Cotton and Grains Workshop Series

Irrigation Benchmarking & Water Budgeting

CONTENTS

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Please contact the Cotton Research & Development Corporation with any feedback that can be incorporated in the next edition.

DISCLAIMER AND WARNINGS

The information in this publication is designed as an information source to improve the sustainable use of water on irrigation farms in eastern Australia growing cotton. The information has been prepared from research studies and grower trials with specialist input from researchers, extension staff and irrigators. While these authors provide comprehensive coverage of on-farm water-related issues, they do not purport to address every eventuality that may arise on irrigation farms.

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Cotton and Grains Workshop Series

Irrigation Benchmarking & Water Budgeting

Key points

- Benchmarking is flexible – you can compare over various spatial scales and timeframes
- Water Use Efficiency is a generic term.
- Compare apples with apples – Water Use Indices must be clearly defined with units specified
- Different indices do different jobs. Some of the most useful include:
    - Irrigation Water Use Index (IWUI)
    - Gross Production Water Use Index (GPWUI)
    - Application Efficiency (Ea)
    - Farm Efficiency (Ef)
    - Distribution Uniformity (DU)
- A Water Budget is the process used to allocate irrigation water and involves an assessment of risk.

Benchmarking is a process of collecting data to enable comparison. It allows an enterprise to strive for improvement by comparing current performance to appropriate internal or external performance measures.

Using Benchmarking On-Farm

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 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 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'

What is WUE?

Water Use Efficiency is a generic label that encompasses an array of performance indicators (Figure 1) that can be categorised as one of the following:

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

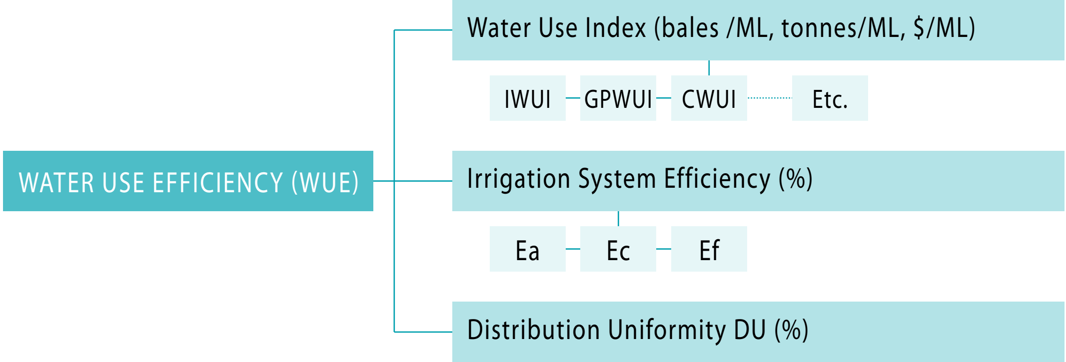


Figure 1: Irrigation performance indicators.

Figure 2 shows the relationship between a number of water use indices and irrigation system efficiency terms across the different spatial scales of a farming enterprise.

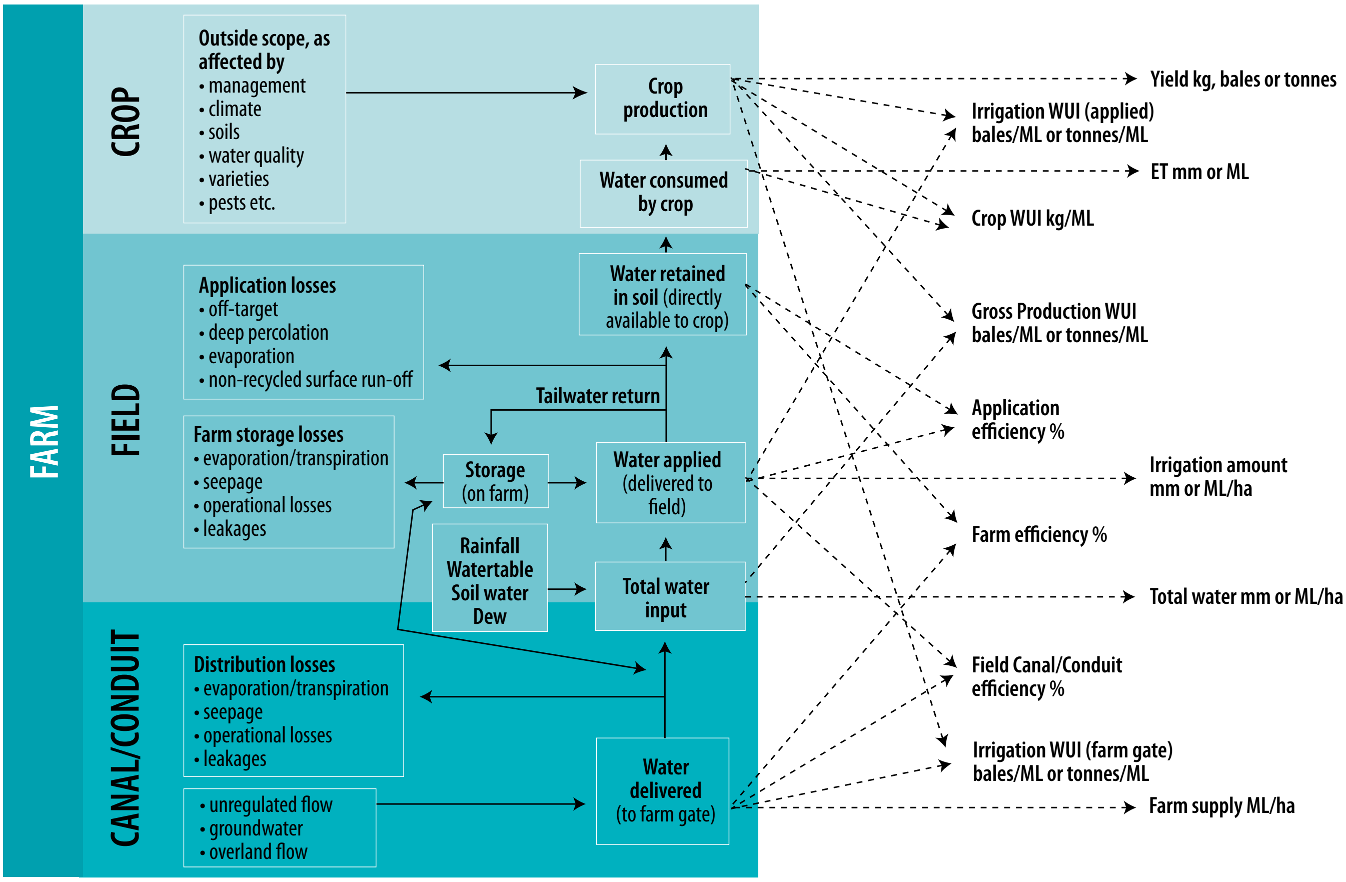


Figure 2 Framework for on-farm water use efficiency.

What's the Difference?

- Water Use Indices describe two different units, such as yield per ML or profit per ML and are linked to production.
  - They are very flexible but more easily used out of context.
  - They describe the output of a system i.e. production per ML
- Irrigation System Efficiencies describe a ratio of water inputs to water outputs.
  - What proportion of water is lost
- Distribution Uniformity is only relevant for application systems
  - Poor uniformity will result in poor indices or poor efficiency – or both!

Water Use Indices

Water use indices typically compare a production output (e.g. yield, return, gross margin) to a water input (e.g. irrigation water, total water, evapotranspiration) at some level in the farm or production system.

- They have defined units (e.g. kg/mm, bales/ML, t/ML, $/ML).
- It is important to explicitly define the inputs used and the measurement units, to allow others, such as your workers or consultant, to understand what they incorporate.
- However, Indices are flexible and can be tailor-made to suit a particular purpose – state the inputs and give the index a unique name.

Some useful WUI's include:

Gross Production Water Use Index (GPWUI)

Gross production water use index (farm) =

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

Gross production water use index (applied) =

$$\frac{\textbf{total yield}\text{ (bales or tonnes)}}{\textbf{\textit{total} water used}\text{ applied (ML)}}$$

Note the different scales: farm scale and field (applied) scale.

Note also that both effective and total rainfall can be use; see WATERpak Chapters 2.1 & 2.9.

Irrigation Water Use Index (IWUI)

Irrigation water use index (farm) =

$$\frac{\textbf{total yield}\text{ (bales or tonnes)}}{\textbf{irrigation water supplied to farm gate}\text{ (ML)}}$$

Irrigation water use index (applied) =

$$\frac{\textbf{total yield}\text{ (bales or tonnes)}}{\textbf{irrigation water applied}\text{ (ML)}}$$

Economic Indices

Economic indices are a group of indices which can be used to compare the economics of irrigating crops. Three economic terms that can be used to generate economic indices are:

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

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) =

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

Gross margin WUI (farm) =

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

Operating profit WUI (farm) =

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

Variations on these indices are possible – for example you could also calculate them using only the applied irrigation water (without rainfall) 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

- Gross Return WUI (applied)
- Gross Margin WUI (applied)
- Operating Profit WUI (applied)

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 return ($) =

production (bales or tonnes)
× **on-farm price** ($/bale or $/tonne)

Gross margin ($) =

gross return ($) – **variable Costs** ($)

Operating profit ($) =

gross margin ($) – **overheads** ($)

Variable costs – costs that change according to the area of crop grown

Overheads – costs that do not vary greatly with area of crop grown (fixed costs)

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.

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 (%)

The three main efficiency terms commonly used in the irrigation industry that apply within the farming system are:

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

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

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

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

Calculation of application efficiency for a furrow irrigation system can be described using Figure 3. In this figure the irrigation water available to the crop is shown in light blue. Because the volume of water contained within the light blue coloured area cannot be measured, computer modelling of this process (for example using the Irrimate™ system) can be undertaken to determine the application efficiency. Calculation of application efficiency for drip and sprinkler systems can also be very difficult to measure as it is possible for the losses in these systems to be very small. The procedure follows the same process as for surface irrigation systems.

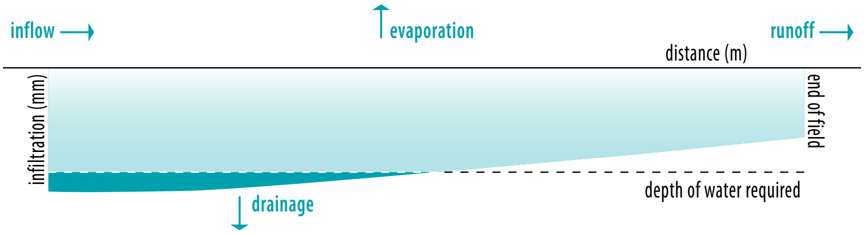


Figure 3: Infiltration for a surface irrigation event.

Distribution Uniformity

- Distribution uniformity only applies to irrigation application systems (i.e. the field scale).
- It is a measure of how evenly water has been applied
- Also expressed as a percentage (%)
- Poor (low) distribution uniformity results in portions of a field being under-watered, over-watered or both.
- Calculating distribution uniformity for furrow-irrigated fields typically requires computer modelling to simulate an irrigation event.

Poor uniformity may often result in waterlogging, particularly in surface irrigated fields, because irrigation events are run for an extended time to ensure the under-watered portion of a field receives the minimum desired application amount. Figure 3 demonstrates the uniformity of a typical surface irrigation event. Because water is applied to the top of the field for longer than the bottom, it has a longer period of time to infiltrate. Applying water more quickly may improve the uniformity of furrow irrigation events.

$$\text{Distribution Uniformity (DU)} = \frac{\text{Average of smallest 25\% of infiltrated amounts}}{\text{Average of all infiltrated amounts}}$$

Whilst the concept of distribution uniformity remains the same for Sprinkler and Drip irrigation systems, often other uniformity terms such as Christiansen's Coefficient of Uniformity or Emission Uniformity are used as they are a better uniformity measure for these systems.

What do we Benchmark?

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 2.09 and the surface irrigation training workshop.
- 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 2.6 and in the Storage and Distribution Workshop

Calculating Benchmark Figures

Accurate calculation of Irrigation System Efficiencies can be a complicated and detailed procedure which may require expert advice. More information about calculating efficiency figures is contained in WATERpak or the irrigation workshops on Storage and Distribution Systems and Surface Irrigation Systems.

Here we will focus on the calculation of Irrigation Water Use Indices that can be performed reasonably easily. Firstly, we will perform some calculations for the whole farm.

We will use the calculation sheet attached to the back of this workbook.

It is also possible to calculate similar benchmark figures for individual fields, channels or storages. This process is achieved using the same logic as used previously at the whole farm scale, but using water measurements obtained for the individual element under consideration (e.g. the yield obtained from an individual field and the irrigation applied to an individual field can be used to calculate IWUI(applied)).

Calculating benchmark figures for individual irrigation system components can be an intensive process due to the often more detailed measurements required and is covered in more detail in the irrigation workshops on Storage and Distribution Systems and Surface Irrigation Systems. These methods are also covered in WATERpak Chapters 2.6 and 2.9.

Other Benchmarking Tools

Hydrologic is a free software tool which is available from the Cotton CRC. This tool enables you to keep track of water applications to individual fields as well as predict yield and irrigation requirements.

WaterTrack™ is a commercial software package which not only enables calculation of whole farm benchmark figures but also allows you to determine the performance of individual storages, channels and fields.

- WaterTrack Rapid™ provides a simple approach to calculating essential irrigation performance indicators. It does not have prediction capabilities but provides accurate calculations which account for effective rainfall and the capture of rainfall runoff or captured overland flow.
- WaterTrack Optimiser™ is a comprehensive water balance program which calculates water consumption in every element on the farm. This tool is also able to predict future irrigation performance, calculate benchmark figures, simulate water movement and predict water availability.

Comparing Benchmark Figures

You are able to compare your benchmark figures both internally and externally. With respect to Water Use Indices (WUI's), it is important to understand what each index is useful for:

- 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 contribution of irrigation to total water.
- Crop Water Use Index (CWUI) includes only the water used by the plant (ETc).
    - It does not include the total 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.

To compare your benchmark figures externally there are a number of options:

- It is hoped that there will be an industry wide process for comparing farm scale indices in the near future.
- 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 2.2 of WATERpak contains some benchmark data for the cotton industry.
    - Table 1 demonstrates a number of these figures for a range of both cotton and grain crops.

Note: 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.

Table 1: Water use indices for cotton and grain crops from Australian literature.

CROP	IRRIGATION METHOD	IWUI	GPWUI
		cotton bales/ML, other crops t/ML	
Field			
Cotton	surface	1.67	
Cotton	surface	2.75[a]	1.25[a]
Cotton	surface	1.21	0.74[a]
Cotton	SDI		1.4
Cotton	surface		1.48
Cotton	SDI	2.4[a]	
Cotton	CPLM	1.9[a]	
Cotton	surface	1.0[a]	
Cotton	surface		0.97
Cotton	surface	1.63	
Cotton	surface	2.16	1.77
Cotton	surface	1.53	0.68
Cotton	surface	0.66	
Cotton	surface	1.0	
Cotton	surface	2.25	
Cotton	SDI	2.46	
Barley	all systems	5.63[a]	2.36[a]
Maize	all systems	4.14[a]	1.55[a]
Sorghum	all systems	6.2[a]	1.56[a]
Soybean	all systems	1.41[a]	0.52[a]
Sunflower	all systems	2.03[a]	0.59[a]
Triticale	all systems	4.48[a]	2.03[a]
Wheat	all systems	4.41[a]	1.63[a]
Whole Farm			
Cotton	all systems		0.98[a]
Cotton	surface	1.48	0.82
Cotton	surface	1.32	0.79
Cotton	surface		0.93
Cotton	surface		0.8[a]
Cotton	SDI		0.97[a]
Cotton	surface		1.01[a]
Lablab	surface		5.1[a]

[a] – contains a high proportion of estimated (not measured) data

SDI – sub-surface drip irrigation

CPLM – centre pivot or lateral move irrigation

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:

1. To determine what area of crop should be planted for the water resource available at the beginning of the season.
2. 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).
- 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. Hydrologic, APSIM, Water Track)

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 BOM website (Bureau of Meteorology) or your local Irrigation or Water Use Efficiency officer may be able to help.

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 the Irrigation Scheduling workshop 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.

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

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

System Efficiency: 64%

Area = 1500 ÷ 5.5 × 0.64 = 175 ha

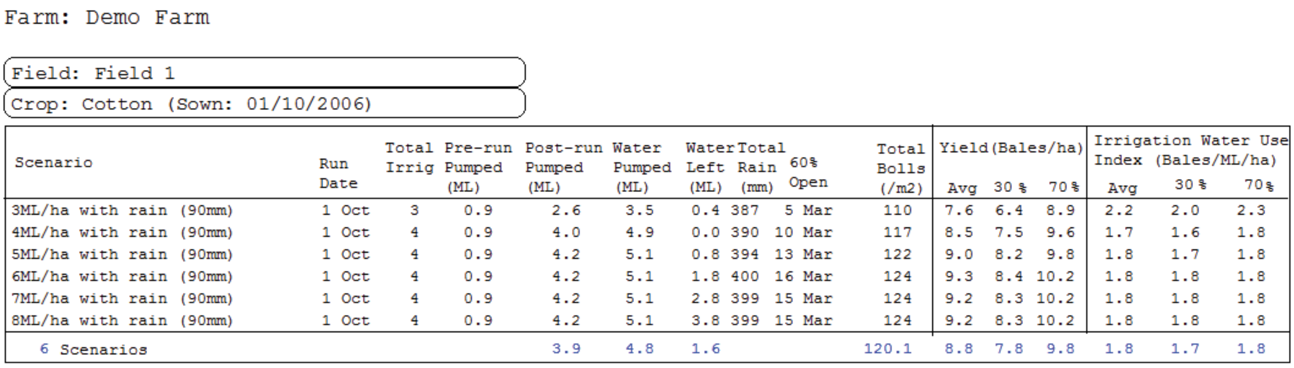
Estimating crop water use

Crop water use can be estimated in a number of ways. Tools such as Hydrologic, Watersched and WaterTrack allow you to calculate the crop water requirements.

Alternatively, you could use benchmark figures (IWUI) from a previous season. If using figures for IWUI at the farm scale, your water losses have already been taken into account and hence you do not need to include the system efficiency in the above calculations.

Water budgeting tools

Hydrologic can be used to help produce a water budget. Hydrologic allows you to enter crop information and predict the likely yield with a variety of available water inputs. This enables you to compare different scenarios of water availability in terms of final yield, as illustrated in Figure 4. In this example, historical rainfall records have been used. You could also perform this analysis using rainfall averages, no rainfall, or rainfall records from a



Farm: Demo Farm

Field: Field 1

Crop: Cotton (Sown: 01/10/2006)

Scenario	Run Date	Total Irrig	Pre-run Pumped (ML)	Post-run Pumped (ML)	Water Pumped (ML)	Water Left (ML)	Total Rain (mm)	60% Open	Total Bolls (/m2)	Yield (Bales/ha)			Irrigation Water Use Index (Bales/ML/ha)		
										Avg	30 %	70 %	Avg	30 %	70%
3ML/ha with rain (90mm)	1 Oct	3	0.9	2.6	3.5	0.4	387	5 Mar	110	7.6	6.4	8.9	2.2	2.0	2.3
4ML/ha with rain (90mm)	1 Oct	4	0.9	4.0	4.9	0.0	390	10 Mar	117	8.5	7.5	9.6	1.7	1.6	1.8
5ML/ha with rain (90mm)	1 Oct	4	0.9	4.2	5.1	0.8	394	13 Mar	122	9.0	8.2	9.8	1.8	1.7	1.8
6ML/ha with rain (90mm)	1 Oct	4	0.9	4.2	5.1	1.8	400	16 Mar	124	9.3	8.4	10.2	1.8	1.8	1.8
7ML/ha with rain (90mm)	1 Oct	4	0.9	4.2	5.1	2.8	399	15 Mar	124	9.2	8.3	10.2	1.8	1.8	1.8
8ML/ha with rain (90mm)	1 Oct	4	0.9	4.2	5.1	3.8	399	15 Mar	124	9.2	8.3	10.2	1.8	1.8	1.8
6 Scenarios				3.9	4.8	1.6			120.1	8.8	7.8	9.8	1.8	1.7	1.8

Figure 4: Multiple scenario comparison – end of season status

You are then able to use this data to determine the most economically viable option, as illustrated in Figure 5. When including average rainfall data, the most economical option was to allocate 3 ML/ha. For the same example and assuming no rainfall, the most economical option was to allocate 5 ML/ha. The final decision might lie somewhere between these extremes and is dependant upon the decision maker's risk tolerance. Only the example *with rain* is shown here.

ALLOCATION	TOTAL	COTTON AREA	YIELD (BALES/ha)			RANGE	TOTAL BALES		
ML/ha	(ML)	(ha)	30th	AVERAGE	70th	BALES / ha	30th	AVERAGE	70th
3	1000	333	6.4	7.6	8.9	2.5	2133	2533	2967
4	1000	250	7.5	8.5	9.6	2.1	1875	2125	2400
5	1000	200	8.2	9.0	9.8	1.6	1640	1800	1960
6	1000	167	8.4	9.3	10.2	1.8	1400	1550	1700
7	1000	143	8.3	9.6	10.2	1.9	1186	1314	1457
8	1000	125	8.3	9.2	10.2	1.9	1038	1150	1275

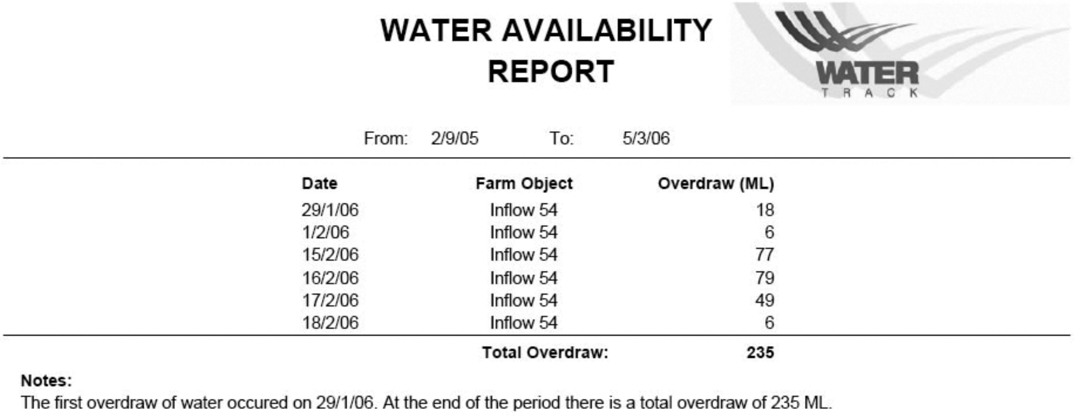
RETURN @$400/BALE			GROWING COSTS	TOTAL	GROSS MARGIN ($)		
30th	AVERAGE	70th	$ / ha	COST ($)	30th	AVERAGE	70th
853 333	1 013 333	1 186 667	1734	578 014	275 319	435 319	608 652
750 000	850 000	960 000	1825	456 327	293 673	393 673	503 673
656 000	720 000	784 000	1921	384 275	271 725	335 725	399 725
560 000	620 000	680 000	2023	337 084	222 916	282 916	342 916
474 286	525 714	582 857	2129	304 136	170 150	221 579	278 721
415 000	460 000	510 000	2241	280 125	134 875	179 875	229 875

Figure 5: Comparing economics of various irrigation allocations using data from Hydrologic.

WaterTrack Optimiser™ is another tool that can be used to budget irrigation water. As previously mentioned, WaterTrack™ is able to model each element of the irrigation system to quantify losses and produce benchmarking reports. Furthermore, this tool is also useful for making irrigation predictions. At any time before planting or during the season the prediction module allows accurate water budgeting *including* losses.

Predictions may be conducted prior to the ordering of seed to check how much planted area can be irrigated including likely rainfall. Predictions are then conducted throughout the season to assist in key decisions such as purchasing extra water, ploughing in a crop, or changing row configurations. Predictions can also assess infrastructure changes or capital investments such addition water licenses, increased farm area, more or fewer storages, and deeper storages.

Figure 6 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.



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 occured on 29/1/06. At the end of the period there is a total overdraw of 235 ML.

Figure 6: Watertrack water availability report that can be used for water budgeting.

Whole Farm Benchmarking Activity

Name:

Address:

Phone:

Email:

Production details		
(A) Area grown (ha)	1309	
(B) Total production (bales / tonnes)	10381	
(C) Average yield (bales / ha, t / ha) = **B** ÷ **A**	7.93	
Water supply		
(D) Total water pumped (bore)	261	
(E) Total water pumped (river)	6291	
(F) On farm storage at pre-irrigation (ML)	5124	
(G) On farm storage at harvesting (ML)	2600	
(H) Used from farm storage (ML) = **F** – **G**	2524	
(I) On farm harvested (ML)	1000	
(J) Water used on other crops (ML)	0	
(K) Total irrigation applied on cotton (ML) = D + E + H + I – J	**10076**	
(L) Irrigation WUI (farm) (Bales / ML, t / ML) = B ÷ K	**1.03**	
Soil water		
(M) Used soil reserve (mm) average of all fields for this crop = soil moisture prior to pre-irrigation – soil moisture at harvest	118	
(N) Used soil reserve (ML) = (**M** ÷ 100) × **A**	1545	
Rainfall		
(O) In season rainfall (mm)	351	
(P) Total in season rain (ML) = (**O** ÷ 100) × **A**	**4595**	
(Q) Seasonal water usage (total) (ML) = K + N + P	**16215**	
(R) Gross production WUI (farm) (total) (bales / ML, t / ML) = B ÷ Q	**0.64**	
Effective rainfall		
(S) In season effective rainfall (mm)	285	
(T) Total in season effective rain (ML) = (**S** ÷ 100) × **A**	**3731**	
(U) Seasonal water usage (effective) (ML) = K + N + T	**15351**	
(V) Gross production WUI (farm) (effective) (bales / ML, t / ML) = B ÷ U	**0.68**	

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NATIONAL PROGRAM FOR
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Cotton Research and
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GRDC
Grains
Research &
Development
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Department of **Primary Industries and Fisheries**

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Metering

Key Points

- A water metering solution consists of the meter and installation conditions. A meter is only as accurate if it is installed and maintained correctly.
- There are many different types of meters with different characteristics, accuracy levels and prices.
- A whole farm metering solution might consist of a variety of meters measuring different components of the system
- Installation and maintenance are key for reliable metering

The need for metering

The value of measuring volumes of irrigation water has become increasingly important, especially in times when water availability becomes scarce (due to drought, water reform or other reasons). In an on-farm context, irrigation water is typically metered for 2 main reasons:

- Measurement for use. This has historically been the most common reason for metering. Metering is used by authorities to monitor individual customer use against entitlement, to find out how much water is being extracted from the system (to improve modelling and management) and to bill customers for water used. As charges for water get higher, users demand more accuracy in measurement.

  Key programs to improve measurement of water resources exist at both the state and federal level, including the NSW Water Extraction Monitoring Policy, the Qld Metering Water Extractions Policy and the National Plan for Water Security and National Water Initiative.
- Measurement for farm management. Irrigators are increasingly metering irrigation water to make more informed management decisions. Metering helps them to calculate the efficiency of their system, to identify and minimise water losses such as seepage and evaporation and to make better planning decisions and, ultimately, more profitable farming systems.

There is an increasingly wide range of meters available, but irrespective of which meter is used, it is essential that water meters are:

- Installed correctly
- Well maintained
- Read accurately.

Further information is available in WATERpak Chapter 2.8 and in the 'Know the Flow' manual available at www.irrigation.org.au

Basic Flow Hydraulics

Flow occurs when there is a difference in pressure or head (height) between the two ends of a pipe or channel. Water will flow from high head to low head (from high pressure to low pressure).

Flow rate increases with pressure or head. The larger the pipe or channel cross-section, the higher the flow rate capacity.

One of the fundamental hydraulic equations that governs the measurement and calculation of flow is:

Q = A x V

Where:

Q is the flow rate, or discharge rate (m^3/s)

A is the cross-sectional area (m^2) and

V is the average velocity of the water (m/s)

You can convert flow rate in m^3/s into the more commonly used terminology as follows:

1 m^3/s = 86.4 ML/day

1 m^3/s = 1000 L/s

To determine the total volume of flow (rather than the flow rate) you simply multiply the flow rate (Q) by the total time over which flow occurs.

Example:

A rectangular section of concrete channel is 1 m across and has water flowing at a depth of 0.5 m. The average velocity of the water is 1.6 m/s.

Area = 1 x 0.5 = 0.5 m^2

Flow rate = 0.5 x 1.6 = 0.8 m^3/s (or 800 L/s)

How much water has flowed through the channel over a period of 36 hours?

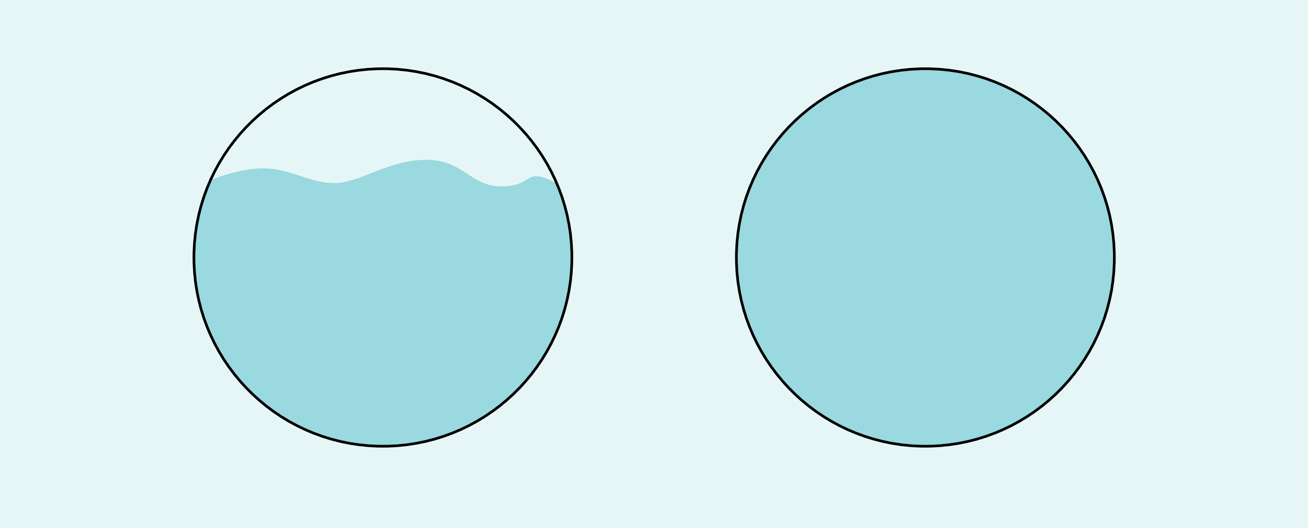
Volume = 800 L/s x 60 (min) x 60 (hour) x 36 = 103 680 000 L = 103.68 ML

Virtually all flow meters use the above equation in order to calculate flow rate. That is, they actually measure the speed of the water and the area of flow and then calculate the flow rate from the equation.

This means that to calculate the rate of flow you need to know:

1. The size of the inside of the pipe or channel dimensions. Larger pipes and channels will allow for a higher flow rate than smaller pipes or channels.
2. The average velocity (speed) of the water. Velocity can be increased by increasing the pressure (head).

Figure 1 – Partially full pipe on the left is classified as open channel flow. Full pipe on the right is closed conduit flow (Panametrics)



How water flows

Open channel flow - Water in an open channel will only flow if there is a downward slope of the water surface. As mentioned previously, water will flow from high head to low head. The greater the fall, or head, the faster the water will flow.

Closed conduit flow - This is commonly known as full pipe flow, but applies to any closed conduit, not just circular pipes. Regardless of the structure, the conduit must be completely full - if water does not completely fill the pipe then the water movement is classified as open channel flow, irrespective of whether or not it is in a fully enclosed conduit (pipe).

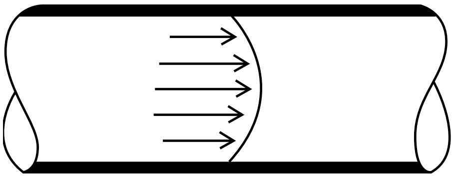
Turbulent flow - Turbulent flow occurs when the water swirls in the pipe or channel. This may be caused by obstructions in the flow stream, including the presence of the water meter itself (for example when a mechanical meter is running too fast). Other obstructions can include weeds, incorrectly placed gaskets protruding into the flow, shells, chemical build-up, valves, bends and other fittings.

Established flow - After turbulence distorts the velocity profile it takes a long length of straight pipe before the profile becomes established again. Established flow occurs when the water is flowing through a pipe or channel in a straight line, without turbulence. Most water meters are designed to only measure accurately in established flow conditions

Most manufacturers recommend a length equivalent to 10 diameters in order to restore established flow conditions, although some people suggest that this distance maybe more like 60 or even 100 diameters. There is also a requirement for straight pipe after the meter location as well, to ensure that any subsequent turbulence does not have an effect on the upstream flow conditions near the meter.

Laminar Flow *– Often the term laminar flow is used to describe the conditions under which metering must occur. In practice, few of the flows that we measure are laminar, but are more accurately described as 'smooth turbulent'. What we require are established flow conditions, so that the velocity profile is regular and predictable*

Figure 2 - Velocity profile in horizontal pipe for established flow (Panametrics)

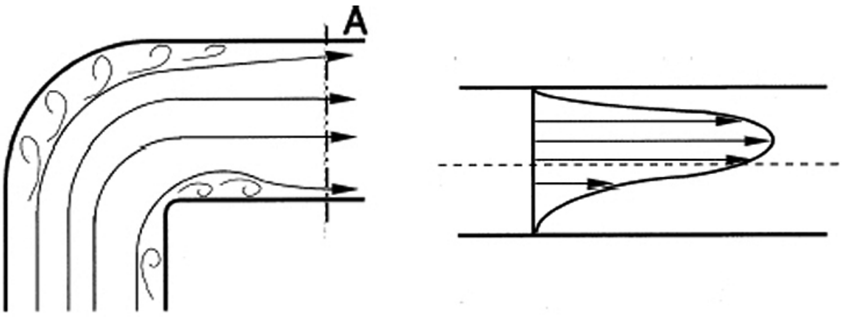


Effects on metering

Because flow meters measure the velocity of the water in order to calculate flow rate, the concepts related to how water flows are important. In particular, it is important to understand how the velocity of water varies across a pipe or channel.

As indicted in in figure 2, the velocity of water moving a pipe (or channel) is not the same across the entire width of flow. It is fastest in the middle, where there is the least impact from friction with the walls. When flow is established, the velocity profile is very predictable, as illustrated in the figure.

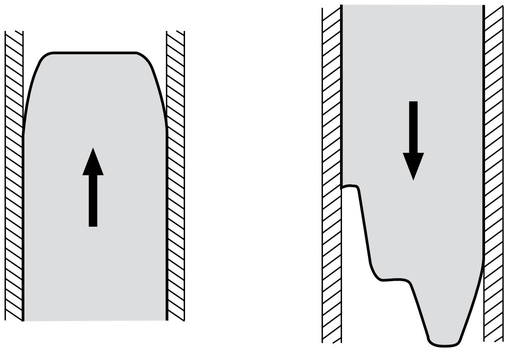
Figure 3 - Slow streamlines in an elbow and the corresponding velocity profile application A (source: Guide to Flow measurements, Bailey-Fischer & Porter)



When the flow is not 'established', the velocity profile changes, as indicated in figure 3. In this case, following an elbow, the velocity profile is skewed and cannot be correctly interpreted by a flow meter, hence the accuracy of the metering device is affected

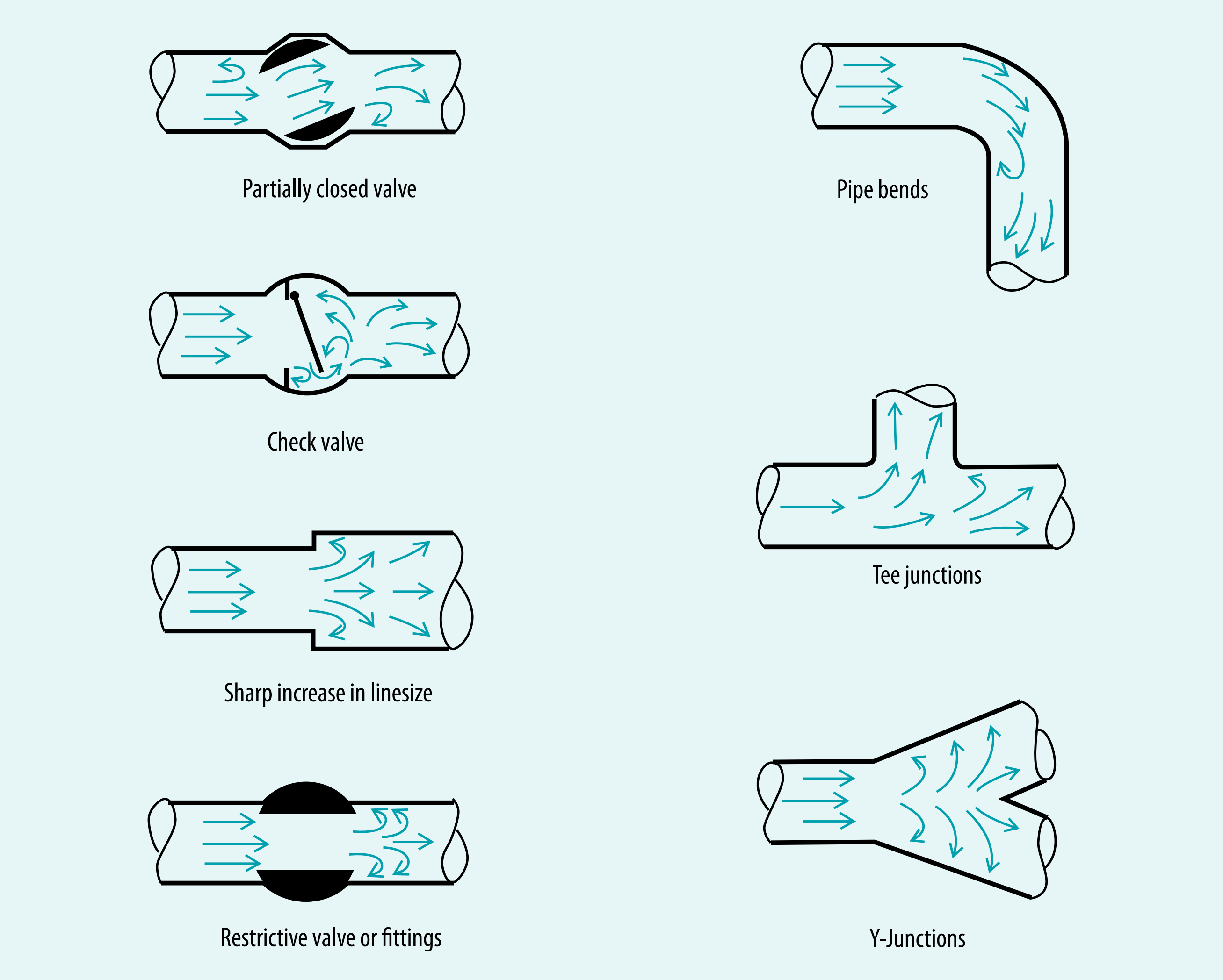
Velocity profiles can be allowed for in the metering calculations if they are consistent. This is achieved when the pipe orientation is anywhere between horizontal and vertical. However, downward flows in pipes have a more uneven profile due to gravity.

Figure 4 - Difference in flow profiles in a vertical pipe for upwards flow and downwards flow (Panametrics)



For this reason, it would not be wise to try and measure flow in a vertical pipe with water flowing down the pipe. You also must avoid measuring flow in other situations where turbulence is created such as illustrated in Figure 5. In these situations, the meter should be situated away from the turbulence as indicated by the manufacturer's specifications.

Figure 5 – Ways that turbulance can develope due to bends, valves and obstructions (Trimec)



Partially closed valve

Pipe bends

Check valve

Tee junctions

Sharp increase in linesize

Restrictive valve or fittings

Y-Junctions

Principles of water measurement

There are some key considerations when it comes to measuring water.

Accuracy and Error

Accuracy of measurement relates to the quality of the result. For water meters it is the degree to which a meter conforms to a standard or true value. For example, the accuracy of scales in food stores is tested against known or "Standard" weights. Accuracy is usually discussed in terms of deviation from the standard.

Field conditions can influence the accuracy of a meter. It is important that meters are installed correctly so that, when operating under field conditions, they have an acceptable level of accuracy. The accuracy required usually does not need to be to laboratory standard, for example, you expect greater accuracy for measurement of small amounts of medicine than for bulk water, but incorrect installation may cause too much inaccuracy.

Accuracy is reported in percentages of error, for example, a manufacturer will claim that a meter will be accurate to within ±2%, that is, it can have up to 2% error. This meter is deemed accurate if it reads anywhere between 2% below or 2% above the correct reading.

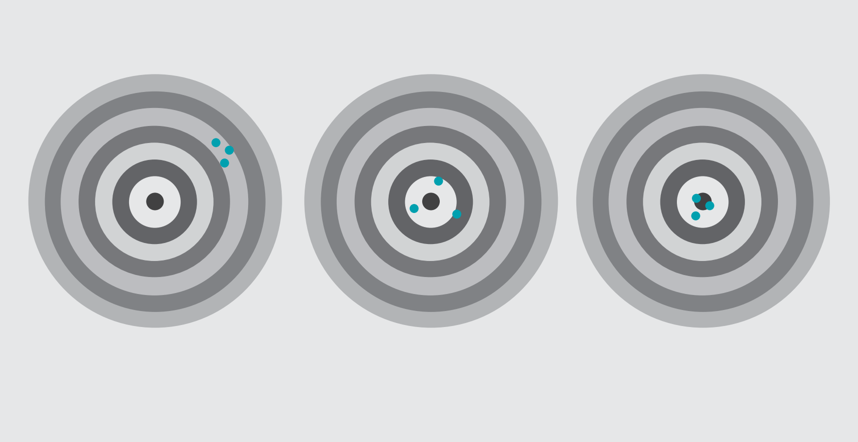
The level of accuracy that is acceptable depends on the situation. Manufacturers test their meters in what is called fully developed flow conditions therefore achieving laminar flow. In these conditions they can claim accuracies of ±2%. Similar accuracies are found when meters are tested in laboratories. In the field, the meters are often operating in a non-perfect environment. Most operators are happy if their meter is operating within 5% in a field situation.

Repeatability

Accuracy is different to repeatability, which relates to the quality of the measuring process. Repeatability is the degree of consistency or uniformity of a result. A measurement can be precise, or repeatable, without being accurate as illustrated in the figure 6. In this case, the application of some systematic adjustment (aim lower and further left) would result in better accuracy.

Meters are often precise and then calibrated for accuracy in this way.

Figure 6 – From left to right, showing repeatability without accuracy, accuracy with a moderate degree of repeatability, and accuracy with high degree of repeatability.



Types of flowmeters

We have discussed that flow rate is directly proportional to the average velocity of the water and the cross-sectional area of the conduit. In turn, the velocity is related to the pressure or head in the system at the point of measurement.

Flow measurement devices do not measure flow directly. Instead, some measure the velocity of the flow and others measure changes in head or pressure. This information is then used to calculate flow. Common types of flowmeters are listed in the table below:

We will discuss some of these types of meters that are most applicable to measuring irrigation water.

