Soil moisture probes are used to monitor moisture thoughout 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 makes 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 ▲

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 to1000 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.

An advancing front of monolayer film in the foreground on 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.

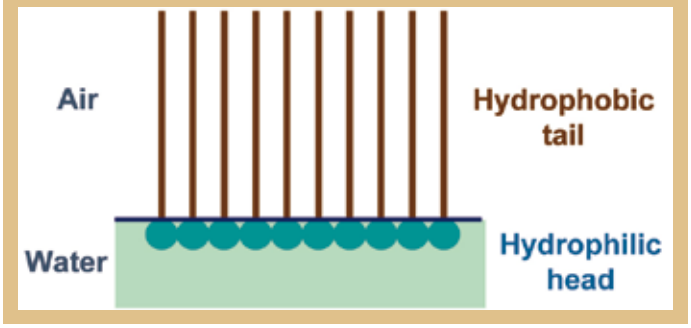
For such large storages, chemical ultra-thin films (for example chemical or polymer-based monolayers), either on their own or in combination with other systems, provide a compelling option. They offer the advantage of being applied to stored water only during periods when the evaporation rates are high 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 m^2 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 m^2 troughs, 135 m^2 ponds and 330 m^2 dams at Dookie, Victoria and 220 m^2 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 peryear 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 shadecloth 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 Normailised 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 trialled 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 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.

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

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 ▲

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).

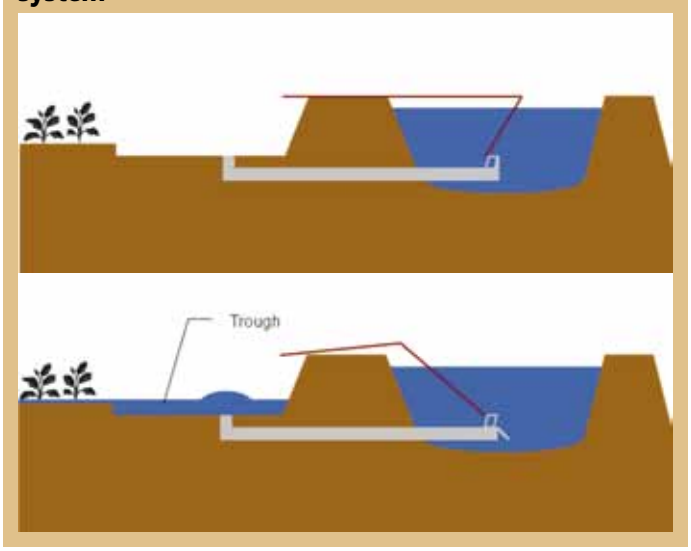
The 2011–12 season will see the entire cotton irrigation area being watered with the PTB pipes and one centre pivot machine.

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).

"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."

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 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.

FIGURE 2: Aerial view of PTB irrigation demonstrating pipe outlet situated in guess row away from wheel tracks

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.

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:

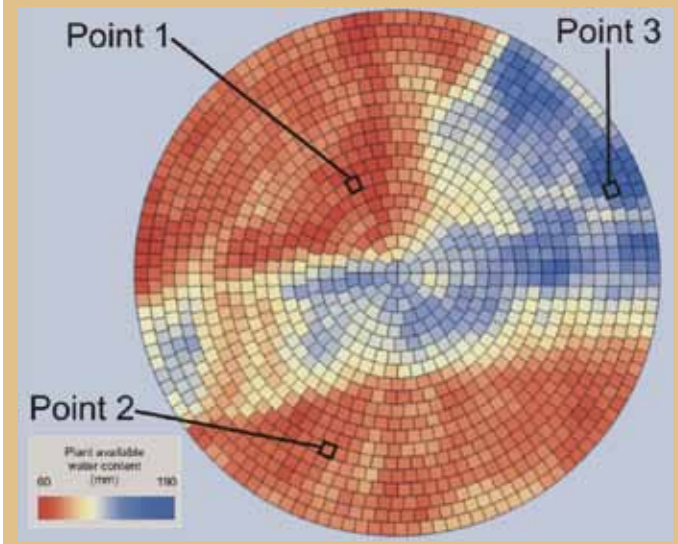
Smith, RJ, Baillie, JN, McCarthy, AC, Raine, SR and Baillie, CP (2010) Review of precision irrigation technologies and their application. Report for the National Program for Sustainable Irrigation, NCEA Publication 1003017/1. www.npsi.gov.au

