

1.2 Water use efficiency, benchmarking and water budgeting

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Key points

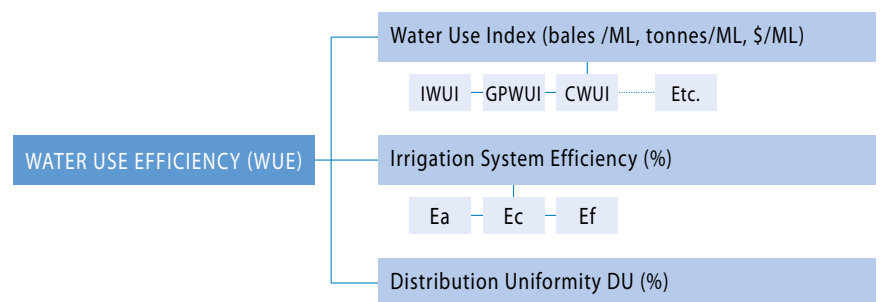
- Water Use Efficiency is a generic label that encompasses an array of performance indicators used to describe water use within a cropping system.
- A Water Use Index (WUI) relates production outputs (\$, bales, tonnes, etc.) to water input (ML).
- An Irrigation System Efficiency (%) relates water output (ML) to water input (ML).
- It is important to always understand the inputs and dimensions of water use efficiency terms as well as the scale at which they are applied.
- Benchmarking involves comparing performance indicators or management processes.
- A water budget is used to determine how best to use the available water resource by balancing seasonal risks

Water Use Efficiency (WUE) is a concept that has historically caused much confusion for scientists, water suppliers and end users alike. Much of this confusion has stemmed from the range of terms available to describe water use efficiency and a lack of understanding of what WUE represents. The Australian irrigation industry developed a framework ([Barrett, Purcell and Associates, 1999](#)) to standardise the array of terms and definitions used to minimise this confusion. The concepts and definitions employed in WATERpak reflect this framework.

Water Use Efficiency is itself a generic label that encompasses an array of performance indicators used to describe water use within a cropping system (Figure 1.2.1). The performance indicators can be categorised as one of the following:

- Water Use Index (WUI) (relating production to water use)
- Irrigation System Efficiency (relating water inputs to water outputs at different locations)
- Distribution Uniformity (DU) (a measure of how even an irrigation application is)

Figure 1.2.1. Irrigation performance indicators.

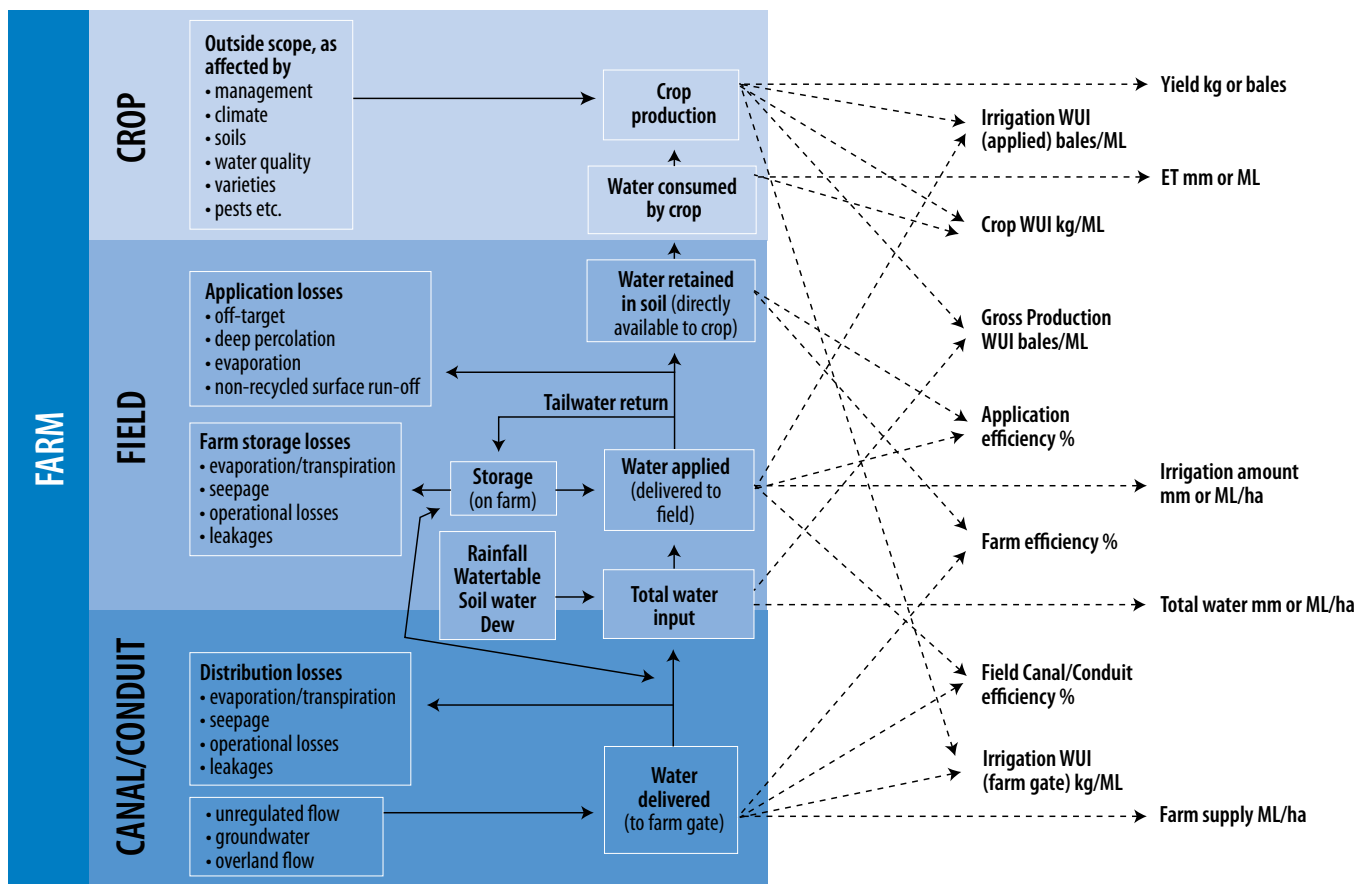


Different indicators can be used in different situations according to the intended purpose, inputs, outputs and boundary conditions. Boundaries, both spatially (area) and temporally (time) need to be specified. Area boundaries might include a field, farm or region whilst time boundaries could be a single irrigation event, a month, the growing season or a year.

