

## **WATER TIGHT: Whole Farm Water Use Efficiency - Determining your own water security**

Paul Dalton

Dalton Consulting, Toowoomba Q

### **Introduction**

Water is one of the key resources for industry and economic development in Australia. It is one of the main inputs to maximise the production of the cotton plant. Due to the rising pressures on the use and allocation of the national water resource (and in particular the Murray Darling Basin) "water use efficiency" has gained an ever increasing profile. The term typically means different things to different people. If one thing were common however it would be to maximise the opportunities for benefit from the water through optimal management of that water.

Australia consumes 22,185 GL of water annually. Seventy percent (15,502 GL) is consumed for agricultural production and from that amount the cotton industry consumes 11.9% (or 1,840 GL). On a dollar return per ML of water consumed basis the farm gate value of irrigated cotton is \$613 per ML which, in the agricultural sector, is second only to the horticultural industry as a value adder to the water resource (ABS, 2000).

Consequently the security of the water resources is a major factor in determining a bright future for the Australian cotton industry. We could speculate that water resource "security" is determined by three factors:

- *The weather:* On an industry and indeed individual basis any degree of water resource security is fundamentally difficult in an arid continent with a spatially and temporally variable climate.
- *The political climate:* While industry groups continue to lobby and debate with government and environmental bodies, on an individual basis the political climate is no more predictable or controllable than the meteorological climate.
- *The efficiency of water use on the whole farm:* On an individual and industry basis part of the water security equation lies fairly and squarely in the hands of the water manager or irrigator. Water security can be determined to some degree at the farm scale where some measure of individual control can be exercised. It is important that we do not rely solely on the meteorological or political climates of the day to determine water security. There remains one sure way of ensuring and optimising our individual whole farm water security, and that is to optimise the whole farm water use efficiency. However in order to participate individually in water security it must first be recognised that there is an opportunity to improve the management and efficiency of water use on the whole farm scale.

## What is Whole Farm Water Use Efficiency?

The term "efficiency" is defined as the "ratio of useful work done to the total energy expended" (Turner, 1987). This ratio can be expressed as a percentage and applied to other inputs within any system including water in an irrigation context. Hence, a 100% efficient system (which only exists in an ideal world) is able to convert all of its inputs to output. A major aim in managing any real world system (eg. a machine, or irrigation system) is to maximise its efficiency by minimising the outputs that escape as system losses or inefficiencies. Leading on from our original discussion, "whole farm water use efficiency" is the ratio of output from the water (or input) that is managed at the whole farm scale.

A large number of other performance indicators or "indices" have also been proposed under the banner of water use efficiency. These can also be applied to whole farm water use efficiency. The Irrigation Association of Australia (IAA) has recently suggested that a uniform system of whole farm irrigation efficiency definition and measurement would allow meaningful comparison of water use within the various sectors of the irrigation industry (IAA, 1998). Similarly, the Land and Water Resources Research and Development Corporation (LWRRDC) recently commissioned Barrett, Purcell and Associates (BPA, 1999) to consult with the Australian irrigation industry on the potential to adopt a consistent framework including terms and definitions for irrigation water use efficiency. As summarised in these reports water use efficiency has historically been defined in three main areas:

- Economic water use efficiency
- Agronomic water use efficiency
- Volumetric water use efficiency

### **Economic Water Use Efficiency – Getting the most bang for your buck! (\$/ML)**

The aim is to achieve the highest farm gate value for the water being used. While the current price of water does not necessarily motivate high economic efficiencies, the corresponding value of production from that water should. High economic water use efficiency is not principally due to efficient irrigation water management but may be influenced by world markets etc. As it relates to irrigation, it might include: irrigating the higher value crops within your system/rotations; the cost/benefit of irrigation development; irrigation vs rainfed (dryland production); irrigation systems – eg surface vs spray vs drip; the cost of water; the cost of pumping and re-pumping water; irrigating larger areas (if not land limited); water budget on smaller ML/ha (higher risk water use); and greater reliability on rainfall.

$$\text{Gross Production Economic Water Use Index} = \frac{\$}{\text{Total Water Applied (ML)}}$$

$$\text{Irrigation Economic Water Use Index} = \frac{\$}{\text{Total Irrigation Water Applied (ML)}}$$

$$\text{Marginal Irrigation Economic Water Use Index} = \frac{\$ \text{ due to Irrigation}}{\text{Irrigation Water Applied (ML)}}$$

$$\text{Crop Economic Water Use Index} = \frac{\$}{\text{Evapotranspiration (mm)}}$$

The term "index" has been preferred in these definitions since the input and output have different dimensional units and therefore are not totally dependant variables (eg \$ and ML) Conversely, the term "efficiency" is classically defined as a percentage or ratio of input to output of the same kind (eg ML/ML)

### **Agronomic Water Use Efficiency**

The aim is to maximise the amount of useful (saleable) product for the unit of water used in the system. Again this value is not necessarily principally determined by efficient irrigation water management but may be influenced by crop nutrition, pest management and climate. This might include maximising yield and crop response to water by improved irrigation scheduling.

