# Benchmarking Water Use on Farm:

## If you don't measure It, you can't manage it.

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## INTRODUCTION

It hardly needs to be said that the supply of irrigation water is a major issue for the industry and a major limit to production, and that there are economic and environmental dimensions to the debate about water, which is characterised more by rhetoric than fact. For example, we have heard....

- *"The cotton industry has a voracious appetite for water."*
- *"You and I know 6Ml/ha is not enough to water a successful cotton crop."*

One assertion relates to the industry as a whole and the other to the operation of a farm, so providing a convenient introduction to two questions addressed in this paper...

- How much water does the industry actually use?
- How much water does a cotton crop need?

The corollary to these questions is: how well does the industry use this water, and is there room for improvement? In order to answer these questions, this paper will report the facts on water use by the industry, assess the industry's performance against provisional benchmarks and point to some strategic ways forward on the farm.

## HOW MUCH WATER DOES THE INDUSTRY USE?

The volume of irrigation water used on cotton from 1988 to 1994 averaged 1261 Gl per season, ranging from 1026 Gl in 1992-93 to 1498 Gl in 1990-91 (Gl = gigalitre = 1000 Ml or megs). These volumes include surface and ground water. The mean irrigated area for those seasons was 199,263 ha, giving an average input of irrigation water of 6.33 meg per ha. Water input declined from 8.43 meg per ha in 1989-90 to 5.48 meg per ha in 1993-94, reflecting the increasing severity of drought. The range in megs per ha among regions (3.9 to 11.7) reflected the extent of dependence on water harvested from off-allocation and unregulated flows with consequent large evaporation losses during on-farm storage, and the severity of drought.

The industry produced an average of 1.12 bales per meg of irrigation water. Variation among seasons and among regions reflected the same factors that affected megs per ha. Production per meg is also influence by the extent to which rainfall supplements irrigation, to which we will return later. Bales per meg increased during the drought from 0.87 in 1988-89 to 1.42 in 1992-93, as growers fine-tuned their operations when water was in short supply.

### Sources of Data

Information on the amount of irrigation water used on cotton (or any other crop) was not available in the public domain, in contrast to crop area and production. It was only the unfailing helpfulness of some officers in the relevant State Government departments that enabled the data to be unearthed. A further problem was matching the water supply data with crop production data.

The difficulty in obtaining the information is disturbing. If the country is serious about responsible management of water resources, and if debate on the issue is to be informed, the information must be readily available in the public domain, so that informed decisions are made on the competing claims for water. With the lack of data in the public domain it is doubtful if current decisions are informed.

## The National Perspective

The amount of water used to irrigate cotton is less than 0.1% of the total water resources in the relevant catchments, when assessed by the volume of rainfall. The crop used 9% of the irrigation water in Australia, and also 9% of the surface irrigation water in the Murray-Darling Basin, where most irrigated cotton is grown. A more detailed comparison of irrigated crops is given in Table 1.

**Table 1: Comparisons among irrigated crops in 1992-3 in Australia.**

| Crop | Megs per ha | Percentage of total irrigation water used in Australia | Percentage of farm gate value of irrigated production | Farm gate value $ per meg |
|---|---|---|---|---|
| Pastures | 8.25 | 58.2 | 14.5 | 101 |
| Horticulture | 7.05 | 18.2 | 58.4 | 1300 |
| Rice | 12.31 | 9.4 | 3.8 | 162 |
| Cotton | 7.00 | 8.2 | 9.4 | 464 |
| Sugar | 7.69 | 6.0 | 13.9 | 960 |

Source: Thomson & Schofield, handout at IAA Conference, 1998.

These figures show that the cotton industry is not the voracious consumer of water the media like to portray. Moreover, cotton returns more per meg than pastures and rice, which use two thirds of the country's irrigation water for less than 20% of the farm gate value. Cotton produces 35% of irrigation export income from 9% of the water.