METERS THAT MEASURE VELOCITY ARE:

Meters	Subtypes	Alternative names
Mechanical meters	Propeller meters, closed type Propeller meters, open type Paddlewheel meters Turbine meters Positive displacement meters	Propeller actuated or PA meter Helical rotor PD meters
Electromagnetic meters		Magmeters
Ultrasonic meters	Doppler meters Transit time meters	Acoustic meters

METERS THAT MEASURE PRESSURE OR HEAD ARE:

Meters	Subtypes	Alternative names
Venturi meters Office meters	Velocity head	
Ultrasonic meters in conjuction with calibrated weirs and flumes		

Figure 7 – Dethridge meter

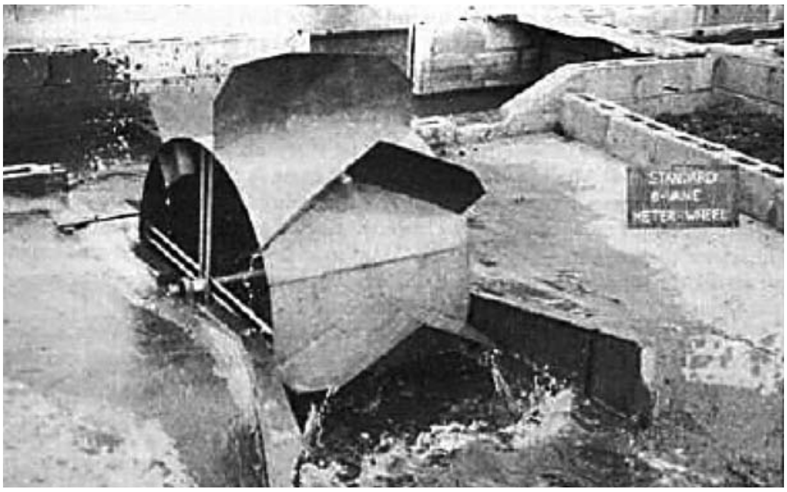


Figure 8 – Dethridge-Long meter showing the elongated vanes (Sunwater)

Dethridge Meters

Dethridge meters (also known as Dethridge wheels) have been installed in Australian irrigation systems for over 90 years and there are approximately 60,000 still in use today, although in some areas they are being phased out to be replaced by more accurate automated systems.

They are cheap, reasonably accurate and easy to use, leading to their widespread use, particularly for measurement of water supply to farms from regulated schemes

The Dethridge meter consists of a circular drum to which vanes are attached and which revolves in a concrete emplacement. The wheel is turned by water pressure on the vanes and, in turning, displaces a fixed quantity of water between each pair of vanes. A counting device records the number of wheel revolutions and thus a direct measure of the volume of water passing.

The standard Dethridge meter is available in several sizes. Large meters will measure flow ranges between 3.5 to 12 ML/day while small meters measure flow range from 1.5 to 6 ML/day.

Flow rates are easy to estimate in the field as the number of revolutions of the wheel each minute can be counted and multiplied by a factor to get an approximate flow rate in ML/day.

The Dethridge meter was refined during the 1980s and the Dethridge-Long meter was adopted for general use about 1990. It is very similar to the original Dethridge meter but was designed for use when the maximum flow is higher than 12ML/day and/or where there is a large amount of very level land and head losses need to be minimised to maintain good flow conditions and measurement accuracy.

Propeller meter – open flow

The open flow propeller meter consists of a propeller and extended spindle shaft. It is mounted on the downstream end of a pipe culvert with the propeller projecting inside the pipe and its axis located at the centre of, and parallel to, the flow. The culvert pipe must always flow full of water – for accuracy, it must never operate in an 'open channel' condition. The rate of propeller rotation provides a measure of flow rate from which flow volume can be derived and recorded.

There is little head loss through a propeller meter. Installation is critical as the propeller may only sample a small proportion of the flow.

Propeller meter – closed flow

The meter consists of a metal or plastic propeller mounted inside a pipe section with its rotation axis set parallel to the water flow. As water flows past the propeller it causes it to turn. The faster the water is flowing, the faster the propeller spins. This provides a measure of flow velocity from which volumetric flow can be calculated for a given pipe cross section.

Meters are produced in a range of standard sizes with calibrations determined by the manufacturers from laboratory testing.

Closed flow propeller meters are usually configured as an in-line meter in a closed pipe system. It is also used where water is pumped from an open channel or natural water course to irrigate land situated above the level of the water supply. In the latter case the meter is located in the pipework on either the suction or delivery side of the pump. For accuracy, the meter must be carefully located clear of pipe bends or fittings and configured so that the pipe flows full at the meter.

All propeller meters are susceptible to wear and damage because they have moving parts.

Models include (for both open and closed flow):

ABB - R2000
Tempress - Water Specialties
McCrometer - McPropellor

Figure 9 – Open flowmeter (ABB Metering)

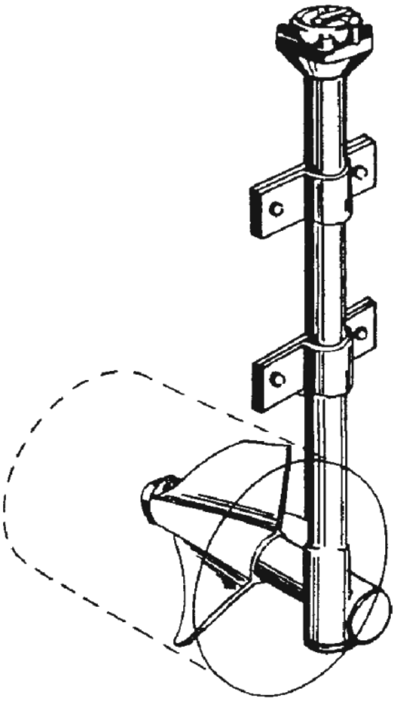


Figure 10 – ABB R2000 casing and display (ABB Metering)

Figure 11 – Amiad IRT meter, paddlewheel can be seen at the top of the bore

Paddlewheel Meter

A vertically orientated impeller is rotated by the velocity of water passing through the bore of the meter. Unlike propeller meters, which record velocity in the middle (fastest) portion of the flow, paddlewheel meters often record velocity nearer to the pipe edge. Some versions, which are designed to be used in pipes of various sizes, have an adjustable calibration which must be pre-set for the conditions in which the meter is mounted and tested after assembly in the manufacturers test facility.

These meters are available in various sizes and must be full of water during times of measurement. In pumped systems the meter can be installed in the suction or discharge pipework.

The paddle wheel meter can be used for gravity channel off-takes, pressurised and pumped systems or bore water applications. Due to the large free passage though the meter it is well suited to poor quality water with a high content of impurities and is often used in drainage systems. However some impeller designs have been known to catch debris and drastically reduce accuracy or even stop the meter from turning.

Paddlewheel type meters are also prone to wear and damage as they have moving parts.

Models include:

Amiad IRT (inline meter)
Trimec Dual Pulse
Irrimate Siphon meter

Ultrasonic Meter

Ultrasonic meters (sometimes called acoustic meters) are in widespread use for urban water and wastewater systems and many industrial applications and have found significant use in the irrigation industry in recent years. They operate by producing ultrasonic waves (sound waves) which travel through the water and are either sped up or slowed down by the velocity of the water.

Some meters combine both velocity and depth measurements which allows for measurement in open water surfaces and partially full conduits. Ultrasonic meters use transducers or sensors to measure water velocity in full pipe applications and convert this to flow rate for a particular conduit cross section. Those meters which also measure depth are able to constantly adjust this cross section as water level varies, hence their usefulness in open channel and partially full pipe conditions.

The velocity sensing transducers may be fixed on the outside of the pipe ('non-wetted' types) or may be inserted into the pipe ('wetted' types). Some meters even use multiple transducers to measure velocity in more than one plane, which generally provides greater accuracy.

There are two methods used to calculate the velocity:

Transit Time

This method measures the small variations in time for an ultrasonic sound wave travelling upstream and downstream between fixed points. The velocity of sound pulses in the direction of flow is compared to the velocity of sound pulses opposite to the direction of flow to determine mean velocity and therefore flow rate.

The transducers are often located on or outside the pipe circumference so that there are no obstructions or moving parts to impede the flow. Many of these meters are used only for full pipe flow; however some variants are available that can be used to measure flow in part full pipes or open channels with a free surface. This is more complex and requires additional numbers of transducers and sound paths together with a means of water level measurement.

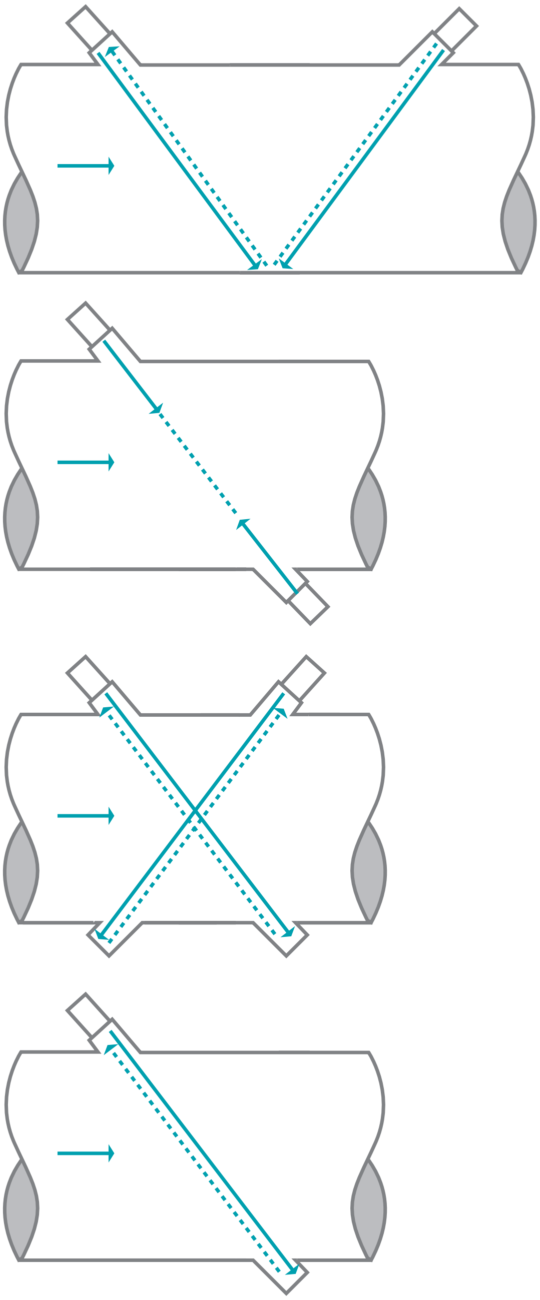
The transducers may be 'wetted' or 'non-wetted'. Non-wetted transducers transmit the acoustic pulses through all or part of the channel's containment structure.

Strap-on, external (non-wetted) meters are quite commonly used for one-off measurements. The thickness of the pipe material must be known or measured for these units.

Models include:

Panametrics
Dynasonics

Figure 12 – Examples of the various ways that transit time sensors may be setup (Source - Pat Weldon NSW DPI).



Doppler

This method calculates the velocity by bouncing sound pulses out into the water mass and reading the pulses that are returned after reflecting from moving particles within the water mass such as air bubbles. This is similar to how radar works.

Meters using the Doppler method generally consist of a sensor that is installed within an existing pipe or structure so the sensor is wetted, although externally mounted units are available. There is no need to install new pipe sections or concrete structures unless there is a need for straight lengths to straighten the flow.

There are various ways to mount the sensors depending on the application. Some may be installed through one inch or two inch ‘BSP’ fittings welded or clamped onto the external face of the pipe and others by strapping them inside a pipe or structure.

Ultrasonic Doppler meters are capable of measuring flow in open channels or closed conduits, full or partly full flow and pumped or gravity fed conditions. In situations where full flow cannot be achieved, the ultrasonic Doppler meters can have an additional sensor installed to measure the depth of flow. By measuring the depth within a conduit it is possible to then calculate the cross-sectional area and therefore the flow rate. Depth transducers may be ultrasonic, pressure or bubbler type. The most common are pressure transducers due to their high reliability.

Doppler flowmeter performance is highly dependent on physical properties such as the liquid’s sonic conductivity, particle density, and flow profile. Likewise, non-uniformity of particle distribution in the pipe cross section results in an incorrect mean velocity. Therefore, the meter accuracy is sensitive to velocity profile variations and to distribution of acoustic reflectors in the measurement section.

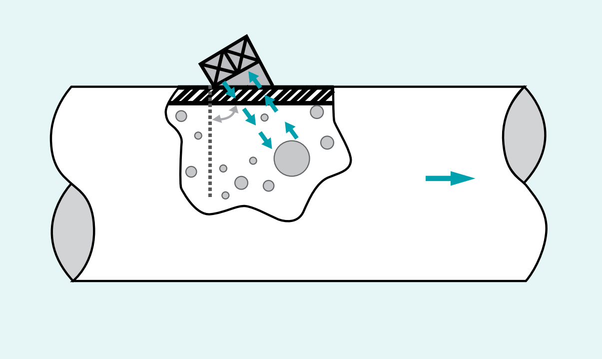
Models include:

Mace Agriflow

Starflow

Dynasonics

Figure 13 - Schematic of a Doppler meter showing the reflected path from a non-wetted transucer. (Mace)



Electromagnetic Meter

An electromagnetic meter consists of a section of pipe with a magnetic field across it and electrodes to detect electrical voltage changes. Under the laws of induction, when a conductive fluid passes along the pipe an electrical voltage is created in the fluid, which is proportional to the fluid velocity.

Electrodes in the probe detect the voltages generated by the flowing water. Measurement of the voltage is then converted to velocity from which the flow rate can be derived for a given pipe section.

This type of meter is produced in a range of standard sizes and flow capacities and comes in two types – insertion and in-line. In-line meters have no parts protruding into the flow and hence are very robust and can easily handle sand, silt and trash. Because of this robustness and very low maintenance requirement, they can be buried and forgotten.

Models include:

Magflow
Aquaprobe
Emflux
Magmaster
Dynasonics.

Flumes and Weirs

In Australia, flumes and weirs are commonly used to measure flow in supply channels. A weir is a small holding wall. This can be used for flow measurement by recording the height of the water as it flows over the wall, or through a cut-out in the wall. For example, a v-notch weir is one with a v-shaped notch cut out of the wall and the height of the water is measured as it falls through the notch. A flume is a narrowing of a channel.

Water height can be read with measuring sticks but are now more commonly being measured with ultrasonic meters, which also allow flow to be automatically logged.

Whilst virtually any weir or flume structure can be used to measure flow, the greatest challenge for custom made weirs and flumes is the rating process (calibration). Some configurations have extremely poor precision.

Examples of standard flumes or weirs in use (which are already rated) include Rubicon's 'FlumeGate' system of supply channel control and measurement, and the Irrimate® Flume for measurement of runoff from individual furrows.

Storage Meter

Whilst all the other meters discussed above measure water as it flows past a certain point (in a pipe or channel), it is also possible to measure the change in volume of water within an on-farm storage. Recent developments of automated storage volume meters, have made it much easier to measure and continuously record storage volumes, and then estimate the volume of water that has been moved to other parts of the farm.

There are a few important points to keep in mind:

- The accuracy of the meter is primarily influenced by the accuracy of the known relationship between storage depth and volume – it is recommended that the storage is surveyed to confirm this relationship
- A record of where water is moved to and from at any given time is required if you want to make best use of this data
- The measured volumes do not take account of losses outside of the storage so accuracy declines as you try to apply the data to other parts of the system, the further from the storage, the worse the accuracy.

The most widely available example of an automated type of this meter is the Irrimate™ Storage Meter.

Metering On Farms

Most often, the use of data collected from flow meters on farms is used to inform management decisions. Examples might be to determine how much water is available for use in a season, or to evaluate how well an irrigation system is performing. Hence the location of metering points will determine how the data may be used.

Benchmarking irrigation performance is discussed in another workshop in this series "Benchmarking and Water

Budgeting". Benchmarking may be undertaken on the whole irrigation system (farm scale) or on individual components of the irrigation system (storages, distribution system, fields, individual channels). The location of meters will influence the types of benchmark calculations that can be performed.

Whole Farm

Calculation of performance indices at the whole farm scale requires water inputs from all sources to be accounted for. If all water used on the farm goes through a storage, then a storage meter may be the most effective way of measuring this water volume (although some losses may not be measured, e.g. channel losses from river pump to storage). If not, then all bores, river pumps and other sources must be metered separately. In this situation an on-farm storage will still need to be monitored to account for rainfall capture or on-farm water harvesting

Storage

Storage efficiency can be calculated if you know the volume of water in storage over a period of time and the volume of water used from the storage. This is most easily achieved using a storage meter.

Distribution System

In order to evaluate a distribution system, you need to compare the volume of water entering the system and the volume of water leaving the system. In the simplest form, measurement of a single channel requires a meter at the start of the channel and a meter at the end of a channel (provided there are no outlets in between).

For an entire distribution system, the process becomes much more complex, as all outlets need to be accounted for, theoretically requiring a separate meter for every offtake. It may be easier to use a product like Watertrack for this purpose, or to measure smaller components of the system separately.

The efficiency of distribution systems will vary from season to season depending upon the time that channels contain water, the volume of water transported and the proportion of channels in use.

Ultrasonic Doppler meters with in-built depth sensors are most often used for measuring flows through channels and are best located in culverts or structures where they are not likely to be covered with silt and sediment and the channel cross section can be accurately determined.

Field

In order to calculate basic water use indices for a field, you need to know the amount of water delivered to an individual field. For a furrow irrigated field this can be achieved by measuring the amount of water entering the head ditch. If subsequent fields are also irrigated from the same head ditch, it may also be necessary to measure the amount of water leaving the head ditch to be used on these other fields. Again, an Ultrasonic Doppler meter is most often used for this task.

Another way to perform this measurement would be to measure individual siphons and add the results together. This can be achieved using commercial meters like the Irrimate siphon meter, or by measuring individual siphons with a bucket and stopwatch, or using head-discharge charts. However, results will be strongly influenced by any variation between siphons and the number of siphons measured so it is possible for accuracy to be quite poor. Head ditch losses will not be included.

More detailed evaluation of surface irrigation systems may require measurement of the volume of runoff water. Meters can be installed in taildrain structures to measure bulk runoff volumes, although there are often many technical and installation issues to overcome. A system that includes both furrow flumes to measure runoff and computer simulation to predict runoff as well as detailed calculation of performance indicators, such as the Irrimate™ system, should be seriously considered by anyone wanting to better understand their surface irrigation system.

For drip or overhead systems, any suitable pipe-mounted meter can be appropriately installed in the system. In recent times, overhead systems have had Ultrasonic Doppler insertion meters fitted. Meters installed in drip systems will not be affected by issues with contaminants in the water as they usually have filtration systems installed.

Meter Selection

Selecting the right meter for the job can be a complex process, particularly since many on-farm applications involve difficult conditions for meter siting and accurate operation. There are some key parameters to consider.

Flow conditions

Are you metering in full pipe, open channel or partially full pipe? As discussed, some meters can operate in all three situations whilst others are more restricted in their application.

Nearly all meters require established flow conditions to operate accurately. This means that the installation location must have sufficient straightness and a lack of obstructions to ensure the flow is not turbulent. Manufacturers will specify the length of conduit required to ensure appropriate flow conditions.

Water Source

The source could be a river, surface water, groundwater, open channel or pressurised pipe. The source will have a bearing on water quality with surface water and river water carrying trash and other foreign material while some groundwater can cause iron oxide and iron bacteria buildup on the internal surface of meters and pipes. The source will also have a bearing on the range of flow rates and operating head.

Head

The amount of available head can influence meter selection, particularly for gravity fed open channel systems. Because many metering devices require a certain amount of head in order to operate, this often limits their application in these systems. You also need to take account of how water levels might change over time.

Flow Range

Many meters have an operating flow range over which they can be used. If you operate a meter outside this flow range, then accurate readings cannot be expected. Meters (especially mechanical meters) continually operated at the high end of their flow range may wear out more quickly than meters operated in the middle of their flow range.

Power

Some meters do not need electricity whilst others may have a variety of power source requirements. Many meters that require power can be satisfied by battery/solar systems although there may be some meters which still require mains power. It is important to know what might happen if the power supply is interrupted for some reason – will recording stop? Will existing data be erased?

Accuracy

If there is a requirement for a data accuracy of 2% then it would not be useful to choose a meter that only reads with accuracy of 5%. The reverse may also be true, particularly if it is more expensive to purchase a more accurate meter, when this accuracy is not required.

A manufacturer's claims for meter accuracy are usually well substantiated by laboratory tests supplemented by standardised field tests. However, in practice, a flow meter should be considered as including not only the physical meter but the fully installed system – the data obtained will only be accurate if the metering installation meets all the manufacturers requirements of flow profile, temperature, humidity, flow range, radiation, vibration etc.

Reliability

A meter needs to be reliably accurate so it provides the correct reading time after time

Data Output

There are many different ways that data can be recorded (logged). Some meters include inbuilt data loggers to store the information, whilst others need external data logging capabilities, at additional expense. Some systems may be accessed remotely via telemetry systems.

If you are going to physically download the data yourself, you need to know that there are numerous signal types and methods for connecting to and interrogating the meter. You should have these explained to you and demonstrated so that you are comfortable with the process as some systems are more user-friendly than others.

Accessibility

Some meters may require regular access whilst others could be left alone for years without needing to be seen. Some meters can even be buried and then covered over, which may be useful where the only suitable metering point is underground or where a meter might be vulnerable to damage.

Longevity

The life of the meter will have a direct bearing on the long term economics of a metering decision. On-going maintenance requirements should also be taken into account. Some operating conditions may vary the recommended operating life (for example water quality).

Cost

Cost is often one of the most crucial parameters for meter selection. As mentioned before, the more accurate and reliable the meter, the more expensive it usually is to buy. Additional costs might include installation, maintenance, staff training, data collection, software and lifespan. Don't forget to include the value of the data collected when determining how much you should spend.

Installation

Many key installation issues have already been discussed. These include:

- Nearly all meters require established flow conditions to measure accurately
- Turbulence can be caused by any obstruction including bends, contractions, pumps, valves, etc. and therefore meters should be installed in a straight pipe section away from any of these obstructions.
- Manufacturers should provide recommendations for how much obstruction-free straight pipe or channel is need both upstream and downstream of the meter.
- Many meters require full pipe flow to operate
- In vertical pipe situations, a meter should only be used when the water is moving upwards.
- The accuracy of a metering solution is greatly influenced by the surrounding system

However there are some specific additional points that should be considered for different meter types.

Ultrasonic Doppler Strap-on

Ultrasonic Doppler strap-on meters have become extremely valuable for measurement of open channel gravity systems because they have flexibility in siting and the ability to measure over a wide range of water depths. When setting up a meter for open-channel or partially-full flow, you must program the meter with the channel cross section where it is installed. This is because the meter will automatically measure the water depth and then calculate the cross-sectional area based upon the pre-programmed cross section data.

In most of the applications for these meters, sediment can be a major issue. There are two things you must take into account. Firstly, if the build up of sediment is significant, the cross sectional area of flow will gradually change (reduce) thus influencing the accuracy of the meter. If this is the case, you should investigate redesign of the structure as the hydraulic efficiency of your system will also be suffering.

Secondly, a small build up of sediment is tolerable, provided it does not cover the meter and obstruct the sensing apparatus. To overcome this, you could mount the meter on a raised platform (e.g. a brick or raised bracket) or you could mount the meter so that it is not in the bottom portion of the flow (e.g. mount it partially up one wall of a pipe). You must tell the meter where it is mounted in relation to the water surface so that it can perform calculations correctly.

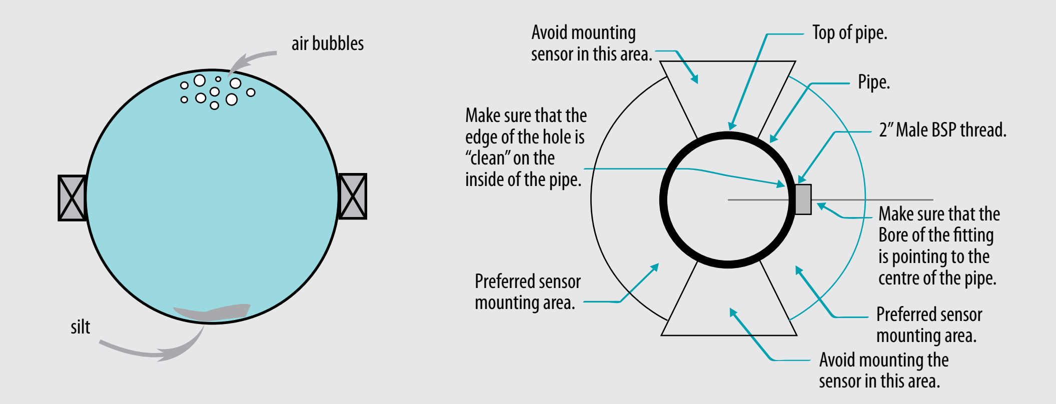


Figure 14 – Examples of appropriate installations of non-intrusive transit time (left) and insertion Doppler (right) meters.

Ultrasonic Doppler Insertion

Ultrasonic Doppler insertion meters must generally be aligned with the direction of flow so that the signals that they emit are projected at the appropriate angle. Often these meters come with an alignment tool to ensure that they are appropriately aligned to the pipe – make sure that this tool is used during the installation process or an appropriate alignment tool is constructed to ensure this alignment is accurate.

In many cases, the very top and bottom of a pipe are not ideal locations for mounting of an insertion meter, as illustrated in figure 14. Sediment and air bubbles can congregate in these regions and affect the readings. For transit-time meters (as in the figure) the transducers must directly face each other. For a Doppler insertion meter, the mounting point must be square with the pipe and directly face the very centre of the pipe.

Mechanical Meters – Pipes

When installing mechanical meters in pipelines, all general guidelines need to be considered. They need:

- full pipe
- a straight flow of water with no turbulence
- to be accessible for operation and maintenance.

Most mechanical meters will operate at any angle from horizontal to vertical or oblique. However, they will not be able to read accurately if the activating rotor is not parallel with the sides of the pipe and therefore the straight flow.

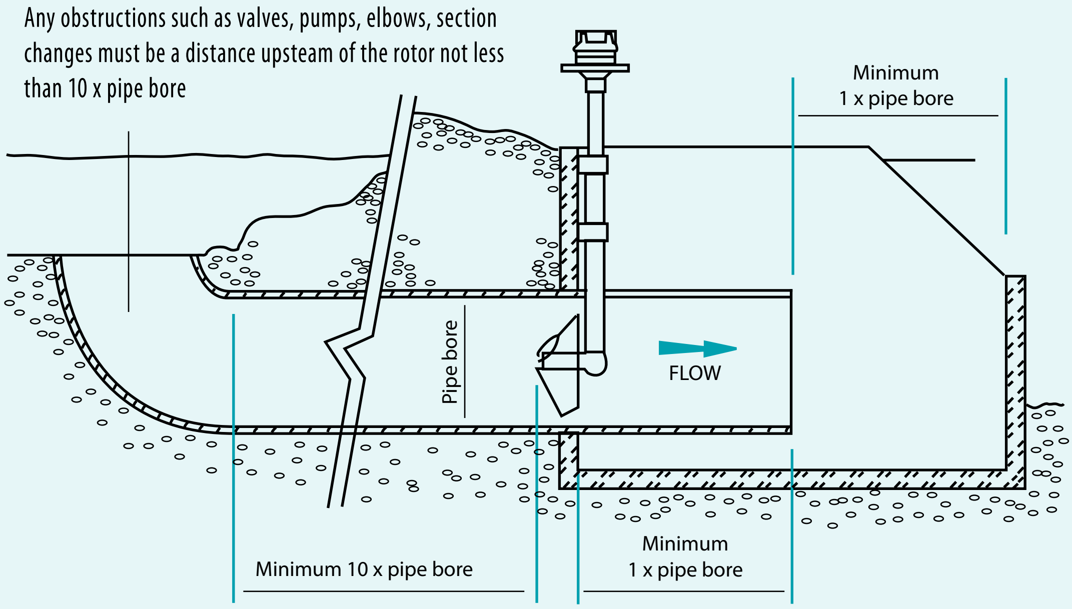
Where these types of meters are moved and used in a number of different locations (e.g. the Irrimate siphon meter) you must ensure that the propeller or impeller is accurately aligned with the flow to maintain accuracy.

Whilst the majority of meters need to be installed in a straight section of pipe, the Irrimate siphon meter is typically installed in a slightly curved section of pipe (the siphon). This is because the meter is calibrated in the laboratory in a curved siphon tube of the appropriate diameter.

Mechanical Meters – Open Channel

An open channel mechanical propeller meter must be installed within a structure that flows full. This is because these meters do not measure across the whole flow profile and because they cannot determine any change in water depth. Therefore an appropriate structure must be installed or used as per figure 15. All installation rules already mentioned must be obeyed.

Figure 15 - Example of minimum requirements for straight pipe before and after an open flowmeter installation (ABB Metering).



Any obstructions such as valves, pumps, elbows, section changes must be a distance upsteam of the rotor not less than 10 x pipe bore

Electromagnetic meters

In-line electromagnetic flowmeters are usually manufactured as a pre-formed pipe section with the detectors and transmitters welded or bolted in place. This makes them extremely simple to install.

These meters have the same requirements for full pipe and straight pipe as all other meters, with 5 to 10 diameters upstream and 3 to 5 diameters downstream the norm.

Reducers can be used for installation in larger size pipelines provided they abide by the rule above so as to ensure laminar flow. Be aware of any hydraulic impact of reducing the size of an existing pipe.

If there is interference or “noise” they may need to be grounded with a ground strap.

Maintenance

Mechanical meters

Mechanical meters, like all things mechanically driven, require maintenance. These meters should be maintained in good condition without wear and correctly adjusted.

It is recommended that these meters are dismantled for cleaning, inspection and routine maintenance every two years. At this time, the complete meter should be removed from the line so that rubbish in the pipe upstream of the propeller may be removed and the meter thoroughly cleaned. Unfortunately this is rarely done in practice, potentially affecting readings.

If wear is too great, the meter should be replaced. In aggressive water (eg. chemically corrosive, high sand content, etc.) it may need fairly frequent replacing or to be made of special material.

Meter failure can be detected by the vigilance of the meter reader or monitoring of readout data to identify faulty meters. Some newer displays have a red flashing light to verify that the propeller is working.

There are two types of meter failure:

- mechanical failure
- environmental failure.

Mechanical failure includes excessive wear of parts such as gears and the complete failure of parts such as broken propeller vanes. This type of failure is usually caused by one of the following:

- flow rates too high
- poor quality parts
- tampering
- fatigue
- vibration

Environmental failure occurs when the mechanism of the meter is fouled or damaged by foreign matter or objects in the water supply system. This type of failure is usually caused by:

- shellfish
- gravel or sand
- weeds
- algae
- iron oxide
- fish or eels
- rubbish eg. sticks.

Errors in meter operation could be caused by:

- changes to the pipeline since meter installation, such as new pumps or valves in the pipe section adjacent to the meter
- air bubbles in the flow
- full-pipe situations not running full due to air entering the system. (Note that this causes meters to record more than the true flow)
- mechanical meters being jammed or slowed by weeds, twigs or fibre in the propeller/rotor/paddle
- build up of iron oxide or iron bacteria or shells on the internal surface of the meter housing or meter pipe
- operating the meter outside it’s minimum and maximum flow range.

Ultrasonic Meters

Ultrasonic meters require little maintenance once installed.

Batteries will last several years (5-10 years depending on the frequency of complete discharge). Some meters provide an early warning indicator of low battery power on the LCD readout. Solar panels will need to be cleaned occasionally and inspected for damage.

Internal (wetted) sensors will need to be cleaned occasionally, depending on water quality. However in many sites, they will not require cleaning for several seasons. They may need to be checked periodically to ensure that they are not being fouled or covered with sediment or weeds.

Electromagnetic Meters

Electromagnetic meters also require little maintenance. The straight-through section of pipe has no obstruction to restrict flow, and no moving parts to wear or break. As with the ultrasonic meters, the power source will need to be checked.

WATERpak Table 2.8.1. Irrigation guide to flow measurement – Dethridge meter and electromagnetic flowmeter

	DETHRIDGE METER STANDARD	ELECTROMAGNETIC FLOWMETER
Applications		
Open Channel	Yes	Yes
Piped systems	No	Yes
Specifications		
Accuracy (typical)	2%	0.5% to 2%
Flow range	3 to 9 ML/day	Depends on size
Turn-down (flow range)	3 to 1	Up to 1000 to 1
Ideal piping requirement upstream	560 mm	5 diameters
Ideal piping requirement downstream	310 mm	3 diameters
Other special installation requirements	Requires 380 mm level upstream	Requires full pipe
Reliability including tamper-proof protection	Low	Very high
Flow rate indication available	No	Yes
Remote reading capability	Requires separate device	Yes
Output signal type	Requires separate device	Analog & pulse
In-built telemetry output	NA	Yes
Can meter be buried	No	Yes
Average operating life before overhaul	10 years for wheel	20 years
Pressure loss (headloss)	75 mm	Negligible
Resistance to blockage	Low to medium	Very high
Resistance to weed	Medium	High
Relative installed cost	Medium	Medium to high
Power required	No	Yes or solar
Advantages	Easy to use No power Robust Low head Reliable	Highly accurate No moving parts No wear Robust Low pressure loss
Disadvantages	Variable accuracy Inaccurate at low flows Affected by varying water levels Wear of bearings and vanes OH&S hazard Restricts access along channel Yabbies cause channel leakage	Requires power Requires full pipe Specialist skills to repair

Source: ANCID 2000

Please note: The above table is a guide only based on general information and manufacturers' literature where available. You should contact the manufacturer for complete details.

WATERpak Table 2.8.2. Irrigation guide to flow measurement – mechanical flow meters

	MECHANICAL Insert (paddle or turbine) meter
Applications	
Open Channel	No
Piped systems	Yes
Specifications	
Accuracy (typical)	2% to 5% of rate
Flow range	Depends on size
Turn-down (flow range)	Size dependent (9 to 1) to (15 to 1)
Ideal piping requirement upstream	10 diameters
Ideal piping requirement downstream	5 diameters
Other special installation requirements	Requires full pipe
Reliability including tamper-proof protection	Medium
Flow rate indication available	No
Remote reading capability	Optional
Output signal type	Pulse
In-built telemetry output	No
Can meter be buried	No
Average operating life before overhaul	4 years depending on water quality
Pressure loss (head loss)	400 mm
Resistance to blockage	Medium
Resistance to weed	Medium
Relative installed cost	Medium
Power required	No
Advantages	Reasonably accurate Easy to use No power Reasonably robust
Disadvantages	Accuracy deteriorates with wear Inaccurate at low flows Wear of bearings and vanes Difficult to detect tampering Propeller can be fouled Specialist skills to repair

Source: ANCID 2000

Please note: The above table is a guide only based on general information and manufacturers' literature where available. You should contact the manufacturer for complete details.

WATERpak Table 2.8.3. Irrigation guide to flow measurement – propeller meter and Ultrasonic flowmeter

	PROPELLER METER Closed type & open flow	**ULTRASONIC FLOWMETER**
Applications		
Open Channel	Yes	Yes
Piped systems	Yes	Yes
Specifications		
Accuracy (typical)	2% of rate	Better than 2%
Flow range	Depends on size	Based on velocity (0-8 m/s)
Turn-down (flow range)	Size dependent (6 to 1) to (16 to 1)	150 to 1
Ideal piping requirement upstream	5 diameters	6
Ideal piping requirement downstream	1 diameters	2
Other special installation requirements	Requires full pipe	Nil
Reliability including tamper-proof protection	Medium	High
Flow rate indication available	Yes	Yes
Remote reading capability	Optional	Yes
Output signal type	Pulse	Analog & pulse
In-built telemetry output	No	Yes
Can meter be buried	No	Yes
Average operating life before overhaul	4 years depending on water quality	15 years
Pressure loss (head loss)	120 mm	Negligible
Resistance to blockage	Medium	High
Resistance to weed	Low to medium	High
Relative installed cost	Medium	Medium
Power required	No	Yes or solar
Advantages	Reasonably accurate Easy to use No power Reasonably robust	Highly accurate No moving parts No wear Capable of measuring bidirectional flow Can be used for a range of pipe diameters Negligible pressure loss
Disadvantages	Accuracy deteriorates with wear Inaccurate at Low Flows Difficult to detect tampering Propeller easily fouled Specialist skills to repair	Not suitable for filtered water Specialist skills to repair

Source: ANCID 2000

Please note: The above table is a guide only based on general information and manufacturers' literature where available. You should contact the manufacturer for complete details.

WATERpak Table 2.8.4. Irrigation guide to flow measurement –weirs and flumes

	WEIRS AND FLUMES
Applications	
Open Channel	Yes
Piped systems	No
Specifications	
Accuracy (typical)	5%
Flow range	Depends on size
Turn-down (flow range)	(10 to 1)V notch, (100 to 1) flume
Ideal piping requirement upstream	20 times flow head
Ideal piping requirement downstream	Sufficient for non restricted flow
Other special installation requirements	Sufficient gradient for free flow
Reliability including tamper-proof protection	Low
Flow rate indication available	Requires separate device
Remote reading capability	Requires separate device
Output signal type	Requires separate device
In-built telemetry output	Requires separate device
Can meter be buried	No
Average operating life before overhaul	15 years
Pressure loss (headloss)	Varies 75 mm to 1000 mm
Resistance to blockage	Low to medium
Resistance to weed	Medium
Relative installed cost	Medium to high
Power required	Yes for flow indication
Advantages	Reasonably accurate Easy to use No power Reasonably robust
Disadvantages	Accuracy deteriorates with wear Inaccurate at low flows Specialist skills to repair Requires cleaning

Source: ANCID 2000

Please note: The above table is a guide only based on general information and manufacturers' literature where available. You should contact the manufacturer for complete details.

Cotton and Grains Workshop Series

Pumps

CONTENTS

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DISCLAIMER AND WARNINGS

The information in this publication is designed as an information source to improve the sustainable use of water on irrigation farms in eastern Australia growing cotton. The information has been prepared from research studies and grower trials with specialist input from researchers, extension staff and irrigators. While these authors provide comprehensive coverage of on-farm water-related issues, they do not purport to address every eventuality that may arise on irrigation farms.

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TRADEMARKS ACKNOWLEDGEMENT

Where trade names or products and equipment are used, no endorsement is intended nor is criticism implied of products not mentioned.

Cotton and Grains Workshop Series

Pumps

Key points

- Pumps are designed to operate within a range of duty points (flow and head)
- Pump curves contain information that is vital for pump selection or evaluation
- It is possible to measure pump characteristics and determine pumping costs
- pumping costs can be monitored as an indicator of pump wear/failure
- Pump selection is very important – choosing the wrong pump may compromise the operation of the whole irrigation system.

Introduction

A poorly performing pump may affect the entire irrigation system, reducing irrigation efficiency and productivity. For example, if a lateral move requires a specific flow rate and pressure but the pump is performing poorly, the flow rate and pressure may not be adequate to operate the sprinklers correctly. The result may be insufficient water applied and uneven distribution, reducing yield and increasing paddock variation.

This workshop contains information about:

- pump types
- pump duty
- pump curves
- pump efficiency and energy use
- pump selection.

Additional relevant information may also be found in other Workshops in this series:

- Storage & Distribution Systems
- Irrigation Systems
- Benchmarking
- Metering

More information on pumps can be found the WATERpak appendices, whilst information contained in this workshop is relevant when considering WATERpak Section 4 'Irrigation Systems'.

Common types of irrigation pumps

The main types of pump used for irrigation are:

- radial flow ('centrifugal') pumps
- mixed flow pumps
- turbine pumps

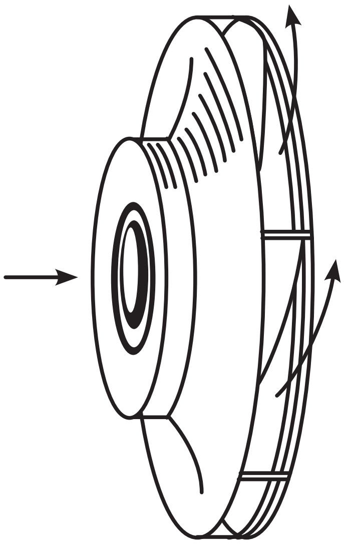
Radial flow ('centrifugal') pumps

Radial flow pumps are commonly referred to as 'centrifugal' pumps. (This may cause confusion, as mixed flow, electro-submersible, most sump and packaged pressure systems are also types of centrifugal pump.)

Radial flow impeller – high head – low flow

Liquid enters the impeller axially and is discharged radially. This changes the direction of water by 90 degrees.

The head developed is due to the centrifugal force exerted on the fluid by the impeller.

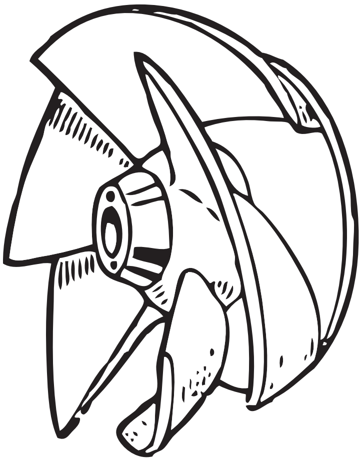


Mixed flow volute pumps

Where large quantities of water have to be pumped against low heads, mixed-flow volute (MFV) pumps are used because it is possible to get higher efficiencies than with radial flow pumps.

Mixed flow impeller – medium head – medium flow

Liquid enters the impeller axially and is discharged both axially and radially. In this case the head developed is the result of a combination of the centrifugal force and the lift produced by the vanes on the liquid.

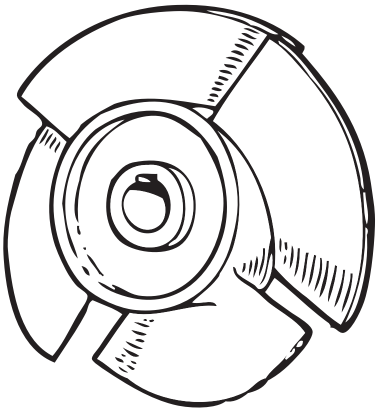


Turbine pumps

Turbine pumps are mixed-flow and axial flow pumps which direct water to the discharge outlet with diffusion vanes. Turbine pumps are most often used for pumping from bores. Because the bore hole diameter limits the impeller size, the pressure which can be developed at a given speed is also limited. High pressures are achieved by adding extra impellers, called stages, to the pump. These are called multi-stage pumps.

Axial flow impeller – low head – high flow

Liquid enters and leaves the impeller in an axial direction. In this case the head developed is entirely due to the lift produced on the liquid by the vanes.



Pump duty

The term 'pump duty' defines the operating conditions of a pump doing a certain job. Pump duty has two components:

- the *flow rate*, and
- the *head or pressure*

Flow rate

The flow rate is the quantity of water your pump is required to deliver over a specific period of time. It is commonly expressed as *litres per second (L/s)*.

A designed irrigation system should have the flow rate or range of flow rates specified. It is good practice to check your flow rate regularly to determine if your system is still operating as it should. Changes to the flow rate in your irrigation system may be due to wear in the pump, blocked or worn sprinkler components, corrosion in pipes and valves, and changed number or size of outlets.