Due to the complexity of the system it is not practical to calculate all the possible water use efficiency indicators, nor is it necessary, as a meaningful picture of water use efficiency is obtained through calculation of those indicators with the most pertinence.

The relationship between these performance indicators at different scales within an entire irrigation system is illustrated fully in the framework provided in Figure 1.2.2

Figure 1.2.2. Framework for on-farm water use efficiency



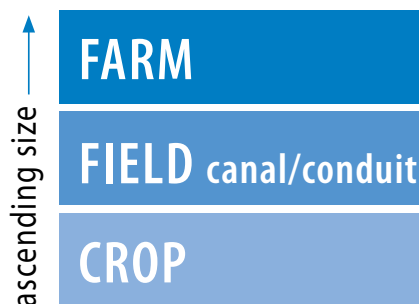
Source: modified from: Barrett, Purcell and Associates, 1999



As previously discussed and indicated in Figure 1.2.2, indices and efficiencies can be calculated over a range of spatial boundary conditions (scales). This concept is important for calculation of WUE indicators because:

- Indices are differentiated on the basis of the scale at which they are applied. For example, Irrigation Water Use Index (Applied) and Irrigation Water Use Index (Farm) both compare yield and irrigation water input but are applied at different scales, the field and farm respectively. Therefore it is important to understand at which scale the inputs have been measured.
- As will be discussed later, efficiency terms at different spatial scales are all related, so that they may be multiplied together to gain an efficiency at the next greatest scale. This concept is termed a 'nested' approach.

The order of spatial scales is as follows:



Effective Rainfall

Before discussing water use efficiency terms in more detail, it is worth briefly discussing effective rainfall, as this is an important concept for some specific terms. Rainfall is considered effective if it contributes to the water requirement of the crop.

Effective rainfall includes:

- water intercepted by vegetation,
- soil evaporation losses,
- evapotranspiration losses; and
- the contribution to leaching requirement.

Ineffective rainfall includes:

- uncaptured surface runoff,
- deep drainage; and
- any remaining soil moisture that is not used for subsequent crops.

In the simplest of terms, accounting for the major losses, effective rainfall is approximated by:

Effective rainfall =

total rainfall – run-off – deep drainage

This definition assumes that variables such as rainfall intensity and initial soil moisture (rain falling on a full soil profile has little effectiveness) are taken into account by the runoff and deep drainage terms; however these terms themselves can be quite difficult to measure.

Effective rainfall can also be estimated using:

- Computer programs such as Watertrack™ and HydroLOGIC
 - HydroLOGIC is cotton specific and accounts only for losses due to run-off.
 - Watertrack™ accounts for both run-off and deep drainage losses.
- The change in soil moisture due to rainfall. This method relies on the accuracy of the measurement equipment (most soil moisture probes give only approximate values - see WATERpak Chapter 2.7), does not indicate the volume of water lost through the profile and does not account well for spatial variability.
- A guess of the effective proportion: it is sometimes taken that 75% of the rainfall for the season is effective.

It is important to note that all of these methods include some substantial assumptions, particularly the soil moisture measurement and 75% methods.

Water Use Indices

Water use indices typically compare a production output (yield, return, gross margin) to a water input (such as irrigation water, total water or evapotranspiration) at some level in the farm or production system. In other words, they compare two different units (bales/ML, \$/ML, kg/mm, etc.).

- They are very flexible and can be tailored to a particular situation, but can be quite easily used out of context if the units are not well defined.
- Production can be defined in terms of yield (bales or tonnes), lint yield (kg), gross return (\$), gross margin (\$) or any other appropriate measure.
- Water inputs are usually defined in terms of crop water use (mm), irrigation water input (ML) or total water input (ML). Such water inputs across a whole farm may include water pumped from rivers and bores, the amount used from storage reservoirs, water harvested during the season, effective rainfall or total rainfall and soil moisture reserves depleted during the season.

As discussed previously, Water Use Indices can be applied at different spatial scales within the farming system. This concept is very useful as it allows for comparison of production and water use at very specific locations (crop scale), within individual management units (field scale) or to assess the performance of the whole farm. By calculating WUI's at these different scales, appropriate management options can be formulated to try and improve the effectiveness of water use.

Water Use Index (IWUI)

Irrigation water use index is a measure that relates the total amount of production to the amount of irrigation water that was applied to produce this yield. It is a useful measure and is commonly used, particularly for internal analysis, as it only accounts for irrigation water and therefore it can reflect differences in irrigation management. However it is less useful as a comparison, particularly between different farms or regions, as it takes no account of differences in rainfall (which can significantly influence the amount of irrigation required).

IWUI can be applied to either the field or the farm scale.

Field scale:

$$\text{Irrigation water use index (applied) (\%)} = \frac{\text{total yield (bales)}}{\text{irrigation water applied (ML)}}$$

Farm scale:

$$\text{Irrigation water use index (farm) (\%)} = \frac{\text{total yield (bales)}}{\text{irrigation water supplied to farm gate (ML)}}$$

For example, a cotton field has a yield of 80 bales and 50 ML of irrigation water was applied to the field during a season.

$$\text{IWUI (applied)} = (80 \div 50) = 1.6 \text{ bales per megalitre}$$

Across the whole farm, 450 bales of cotton were produced using 350 ML of irrigation water.

$$\text{IWUI (farm)} = 450 \div 350 = 1.3 \text{ bales per megalitre}$$

Note that the scale at which the term has been applied has been specified explicitly in each case (applied or farm).