These facts are important, not primarily in order to defend the industry, but rather to provide a platform from which to ask and answer the questions: could the industry do more with the water it uses? Are there gains to be made? To answer this we need to take a closer look to at production per meg. Is 1.12 bales per meg of irrigation water a good outcome? Its dollar value puts cotton ahead of irrigated pastures and rice, but behind horticulture and sugar, in terms of value of production per meg. One valley averaged 1.8 bales per meg, and achieved 2.22 bales per meg in one year. Is this the benchmark against which to assess the industry, and for which we should be striving? These questions bring us to the topic of Water Use Efficiency (WUE).

## WATER USE EFFICIENCY

WUE, like sustainability and IPM, means different things to different people, not least to growers, to engineers, to agronomists and to physiologists. Like sustainability and IPM it is in danger of becoming meaningless by careless use. Unlike sustainability and IPM, WUE can be precisely mathematically defined. Moreover it can be calculated in different ways, depending on how water input is assessed. It is crucial, not only to define it precisely, but to use the right definition for the purpose, if we are to assess and improve our practices. Different definitions are a source of confusion and it is not pedantic to be precise, otherwise we may not be comparing like with like.

Production per meg of irrigation water, which averaged 1.12 bales for the industry, is a simple estimate of WUE. Although increasing bales per meg of irrigation water is the ultimate aim, this definition of WUE is too simplistic to evaluate industry practices does not take rainfall or water stored in the profile into account, nor does it separate the engineering and agronomic aspects. Engineering factors determine how much of the water received at the farm gate is used by the crop. Losses between farm gate and crop plant consist of evaporation and seepage from storages and channels, and deep drainage in the field, and are strongly influenced by the design and operation of the irrigation system. On the other hand agronomic factors determine what the crop produces with the water it uses. It is crucial to separate the engineering and agronomic components if WUE is to be properly assessed and improved. Without this separation, and without taking rainfall into account, it is impossible to determine whether low WUE is an engineering or an agronomic problem, or due to weather, or all three.

## Components of WUE

The engineering component of WUE is the percentage of water input (from all sources) actually used by the crop, and is referred to as irrigation efficiency (IE). The agronomic component is crop water use efficiency (CWUE), and is the production of lint per unit of water used by the crop. Thus:

Irrigation efficiency..................... $\mathrm{IE} = \dfrac{\text{water used by crop}}{\text{water input to farm}}$

Agronomic water use efficiency.... $\mathrm{CWUE} = \dfrac{\text{cotton produced}}{\text{water used by crop}}$

The terms used in these calculations also need defining: water inputs and water used.

**Water inputs.** Water inputs include not only irrigation water, for which the grower accounts to the relevant agency, but also water in the soil profile at the start of the season and rainfall. All rainfall should be included. Light falls should not be discounted as ineffective, even if they only wet leaves and the soil surface, and do not register in the probe reading. Energy is still needed to evaporate that water, and cannot then be used again to draw water from the soil profile. Such falls therefore substitute for water from the profile, and constitute water saved.

As it is mandatory in NSW, and recommended in Queensland, that no rainwater run-off (storm water) leaves the farm, no allowance is made for run-off that results from heavy falls. IE is then measuring the effectiveness of the irrigation system in harvesting rainfall run-off as well as in handling irrigation inputs.

Water inputs to farm.......... = irrigation water + rainfall + soil water

**Water used by the crop - Evapotranspiration.** Crops use water for evapotranspiration (ET). This is the process in which water is evaporated from leaves (transpiration) and from the soil surface to dissipate heat in order to keep the crop cool. ET is primarily a meteorological or atmospheric process driven by solar energy, and modulated under some conditions by the plant or the soil. Thus it is a physical rather than a biological process. The amount of energy received at the outer boundary of the atmosphere is constant. The fraction that reaches the crop surface and is used in ET is determined by meteorological conditions and can be measured. An additional source of energy is advection, which is solar energy received indirectly from another location coming in hot dry winds, and can also be measured.

