the soil matrix.

We found the quantity of drainage generated by individual

FIGURE 1: The ACRI lysimeter facility. A: View looking down into the access shaft, showing the window through which the collection trays are installed (top) and the six collection tanks into which the drainage passes for measurement (left and bottom). B: one of six collection trays during installation, showing the horizontal tunnel, drainage and vacuum tubes and space for a second tray in front. Two other pairs of trays were later installed either side of the tunnel shown.



irrigation events varied considerably (Table 1). There is some evidence that the amount of bypass drainage is greater when the upper 0.5 metres is drier – presumably due to larger cracks. On the other hand, drier soil between 0.5 and 1.0 m reduces the quantity of bypass drainage, possibly because the drier soil ‘sucks’ more water into the matrix as it flows down the macropores. This is why irrigations later in the season generally produce less drainage since the crop has extracted more water from the subsoil.

Conversely irrigations early in the season, before the crop is extracting water from the sub-soil, can generate large quantities of drainage as, for example, during 2006–07 season when early irrigation was required due to a lack of early season rain (Table 1).

We also attempted to understand what happens to drainage

once it leaves the root zone and how long it takes to reach the watertable, which is about 16 metres below the surface under the lysimeter. We used two piezometers (screened at 20 and 34 metres below ground surface) to monitor the groundwater in the upper two aquifers. We could estimate when recharge into the upper aquifer was occurring using the relative changes in the heads of the two aquifers. Preliminary results suggest that the peak in seasonal recharge into the upper aquifer may occur just 15 days after the peak in seasonal deep drainage at two metres.

Some drainage is necessary in irrigated systems in order to leach salts that would otherwise build up near the bottom of the root zone. Electrical conductivity (EC) measurements of the

FIGURE 2: Fluctuations in the drainage rate during part of the 2009–10 fallow showing a period of matrix drainage.

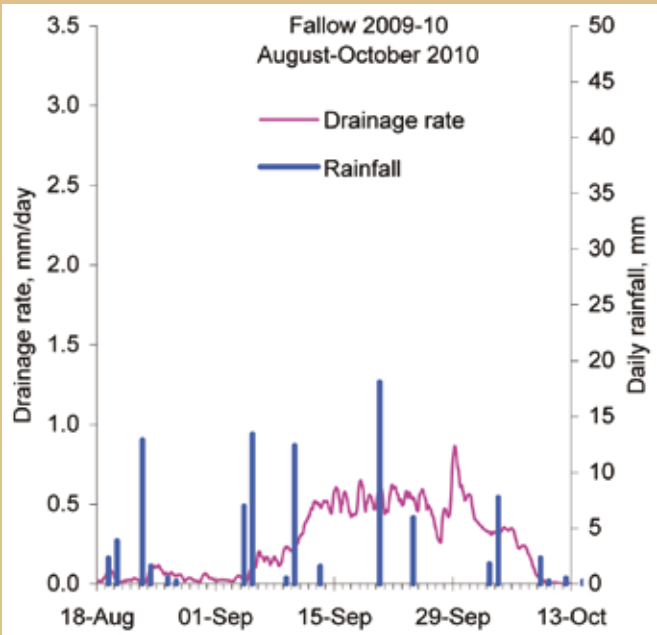


FIGURE 3: Fluctuations in the drainage rate during the 2008–09 cotton season showing a peaks of bypass drainage following each irrigation event and periods of heavy rain.

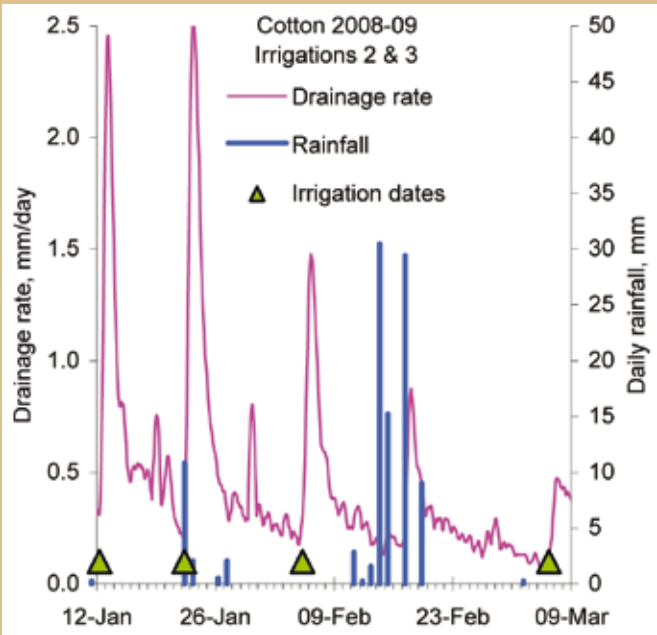


TABLE 1: Drainage and electrical conductivity of the leachate after each irrigation during the 2006–07 2008–09 and 2010–11 cotton seasons as measured by the ACRI lysimeter. Amounts shown are from the date of the event until the date of the next event shown on the next row. “↓” indicates there was too little drainage for collection and analysis, so drainage was accumulated over several events. The small quantities of drainage during the 2010–11 season may have been partly due to soil compaction above the lysimeter, which has since been rectified by deep cultivation.

Event	2006–07			2008–09			2010–11		
	Date	Drainage mm	EC dS/m	Date	Drainage mm	EC dS/m	Date	Drainage mm	EC dS/m
Sowing	19–Oct–06	0.0		09–Oct–08	5.5	3.4	04–Nov–10	0.4	↓
Irrigation 1	24–Oct–06	8.8	3.1	22–Dec–08	13.3	3.8	20–Jan–11	0.1	↓
Irrigation 2	22–Nov–06	22.0	2.2	12–Jan–09	7.3	2.9	02–Feb–11	0.1	4.9
Irrigation 3	12–Dec–06	34.7	2.1	22–Jan–09	8.6	2.6	17–Feb–11	0.1	↓
Irrigation 4	03–Jan–07	3.6	2.1	05–Feb–09	9.3	3.6	01–Mar–11	0.1	↓
Irrigation 5	16–Jan–07	0.2	2.2	06–Mar–09	2.5	5.5	16–Mar–11	0.1	3.7
Irrigation 6	30–Jan–07	0.5	2.5	19–Mar–09	7.4	8.1			
Irrigation 7	14–Feb–07	2.1	2.6						
Irrigation 9	28–Feb–07	2.3	3.2						
End	18–May–07			23–Jun–09			24–Jun–11		
Season total		74.2			53.9			0.7	



Using flume meters to measure water flow rates.

drainage give an indication of how effectively it leaches salt (Table 1). We found that bypass drainage generally has relatively low EC – two to three deciSiemens per centimetre, because the irrigation causing it does not pass through the matrix of lower root zone where salt has accumulated.

Matrix drainage leaches salt much more efficiently, as shown by the increase in EC in the drainage at the end of most seasons. The greatest EC values, 13 deciSiemens per centimetre, occurred in drainage towards the end of the 2009 wheat crop.

Drainage can also remove nitrogen fertiliser from the soil root zone. For example, 9.5 kilograms per hectare were leached out during the 2008–09 season, mainly following the first four irrigations. Unfortunately, nitrogen (unlike salt) is most available in the top soil where it is efficiently mobilised by irrigation water, so that it can be leached by bypass drainage. This again shows the importance of avoiding early season drainage, when nitrogen is most available.

Further reading at www.cottoncrc.org.au

Funding: Cotton Catchment Communities CRC and Cotton Research & Development Corporation



Deep drainage – where is it going and what is it doing?

■ Jenny Foley and Mark Silburn, QLD Department of Environment and Resource Management



Jenny Foley.

Mark Silburn.

IN BRIEF...

- Soil water balance models can be used today to answer critical questions affecting the industry
- Researchers in Queensland have investigated the catchment scale trends and consequences of deep drainage.
- An exciting new research method was developed to take two-dimensional 'snapshots' of water patterns deep to unlock some of the mysteries surrounding deep drainage.

In this project, two-dimensional transects were imaged through native vegetation and adjoining irrigated paddocks to look at historical changes in water and salt fluxes due to land use change. All soils under native vegetation were found to be highly resistive (very dry) even when sparsely populated by trees. In contrast, significant long-term migration of water has occurred to deep within the regolith (up to 15 metres) in most irrigated paddocks.

These wet layers in the profile would not be a static store of irrigation waters, but would be draining into the deeper regolith at a rate proportional to the conductivity of the deeper clay and sand layers. There is tremendous potential to capture and use this currently under-utilised water.

Considerable time, effort and money has been invested in 'water balance' related research over the past two decades. And while soil water balance models can be used today to answer critical questions affecting the industry, a lack of key soil physical data, particularly the soil water holding capacity, has limited

the use of water balance models to determine the relationships between irrigation management and deep drainage.

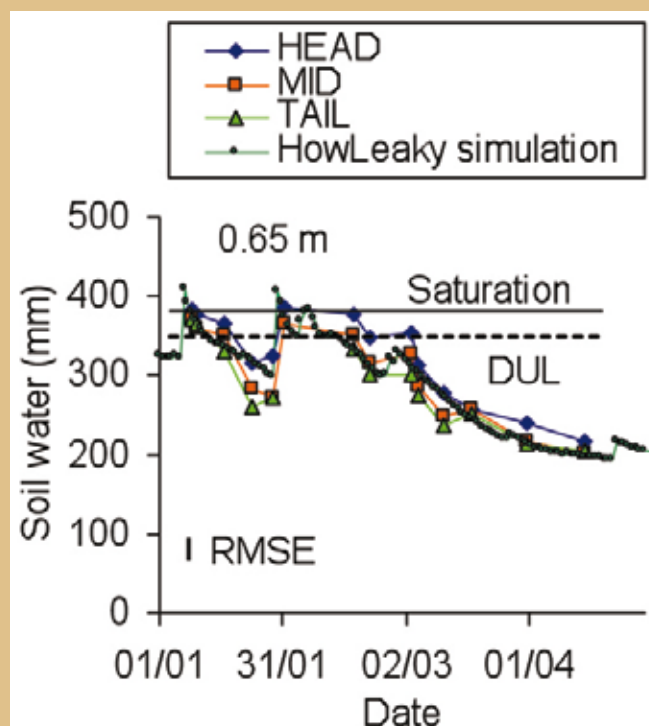
Our project set about to rectify this. In this project we captured data from past and current studies of water balance and deep drainage under irrigation in northern NSW and south-west Qld in a form useful for modelling, and 'filled in' some of the gaps with additional paddock measurements at key sites. We used the data to test the models, derive parameters that make them work well and provide insights across landscapes and over longer time periods.

Measure a paddock to test a model

Soil water balance models such as *HowLeaky?* are used to look at the relationships between management options such as irrigation frequency and amount, and components of the water balance that we wish to manage, such as deep drainage. But how well do they perform? To test this model we measured the fate of irrigation water – in the paddock – during the summer cotton growing season of 2007-08.

We used an EM38 device (Geonics Limited) to indirectly measure soil water and calibrated these readings against soil

FIGURE 1: Cumulative soil water to 0.65 m measured with the EM38 for head, mid and tail positions in the paddock – and simulated using the *HowLeaky?* model.



EM38 devices are an attractive tool for industry consultants and growers for precision irrigation scheduling.

water measured in cores taken with a soil coring rig. We also took EM38 readings at a number of heights above ground (called depth slicing) to get specific detail on where the water was within the root zone during the season.

The EM38 provided soil water estimates for various soil layers with better accuracy and less time taken than most other soil water monitoring methods (once paddock calibrated).

Measurements were made before and after irrigations (two irrigations – each about one megalitre per hectare) and then frequently during the course of the growing season. We were able to estimate with great precision the variations in water application from head, mid and tail positions in the paddock, and also variability in row and inter-row wetting during irrigations. The paddock was very wet (draining) for much of January-April.

We modelled the data with *HowLeaky?* and found the model capable of simulating, with reasonable accuracy, the changes to soil water during the growing season (see Figure 1). The model agreed to a large degree with the data, estimating that during two periods in the season, a significant amount of deep drainage (1000 mm) occurred).

How full is the buffer?

Inevitably we then ask ‘where does all the water go? We expect that deep drainage losses occurring under irrigated cropping should create greater groundwater recharge. But this is often not detected in changes to groundwater levels.’ It may be filling a historic moisture deficit in the unsaturated zone (between the root zone and the groundwater surface) and is therefore not yet causing greater recharge to groundwater. If so, how long before this moisture deficit ‘buffer’ is full and deep drainage becomes groundwater recharge?

In seeking to answer these questions, we used geophysical

surveying methods and deep coring (six to 20-metres deep) to look at the moisture status in the deeper regolith/unsaturated zone. We used electrical resistivity tomography (ERT) to take two-dimensional ‘snapshots’ of the underground landscape.

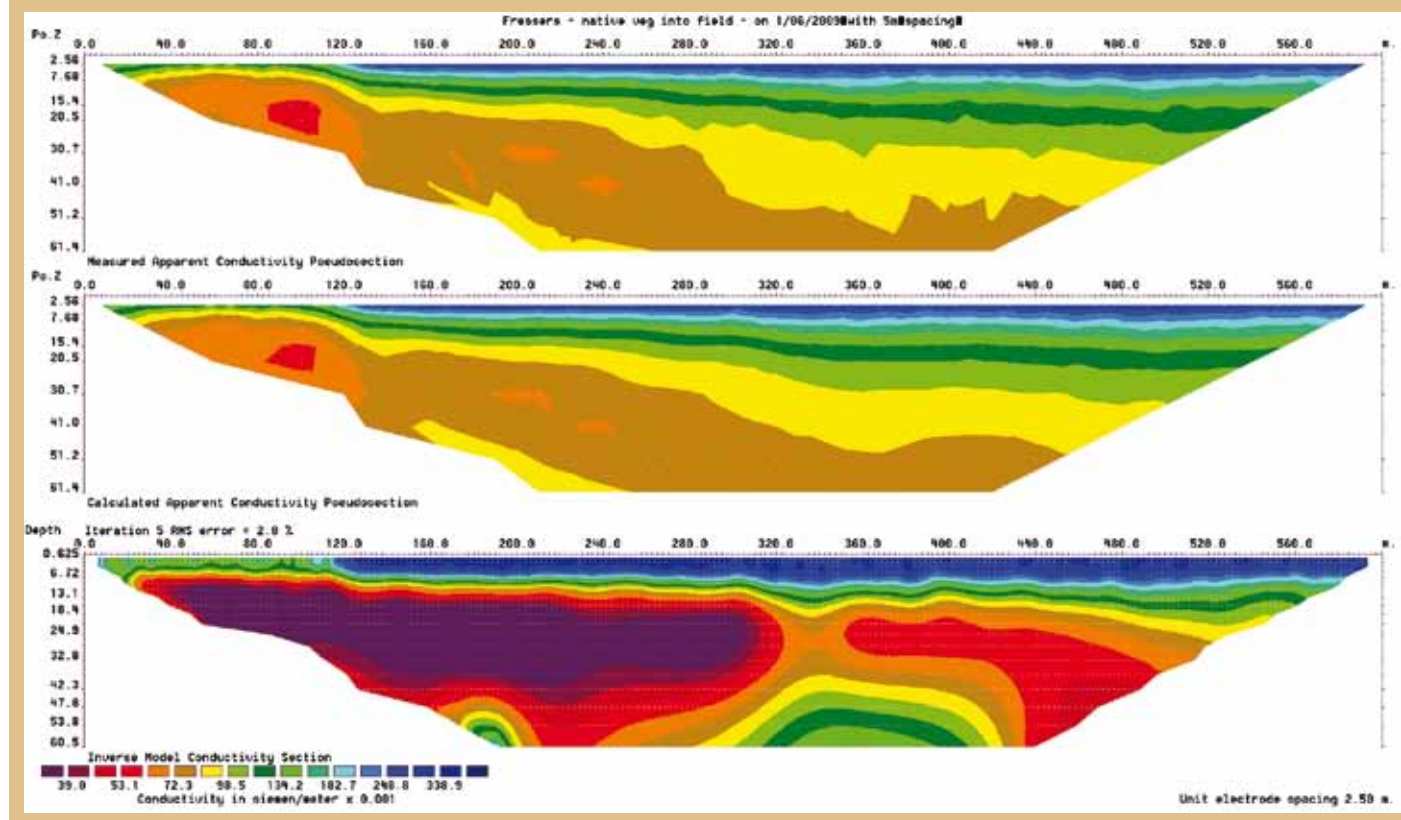
The resistivity measurements tell us a great deal about the amount of salt, water and clay at any point in the deeper profile (up to 60 metres deep). When used in combination with deep coring and soil analysis these elements can be isolated and geophysics models improved.

We ran ERT images along transect lines in both irrigated and uncleared landscapes throughout the Condamine and Border Alluvia’s (see Figure 2). Transects imaged from naturally vegetated landscapes into irrigated paddocks found all soils under native vegetation to be very dry even when only sparsely populated by trees. In contrast, significant long-term migration of deep drainage was evident to deep within the regolith (up to eight to 15 metres) in most irrigated paddocks.

Deeper coring with a Geoprobe and coring to four to six metres with the soil coring rig has provided considerable data to support the widespread occurrence of a historic change in regolith water storage as a result of deep drainage under furrow irrigation.

A layer of near-saturated soil in the profile between two to six metres was found in nearly all irrigated paddocks. Deep coring in native vegetation sites close to the irrigated sampling sites confirmed the dryer soil profile under native vegetation. In the extensive buffer of dry soil historically in the regolith under trees there is virtually no deep drainage as trees are able to extract more water from the soil and to extract water deeper in the profile.

FIGURE 2: ERT transect running from native vegetation into fallow irrigated paddock in the Central Condamine Alluvia (tail drain at 120 m). Blue colour indicates highly wet and conductive clay layers.



How is this deep drainage affecting catchment health?

The answer a few years ago was 'we don't know because we haven't looked'. But in light of the potential broad scale landscape impacts of deep drainage, a monitoring program was developed for the Border-Moonie catchment. This catchment was recognised as having potential future salinity risks in a salinity audit, particularly on the Border-Weir Rivers alluvia where irrigation occurs.

While no larger project was funded to investigate these issues, a multi-point plan was prepared (Border-Moonie drilling program) and implemented over time. This included preliminary groundwater modelling of part of the Macintyre alluvia, a subsequent drilling program and geophysical surveying.

The latter two components of this plan were led by Andrew Biggs (DERM). In 2008–09 35 holes were drilled and 31 monitoring bores constructed with several nested bores. Bores were drilled in lines across the landscape at right-angle to the streams, providing a systematic groundwater monitoring network for the region and linking up with monitoring bore lines in NSW. Water level loggers were installed in bores near irrigated fields. Transient electromagnetic (TEM) geophysical techniques were used to survey hundreds of kilometers of the Border-Moonie (mobile ground survey). This provided depth sliced conductivity images to below 30 metres in lines across the landscape, similar to our ERT paddock surveys but at a catchment level. Likewise, features of interest in these images were investigated using rotary core drilling.

The Final Report at www.cottoncrc.org.au

Funding: QLD Murray Darling Commission, Department of Environment and Resource Management, Border Rivers Gwydir Catchment Management Authority, Cotton Catchment Communities CRC and Cotton Research & Development Corporation ▲

Irrigators to benefit from 3D moisture probes

■ Anna Greve University of NSW

IN BRIEF...

- A better understanding of soil crack dynamics and the influence on soil moisture distribution are useful for improving water use efficiency.
- A newly developed 3D resistivity probe monitors soil moisture status as well as the nature of water flow within the soil profile.
- A new technique to detect subsurface cracks will improve understanding of crack dynamics, which has been hampered by the lack of techniques to observe or monitor these dynamics below the soil surface.

THE majority of irrigated agriculture in Australia is located on fine grained cracking soils. While their high nutrient content and water holding capacity support high yielding crops and profitable farming, the formation of shrinkage cracks during drying intensifies the adverse effects of suboptimal irrigation scheduling. Preferential flow through soil cracks can rapidly move irrigation water into deep parts of the soil profile and can quickly transport solutes and agrochemicals through the unsaturated zone.

Additionally, preferential drying and wetting along crack faces increases the soil moisture variability within a soil profile. The commonly used point measurement techniques to measure soil moisture (Neutrone Probes, Capacitance Probes) are hence inadequate to capture the spatially highly variable soil moisture in cracking soils.

To allow the most appropriate irrigation management of cracking soils, a better understanding of soil crack dynamics and the resulting influence on the soil moisture distribution are essential. The newly developed 3D resistivity probes monitors soil moisture status as well as the nature of water flow within the soil profile. These probes detect cracking depth and crack dynamics.



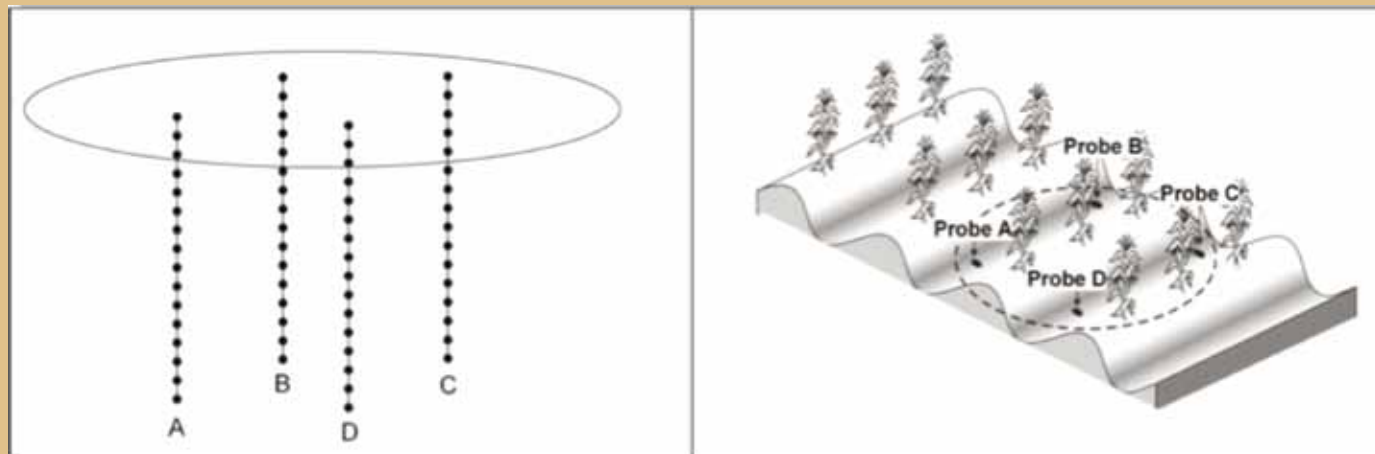
PhD student Anna Greve investigated the most appropriate irrigation management of cracking soils.

3D tomography monitors soil moisture

3D electrical resistivity tomography (ERT) undertaken on a small scale between four vertical boreholes allows three dimensional monitoring of moisture changes in the undisturbed soil between the resistivity probes (Figure 1).

Borehole resistivity probes have been designed and constructed and were tested in laboratory weighing lysimeters. The equipment has successfully been used in the field during the 2007–08 and 2008–09 seasons in irrigated sorghum and cotton. Results allow detecting different water migration processes during irrigation between cracked and non-cracked soil (Figure 2).

FIGURE 1: Left – Subsurface electrode arrangement to carry out 3D cross-hole ERT. Electrode stings are located in four vertical holes (A,B,C and D) that are installed in the corners of a surface square. Right – Schematic of field installation of the probes.



Index to monitor soil cracking

To date, an understanding of crack dynamics has been hampered by the lack of techniques to observe or monitor crack dynamics below the soil surface.

This study introduced a new technique for the detection of subsurface cracks that relates the development of soil cracks to changes in the electrical anisotropy of the soil. Electrical anisotropy is the ratio of the apparent resistivity measured with the alpha and the beta square array. In a non-cracked soil the current flow in the soil shows no directional dependence, and the ratio between these two apparent resistivities is close to unity. But if soil cracks are present, a directional dependence of the current flow is introduced causing this ratio to deviate from unity.

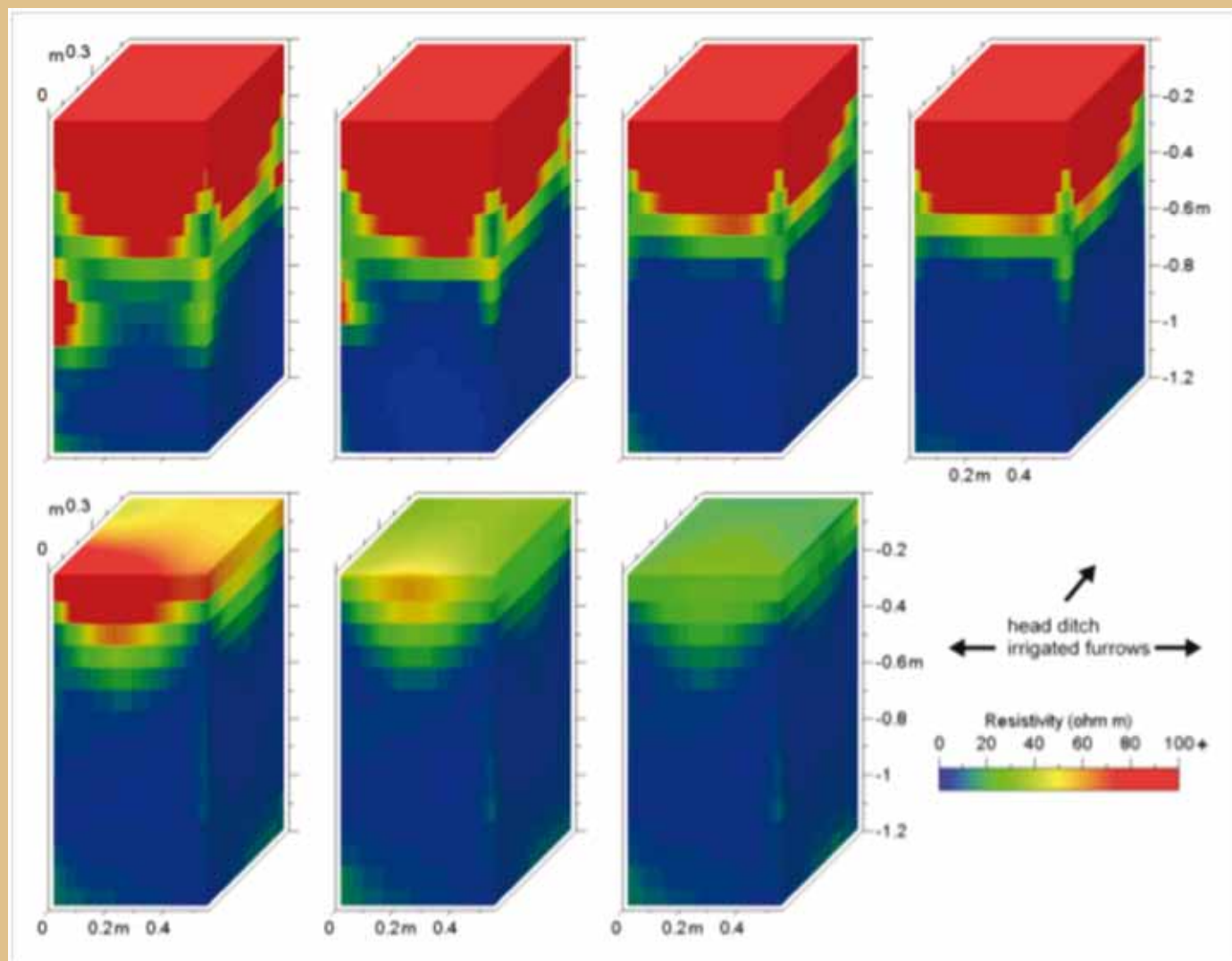
The electrode array proposed for the collection of 3D electrical resistivity tomography (Figure 1) also allows anisotropy measurements at regular depth intervals throughout a soil profile. Results of numerical modelling, laboratory and field tests show that the anisotropy index is an excellent tool to monitor dynamics of subsurface cracks, to measure the depth of crack extension and to monitor the transition from preferential flow to matrix flow during crack closure.

Further reading www.connectedwaters.unsw.edu.au/technical/research/projects/projects_3dresistivity.html

Funding: Cotton Catchment Communities CRC.



FIGURE 2: 30 minute steps of a time-lapse series during furrow irrigation on cracked soil (surface cracks of 30 mm width). Irrigation of the measurement area commenced immediately after image 1 was taken. Wetting occurs from the bottom upwards, indicating crack filling.



CASE STUDY

Converting furrow irrigation to overhead systems at Goondiwindi

■ Bec Raymond and Mary Philp, QLD Department of Agriculture Fisheries and Forestry

'UNDABRI' and 'South Giddi Giddi' situated 20 km west of Goondiwindi cover around 12,000 hectares and were purchased by Craig Doyle Rural Holdings (CDRH) in 2007–08. Each property has close to 1000 hectares of irrigation and there is a combined 5500 hectares of improved grazing country.

CDRH are focussed on both water and labour savings and successfully applied to the Healthy HeadWaters Water Use Efficiency (HHWUE) project to upgrade 90 per cent of their irrigation from furrow to overhead systems.

For CDRH, the main reason for implementing the change from furrow irrigation to overhead systems was the ability to save water and hence irrigate a larger proportion of their cultivated area each season, whilst also saving on labour.

The project was timely as CDRH were looking to upgrade their infrastructure and this project allowed them to implement the changes in a faster and more streamlined timeframe.

"It came to our attention (the HHWUE project) last year, I think because the year before we put a lateral and a centre pivot in, and found them good to work with, the efficiencies were great. So when this opportunity came available, we put the two applications in, one for Undabri and one for South Giddi Giddi," said Pastoral Manager Jeff Carter.

The upgrade includes the installation of eight lateral moves (four

"We had put a lateral and a pivot in and found them good to work with, the efficiencies were great."

"The infrastructure is enabling the planting of a greater percentage of cultivated area and lessening the man hours to complete irrigation cycles."

"A reduction in water use for cotton from eight to five ML/ha is expected."

on each property) and two centre pivots, as outlined in Table 1.

Other aspects which have been considered in the application and are vital to its success include the installation of irrigation scheduling and monitoring equipment and appropriate training for farm employees.

Jeff explained that the first steps to this change were early design discussions with SMK Consulting in Goondiwindi to identify what type of development would be suitable for the properties. This was completed regardless of any application to the HHWUE project. FSA Consulting, Toowoomba was then contracted to complete the actual application for both farms as it is a requirement of the project to have it completed/approved by a licensed engineer, certified irrigation designer or certified irrigation agronomist.

System installation was completed in June 2012.

Crop management and water savings

In the 2009–10 season, cotton was grown successfully under previously installed furrow and overhead systems. The soils, slopes and locations of all of the systems were similar. The average water applied per hectare to irrigate the cotton for each type of system is shown in Table 2.

To place this in perspective, the 610 hectare development of

TABLE 1: Proposed changes following upgrade of furrow to overhead irrigation

Current setup	With proposed changes
Undabri	
730 ha – furrow irrigation	16 ha – furrow irrigation
375 ha – 1 lateral (183ha) + 1 centre pivot (192 ha)	984 ha – overhead irrigation
South Giddi Giddi	
950 ha – furrow irrigation	717 ha – overhead irrigation

TABLE 2: Water applied to 2009–10 cotton crop

System	Water applied
Furrow	8.0 ML/ha
Lateral Move	5.0 ML/ha
Centre Pivot	5.0 ML/ha



Endfeed Stage 2.



Sunflowers growing in Stage 1 of the development.

‘Undabri’ will provide a saving of 1830 megalitres and the 717 hectare development of ‘South Giddi Giddi’ provides a saving of 2151 megalitres – a total saving of 3981 megalitres per annum (see Table 3). Of this water saving, the infrastructure proposal includes a transfer of 2100 megalitres to the Commonwealth Environmental Water Holder (CEWH).

Economics

A benefit/cost analysis using a discounted cash flow was conducted to determine the potential return from the Water Use Efficiency (WUE) investment for each property (Table 4). The analysis considered two scenarios: with and without participation in HHWUE Infrastructure program. In both cases, it was assumed that any water savings (after transfer to the CEWH

TABLE 3: Total water savings

Property	Volume saved	Volume transferred to CEWH
Undabri – 610 ha x 3.0ML/ha	1830 ML	1000 ML
South Giddi Giddi – 717 ha x 3.0ML/ha	2151 ML	1100 ML
TOTAL	3981 ML	2100 ML

as appropriate) would be used to grow additional area of the highest value crop (cotton) on the remaining furrow country. The total cost of the project and the federal government contribution were included in the initial discounted cash flow.

In both cases it is evident that assistance from the HHWUE Infrastructure grant greatly improves the expected return on infrastructure development and decreases the time taken to pay back the capital expenditure. It should be noted that some benefits and costs were not included in the model, including changes in labour, maintenance, yield and energy. In addition, neither tax nor seasonal and market price variability is accounted for in this analysis.

Sensitivity tests

A number of sensitivity tests were conducted to determine the effects of varying the water savings achieved and expected gross margins. Changes in the water savings achieved had a greater effect on profitability than changes in gross margin. As can be seen in Table 5, if both the water saving and gross margin were reduced, it is possible that there would be no positive return.

As explained earlier, the water savings for each infrastructure project were assumed to be three megalitres per hectare based on previous experience with both irrigation systems. However, QLD Department of Agriculture Fisheries and Forestry's CropWaterUse tool (cropwateruse.dpi.qld.gov.au) suggested that on average 5.6 megalitres per hectare would be required to grow a cotton crop at Goondiwindi using overhead irrigation. If the realised water saving were reduced to only two megalitres per hectare, there will be little water saving available once the proposed 2100 megalitre allocation is transferred to the CEWH.

While the usefulness of the results from the models are limited due to the number of variables excluded, this analysis does highlight how important it is to correctly estimate the amount of water saving the project will achieve.

This is one of a series of Case Studies prepared by Queensland Department of Agriculture, Fisheries and Forestry as part of the Healthy HeadWaters Water Use Efficiency (HHWUE) project. This project is managed by the Queensland Department of Natural Resources and Mines and funded by the Australian Government as part of the Sustainable Rural Water Use and Infrastructure Program under the Water for the Future initiative. ▲

TABLE 4: Summary of benefit/cost analysis for Undabri and South Giddi Giddi developments

	UNDABRI		SOUTH GIDDI GIDDI	
	With HHWUE Infrastructure Grant	Without Grant – All Water Savings Retained	With HHWUE Infrastructure Grant	Without Grant – All Water Savings Retained
Net present value (NPV)	\$1,317,497	\$495,198	\$1,786,563	\$781,889
Cashflow period	20 years	20 years	20 years	20 years
Internal rate of return (IRR)	19%	6%	22%	7%
Payback period	6 years	17 years	6 years	16 years

TABLE 5: Sensitivity analysis for South Giddi Giddi benefit/cost analysis

	Current values	Water saving 2ML/ha & low gross margin	Water saving 2ML/ha & high gross margin	Water saving 3ML/ha & low gross margin	Water saving 3ML/ha & high gross margin
Water saving available	1051 ML	334 ML	334 ML	1051 ML	1051 ML
Gross margin (\$/bale)	\$165	\$116	\$213	\$116	\$213
NPV	\$1,786,563	-\$356,502	\$159,058	\$967,042	\$2,589,359
Cash flow period	20 years	20 years	20 years	20 years	20 years
IRR	22%	0%	7%	15%	22%
Payback period	6 years	>21 years	16 years	8 years	4 years

CASE STUDY

Survey for best probe placement

IRRIGATION scheduling involves applying the right amount of water, in the right place at the right time in order to maximise production and improve water use efficiency. Soil moisture monitoring tools are commonly used in the irrigation industry to assist growers like Andrew Parkes formerly of 'Keytah', Moree and Von Warner, manager of 'Bullamon Plains', Thallon with their scheduling decisions. They provide soil moisture information at a specific location within a field. To have confidence in any soil moisture monitoring tool you need to ensure it is located in the most representative part of the field, or fields in which it is used to schedule irrigations.

Have you ever considered how representative your moisture probe site is to the rest of your field? Traditionally growers like Von and Andrew would site their probes visually, from experience or 'gut feel', but today these growers believe they can do it better. A visual only offers an inspection of the surface and until recently this has been good enough but today we have the technology to look below the surface, to build a more defined and accurate picture of the majority soil types and ultimately remove the human error.

A moisture probe placed in the wrong spot can result in over or under irrigating the majority soil type in that field or management unit. For example, a probe sited in a section of field where the soil is lighter (hence lower water holding capacity), will not be representative of the majority soil type of the field. If this is not factored into the scheduling decision it may result in more frequent irrigations than is required for the majority of the field, costing you valuable resources.

Electromagnetic Induction (EM) surveying, used in conjunction with soil sampling, can be used to map soil variations across fields and farms. It does this by measuring the soils apparent electrical conductivity (ECa), which is related to factors such as soil texture, soil moisture and salinity.

So how do you know if high readings are due to salt, high soil moisture or a heavier soil type? To account for soil moisture the EM survey should be conducted when the profile is full

of moisture, ideally at the end of a fallow period or after an irrigation. If the soil is non-saline this map will give a surrogate measure of soil texture. In saline conditions, the ECa readings will be a function of both texture and salts. Either way ground truthing is essential to calibrate the instrument. This involves the collection and analysis of soil samples from known positions and relating the results to the EM readings. Therefore an EM survey can give an indication of texture changes over the field and analysis of the data provides maps of similar soil types and consequently can be used to locate the 'majority' soil type within a field.

Andrew and Von are convinced about the benefits of EM soil surveys on their farms. Both growers have used calibrated EM maps to examine soil variability across their fields in order to position moisture probes in sites that are representative of the field, ensuring that their probes are located within the majority soil type, year in and year out.

"Using EM survey to assist siting moisture probes has given me more confidence with my scheduling decisions" Von said.

"It gives me the ability to draw down water and stretch irrigations if necessary".

Von did point out that moisture probes are just one tool he uses to schedule irrigations. "Keeping a close eye on weather forecasts and visual inspection of the crop is still vital," he said.

For Andrew, the change in practice for siting moisture probes occurred when capacitance probes first came to the fore. The use of telemetry meant these probes could be placed anywhere in the

FIGURE 1: Shows a trend that as EM increases so does yield to around mid-range where it starts to trend down again.