Accurate measurement of your flow rate is essential. Refer to WATERpak Chapter 2.8 or the Metering Workshop in this series for further information on metering.

Some other flow rate terms:

- *kilolitres per hour (kL/hr)* or 1,000 litres per hour
- *megalitres per hour (ML/hr)* or 1,000,000 litres per hour
- *megalitres per day (ML/d)* and
- *cumecs (m^3/second)* (1 m^3 = 1,000 litres)

Note that some overseas manufacturers use gallons per minute (gpm) - this can be common for centre pivot and lateral move systems. *Be Careful!* Imperial (UK) Gallons and United States Gallons are different!

- 1 Imperial gallon – 4.55 litres
- 1 US gallon – 3.79 litres

Head

Head is the term given to the pressure that a needs to be supplied for a specific pumping task. It is often expressed in metres, meaning the pressure at the bottom of an equivalent vertical column of water at sea level.

1m Head – 10kPa – 1.45 psi

1psi – 6.89kPa – 0.69m Head

It is better termed *Total Head (H or TH)* because it is made up of four components added together:

- *Static Head (SH)*
- *Friction Head (FH)*
- *Pressure Head (PH)*
- *Velocity Head (vh)*

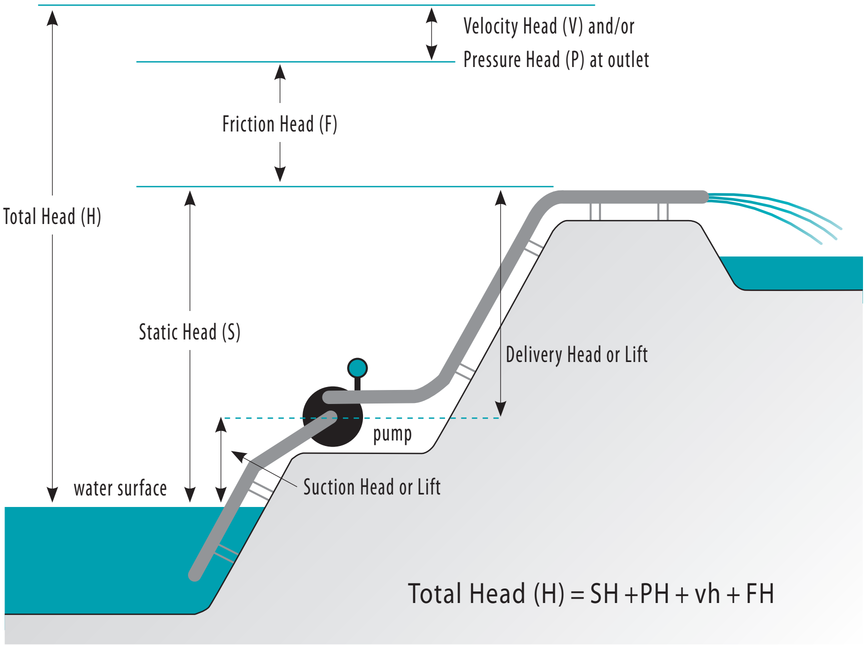


Figure 1: Components of Total Head

Static Head (SH)

The difference in height between the water level and the outlet is called the static head.

This can be broken into two components:

- Suction Head or Lift (SuH) – vertical height difference between the water level and centre line of the pump
- Delivery Head or Lift (DH) – vertical height difference between the centre line of the pump and the water outlet

Friction Head (FH)

Some loss of head occurs in all pipes and fittings in the system due to friction. The amount lost increases with higher flow rates, smaller pipes, pipe length and rougher materials. Smaller pipes may cost less to purchase but they create additional head through increased friction.

For instance:

- Distributing 400 L/s (35 ML/d) through a 450 mm concrete pipe will result in a friction head loss of 1.1 metres in every 100 metres of pipe length. The same flow through a larger 600 mm pipe results in only 0.25 metres of head in every 100 m of pipe.
- 675 mm concrete pipe carrying 78 ML per day and lifted 3 m has water velocity around 2.5 m/s. The friction losses from the suction pipe entry and the discharge pipe outlet become significant, perhaps as much as 40% of the Total Head.

- 200 mm (8 inch) PVC pipe carrying 35 L/s will result in a friction head loss of 0.42 m (4.2 kPa) in every 100 metres of pipe length, whereas a larger size 225 mm (9 inch) pipe will only lose 0.25 m (2.5 kPa) of head in the same length of pipe.

Pressure Head (PH)

Pressure Head is the pressure required to make an emitter (eg. sprinkler, dripper, etc.) work. It is also known as the operating pressure.

The pressure at or near an outlet is measured by a pressure gauge which should read in kPa. To convert this to metres of head, divide by 10. For instance 300 kPa = 30 m head.

Note: Pressure gauges should be checked to ensure they are reading accurately. Pressure gauges become inaccurate after a few years, or, if attached to a pump, maybe only after a few months.

Velocity head (vh)

This is the kinetic energy, or energy due to motion, in the water at any point.

Generally the numeric value of velocity head in a pipeline is quite small compared to Total Head and often disregarded. For example, water flow velocities in pipes up to 3 m/sec give velocity head values of less than 0.5 metres or 5 kPa which maybe only 1–2% of a pressurised system.

When large volumes of water are pumped against a low head (eg. storm water harvesting), Velocity Head in the pipeline may be a significant amount of the Total Head. This results from having no Pressure Head (because the discharge is an unrestricted pipe) and the high kinetic energy of a very large volume of water moving at high speed.

For example, water pumped at 78 ML per day through a 675 mm concrete pipe and lifted 3 m has water moving at around 2.5 m/s. The Velocity Head is 0.32 metres. This is around 11% of the Total Head. The design should evaluate the costs of larger pipe sizes vs operating savings from lower friction and velocity head.

When water leaves a pipeline, say through a sprinkler, Pressure Head is converted to Velocity Head which carries the water into the trajectory or pattern determined by the sprinkler design. This may be significant outside the pipeline but it does not impact on pump selection as Velocity Head was originally part of the nominated Pressure Head.

Activity – Total Head

Calculating pumping head in metres

	EXAMPLE – PRESSURE	EXAMPLE – SURFACE
Static Head – Suction Lift (river to pump)	3.5 m	0 m (submersed inlet)
Static Head – Delivery Lift (pump to outlet)	5 m	3.0 m
Friction Head	8.5 m	0.1 m
Pressure at outlet in metres (100 kPa = 10 m)	500 kPa ÷ 10 = 50 m	nil
Velocity Head	0.5 m	0.4 m
Irrigator hose losses (if applicable)	100 m × 76 mm poly @ 8 L/s = 12.5 m	n/a
Total Head	3.5 + 5 + 8.5 + 50 + 0.5 + 12.5 = 80 m	3.0 + 0.1 + 0.4 = 3.5 m

For pressurised systems, a simple way to find out the Total Head is by fitting a pressure gauge at or close to the outlet of the pump. The reading here is the combined Pressure Head, Friction Head and Static Head from the pump to the outlet. The Static Head from the pump to the water supply (the Suction or Static Lift) needs to be added to this to give Total Head.

At sea level, the pressure at the bottom of a pipe of water 10 metres high is about 100 kPa (14.5 psi).

Understanding pump curves

Pump manufacturers produce performance charts called pump (characteristic) curves. The main curves show the flow rate at various heads for certain impeller sizes or speeds. The curves for power required and pump efficiency are overlaid on the same axes for convenience. For computer selection of pumps, these curves are built into the computer software.

Flow v head curves

Chart 1 shows the curves for a particular pump at a set speed but with different impeller size options.

CENTRIFUGAL PUMP CHARACTERISTIC CURVES – IMPELLER DIAMETER

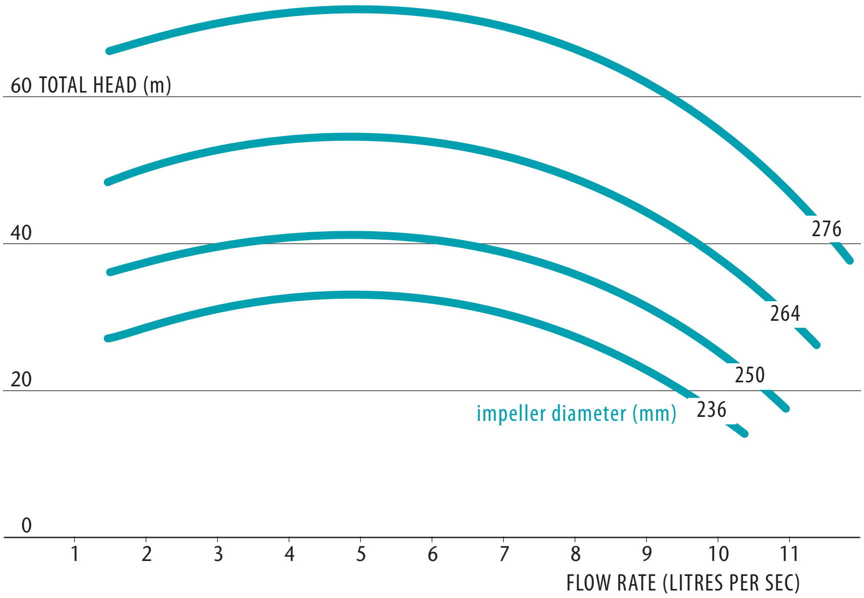


Chart 1: pump curves for different impeller diameter at one speed.

Chart 2 shows curves for the same pump with one particular impeller size at several different operating speeds.

Using either of these examples, the pump is capable of pumping at rates varying from about 2 L/s to about 10 L/s at a head varying from 15 metres to about 70 metres.

Larger pump examples are included later (Charts 6 & 7).

CENTRIFUGAL PUMP CHARACTERISTIC CURVES – IMPELLER SPEED

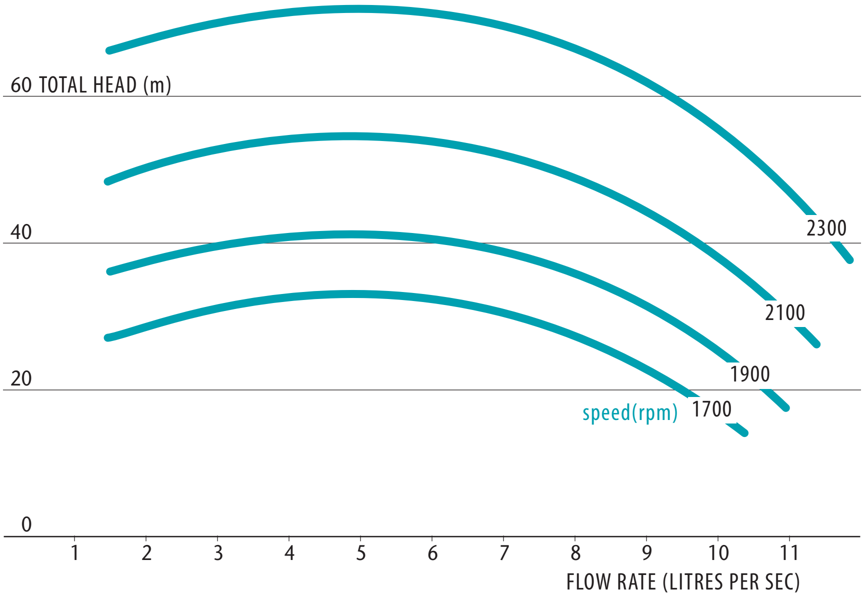


Chart 2: Pump curves for one impeller at different operating speeds.

Efficiency curves

The operating efficiency of the pump at each duty point is also marked on the pump curves. They are usually marked with percentages. They show how efficiently the input power (from the engine or motor) is transmitted into energy to pump the water at a particular duty point. This is the pumping efficiency. Like most mechanical devices, it is not possible to achieve 100% efficiency, primarily due to friction.

It is best to select and operate a pump near its peak efficiency. This results in more efficient use of electricity or diesel and thus reduced operating costs. Note that efficiency decreases if the flow rate is too high or too low and if the head is too high or too low.

CENTRIFUGAL PUMP CHARACTERISTIC CURVES – EFFICIENCY

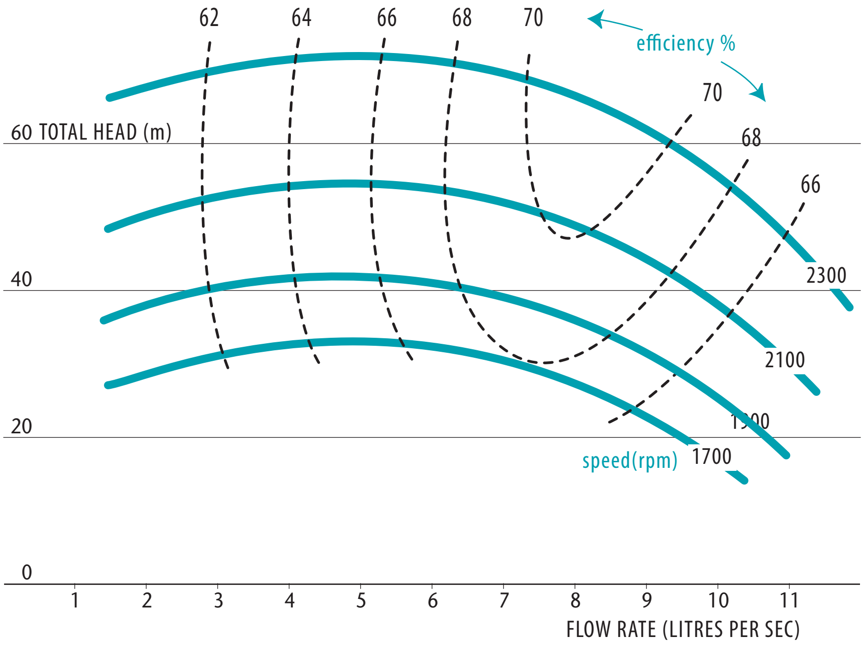


Chart 3: Efficiency curves overlaid on Flow v Head curves

Power curves

The amount of power required to drive the pump (at the pump shaft) is also shown across the other curves (Charts 4 & 5) or separately (as in Chart 7). The power curve is usually marked in kW (kilowatts). You can work out the power at any point by estimating the figure from the closest power curve.

NB. This is the NET power required. Typically the prime mover needs to be 20% more for an electric motor, and 40% more for an internal combustion engine.

CENTRIFUGAL PUMP CHARACTERISTIC CURVES – POWER

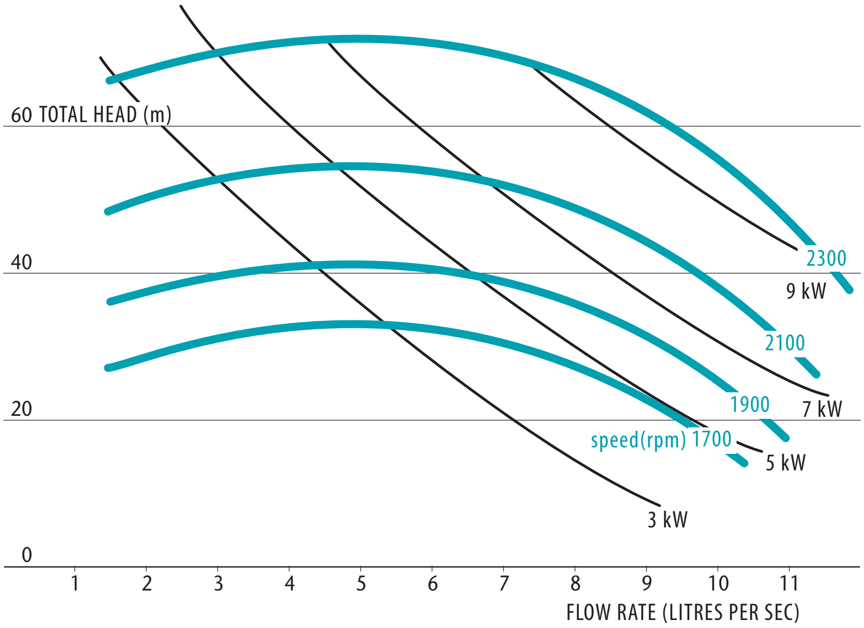


Chart 4: Power curves overlaid on Flow v Head curve

NPSHR

Pump curves supplied by manufacturers often show a separate curve that gives the 'Net Positive Suction Head Required' (NPSHR). An example is in Chart 5. This is the ability of the pump to suck water from the supply source (eg. creek) without causing cavitation of the pump. (Some manufacturers, eg. Macquarie, use the term Hs for NPSHR.)

Turbine pumps are usually fully submerged, including the pump inlet. This means there is no suction lift. Care needs to be taken that the inlet is submerged according to the supplier's specifications to avoid vortexing and sucking air.

NPSH is discussed in more detail in *Pump selection* section.

Some manufacturer's web sites allow you to enter your pump duty and all calculations are done for you with the curves presented on screen. For example: www.tasonline.co.za/pumpsel/standard.htm

CENTRIFUGAL PUMP CHARACTERISTIC CURVES

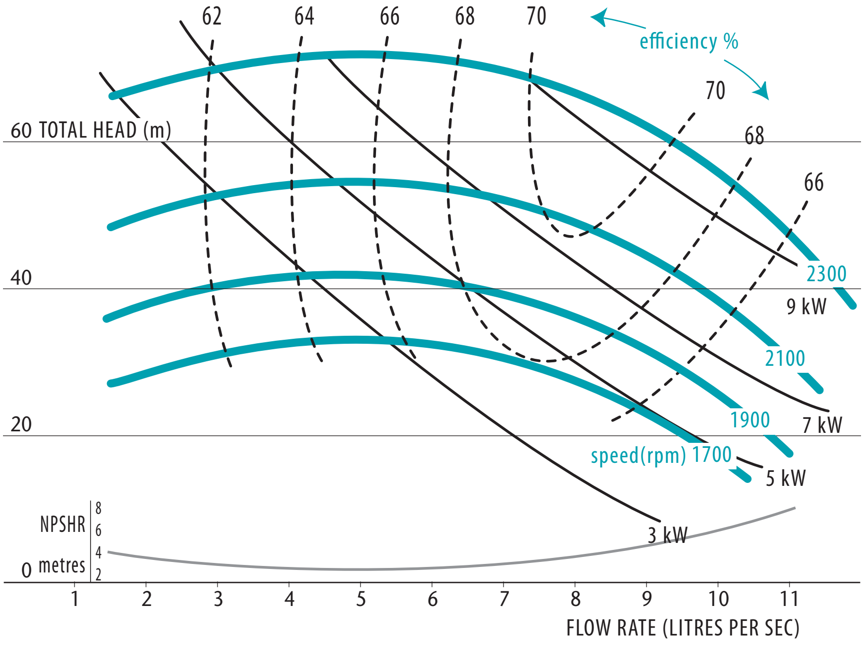


Chart 5: Complete centrifugal pump curve

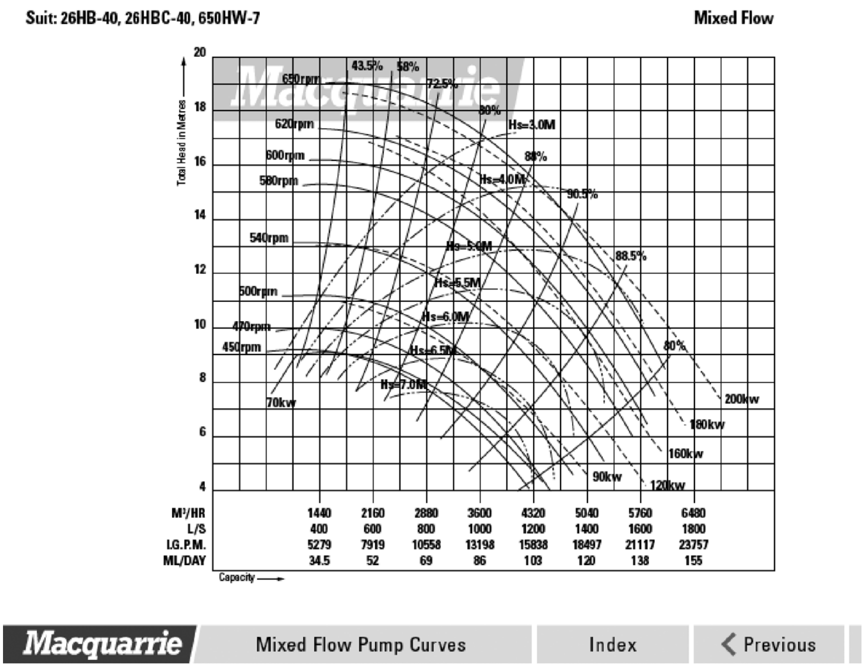


Chart 6: Example of curves for a mixed flow pump

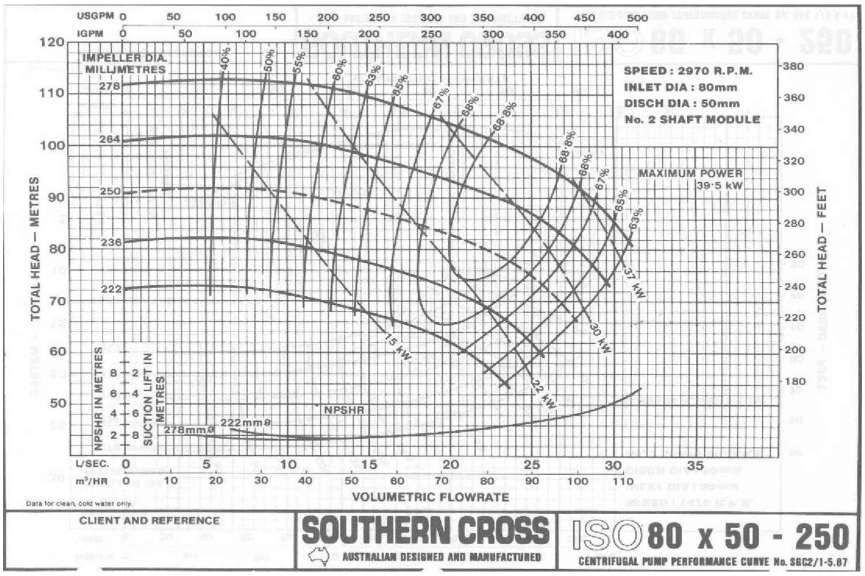
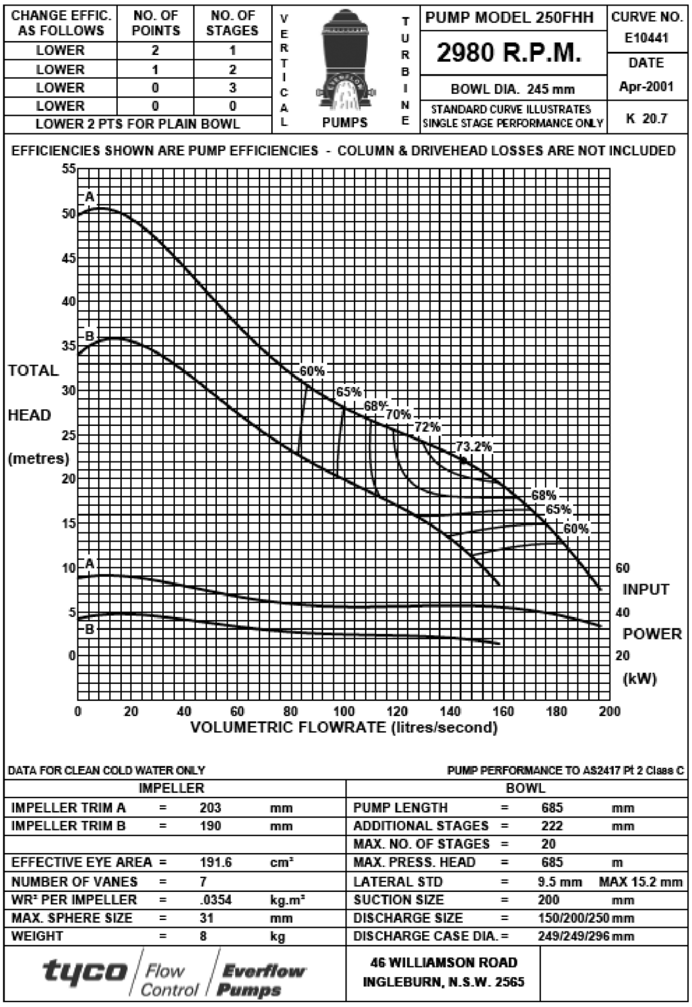


Chart 7: Example curves for a radial flow pump.



CHANGE EFFIC. AS FOLLOWS	NO. OF POINTS	NO. OF STAGES
LOWER	2	1
LOWER	1	2
LOWER	0	3
LOWER	0	0
LOWER 2 PTS FOR PLAIN BOWL		

PUMP MODEL 250FHH

2980 R.P.M.

BOWL DIA. 245 mm

STANDARD CURVE ILLUSTRATES SINGLE STAGE PERFORMANCE ONLY

CURVE NO. E10441

DATE Apr-2001

K 20.7

EFFICIENCIES SHOWN ARE PUMP EFFICIENCIES - COLUMN & DRIVEHEAD LOSSES ARE NOT INCLUDED

DATA FOR CLEAN COLD WATER ONLY

PUMP PERFORMANCE TO AS2417 Pt 2 Class C

IMPELLER				BOWL			
IMPELLER TRIM A	=	203	mm	PUMP LENGTH	=	685	mm
IMPELLER TRIM B	=	190	mm	ADDITIONAL STAGES	=	222	mm
				MAX. NO. OF STAGES	=	20	
EFFECTIVE EYE AREA	=	191.6	cm²	MAX. PRESS. HEAD	=	685	m
NUMBER OF VANES	=	7		LATERAL STD	=	9.5 mm	MAX 15.2 mm
WR² PER IMPELLER	=	.0354	kg.m²	SUCTION SIZE	=	200	mm
MAX. SPHERE SIZE	=	31	mm	DISCHARGE SIZE	=	150/200/250	mm
WEIGHT	=	8	kg	DISCHARGE CASE DIA.	=	249/249/296	mm

46 WILLIAMSON ROAD
INGLEBURN, N.S.W. 2565

Chart 8: Example of curves for a turbine pump.

Pump efficiency and power requirements

From the pump charts, the theoretical pump efficiency can be determined. This section outlines how to calculate the actual pump efficiency. This value may be lower because:

- the wrong pump was chosen for the job
- the pump is worn and needs repair
- it is performing a duty different to the original design

If a pump is not working to maximum efficiency it will cost more than it should to operate. The pump duty and the energy being consumed should be shown on design plans, with this you can benchmark your pump's operating costs and efficiency over time. This indicates if it is still operating satisfactorily.

Pump efficiency of 70 to 85% should be achievable in most circumstances. An acceptable minimum is 65%.

Determining pump efficiency and operating costs

To find out if your pump is performing appropriately, a three step process is needed:

1. determine the theoretical efficiency and power requirement
2. determine the actual efficiency and power requirement, and
3. compare the difference.

Calculation of Pump Power requirement is achieved using the following equation:

$P = Q \times H \div Pe$

Where: P = Power (kW), Q = Flow Rate (L/s), H = Head (m) and Pe = Pump Efficiency (%)

or

$P = (Q \times H) \div (Pe \times 100)$

Where: P = Power (kW), Q = Flow Rate (L/s), H = Head (m) and Pe = Pump Efficiency (decimal)

Step 1 – Determining theoretical pump efficiency and power requirement:

The theoretical pump efficiency and power requirement can be read directly from the pump chart. Alternatively, it can be calculated as follows:

- Flow rate (Q) *= 93 ML/d (1076 L/s)*
- Total head (H) *= 7 m*
- Efficiency from the pump curve (Pe) *For pump '26HBC-40' (Chart 6) = 89% (or 0.89)*
- Theoretical Power required at the pump for this 'duty' and efficiency. *= Q × H ÷ Pe = 1076 × 7 ÷ 89 = 85 kW*

Step 2 – Determining actual pump efficiency and power requirement

To determine what is actually happening to an installed pump, we need to take some initial measurements. The power equation above contains 4 parts:

- *Flow rate* – we can measure this
- *Head* – we can measure this
- *Power* – we can determine this by measuring energy (electricity or fuel) usage
- *Pump Efficiency* – this is what we need to calculate

By rearranging the power equation above:

$Pe = Q \times H \div P$

Measuring flow and head can be performed quite accurately. But measuring the energy used by the motor driving the pump includes inefficiencies in the motor and drivetrain as well as the pump. In order to calculate pump efficiency correctly, energy losses due to the motor, transmission, climatic conditions, etc. are accounted for through a process called *de-rating*. The tables below provide the information needed to do this.

Table 1: Motor Efficiency (Me) – electric motors

POWER – APPROX. MOTOR EFFICIENCY
Below 5 kW – 82% (0.82)
5 to 15 kW – 85% (0.85)
15 to 50 kW – 88% (0.88)
50 to 100 kW – 90% (0.90)

Submersible motors lose about 4% more than air-cooled electric motors (eg. where Me is 88% for an air-cooled motor it would be 84% for a submersible).

Voltage losses through long electrical cables may also be significant. This should be checked with an electrical engineer.

Table 2: Altitude losses (Dr) – internal combustion engines

m ABOVE SEA LEVEL	100%, 1.00
200	99, 0.99
400	98, 0.98
600	97, 0.97
800	96, 0.96
1000	95, 0.95

100% at sea level means no reduction of power due to altitude – this is 100% of the potential efficiency, not that the engine is 100% efficient.

The altitudes of some irrigation regions are:

Emerald Qld – 189 m

Dalby Qld – 344 m

Moree NSW – 212 m

Gunnedah NSW – 264 m

Dubbo NSW – 260 m

Hillston NSW – 122 m

Wagga Wagga NSW – 147 m

Griffith NSW – 134 m

Tatura Vic – 114 m

Mudgee NSW – 454 m

For example, a diesel engine located at Moree, NSW, will produce 99% of its stated power rating. This is expressed as a decimal, 0.99, for our calculations.

Table 3: Temperature losses – internal combustion engines (Dt)

AIR TEMPERATURE °C	NATURALLY ASPIRATED ENGINE, % LOSS	DT	EXHAUST GAS TURBOCHARGED ENGINE, % LOSS	DT
20	0	0	0	0
25	1.8	0.982	2.8	0.972
30	3.6	0.964	5.6	0.944
35	5.6	0.944	8.0	0.92
40	7.2	0.928	10.8	0.892

For example, at 30oC a naturally aspirated engine will have a power loss of 3.6% ie. it produces only 96.4% of the power compared to 20oC. This means the temperature factor (Dt) is 0.964.

Turbocharged engines are typically already more efficient than naturally aspirated, so although the percentage loss due to air temperature is greater, the engine efficiency may still be higher.

Table 4: Transmission or Drive Losses (Df)

This table assumes the transmission is in good condition and set up properly ie. V-belts in good condition and tensioned, gear drive maintained, etc.

TRANSMISSION TYPE	ENERGY TRANSMITTED %	DF
V-belt drives	90	0.9
Gear drives	95	0.95
Direct drive	100	1.0

For example, a 100ÂkW motor connected by vee belts will only transfer 90 kW to the pump.

Standard speeds for electric motors are 1450 rpm and 2800 rpm. If the operating speed of the pump is the same as these, direct drive is usually employed. If it is different, a transmission will be needed to gear the speed up or down.

Step 2.1 – Determining energy usage – electric motors

It is important to understand the difference between energy and power. Power is the rate at which energy is used. When measuring electricity, power is usually specified in kilowatts (kW) and energy in kilowatt-hours (kWh).

power (kW) = energy (kWh) ÷ time (h)

		EXAMPLE
	First reading (**R1**)	7517.29 kWh
	Second reading (**R2**)	7518.80 kWh
	Multiplier (**M**) For this example we will use a multiplier of 40 (often found only on the power bill)	40
	Difference between readings (**C**) (energy used during test time)	R2 – R1 = 7518.80 – 7517.29 = 1.51 kWh
	Total Energy Used (kWh) (**E**) (use the multiplier to obtain the actual energy use)	C × M = 1.51 × 40 = 60.4 kWh
	Time between readings in hours (**T**)	30 minutes = 0.5 hours
	Power supplied (kW) (**Ps**) (this is the power supplied to the motor)	C ÷ T = 60.4 ÷ 0.5 = 120.8 kW

Power supply figures may also be used to indicate if the electric motor is correctly sized for the job – if the power supplied is about the same or greater than the rated kW for the motor, the motor is undersized and at risk of burning out.

Meters operate with different tariffs. Electronic types, such as the top picture, may have a separate register for each tariff, and each register is read separately from the one meter. For example, the off-peak tariff may be given register '203', and full tariff may be '126'.

Mechanical or disc meters, such as the lower picture, more commonly have one meter for each tariff.

There also may be one for each phase of a 3-phase power supply, in which case you should add the readings from each meter, provided you measure each meter at the same time and for the same length of time. If in doubt about how to read your meters, check with your electricity supplier.

Calculate power supplied to pump:

	EXAMPLE
Power supplied to motor (**Ps**), from above	120.8 kW
Electric motor efficiency (**Me**) Table 1	90% (0.9)
Drive factor (**Df**) Table 4	Gear drive = 0.95
Power supplied to pump (**Pp**), after derating	Ps × Me × Df = 120.8 × 0.9 × 0.95 = 103 kW

Calculating actual pump efficiency:

Actual pump efficiency (**Pe**) (using re-arranged power equation)	Q × H ÷ P = 1076 × 7 ÷ 103 = 73%
Compare actual efficiency with theoretical efficiency	73% is less than the 89% on the pump curve, so improvements can be made!

Step 2.2 – Determining energy usage – Diesel Engines

A similar process can be done for pumps with diesel engines. Greater caution is needed, however, because there are more assumptions in this process.

The main assumption is that the diesel engine itself is running efficiently – if it is actually performing poorly, the results will indicate that the pump is running less efficiently than it really is. The measure of efficiency for internal combustion engines is called Specific Fuel Consumption. It is usually reported as litres of fuel used (L) divided by the energy (kWh) produced. It is difficult to measure so a reasonable estimate (at sea level at 25°C) for engines in good condition is about 0.25 L/kWh for most large diesel engines (over 70 kW) and 0.3 L/kWh for smaller engines.

The process requires some way of measuring diesel fuel consumption. The example below assumes the fuel tank is supplying only one engine and that it has a calibrated dip stick. The accuracy of the result will depend on how accurately the fuel consumption can be measured. (Calibrated dipsticks and flow meters can be obtained from retailers such as Australian Fuelling Systems & Equipment *www.fuelequipment.com*). (If using in-line fuel flow meters to obtain fuel consumption, ensure fuel return is taken into account.)

The Power equation is slightly modified to account for conversion of diesel fuel to energy:

$$Pe = (272 \times H \times SFC) \div (L/ML \times Dr \times Df \times Dt)$$

Where:

272 – a conversion factor

SFC – Specific Fuel Consumption (as above) (L/kWh)

L/ML – Fuel use per ML of water pumped (L/ML)

H – Head

Dr, Df, Dt – De-rating factors.

FUEL USE	EXAMPLE
Start time (**T1**)	2.12 pm
First dipstick/meter reading (**F1**)	1800 L
Finish time (**T2**)	8.12 pm
Second dipstick/meter reading (**F1**)	1634 L
FUEL CONSUMPTION **(L/h)**	
(F1 – F2) ÷ (T2 – T1)	(1800 – 1634) ÷ (8.12 – 2.12) = 27.7 L/h

Calculating actual pump efficiency:

Specific Fuel Consumption (**SFC**)	0.25 L/kWh
Water flow rate (**Q**)	1076 L/sec = 3.875 ML/h
Fuel Use per ML Water Pumped = Fuel (L/h) ÷ Q (ML/h)	= 27.7 ÷ 3.875 = 7.15 L/ML
Pressure gauge or Delivery Head (**DH**)	7 m
Suction lift (**SuH**), assumed value	0 m
Total head (**H**), DH + SuH	7 m
Altitude derating (**Dr**), at 200m (Table 2)	0.99
Temperature derating (**Dt**), 30°C (Table 3)	0.964
Transmission (**Df**), gear drive (Table 4)	0.95
Conversion factor	272
Pump efficiency %(**Pe**) = (272 × H × *SFC*) ÷ (L/ML ×Dr × Df × Dt)	= (272 × 7 × 0.25) ÷ (7.15 × 0.99 × 0.95 × 0.964) = 476 ÷ 6.482 = 73%
Compare actual efficiency with theoretical efficiency	73% is less than the 89% on the pump curve, so get pump checked further!

Because this efficiency figure is approximate, use it as a guide only. If it is much worse than the manufacturer's performance sheets indicate, have the pump checked by a pump specialist.

Is it worth taking action? – determine the cost/benefit

Determining if taking some action to improve your pump's performance is economically worthwhile involves some simple calculations.

The money lost by operating an inefficient pump can be substantial. The more water you pump when you use an inefficient pump the more money you lose.

Inefficient pumps may impact upon your enterprise in many ways, including:

- Increased fuel costs
- *Production losses* – reduced yield and/or quality
- Increased water use
- *Environmental cost* – greenhouse gas emissions in extra energy consumed

Calculating cost per megalitre pumped (electric):

Using the example data from the previous section:

First calculate the energy used per ML of water pumped. This can be calculated as follows:

Power supplied (kW) ÷ Flow Rate (L/s) ÷ 0.0036 (to convert L/s into ML/h)

Power Supplied (Ps)	120.8 kW
Flow Rate (Q)	1076 L/s
Energy used per ML pumped (Z)	Ps ÷ Q ÷ 0.0036 = 120.8 ÷ 1076 ÷ 0.0036 = 31.2 kWh/ML

The above figure is useful for comparing your pumping performance regardless of energy costs.

The cost of pumping can now be calculated from your electricity tariff. If your electricity supplier has different tariffs for day, off-peak, weekends etc., base your calculation on the tariff most applicable to obtain a good estimate, or work out the cost for each tariff and time of operation to get an exact cost.

Pumping cost per megalitre @ 15c per kWh, G = Z × $	= 31.19 × $0.15 = $4.68 / ML
Pumping cost per ML per metre head = G ÷ TH	= $0.67 / ML / m head

Calculating cost per megalitre pumped (diesel):

Using the diesel example from the previous section.

Cost of diesel per litre on-farm	$ 1.10 /L
Pumping cost per ML (**G**), L/ML × cost	= 7.15 × 1.10 = $7.87 /ML
Pumping cost per ML, per metre head = G ÷ TH	= 7.87 ÷ 7 = $1.13 / ML / m head

Determining the cost/benefit of improving pump efficiency:

Using the diesel example from above; if your pump is 73% efficient and your pumping cost is $7.87/ML, how much would be saved by improving the efficiency to the original design efficiency of 89%?

Saving per ML

= $7.87 – ($7.87 × 73 ÷ 89)

= $7.87 – $6.46

= $1.41

For a season where 1200 ML are pumped, the total cost saving would be:

$1.41 × 200 = $1692.00

If the cost of replacing the pump is $9,500 and the impeller $1,800, the cost of replacement is recovered in less than 6 seasons and repair in a little over 1 season.

Notice that a *reduced pump efficiency* of 16% (89% down to 73%) *increases* the cost of pumping by 22% (from $6.46 to $7.87 per ML).

Additionally, production losses from poor operation of a pressure irrigation system are likely to far exceed these pump operation losses, so serious consideration would be given to replacing the impeller earlier.

Pump selection using performance curves

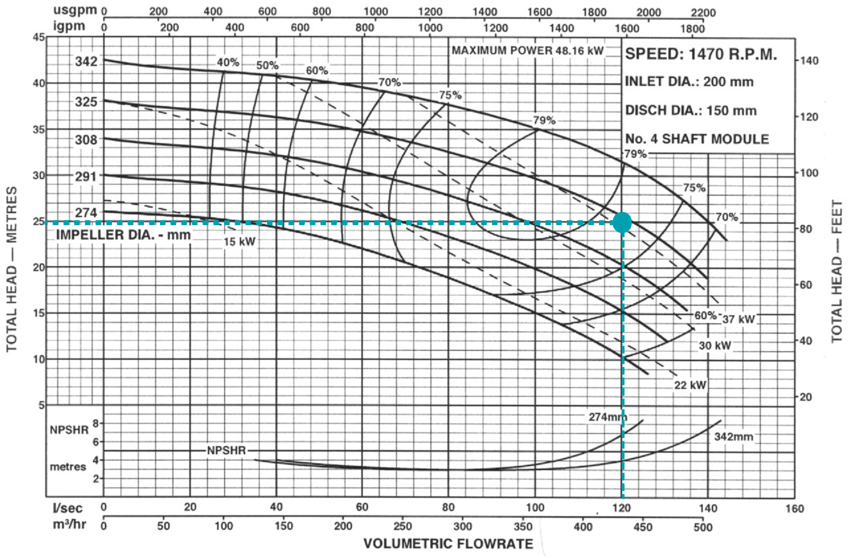
Do not make your choice of a pump simply on cost. The pump on sale at the local supplier or the second-hand one for sale next door is unlikely to meet the demands of your system and crop.

1. Select the duty point

To select a pump, the duty point must first be known. The pump must be matched to the requirements of the irrigation system, not vice-versa. For a new irrigation system, the flow rate (Q) and total head (H) should be readily obtained from the irrigation design. For an existing system, measure them using the methods described earlier.

The duty point will be the intersection of the flow rate and the total head. Once the duty point is known, locate it on the H-Q curve for a pump. If you cannot locate the duty point on a particular curve, then that pump will not suit your task. For example, for a centre pivot with a duty point of 120 litres per second and pump pressure gauge reading or Total Head of 250 kPa (25 metres):

Duty point

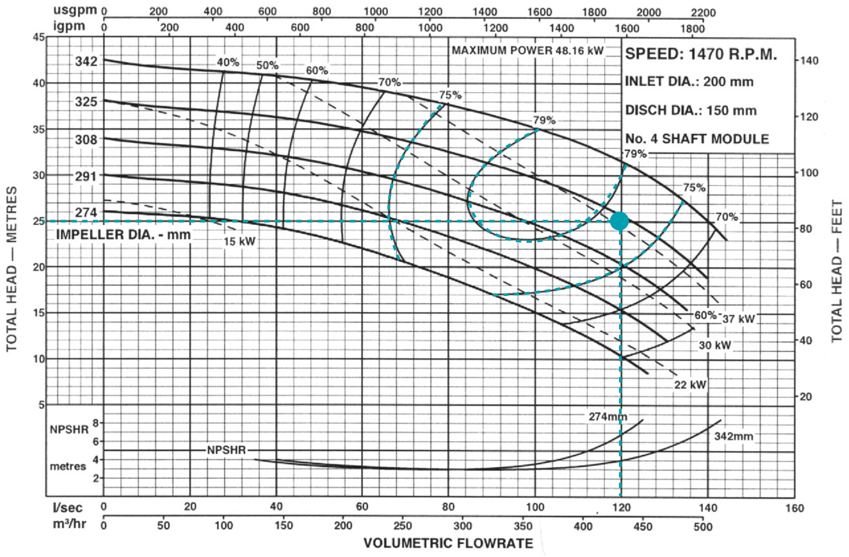


Note the impeller size and speed – for this example the size is 325 mm and the speed is 1470 rpm.

2. Check the pump efficiency

When the duty point is located on the H-Q curve, find the corresponding efficiency on the efficiency curve. The aim is to have the efficiency as high as possible. If it is below 65%, try another pump/curve. For most irrigation systems, you will find a number of pumps over 65% – select the highest efficiency unit that has a competitive price. In the example below, the efficiency is 78%.