$$\text{Gross Production Water Use Index} = \frac{\text{Total Product (kg)}}{\text{Total Water Applied (ML)}}$$

$$\text{Irrigation Water Use Index} = \frac{\text{Total Product (kg)}}{\text{Irrigation Water Applied (ML)}}$$

$$\text{Marginal Irrigation Water Use Index} = \frac{\text{Marginal Production due to Irrigation (kg)}}{\text{Irrigation Water Applied (ML)}}$$

$$\text{Crop Water Use Index} = \frac{\text{Production (kg)}}{\text{Evapotranspiration (mm)}}$$

### **Volumetric Water Use Efficiency (ML used per ML diverted or %)**

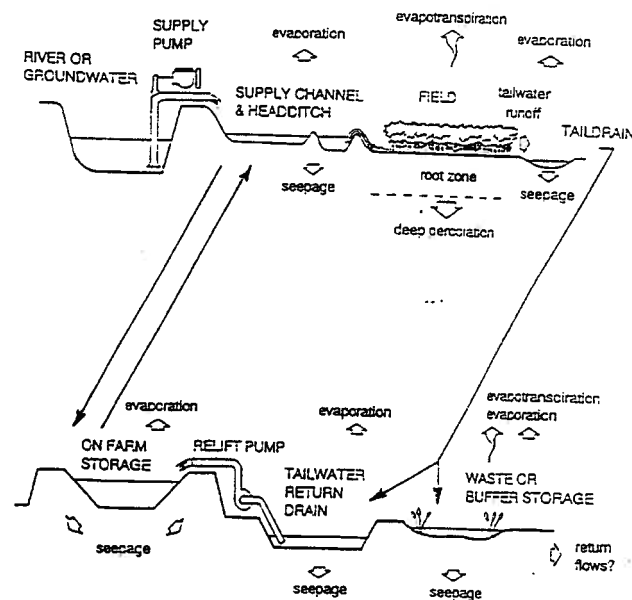
The volumetric approach to water use efficiency aims at maximising the volume of whole farm water that is of direct benefit to the crop. Conversely the aim is to reduce the volume of water that is lost in the whole farm system. This measure is perhaps the best measure of the whole farm level of performance and efficiency of water and irrigation management. This area of

whole farm water use efficiency shall form the main part of this paper and has been used by the author in the bulk of the work performed over the last two years in the cotton industry.

## The Measurement of Whole Farm Water Use Efficiency and its Components

The following water management sub-systems exist on most irrigated farms:

- Supply systems (eg. harvesting or lifting from river and captured overland flows; pumping groundwater from bores; and/or supply from irrigation scheme dams, channels and/or pipes);
- On-farm storage systems (eg. ring tank storage cells; buffer holding dams; or catchment dams);
- On-farm distribution systems (eg. earthen channels; gated pipes; or pressurised enclosed systems);
- Application systems (eg. surface, spray, micro-systems); and
- Recycling systems (eg. tail drains and tail water recycling channels and utilising supply harvesting pumps; or catch drains feeding into holding dams).



**Figure 1:** Whole farm irrigation flow and water balance

The efficiency of water use can be defined for each of these sub-systems based on the volumetric water inputs and outputs, or uses and losses. Potential volumetric losses (or inefficiencies) within each of the sub-systems must be measured or estimated accurately to quantify whole farm water use efficiency. Volumetric measurements of the water flows into

and out of each unit are required and include, supply to and from the unit, rainfall, seepage (or percolation), evaporation, stored soil moisture, overland flows and tailwater recycling. In a purely volumetric sense, the efficiency of the system should be determined as the ratio of the water used by the plant to the water input. However, both the input and output water volume can be defined at a range of locations and over a range of time scales within the overall irrigation system.

The most commonly adopted definitions of irrigation water use efficiency are shown in Table 1 (BPA, 1999). It should be noted that the performance of scheme level water storage systems is commonly included in the conveyance efficiency term while the performance of on-farm storage systems is included in the distribution efficiency term.

**Table 1:** Recommended Irrigation Efficiency Definitions for Australia  
(from Barrett Purcell and Associates, 1999)

<b>Term</b>	<b>Definition</b>
Overall Project Efficiency ( $E_p$ )	$\frac{\text{Irrigation water available to crop}}{\text{Total inflow into system supply}}$
Conveyance Efficiency ( $E_c$ )	$\frac{\text{Total outflow from system supply}}{\text{Total inflow into system supply}}$
Distribution Efficiency ( $E_d$ )	$\frac{\text{Water received at field inlets}}{\text{Total outflow from system supply}}$
Field Application Efficiency ( $E_a$ )	$\frac{\text{Irrigation water available to the crop}}{\text{Water received at the field inlet}}$

The definitions proposed by BPA (1999) provide for a “nested” approach to a particular irrigation event (assuming no rainfall or unregulated flow into the supply system) where the overall project (or whole farm) efficiency can be calculated as:

$$E_p = E_c \cdot E_d \cdot E_a$$

A major concern with the sole use of volumetric efficiency terms for irrigation evaluation is that they do not provide any assessment of the overall irrigation performance in relation to crop production and economic returns. Hence in the assessment of the commercial viability or performance of an irrigation enterprise the economic and agronomic performance may also be used.