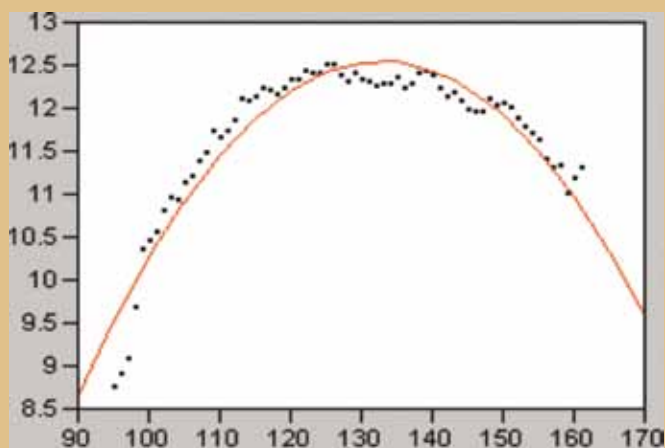
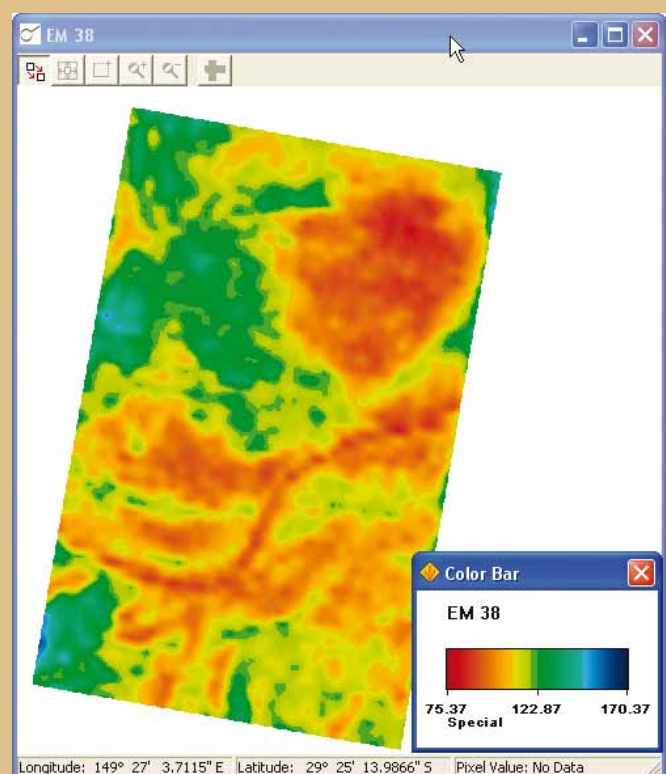


FIGURE 2: EM 38 map showing field soil variability.



field. Previously he would position the probe tubes in a section of paddock that looked representative, but was also easily accessed. Back in 2001–02 he was sitting down with Andrew Smart from Precision Cropping Technologies, Narrabri, looking at yield maps.

“I asked him how he knew the probe was placed in the right area in terms of soil water holding capacity.” Andrew Smart said.

“An initial EM survey using an EM38 showed that the EM data on Keytah was heavily influenced by clay content and therefore data from the EM survey could be used to provide a detailed map of potential water holding capacity to around 1.2–1.5 metres.”

Andrew Parkes then took a GPS reference of the probe site and found that as luck should have it, he had placed the probe in a site that was close to the fields ‘majority’ soil type (hence “majority” water holding capacity), but it also pointed out the variability of soil in this field. In fact, close to the probe site was a section of field that was much lighter in texture, and he could have just as easily placed the probe there by mistake and then irrigated the field by that area. How did he know that scheduling based on the soil majority had a positive impact in terms of production?

“Yield maps were examined with the data collected from the EM survey and a close correlation between yield and EM readings was found.” Andrew Smart said.

Figure 1 shows a trend that as EM increases so do yields, to around mid range where it starts to trend down again. The majority soil type had an EM reading between 120–140, which matched the areas of the field with the highest yield. This illustrates that they are managing the field and its water based on the majority soil type, as the highest yields are occurring

in the majority soil area. Figure 1 also shows the lighter soils yielding less because they would have been more stressed from lack of timely water. The higher clay areas or higher EM readings (ECa>140) were more than likely water logged, but both these soil types only make up a small area of the field.

To further enhance probe placement, an EM soil variability map (Figure 2) can be overlayed with a slope map (Figure 3) to analyse variations from perfect plane (to make sure the probe is not placed in a hollow or a ridge) and also a cut and fill map if the field was laser levelled in the past two to three years.

These layers of data can then be combined to produce a map (Figure 4) which best represents majority soil type, closest to majority slope and in some cases removal of areas of high previous cuts and is then used to site the location of the probe in the field. In conjunction with this type of map, Andrew Parkes reminds us that ground truthing is still critical, “You need to check your probe is placed in an average plant stand which is also representative to the rest of the field”.

FIGURE 3: Slope map showing minor variations in slope that could affect water retention or runoff on soil moisture.

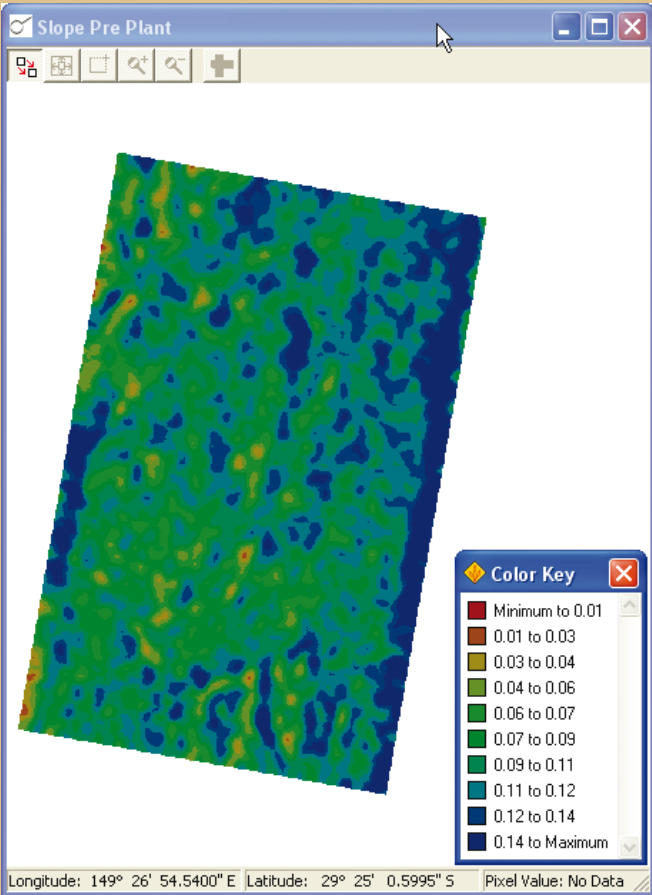


FIGURE 4: Final map which best represents majority soil type, closest to majority slope and in some cases removal of areas of high previous cut.



Breeding for irrigated and dryland cotton systems

■ Greg Constable, Warwick Stiller, Shiming Liu and Peter Reid, CSIRO Plant Industry

IN BRIEF...

- Crop management and varietal characteristics which increase yield also increase water use efficiency.
- Historically, breeding has been responsible for at least half the yield increases in Australia.
- Breeding has also measured and assessed important varietal characteristics for best production under dryland systems.

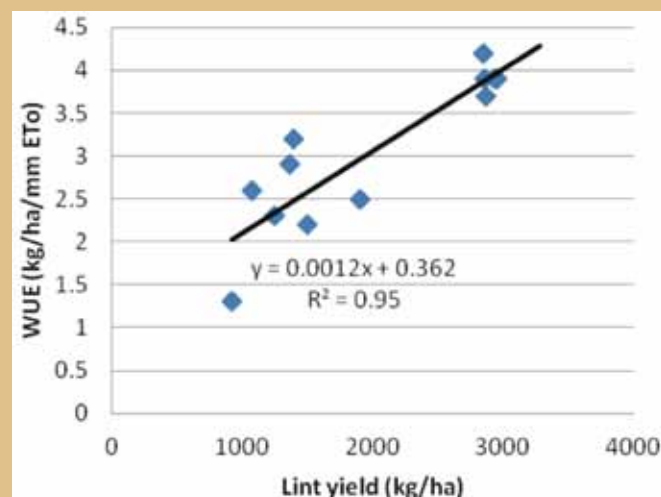
GIVEN the variable nature of Australia's rainfall and irrigation supply, research into water and irrigation requirements of cotton has been a high priority. The old folklore of stressing cotton pre flowering in order to stimulate fruit set was still in practice up to the early 1970s. Yield expectations and outcomes were low compared with today's standards. Increase in disease incidence and soil compaction led to rotations with wheat which lifted cotton yield, as did more adapted varieties and better agronomy in later decades.

Lint yield progress in the industry has averaged about 27 kg per hectare per year since the mid 1960s and water balance research has shown that water use per hectare has not increased much, so water use efficiency has continually increased as yield has increased (see Figure 1). Note these data were from cotton grown in central regions with optimised irrigation scheduling.

Hotter regions will have lower water use efficiency as will excessive irrigation scheduling. Detailed analysis has shown at least 50 per cent of the industry yield increase has been due to better varieties (ie up to 50 per cent of yield increase was due to better management), so the improvement in water use efficiency (WUE) could be attributed in a similar ratio. In fact our analysis shows that modern varieties such as Sicot 71 (and its transgenic versions) respond more to modern intensive management than old varieties do.

Plant breeding began to address stress tolerance and adaption to stress as the dryland industry was being developed

FIGURE 1: Association between cotton lint yield and crop water use efficiency. Data from Australian research projects from 1975 to 2010 where more accurate water balance has been done in central production regions; sources listed below.



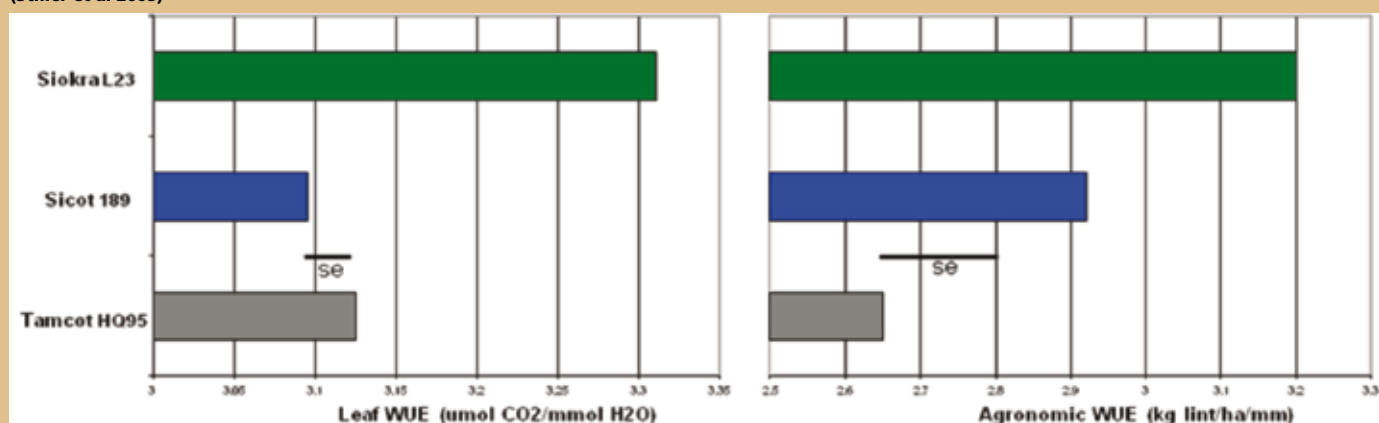
in the 1980s. After some intensive research it was found that indeterminate growth habit (to take advantage of summer rain), good root systems, okra leaf and good fibre length were desirable characteristics for a dryland variety. Varieties such as Siokra 1-4, Siokra L22, Siokra L23 and Siokra V-16 were the standards for dryland cotton production systems for many years.

We have assessed many measures to describe cotton's reaction to stress and how those measures might be used to enhance the power of selection during breeding. It was found that a full season okra leaf variety had better WUE at the leaf level than a full or short season normal leaf variety.

For WUE at the agronomic level, the full season okra leaf

FIGURE 2: Leaf and crop level water use efficiency comparisons of leaf shape and varietal maturity.

(Stiller et al 2005)





Greg Constable, Shiming Liu and Warwick Stiller.

variety had 11 percent better WUE than a full season normal leaf variety, which was another nine percent better WUE than a short season normal leaf variety (Figure 2). We have found that varieties more suited to dryland can extract up to 40 mm more than a less dryland suited variety.

In 2011–12, the majority of dryland cotton was sown to Sicot 71BRF and Sicot 74BRF – the two highest yield potential varieties available.

What has changed in dryland or production systems; why has there been a transition from specialist dryland varieties to use mainstream irrigated varieties? There can be many reasons, but it is more important to focus on yield and yield potential than on okra leaf.

- Yield is a stress tolerance characteristic as long as stress reaction of the different varieties is similar.
- It is likely that Siokra 24BRF would be superior to Sicot 74BRF in a dry season with hot January during peak boll load, albeit at low yield levels.
- Fibre quality characteristics have improved in mainstream irrigated varieties; they are now even better than older dryland varieties.
- A broad disease resistance package is now required under dryland as much as in irrigation production.

Biotechnology traits are under development for water stress and water use efficiency. These traits may be some time before release and in particular, research will be required to match that

trait with growth habit and with irrigation management strategy to maximise the potential benefits.

Further reading:

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 Stiller, Read, Constable and Reid. (2005). *Crop Sci.* 45: 1107-1113.

Funding: CSIRO cotton breeding is funded by the Cotton Breeding Australia Joint Venture between CSIRO and Cotton Seed Distributors; prior to 2006 breeding was supported by CRDC. ▲

Dryland cotton water use efficiency

■ Greg Constable, Warwick Stiller and Loretta Clancy CSIRO Plant Industry

IN BRIEF...

- The rainfall use efficiency (yield per mm rainfall) of dryland cotton from more than 20 sites was assessed using production and rainfall records.
- On average, dryland cotton produces about 0.5 bales for each megalitre (100 mm) of summer rain.
- This efficiency has increased through time and has allowed dryland cotton to maintain productivity during the recent drought.

A DEPARTMENT of Agriculture Fisheries and Forestry report in 2009 Australian Commodities Report indicated dryland cotton yield had not changed over the years 1995 to 2008, implying that there had not been any production improvements. Such a lack of trend is at odds with irrigated cotton yield data which shows an absolute increase of 0.1 bales per hectare per year. In earlier analyses we had concluded the static dryland yields were due to drought and that in fact yield per unit of summer rain had increased at approximately the same rate as irrigated cotton, that is, by 0.1 bales per hectare per year.

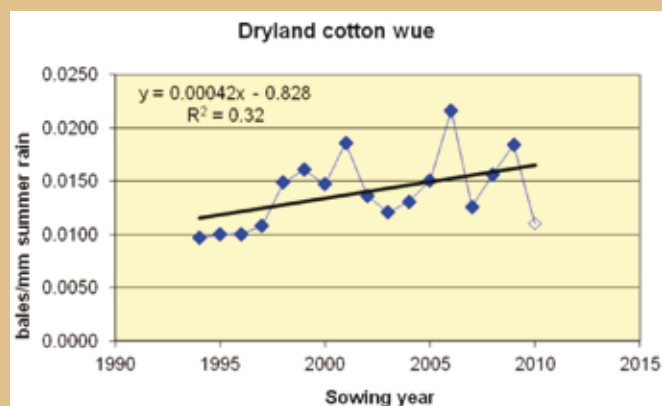
We have assembled Australian Government Bureau of Meteorology summer rainfall figures from many sites in all dryland production regions and compared that with dryland yield from each region as published each year by the *Australian Cottongrower Cotton Yearbook*. The sites used were Emerald, Biloela, Dalby, Pittsworth, Oakey, Cecil Plains, Chinchilla, Condamine, Warra, Goondiwindi, Boggabilla, Tulloona, Moree, Croppa Creek, Gurley, Garah, Gunnedah, Breeza, Mullaley, Boggabri, Narrabri, Bellata and Wee Waa. The data used for each region was the total rain in December, January and February for all the sites.

We calculated rainfall use efficiency of every season averaged across all regions by simply dividing yield by summer rainfall (Figure 1) and depicts the improvement in rainfall use efficiency. If that slope of improvement (0.00042 bales per mm per year) is multiplied by the average summer rainfall over this period (242 mm), the average yearly increase in yield of dryland cotton over this period with constant rainfall would be 0.10 bales per hectare per year, the same as the long-term irrigated industry rate. In other words, dryland cotton through this period was improving at the same rate as the rest of the irrigated cotton industry.

The scatter with this data would reflect the effectiveness of rainfall. Small daily rainfall would not be effective on many occasions, particularly if the crop was relying on deeper roots at that time. Large rainfall amounts will usually run-off, so much of the rain is lost or poorly distributed on a field.

A comparison of 2009–10 with 2010–11 illustrates the importance of rainfall distribution during the season for dryland crops. Although 2009–10 had half the summer rain (145mm) than 2010–11 (327mm), yields were higher in 2009–10 (4.3 bales per hectare versus 2.7 bales per hectare). This was no doubt due to the distribution and effectiveness of rainfall: 2010–11 had about 200mm in December overall (336 mm on the Downs)

FIGURE 1: Rainfall use efficiency over time calculated as bales per mm of summer rain. Each point represents the average rainfall use efficiency for all the regions mentioned earlier.



the majority of which would have run off. Many crops were also damaged by flood. It is clear the 2010–11 data is an outlier.

For dryland systems, fallow, wide row configuration, stubble retention and minimum tillage have been widely adopted and there has been specific breeding for stress tolerance, yield and quality.

There have been many changes in dryland cotton production systems and economics that would affect yield and water use efficiency through time. There has been movement of dryland cotton further west to drier regions; much of this cotton and even other common dryland cotton regions have been on wider row systems (double skip and super single row configurations have lower yield potential, albeit more reliable, especially for fibre quality); and pricing of transgenic traits with end point royalty and later plough in dates has encouraged sowings in drier regions, which may have marginal yield in dry seasons.

Our analysis with irrigated cotton has shown that at least 50 per cent of the industry's yield progress has been due to better varieties; the other up to 50 per cent is due to better crop management. In fact there is a clear variety and management interaction in that modern varieties respond much more to modern management than old varieties do. It is likely that a similar relative contribution has occurred in dryland systems.

We confirm our previous conclusion that yield of dryland cotton through the 1995–2011 period was related to effective rainfall. The data shows increasing water use efficiency through time and if there had been average rainfall in the period 1995–2011, dryland cotton would have had similar yield increases to that obtained under irrigation.

Funding: CSIRO cotton breeding is funded by the Cotton Breeding Australia Joint Venture between CSIRO and Cotton Seed Distributors; prior to 2006 breeding was supported by CRDC.

Matching irrigation to plant requirements in a variable climate

■ Rose Brodrick, CSIRO Plant Industry

IN BRIEF...

- Irrigation scheduling can be improved by taking into account the current crop stress and soil moisture, and how the weather forecast (evapotranspiration) affects crop stress. This is called a 'dynamic deficit' approach.
- Large scale field experiments compared the 'dynamic deficit' approach with a more traditional approach to irrigation scheduling and found no significant differences in yield, water use or efficiency.
- When evapotranspiration is low, irrigations can be delayed which can extend the opportunity to capture rainfall and hence save on irrigation water.
- For the effective timing of irrigations based on a 'dynamic deficit' approach, it is important to combine a measure of plant stress with soil moisture and weather forecasts.
- Practical measurements of plant stress using canopy temperatures could be used to establish the value/risk of bringing forward and delaying irrigation.

To improve water use and efficiency a flexible or 'dynamic' soil deficit may need to be employed in irrigation scheduling.

Current irrigation strategies rely strongly on information from soil moisture probes or on schedules based on what has worked in the past for a particular field. An opportunity exists to improve irrigation efficiency by taking into account the current crop stress, the current soil moisture, and how the weather forecast affects crop stress. Our research showed that changes in evapotranspiration (ET_o) affected the level of plant

stress regardless of soil moisture, highlighting the need for irrigation scheduling to reflect both factors (a "dynamic deficit" approach). The outcomes of field experiments that applied this approach supported our idea of refining irrigation scheduling to help reduce the effects of plant stress during periods of high evapotranspiration and to irrigate less during periods of low evapotranspiration. Periods of low evapotranspiration are often associated with a depression or low pressure weather front which may bring an opportunity to capture rainfall.

Climatic factors such as relative humidity and temperature can influence the demand for moisture by the crop to enable effective cooling (evaporative demand). Different levels of demand can change the water potential of the plant at the same level of soil moisture deficit. In fact, under high evaporative demand the cotton plant can experience short periods of moisture stress even when the water in the soil is close to field capacity (maximum level), because it is unable to match the rate of transpiration required to maintain effective cooling. This may create problems when pre-determined deficits are used for irrigation scheduling as they may not reliably match the plant's water requirements. Conceivably under high levels of soil moisture with high evaporative demand, plants could still experience stress which will impact on growth and ultimately yield. Hence, to maximise yield and irrigation water use efficiency, the 'deficit' for irrigation may need to be dynamic and vary with climatic conditions and soil moisture content.

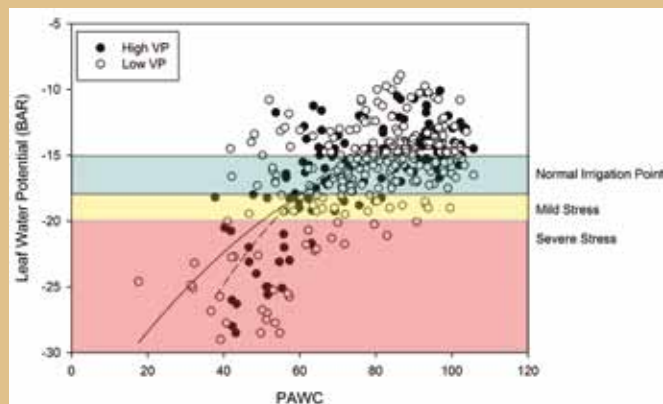
Our analysis of a large data set of soil water, measurements of plant stress (using leaf water potential (LWP) as a measure) and climate experienced by the crop confirmed that evapotranspiration can alter the plant stress response at the same soil moisture content.

This analysis found that generally, when crops experienced high evapotranspiration (greater than seven mm/day) during flowering they were more stressed compared to when they experienced lower evapotranspiration (less than seven mm/day) during flowering (Figure 1). The results also showed that only when soil moisture levels were near to field capacity there was little affect of evapotranspiration.

Validating 'dynamic deficit' approach

Two large scale field experiments were completed to determine whether applying this knowledge could enable irrigation timings to be more 'dynamic' based on soil water measurements and using weather forecasts of either future short term periods of high or low periods of evapotranspiration. Irrigation treatments were designed to evaluate irrigating earlier in response to high evapotranspiration, delaying irrigation timing in response to low evapotranspiration and no response to forecast for the whole season. To determine the implications of using a dynamic deficits approach, detailed measurements were taken in all three experiments including crop growth, soil moisture, plant stress and yield.

FIGURE 1: The effect of evapotranspiration (ET_o) on the relationship between plant stress (leaf water potential) and fraction of transpirable soil water. LWP less than -20 indicates the plant is suffering stress. Data is grouped into high ET_o (ET_o>7mm/day; solid circles and solid line) and normal ET_o (ET_o<7 mm/day; open circles and dashed line).



2009–10 dynamic deficit experiment

The dynamic deficit experiment in 2010–11 in Narrabri had a total of four irrigation treatments applied during the course of the season. Treatment 1 – was the control treatment, with irrigations scheduled at the normal 65–75 mm deficit for that soil type. Treatment 2 – was irrigated earlier than the control at a smaller deficit in response to forecasted high evapotranspiration. Treatment 3 – was irrigated later than the control at a larger deficit in response to forecasted low evapotranspiration conditions. Treatment 4 – was dynamic, with irrigations scheduled either earlier or later in response to forecasted high or low evapotranspiration – in this experiment this treatment was irrigated with later than the control on two occasions. Dynamic irrigation timing was only implemented between flowering and cut-out as previous research had already determined that this is the most critical period for precise irrigation timing. The 2009–10 season was characterised by long periods of low evaporative demand, so the season provided excellent opportunity to evaluate the impact of delayed irrigation using a low evapotranspiration forecast.

There were no significant differences found in yield, water use or efficiency (see Table 1). While irrigations were delayed this did not equate to improvements in yield, total water use or water use efficiency (kg/ha/mm). Irrigations were delayed up to deficits of 103 mm during late flowering compared to 75 mm, with no impact on yield.

2010–11 dynamic deficit experiment

The dynamic deficit experiment in 2010–11 in Narrabri had a total of three irrigation treatments applied during the course of the season. Treatments 1 to 3 were the same as in the 2009–10 experiment. As there were fewer irrigations between flowering and cutout in 2010–11 the ‘dynamic’ treatment had one delayed irrigation which was the same as treatment 3.

The season provided different conditions to the previous experiment, in that irrigations did not start until January due to above average rainfall; but the remainder of the season had very little rainfall with some distinct periods of very high and low evaporative demand. In treatment 2, an irrigation was applied at a smaller deficit (40 mm) compared with the control in response to a high evapotranspiration forecast. In the second treatment in response to forecasted low evapotranspiration, irrigation was delayed four days to a planned deficit of 90 mm, and in that period there was 33 mm of rain which further delayed



Soil moisture probes monitoring different irrigation treatments.

the irrigation another four days. This resulted in this treatment receiving one less irrigation over the season translating into irrigation water savings of approximately 0.8 megalitres per hectare compared to the control (Table 1).

Once again there were no significant differences found in yield or total water use efficiency (Table 1). The plant based measurements showed that the control treatments were more stressed compared with the earlier irrigation treatment but still remained under a LWP of –20 bar in the control. Importantly, the plant stress measurements in the delayed irrigation treatment showed that despite the delay of four days, the crop was still not showing stress (LWP of –16 bar compared with –15 bar in the control).

Neither irrigating earlier or later resulted in any yield penalty in either year. Irrigating early to maintain higher soil moisture content during periods of high evapotranspiration did result in lower leaf water potential and hence less stress, but this did not translate into differences in crop yield. The control irrigation (normal deficit) in these experiments generally maintained the crop below a stress threshold (LWP < –20 bar). We are currently investigating in more detail when the crop was stressed and for how long in these treatments to ascertain why the earlier treatments had little effect.

Results from these experiments show that when

TABLE 1: Lint yield and estimated water use for 2009–10 and 2010–11 dynamic deficit experiments.

Treatments	Average Lint Yield (bales/ha)	Irrigation Water Applied (ML)	Effective Rainfall (ML)	Total Water (mm)	Bales/ML total water	Bales/ML applied
2009–10						
1 Control	13.0	3.26	3.19	680.8	1.9	4.0
2 Smaller Deficit (High ETo)	14.2	3.24	3.20	678.2	2.1	4.4
3 Larger Deficit (Low ETo)	13.7	3.28	3.20	679.2	2.0	4.2
4 Dynamic	14.5	3.66	3.20	725.8	2.0	4.0
L.S.D	2.5	*0.30	0.09	41.4	0.4	0.9
2010–11						
1 Control	12.7	3.92	2.84	735.9	1.73	3.3
2 Smaller Deficit (High ETo)	12.1	3.65	2.88	731.2	1.65	3.3
3 Larger Deficit (Low ETo)	11.5	3.11	2.90	682.1	1.68	3.7
L.S.D	1.8	**0.34	0.06	*43.15	0.2	**0.2

Significant differences indicated by * 95% significance level; ** 99% significance level.



Yield on different irrigation treatments was monitored.

evapotranspiration is low irrigations can be delayed which consequently extends the opportunity to capture rainfall. This could potentially save water and allows for more flexibility in cotton systems that require a large number of fields to be irrigated at in the same time. In both years there was no effect on yield or water use efficiency. In 2009–10 there was no difference despite considerable delays (up to six days) in one irrigation, and in 2010–11 the forecasted low evapotranspiration period also allowed an opportunity to capture a rainfall event resulting in water savings of 0.8 megalitres over the season in one treatment. Delaying irrigations during flowering without taking into account evapotranspiration can have significant impacts on yield with other studies reporting a yield loss of 2.7 per cent (for Bt cotton) for every day that an irrigation was delayed.

The results show that even when there are instances of high evapotranspiration, crops are not as stressed as they should be, based on our current understanding. This indicates the need for a measure of plant stress combined with soil water measurement and weather forecasts to assist with the dynamic deficit irrigation approach.

Practical measurements of plant stress using canopy temperatures could be used to establish the value/risk of bringing forward and delaying irrigation. Other opportunities involve

determining a plant stress prediction model incorporating current and future soil moisture with short term evapotranspiration forecast as well as crop stage. Considering we presently use an average response of soil water, plant stress and evapotranspiration, this model would refine and improve the dynamic deficit approach.

Further reading: www.cottoncrc.org.au

Funding: Cotton Catchment Communities CRC and the Cotton Research and Development Corporation (CRDC) ▲

Identifying cotton's heat tolerance

■ Nicola Cottee, CSIRO Plant Industry

IN BRIEF...

- Heat tolerance plays an important role in the response of cotton to water stress.
- Improving heat tolerance of cotton may improve yield in hot or water limited conditions.
- Biochemical assays were used to detect differences in heat tolerance between cotton cultivars.
- These assays are currently being applied to screen a range of varieties and breeding lines for heat tolerance.
- This approach in detecting heat tolerance can be readily applied to cold or drought tolerance screening programs for cotton.

THE identification of heat tolerance in cotton may play an important role in improving the performance of cotton crops during heat waves or drought. Very high temperatures (greater than 35°C), particularly during flowering can reduce photosynthesis, cause fruit to shed and reduce yield. Heat stress is exacerbated when soil moisture is also limiting, as plants require additional water to transpire excess heat out of the leaves when air temperatures are high.

Screening for tolerance

To develop new methodologies to estimate heat stress in cotton, a collaborative project involving researchers at CSIRO Plant Industry in Narrabri and Canberra, The University of Sydney and Texas A&M University (USA) was established. Methodologies from this project will be further developed to screen Australian cotton cultivars for heat tolerance.

Previously established biochemical assays were used as screens to detect heat tolerance in controlled laboratory experiments. These work by measuring the stability of cell membranes and respiratory enzymes following a heat treatment.

Using these assays, cultivar Sicot 53 was better able to maintain cell membrane structural stability and enzyme viability than cultivar Sicala 45 when exposed to moderate heat stress in a water bath. When exposed to prolonged periods (four days) of high temperature (42°C) in a growth cabinet, these differences were coupled with decreases in the rate (measured using an infra-red gas analyser) and efficiency (measured using chlorophyll fluorescence) of photosynthesis. This indicated a higher relative heat tolerance of cultivar Sicot 53 than Sicala 45. Further analyses under high temperatures indicated that the expression of a number of genes associated with drought stress were stimulated, thus highlighting the close interaction between heat and drought stress.

To test these assays in the field, an experiment was conducted over three seasons in Narrabri and Texas (USA). This experiment used tents which increased maximum air temperatures by six to 20°C. These tents were put over the crop at various times throughout the season to create heat stress. Using the assays, Sicot 53 showed a lower level of cell membrane structural damage and deactivation of respiratory enzymes indicating a higher relative heat tolerance than Sicala 45 under hot field

conditions. Furthermore, Sicot 53 was found to be higher yielding than Sicala 45, had a higher rate and efficiency of photosynthesis. This indicates that under high temperatures in the field, Sicot 53 has higher heat tolerance and a greater capacity to maintain yield.

Future of the research

Results of this research indicate that biochemical assays were rapid, repeatable and are an effective way to identify heat tolerant cultivars. All measurements tested as part of this research are being used to screen a diverse range of cotton cultivars, including advanced breeding lines for heat tolerance. The results of this combined research effort will enable effective identification of heat tolerant and agronomically superior cotton lines for breeding programs. Cultivars produced will be most relevant for the warmer cotton growing regions of NSW and Queensland, particularly under water limited production systems. Furthermore, modification of these assays and measurements for heat tolerance determination will enable the development of a protocol for identification of cold or drought tolerance in cotton, thus improving yield in any production system.

Funding: Cotton Catchment Communities CRC and Cotton Research and Development Corporation (CRDC).



PhD student Nicola Cottee measuring crop photosynthesis efficiency.

Irrigation scheduling using canopy temperatures

■ Warren Conaty, CSIRO Plant Industry

RESearch conducted at the Australian Cotton Research Institute has paved the way for the use of canopy temperatures to schedule the irrigation of cotton.

Irrigation scheduling for efficient water use is central to the sustainability of irrigated cropping in Australia. Irrigators aim to optimise crop water use through timely irrigation scheduling and the efficient utilisation of in-crop rainfall.

Even though the aim of irrigation scheduling is to maximise crop productivity, the plant itself is often ignored in favour of measurement of soil and atmospheric conditions. Canopy temperature is a plant based measurement that represents the combined influence of the soil and atmospheric conditions contributing to water stress, therefore using canopy temperatures to schedule irrigations should be advantageous.

Water stressed plants have higher canopy temperatures compared to well watered plants. This is a consequence of the loss of transpirational cooling due to stomatal closure in the leaf in an effort to conserve water.

Use in scheduling tested

Irrigation experiments at Narrabri tested the use of canopy temperatures for irrigation scheduling. Surface drip irrigation experiments were conducted in the 2007–08 and 2008–09 seasons, where irrigation treatments were based on daily crop evapotranspiration (ET) rates. A furrow-irrigated experiment was also conducted in the 2008–09 season, where irrigation treatments were based on plant available soil water deficits (mm) calculated from neutron probe data.

Both experiments used the commercial cotton cultivar Sicot 70BRF. The objectives of this research were to: confirm the optimum temperature (T_{opt}) of a current commercial Australian cotton cultivar; determine if canopy temperature can define plant water stress by comparison with soil and atmospheric conditions and determine the potential of the thermal optimum approach to scheduling irrigation in Australian cotton systems.

To determine when water and temperature stress occurs, the optimum plant temperature of a cotton crop was determined. Using chlorophyll fluorescence recovery rates and analysis of plant physiological function under field conditions, the optimum plant temperature of an Australian cultivar was identified to be 28°C. From the irrigation experiments, treatments generated differences in lint yield, plant growth and canopy temperature. Canopy



Researcher Warren Conaty, ACRI, Narrabri.

temperatures were correlated with crop lint yield and the volume of water applied to the crop.

Maintain canopy temperatures close to optimum

Reductions in lint yield occurred when average day-time canopy temperatures exceeded 28°C in surface drip irrigated experiments and 29°C under furrow irrigated conditions. This highlights the benefits of maintaining cotton canopy temperatures close to 28°C, and supports the potential of using canopy temperature to schedule irrigations in Australian cotton systems.

Even though the optimum plant temperature was 28°C, the canopy in a well-watered crop can still exceed 28°C. This gives rise to the stress time (ST) concept, where ST represents the average daily period of time that a well-watered crop's temperature exceeds 28°C. This concept was tested and adapted to Australian field-based drip and furrow irrigation systems.

Maximum lint yields and crop WUE in drip-irrigated cotton occurred at 4.5 hours ST. Therefore, drip irrigated crops would require irrigation on a given day when canopy temperatures exceed 28°C for 4.5 hours.

Due to differences in the nature of drip and furrow irrigation, this threshold for drip irrigation was not suitable for use in furrow irrigation systems. A new approach for furrow irrigation using a cumulative ST was developed, where one ST hour represents 0.6 mm plant available soil water depletion. This can be used to estimate the desired soil water deficit and schedule irrigations based on cumulative ST. These modified stress time thresholds provided the information required for determining water stress for irrigation scheduling.

Funding: Cotton Catchment Communities CRC and CRC for Irrigation Futures and supported by CSIRO, Sydney of University and The US Department Agriculture Research Service.



Thermal infrared sensors measuring crop canopy temperature

Irrigation requirements of Bollgard II

■ Stephen Yeates, Dirk Richards, Jenny Roberts, CSIRO Plant Industry, Marcelo Paytas INTA Argentina & The University of Queensland (UQ), Shu Fukai UQ, Janelle Montgomery, NSW DPI and Andrew Parkes

IN BRIEF...

- The effect of the increased pest protection of Bt cotton (Bollgard II) on plant growth and response to water compared to non-Bt varieties was measured.
- When pest damage to the non-Bt variety was moderate to high the Bollgard II variety matured earlier and seasonal water use was nine per cent less.
- Where pest damage was low, differences in water use efficiency (WUE) were minimal.
- WUE of Bollgard II could be further improved by changing irrigation scheduling to account for a higher, earlier boll load.

WHEN exposed to similar pest numbers, the number of fruit retained is far higher for Bollgard II than for non-Bt varieties. This is a result of increased pest protection of Bollgard II. Our research conducted between 2005 and 2009 aimed to measure whether such high levels of fruit retention and the early development of this fruit would change water requirement and the scheduling of irrigation for Bollgard II.

Differences in water requirement, yield and WUE between non-Bt and Bollgard II cotton (Table 1) were due to changes in fruit retention and terminal damage to the main stem (tipping). Where insect damage to both varieties was low, varietal differences in water use efficiency were minimal, or favoured the non-Bt variety where terminal damage occurred.

When damage was more severe the effect of this damage was to delay time to maturity and increase leaf area of the non-Bt variety, which, in turn, increased crop water use and occasionally reduced yield.

Table 2 shows measured differences in water requirement where insect damage to the non-Bt variety was medium to high (typical for Australian cotton systems) and sufficient to delay maturity with minimal impact on yield. An additional irrigation was required on the non-Bt variety in 2004–05.

Sensitivity to moisture stress

Bollgard II cotton was more sensitive to stress than non-Bt cotton at cut-out. The lint yield reduction at cut-out equates to a loss of 2.7 per cent per day of stress compared to 1.2 per cent



Stephen Yeates discusses the irrigation requirements of Bollgard II with St George grower Glenn Rogan.

per day for the non-Bt variety. The greater sensitivity of Bollgard II to stress late in flowering was due higher fruit retention early in flowering creating to a much higher boll demand for assimilate at the time of stress in the Bollgard II variety. The non-Bt variety could compensate because it had a greater proportion of smaller bolls that were filled after the water stress was removed.

This was an important finding at a time when growers were still adapting irrigation strategies for high retention Bollgard II varieties and when drought necessitated stretching of irrigation intervals to save water. Hence the message “don’t stress Bollgard II varieties during flowering or grow non-Bt varieties instead”, was widely extended to industry.

The response of Bollgard II to changed irrigation scheduling

We found further increases in yield and WUE by changing the irrigation scheduling for Bollgard II. Figure 1 shows that significant increases in yield and WUE were measured where

TABLE 1: Impact of changes in plant growth due to the greater protection from *Helicoverpa* spp. of Bollgard II on water use, yield and WUE compared with non-Bt cotton. Where +, – and = the Bollgard II was higher, lower or equal to the non-Bt variety respectively.

Insect damage to non-Bt cotton	Effect of damage on plant morphology	Performance of Bollgard II compared with non-Bt		
		Water use	Yield	WUE
Pre squaring tip damage	High early tipping + High fruit retention	=	–	–
Pre squaring tip damage and early square removal	High early tipping % + lower early retention	–	=	+
Tip damage and fruit removal up to late flowering	High late tipping % + low fruit retention at cut-out.	–	+	+
Minimal due to low pest pressure.	Similar morphology to BollgardII.	=	=	=



Bollgard II requires an earlier first irrigation to produce a larger plant at flowering.

Bollgard II was irrigated more frequently during flowering with smaller water volumes than previously established for non-Bt cotton (80 mm deficit). These increases were greatest in hot and drier seasons. In 2006–07 this equated to 17 per cent yield and eight per cent WUE gains over the 80 mm deficit. Greater availability of soil water permitted vegetative growth to continue while the plant met the demand of a large number of early bolls.

Consequently more frequently irrigated plants produced more yield on later flowering nodes. In contrast a crop with a lower number of early bolls would produce excessive vegetative growth when irrigated at smaller deficits. But in the milder wetter 2007–08 season there was less difference between irrigating at larger and smaller deficits, suggesting that deficits could be varied depending on the season.