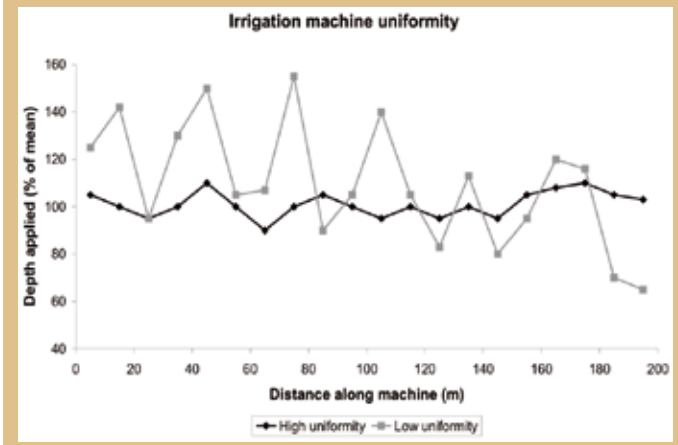
Smith, RJ, Raine, SR, McCarthy, AC and Hancock, NH (2009) Managing spatial and temporal variation in irrigated agriculture through adaptive control. Australian Journal of Multi-disciplinary Engineering, 7(1): 79-90. ▲

CASE STUDIES

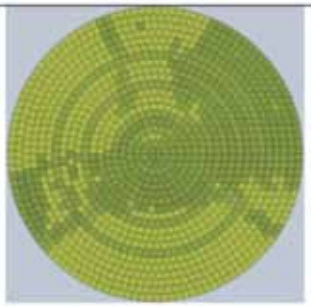
A centre pivot-irrigated cotton field with spatially varying soil properties shown in figure below was simulated with two irrigation machine uniformity distributions.

The field used for the case study simulations

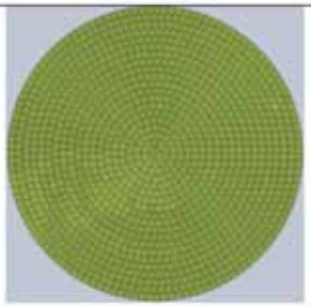




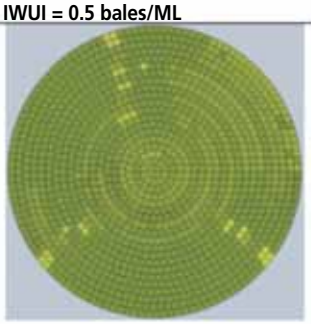
CASE STUDY A: Effect of irrigation application uniformity



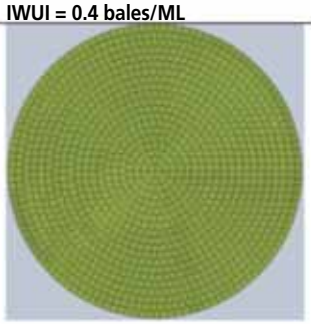
40 mm every 6 days
High uniformity machine
Yield = 5.6 bales/ha
Irrigation supplied = 132 ML
IWUI = 0.5 bales/ML



60 mm every 6 days
High uniformity machine
Yield = 6.2 bales/ha
Irrigation supplied = 196 ML
IWUI = 0.4 bales/ML



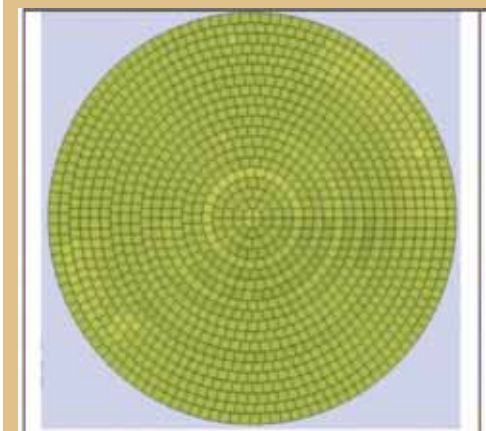
40 mm every 6 days
Low uniformity machine
Yield = 6.4 bales/ha
Irrigation supplied = 134 ML
IWUI = 0.6 bales/ML



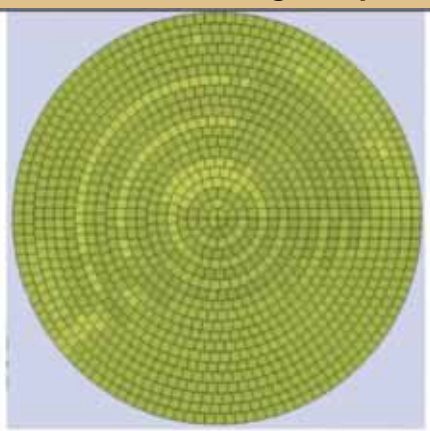
60 mm every 6 days
Low uniformity machine
Yield = 6.2 bales/ha
Irrigation supplied = 200 ML
IWUI = 0.4 bales/ML