ET is thus an environmental demand that has to be met if the crop is to function unimpaired by heat stress. ET is estimated either by calculating the energy available for evaporation or by the accumulative changes in soil water for the season. These methods are robust and consistent with one another. Thus:

Water used by the crop........ ET = energy used in evaporation + transpiration

= water removed from soil

A typical seasonal value for a cotton crop is 750mm or 7.5 megs per ha, with a range of 6.5 to 8.5 megs.

## Irrigation Efficiency

Irrigation efficiency of cotton, and research into it, has not received the attention due to it until recently. The available information is presented in Table 2 from situations where both ET and water inputs have been measured. The average for the 1980s and 90s is 75% (excluding 2 aberrant points), and experience confirms that this is achievable when water is not stored for long periods in on-farm storage, and is suggested as a provisional benchmark.

**Table 2:** Estimates of farm irrigation efficiency.

| | | | | | |
|---|---|---|---|---|---|
| **Cull *et al* 1981b**<br>Whole Namoi valley | 1975-76<br>42% | 1975-77<br>32% | 1977-78<br>54% | | |
| **Cull *et al* 1986**<br>1 Farm in Gwydir Valley | 1985-86<br>75% | | | | |
| **Hearn *et al* 1997**<br>1 Farm in Namoi Valley | 1991-92<br>80% | 1992-93<br>92% | 1993-94<br>68% | 1994-95<br>25% | 1995-96<br>53% |
| 1 Farm in Gwydir Valley | 1988-89<br>73% | 1989-90<br>30% | 1990-91<br>68% | 1991-92<br>85% | |
| 1 Farm on the Darling | 1994-95<br>85% | 1995-96<br>71% | | | |

Smith *et al* (1982) and Dawson (1997) report that IE of surface irrigation in Australia and overseas averages from 30 to 50%, sometimes falling as low as 10%. Clearly cotton on grey cracking clays is achieving far greater IE than these reports.

Irrigation efficiency (IE) as defined measures whole farm irrigation efficiency, and indicates the magnitude of the losses in the system without indicating how or where they occur. IE can be partitioned into conveyancing, storage and application efficiency.

### Application Efficiency

The application efficiency is the percentage of the water delivered to the field that is available in the soil for ET. The important component of loss is deep drainage beyond the root zone. It has been measured in whole or part using a number of techniques, and the results are summarised in Table 3. Drainage losses are small in most cases, though there are exceptions. If it is assumed on the basis of farm efficiency that tailwater is recycled with 75% efficiency, unrecoverable losses from drainage and run-off then mount to 3%, giving an effective application efficiency of 97%.

In general, apart from the exceptions about which more information is needed in order to identify high risk soils, application efficiency is high on the grey cracking clays on which 90% of cotton is grown in Australia. High application efficiency is a result of the low saturated hydraulic conductivity of these vertisols, limiting drainage to small amounts. This feature led Farbrother (1972) to describe similar vertisols in the Sudan Gezira as self-regulating for surface irrigation, as the amount of water entering the profile is determined by the depth and amount of water extracted by the crop, so that the soil takes no more and no less water than is needed to restore it to the upper limit, leaving additional water to run-off and be recycled.

**Table 3:** Application efficiency of furrow irrigation of cotton, on grey cacking clay unless other wise stated.

| **Per day or per irrigation** | | Applied mm | Runoff mm | Drainage mm | Application efficiency(a) |
|---|---|---|---|---|---|
| **Mason** *et al* **1980**<br>Namoi | per day during irrigation | | | 1.3 | |
| **Yule & Keefer 1984**<br>Emerald<br>1983-84 | mean of 5 irrigations | 80 | 9.5 | nil | 97.0% |
| | mean of 2 irrigations | 106 | 13.7 | nil | 96.8% |
| | mean of 2 irrigations | 142 | 15.6 | nil | 97.3% |
| **Douglas** *et al* **1998**<br>Namoi<br>1995-96 | 2nd irrigation | 94 | 2.4 | 2.04 | 97.2% |
| | 3rd irrigation | 82 | 6.4 | 1.02 | 96.8% |
| **Per season** | | Saturated conductivity mm/d | Applied mm incl. rain | Drainage mm | Drainage % |
| **Willis** *et al* **1997**<br>Macquarie<br>1992-93 | | 0.51 | 758 | 67 to 236 | 8 to 31 |
| | Red-brown earth | 0.36 | 630 | 104 to 145 | 17 to 23 |
| **Triantafilis** *et al* **1998**<br>Gwydir | | | 1184 | 25 | 2.1 |
| | Prior stream channel | | 1184 | 34 to 227 | 2.9 to 19.2 |