Pump efficiency curves



3. Check the suction lift

The suction lift must be checked against the Net Positive Suction Head Required. The theoretical maximum vertical height any pump can lift water is about 10 metres at sea level, less than 10m at higher altitudes. The NPSHR is the amount of this 10 metres used by the pump just getting the water into it. If the suction lift or height is more than what is left, the pump will cavitate or simply not pump water.

What is Net Positive Suction Head (NPSH)?

Net Positive Suction Head (NPSH) is the head that causes water to flow into the pump. The water is pushed by the atmosphere into the pump because there is negative pressure, or suction, at the eye of the impeller.

Net Positive Suction Head Required (NPSHR) is a function of pump design and varies between make of pump, type of pump, speed and capacity. This value is usually found on the pump performance curves.

Net Positive Suction Head Available (NPSHA) is the available head at the suction flange of the pump and is a function of the suction pipe system. NPSHA must be greater than the NPSHR. A conservative minimum is 1 metre.

Suction lift is the vertical distance between the water level and centre of the pump. It can be measured directly or read from the irrigation design plan. The suction lift often varies with river height, storage level, bore depth, etc. so the greatest likely figure should be used for pump selection.

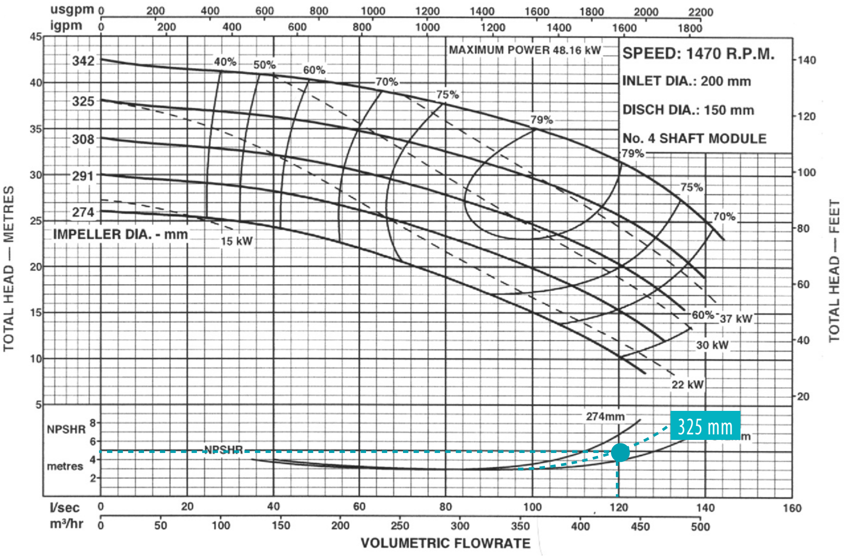
Read the NPSHR from the curve, subtract it and the Friction Head of your suction pipe from the average atmospheric pressure (10 m at sea level), and check that it is less than your suction lift. If not, try another curve. Pressure variation due to altitude is indicated in the table.

ALTITUDE (m)	ATMOSPHERIC PRESSURE (m)
Sea level	10
500	9.5
1,000	9
5,486	5

Max Suction Lift
= Atmospheric pressure – NPSHR – suction pipe friction
= 10 – NPSHR – suction pipe friction

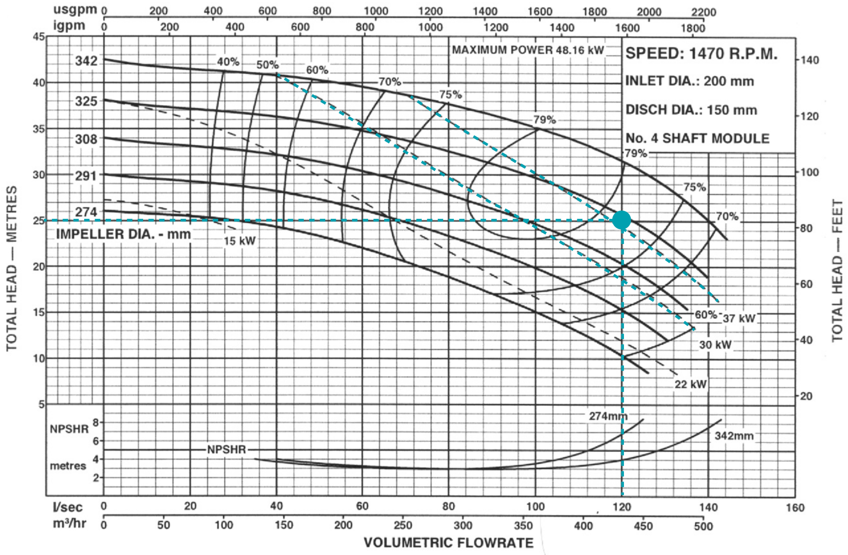
For the example below, the NPSHR for a 325 mm impeller is 5 m.

Max Suction Lift
= 10 – NPSHR – suction pipe friction
= 10 – 5m – 1m (est) = 4m



4. Pump power required

Read the power required at the pump shaft from the curve. For our example below, it is about 38 kW.



5. Record the pump specifications

Having found a suitable pump, write down all the specifications. There are many pumps from many manufacturers available, often appearing very similar, so every important piece of information should be recorded to ensure you get the pump you've selected.

Pump specifications

	PUMP CHOICE 1	PUMP CHOICE 2	PUMP CHOICE 3
Discharge Q (L/s)	120 L/s		
Total Head H (m)	25 m		
Pump Brand	Pumpit		
Pump Model	Whoosher		
Impeller Size (mm)	325 mm		
Impeller type	Fully enclosed		
Pump Speed (rpm)	1470 rpm		
Efficiency Pe (%)	78% (0.78)		
Nett Power required (kW)	38 kW		
NPSHR (m)	5 m		
Inlet size (mm)	200 mm		
Outlet size (mm)	150 mm		
Transmission	Direct drive – electric v-belt – diesel		

6. Determine the drive unit size

Double check the power required at the pump by calculation:

Power (kW) = Q (L/s) × H (m) ÷ Pe ÷ 100

For our example:

Power = 120 L/s × 25 m ÷ 0.78 ÷ 100

= 3000 ÷ 0.78 ÷ 100 = 38.5 kW

It is advisable to choose a motor or engine that provides for additional power in reserve. This means the power unit will not be struggling to do its task, and as it ages it will still perform satisfactorily. As a guide, for electric motors add 10% to the calculated figure, and 30% for internal combustion engines:

Size of electric motor to purchase = Pump power + derating factors + 10%

Size of diesel engine to purchase = Pump power + derating factors + 30%

Derating – electric

Motor efficiency Me (as a decimal)	0.88
Submersible?	No
Df (as a decimal)	1.0
Electric motor power required (kW)	= kW ÷ Me ÷ Df (+ 10% reserve) = 38.5 ÷ 0.88 ÷ 1.0 (+ 10%) = 43.8 kW (+ 4.4 kW) = 48.2 kW 55 kW is the nearest stock electric motor

Derating – diesel

Altitude (m) Dr	200 m – 0.99
Turbo?	Yes
Air temperature (°C) Dt	40 °C – 0.892
Df (as a decimal)	0.9
Diesel engine power required (kW)	= kW ÷ Dr ÷ Df ÷ Dt (+ 30% reserve) = 38.5 ÷ 0.99 ÷ 0.9 ÷ 0.892 (+ 30%) = 48.4 kW (+ 14.5 kW) = 63 kW

Appendix – Pump maintenance

All pumps and their power sources need to be correctly maintained for efficient operation. Any change can have a major effect on operating efficiency. A check of your pump and fittings should be carried out before each irrigation season.

Installation and maintenance checklist

THINGS TO DO:	THINGS NOT TO DO:
• site the pump as close as practical to the water • make sure suction and delivery pipes do not strain the pump casing • check that all pipe connections are tight and suction lines are airtight • use a strainer recommended by the pump manufacturer • anchor the pump securely so that it doesn't move during operation • work the pump within its limits • provide ventilation for the motor or engine • keep pump and motor connection aligned • make sure pump is primed before starting • keep the strainer clean • service the pump regularly	• do not operate pump without water • do not operate pump for long if discharge valve is closed • do not operate pump if strainer is blocked • do not operate pump if it is vibrating excessively • do not install suction pipes so that air can build up in them.

Managing water in plant nurseries by C. Rolfe, W. Yiasoumi, E. Keskula,
NSW Agriculture 2000, p.196

Suction

A major cause of poor pump performance is problems in the suction line. Things to look for on the suction side of the pump are:

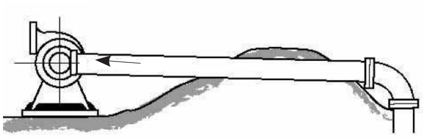
- *Suction lift too high*
  About 4.5 metres from the water level to the pump is generally the maximum recommended lift. This will vary with the pump and its duty and should be checked with your local pump distributor.
  Excessive lift causes cavitation and perhaps damage to the pump. If the pump is cavitating it usually sounds like it is pumping gravel.
- *Air pockets*
  Incorrect installation of suction pipes and fittings may cause pockets of trapped air. These reduce the effective internal diameter of the pipe or fitting and create additional friction loss.
- *Air leaks at joints*
  Air entering through joints or through the footvalve causes a severe drop in pump performance and causes damage to the pump itself. Check all joints for leaks and if necessary replace any worn flange gaskets.
- *Footvalve*
  Ensure that the footvalve is sufficiently submerged below water level to prevent a vortex of air being drawn into the suction. A minimum depth of about 0.5 metres is desirable. Ensure the footvalve is not blocked with sand, weed, algae, or other foreign matter.

PUMP SUCTION LINE SETUP

Suction lines that are not set up correctly are a sourde of inefficient pump performance.

Here are some common examples:

Correct



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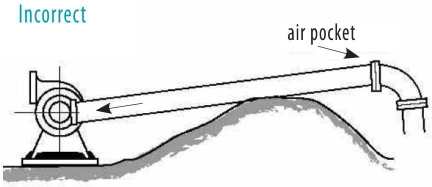

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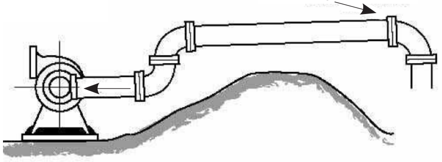

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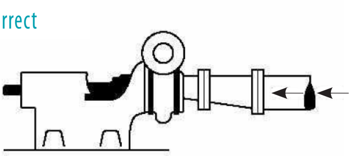

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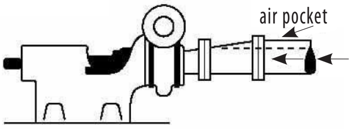

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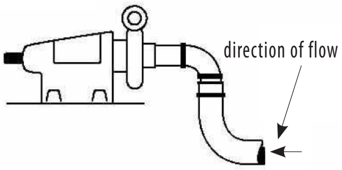

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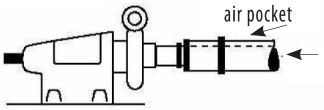

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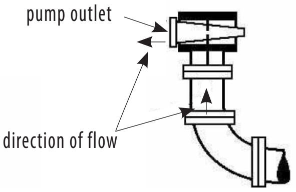

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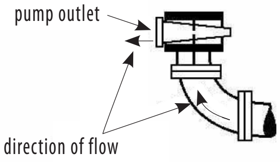

Pump

Main check points on the pump are:

- *Bearings*
  A screwdriver (preferably one with metal through the handle) held against the pump near the bearings and also held against the ear will help check for bearing wear. A smooth hum will indicate the bearings are sound. A grinding noise, rattle or bumping noise indicates bearings are worn. Bearings should be lubricated to manufacturer's recommendations. Hot bearings can be an indication of too much grease. If the bearings are oil lubricated the oil should be changed annually or every 1000 running hours, whichever comes first.

- *Packing Glands*
  The packing gland material should be replaced periodically and the gland follower should not be too tight. A steady drip from the gland is normal and is an indication of correct adjustment. If the pump at the packing gland is running hot it indicates the gland follower is too tight and should be loosened to allow more water leakage.
- *Mechanical Seals*
  If the pump has a mechanical seal, as opposed to a packing gland, then leakage indicates the mechanical seal to be worn and in need of replacement.
- *Impeller*
  The impeller should be inspected for general wear of the vanes and the face. The clearance between the impeller wear ring and suction eye ring should be measured accurately. Generally this clearance should be in the range of 0.13 to 0.25 mm. This should be confirmed with the pump manufacturer. A clearance outside the pump manufacturer's range indicates new wear rings or a new impeller are needed.
- *Pump Shaft*
  This should be checked for scoring and straightness. Shaft straightness can be checked by using a dial indicator on the impeller end of the shaft while the shaft is supported on the bearing housing. The total run-out should not exceed 0.05 mm.
- *The Pump Bowl*
  The pump bowl, and also the impeller, should be cleared of any build-up of rust or corrosion. If there is wear or damage to the metal it can often be repaired by the use of a Water Resistant Epoxy such as Devcon®, Vepox cc 65® or Chesterton® Pump Repair Compound.
- *Seal & 'O' Ring*
  The condition of the seal at the drive end of the shaft and the 'O' ring on the back cover should also be checked for wear and replaced if necessary.

Cavitation

Cavitation occurs when a pump has to get water from a height which exceeds its suction lift ability ie. the Net Positive Suction Head (NPSH) is not adequate. If cavitation is occurring during normal irrigation, the suction lift is probably too high. Cavitation will damage your pump, decrease its performance and ultimately limit its life. A cavitating pump will usually vibrate and make a noise like gravel rattling in a drum.

Cavitation occurs because in the suction line the pressure on the water is reduced below atmospheric pressure. This causes the water to boil at ambient temperature and create tiny bubbles of vapour. When these bubbles reach an area of high pressure (at the face of the pump impeller) they collapse (implode). These implosions cause pitting and eventually holes in the impeller.

Cavitation is sometimes experienced when filling a pressure line at the start of an irrigation. Because the pressure takes a little while to reach operating level, the Total Head is temporarily low, and the flow rate is higher than the design duty. The higher flow increases the friction head in the suction line and fittings. This causes a greater pressure drop in the suction line, which may result in cavitation. To overcome this, control the filling flow rate by closing the gate valve at the pump before starting up, and opening it slowly as the pipe fills.

Cavitation may also occur if the flow rate has increased, for example, through worn sprinkler nozzles, leaks, or extra sprinklers being added.

Common solutions for cavitation are to relocate the pump to a lower level or alter the pump duty, possibly by making a better pump selection or restoring the irrigation system to its original design. Seek the advice of an experienced designer.

Pumps Module – diesel pump exercise

	EXAMPLE
Fuel use 1. Start time **T1** 2. First dipstick/meter reading **F1** 3. Finish time **T2** 4. Second dipstick/meter reading **F2**	
5. Fuel consumption (L/h) = (F1 – **F2**) ÷ (**T2** – **T1**)	

Calculating actual pump efficiency:

Specific fuel consumption **SFC**	
Water flow rate **Q**	
Fuel use per ML water pumped = Fuel (L/h) ÷ **Q** (ML/h)	
Pressure gauge or delivery head **DH**	
Suction lift, assumed value **SuH**	
Total head **H** = DH + SuH	
Altitude derating **Dr** at 200 m (Table 2)	
Temperature derating **Dt** 30°C (Table 3)	
Transmission: gear drive **Df** (Table 4)	
Conversion factor	**272**
Pump efficiency % **Pe** = (272 × **H** × **SFC**) ÷ (L/ML × **Dr** × **Df** × **Dt**)	
Compare actual, with theoretical efficiency	

Calculating cost per megalitre pumped

Cost of diesel per litre on farm **$**	
Pumping cost per ML ($/M) **G** = fuel use per ML (from above) × cost	
Pumping cost per ML per metre head = **G** ÷ **H**	

Pumps Module – Pump selection exercise

	PUMP CHOICE 1	PUMP CHOICE 2	PUMP CHOICE 3
Discharge **Q** (L/s)			
Total head **H** (m)			
Pump brand			
Pump model			
Impeller size (mm)			
Impeller type			
Pump speed (rpm)			
Efficiency **Pe** (decimal)			
Nett power required (kW)			
NPSHR (m)			
Inlet size (mm)			
Outlet size (mm)			
Drive type			
Prime mover type (electric or diesel)			

Double check the power required at the pump:

Power (kW) = **Q** (L/s) × **H** (m) ÷ **Pe** ÷ 100

Derating – electric

Motor efficiency (**Me**) (as a decimal)			
Submersible?			
Df (as a decimal)			
Electric motor power required (kW) = kW ÷ **Me** ÷ **Df** + 10%			

Derating – diesel

Altitude (m) **Dr**			
Turbo?			
Air temperature (°C) **Dt**			
Df (as a decimal)			
Diesel engine power required (kW) = kW ÷ **Dr** ÷ D ÷ **Dt** + 30%			

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Scheduling 1

Key points

- **Evapotranspiration (ET)** is the combined loss of water to the atmosphere due to evaporation from soil and plant surfaces, and transpiration through plants.
- Calculations of crop evapotranspiration (crop water use) can be used to schedule irrigations.
- Plant response to stress varies with the timing and degree of stress, and crop development stage.
- Irrigation scheduling is the decision of when and how much water to apply to an irrigated crop to maximise crop productivity.
- Trends in daily water use from uncalibrated soil moisture probes can be analysed to schedule irrigations
- Soil probes do not need to be calibrated to analyse trends, but should not be used to infer total water use.

Evapotranspiration (ET)

Evapotranspiration (ET) is the combined loss of water to the atmosphere due to evaporation from soil and plant surfaces, and transpiration through plants.

- *Transpiration* results from the vaporisation of water within plant tissues and its subsequent loss through the small openings on the plant leaf called stomata.
- *Evaporation* is the conversion of water from liquid to vapour.

Reference Evapotranspiration (ETo) is the loss of water to the atmosphere by evaporation and transpiration from a reference crop, usually a well-watered and mown lawn 100 mm in height. By applying an appropriate coefficient, this value can be used to estimate the crop evapotranspiration (ET_C) and the evaporation losses from storage and reticulation systems.

Crop Evapotranspiration (ET_C) describes the actual ET of a crop given standard conditions of optimum soil water, excellent management conditions, large fields and full production. Understanding and determining crop evapotranspiration is critical for scheduling irrigations to meet the crops water use demands and to optimise crop production.

The ET rate is normally expressed in millimetres (mm) per unit time (often mm/day) – it represents the amount of water evaporated from a cropped surface in units of water depth.

100 mm depth of water is equal to 1 ML of water per Ha

Factors Affecting Evapotranspiration

Weather

- Radiation
- Air temperature
- Humidity
- Wind speed

The evaporation power of the atmosphere is expressed by the reference crop evapotranspiration (ET_O), which represents the ET from a standardised vegetated surface (well watered grass). Calculation of ET_O is generally performed by automatic weather stations, software packages or ET data providers (such as SILO *http://www.bom.gov.au/silo/*), and is not covered in detail here.

The current standard for calculating ET_O is the Penman-Monteith method – also referred to as the FAO 56 method. Calculations based on pan evaporation are no longer used as the standard.

Crop

- Crop type
- Variety
- Crop Development stage

These factors affect the rate of ET_C from crops grown in large, well-managed paddocks. Differences in crop height, reflection, ground cover, resistance to transpiration, etc., will result in different ET_C levels in different crop types under identical environmental conditions.

Environmental and Management Conditions

The actual crop evapotranspiration may be influenced by factors that impact on the ability for the standard conditions mentioned above to be satisfied such as:

- Soil salinity
- Inadequate nutrition
- Soil compaction
- Diseases and pests.
- Cultivation and irrigation practices
- Windbreaks which reduce wind velocities across the adjacent field
- Irrigation systems that apply water directly to the root zone of crops (limiting evaporation losses as soil surface is dry)
- Surface mulches which substantially reduce soil evaporation when crops are small.

Where these factors are significant, calculation of ET_c should be modified accordingly.

Determining Crop Evapotranspiration

A Crop Coefficient (K_c) is used to convert the weather derived Reference Evapotranspiration (ET_o) to an estimate of Crop Evapotranspiration (ET_c) using the formula below

$$ET_c = K_c \times ET_o$$

The relationship between Reference Evapotranspiration (ET_o) and standard Crop Evapotranspiration (ET_c) through the Crop Coefficient (K_c) is represented in Figure 1.

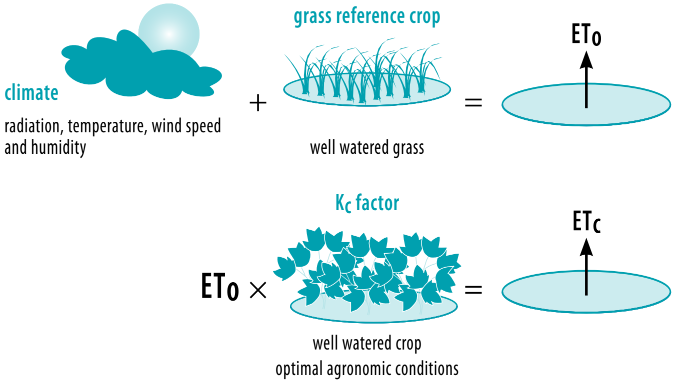


Figure 1. The relationship between Reference Evapotranspiration (ET_o) and standard Crop Evapotranspiration (ET_c)

Source: Allen, R.G. *et al* (1998) Crop evapotranspiration: guidelines for computing crop water requirements, FAO Irrigation and Drainage Paper 56.

The K_c integrates the effect of characteristics that distinguish the crop from the grass reference crop used to calculate ET_o. Different crops have different K_c values due to different crop characteristics. The K_c value also changes over the growing season with changes in crop development and with changes affecting soil evaporation. Estimates of K_c values for the major irrigated crops are presented in Table 1.

Table 1: Crop Coefficients (K_c) for major irrigated field crops.

CROP	K_c INITIAL	K_c MID-SEASON	K_c END OF SEASON
Barley	0.30	1.15	0.25
Chickpea	0.40	1.00	0.35
Cotton	0.35	1.15 – 1.20	0.70 – 0.50
Maize	0.30	1.20	0.35
Navy bean	0.40	1.15	0.35
Peanut	0.40	1.15	0.60
Sorghum	0.30	1.00 – 1.10	0.55
Soybeans	0.40	1.15	0.50
Sunflower	0.35	1.15	0.35
Wheat	0.30	1.15	0.25

Source: Allen, R.G. *et al* (1998) Crop evapotranspiration: guidelines for computing crop water requirements, FAO Irrigation and Drainage Paper 56.

The crop development stages used to select a K_c value (Figure 2) are:

1. Initial stage – planting until 10% ground cover.
2. Crop development stage – 10% to effective groundcover (around 70–80%).
3. Mid-season stage – 70–80% groundcover to the start of maturity.
4. Late season stage – the start of maturity until harvest.

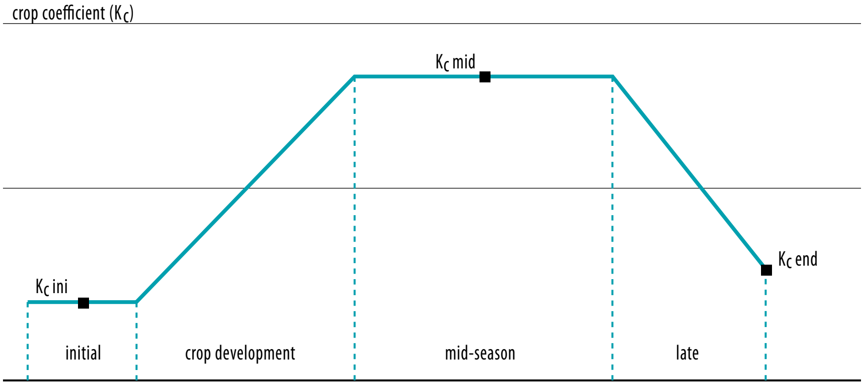


Figure 2. Example Crop Coefficient curve.

Example:

We want to determine the crop water use over a period of a week in mid February for a crop of soybeans. The soybeans are in their mid-season phase, so the crop coefficient (K_C) will be 1.15 (from Table 5).

Daily crop water use (ET_C) = $ET_0 \times K_C$

The following table contains the ET_0 data obtained from SILO as well as the calculations of daily ET_C:

DATE	*ET_0*	*K_C*	*DAILY CROP WATER USE ET_C mm/DAY*
15 Feb	*4.6*	*1.15*	*5.3*
16 Feb	*3.1*	*1.15*	*3.6*
17 Feb	*4.4*	*1.15*	*5.1*
18 Feb	*4.2*	*1.15*	*4.8*
19 Feb	*5.5*	*1.15*	*6.3*
20 Feb	*4.4*	*1.15*	*5.1*
21 Feb	*5.7*	*1.15*	*6.6*

Crop Water Use and Plant Growth

A crop's requirement for water changes throughout the growing season, following the pattern of evapotranspiration (Crop Water Use). The rate of evapotranspiration is determined primarily by meteorological factors and the availability of soil water. Total crop evapotranspiration will also vary with canopy size, or leaf area.

Using cotton as an example, the figure below shows that the period where crop leaf area peaks (3 to 5 weeks after the start of flowering) is also the time of maximum daily water use of between 8 and 10 mm (Figure 3).

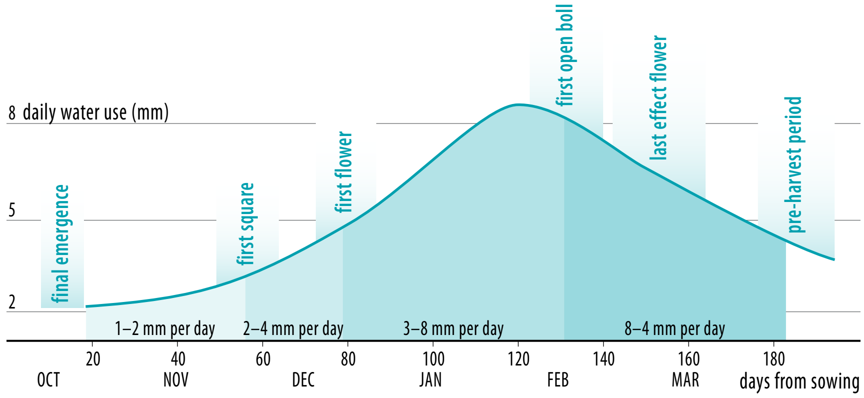


Figure 3. Nominal seasonal Daily Water Use (mm/day) for cotton production.

The maximum demand for water also coincides with the growth period between peak flowering and early boll development. Exposing the plant to water stress at this stage of growth can result in significant yield reductions. The impact of water stress at different crop growth stages on final yield is directly related to the water demands expressed by the crop. Stress during periods of high water demand can produce large reductions in yield. Stress during peak flowering can double yield losses compared with early or late seasonal stress. The impact of any one stress period is increased if followed by further stress.

Table 2. Water Requirements of Crops

CROP	CROP EVAPOTRANSPIRATION REQUIREMENT[1] (mm)	PEAK DAILY WATER USE (mm/DAY)			CRITICAL IRRIGATION PERIODS
		$ET_0 = 6$ mm	$ET_0 = 8$ mm	$ET_0 = 10$ mm	
Barley**	350 to 500	6.9	9.2		Shot – blade to late flowering
Chickpeas**	350 to 500	`6.0	8.0		4 to 5 weeks after flowering
Cotton***	650 to 770	6.9–7.2	9.2–9.6	11.5–12	Peak flowering and early boll development
Maize*	600 to 850	7.2	9.6	12	Tasselling through seed fill
Lucerne for hay**	750 to 1500	6.9	9.2	12	From one week after cutting to flowering
Navy beans**	300 to 450	6.9	9.2	11.5	Flowering
Peanut**	500 to 700	9.2	9.2	11.5	Flowering and pegging to pod maturity
Sorghum*	450 to 850	6.0–6.6	8.0–8.8	10–11	Boot to dough stage
Soybeans**	500 to 775	6.9	9.2	11.5	Flowering to leaf drop
Sunflower*	600 to 800	6.9	9.2	11.5	Once bud is visible, start of flowering and just after petal drop
Wheat**	350 to 500	6.9	9.2		Boot stage and flowering until soft dough stage

1. The crop evapotranspiration is the demand that must be met by in-season rainfall, irrigation stored soil water at planting.

Sources: *Pacific Seeds 2006/07 Cropping yearbook. **Graham Harris, DPI&F, pers.comm. ***WATERpak 2001

Water Stress and Crop Response

The degree of plant response to stress varies, depending on the level of stress occurring and the crop development stage at which the stress is imposed. The crop responses to varying levels of water stress and water logging at different crop development stages and the expected impact on yield for a number of different crops is summarised below.

Chickpeas

Chickpeas are more sensitive to waterlogging than most other crops and appear especially sensitive during:

- Any growth stage if the soil has cracked open to depth
- The later half of pod filling (October onwards)
- The recommended surface irrigation strategy for chickpeas is:
- Pre-irrigate to fill the profile wherever possible.
- Irrigations should be timed at 30 to 40% depletion of Plant Available Water (PAW). Irrigation beyond 50% depletion (soil cracked open wide to depth) will result in an increasingly greater risk of waterlogging and crop damage. The drier the soil the greater the risk.
- Use strategies to reduce the period of inundation – water every second furrow, increase the flow rate (increase siphon size or double up siphons) and do not irrigate if rain is likely

Good irrigation layout, higher beds and quick irrigation will help minimise risks associated with waterlogging.

The use of sprinkler irrigation systems significantly reduces the waterlogging risk. However, the risk of foliar diseases is increased, particularly Ascochyta blight and botrytis grey mould. Application of the recommended fungicides before irrigating is recommended.

Cotton

- Cotton plant responses to water stress varies with the stage of growth at which the stress occurs, the degree of stress, and the length of time the stress is imposed.
- The plant aims to establish a balance between carbohydrate supply and demand. Water stress at any stage of growth will affect both the production and distribution of carbohydrates throughout the plant.
- Carbohydrate demands on the plant, primarily made by developing bolls, restricts excessive vegetative growth.
- Through adaptation, the cotton plant survives during periods of water stress by prioritising the maintenance of different physiological processes to ensure the production of viable seed and therefore cotton fibre. The impact of water stress on final yield depends on the degree to which each physiological process is affected.

Refer to Table 3 for more information about different levels of water stress in cotton.

Table 3. Summary of responses to water stress in cotton

DEGREE OF WATER STRESS	POSSIBLE CAUSES	PHYSIOLOGICAL PLANT RESPONSES	YIELD EFFECTS ON MATURITY AND WUE
Minimal stress	Reduced irrigation deficit Excessive rainfall Cloudy weather Excessive early insect damage High plant stands	Excessive vegetative growth Increase in leaf area Extended flowering cycle Reduced carbohydrate surplus for bolls Reduced root development High boll capacity but poor boll retention	Reduced yield Reduced boll size Delayed maturity Normal fibre length but low micronaire Poor WUE
Mild stress	Optimum irrigation deficit Average temperatures (not excessively hot)	Optimum vegetative growth rate Leaf expansion restricted Photosynthesis remains unaffected Maximum carbohydrate surplus Maximum boll development Good fibre development	Maximum yield High quality cotton No delay in maturity Maximum WUE
Moderate stress	Increased irrigation deficit Extremely hot temperatures with low humidity, windy conditions Little cloud cover	Reduced vegetative growth and leaf expansion Reduced photosynthesis Reduced surplus carbohydrates Reduced boll carrying capacity Increased fibre development	Reduced yield Early maturity Increased short fibre micronaire Slight decrease in WUE
Severe stress	Less than 3 irrigations Dryland crops	Vegetative growth greatly reduced - stops after flowering Greatly reduced carrying capacity Little surplus carbohydrates Low boll retention	Low yields Short fibre High or low micronaire depending on stress pattern WUE depends on rainfall

Corn

Early Growth Stage: effects of cell enlargement resulting in smaller leaves, a shorter canopy and a reduction in potential yield. Crop needs to be in peak condition by week 5 to maximise potential yield, and all nutrients should be supplied by 10 weeks post emergence.

Pollen Shed: Severe moisture stress at pollination will give poor pollination and reduced kernel development. Yield reduction at this stage can be as high as 5% per day.

Silking/fertilisation: During this three week period, maximum water usage occurs and stress during the early part of this period will affect kernel set whilst stress during the later part decreases kernel weight.

Grain fill: Stress at this point hastens maturity, reducing photosynthesis and starch production. After a period of sever water stress, the corn plant may take several days to recover despite plentiful soil moisture.

Pre-physiological maturity: The last watering is important for final kernel size and therefore weight, especially for producers growing contracted grit. Water logging (too much water in the root zone) can be just as detrimental as moisture stress.

The yield decline associated with four consecutive days of water stress sufficient to cause wilting is demonstrated in Table 4.

Table 4. Yield decline after 4 days of wilting for various crop stages.

GROWTH STAGE	POTENTIAL YIELD REDUCTION %
End of pollination	50
Dough stage	40
Week prior to tasselling	10

The critical period for water in corn is week 7 to week 13–14, as any water limiting event in this period will result in yield loss. The key is to have a yield target in mind, and match either area sown to known water quantity, or vary population to known soil plus irrigation water.

Navy beans

Peak water use occurs during a 3 week period beginning with flowering and ending with initial pod fill. It is critical that they are planted on a full soil profile. The first irrigation in-crop should be when 50% of the available water in the root zone has been used. Thereafter irrigations should be applied to keep the soil water levels above the 50% deficit until the first pods have fully expanded. A complicating factor with irrigation management in navy beans is its interaction with Sclerotinia post-flowering.

Peanuts

The most critical stage for water stress in peanuts is following flowering. Water deficit during pegging and pod formation will reduce the number of pods formed. Soil water deficit in the root zone affects plant growth, photosynthesis, and transport of water and assimilates to the developing pod. Soil water deficit in the podding zone (top 5 cm of soil) affects peg penetration, pod formation and pod uptake of calcium and water. Poor water availability and calcium in the podding zone can lead to seed abortion ('pops') and poorly formed seed. Care also needs to be taken in avoiding excessive irrigation as this will promote vegetative growth at the expense of pod and seed formation. Irrigation also interacts with a number of diseases which are important in peanut production. Excessive irrigation can increase the incidence of foliar diseases but severe moisture deficit during the 50 days period prior to harvest can increase the incidence of aflatoxin contamination brought about by Aspergillus infection.

Sorghum

Growth Stage One (*Vegetative phase*) – heatwave conditions will have less impact if sub-soil moisture is sufficient and secondary roots are well developed. The result will be withered leaves and a burnt appearance. For a crop with a poorly developed secondary root system under the same circumstances, secondary root development will not continue. If moisture stress is combined with heat stress, the potential number of grains per head is reduced through head size reduction.

Growth Stage Two (*Floral initiation to flowering*) – Floral initiation begins at 3 to 4 weeks after planting – heat and moisture stress during this phase will result in floral abortion, pollen sterility or heat blast, seriously affecting yield. If the heads are in boot stage, the stress can physically damage the head to a level that it will not set seed, or in extreme cases, not even be exerted from the boot. The physical symptoms include: leaf rolling and exaggerated leaf erectness, bleaching and burning of the leaf tips, delayed flowering, poor head exertion, head blasting and floral abortion.

Growth Stage Three (*Post flowering*) – Severe moisture stress post-flowering results in the plant shutting down with premature leaf and stem death, stalk collapse and lodging, stalk rot, and sometimes a significant reduction in seed size.

Moisture stress from the boot stage through to grain fill can reduce yields by 30 to 40%.

Soybeans

A full moisture profile at planting is preferred to encourage root development. Frequent irrigations during the vegetative stage should be avoided as this will encourage excessive vegetative growth. Irrigation should be applied from flowering right through the pod stage until seeds are fully developed. Water stress during this period has the greatest impact on yields. With soybeans adequate soil moisture must be maintained until the crop is physiologically mature. This is when the seed has separated within the pod and the plant has half defoliated. Failure to maintain these soil water levels will result in significant yield loss and poorer seed quality through shrivelling.

Sunflowers

Sunflower is a deep-rooted crop with peak water use from bud formation to petal fall. It will use water to depth and is best planted on a full profile of moisture. With sprinkler systems irrigation should start just prior to bud formation and continue until petal drop. With surface irrigation applications at bud formation and full bloom are ideal. Results from limited water research trials in Kansas showed that a single in-season irrigation at either bud or bloom stage was equally effective (see Table 5).

Table 5. Limited Water Sunflower Study, Tribune Branch Agricultural Experiment Station, Kansas 1979 to 1985

IRRIGATION TREATMENT	YIELD (t/ha)	TOTAL WATER USE (ML/ha)
Pre-plant only	2.13	3.84
Pre-plant and bud	2.48	4.98
Pre-plant and bloom	2.47	4.72
Pre-plant, bud and bloom	2.82	5.36

Source: Meyer, R., Belshe, D., O'Brien, D. and Darling, R. (1999) High Plains Sunflower Production Handbook, North Dakota State University, Cooperative Extension Service

Sunflowers do not tolerate water logging, with over-watering or saturation resulting in plant mortality if water lies in the root zone for more than 24hrs.

Wheat

Wheat is only moderately sensitive to critical-stage plant water deficits compared to other field crops. Water stress during early crop development can reduce tillering and the number of heads per m^2 and the seeds per head. However, the most sensitive period for water stress is from 10 to 20 days preceding flowering through the flowering period. Stress during this period can significantly reduce the number of seeds produced per m^2. Development during grain filling is less normally less sensitive to water stress as the plant is able to relocate pre-flowering assimilate to filling grain as late-season water stress reduces photosynthesis. However, hot and dry conditions during the milk stage can cause grain shrivelling leading to yield loss.

Irrigated wheat performs best when planted on a full soil profile and with irrigation applied during the boot stage through to the soft dough stage. The amount of irrigation needed will vary with evaporative demand, rainfall and soil type.

Scheduling Irrigations

Irrigation scheduling is the decision of when and how much water to apply to an irrigated crop to maximise crop productivity. Good scheduling should provide plants with water that is within a desired range and should limit over or under irrigation.

The advantages of irrigation scheduling include:

- The management of water between fields to minimise crop water stress and maximise productivity.
- Improvements in energy, water and labour efficiency through more effective irrigation.
- An increase in Water Use Efficiency and fertiliser effectiveness through reduced surface runoff and deep drainage.
- Increased net returns through increased yields and improved crop quality.
- A minimisation of water-logging problems.
- Assisting control of root zone salinity problems through controlled leaching.
- Additional crops through savings in irrigation water.
- The ability to precisely control availability of soil moisture when using precision application techniques.

It is very important to remember that irrigation scheduling is reliant upon system performance. System efficiency and uniformity should be taken into account when making irrigation scheduling decisions.

Scheduling methods & tools

ET Based

Crop evapotranspiration is calculated from climatic factors and crop coefficients as described above. This data can be used for daily accounting of the amounts of water entering and leaving the crop root zone.

This procedure is based on estimating the soil water content in the crop root zone by balancing the water inputs and outputs, as illustrated in Figure 4.

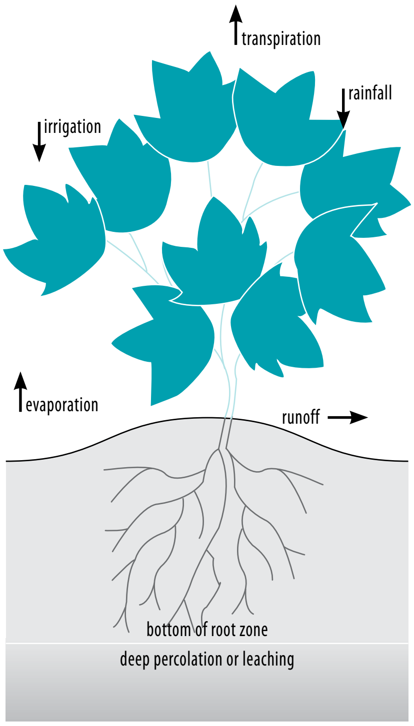


Figure 4. Soil water balance in irrigated cropping systems (courtesy of Colorado State University, USA).

Irrigation and rainfall add water to the root zone. Some of this water may be lost as runoff or drainage below the root zone. Conversely, in some situations water can also enter the root zone from a high water table or lateral water movement through the soil. Water is also lost from the root zone through evapotranspiration.

The current soil moisture deficit can be calculated on a daily basis to indicate when the amount of water in the root zone is insufficient, suggesting that irrigation should be applied.

Deficit (today) = Deficit (yesterday) – irrigation – rainfall + ET_C

Where:

Deficit = soil moisture deficit (amount of available water in the root zone below field capacity)

ET_C = Crop evapotranspiration (crop water use)

Irrigation and rainfall figures have already had runoff and drainage taken into account

Note: we are using soil moisture deficit in this calculation, as that is the terminology that is most often used throughout the industry. The concept of deficit must be understood: as the deficit increases, the amount of water in the soil is less. Adding water to the soil (e.g. irrigation) reduces the deficit, bringing it closer to zero. A Deficit of zero indicates the soil cannot hold any more water.

Example:

We will use the ET_C data for the soybean crop illustrated above. The items required to perform the calculations have been placed in the table below. Following the logic above:

Deficit (today) = Deficit (yesterday) – irrigation – rainfall + ET_C

*or, **Column 6 = Col 2 – Col 3 – Col 4 + Col 5***

1	2	3	4	5	6
DATE	DEFICIT (YESTERDAY) (mm)	IRRIGATION (mm)	RAINFALL (mm)	CROP WATER USE (ET_C) (mm)	DEFICIT (TODAY) (mm)
15 Feb	14			5.3	19.3
16 Feb	19.3		7	3.6	15.9
17 Feb	15.9			5.1	21
18 Feb	21			4.8	25.8
19 Feb	25.8	40		6.3	0 (–7.9)
20 Feb	0			5.1	5.1
21 Feb	5.1			6.6	11.7

In this example we can see the daily deficit increasing in the right hand column. A small rainfall event on Feb 16th corresponds with a lower ET_C value and reduces the deficit by 7mm. On February 19th an irrigation event takes place. The amount applied (40mm) is greater than the deficit in the soil. As the soil is full when the deficit is zero, the additional water (7.9mm) is removed from the calculation and the deficit is manually set to zero.

Plant Based Methods

Whilst calculations of soil moisture can infer the likelihood of crop stress, direct observation of the crop can reveal the actual level of stress being experienced. Visual signs of water stress may include wilting, fruit drop and death in sections of the crop. However these signs often occur after stress has been present for some time, and are of limited use in accurate irrigation scheduling.

Furthermore, plant indicators may not necessarily be a result of water stress, but of other causes such as heat, salinity or nutritional deficiencies. For example, some plants roll their leaves up in response to an extremely hot, windy day - referred to as Midday Wilt in cotton. Other plants only show wilting when water is severely limited. These crops move into a "shut-down" phase which can impact yield depending on crop development stage at which this occurs. Other plants will wilt in response to water logging or root disease.

Whilst simple visual indicators are of restricted use for irrigation scheduling, more technologically advanced methods of plant monitoring can provide highly accurate responses to small changes in plant stress levels. In the past, these methods have often been costly and complicated, with use predominantly restricted to research.

Plant based scheduling tools can be classified as either contact or non-contact depending upon whether they have to come into physical contact with the plant. *Contact sensors* typically provide point source data, with multiple sensors required wherever instrumentation is left in-situ to provide time series data. Contact sensors may be either destructive (pressure bomb) or non-destructive (sap flow, stem diameter).