The same calculation can be performed for different crops. For example, on another field, 50 ML of water was applied to produce 160 tonnes of sorghum.

$$\text{IWUI (applied)} = (160 \div 50) = 3.2 \text{ tonnes per megalitre}$$

Across the whole farm, 880 tonnes of sorghum were produced using 350 ML of irrigation water.

$$\text{IWUI (farm)} = (880 \div 350) = 2.5 \text{ tonnes per megalitre}$$



Gross Production Water Use Index (GPWUI)

Gross production water use index is the amount of yield produced compared to the total water input. The total water input includes irrigation, rainfall and total used soil moisture. The rainfall component can comprise either total rainfall or effective rainfall and therefore must be specified. GPWUI can be applied to multiple spatial scales, typically to the field or farm.

Gross production water use index is a measure that is helpful for comparing the irrigation performance of different fields or farms across different regions and seasons because using the total water input helps to account for spatial and temporal differences (in rainfall, for example) that lead to different irrigation requirements.

Although calculation of this index is typically simpler if total rainfall is used, a better result is obtained by using effective rainfall. For example you may wish to compare two fields that both received 350 mm of rain throughout the season. If one field received all of that rain in one event, much more irrigation water would be required for the rest of the season than on another field that may have received the rain in regular, effective events. This may bias the index to indicate that one field produced more yield per ML of water applied even though the actual performance of the irrigation systems may be similar.

Field scale:

Gross production water use index (applied) (b/ML) =

$$\frac{\text{total yield (bales)}}{\text{total water applied (ML)}}$$

Farm scale:

Gross production water use index (farm) (b/ML) =

$$\frac{\text{total yield (bales)}}{\text{total water used on farm (ML)}}$$

From the previous example, a cotton field has a yield of 80 bales which used 85 ML of total water (irrigation, effective rainfall and used soil moisture).

GPWUI (effective) (applied) = $(80 \div 85) = 0.94$ bales per megalitre

Across the whole farm, 450 bales were produced using 530 ML of total water (irrigation, effective rainfall and used soil moisture).

GPWUI (effective) (farm) = $(450 \div 530) = 0.85$ bales per megalitre

Note that the use of effective rainfall and the scale of the calculation has been made explicit in the title of the term. In this case, the whole farm GPWUI is lower than for the individual field. This is typically the case as the whole farm figure includes additional sources of water loss such as on-farm storages.

A sorghum field has a yield of 160 tonnes and used 100 ML of total water (irrigation, effective rainfall and used soil moisture).

GPWUI (effective) (applied) = $(160 \div 100) = 1.6$ tonnes per megalitre

Across the whole farm, 880 tonnes were produced, using 490 ML of total water (irrigation, effective rainfall and used soil moisture).

GPWUI (effective) (farm) = $(880 \div 490) = 1.8$ tonnes per megalitre

In this case, the yield from the field happened to be lower than for the rest of the farm and this meant that the field GPWUI was smaller than the farm GPWUI.

Crop Water Use Index (CWUI)

Crop water use index (CWUI) is an indicator that describes plant-water interactions at the crop scale and is represented as the yield (lint yield for cotton) produced per millimeter of water evapotranspired from a field during the growing season. It is usually reported in kilograms per hectare per millimeter but may also be reported in bales per megalitre.

Daily evapotranspiration data is available from the [Bureau of Meteorology](#) and [SILO](#). Such data needs to be converted to daily crop water use using an appropriate crop coefficient as explained in WATERpak Chapter 2.8.

In essence, CWUI represents the ability of the plant to produce yield (rather than vegetative growth) for the given water use. This indicator is influenced by many factors such as variety, nutrition, pests, disease and climate.

Some irrigation management factors (such as irrigation timing and prevention of waterlogging) can affect the amount of energy that is being expended on crop reproduction, thus influencing CWUI. However, because of the wide range of factors that influence the inputs to this index, it provides a broad measure of crop performance rather than a specific measure of irrigation performance.

$$\text{CWUI (kg/ha/mm)} = \frac{\text{lint yield (kg/ha)}}{\text{seasonal evapotranspiration (mm)}}$$

For example: A cotton field with 2000 kg/ha of lint yield and 750 mm of seasonal evapotranspiration:

$$\text{CWUI} = (2000 \div 750) = 2.67 \text{ kg/ha/mm}$$

Note that this term only applies at the crop scale and therefore does not need to have the scale explicitly defined as is the case with the previous indicators.

This figure can be converted into bales per megalitre by dividing by 227 (kg → bale) and multiplying by 100 (mm → ML):

$$\text{CWUI} = (2.67 \div 227) \times 100 = 1.17 \text{ bales/ML}$$

A sorghum field yields 8 t/ha (i.e. 8000 kg/ha) and uses 480 mm of seasonal evapotranspiration:

$$\text{CWUI} = (8000/480) = 16.7 \text{ kg/ha/mm}$$

Economic Indices

Economic indices can be calculated by applying an economic production measure to any of the indices described above. This measure could be gross return, gross margin, marginal return, or any other appropriate economic measure. The economic calculation is typically achieved by multiplying the economic measure and the appropriate WUI, to achieve a \$/ML result.

Economic indices can be used to compare the economic return on water inputs. Three economic terms that are often used to generate economic indices are:

- Gross income (GI)
- Gross margin (GM)
- Operating profit (OP)

Whatever economic indices are used it is important to state the inputs and give it an appropriate name. Often the economic inputs used in these calculations can be confusing. The relationships between the economic terms used in these calculations are as follows:

Gross income (\$) =

$$\text{production (bales or tonnes)} \\ \times \text{on-farm price (\$/bale or \$/tonne)}$$

Gross margin (\$) =

$$\text{gross income (\$)} - \text{variable Costs (\$)}$$

Operating profit (\$) =

$$\text{gross margin (\$)} - \text{overheads (\$)}$$

- Variable costs are costs that change according to the area of crop grown
- Overheads are costs that do not vary greatly with area of crop grown (fixed costs)

Three economic indices that can be calculated at the farm scale to relate these economic terms to the total water used on farm (including rainfall) are:

Gross return WUI (farm) =

$$\frac{\text{gross income (\$)}}{\text{total water used on farm (ML)}}$$

Gross margin WUI (farm) =

$$\frac{\text{gross income (\$)} - \text{variable costs (\$)}}{\text{total water used on farm (ML)}}$$

Operating profit WUI (farm) =

$$\frac{\text{total gross margin (\$)} - \text{overhead costs (\$)}}{\text{total water used on farm (ML)}}$$

The advantages and drawbacks of these economic indices are provided in Table 1.2.1.