Note: (a) calculated assuming runoff is recirculated with 75% efficiency.

### Conveyancing and Storage Efficiency

If overall farm efficiency is 75% and application efficiency is 97%, then most losses must occur in on-farm conveyance and storage. The industry is aware of losses during on-farm storage, which are of particular concern in regions where growers depend on harvesting and storage of water from off allocation and unregulated flows. Sainty & Scott (1996) at the last Conference reviewed a number of studies of methods of reducing evaporative losses. Mono-molecular chemical films were proposed many years ago but in trials wind and waves break up the films making them ineffective. Computer studies of windbreaks of trees are not promising. Sainty & Scott (1996) report that floating plastic covered rings show potential in reducing evaporation losses by up to 65% giving a payback period of 3 years. Further testing is being done.

No research or data is available on conveyancing efficiency. CRDC has recently commissioned a project to rectify this, and in the last issue of the *Australian Cotton Grower* Steven Raines described the work started in this project which includes developing farmer friendly devices to measure efficiency in the distribution system.

## Crop Water Use Efficiency

The second component of WUE, crop water use efficiency, is calculated by dividing yield by ET in mm or megs per ha, and expressed either as kg per mm or bales per meg. Some results from research and commercial production are given in Table 4.

**Table 4:** Agronomic water use efficiency in experiments and on farms (kg per mm of ET).

| | | | | | |
|---|---|---|---|---|---|
| **Cull *et al* 1981a** | | | | | |
| Experiments in Namoi valley(a) | 1975-77 | | | | |
| | 3.7 | | | | |
| **Bourne 1988** | | | | | |
| Queensland (a) | Dalby | South Burnett | Biloela | | |
| | 2.60 | 2.98 | 2.68 | | |
| **Hodgson *et al* 1990** | | | | | |
| Experiments in Namoi valley | 1983-84 | 1984-85 | 1985-86 | 1986-87 | |
| | 2.29 | 2.39 | 2.48 | 1.91 | |
| **Cull & Robson 1994** | | | | | |
| Industry wide data-base | 3.08 | | | | |
| **Hearn *et al* 1997** | | | | | |
| 1 Farm in Namoi Valley | 1991-92 | 1992-93 | 1993-94 | 1994-95 | 1995-96 |
| | 3.63 | 2.58 | 3.09 | 5.27 | 2.61 |
| 1 Farm in Gwydir Valley | 1988-89 | 1989-90 | 1990-91 | 1991-92 | |
| | 2.93 | 2.64 | 2.66 | 2.97 | |
| 1 Farm on the Darling | 1994-95 | 1995-96 | | | |
| | 2.61 | 2.55 | | | |

Note: (a) calculated as slope of yield plotted against ET

When comparing regions or countries, differences in WUE may reflect differences climate rather than differences in efficiency of agronomic technology. A desert environment like Arizona has very high advection and very high ET, giving a relatively low value of 1.32 kg per mm for CWUE whereas Israel has values of 3.7 kg per mm.

The CWUE data in Table 4 average 1.33 bales per meg (3 kg per mm), which compares well with data from other countries with similar climates (see Hearn 1995b, Hearn *et al* 1997) and provides a reasonable provisional benchmark.