Bollgard II also required an earlier first irrigation to produce a larger plant at flowering to support the high number of fruit retained. Yield was increased by six to 35 per cent through irrigating earlier.

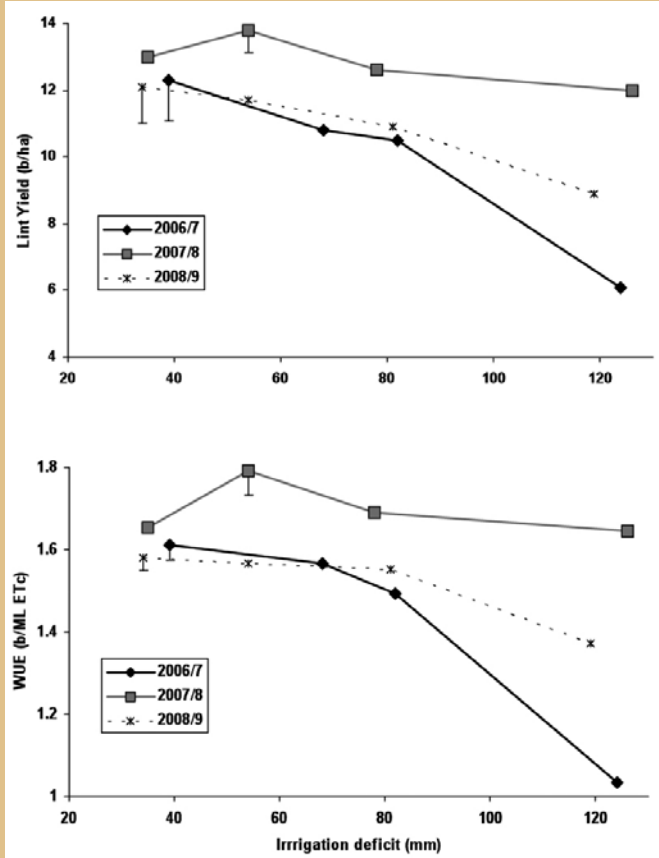
This research has shown that the improved pest protection of Bollgard II results in high fruit retention during early flowering which consequently changes its water requirement under typical pest numbers. Furthermore Bollgard II required different irrigation scheduling to maximise yield and WUE.

Further reading:
Project Final Report available at www.cottoncrc.org.au

Funding: Cotton Catchment Communities CRC and Cotton Research and Development Corporation (CRDC)

TABLE 2: Measured total irrigation water applied (ML/ha) where insect damage to non-Bt was typical for Australian cotton systems.		
Season	Bollgard II	Non-Bt
2004/2005	6.9	7.8
2005/2006	5.7	6.1
2006/2007	6.3	6.5
Average	6.3	6.8

FIGURE 1: The lint yield and WUE (bales/mm Etc) response of high fruit retention Bollgard II cotton to irrigation deficit. Bars are Lsd0.05. Where the 2006–07 season was hotter and drier, the 2007–08 season had mild temperatures and above average rainfall and in 2008–09 evaporative demand was high during flowering.



Knowledge management for irrigated cotton and grains

■ Peter Smith Irrigation Officer NSW DPI

IN BRIEF...

- Our project developed and tested a knowledge system model to improve the effectiveness of the transfer of irrigation information to cotton and grains growers.
- A major output of our project was a very well received 'Irrigation Workshop Series'.
- Through this project irrigators and consultants were informed and skilled in a range of irrigation practices.

THE project 'Knowledge Management in Irrigated Cotton and Grains' was developed with the hope of improving the management of irrigation knowledge and impacting on the rate of adoption of better irrigation practices.

The project was undertaken in two stages in 2004 and 2008:

- **Stage 1:** The objective of the first stage was to identify the major components of irrigation information and knowledge transfer that existed in the cotton and northern grains industries. This stage identified that growers prefer personal one-on-one contact for information about water management; consultants are a major source of information to growers; growers and consultants learn from each other; and information is best delivered in short, concise, practical and timely formats.
- **Stage 2:** The objective of the second stage was to develop and implement an improved knowledge system. This stage identified several effective strategies as well as a number of barriers. A key strategy was the implementation of a series of training workshops.

Past studies relating to effective information transfer have concluded that using a number of methods or models of extension is much more effective than concentrating on only one or two methods. It was identified that out of the five recognised models of extension, irrigation extension has focused mainly on the 'Technology Development' and the 'Information Access' extension models. This project achieved an improvement in the balance of the use of all five extension models.

A major output of the project was the Cotton & Grains Irrigation Training Series which was seven short, single-topic, stand-alone but integrated workshops. These workshops were designed to integrate several of the extension models. The delivery of this training that took place during the project was well received, validating the new approach.

In addition, we developed a support program to assist consultants deliver irrigation services. This was a key goal of the project and it increased the use of the 'Consultant/Mentor' extension model. This program had varied success across the different growing regions. Unfortunately our program did not continue past the one season as the impact of prolonged drought drastically reduced the demand for consultants' services.

Our project also instigated the development of an on-line database for keeping records of training including who



Irrigation workshops on the farm were well received.

participated in which workshops and the progress they made. This database allows trainers located anywhere to enter details of participants, their attendance at specific workshops and to upload activity sheets from the workshops.

The project also developed an extensive range of extension material including case studies, media articles, a website – www.cottonandgrains.irrigationfutures.org.au and an update of WATERpak to include a new section on irrigated grain crops.

The major recommendation that came from our project was that the successful and flexible workshop training model has potential to be extended to other industries and regions.

Further reading:

www.cottoncrc.org.au

www.cottonandgrains.irrigationfutures.org.au

<http://npsi.gov.au/files/products/national-program-sustainable-irrigation/pr040957/pr040957.pdf>

Funding: Cotton Catchment Communities CRC, NPSI and CRDC. ▲

Increasing the resilience of Eastern Australian irrigated farms

■ Daniel Rodriguez Queensland Alliance for Agriculture and Food Innovation (QAAFI), The University of Queensland, Don Gaydon CSIRO, Brendan Power and Peter deVoil, QLD Department of Agriculture Fisheries and Forestry

IN BRIEF...

- All case study farms could identify and quantify strategies that would allow them to improve returns without increasing risk.
- Maximising long-term average farm returns requires irrigation and management strategies which vary on a season-by-season basis based on allocations.
- Gave farmers' knowledge of implications of alternative decisions in the use of their assets, to feel more confident with their decision or give them new ideas to explore and practice on-farm.
- For farmers on river entitlements, the value of the Australian Government Bureau of Meteorology seasonal stream flow forecasts was a positive surprise.

AUSTRALIAN irrigators are under increasing pressure to maintain the viability of their farm businesses in the face of reduced surface and ground-water allocations. The key challenge is then how to identify practical and actionable strategies that increase returns per megalitre of water available at the whole farm level while at the same time reducing or minimising risks.

Farming systems researchers from QAAFI, CSIRO and Agri-Sciences Qld explored farmers' opportunities to develop more profitable and less risky irrigated cotton/grains and rice/grains businesses.

Initially we engaged farmers to help identify and understand

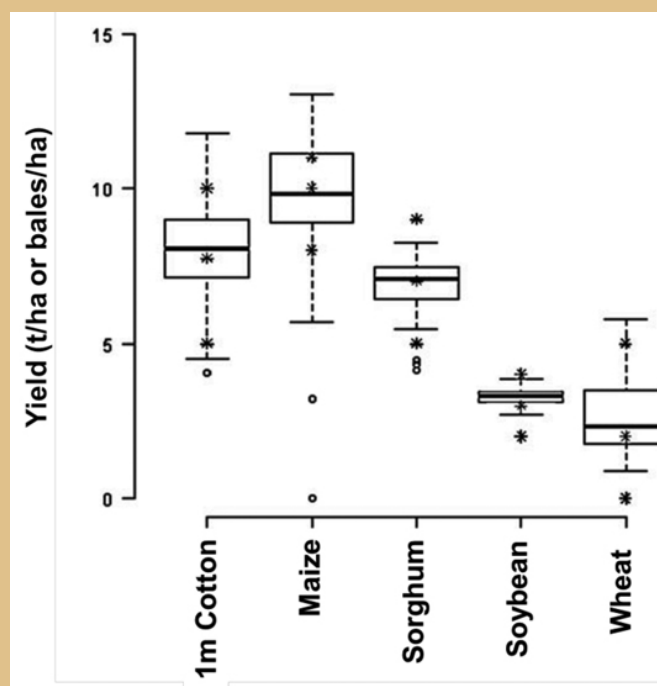
their issues, constraints, and opportunities for improvement. This involved rice-grain growers from the Riverina in Victoria and NSW and grain/cotton growers from Northern NSW, southern and Central Queensland

In collaboration with these farmers we developed whole farm modelling tools capable of realistically representing farm assets, management strategies and practices. To achieve this we needed to describe and understand our farmers' businesses, so we discussed 'what do they do on their farms?', 'how they do it?', and 'why they do it?'

After a number of interviews and discussions where modelling results were presented, our farmers were confident the model was able to represent their farm business (Figure 1) and that it was a good tool to explore a range of 'what if?' questions in terms of their practices, tactics and strategies.

We used the new model to research the farmers' questions

FIGURE 1: Validating the models with farmers – Comparison of farmer yield expectations with APSFarm yield predictions. The asterisks show expected yields from one farmer according to their experience, their minimum, most likely and maximum yields. In general the farmer's most likely yield coincided with the most likely yield simulated by the model. This gave this farmer confidence that the model could be used to further explore his farming system.



Daniel Rodriguez demonstrating the Irrigation Optimiser (<http://www.apsim.info/irrigationoptimiser/>) at Auscott in Moree, NSW.

and ideas on how to improve the profitability of their farm business, or how to achieve particular objectives of their interest, for example, use less water, improve soil health, etc.

The computer-generated information was then used in discussions with farmers, where the results were contrasted

with farmers' expectations. The aim of the exercise was to help farmers' gain new 'experiential' knowledge of the implications of alternative decisions in the use of their assets, so they would feel more confident with their decision or gave them new ideas to explore and practice in their farms.

We found that with our grain-cotton farmers from the Darling Downs that by changing the allocation of irrigation water and land area between different crops farm profits and risks could be increased by up to 10 per cent without increasing economic risks (Figure 2).

Simulating farms and farmers

Using the APSFarm simulation model we calculated the impact of varying the allocation of irrigation water across alternative crops and then used this in discussions with farmers. Figure 2 shows the relationship between the simulated average whole farm gross margin (per year) and a measure of its variability (standard deviation) for an irrigated farm from Dalby, QLD. The red dot represents the present performance of the farm, which is achieved by reserving the following amounts of water at sowing: four megalitres per hectare for cotton and maize crops, three megalitres per hectare for soybean, and none for wheat and sorghum.

The black dots represent the outcome of alternative allocations of water to those crops. When this graph was shown to our farmers they immediately identified that the present management of the farm could be improved in a number of ways. The farmer could increase profits at the expense of higher risks, or reducing risks while keeping the same level of profits (shown by the two red circles, respectively). Though more interesting to our farmer was the idea that by slightly changing the allocation he could on average make another \$30,000 per year without increasing his risk (green circle). In general terms this change would involve slightly reducing the allocation to cotton while increasing the allocation to soybean and wheat crops.

FIGURE 2: The relationship between simulated average whole farm gross margin (per year) and a measure of its variability (standard deviation) for an irrigated farm at Dalby.

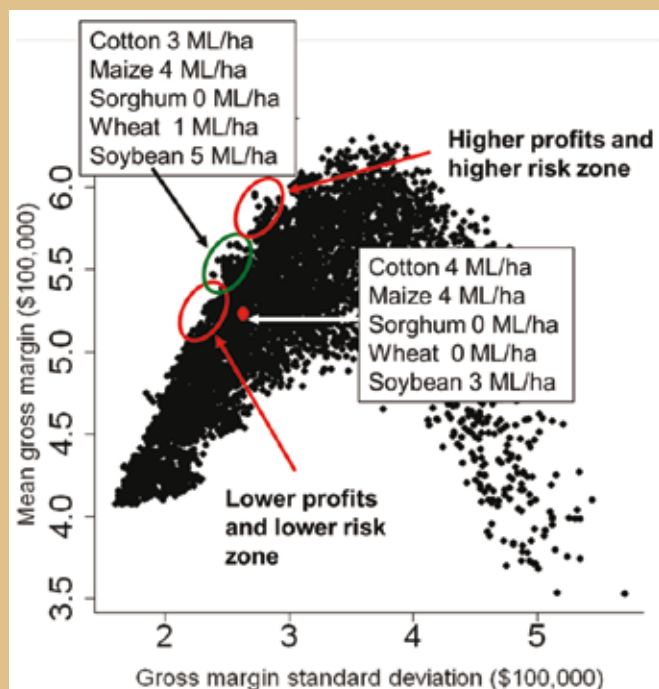
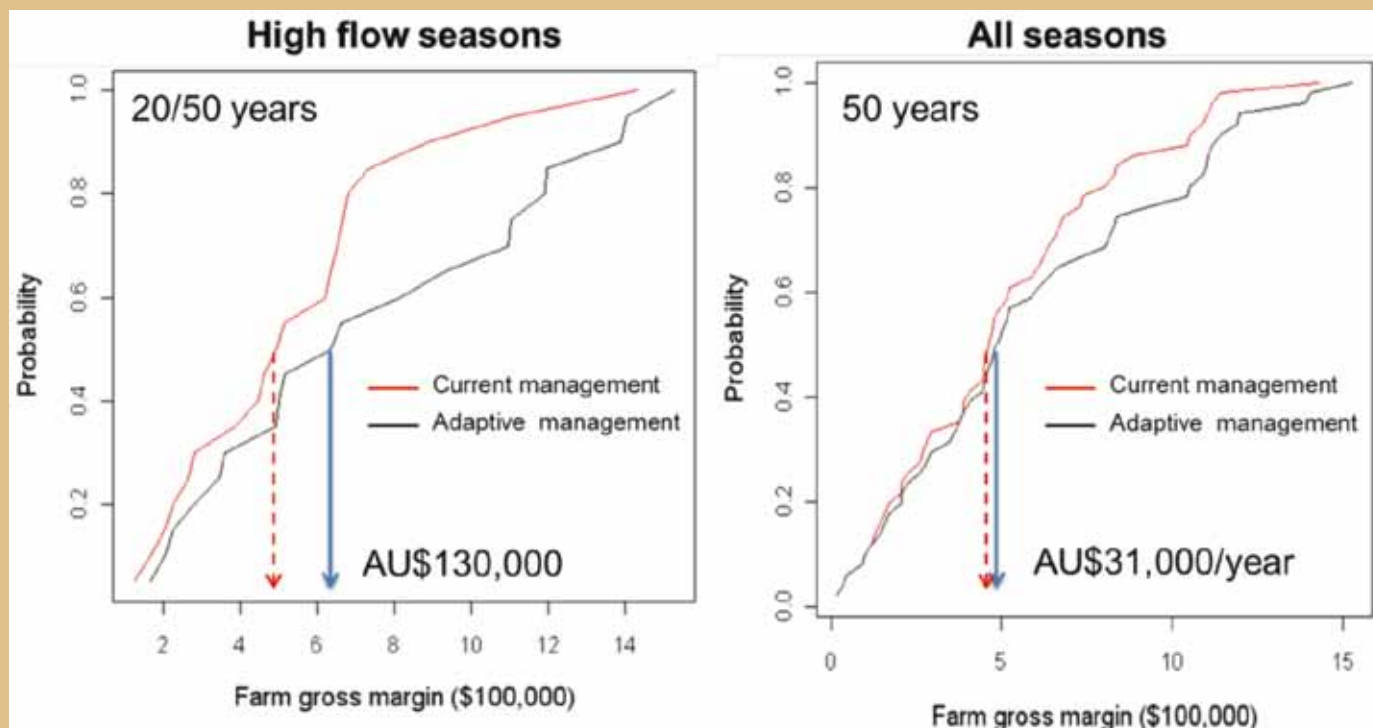


FIGURE 3: Comparison of current management and an adaptive management for those seasons when a NINO3 based prediction of either high or low flow was available.





Peter deVoil and extension officer Susan Maas from DEEDI Queensland inspecting a cotton crop at Tandawanna, Emerald.

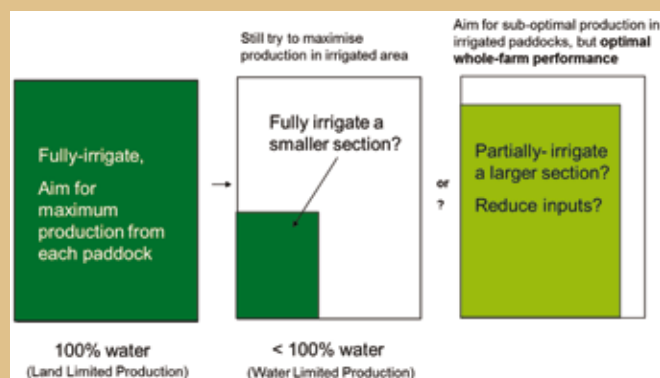


Don Gaydon from CSIRO inspected an irrigated maize crop in the Riverina with Gavin Katternach.

Clearly variability in water allocations and commodity prices will affect the results in Figure 2. The farmers were interested to know if additional information from a seasonal or river flow forecast could help them make better informed decisions. In the case study farm in Dalby the area planted to cotton each year depends on the amount of stored water available for irrigation at the time of sowing. We used an NINO3 index (<http://amath.colorado.edu/courses/2460/2004Spr/Lab1/nino3.html>) that has a reasonable ability to predict the relative size of summer Condamine River flows. The NINO3 predictions of river flows was used to set up an adaptive management strategy that adjusts the amounts of stored water required at sowing for each hectare of cotton being considered for planting. When a higher river flow than normal was expected, less stored water at sowing per hectare of cotton was required due to the increased probability of additional river flows and in-crop rainfall. This allows for a greater area of cotton to be sown.

We found that the predictive capacity of NINO3 was particular high for the prediction of high flow seasons, justifying its use as a predictor of stream flow. In those years when the forecast is available and incorporated into farmer's sowing rules, we estimated that farmer's returns could increase by up to \$130,000 (Figure 3).

FIGURE 4: Planting management strategies by Riverina irrigator in response to reduced water availability.



Making water allocation rules based on a river flow forecasting system

Figure 3 shows the differences between current farmer's management (red line), and an adaptive management (black line) for those seasons when a NINO3 based prediction of either high or low flow was available,

For the case of Riverina rice and grain growers spreading the available water and supplementary irrigating winter cereals in years of low allocations can increase farm profits. Some of the water-spreading strategies offered up to 90 per cent improvement in farm returns over traditional practices, but up to 30 per cent worse performance in years of high irrigation levels.

Making water last

Figure 4 shows a schematic representation of a Riverina farmer's options in seasons of lower than 100 per cent water availability. As indicated by our participating farmers

We also found that maximising long-term average farm returns requires irrigation and management strategies which vary on a season-by-season basis based on allocations. Delaying permanent water irrigation in rice provided an eight to 17 per cent increase in water productivity resulting in either a similar percentage increase in rice production for the same amount for water, or more available water for other cereal irrigation.

We also developed a framework on which on-farm and off-farm water exploitation options (for example, irrigating and growing crops, compared with sale of allocation or entitlement on the open market) could be compared based on their risk-return characteristics. This framework uses Modern Portfolio Theory.

For all our case study farms we could jointly identify and quantify strategies that would allow them to improve returns without increasing risk. In some cases our results confirmed farmer's intuitive expectations. Farmer's response to this new information varied, though a key learning was a better understanding the trade-offs between potential gains in profits at the cost of taking a little extra risk.

Clearly for farmers on river entitlements, the value of seasonal stream flow forecasts (www.bom.gov.au/water/ssf) was a positive surprise. Though further work would be required to develop the required tools to fully integrate and capture the value of this additional information on the management of irrigated farms across eastern Australia.

Case study farms at www.irrigatedcropping.blogspot.com

Funding: National Program for Sustainable Irrigation (NPSI) and the Grains Research and Development Corporation (GRDC).

Preparing irrigators for the next grain price spike

■ Allan Peake, CSIRO

IN BRIEF...

- Grain price volatility provides opportunities for irrigators to grow irrigated grain crops.
- Irrigated wheat can yield eight to nine tonnes per hectare across the northern region, while irrigated sorghum can yield 10–12 tonnes per hectare, with some variation due to location and season.
- Potential water use of fully irrigated wheat and sorghum is 550–650 mm, not including storage or distribution losses.
- Lodging risk in irrigated wheat can be reduced with improved agronomic management.

THE possibility of more grain price spikes that make irrigated grain production an attractive option (as experienced in 2008) has led to recent strategic research into irrigated grain growing. With many new irrigated wheat growers experiencing major problems with lodging (crops leaning or laying flat on the ground) in 2008, projections for continued high grain price volatility suggest that we need to develop better irrigated wheat growing techniques for the next occasion that irrigated wheat growing is an attractive prospect.

In order to identify opportunities for profitable grain growing, irrigators need to know the likely yields and water use requirement of cereal crops so they can compare the profitability of different crops. In the past four years, growers applying different agronomic management practises have achieved yields of eight tonnes per hectare in commercial wheat paddocks in both Queensland and Northern NSW without lodging, so high-yielding irrigated grain production shouldn't be ruled out by growers who are looking for alternative crop options when the price is right.

The objectives of the GRDC funded 'Achievable Yields' project (2008–2012) were to set benchmarks for yield and water use of irrigated wheat and sorghum, and to make recommendations for irrigated wheat and sorghum production across the northern region. We used APSIM (The Agricultural Production Systems Simulator) to produce the benchmarks after first checking that APSIM worked well in irrigated paddocks.



Lodging begins in a lodging risk assessment trial, Gatton 2011.

What we found was that quick maturing wheat varieties such as Kennedy have a maximum yield of eight to nine tonnes per hectare in the Northern Region, and use around 500–550 mm of water from sowing to harvest at this yield level, although the benchmark figures do vary a little between locations and years.

TABLE 1:

Location	WHEAT		EARLY SOWN SORGHUM			
	Range of maximum yield (t/ha)	Range of maximum evapotranspiration water use (mm)	Range of maximum yield (t/ha)		Range of maximum evapotranspiration water use (mm)	
			Irrigation capped at 3.5 ML/ha	Unlimited irrigation	Irrigation capped at 3.5 ML/ha	Unlimited irrigation
Emerald	6.2–7.8	360–480	7.4–10.1	8.8–11.1	390–520	430–640
Dalby	7.0–9.5	430–550	9.7–11.5	10.3–11.8	490–620	500–650
St George	6.4–8.2	360–480	7.8–10.5	10.1–11.7	440–530	480–660
Goondiwindi	6.8–8.7	410–490	8.7–10.8	10.4–11.8	450–560	520–670
Walgett	6.7–8.3	420–500	6.0–10.3	8.8–11.7	460–570	590–760
Gunnedah	7.6–9.6	440–540	7.6–11.6	10.4–12.2	510–620	550–720



Nick Poole from the Foundation for Arable Research (NZ) inspects a lodged wheat crop at Rolleston, Central Queensland.

Fully irrigated sorghum grown in the Northern Region has a potential yield of 10 to 12 tonnes per hectare and the crop will use from 500 mm up to 750 mm in extreme years at some locations.

But it is important to note that these water-use benchmarks are evapotranspiration water use: ie they do not account for any seepage losses of irrigation water from dams or distribution channels (or losses in runoff from storms), and they do vary with season and location (Table 1).

To achieve these high yields in wheat, growers need to be willing to irrigate the crop heavily later in the season. As seen in the table, high yielding wheat uses a lot of water (particularly once temperatures increase in spring) and should be irrigated frequently during the critical period from flag-leaf emergence to the middle of grain-filling. And don't forget that controlling leaf disease is also vital crop insurance for a leafy, irrigated, high yielding wheat crop.

Of course a major challenge for many irrigators targeting high yielding wheat crops is the high risk of lodging which can substantially reduce yields as seen in 2008. Lodging generally occurs in paddocks with high yield potential, when the top of the plant is so heavy or buffeted by wind, that the plant buckles (stem lodging) or levers the root system partially out of wet soil (root lodging). It's more likely to occur in paddocks that have an extremely thick canopy at the beginning of stem elongation (the end of tillering).

Research from the UK has shown that as these crops grow through stem elongation they tend to develop weaker surface roots and weaker stems, and this has been related specifically to shading within the canopy. Many irrigated growers have seen this in east-west configured beds where the lodging nearly always occurs first on the southern side of the bed, where shading is greater due to the angle of the sun.

So some of the methods we have found that reduce lodging risk relate to 'holding the crop back' early to make sure we don't have such a thick, leafy crop by the end of tillering. In particular this can be achieved through delayed nitrogen application, by applying the bulk of your nitrogen requirement 'in- season' (at the beginning of stem elongation) rather than before sowing.

For growers looking to grow a high yielding wheat crop, testing for soil nitrogen is critical for making better decisions about subsequent nitrogen strategies. For the small investment it involves, this allows growers to know whether you are dealing with a high-nitrogen lodging-susceptible paddock or not.

To minimise lodging risk, growers should also keep the plant population at standard dryland wheat populations (around 100 plants per square metre on the bed area), and use quick maturing, lodging resistant varieties. There are varietal differences in lodging resistance, although testing has only been done on a small scale so far. Plant growth regulators also have an effect on reducing lodging risk. There is no single, silver bullet to stopping lodging – the more control measures you use, the greater lodging risk reduction you will achieve.

Unfortunately, it isn't possible to completely eliminate lodging risk. In the event of a severe storm with heavy rain or hail, even the best managed paddock may still lodge. And while these recommendations provide a brief guide it isn't possible to test all agronomic strategies, on all varieties, for every soil type and location. Growers should always test new agronomy or varieties on a small scale to see how well it works on their own farm.

Funding: Cotton Catchment Communities CRC and Grains Research and Development Corporation.



Australian grains industry benchmarks water use efficiency

■ Janelle Montgomery, NSW DPI



Janelle Montgomery.

IN BRIEF...

- The $GPWU_{farm}$ for irrigated wheat in 2008 was 0.85 tonnes per megalitre.
- It is this figure that can be used to benchmark water use so industry can gauge if it is further improving and determine the rate of improvement over time.

NSW DPI carried out the first industry wide survey to obtain irrigation benchmarks for irrigated wheat. Having seen the value of having standardised irrigation benchmarks like those collected for the Australian cotton industry, the grains industry decided to fund the collection of irrigation benchmarks. This was the first time industry-wide irrigation benchmarks were to be established for irrigated wheat.

In 2009, 24 irrigated wheat farms located between Hillston in southern NSW and Emerald in Central Qld were surveyed by NSW Department of Primary Industries to benchmark their irrigation water use and performance for the 2008 wheat season. The majority of these crops were grown using furrow irrigation, with only a small area under overhead systems.

During 2008 many irrigators chose to allocate their limited water supplies to wheat instead of conserving water for traditional summer crops such as cotton. This was driven by a combination of historically high wheat prices and reduced surface water availability.

The project aimed to have a larger sample size, but the data was difficult to obtain. Much of the irrigated country had been

prepared for cotton so it had high nitrogen levels. A wet winter saw tall vegetative growth and, coupled with a wet harvest, resulted in a large number of lodged crops. Some irrigators were reluctant to provide data, just wanting to forget the season. Others were unable to provide accurate harvested water volumes, especially where excessive rainfall had fallen.

The irrigation benchmarking tool Watertrack™ Rapid was used as it evaluates water use and irrigation performance using a range of water use indices, such as Gross Production Water Use Index (GPWUI), Irrigation Water Use Index (IWUI) and Crop Water Use Index (CWUI). Watertrack Rapid also calculates crop water use and provides an estimation of on-farm water losses. Importantly it produces standardised results that enable meaningful comparison.

Figure 1 shows the results of 24 wheat farms, ranked by their Total Water Loss per Hectare. Each farm is in the same position for each grouping. Also shown are the Crop Yield (tonnes/ha), Total Gross Available Water (ML/Green ha) and Crop Transpiration (ML/Green ha).

There were seven irrigated wheat farms that reported a negative water loss (refer Figure 1). In theory this is not possible as the total amount of water used on the farm cannot be less than the amount required to grow the crop. The only two variables that influence estimated Total Losses are Total Gross Available Water and Crop Transpiration. The Watertrack Rapid model assumes a healthy fully irrigated crop.

Crop transpiration values were checked with neighbouring farms and found to be similar so it is likely water volumes on farm were underestimated. As this water includes water pumped, storage volumes, harvested rainfall and soil moisture reserves, inaccuracies invariably occur as water is not always metered within the farm. On some farms the final wheat irrigation coincided with a pre-water for cotton and splitting water between crops proved difficult. For these reasons the farms with negative losses were not included in the industry averages.

On-farm water losses for the 17 positive farms averaged 1.78 per megalitre per hectare. This was around 30 per cent of all water used on farm for the crop including water diverted from river and/or bores, water harvested on farm, effective rainfall and stored soil moisture used during the season.

The average irrigated wheat yield was 4.78 tonnes per hectare within a range between 2.5 and 6.35 tonnes per hectare. On average the total amount of water used on farm for that crop, shown as Total Gross Available Water in Figure 1 was 5.86 megalitres per hectare, ranging between 3.75 and 7.85 megalitres per hectare. The average crop transpiration was 4.08 megalitres per hectare.

Three water use indices, Crop Water Use Index (CWUI), Irrigation Water Use Index (IWUI_{farm}) and Gross Production Water Use Index (GPWUI_{farm}) calculated for each irrigated wheat farm for the 2008 season are presented in Figure 2.



On some farms the final wheat irrigation coincided with a pre-water for cotton and splitting water between crops proved difficult.

The average CWUI for wheat is 1.18 tonnes per megalitre. Crop Water Use Index (CWUI) relates total production to the amount of water consumed by the crop (transpiration).

The average IWUIfarm for the irrigated wheat farms surveyed for the 2008 season was 1.77 tonnes per megalitre, ranging between 0.76 and 3.45 tonnes per megalitre (refer Figure 2). The average GPWUIfarm for the 2008 wheat season was 0.85 tonnes per megalitre, ranging between 0.55 and 1.38 tonnes per megalitre. This is the first industry wide survey for irrigated wheat, so these figures provide benchmarks for future comparison.

The significance of these results is that the collection and calculation of the water use indices for the grains industry have been standardised enabling meaningful comparison. The average GPWUIfarm of 0.85 tonnes per megalitre is representative of irrigated wheat water use in 2008. It is this figure that can be used to benchmark water use so industry can gauge if it is further improving and determine the rate of improvement over time.

Further reading at www.npsi.gov.au

Funding: National Program for Sustainable Irrigation, Cotton Research and Development Corporation and Grains Research and Development Corporation. ▲

FIGURE 1: Variation in total water loss compared to yield, total gross available water (includes water diverted, harvested, used from storages, rainfall and soil water) and crop transpiration – wheat 2008.

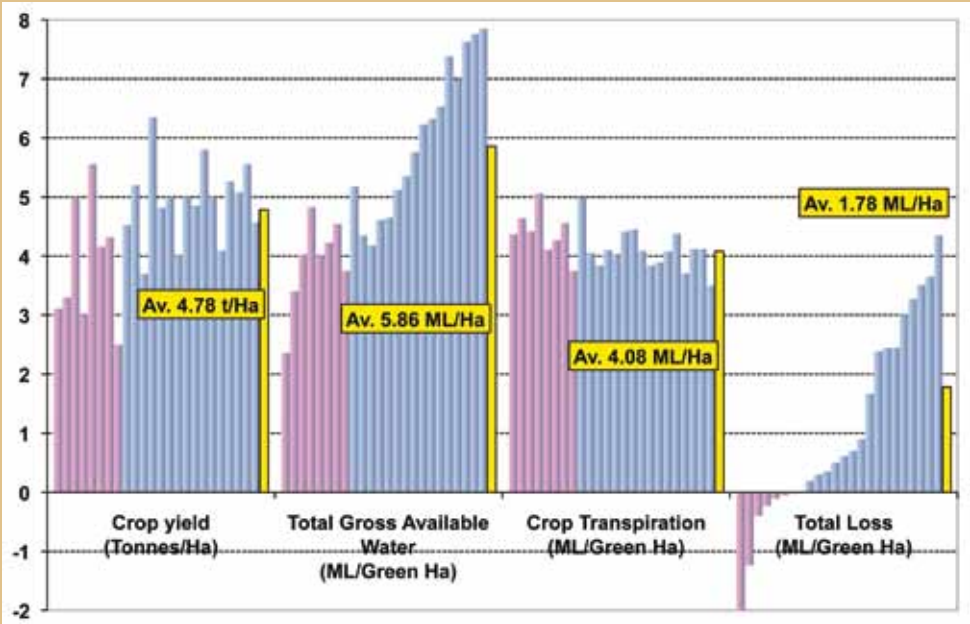
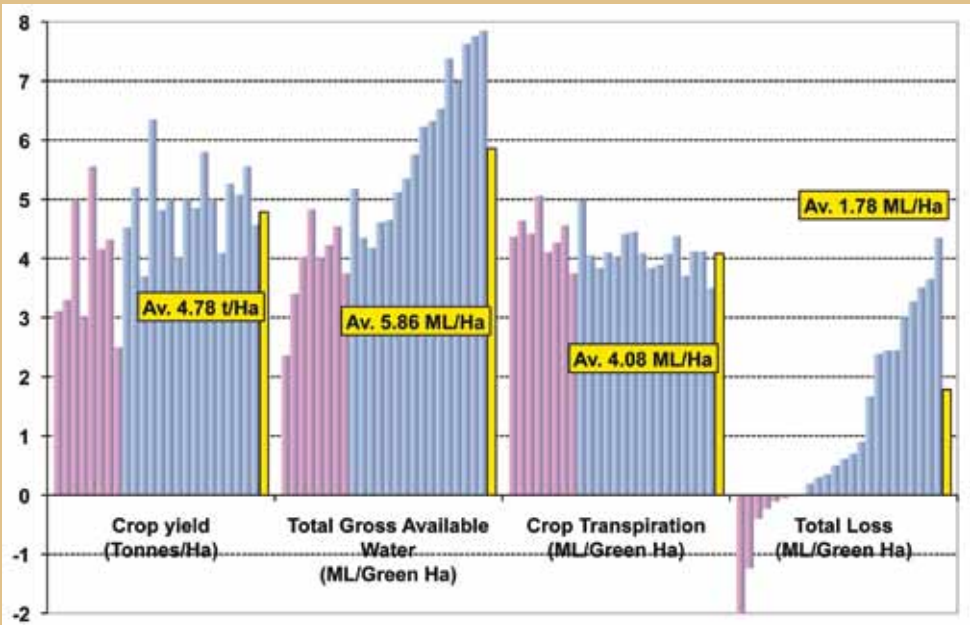


FIGURE 2: A Comparison of the Water Use Indices calculated using Watertrack™ Rapid – Wheat 2008



Irrigated wheat in cotton systems

■ Rod Jackson, Verity Gett, Tim Burley, NSW Department of Primary Industries; Brendan Griffiths, Griffiths Agronomy Pty Ltd; Graham Harris, Jose Payero, QLD Department of Agriculture Fisheries and Forestry; Allan Peake CSIRO and Nick Poole New Zealand Foundation for Arable Research

IN BRIEF...

- Research in the northern cropping region successfully identified key management strategies for high yielding irrigated wheat in both high and low soil-nitrogen fields.
- Wheat yields of eight tonnes per hectare can be achieved by selecting varieties that have the highest yield potential and disease resistance.
- It is important to identify starting soil-N in order to properly manage water and nitrogen availability during the growing season to minimise lodging risk and maximise yield potential.
- Experiments and modelling also suggest up to 550mm of soil water (depending on location and in-crop rainfall) or as many as five spring irrigations may be required to achieve maximum yield.



Small plot trials were used to determine yield impact of treatments.

COTTON in rotation with winter cereals, particularly wheat, is common practice in the northern cropping region of eastern Australia. Despite this, the majority of irrigated cereal crops achieve relatively low or inconsistent yields, and only partly deliver the rotational benefits and profitability possible in the cotton farming system.

Before 2007 very little research had been done to develop management guidelines for irrigated wheat in the northern cropping region. Information was utilised from southern NSW irrigated areas but the northern region is climatically different. For example the start to autumn in the north is milder and conducive for early vegetative growth (tillering), and spring is warmer, hence a shorter grain-fill period and a bigger demand for late-season nutrients and water.

In 2008, NSW was in the midst of a serious drought. A combination of low cotton prices and low water allocations along with high wheat prices ultimately saw cotton growers swapping to high-yielding irrigated wheat. Many wheat crops unfortunately

encountered a very wet establishment period and a large percentage produced excessive biomass (due to high soil nitrogen and water availability). Crop lodging (crops leaning or laying flat on the ground) resulted in a reduction in harvestable grain yield and the economic losses experienced by irrigators in northern NSW and southern QLD were enormous.

The “High Yielding Irrigated Grains in Cotton Farming Systems” (HYIGCFS) and “Achievable Yields” (AY) projects were initiated by industry to investigate the causes of poor yield (often from lodging) and to develop specific agronomic and irrigation recommendations to achieve the industry benchmark of eight tonnes per hectare. The HYIGCFS project focused on low soil-N (soil nitrogen) paddocks sown to wheat straight after cotton; while the AY project focused more on high soil-N/long fallow paddocks.

Researchers used on-farm monitoring, small plot trials and computer modelling to determine the yield impact of plant establishment, nutrition and irrigation treatments. Trial sites were in the northern cropping region at the Australian Cotton Research Institute (ACRI) Narrabri and farms in the Namoi and Border River valleys. Lysimeters were also installed at Kingsthorpe in the Darling Downs to identify optimal soil water depletion.

Key points and critical management findings have been identified from recent irrigated wheat research projects between 2007 and 2011.

Soil nitrogen and phosphorous at sowing

Soil nitrogen (N) and phosphorous (P) (N at 90 cm depth, P at 20cm) status needs to be determined prior to sowing. Long fallow paddocks (high soil-N) require careful management of canopy growth from establishment to avoid lodging. Paddocks sown straight after cotton (low soil-N) are ideal to target maximum yield and manage early season canopy. In post-cotton paddocks with low soil-N, apply 10–20 kg P per hectare as starter-fertiliser to improve establishment.

TABLE 1: Range of simulated maximum yield (t/ha) and evapotranspiration for 90% of years*, for quick maturing irrigated wheat (Kennedy) on 2m beds in the Northern Region#

Location	Range of maximum yield (t/ha)	Range of maximum evapotranspiration water use (mm)
Emerald	6.2–7.8	360–480
Dalby	7.0–9.5	430–550
St George	6.4–8.2	360–480
Goondiwindi	6.8–8.7	410–490
Walgett	6.7–8.3	420–500
Gunnedah	7.6–9.6	440–540

*Excludes the top and bottom 5% of years.

#In the absence of lodging, disease, pest and frost damage.

Source: Allan Peake CSIRO.

Establishment

The ideal row spacing for reduced or maximum yield targets is 30 cm (six rows on a 1.8-metre bed). The 15 or 45 cm row spacings (four or 12 rows on a 1.8-metre bed) yielded significantly less than 30 cm spacing at high yield levels in small pot trials.

Growers should aim for a plant population of 100 to 150 per square metre. Plant populations above 150 plants per square metre of bed are not essential for achieving high yields in the northern region. Low plant populations of 50 to 100 plants per square metre of bed can achieve high yield levels, but adequate soil tilth is critical for seed placement and emergence.