Point source measurements typically record data for only a single plant; hence the way in which this plant represents the rest of the field is very important. This issue is the same for point source soil moisture measurements.

Non-contact sensors do not come into contact with the plant and usually can be used to measure numerous points across a number of fields, or even entire fields at once. Cloud cover can be a major influence as airborne and satellite sensors must be able to view the field, whilst ground level and hand held sensors usually require clear conditions to provide meaningful data.

On the whole, most plant based sensors are not yet practical for wide spread use, or do not yet offer significant advantages over other existing scheduling techniques. This may improve in the future as further research and development occurs.

Plant Based Monitoring Tools Available

ADVANTAGES	DISADVANTAGES	COMMENTS
Plant Based Monitoring Tool: Stem water potential *Specifications:* A pressure chamber measures the water potential of a non-transpiring leaf		
More robust than leaf water potential Relatively cheap	Destructive measurement Requires a lot of practice to make reliable measurement Point source measurement – many points required for representative sample No continuous data – new measurements Required each time.	Need more testing to determine critical levels. Research tool.
Plant Based Monitoring Tool: Canopy Temperature and Infra-red Thermograph *Specifications:* Infra-red thermometer and thermal imager		
Good relationship with standard measurements for IR thermograph. Automation possible Can get a picture of whole field or many points within field Many fields can be measured with a single instrument	Canopy temperature can be uncertain and less reliable Thermograph can be expensive Readings usually need to be taken on a clear day	Need more testing May have potential for non-point source data collection, but not yet commercially practical.
Plant Based Monitoring Tool: Leaf Water Potential *Specifications:* A pressure chamber measures the leaf water potential of a transpiring leaf.		
A classic, standard measurement Equipment relatively cheap	Destructive measurement Requires a lot of practice to make a reliable measurement. Time/conditions of day dependent for consistency over time Point source measurement No continuous data – new measurements required each time.	Research tool
Plant Based Monitoring Tool: Plant growth measurements *Specifications:* A range of plant growth technologies including stem and fruit diameter sensors		
Relatively cheap Easier for grower or consultant gives continuous data	Not accurate in all situations Additional measurements required Point source measurement - multiple sensors required	Plant growth measurements will likely provide similar function of trend analysis as current soil moisture monitoring.
Plant Based Monitoring Tool: Satellite Imagery and remote sensing of crop water stress *Specifications:* Spectral data and images of varying characteristics, resolution and coverage		
Applications are wide ranging	Accuracy is uncertain Ground truthing can be expensive	Mobile, low altitude sensors may provide a better resolution and improve application.

Source: CRC for Irrigation Futures

Soil based methods

Measurement of soil moisture characteristics allows us to infer the likely stress that a plant may be undergoing. There are three main measurement types for determining the availability of water in the soil.

- *Gravimetric* – the amount of water in the soil based on weight. This is calculated by oven drying soil samples to find the difference between their wet and dry weight. This measure is of little use for scheduling due to the difference in density of different soils.
- *Volumetric* – the amount of water in the soil based on volume (cm^3/cm^3). This is the most common way of expressing soil moisture, usually in mm of water per depth of soil (e.g. 300 mm of water per 1 m of soil = 30% Soil Moisture). Requires calculation of soil bulk density.
- *Soil Water Potential* – measures the soil suction (pressure) and is the measure that most accurately relates to actual plant stress. The soil water potential indicates how difficult it is for a plant to remove water from the soil.

Volumetric measurements of soil moisture have become popular as they enable an irrigator to relate the volume of water required to refill the soil profile (deficit) to the amount of water applied in an irrigation event. However additional information is required such as the volumetric moisture content at field capacity and refill point. This information is obtained from physical soil tests which are often time consuming to obtain,. Therefore analysis of volumetric soil moisture data is often undertaken using uncalibrated data by looking at trends in daily water use.

On the other hand, measures of soil water potential can directly indicate how difficult it is for a crop to extract moisture from the soil. Thresholds of suction at which crops are able to readily extract water are generally well known, therefore a single measurement can indicate whether an irrigation is required or not. However as the information is not volumetric, determining how much water should be applied, or how long it will take to deplete the existing soil water reserves is more difficult.

Soil Moisture Monitoring Tools Available

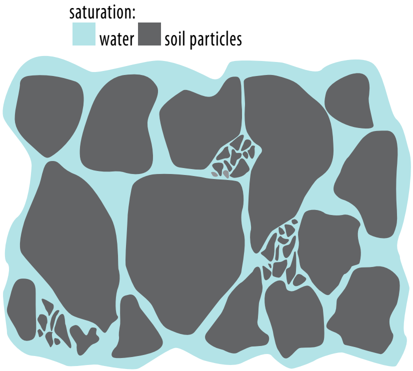
ADVANTAGES	DISADVANTAGES	OVERALL
Soil Moisture Monitoring Tool: Capacitance probes – stationary (C-probe, Enviroscan, Buddy, Profile Probe, Theta Probe, ECH20, etc.) *Specifications:* **Type of sensing** – capacitance **Type of reading** – volumetric (often uncalibrated) **How does it work?** By measuring the dielectric constant of the soil. The amount of water in the soil is related to its ability to transmit electromagnetic waves or pulses		
Continuous logging Remote access Multiple access tubes to one logger Gives indication of variation in crop water use on a daily basis	10 cm diameter reading zone is reasonably small Cracking soils can effect soil moisture reading Generic calibrations give poor estimate of total water content Some models have cables from access tube to logger Unit is stationary so number of sites limited	Suitable tool for growers, be aware of issues on cracking soils. Expensive but gives detailed soil moisture record.
Soil Moisture Monitoring Tool: Neutron Probe *Specifications:* **Type of sensing** – radioactive **Type of reading** – volumetric (often uncalibrated) **How does it work?** The radioactive source emits neutrons which are slowed down by collision with hydrogen in water molecules. The number of slow returning neutrons measured is related to the amount of water in the soil		
Large reading zone (average diameter 30 cm) is beneficial in cracking soils Predictive Software Portable, multiple access tubes Usually more accurate than most other volumetric sensors	Require a license to use the probe and approved transport and storage facilities. Manual data collection Data reading of each access tube is time consuming No remote access or continuous logging Soil specific calibrations required for accurate readings Regular readings required for comprehensive date set and to identify trends. Reasonably heavy and expensive instrument. Radioactive source must be properly disposed of.	Most accurate for clay soils Need to be licensed due to radioactive hazard
Soil Moisture Monitoring Tool: Capacitance probe – portable (Diviner 2000, Gopher, Aquaterr, Profile Probe, Theta Probe, etc.) *Specifications:* **Type of sensing** – capacitance **Type of reading** – volumetric		
Quicker read than neutron probe Readout in-field Can determine change in daily water use from output graphs if readings are frequent Portable, multiple access tubes. Reasonably inexpensive	Small (10 cm diameter) reading zone Cracking soils will effect soil moisture reading Generic calibrations give poor estimate of total water content Absolute numbers obtained are of little value without calibration Frequent readings required to identify trends.	
Soil Moisture Monitoring Tool: Porous media (tensiometers, gypsum blocks, matrix sensors, etc.) *Specifications:* **Type of sensing** – pressure (suction) **Type of reading** – soil water potential **How does it work?** Porous media (gypsum, ceramic, etc) allows water to flow from soil. Pressure sensor within the device measures suction directly.		
Cheap Gives direct reading of when to irrigate Calibration is usually unnecessary Many products can be logged to provide time series data	Some products may not work well in very wet or very dry soil Does not give an indication of the volume of irrigation required Permanent installation of block devices not well suited to field crops Some products may not respond quickly to change in moisture content	Only devices to give a direct reading of how difficult it is to extract water from the soil regardless of soil type.

Source: RWUE3 2007

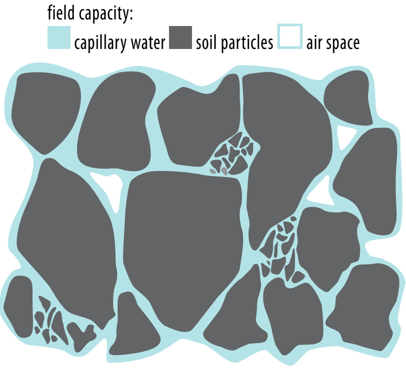
Analysing Soil Moisture Data for Irrigation Scheduling

In order for us to consider scheduling irrigations based upon measurements of soil moisture, we need to understand some basic soil water terms.

Saturation may occur after heavy rain, during surface irrigation, or following over-irrigation. This is when even the largest pores are filled with water. When the soil is saturated, there is no air for the plant roots. This will stress many plants and is often described as waterlogging.



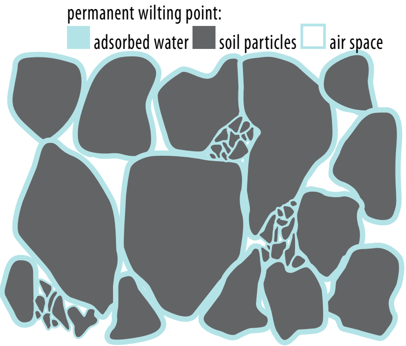
Field capacity (full point) occurs after large soil pores (macropores) have drained due to gravity. Depending on the type of soil, this drainage may take from a few hours up to several days. When the large pores have drained, the soil is still wet, but not saturated. The soil is said to be at field capacity. Field capacity in most soils is at a soil-water tension of about –8 kPa.



Refill Point is the point at which a particular crop finds it difficult to extract water from the soil and begins to stress, slowing crop growth. For most cotton and grain crops, this usually occurs when the soil water potential is between – 60 and –100 kPa.

The refill point changes during the season. Young plants have small roots that only have access to a limited part of the soil profile. As the plant grows, the roots can access more of the profile and therefore tolerate a larger soil moisture deficit before reaching refill point. Determining the refill point can be achieved by measuring soil water potential or by analysing daily water use patterns to determine when the crop is finding it difficult to remove water. If irrigation is not applied prior to soil water levels passing an accurate refill point, then a yield reduction will occur, depending on the stage of the crop

Permanent Wilting Point occurs when the soil reaches a point where the plant can no longer extract moisture. Once the soil has passed this point, water is held by the soil so tightly that the plant cannot extract it and will start to die.



Most soils have are able to hold a similar amount of water in total, generally between 400–500 mm per metre depth of soil, as illustrated in Figure 5. However, the amount of water actually available for use by the plant varies greatly due to different soil textures and their influence on soil moisture.

The shaded section in the middle of each column shows the average amount of water available to plants. Water held below permanent wilting point is shown by the bottom section of each column, and free-draining water (above field capacity) is shown in the top section.

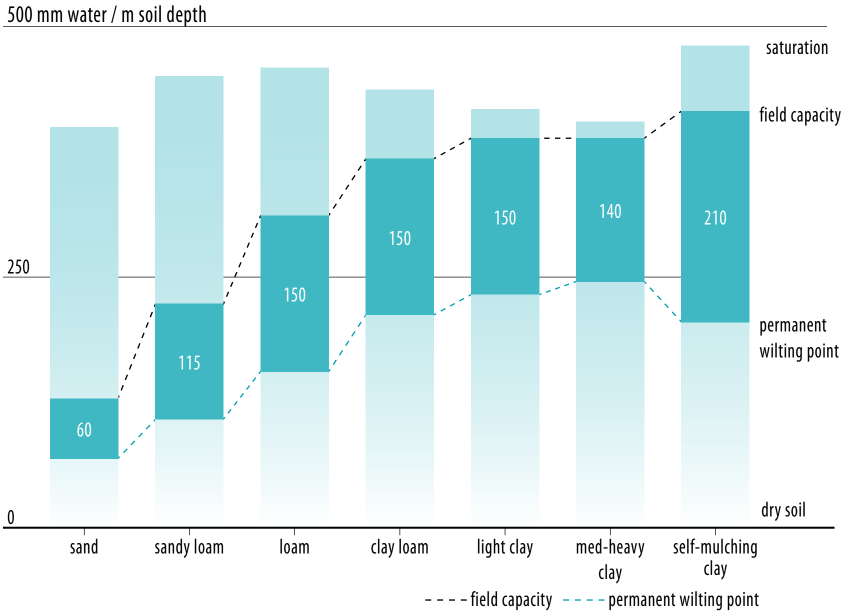


Figure 5. Total amount of water held in different soils

The amount of water held in the soil between field capacity and the permanent wilting point represents the Plant Available Water Capacity (PAWC). However irrigation scheduling decisions should be undertaken when the soil moisture is between the full and refill points, known as the Readily Available Water (RAW). This can be visualised like a fuel gauge as in Figure 6.

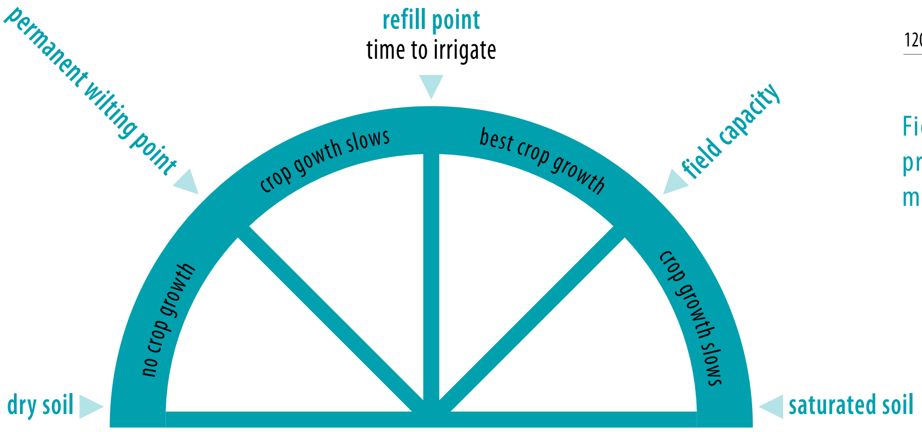


Figure 6. Soil Water '*Fuel Gauge*'

Analysing Soil Moisture Probe Data

Data from soil moisture probes will generally be presented in one of two ways:

1. Non-continuous data (obtained from manual recording devices such as *Neutron probes* or *Diviners*) is often presented as a graph of soil depth vs. moisture content (Figure 7). Each line on the graph represents a reading taken at a different time.

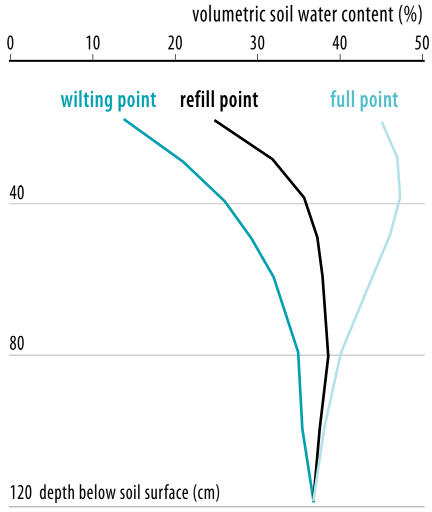
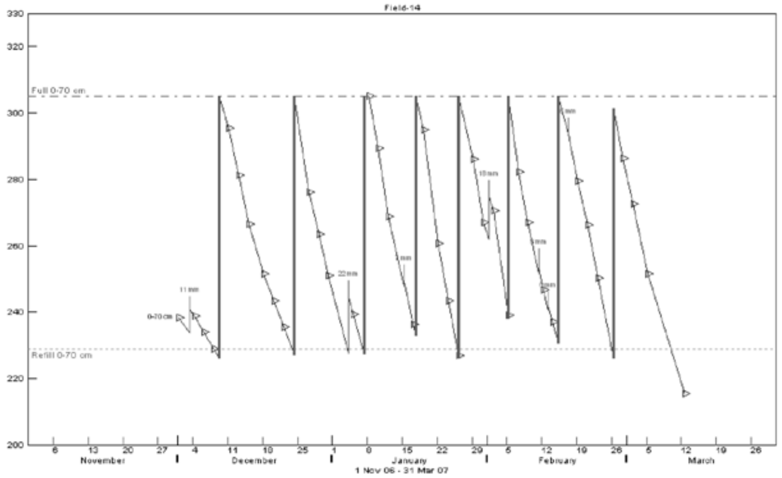


Figure 7. Soil moisture data presentation typical of manual measurement devices (e.g. NMM)

However, data may also be represented as a graph of moisture vs. time for the total of the whole profile (Figure 8). This graph is usually most useful if readings are taken regularly.



RootZone	Full	REFILL	Previous	Current	Deficit	Probe Dwu	Pdwu Date	EDWU	Date	Amount
0-70 cm	305 mm	229 mm	252 mm	216 mm	90 mm	4.9 mm/day	26 Jun	4.3 mm/day	26 06 16:20	76 mm

Figure 8. Presenting non-continuous soil moisture data over time

2. Capacitance probe data is typically presented as a graph of moisture content vs. time (Figure 9). The line(s) on the graph can either represent a sum (total) of all soil moisture readings within the entire profile (summed graph) or each line may represent the moisture reading at a different depth in the soil profile (stacked graph).

*Note that data from either device may be presented in either fashion.

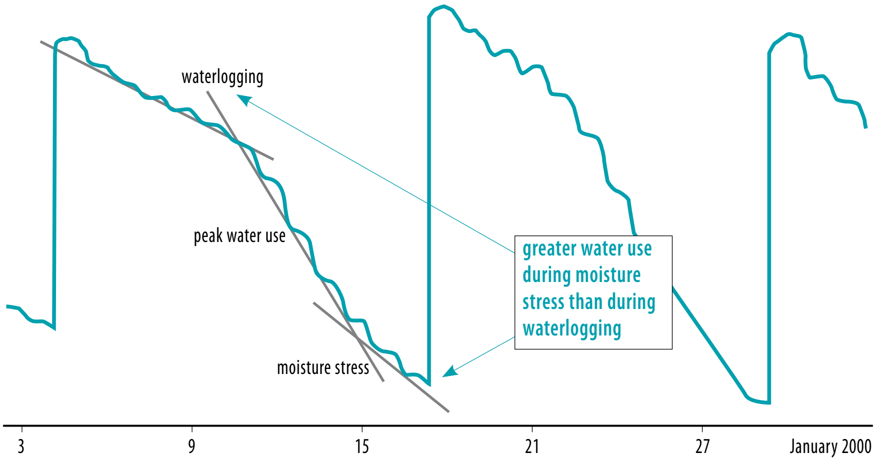


Figure 9. Soil moisture data presentation typical of continuous logging devices
Source: Sloane 2003

Remember that uncalibrated probes do not give absolute measures of soil moisture. This means that you cannot simply take a reading of soil moisture and compare it to a refill point determined from physical soil sampling. For manual (portable) probes there are a couple of options:

- Take readings regularly (every 2 or 3 days) as well as before and after irrigations. This will give enough data to perform some basic trend analysis as described below.
- Use historical data. Provided you have data for a number of previous seasons, and ensuring you have enough access tubes to average out individual readings, it is possible to reduce the frequency of manual readings. Be cautious of this method where soil properties are likely to change significantly due to compaction, ripping or extended drying

Frequent manual readings or data collected using a continuous logging device can be used to deduce a refill point based upon trends in water extraction over time. Water extraction patterns are stepped on a daily basis, being flat at night (little or no water use) with a rapid decline during the day. The overall slope indicates how readily extraction is occurring:

- Steep slope – high water use
- Flat slope – water logging or stress

Summed graph

- Displays total soil moisture for the probe depth (typically 1 m)
- Useful as a 'quick reference' of soil moisture or to indicate irrigation when refill point is already determined.
- Can be used to determine field capacity (full point)

Figure 10 shows a summed soil moisture graph, illustrating differences in water use over time.

- In this figure, the soil has been irrigated, becoming saturated (A).
- After irrigation ceases, soil water drains due to gravity until field capacity is reached (B). This can occur quite quickly, as illustrated here, or may take a number of days causing waterlogging (Figure 9).
- Under optimal conditions, the plant extracts water freely, until the refill point is reached and crop stress occurs (C).
- In this case, irrigation has been delayed and the crop has been stressed until irrigation occurs (D)

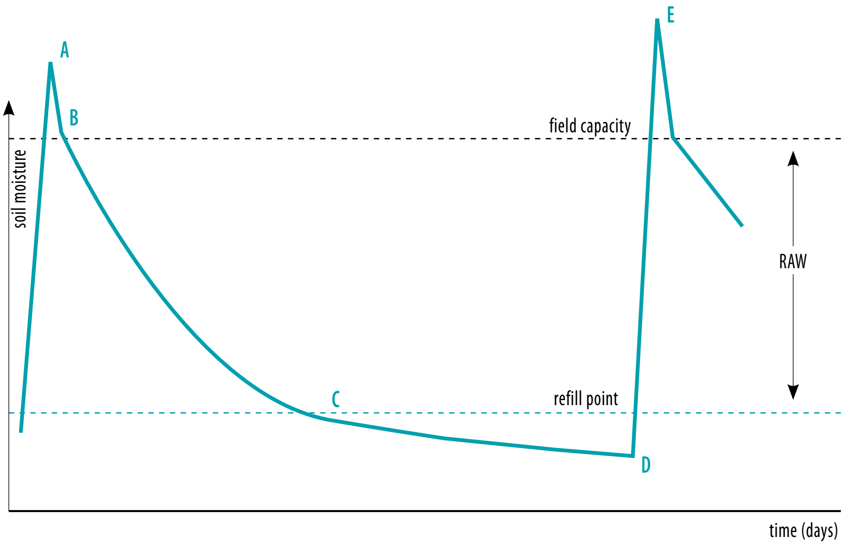


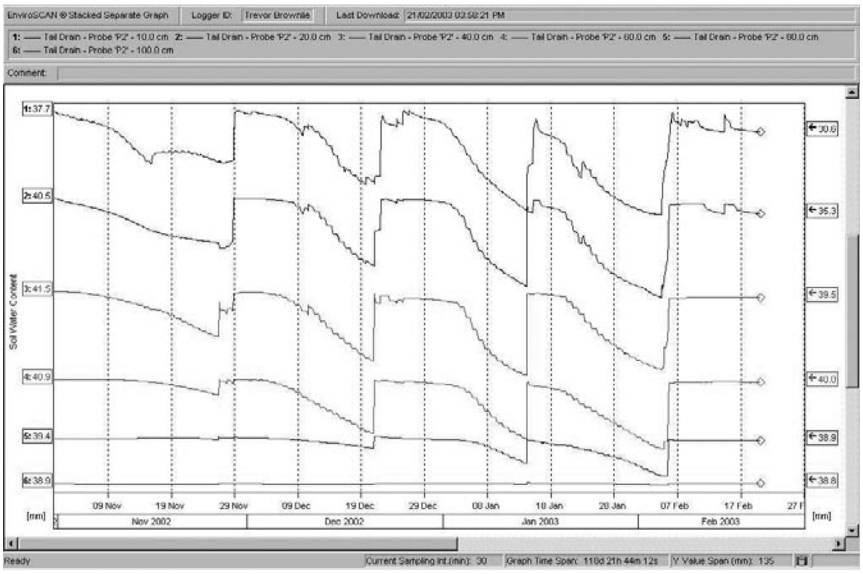
Figure 10. Summed soil moisture graph

Whilst the refill point is clearly evident in this figure (at C), in practice, we cannot predict in advance when stress is going to occur, therefore determining the refill point from the summed graph can be difficult.

Stacked Graph

- Displays soil moisture at each sensor depth
- Useful for determining refill points and examining extraction patterns

Crops use most soil moisture in the top of the soil profile first and proportionally less, deeper in the profile, depending on root growth. Figure 10 shows a stacked soil moisture graph, illustrating differences in the amount of water used at different depths.



EnviroSCAN ® Stacked Separate Graph

Logger ID: Trevor Brownlie

Last Download: 21/02/2003 03:58:21 PM

1: —— Tail Drain - Probe 'P2' - 10.0 cm 2: —— Tail Drain - Probe 'P2' - 20.0 cm 3: —— Tail Drain - Probe 'P2' - 40.0 cm 4: —— Tail Drain - Probe 'P2' - 60.0 cm 5: —— Tail Drain - Probe 'P2' - 80.0 cm
6: —— Tail Drain - Probe 'P2' - 100.0 cm

Comment:

Ready

Current Sampling Int.(min): 30

Graph Time Span: 110d 21h 44m 12s

Y Value Span (mm): 135

Figure 11. Stacked soil moisture graph

We can use a stacked graph to help determine an appropriate refill point. Because a plant will typically extract water from closer to the surface first, the sensors close to the surface will show a decline in daily water use before the crop is under stress, as it is still accessing plentiful water at lower depths.

For most crops with an effective rootzone of around 1 metre, you can determine the refill point by analysing the trend of sensors at 40, 50 or 60 cm, depending upon local conditions. Often a slowing of water extraction at this depth indicates that the plant is about to stress as it will have more difficulty accessing water from deeper in the profile.

Many experienced operators will perform this function visually, however it is simple to undertake this procedure by analysing the daily water use figures. Most software packages will either display the daily water use figures or will allow them to be exported. You simply look for a decrease in the daily water use at either the 40 cm or 60cm depth (depending upon local conditions). Don't forget that for an uncalibrated probe, these daily water use figures do not correlate to the actual amount of water used by the plant in a day.

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Cotton and Grains Workshop Series

Scheduling II – Advanced Scheduling

Key points

- Plant Available Water Capacity (PAWC) is the amount of water available to a crop on a particular soil type
- Understanding the PAWC enables you to understand potential productivity and yield variations, and align management of inputs, irrigation schedules, and precision irrigation techniques accordingly
- Calibrating soil moisture probes is helpful for calculating the soil water balance, determining actual deficit and determining effective rainfall but may be time consuming and give misleading readings
- Soil moisture probe sites should be placed in the 'majority' soil type

Introduction

To implement an efficient scheduling program for your enterprise a sound understanding of how water moves through the atmosphere, plant and the soil is needed. Knowledge is then required to identify how best to schedule irrigations using different methods and techniques in different crops. The principles and methods of scheduling water are universal for all crops. However it is the timing and implementation of this management action that is critical.

This workshop will build on the information delivered in the Scheduling 1 workshop and discuss strategies for implementation on your farm or to your clients, for fine tuning of irrigation scheduling and for maximising profit, by optimising irrigations for your soil types to meet your target deficit and minimise losses through deep drainage.

- Determining soil water content
- Calibration of scheduling tools
- Deficits using soil water data, ETc, WaterTrack™ & HydroLOGIC
- Optimised furrow irrigation, regulated deficit irrigation, deep drainage
- Probe placement

1 Soil Water Capacity

An understanding of soil water capacity is essential for accurate irrigation scheduling. As illustrated by the soil water 'fuel gauge', crop growth and irrigation decisions are fundamentally linked to soil water status.

Following heavy rainfall or irrigation, water will drain out of the root zone until the Field Capacity or Drained Upper Limit (DUL) is reached. This is the amount of water that the soil can hold against gravitational forces. Crops will use this water and, as the soil water content falls, the remaining water is held by the soil with greater force, making it more difficult for the plant to extract. Eventually the soil water is depleted to an extent where the crop can no longer extract water – the Permanent Wilting Point or Crop Lower Limit (CLL).

Further Reading:

WATERpak	2.10, 2.11, 3.1, 3.2, 3.3, 3.4, 3.5, 3.7, 5.1, 7.2, 9.5, 9.6
Cotton BMP Manual	3.5, 3.6, 3.7, 5.3, 6.3, Appendix 5, L&W Management Worksheets 9, 12, 13
SOILpak for cotton growers	C3, C9, E7
Irrigation Insights No. 1: Soil Water Monitoring	CSIRO Land & Water www.npsi.gov.au/Publications_and_Tools/Irrigation_Insights/index.aspx

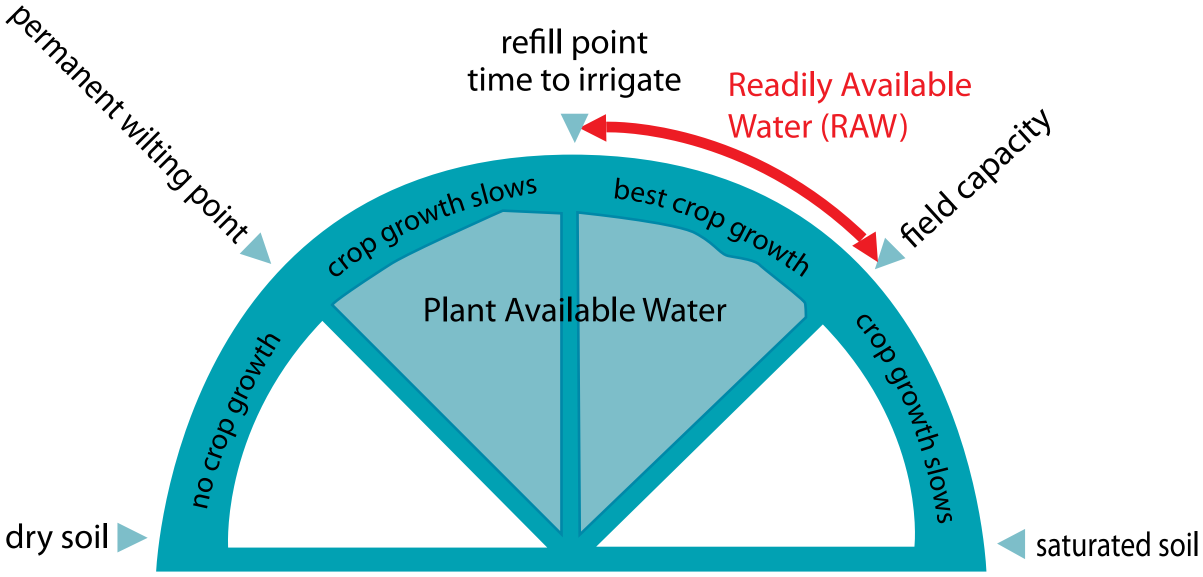


Figure 1: Soil Water 'Fuel Gauge'

Saturation may occur after heavy rain, during surface irrigation, or following over-irrigation. This is when even the largest pores are filled with water. When the soil is saturated, there is no air in the soil for the plant roots resulting in stress for many plants, usually described as waterlogging.

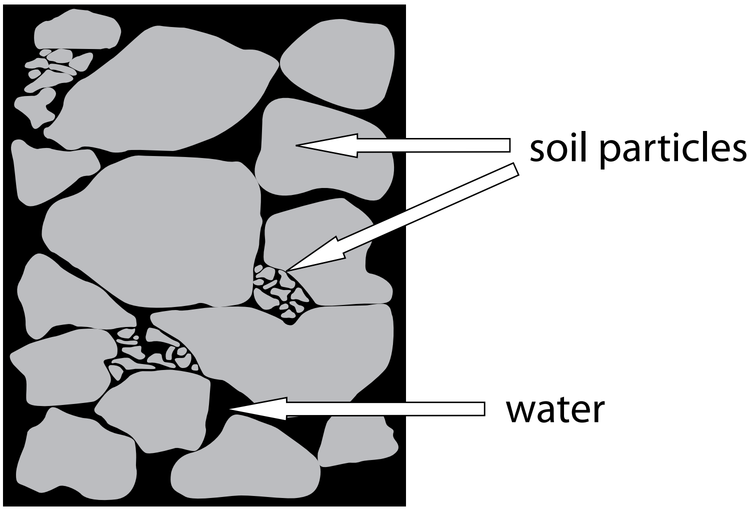


Figure 2: Saturated soil

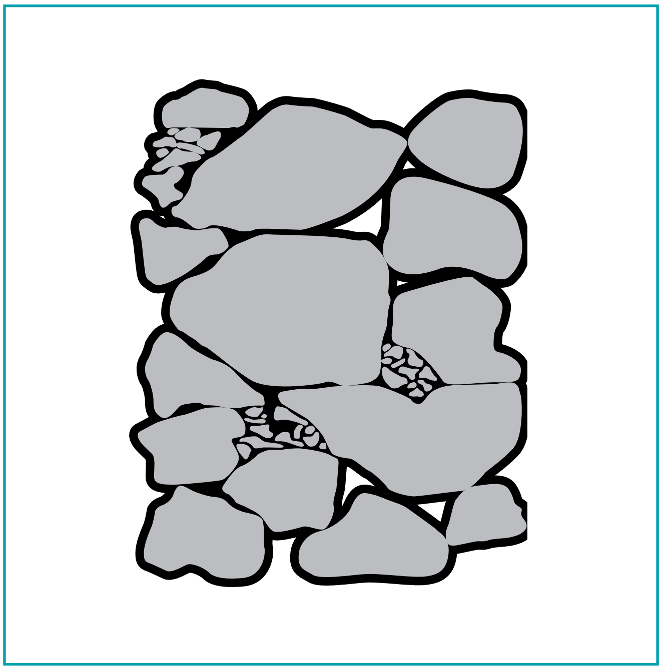


Figure 3: Soil at Field Capacity

Field Capacity is also known as full point or Drained Upper Limit (DUL) and occurs after large soil pores (macropores) have drained due to gravity. Depending on the type of soil, this drainage may take from a few hours up to 48 hours. When the large pores have drained, the soil is still wet, but not saturated and the soil is at Field Capacity. Field Capacity in most soils is at a soil water tension of –8 kPa to –30 kPa soil structure dependent. It can be determined following a rainfall or irrigation event that saturates the profile.

Refill Point (or Target Deficit) is the point at which a particular crop finds it difficult to extract water from the soil and begins to stress, slowing crop growth. For most cotton and grain crops, this occurs when the soil water tension is between –60 kPa and –100 kPa. The amount of water this represents varies with soil type – lighter soils generally hold less than heavier soils at the same soil water tension.

The refill point changes during the season. Young plants have shallow roots that access only a limited part of the soil profile. As the plant grows, the roots extend deeper, accessing more of the profile and therefore a larger amount of soil water before reaching refill point.

Determining the refill point can be achieved by measuring soil water tension or by analysing daily water use patterns to determine when the crop is finding it difficult to remove water. If irrigation is not applied prior to soil water levels passing the refill point, then a yield reduction will occur, depending on the stage of the crop. There is often no visible change to the plant at this point.

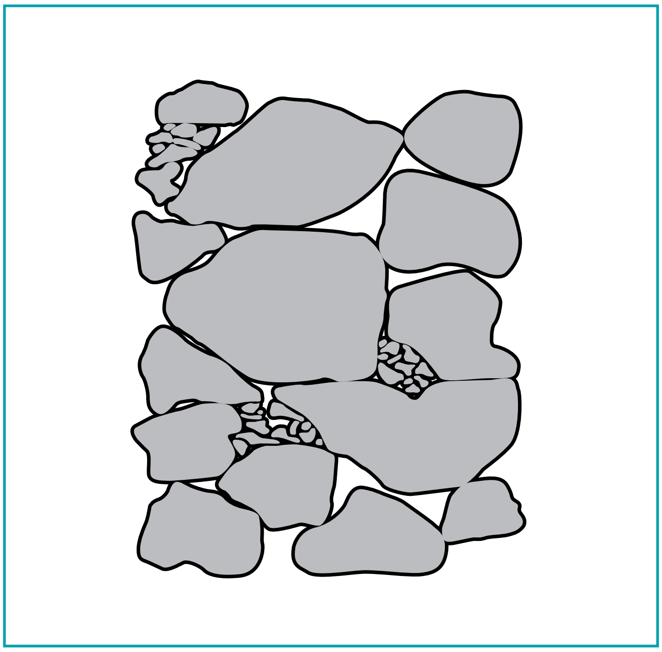
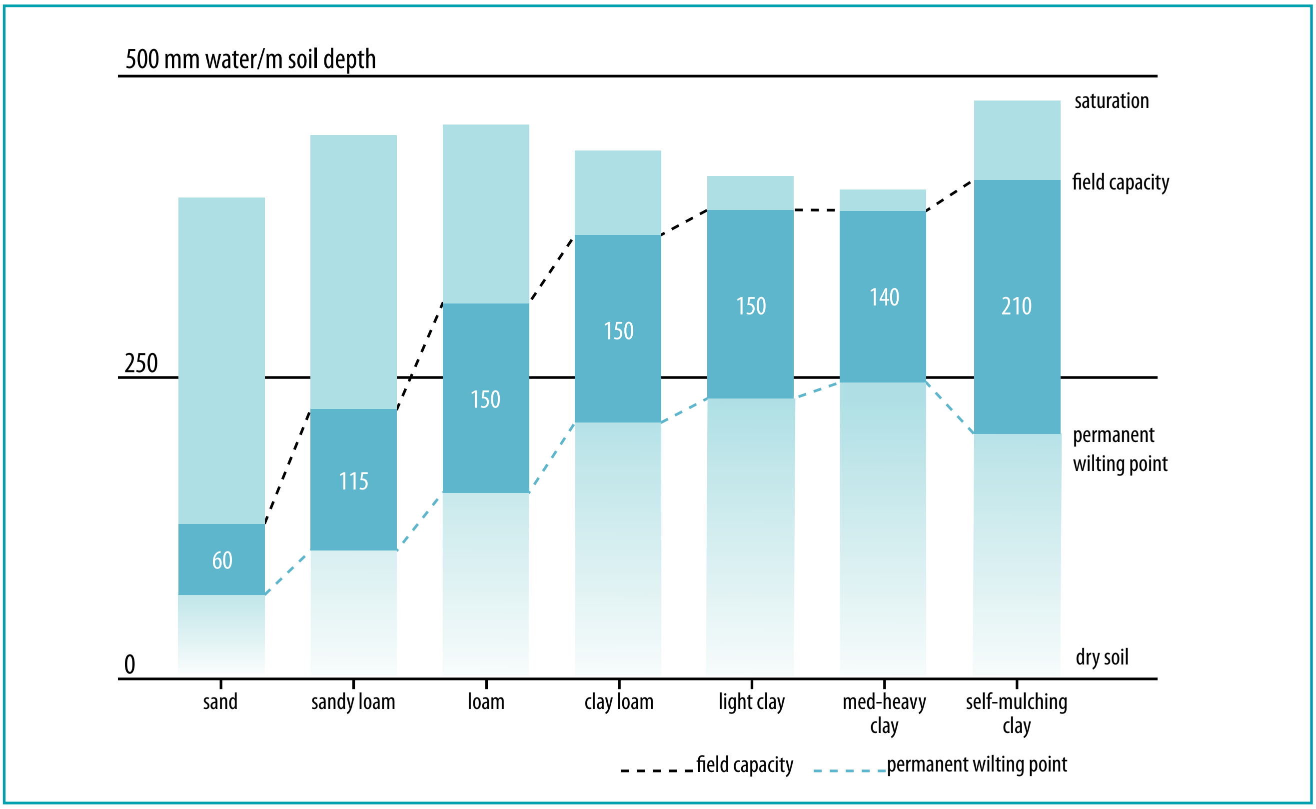


Figure 4: Soil at Permanent Wilting Point

Permanent Wilting Point or the Crop Lower Limit (CLL) occurs when the soil water depletes to a point where the plant can no longer extract it. At this point, water is held by the soil so tightly that the plant cannot extract it and will start to die. Conventionally, permanent wilting point is defined as a soil water tension of –1500 kPa, but in practice this varies with crop type. The actual volumetric water content of the soil at this tension varies with soil characteristics.

Plant Available Water Capacity (PAWC) is the amount of water that a plant is able to extract from the soil, and is illustrated by the dark blue shaded area in Figure 5. It is the difference between Field Capacity and Permanent Wilting Point and is measured in mm of water per metre of soil depth (mm/m). Different soils hold different amounts of PAWC.

Total Available Water (TAW) in the root zone is found by multiplying the PAWC by the depth of the effective root zone.



PAWC varies due to:

- Soil characteristics such as texture, structure, compaction, etc.
- Plant characteristics such as variety, type, rooting depth, health, etc.

Figure 5: Plant Available Water Capacity The dark section in the middle of each column shows typical values for PAWC. Water held below Permanent Wilting Point is shown by the light section at the bottom of each column, and free draining water (above Field Capacity) is shown by the light section at the top.

Table 1 shows typical values of PAWC for a range of crops and soil types.

Table 1: RAW and PAWC values for different soil textures

Water Tension*	To –20 kPa	To –40 kPa	To –60 kPa	To –100kPa	To –1500 kPa
	A	B	C	D	E
	Water-sensitive crops such as vegetables and some tropical fruits	Most fruit crops and table grapes, most tropical fruits	Lucerne, most pasture, crops such as maize and soybeans, and grapes**	Annual pastures and hardy crops such as cotton, sorghum and winter crops	PAWC is the total water available in the soil. Plants stress well before this level is reached.
Soil texture	**Readily Available Water (RAW) (mm/m)**				**PAWC (mm/m)**
Sand	35	35	35	40	60
Sandy loam	45	60	65	70	115
Loam	50	70	85	90	150
Clay loam	30	55	65	80	150
Light clay	25	45	55	70	150
Medium to heavy clay	25	45	55	65	140
Self-mulching clay	38	68	83	98	210

** Tension is 0 kPa at saturation point. The figures are only approximate.*

*** grapes should be irrigated before –60 kPa is reached except where partial rootzone drying is being practised*

1.1 Why do we need to know the water capacity of a soil?

- PAWC indicates the storage capacity of individual soils which:
- Gives a greater understanding of yield potential and scheduling requirements of different soil types.
- Gives a better understanding of the available soil moisture prior to planting to assist seasonal planning, yield prediction, irrigation requirements and fertiliser strategies. (A software tool available to help you determine likely starting soil moisture conditions from farm rainfall records is HOWWET.)
- Allows an appropriate refill point to be determined for each crop, soil type and development stage so irrigations can be accurately scheduled.
- Is used when undertaking irrigation benchmarking or determining a crop water balance.

While an understanding of PAWC is very useful, natural soil variability and the difficulty of measuring PAWC means that it is not generally feasible to obtain an intensive map of PAWC of a field. This is only likely where on-farm research or trials are being undertaken. PAWC data is more likely to be available within each important soil type across large farms, districts or catchments.

1.2 Determining PAWC

There are two ways to determine PAWC. The first is by field sampling.

For this, we need to measure the volumetric water content at Field Capacity (or DUL) and Permanent Wilting Point (or CLL) and determine the Bulk Density of the soil.

Volumetric water content at Field Capacity must be measured after the soil has reached saturation and allowed time for free drainage to occur. Measurement of Field Capacity may be undertaken after a significant rain or irrigation event after artificial wetting up. Ensure the entire soil profile becomes saturated.

Volumetric water content at Permanent Wilting Point must be measured once a crop has extracted as much water from the soil as it can. It will vary depending on the particular crop and soil type combination you are evaluating. It is often difficult to obtain because:

- Unless fresh roots are visible, it is not known to what depth current crop roots have explored and extracted
- Where water is available to the crop in the near surface, the roots may not fully exploit the profile
- A poor performing crop does not represent the correct extraction pattern
- Late rain at end of the season may re-wet the profile

Soil Bulk Density (BD) is a measure of the weight of dry soil per unit volume of soil (g/cm^3).