## Assessment of Current Commercial Practice

This review of WUE of Australian cotton crops has provided provisional benchmarks for irrigation efficiency and agronomic water use efficiency, as follows:

Irrigation efficiency...................... IE = 75%

Crop water use efficiency............. CWUE = 1.33 bales per meg

The benchmarks were derived from farms, and are therefore achievable commercially. However ET is not yet widely measured in Australian cotton crops. In order to assess the performance of the industry, IE and CWUE can be combined to give a benchmark for gross water use efficiency (GWUE), thus:

Gross water use efficiency............ $\text{GWUE} = \dfrac{\text{cotton produced}}{\text{water input to farm}}$

$= \text{IE} * \text{CWUE}$

$= 1 \text{ bale per meg}$

GWUE therefore differs from the simple irrigation water use efficiency (production per meg of irrigation water) because it takes rainfall into account.

### Assessment of the Industry

In order to determine the gross water use efficiency of the industry, rainfall was taken into account by calculating the amount of cotton produced in each region, in excess of what would have been produced from rainfall alone had the crop not been irrigated. This amount is then divided by the irrigation water input. The amount that would have been produced from rainfall alone was estimated from the dryland yields for the region.

The average for the industry was 0.77 bales per meg, which it is valid to compare with the benchmark of 1 bale per meg. This means that on average the industry only achieved 77% of the benchmark. However gross water use efficiency increased from 0.55 bales per meg before the drought to 1.14 bales per meg when the drought was severest, which means the industry reached the bench mark when supplies were severely restricted but achieved only just over half the benchmark with full allocations.

Looking at the data another way, 84% of the yearly values for regions were below the benchmark, and 34% were less than half the bench mark. When the regional means were examined, the Gwydir valley exceed the benchmark, Macquarie valley and the Darling Downs were close to it, while the Namoi and Macintyre valleys, Biloela and Emerald only just exceed 50% of the benchmark. Some regions could not be assessed because dryland production was not sufficient to estimate the amount that would have been produced from rainfall alone.

### Assessment of Farms

Data was collected from 11 farms for two to five seasons in four regions as part of the study described by Hearn *et al* (1997). Gross WUE for these farms was calculated by dividing production by the total water input, irrigation plus rainfall. When the individual years for farms are examined, 79% were below the benchmark, and 16% were less than half the bench mark, and these farms were a better than average sample.

### Conclusion on Benchmaking

The large percentages of farms and regions that fall below the benchmark suggests that there is scope for improving WUE of irrigated cotton in Australia. The calculations do not include water stored in soil and depleted during the season, which might amount to 1 Ml per ha. Adjusting water inputs by this amount would decrease the gross WUE, increasing the numbers below the benchmark. The assessment does not indicated whether the reason for falling short of the benchmark were agronomic or engineering, for example, evaporation and seepage losses from on-farm storages; rainfall runoff not harvested; agronomic yield depression.

### Achievable Gains.

The industry used 1261 Gl of irrigation water per season from 1988 to 1994. If all this water had been used for ET, at 1.33 bales per meg of ET (the CWUE benchmark), an additional 711,947 bales per season would have been produced. At $450 per bale this would have been worth $M320, or $1608 for every hectare of cotton irrigated. Put another way, 43% of the value of the irrigation water used by the industry was lost.

Such is the challenge facing the industry, the growers and the professionals, both engineers and agronomists. Obviously it is not possible to achieve 100% irrigation efficiency with no loss and using all irrigation water for ET. But what is achievable?

If the whole industry had achieved the gross WUE benchmark of 1 bale per meg of water input from 1988 to 1994, increased production would have been worth $M133 per season, or $668 **for** every ha (but not **from** every ha, as more could have been planted), an increase of 31%. If irrigation efficiency could have been raised above 75%, increased production would have been worth $M7.6 a season per percentage point, or $38 per ha. Of course farms heavily dependent on harvesting water and storing for long periods cannot achieve high IE, but farms dependent on bores conveying water short distance without long term storage should achieve higher IE, so that the industry as a whole should be able to achieve this benchmark.