## What is Known About Whole Farm Water Use Efficiency

### Review of Past Work

#### ***Farm Water Storage and Distribution Systems***

The major system losses in open farm water storage and distribution systems, which occur on a continuous basis, are evaporation and seepage. The major factors affecting the performance of storage and distribution systems include the local evaporation potential, soil percolation rates and the dam or channel design parameters.

The storage and distribution of on-farm water may represent a considerable component within the whole farm water management system. For example, the cotton industry relies heavily on off-allocation and overland flow harvested water and hence, requires a substantial capacity to store and distribute water around the farm. Hence, many irrigated cotton farms require a large ring tank reservoir (2-7 m high and many hectares in area) to ensure a reasonable security of water supply for irrigated production with distribution via large earthen channels.

#### Evaporation Losses

Evaporation losses have been estimated (Sainty, 1996) to be as high as 50% of the stored water for typical ring tank storages in the cotton industry. The cost of evaporation losses alone under these conditions has been estimated to be worth ~\$200,000 for a typical cotton farm (Sainty, 1996) and in excess of \$50M per annum for the Gwydir Valley alone (Condie and Webster, 1995).

The evaporation potential of the earth's atmosphere is a physical phenomenon, which cannot be modified at the gross level. However, evaporation shielding or mitigating the evaporation potential at the water's surface does present some options for evaporation control. Evaporation is most significantly affected by wind speed and surface area suggesting that the modification of these variables would provide the greatest opportunities for evaporation control.

#### Seepage Losses

Seepage is simply defined as the loss of water due to infiltration through the bed or banks of an irrigation channel or dam. Seepage losses have presented considerable problems in many farm storages and distribution channel networks. It has been suggested that conveyance and application losses should not be higher than 15% in properly designed irrigation schemes (Ait Kadi, 1993 in Kirda and Kanber, 1999).

Burt (1995) presented seepage rates (Table 2) depending on soil type for unlined channels (taken from Withers and Vipond, 1980) for relative comparison purposes only. Canal seepage

rates for a range of soil textures were also reported by Worstell (1976). Average seepage rates ranged from 0.06 to 0.6 m<sup>3</sup>/m<sup>2</sup>/day depending on soil type with the majority of rates less than 0.3 m<sup>3</sup>/m<sup>2</sup>/day.

**Table 2: Approximate channel seepage losses**  
(from Burt, 1995)

Type of soil	Seepage Loss (m <sup>3</sup> /m <sup>2</sup> /day)
Impervious clay loam	0.07 – 0.10
Clay loam, silty loam	0.15 – 0.23
Clay loam with gravel, sandy clay loam	0.23 – 0.30
Sandy loam	0.30 – 0.45
Sandy soil	0.45 – 0.55
Sandy soil with gravel	0.55 – 0.75

McLeod *et al.* (1994) conducted seepage measurements at two channel sites in Sheparton Region of the Goulburn-Murray Irrigation District in northern Victoria. They measured seepage rates between 14 and 34 mm/day in the Tatura East channel and 5 and 9 mm/day at the Dhurringile channel operating under normal operating conditions.

### **Field Application Systems**

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

Yule (1984) conducted water balance measurements at Emerald in 1982/83 and 1983/84 and found that irrigation application was generally 70 to 90% efficient. They trialed different irrigation frequencies based on predicted deficits. Water balance data for this work is shown in Table 3. In general the amount of total runoff was determined by the period of runoff. Deep drainage was assumed to be non-existent due to the fact that the applied irrigation minus the runoff (ie. total infiltration) was less than then predicted deficit. The soils in these trials had a clay content of 70% which Hearn (1998) states are self-regulating for furrow irrigation. Final infiltration rates of the order of 2mm/hr were measured in these trials indicating a potential for

deep drainage if irrigations were not managed well. It should be noted that the deficit was predicted in this data and not physically measured and that the experimental plots did not represent the dimensions of a typical commercial cotton production system.

**Table 3:** Water balance data from Yule and Keefer (1984)

Predicted Deficit (mm)	Irrigation Applied (mm)	Total Runoff (mm)	Application Efficiency
51 (av.)	49		74%
75 (av.)	70		88%
107 (av.)	92		87%
140 (av.)	126		89%
44 (indiv.)	54	13	76%
73 (indiv.)	76	9	88%
146 (indiv.)	162	22	86%

Douglas et al., 1996 measured the water balance of an irrigated cotton system at the Australian Cotton Research Institute near Narrabri in NSW on a grey cracking clay soil (60% clay) with 200m furrows and 1:1176 slope. The results of three irrigations are presented in Table 4.