- BD in shrink-swell soils is measured in-field at Field Capacity or calculated from the relationship between gravimetric moisture content and BD
- BD in rigid soils can be measured in-field at any moisture content as it does not change with moisture content

Bulk Density (g/cm^3) = dry soil wt (g) ÷ total volume of soil (cm^3)

Gravimetric water (%) = (wet wt of sample – dry wt of sample) ÷ dry wt of sample x 100

Volumetric water (%) = gravimetric water (%) x BD (g/cm^3)

PAWC (mm) = volumetric water % x depth or thickness (cm) ÷ 10

Table 2: Example of PAWC calculations

Layer	Layer thickness (cm)	BD (g/cm^3)	Gravimetric Water (%)		Volumetric Water (%)		Layer PAWC Wheat (mm)
			FC	PWP	FC	PWP Wheat	
0-15 cm	15	1.15	42.85	27.47	49.3	31.6	26
15-30cm	15	1.14	42.8	27.7	48.8	31.6	26
30-60cm	30	1.15	42.17	28.52	48.5	32.8	47
60-90cm	30	1.16	41.37	28.7	48.0	33.3	44
90-120cm	30	1.19	39.4	30.6	46.9	36.5	31
120-150cm	30	1.23	37.03	31.8	45.5	39.2	19
						Total Wheat PAWC	**194mm**

The second way to determine PAWC is to make an estimate using existing information from similar or average soils. Some examples are shown in Table 3.

Table 3: Typical PAWC for grain crops on Queensland soils

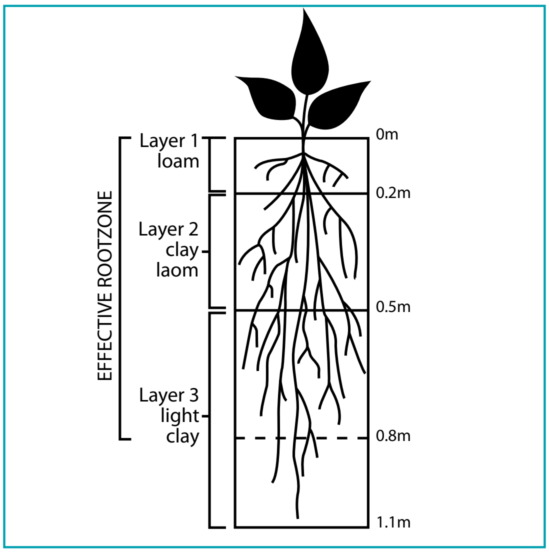
Soil type	PAWC (mm)	PAW (mm/cm/wet soil)
Darling Downs		
Heavy alluvial	230	1.9
Light alluvial	220	1.8
Brigalow clay	205	1.7
Light box clay	145	1.6
Softwood brigalow clay (uplands)	140	1.4
Red brown/red earths	130	1.2
Western Downs & Maranoa		
Heavy alluvial (Coolibah)	215	1.7
Deep open downs (Mitchell Grass)	160	1.6
Deep/heavy brigalow or brigalow-belah clay	190	1.6
Shallow/light brigalow or box clay	145	1.6
Light box clay	135	1.6
Red brown/red earths	130	1.2
Central Queensland		
Heavy alluvial flooded brigalow or yellow wood	215	1.7
Deep open downs	180	1.8
Light Callide alluvial	175	1.5
Brigalow/softwood scrub	160	1.6
Brigalow/Dawson gum/duplex	145	1.5
Shallow open downs	135	1.8

Source: WHEATMAN V4

1.3 Determining RAW from soil texture

RAW can be estimated if the texture of the soil and the effective root zone are known.

For example, a cotton crop growing in a topsoil of loam over layers of clay loam and light clay, with a soil profile 1.1 m deep, but effective root zone of only 0.8 m:



The calculations for determining RAW are:

STEP 1: Identify and measure the soil layers
Layer 1: 0 to 0.2 m = 0.2 m
Layer 2: 0.2 to 0.5 m = 0.3m
Layer 3: 0.5 to 1.1 m = 0.6 m

STEP 2: Determine the soil texture of each layer
Layer 1: Loam
Layer 2: Clay Loam
Layer 3: Light Clay

STEP 3: Select the crop water tension using Table 1 and identify the RAW for each soil layer
RAW values for each layer for cotton (Table 1, column D):
Layer 1: Loam = 90 mm/m
Layer 2: Clay loam = 80 mm/m
Layer 3: Light Clay = 70 mm/m

STEP 4: Identify the effective rootzone
Effective root zone = 0.8 m

STEP 5: Multiply the thickness of each soil layer to the depth of the effective root zone by its RAW value
Layer 1: 0.2 m x 90 mm/m = 18 mm
Layer 2: 0.3 m x 80 mm/m = 24 mm
Layer 3: 0.3 m x 70 mm/m = 21 mm
STEP 6: Add up the RAW values to obtain the total RAW of the soil profile
Total RAW = Layer 1 RAW + Layer 2 RAW + Layer 3 RAW
= 18 mm + 24 mm + 21 mm
= 63 mm

Final soil moisture (mm) = (post-harvest Vol. Water % – Field Capacity vol %) ÷ layer thickness (cm) ÷ 10

1.4 Determining starting and final soil moisture

Estimating available soil moisture (fallow moisture) or moisture remaining in the profile post-harvest may be useful for determining the crop water balance and for obtaining accurate benchmarking figures. (The formula above shows how)

2 Calibration of soil moisture monitoring tools

In this section, we will outline the procedure for calibrating soil moisture sensors. Calibrating soil water monitoring devices requires considerable effort – ensure that doing so is necessary and will be worthwhile. The resulting calibrations are often site specific and not applicable to other probe sites.

It is important to understand the strengths and limitations of these tools, whether calibrated or not. Below are some common uses for soil moisture tools showing where calibration may be required.

Calibration *NOT* required:

- Determining when to irrigate – the optimum time to irrigate is at or before Refill Point. This can be determined with uncalibrated probes by identifying the change of slope in the soil moisture trend lines. The slope changes because the moisture extraction rate is slowing, indicating that the crop is beginning to stress.
- Deficit irrigation scheduling – irrigating to maintain a deficit ie. not completely refill the profile, can also be done by observing the soil moisture trend lines from an uncalibrated probe. A calibrated probe may help by providing greater accuracy. Under deficit conditions, spatial variation may be pronounced, so even a calibrated probe may not give a good indication of average soil moisture. (A neutron probe is more likely to provide a good average value under these conditions.)

Calibration *IS* required:

- Determining volume of water applied or calculating a soil water balance – requires a calibrated probe, although this may be inaccurate under deficit conditions (as mentioned above) or saturated conditions (when probe readings will not increase even if water continues to be applied).
- Determining actual deficit (e.g. to calculate application efficiency) – the inaccuracies mentioned above may cause problems if you are irrigating to maintain a deficit. Using ET0 data and accurate crop coefficients may be better.
- Determining effective rainfall – but don't forget the spatial variability of the rainfall itself.

In addition, the usefulness of probe calibration in shrink-swell soils may be limited. The calibration is likely to vary with changes in Bulk Density, caused by the shrinking and swelling. (Bulk Density may also change due to deep ripping, changes to stubble retention practices, etc.)

2.1 Calibrating neutron moisture meter (NMM)

NMM's work by emitting neutrons from a low strength radioactive source. The neutrons collide with hydrogen atoms in the soil water molecules, causing them to be deflected in different directions and slow down. The meter counts the neutrons that return to it, the number of returns being related to the amount of water in the soil. The volume of soil sampled is a sphere about 15 cm radius around the neutron source.

2.1.1 Calculating count ratio

The counts read by the meter are divided by the standard count (obtained in a water drum) to give a count ratio. The meter counts are usually determined over a 16 second period (if three tubes at one site are averaged) at each position down the profile (see the NMM manual for how to set the count time). It is recommended (but not always done) that a new standard count be determined for each field prior to the soil moisture reading session.

2.1.2 Determining calibration curves for neutron probe

When a formal calibration is determined for a neutron probe, the count ratio (NMM reading to standard count) and the volumetric water content are compared and the relationship determined for each layer of the soil profile.

To determine this relationship:

- Take readings at distance intervals (usually 10 cm) down the profile and calculate the count ratio
- Extract soil cores close to each access tube and determine the gravimetric soil moisture content and Bulk Density for each interval corresponding to the NMM readings. From this information, the actual volumetric water content is then calculated.
- It is recommended that this process is undertaken at a minimum of two different moisture contents
- A regression analysis is performed on this data to generate coefficients 'A' and 'B'. These coefficients and the count ratio are then entered into the NMM software program so that the volumetric soil moisture content is given directly.
- The relationship of NMM counts to volumetric water content may not be linear. This can only be determined by taking readings and samples for at least 3 different soil moisture conditions. If is not linear, the relationship requires a third coefficient 'C'.

This calibration is site specific and cannot be used at other sites without error. In most farm situations, the relationship between soil type and count ratio is not determined and a universal calibration is used. Universal soil calibrations are generalisations based on broad soil categories and are not site specific. If your soil characteristics are similar to these, the readings may be accurate enough, if not the accuracy of the readings is questionable.

2.2 Calibrating capacitance probes

Capacitance probes such as the C-probe™ and Enviroscan® systems work by measuring the transmission of electromagnetic pulses in soil. This is influenced by a number of factors including moisture content.

Capacitance devices have been shown to deliver repeatability of readings with acute sensitivity to changes in soil water content.

2.2.1 Determining calibration curves for capacitance probe

Similar to the neutron probe, a capacitance device is calibrated by comparing sensor readings with measured soil moisture over a range of soil moisture conditions. Readings at a minimum of 3 different soil moistures are required (wet, moist and dry), although 6 readings (2 wet, 2 moist and 2 dry) are recommended.

Air gaps do not transmit the electromagnetic pulse so readings will be inaccurate where cracks develop around the access tubes. This is particularly a problem in cracking clay soils, where it may not be possible to obtain readings near Permanent Wilting Point. In this case, readings should be taken in soil as dry as possible – the results will be accurate to this level of dryness, which is usually well below the moisture range for irrigation.

Calibration process for capacitance probes:

- Measure probe air and water counts (required for both calibrated and uncalibrated probes)
- Measure probe raw counts for each depth for a particular moisture content
- Immediately take soil samples around this tube to determine Bulk Density, gravimetric soil moisture and hence volumetric soil moisture for the corresponding depths
- Repeat this process for the other required soil moisture conditions
- Convert raw counts at each depth level into scaled frequencies:

$SF = (Fa - Fs) \div (Fa - Fw)$

Where SF = Scaled Frequency
Fa = air count
Fw = water count
Fs = field count (soil measurement)

- Plot the scaled frequencies against volumetric water content on a graph for each depth and perform a regression analysis to generate the 'A', 'B' and 'C' coefficients to be entered into the relevant software

2.3 Using data from calibrated probes

2.3.1 For Irrigation Scheduling

Accurate readings of volumetric soil water content can allow you to determine actual full points, refill points and crop daily water use figures. This can improve the precision of your irrigation scheduling practice.

This data should be used with appropriate caution because of spatial variability – even a calibrated probe is sampling only a very small proportion of a whole field. Figure 7 shows traces from three calibrated probes positioned only 250mm apart, one in the plant row and the others on either side (Figure 6).

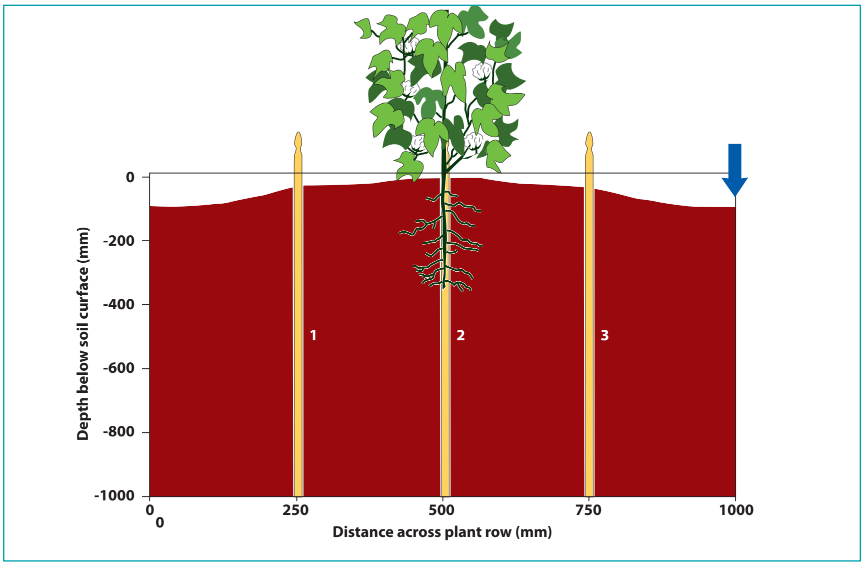


Figure 6: Probe setup for data used in Figure 7

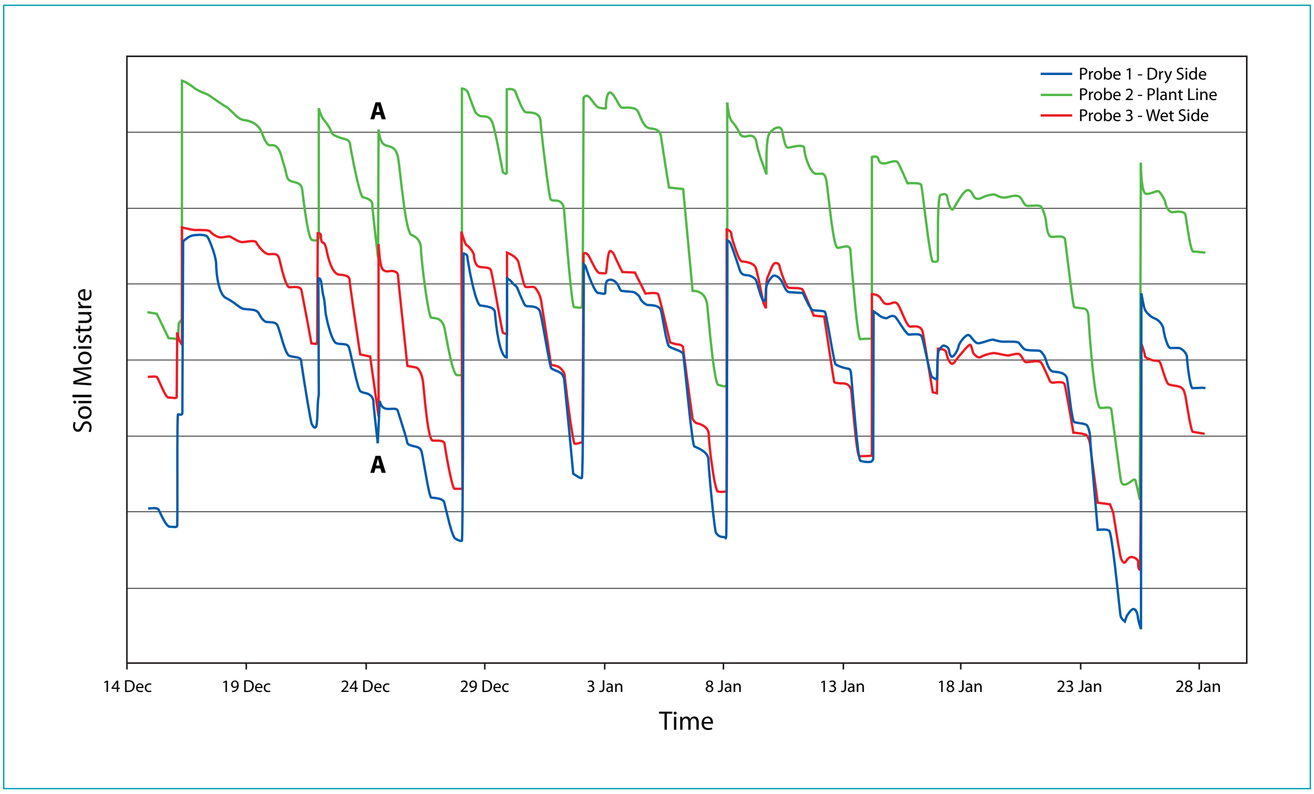


Figure 7: Different soil moisture traces from calibrated probes at adjacent sites

(Source: L Pendergast, J Hare QDPI&F 'Capacitance Probes - To Calibrate or not to Calibrate?')

Calibrated soil moisture probes can be used to estimate water volumes, such as the volume of water required to be applied to a crop, or the volume of rain that has infiltrated the soil. For example, in the management of centre pivot or lateral move machines, it is helpful to relate the increase in soil moisture resulting from the relatively small amounts of water applied, and to determine with more accuracy how much water to apply to meet the target deficit.

2.3.2 For volumetric soil water balance:

Data from calibrated probes can be used to complete the soil water balance which may be helpful for evaluating irrigation performance, fine tuning software programs such as HydroLogic and Watertrack Optimiser™, etc.

Hydrologic is a free software tool available from the Cotton CRC. This tool enables you to keep track of water applications to individual fields as well as predict yield and irrigation requirements. It incorporates SILO weather data and calculates ETc to monitor daily water balance.

WaterTrack Optimiser™ is a comprehensive water balance program which calculates water use for every element on the farm. This tool is also able to predict future irrigation performance, calculate benchmark figures, simulate water movement and predict water availability. The program generates ETc using SILO data.

Both these programs rely on crop coefficients (Kc) to generate ETc

Where:

ETc = ETo x Kc

Where a calibrated probe is used to determine daily crop water use, the above formula can be used to cross check and establish site specific crop coefficients:

Kc = daily CWU ÷ ETo

This may be useful where the crop coefficient for a certain crop type or variety or field configuration is unknown or for adjusting crop coefficients to increase confidence in predicted crop water use (ETc).

A helpful tool for cotton growers can be found on the Cotton CRC website - Crop Development Tool. It is an online web tool that allows you to map your crop and indicate wether its development is above or below the expected simulated crop in relation to day-degrees.

2.3.3 To implement a deficit irrigation strategy:

Research has shown that reproductive growth of cotton is maximised when plants are maintained with a reduced soil moisture deficit without affecting photosynthesis. A reduced moisture deficit therefore has been stated as the most agronomically desirable soil moisture level.

Excessive water deficit or stress should be avoided as it reduces photosynthetic supply, affecting both vegetative and reproductive growth.

Regulated Deficit Irrigation (RDI) may be implemented during part of the growing season by regulating moisture within a desired deficit range. RDI aims to optimise water use efficiency and therefore maximise the yield returned per unit of water applied. Any minor yield loss which may result from the implementation of a mild moisture deficit or stress under RDI is offset by the reduced water use leading to a reduction in excessive vegetative growth.

A range of crops have been found to benefit from a RDI strategy including maize, wheat, sunflower, potatoes, tomatoes and cotton.

The main benefits of implementing a RDI strategy in cotton are:

- reduction in excessive vegetative growth
- maintaining soil moisture in the most agronomically desirable range
- increase in water use efficiency, and
- ability to better capture and use in-season rainfall events after an irrigation event

Furrow irrigation practices generally result in soil moisture returning to near or above Field Capacity after an irrigation event. While the plants do not suffer any moisture stress for a certain time, they do suffer from waterlogging for up to a couple of days.

Drip, centre pivot and lateral move irrigation systems are able to apply smaller quantities of water more frequently, and are therefore better able to maintain soil moisture at the mild deficit required to implement RDI.

There are potential benefits and possible risks associated with the implementation of both RDI and Partial Rootzone Drying (PRD) strategies in cotton. Research is currently being conducted into the use of RDI in cotton grown with both drip and overhead systems.

Results to date have found improved WUE can be achieved through the implementation of an RDI strategy in cotton, and anecdotal evidence and some overseas research findings support this.

Significant improvements in water use efficiency have been achieved from PRD in grapes, but investigations with cotton and broad acre crops on furrow irrigation have shown limited application for this strategy. Before either RDI or PRD is implemented, knowledge of the predicted outcome and plant responses need to be further researched and understood.

3 Probe Placement

The correct siting and installation of access tubes is critical for soil moisture monitoring tools as only a small amount of soil is sampled. The position needs to be representative of crop type, density and vigour, soil type, irrigation system uniformity and application, and kept out of the way of machinery – placed in the centre of the plant line.

Soil moisture monitoring tools are usually located visually, from experience or "gut feel". But a moisture probe placed in the wrong spot can result in over or under irrigating the majority soil type in that field or management unit. For example, a probe sited in a section of field where the soil is lighter (hence lower water holding capacity), will not be representative of the majority soil type of the field. If this is not taken into account, the scheduling decision may result in more frequent irrigations than required for most of the field, costing you valuable resources and yield.

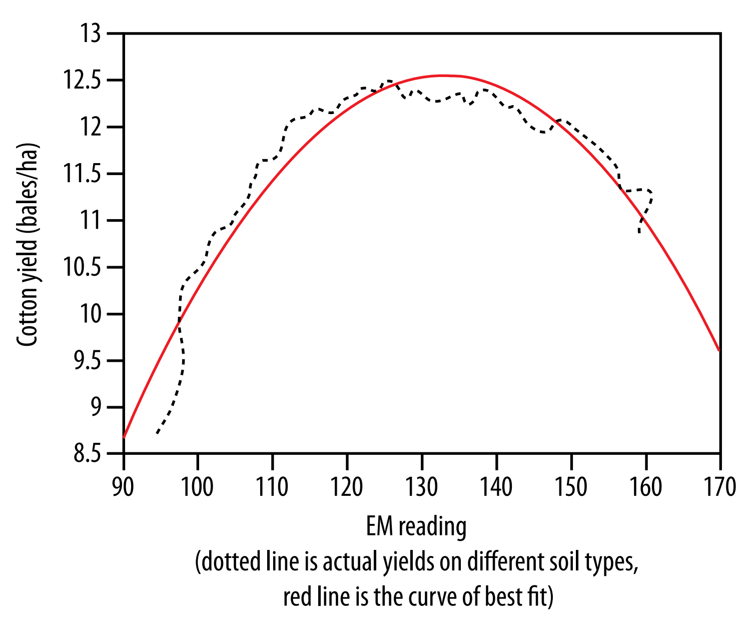


Figure 8: Example of a relationship between EM reading and yield

3.1 EM surveys

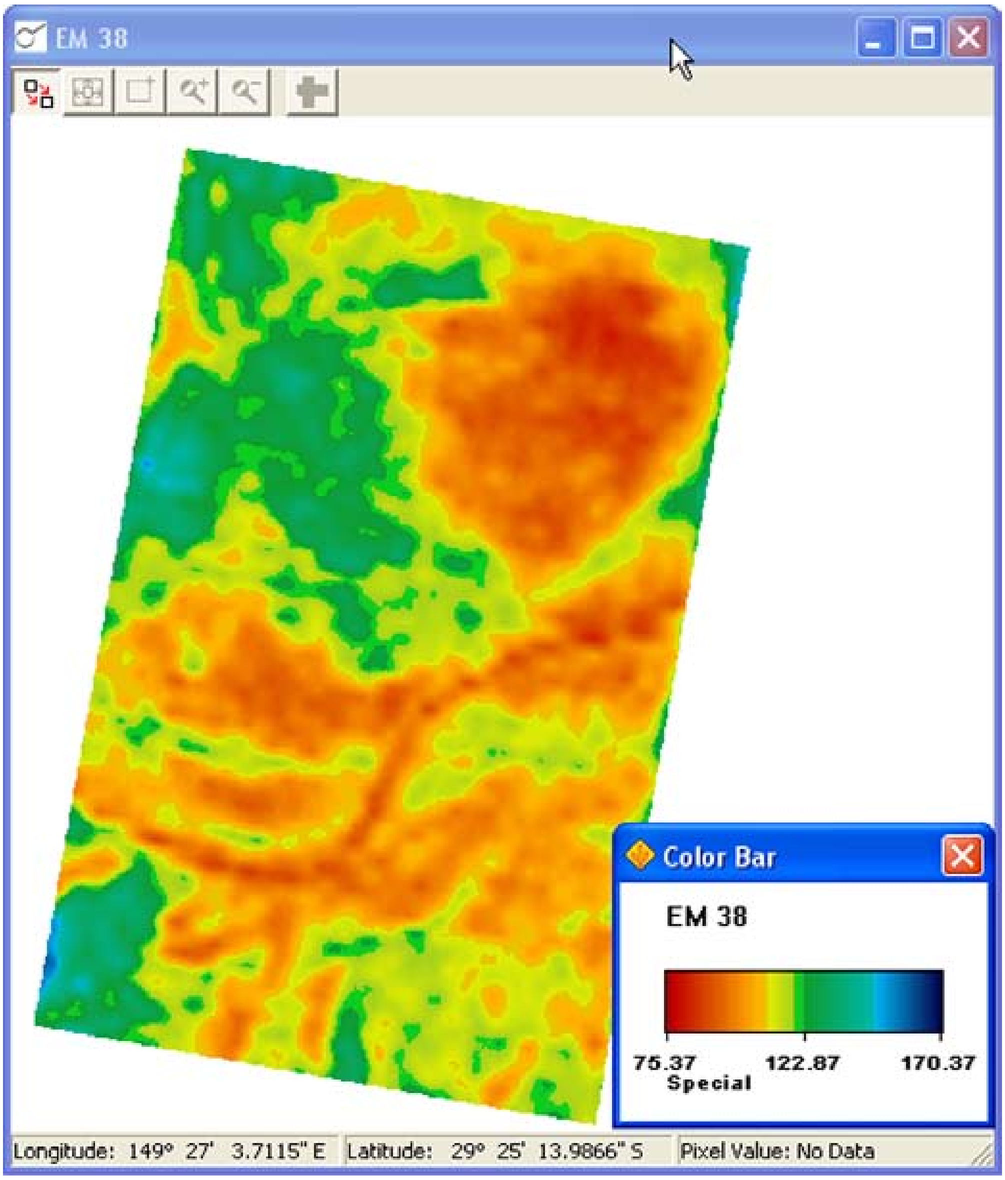
A recent development is the use of Electro-Magnetic Induction soil surveys to locate probes at the most representative site in field and farm. Electro-Magnetic (EM) induction measures the apparent electrical conductivity (ECa) of soil. ECa is affected by a number of influences, primarily soil texture, soil moisture and salinity. Conducting a survey of many readings in a field located by GPS coordinates allows a map of variability to be cheaply produced.

To minimise variation due to soil moisture, the survey should be conducted when the profile is full of moisture, ideally at the end of a fallow period or after an irrigation.

To calibrate the survey, ground-truthing is essential. This requires the collection and analysis of soil samples from known positions within the EM survey area and relating the results to the EM readings. The soil samples need to be analysed in a laboratory to quantify and isolate the effect of texture, salinity, moisture, etc.

This allows texture changes in the field to be identified and the texture classes established. Further analysis is needed to locate the "majority" soil type within a field. Convenient sites within the majority soil type are then located with GPS references, and probes installed in these precise positions.

Figures 9, 10 and 11 are an example of this technique. In this case, both the majority soil type was identified using an EM map and the majority slope was identified using many differential GPS readings. The minority conditions were eliminated by manipulating the data, and soil probe locations within the majority conditions were identified.

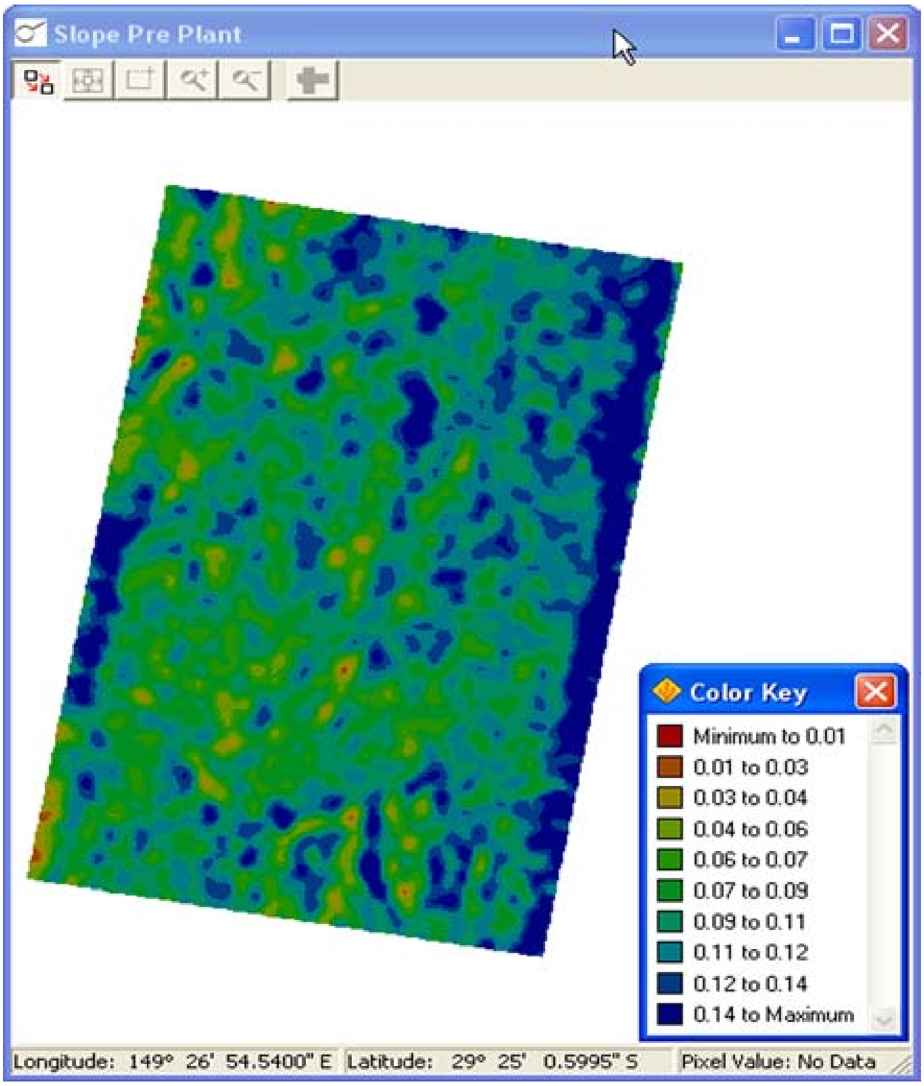


Longitude: 149° 27' 3.7115" E

Latitude: 29° 25' 13.9866" S

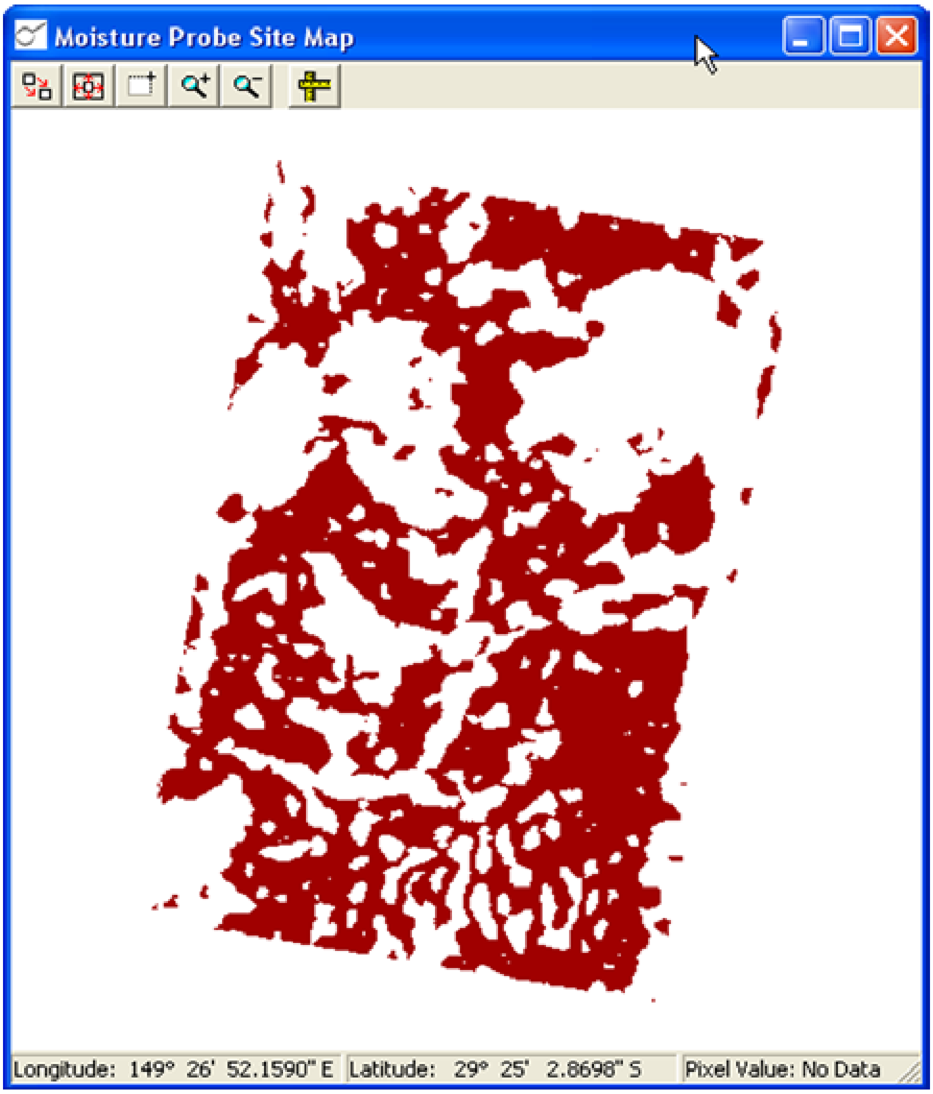
Pixel Value: No Data

Figure 9: EM38 map showing soil variability



Longitude: 149° 26' 54.5400" E Latitude: 29° 25' 0.5995" S Pixel Value: No Data

Figure 10: Slope map showing minor variations in slope that may affect runoff



Longitude: 149° 26' 52.1590" E Latitude: 29° 25' 2.8698" S Pixel Value: No Data

Figure 11: Final map showing best representation of majority soil type with majority slope

For more information see 'EM Surveys for Probe Placement' by J. Montgomery (NSW DPI), E. Brotherton (QDPI&F), and D. Wigginton (NSW DPI) available on the Irrigated Cotton & Grains web site www.cottonandgrains.irrigationfutures.org.au

Cotton and Grains Workshop Series

Surface Irrigation Performance Evaluation

CONTENTS

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New South Wales Department of Primary Industries

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DISCLAIMER AND WARNINGS

The information in this publication is designed as an information source to improve the sustainable use of water on irrigation farms in eastern Australia growing cotton. The information has been prepared from research studies and grower trials with specialist input from researchers, extension staff and irrigators. While these authors provide comprehensive coverage of on-farm water-related issues, they do not purport to address every eventuality that may arise on irrigation farms.

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Users are warned that, by law, the implementation of some of the management approaches and recommendations in this publication require prior authorisation from government and environmental agencies. Any appropriate government and environmental authorisations from the relevant state or territory agencies must be obtained before implementing a management approach or recommendation in the manual. If the user is uncertain about what authorisations are required, he/she should consult the relevant government department or legal adviser.

TRADEMARKS ACKNOWLEDGEMENT

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Cotton and Grains Workshop Series

Surface Irrigation Performance Evaluation

Key points

- Irrigation performance is controlled by a number of variables which influence performance to differing degrees
- Evaluating the performance of a surface irrigation system can be complex, but is absolutely necessary to improve efficiency
- Measures of performance include distribution uniformity, application efficiency and requirement efficiency
- Some practices used to improve performance must be managed precisely otherwise performance may actually be reduced

Surface irrigation is the process of applying irrigation water to the field surface and using the field itself to distribute the water. Common forms of surface irrigation include furrow irrigation, where water flows down narrow furrows between crop rows, or border-check irrigation, where water flows down strips of the field that may be up to 100 m wide. Systems such as bankless channel cannot currently be easily evaluated due to the fact that the water is applied from the bottom of the slope, making the surface hydraulics much more complex.

Surface Irrigation methods, particularly furrow irrigation, are commonly utilised throughout the Northern Cotton and Grain growing regions of Australia. This application system is often viewed as being reasonably low cost and simple to manage, although the performance is often considered to be reasonably poor.

In reality, furrow irrigation systems *may* be quite capital intensive, and a high labour requirement can often result in reasonably high operating costs. Perhaps most importantly, the performance of surface irrigation systems can often be much higher than many anticipate.

However obtaining the optimal performance of a surface irrigation system can be a daunting process for many, so we hope to outline what is involved and give a better understanding of the process.

Surface Irrigation Hydraulics

Unlike any other irrigation system, the application of water in a surface irrigation system is influenced greatly by the soil properties, as it is the soil which acts as the water distribution method.

Water application to a field, as either irrigation or rainfall, typically results in a combination of five processes.

1. Useful water is applied to the root zone, which may continue until the soil profile is filled to field capacity.
2. Additional water applied to the root zone, may increase the soil profile to saturation and cause waterlogging.
3. Excess water infiltrates through the soil profile, leaving the root zone as deep drainage (this process may continue after application ceases, as the saturated soil drains to field capacity).
4. Excess water leaves the field as runoff (tailwater).
5. Water is used through evapotranspiration

An ideal system will satisfy the first condition and provide for the fifth condition, whilst minimising the extent of the remaining three.

Infiltration

The entry of water into the soil is governed by the *infiltration characteristic* of that soil. The infiltration characteristics of different soils can vary considerably.

- Open sandy soils may allow a rapid intake of water which does not diminish markedly over time.
- Many cracking clay soils have a very rapid initial infiltration rate, which decreases over time as the soil swells and the pore space closes up.
- Hard setting soils may have a low initial infiltration rate which also does not vary considerably over time.

The infiltration characteristic can be represented by a cumulative infiltration curve. A *cumulative infiltration curve* shows the total amount of water that can infiltrate into a soil over a given period of time. Figure 1 is an example of some cumulative infiltration curves.

Note that the soils in the figure do not represent the whole range of infiltration characteristics that may be experienced. Similarly, an infiltration characteristic for a single soil may actually change between seasons or even within a season.

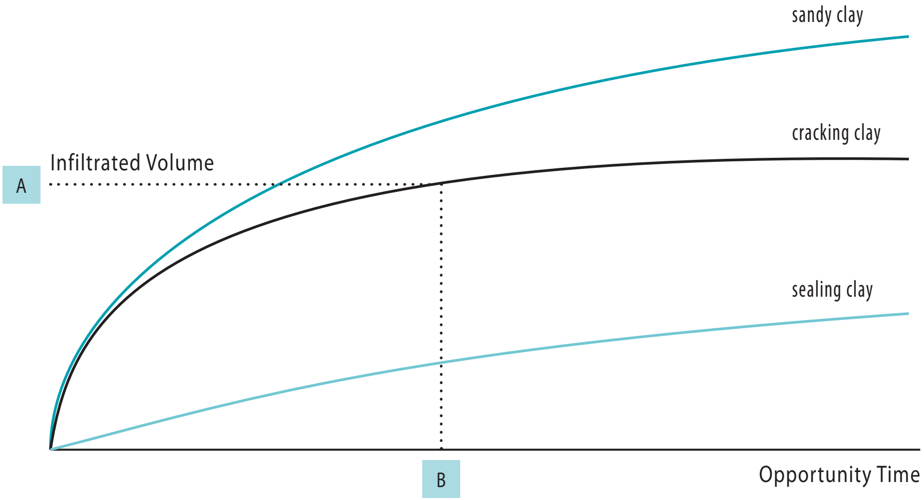


Figure 1. A range of cumulative infiltration curves showing different soil infiltration characteristics. (Source – P Dalton, NCEA)

Opportunity Time

The infiltration opportunity time is the length of time that water is present on the soil surface for infiltration to take place. To achieve the best performance, the opportunity time for an irrigation should equal the amount of time necessary to apply the required depth of water. In figure 1, if the amount of water required is indicated by ‘A’, then the time required to apply that amount of water is indicated by ‘B’.

The opportunity time for a furrow irrigation event often varies along the furrow. This is because the length of time that the water is present on the surface of the soil at any location is the difference between the time the water arrives (*advance*) and the time the water leaves (*recession*). As illustrated in figure 2, the rate at which the water advances down the field is different to the rate at which it recedes.

Even infiltration is achieved when the advance and recession rates are similar, resulting in an opportunity time which is more even along the entire furrow length.

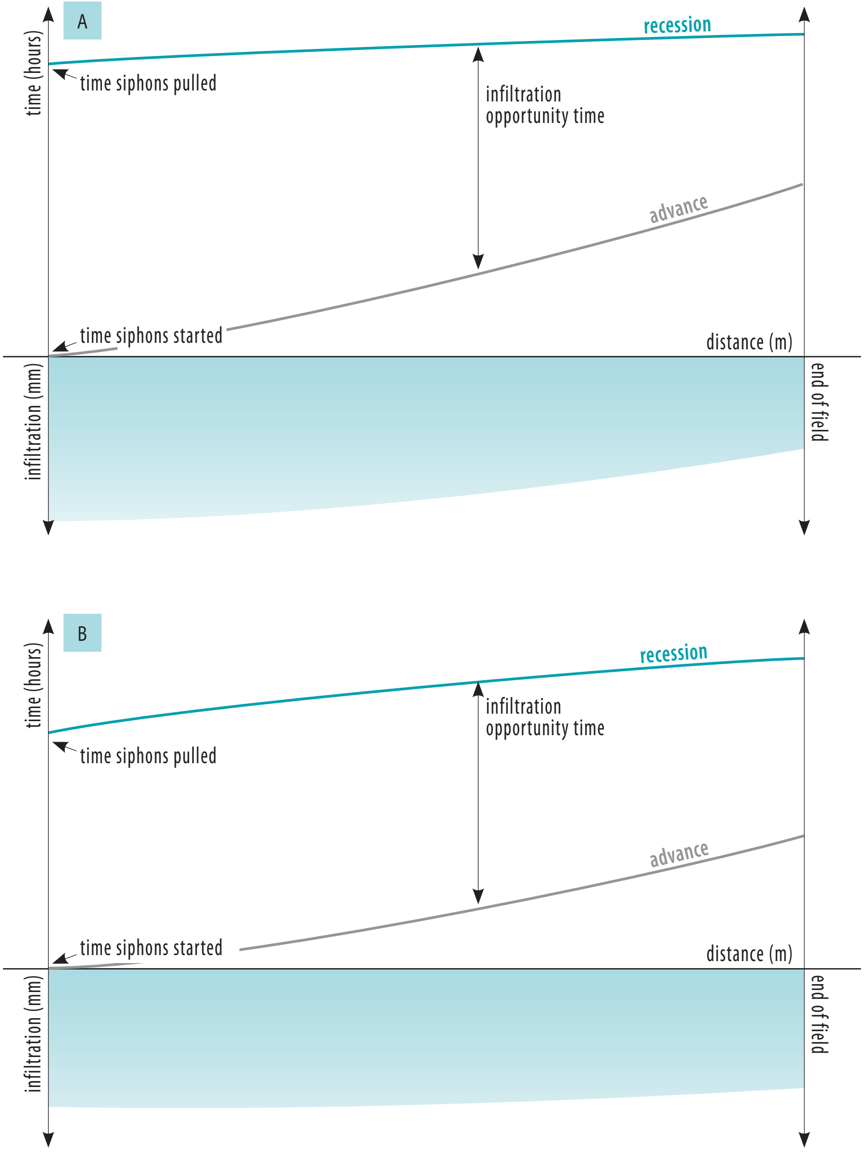


Figure 2. (a) Opportunity time varies with distance down the field (b) More even infiltration results from advance and recession curves which are similar

Distribution Uniformity

Distribution uniformity is a measure of how evenly water has been applied and is expressed as a percentage (%). Low distribution uniformity is caused by an uneven opportunity time along the length of the furrow. The result is either part of a field being under-watered or part being over-watered, in an attempt to apply sufficient water to the rest of the field. It is this practice that most often causes waterlogging to significant parts of a field, which in turn results in potential yield loss. Calculating distribution uniformity for furrow-irrigated fields typically requires computer modelling to simulate an irrigation event.

$$\text{Distribution Uniformity (DU)} = \frac{\text{Average of smallest 25\% of infiltrated amounts}}{\text{Average of all infiltrated amounts}}$$

Application Efficiency

Application efficiency relates the amount of water applied in an irrigation to the amount of water available to the crop for use and is expressed as a percentage. A high efficiency means that most of the water applied has remained in the root zone available for plant use.

$$E_a = \frac{\text{Irrigation water available to crop}}{\text{Water received at field inlet}}$$

A uniform irrigation does not guarantee efficiency and an efficient irrigation does not guarantee uniformity.