Variety choice

Durum wheat consistently yielded one tonne per hectare higher than bread wheat in northern irrigated wheat trials (on low soil-N sites). Durum varieties such as Bellaroi and Caparoi provided the highest yield potential and lodging resistance in 2011. Durum variety Hyperno has high yield potential, but is prone to lodging. Quick maturing varieties such as Kennedy and Longreach Crusader are the most likely APH (Australian Prime Hard) bread wheat varieties to achieve high yields, although Longreach Crusader has shown significantly more lodging resistance than Kennedy in high-N paddocks.

Water availability

Research suggests that as much as 550mm of soil water may be required (depending upon location) to achieve maximum yield (see Table 1). Depending upon in-crop rainfall this means as many as five spring irrigations may be required.

Irrigation scheduling

The largest early season issue in the northern region is achieving adequate secondary root growth, post-sowing to enhance water and nutrient uptake. Dry soil moisture below the sowing depth of seed will prevent the growth of secondary roots. Best practice requires soil moisture status to be assessed at 25 to 30 days after emergence, and if necessary, a winter irrigation to ensure healthy secondary root development. But this practice should only occur in low soil-N paddocks only as irrigating paddocks with a high starting soil-N may create early season crop canopy issues.

Results from the experiments reinforced the usefulness of soil moisture monitoring equipment which provides irrigators with real time soil water information to identify the refill point and schedule irrigations to minimise water stress. Water deficit experiments at Kingsthorpe confirmed ideal soil water depletion at around 50 per cent of plant available water.

Nitrogen application strategy

At least 250 kg N per hectare is required to grow eight tonnes per hectare of wheat. The success of nitrogen application strategies depends on soil type, irrigation system and sowing soil moisture and can change depending on rainfall and temperatures received during tillering. The minimum sowing soil-N required to achieve maximum yield has varied in trials from 15 to 120 kg N per hectare measured to a depth of 90cm. N can be split-applied in low soil-N paddocks (some fertiliser will be required at sowing). In high-N soils nitrogen fertiliser requirements are more safely applied at stem elongation (growth stage GS31) – ideally before rainfall or irrigation.

Use of Plant Growth Regulators (PGRs)

While PGRs for wheat are still being researched, found that the best response to use of PGRs in wheat has come from one application at stem elongation (GS 31) stage. PGR use is recommended particularly in high soil-N paddocks where lodging risk is considerably high.

Disease management

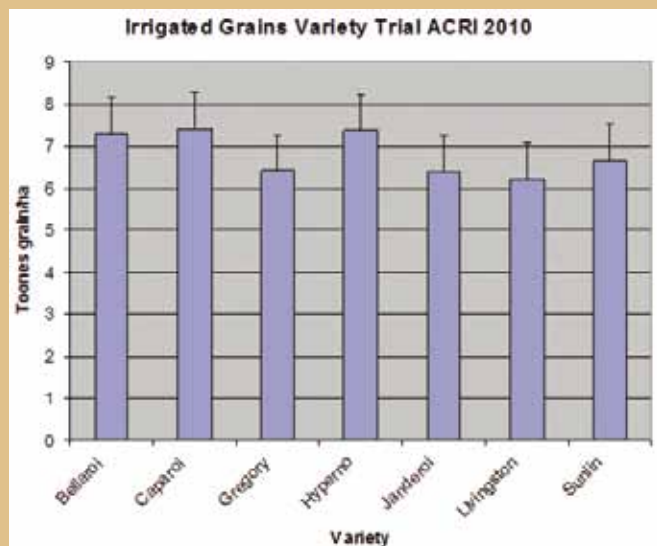
The profitability of a fungicide application increases in high-yielding irrigated wheat, particularly if varieties have disease ratings lower than moderately resistant (MR).

A pre-planned strategy of fungicide application based on growth stage and emergence of the top three leaves is more profitable when susceptible wheat cultivars are subject to disease. Best practice is to aim to apply a fungicide at flag leaf emergence (GS39). This should be preceded by a stem elongation (GS31-32) spray where disease onset is early or where susceptible cultivars are grown with no up-front protection. Consideration should be given to an additional ear-emergence fungicide where stem rust (*Puccinia graminis*) is the primary disease target or a first-flower spray where wheat or durum is at high risk of Fusarium head blight.

Funding: NSW DPI, Cotton Catchment Communities CRC, Cotton Research Development Corporation, Grains Research Development Corporation.

Further reading of the complete publication "Irrigated Wheat – Best Practice Guidelines in Cotton Farming Systems" is currently available at www.cottoncrc.org.au

FIGURE 1: Wheat variety performance – 2010 and 2011 (fully irrigated and sown after cotton).



Managing environmental flows in an agricultural landscape

■ Glenn Wilson and Peter Berney, Ecosystem Management, The University of New England

IN BRIEF...

- This study was one of the first overarching analyses of ecological responses in the Gwydir.
- The study found significantly different patterns of fish assemblages both between lower Gwydir channels and also between sites along each channel.
- Environmental water managers continue to use this information to maximise ecological responses in the Lower Gwydir floodplain ecosystem.
- Both the vegetation and fish components of this research emphasise the need for long-term, consistent data sets to more confidently define relationships between hydrological variability and the life-history responses of wetland biota.

THIS research began in 2005 led by Dr Glenn Wilson from The University of New England, examining the ecological responses of in-stream and floodplain environments to high and low water flows. This included several NSW Government environmental flow releases into the Gwydir River and Gingham Watercourse along with other flow events. The overarching aim of the research was to determine aquatic ecological responses to flow variability in the Gwydir Wetlands and to provide environmental water managers with guidance to underpin their decision making. A mix of existing (1994 to 1998) and field (2006 to 2011) ecological data was collected to assess the effectiveness of environmental water releases in this wetland system and to build models linking biotic response with hydrology.

Links between fish assemblage structure and abundance and flow characteristics were examined from late 2006 to early 2011 in the Lower Gwydir and Mehi rivers and the Gingham Watercourse. Nine native and three exotic fishes were found, with assemblages numerically dominated by only a few species (bony bream, spangled perch, carp gudgeon). European carp was the most common exotic species and dominated assemblage biomass. But despite the common source of flow from the Gwydir River, the three channels differed significantly in their fish assemblages, and these also varied significantly along each channel. The study concluded that longitudinal variation in habitat quality and flow conditions were most likely responsible for shaping fish assemblages.

Recruitment responses were observed in relation to individual Environmental Contingency Allowance (ECA) events, but establishing relationships between discharge and juvenile fish abundance was more complex. There was evidence for maximized recruitment under intermediate discharge levels at the pulse and seasonal scales. The influence of ECA flows on vegetation is likely to differ seasonally, producing longer lasting responses in spring or early summer. Influence may also be limited spatially, but the area and duration of inundation may be maximised when ECAs are 'piggybacked' onto a natural flood event. While abundances generally increased with discharge,



Researchers collecting data to examine fish assemblages in the Lower Gwydir.

relationships were often weak and varied between species, sites, and over differing time frames.

The lower Gwydir floodplain is recognised as a high conservation-value ecosystem. Its extensive terminal wetland areas provide aquatic plant and wildlife habitat in a landscape now largely dominated by intensive agricultural production. In addition, four wetland sites are listed under the international Ramsar Convention on Wetlands. But construction of Copeton Dam in the mid 1970s, and subsequent changes to the region's irrigation, grazing and cropping industries, has placed pressure on the hydrology and extent of these wetlands and their biodiversity values.

The Gwydir Regulated River Water Sharing Plan developed in the early 2000s legislated for an environmental contingency allowance (ECA), and more recent NSW and Australian Government programs have boosted environmental water holdings in the catchment. These volumes are mostly intended for use in maintaining wetland condition and associated ecological processes, and managers of the release programmed clear advice on how aquatic ecosystem components respond to flow variability in order to make effective decisions on timing, duration and depth.

Recommendations for future Lower Gwydir environmental flow deliveries, and for monitoring associated ecosystem responses, are key outcomes of this research. Managers of the

Gwydir ECA releases continue to be the most direct users of these research findings. Both the vegetation and fish components of this research emphasise the need for long-term, consistent data sets to more confidently define relationships between hydrological variability and the life-history responses of wetland biota. Monitoring of water chemistry and fish assemblages is ongoing with the aim of strengthening relationships with flow variability.

Importantly, the study highlights the need for expectations of ECA ecological outcomes need to be realistic. A single release is unlikely to achieve all the desired ecological responses, and a more variable hydrograph may be required for future releases to achieve as many ecological objectives as possible.

Factors likely to improve the effectiveness of ECA releases include:

- Timing environmental water releases to coincide with the growing season of native species;
- Excluding grazing immediately after environmental flows to allow optimal vegetation growth; and,
- 'Piggy-backing' ECA flows onto natural flow events to maximize the duration of wetland inundation.

This information allows ECA managers to make more effective decisions on volume timing, duration and depth in order to maintain wetland conditions and associated ecological processes. Daryl Albertson from the NSW Office of Environment and Heritage says "The impact of this work will be improved decision making to ensure that environmental benefits are maximised or the cost of achieving environmental improvements is minimised".

Information from this research has also been incorporated into NSW wetlands grazing guidelines, the NSW Wetland Recovery Program, and management advice to the Australian Government and Murray Darling Basin Authority. The findings of this research provide a greater understanding of how aquatic ecosystem components respond to flow variability, both spatially and over time.

Going forward, the research recommends ongoing monitoring to determine flow requirements, and that all findings are incorporated into the Gwydir Wetlands DSS which can be used by all flow managers.

Funding: Cotton Catchment Communities CRC, Australian Government's Natural Heritage Trust program and the University of New England (UNE) and was made possible through additional support from the Australian and NSW governments and the Border Rivers – Gwydir Catchment Management Authority. The project team sincerely thanks the landholders for their enthusiasm and support for the project, who not only provided access to their properties but also accommodation and local knowledge.

The full report is available at www.cottoncrc.org.au/general/Research/Projects/2_01_07.



Tobias Bickel monitoring fish assemblages in the Gwydir with a catch of European carp.

The impact of water regimes and grazing in wetlands explored

■ Peter Berney, The University of New England

IN BRIEF...

- A study in the Gwydir Wetlands in Northern NSW illustrated the close links between the water regime in floodplain wetlands and the composition of the plant communities.
- Flooding was found to be the most important factor shaping changes in plant communities over time, while the impacts of grazing differed markedly among plant communities and were not particularly consistent over time.
- An important impact of altered inundation regimes in floodplain wetlands is the effect of prolonged dry periods on the competitive interactions between native species and introduced species such as lippia.

EXTENSIVE floodplain wetland systems are a characteristic feature of the major rivers in semi-arid regions of Australia's Murray Darling Basin. Plant communities in these wetlands are dynamic in nature, having evolved under a highly variable flow regime. Water resource developments have had a dramatic impact on the flow regime of almost all rivers in the Murray Darling Basin, holding back floodwaters, and reducing the frequency and duration of floodplain inundation.

In recent decades environmental flows have been introduced as a means of restoring connectivity between rivers and their floodplains, with the aim of supporting wetland ecological processes. However, interactions with other land use factors such as livestock grazing may potentially diminish the benefits of environmental watering. Grazing of domestic livestock, particularly cattle, is a form of land use that has taken place on many of Murray Darling floodplains for over 160 years. In conjunction with flooding and drought, grazing may be one of the most important agents of disturbance that shape the floristic composition of floodplain plant communities.

This study investigated how factors such as flooding patterns, livestock grazing and competition between native and introduced species can drive compositional changes over time in plant communities in the Gwydir Wetlands in Northern NSW. The key findings of the research were that flooding was the most important factor shaping changes in plant community composition over time.

Following inundation, changes in plant community composition were consistent in areas which were grazed and areas which were not grazed. Plant community changes following inundation were characterised by pronounced increases in the cover of plant species tolerant of prolonged inundation and a related decline in the cover of species typically found in terrestrial plant communities. Furthermore, native species also displayed greater competitiveness, observed as more rapid growth and greater increase in percent cover, compared with invasive introduced species such as lippia (*Phyla canescens*) under conditions of high water availability.

A second key finding was that the impacts of grazing exclusion differed markedly amongst plant communities and



Change in a wetland plant community between August 2008 (top) and December 2008 (bottom) following inundation.

were not particularly consistent over time. In plant communities dominated by tall monocotyledon species, such as marsh club-rush, exclusion of grazing resulted in a decline in species richness as prostrate plants at ground level were shaded out by the taller dominant species. In contrast, excluding grazing in a water couch (*Paspalum distichum*) meadow led to the dominance of taller grazing sensitive plants and an overall increase in species richness but a reduction in cover of dominant species, water couch.

Using GPS tracking collars, cattle movements were recorded and analysis of the data revealed that grazing tended to be concentrated in particular sections of wetland paddocks rather than



Left – A GPS tracking collar fitted to a cow before release into a paddock to graze. Right – Locations of a cow while grazing in a large wetland paddock.



Left – A glasshouse experiment investigating growth responses to soil moisture levels and inundation in water couch and lippia. Right – An example of stem elongation in lippia to form a vegetative propagules to allow the plant to disperse on floodwaters.

across the whole paddock. Cattle grazing activity appeared to be most concentrated in parts of the meadow where water couch was dominant suggesting that grazing may play a role in maintaining the dominance of the species in some wetland plant communities.

In both the marsh club-rush and water couch plant communities, impacts of grazing on plant community composition were most evident during drier times when plants were not growing as vigorously as during wet conditions associated with extended periods of inundation. In contrast to both the marsh club-rush and water couch plant communities, in situations where the invasive species lippia was dominant, there were no differences in plant community composition detected over time.

An important impact of altered inundation regimes in floodplain wetlands is the effect of prolonged dry periods on the competitive interactions between native species and introduced species such as lippia. A glasshouse experiment investigating the effect of soil moisture level on growth of the native grass water couch and lippia found that water couch could successfully compete with lippia when the soil was saturated or when experiencing shallow inundation (10 cm).

However lippia competed more successfully against water couch under dry soil conditions. Under deeper inundation (20 cm)

water couch grew less vigorously, while lippia became dormant. Lippia plants did not die however, but responded to being submerged by developing elongated stems that were fragile and easily broke off and then floated on the water surface. These stem fragments acted as vegetative propagules that could then further spread the species.

This project illustrated the close links between the water regime in floodplain wetlands and the composition of the plant communities. It demonstrated how soil moisture levels affect both competitive interactions at the individual plant level, and at a broader scale, the responses of the plant communities to disturbances such as grazing. As a result of the research managers can develop hypotheses about plant community responses to particular water regimes and to land use changes such as exclusion of domestic grazing, which can be tested in the adaptive management approach now being adopted by wetland managers in major wetland systems in the Murray Darling Basin.

Funding: This PhD was part of a broader study in the Gwydir wetlands funded by the Australian Government's Natural Heritage Trust program, the Cotton Catchment Communities CRC and the University of New England (UNE) and was made possible through additional support from the Australian and NSW governments and the Border Rivers – Gwydir Catchment Management Authority. ▲

Modelling flood pulses and vegetation response in floodplain wetlands

■ Sue Powell, Australian National University

IN BRIEF...

- A model has been developed to explore water management options by combining our knowledge of how water moves through wetlands, and subsequently how the vegetation responds.

THE Gwydir Wetlands are a dynamic mosaic of floodplain wetlands that respond to the highly variable flood-pulse from the Gwydir River. With a broad range of wetland vegetation species, aquatic life and waterbirds that can number in the tens of thousands the system has been recognised for its ecological values both nationally and internationally. Over the years, as water use has expanded, the wetlands have seen a decrease in flooding. A challenge to managing and sharing the water resources between the environment and extractive uses is a full understanding of the water needs across the Gwydir wetland and floodplains through time.

An analysis of how the vegetation in the Gwydir Wetlands responds to flood pulses was analysed using satellite imagery. Using a variety of satellite sensors a time-series was developed of the normalised difference vegetation index (NDVI); a measure of vegetation greenness with good correlation to gross primary productivity. Phenological attributes such as greenup, maturity, senescence and dormancy were extracted from the time series imagery to characterise landscape units, such as channels, billabongs, wetlands and floodplains, and the productivity response to inflow and soil moisture was modelled. The response of much of wetland vegetation can be linked to preceding inflows (of up to 80 days in some areas) and climate driven (rainfall and evaporation) soil moisture. Vegetation that was not flooded could only be linked to climate driven soil moisture indicating a reliance on flooding for wetland vegetation.

This information formed the basis for a node-network model which is used to route water through the system and calculate the water balance in each patch. For each node in the model, a simple water balance model is applied which determines the likely depth and duration of flooding. Put simply, once a channel is 'full', any more water results in 'spill' into and across surrounding wetlands and floodplains.

Wetlands use a simple bucket model where depth is proportional to volume of water, while a floodplain has a variable relationship between volume, depth and area flooded. The results of the remote sensing analysis and field data are used to inform these relationships. This model can be used with any upstream inflow and climate sequence, making it a valuable tool in exploring water management options.

An Inundation and Vegetation Response Model (IVRM) was then developed that provides a means of distributing river inflow and climate variables across the landscape and linking these to vegetation productivity response. The model is used to compare inundation and vegetation response outcomes from different



(Photo: Joshua Smith)

scenarios, such as predevelopment, current development and future climate change (2030) scenarios. Not surprisingly, the model shows us that patches in the Gwydir Wetlands will be less regularly flooded under a 'dry' prediction of future climate change.

This project integrates hydrological and ecological understanding, remote sensing analysis, statistical methods, and good modelling practice to develop the IVRM. The results of this project can be used to extend existing models of the river system into the wetlands, or in its own right to explore water management options. The concepts can be extended to other floodplain and wetland systems, allowing time-series analysis of past events even where there is limited field data.

Sue's work has been used to inform the development of a decision-support tool – the DSS IBIS by the ANU and the NSW Office of Environment and Heritage. The tool is designed to guide environmental flow decisions in the Gwydir. It was used by the Australian Government Department of Sustainability, Environment, Water, Population and Communities (SEWPaC) in the development of the report to the Environmental Water Holder on the valley scale delivery of environmental water in the Gwydir.

Full thesis is available at
<https://digitalcollections.anu.edu.au/handle/1885/8713>

Funding: Cotton Catchment and Communities CRC and NSW Office of Water. ▲

Benchmarking riparian vegetation in the Namoi catchment

■ Eco Logical Australia and GHD

IN BRIEF...

- An objective framework was developed for evaluating and mapping the condition of native vegetation along the riparian corridor in the Namoi catchment and a benchmark for the condition of the vegetation established.
- The assessment found that cotton and other cropping industries do not negatively impact the inherent condition of remnant native vegetation relative to other agricultural land uses in the Namoi catchment.
- Clearing of floodplain vegetation however is likely to have had an impact on the quality of this native vegetation as habitat, or as a corridor to allow the movement, for native species.

RIVERINE vegetation, which includes vegetation associated with the stream or river channel and the adjacent floodplain has multiple benefits in rural landscapes: it influences the form of waterways and prevents erosion and incision, provides important terrestrial and aquatic habitat, and enables native animals to move across the landscape.

Riverine vegetation represents about 25 per cent of the Namoi catchment. There are over 8000 km of major streams and rivers within 40 sub-catchments and a total of 30 regional vegetation communities (RVCs) occur in the riverine zone. Cropland replaces about half of the original native vegetation of the Namoi floodplain.

This landscape condition assessment used metrics including the percentage of woody and non-native cover and the connectedness of natural landscapes, to establish that:

- Best 'condition' sub-catchments were associated with large contiguous blocks of vegetation such as in the Pilliga: and conversely,
- Worst 'condition' sub-catchments were associated with extensively cleared lowlands, such as the Liverpool Plains.

The study established a set of 'benchmarks' for a number of ecological attributes including percentage cover and ecological richness for each RVC. These are based on vegetation condition across 329 sample plots (91 on the floodplain and 238 along major channels) where the ecological attributes were consistently measured in each plot and could be compared and scored to a maximum value of 100. Vegetation condition varied from 98/100 (best condition) to 2/100 (poorest condition), with an overall mean score of 55/100 across all plots sampled in the Namoi catchment.

The following three major patterns were observed:

- Remnant floodplain vegetation appeared to be in better condition than riparian vegetation;
 - Riparian vegetation of upland areas associated with pastoral activities was in poorer condition than that in lowland channels associated with cropping; and,
 - Condition of native remnant vegetation within cotton growing areas was almost identical to that outside cotton growing areas.
- The researchers noted that the local condition of riverine



The Namoi River running through a cotton farm near Pilliga, northern NSW.

vegetation cannot be confidently predicted from landscape-generated estimates of condition. However, the plot-based condition assessment developed during this project provides a robust estimate of average vegetation condition at different scales, has been designed to undertake sampling rapidly and repeatedly, and is consistent with vegetation condition assessment protocols used in NSW, Queensland and Victoria.

This research provides evidence that it is possible to establish an effective network of habitats and corridors while maintaining and developing the cotton industry on the Namoi floodplain. This would require better mapping and sampling of intact areas of floodplain vegetation, working with landholders and to protect the larger areas, and developing a revegetation strategy to link strongholds of good condition native vegetation across the riverine landscape.

Several key recommendations are made with respect to identifying, prioritising, protecting and monitoring areas of key native habitat within the catchment. Subsequent to this project a second study delivered a practical management framework for prioritising management actions for improved waterway conditions in sub-catchments of the Namoi Catchment. The study evaluated the appropriateness, adequacy, effectiveness and efficiency of the Cotton CRC and the Namoi CMA's Monitoring, Evaluation and Reporting (MER) processes. Technical and scientific requirements and issues were also considered.

Collaboration between the researchers and the Namoi CMA ensured this research closely aligned with its needs so its findings could easily be integrated into management and investment decisions. This approach demonstrates the effective way in which scientific research can inform decision-making especially when the findings of the research are immediately available to inform catchment management.

The final report at www.cottoncrc.org.au or Namoi CMA website www.namoi.cma.nsw.gov.au

Funding: Namoi Catchment Management Authority, Cotton Catchment Communities CRC.

Understanding wetland habitats

■ Paul Frazier Eco Logical Australia

IN BRIEF...

- This project delivered multi-scale remote sensing techniques and methods which increase the understanding of the relationship between flow and inundation in a key reach of the Namoi River.
- Medium-resolution Landsat™ satellite imagery and historical gauge data were used to develop a technique that uses upstream flood peaks to reliably predict downstream flood behaviour.
- This methodology could be extended to the entire lowland section of the Namoi River Catchment. High resolution LiDAR and digital images were successfully used to map river habitats at very fine scales.
- When linked to flow data, these maps build a useful tool for quantifying flood regimes and examining and understanding riverine habitats following floods.
- Future research could build on these findings to develop a 3D model that could predict how river habitats will function with different river flows.

UNDERSTANDING the relationship between environmental flow regimes and river health is necessary for effective environmental flows. Environmental flows are assuming a central role in the management of regulated rivers, and reinstalling elements of the natural flow regime is increasingly seen as a goal in river restoration in Australia. But recent reviews highlight there are gaps in knowledge on the relationship between flow regimes and ecological processes. Environmental managers need to understand the relationship between habitat, flooding and functioning in order to set specific criteria and protocols for optimal flows that will achieve ecological and economic sustainability for Australia's inland rivers.

This research sought to develop a better understanding of the environmental flow regime(s) necessary to restore and sustain river health by developing and verifying methods to map habitat and flow (inundation) levels. GIS-based modelling at different scales was applied to lowland areas of the Namoi catchment, where the relationship between river flows and ecosystem processes was examined to predict outcomes for a range of environmental flow scenarios for the Namoi Catchment, as well as to map the location and extent of upland wetlands.

This research examined data at three scales. The multi-scale remote sensing techniques developed will make a valuable contribution to overcoming technical and knowledge-based obstacles to effectively implementing and assessing environmental flows.

Mapping lowland wetlands

Researchers focused on a 40 km reach of the Namoi River around Wee Waa to develop and verify methods of using medium-resolution remotely sensed data (Landsat) to map floodplain wetland inundation. The location was chosen as it is in a lowland area, good gauge records and Landsat data sets were available and a large number of previously mapped wetlands.

The hydrology record over 39 years (1974–2008) was



Nathalie van de Veer (Eco Logical) collecting ground truth information to accuracy assess the mapping of large woody debris (logs) on the Namoi river floodplain downstream of Wee Waa.

examined and crosschecked against the hydrological data and six separate floods were analysed. Techniques were applied to measure and record the extent of non-artificial wetlands which was then used as a template to which the extent of wetland inundation caused by flooding could be compared. The results of this comparison produced useful, reach-scale information about wetland inundation and river flow, showing upstream flood peaks can be reliably used to predict downstream flood behaviour. A recommendation of the research is to extend this mapping technique to other key reaches in the catchment.

Mapping upland wetlands

Researchers developed a method for mapping upland wetlands. In mapping wetlands across the entire Namoi catchment found it to have significantly underestimated upland wetland areas, it is likely that future improvements in satellite

resolution will make automated mapping techniques possible further research using different rules and scale for available data would provide a much more accurate map of the upland wetlands on the region than is currently available.

Using high-resolution data for habitat mapping and modelling

Riverine habitats and the impact of flood regimes on each habitat, was successfully mapped using high-resolution LiDAR and digital image data in this component of the study. This is a significant development as these newly available high-resolution data, which provides sub metre pixel sizes and approximately 0.15 m elevation resolution, generates information about the relationship of riverine habitats to flow regimes at a level of detail that river managers can use to optimise environmental flows.

Researchers combined LiDAR based analysis and airborne digital image data from summer 2008–09 to create a high-resolution 3D habitat map for the reach. By separating the data into elevation ranges, each habitat type was examined relative to river stage height data and historical flood patterns.

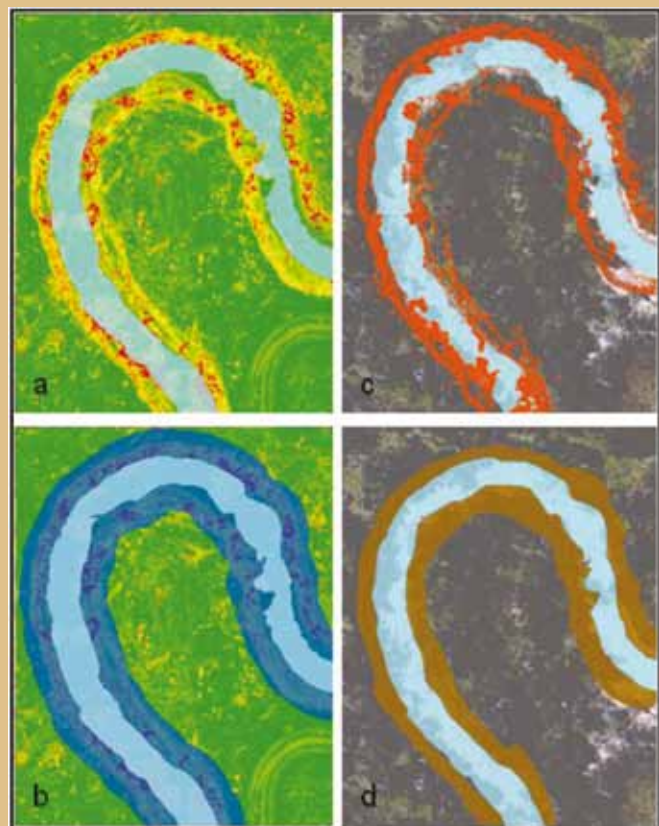
The methodology developed clearly shows that high-resolution data sets can be used to create three-dimensional riverine habitat models, a very useful tool for environmental managers to understand river flow patterns. While this study trialed the technology on a small river reach the methods and datasets could be applied to other reaches on the Namoi, or to similar river systems.

Continuing research in this area would include further research into understanding riverine habitat function following inundation events so that the 3D inundation model can be developed into a three-dimensional riverine habitat function model.

The final report at www.cottoncrc.org.au or the Namoi CMA www.namoi.cma.nsw.gov.au

Funding: Cotton Catchment Communities CRC and Namoi Catchment Management Authority. ▲

FIGURE 1: Steps used to delineate the channel top
a) generate slop layer to examine break of slope b)
place 15 m buffer on water layer to set channel top
zone; c) highlight areas of high slope in channel top
zone; d) visually fit channel top line using line of
best fit.



Riparian vegetation provides benefits to growers

■ Rhiannon Smith and Nick Reid, Ecosystem Management, The University of New England



Rhiannon Smith.

IN BRIEF...

- Research showed river red gum vegetation was the most valuable vegetation type on cotton farms for carbon storage.
- Well-managed riparian ecosystems store more carbon and have more stable soils than floodplain vegetation communities.
- Creek frontage and areas of riparian vegetation are enormously valuable in terms of the ecosystem services they provide to cotton growers and the wider community

As part of the study 260 plant species were recorded at the 54 survey sites on cotton farms across the lower Namoi floodplain, 79 of these were exotic. Some 89 bird species were also recorded (after waterbirds were excluded). Of the species recorded, three (brown treecreeper, grey-crowned babbler and glossy black cockatoo) are of high conservation value.

Many cotton properties have river or creek frontage and areas of riparian vegetation including casuarina, river red gum and coolibah woodland. These areas are enormously valuable in terms of the ecosystem services they provide to cotton growers and the wider community. Many cotton properties have river

or creek frontage and areas of riparian vegetation including casuarina, river red gum and coolibah woodland. These areas are enormously valuable in terms of the ecosystem services they provide to cotton growers and the wider community.

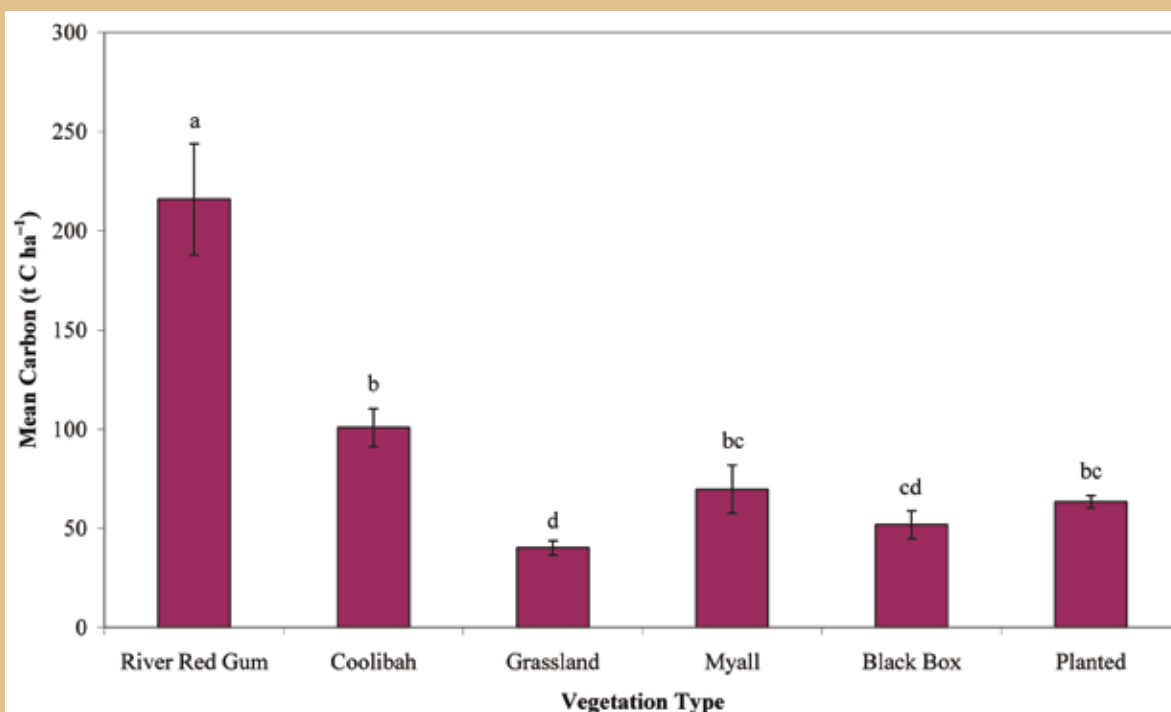
We measured some of the ecosystem services provided by riparian vegetation, namely carbon storage, erosion mitigation and biodiversity conservation, and determined how growers can manage these areas to maximise provision of these ecosystem services.

Carbon storage

Our research has shown that well-managed riparian ecosystems store more carbon and have more stable soils than floodplain vegetation communities. River red gum vegetation was the most valuable vegetation type on cotton farms for carbon storage, having up to 4.5 per cent carbon content in the surface zero to five centimetre soil depth increment, with total site carbon storage (to a depth of 30 centimetres below the soil surface) averaging 216 tonnes of carbon per hectare.

Grasslands were the least carbon-dense with 40 tonnes of carbon per hectare. The greatest proportion of carbon in river red gum sites was in woody biomass, but in all other vegetation types and especially grasslands, the top zero to 30 centimetres of the soil was the most carbon-rich component of the ecosystem. This

FIGURE 1: Mean carbon storage in each vegetation type (including woody vegetation, herbaceous vegetation, litter, coarse woody debris, dead standing timber, carbon in roots and soil organic carbon to 30 cm depth).





Carbon stored as woody biomass is likely to be more stable than that stored in grasses.

is significant because carbon stored as woody biomass is likely to be more stable than that stored in grasses, for example, in the face of disturbances such as drought or grazing.

Erosion mitigation

The abundance of carbon in riparian areas has flow-on benefits in terms of soil stability. Soil erodibility is determined by macro- and micro-aggregate stability when the soil wetted. In our study, soils with high carbon content and carbon to nitrogen ratio contained stable macro-aggregates and tended to be dominated by river red gum. High soil macro-aggregate stability in river red gum soils was attributed to large inputs of eucalypt litter and coarse woody debris.

As a result, soils under river red gum vegetation were less prone to slaking, erosion and mass soil loss than floodplain soils. But at sites where grazing pressure was high, organic matter and soil carbon were impacted by vegetation loss and disturbance of the litter layer, and this had consequences for soil stability.

River red gum vegetation was also associated with high soil micro-aggregate stability, which we attributed to lower soil sodicity. River red gums likely act in two ways to stabilise soil micro-aggregates. Firstly, river red gums work like pumps, bringing up calcium from deep in the soil, cycling it through the foliage and depositing it on the soil surface in leaf litter. In the same way that gypsum stabilises sodic soils, the calcium from eucalypt litter stabilises soil micro-aggregates, slowing dispersion and reducing the risk of hard soil surface crusts developing. Secondly, organic matter contributed by river red gums lowers soil pH, giving naturally occurring calcium carbonate in the soil an opportunity to stabilise soil micro-aggregates.

Biodiversity conservation

Riparian areas supply important habitat for a range of plants, birds, micro-bats and beneficial invertebrates that provide an

array of ecosystem services such as water filtration, nutrient cycling, pollination and natural pest control. These services are vital for crop production. A study in Texas, USA, estimated the value of natural pest control by micro-bats alone at US \$741,000 per year, with a range of \$121,000 to \$1.75 million compared to a US \$4.6 to \$US6.4 million per year annual cotton harvest (Cleveland et al. 2006).

In terms of biodiversity conservation, riparian vegetation in semi-arid farming country is extremely valuable, especially given the paucity of formal conservation reserves in many cotton growing areas. Riparian vegetation provides a corridor through the landscape, encouraging the movement of species to areas where they might otherwise not exist. Many of the plants and birds recorded in riparian areas during our research were unique to riparian vegetation, that is they were not found anywhere else in the landscape.

In addition to the benefits provided to cotton growers, ecosystem services generated by riparian vegetation on cotton farms also benefit the wider community and attract incentive payments for growers that can supply them (eg environmental stewardship payments from the Australian Government). Perhaps one day, riparian vegetation may also be a tradable asset (e.g. for carbon sequestration).

Native vegetation, natural wetlands and river frontage comprise a substantial proportion of many cotton farms, and natural and revegetated areas would contribute significant income streams in the medium term through emerging markets in carbon and biodiversity. Growers should remain vigilant with regards the potential of ecosystem services generated by riparian vegetation on cotton farms to contribute to farm profits.

Funding: Cotton Catchment Communities CRC, Namoi Catchment Management Authority, Cotton Research and Development Corporation (CRDC) and UNE (School of Rural and Environmental Science). ▲

Are dense coolibah stands the grassy woodlands of the future?

■ Megan Good and Nick Reid, The University of New England



Megan Good.

IN BRIEF...

- There is evidence that dense regeneration of coolibah could be vital for the persistence of woodlands in the landscape.
- Dense stands of coolibah contained at least as many plant species as remnant woodlands and grasslands.
- The conditions required for germination and establishment of coolibah trees are rare in space and time and may only occur a few times a century.
- Remnant woodlands were dominated by trees with trunks 40 to 50cm in diameter (DBH) suggesting that they may have regeneration episodically in the past.
- Patterns of tree spacing – increasing distance between trees with increasing tree size – indicated that self-thinning led to the current structure of dense and remnant woodlands.

MOST cotton growers on the northern riverine plains of NSW have areas of remnant coolibah woodland on their property. Historically, these woodlands were far more widespread than we see today. Some properties also have small patches of dense coolibah that regenerated following floods in the mid 1970s.

Dense thickets of regenerating coolibah have been referred to as ‘invasive native scrub’, implying that dense coolibah regeneration is responsible for the conversion of open grassy woodland into scrubland. While it is true that dense regeneration contains many more trees than remnant mature coolibah woodland research suggests that dense regeneration might eventually become the coolibah woodlands of the future.

Most stands of coolibah open woodland (~ five large trees per hectare) were denser in the past and thinned by graziers for livestock production over the past 150 years. We found that dense coolibah regeneration can be rich with native understorey plant species although it might appear that very little grows in dense coolibah thickets. Our results suggest that coolibah depends on dense regeneration just a few times per century to persist in the landscape – so the few remaining unthinned woodlands left today might eventually die out and be replaced by regeneration elsewhere across the floodplain. In other words, dense regeneration might be important for ensuring the persistence of coolibah woodland.

Does dense regeneration affect understorey plants?

Dense coolibah regeneration certainly competes with and suppresses understorey plants. We found that dense regeneration contained significantly less biomass of grasses and forbs compared to nearby open woodland, away from large trees (Figure 1). Surprisingly, though, we found more understorey plant species in patches of dense regeneration than in adjacent open woodland (Figure 2).

We also found that intermittent (as opposed to continuous) grazing was associated with more understorey species in dense coolibah regeneration (Figure 2; site 1). When we compared dense regeneration to remnant woodland and grassland, we found that the former contained many understorey plant species associated with woodland that do not occur in grasslands in the



Remnant coolibah open woodland dominated by large trees.



A stand of dense coolibah regeneration thought to be more than 40 years old.

region. This means that dense regeneration is not a threat to the endangered woodland plant community but instead might provide woodland habitat in a largely cleared landscape.

FIGURE 1: Mean (± 1 s.e.) biomass of all understorey vegetation in dense regeneration and open woodland at the three sites.