LEGEND

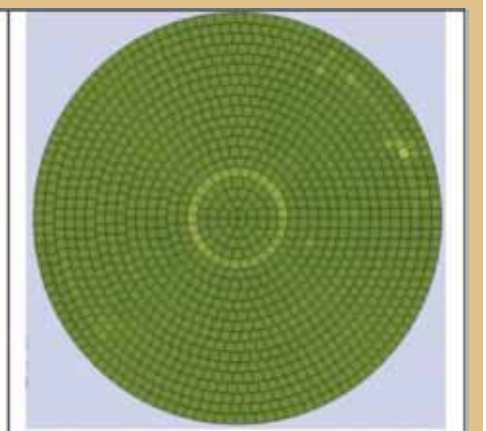
CASE STUDY B: Effect of soil moisture sensor location on irrigation performance



Triggered by Point 1
High uniformity machine
Yield = 7.0 bales/ha
Irrigation supplied = 126 ML
IWUI = 0.7 bales/ML



Triggered by Point 2
High uniformity machine
Yield = 7.1 bales/ha
Irrigation supplied = 111 ML
IWUI = 0.8 bales/ML



Triggered by Point 3
High uniformity machine
Yield = 7.4 bales/ha
Irrigation supplied = 103 ML
IWUI = 0.9 bales/ML

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.

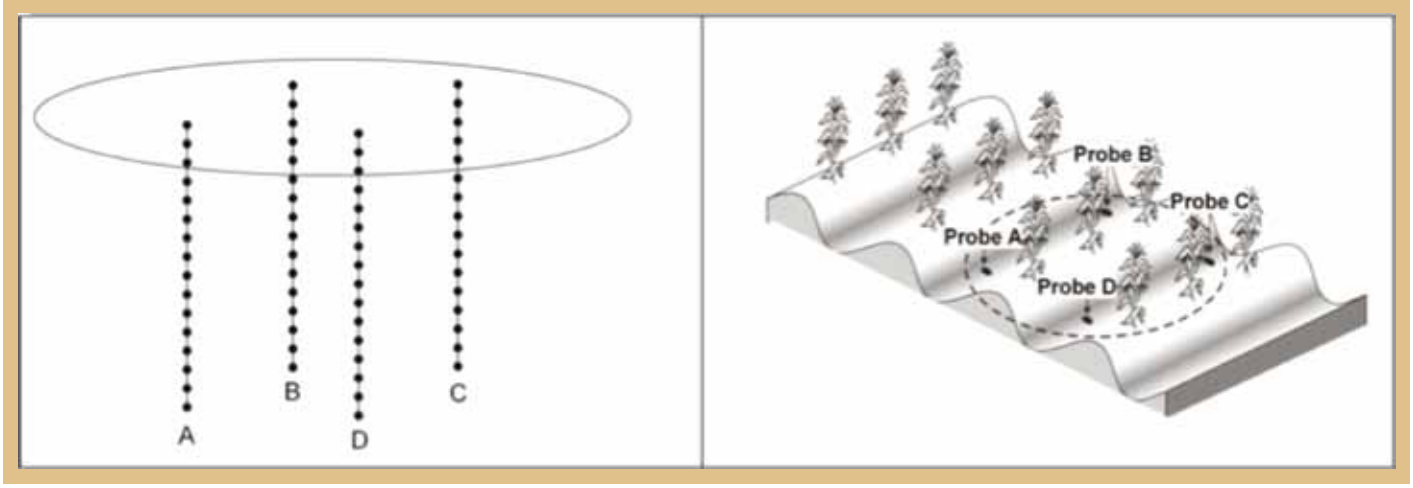
PhD student Anna Greve investigated the most appropriate irrigation management of cracking soils.

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.