For example, an irrigation may be almost perfectly uniform, in that the same amount of water is applied to every part of a field. However if the total amount of water applied were twice that required, the application efficiency would only be 50% (Figure 3).

Figure 3. A Uniform but inefficient irrigation.

In contrast, an irrigation may be perfectly efficient, such that all of the water applied to the field remains in the root zone available for use. However if this water only made it across half of the field, the uniformity will be extremely low (Figure 4).

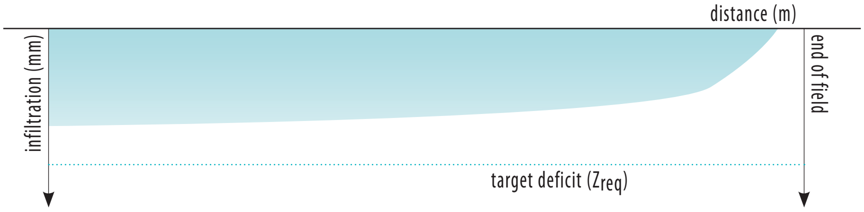


Figure 4. A non-uniform but efficient irrigation

Hence optimum system performance is achieved when both application efficiency and distribution uniformity are high.

Requirement Efficiency

Calculation of both Distribution Uniformity and Application Efficiency are required to achieve a rank 1 for worksheets 10 and 11 of the Cotton BMP Land and Water Management Module

One other term that may be used to describe the performance of an irrigation system is requirement efficiency. The requirement efficiency simply refers to how well the irrigation event satisfied the soil moisture deficit at the time of irrigation.

If any part of a field is under-irrigated, the requirement efficiency will drop below 100%. However, the closer the requirement efficiency is to 100%, the greater the chance that the application efficiency will be reduced, as water will inevitably be lost as drainage or runoff.

Figure 5 demonstrates the components of an irrigation event. Potential water losses are represented by the evaporation, drainage and runoff arrows. The volume of water that is applied to the root zone is indicated by the light blue coloured area.

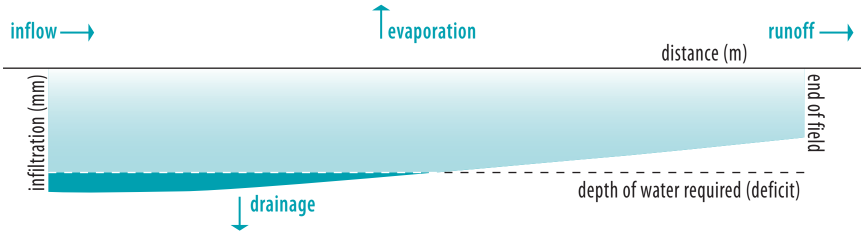


Figure 5. Representation of a furrow irrigation event

Evaluating Surface Irrigation Performance

The theory behind these surface irrigation processes is actually reasonably straightforward. However, most of the action is happening below the soil surface. This makes many of the variables virtually impossible to measure. Perhaps the most important variable used for evaluating performance is the volume of water represented by the blue region in Figure 5. But how can you physically measure this volume? You would need to measure the volume of water that has infiltrated the soil vertically, at every location down the length of the field!

These parameters can be determined by making some much simpler measurements and then using these measurements to operate a computer simulation model. This process is offered commercially as the Irrimate™ service, and we will give an overview of what this process entails and more importantly, what is the output and how can it be used?

What is happening under the soil surface?

Performing a surface irrigation performance evaluation requires measurement of a number of inputs.

- Inflow rate
- A number of advance points (the time it takes water to reach a certain distance down the field)
- The dimensions of the furrow
- The depth of flow in the furrow
- Field length and slope

Advanced simulation techniques can also utilise furrow outflow data and variable inflow data to improve the ability to model some irrigation events.

The rate at which the water moves down the field (advance) is influenced by the infiltration characteristic of the soil. Hence if you are able to measure the advance curve, you can determine the infiltration characteristic. After this is achieved, you can then use this infiltration characteristic to determine what might happen if you change various irrigation management parameters, such as the inflow rate or the time to cutoff.

Improving Surface Irrigation Performance

The performance of a surface irrigation event is influenced by a number of design and management factors. Each of these factors has a different amount of influence over the performance of an irrigation event, as illustrated in Table 1.

Table 1 – Effect of surface irrigation variables on irrigation performance

VARIABLE	INFLUENCED BY	IMPACT ON PERFORMANCE	COMMENTS
Soil infiltration characteristic	Usually cannot be influenced	***	High infiltration soil – slow advance & rapid recession
Inflow rate	Management & design	***	High flow rate – fast advance rate, potential for increased tailwater runoff
Time to cut-off	Management	***	Determines total opportunity time, deep percolation loss and tailwater volume
Length of field	Design	**	High efficiency & uniformity can be difficult on long fields
Application Depth (deficit)	Management	**	Irrigating to a deficit which is very small or very large may reduce performance.
Field Slope	Design	*	Steep slope – increases rate of advance & recession
Surface Roughness	Usually cannot be influenced	*	Rough surface – slower advance
Furrow Dimensions and Shape	Design & management	*	Furrow shape has little impact, although changes in infiltration characteristic (e.g. through compaction) may do.

*** – more impact, * – less impact

Source – National Centre for Engineering in Agriculture

Infiltration Characteristic

The soil infiltration characteristic is essentially a variable which is generally out of the control of the irrigator. In some circumstances the infiltration characteristic may vary, for example in some sealing soils the infiltration characteristic may vary during the season as the soil structure changes. Similarly the infiltration characteristic may be varied through tillage practices or when large deficits produce significant cracking.

If the infiltration characteristic does change throughout the season, then you should have an estimate of how these infiltration characteristics change and what management strategies should be applied, as management may need to vary.

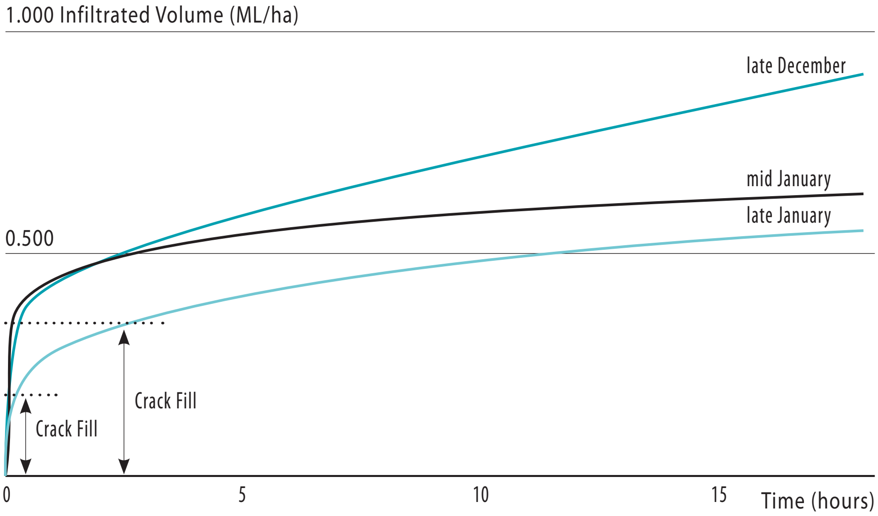


Figure 6 – Cumulative Irrigation Curves demonstrating a change in infiltration characteristic over the course of a season. (Source – D. Richards, CSIRO)

The use of Polyacrylamide (PAM) also affects the infiltration characteristic. PAM maintains an open soil structure, usually resulting in increased infiltration. For any soils where deep drainage already occurs, this will lead to increased deep drainage. It is important when using PAM to understand that this product will change the infiltration characteristic, and thus affect performance. If you have already evaluated performance without PAM, then you will need to re-evaluate the performance with PAM. The effect of PAM is typically reduced or removed following cultivation.

Inflow rate

Inflow rate has a major impact on performance due to the effect on the speed of water advance down the field. A faster advance is typically more desirable on high infiltration soils as the advance curve becomes more closely aligned to the recession curve, improving uniformity. However, as inflow rate increases, the volume of water lost as tailwater increases significantly if the cutoff time is not accurately matched. Inflow rate typically has the largest influence of any variable that can be managed by the irrigator.

Irrigation performance can be affected through both a gross change to the inflow rate as well as variations to the inflow rate during the irrigation event. Often a variable inflow rate occurs when the water level in a head ditch is not kept constant. Variable inflow may have a range of effects on different performance measures. As an example, figure 7 shows a reduction in distribution uniformity due to an unintentional variation in inflow rate.

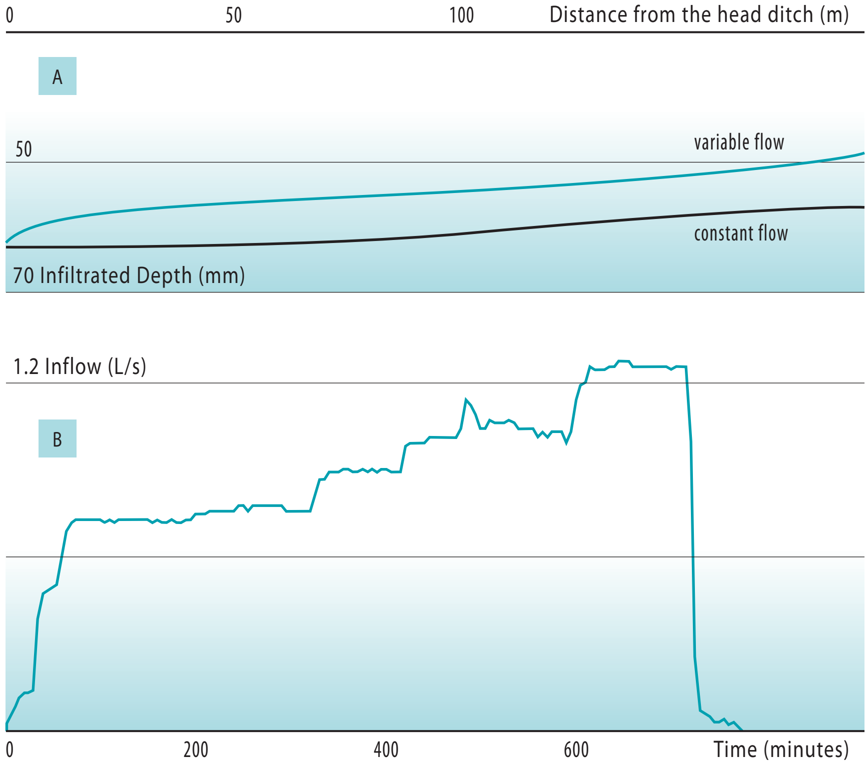


Figure 7 – (A) Infiltrated depth profile for variable and constant (0.825 L/s) inflow (B) variable inflow hydrograph for this example (Source – M. Gillies, NCEA)

Siphon Head – Discharge charts can be used to estimate siphon flow rate and are included in WATERpak – Appendix 9.11

Time to Cutoff

Along with Inflow rate, time to cutoff is a key variable which can be easily managed by the irrigator. In fact, it is typical for these two variables to be managed together.

Depending on soil infiltration characteristic, cutting off the irrigation too soon may result in insufficient depth of water application, poor requirement efficiency and poor uniformity. Cutting off the irrigation too late could easily result in excessive tailwater and deep drainage, decreased application efficiency and a high risk of yield loss due to waterlogging. As mentioned previously, increased inflow rate is likely to result in excessive tailwater unless time to cutoff is managed accordingly.

Figure 8 demonstrates the effect on a number of parameters of changing only time to cutoff for an irrigation event. In this case the optimum strategy is to cutoff at 320 minutes. Cutting off at 240 minutes meant that the water did not reach all the way to the end of the field. Cutting off at 400 minutes resulted in more than twice the amount of tailwater and additional deep drainage. The application efficiency calculations assume an 85% efficiency in tailwater recycling.

SCENARIO	A	B	C
Time to Cutoff (mins)	240	320	400
Inflow (ML/ha)	0.83	1.11	1.38
Outflow (ML/ha)	0.00	0.17	0.41
Infiltration (ML/ha)	0.83	0.94	0.98
Deep Drainage (ML/ha)	0.01	0.07	0.11
Application Efficiency (%)	> 95	87	84
Requirement Efficiency (%)	90	100	100

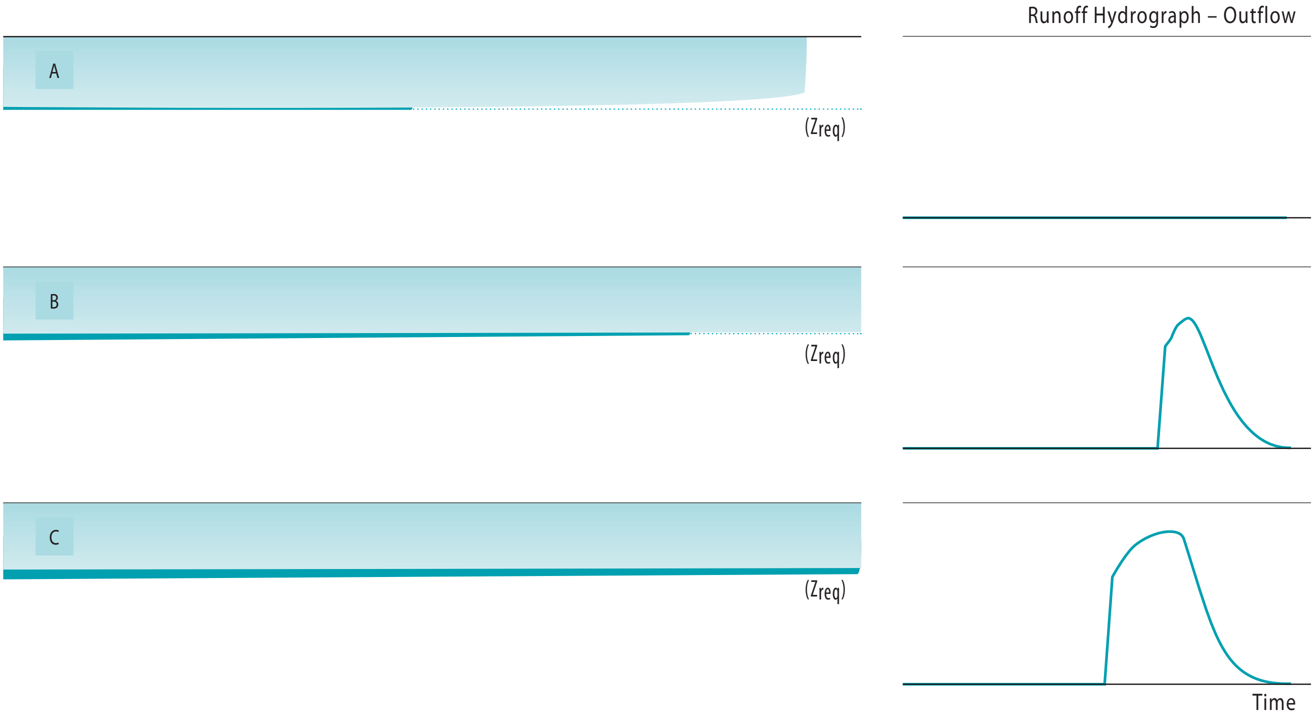


Figure 8 –The effect of cutoff time for an event where inflow = 6 L/s and field length = 520m. Optimum cutoff time is 320 minutes.

Field Length

Field length can influence distribution uniformity because the advance rate becomes slower as the irrigation water has to travel further down the furrow. This makes it more difficult to obtain advance and recession rates which provide for a similar opportunity time along the length of the furrow.

Such non-uniformity can impact upon efficiency by increasing deep drainage at the top end of the field. Field length cannot be managed between irrigation events. However modifying existing furrow lengths may be an appropriate strategy for some situations in the design phase (Table 2).

Table 2 – Improved performance due to a change in field length and management (source – R. Jackson, NSW DPI).

	ORIGINAL FIELD PERFORMANCE	PERFORMANCE FOLLOWING CHANGE IN FIELD LENGTH
Field Length (m)	885	408
Flow Rate (L/s)	2.70	3.8
Time – Water Applied (hr)	20	6
Deficit (mm)	60	60
Inflow (mm)	110	83
Tailwater (mm)	27	21
Water Infiltrated (mm)	83	62
Application Efficiency (85% of tailwater recycled)	69	92
Distribution Uniformity – DU (%)	92	92
Potential Water Saving (ML/ha)		0.22

Application Depth (Deficit)

The application depth for a surface irrigation event is typically viewed as being fixed, as determined by the amount of crop extraction since the last full irrigation. Whilst this is often the case, there are two circumstances in which deficit may become a management variable:

1. In some soils, it may be possible to apply less than the total deficit. This may allow for increased application efficiency, although irrigation frequency will need to be increased. However, in some soils, particularly highly cracking clay soils, it may be difficult or impossible to apply less than the total deficit due to the presence of cracks.

   Conversely some soils have poor infiltration where deficit irrigation is likely to occur as a matter of course. In these situations performance may well be high, although there is insufficient water infiltrating the soil and being made available for the crop.

Be careful – deficit irrigation may allow for improved performance and ability to capture rainfall, but there is less moisture buffering in the soil and a greater number of smaller irrigations will be required.

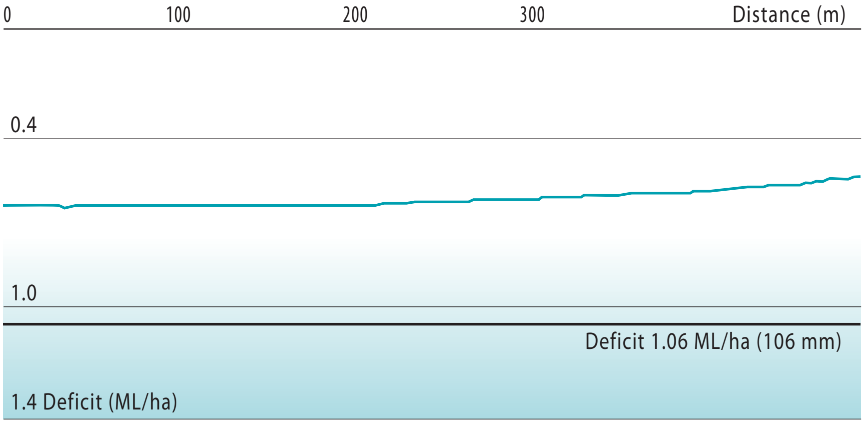


Figure 9 – Example of a deficit irrigation event where the amount of water applied is less than the deficit at the time of irrigation (Source – R. Jackson, NSWDPI).

2. It may also be possible to apply irrigation events earlier or later in order to influence the total deficit at the time the irrigation takes place. Often irrigating to a smaller deficit will allow for a faster advance rate. This may be useful in soils where it is difficult to obtain a fast advance rate when the deficit is large due to the presence of large cracks. Modifying irrigation frequency may also have agronomic impacts.

Table 3 – Example of water applied to different irrigation strategies on the Darling Downs (Source J. Hare, QDPI&F)

	EARLY STRATEGY	NORMAL STRATEGY
Deficit at Irrigation (mm)	80	100
Number of Irrigations	5	4
Water Applied each Irrigation (ML/ha)	1.4	1.65
Total Water Applied (ML/ha)	7.0	6.6
GPWUI (B/ML)	1.66	1.63

Determination of application efficiency and requirement efficiency rely on the accuracy of the deficit before irrigation. Errors in the deficit value may influence these parameters by inaccurately determining the proportion of water applied to the root zone.

Field Slope

The field slope has very little influence on the rates of advance and recession, and virtually no impact on performance. Hence modifying slope without first determining the effect on performance may have very little benefit, particularly for the potentially high cost of earthworks involved.

For the irrigation event in Figure 8, there was absolutely no difference in performance between a slope of 1 in 10000 (0.01%) and a slope of 1 in 1000 (0.1%). The water arrived 28 minutes sooner on the steeper slope (309 mins vs 347 mins), but this did not impact on performance.

A field with variable slope may have a greater impact, particularly where melon holes or similar depressions actually create a minor uphill slope that allows water to pool temporarily. However, some variation in slope may actually 'even out' poor performance cause by other factors such as changes in soil type (infiltration characteristic).

It is **vital** to investigate current performance before spending large amounts of money on modifying slope if the aim of the earthworks is to improve irrigation performance.

Surface Roughness

The roughness of the soil surface provides a resistance to the flow. Typically the surface roughness is not something that can be readily controlled, although it may be modified somewhat due to cultivation practices, stubble retention, etc.

An increase in surface roughness leads to a reduction in the speed of advance across the field and usually only slightly influences performance.

Evaluation Results

When you have a surface irrigation performance evaluation, it is typical to receive a report that demonstrates the measured performance, as well as one or more alternative management strategies that could be implemented, and the likely performance of these strategies.

Interpreting these results is usually a matter of comparing the various performance measures (as discussed earlier) for the different optimised scenarios and determining which of the options can be practically and economically applied.

Usually, evaluations have been undertaken for a few different events during the season, so it is important to remember that the optimum practice for an early season irrigation may not be the same for an irrigation event later in the season.

Implications of Management Changes

Precision – Stick to the Prescription

Often (although importantly, not always), improved performance is obtained from a combination of increased inflow rate and decreased time to cutoff. When inflow rate is increased, more precise control is typically required as it becomes easier to adversely affect performance when the inflow rate is high.

For this reason, it is important to objectively evaluate your system performance, rather than simply increase the inflow rate using some kind of *Rule of Thumb*.

One of the major secondary effects that occurs when increasing inflow rate is that the opportunity for larger volumes of tailwater is increased. This is illustrated in Table 3, where a measured irrigation event had an inflow rate of 2.63 L/s for a duration of 860 minutes. In optimising this irrigation event, the recommended change was for an inflow rate of 6 L/s for a duration of 320 minutes. Management for this scenario must be more precise to capitalise on the benefits of the recommendation.

The table demonstrates the volume of water applied and runoff if the siphons are left for periods of time in excess of the recommendation. For example, if the optimised event is left to run for an hour longer than the recommendation (a total of 380 minutes), not only has there been more runoff than for the measured event, but also more than if the measured event had run for an extra hour (a total of 920 minutes). The infiltrated amount and potential for deep drainage may also be adversely affected.

Table 3 – Control of cutoff time becomes more important as flow rate increases

	MEASURED EVENT	OPTIMISED EVENT
Field Length (m)	520	520
Flow Rate (L/s)	2.63	6
Time – Water Applied (min)	860 14 hrs 20 mins	320 5 hrs 20 mins
Time – Advance to end of field (min)	710 11 hrs 50 mins	310 5 hrs 10 mins

ADDITIONAL TIME TO CUTOFF (hr)	MEASURED EVENT (ML/ha)		OPTIMISED EVENT (ML/ha)	
	INFLOW	OUTFLOW	INFLOW	OUTFLOW
0	1.31	0.25	1.11	0.17
0.5	1.35	0.29	1.21	0.26
1	1.39	0.33	1.32	0.35
1.5	1.44	0.37	1.42	0.44
2	1.49	0.40	1.52	0.54
2.5	1.53	0.44	1.63	0.63
3	1.58	0.48	1.73	0.72

Often the volume of tailwater is dismissed as being only a minor cost; however it is important to understand that there are a number of reasons to manage tailwater volumes. It is not uncommon for the cost of pumping tailwater to be in the order of $20 per ha.

In the example above, the measured event had tailwater of 0.25ML/ha per irrigation. For 7 irrigations with a pumping cost in the order of $10/ML, this is a total of $17.50 per ha.

In addition, research has shown that it is possible to lose 15% of tailwater as it is recirculated around the farm. Therefore as the volume of tailwater increases, so do the potential losses. Finally, there is often little thought given to the secondary effects of tailwater such as sediment and nutrient losses. Recent research has indicated that the quantities of sediment and nutrients being lost in tailwater can be significant, and that the concentration of these generally increases with the flow rate.

Nutrient and Sediment Losses

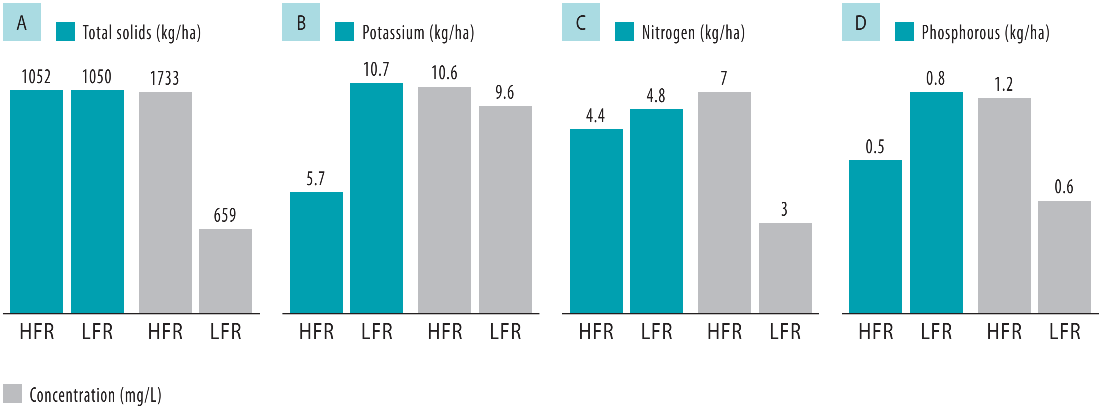
It is not uncommon for 1 t/ha of sediment per season to be lost from surface irrigated fields in irrigation tailwater only, in addition to losses from rainfall runoff. As the flow rate increases, the concentration of sediment and some nutrients increases.

Therefore the total volume of tailwater must be reduced accordingly to prevent an increase in these sediment and nutrient losses.

Figure 10 shows the results of the analysis of irrigation tailwater for every event of a single field in the Dawson Valley for the 2005-06 season. The concentration of various contaminants was measured over the duration of the runoff event and was scaled up by the volume of tailwater measured to give the total amounts indicated below.

For all of the contaminants, the concentration was greater when the flow rate into the furrow was higher. However, the total amount of contaminant was lower because the volume of tailwater was reduced accordingly. If the cutoff time under the high flow rate scenario was not correctly selected and the volume of tailwater was too high these figures would change dramatically.

The low flow rate was the grower standard practice at 1.5 L/s and the high flow rate was the improved practice at 4 L/s. The field was approximately 700 metres long.



HFR – high flow rate, LFR – low flow rate,

Figure 10. The total amount and concentration of (A) Total Solids (B) Potassium (C) Nitrogen and (D) Phosphorus removed from a field trial site in a single season (Source – A. McHugh, NCEA).

The volume of tailwater is also a significant consideration when water running urea, as much of the Urea being applied may leave the field in the tailwater,

Agronomic Management

As we have seen, the performance of surface irrigation events can be influenced by the infiltration characteristic of the soil, which in turn can be influenced by the deficit at which an irrigation takes place. For this reason, irrigation scheduling can influence the performance of a surface irrigation event. There are subsequently many related agronomic impacts associated with irrigation scheduling.

- A smaller irrigation deficit will influence performance by typically increasing the rate of advance. This may lead to a greater number of smaller applications. Agronomically, smaller deficits **may** promote rank growth in indeterminate crops, such as cotton, due to the balance between vegetative and reproductive growth.
- A large irrigation deficit will influence performance by typically decreasing the rate of advance. This may lead to fewer large irrigations. If the deficit is too large the plant may stress too much before the irrigation takes place.

Regardless of the scheduling chosen, if the irrigation event is not managed accordingly, performance may be adversely affected.

Many other practices can also influence, surface irrigation performance, such as:

- Stubble retention in furrows
- Use of Polyacrylamide (PAM)
- Soil treatments and surface cracking
- Mulch cover
- Row configuration

It is suggested that appropriate monitoring of plant stress or soil moisture, along with evaluation of irrigation performance, will provide the information necessary to maximise both plant productivity and water use efficiency.

Further Information

Further information is available in WATERpak Chapters 2.9 and 4.2 and on the internet at www.cottonandgrains.irrigationfutures.org.au

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Storage and Distribution Systems

Key points

- Storage and Distribution Systems should be actively managed to reduce water losses
- Efficient storages and distribution systems are an essential part of improving whole farm water efficiency.
- Maintenance of storages and delivery and supply systems should be a planned component of the operation of the irrigation farm
- soil types and variation are important in the performance of on-farm storages and distribution systems
- avoid construction of storages and channels on sites with highly permeable soils
- Seepage issues are most commonly caused by unplanned or poor construction of structures – unsuitable soil type, poor design, poor compaction, poor maintenance.
- Storage efficiency and Distribution (Conveyance) efficiency are useful terms for indicating performance
- recording measurements is essential for assessing the loss factors
- whether to mitigate evaporative or seepage losses is mainly an economic decision

Introduction

Efficiency of storage and distribution systems has three aspects:

1. supplying water to the plants in the volumes and at the times required,
2. draining excess water from plants and fields as quickly as possible, and
3. minimising losses from the system.

Monitoring and evaluation of a farm's storage and distribution system has become easier with recent developments in measuring equipment, software and benchmarking protocols.

Performance of distribution and drainage systems

The ability to move water around your farm efficiently so that the plants have the right amount delivered to them at the right time requires a properly designed and maintained channel system. This is especially so on large farms where the channel network is quite extensive. This section details some characteristics of good channel systems.

Efficient channel systems have the following characteristics:

- Capacity to meet the crop's peak water requirement.
- At least 0.15m freeboard
- minimum number of structures
- all components large enough to handle high pump flows, high rivers, tailwater flows, rainfall runoff and any future expansion
- Channels crossing lighter soils are lined with an impervious layer (eg. clay)
- Able to be completely drained when not in use
- Free of weeds
- de-silted regularly
- pipes and culverts in good condition eg. no fractures, damage, etc.
- structures with minimal head loss
- culverts that flow full without sucking air (vortexing)
- Structures have headwalls or wingwalls – to reduce head loss and erosion

Further Reading:

WATERpak	Chapters 2.6, 2.7, 4.2 (part)
Cotton BMP Manual	Land & Water Module 2.18, 3.1 to 3.4, Appendices 3 & 4, Worksheet 8
Guidelines for Ring Tank Storages	Irrigation Australia www.irrigation.org.au
NCEA Evaporation ready reckoner	http://www.npsi.gov.au/readyreckoner/index.html

Figure1 - Example of a broadacre storage and distribution system.

Distribution capacity affects irrigable area

The flow rate of the distribution system is one factor determining how much area can be irrigated. If the capacity of the channels, structures, etc. is insufficient, water will not be delivered at the required rate.

Example:

Channel capacity: 29 ML/day
Overall farm irrigation efficiency: 70% (0.70)
Readily Available Water or Irrigation Deficit: 100mm
For one irrigation set per day this = 1 ML/d
Irrigable area: 29 x 0.70 ÷ 1 = **20.3 ha**
(1 ML of water spread over 1 ha covers to a depth of 100 mm)

Head and head loss

Water movement requires energy. The energy driving a gravity system is called ‘head’ and the loss in energy is called ‘head loss’. Overcoming the resistance or friction as water moves through channels or pipes accounts for much of this energy use. Head loss increases when water moves through bends, structures or other restrictions, sudden changes in channel or pipe size, and with length of pipe. Head is measured in metres for gravity systems and for pressure systems head is measured in metres or kilopascals
(1m = 9.806 kPa = 1.42 psi).

Careful design and management of a system aims to minimise overall head loss and variation in head throughout the system. This enables water to be moved with the greatest possible ease, minimises energy costs, channel and pipe sizes, and reduces the risk of overtopping. This often justifies investing in slightly larger pipe sizes due to reduced head loss.

Minimal head loss throughout the system means maximum head at the field. This will allow watering at rates that enable high field application and distribution efficiencies and may allow you to irrigate distant or higher blocks.

Flow rates vary with the head available. If the head is high, the flow through the outlets, such as siphons or gates, is greater and therefore more outlets irrigating more of the field may possibly be utilised. Smaller outlets in any one bay or furrow may be possible where the water level in the supply channel is high. If the head in the channel varies during irrigation events, so will the flow through the outlets and the amount of water applied to the field. This will affect the amount of water going on to the field and may mean inadvertently over or under watering the crop.

The tables below show the variation of flow through two types of outlets with variation in head.

Table 1. Flow rate in litres/second, siphon length 4.0 metres

(Refer to WaterPak Appendix 9.11 for a more extensive table of siphon sixes and flow rates, and to Section 4.2 for Pipe-through-the-bank flow rates)

Imperial sized siphons are specified according to their internal diameter (ID) while metric siphons are specified according to their outside diameter (OD). This means that the ID (the dimension that affects flow) of a metric siphon is always smaller than the specified measurement, and is always smaller than an equivalently specified imperial siphon.

OPERATING HEAD (mm)	NOMINAL SIPHON SIZE							
	INTERNAL DIAMETER							
	1 ¼″ 31.75	1 ½″ 38.1	2″ 50.85	50mm 44.0	50mm 47.0	63mm 55.5	63mm 59.0	75mm 65.1
100	0.6	0.8	1.6	1.2	1.3	1.9	2.2	2.7
150	0.7	1.0	1.9	1.4	1.6	2.3	2.7	3.3
200	0.8	1.2	2.2	1.6	1.9	2.7	3.1	3.8
250	0.9	1.3	2.5	1.8	2.1	3.0	3.5	4.3
300	1.0	1.4	2.7	2.0	2.3	3.3	3.8	4.7
350	1.0	1.6	3.0	2.1	2.5	3.6	4.1	5.1
400	1.1	1.7	3.2	2.3	2.7	3.8	4.4	5.4
450	1.2	1.8	3.4	2.4	2.8	4.1	4.6	5.8
500	1.2	1.9	3.5	2.6	3.0	4.3	4.9	6.1

Table 2. Door Outlet flow (L/s)

	OPENING WIDTH (mm)					
Head (mm)	300	450	525	600	750	900
100	18	26	31	35	44	52
150	32	48	56	64	80	96
200	49	74	86	99	123	148
250	69	104	121	138	173	207
300	91	136	159	181	227	272

Example:

A field 800m long with 1 m furrows with one 63mm siphon per furrow, has 100 siphons operating in a set for 6 hours. If the head in the supply channel is 300mm for the first set and increases to 400mm for the second set, the difference in the amount of water applied between the two sets is shown in the table.

HEAD FROM SUPPLY CHANNEL TO FURROW:	300 mm	400 mm
Siphon flow (from table above)	3.8 L/s	4.4 L/s
Total Flow over 8 hours	109,440 L	126,720 L
Volume applied to field (100 siphons)	10,944,000 L 10.944 ML	12,672,000 L 12.672 ML
Irrigated area	8 ha	8 ha
Volume applied	1.37 ML/ha	1.58 ML/ha
Average depth applied over field	137 mm	158 mm

The difference is **21mm** or **15% extra.**

Lower head loss usually means water velocity is lower, minimising erosion in channels and around structures. Velocity should be below 1 m/s for heavy clay channels or 0.6 m/s for slightly lighter soils to avoid scouring but should also be above 0.15 metres per second to avoid excessive silting.

In surface irrigation systems, head loss is evident as a drop in water level from upstream to downstream. This means it can be measured reasonably accurately across any structure such as culverts, checks or through-the-bank pipes and siphons. The diagram below shows where head loss may occur, and be measured, in a surface irrigation system.

Tail water system

Tailwater return systems significantly increase the overall efficiency of a surface irrigation system by allowing the capture and reuse of water draining from the irrigation fields. In most areas, they also enable irrigators to comply with regulations preventing water with unacceptable contaminant levels from leaving the farm.

The capacity of the tail water system is dictated by storm flows and depends on the time over which drainage must occur ie. the time to remove excess water from the field so that waterlogging impacts will be minimised. Unlike supply channels, the flow rates in drainage systems fluctuate rapidly and often. Most crops require stormwater to drain within 12 to 24 hours. Tailwater pumps should be matched to the flow capacity of the tailwater return drain.

Drainage systems are usually designed for a one-in-five-year storm because the cost of earthworks and culverts increases with capacity. For high value crops, it may pay to provide capacity for a less common storm event (e.g. 1 in 10 year event).

For drainage systems to operate effectively there must be a well-defined drain at the end of the bay to remove run-off and prevent water from backing up the field or bay. The capacity of a tail drain depends on soil conditions, the area it is draining and management practices.

Figure 2. Head loss at the meter (Dethridge wheel in this case), culvert, and channels

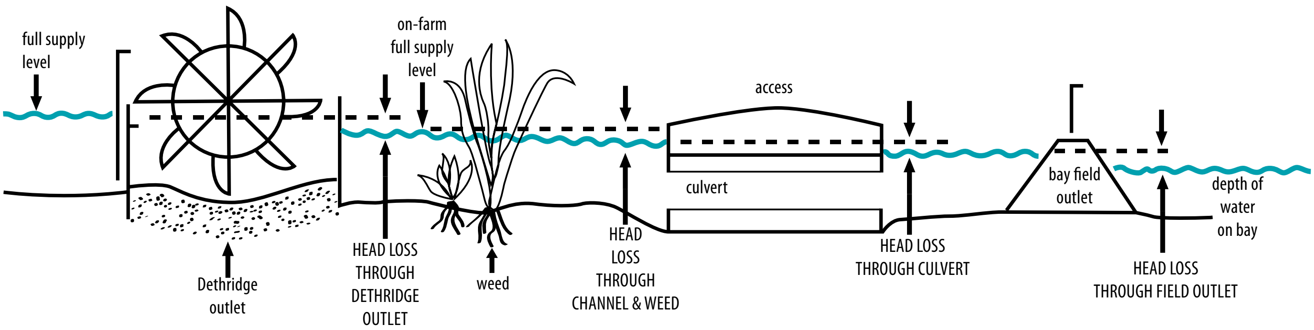
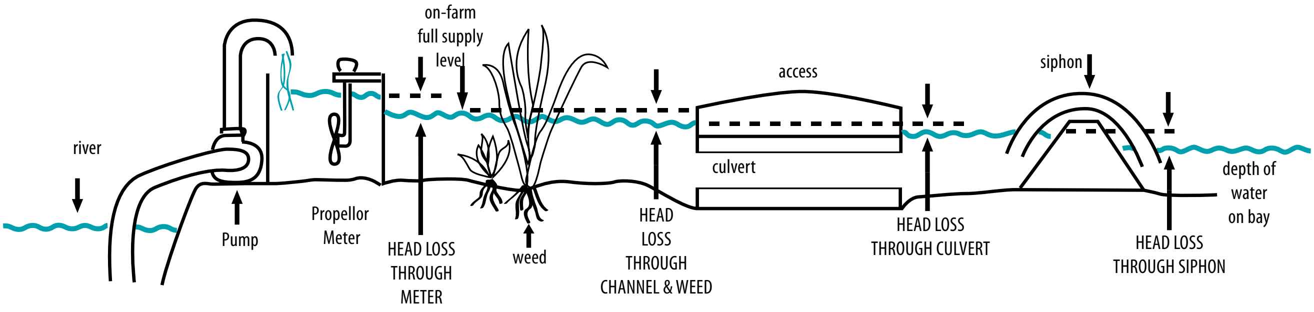


Figure 3. Head loss from the pump, culvert, and channels



As a general guide, for areas up to 40 hectares, the drain should have a capacity of at least 6 ML/day; for areas of 40-100 hectares, the capacity should be at least 10 ML/day; and for areas larger than 100 hectares, drains should be constructed to cope with 0.25 ML/ day for every hectare drained.

The furrow level at the drainage end of the lowest field controls the depth of the tail water return system. If the drain starts at this point, use a minimum depth of 0.5 m below furrow level to allow complete drainage from the field. The depth of the tail drain should increase, usually at a grade of 1:5000, as the tail water from additional fields is added.

Drain batters should be very flat to allow access for machinery across the drain when it is dry and to provide a turning area at the bottom of the field during cultivations or harvesting. Generally, a 10:1 batter is used on the field side and 5:1 batter on the roadside.

Surge areas

Surge areas are an extension of the tail water return system. The concept is to store excess water below crop levels with the option of allowing this water to flow back into the tail water return system. Surge systems are therefore usually located on the lowest part of the farm, or in a position where surplus tail water flow can be directed under gravitational flow.

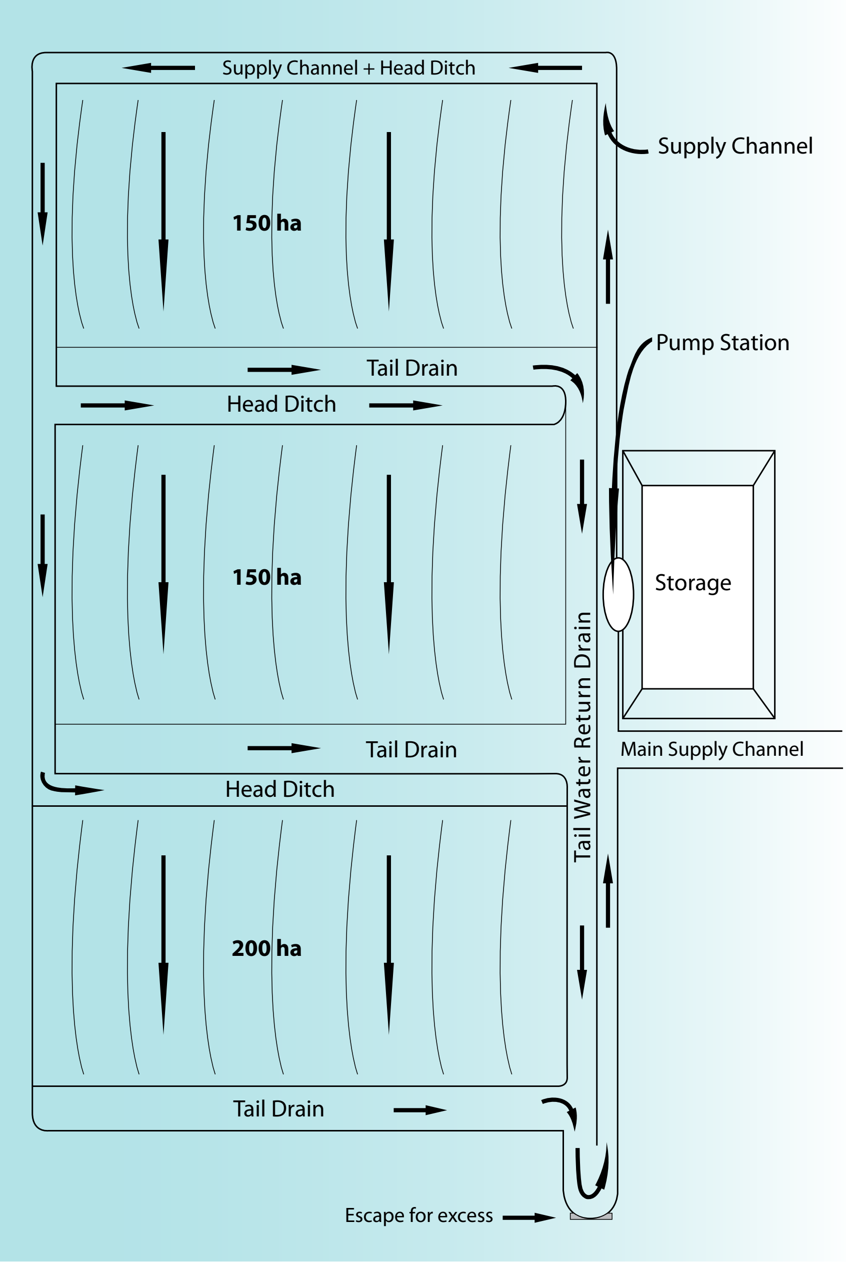
The effect is to extend the storage capacity to delay the flow of run-off back to a pump site at times when the capacity of the system is exceeded. Benefits include reduced waterlogging of the irrigated fields and capture of more stormwater. They also provide an area where the run-off water slows sufficiently (less than 0.2 m/s) so suspended material can drop from the water and be retained on farm.