Table 1.2.1 - The advantages and drawbacks of different economic indicators

The advantages and drawbacks of these different economic indices are:

Advantages	Drawbacks
Economic Index – Gross Return WUI	
Easy to calculate as on-farm price is easily obtained	Limited value as gross return is not necessarily a good indicator of profit. Not possible to compare between farms in the same year due to commodity price differences. Difficult to compare between years on the same farm due to commodity price changes from year to year
Economic Index – Gross Margin WUI	
Inclusion of variable costs enables comparison between alternative crops on the same farm.	Differences in variable costs between farms make it difficult to compare this index between farms, particularly those in different districts. Gross margins exclude overhead costs so are not an adequate measure of profit.
Economic Index – Operating Profit WUI	
The inclusion of farm overhead costs to calculate operating profit provides the most meaningful economic index for a farm. The benefit of minimising overhead costs to maximise profits is clearly demonstrated.	Overhead costs can vary significantly between farms so difficult to use to compare between farms. Slightly more difficult to calculate than the other indices because of the need to sum overhead costs for the farm.

Variations on these indices are also possible. For example you could also calculate them using only the applied irrigation water rather than the total water. Note the term is now called an Irrigation Water Use Index (IWUI):

- Gross Return IWUI (farm)
- Gross Margin IWUI (farm)
- Operating Profit IWUI (farm)

Or you could calculate them for individual fields using total water applied or only irrigation water applied. It is important to remember to clearly define the scale at which they are being applied (field or farm) and the inputs being considered (gross return, gross margin, operating profit, irrigation water, total water).

For example, we previously calculated the GPWUI (effective)(applied) for a cotton field to be 0.94 bales/ML. If the cotton price is \$400 per bale, we can calculate a gross return per megalitre of total water:

$$\text{Gross return WUI (effective)(applied)} = (0.94 \times 400) = \$376 \text{ per megalitre}$$

Alternatively, we can calculate the gross return on the irrigation water only. We previously calculated the IWUI (applied) for this field to be 1.6 bales/ML. For the same cotton price (\$400 per bale) the gross return per megalitre of irrigation water is:

$$\text{Gross return IWUI(applied)} = (1.6 \times 400) = \$640 \text{ per megalitre}$$

Irrigation System Efficiencies

Irrigation system efficiencies are different to indices. This is because they compare the water output (or available) to the water input (supplied) at different points of the farm or irrigation system. Efficiencies do not have units, they are expressed as a percentage (%).

Although it is possible to determine the efficiency of any component of the irrigation system, three main efficiency terms are used widely in the irrigation industry and are applicable within the farming system:

- Application Efficiency (E_a)
- Field Canal/Conduit Efficiency (E_b)
- Farm Efficiency (E_f)

The dual use of the terms 'canal' and 'conduit' indicates that this efficiency term is used for any type of distribution system (i.e. it is equally applicable to channels and pipes).

Application Efficiency (E_a)

Application efficiency relates the amount of water supplied to the field to the amount of water available to the crop. Calculation of application efficiency is very useful as it can indicate the potential for water savings within the field and the associated production benefits.

However it can be difficult to determine the amount of water available to the crop, as run-off and drainage losses need to be taken into account. For a system that completely refills the soil profile, the amount of water delivered to the crop may be taken to be the soil moisture deficit prior to irrigation. For systems that only partially refill the soil profile, run-off and drainage will need to be measured.

$E_a = \frac{\text{irrigation water directly available to the crop for use}}{\text{water received at field inlet}}$

For surface irrigation systems, the amount of water received at the field inlet may be measured with flow meters installed on pump sites or in pipes that deliver water to the head ditch. For drip and overhead irrigation systems, water applied to the field can usually be obtained from a calibrated control panel or measured directly with flow meters attached to the system.

Under most circumstances, the amount of water available to the crop for use is the amount of irrigation water that is delivered to the root zone, that is, the change in soil moisture (ΔSM). For a system aimed at completely filling the soil profile, this is equal to the target deficit. Note that if actual soil moisture readings are used for this calculation the probes must be calibrated (see WATERpak Chapter 2.7) and that point source readings do not account for spatial variability within the field.

Example:

Furrow irrigation

Soil moisture deficit before irrigation = 70 mm

Soil moisture deficit after irrigation = 0 mm

Water delivered to rootzone = 70 – 0 = 70 mm

Total water applied = 1.2 ML/ha = 120 mm

Application efficiency (E_a) = 70 ÷ 120 = 58.3%

Overhead irrigation

Soil moisture deficit before irrigation = 70 mm

Soil moisture deficit after irrigation = 30 mm

Water delivered to rootzone = 70 – 30 = 40 mm

Total water applied = 40 mm

Application efficiency = 40 ÷ 40 = 100%

Note that this calculation of application efficiency does not account for losses such as wind interception or evaporation. For overhead sprinkler systems, these losses are less than 5% (see WATERpak chapter 5.5) and are extremely difficult to measure. For surface irrigation systems, evaporation from furrows is extremely small and also very difficult to measure.

Where tailwater recycling is practiced, the field application efficiency is effectively increased by reuse of this irrigation water. It is important to calculate a volumetric efficiency of the tailwater return system to be incorporated into the application efficiency term, particularly if a farm irrigation efficiency is to be calculated (see below). Confusion will be minimised if the method of handling tailwater is briefly defined.