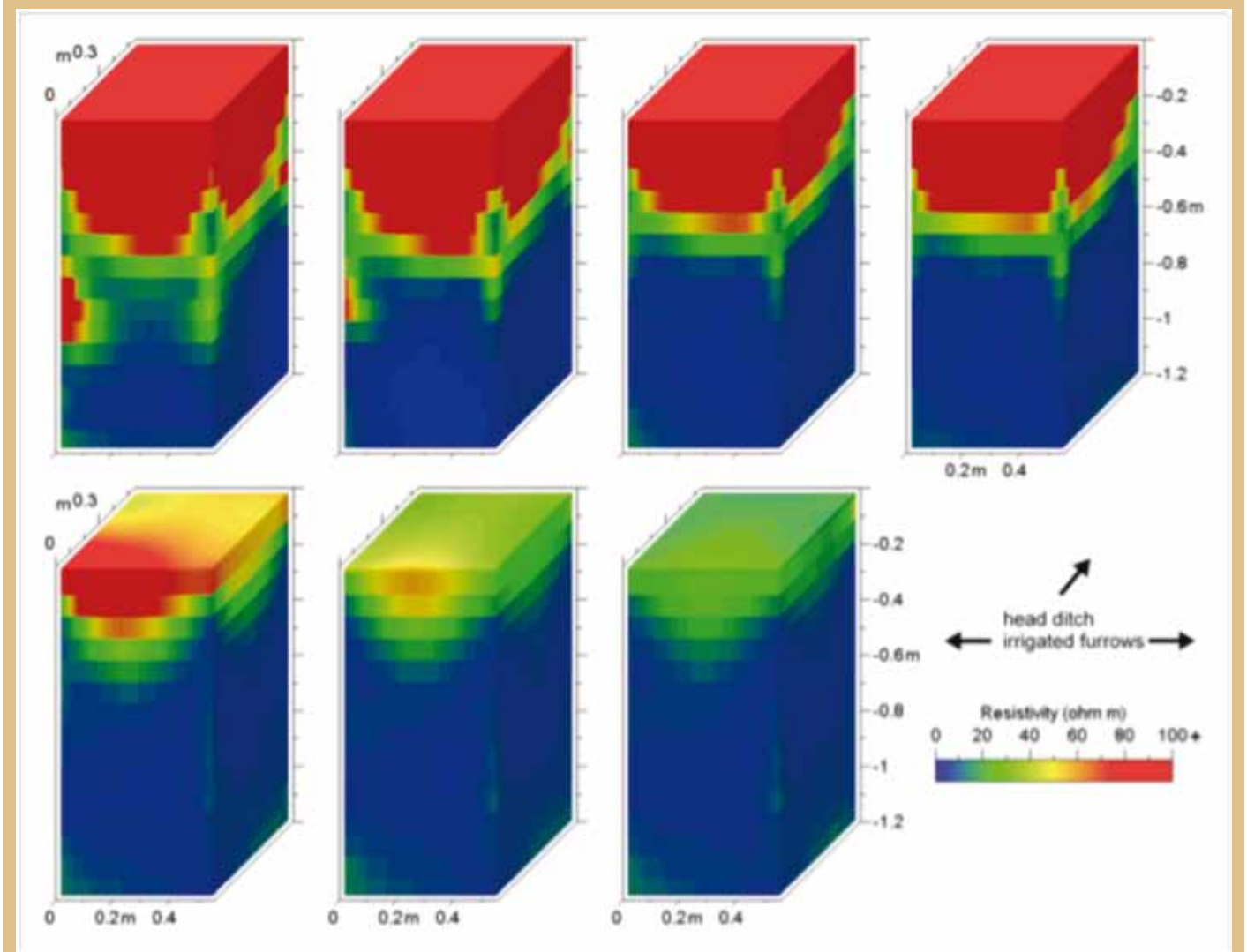
This study introduced a new technique for the detection of subsurface cracks that relates the development of soil cracks to changes in the electrical anisotropy of the soil. Electrical anisotropy is the ratio of the apparent resistivity measured with the alpha and the beta square array. In a non-cracked 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 on each property) and two centre pivots, as outlined in Table 1.

> *"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."*

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 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.

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**

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.