**Table 4:** Components of the soil water balance measured by Douglas et al., 1996 during the 1995-96 season at ACRI.

	Irrigation (mm)	Runoff (mm)	Et (mm)	Deep Drainage (mm)	Soil Storage (mm)	Efficiency (%)
Irrigation 1	95					
Irrigation 2	94	2.4	22.9	2.04	65.1	95%
Irrigation 3	82	6.4	10	1.02	55.9	90%

This data shows high efficiency of irrigation application. However it should be noted that these measurements were under controlled conditions on relatively small field lengths.

### Findings from Current Research by the Author

The Cotton Research and Development Corporation (CRDC) has funded the National Centre for Engineering in Agriculture (NCEA) to undertake whole farm irrigation performance benchmarking on seven farms in the McIntyre Valley during the 1998/99 and 1999/00 seasons. For the purposes of this paper only the 1998/99 season is presented since the 1999/00 season's data is still not fully compiled. These farms include a wide range of soil types, including black and grey clays, brown earths and lighter hard setting red soils. Farm A and B have the most complete data set.

### ***Farm Water Storages***

#### **Method**

To effectively monitor volume balances and water storage efficiencies in a large ring tank structure a system of accurate water level sensing along with a specific depth vs volume relationship for each storage was proposed for the 98/99 season's monitoring program. Water level, evaporation, rainfall and the ambient weather conditions were directly measured and logged at 15-minute interval continuously with modified weather station and water level and evaporation pan sensors. The combination of accurate water level and a depth volume relationship specific to that storage gave a continuous record of water inputs and outputs.

When the system was behaving in a dynamic mode (ie. either inflow or outflow occurring at high rates) seepage could not be separated out of the volume balance. This was the case through most of the irrigation season. However during non-pumping periods (typically in the off season) when the storage was in a static mode seepage was separated from the volume balance as the other rainfall and evaporation inputs and outputs were monitored. Table 3 and Figures 3 and 4 describe the water storage volume balance and efficiency monitoring equipment.

#### **Results**

The results of storage efficiency measurements on four storages during the 1998/99 and 1999/00 seasons are presented below. The efficiencies are principally determined by the period of storage (and therefore opportunity time for evaporation and seepage) and the surface area to volume ratio of the total volume stored.

**Table 5:** Storage volume balance, efficiency and losses by volume and (percentage).

<b>Storage Description</b>	<b>Storage Period</b>	<b>Stored Water</b>	<b>Used</b>	<b>Seepage</b>	<b>Evaporation</b>	<b>Storage Efficiency</b>
Farm A 4m max depth 1800 ML	27/11/98 to 28/12/98	1272	1082 (85%)	14 (1.1%)	177 (13.9%)	85%
Farm A 4m max depth 2500 ML	27/11/98 to 5/7/99	2388	1313 (55%)	255 (10.6%)	930 (39%)	55%
Farm B 3m max depth 500ML	2/12/98 to 5/5/99	729	581 (79.7%)	34 (4.7%)	121 (16.6%)	79.7%
Farm E 4m max depth 1800ML	13/8/99 to 16/2/2000	3649	2776 (76.1%)	180 (4.9%)	701 (19.2%)	76.1%

For example the first storage listed has a high storage efficiency (85%) since it was effectively emptied in one month. Similarly the third and fourth storages listed were emptied and filled several times during the storage period such that the ratio of water used to water stored was high. Conversely the second storage listed had a poor efficiency (55%) since it operated in a static mode for a long period allowing for evaporation to be a significant percentage.

### ***Distribution Channels***

#### **Method**

A system of monitoring inflows and outflows in a distribution channel was proposed such that the difference between inflow and outflow would be equivalent to the system loss in that section of channel. To separate out evaporation and seepage, local evaporation pan data was used. To minimise flow monitoring inaccuracies in channels due to changing cross sectional area the flow meters were mounted (where possible) in fixed cross section pipes or culverts.

Channel depths were also monitored continuously over the season in three locations over each farm. Locations typically included main supply, head ditch and tailwater return channels. This data was used to estimate the channel seepage and evaporation losses during periods when these channels were in a static mode of no inflows or outflows, and purely subject to only seepage and evaporation losses.

#### **Results**

Of the two methods for estimating channel losses the depth sensors provided for best means for estimating these losses. Table 6 shows the data for three channel depth monitoring systems during the season. While the use of channel depth and evaporation monitoring may be considered crude it does give an estimate for the seepage of an integrated length of channel.

There is little evidence to explain the order of magnitude difference between the seepage values at the main supply channel and the tailwater channel at Farm A.