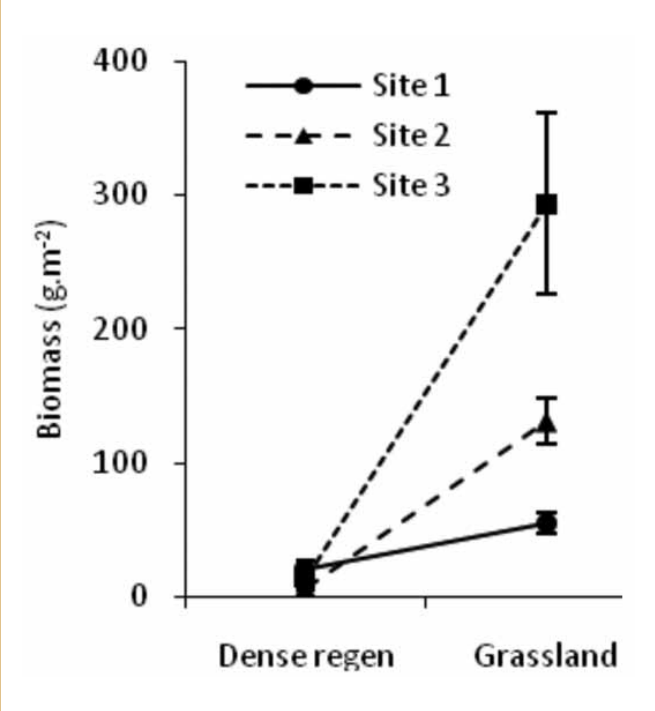
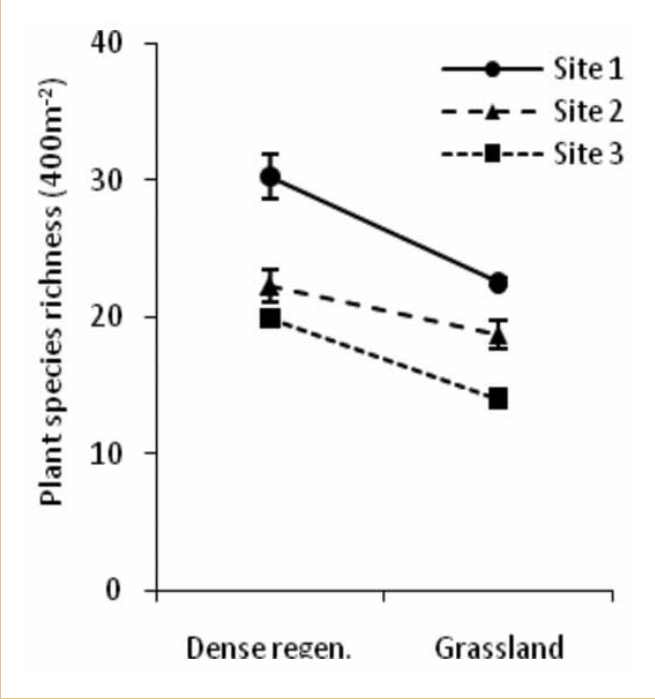


FIGURE 2: Mean (± 1 s.e.) number of understorey plant species in dense regeneration and grassland plots at the three sites.



How, when and where does dense regeneration occur?

Regeneration of coolibah is thought to occur following floods when soil moisture is near field capacity. The timing of floods may also be important since the optimum temperature for coolibah seed germination is around 35°C, but seedling survival is low if there is not enough follow-up rainfall or if temperatures are too high. Further, a recent study found that tree leaf litter can impede germination, so seeds would do better away from areas with high tree cover. We found that dense regeneration only occurs in areas with a low density of mature trees and that unthinned remnant woodland does not contain small trees. This means that the conditions required for germination and establishment of coolibah trees are rare, both in time (flooding must occur at the right time and must be followed by favourable conditions for seedling survival) and space (seed and appropriate microsites occur patchily in the landscape). Yet, when these conditions are met seedling emergence can be dense.

Could dense coolibah patches be future open woodlands?

If you have seen a patch of dense coolibah regeneration (see photo previous page), it may be hard to believe that remnant mature coolibah woodland was once a dense sapling thicket. But dense even-aged stands of trees self-thin over time, just over very long periods of time compared to a human’s lifespan. Self-thinning occurs when individual trees compete with neighbouring trees for limited resources; trees that are better competitors win and the losers die.

There is some evidence that areas of remnant coolibah woodland regenerated episodically in the past. All five remnant (unthinned) woodland sites that we measured were dominated by trees with trunks 40 to 50 cm in diameter (DBH), suggesting that they were roughly the same age. The trees were evenly spaced, suggesting that the current arrangement of trees resulted from self-thinning of formerly denser stands of trees. Thus, we hypothesise that coolibah trees persist in the landscape through a long cycle of dense regeneration followed by self-thinning.

At any one time, patches of woodland at different stages of this cycle are present in the landscape. For instance, near Walgett, landowners pointed out stands of mid 1950s coolibah regeneration to us: the trees had larger stem diameters (DBH ~25 cm) and were less dense than the mid 1970s regeneration, but were smaller and denser than remnant woodland. Therefore, the dense regeneration we see in the landscape today could be on a trajectory towards remnant woodland. Considering the endangered status of coolibah woodland, this means that the relatively few patches of dense coolibah regeneration across the riverine plains of northern NSW are important for the persistence of this iconic Australian woodland type.

Funding: Cotton Catchment Communities CRC and the Namoi Catchment Management Authority. ▲

Regeneration of floodplain trees: Just add water?

■ Samantha Capon, Australian Rivers Institute, Griffith University

IN BRIEF...

- The successful establishment of floodplain trees, like river red gums in the northern basin is far more complex than merely 'just adding water'.
- The conditions necessary for successful germination and seedling survival in these species may include particular timing, duration and rates of drawdown of flooding as well as specific weather conditions and local factors.
- Research suggests leaf litter and woody debris in the riparian zone may be significant in creating 'safe sites' for seedling establishment amongst river cooba.

It is widely believed that seedling establishment of key inland floodplain tree species such as river red gum and coolibah is induced by major flooding. In our project investigating the regeneration of floodplain trees and shrubs in the Condamine-Balonne and Border Rivers we expected to find a clear response among these species to the significant overbank flooding that occurred in these catchments in early 2011. Instead, we found virtually no recent establishment of Eucalyptus seedlings suggesting that successful recruitment in these important species requires far more than just adding water.

More specifically, we sought in this project to determine particular factors that influence the number, type and health of seedlings establishing in floodplain habitats of the northern Murray Darling Basin following flooding such as flood depth and duration or the influence of soil type, leaf litter or density of the tree canopy. We conducted extensive surveys of nine sites spread across the Macintyre, Weir, Condamine and Narran Rivers, initially in September 2011 and, where return visits were possible given further flooding and rainfall, again in November 2011 and March 2012.

Despite the presence of mature trees and fruit at all of these sites, no river red gum seedlings were observed at any of these sites in either September 2011 or March 2012 and only a single coolibah seedling was recorded in the final survey. Resprouting juvenile coolibahs were present at the majority of sites. Seedlings of river cooba (*Acacia stenophylla*) were abundant at all but one site and represented approximately 65 per cent of all recruits recorded. Whitewood (*Atalaya hemiglauc*) seedlings were also observed relatively frequently and were present in September 2011 at just over half of the sites. Additionally, lignum recruits were present at all except one site during the September field trip and were also observed relatively frequently in February 2012. Other species observed in the seedling surveys included *Casuarina cristata*, *Eremophila* spp. and *Acacia* spp.

Appraisal of spatial patterns in the distribution of seedlings recorded in our surveys suggests that each recruitment of each species responds to different processes and is far more patchy and limited than might be assumed. The distributions of coolibah and river cooba, for instance, suggest these recruits represent a



The field crew at Weir River, Talwood. From left: Laurisse Frampton, Samantha Capon, Andrea Prior (seated), Aaron Nix, Jacqui Lee and Rob Rolls.

single triggering event although this is likely to differ between these species with the coolibah establishment event being considerably earlier. In contrast, the range of sizes of lignum recruits recorded suggests relatively sustained recent recruitment.

This project has demonstrated that large flood events do not necessarily trigger recruitment amongst dominant riparian species in these habitats and conditions for successful germination and seedling establishment therefore entail more specific requirements than simply inundation. These conditions may involve particular flooding attributes (flood timing, duration, rate of fall, etc), or relate to weather (for example rainfall and temperature following flooding or other aspects such as absence of herbivory).

The implications of our findings are that the criteria for successful establishment of seedlings of key riparian eucalypts in the northern Murray Darling Basin are far more complex than might have previously been assumed from observations in the southern Basin.

Clearly, having good overbank flooding does not necessarily result in riparian vegetation regeneration, at least among key Eucalyptus species. The conditions necessary for successful germination and seedling survival in these species may include



Field sampling at the Macintyre River, Stuartville.

particular timing, duration and rates of drawdown of flooding as well as specific weather conditions and local factors. Our observations suggest, for instance, that leaf litter and woody debris in the riparian zone may be significant in creating 'safe sites' for seedling establishment among river cooba.

The findings of this preliminary research indicate that understanding riparian vegetation dynamics and elucidating appropriate management approaches for ensuring the maintenance and improvement of riparian vegetation condition in these catchments is likely only to be addressed by long-term monitoring of seedling establishment and survival and the factors likely to influence these.

Final Report at www.cottoncrc.org.au

Funding: Cotton Catchment Communities CRC and the NSW Office of Water with support from QLD Department of Energy and Resource Management. ▲

Scoping study of river flow measurements

■ Bryce Kelly, University of Technology, Sydney

SOON after the commencement of the Cotton Catchment Communities CRC a scoping study of river flow measurements was undertaken by Dr Bryce Kelly, at the University of Technology Sydney to identify issues and recommend priority projects to address key questions around the accuracy of river flow measurement and modelling in various NSW and Queensland cotton growing catchments. Irrigators, modelers and catchment managers' concerns centered around significant errors at measuring stations that can impact on modelling, environmental flow and allocation decision making and management.

In its review of river flow measurement methodology this study examined issues of precision and accuracy in measuring stream flows. A key recommendation is to compare the methodology developed by Fenton and Keller (2001) in a CRC-commissioned research project with the current AS3778 calibration procedure to calibrate a streamflow rating curve at key gauging station with view to improve measurement quality. Further priority collaborative research projects with government agencies proposed to advance the use of the stream flow gauging station network are:

- Extrapolating gauging station measurements in their area of influence; and,
- Developing a tool to optimise the density of gauging stations to minimise errors.

While the recommendations from this study were largely not acted upon, as the investments required were far greater than the CRC had available, it is important to mention here to demonstrate the systematic approach of the Cotton CRC directing its investment widely to fund research which would ultimately improve the understanding and management of water resources in cotton catchments.

Scoping studies can be found at www.cottoncrc.org.au

Funding: Cotton Catchment Communities CRC. ▲

When is next big flow?

■ Floris van Ogtrop and Willem Vervoort, The University of Sydney

IN BRIEF...

- Areas with groundwater show more 'memory' so future streamflow can be easier predicted from the current streamflow level. Knowledge of these patterns can aid in developing rainfall runoff models in regions where little data is available.
- New rainfall and streamflow simulation methods were developed for cotton growing regions in South Western Queensland.
- A flexible method for predicting and forecasting streamflow in all semi-arid regions of south-western Queensland was developed.

KNOWLEDGE of future availability of water is crucial for profitable farming. For cotton growers, water use efficiency could be increased if the time water is stored in storages is minimised due to high losses from evaporation. On unregulated rivers, this means that you would need to know when your next flow is coming along

The idea behind this research was that flows cluster in time, in other words, there are distinct wet and dry periods and it is possible to pick those periods and the intensity of these periods a long time in advance using predictors such as the Southern Oscillation Index.

At the end of the PhD we were confident in our long term (12 months in advance) predictions of above and below average flows (Figure 1) in the lower Balonne (QLD) and could make reasonable predictions of the probability of certain flows that would occur. We checked our model a couple of times since completing the thesis in 2010 against the recent wet periods in Southern Queensland and found that it continues to perform well for long range forecasts.

The key difference with other earlier flood forecasting work is that we worked from observed long-term data, using statistics, rather than modelling the streamflow in a mechanistic way (such as in rainfall runoff models) and worked on long range forecasts. A number of novel statistical approaches to model hydrology in intermittent rivers in Australia were explored.

Initially, the memory structure of streamflow across Australia was studied. Clear spatial patterns were identified, particularly with respect to regions which are dominated by direct runoff and regions where groundwater is a major component of total streamflow. Areas with groundwater show more 'memory' which means the future streamflow can be easier predicted from the current streamflow level. Knowledge of these patterns can aid in developing rainfall runoff models in regions where little data is available.

Secondly, new rainfall and streamflow simulation methods were developed for cotton growing regions in South Western Queensland. Millions of statistical simulations based on observed data from 1960–2000 can be used to build a better picture of expected maximum length of a period with no rain/flow or rain/flow below a certain volume and how often these events reoccur. This knowledge can aid cotton farmers in developing strategies

for coping with these climatic extremes, such as being well prepared for upcoming drought or flood.

Finally, a new flexible method for predicting and forecasting streamflow in all semi-arid regions of south-western Queensland was developed. The approach was also used to identify the influence of sea surface temperatures on rainfall and streamflow across the Australian continent. As highlighted in the beginning, skilful streamflow forecasts were developed up to 12 months in advance, where skilful means we were doing much better than just assuming the average past flow will occur. Information from these very long range forecasts can assist cotton irrigators with longer term strategic planning.

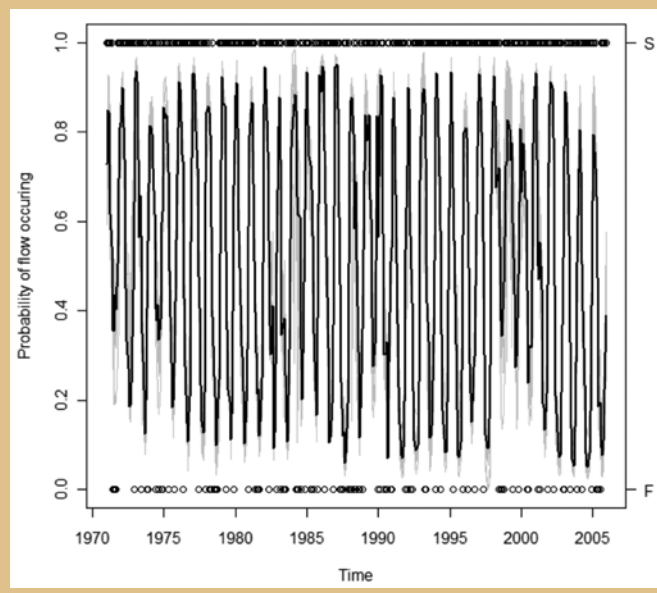
An interesting observation which sounds obvious, is that, because we worked from data, we were better in predicting the lower to medium flows than the higher flows. This is purely because there are currently more observations of low to medium flow in the data that we could use, which highlights some of the limitations of the statistical approach that we used. But with more data becoming available, our forecasts are easily updated to include new observations such as flows in 2010–12.

Research into further improving the forecasts is still continuing in the Faculty of Food, Agriculture and Natural Resources, The University of Sydney by Willem Vervoort and Floris van Ogtrop.

This thesis can be found at www.cottoncrc.org.au

Funding: Cotton Catchment Communities CRC.

FIGURE 1: The black solid line shows the probability of exceeding median streamflow 12 months ahead. The S indicates where a forecast was successful and the F indicates where a forecast was not successful. The Grey line shows the actual probabilities of exceeding median streamflow based on the observed data.



Screens protect fish at water diversion points

■ Craig Boys, NSW Department of Primary Industries

IN BRIEF...

- This study aimed at developing design criteria to protect native fish from entrainment and injury at water diversion points.
- The installation of fish screens has great potential to significantly reduce fish entrainment at intakes, in some cases reducing fish mortality at from over 90 per cent (unscreened) to less than two per cent (when screened).
- Approach velocities (eight centimetres in front of the screen face) of up to one metre per second are recommended as these provided the greatest protection of the largest size range of fish.

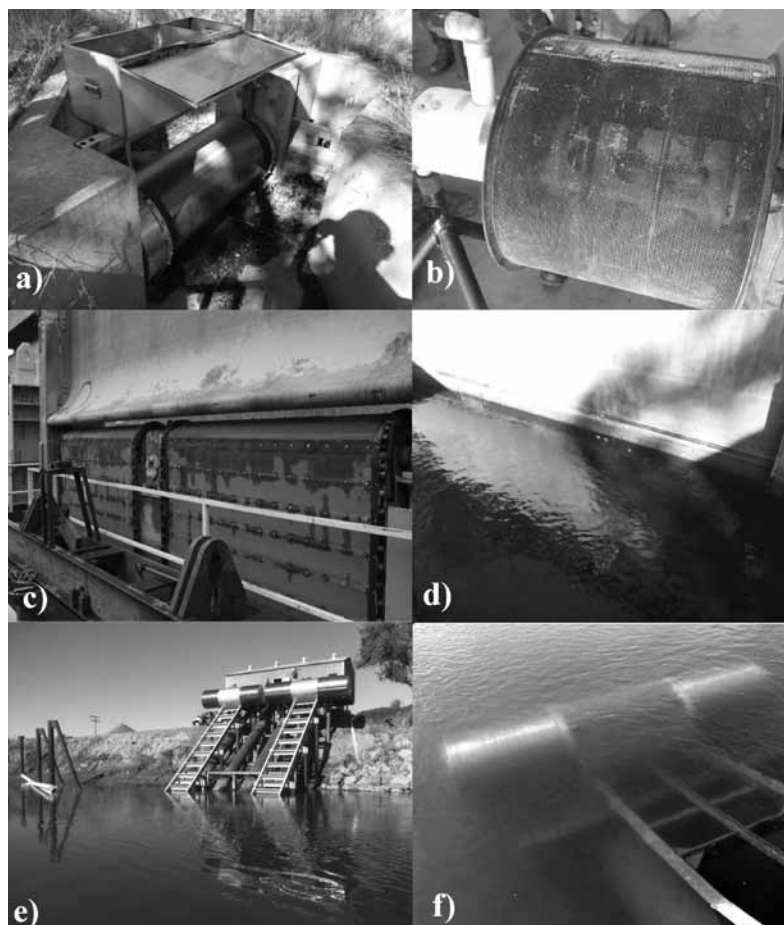
FISH screens are an important fisheries management tool used globally to protect fish populations whilst maintaining irrigator entitlements. Although many different screening approaches are currently applied elsewhere in the world, most of which would be suitable for application in the Murray Darling Basin, it is essential that technologies are designed with the needs of local fish species in mind.

A combination of field and laboratory-based experiments at simulated intake screens was used to test a variety of approach velocities (velocities eight centimetres in front of and perpendicular to the screen face) and screening materials. It was found that the installation of fish screens has great potential to significantly reduce fish entrainment at intakes and in some cases, mortality at an experimental intake was reduced from over 90 per cent (unscreened) to less than two per cent (when screened) in the laboratory. Approach velocities of up to 0.4 metres per second (equivalent to 1.5 metres per second slot velocity through the screen) were effective in reducing entrainment of juvenile golden perch and silver perch in laboratory trials, with very little injury or mortality resulting from incidental screen contacts or impingement.

In comparison, field observations of an assemblage of fish at a screen in a river demonstrated that even modest increases in approach velocity (from 0.1 to 0.5 metres per second) produced a significant increase in the rate of screen contact for fish smaller than 150mm, with the impact being greater the smaller fish were.

Screening material may not be as important a consideration (as approach velocity) when designing screens for the protection of fish. Perforated plate is a material commonly used for fish screens elsewhere in the world. It is readily available, cost effective and has reliable long-term performance when combined with appropriate cleaning techniques. Golden perch and silver perch could easily free themselves after contacting a perforated plate screen over a large range of approach velocities, with few injuries recorded. Further, there was little difference in the rate of screen contact or entrainment when using three different sizes of woven wire mesh (five, 10 and 20 mm).

Given that no screen design criteria currently exist for Australian native fish, appropriate guidelines urgently require preparation. Based on the findings of this study, it is recommended that fish screens in the Murray Darling Basin be



Various fish screen designs for potential application in the Murray Darling Basin. (a) rotary drum screen (b) rotating pump screen with rotating head and internal jet (c) travelling belt screen, (d) vertical panel screen with travelling brush and (e & f) brushed cylinder pump screen. (Photos: (a-d) NSW DPI, (e & f) reproduced with permission of Intake Screens, Inc.)

designed so that approach velocities not exceed 0.1 metres per second. Such a guideline will protect small fish which appear most vulnerable to entrainment and it reflects acceptable limits in other parts of the world.

A review of overseas screening programs revealed that fish screening co-ordinating committees are a key factor to overseas successes and could be established in the Murray Darling Basin to provide guidance regarding the setting and refinement of screen design criteria based on the latest science, to identify funding opportunities and to prioritise projects for implementation. Committees need to engage community members, particularly irrigators, to support the program. Government-irrigator cost-share programs and tax concessions have proven to be strong incentives to screen diversions elsewhere in the world and their use should be further explored for the Murray Darling Basin.

Funding: Murray Darling Basin Authority, the Namoi Catchment Management Authority and the Cotton Catchment Communities CRC with support from local businesses and irrigators in the Narrabri district.

Project Final Report at www.cottoncrc.org.au

Riparian areas – arteries of the cotton landscape

■ Guy Roth, Cotton Catchment Communities CRC

RIPARIAN land is any land adjacent to a river, creek or wetland and is critical for sustainable cotton farming. Riparian vegetation protects river banks from erosion, acts as a filter strip to trap sediment and nutrients. It provides shade which impacts on light and temperature of the stream, provides habitat and food for in stream organisms and animals and plants that live near rivers. The health of riparian land therefore directly influences river health and water quality.

Cotton farms occupy less than five per cent of the catchment areas in which they operate, but they are generally located adjacent to rivers and riparian areas. Research has found 70 per cent of growers have river frontage and that 85 per cent actively manage their riparian areas (CRC Grower survey 2011).

Tactics used by growers to manage riparian areas include:

- Fencing and selectively grazing;
- No grazing at all;
- Control of weeds and pests;
- Provision of alternative water points for stock;
- Maintain filter, buffer strips and Planted native trees/vegetation; and,
- myBMP.

The image below shows a section of the Gwydir River, north west of Moree. The prominence of the riparian corridor is clear.

This corridor has complex vegetation (understory and over story over the river). It also shows the importance of connected corridors for wildlife and fish along 'nature's highway'.

To stimulate interest a publication *Managing riparian lands in the cotton industry* was produced by the Cotton Research and Development Corporation (CRDC). The publication raised awareness of riparian land concepts for growers and industry leaders, and led to the inclusion of riparian land management in the Cotton BMP Program. More recently the Cotton CRC has produced other resources to promoting effective riparian land management such as *Birds and Fish on Cotton Farms* publications, and other specific resources such as the *Lippia Weed Management Guide*.

Research has found 70 per cent of growers have river frontage and that 85 per cent actively manage their riparian areas.



Riparian areas are the arteries of the cotton landscape providing a buffer between agricultural fields and waterways and helping to maintain water quality.



The Namoi River before (left) and after (right) riparian revegetation works at Kilmarnock, Boggabri.

CASE STUDY...

Reducing bank slumping and pesticide contamination

John and Robyn Watson, Kilmarnock, Boggabri, NSW.

In 1995, the Watsons started a program of improving riparian areas as they were concerned about bank slumping and pesticide contamination of the river. They identified the places where action was needed along the seven kilometres of river that runs through their property and worked to rehabilitate these areas. Most of the work involved planting a mix of native grasses, shrubs and trees to stabilise the riverbank and prevent erosion and loss of valuable land. John and Robyn also kept their cattle out of riparian areas as they were causing a lot of damage to the riverbank and increasing erosion.

Some of the lessons John and Robyn wanted to share with other cotton growers are:

- Do not try to do too much at once. Pick your sites and do a little every year as conditions allow.
- Exclude stock if you have them. Once the area has been rehabilitated light grazing is okay, but do not let in the bulls!
- Do not think that you have to use expensive machinery to restore riverbanks. You can do a lot with plants and repair steep banks without spending a lot of money.
- The ideal time to plant trees is when there is moisture in the bank, such as from a 'fresh' in the river. On steeper banks, use long stem stock for seedlings (up to one metre high). The species they have had most success with are river red gum, casuarina and river cooba.

- Planting native grasses is very important for stabilising the toe of the bank. The grasses used are phragmites at water level, queensland cane grass in the middle of the bank and native vetivia a bit higher up. Once established, other grass species naturalise around them.
- Weed management is important.
- Do not water unless it is really dry.
- Grow your own plants by collecting the seeds from those areas along the riverbank and on the property that are regenerating or protected. Use local tree stock as it is native to the area and most likely to survive.
- Use riparian buffers between the riverbank and cotton paddocks as this protects the river from spray drift as well as trapping sediments and nutrients running off the paddocks.

For more information: www.cottoncrc.org.au or www.crdc.com.au



Bold project to restore river

■ Anthony Townsend, Milly Hobson NSW DPI

COTTON growers have been working with the Cotton CRC, Namoi Catchment Management Authority and NSW DPI to establish the Namoi Demonstration Reach – a collaborative effort to restore over 120 km of the Namoi River from Gunnedah to Narrabri, improving river health and bringing native fish back to the Namoi River.

The five cotton growers involved in the project have completed a range of works including:

- Managing 26 km of riparian vegetation along the Namoi River and Maules Creek by supplying off-stream watering, fencing along the river to restrict stock access and removing willows.
- Planting over 3500 trees to establish 10.5 km of native riparian vegetation.
- Controlling 50ha of lippia by herbicide application and managing grazing.
- Resnagging, bank battering and revegetating eight river bends.
- Undertaking the cotton myBMP Land and Water Module with the Namoi BMP Officer.

These works have contributed significantly to the overall outcomes of the Namoi Demonstration Reach, which has achieved many onground activities, much community engagement, and monitoring and evaluation since 2007, including:

- Reintroducing over 340 snags at priority sites.
- Planting over 14,000 native aquatic and riparian plants along the reach.
- Managing over 33km of woody weeds.

- Managing over 23km off river banks through fencing and installing over 20 off-stream watering sites.
- Fixing fish passage at three priority sites opening up 15km of aquatic habitat.
- Establishing two community water quality monitoring groups.
- Holding seven carp musters that have been attended by over 2300 people.
- Hosting 17 workshops that have dealt with plant propagation, open days, school events, Waterwatch training, and cultural survey days.
- Establishing a Namoi Angler Monitoring Program with local fishers.
- Producing over 20 publications and promotional materials including brochures, case studies, guides, caps, shirts, and interpretive signs, and distributing hundreds of media articles through radio, print and television.
- Establishing a Monitoring and Evaluation program that focuses on native fish, including investigating the use of screening technology to reduce the potential impacts of irrigation off-takes on native fish.

As a result of these activities, the Namoi River will see an improvement in water quality, fish habitat, riparian and aquatic vegetation and even an increase in on farm productivity. This project has benefits for our native fish and river health in general, but also provides significant opportunities for the local community to get involved and take ownership of the river.

Further information milly.hobson@industry.nsw.gov.au



Conservation Volunteers Australia help out with tree planting on 'Therribri', part of the Namoi Demonstration Reach.
(Photo: Milly Hobson)

Quick Tests for herbicides in water

■ Ivan Kennedy and Angus Crossan, The University of Sydney

IN BRIEF...

- Rapid test kits have been developed for the detection of diuron, fluometuron, and prometryn in water.
- The technology provides cost savings in the order of 80–90 per cent over existing analytical systems.
- QuickTests are currently being used in a project designed to rapidly develop a risk assessment of diuron in for the Namoi and Fitzroy catchments.

TEST kits for the rapid detection of pesticides in water have been developed. The test kits have been developed for the rapid detection of diuron, fluometuron, and prometryn. This project established proof-of-concept for the technology, developed a series of prototype tests and has now commercialised the products.

Pesticide use brings the potential for off-target contamination, and the rapid tests will enable rapid certification in the field that any contamination is below hazardous levels, thereby verifying good practice. Pesticide analysis has typically been an expensive process because of the costs associate with collection, transport and quantification.

The tests eliminate the need for collecting and analysing numerous samples at a laboratory, thus offering significant time and cost savings over the current analytical systems. This technology provides users with savings in the order of 80 to 90 per cent.

The test kits are easily portable and take less than five minutes to provide a yes/no result for ecologically hazardous concentrations of herbicide target chemicals in water. A provisional patent has been lodged in China and Australia for the technology developed in the project. The research group is now working towards identifying addition target analytes and applying the technology to benefit other primary industries.

The tests could be used to validate benefits from improved practices, such as *myBMP* growers in the cotton industry and manage stormwater events.

Jane Trindall, Cotton CRC Program leader said this is a very young product and the researchers have done exceptionally well to get to this commercial stage in a very short period.

“The project really demonstrates the research capacity Ivan Kennedy and his many students have built over the years. The quick tests truly illustrate the cotton industry’s proactive approach to address social and environmental responsibilities by providing management tools for growers.”

Professor Shuo Wang from Tianjin University of Science and Technology, China, was originally one of Ivan’s PhD students funded through CRDC in the early 1990s working on environmental fate of pyrethroids. Professor Wang now heads a Key Laboratory for Food Safety with 10 academic staff and almost 100 post-graduate students at the Tianjin University of Science and Technology. As University Vice-President for International Affairs, Shuo was an important international collaborator in this project.

The diuron herbicide quick tests are currently being used in collaboration with the Cotton Research and Development



Project team (from left) Dr Angus Crossan, Professors Ivan Kennedy and Shuo Wang examining new equipment at the Tianjin University of Science and Technology, China.



Dr Guy Roth using the first diuron QuickTest commercialised by the Cotton CRC (Namoi River, Narrabri, March 2012).

Corporation and Cotton Australia, in a project designed to rapidly develop a risk assessment of diuron in for the Namoi and Fitzroy catchments.

In view of environmental concerns, there is an increasing focus on the continued use of diuron. Recently, the APVMA reviewed and suspended its registration. Although the regulatory review is not complete, the preliminary indication is that application levels of 1.8 kg per hectare may be retained for use where such use does not create a ‘high risk situation’.

The low-cost QuickTests provide a good opportunity to undertake low-cost sampling of rivers in cotton catchments. These data will be used to build on exiting knowledge of diuron concentration and ecological toxicity to characterise environmental risk.

For more information contact ivan.kennedy@sydney.edu.au

Funding: Cotton Catchment Communities CRC in collaboration with The University of Sydney and Tianjin University of Science and Technology, China, Cotton Research and Development Corporation and Cotton Australia. ▲

Constructed wetlands provide benefits with improved water quality

■ Michael Rose, Angus Crossan, Paco Sanchez-Bayo, Mitchell Burns and Ivan Kennedy, The University of Sydney

IN BRIEF...

- Water storage dams and tail water drains can be designed to improve water quality and habitat value.
- Areas of vegetation, particularly in tail drains, can improve sedimentation and microbial breakdown of pesticide residues; but areas of open water are also important for pesticide breakdown by sunlight. Networks of smaller storage dams are better at self-cleansing than single, large storage dams.
- Inclusion of gently-sloped mud-flats, islands and trees around wetland margins greatly improves the habitat value of waterways on cotton farms.
- Diversity in design means diversity in function.
- Growers should always consult the industry storage design guidelines.

In early 2000 the Cotton CRC began to look at ways to improve the environmental function of cotton farms over and above that of production-focused enterprises. On-farm tail drains and storage dams in particular appeared to be under-utilised resources from an environmental point of view. Our research focused on optimising the design of on-farm waterways to improve the quality of tail and runoff water while providing better habitat for native wetland plants and animals.

We found that large, open (non-vegetated) tail drains and storage dams did have some benefits in terms of promoting pesticide breakdown and removal, but they could be enhanced by wetland vegetation and structural modifications. Increasing the physical and vegetative diversity of waterways was also found to have flow-on benefits to native fauna, particularly waterbirds and reptiles.

Initially, the dissipation of five pesticides – endosulfan, chlorpyrifos, aldicarb, prometryn and diuron was studied in glasshouse columns of cotton field tail water. For all pesticides studied, except chlorpyrifos, dissipation was significantly faster in the storage dam samples than the vegetated wetland samples. These surprising results suggested that the presence of more organic matter in the wetland samples could actually stabilise contaminants, limiting their breakdown. These results gave some insight into how certain pesticide dissipation pathways may be enhanced or limited by vegetated wetlands.

At the same time, we also built a pilot-scale ponded wetland on a cotton farm in the Namoi Valley, consisting of a non-vegetated and a vegetated pond, to directly determine the effects of aquatic plants on pesticide removal from tail water in the field. Irrigation tail water containing various pesticide residues was diverted into these ponds.

In the first season of operation no significant difference was observed in the breakdown of three pesticides: the insecticide



Constructed wetlands can improve water quality.



aldicarb (half life = 26.4 ± 7.0 days), and the herbicides fluometuron (half-life = 25.4 ± 8.6 days) and diuron (half-life = 21.3 ± 4.2 days) between each pond. But this was partly a result of the slow growth of plants in the vegetated pond, which still only covered less than 20 per cent of the total pond area by the end of this season.

Early in the second season, the removal of fluometuron was significantly greater in the vegetated pond (10.2 ± 1.3 days) than the non-vegetated pond (13.8 ± 1.0). But an algal bloom in the non-vegetated pond later in the second season reduced the fluometuron half-life to 5.5 ± 0.4 days, significantly less than the vegetated pond throughout the entire season. In the third season, the reduction of fluometuron and endosulfan was significantly greater in the vegetated pond than the non-vegetated pond ($p < 0.05$). Endosulfan removal was correlated with the removal of total suspended solids in both ponds. Overall, aquatic plants increased pesticide removal compared to open zones, but less than anticipated by previous glasshouse trials.

To further investigate the difference in pesticide dissipation from open versus vegetated storage dams, we modelled the individual pathways pesticides are lost from waterways using data from numerous previous studies funded by the Cotton CRC and CRDC. These 'pesticide dissipation pathways' included sedimentation and burial; volatilisation to the atmosphere; chemical breakdown; sunlight-induced breakdown and biodegradation by microorganisms. We used two common cotton pesticides as a case study:

- The pre-emergent and relatively water soluble fluometuron; and,
- The less water soluble insecticide endosulfan.

We found that dissipation was initially fastest in vegetated

ponds, because of the greater microbial degradation and sedimentation rates caused by aquatic plants. Photolysis was also prominent in the vegetated pond, despite shading, because of greater light penetration induced by fast sedimentation. But after 21 days, the extent of fluometuron removal in the open pond matched that of the vegetated pond because of the lack of shading meant a greater overall rate of light-induced breakdown.

Endosulfan removal was heavily dependent on the pH of the runoff water and sedimentation, as most endosulfan in runoff is actually bound to sediment. Generally the higher pH of water of open (non-vegetated) ponds increased endosulfan degradation, but the higher rate of sedimentation in the vegetated pond caused a faster overall rate of loss.

Overall, our field studies showed that the greatest toxicity risk to aquatic species on cotton farms is from high insecticide pulse concentrations soon after insecticide application. We therefore also examined the potential for 'sub-surface flow' wetlands to reduce and spread out peak pesticide concentrations while physically preventing exposure to native species. Our results showed that gravel beds could achieve this, but were less effective against lower levels.

Nevertheless, our previous results demonstrate that the removal of remaining pesticide residues can be accelerated by including aquatic plants; by breaking up large storage dams into smaller storage dams; and by leaving some areas of non-vegetated water surface to allow for sunlight-induced pesticide breakdown. The inclusion of such diverse design structures in on-farm waterways will also promote a biological diversity through the provision of different habitats.

Funding: Cotton Catchment Communities CRC.



Storages are aquatic refuges

■ Susan Lutton, PhD Student Australian Rivers Institute, Griffith University

IN BRIEF...

- Investigation into the possibility of using irrigation storages as an environmental refuge for native fish found some native species can indeed thrive in farm dams.
- Water storages on irrigation properties may prove an important habitat for native aquatic species.
- Changes to design and management of storages and resulting increases in biodiversity could boost long term farm sustainability.

PRINCIPAL Researcher Susan Lutton from the Australian Rivers Institute at Griffith University in Brisbane carried out a three-year research project looking at aquatic biodiversity and the ecological value of on-farm storages on irrigation farms, particularly ring tank water storages. The study focussed on the Border Rivers Catchment in Queensland, where the expansion of the irrigation industry on a river system that alternates between floods and long dry spells, has necessitated the building of large on-farm water storages. The research project investigated the diversity of storages and the structure and function of the species they were able to support compared with nearby natural wetlands.

While not all native fish can cope with the conditions in an artificial storage, many species were found in significant numbers in the ring tanks. Surprisingly, much larger catches of fish were recorded in the dams than in the wetlands. In fact the typical catch size in the ring tanks was 10 times the average number of fish caught in natural wetlands. But in the artificial storages the catch was dominated by native bony bream or *Nematalosa erebi*, while in natural wetlands there was a more even distribution of the different species.

Another surprise result from the study was that the percentage of non-native fish, including carp, was found to be much lower in irrigation storages, (where they made up less than eight per cent of the catch), compared with more than 40 per cent in the natural wetlands.

There were also significant differences in the diversity of macroinvertebrates and zooplankton. While there was a much wider variety of these tiny creatures found in natural wetlands, there were substantial populations found in the artificial storages.

The study found, given the large numbers of artificial storages across the catchment, if managed effectively, they may provide an additional source of aquatic habitat and help maintain regional biodiversity. But to maximise the potential of farm dams to act as a biodiversity refuge, changes to the design of new storages, and alterations to existing tanks may be necessary to increase habitat diversity.

Suggestions to increase fish friendly habitat include reducing the steepness of slope on the sides of ring tanks, creating shallow areas and central islands, adding woody debris to the storages, and planting aquatic vegetation.

As on-farm storages are a permanent part of the floodplain in the Border Rivers Catchment and other irrigation areas of Australia, the research project concluded that the long term



***Berosus* larvae – one of 34 macroinvertebrate taxa found in a cotton water storage.**

preservation of the biodiversity and health of aquatic areas will require “a balanced approach between the conservation of natural wetlands and the improvement of artificial water bodies as aquatic habitat”.

While some of the ecosystem services supplied by natural wetlands may never be replicated by storages given the increasing prevalence of artificial storages on the landscape, these man made storages may usefully off-set some of the losses of natural wetlands in the region.

Susan says there’s certainly a lot of food for thought in her PhD research project, and it’ll be up to farmers themselves to consider what changes they can viably make to storage design and water harvesting technology.

The research found many native fish and macroinvertebrate species are already living in irrigation storages, and changes to the design and management of farm dams could be implemented to make them even more fish friendly.

Funding: This PhD was funded by the Cotton Catchment Communities CRC. ▲

Catchment-scale ecological risk assessment

■ Mitchell Burns, Angus Crossan, Michael Rose, Ivan Kennedy, The University of Sydney

IN BRIEF...

- As natural resources are typically managed at the catchment level in Australia, it is logical that pesticide management approaches be adapted to this scale.
- A catchment-based ecological risk assessment of diuron, prometryn and endosulfan use in the Gwydir River catchment identified areas of concern.
- A laboratory toxicity study showed two duck weed species (*Lemna minor* and *L. gibba*) were able to recover from a pulse of diuron concentrations commonly deemed significant in ecological risk assessments.
- A modelling framework can characterise sub-catchments' contributing pesticide loads, potential pulse durations and their probabilities of re-occurrence.