## THE WAY FORWARD

### Is There a Case for Drip Irrigation?

With large losses of water between point of supply and uptake by the crop, drip irrigation seems an obvious solution, with the possibility of delivering precisely controlled correct amounts of water into the root zone. It is not surprising that drip irrigation is suggested from time to time for improving WUE, and there have been a number of research and commercial drip irrigation projects over the last twenty years.

The best documented work was Hodgson *et al* (1990) who compared surface and buried drip with furrow irrigation for four seasons. Drip irrigation slightly increased yield but not enough to pay for the high capital cost. It was expected that drip irrigation would increase yield by eliminating the temporary waterlogging that occurs when the crop is irrigated; this did not happen. It was also expected that the buried drip would reduce the evaporation component of ET (evaporation from the soil surface when wet), leading to a reduction in ET; again this did not happen. Drip irrigation increased ET by similar proportion to yield so CWUE was not affected. These results have been confirmed by several commercial ventures with drip irrigation, most of which have been abandoned as uneconomic.

There is not much room for improvement with well managed conventional irrigation on most grey cracking clays. With whole farm efficiency at 75% and application efficiency at 97% most losses are in storage and conveyance, which will not be reduced by drip irrigation.

Some current commercial projects are said to be promising. It is vital to ensure that comparisons of drip and furrow irrigation are valid. Comparisons are not valid if the water used by furrow irrigation is measured at the farm boundary while that for drip is measured at the field boundary, so that conveyance and storage losses are debited to furrow but not to drip, indeed the losses for drip are debited to furrow. Furthermore the general agronomy of drip may be more intensively managed, so that the yield response to drip is not to the technology per se but to the better management. Beware!

Having said that, drip irrigation is undoubtedly of value on more permeable soils, and on soils that are marginal for conventional irrigation, for example on shallow soils with decaying basalt near the surface, on steep slopes and very flat fields. In these situations drip can save water and raise yields to the level of good soils. This has been the case in Israel, where drip irrigation of cotton has been an outstanding success. Limited commercial experience suggests there is a case for drip irrigation in such situations in Australia. An article in the last issue of the *Australian Cotton Grower* magazine describes the experience at Tandou where Bob Smith says the value of drip is in reducing waterlogging on the very flat slopes, and not in saving water. These are special cases and it does not apply to conventional production on most cracking grey clays.

There may be other reasons for using drip, unrelated to water use efficiency, including environmentally friendly distribution of nutrients, insecticides and herbicides through the system and saving of labour, particularly avoiding night shifts.

## Varieties with Improved WUE

Varieties with improved WUE are advocated as a means of increasing the WUE of the industry. However this strategy is being continually followed and achieved. Every variety introduced in the last 30 years has had a higher WUE, even though, there was no selection specifically for that purpose and the plant's water relations are unchanged. This is because when yield is increase genetically it is most unlikely for ET to increase as much, if at all. (Incidentally this is also true of most agronomic practices that in increase yield.) As a result the WUE of the industry has doubled over the last twenty years; it is just another way of saying yields have doubled.

Nevertheless Warwick Stiller has a program to identify genotypes with higher physiological WUE. The first outcome has confirmed the observation that early maturing varieties have lower rather than higher CWUE, thus debunking a widely held myth. Warwick has found some genotypes with higher physiological WUE, but there is a long way to go for these to translate into varieties with higher CWUE. This has been the aim of several programs around the world, but none has yet delivered.

## Rotations

Rotations are another perennial suggestion for improving water use efficiency. The rationale is that water stored during the fallow break after a winter crop will reduce the irrigation requirements of the following cotton crop. It is noteworthy that 4 of the 6 entrants to the *Australian Cotton Grower* magazine "Cotton Grower of the Year Award" practiced a 1:1 rotation which maximises potential for storing water. Scott MacCullam has combined this with zero-till planting of the cotton crop resulting in saving of more than 2 megs per ha of irrigation water. These are highly desirable achievements, but are water conservation practices rather than WUE practices because IE and CWUE are unaffected. Any yield increase from rotation will result in increased CWUE, as will any agronomic yield increase, apart from any irrigation water saved.