**Table 6:** Distribution channel depth monitoring and resultant seepage estimations

<b>Site</b>	<b>Average Daily Loss for period (mm/day)</b>	<b>Average Daily Evaporation for period (mm/day)</b>	<b>Resultant Seepage</b>
Farm A main supply channel	14.6	13.6	<b>1.01mm/d (0.042mm/hr)</b>
Farm A TW channel	34	10.8	<b>23.04 mm/d (0.96mm/hr)</b>
Farm B TW channel	31.2	12	<b>19.2 mm/d (0.8mm/hr)</b>

Using the higher value of seepage at farm A and the seasonal evaporation figures from the weather station, a conservative estimate of combined losses over 10km of main supply channel, 5km of tailwater return channel and 6km of head ditches can be made. For the opportunity time relating to seven irrigations (depending on whether it is main supply, tailwater return or head ditch) and measured channel width the losses were 270ML seepage and 130ML evaporation. In this case approximately 5000ML of water is distributed through the system for the season, which equates to an 8.6% distribution loss (6% seepage and 2.6% evaporation) through the system. Hence this equates to a whole farm water distribution efficiency of 91.4%.

Similarly using the only measured value of seepage for Farm B and seasonal evaporation figures a conservative estimate of combined losses over 12 km of combined main supply/head ditches and 10 km of tailwater return channel would be 109 ML seepage (or 8.4% of 1300 ML total farm water distributed) and 68 ML evaporation (or 5.2 % of total farm water distributed). Hence this equates to a 86.4% distribution efficiency.

### ***Field Application Systems***

#### Method

Two approaches to determining the application efficiency of irrigation at a furrow scale were used during the 1998/99 season. These were a monitoring system (as in the storage and distribution volume balances) and a modelling system (SIRMOD surface irrigation model) which relies on well proven theory and some simple furrow scale measurements.

The monitoring system involved the acquisition of furrow inflow and tailwater data logged continuously over the irrigation period and an assessment of the pre-irrigation soil moisture deficit using a Neutron probe. A review of methods for directly measuring deep percolation over the season revealed that this would also be a complicated and costly exercise. Hence in keeping with the simple measurement methods and minimal cost deep percolation and evaporation during furrow irrigation application were not attempted to be measured but rather formed the remainder of the volume balance as a combined loss component. This level of monitoring coupled with the modelling program gave sufficient data for both performance benchmarking and identification of the factors influencing in-field losses and inefficiencies.

#### Results

The following application efficiency and volume balance data tables report the results collected over the 98/99 irrigation season at farm A and B. These tables give an indication of the amount of water applied during each irrigation, the length of irrigation and subsequent runoff volumes. Along with infiltration losses and the soil moisture deficit (calculated from pre and post irrigation neutron probe soil moisture readings), the efficiency of the irrigations has been determined considering tailwater recycling and no tailwater recycling.

Individual irrigation application efficiencies range from 63% to 98% on farm A and from 47% to 80% on farm B. Average seasonal efficiencies were 86% on farm A and 71% on farm B (assuming full tailwater recycling). On farm A tailwater runoff amounted to 13% (or 1 ML/ha) and deep drainage 14% (or 1.05 ML/ha) of the total water applied to the field. On farm B tailwater was 4% (0.27 ML/ha) and deep drainage was 29% (1.97 ML/ha)

### **Opportunities for Improving Whole Farm Water Use Efficiency**

The data presented above represents probably for the first time an objective assessment of the efficiency of whole farm water management units on commercial cotton farms. It should be kept in view that the data presented is for three farms during the 1998/99 season in the McIntyre valley and that broad generalisations of this data to the whole cotton industry would not be objective. For example, the McIntyre valley has a high local net evaporation contributing to lower storage efficiencies. On the Darling Downs where evaporation is lower storage efficiency would be expected to be higher. Also, soil types will determine the seepage rates of storage and distribution systems and the in-field application efficiencies to a large degree. While a large range of soil types were represented in the measurements other soils may behave more or less efficiently in furrow irrigation applications.

However considering the data above a best and worst case scenario for the whole farm water use efficiency could be presented using the "Project Efficiency" nested approach described earlier:

$$\text{Whole Farm Efficiency} = \text{Storage Efficiency} \times \text{Distribution Efficiency} \times \text{Application Efficiency}$$

**Table 9:** Benchmark data of whole farm water use efficiency as measured in the trial farms in the McIntyre Valley region.

	<b>Storage Efficiency %</b>	<b>Distribution Efficiency %</b>	<b>Application Efficiency %</b>	<b>Whole Farm Efficiency %</b>
<b>Best Case</b>	80	91	86	63
<b>Worst Case</b>	55	86	71	34

While the benchmark data represented in Table 9 is derived from three farms only (with only two farms with complete data sets) it paints a clear picture of the degree of accumulated water loss around the whole farm. Further it highlights that significant opportunities exist to save and secure water for irrigation at the farm scale.