Furrow irrigation with tailwater recycling

Soil moisture deficit before irrigation = 70 mm

Soil moisture deficit after irrigation = 0 mm

Total water applied = 1.2 ML/ha = 120 mm

Tailwater available for reuse = 25 mm

Net water applied = 120 – 25 = 95 mm

Application efficiency (E_a) = 70 ÷ 95 = 73.7%

Here the volume of tailwater available for re-use is not equal to the amount of tailwater actually leaving the field. In this case, 0.3 ML/ha of water left the field as tailwater, but following distribution losses before reuse, only 0.25 ML/ha (85%) was subsequently available. The application efficiency has been appropriately modified by including the net water application (water applied minus water available for subsequent use).

Field Canal/Conduit Efficiency (E_b)

The field canal/conduit efficiency effectively covers the on-farm distribution system. The terminology 'Distribution Efficiency' is not used because it is typically reserved to describe the efficiency of the whole distribution system, from the headworks to the field (i.e. it includes river, irrigation scheme and on-farm distribution systems). Similarly, the term E_c is already in use for describing the conveyance efficiency of irrigation schemes, so the term E_b is the industry standard.



Field canal/conduit efficiency relates the water received at the field inlet to the water received at the farm gate; hence, it usually accounts for losses in all components of the on-farm distribution system including storages and channels.

$$E_b = \frac{\text{water received at field inlet}}{\text{water received at the inlet to a block of fields (farm)}}$$

The same methodology of comparing water input to water output can be applied to the individual components of the on-farm distribution system (such as individual storages or channels) and is discussed further in WATERpak Chapter 1.6.

Farm Efficiency (E_f)

The use of the Application Efficiency (E_a) and Field Canal/Conduit Efficiency (E_b) terms allows a 'nested' approach for calculation of the Farm Efficiency. In other words, the farm efficiency is the product of the other efficiency terms:

$$E_f = E_a \times E_b$$

$$E_f = \frac{\text{irrigation water available to crop}}{\text{water received at field inlet}} \times \frac{\text{water received at field inlet}}{\text{water received at a block of fields (farm)}}$$

So:

$$E_f = \frac{\text{irrigation water available to crop}}{\text{water received at a block of fields (farm)}}$$

Calculating farm efficiency is useful for determining the potential for water savings, but it is not possible to establish where these savings can be made. Determining efficiency at the field scale is more useful for assessing the potential management or infrastructure changes that should be made. The nested approach for calculating efficiencies also means that once any two of the efficiency terms (E_a , E_b or E_f) are known, the other can be deduced.

Estimating farm irrigation efficiency

In practice, calculating whole farm irrigation efficiency can be complicated. To start with, there are likely to be many fields, and the irrigation water available to the crop needs to be determined for each irrigation and for each field. Furthermore, tailwater recycling complicates the calculation of farm efficiency, and it may be confusing to try and apply the nested approach.

However farm irrigation efficiency can be estimated through the process of water accounting. Water accounting is a process of tracking irrigation water and estimating the proportion of this water that is actually used by the crop across the entire farm. The result gives a benchmark of farm management, indicates the performance of water, and identifies the potential for water savings and maximisation of economic returns. This process accounts for rainfall and evaporative demand and results in an estimation of the farm efficiency, which can be used to compare between properties, regions or seasons.

From the formula for farm efficiency given above, we need to know the amount of irrigation water available to the crop and the amount supplied to the farm. The amount of irrigation water actually used by the crop, evapotranspiration or ET_c (WATERpak Chapter 2.8), is often used to help determine the amount of water available to the crop from irrigation. This is only an estimation of the water available to the crop, because the irrigation system may efficiently deliver water that the crop does not use for some other reason (e.g. disease). However it should be sufficient for most purposes.

Working out the proportion of irrigation water used by the crop involves starting with the crop's total water use (ET_c), subtracting the effective rainfall (RE) and accounting for the difference between the soil moisture at planting and the soil moisture at harvest (ΔSM). In this way, we have subtracted that water which was not supplied by irrigation from the crop's total water use.

Irrigation water available to crop =

$$ET - RE - \Delta SM$$

Working out the amount of irrigation water supplied to the farm is somewhat easier and involves accounting for water from all sources:

- River
- Bore
- Scheme
- On-farm Harvesting (not recycling)
- Water used from on-farm water storages (ΔSW).

Water received at a block of fields (farm) =

$$\text{river} + \text{bore} + \text{scheme} + \text{harvested} + \Delta SW$$

Table 1.2.2 illustrates the water account for an irrigated farm over two seasons. The water inputs from different sources, crop water use and some important water use indices are presented in the example.

Table 1.2.2 – Water account for an irrigated farm over two seasons

Season	1996/97	1997/98
Production details		
Area grown (ha)	3064	3173
Total production (bales)	19234	25495
Average yield (bales/ha)	6.3	8
Water supply		
Total water pumped (bore)	0	1445
Total water pumped (river)	7447	12100
Total water pumped (ML)	7447	13545
On farm storage at planting (ML)	6250	6500
On farm storage at harvesting (ML)	3975	4473
Used from farm storage (ML)	2275	2027
On farm harvested (ML)	3710	1402
Water used on other crops (ML)	2300	2800
Total irrigation applied on cotton (ML) = total pumped + used storage + harvested – other crops	11132	14174
Rainfall		
In season rainfall (mm)	518	459
Run-off (mm)	171	159
Effective rainfall estimate (mm) = (rainfall – run-off)	347	300
Estimated effective rainfall for farm (ML) = (Effective rainfall (mm) ÷ 100) × area (ha)	10632	9519
Rainfall efficiency (%) = effective rainfall ÷ total rainfall	67	65
Soil water		
Used soil reserve (mm) average of all fields (soil moisture at sowing – soil moisture at harvest)	119	133
Used soil reserve ML = (Used soil reserve (mm) ÷ 100) × area (ha)	3646	4220
Total seasonal water usage (ML) = total irrigation + effective rainfall + harvested water + used soil reserve	25410	27913



Water use summary

ML/ha pumped	2.42	4.03
ML/ha effective rainfall	3.47	3
ML/ha harvested	1.21	0.44
ML/ha used soil reserve	1.19	1.33
ML/ha total water usage	8.3	8.79
Total seasonal crop water use (ET) mm	690	772

Water use indices

Crop water use index (kg/mm/ha)	2.06	2.36
Crop water use index (bales/ML) = yield ÷ ET	0.91	1.04
Production WUI (farm) (bales/ML) = yield ÷ total water (with effective rain)	0.76	0.91
Irrigation WUI (farm) (bales/ML) = yield ÷ irrigation water	1.73	1.8

Farm irrigation efficiency

Irrigation water used in ET (mm) = ET – effective rainfall – Δsoil moisture	226	343
Irrigation water used in ET (ML) = (mm) × area (ha) ÷ 100	6924	10883
Whole farm irrigation efficiency (%) = irrigation water used in ET ÷ total irrigation water	62	77

Such water accounting has been made significantly easier in recent years by software such as [Watertrack™](#) (see below) which can calculate crop water use for each field, track losses through each irrigation system component and accurately calculate farm efficiency.