ECOLOGICAL risk assessment (ERA) used to support pesticide management decisions at the catchment-scale can deliver environmental protection while retaining farm production benefits from agrochemicals.

Presently, ERAs in Australia are mainly used to evaluate ecological impacts of pesticides at the farm-scale. But pesticide concentrations in rivers are usually a result of the activities of

more than one farmer and affected by many factors such as climate, hydrology, geomorphology and land use.

As natural resources are typically managed at the catchment level in Australia, it is logical that pesticide management approaches be adapted to this scale. A PhD thesis explored ways to combine spatial modelling and ecotoxicology in order to characterise the most reliable approach for investigating pesticide concerns in agricultural catchments.

Initially, a catchment-based ERA of diuron, prometryn and endosulfan use in the Gwydir River catchment, NSW, identified sites of concern. From measured aquatic concentration and toxicity information, the probabilities that diuron, prometryn and endosulfan were exceeding toxicity thresholds were determined, allowing for the identification of concentration 'hotspots'.

With the exception of prometryn, low risk from diuron (maximum risk 13 per cent) and endosulfan (maximum risk nine per cent exposure) was found to occur in some reaches of the Gwydir River catchment (an example of Diuron is given in Figure 1). The output from this study allowed for a more focused diagnosis of exposure concerns.

But the variability of pesticide concentrations occurring in the catchment were likely to result in variable toxicity responses and the hot spot characterisations were not sufficient to indicate likely sources of pesticides resulting in the level of risk observed for

FIGURE 1: Map of the level of estimated diuron risk, represented by the height of the black bars, at the monitoring sites of the Gwydir River catchment.

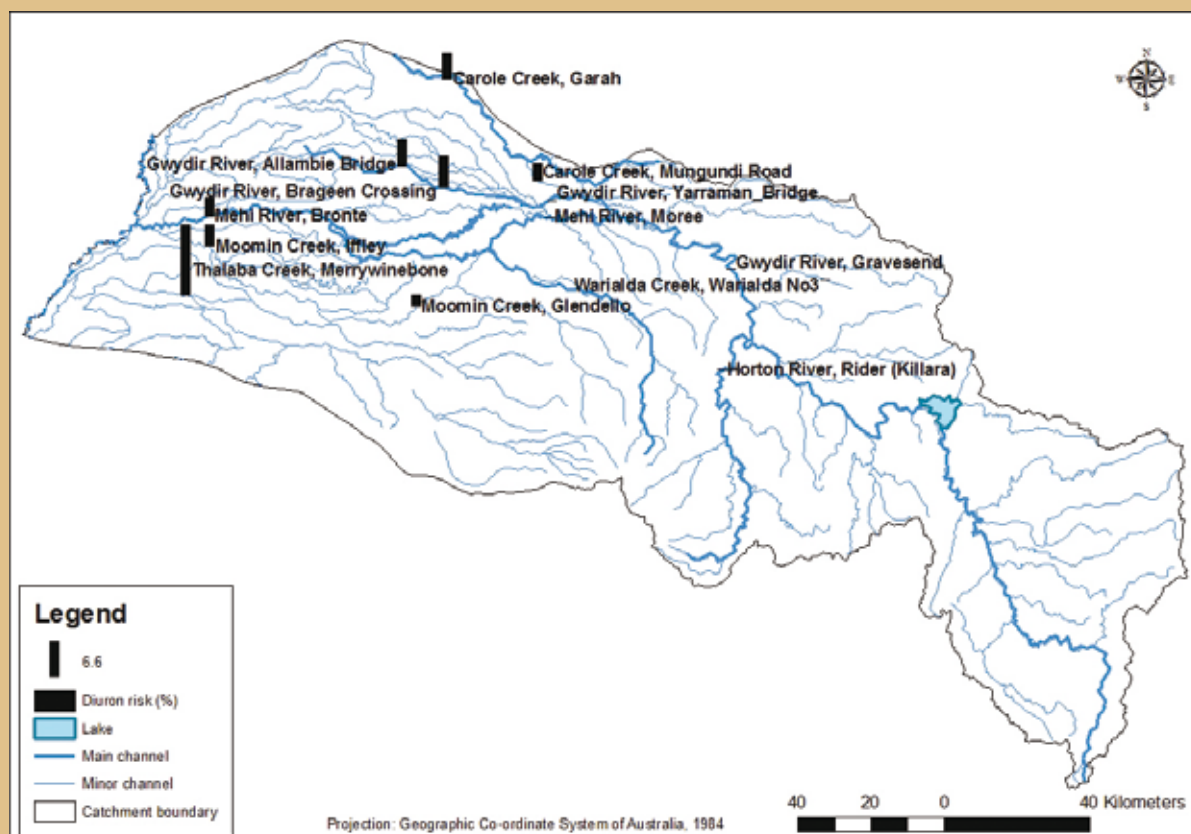
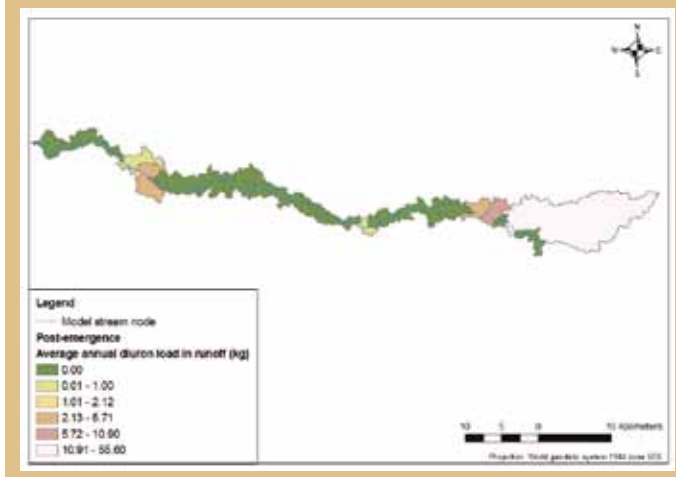


FIGURE 2: Map of average annual sub-catchment diuron loading (kg) in runoff predicted to occur for the cotton post-emergence scenario.



each monitoring site. These identified uncertainties led to further research.

As diuron was found to pose the highest concentrations of concern, a laboratory study was undertaken at the University of Guelph, Canada, as part of the scientific exchange program at the Cotton CRC and CRDC, to understand how permanent the toxic effect of diuron was likely to be in a worst-case Gwydir River catchment pulse exposure scenario.

Two duckweed species (*Lemna minor* and *L. gibba*), which are a common aquatic plant and food source for animals, were tested for their ability to recover from a seven-day exposure to different concentrations of diuron. Following the exposure phase, two seemingly healthy plants were placed in to clean growth media for a further seven days to simulate a recovery phase.

Significant inhibition from the exposure to diuron occurred under the initial seven-day exposure treatment at certain concentrations. The populations of both duckweed species were able to recover from diuron inhibition to growth levels that were not significantly different from the control treatments. These results suggest that for pulsed exposure to diuron, some level of ecosystem resilience is possible and should be considered as a source of uncertainty in the assessment of ecological risk of diuron occurring in catchments.

To investigate the potential sources contribution to the diuron concentrations occurring, final study at Waterborne Environmental Inc, US, imulated sub-catchment loading. A modelling procedure, with the capacity for daily time step estimations of catchment areas contributing to chemical load, was selected. All maximum pesticide product label application rates were used for the respective land uses of cotton, wheat, chickpea, canola and pasture in the simulations, as a worst-case scenario. Specifically, pre- (i.e. chemical incorporated in the top four centimetres of soil) and post-emergent (chemical applied directly to the surface) diuron applications were simulated for cotton.

The simulations showed that with post-emergence diuron application the highest chemical loading for streams was predicted (Figure 2). This was the result of chemical being more readily available at the surface to be entrained in runoff. Specifically, the post-emergence application scenario reflected more closely the concentrations and timing observed in the monitoring data.

But the model framework was unable to predict exposure

concentrations on precisely the same dates as the monitoring data.

This model framework has the ability to characterise sub-catchments contributing chemical loads (Figure 2), potential pulse durations and their probabilities of re-occurrence, with the longest pulse exceeding the toxicity threshold lasting six to nine days. This approach for estimating pesticide concentrations at the sub-catchment level could be a useful tool for catchment management, specifically for devising and directing risk management strategies associated with monitoring, not before further calibration and validation efforts are undertaken.

This study provides justification for further development of catchment-based ERA strategies in Australia. Recommendations arising from this study include integrating site specific chemical loading into current models, using probabilistic risk characterisation techniques on a regular basis and accounting for ecosystem biodiversity value and resilience. This strategy would be inclusive of catchment managers operating at the local level interacting directly with stakeholders. Pesticide exposure concerns identified through an ERA should then be addressed through the implementation of a management strategy. This strategy would utilize outputs from spatial modelling supported by monitoring, as a basis for directing management to areas of a catchment where it is most needed. Managing pesticide exposure in agricultural catchments with more informed ERA can provide a sounder basis for pesticide use in crop production coexisting with ecosystem protection.

The experience gained from this PhD thesis and scientific exchange has led this student to take up a post-doc position at CIRAD, Montpellier, France. This current research involves investigating the ecological impact of pesticides within the life-cycle assessment (LCA) framework. Specifically, improvements to the environmental fate models used to predict pesticide exposure in terrestrial and aquatic environments, in the LCA framework, are being undertaken. This work will serve to distinguish the long-term ecological sustainability of different pesticide management practices in a range of cropping environments.

For more information contact ivan.kennedy@sydney.edu.au

Acknowledgements: This project was jointly funded by the Cotton Catchment Communities CRC and Cotton Research & Development Corporation. Other important contributions to this project were made by the NSW department of Water, Dr Mark Hanson (University of Manitoba, Canada) and toxicologists at the University of Guelph, Waterborne Environmental Inc (USA) and DuPont crop protection (USA).

The final report will be available from The University of Sydney library website.



Simple test to measure nutrient concentration in runoff

■ Angus Crossan, The University of Sydney

IN BRIEF...

- Twenty water quality test kits were developed and distributed via cotton industry extension personnel.
- Results illustrated that nutrients are exported off fields in irrigation tailwater.
- Participants in the trial could see the benefit of using the kits to manage their water quality.

TWENTY water quality test kits were distributed throughout the Namoi, Border Rivers, Hillston and Burdekin irrigation areas. The aim of the work was to develop a simple kit for water quality analysis and to assess the enthusiasm for adoption of such kits within agricultural practice.

It is clear that nutrients are exported off fields in irrigation tail water. Based upon these indicative calculations at least 15 per cent of the applied nitrogen nutrient is lost in irrigation runoff; similar concentrations would be expected to leach with any sub-surface deep drainage water.

Excluding potential sub-surface nutrient loss, there is strong evidence that nitrate is distributed within the irrigation return

Irrigation	NO ₃ ⁻ Concentration (mgL ⁻¹)	Runoff volume (ML Ha ⁻¹)	NO ₃ ⁻ Mass (kg Ha ⁻¹)
1st	33.33	1.5	49.9
2nd	9.5	1	9.5
3rd	18.75	0.4	7.5
4th	8	1	8
Total Loss (NO ₃ ⁻)			74.9
^a Equivalent NH ₄ ⁺			22.5
Applied NH ₄ ⁺ (kg Ha ⁻¹)			150
Indicative loss per hectare			15%
^a Determined from mole ratio			

systems, shown by the concentration of nutrient in headwater; but approximately 35 per cent of this ‘re-applied’ nitrate can be detected in runoff (although the nitrate concentrations in tail water are generally higher than headwater concentrations, see Tables 1).

Because of the variables involved in efficient nutrient use and the poor return of data in this pilot study, it was not possible to draw any generalisations with regard to nutrient use and losses in the cotton industry. Variables that influence efficient nutrient use include: the amount, method and timing of nutrient applications; the timing of irrigations; and the physical and chemical characteristics of the nutrient mixture.

As it is often the case, obtaining site-specific data is the most relevant for environmental management because it reflects more precisely local practices, such as type and timing of nutrient application. This pilot study has demonstrated that the introduction of tools for measuring the efficiency of nutrient use can provide site-specific data to facilitate improvement in practice. Participants in the trial indicated that they could see the benefit of the kits in management of water quality. Most participants appreciated that whilst the accuracy of the tests may be lower than laboratory methods, the results are immediately available.

The test kits used in this study are a rapid and inexpensive approach to measure the concentration of nutrients in water with each suite of analyses costing approximately \$4.30. Therefore any changes in practice can be quickly assessed with respect to nutrient use efficiency together with economic budgets that can be quickly calculated to justify improving practices. In conclusion, these water quality tests provide the cotton and irrigation industry with a simple tool to measure and record economic and environmental improvement through better practice.

Further reading www.cottoncrc.org.au

Funding: Cotton Catchment Communities CRC and Cotton Research & Development Corporation.



Auscott Narrabri farm manager Martin Mead and CRDC NRM manager Jane Trindall.

Water quality in Northern NSW

■ Warwick Mawhinney, New South Wales Office of Water



Warwick Mawhinney.

IN BRIEF...

- Pesticide detections in rivers have dropped significantly since monitoring began in 1991.
- BMP (*myBMP*) remains an important tool/process for growers and advisers to ensure good outcomes.
- Look after your riparian zone. In turn it will look after your water quality.

So, how are our brothers the rivers? Water quality can be an important indicator of river health and can be influenced by catchment condition. It reflects the interactions of natural, physical and man made practices that occur in a drainage area and the riparian zone. Runoff from cropping areas, erosion of soil and nutrients from stream banks and discharge from saline areas can lead to increased turbidity (a measure of water clarity), salinity, sedimentation, increased nutrient load and chemical residues which in turn can degrade aquatic ecosystem health.

The NSW Office of Water and its predecessors have been monitoring water quality in the northern Murray Darling Basin under various programs for the past 30 years. These programs have included monitoring a range of pesticides, nutrients and physical parameters over different time periods for varying reasons.

A high profile issue in the northern basin has been the detection of agricultural chemicals (including insecticides and herbicides) in surface water. There has been concern among water managers, industry groups and the community as a whole about the effects of exposure to agricultural chemicals on humans and the environment.

In the 1990s the most commonly detected insecticide in surface waters of the northern Murray Darling Basin was endosulfan; over 50 per cent of samples contained residues of this chemical. The introduction of restrictions on endosulfan use, further emphasis on the development and implementation of the cotton industry's best management practice guidelines and the introduction of genetically modified Bt resistant cotton have each contributed to a continued trend of declining levels of endosulfan in waterways. At the same time there was a decline in the detection of herbicides used in cotton production in our waterways, but herbicides used in dryland agriculture continued to be detected as shown in Table 1.

Improved tail water return systems, integrated pest management, the introduction of Bt cotton and continued education regarding industry best practice have all helped to further reduce the movement of chemicals into river systems. But the continued detection of agricultural chemical residues shows a need for an ongoing concerted effort by all growers, agricultural chemical suppliers and sprayers to follow the guidelines for the handling, storage and application of pesticides and continuing

"The rivers are our brothers. They quench our thirst... and feed our children. So you must give to the rivers the kindness you would give to any brother."

— Chief Seattle¹

good agronomic practices. Natural filters such as grassed waterways, natural grasslands or vegetated buffer strips can also reduce chemical concentrations in runoff and aerial drift.

Agricultural chemicals are often seen as the cause of fish kills, but this is not always necessarily the case, as shown when NSW DPI investigated a large fish kill in the Barwon River at Bourke in 2011 and found this to be the result of a natural process triggered by floodwaters. The Office of Water undertook an assessment of water quality trend in NSW in 2008. The aim of this trend analysis was to identify whether our water quality is getting better or worse. The three parameters investigated were those most likely to demonstrate an improvement in riverine ecosystem condition from the implementation of natural resource management; namely electrical conductivity (salinity),





salinity concentrations increase again as catchments ‘wet up’ and groundwater aquifers are recharged, or if recent lower salinity observations persist into the future.

The turbidity results were not as clear. Inland turbidity behaviour was a mixture of increasing trends, stable or no clear trend being evident. Some underlying soil types can lead to higher turbidity levels naturally in some inland streams. Turbidity is only likely to decrease with significant stabilisation of stream bed, banks and gullies throughout the catchment. Ultimately a reduction in turbidity levels will take time, as the large volumes of soil eroded from the landscape over past decades percolate through the river system.

Water temperatures in the western lowland rivers were found to be stable over the past 30 years. This could be attributed to the extent of riparian vegetation, which has a major influence on water temperature, remaining relatively unchanged in these western flowing rivers.

An improvement in water quality is achievable through improved land management practices. Pollutants such as sediment, nutrients and pesticides can be prevented from entering our waterways through land, soil and vegetation management. Maintaining groundcover, vegetated buffer strips, best management practices for chemical handling and application and good agronomic practices in conjunction with the management of riparian vegetation to reduce stream bank erosion provide simple and effective means to improve water quality.

In overview it appears that the level of kindness to our brothers the rivers, has increased over past decades when it comes to levels of pesticides, but only time will tell if salinity and turbidity levels improve.

Reference: ¹Attributed to Chief Seattle from a letter to President Pierce, 1855.

Further reading:
Mawhinney, W. (2011). *Namoi Water Quality Project 2002-2007 – Final Report*. NSW Office of Water, Sydney. ▲

turbidity and water temperature. In answering this question, the assessment attempted to describe the trend of these parameters over the past three decades.

Electrical conductivity (salinity) was found to have a cyclical behaviour at a majority of lowland river sites, linked to prevailing conditions, with a decline during the 2000s most likely caused by extended drought conditions. Long periods of drought can cause a drop in shallow groundwater levels resulting in a disconnection between saline groundwater and fresher surface water. This causes the observed lower salinity levels in affected streams. Continued long term monitoring will assist in identifying whether

TABLE 1: Number and percentage of detections of common pesticides from samples collected from rivers in the main cotton growing areas of northern NSW (Namoi, Gwydir and Macintyre Valleys) from 1991–92 through to 2006–07

Major user	Endosulfan	Fluometuron	Prometryn	Diuron	Metolachlor	Atrazine	Simazine	Number of samples
	Cotton	Cotton	Cotton	Cotton, broadacre	Cotton, broadacre	Broadacre	Broadacre	
1991–92	173 (67%)	16 (6.2%)	41 (16%)	60 (23%)	0	130 (51%)	ns	257
1992–93	193 (79%)	17 (7%)	32 (13%)	28 (12%)	0	109 (45%)	ns	244
1993–94	161 (75%)	23 (11%)	15 (6.9%)	32 (15%)	14 (6.5%)	77 (36%)	ns	216
1994–95	126 (54%)	6 (2.6%)	13 (5.6%)	23 (9.9%)	2 (0.9%)	117 (50%)	ns	233
1995–96	170 (65%)	2 (0.8%)	23 (8.8%)	17 (6.5%)	23 (8.8%)	165 (64%)	0	260
1996–97	206 (55%)	35 (9.3%)	38 (10%)	25 (6.6%)	21 (5.6%)	134 (36%)	1 (0.3%)	377
1997–98	193 (51%)	71 (19%)	49 (13%)	38 (10%)	40 (11%)	80 (21%)	4 (1.1%)	379
1998–99	182 (47%)	70 (18%)	30 (7.8%)	81 (21%)	54 (14%)	142 (37%)	6 (1.6%)	387
1999–00	122 (30%)	74 (18%)	39 (9.7%)	81 (20%)	55 (14%)	179 (44%)	2 (0.5%)	404
2000–01	65 (17%)	81 (21%)	24 (6.2%)	47 (12%)	58 (15%)	176 (45%)	19 (4.9%)	390
2001–02	14 (6.6%)	17 (8%)	14 (6.6%)	28 (13%)	15 (7%)	70 (33%)	15 (7%)	213
2002–03	4 (1.5%)	18 (6.6%)	12 (4.4%)	25 (9.2%)	7 (2.6%)	59 (22%)	2 (0.7%)	272
2003–04	1 (0.4%)	18 (6.5%)	10 (3.6%)	29 (10%)	15 (5.4%)	106 (38%)	5 (1.8%)	279
2004–05	33 (12%)	24 (9%)	31 (12%)	32 (12%)	43 (16%)	154 (58%)	2 (0.8%)	266
2005–06	13 (4.7%)	17 (6.1%)	19 (6.8%)	25 (9%)	29 (10%)	157 (57%)	27 (9.7%)	278
2006–07	1 (0.6%)	6 (3.9%)	5 (3.2%)	16 (10%)	12 (7.8%)	88 (57%)	14 (9.1%)	154

ns = not sampled



The Fitzroy partnership for river health involves 26 organisations.

A partnership for river health

ALMOST \$1 million dollars will be invested over 18 months to create a report card on the health of waterways throughout the entire Fitzroy Basin in a partnership of 26 organisations.

This investment is backed up with water quality monitoring data from current programs that cost participating organisations more than \$3 million dollars collectively.

The newly formed Fitzroy Partnership for River Health hosted by the region's leading natural resource management group Fitzroy Basin Association, is one of Australia's largest waterway monitoring alliances in terms of organisations involved and catchment size. The Fitzroy Basin is the second largest seaward draining catchment in Australia and the largest flowing to the world heritage listed Great Barrier Reef lagoon.

In recent years the Central Queensland community has expressed growing concern over the quality of water. The Fitzroy Partnership for River Health aims to ensure the community is well informed on the health of our waterways by drawing on data collected across the basin from 450 different locations to prepare a report card and communicate the results in a way people can understand.

All water quality monitoring data collected from rivers, estuaries and near-shore coastal and marine environments will be shared through the partnership to deliver a report card in mid 2013.

By establishing the Fitzroy Partnership for River Health and working together, all partners are committing to ensure water quality is acceptable and meets the needs of aquatic ecosystems and the community both now and in the future.

For more information: www.riverhealth.org.au



Understanding surface and ground water connectivity

■ Ian Acworth, Connected Waters Initiative Director, The University of NSW

IN BRIEF...

- A major investigation site has been established at Maules Creek, south east of Narrabri, to investigate the processes that determine the exchange of surface water and groundwater.
- The resulting concentration of groundwater infrastructure, surface water gauging, sampling and climate monitoring has made this site of international significance.
- In developing an understanding of the groundwater dependent ecosystems along the creek it was found that the water level rises and falls each day, even in dry periods.

INVESTIGATIONS from a small creek near Narrabri are reaching the world via a website that receives more than 500 hits per week – usually from more than 70 countries.

The site was developed by the UNSW Connected Waters Initiative (CWI) Research Centre team at the Water Research Laboratory in Manly Vale, who also undertook the Maules Creek study.

The work at Maules Creek has spanned the end of one of the longest droughts on record and the return to wetter conditions in 2011, 2012. Data loggers installed in the various boreholes have captured much of the response of the hydrological system to this major variation from drought to flood.

For the first few years of the site operation, we measured the responses of the system as the creek slowly dried out and became disconnected from the underlying aquifer. With the end of the drought, we have been able to monitor the return to wetter conditions as the aquifer has slowly filled and resulted in much longer duration surface flow to the current time (April 2012) where there is again a steady flow across the road at Elfin Crossing. The changes through this period are clearly shown in Figure 1 which depicts hourly water levels at Elfin Crossing since



Two time-lapse video cameras have also been installed: one at Elfin Crossing and a second on Middle Creek. The Elfin Crossing camera is mounted close to the Bureau of Meteorology gauging station.

January 2006. This data also reflects the difficult years for the cotton industry.

Maules Creek and groundwater of the underlying aquifer are being studied using a combination of geological data, hydraulic data, stream water levels, fluid EC, temperature and resistivity imaging.

A comprehensive monitoring facility has been completed at Elfin Crossing on Maules Creek. The location of bores and a cross-section showing monitoring locations beneath the creek are shown in Figures 2 and 3. These installations are being monitored and allow us to see how water moves beneath the creek in response to surface flooding or groundwater abstraction.

The monitoring facility at Elfin Crossing has built on the

FIGURE 1: Hourly water levels at Elfin Crossing 2006–12.

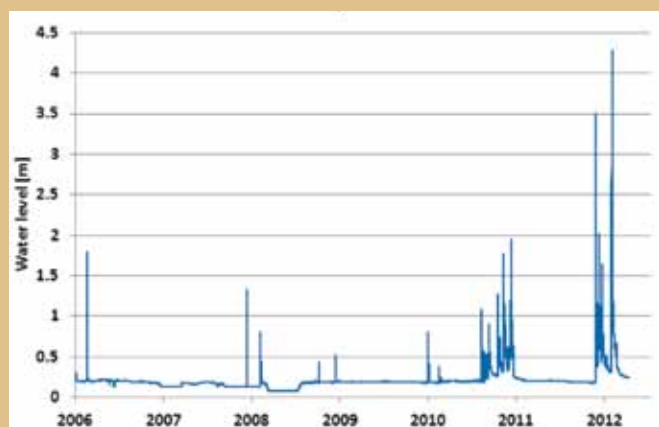


FIGURE 2: Location of bores at Elfin Crossing.

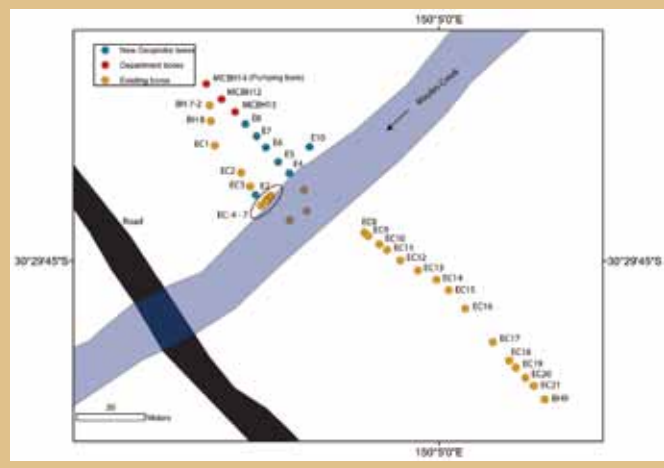
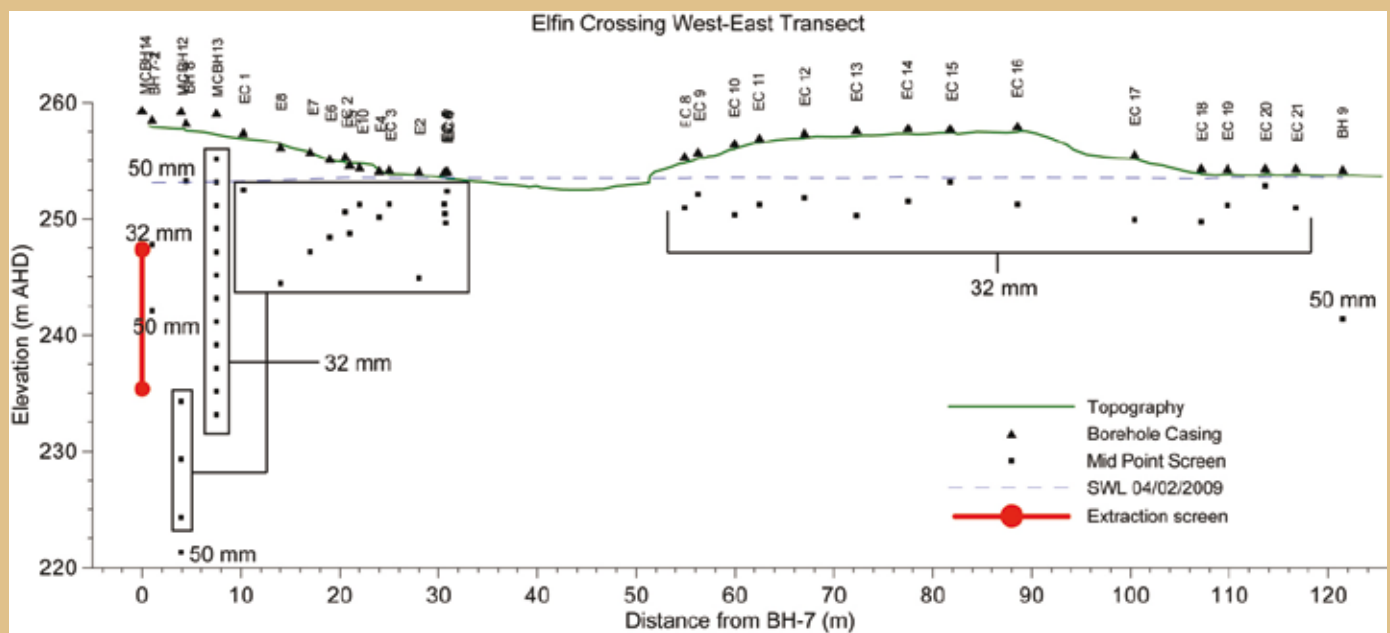


FIGURE 3: Cross-section showing monitoring locations beneath Maules Creek.



initial investment by the Department of Water Resources in the establishment of deep piezometers to monitor groundwater levels. More recently, the Department has been reengaged to drill on the north bank (locations shown Figure 2) as shown in Figure 4.

These bores have been supplemented by shallow piezometers installed by the UNSW team using a GEOPROBE rig (Figure 5).

There have been many periods of field work as the team have built an understanding of the surface water and groundwater dynamics. Major data sets have been established and papers presented in a series of international conferences and in journals. Three PhD theses have been presented on various aspects of the data. In addition to this academic and research output, the team have spent many hours talking with the local residents and presenting results in farm yards, village halls or the cotton research meetings. This work will continue for many years to come.

One area of interest has been to develop an understanding of the groundwater dependent ecosystems along the creek. It was

noticed that the water level rises and falls a little each day, even in dry periods. Investigation of the creek base and the observation that water levels seem to be higher at night, as shown by the higher water mark on the tree (Figure 6), have led to the understanding that the trees begin to transpire water as soon as the sun rises above the horizon and continues till the sun sets.

In February 2012, Maules Creek experienced the second highest flood on record. There remains much analysis work to understand the catchment response to these events.

The team has included Martin Andersen, Wendy Timms, Bryce Kelly, Ian Acworth, Andrew McCallum, Anna Greve, Beatrice Giambastiani, Gabriel Rau, Mark Whelan, Josh Larsen, Adam Hartland, Sam McCulloch, Hamish Studholm and a number of fourth year and master's students from UNSW. Professor Ian Acworth (CWI Director) has been the team leader.

FIGURE 4: Establishment of deep piezometers.



FIGURE 5: Installation of shallow piezometers.



Final reports at www.cottoncrc.org.au.

Presentation by Martin Andersen to the International Association of Hydrogeologists (IAH) at https://www.connectedwaters.unsw.edu.au/downloads/Surface_water_groundwater_interactions_IAH-NSW_9Sep2008.pdf

Data from the sites are being posted to the Groundwater EIF web site and can be downloaded from:
https://www.connectedwaters.unsw.edu.au/technical/groundwater EIF/geif_namoi.html and
<http://groundwater.anu.edu.au/fieldsite/namoi>

Funding: Initial funding for this research was provided by the Cotton Catchment Communities CRC in 2006 and again in 2010. This was augmented with funds from the National Water Commission in partnership with Land

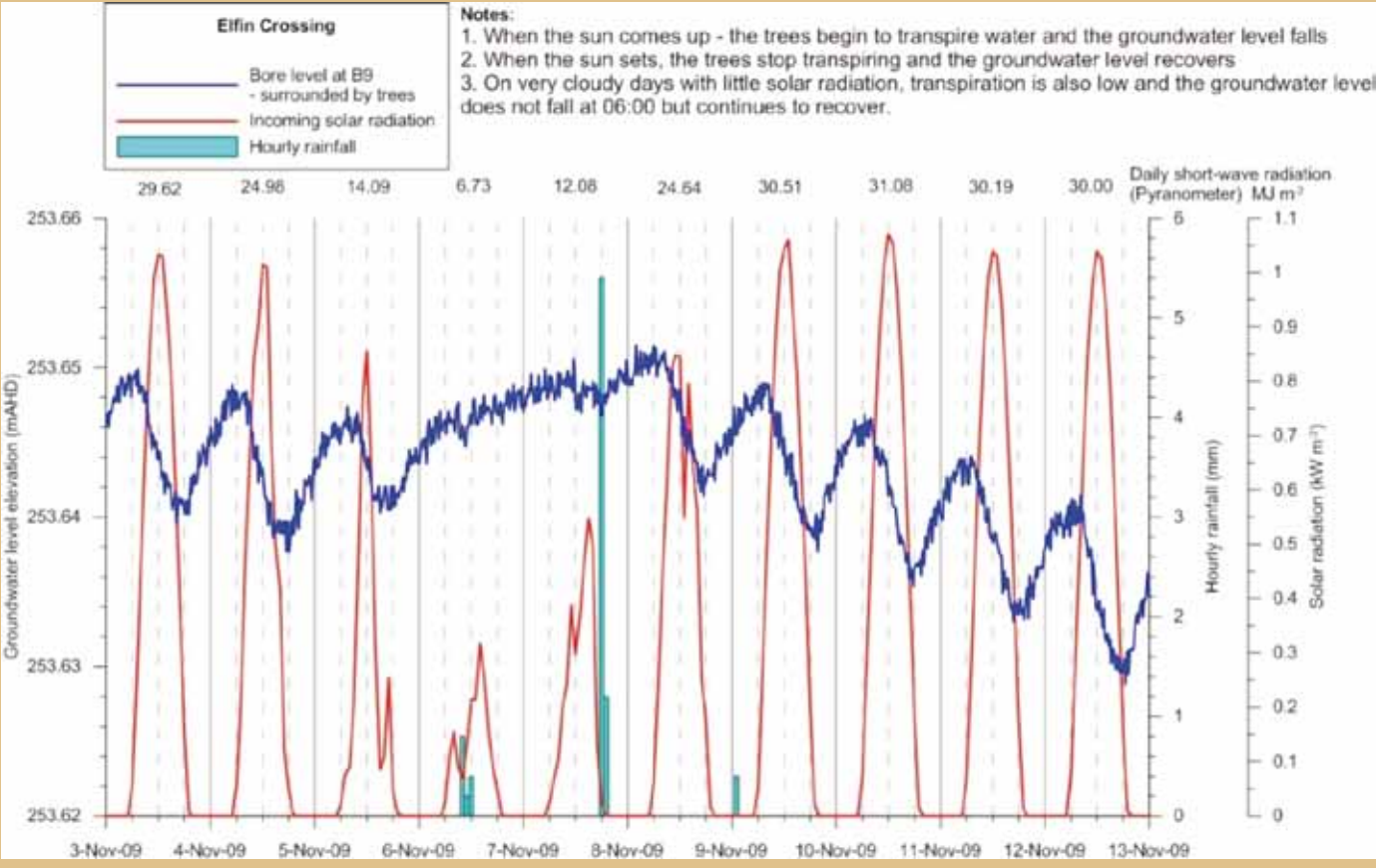
and Water Australia (later CRDC) in 2009 and then significantly expanded in 2010-2012 with funding from the Department of Innovation, Industry, Science and Research (DIISR) under the Groundwater Education Investment Fund (EIF) Project (Super Science). The first international researcher will commence work later in 2012 with funding from the EEC (Marie Curie Scholarship) to work for three years at the site. The infrastructure will be monitored into the future to assist with the DIISR Groundwater EIF plan to determine the influence of climate change on groundwater resources. ▲

FIGURE 6: Tree showing water level mark.



Martin Andersen taking groundwater measurements.

FIGURE 7: Daily water level fluctuations shown as groundwater levels plotted against rainfall and solar radiation.



3D geological modelling shows trends in groundwater levels

■ Bryce Kelly, The University of NSW

IN BRIEF...

- 3D aquifer models help us map the bores that have high river connectivity, as well as the bores that have low recharge.
- Establishing baseline groundwater conditions is essential to inform aquifer management decisions.
- The ability to visualise the aquifer architecture provides improved insights about the evolution of the alluvial aquifers.
- Researchers have shown that a significant proportion of the water being used in the Namoi catchment, and most likely throughout the Murray Darling Basin, is 10,000 to 20,000 years old.

THE UNSW Connected Waters Initiative has developed a new 3D modelling environment and groundwater level hydrograph data analysis software called Crystallize. This software improves the way we map the connectivity between surface and ground water. 3D groundwater hydrographs have been developed for the Namoi, Gwydir, Lachlan, and Macquarie catchments. Mapping the connectivity of surface and ground water helps us identify which bores are well connected to the rivers and flood recharge zones, and which bores are located in regions that receive little recharge.

There are numerous historical data sets that relate to groundwater management. As yet there is no internationally recognised standard approach for collating the information, or rules for how to interpret climatic data, construct 3D geological models, or build comprehensive catchment scale groundwater flow models as part of estimating available water resources. UNSW researchers set out with the goal of providing an improved environment for coordinating hydrological and geological data, and streamlining the analysis.

The 3D geological models have helped us to better understand the aquifer architecture, which can help with mapping aquifer connectivity. Being able to visualise the aquifer architecture also provides improved insights about the evolution of the alluvial aquifers. Twelve million years ago, during the mid-Miocene period, the palaeovalleys, up to 150 metres deep, that had been carved through the bedrock of the Murray Darling Basin began to fill with sediments. During this period the climate was much wetter. Pollens found in the ancient sediments indicate that the Namoi received at least 1500 mm of rainfall a year, and similarly high rainfall must have occurred in the other catchments of the Murray Darling Basin. The rivers flowing through the valleys were fast flowing, and they left behind thick units of sand and gravel. It is from these units that we now extract the fresh groundwater used for irrigation.

Around two million years ago the climate slowly became drier to the point that we now have around 600mm of rainfall in many irrigation districts. As the climate dried out the rivers became smaller and less gravel and sand was deposited across the wider landscape. The upper 20 metres of our alluvial aquifers

is dominated by a mixture of flood and wind deposited clays and silts, through which isolated meandering palaeochannels occur. This means that in places there is poor connectivity between the shallow aquifers that are recharged during heavy rains and floods, and the deeper aquifers used for irrigation. These flood and windblown deposited sediments also contain higher concentrations of salt.

FIGURE 1: A groundwater hydrograph showing that the aquifer is recharged by floodwaters. Groundwater irrigation bores near this monitoring location will have ongoing access to groundwater.

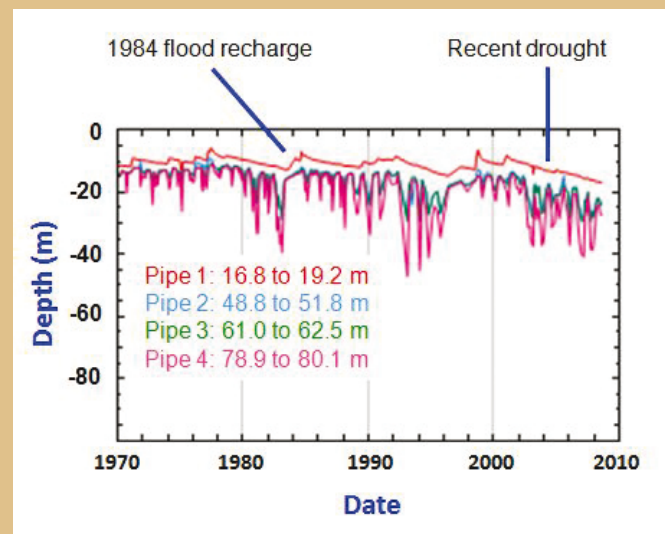


FIGURE 2: A groundwater hydrograph indicating that groundwater extractions are in excess of the aquifer recharge. This is indicated by the continuous fall in the winter recovered water level from the late 1970s through to 2009.