Table 7: Application Efficiency and Volume Balance Data at Farm A

APPLIED				TAILWATER	DEFICIT	TOTAL INFILTRATION	DEEP DRAINAGE (+error & "other losses")	EFFICIENCY	
Irrigation No. and Date	Av. Furrow Application Rate (l/s/fur)	Application Time (min)	Application to Furrow (mm)	Runoff Tailwater Furrow (mm)	Added to Soil Moisture Deficit (mm)	Total Infiltrated (mm)	Deep Drainage + surface evap + error (mm)	Application Efficiency (TW recycling) %	Application Efficiency (no TW recyc) %
3 – 10/12/98	1.25	719	89.8	21.7	35.5	68.1	32.6	63.7	39.5
4 – 21/12/98	1.34	1216	130.0		50.2				38.6
6 – 7/1/99 Low Head High Head	1.55	685	84.9	39.1	39.9	45.9	6.0	93	47.0
	1.94	650	100.9	23.9	39.9	77.1	37.2	63.2	39.5
7 – 17/1/99 Low Head High Head	1.58	818	103.6	18.4	84	85.2	1.2	98.8	81.1
	2.01	540	86.7	6.5	78	80.2	2.2	97.5	90.0
8 – 15/2/99 Low Head High Head	1.52	973	118.6	7.8	99.3	110.9	11.6	90.3	83.7
	2.34	648	105	8.5	89	96.5	7.5	92.8	84.8
<b>Total</b>			<b>750mm *</b>	<b>100mm #</b>	<b>545mm @</b>	<b>650mm †</b>	<b>105mm</b>	<b>86%</b>	<b>73%</b>
<b>%</b>			<b>100%</b>	<b>13%</b>	<b>73%</b>		<b>14%</b>	<b>86%</b>	<b>73%</b>

(\* assumes averages between measured applications when more than one is recorded and that initial two unmeasured irrigations were 70mm and irrigation 5 was 100mm)

(# assumes tailwater of 10mm per irrigation on irrigations that were not recorded)

(@ assumes deficits of 50 mm in irrigations 1,2 and 5)

(† assumes infiltration of 80mm in irrigations 1,2,4 and 5)

Table 8: Application Efficiency and Volume Balance Data at Farm B

APPLIED				TAILWATER	DEFICIT	TOTAL INFILTRATION	DEEP DRAINAGE (+error and "other losses")	EFFICIENCY	
Irrigation No. and Date	Av. Furrow Application Rate (l/s/fur)	Application Time (min)	Application to Furrow (mm)	Runoff Tailwater Furrow (mm)	Added to Soil Moisture Deficit (mm)	Total Infiltrated (mm)	Deep Drainage + surface evap + error (mm)	Application Efficiency (no TW loss) %	Application Efficiency (full TW loss) %
1 - 16/10/98	1.53	632	96.6		50				52
2 - 09/12/98	1.94	550	106.7	7	43	100	57	47	40
High Head									
Low Head	1.35	474	64.4	7	43	57	15	77	66
3 - 23/12/98	2.34	549	128.6	7.7	71	121	50	62	55
4 - 07/01/99	2.16	345	74.7	0.4	54	74		73	73
5 - 19/01/99	2.25	495	111.9		85				76
7 - 11/02/99	1.88	359	67.7	1	53	67	14	80	79
8 - 22/02/99	2.16	556	120.4	1.41	87	119	32	73	72
<b>Total</b>			685mm	27mm #	443mm	640mm @	197mm	71%	67%
<b>%</b>			100%	4%	65%		29%	71%	67%

(# assumes average tailwater per irrigation on irrigations that were not recorded)

(@ assumes infiltration of 80mm in irrigation 1 and 100mm on irrigation 5)

## Management Practices to Improve Whole Farm Water Use Efficiency

From the data presented above, the main opportunities for whole farm water use efficiency improvement exist in:

- water storage evaporation mitigation
- reduction of in-field deep drainage and tailwater losses through improved management of irrigation application

### Water storage evaporation mitigation

Some 14% - 40% of stored water measured on the trial farms was lost due to evaporation. Evaporation mitigation could be achieved through several methods including:

- deepening storages to reduce the surface area to volume ratio of the storage
- using multiple cells to reduce the surface area of free water available to evaporation
- tree shelter belts to reduce the wind speed and thus the evaporation over storages
- storage surface coverings

As an example a cost benefit analysis for building deeper storages is presented in Table 10.

**Table 10:** Cost benefit of deepening water storages to reduce evaporation volume and percentage - Water Storage Design Comparisons for a 3500ML storage at Goondiwindi

Wall Height (m)	5	7.5	7.5	10
Water depth (m)	4.2	8.7	8.7	12.4
Shape	Square	Square	Round	Round
Area (ha)	76	42	44	28
Earthworks (m <sup>3</sup> )	349,600	654,887	592,876	888,483
Earthworks unit cost (\$/m <sup>3</sup> )	1.00	1.33	1.3	1.25
Earthworks cost (\$)	\$349,600	\$871,000	\$770,739	\$1,110,604
Av. Evaporation on Yearly basis (m)	1.8			
ML lost to Evap.	1521	734	736	516
% Evap Loss	43%	21%	21%	15%
Extra ha of crop production (@ 6ML/ha)	0	131	131	167
Extra \$ (@ \$1976/ha gross margin)	0	\$258,856	\$258,856	\$329,992
<b>Years to pay back extra investment</b>	-	<b>2.01</b>	<b>1.62</b>	<b>2.3</b>

Mitigation of storage evaporation remains the Holy Grail of improving whole farm water use efficiency. Practices such as building deeper storages, multiple cells and wind shelters serve only to reduce the evaporation by a certain percentage (often difficult to predict the benefit to undertake a cost benefit analysis). Perhaps the only solution that could completely mitigate evaporation would be to cover the storage. Cost, construction, life of the product and pay back period all need to be considered in the cost benefit equation. To date, the cost of such a scheme has been largely prohibitive. Practical limitations have also been difficult to overcome.