Uniformity

Uniformity is a measure of how evenly water has been applied to a field and is expressed as a percentage (%). It is only applicable at the field scale. Low uniformity results in parts of a field being under-watered and/or over-watered, which can result in poor crop uniformity and waterlogging. The standard calculation of uniformity is called Distribution Uniformity (DU) and compares the lowest quarter of infiltrated depths to the average of all infiltrated depths

Distribution uniformity (DU) =

$$\frac{\text{Average of lowest 25\% of infiltrated depths}}{\text{Average of all infiltrated depths}}$$

Some irrigation system types, such as drip and centre pivot, have different uniformity measures that are more appropriate for their specific characteristics. These indicators and the methods for obtaining measurements are detailed in WATERpak chapters 5.5 and 5.6.

Calculating distribution uniformity for furrow-irrigated fields typically requires computer simulation, because it is otherwise not practical to obtain the depth of infiltrated water at a sufficient number of points down the field. WATERpak chapter 5.3 has more information on determining DU for surface irrigation fields.

Irrigation Benchmarking

Benchmarking is a process by which a comparison is made between practices, processes or performance indicators. Irrigation benchmarking most typically takes the form of performance benchmarking; that is, comparing performance indicators such as WUI. Performance benchmarking is useful to gauge historical performance but is not particularly good at identifying pathways to best practice.

On the other hand, process benchmarking involves comparing the processes of one business with those of another, that is regarded as demonstrating 'best practice'. In this case, performance benchmarking is often a first step to identify the best practice business, but then a much deeper comparison of the processes and decisions that result in this high performance is undertaken.

For the purposes of this discussion, we will concentrate on performance benchmarking. However the value of process benchmarking should be recognised by those who wish to meaningfully improve their performance.

When undertaking irrigation benchmarking, there are no set rules to suggest what data to compare or what it could be compared to. You might want to compare the amount of water you applied this year to the amount applied last year for example.

However, some comparisons are going to be more useful than others. A good example is when comparing between different regions if you don't take rainfall into account, then you will not get a very good comparison.

Calculating recognised water use indices and irrigation efficiencies will give you a standard calculation which can then be compared spatially (to another field, another farm, another region, another country) or over time (season, years). The advantage of using standard performance measures is to ensure meaningful comparisons.

Some benchmarking examples:

- Comparing the performance of different farming enterprises, for example the growers in a local area
- Compare the performance of a single field over a period of 3 seasons, to see if management changes are having a positive effect
- Comparing the performance of your enterprise to industry averages or targets
- Comparing performance within a farm, for example between a number of adjacent fields, to determine which need additional work to increase their performance and bring them 'up to scratch'



It is typical for benchmarking to be undertaken on a number of individual farm elements (e.g. fields, storages, distribution system, etc.) as well as for the whole farm. There are a number of reasons for this, which are summarised below.

Whole Farm

Advantages	Drawbacks
Includes all water and production	Includes all losses – does not distinguish between where water losses or low production occurs
Good for comparison between enterprises	Does not identify the individual areas that need attention
May be easier to obtain data for the whole farm	
Able to relate production to water use (WUI's) for the whole farm	WUI's calculated include all losses – not just those within fields

Individual Elements (e.g. Field, Storage, Channel)

Advantages	Drawbacks
Gives greater information that can be used to guide management decisions	Requires more detailed inputs which can be more difficult or expensive to obtain
Can provide a wealth of internal information	The amount of information can be time consuming to analyse
Can still allow comparison with external benchmarks for individual irrigation system elements	Calculation methods (i.e. for WUI's) must be standardised to allow meaningful comparison.
	The large number of different indices can be confusing (e.g. rainfall/no rainfall, effective rainfall/total rainfall, tailwater included/not included)

Fields

- Figures can be calculated using outflow (tailwater) to give more accurate figures, however accounting for the loss of tailwater during recycling usually requires estimation or use of a comprehensive farm water model such as WaterTrack™.
- Calculating Application Efficiency accurately for surface irrigated fields requires detailed modelling (Irrimate™)
- Calculating Distribution Uniformity for surface irrigated fields also requires Irrimate™
- Further information can be found in WATERpak Chapter 5.3
- As there is often little or no drainage or runoff from drip or sprinkler irrigated systems, calculation of application efficiency requires accurate measurement of evaporative losses and remains a detailed research task.
- Calculation of uniformity measures for sprinkler or drip systems is undertaken using catch cans or by measuring flow and pressure of individual emitters.

Storages, Channels

- Requires inflow and outflow to calculate storage or distribution efficiencies
- Indices are not appropriate as there is no production output
- To determine whether losses are due to seepage or evaporation requires more detailed measurement (e.g. storage meter, storage survey, WaterTrack™)
- Further information can be found in WATERpak Chapter 1.6

Calculating Benchmark Figures

Methods for calculating benchmark figures can vary depending upon the complexity of your irrigation system and the type of benchmark being calculated. For example, the process above for determining whole farm efficiency is a reasonably complicated procedure that is probably best undertaken using a specialist software tool. On the other hand, determining simple water use indices such as IWUI and GPWUI for an individual field is generally much simpler and could be undertaken by hand.

Table 1.2.2 provided a template that could be applied to most basic calculations. This template involves:

- recording the yield and area under consideration;
- recording the water supplied to this area from the relevant sources required for the indicators to be calculated (irrigation water, rainfall, effective rainfall, soil moisture, etc.); and,
- determining the required indicators.