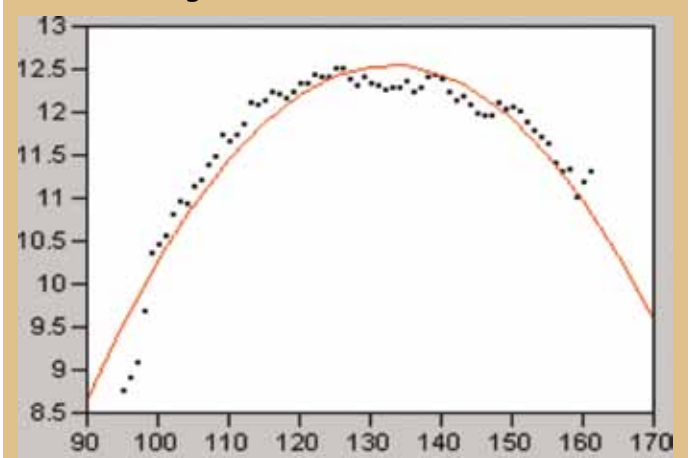
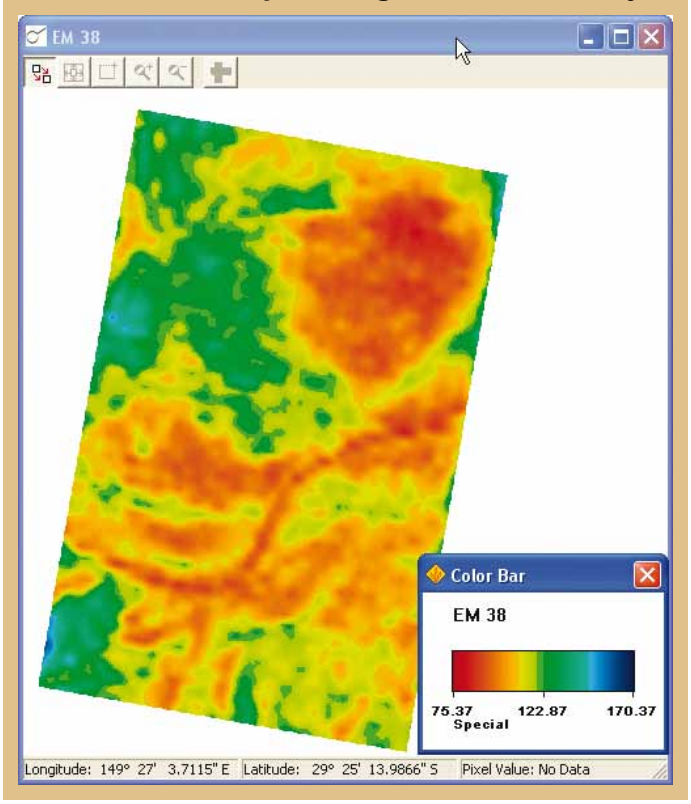


FIGURE 2: EM 38 map showing field soil variability.



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.

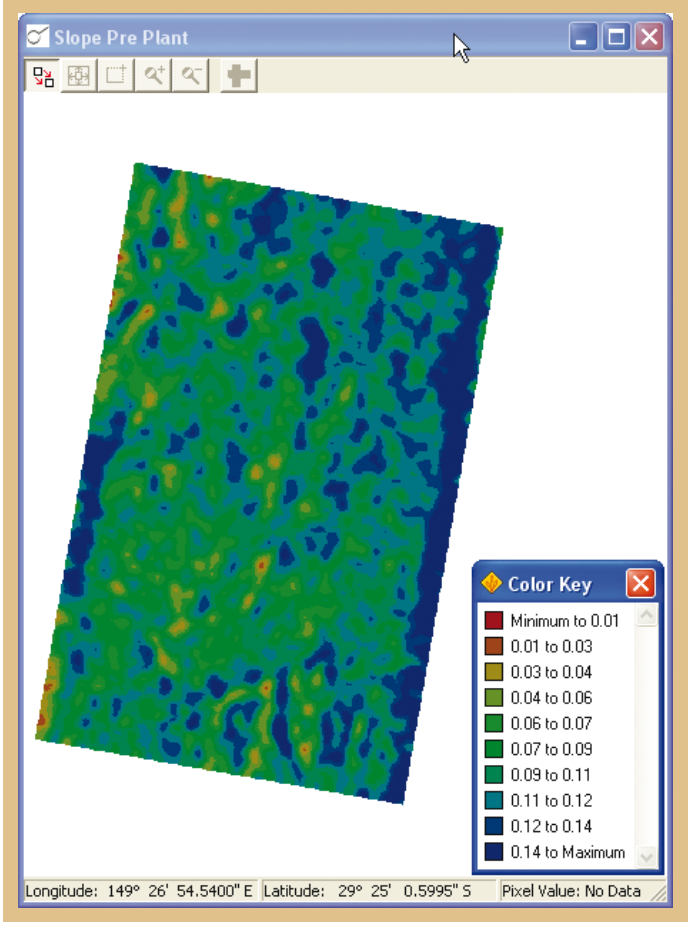


FIGURE 4: Final map which best represents majority soil type, closest to majority slope and in some cases removal of areas of high previous cut.