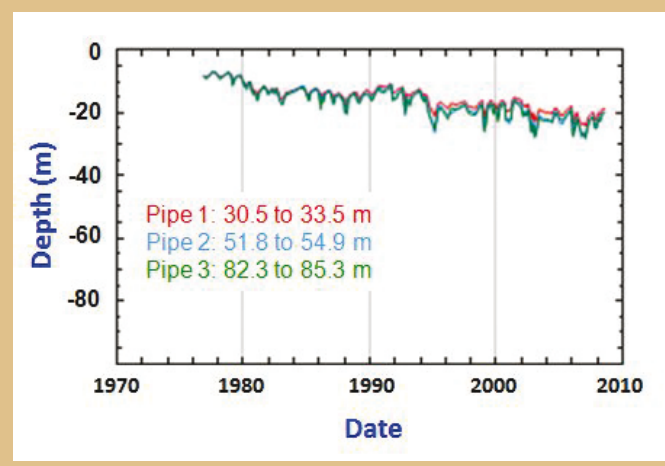
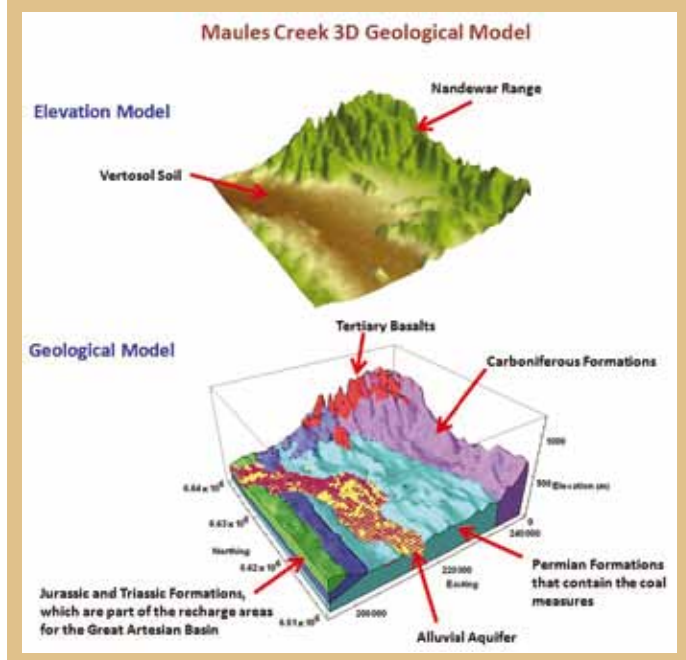


FIGURE 3: A 3D geological model of the Maules Creek catchment, constructed using Crystallize.



Establishing baseline groundwater conditions is essential for informing aquifer management decisions. Since the 1960s various government water departments have installed and monitored the groundwater levels in our irrigation districts. Simple graphs of the groundwater levels recorded in the monitoring boreholes highlight if groundwater usage nearby is sustainable or likely to be restricted in the future. An example where the aquifer is replenished during floods is shown in Figure 1, while in Figure 2 an example is presented where groundwater extractions are in excess of recharge. This research has shown, it is a good thing for groundwater extraction points to be well connected to a river, floodway recharge zone, or mountain-front recharge zone. In areas remote from recharge zones, groundwater levels will not recover in our lifetime.

UNSW researchers have co-ordinated all the groundwater level data and developed methods to analyse the data in 3D. This has also allowed UNSW researchers to produce videos that show the groundwater levels rising and falling with changing rainfall, streamflow and groundwater extractions.

UNSW researchers have shown that a significant proportion of the water being used in the Namoi catchment, and most likely throughout the Murray Darling Basin, is 10,000 to 20,000 years old. This water is now being replaced by modern river water, which is being pulled deep down, 50 metres or more, into the alluvial aquifers as a result of groundwater extractions. A study across the Namoi catchment found that at some locations groundwater salinity was increasing at depth, probably due to saline water previously entrapped in the near surface clayey units being mobilised and moved to depth. It is important to understand that once there is an impact detected at the point of use then significant zones of the aquifer will already have undergone an irreversible deterioration in water quality.

New groundwater chemistry surveys of water quality are required in all catchments of interest for the cotton industry. In addition to the routine water quality parameters, these water quality surveys need to include organics to provide baseline conditions to assess the potential impact of the coal mining and

coal seam gas sectors.

With the expansion of coal mining and coal seam gas extraction in our farming catchments there is considerable concern about the impact of these activities on irrigation water supplies. The 3D geological models provide a framework for understanding the relationship between the coal measures and the alluvial aquifers. An example is shown for the Maules creek catchment in Figure 3. These 3D geological models also form the framework for flow simulations used to predict the cumulative impact of all groundwater uses.

In regions where there are continuously declining groundwater levels, managed aquifer recharge may be a way of replenishing the groundwater supplies. There are zones in the Namoi, Lachlan, Gwydir, Macquarie, and Condamine catchments where the groundwater levels have fallen 10 m or more. These areas would benefit from managed aquifer recharge (MAR). Exploring the potential benefits of MAR is particularly important if all areas are to have continued access to groundwater supplies. The water used for MAR could come from either floods or coal seam gas produced water. The newly developed 3D geological models of our aquifers map the location of palaeochannel belts that can be targeted for recharge.

Land use is constantly evolving in our catchments, and Australia has a highly variable climate. This means that water management will be an ongoing issue. Groundwater moves slowly, and it can take years for the impact of management decisions to show in the groundwater level monitoring data. In many of our catchments we have only just implemented new water sharing plans. The expansion of mining and gas production will add to the environmental stresses in our catchments. The 3D geological model software and hydrograph data analysis tools developed by UNSW researchers will enable us to better monitor and evaluate the impact of water management decisions and changes in land use.

Further reading:

Final report at www.cottoncrc.org.au

https://www.connectedwaters.unsw.edu.au/resources/video/video_maules.html

Funding: Cotton Catchment Communities CRC, National Water Commission, Namoi Catchment Management Authority. ▲

Namoi research in the spotlight

■ Ian Acworth, Wendy Timms, Andrew McCallum, Anna Greve, Bryce Kelly, and Gabriel Rau, Martin Andersen, The University of NSW

GROUND BREAKING research on the interconnection between groundwater and surface water in the Namoi Valley has been recognised at the most prestigious awards in Australian science. The Connected Water Initiative (CWI) Team from the University of NSW became one of just two finalists in the 2011 Australian Museum Eureka Prize for Water Research and Innovation, highlighting the significance of the Team's findings on the interconnectivity of water in our landscape, a subject which has been poorly understood in the past.

The research team has developed new science and computer modelling methods to quantify the impact of extraction on groundwater resources and to reveal the extensive linkages between aquifers and river flows. Their innovative research techniques have created the most detailed modelling of aquifer interconnectivity ever compiled in Australia's agricultural regions, demonstrating the extensive interaction of water flows. The development of new scientific tools to accurately assess groundwater storages is providing greater certainty for both irrigators and the environment. The CWI research will enable farmers to make informed decisions about water usage and to plan new strategies for a sustainable future.

The CWI Team's research findings are already being incorporated into local water management planning in the Namoi Valley, with irrigators in areas close to Water Sharing Plan limits, proactively adopting strategies such as water rostering at low flows to protect riparian vegetation, aquatic ecosystems and general river health.

This research has been funded by the Cotton Catchment Communities CRC, the National Water Commission, the Namoi Catchment Management Authority, the Cotton Research & Development Corporation, and Cotton Seed Distributors. The generous support of the Cotton CRC and fellow contributors has played a key role in the development of new science that will be crucial to ensuring the ongoing viability of the Australian cotton industry. ▲



UNSW Connected Water Team Professor Ian Acworth, Dr Wendy Timms, Research Associate Andrew McCallum, Dr Anna Greve, Associate Professor Bryce Kelly, and Gabriel Rau, finalists in the 2011 Eureka Water Innovation Prize.

What's in my aquifer?

■ Wendy Timms, The University of New South Wales

IN BRIEF...

- A new database of groundwater quality in the Namoi catchment showed trends since the 1970s.
- Monitoring bores showed about half with stable salinity, a quarter with increasing salinity, and a quarter with freshening.
- Significant aquifer freshening had occurred near rivers, while salinization had occurred at a few hot spots, including the Breeza Plain.
- Groundwater levels have generally declined in irrigation areas in the since the 1970s, with some recovery during recent wet periods, except in disconnected aquifers.
- DIY monitoring of bore levels and quality at point of use is encouraged for all landholders and irrigators and a cotton industry *myBMP* for groundwater monitoring is available.

PROTECTING aquifers is a critical priority in many communities that are reliant on underground water, particularly for irrigating food and fibre crops, domestic water supplies and base flow in rivers. Sand and gravel aquifers below the plains yield high volumes of good quality water, supporting agricultural productivity of at least \$380 million each year in the Namoi alone.

This project helped define how groundwater levels and salinity vary both spatially and over time within the Namoi catchment, while related projects during 2008–10 focused on industry training and researching knowledge gaps.

Myths and facts in groundwater story

There are many facts and myths as to where water comes from, how much rainfall and irrigation drainage can recharge aquifers and how aquifers and water quality could be damaged. To start with, it's important to consider two facts: useable groundwater is mostly in gravels and sands that are bounded by

low permeability rock basin; and recharge to aquifers is usually only about one per cent of rainfall.

Alluvial aquifers are often found between 30 and 200 metres deep, and were deposited by flowing water in geological basins that act like a bathtub. Relatively little water flows through the walls and floor of the bathtub which is made of rocks that are mostly of low permeability. For example, data shows only a small volume of water leaking into the base of gravel aquifers in areas where the base is formed by sandstones and shales of the Great Artesian Basin.

Regional groundwater flow systems can extend for hundreds of kilometres, with water moving at an average of only one metre or so every year. Flow rates can actually vary between approximately 0.01 and 10 metres per year, with the highest flow rates through gravel aquifers and fractured rock. Water pressure changes can move even faster than water itself.

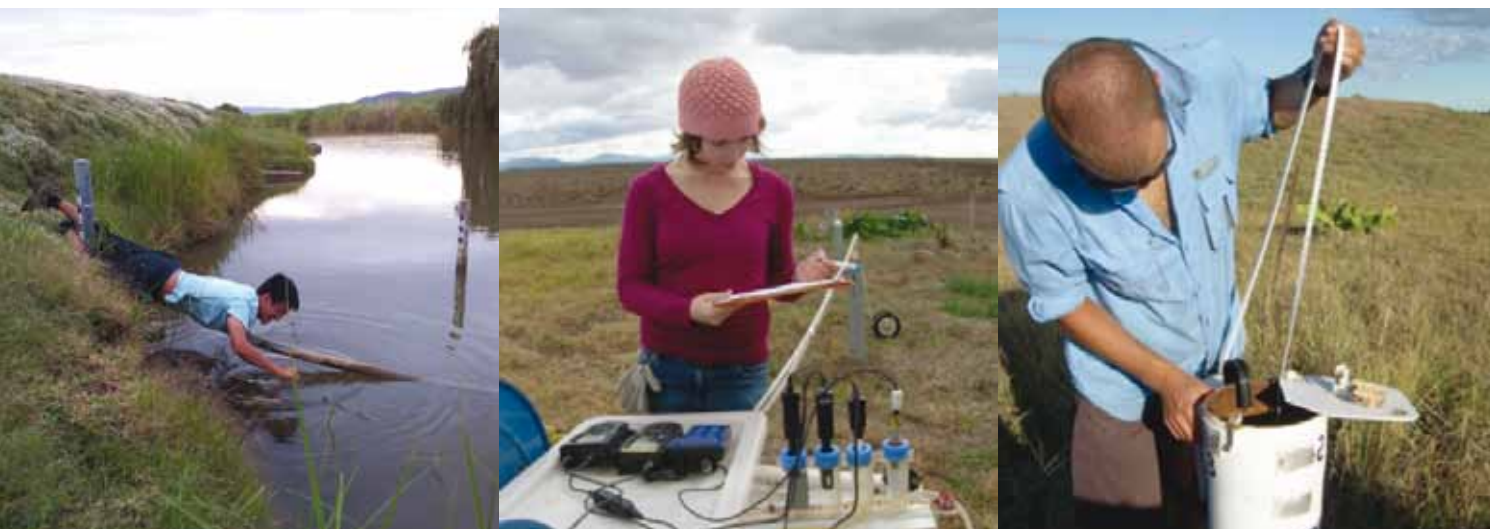
Most recharge occurs through sandy river beds near the top of catchments, and through leaky sediments on the plains even through silty clay. Leakage rates can also increase in areas where groundwater depressurisation has resulted in a large downwards gradient.

Namoi groundwater monitoring project

Monitoring of groundwater levels and groundwater quality is essential to ensure that aquifers remain in balance and continue as the life blood of catchments and communities. This project helped define how groundwater levels and salinity vary both spatially and over time within the Namoi catchment. Historical data and data collected between January to July 2009 from production bores and key government groundwater monitoring bores were used for the evaluation.

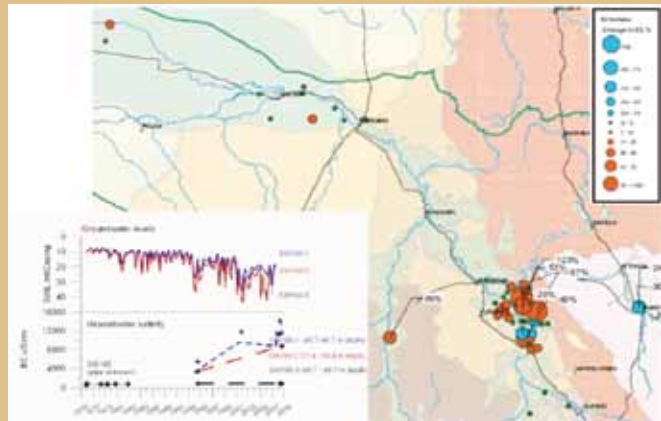
It was found that groundwater recovery levels each season remain relatively low compared to pre-extraction levels. But groundwater level drawdown appears to have stabilised in Zone 3 of the Upper Namoi and the unconfined aquifer of Cocks Creek.

Groundwater salinity was relatively stable at most sites where



Monitoring of rivers and groundwater for the Cotton CRC (left to right) summer student Mukhlis Mah, Honours student Malinda McDonnell, and UNSW engineer Duncan Rayner.

FIGURE 1: Salinity change upper aquifer – averages of 1980–99 compared with 2000–09. INSET: Hydrograph and groundwater salinity trend for worst case site, Breeza plain in the Namoi catchment. In general groundwater levels in all aquifers are lower than pre-extraction.



sufficient historic data was available (105 monitoring pipes), but significant groundwater salinity increases have occurred over the past two decades at about 20 per cent of sites. Freshening had occurred at about 25 per cent of sites. Some groundwater in Zone 3 of the Upper Namoi has become significantly more saline. The worst case was a 123 per cent Electrical conductivity (EC) increase up to 2009 with groundwater at 80 metre depth that had become too saline for irrigation of cotton. Yet groundwater in grower bores several kilometres away was found to be fresh, so further investigation of this finding is required.

A risk assessment identified four areas where changes in aquifer salinity might occur in the future, with the need for strategic monitoring. The groundwater resource is at risk in parts of the Upper Namoi alluvium (Zone 3 and 8) and Lower Namoi alluvium (north of Wee Waa and near Wee Waa). A greater than 10 per cent EC increase in a bore would provide an early warning indicator of changes in aquifer salinity.

Interviews and workshops were used to survey grower attitudes, identifying the following priority needs:

- Improve communication of groundwater information at the start of each irrigation season.
- Developing and promoting protocols for groundwater users to gather and track their own groundwater data.

In response to this feedback, the project further developed strategic monitoring guidelines with a level 4 Best Management Practice (BMP) for irrigation bore monitoring and a level 3 guideline regional scale. For example, a level 2 BMP is to maximise crop yields by using bore water within appropriate salinity guidelines.

To date the monitoring of groundwater water quality has been irregular, making statistical analysis difficult. Future catchment wide monitoring should focus on potential salinity hot spots in alluvial aquifers and should be extended to rock aquifers. A wider range of baseline water quality parameters such as nutrients, organics, trace metals and dissolved methane should also be assessed. Investing in strategic groundwater quality monitoring by individual growers and at a regional scale is vital to ensuring continued access to fresh groundwater resources by all users including the environment.



Duncan Rayner and Wendy Timms.

Groundwater – building human capacity

A study of water quality during the summer of 2011-12 has resulted in a few surprises. Thanks to a summer student scholarship provided by the Cotton Catchment Communities CRC, UNSW student Mukhlis Mah looked at water quality issues in the Upper Namoi catchment. In combination with National Centre for Groundwater Research and Training (NCGRT) projects in the Breeza area, Mukhlis Mah looked at salinity, nutrients and trace chemicals in creeks from Quirindi to Gunnedah, monitoring bores and several irrigation bores.

The good news is that the annual salt load during 2011 in the Mooki River and Namoi River was less than previous years, and far less than warnings of increased salt loads over time. Interestingly, trace organics of anthropogenic origin were widely detected in surface waters, and sometimes groundwater. What this indicates is, overall, while salinity continues to be a potential water quality issue, future monitoring should also include a wider range of parameters.

Funding: Cotton Catchment Communities CRC and the Namoi Catchment Management Authority.

The study team from the University of New South Wales (UNSW) included Dr Wendy Timms, Alexandra Badenhop and Duncan Rayner. The UNSW team worked with local collaborators on these groundwater projects for the Cotton industry. For example, GHD Hassall carried out industry surveys and assisted landholders with the "Groundwater sampling in July" bore sampling initiated by the UNSW Water Research Laboratory.

Further reading:

The final report can be found at www.cottoncrc.org.au and www.namoi.cma.nsw.gov.au.

Factsheets on groundwater and monitoring are available at <http://www.cottoncrc.org.au/industry/Publications/Water/Groundwater>.

<http://www.wrl.unsw.edu.au/namoi>

http://www.connectedwaters.unsw.edu.au/resources/fact/groundwater_myths.html

Looking deeper at Coxs Creek

■ Sarah Bennett and Willem Vervoort, The University of Sydney

IN BRIEF...

- In the Coxs Creek catchment, the lack of knowledge about the exact location and amount of rainfall is the largest source of uncertainty in deep drainage model predictions.
- The predicted change in timing in the future rainfall has a greater effect on modelled deep drainage than the predicted change in amount, which means that crop rotations will need to be adapted for better production and to minimise deep drainage losses.
- We need to estimate rainfall more accurately at all locations in the catchment, where particularly the timing of the rainfall is crucial.

DEEP drainage is linked to dryland salinity, but is also a natural process to recharge groundwater in the Coxs Creek catchment. We developed a method to create deep drainage maps that can be used as input into groundwater models. Simulation models are often used to assess management alternatives, but models are only representations of reality. To increase our trust in the predictions of simulation models, we need to understand where they can go wrong and where they do a good job.

Part of the problem with simulation models is that models are only as good as the input data and this input data can be quite uncertain. In our method we included the uncertainty (how unsure we are) of three different input values, rainfall, landuse and soil properties.

We found that in the Coxs Creek catchment, the lack of knowledge about the exact location and amount of rainfall is the largest source of uncertainty in deep drainage model predictions (Figure 1). This was followed by the lack of knowledge of the exact rotations that take place, as these can be quite flexible and vary from farm to farm. Soil properties, which we found in another research project to be of a large influence, had less influence on the prediction uncertainty, this is probably because landuse and soil properties are aligned and therefore these two interact with each other.

We also investigated the effect of changes in the rainfall amount and distribution under possible climate change. The predicted change in timing in the future rainfall has a greater effect than the predicted change in amount, and this means that crop rotations will have to adapt to these future shifts to minimise deep drainage losses.

The way we determined this for example, for rainfall, we used observations from the region to come up with statistical parameters showing where, when and how much falls. These parameters describe the possible rainfall that could occur in a region which we then used to generate rainfall randomly 50 times. These rainfall values (together with similar random samples from landuse and soil property distributions) were then used in a numerical one-dimensional soil water and plant model to calculate deep drainage at 143 soil points in the catchment.

The deep drainage output was a series of values for 25 years and we had 50 by 50 of these series for each location.

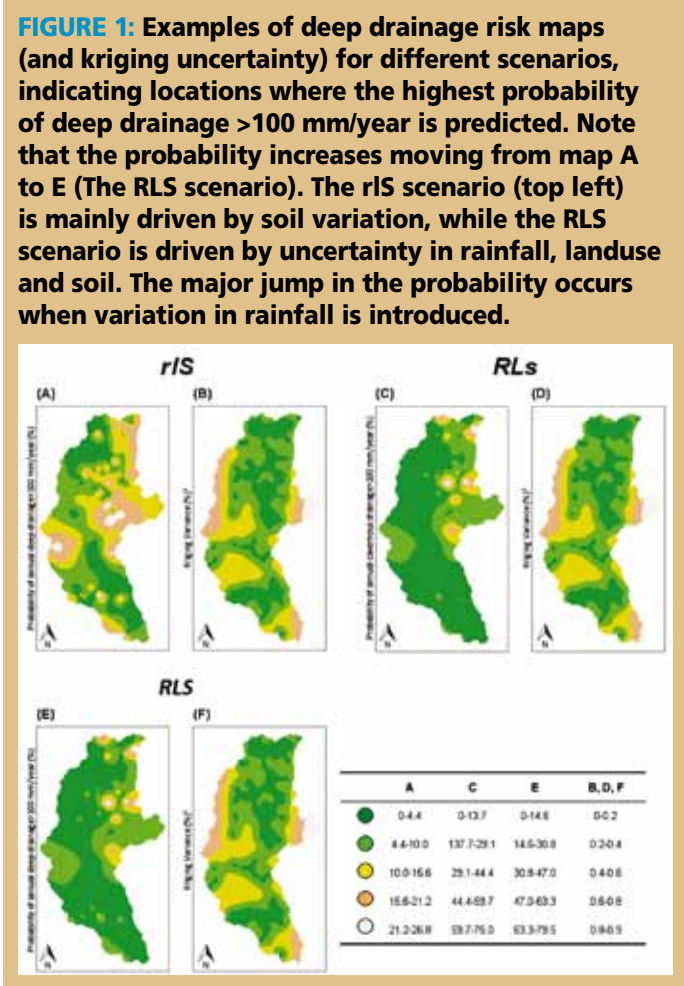
This meant we could calculate the probability of deep drainage, as well as determining which input had the highest influence on our deep drainage predictors. For this we looked how much variability was introduced by the 50 different input series in the final output series.

The deep drainage probabilities, as well as the mean and variability of the deep drainage values can then be mapped onto the catchment.

The conclusions of our research focused on the need to estimate rainfall more accurately at all locations in the catchment, where particularly the timing of the rainfall is crucial. Better understanding of landuse and rotations will also allow better landscape assessment of hydrology, a crucial component for future water resources management.

The research also highlighted that the uncertainty in the deep drainage estimates is actually quite high, purely because we don't have enough exact spatial and temporal information of rainfall and landuse. Satellite and radar derived rainfall will help resolving some of these uncertainties in the future.

Funding: Cotton Catchment Communities CRC.



Measuring streambed losses

■ Dawit Berhane, The University of Sydney

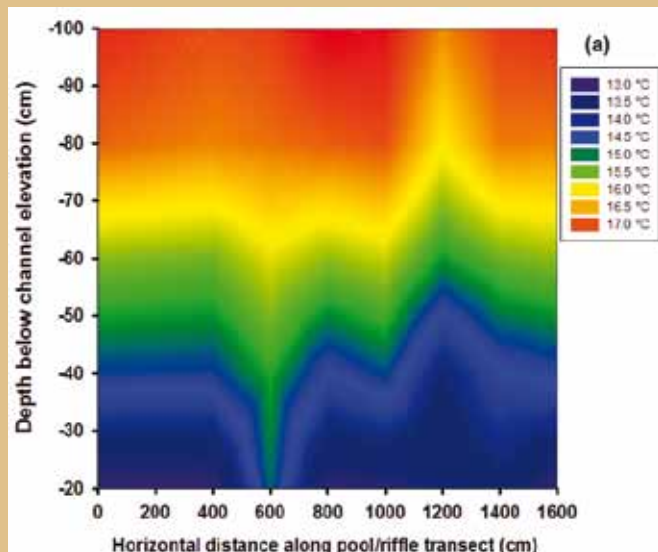
IN BRIEF...

- The flux (of water) through the streambed in the Cockburn River near Tamworth varies significantly in time and space.
- When measuring streambed losses, the location of the measurement is important due to spatial variability
- Changes in water temperature affect the losses of water through a streambed.
- During wet periods groundwater may rise along the banks of the river and water flows into the river, while during dry periods, the groundwater is below the river bed and water is lost from the river.

In many arid and semi-arid climates, losses of water through the streambed is one of the most important mechanisms for groundwater recharge. In other words, the surface water loss is the potential groundwater gain. Modern techniques using heat as a tracer can be used to estimate such losses. In literature, most of the citations on near streambed water exchanges are based on flume studied in a controlled laboratory environment. As part of heat tracing study in the Cockburn Valley, we were able to demonstrate the issue of scale in a field environment.

We found that the flux through the streambed in the Cockburn River near Tamworth actually varies quite significantly in time and space. At very fine scales, we have variations in the streambed (pools and riffles) that affect the fluxes and we observed that heads of riffles lose water, while tails of riffles gain water (Figure 1). This means that where you measure becomes important. At a larger scale, the fluxes from a water balance are mostly losses, but do not match up with the integrated losses

FIGURE 1: (a) Occurrence of a positive head of six cm at a tail of riffle; (b) Streambed isotherms along the Ballantines transect showing upwelling at 600cm and downwelling at 1200 cm.



Installation of in-stream piezometers at the Kootingal transect in the Cockburn Valley.

at the smaller scale, indicating a clear scale dependency in the losses.

Finally we were able to show that there is also a difference in the water exchanges through the river bed in time. During wet periods groundwater may rise along the banks of the river and water flows into the river, while during dry periods, the groundwater is below the river bed and water is lost from the river. In the study area, summer flooding is more frequent than winter flooding. Due to the frequency of occurrence of floods and difference in the actual viscosity (or 'fluidness' of the water), summer losses are greater than in winter. For instance, in the study area, stream temperatures varied from 9° to 30°C, resulting in a decrease of viscosity and an increase in infiltration rates by almost 50 per cent. In fact, stream temperatures exceeded or equaled groundwater temperature 50 per cent of the time.

We measured all this using a combination of different methods. With assistance from the Office of Water in NSW we installed temperature sensors combined with water level sensors in the river bed. We combined this with the regular monitoring network data from the Cockburn River valley and with hydrogeochemical sampling. Hydrogeochemistry uses the chemical signature of water to identify the source of water and the degree of mixing of different sources. This is a well-established method in hydrology. Newer was our application of temperature sensors. We learned this technique from the United States Geological Survey (USGS) and had invited Dr Jim Constantz (sponsored by the Cotton Catchment Communities CRC) over to Australia to help us understand the technique and installation requirements.

Funding: Cotton Catchment Communities CRC and support from the NSW Office of Water.

Groundwater dependent ecosystems

■ Kathryn Korbel, PhD student, University of Technology Sydney

GROUNDWATER dependent ecosystems (GDEs) are ecosystems that, at least periodically, rely on groundwater to maintain their ongoing health, structure and function. The dependence of GDEs on groundwater ranges from intermittent (drawing on groundwater in periods of drought), to total, continual reliance.

Groundwater ecosystems, although still largely understudied in Australia are home to a unique assemblage of invertebrates (stygo fauna) and microbes that are highly adapted to life under the earth's surface. These biota are believed to provide ecosystem services essential in retaining groundwater quality and flow within aquifers, thus the maintenance of these ecosystems is important.

The concept of groundwater health and the factors influencing groundwater biota are central to this PhD research which examines the distribution of groundwater biota in relation to agricultural practices in the Gwydir and Namoi catchments. This research is being used to develop a framework for assessing ecosystem health. A 'toolbox' of indicators that, when used together, will be able to rank groundwater health within bores.

The research identified Tier One and Two indicators of a healthy groundwater ecosystem that together can be used to generate a multi-metric index of groundwater health.

To date a number of new macroinvertebrate species have been discovered and the research has established which biota are robust in assessing water quality and groundwater health. A photographic library of the stygo fauna collected during the study will serve as a valuable reference tool for inclusion in the final toolbox product.

Funding partners: Cotton Catchment Communities CRC with in-kind support from UNE, UTS and the NSW Office of Water. ▲



PhD student Kathryn Korbel undertaking field sampling in the Gwydir catchment.

Best practice in the Namoi

■ Peter Verwey, Cotton Catchment Communities CRC



Peter Verwey.

AT the 2010 Australian Cotton Conference the industry launched the new and heavily revised *myBMP* best management practice system. One of the practices growers need to comply with to operate at the current accepted best management level is to monitor the salinity (electrical conductivity, EC) of their irrigation bore water.

From the results of a Cotton CRC survey, looking at grower management practices for the 2010-2011 cotton season, it was found that:

- 23 per cent of Namoi growers monitor their groundwater salinity at least annually; and,
- 67 per cent of Namoi growers monitor their groundwater salinity at least every few years.

The recommendations from a grower survey on groundwater monitoring conducted by Wendy Timms says that groundwater monitoring for at least EC should be conducted every year, and it would be better if it could be done more frequently throughout the cotton season. In addition to testing for EC, growers are encouraged to do more comprehensive testing through an environmental laboratory, either private or such as NSW DPI. The standard tests conducted in the NSW DPI kits include: pH, salinity, chloride, alkalinity, turbidity, hardness, saturation index, and sodium absorption ratio. Information from these tests can be used to determine if the water will affect crop yield and encrust or corrode your irrigation equipment

Knowing and understanding the quality of your groundwater has never been as important as it is now. We all know that the quality of irrigation water has an effect on crop yield, and through using tools such as the COTTassist Water Quality Calculator cotton growers can successfully shandy lower quality water with higher quality water to eliminate or reduce any yield impact.

But with coal seam gas (CSG) and other mining industry moving into cotton growing areas, it is now vital to actively manage the quality of our water (both surface and ground) to safeguard our industry. The specific tests required to establish these baselines are in addition to the standard suite of irrigation water quality parameters and expert local advice should be sought to determine which tests need to be done. For further information see the FAQ sheet: 'Coal Seam Gas – Environmental Monitoring and Testing' (link shown below).

Groundwater and *myBMP*

Level 1: Identified legal requirements

- Bore construction and decommissioning of old bores is performed in accordance with Departmental bore license and guidelines for Australia.
- Any new groundwater bores are constructed by licensed drillers.
- Groundwater license holders are familiar with their license conditions, and in particular any specific conditions that may apply.

Level 2: Current best management practice

- Groundwater salinity (Electrical Conductivity, EC) has been measured.
- Crop yields are maximised by using irrigation bore water which is within appropriate guidelines for salinity (EC) and is mixed with alternative water sources where appropriate and available.
- The ground water level is measured at the start and end of each irrigation season using minimum standard methods and is recorded to detect potential trends over time.

Further reading:

COTTassist website: <http://cottassist.cottoncrc.org.au>

myBMP website: <http://www.mybmp.com.au>

Cotton CRC website: <http://www.cottoncrc.org.au>

Namoi CMA website: <http://namoi.cma.nsw.gov.au>

Coal Seam Gas – Environmental Monitoring and Testing FAQ: <http://www.measurement.gov.au/Services/EnvironmentalTesting/Documents/Coal-Seam-Gas.pdf>

Funding: Cotton Catchment Communities CRC, Namoi Catchment Management Authority, *myBMP*. ▲

Annual water test recommended

■ Peter Verwey, Cotton Catchment Communities CRC

IN BRIEF...

- Keeping record allows growers to see trends such as extra drawdown during drought periods as well as periods of recharge during wetter years.
- Grower John Hamparsum sees regular testing and well-kept records as a powerful tool for sustainability on the farm.
- Records graphically show changes in groundwater over time.

AT groundwater workshops in the Namoi Valley the major recommendation was to have groundwater tested at the least once a year, ideally at the very start of the irrigation season.

An annual groundwater test should be a full irrigation analysis through an accredited laboratory. Added to this, regular in-season testing conducted by growers themselves helps identify trends in resource condition throughout the season.

By keeping records year to year, any changes in the groundwater resource will be easier to identify and farm management of the groundwater resource and water quality will help achieve maximum crop yields.

Upper Namoi cotton grower John Hamparsum is setting the benchmark for sustainable management of his farm's groundwater resources through regular monitoring of bore water levels and water quality.

John is the second generation to farm at 'Drayton' on the Breeza Plains. His father Ian began farming there in 1961 and it was four years later the farm's first production bore was commissioned.

What is outstanding is that the Hamparsums have continually monitored their farm bores since the first bore was drilled, giving them 46 years of water records.

Today, 11 bores have their standing water level measured at least both pre and post-season. Three bores have a full irrigation suite of water quality tests done annually through a NATA (National Association of Testing Authorities) accredited laboratory. John can also do on-farm water quality testing and monitors the surface water used on farm using inexpensive handheld EC meters.

"When asked what parameters had been tested back in 1965 John produces a folder with handwritten laboratory reports from that year right through to current printed reports for testing this season," said CRC Catchment Officer Pete Verwey, who works with growers in the Namoi to assist them with resources to successfully implement natural resource management activities.

"All results have been entered into spreadsheets for backup and to also graphically show changes over time. Other related records kept are climate and rainfall data, and bore construction details."

Pete said from the graphs it is clear to see trends such as extra drawdown during drought periods as well as periods of recharge during wetter years. Another trend is a small but noticeable increase in EC from an untouched system to an extracted system.

John said he sees regular testing and well kept records as a powerful tool for sustainability on the farm.



John Hamparsum's family has been testing the groundwater continuously for 46 years on their property on the Breeza Plains of NSW.

The groundwater resource changes over time and with land use change and increased pressure from more bores being drilled for other types of industry. Mining in the area is one of the newest and groundwater is being carefully monitored for any changes.

"Some years you just get busy and feel you don't have time to do the testing, but you just have to make sure that as you start the bores up to make the time and always do the tests," he said.

"All irrigators are interested in the water they are using, and with regular monitoring and record keeping the data they collect will be there for future generations to help them sustainably manage their farm," he said.

Presentations from groundwater workshops at www.cottoncrc.org.au -follow links on the "Catchments" home page.

Other water quality tools available for growers are available through NSW Office of Water's on-line, real-time groundwater database, CottASSIST water quality tool and myBMP.

Funding: Cotton Catchment Communities CRC and Namoi CMA





Relationships demonstrated between the cotton industry and communities

■ John Storer, Judith Stubbs and Associates

IN BRIEF...

- In 2012 cotton will provide employment for 8000 people across Northern NSW and southern Queensland.
- Each gegalitre of water used for cotton production results in 1.3 direct jobs and generates \$0.5 million in gross value of agricultural production (GVAP).
- The main indicators of community resilience and wellbeing in the Murray Darling Basin are population, remoteness, indigenous population and age with different industries or agricultural commodities having little impact.

THE growth of the cotton industry in Australia has been remarkable; and for many small communities growth in cotton production has meant that trends of declining jobs and population over many decades can be slowed or reversed. That's because compared to dryland cropping, cotton production employs five times as many people per hectare, and compared to grazing, it employs fifteen times as many people. Irrigation means

that communities can increase the productivity of their farming land and generate additional employment to offset job loss from technological change.

In 1966 there were 17,000 hectares planted to cotton in Australia. ABARES predicts 600,000 hectares will be sown to cotton in the 2011–12 season, with three quarters of that irrigated, an annual growth rate of 6.7 per cent. If you don't think that's remarkable, consider that over the same period the mining industry grew by 4.5 per cent each year, two thirds of the rate achieved by the cotton industry. Sure, mining employs lots more people, around twenty six times as many, but even so I estimate this year cotton will directly provide employment for over 4000 people across northern NSW and southern Queensland. Those jobs will support another 4000 jobs in areas like retail and service industries. These are important jobs, especially for small communities that are heavily dependent on agriculture for employment and for their existence.

Compared to the numbers for cotton, the numbers for agricultural communities are gloomy. Between 1966 and 2006, improvements in technology meant that agricultural employment



in Australia nearly halved, falling from 460,000 people to 280,000 people; the number of farms fell from 252,000 to 130,000; and the area farmed fell by 10 per cent, from 486 million hectares to 443 million hectares. That loss of jobs and consolidation of ownership has meant that many small towns have declined or, in some cases, faded away completely.

At a large enough scale, the loss of employment is more than offset by growth in service sector jobs. Agriculture now provides around three per cent of employment in Australia, compared with nine percent in 1966. Manufacturing used to provide 27 per cent of employment, now it provides 10 per cent. Importantly, jobs growth has not been restricted to metropolitan areas. Non-agricultural employment in the Murray Darling Basin increased by 118,000 jobs between 2001 and 2006, more than offsetting the 25,000 agricultural jobs lost through drought. But it's all a matter of scale, and the scale where the adverse impacts of decreasing levels of employment in agriculture are most heavily felt is in smaller, remoter rural areas where the main industry is agriculture.

Today when we talk about communities, particularly rural communities, it's fashionable to talk about sustainability using notions like wellbeing and resilience. Wellbeing is about how well people in a community live. We can measure it using indicators like disadvantage, access to resources, health outcomes, crime, household income and participation in the workforce.

Resilience is about how a community responds to shocks. A resilient community will bounce back quite quickly when placed under stress, although perhaps not in the same form. Indicators

of resilience include measures such as population change, employment change, whether the community is young or old, levels of unemployment and diversity of the economy.

Sustainability is a much more contested notion, and often the word is used in different ways to support particular social or environmental agendas. We say that a sustainable community is one that adapts to change by optimising social, economic and environmental outcomes to maximise the wellbeing of its members. We can't measure sustainability, but we would consider a sustainable community to do well on indicators of resilience and wellbeing, both things we can measure.

When we looked at indicators in our research, remoteness, population, age and indigenous population accounted for most of the variation across the Murray Darling Basin. For some indicators they accounted for as much as 90 per cent of the variation, and they accounted for at least 50 per cent of the variation for all variables.

How many people live in an area and how remote it is are important predictors of measures of resilience related to economic growth. Remoter and less populous areas are more likely to lose jobs and population, have older workforces and have lower levels of household income and skills.

Age and remoteness are the most important predictors of indicators for community resilience related to sharing of wealth. Older and more remote communities typically have a more equitable spread of incomes (although this may reflect people being equally poor rather than equally rich), and have lower levels of unemployment.

TABLE 1:								
Area	Balonne	Bourke	Campaspe	Dalby-Wambo	Griffith	Mildura	Moree Plains	Murray Bridge
Predicted reduction in employment	4.8%	5.2%	5.4%	0.3%	9.5%	7.3%	3.8%	1.3%

Variation in the wellbeing of a community is largely accounted for by indigenous population, followed by age. Communities with larger indigenous populations score poorly with regard to social indicators of disadvantage, crime, household income, premature death and chronic ill health. The trend is similar for older communities with the exception of crime, reflecting decreasing incomes with retirement and decreasing health with age.

Smaller communities are much more reliant on agriculture, with areas with populations below 5000 heavily reliant on agriculture for employment and becoming more so with time. Larger centres with populations over 10,000 are less reliant on agriculture to provide jobs and their reliance is decreasing. Not surprisingly, larger and less remote areas have more diverse economies.