The simplest of these calculations could be undertaken by hand or using a spreadsheet. A simple [whole farm calculator](#) which follows this format is available online to undertake the basic farm scale water use index calculations. However none of these methods assist with determining any of the difficult to estimate input parameters such as effective rainfall or crop water use.

Some tools can assist with determining some of these input parameters. For example, tools such as [CropWaterUse](#) and [Hydrologic](#)

can calculate crop water use and basic field scale water use indices.

However there are few full water accounting packages that can account for the necessary inputs at the field scale and aggregate them to the farm scale, especially for the type of surface irrigation systems utilised in cotton growing regions. [Watertrack™](#) is one such package which not only determines input parameters such as crop water use and effective rainfall but also allows you to determine benchmark figures for individual storages, channels and fields as well as for the whole farm.

Comparing Benchmark Figures

Benchmark figures can be compared internally and externally, between different fields or regions and across seasons. However, it is important to understand what each indicator is most useful for, so that comparisons are credible.

- Irrigation Water Use Index (IWUI) does not include rainfall.
 - IWUI is useful for comparing between nearby fields or farms in the same season
 - Comparing over significant distances or between seasons can introduce variability due to differences in rainfall.
- Gross Production Water Use Index (GPWUI) includes rainfall.
 - The rainfall component can be either total or effective and should be specified as such.
 - GPWUI is more useful for comparing between seasons and across regions but does not reflect the proportion of total water contributed by irrigation.

- Crop Water Use Index (CWUI) includes only the water used by the plant (ET_c).
 - It does not include the total water applied (whether this is from rainfall or irrigation)
 - Hence it is possible to apply significantly more water than necessary and still obtain a reasonable CWUI.
 - CWUI is really a crop performance measure, not an irrigation performance measure and variations in CWUI may be due to, for example, variety, nutrition, climatic variables, timing of water application.
 - For a definition of CWUI see WATERpak Chapter 2.1.

Because of these differences, it is suggested that a suite of indicators is used for comparison. In particular, it is recommended that both IWUI and GPWUI should be used when benchmarking. This allows the regional or seasonal differences in evaporative demand or rainfall that are included in the GPWUI to be accounted for in the comparison. If IWUI were to be used in isolation for such comparisons, such differences could be mistaken for poor irrigation system performance.



Internal comparison is reasonably simple to facilitate, by determining indicators across a range of irrigation system components and recording these over time. However to compare your benchmark figures externally there are a number of options:

- You may decide to compare informally with your neighbours
- You may compare data formally through existing economic benchmark groups.
 - If you are part of a benchmark group and would like them to include standardised water use benchmarks, please discuss this with your local Irrigation or Water Use Efficiency Officer
- Your consultant may like to coordinate a benchmark group amongst their client base.
 - Again, your industry extension officer can help to establish this process.
- Some benchmark figures exist from previous research studies.
 - Chapter 1.3 of WATERpak contains some historical benchmark data for the cotton industry.

Note that the extent and accuracy of on-farm water measurement has increased significantly in the last five years, and will continue to do so. This is important to remember as benchmark figures calculated in historical studies may be less accurate. The availability of increasingly accurate benchmark data will improve as more growers undertake coordinated benchmarking studies

Water Budget

A water budget is used to determine how best to use the available water resource. A water budget is often quite different to a budget prepared for other inputs such as fertiliser, as the water budget is used to partition a limited resource (water) where the availability of the resource may vary significantly during the season due to rainfall.

Because of this, a water budget will always include risk based decisions.

A water budget has two main purposes:

- To determine what area of crop should be planted for the water resource available at the beginning of the season.
- To determine how to best utilise crop inputs during the season as water availability changes (includes determining when to plough out crops due to insufficient water availability).

Some things to take into account:

- The seasonal water requirements for your crop (benchmark data or crop ET calculation).
- Historical median rainfall.
- Probability of above or below median effective rainfall (seasonal forecast).
- Typical and/or forecast rainfall timing. Will this affect irrigation, dam supplies, or extraction limits?
- Ability to adjust crop water availability without jeopardising yield or quality?
- Available water supply (e.g. flow rate, on-farm capture, total storage capacity, trading)
- Acceptable risk level
- Economics (is it better economically to fully irrigate a smaller area, or partially irrigate a larger area?)
- Available Tools (e.g. CropWaterUse, CottBASE, Whopper Cropper, WaterTrack)

We may 'predict' whether the season will be wetter or dryer than the median year and plan accordingly by investigating the climate, past rainfall records, and current climatic patterns (for example SOI and El Niño). By making a decision on the contribution of rain, we are allocating risk.

For example, a low risk decision would be to plant only the area for which you currently have enough water. However, this would limit the opportunities presented by significant in-season rainfall and water capture.

Information on climate variability and records of climatic data may be found at the [Bureau of Meteorology](#) website or your local Irrigation or Water Use Efficiency officer may be able to help. Further information on risk and decision making is included in WATERpak Chapters 2.2 and 3.3.

Water Budget vs. Water Budget Irrigation Scheduling

Some people refer to the process of scheduling irrigation based upon a balance of soil water inputs (irrigation & rainfall) and outputs (ET, runoff, drainage,) as 'water budget scheduling'. A better name would be water balance scheduling or soil water accounting. This process is covered in WATERpak Chapter 2.1 and should not be confused with the preparation a water budget.

Budgeting Methodology

The maximum area of crop that can be irrigated is determined by the crop water requirements, the irrigation system capacity and efficiency, and the availability of water.

Area =

$$\frac{\text{irrigation water available}}{\text{annual crop water requirement} \times \text{irrigation system efficiency}}$$

For example:

A cotton crop in Southern Queensland might require about 900 mm (9 ML/ha) of water. Historical figures indicated that the median rainfall during the season for this location is 350 mm (3.5 ML/ha). So for a median year the irrigation requirement is 5.5 ML/ha.

At planting, the grower has 300 ML in storage and 700 ML of available allocation. The grower estimates that another 500 ML will be harvested during the season.