### Improved Management of Irrigation Application

The data presented in Tables 7 and 8 highlights that the other significant loss on the whole farm is potentially deep drainage in the field application system. On the farms measured during the 1998/99 season, deep drainage represented 1 – 2 ML/ha (or 13 – 30%) and tailwater volumes represented 0.27 – 1 ML/ha (or 4 – 13%) of the 6.8 – 7.5 ML/ha applied to the field.

**Table 11:** Effect of irrigation cut-off time on Application Efficiency ( $E_a$ ) and Distribution Uniformity (DU) of a mid-season irrigation, field length of 1000m, slope 1:2500, and deficit of 70 mm.

Cut off time (hr:min)	Cut off distance from end (m)	Applied (mm)	Infiltrated (mm)	Tailwater (mm)	Deep Drainage (mm)	$E_a$ (no TW recyc.)	$E_a$ (90% TW recyc.)	DU (%)
8:00	past end	144	108	36.1	38	48.6	62.8	94
7:20	past end	132	104.5	27.5	34.5	53.0	65.3	93
6:40	50	120	100.5	19.5	30.5	58.3	68.3	92
6:00	120	108	96.5	11.5	26.5	64.8	71.7	90

Some trial work into the effectiveness of managing irrigation application rates and cut-off times in reducing deep drainage and thus increasing application efficiency have been undertaken in this project. The results of these are presented in Tables 11 and 12. Note the values also for distribution uniformity, which is also an indicator of the irrigation performance and should be used along with application efficiency.

This data shows that management of irrigation application rate and the siphon pull time significantly effects the efficiency of the irrigation. In most cases the optimum siphon pull time was when the water was at a significant distance from the end of the furrow. Existing applications rates are also far from optimal, determined by low heads and small siphon sizes.

**Table 12:** Effect of pulling siphons early and increasing the application rate by 1.5 times on a 1100m furrow with 3" siphons and a 50mm irrigation requirement

Siphon pull / application rate	Irrigation Application Efficiency	Applied Volume (mm)	Tailwater (mm)	Deep Drainage (mm)
actual - after 90mins of tailwater	57 %	88	8.5	29.5
when water reaches the end	65 %	77	3	24
and with 1.5 x app rate	71 %	70	5.3	15
when water is at 25m from the end	69 %	72	0	22
and with 1.5 x app rate	73 %	68.5	4.2	14.3
when water is at 50m from the end*	70 %	71	0	21
and with 1.5 x app rate	75 %	66.7	3.1	13.6
when water is at 100m from the end*	72%	65	0	15
and with 1.5 x app rate	80 %	62.3	0.5	11.8

\* Note in these two cases the end was marginally under-irrigated

Farm design parameters such as field length also have a strong relationship with the optimum application efficiency that can be achieved. In the case of this field it is inherently difficult to irrigate efficiently due to the length of 1000m and the low slope of 1 in 2500. Even at a high level of management of the application rate and cut-off time only 74.4% efficiency can be achieved. However at the trial runs of 600, 700, 800 and 900 higher efficiencies can be achieved at smaller field lengths. Trading off costs against the benefits of shorter field lengths, optimum field lengths of 600 to 700m would be advisable in this case. In other cases factors such application rate (determined by head and siphon size) and field slope should be considered.

**Table 13:** Optimising Application Efficiency ( $E_a$ ) and Distribution Uniformity (DU) of a mid-season irrigation by modifying field length for a slope 1:2500 and soil moisture deficit of 70 mm, optimised siphon cut off times and application rate of 8 l/s.

Field Length (m)	Application Rate (l/s/furrow)	Optimum cut off time (min)	Optimum cut off distance from end (m)	$E_a$ – with 90% tailwater recycling (%?)	DU (%)
600	8	200	110	91	86
700	8	240	130	86.9	84
800	8	280	140	83.8	84
900	8	360	140	75.9	85
1000	8	400	180	74.4	83

The data representing the effect of the improved irrigation application practices above was firstly tested using the SIRMOD surface irrigation simulation and design package. As a first step towards optimising irrigation application, the testing of different design and management strategies to improving irrigation application efficiency can be undertaken using the SIRMOD package. This approach would be recommended rather than taking generic conclusions from the site specific data generated in Tables 11, 12 and 13.