Surge areas have limitations and, like all the other system components, need to be designed properly.

Drainage structures

Structures within drains that are too small or set too high make water back up onto the field, and incorrectly sized pipes and culverts with low velocities are likely to silt up. Full capacity may not be needed very often, but the benefits are usually clear following one significant storm event.

Figure 4. Example of inadequate drainage system



Example:

- irrigated farm with 500 irrigable hectares
- 200ha of cotton and 300ha of grain crops
- concrete culvert of 600mm inside diameter at bottom end of the fields

A storm of 100mm after irrigation results in 500ML of runoff water, with a peak flow of 75 ML/day. The existing culvert can manage only 55 ML/day, which means 20 ML/day is lost out of the system.

- If the water runs at peak flow for 2 days, 40 ML is lost from this event.
- additionally, 10% of the cotton area (20ha) is waterlogged because of tail drains backing up – loss of production of 0.5 bale/ha on this area.

If a 750mm ID concrete culvert 25 m long is installed to replace the existing culvert at a cost of $9,000 then there will be benefits from reduced cotton waterlogging and additional water captured that can be used to irrigate a wheat crop.

- The crop benefit will be an additional 10 bales of cotton at $350/bale – $3,500 p.a.

Assuming that 75% of the 40ML is available (25% lost during storage) to irrigate an additional area of wheat and this crop requires 2.5ML/ha:

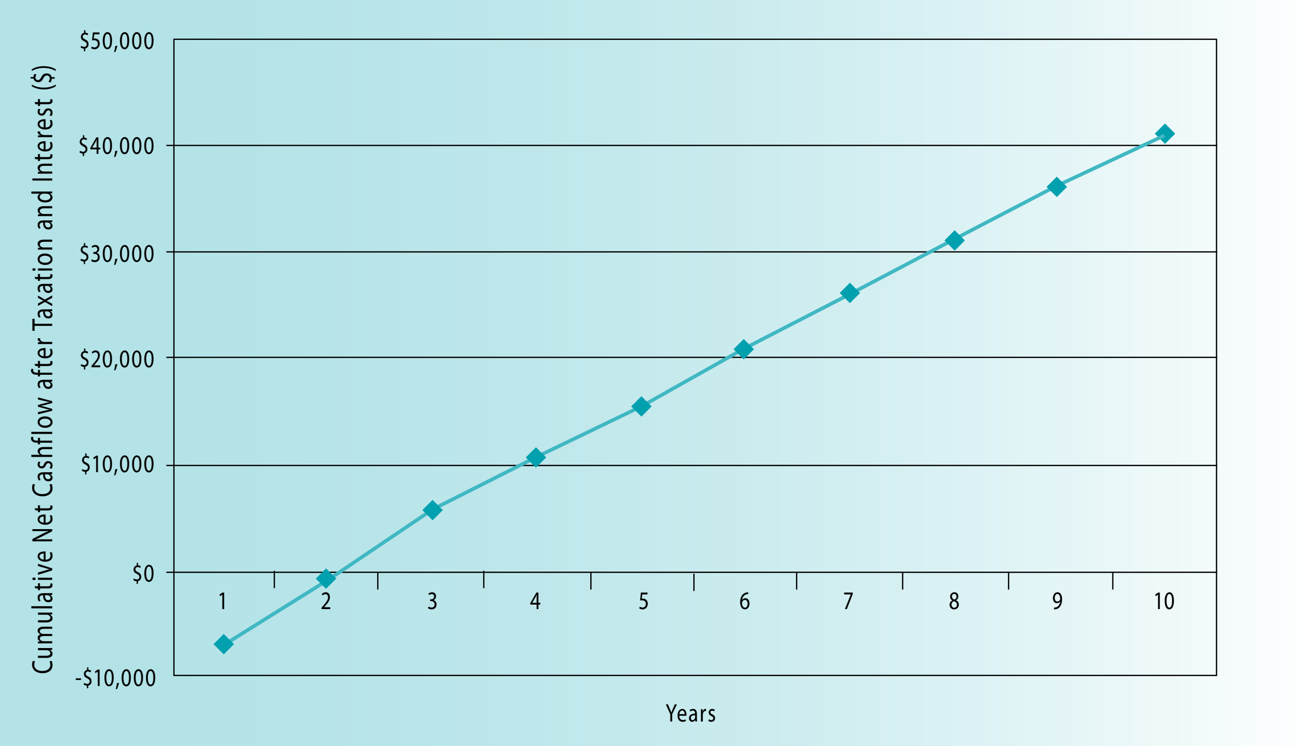
- an additional 12ha can be planted.

If the wheat gross margin is $230 per ha, the extra income when combined with the increased cotton production is $14,300 in one season.

The benefit cost for this investment is 1.5:1 with an internal rate of return of 87%. The investment is repaid in the year following installation (allowing for a 30c in the $ marginal tax rate and 10% interest on borrowed capital) – see the following figure.

Activity 1: Consider the irrigation system on your farm (or the farm visited) and complete the check list. Is there room for improvement?

Figure 5. Cumulative net cash flow following installation of higher capacity culvert



Efficiency of storages and distribution systems

Whole farm water use efficiency is reduced by excessive evaporation or seepage losses while water is being stored in dams, conveyed around the farm, applied to fields or returned to the storage. It is important to quantify these losses in order to assess whether they are acceptable.

By measuring or estimating these components, the efficiency of storages and channels can be determined. The efficiency is a measure of the proportion of water available for use from a component of the irrigation system compared to the amount of water supplied to this component – water out compared to water in. That is, if an efficiency figure is quoted as 60%, then that means that 60% of the water that was put into that part of the system is available to be used. The other 40% has been lost. Other irrigation efficiency measures are Application Efficiency (Ea), Field Canal/Conduit Efficiency (Eb) and Whole Farm Efficiency (Ef). Refer to the Irrigation Benchmarking & Water Budgeting Module for more on these.

Storage efficiency (%)

$$= \frac{\text{water used from storage during a period of time}}{\text{water stored in storage during a period of time}} \times 100$$

$$= \frac{\text{water used from storage} - \text{tailwater return}}{\text{starting volume} + \text{water pumped from the river} + \text{rainfall} + \text{overland flow} - \text{ending volume}} \times 100$$

Example: Over a season, 1950 ML of water was pumped from a storage for irrigation, and 200 ML was returned to the storage from tailwater. The starting volume at the beginning of the season was 450 ML, water pumped into the storage was 1100 ML, rainfall on the storage was 400 ML, overland flow collected was 800ML, and the volume at the end of the season was 100 ML.

Storage efficiency:

$$= \frac{1950 - 200}{450 + 1100 + 400 + 800 - 100} \times 100$$

$$= \frac{1750}{2650} \times 100$$

$$= 66\%$$

A study of four storages in 1998 and 1999 found a range of 50% to 85% for storage efficiency.

Field canal/conduit efficiency (%)

$$= \frac{\text{water received at field inlet}}{\text{water received at the inlet to the farm or a block of fields}} \times 100$$

Example: A total of 26 ML of water was pumped into an on-farm channel system. The volume of water that was delivered to the irrigated field was 18 ML.

(Care needs to be taken with this calculation. For example, it could be done for a channel that is already full and stays full at the end. In this case, the losses are only the seepage and evaporation during the irrigation event. Or it could be done for a channel that has been filled for the irrigation event and drained afterwards, leaving some residual. In this case, the water used to fill the dry channel and that was left to evaporate away is a loss. Remember always to compare like with like.)

$$\text{Field canal efficiency} = \frac{18}{26} \times 100 = 69\%$$

Note: The reason that we do not refer to this term as distribution system efficiency, is because that term is used to describe the efficiency of the whole distribution system, including on-farm canal/conduit efficiency and irrigation scheme conveyance efficiency.

Tailwater efficiency (%)

$$= \frac{\text{outflow from tailwater system} \times 100}{\text{inflow to tailwater system}}$$

Example: runoff from fields into tail drain was 5 ML,
Volume pumped into storage from tailwater system 4 ML

$$\text{Tailwater efficiency} = \frac{4}{5} \times 100 = 80\%$$

Efficiency figures are useful for comparing how well a storage, cell or sections of channels are performing. Once the efficiency of different components is known, you can make decisions about which components to use, which should be avoided and which can be cost-effectively remediated. Measurement is essential!

Dalton et al. (2001) calculated the efficiency for a range of cotton and grain farms and farm components. Some of the results are shown below.

Figure 6 – Components of the Water Balance for the (a) best and (b) worst case measured whole farm efficiencies.

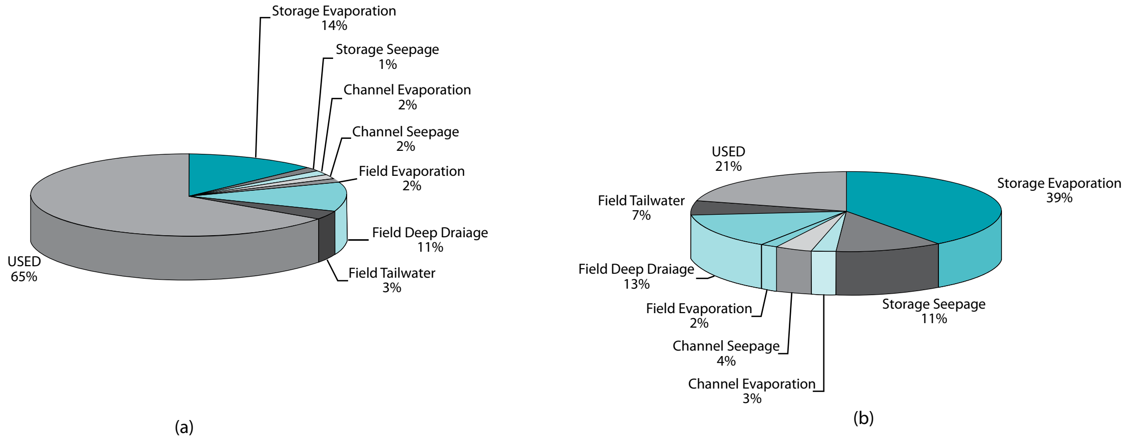
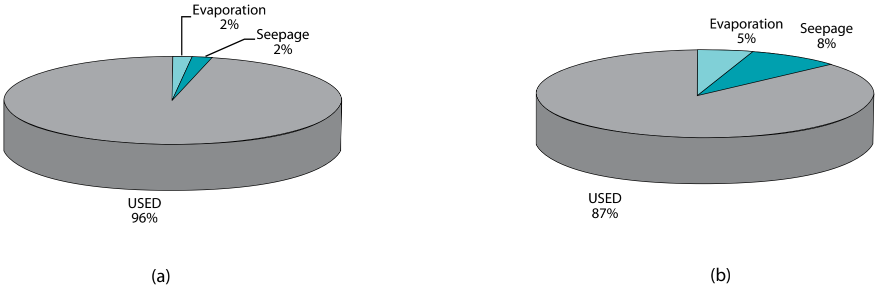


Table 3: Storage volume balance, efficiency and losses by volume (ML) and (percentage)

STORAGE DESCRIPTION	STORAGE PERIOD	STORED WATER	USED	SEEPAGE	EVAPORATION	STORAGE EFFICIENCY
Farm A	27/11/98	1272	1082	14	177	85%
4m max depth	to		(85%)	(1.1%)	(13.9%)	
1800 ML	28/12/98					
Farm A	27/11/98	2388	1203	255	930	50%
4m max depth	to		(50.4%)	(10.7%)	(38.9%)	
2500 ML	5/7/99					
Farm B	2/12/98	729	581	34	121	80%
3m max depth	to		(79.7%)	(4.7%)	(16.6%)	
500 ML	5/5/99					
Farm E	13/8/99	3649	2776	180	701	76%
4m max depth	to		(50.4%)	(4.9%)	(19.2%)	
1800 ML	16/2/2000					

Figure 7 – Components of the volume balance for (a) best and (b) worst case measured canal/conduit efficiencies.



Measurement of Storage and Distribution Systems

Whilst the efficiency calculations illustrated above are fairly simple, often the difficulty lies in obtaining accurate input data. The efficiency figures you calculate will only ever be as accurate as the data you use to calculate them.

Furthermore, you need to understand whether losses that do occur are due to evaporation or seepage before you can decide how to proceed.

As storages, channels and tailwater return systems all have the same water balance components, the same approach can be used to measure evaporation and seepage losses. The hydraulic input and output components of channels, storages and return systems are shown below.

The process for determining losses due to seepage and evaporation has three components.

1. Measure inflow, rainfall and outflow.
2. Estimate evaporation.
3. Determine seepage.

Seepage is the most difficult part of the water balance to estimate and thus it is usually determined as the remainder after summing the inflow, outflow, rainfall and evaporation. Seepage loss is assumed to be the difference between how much water has been supplied and how much has been extracted, evaporated, or remains in the system.

Accurate measurement of as many of the components as possible is critical, otherwise evaporation or seepage losses will be over or under estimated. This may mean that management strategies may be undertaken unnecessarily or not undertaken when they should be.

Figure8. Hydraulic components. Source: Dalton et al. 2002

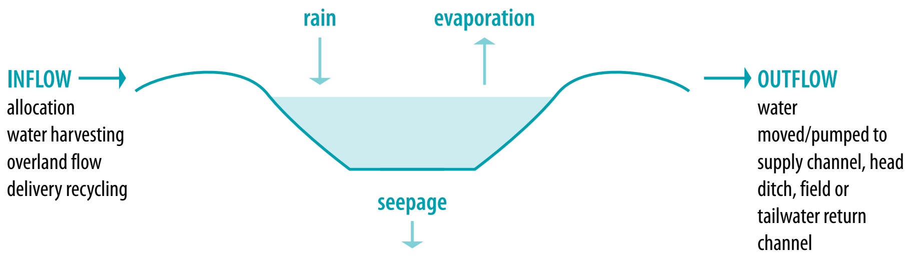


Table 4. Methods for obtaining the required information are outlined below. (Case study examples can be found in WaterPak Chapter 2.6.)

COMPONENT	SOURCE OF DATA	DIFFICULTY	ACCURACY	COMMENT
Inflow	Pump curve	low	Low	Requires accurate record of pumping time. Pump often does not perform to pump curve standard.
	Flow meter	medium	High	Requires accurate installation
	Irrimate™ Storage meter	Medium	High	Requires accurate storage survey
Outflow	Pump curve	low	Low	Requires accurate record of pumping time. Pump often does not perform to pump curve standard.
	Flow meter	medium	High	Requires accurate installation
	Irrimate™ Storage meter	Medium	High	Requires accurate storage survey
Rainfall	Rain gauge	low	High	Does not account for spatial variation
Evaporation	Eddy correlation equipment	Very high	Very high	Research tool
	Bowen ratio	Very high	Very high	Research tool
	ET Penman-Monteith	medium	Low to Medium	World-wide standard
	Class A pan	low	Low	No longer standard and data may not be available.
	Irrimate™ Seepage and Evaporation meter	high	High – Very High	Consultant tool, measures only depth of water
Seepage	Drainage lysimeter	Very high	Very High	Research tool
	Water balance equation remainder	low	depends upon accuracy of other measurements	
	Idaho seepage meter	Medium	Medium to High	Research tool, measures only local seepage
	Seepage and evaporation meter	high	Very High	Consultant tool, measures depth of water and evaporation is removed.
Storage Volume	Irrimate™ Storage meter	medium	High	Affordable for farmer. Requires accurate calibration
	Gauge board	low	Medium to high	Requires accurate calibration

Measurement of storage volumes

Measuring water volumes in or out of a storage can be achieved using flow meters on inlet or outlet pipes or by measuring the change in volume of the storage. This volume change can be determined through measurements of the water depth, however the relationship between storage volume and water depth is required to do this.

Engineers produce curves demonstrating this relationship for each dam they build. However, measurements from the completed job, rather than from the design specifications, should be used as it is common for them to vary significantly.

An example of a storage curve for a dam situated at St George, Queensland is shown in Figure 9. In this example, the height of the water is recorded as its height above sea level.

Gauge boards are designed from storage curves. Figure 10 is a photograph of the gauge board that corresponds to the storage

Figure 10. Gauge board for the above storage curve (Waterpak Figure 2.6.3)

Figure 9. Storage curve for a St George farm dam (Waterpak Figure 2.6.2)

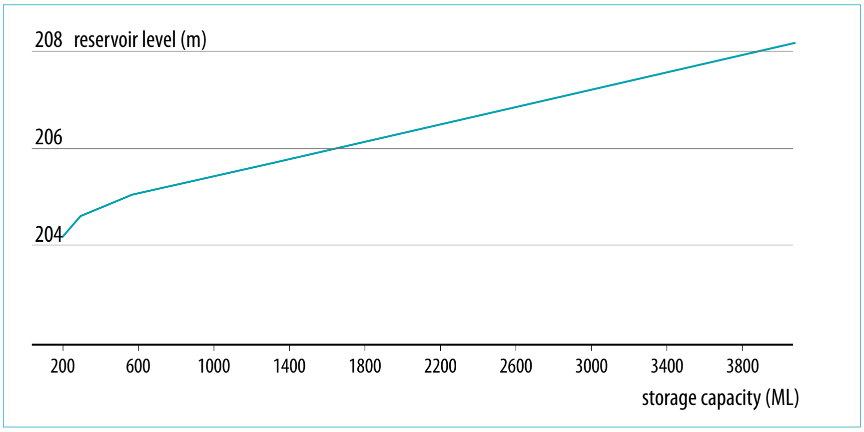
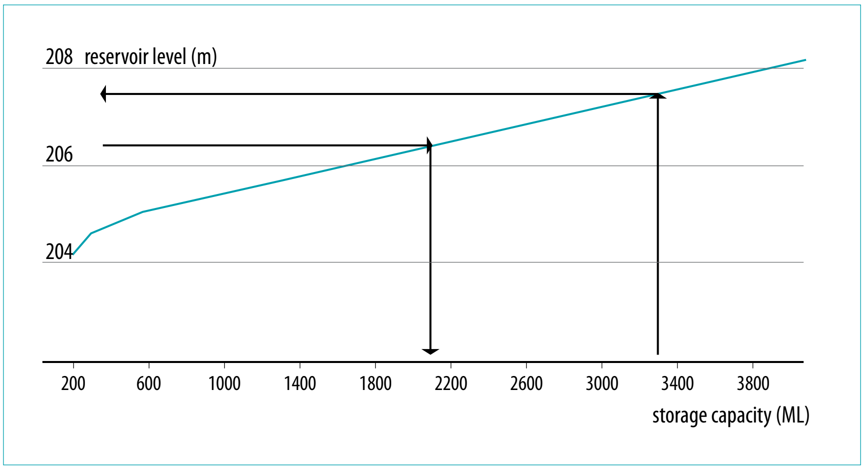


Figure 11. (Waterpak Figure 2.6.5)



curve in Figure 9. This is a manual gauge board, because you have to physically observe and record the height of the water. 'Electronic' gauge boards, or depth sensors and loggers, are available from some engineering companies – an example is the Irrimate™ Storage Meter. These automatically record the height of the water at short time intervals eg. 15 minutes, and can be manually downloaded or transferred by telemetry to an office computer.

By using a manual gauge board to determine the height of the water the grower is able to estimate the volume of water in storage by reading the corresponding storage capacity on the storage curve. For example, in Figure 11, the storage is estimated to be storing 2100 ML.

By recording measurements often enough, the storage height provides a record of quantity and time of water movements. For example, in the figure above, the storage is estimated to be storing 2100 ML. If a pumping event occurs and the water level rises from 206.5 to 207.5, this is an inflow of 1200 ML. If the time period between these readings was three days, the inflow rate was 400 ML per day.

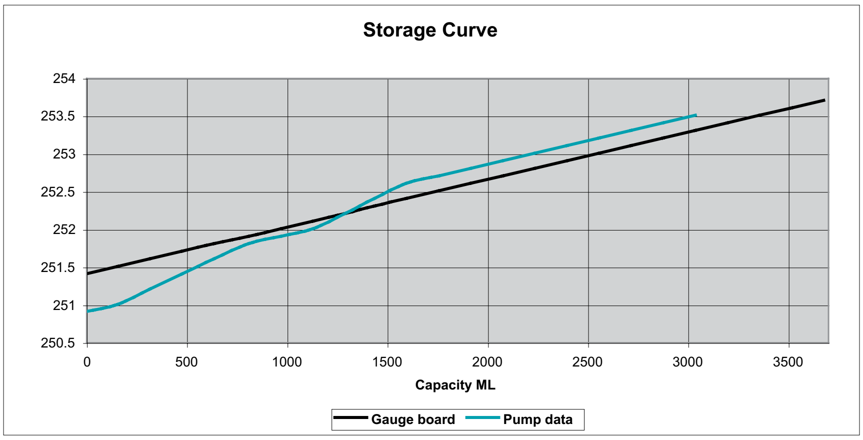
Where flow meters have been installed on the inlets or outlets of storages, a water movement event can be used to establish the volume/depth curve. Flow rate multiplied by duration of the event (eg. pumping time) gives the volume moved. Recording change in storage height will then give a volume-depth relationship.

Flow meter readings can also be used to check the accuracy of an existing storage gauge board. If the volume recorded from meter readings and the volume recorded from the gauge board do not correspond, the accuracy of both instruments should be checked. For the gauge board this may involve re-surveying the dam and preparing a new storage curve. In the example below, 3,040 ML have been pumped into the storage giving a final gauge board reading of 253.5m. From the existing storage curve, this reading equates to 3,360 ML. Both the gauge board and water meter should be checked for accuracy.

Example: Table 5. Pump flow rate 160 ML/d

DATE	TIME	METER READING	VOLUME PUMPED PER DAY	CUMULATIVE VOLUME ML	STORAGE HEIGHT (M)	COMMENT
1/12/2006	8:00am	17965.50	0	0	250.9	Pumping commenced
2/12/2006	8:00am	18125.50	160	160	251	
3/12/2006	8:00am	18285.50	160	320	251.2	
4/12/2006	8:00am	18445.50	160	480	251.4	
5/12/2006	8:00am	18605.50	160	640	251.6	
6/12/2006	10:00am	18778.50	173	813	251.8	
7/12/2006	10:00am	18938.50	160	973	251.9	
8/12/2006	10:00am	19098.50	160	1133	252	
9/12/2006	10:00am	19258.50	160	1293	252.2	
10/12/2006	8:00am	19405.50	147	1440	252.4	
11/12/2006	8:00am	19565.50	160	1600	252.6	
12/12/2006	8:00am	19725.50	160	1760	252.7	
13/12/2006	8:00am	19885.50	160	1920	252.8	
14/12/2006	8:00am	20045.50	160	2080	252.9	
15/12/2006	8:00am	20205.50	160	2240	253	
16/12/2006	8:00am	20365.50	160	2400	253.1	
17/12/2006	8:00am	20525.50	160	2560	253.2	
18/12/2006	8:00am	20685.50	160	2720	253.3	
19/12/2006	8:00am	20845.50	160	2880	253.4	
20/12/2006	8:00am	21005.50	160	3040	253.5	Pumping ceased

Figure 12. Comparison of gauge board and pump meter readings.



For flow meters, installation is critical for accuracy. Adequate established flow either side of where they are installed is essential. Established flow requires straight pipe for a considerable distance from inlets and outlets so as to avoid turbulence. Some meters also need to be fully submerged before they begin recording. Ensure that all the manufacturer's recommendations are adhered to. (See the Metering Workshop or WATERpak Chapter 2.8 for more on this.)

Determining storage evaporation and seepage losses

In broadacre irrigation, the losses from storages are often the greatest loss in the whole irrigation system, so it is very important to measure them. When water is stored over a period of time without any inflow or outflow, the drop in water height directly corresponds to the combined evaporation and seepage losses. If evaporation rates for that period of time were known accurately enough, then these could be subtracted from the net loss in order to estimate seepage losses.

It has been difficult to obtain these measures with any accuracy until recently. This is because there are no evaporation coefficients for on-farm storages and the only way of measuring evaporation has been through the use of highly technical research equipment.

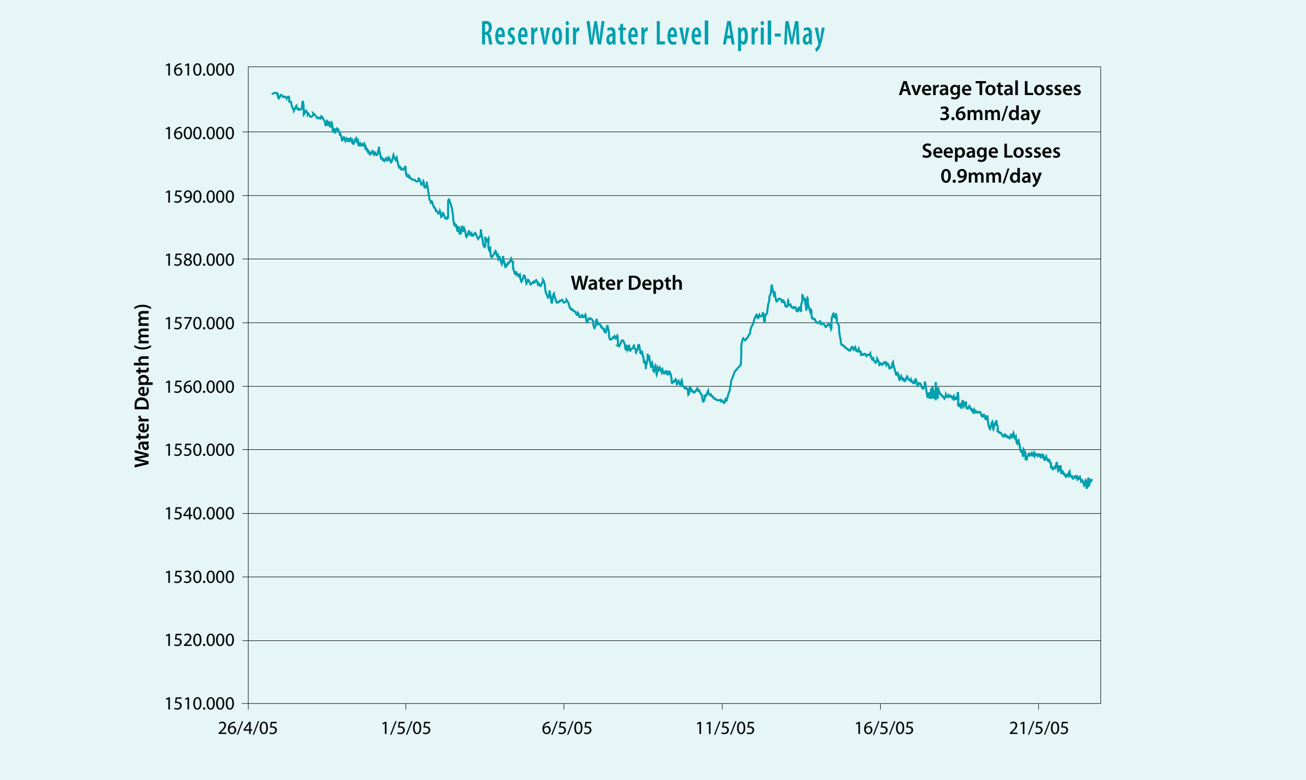
One simple method of obtaining the combined evaporation and seepage losses is by manually recording gauge board readings. There are often errors in reading due to parallax and wind effects and the time interval between readings is usually days, so the depth change curve is not very accurate and the loss estimates are not very precise. They are, however, a measurement giving a good indication of the magnitude of the losses.

Recent developments mean it is now affordable and practical to achieve much better measures of storage losses using an Irrimate™ Seepage and Evaporation meter. These utilise a highly sensitive water depth sensor (accurate to within 1 millimetre) and log the readings at frequent intervals. It is possible to use this meter to measure the seepage and evaporation losses, and by comparing the rate of loss to other evaporation data (such as Penman-Monteith), the seepage loss component can be isolated.

An example of output from an Irrimate™ Seepage and Evaporation Meter is shown below.

The significance of the losses is made more apparent when they are converted to a volume. By multiplying the loss in mm by the surface area (ha) of the storage at the current water level and dividing by 100, the total volume of water lost can be determined in ML. To do this accurately, you will need a storage survey that shows the relationship between depth and surface area. This should be obtained when the storage curve is determined. A significant error comes with assuming the surface area of the storage is the same as the ground area occupied by the storage. It is always significantly less

Figure 13. Output data from an accurate storage meter



due to the effect of batter slopes, as well as width of the crest and width if any access roads, channels and clear area around the base, and if the storage is well below full.

As a rough guide, seepage above 5mm per day should be investigated further. For seepage less than 5mm per day, it would be wise to calculate the total volume lost in ML and then decide if further investigation is warranted.

Example: For a storage that is 400m long and 400 m wide, the nominal area is 16,000 m2 or 16.0 ha. Engineering specifications are usually to the centre line of the crest, and the usual freeboard allowance is 0.5m. With an 8:1 batter on the inside wall, the surface area of the water at full supply level is 15.4 ha. To determine the loss of water that has been stored for the month of May, using the seepage and evaporation meter data from the graph above (average daily loss = 3.6mm/day):

Daily loss

= 3.6 mm/day × 15.4 ha ÷ 100

= 0.55 ML/day

For the month of May in the example:

Monthly loss

= 3.6 mm/day x 31 days

= 111.6 mm

= 111.6 mm × 15.4 ha ÷ 100

= 17.2 ML

(The decrease in storage height of 111.6mm would reduce the surface area of the water a little, from 15.4ha to 15.37ha, which changes the calculated volume lost by 0.03 ML. If you were working this out for a large difference in storage height, the error should be allowed for.)

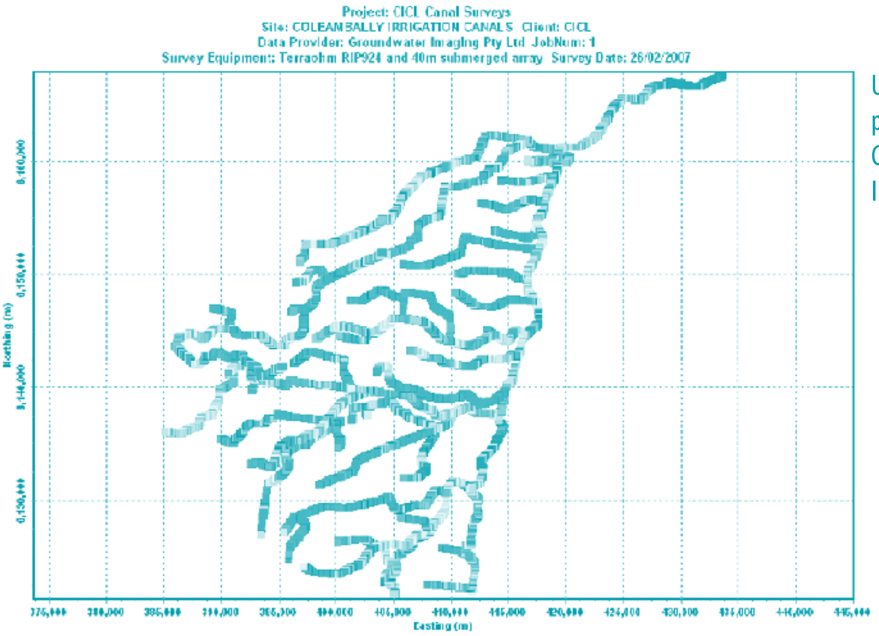
Measurement of losses in channels

Measuring losses in channels is done by the same process as for storages: determine the inflow to the channel and the outflow from the channel, estimate the evaporation and either calculate or measure the seepage. While losses are usually not as much as storages, large broad acre farms may have many kilometres of channels. This means the losses are worth investigating especially from larger channels that have water in them for long periods of time.

A fairly accurate measure of seepage from channels can be made by ponding water in a length of channel and measuring the water depth at the same place and time of day for several days or weeks. Good opportunities to take these measurements are in between irrigation events or at the end of the season when the channels are already full. Avoid doing so at the beginning of the season as cracks in dried channels may give a falsely high result.

If the loss is similar to evaporation, the channel has little seepage loss. If it is greater than evaporation, partition the channel off in smaller lengths and repeat the

Figure14. Schematic representation of EM survey of a channel system.



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measurements. This will define the section of greatest loss and identify where any remedial action would be best done. EM soil surveys of channel lengths are also helpful for locating problem spots. The schematic in Figure 14 shows an EM survey of a major supply channel system. The dark areas are likely high seepage zones.

Example: a 3km (3000m) length of supply channel was sealed off between irrigation events and found to lose 15mm a day. The water in the channel was about 4m wide.

Surface area of water in the channel
= 3000m x 4m
= 12,000 m2
= 1.2 ha

Loss of water (evap + seepage)
= 1.2 x 15mm
= 0.18 ML per day

Channel efficiencies should be higher than dams because water is not usually stored for long periods of time before it is used, and this reduces the opportunity for evaporation and seepage.

Evaporation and seepage mitigation strategies

Cells and cell management

Evaporation is highly affected by the exposed water surface area. Dividing a single storage into a series of smaller storages or cells allows water to be transferred between them in order to minimise the total surface area exposed. Minimising the time water is held in storage also reduces the total loss.

For example, at Goondiwindi, a cell that was filled for only a month at the start of the season with water that was used straightaway on pre-irrigation, had a storage efficiency of 85%, while another cell that was filled and not used for 7 months until later irrigations, had a storage efficiency of 55%.

Dividing a single storage into smaller cells also reduces the impact of erosion on banks from wave action.

Deeper cells

Dam size and shape are important when you are trying to minimise evaporation and drainage. Very shallow water is particularly bad, as the large surface area compared to the volume means the proportion of water evaporated is high. For a given volume of water, the deeper the storage, the smaller the surface area.

Having separate cells allows flexibility to store water as deeply as possible. But increasing the depth may increase the hydraulic head, increasing the risk of seepage. Ensure there is the recommended thickness of appropriate impermeable material on the floor and walls. When constructing deep cells, be careful not to expose base rock or a permeable seam. If you do happen to expose base rock, be sure to cover it with at least 300 mm of compacted clay to prevent seepage.

If you are considering constructing a new farm dam or increasing your dam size, be sure to consult local authorities about any regulations that may affect this.

Surface barriers

A monolayer is approximately one molecule in thickness that floats and spreads across the water surface. Pilot scale trials indicate they can be quite effective under ideal conditions, reducing evaporation by up to 40%. On large open storages they are less effective, perhaps reducing evaporation by a maximum of 30%, because wind and wave action move the monolayer around. Due to breakdown by UV light, they need to be reapplied regularly (every 3 or 4 days in the middle of summer). Research on more suitable polymers is currently being undertaken.

Floating covers act as an impermeable barrier that floats on the water surface. They are typically constructed of continuous plastic or modular units and reduce evaporation by providing a barrier to solar radiation and a reduction in wind speed. On open storages they can reduce evaporation by 95%. However their application may be limited on very large storages due to economics or practicalities.

Suspended structures consist of shadecloth that is suspended over a water surface. These structures can reduce evaporation by 70-80 per cent by reducing solar radiation, reducing wind speed and trapping humid air between the structure and the water surface. Their application is often limited by the size of the storage.

Seepage mitigation strategies

Pinpointing the cause of seepage issues can be a very difficult task. Common causes include poor or unplanned construction, location where soils are unsuitable and/or use of unsuitable soil types, poor soil compaction, and poor maintenance, to list a few. EM surveys are very useful for checking the suitability of soils at existing storage locations or for locating new storages. There are many methods and materials available to mitigate seepage problems. Which method to use depends on the nature of the problem, and the cost and lifespan of the solution. Several of the most common methods are clay lining, bentonite, synthetic lining and impact roller.

Other mitigation strategies

For irrigators using groundwater, the period that water is held in storage will impact overall storage efficiency. Investing in larger or additional groundwater pumps will allow for shorter pumping periods and hence less evaporation from stored water. There is no evaporation from groundwater.

When should I take action?

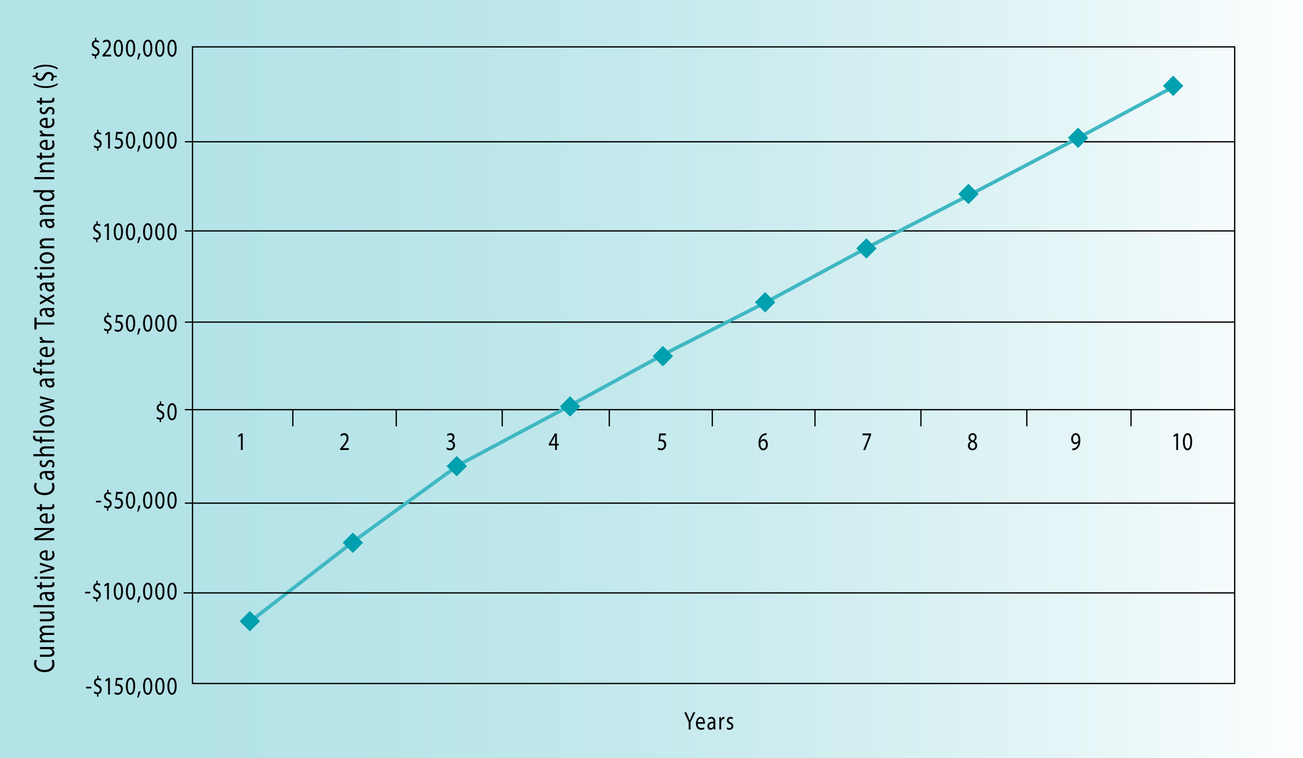
The decision to mitigate either evaporation or seepage is usually based on economics: the cost of mitigation must be less than the expected return from the water that is saved.

Example: The storage in the earlier example had an efficiency of 66%, which means it lost 34% of its water over the season, a volume of 900 ML. If the efficiency could be improved to 85% the loss would be reduced to about 400 ML, a saving of 500ML. Assume this allows an extra 200ha of irrigated wheat to be planted. If this gave a profit of $230 per ha, the extra gross margin is $46,000 in one season. If the cost of remediation was $150,000, this is repaid in four years allowing for a marginal tax rate of 30c in the $ and interest of 10% on borrowed capital. The internal rate of return on repairing the seepage is 27%. The outcome over 10 years is presented in the graph below.

Cumulative net cash flow (after tax and Interest) for repair to case study storage

For more information on evaporation mitigation, including an economic ready reckoner, see the National Centre for Agricultural Engineering website www.ncea.org.au/Evaporation%20Resources/index or the NPSI website www.npsi.gov.au/readyreckoner/index

Figure 15. Example of economic evalution of mitigation works.



Activity 2: using the data from a local farm, calculate the loss rate in mm per day and the total volume of losses in ML from the storage.

Calculate storage efficiency using the equation at the beginning of these notes.

Is it worth doing anything about it? If so, which of the mitigation strategies would you use? (Use the Ready Reckoner as a guide.)

Storage maintenance

Simple storage maintenance and monitoring will maximise efficiency and minimise the long-term costs of seepage mitigation strategies. Prevention is better than cure!

Steps involved in maintaining a storage and techniques to monitor the state of a storage include:

- regular grading of roads and batters
- Maintain both inside and outside batters completely free of vegetative cover. Trees, shrubs or grass on or close to embankments may put roots through the embankment creating seepage and potential failure pathways.
- The outside of your dam wall can be maintained by filling cracks and rills with compacted clay, grading the wall and the crest.
- Prevent the formation of cracks and rills on the inside of the dam banks.
- An early sign of slumping is cracks along the length of the dam wall. It is best to seek professional advice if this occurs.
- If wet patches are occurring along your dam wall, seepage is a problem. Areas of concern can be packed with compacted clay materials. If the problem spans a large area, the dam can be lined with a natural material or synthetic liner.
- Tunnelling can be controlled through plugging the hole with carefully compacted soils or lining your dam with a synthetic liner. Tunnelling is an indication of poor dam structure and high risk of failure. You should seek professional advice.
- Laying stone along areas affected by wave action can reduce the damage.
- Keep weeds in and around the storage under control
- Keep out livestock.
- High nutrient levels in a dam can encourage algae growth. Kits are available to monitor the nutrient levels in your dam.
- Do not allow the dam wall to dry out. Drying of a dam causes shrinkage cracks that may weaken the wall, and perhaps penetrate the core. Where possible, keep the embankment at a constant moisture level.
- When filling a newly constructed or dry dam, carefully observe the dam and its foundations. The rate of filling should be no more than 300 mm of water a day, and preferably less than 100 mm a day. If problems are observed, filling should cease and water levels should be lowered so the problem can be rectified.
- Keep the water level at or below the designed freeboard limit. The following table provides a guide.

Table 6. Freeboard for Various Fetch Lengths

(from Guidelines for Ring Tank Storages, Irrigation Australia, 2007)

Fetch Length (m)	Wave Height (m)	Freeboard (m)
Less than 600	0.3	0.8
1,000	0.4	1.0
2,000	0.6	1.2
3,000	0.8	1.3
4,000	0.9	1.5

Further information on storage maintenance and other topics can be found under the Resources section of www.cottonandgrains.irrigationfutures.org.au