Irrigation water available: 1500 ML

Irrigation requirement: 5.5 ML/ha

Whole Farm Efficiency: 64%

Area = $1500 \div 5.5 \times 0.64 = 175$ ha

Your seasonal crop water use can be estimated in a number of ways. The simplest method is to use one of the available tools such as [CropWaterUse](#) which will allow you to calculate the crop water requirements. Alternatively, you could use benchmark crop water use figures from previous seasons. However, be careful; if you base your crop requirements on IWUI calculated at the farm scale, your water losses will have already been taken into account and hence you do not need to include the system efficiency in the above calculations.

Water budgeting tools

A number of tools can be used to help produce a water budget. For example, crop modelling tools such as [CottBASE](#) and [WhopperCropper](#) can be used to predict likely yield given different conditions and available water inputs.

From these predictions, you can choose an amount of water to allocate to each field in order to maximise your yield or economic return.

This enables you to compare different scenarios of water availability in terms of final yield, as illustrated in Figure 1.2.3. The 25th and 75th percentile figures are used to indicate the likely range of values that might be expected.

Figure 1.2.3 – CottBASE comparison of predicted yield for multiple scenarios of available irrigation water

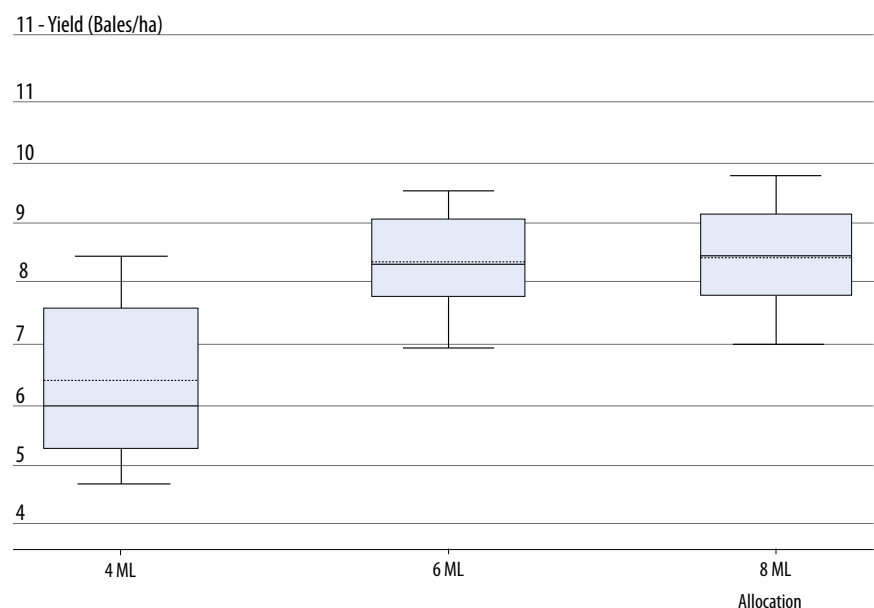


Table 1.2.3. An example method for comparing the economics of various irrigation allocations using data from CottBASE

Allocation	TOAL	Cotton Area	Yield (Bales/ha)			Range	Total Bales		
ML/ha	(ML)	(ha)	25%	Average	75%	Bales / ha	25%	Average	75%
4	1000	250	5.2	6.4	7.6	2.4	1300	1600	1900
6	1000	167	7.7	8.4	9.1	1.4	1283	1400	1517
8	1000	125	7.7	8.5	9.1	1.4	963	1063	1138

Return @\$400/bale			growing costs	Total	Gross Margin (\$)		
25%	Average	75%	\$ / ha	Cost (\$)	25%	Average	75%
\$520,000	\$640,000	\$760,000	\$2,268	\$567,000	-\$47,000	\$73,000	\$193,000
\$513,333	\$560,000	\$606,667	\$2,520	\$420,000	\$93,333	\$140,000	\$186,667
\$385,000	\$425,000	\$455,000	\$2,800	\$350,000	\$35,000	\$75,000	\$105,000

These particular tools also allow the SOI (Southern Oscillation Index) phase to be taken into account, which means that the potential for different seasonal conditions can be taken into account when making decisions. In the example above, this means that it would be possible to determine the optimum amount of irrigation water to allocate for crops given the current SOI phase. Further examples of this functionality are included in WATERpak Chapter 2.3.


[WaterTrack Optimiser™](#) is another very powerful tool that can be used to budget irrigation water. WaterTrack™ does not predict yield like CottBASE or WhopperCropper, but it does model each element of the irrigation system to quantify losses and produce benchmarking reports. In prediction mode, it can use historical climate data to predict when irrigations will occur, how much water will be used, what the losses will be, and when insufficient water is available.

As predictions can be performed at any time before planting or during the season, this tool is an extremely useful way to verify if you will be able to irrigate the proposed cropped area and to refine your water budget given the actual weather patterns experienced as the season progresses.

It would even be possible to use this tool to help make key decisions such as purchasing extra water, ploughing in a crop or assessing infrastructure changes or capital investments such as increased farm area, more or fewer storages, and deeper storages.

Figure 1.2.4 shows an example output report from WaterTrack Optimiser™ which predicted the dates at which insufficient water was available on-farm. In this particular example, an extra 235 ML was required. This prediction utilised weather data from a known dry year, so the grower could make a decision to accept this risk and hope for extra rainfall, or to decrease the area planted. Further simulations can be run during the season with updated weather records to modify management decisions if necessary.

Figure 1.2.4 - Watertrack water availability report that can be used for water budgeting.

WATER AVAILABILITY REPORT		
From: 2/9/05	To: 5/3/06	
Date	Farm Object	Overdraw (ML)
29/1/06	Inflow 54	18
1/2/06	Inflow 54	6
15/2/06	Inflow 54	77
16/2/06	Inflow 54	79
17/2/06	Inflow 54	-49
18/2/06	Inflow 54	6
Total Overdraw:		235

Notes:
The first overdraw of water occurred on 29/1/06. At the end of the period there is a total overdraw of 235 ML.

Further Information

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