For most of the variables we considered, wellbeing and resilience of communities was largely independent of the mix of industry in an area. There was some negative association between agricultural sectors and indicators of economic growth, suggestive of residualised populations, such as older workforces, older populations and lower levels of skills. Other relationships were positive; with grazing and agriculture associated with greater labour force participation and lower levels of unemployment, but this could also be considered evidence of residualisation of populations in some farming areas.

There were two other trends of particular interest. Firstly, over time agriculture is associated with progressively higher household incomes, reflecting an underlying trend of diminishing rural poverty and in line with larger trends of amalgamation of smaller farms.

Secondly, the expansion of agriculture, and particularly the cotton industry, between 1996 and 2001 had a number of positive effects. These included increased household incomes in smaller remote areas, population growth in cotton growing areas, and increased levels of employment. Conversely the contraction of agriculture and the cotton industry between 2001 and 2006 was associated with loss of employment and population.

But the real importance of irrigation, including cotton, to rural communities is in the opportunity it provides for economic growth and employment. As part of our study we looked at the cotton growing case study communities of Balonne, Bourke, Moree Plains and Dalby-Wambo. We also considered the horticultural, dairy and rice growing irrigation communities of Murray Bridge, Campaspe, Mildura and Griffith.

Five of these communities were very sensitive to changes in irrigation from reduced availability of irrigation water because of their degree of reliance on irrigated agriculture. The impacts were much greater in horticultural, dairy and rice growing communities, because these commodities are much more intensive users of irrigation water compared to cotton.

Grape growing, for example, employs 15 times as many people per giga litre as cotton, so that the differences in employment between irrigation uses and non-irrigation uses of land such as grazing or dryland cropping, is enormous, with employment per hectare dropping from around 100 jobs per thousand hectares for horticulture to 0.4 jobs per thousand hectares for dryland grazing. The table below shows predicted impacts of a 25 per cent reduction in irrigation water use compared with usage in 2006 based on our results (Table 1).

Some communities had advantages which might mitigate these predicted impacts, for example Murray Bridge had opportunities for economic growth from its proximity to



(Photo: Joshua Smith)

Adelaide, but generally the social impacts were predicted to be an overall decrease in the size of the economy from a loss of jobs, and increasing disadvantage from older populations and indigenous populations left behind as the economy contracts.

While our study has been widely criticised by people within the Murray Darling Basin Authority, responsible for delivering the Basin Plan under the Water Act, and by groups advocating increased environmental flows at the expense of irrigation, there is empirical evidence in support of our prediction. In Mildura, around 26 per cent of irrigation has dried off since 2006, largely as a result of federal government buybacks estimated at 44 giga litre of irrigation water. Over the period 2006-2010, ABS data shows an additional 199 jobs in Mildura LGA, and an increase in welfare dependence of 1693 people. Compared to Victorian averages, an additional 1700 jobs should have been gained in the period through economic growth, suggesting a net loss of 1500 jobs. Our modelling approach predicts a loss of 1500 jobs from this reduction in irrigation water.

The economic importance of cotton is also considerable, with analysis of ABS data showing that each giga litre of water used in cotton production generates around \$0.5 million in GVAP.

The importance of irrigation industries, including cotton, to rural communities is evident. Irrigation industries have meant that many communities can buck underlying trends of regionalisation and decline, contributing greatly to the wellbeing and resilience of those communities. As a crop, cotton is the favoured irrigation crop in much of the Murray Darling Basin, and irrigation gives farmers in cotton growing areas flexibility to opportunistically grow other crops.

But the converse is also true. If irrigation is reduced in these communities, jobs will disappear and the economies and populations of associated country towns will contract. Those people who are left behind will be more disadvantaged than those who leave, and many towns, particularly those with larger indigenous populations, are at risk of becoming centres of entrenched disadvantage.

The social and economic impacts on smaller communities from policy changes around water usage will be significant, and policy makers cannot afford to ignore or understate adverse impacts.

Further information at http://www.cottoncrc.org.au/communities/Cotton_Info/Publications

Funding sources: Cotton Catchment Communities CRC and Cotton Research and Development Corporation. ▲

Cotton – a regional economic success story

■ Roy Powell, Centre for Agricultural and Regional Economics (CARE)



Roy Powell.

IN BRIEF...

- Cotton is a major contributor to agriculture's share of gross regional product in all regions – from one-third in Darling Downs, half in Warren and three-quarters in Narrabri.
- Industry has above average levels of output per unit of labour relative to the rest of the economy.
- Cotton industry record of research, its development and application in the industry has boosted overall productivity.
- Need remains for more frequent key agriculture and industry production data.

BY any account, the development of the cotton industry has been a regional success story. Like any new natural-resource based industry in a region, it boosted economic output and employment and contributed to a more diversified economy. It is a key part of many region economies and actions that impact on the cotton industry will have a noticeable impact on that economy.

The Cotton CRC commissioned analyses to document the economic contribution in a variety of regions where cotton is a significant industry. Those communities varied from a relatively remote agricultural region (Warren NSW) to the Darling Downs (QLD) which is less remote (relatively close to Toowoomba and Brisbane) and relatively diversified. Moree and Narrabri (NSW) represent two of the most productive agricultural areas in Australia while Narramine (NSW) is basically agricultural but close to Dubbo.

The analysis was based on data for 2005–06. This was prior to most of the developments associated with coal and coal seam gas, and in the middle of the lengthy dry cycle. Cotton production in that year was modest being restricted by access to water for irrigation.

The results are summarised in Table 1.

The regions vary in size and diversity with the most remote having least diversity. The low diversity (measured by a large value) is related to the high proportion of Gross Regional Product (GRP) attributed to agriculture. This share ranges from 18 per

cent in the Darling Downs to 44 per cent in Warren and Moree. Cotton is a major contributor to agriculture's share of gross regional product in all regions ranging from one-third in Darling Downs to one-half in Warren and three-quarters in Narrabri.

The cotton industry share of employment is generally smaller than that of gross regional product. That indicates above average levels of output per unit of labour in the industry relative to the rest of the economy, that is, it is a high productivity industry.

The implication for region's economies with a high dependence on agriculture and cotton is that their competitiveness needs to be maintained. A culture of research and innovation is critical and the cotton industry is a leader in that respect. Policy initiatives that may impinge on that industry and its productivity (water buy-backs for example) need to be carefully considered, especially in the relatively remote areas where new industries are problematic.

The cotton developments shared many of the characteristics of irrigated agriculture in general. Production intensity on the irrigated areas is high and the concentration of production in a small area provides the scale necessary to allow the development of specialist industries to supply industry inputs and to handle and market the outputs.

The cotton industry was a new industry and so did not inherit much of the accumulated history of regulation and politics that are evident in most broad acre industries in Australia. It attracted new participants to the industry, as well as existing landowners. The new participants brought a variety of experience from other industries as well as their capital. Cotton was also an effective crop on the black soils of the area where some crops difficult to grow.

A further contrast with other irrigation developments was that the public sector investment was limited to funding water storages. The rivers were used as the delivery system and most of the substantial investment in irrigation development was funded by the landowners. And specialist local firms did most of that work, thereby capturing substantial benefits.

The downstream processing of cotton is limited to ginning and the processing of the cotton seed. It is unlikely that fibre processing and textile product manufacturing will ever exist

TABLE 1: Summary of economic analysis

Measure	Narrabri	Moree	Narramine	Warren	Darling Downs
Gross Regional Product (GRP, 2005–06, \$m)	520	605	205	110	1278
Employment by workplace (2006)	5350	5691	2159	1150	14,450
Diversity Index ¹	30	29	33	48	25
Agriculture Share of GRP (2005–06, %) ²	28	44	35	44	18
Cotton Share of GRP (2005–06, %) ²	21	29	11	22	6
Cotton Share of Employment (2005–06, %) ²	18	28	11	18	4

1. An index ranging from 1 to 100: Australia = 4, NSW = 7, Hunter region = 16 (2005–06) A high index number means less diversity.

2. These values include the direct and flow-on effects (flow-on effects are defined to include the linkages back to supplies, the ginning and marketing of cotton and research).



The Cotton CRC commissioned analyses to document the economic contribution in a variety of regions where cotton is a significant industry and Warren was one of those regions.

in these regions. The marketing of the crop and the risk management systems used by the cotton growers are also operated in the regions.

The cotton industry has a proud record of research, its development and application in the industry. That has boosted overall productivity, the efficiency of resource use (especially water) and reduced environmental effects associated with chemical and energy use.

A corollary of the above is that regions where cotton is a major industry have a high proportion of the workforce with tertiary education qualifications. This is most evident in Narrabri where the industry began and now hosts much of the cotton research and research management activities. Tertiary qualified people build the capacity of regional communities to create the social infrastructure and broaden their contacts with the world in general.

It also became apparent that local government and regional development authorities generally do not have this type of economic data available. The ABS now produces value of agricultural production data every five years (next due for 2010–11), and there are no ABS data on Gross Regional Product, yet these local bodies are expected to play a key role in the development of their economies. Can you imagine a federal government managing the economy without national accounts data and with key industry production data, like mining, being produced every five years? There is a clear need for action here.

Full reports can be found at www.cottoncrc.org.au (search communities program publications)

Funding: Cotton Catchment Communities CRC.



Socio economic impact of climate change, technology and water policy

■ Tony Jakeman, Australian National University, National Centre for Groundwater Research and Training



Tony Jakeman.

A LARGE team of scientists with different expertise including social, ecological, hydrological, governance and modelling worked with local government agency staff to assess the social, economic and environmental consequences of climate and policy change, and the potential for adaptation at the farm level to minimise negative consequences. The project considered both surface water and groundwater, and the linkages between these two systems using two case studies with different water access in the Namoi catchment in Northern NSW.

Social research, legal and institutional aspects, hydrology and hydrogeology, economics and ecology were examined to understand: the impact of various factors associated with climate change on ground and surface water availability; farmers' ability to adapt to related changes in water availability; and a complete picture of economic value of water in the Namoi. Socially acceptable, cost-effective outcomes that reduce the environmental impacts of extractions were investigated, and the social, economic and environmental impacts of changing water availability as a consequence of climate change were assessed. The social, economic and environmental trade-offs associated with various policy and climate scenarios for the Namoi region were explored using an integrated model they developed.

Understanding landholder views

Two key groundwater licence-holder types were identified through a survey to all 447 farming properties (54 per cent response rate) associated with a groundwater licence in the Namoi catchment (excluding the Peel River sub-catchment):

- *More committed to farm business viability (MCFB)* were more likely to have larger properties, larger areas cultivated and irrigated, larger total dam capacities, and are more likely to take actions which allow them to maintain or expand production.
- *More committed to environmental sustainability (MCES)* were more likely to have pro-conservation and altruistic values and beliefs, agree with the science used to develop sustainable diversion limits, believe in human-induced climate change, rate its nature of impact as negative and be less optimistic about their capacity to adapt to climate change impacts. (Full technical report available at <http://athene.riv.csu.edu.au/~acurtis/index.htm>).

Further, the survey suggests that a lack of knowledge or understanding underpins beliefs or attitudes that are inconsistent with contemporary NRM policy and management objectives. Difficulty engaging licence-holders on water reform or climate change is often attributable to a clash of values, beliefs and risk perceptions and distrust of government agencies.

Interviews were conducted in the lower Namoi catchment to understand likely water management choices that growers would make in the case of reduced water availability. The following three were included in economic modelling:

- An improved furrow scenario – with redevelopment of fields and rescheduling of irrigation;
- Mechanical irrigators – either lateral or centre pivot, depending on soil suitability; and,
- Changes to water storages – either deepening of the storage or increasing wall heights.

This economic model can be used to simulate the financial impacts on farm profit from a range of different scenarios, including grower adoption of the above management options, changes in government policy in relation to water allocation and policy to support improved water use efficiency, and variations in climate.

Governance and water sharing plans

One component of the governance research explored the experience of the collaborative consultation process involved in the development of the Water Sharing Plans (Water Sharing Plans) for one 'zone' in the Namoi region. Water Sharing Plans are intended to be developed via community and government partnerships and pursue "consensus in reaching decisions". For the Water Sharing Plan, community participation occurs during the initial water planning stage with limited scope for participation beyond that.

The study revealed a number of factors, including the very different perspectives, priorities and outcomes expressed by the diverse stakeholder groups, and the complexity of technical information suggest that the collaborative process used to develop the Water Sharing Plans, at least in this particular zone, fell short of participant expectations. Of 210 groundwater management licence holders surveyed across different areas of the Water Sharing Plan catchment, only 19 per cent felt that input from local farmers helped shape the current water sharing plan in their area, and only 10 per cent agreed that the Water Sharing Plan decision-making process was fair.

A legal framework for compensation

Together with a wider group of researchers, the legal team constructed three scenarios for the integrated model that relate to the economic loss incurred as a result of reductions in access entitlements.

This scenario will illustrate how an integrated model could provide information for calculating sanctions in legal proceedings to enforce access entitlements and environmental water provisions, and to deter water theft.

Surface and groundwater resources

In order to model the hydrology at a scale appropriate for management and the needs of the social, economic and ecological components of the larger integrated project, the Lower Namoi catchment was divided into a number of zones (Figure 1). The hydrological model takes rainfall, temperature and extraction data and produces estimates of daily streamflow and groundwater levels at selected locations within each catchment.

Environmental impact

Using historical flow and groundwater level data, the suitability of water regimes for river red gum, black box, lignum and water couch since the 1970s were explored. It was found that the suitability for the river red gum and black box has been far better than that for lignum and water couch, with the riverine vegetation along the Namoi River dominated by river red gum forest and woodland, or black box woodland. Wetlands species such as lignum and water couch generally only existed in small patches, and water suitability for these species has not changed significantly over time.

This type of study indicates the location and types of vegetation which are most likely at threat of disappearing due to lack of water and those most likely to be sustained through dry periods, and therefore where investments might be best warranted. It also shows the locations where the water suitability for different vegetation types varies throughout time, which could be a suitable location for monitoring change over time.

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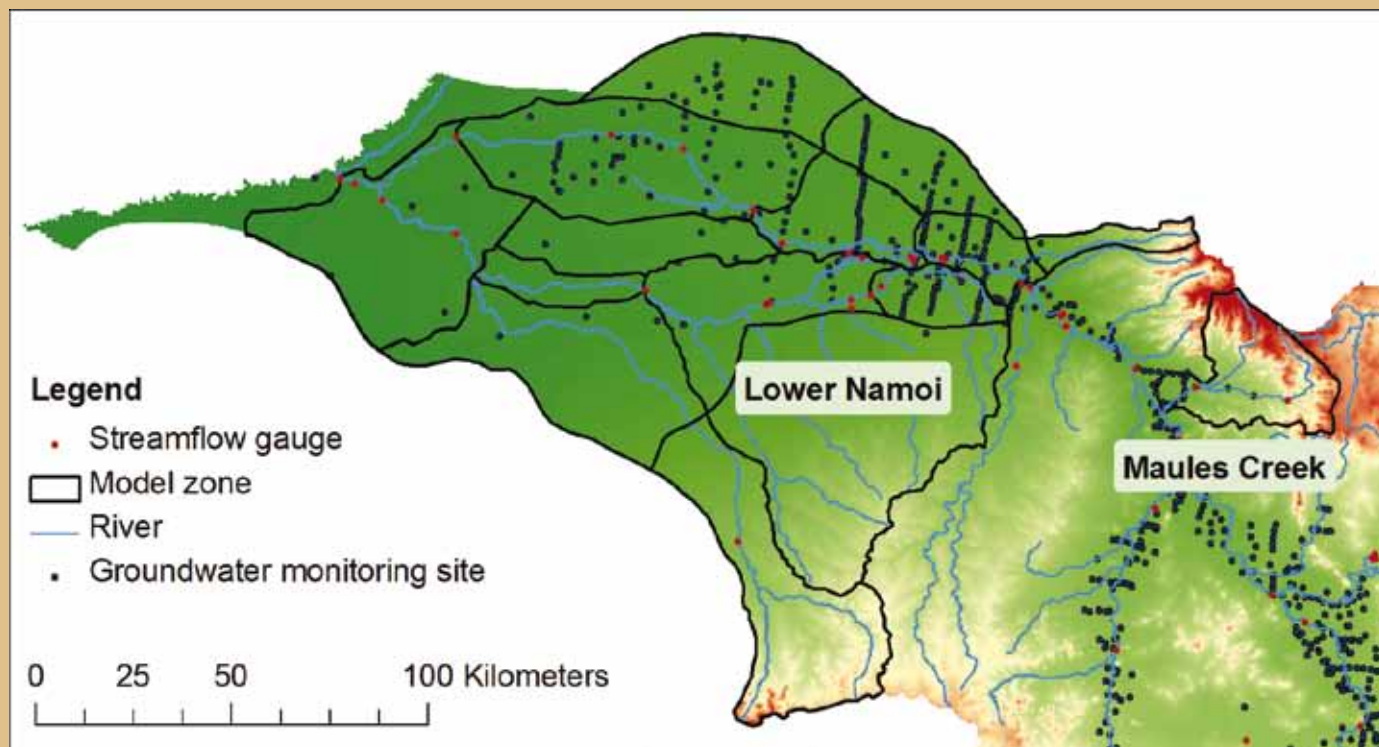
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Further reading: www.cottoncrc.org.au

Funding: Cotton Catchment Communities CRC, National Centre of Groundwater Research and Training.



FIGURE 1: Hydrological Zones used for modelling the surface water and groundwater resources in the Lower Namoi and Maules Creek catchments. Also shown are the stream gauge and groundwater monitoring site locations.



2011 Namoi groundwater management survey

■ Allan Curtis and Emily Sharp Institute for Land, Water and Society, Charles Sturt University Albury, NSW

IN BRIEF...

- The 2011 groundwater management survey provided a snapshot of groundwater licence-holder opinions about a range of issues which may impact property management and the types of management actions licence-holders are taking in the catchment.
- Respondents were generally optimistic about the potential use of aquifer storage and recovery.
- Management actions being considered in the next five years were very similar to those taken in the previous five years.
- Forty-one per cent of respondents agreed that human activities are influencing changes in climate.

SUSTAINABLE groundwater management is critical for irrigators, regional communities and, in the case of the Namoi River, water use, as the systems are highly connected. As part of a larger, integrated project assessing the social, environmental and economic impacts of changes in water availability in the Namoi catchment, a survey was undertaken to better understand landholders' views about groundwater management and how landholders are adapting their farming practices in response to reduced water availability.

Quantitative data was collected through a questionnaire mailed to all 447 farming properties associated with a groundwater licence in the Namoi catchment, with the exception of the Peel River sub-catchment. Useable surveys were returned by 210 licence holders, which constitutes a response rate of 54 per cent.

The majority of respondents showed concern about potential impacts from the Murray Darling Basin Plan. While 54 per cent of respondents agreed that it is possible to calculate a sustainable yield for groundwater, many respondents did not agree that the science used to calculate sustainable diversion limits in the Guide to the Murray Darling Basin Plan released in October 2010 was sound (only five per cent agreed compared to 63 per cent disagreed).

The survey data also showed that the majority of respondents did not agree that they could adapt their enterprises to further groundwater entitlement reductions (78 per cent) or surface water entitlement reductions (62 per cent). Only 13 per cent of all respondents would be willing to sell part of their groundwater entitlements to the government if buybacks were offered as part of the sustainable diversion limits set under the Murray Darling Basin Plan.

Respondents were generally optimistic about the potential use of aquifer storage and recovery. Research suggests this process may lift groundwater levels, reconnect surface water and groundwater flows, reduce pumping costs for irrigators and provide other environmental benefits. One section of the questionnaire gauged respondents' interest in this technology based on its use with large flood events. Sixty-five per cent of respondents agreed that aquifer storage and recovery based on intercepting large flood events was a good idea.

The risk of climate change is one factor which may influence landholders' decision-making. Forty-one per cent of respondents agreed that human activities are influencing changes in climate while 33 per cent were unsure and 27 per cent disagreed.

More than one-quarter of respondents who believed that human activities are influencing climate change rated the likelihood of impact as 'likely' or 'highly likely' for:

- Personal health and well-being (25 per cent); property water supply (36 per cent); and,
- Property production (38 per cent).

But given these concerns, more than half of the respondents indicated that their ability to adapt property production (53 per cent), water supply (50 per cent) and personal health and well-being (66 per cent) to the impacts of climate change was 'adaptable' or 'highly adaptable'.

Licence-holders are faced with the task of finding ways to adapt their enterprises to many changing conditions. Survey respondents were asked to indicate whether or not they had undertaken 26 property management actions in the past five years which were considered strategies landholders might undertake to adapt to changes in water availability. The top 10 management actions taken in the past five years included:

- Changed tillage technique;
- Changed crop types in rotation;
- Changed crop rotation frequencies;
- Invested in new planting machinery;
- Modified flood irrigation approach;
- Deepened dam, decreased cropping area;
- Changed to spray irrigation;
- Sought additional off-property work; and'
- Changed drainage method.

Management actions being considered in the next five years were very similar to those taken in the previous five years. But the top 10 actions being considered did not include:

- Change drainage method;
- Seek off-property work; or,
- Decrease cropping area.

These three items were replaced in the top ten actions being considered by:

- Routinely test water quality.
- Implement soil moisture mapping.
- Measure dam evaporation losses.

A technical report further detailing these findings at http://www.csu.edu.au/research/ilws/research/reports/docs/67_Namoi.pdf

Funding: Cotton Catchment Communities CRC and the National Centre of Groundwater Research and Training. ▲

Impact of drought on small businesses

■ Guy Roth and Stacey Vogel, Cotton Catchment Communities CRC, Narrabri NSW

IN BRIEF...

- Wee Waa based businesses are highly dependent (82 per cent) on agriculture and irrigation water availability. Cotton accounts for over half of their business income (51 per cent).
- Business turnover has increased significantly (77 per cent) with increased irrigation water supplies during 2012, but employment levels in small business have not. One third of businesses in the main street have changed ownership since the worst of the drought in 2008.
- Staff recruitment, especially skilled labour, is one of the biggest challenges facing small businesses as employment levels slowly increase with better water availability.
- Drought caused significant social and community impacts due to the reduction in population
- There is a high degree of social and economic interdependence of Wee Waa businesses, surrounding farms and community services.
- There is a currently a changing socio demographic in Wee Waa due to rising housing costs in Narrabri associated with the expanding minerals industries. Housing is now in short supply in Wee Waa, which is the complete opposite situation being experienced during the drought.

THE 2002–03 and 2006–07 droughts have widely been considered as one of the driest in Australian history, both in terms of severity and its extent. It is no secret drought impacts rural communities. The direct impacts on farmers are well documented. However, the flow on impacts on small business in towns is less well understood.

The purpose of this project was to quantify the impact of the drought and irrigation water availability on small business using Wee Waa as a case study. The studies were conducted in partnership with the Wee Waa Chamber of Commerce using a questionnaire to local business in 2004, 2007 and 2012. Figure 1 shows how cotton production for the Namoi Valley varied between 2000 and 2012 reaching lows in 2004 and 2008. This has since recovered to record levels in 2012.

Key findings from project

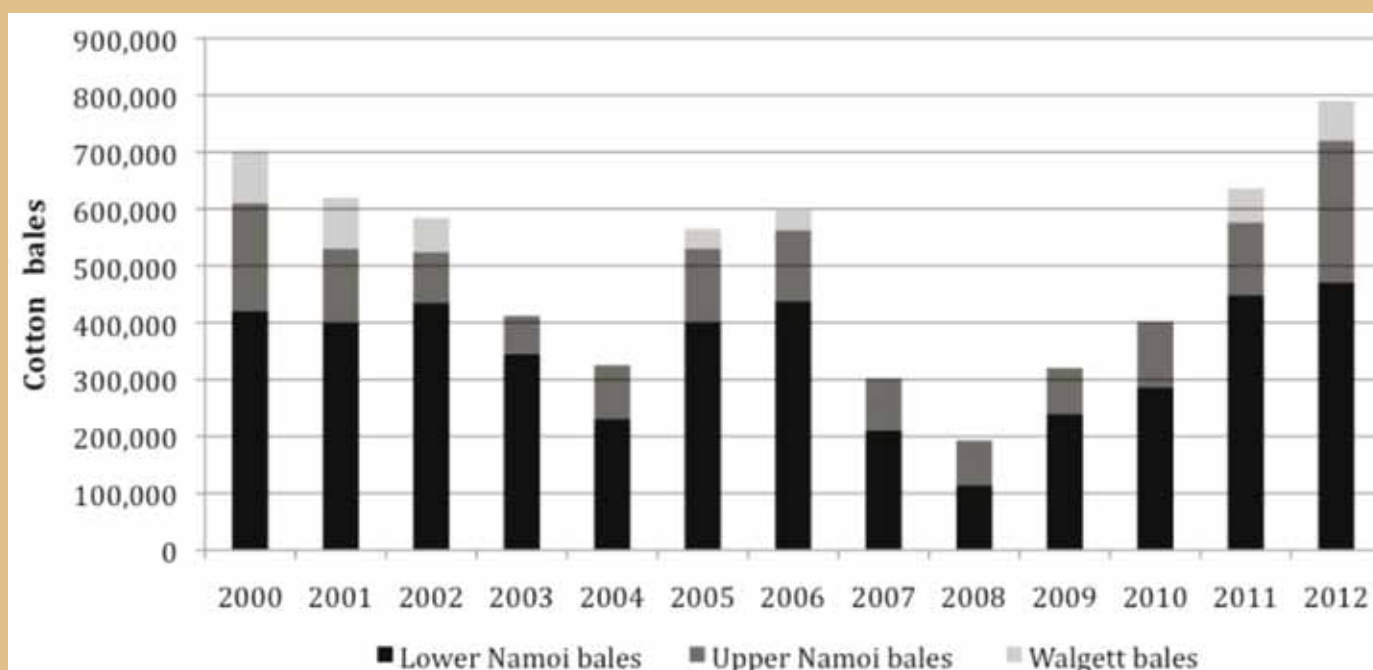
Wee Waa businesses reported a high (82 per cent) dependence on agriculture (51 per cent cotton, 23 per cent grain, eight per cent cattle), while tourism was three per cent and coal seam gas and mining was one per cent.

The drought impacted the Wee Waa businesses in a number of ways including;

- Reducing cash flows and business employment;
- Increasing business overhead costs and debt;
- Lowered staff morale and business owner confidence;
- Increased stress and medical depression of people in these businesses;
- Employee departure often meant an entire family left the district;
- Depleted quality of the labour pool (as well as the quantity);
- Any expansion plans or capital works were delayed; and,
- Reduced profitability due to less income but same overhead costs.

The survey found small businesses in Wee Waa experienced a 47 per cent fall in business turnover at 2008 due to the drought, which has since increased significantly on average by 77 per cent (Figure 2).

FIGURE 1: Cotton production in the Namoi Valley between 2000 and 2012.





Wee Waa businesses reported a high of 82 per cent dependence on agriculture.

However, despite this large increase in business turnover, they have not increased their levels of employment. Table 1 shows the employment levels between 2008–12.

The small increase in employment in the larger Wee Waa businesses is at the cotton gins. During the drought these businesses experienced significant loss of both permanent and casual employees. Although, many of these business did retain skilled staff as they knew it would be difficult to recruit new staff when better times returned.

In the main street of Wee Waa, there has been no real change

in employment levels in these small businesses. This is because these small businesses have experienced significant financial and social stress and have been operating at the bare bones during the drought. They are family businesses and they are still feeling pressures of the drought years. There has been a large change in ownership of main street businesses (one third changed hands since 2008), which is further evidence of this financial pressure.

- Other findings of the survey were
- Staff recruitment is a major challenge.
 - Climate variability is a greater risk to their business than climate change.
 - They were very concerned about the carbon tax.
 - A viable cotton and grains industry is important to their business.
 - Most permanent staff live in Wee Waa (82 per cent) with 16 per cent living in Narrabri.
 - School student numbers have increased.

Full reports at www.cottoncrc.org.au

Funding: Cotton Catchment Communities CRC, NCGRT.

FIGURE 2: Business turnover was down 47 per cent in 2008, but has since recovered by 77 per cent.

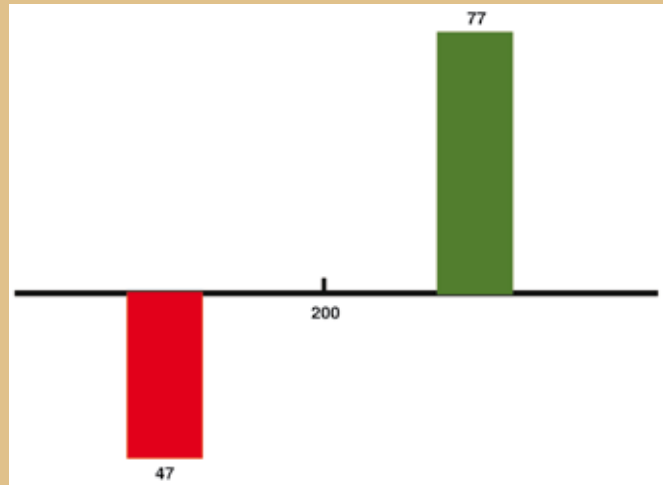


TABLE 1: Average permanent staff employment per business in Wee Waabusinesses between 2008 and 2012.

	2008	2011	2012
Large business (>10 employees per business)	34	37	38
Small business (<10 employees per business)	3	3	3

The challenges for catchment-level management

■ Olive Hood, The University of Queensland



Olive Hood.

IN BRIEF...

- This study examines multi-levelled (local, state and federal) decision-making in relation to the Condamine (Local) catchment waters, where over 650 individuals collaborate through 80 different policy processes across all levels of government and in relation to multiple water issues.
- It seeks to identify and understand factors affecting effective participation by stakeholders in such complex water governance contexts.
- Initial findings indicate while the high level of participation is valuable to enable diversity, flexibility and collaborative outcomes, participation may be compromised by fragmentation, duplication and incoherence between levels and processes.
- The goal is to use these findings for improved water governance and natural resource management outcomes.

In mid 2009, collaborative governance was being promoted by all levels of government within Australia. At this time the Cotton CRC Communities Program began investigating ways in which the Cotton industry could improve participation in natural resource governance. In late 2009, Olive Hood of The University of Queensland was awarded a Cotton CRC PhD scholarship to investigate natural resource governance from a cotton catchment context. This was fortuitous given the Localism, or catchment based process, that emerged as a preferred mechanism for delivery of the Murray Darling Basin reforms in 2011.

The research framework

1. Identifying emerging resource governance issues

Through consultation with growers and industry stakeholders, water governance was identified as an escalating natural resource governance issue for the Australian cotton industry. A heightened need for maintaining water rights through effective participation across a range of processes by cotton catchment communities was identified.

Water availability and variability, associated water sharing and competition for water resources from new water uses were key issues that cotton communities needed to effectively participate in. Developing minerals industries, the increase in cultural and environmental flow requirements and increasing municipal requirements increasingly compete for water rights in Australia in general, not least in cotton catchment communities.

2. Examining participation at the catchment level

The research focus was narrowed to the catchment level to identify key participation issues. Governance (and therefore

participation) at this level is reflective of current best practice management approaches through Integrated Catchment Management (ICM) and Integrated Water Resource Management (IWRM). A literature study revealed emerging discourse on the disappointing contrast between theory and practice of ICM and IWRM.

A key issue to be addressed was that although governance is undertaken at the catchment level there are a myriad of other processes operating simultaneously both within the catchment, between interacting catchments and basins and at various other levels such as economic or administrative. In Australia for example, mining governance occurs at the mineral province level, the National Water Commission at the federal level, and the native fish strategy operates at the sub-catchment level but nested into a national process. Managing water at the catchment level is a complex, multi-levelled process and participation becomes more problematic than previous theories of water governance had traditionally engaged with.

3. Participation in water governance

The complexity of water decision-making in catchments is a significant factor for those participating in the decision making process. The 'participation burden' is high, particularly for those who understand the connectivity between multiple processes and when multiple issues have equal priority. Administrative frameworks also dictate the nature and level of representation for various agencies. Together, these factors affect individuals involved in the various processes and the outcomes of the accumulated participation effort.

Issues for participants include pervasive and repeated participation dilemmas, fatigue, tokenism and exclusion. The impact on outcomes includes an increased potential for less than effective outcomes when multiple separately managed processes interact and cancel each other out. In addition, there may be compromised collective learning about each other's needs and values when issues and participants have been separated through governance by level and focus.

Within the framework this research will examine how is water governance being enacted at the catchment level in an advanced multi-levelled democracy like Australia? It will specifically address the following:

- What governance processes are operating both across and within levels in relation to Condamine catchment water? Who was participating, where, at what level, with whom, to what degree and about what?
- How are contemporary issues being managed at the catchment level such as Murray Darling Basin and coal seam gas given the obvious interrelatedness?
- What are the outcomes of this participation for the water resources and the local catchment communities who depend upon them? That is, what is being lost and gained for participants and water resources in this governance?

The research will be applied in the Condamine catchment in South East Queensland. Located at the headwaters of the Murray Darling Basin, on the eastern edge of the Great Artesian Basin and within the recently gazetted Surat Basin minerals province, the Condamine catchment is significant to the cotton industry.

Using desktop analysis and consultation, how governance is being enacted and by whom, including sharing water volumes, managing water quality and improving fish habitat, was examined. All aspects of the hydrological cycle including surface water, alluvial water, artesian water, wetlands overland flow were considered. In total, there are over 80 collaborative policy processes operating in relation to Condamine catchment waters and over 650 active participants have been mapped.

The following trends have been identified:

- Differences have emerged in the type of policy processes, policy issues and sector representation at various levels.
- Differences between the centrality or 'importance' of certain levels (local, state and federal), policy issues (mining, Murray Darling), processes and participants (government, agriculture, mining) can be seen. Moreover, there appears to be a lack of connectivity between more and less central processes (water quality, fish habitat) and their policy forums and actors.

These observations will be explored further in the subsequent thesis as they raise interesting debates. For example, some say, that centrality and boundaries are necessary for solving problems because information needs to be transmitted rapidly between key participants. Others say, it may be a problem because of the difficulty for alternative information and ideas to be incorporated in the problem solving. This is particularly interesting given the level effects (local, state and federal) on participation and the contemporary renewed 'localism' agenda of the Murray Darling Basin Authority.

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- Surface and groundwater connectivity tool based on water temperature developed
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- 471 cotton and grain growers involved in projects
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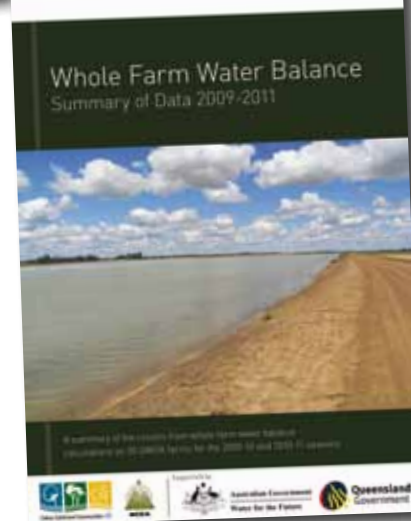
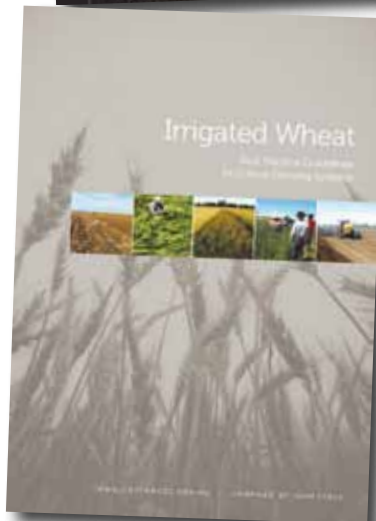
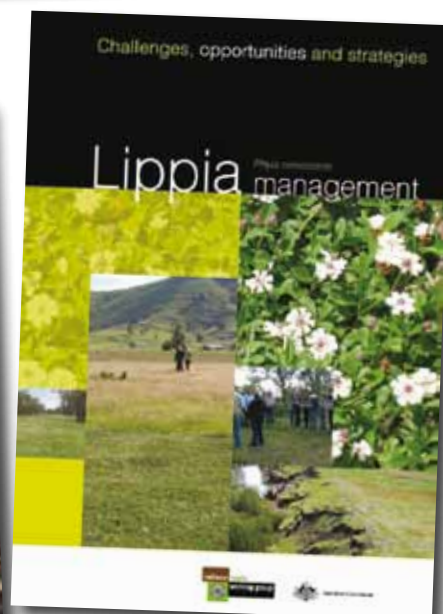
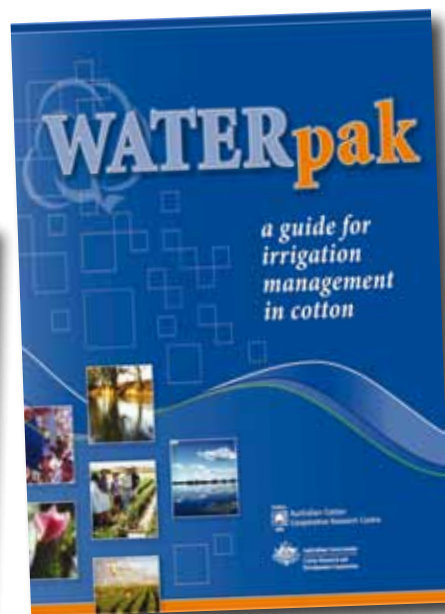
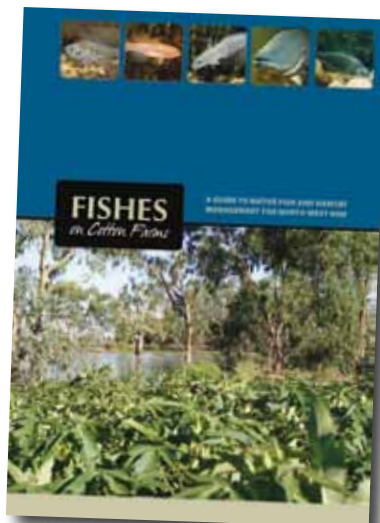
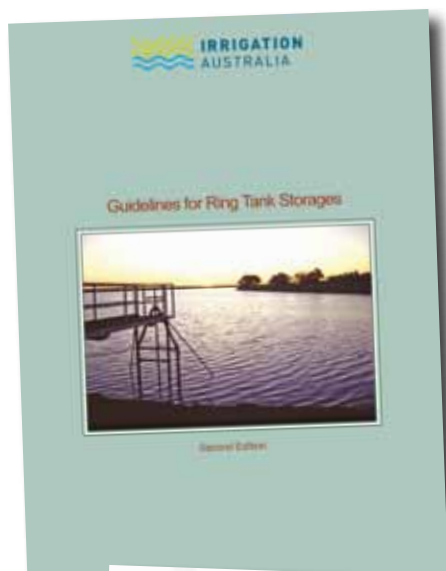
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Cotton industry water information resources

A set of information resources and tools have been developed that are consistent with good science and best practice.

These guides can be found on the Cotton CRC website – <http://www.cottoncrc.org.au/catchments/Publications>. For further information please contact the Cotton Research and Development Corporation on 02 67924088 or the Namoi Catchment Management Authority on 02 67429200.



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