## **Conclusion**

While there is a significant amount of data in the literature to support the fact that surface irrigation is efficient the data collected from commercial farms in the McIntyre valley suggests that there is considerable room for improving the whole farm water use efficiency. The main losses that have been measured during the current whole farm water use efficiency project are storage evaporation and in-field deep drainage. The greatest opportunities for improved whole farm water use efficiency are therefore in evaporation mitigation from water storages and the optimisation of surface irrigation application through reducing deep drainage and tailwater by controlling the water applied to match the soil moisture deficit.

Current trials into the effect of alternative (better) management practices is demonstrating that through low cost changes in the management of the application of irrigations at the field scale water can be saved from deep drainage and tailwater. Irrigation efficiency can be optimised at a high level if controlled and managed at a higher level.

Certainly the answer to improved irrigation application efficiency lies in broadening the ability to control the irrigation application. Current siphon and pipe-through-bank surface irrigated systems have little avenue to control flow to optimise efficiency. Subsequent non-uniformity of individual furrow watering times contribute to significant volumes of tailwater and deep drainage (and water logging).

Looking towards the future of irrigation technology in the Australian cotton industry, some may argue that it will hold significant developments in the implementation of drip irrigation. However this is a quantum leap in cost and technology from the existing furrow irrigation systems that are used. While these types of systems have an inherent level of control, it would be unwise to assume that this guarantees high efficiency or that a similar amount of control and management could not be achieved through optimising furrow systems.

**References:**

- ABS, (2000). Water Account for Australia 1993-94 to 1996-97, ABS report No. 4610.0
- Anthony, D. (1995). On-farm productivity, current and potential: options, outcomes, costs. *Irrigation Australia* 10:20-23.
- Barrett, Purcell and Associates (1999). Water use efficiency in irrigation in Australia. Draft Project Report. August. LWRRDC, Canberra.
- Burt, C.M. (1995). *The Surface Irrigation Manual*. Waterman Industries, Exeter, California.
- Condie, S.A. and Webster, I.T. (1995). Evaporation mitigation from on-farm water storages. Report to Sainty and Associates. CSIRO Centre for Environmental Mechanics, Technical Report No. 90. Canberra.
- Douglas, J. McLeod, D. and Falukner, R. (1996). Proceeding from the irrigation water use efficiency workshop, 29 Nov 1996, Goondiwindi, CRDC Publication.
- Elliott, R.L. and Walker, W.R. (1982). Field evaluation of furrow infiltration and advance functions. *Trans. ASAE* 396-400.
- Hanson, B.R., Pritchard, T.L., and Schulbach, H. (1993). Estimating furrow infiltration. *Agric. Water Management* 24: 281-98.
- Hearn, A.B. (1998). Summer rains on vertisol plains: a review of cotton irrigation research in Australia. *Proc. Nat. Conf. and Exhibition, Irrig. Assoc. Aust.*, p89-99. 19-21 May, Brisbane.
- Irrigation Association of Australia (IAA) (1998). The definition of irrigation efficiency as adopted by the Irrigation Association of Australia. *J. Irrig. Assoc. Aust.* 13(1).
- Kirda, C. and Kanber, R. (1999). Water, no longer a plentiful resources, should be used sparingly in irrigated agriculture. In Crop yield response to deficit irrigation, C.Kirda, P. Moutonnet, C. Hera, and D.R. Nielsen (eds). Kluwer Academic Publishers, Dordrecht.
- McLeod, A.J., Earl, G.C., McMahon, T.A., and Moore, P.J. (1994a). Measurement of Irrigation Channel Seepage in Northern Victoria. *Proc. Water Down Under Conference*, 21-25 Nov, Adelaide.
- Raine, S.R. and Bakker, D.M. (1996a). Increased furrow irrigation efficiency through better design and management of cane fields. *Proc. Aust Soc. Sugar Cane Tech.* 19, 119-124.
- Raine, S.R. and Bakker, D.M. (1996b). Increased productivity through better design and management of cane fields. *BS90S Final Report*. Sugar Research and Development Corporation, Brisbane.
- Sainty, G. (1996). Reducing Evaporation from On-Farm Storages. *Australian Cotton Grower*. Sept-Oct 1996, p84-86.
- Smith, R.J. (1988). Irrigation in the 90's - Efficient, uniform and effective? *Proc. of the Southern Engineering Conference*. (Institution of Engineers, Australia)
- Turner, G.W. (ed) (1987). *The Australian Concise Oxford Dictionary of Current English*. 7<sup>th</sup> Edn. Oxford University Press, Melbourne.
- Worstell, R.V. and Caprenter, C.D. (1969). Improved seepage meter operation for locating areas of high water loss in canals and ponds. *Oregon Reclamation Congress*, Klamath Falls, Oregon.
- Worstell, R.V. (1976). Estimating seepage losses from canal systems. *J. Irrig. Drain. Div. ASCE* 102:137-147.
- Yule D.F. and Keefer G.D., (1984). *Proc 2<sup>nd</sup> Australian Cotton Conference*. ACGRA, Wee Waa, pp282-297.