## On-Farm Assessment of Irrigation Systems.

The urgent need is for on-farm assessment of irrigations systems, before introducing more technology to improve WUE, such as drip irrigation, varieties with high physiological WUE and infra-red sensing for more precise scheduling. These technologies are further fine tuning, and to pursue the analogy further, the industry is like a car with poor fuel economy. Having a tune up, or electronic fuel injection is of little value if there is a leak in the fuel tank. We need to find the leaks!

## Measuring WUE

The first step is to assess the performance of the system by determining IE and CWUE and compare these with the benchmarks. Some growers have spreadsheets to budget and account for water inputs. These could be extended to calculate IE and CWUE at the end of the season. Farmscape type growers' participatory learning groups could be convened to share these experiences and standardise book-keeping so that valid comparisons can be made. We need to make the most of data already collected.

Accounting for water inputs and determining WUE on-farm are the major part of the CRDC WUE project being done by Steve Milroy and Sunil Tennakoon at ACRI.

Determining ET is crucial to separating the engineering and agronomic aspects of WUE in order to analyse the WUE performance of a farm rigorously. ET is a surgeon's knife for separating the key components. There are several options for determining ET. Neutron Probe Services' software for irrigation scheduling has an option to estimate seasonal ET from the "total gain" calculated for the season (Cull & Finch 1994). Alternatively ET can be calculated with data from the nearest weather station. Stations installed to monitor weather conditions for spraying could be extended to collect data to determine ET. Sunil Tennakoon at ACRI has developed a spreadsheet program to integrate probe readings and weather data to estimate ET.

In order to make a start to on-farm assessing, until ET data is available assume a typical value of 7.5 megs per ha. This is a robust conservative number because ET is energy driven and solar energy input is constant.

## Strategic Planning.

WUE can be improved by strategic planning in the use of water supply with risk analysis and yield probability. The main strategic decision is what area of crop to grow with a given supply of water, taking into account the probability of the extremely variable rainfall to supplement irrigation. This is a crucial issue in years of reduced allocations, but it should also be a relevant issue every year if WUE and returns per Ml of irrigation water are to be maximised. Note how gross WUE increased in drought years - treat every year as a drought year.

The OZCOT model has been used with long term weather data to evaluate these strategies with results published in the *Australian Cotton Grower* from time to time (Hearn 1992, 1995a). The work of Yahya Abawi and Sunil Dutta in the DPI at Toowoomba in a project funded by the Murray-Darling Basin Commission will enhance such strategic planning by incorporating the influence of the Southern Oscillation Index (el Nino / la Nina) on the probability of stream flows. Mike Bange at ACRI is working on a user friendly version of OZCOT so that growers or consultants can customise strategies, and plans to start Farmscape type groups.

## CONCLUDING REMARKS.

The topic of strategic planning returns us to one of the initial questions: how much water does it take to grow a successful crop? Many growers have grown successful crops on 6 megs of irrigation water per ha, or less. During drought they have had to! Risk analysis shows that in most regions this supply will maximise WUE and returns per Ml in most seasons. In the drier south and west 7 Ml may be optimum. Of course it would be handy to have more as insurance for a dry season, but in most seasons not all of it would be needed, and could better be used to grow a larger area.

With ET of 750 mm, 200 mm of rainfall, 100 mm of water stored in the soil, and an irrigation efficiency of 75%, the seasonal irrigation requirement is 6 Ml per ha. If more is needed, it probably means that irrigation efficiency is less than 75%. For example if 9 megs is needed, then IE has fallen to 62.5%. This emphasises the need to measure these parameters on-farm in order to do strategic planning with the same rigour that is applied to tactical scheduling. Let's fix the leaks as well as tune the carburettor!

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